Aeronomy of Ice in the Mesosphere (AIM) Small Explorer (SMEX)

Concept Study Report Summary

The overall goal of AIM is to resolve why Polar Mesospheric Clouds (PMCs) form and why they vary. By measuring PMCs and the thermal, chemical and dynamical environment in which they form, we will quantify the connection between these clouds and the meteorology of the polar mesosphere. This goal will be achieved by measuring PMC abundances, morphology, trends, particle size distributions and gravity wave effects and by conducting precise, vertical profile measurements of temperature H_2O, OH, CH_4, O_3, CO_2, NO, and aerosols over altitudes ranging from 10 km to 110 km depending on parameter. This research will provide the basis for study of long-term mesospheric climate variability and its relationship to global change. The results of AIM will be a rigorous validation of predictive models that can reliably use PMC observations to assess global change in the mesosphere. AIM includes four instruments: SOFIE (Solar Occultation for Ice Experiment), an infrared solar occultation radiometer; SHIMMER (Spatial Heterodyne Imager for Mesospheric Radicals), a UV limb imaging interferometer; CIPS (Cloud Imaging and Particle Size experiment), a panoramic UV imager; and CDE (Cosmic Dust Experiment), an in-situ dust detector. A Pegasus rocket will launch the AIM satellite into a 500 km, 12:00 PM sun-synchronous orbit.

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Type of Investigation: Free Flying Satellite Mission
Sun-Earth Connection Theme

Total Cost To NASA: $ 81.22M
FY2000 $

December 18, 2001

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Aeronomy of Ice in the Mesosphere (AIM)

Science Goal

The overall goal of AIM is to resolve why Polar Mesospheric Clouds (PMCs) form and why they vary. AIM will 1) quantify the connection between these clouds and the meteorology of the polar mesosphere and 2) provide the basis for study of long-term changes in mesospheric climate and its relationship to global change.

Science Objectives

Understand PMCs and key processes affecting their formation:

- PMC morphology and microphysics
- Effects of gravity waves
- Temperature and dynamical effects
- Hydrogen chemistry
- Nucleation environment

Importance to NASA Science Themes

AIM will address key questions posed by the NASA Sun Earth Connection (SEC) Roadmap: How might the upper atmosphere respond to either global climate change or solar/terrestrial forcing? How does the upper atmosphere shield our planet and its biosphere from harmful radiation and particles? PMCs are sensitive to global change and solar/terrestrial influences.

Mission Objectives

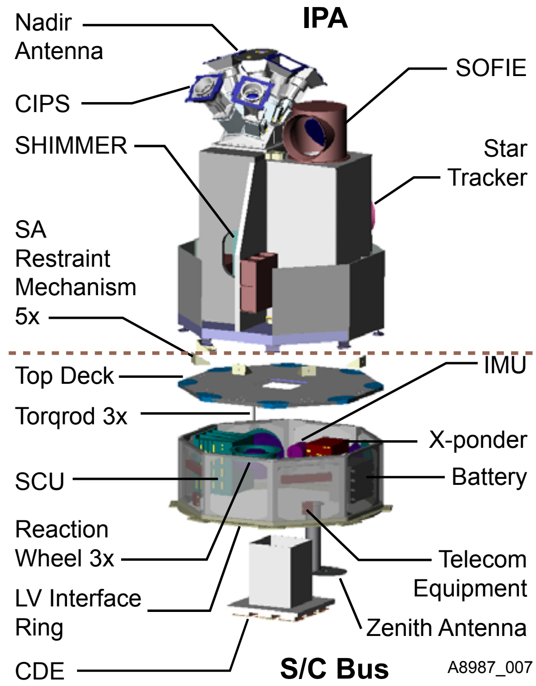
AIM will make global measurements of PMCs and their environment in two observing geometries (limb and nadir) and nearly simultaneously by three instruments for four polar summer seasons (two in each hemisphere). AIM will also monitor dust influx as a possible extraterrestrial forcing.

Mission Characteristics

- Direct injection launch into a circular, 500km, sun-synchronous, noon orbit
- A 23-month lifetime
- Four instruments: two limb, one nadir, and one zenith-pointing
- 2.7Gbits of data per day, downloaded in two contacts

Science Payload

- **SOFIE**, Solar Occultation For Ice Experiment
  - 8-channel differential absorption radiometer
  - IR, solar occultation
  - Measures: Temperature, PMCs, H_2O, CO_2, CH_4, NO, O_3 and Aerosols
  - Heritage: Halogen Occultation Experiment (HALOE)
- **SHIMMER,** Spatial Heterodyne IMager for Mesospheric Radicals
  - Limb imaging interferometer
  - Measures Temperature, OH and PMCs
  - Heritage: Middle Atmosphere High Resolution Spectrograph Investigation Experiment (MAHRSI), Shuttle instrument
- **CIPS**, Cloud Imaging and Particle Size Experiment
  - Panoramic Ultraviolet (UV) nadir imager
  - Provides PMC images and particle properties
  - Heritage: Rosetta, Solar Backscatter Ultraviolet Experiment (SBUV)
- **CDE**, Cosmic Dust Experiment
  - In-situ dust detector
  - Measures cosmic dust input in PMC region
  - Heritage: VEGA, CASSINI



AIM in launch orientation (exploded view)

Key Spacecraft Characteristics

Mass:	252 kg (including reserve)
Basic Design:	Simple 3-axis stabilized control body-fixed solar arrays
Power:	3.1 m^2 GaAs solar cells 35 A-h Li-ion battery 290 W end-of-life orbit avg.
Telemetry:	S-band Universal Space Network
Downlink Rate:	4.0 Mbps
Science Data Storage:	3.0 Gbit

Launch Vehicle

Pegasus XL with Hydrazine Auxiliary Propulsion System (HAPS)

Education and Public Outreach (E/PO)

- Formal/informal education and public awareness components
- Two lead educator workshops, with graduate credit, held in Alaska
- 20 regional educator workshops held in five NASA regions of the US
- Focus on minority-serving teachers from US urban schools and rural Alaska schools
- Incorporation of Association for the Advancement of Science (AAAS) Benchmarks, Atlas of Science Literacy, and National Science and Mathematics Standards in all workshops and education materials
- Strong leveraging of experience and commitment of all team members
- Collaborations with other NASA outreach programs

Mission Management

- Principal Investigator (PI) Institution, science leadership, E/PO, program coordination, and prime contractor: Hampton University (HU)
- Project management, spacecraft and instrument subcontracts, CIPS and CDE provider, and mission operations: University of Colorado Laboratory for Atmospheric and Space Physics (LASP)
- SOFIE provider: Utah State University Space Dynamics Laboratory (SDL)
- SHIMMER provider: Naval Research Lab (NRL)
- Spacecraft Provider: Ball Aerospace & Technologies Corp. (BATC)
- Data Processing Management: Gordley and Associates Technical Software, Inc. (GATS)

Schedule

Phase	Milestone	Date
B	Phase B Start	7/2/2002
	SRR	10/2/2002
	PDR	12/15/2003
C/D	CDR	11/15/2003
	Ship to Launch site	7/5/2005
	MRR	8/1/2005
	Launch	9/30/2005
	In orbit checkout	10/2005
E	Operations	10/2005 – 8/2007
	Archival Complete	9/2007

Cost

Program Element	AIM Cost ($M) FY2000
Science	
AIM Science	3.8
Guest Investigator	0.3
E/PO	0.9
Total Science	**5.0**
Management	
Project Management	2.8
Program Coordination	0.5
NIAT Activities	3.5
Total Management	**6.8**
Flight Segment	
SOFIE	4.8**
SHIMMER	4.1*
CIPS	5.1
CDE	1.0
Inst. Platform Assembly	0.9
Spacecraft	15.3**
Launch Vehicle	24.6
Total Flight Segment	**55.8**
Ground Segment	
Mission Operations	2.5
Data Processing/Archival	3.6
Total Ground Segment	**6.1**
Budgeted Reserves	**7.1**
Phase A	**0.4**
Total Costs	**81.2**

* without contributions ** includes fees

Science Team

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D. Executive Summary

Science Objectives and Background. One of the most compelling problems in atmospheric science is to understand how and why climate is changing. One possible manifestation of climate change at high altitudes is the dramatic increase over the past 30 years in the number of noctilucent, or "night-shining," clouds (NLCs). NLCs are the highest altitude clouds in the atmosphere, occurring near 85 km in summer. This region, known as the mesopause, is also the coldest place on Earth, reaching temperatures as low as ~130 K. The term "night-shining" derives from the fact that the clouds are seen just after sunset, when the ground is in darkness, but the upper atmosphere is still sunlit. These ice clouds (**Fig. D-1**), known to satellite observers as Polar Mesospheric Clouds (PMCs), are believed to respond dramatically to small changes in their environment and therefore would respond to high altitude cooling that may accompany greenhouse warming at the surface due for example to CO_2 increases. If reported NLC increases are representative of the entire polar region, then this beautiful sky phenomenon may be our most visual manifestation of anthropogenic change in the atmosphere (Thomas, 1996).

PMCs have traditionally been seen at high latitudes. However, on June 22-23, 1999 a huge noctilucent cloud was sited at Colorado and Utah, where they had never before been seen (~40° N). Dozens of news accounts appeared in the media. Mid-latitude noctilucent clouds have now been sighted in the two successive northern summers since 1999. Rather than being an isolated event, as described in our first proposal, these new sightings (including measurements from the Student Nitric Oxide Explorer (SNOE) spacecraft) occurring far south of their normal latitude range (>55 deg), suggest a pervasive long-term change in upper atmosphere climate. Because these events may be the beginning of a response to changing atmospheric conditions, the time is right for a carefully focused space mission to address this phenomenon. Now that people in highly populated areas can see NLCs the need to understand their formation and possible relationship to global change is even more pressing.

Figure D-1. NLC photograph taken near Juneau, AK

The overall goal of the Aeronomy of Ice in the Mesosphere (AIM) experiment is to resolve why PMCs form and why they vary. By measuring PMCs and the thermal, chemical and dynamical environment in which they form, we will quantify the connection between these clouds and the meteorology of the polar mesosphere. In the end, this will provide the basis for study of long-term variability in the mesospheric climate and its relationship to global change. The results of AIM will be a rigorous validation of predictive models that can reliably use past PMC changes and present trends as indicators of global change. This goal will be achieved by measuring PMC abundances, spatial distribution, particle size distributions, gravity wave activity, cosmic dust influx to the atmosphere and precise, vertical profile measurements of temperature, H_2O, OH, CH_4, O_3, CO_2, NO, and aerosols. These data can be obtained only by a complement of instruments on an orbiting spacecraft because of the need for global coverage and because extinction and foreground emissions compromise optical sensing from the ground.

The AIM goal can be characterized by six specific scientific questions. The first five of these deal with mechanisms for PMC formation, i.e., when and where they occur and how they respond to changes in their thermal, chemical and dynamical environments. The AIM mission will answer these five questions directly. The sixth question links PMCs to the larger question of mesospheric climate change. The models we will develop and validate to answer the first five questions will be used to address this last question. The six objectives are:

1. *PMC Microphysics*: What is the global morphology of PMC particle size, occurrence frequency and dependence upon H_2O and temperature?
2. *Gravity Wave Effects*: Do gravity waves (GWs) enhance PMC formation by perturbing the required temperature for condensation and nucleation?
3. *Temperature Variability*: How does dynamical variability control the length of the cold summer mesopause season, its latitudinal extent and possible interhemispheric asymmetry?
4. *Hydrogen Chemistry*: What are the relative roles of gas phase chemistry, surface chem-

istry, condensation/sublimation and dynamics in determining the variability of water vapor in the polar mesosphere?

5. *PMC Nucleation Environment*: Is PMC formation controlled solely by changes in the frost point or do extraterrestrial forcings such as cosmic dust influx or ionization sources play a role?
6. *Long-Term Mesospheric Change*: What is needed to establish a physical basis for the study of mesospheric climate change and its relationship to global change?

Importance to NASA Science Themes. The overall goal of NASA's SEC program is to understand the coupling between the heliosphere and the Earth's atmosphere. AIM deals with Quest #4 of the SEC Roadmap (http://www.Lmsal.com/sec/), "How does solar variability affect life and society" which is a key element of the "Living with a Star" initiative. The key to this quest is an improved understanding of the upper atmospheric regions that shield the planet and its biosphere from harmful solar radiation and particles. The study of anthropogenic influences on the upper atmosphere is an important aspect of Quest #4. PMCs are of special interest as they are sensitive to both global change and solar/terrestrial influences. Also, a recent National Research Council (NRC) book entitled *The Atmospheric Sciences Entering the 21st Century* notes the "need to closely monitor the occurrence and latitudinal extent of PMCs as a marker of global change".

Technical Approach. The AIM team recognizes the challenges of implementing a Small Explorer Satellite (SMEX) mission within mass, schedule and costs restraints. AIM will be implemented by an experienced team using proven processes, techniques, and systems including many systems with broad space flight heritage. The result will be a system with low cost, high reliability and unprecedented sensitivity to address the AIM science requirements. The AIM observatory (Fig. D-2) consists of two principal subsystems: 1) the instrument platform assembly (IPA) and 2) the spacecraft (S/C) bus. Use of an IPA enables parallel integration of the instruments and spacecraft bus. A key feature of our approach is use of subsystems designed to have uniform interfaces and common ground test software. This plan streamlines the spacecraft businterface and allows for detailed system and subsystem testing that maximizes efficiency of the integration process. The

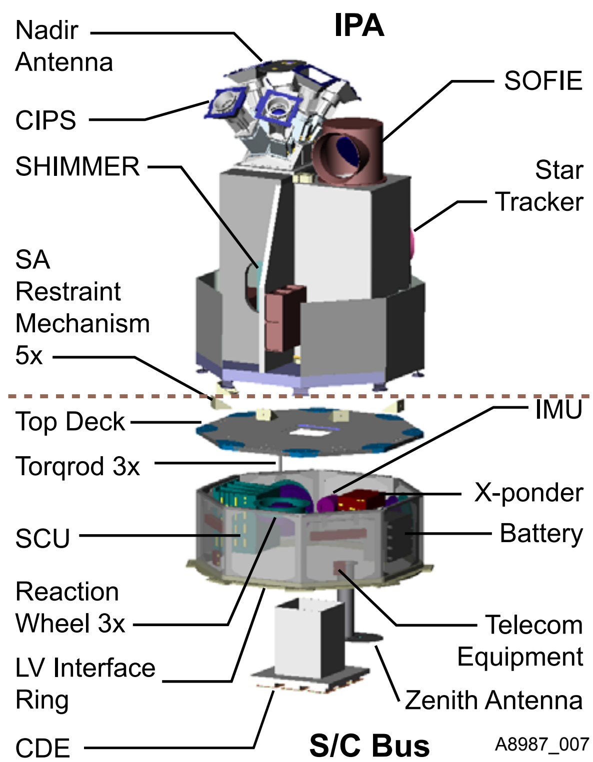


Figure D-2. The AIM Spacecraft Bus Provides the Required Power, Data Rate and Pointing With Reaerve.

instrument and platform are assembled and checked out at the platform level to assure a fully functional instrument package prior to delivery for final integration with the spacecraft bus. This approach has been tested on two past missions, Solar Mesosphere Explorer (SME), and Solar Radiation and Climate Experiment (SORCE) and found to reduce overall cost and risk to the program.

IPA. The IPA consists of four instruments, a Star Tracker and the platform structure. The instruments are:

- SOFIE (Solar Occultation For Ice Experiment), an eight channel infrared solar occultation differential absorption radiometer that measures temperature, PMCs, H_2O, CO_2, CH_4, NO, O_3 and aerosols.
- SHIMMER (Spatial Heterodyne IMager for Mesospheric Radicals), a UV limb imaging interferometer that measures OH, PMCs, and temperature.
- CIPS (Cloud Imaging and Particle Size experiment), a panoramic UV nadir imager that

provides PMC images and particle property information.

- CDE (Cosmic Dust Experiment), an in-situ dust detector that measures cosmic dust input which is a potential key factor in PMC formation.

CDE is mounted directly to the spacecraft but is considered part of the IPA because it shares the common interface to the spacecraft.

This instrument suite provides the comprehensive measurements needed to meet the AIM scientific objectives. Required precisions have been demonstrated using instrument designs and detailed end-to-end signal, noise and science retrieval simulations. The University of Colorado, Laboratory for Atmospheric and Space Physics (LASP) will provide the CIPS and CDE instruments and the instrument platform assembly. The Utah State University (USU) Space Dynamics Laboratory (SDL) will provide the SOFIE instrument and the Naval Research Laboratory (NRL) will provide SHIMMER. The SOFIE design is based on the highly successful HALOE instrument operating on the Upper Atmosphere Research Satellite (UARS) satellite. The SHIMMER experiment builds on the Spatial Heterodyne Spectroscopy (SHS) instrument of similar design soon to be launched on the Space Shuttle and on implementation methods and science data processing algorithms developed for the MAHRSI experiment flown on the Cryogenic Infrared Spectrometer and Telescopes for the Atmosphere-Shuttle Pallet Satellite (CRISTA-SPAS) mission. CIPS heritage derives from the charged couple device (CCD) array and filters used for the Rosetta mission soon to be launched to study comets. Use of backscattered ultraviolet light to observe PMCs has been demonstrated in orbit by the SBUV experiments. The CDE design builds on technology demonstrated in the successful VEGA 1 and 2, STARDUST, CASSINI and ARGOS missions.

Spacecraft. The spacecraft is the Ball Aerospace & Technologies Corp. (BATC) RS300 bus modified to accommodate the requirements of the AIM mission. The RS300 includes 85% space heritage components and proven BATC approaches that have provided a highly successful track record of space flight systems. All successfully launched BATC spacecraft have met/exceeded or are meeting/exceeding mission objectives. This low-cost bus capitalizes on ongoing Independent Research and Development (IR&D) activities, innovative design, and Ball's 40-year history of successful space systems. BATC has developed the RS300 baseline design concept to a Phase B level, and it has successfully passed a peer design review. The RS300 meets all AIM requirements with sufficient margins and with only a few modifications to the baseline design. The spacecraft includes a fine pointing system and can yaw twice per orbit before the spacecraft reaches 17 deg latitude in the PMC hemisphere, thereby meeting science requirements. The S/C can also perform small (< 9 deg) yaw maneuvers in the polar regions to ensure measurement of the same atmospheric volume by SOFIE, CIPS and SHIMMER. The yaws in the polar regions to obtain the required spatial coincidence have been planned using orbital coverage simulations with interactive graphics.

Launch Vehicle and Orbit. A Pegasus XL-Hydrazine Auxiliary Propulsion System (HAPS) rocket will launch AIM into polar orbit from the Vandenberg Air Force Base launch facility. The desired orbit is 500 km, 97.4 deg inclined, circular, sun-synchronous at a local time of noon/midnight. The Pegasus XL has the ability to place AIM into this orbit with a 42.5 kg mass reserve. The selected orbit provides the required geographical coverage, optimal overlap of measurements with different observation strategies and Earth sunset observations by SOFIE in the north. In addition, the noon/midnight orbit is optimal for SHIMMER measurements because the OH concentration peaks at this local time at most latitudes. The nominal mission lifetime is 23 months providing coverage of four PMC seasons (two in each hemisphere) and the planned launch date is September 30, 2005. The nominal orbital altitude is sufficient to provide the desired mission lifetime; therefore, no propulsion systems are needed for the AIM spacecraft for orbit boost or orbit maintenance.

Mission Operations. The science requirement for spatial and near-temporal measurement coincidence is achieved by judicious instrument orientation on the spacecraft, by taking advantage of the sun-synchronous orbit geometry, and by using the aforementioned yaw maneuvers (**Fig. D-3**).

With the instrument mounting configuration shown, SHIMMER observes ahead of the spacecraft as it orbits the earth in the day-to-night direction; a few minutes later CIPS makes measurements in the nadir direction when over-flying the region previously sampled by SHIMMER; during sunset SOFIE stares at the sun with the limb tangent point passing through the atmospheric sample previously observed by the other

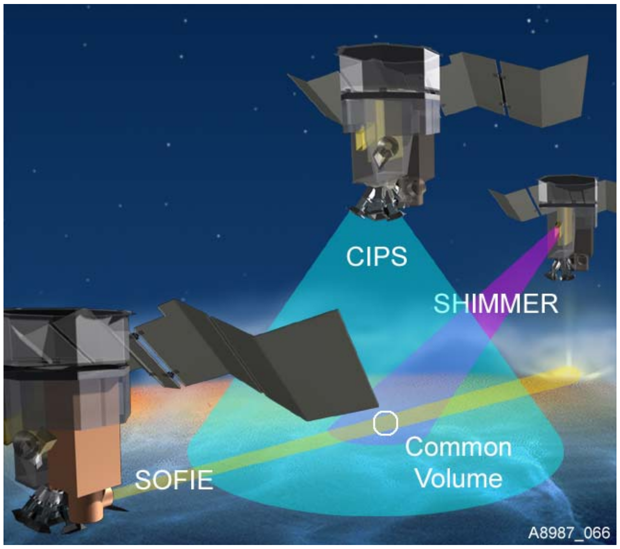


Figure D-3. AIM Observation Strategy Provides Required Spatial and Near Temporal Coincidence

two instruments. SHIMMER and SOFIE data are taken within ± 6 minutes of CIPS.

Mission operations will be conducted by LASP. LASP is currently operating two spacecraft, SNOE and QuickSCAT, and is preparing to operate two more missions, ICESat and SORCE. The AIM mission operations center will be built using existing hardware, software, and procedures, as well as personnel already in place at LASP. The approach used is state-of-the-art, low cost and space flight operations proven. The primary ground stations will be the Honeywell DataLynx PF1 11-meter antenna at Poker Flat, Alaska and the Kongsberg 11-meter SKS antenna in Svalbard, Norway. An S-band communication pass will be executed for up to 11 minutes duration. Passes will be scheduled approximately one week ahead of time with one of the antenna facilities listed above. Nominally two passes per day will be executed. **Table D-1** summarizes our detailed study of uplink/downlink requirements and link margins.

The AIM Data Management Plan calls for rapid data dissemination to the scientific community-

Table D-1. AIM Downlink And Uplink Requirements Show Adequate Margins

Element	Uplink	Downlink
Spacecraft Antenna	LGA	LGA
Coverage Az/El	Omni 2 antennae	Omni 2 antennae
Min Reqd. Gain (dBi)	-6	-2
Data Rate	2 kbps	4 Mbps
Worst-Case Margin	**35.0 dB**	**9.3 dB**

Note: Margins for maximum link range (2330 km)

on a schedule of five days after receipt- starting six months after launch with final data archival in the National Space Sciences Data Center (NSSDC).

Management. The AIM management approach provides an efficient organizational structure with clean interfaces and clear lines of authority. The PI, Dr. James M. Russell, has more than 26 years experience leading space experiments and the Project Manager (PM), Mr. Michael T. McGrath, has 28 years in project management and engineering administration. Mr. James L. Raper, Sr., the HU Program Coordinator (PC), who has 33 years experience managing and coordinating flight projects at NASA will assist them. The PI is the single point of contact for AIM and maintains overall responsibility and decision-making authority for the program. He will ensure the technical and scientific success of the mission, the integrity of the investigation and the successful implementation of the E/PO program. Dr. Scott Bailey, the Co-PI, will assist the PI in managing all AIM activities and will also oversee the E/PO effort. The AIM Co-I team collectively has broad expertise and experience implementing satellite experiments and conducting data analysis. HU, the PI institution, will serve as the Prime Contractor to NASA and will issue subcontracts to LASP and GATS. LASP will issue and manage subcontracts to BATC and SDL. NRL funds will be received directly from NASA.

The PM at LASP will report directly to the PI. He will manage the overall mission technical implementation including all instrument, and spacecraft activities; he will maintain detailed schedule, cost tracking and earned value assessment systems at LASP and keep the PI informed of progress and problems. HU will oversee data management activities.

Reserve Management. The AIM team has developed an ordered, efficient and streamlined approach for reserve management that is described in Section G. The general philosophy is to empower key team leaders to keep decision making at the lowest level. The central focus of the reserve management plan is compartmentalizing schedule and costs and tracking these changes using the Work Breakdown Structure (WBS). AIM cost and schedule will be tracked at the WBS Level 4. Project reserves are 20% in cost and mass, 12% (18.5 weeks) in schedule and 18.4% in power with an additional 19% power margin. Decision approaches to technical, schedule and cost resource management are based on reserve requests compared against allocation versus time curves. Planned costs and cost reserves allocated by project phase are given in **Table D-2**.

Costs. AIM costs have been estimated using a "grass roots" approach working at the WBS Level 5. This AIM SMEX activity represents the third proposal effort for this mission and consequently, the cost areas and work complexities have been thoroughly studied, clearly defined and are understood. We have updated estimates based on the Phase A effort, which in some technical areas, extended into Phase B-level work. The cost reserve allocation is 20% in all areas except science, mission operations and the launch vehicle. Science costs are well known based on team experience. Similarly, LASP's current and past involvement, and direct experience in mission operations allow very accurate cost estimates to be made. Our study result is a cost plan that provides the clear roadmap needed for cost management and control throughout the project development.

Education and Public Outreach. The AIM E/PO plan is mature, capitalizes on the high public visibility of the science being done by AIM, includes real involvement by science team members and is focused on contributing to training of underserved groups in science and technology including African Americans and Native Americans. Our plan addresses the three key areas of K-14 Education, Informal Education, and Public Awareness, and establishes an approach for performance evaluation and program adjustment. Key elements of the program include a professional development workshop for educators; web based instruction with *WebQuests*, National Center for Atmospheric Research (NCAR) Windows on the Universe and an official AIM E/PO website; students collecting NLC digital images; regional teacher's workshops; a teacher intern program at HU; NASA connect video production; public television and radio productions; SEC Forum participation; and science center and after school science club involvement. The AIM E/PO director, Diane Q. Robinson, is a science educator with extensive outreach experience. She is currently the E/PO Director for the satellite-research based Earth System Science Pathfinder 3 (ESSP3) mission and serves on numerous science education advisory boards.

New Technology and Small Disadvantaged Business (SDB) Plan. The AIM team is committed to placing at least 8% of its subcontracts with small disadvantaged business concerns, Historically Black Colleges and Universities (HBCU), and minority educational institutions. AIM partners have a strong track record showing their commitment to SDB contracting. HU, an HBCU, will receive 6% of the contract funds with total funding to HBCU's and SDB's of 12%. New technology is being used for the spacecraft (Li-ion batteries; virtual machine extension (VME) Bridge chips; Starys heat switch) and SHIMMER (monolithic interferometer). All technologies are at an advanced stage of development and risk mitigating steps have been identified.

Table D-2. Costs and Reserves by Project Phase

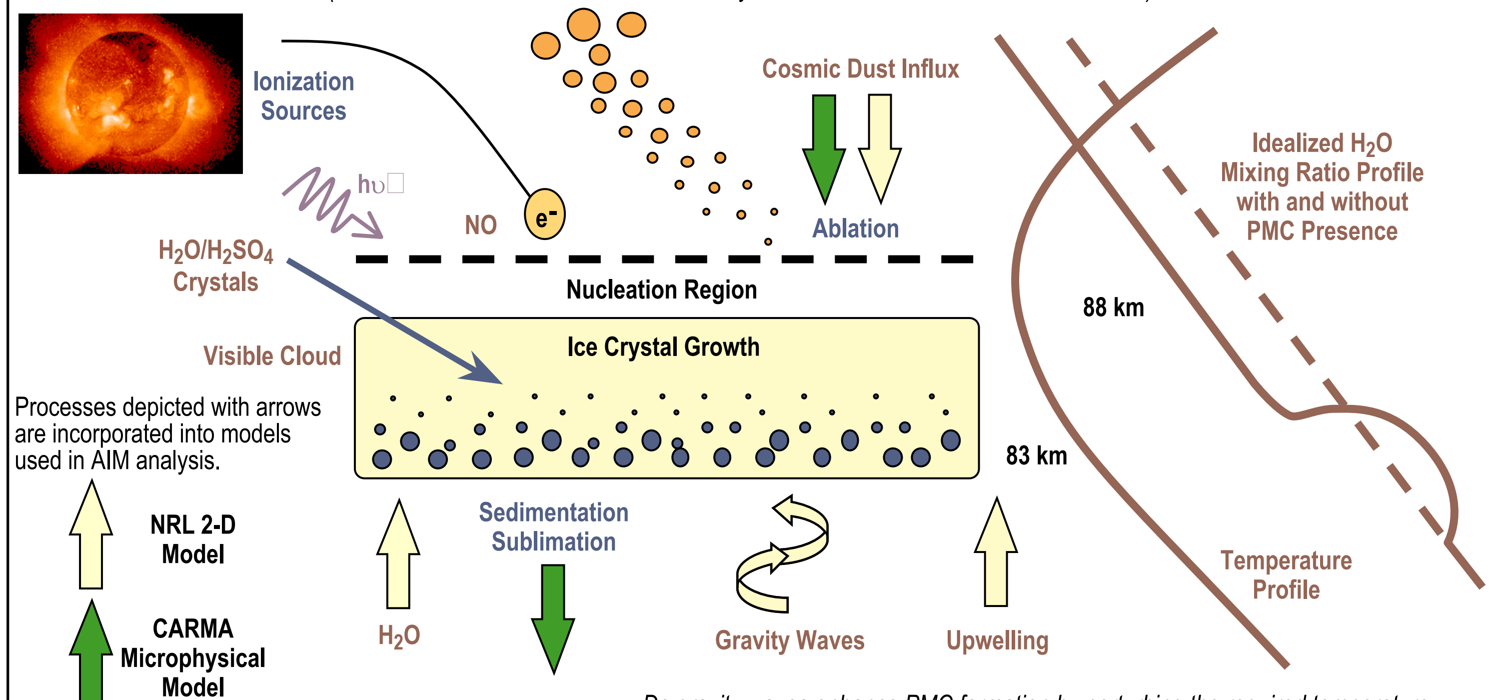
Mission Phase	Cost* $ M	Available Reserve $M (%)
B	8.4	1.1 (15)
C/D	53.0	5.5 (78)
E	12.3	0.5 (7)
Total	73.7	7.1 (100)

* FY00 $
Total, with Phase A (0.4), cost; $81.21M

Change in Launch Date Plan. The optimal launch date for AIM is September 30, 2005. Changing this launch date affects science because it could alter our ability to measure four complete contiguous PMC seasons. Since PMCs occur every 180 days, this impact is minimal assuming a full 23-month mission. The impact is periodic and maximizes at about a 15% PMC coverage loss for a 90-day change (because the four seasons are not each contiguous) and zero loss for a 180-day change. The greatest technical impact is for an earlier launch, primarily due to shorter instrument development time, which leads to both increased instrument costs and mission risks. A cost impact will occur for launch delays due to maintaining the engineering team for a longer period of time.

Figure E-4. How AIM Addresses Key Science Questions

(Quantities and text in red are measured by AIM. Blue indicates inferred information.)



What are the global morphologies of PMC particle size, occurrence frequency, and dependence upon H_2O and temperature? (Sec E.1.4.1)

SOFIE, SHIMMER, and CIPS each observe PMCs and are able to observe the same atmospheric volume within 12 minutes time. SOFIE and SHIMMER measure or infer H_2O and T while CIPS determines particle sizes and other cloud parameters. PMC occurrence frequencies and cloud properties will be correlated with H_2O and T.

Do gravity waves enhance PMC formation by perturbing the required temperature for condensation and nucleation? How does dynamical variability control the length of the cold summer mesopause, its latitudinal extent, and observed interhemispheric asymmetry? (Sec E.1.4.2 and E.1.4.3)

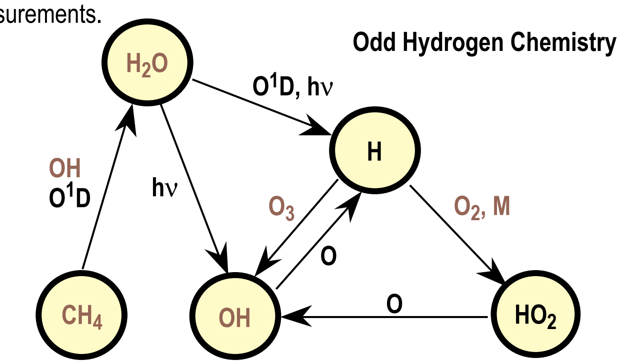
Dynamical measurements by CIPS (gravity waves) as well as SHIMMER (gradient wind) and SOFIE (long lived tracers) coincident with the measurements of PMC properties will allow a determination of the roles that the various dynamical processes play in PMC development. The NRL CHEM 2-D model will be constrained by AIM measurements. When the model can reproduce the AIM PMC observations, it will be validated as a basis for global change studies.

What is needed to establish a physical basis for the study of long-term mesospheric variability and change? (E.1.4.6)

PMCs are dramatic indicators of mesospheric meteorology and climate. In order to understand mesospheric climate changes, we must understand the variability in PMCs.

Is the variability of PMC formation controlled solely by changes in the frost point or do extraterrestrial forcings such as cosmic dust influx or ionization sources play a role? (Sec. E.1.4.5)

AIM will measure the cosmic dust influx and NO, a proxy for ionization sources, and will correlate these with PMC frequency of occurrence measurements.



What are the relative roles of gas phase chemistry, surface chemistry, condensation/sublimation, and dynamics in determining the variability of H_2O in the polar mesosphere? (Sec. E.1.4.4)

AIM will make accurate high vertical resolution measurements of T and H_2O (even in the presence of PMCs) as well as changes in T and H_2O throughout the PMC seasons. Simultaneously, AIM will measure wave activity and atmospheric motions as well as key chemical constituents. A 1-D photochemical model with parameterized heterogeneous processes will be used to compare with AIM observations. A complete model of H_2O variability will be developed for use in the NRL CHEM 2-D model which will then be used for global changes studies.

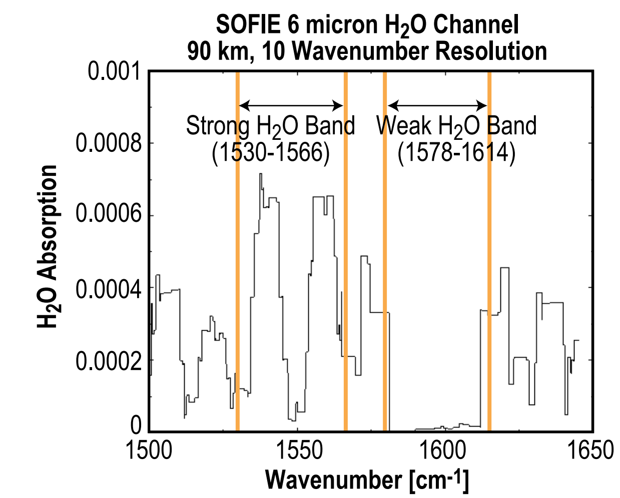


Figure E-6. *Dominant high altitude H_2O absorption feature used by SOFIE.*

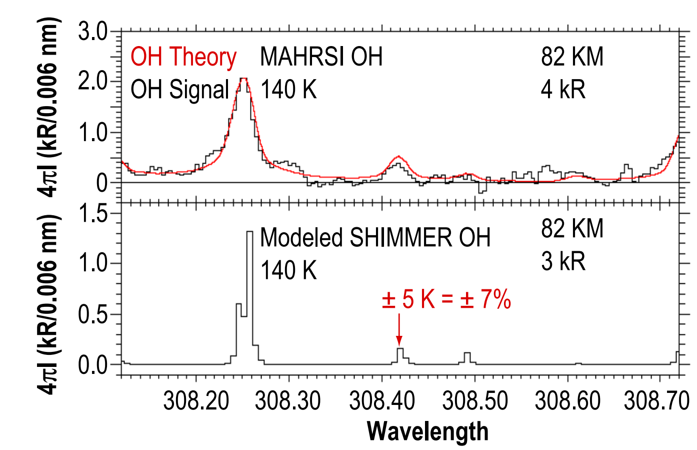


Figure E-7. Upper Panel: *A MAHRSI spectrum obtained from averaging 79 high latitude limb scans (avg. latitude is 69 N).* ***Lower Panel:*** *A modeled SHIMMER OH emission spectrum with the projected 1σ error envelope for an 8s integration overplotted as the shaded region (±0.01 kR/0.006 nm). The OH band radiance used is the average radiance observed by MAHRSI at the top of a PMC.*

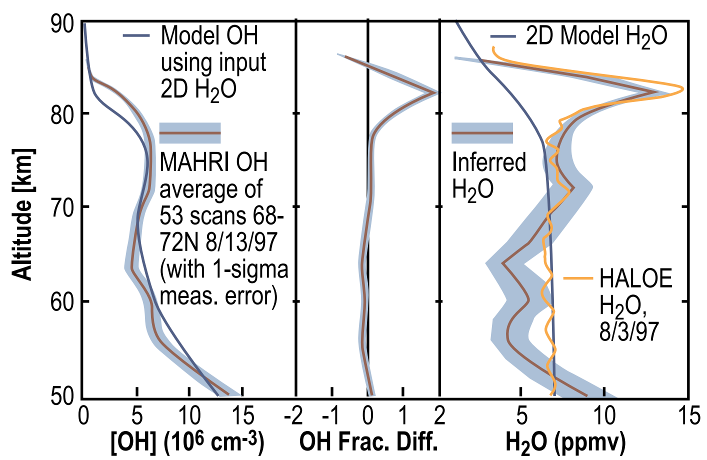


Figure E-3a. *CRISTA-SPAS MAHRSI OH and UARS HALOE H_2O.*

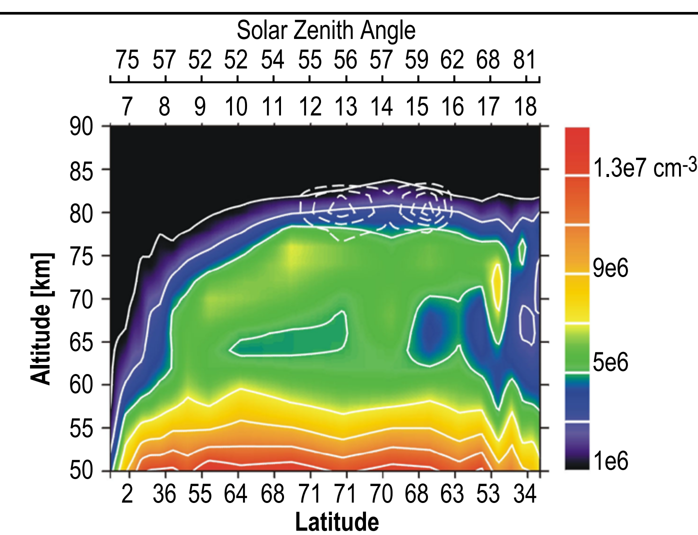


Figure E-3b. *An orbit of MAHRSI OH data August 9, 1997. 22 OH limb scans (46 min. of observation) are interpolated. Dashed contours indicate the simultaneous detection of excess brightness due to PMCs. Dashed contour intervals are in units of BSR where a BSR of 1 is a cloud brightness equal to the Rayleigh background.*

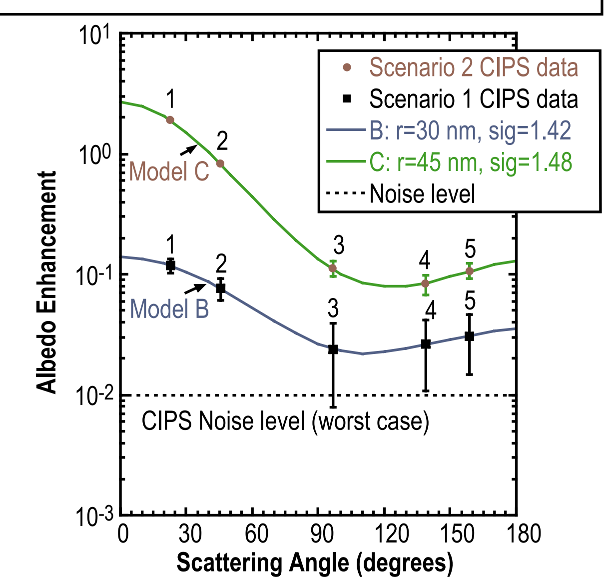


Figure E-9. *Synthetic CIPs albedo enhancement of a cloud element as seen by 5 successive images. Smooth curve: PMC albedo scaled from 3 SME brightness classes (Thomas, 1996). Model D, not shown is >10* background.*

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Foldout E1. AIM Addresses Key Science Questions

E. Summary of Changes from the Original Proposal

Changes in Section E are indicated by blue lettering in the text and vertical bars in the margins. The changes are also summarized below.

Summary of Changes			
Activity Area	**Change**	**Comments**	**Section and Pages**
Science Objectives	None	N/A	N/A
Science Background	PMC sightings at latitudes of ~ 40 deg N have occurred in the three most recent summers; 1999, 2000 and 2001	Suggests that low latitude events are becoming more common. Such sightings, occurring far south of their normal occurrence (55 deg N) make it more likely that these events are signals of a pervasive long-term change in upper atmosphere climate.	Section E.1. 1, Pg. E-2 and E-3
SOFIE Implementation	Short wavelength channel added giving a total of eight. Photoelastic Modulator (PEM) dropped in lieu of simpler mechanical chopper. Number of detectors and thermoelectric (TE) coolers increased from 7 to 16. Telescope diameter reduced from 20 cm to 15.24 cm; focal length reduced from 60 cm to 40 cm.	Eliminates PEM technical risk and removes a single point failure mode. Mechanical chopper is driven by HALOE-like hysteresis synchronous motor providing high reliability and heritage. Telescope reduction decreases mass with no science impact.	Section E.2.1, Pgs. E-9, E-11, and E-12
SHIMMER Implementation	Spectral passband and integration time reduced from 2 nm and 4 sec to 0.33 nm and 10 sec respectively. Data rate and number of images cut from 18 to 4.7 Mbytes/orbit and 250 to 130 images/orbit.	Provides increased signal-to-noise (S/N) for the temperature dependent OH feature. Decreases come from sampling only the PMC (summer) hemisphere and using the smaller passband.	Section E.2.1, Pg. E.12, E-13, and E-14
CIPS Implementation	Panoramic images per orbit reduced from 70 to 34. Integration time reduced from 2 sec to 0.24 sec. Data compression reduced from a factor of four to two (250 to 523 Kbytes/image)	Allows lossless compression and gives better image fidelity with no change in data rate. Image reductions occur in the non-PMC, i.e., winter, hemisphere	Section E.2.1, Pg. E-14, E-15, and E-16
CDE Implementation	Time-of-flight dual film design changed to single film design with nine Polyvinylidene Fluoride (PVDF) segments.	Lowers mass detection threshold enhancing science; doubles detection surface area and increases the particle hit count rate; provides weekly (perhaps daily) cosmic dust influx variations	Section E.2.1, Pgs. E-16 and E-17
Figures and Foldout Changes	Some figures on Science FO-E1 moved to Fig. F-19. Science implementation FO-E2 deleted; some figures placed in text; others updated and/or moved to Section F.4. Data in Table E.2-1 moved to FO-F1; table deleted.	Eliminates repetitive or redundant figures and information; moving Section E figures into the text and other figures and information to Section F aids the reader.	Section E.1 and E.2
Minimum Mission	Minimum mission clarified	Minimum mission and science impacts more clear.	Section E.2.3, Pg. E-18 and E-19
Data Plan Schedule	Updated to conform with new SMEX schedule	N/A	Section E.2.4, Pg. E-19, E-20, and E-21
Co-Is	Two Co-Is added to the Science Team, one dropped and one Co-I confirmed	R. Meir and C. Englert, NRL, added when R. Conway retired. P. Espy confirmed as Co-I. G. Sachse, NASA, LaRC asked to be released as Co-I when the PEM was deleted.	Section E.2.5, Pg. E-21

E.1 Science Investigation

E.1.1 Overview

Noctilucent, or "night-shining" clouds (NLCs) are the highest altitude clouds in the atmosphere, occurring near 85 km in summer. This region, known as the mesopause, is also the coldest place on Earth, reaching temperatures as low as ~130 K. The name derives from the fact that the clouds are seen just after sunset, when the ground is in darkness, but the upper atmosphere is still sunlit. The past 30 years of ground-based observations from northwest Europe show a dramatic increases in the number of NLCs (**Fig. E-1**). These clouds, known to satellite observers as Polar Mesospheric Clouds (PMCs), are believed to respond dramatically to even small changes in their environment. Since cooling of the upper atmosphere is expected to accompany the possible warming of the lower atmosphere due to an increased greenhouse effect, increasing mesospheric cloudiness could be one consequence of mesospheric climate change. If reported NLC increases are truly representative of the entire polar region, then this beautiful sky phenomenon may be our most visual manifestation of anthropogenic change in the atmosphere (Thomas, 1996).

The science community does not understand why NLC numbers have significantly increased over the past 35 years and whether they are representative of all high latitude regions. The apparent inverse correlation with solar activity but with a two-year lag is also not understood. North-south differences in PMC brightness, and in the related radar phenomenon of Polar Mesosphere Summertime Echoes (PMSE), are also not understood. If we could ascribe the changes in cloud occurrence and brightness to the various atmospheric and extraterrestrial forcings to be described later, we could use the historical record to explain the changes that have already occurred. Even more exciting, we could use current and future observations of PMCs to assess the role of both natural and anthropogenic influences on the atmosphere. The problem is that the present-day physical properties at the summertime mesopause are poorly known, their changes over time are even less well understood and models poorly describe the phenomena; all because of an insufficient data base. Thus we cannot currently interpret PMC changes in terms of fundamental atmospheric changes. To establish the basis for new predictive PMC models, we need high precision measurements of PMCs and key chemical constituents for various conditions of temperature, pressure, density and H_2O concentrations.

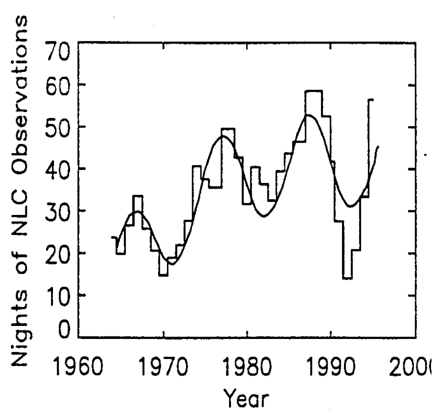


***Figure E-1**. The variation in the number of nights that NLCs were seen in a particular year, for the period 1964 to 1995. The superposed curve is a least squares fitted logistic curve plus a sinusoid (Gadsden, 1998). Maxima in the 11-year solar cycle occurred in 1958, 1969, 1980 and 1991. Each maximum in NLC occurrence follows the time of solar minimum by about two years.*

The overall goal of the Aeronomy of Ice in the Mesosphere (AIM) experiment is to resolve why PMCs form and why they vary. By measuring PMCs and the thermal, chemical and dynamical environment in which they form, we will quantify the connection between these clouds and the meteorology of the polar mesosphere. In the end, this will provide the basis for study of long-term variability in the mesospheric climate and its relationship to global change. The results of AIM will be a rigorous validation of predictive models that can reliably use past PMC changes and present trends as indicators of global change. This goal will be achieved by measuring PMC abundances, spatial distribution, particle size distributions, gravity wave activity, dust influx to the atmosphere and precise, vertical profile measurements of temperature H_2O, OH, CH_4, O_3, CO_2, NO, and aerosols. These data can only be obtained by a complement of instruments on an orbiting spacecraft (S/C).

During the summer of 1999, PMCs attained the highest degree of U.S. public awareness in history, with the remarkable sighting on June 22-23 of a vast noctilucent cloud at locations (Colorado and Utah) where they have never before been seen. While PMCs are often observed in the polar summer mesosphere, the sudden occurrence of such a dramatic low latitude display was unexpected. Dozens of news accounts appeared in the media. If this event was due to mesospheric climate change, we cannot explain to the public why it happened so fast. Mid-latitude NLCs have now been sighted in the two successive northern summers since 1999. Rather than being an isolated event, as described in our first proposal, these new sightings (including a measurement from the SNOE spacecraft) make it more likely that these extraordinary events, occurring far south of their normal occurrence latitude (> 50 deg), are signals of a pervasive long-term change in upper atmosphere climate. Accounts of the observations on June 22-23, 1999 have been described in recent papers submitted for publication (Wickwar et al. 2001; Taylor et al. 2001).

Thus the time is right for a carefully focused space mission to address this issue. The fact that people in highly populated areas can now view NLCs highlights the pressing need to understand their formation and their possible relationship to global change.

The AIM experiment includes four instruments:

- SOFIE (Solar Occultation For Ice Experiment), an infrared (IR) solar occultation radiometer.
- SHIMMER (Spatial Heterodyne IMager for Mesospheric Radicals), an UV interferometer.
- CIPS (Cloud Imaging and Particle Size experiment), a panoramic UV imager.
- CDE (Cosmic Dust Experiment), an in-situ dust detector.

A Pegasus rocket will launch the AIM satellite into a 500 km, 12:00 PM sun-synchronous orbit. Flight operations will be conducted by the University of Colorado (CU).

E.1.2 History and Basis for the Proposal

Clouds form each summer in the polar mesopause region (82-87 km). First recorded by Backhouse (1885), they occasionally provide spectacular displays to observers usually between 50 deg and 65 deg latitude. The existence of clouds during a three-month period around summer solstice is related to the peculiar dynamically driven seasonal drop of temperature below the frost-point (150 K). The true spatial extent of mesospheric clouds was not known until space observations revealed clouds over the entire dayside polar cap region (Donahue et al. 1972). In this manifestation, they are known as PMCs, and are believed to be the same phenomenon as NLCs (Thomas, 1991). The long standing assumption that these clouds consist of tiny water-ice crystals (sizes < 100 nm) (Rusch et al. 1991; Lubken, 1996), was only recently proven using HALOE measurements (Hervig et al. 2001).

The interest in PMCs as a climatic indicator stems from their sensitivity to temperature, and to theoretical predictions of the temperature response of the mesosphere to increased greenhouse gas emission. Climate models predict that, as greenhouse gases increase, the optically-thick troposphere is back-warmed by the additional opacity while the optically transparent upper atmosphere (>20 km) is cooled. To explain the NLC increase observed over 25 years Gadsden, (1990) estimated that a mesopause cooling of 7 K is needed. Such a dramatic cooling would equal that expected from a doubling of CO_2 (Roble and Dickinson, 1989) in contrast to the actual CO_2 increase of 10%. The limited data shown in **Fig. E-2** do suggest unexpectedly large cooling; however, it is unclear whether the widely distributed observations, mainly below 80 km, are relevant to the high-latitude summertime mesopause region.

First, there is increasing evidence that the cooling trend above 75 km decreases with height, and possibly even reverses. The recent report of Bittner et al. (2000) shows no comparable cooling trend at 87 km since 1980. In addition, a CO_2-induced trend reversal is predicted by a 3-D model (Akmaev and Fomichev, 1998, 2000). Also, newer ground-based data (Golitsyn, 1996) suggest that the cooling trends seen in Fig. E-2 are predominantly due to changes in winter. Alternatively, if temperature changes are not responsible for the dramatic NLC changes (Fig.

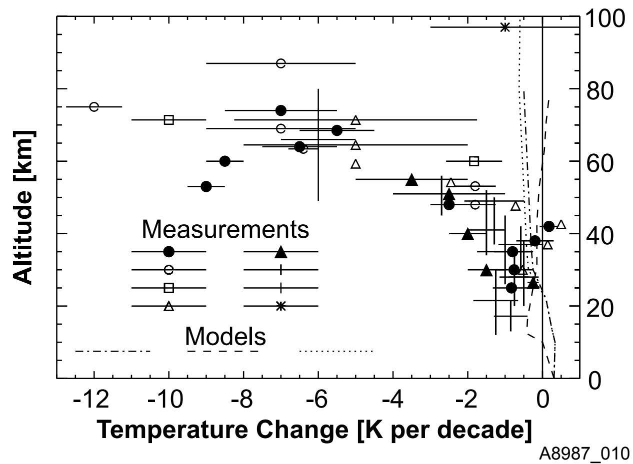


Figure E-2. Decadal rate of temperature change according to long-term data sets and models. The Stratospheric Sounding Unit (SSU) satellite values (vertical bars) apply to global averages. The Union of the Soviet Socialist Republic (USSR) data sets are divided into high-latitude (closed circle), mid-latitude (open circle), and tropical regimes (open square). The remaining measurements apply to mid-latitude data. The models are taken from doubled-CO_2 runs and linearly scaled assuming a 4% CO_2 per decade increase (See Fig. E-2 references in Appendix M14).

E-1), the cause could be increases in mesospheric H_2O. Water vapor did increase by 10% in the stratosphere from 1992-1996, but has since leveled off (Randel et al. 1999). Over longer time scales, the increase in cloud occurrence appears to be much greater than can be explained from increasing H_2O (Gadsden, 1999).

Confounding our ability to understand PMCs as a global change indicator are fundamental limitations in our understanding of how these clouds nucleate, the environment in which nucleation occurs, and how the mesosphere responds to either lower atmospheric or extraterrestrial forcing. The simplest models of PMC formation suggest that super-saturated conditions must be present before nucleation occurs (see **Foldout (FO)-E1**). However even this hypothesis remains untested because we have no comprehensive knowledge of the chemical/ thermal environment in which PMCs form. *Simultaneous measurements of PMCs, temperature, and H_2O in the PMC region are the essential foundation for studying cloud formation*. They are the basis for determining the extent to which PMC occurrence is controlled by other factors, including cooling in the cold phase of gravity waves (GW), the influx of ablated meteoric “smoke” particles (Turco et al. 1982: Jensen, 1989), and the presence of proton hydrate ions (Reid, 1989). The possible correlation of these factors with PMC formation has never been tested with relevant global data.

A thorough understanding of H_2O chemistry is also critically important since PMC particles most likely consist of water ice. No measurements exist of H_2O in the summer polar mesopause region with the necessary vertical and time resolution. Additionally, our understanding of mesospheric H_2O chemistry has been thrown into doubt by new measurements from two different experiments—HALOE and MAHRSI (inferred from OH; **Fig. E-3a, FO-E1**). These experiments show an unexpected layer of H_2O in the mid-mesosphere (70 km) at high latitudes where conventional theory says no in-situ source of H_2O should exist (**Fig. E-3b**, **FO-E1**; Summers et al. 1997b). One possible mechanism is that heterogeneous chemistry on the surfaces of cosmic dust particles converts O and H_2 into H_2O (Summers and Siskind, 1999; Thomas, 1991). H_2O and its photodissociation products, H and OH, are closely coupled to the odd oxygen species, O and O_3. In order to confidently infer H_2O from OH measurements, knowledge of this coupling is essential (Summers et al. 1997a). Thus to understand mesospheric H_2O and ice, one must measure O_3.

Finally, the distributions of longer-lived constituents (e.g., H_2O) and temperature depend upon the large-scale circulation. The high latitude mesosphere experiences the largest vertical velocities in the entire middle atmosphere (2-3 cm/sec). The intense summer (winter) upwelling (downwelling) causes the mesopause temperature to depart dramatically (50-100 K) from radiative equilibrium. Summer ascent leads to enhanced H_2O which, we believe, sets the stage for cloud formation. Furthermore, GW are important in shaping the PMC layer (see cover image), and they affect cloud lifetimes (Jensen and Thomas 1994). It is thus essential to simultaneously measure chemistry, large-scale dynamics and wave activity in order to obtain closure in understanding cloud microphysics.

E.1.2.1 Significant New Science Developments Since January, 2000

A number of recent developments in the study of PMCs have occurred since the Step-1 proposal was submitted emphasizing the accelerating importance and interest in understanding why these clouds form, how they vary and their relationship to climate change.

- A breakthrough in our understanding of PMC composition was recently published by our group proving that at least some bright PMCs are composed of water-ice (Hervig et al. 2001). By inference, this implies that most PMC are ice clouds. This result was achieved through the analysis of multi-spectral HALOE extinction measurements, a method that will be applied in the AIM mission, and even improved upon with SOFIE's significantly enhanced sensitivity. An unexpected bonus is the sensitivity of the near-IR extinctions to particle size, which means that we will have two separate and independent determinations of the cloud microphysics at the constant volume intersection of the CIPS and SOFIE measurements.
- A paper documenting new evidence for a significant brightening of PMC between the 1980's and 1990's was recently accepted (Shettle et al. 2001).
- An important paper by an AIM team member validating the technique of inferring water vapor from OH in the summer polar mesosphere recently appeared in GRL (Summers et al. 2001).
- A key paper exploring the relationship between water vapor supersaturation and PMCs in the summer polar mesosphere (Science

Foldout E1

Objective E.1.4.5) by providing a brief 17-minute snapshot of temperature, OH and PMC data was accepted by *GRL* (Stevens et al. 2001).

- An article on noctilucent clouds by an AIM team member appeared in the November, 2001 issue of *Smithsonian Magazine*, which has a circulation of 2 million (Stevens et al, 2001).
- An AIM Science Team member (M. Stevens) was interviewed on NLCs in a National Public Radio segment aired in November, 2001 showing the heightened public interest in this science subject.
- AIM is a SMEX mission recommended for funding in a preliminary National Academy of Sciences report on future needs of space science.
- A one-and one-half day Symposium entitled *Polar Mesospheric Clouds, Noctilucent Clouds and Polar Mesospheric Summer Echoes* was held at the Spring American Geophysical Union (AGU) meeting on May 29 and 30, 2001. A total of 48 papers were given, and the sessions were well attended. A paper on PMC observations from the SNOE satellite by A. Merkel at LASP won the award for the best student presentation in her section. In addition, a three-day International Workshop on *Layered Phenomena in the Mesopause Region* was held in Monterrey, California, October 10-12, 2001. More than 55 papers were presented. Two topical meetings in one year illustrates the vigor and growing importance of the subject.
- A new international working group on trends in the upper atmosphere, with emphasis on the mesosphere, was recently formed under the auspices of Scientific Committee on Solar-Terrestrial Physics (SCOSTEP) and Stratospheric Processes and Their Role in Climate; Computer Workstation (SPARC). The first meeting of the group which is entitled, *Understanding Mesospheric Change* will occur in May, 2002 in Kuehlingsborn, Germany at the Institute for Atmospheric Physics.
- A five-day workshop on the subject of trends in the middle atmosphere and lower thermosphere was held in Prague, Czech Republic, on July 1-6, 2001. This workshop was such a success that a similar symposium is planned for the 2003 International Union of Geodesy and Geophysics (IUGG) meeting in Sapporo, Japan.

E.1.3 Need for the Investigation

The possibility that PMCs are increasing as a result of industrial and/or agricultural activity is of great societal concern and their study should be included in a national program of climate assessment. Until the theory of PMC formation is placed on a better observational and theoretical footing, the separation of natural and human-induced forcing will not be possible. This and the fact that PMCs are so highly variable requires a comprehensive, space-borne, observational and theoretical investigation of the polar summer regions. AIM ties directly into NASA's Sun-Earth Connection (SEC) program goals and objectives. One goal in the SEC Roadmap calls for study of PMCs and the global mesospheric water vapor cycle in the context of global change. AIM will accomplish this goal.

E.1.4 Science Goals and Objectives

The overall goal of AIM is to resolve why PMCs form and why they vary. This will be achieved by addressing six specific science questions. Five of these questions (Sections E.1.4.1-E.1.4.5) deal with mechanisms for PMC formation, i.e., when and where they occur and how they respond to changes in their thermal, chemical and dynamical environments. The AIM data and their interpretation will answer these five questions directly. The sixth question (Section E.1.4.6) links PMCs to the larger question of mesospheric climate change. The models we will develop and validate to answer the first five questions will be used to address this last question. The questions and our approach to addressing them are detailed below and in **Fig. E-4** on **FO-E1**.

E.1.4.1 PMC Microphysics

What is the global morphology of PMC particle size, occurrence frequency and dependence upon H_2O and temperature?

The simplest model of PMC formation presumes the existence of supersaturated conditions; however, even this most basic assumption has not been validated because we lack comprehensive data on the relative humidity of the polar mesopause region and its association with PMC occurrence. More detailed microphysical modeling suggests that after nucleation, the cloud particle eventually grows large enough that it falls into a region of warmer temperatures where it sublimates. It has been suggested that the resultant evaporated H_2O can be then relofted into the region of cold temperatures where the condensation/growth/decay process cyclically repeats. Sugiyama (1994) has postulated that an apparent periodicity in the strength of PMSEs is consistent with this view. One signature of this process would be a layer of enhanced H_2O lying just below the cloud layer; indeed we may have already detected such a layer (e.g., Fig. E-3b, FO-E1). The cycling time is also sensitive to the particle size; large particles would fall more quickly and would require higher H_2O abundances to form. They would also need stronger upwelling rates to remain buoyant long enough to grow.

The AIM measurement complement will be able to finally verify the ideas discussed above by producing daily, simultaneous global maps of mesospheric temperature, H_2O and PMC morphology. Statistical studies of H_2O/T/PMC correlations will be invaluable in validating various microphysical scenarios. The possible correlation of PMCs with either H_2O or temperature will allow us to isolate which of the two is the key driver for cloud formation. We will also be able to estimate the amount of water taken up in clouds and compare this with the measured cloud densities and particle sizes.

E.1.4.2 Gravity Wave Effects

Do GW enhance PMC formation by perturbing the required temperature for condensation and nucleation?

Gravity waves have long been believed to be highly relevant to PMC microphysics. Qualitatively this is suggested by the wavelike patterns observed in NLC displays (see cover and Fritts et al. 1993). The seasonal change of waves in the mesopause region are considered to be the single most important factor in driving the vigorous upwelling and low temperature (T) during summer (Luo et al. 1995; Kirkwood et al. 1998). Quantitatively, Jensen and Thomas (1994) suggested that the sublimation of cloud particles in the warm phase of the wave occurred more rapidly than condensation in the cold phases. Thus GW would lower the temperature required for cloud formation below the nominal saturation temperature. By contrast, Klostermeyer (1998) concluded the opposite: cloud condensation would be enhanced by GW. His simulations resemble lidar soundings of NLCs, which indicate an important role for GW in shaping NLCs. Klostermeyer's hypothesis depends upon more H_2O (>6 parts per million by volume (ppmv) than generally accepted for the mesopause region, as suggested by HALOE data (Siskind and Summers, 1998). This accelerates the nucleation process to the point where it is comparable to typical gravity wave periods (minutes to hours). This could explain the observation of clouds in regions where supersaturation is not thought to exist (e.g., last summer over the continental U.S.) and is analogous to processes known to occur with stratospheric mountain waves and PSCs (Bacmeister et al. 1999). AIM will simultaneously measure gravity wave activity, clouds, temperatures and H_2O to test this hypothesis. We will observe GW at two altitudes: at 50 km, through fluctuations in the Earth's UV albedo from temperature perturbations on ozone (McPeters, 1980) and at 80-85 km, by imaging wave patterns in clouds directly. We will also be observing temperature and H_2O over the same latitude range as our imager (see Section E.2.2).

E.1.4.3 Temperature Variability

How does dynamical variability control the length of the cold summer mesopause season, its latitudinal extent and possible interhemispheric asymmetry?

Given that PMCs are likely indicators of extremely cold temperatures and thus of dynamically induced departures from radiative equilibrium, it follows that to understand why PMCs form, we must understand the dynamical factors controlling the existence of the cold summer mesopause. AIM will measure the temperature and dynamical quantities, gravity wave activity and the mean upwelling, which govern the large deviations of the mesopause temperature from radiative equilibrium. Concerning GW, AIM will observe them at two altitudes, near the stratopause and at cloud altitude (see Section E.2.1); the difference between the wave activity at these altitudes can serve as a qualitative indicator of momentum deposition between these two altitudes. Luo et al. (1995) suggested that seasonal variations in wave activity are responsible for the abrupt seasonal temperature changes that are observed. The combination of AIM temperature measurements and wave imagery will allow us to test this hypothesis.

Concerning the upwelling rate, Gadsden (1999) has recently suggested that there is a distinct outer edge (i.e., low latitude boundary) to this upwelling and that changes in the latitude of this edge could help define long-term trends. AIM will measure key tracers that exhibit vertical gradients at different altitudes thus allowing vertical winds to be inferred. This has been done in the stratosphere using UARS data (e.g., Strahan et al. 1998). AIM CH_4 data will be used in the upper stratosphere and lower mesosphere, H_2O in the middle mesosphere and CO_2 at higher altitudes. Temperature measurements will allow the gradient wind to be derived (Manson et al. 1990). These tracers and gradient wind will constrain

2-D models of the mesospheric residual circulation.

Finally, the relative weakness of Mesosphere-Stratosphere-Troposphere (MST) radar echoes (PMSE) in the Southern Hemisphere (SH) has led some to assert that the Southern summer is 5-10 K warmer than the Northern summer (Huaman and Balsley, 1999) (although this is controversial, e.g., Luebken et al. 1999). If true, this would have important implications for the relative brightness of PMCs between the Northern Hemisphere (NH) and SH. Indeed, there is evidence of brighter PMC in the NH (Thomas and Olivero, 1989). The AIM temperature measurements will resolve this question directly. Using AIM results we will also look for possible North/South (N/S) differences in gravity wave activity and upwelling rates which might affect variations in PMC brightness.

E.1.4.4 Hydrogen Chemistry

What are the relative roles of gas phase chemistry, surface chemistry, condensation/sublimation and dynamics in determining the variability of water vapor in the polar mesosphere?

Despite the centrality of H_2O variability (in both vapor and condensed phases) to PMC variability, direct measurements of the H_2O abundance in the PMC region are sparce. H_2O is also the source molecule for the odd hydrogen radicals ($H + OH + HO_2 = HO_x$) which catalytically destroy mesospheric odd oxygen ($O + O_3 = O_x$). By analogy with Polar Stratospheric Clouds (PSCs) and HNO_3/HCl, it is likely that cloud microphysics is intimately tied up with O_x and HO_x photochemistry, both in the gas phase and on aerosol surfaces. Support for this suggestion comes from our previous work where we have used OH as a proxy for mesospheric H_2O and confirmed the existence of a narrow layer of mesospheric H_2O which cannot be explained by conventional gas phase chemistry (Summers et al. 1997a; Summers and Siskind, 1989). Recently, we have used high latitude OH data to infer H_2O. The result, shown in Fig. E-3a on FO-E1 along with newly reprocessed HALOE H_2O, provides provocative evidence in support of a two-layered H_2O distribution.

AIM will dramatically expand the above isolated snapshots of polar mesospheric H_2O using high vertical resolution measurements, unobtainable from current ground based techniques for measuring H_2O (Nedoluha et al. 1998). This is essential given the layering that appears to be present. Vertical diffusion may also be important in controlling the H_2O distribution; this may be inferred from the gravity wave observations combined with models (Section E.1.4.3). Observations of PMCs and O by Gumbel (2000) suggest that O is depleted in the presence of clouds; however, the chemical implications of such depletions are not clear. Simultaneous measurements of H_2O, OH and O_3 by AIM will allow for a rigorous test of our understanding of HO_x/O_x chemistry. By studying the chemical relation between HO_x and O_x under conditions with and without PMCs, the role of heterogeneous chemistry can be statistically isolated, (e.g., Summers and Siskind, 1999; Thomas, 1991). We note that atomic oxygen measurements are not needed for the basic AIM science although we will derive it from our O_3 data.

E.1.4.5 PMC Nucleation Environment

Is PMC formation controlled solely by changes in the frost point or do extraterrestrial forcings such as cosmic dust influx or ionization sources play a role?

As with tropospheric clouds, mesospheric ice particles should form when mesospheric H_2O becomes super-saturated, but only if there are suitable nucleation sites available on which the water vapor may condense. For PMCs, it is unknown which of these conditions is the rate-limiting step controlling their temporal variability. Cosmic dust is thought to serve as a primary nucleation site for PMCs (Hunten et al. 1980). In addition to the AIM frost point data, we will provide a simultaneous determination of the incoming flux of cosmic dust. Dust particles travel in about one minute from the satellite altitude of 500 km to the upper mesosphere where they ablate and recondense as "smoke" particles. AIM in-situ measurements of the incoming dust flux will be used in conjunction with microphysical models of dust ablation and coagulation to deduce the average number of condensation nuclei available in the mesosphere through this process. Modeled profiles of meteoric smoke size distributions were recently used to simulate the SOFIE response. These results indicate that smoke extinctions could be a factor of 10 above the SOFIE noise floor and thus readily detected. Combining these measurements with the incoming dust flux will provide a more complete understanding of meteoric particles and their role in PMC microphysics. We will correlate large changes in the dust influx with possible changes in the occurrence rate and brightness of the PMCs for cases of nearly identical frost-point conditions.

A second possible nucleation site is proton hydrate ions (Witt, 1962). Reid (1989) has suggested that increased ionization would decrease the heavy proton-hydrate ion density through increased recombination and thus decrease PMC formation. We will use observations of the nitric oxide (NO) abundance as a proxy for the ionization rate (Siskind et al. 1997) and correlate this quantity against PMC morphology for air parcels under similar frost-point conditions. National Oceanic and Atmospheric Administration (NOAA)/Television Infrared Observation Satellite (TIROS) electron flux data (Codrescu et al. 1997) will be used to extend this correlation to locations where we will not have NO data (NO will be measured solely by solar occultation at specific latitudes), but still have cloud and frost point data. An anticorrelation between the inferred ionization rate and PMC brightness would support the Reid (1989) hypothesis. This would have important implications for interpreting long term PMC variability since it is well-known that the ionization rate varies roughly with the 11 year solar cycle.

AIM data will not answer all the questions pertaining to the specific mechanism of PMC nucleation. For example, sulfuric acid particles may be a nucleation source, but we will not measure H_2SO_4 directly. This mechanism will be considered theoretically, and its contribution to the nucleation processes will be inferred based on conclusions from the dust and ionization investigations. Despite this limitation, we will provide direct tests of published nucleation hypotheses that are relevant for the larger study of mesospheric climate.

E.1.4.6 Long-Term Mesospheric Change

What is needed to establish a physical basis for the study of mesospheric climate change and its relationship to global change?

As shown in Figs. E-1 and E-2, NLC (and by implication, PMC) occurrences have been increasing and mesospheric temperatures appear to have been declining over the last several decades. Our hypothesis is that PMC occurrence and change are sensitive indicators of global climate change. To test that hypothesis, AIM will provide a new understanding of why such clouds form and how they respond to short term environmental changes. By quantifying the roles of temperature, H_2O and dynamics in forming clouds and by assessing the role of extraterrestrial forcing, we will develop precision criteria for monitoring the upper mesospheric environment. Also, by validating the ability of a global chemical/transport model to simulate the observed seasonal, latitudinal and N/S variations of PMC occurrences, we will develop the capability to do trend assessments. This approach is similar to that taken by 2-D models for stratospheric ozone (World Meteorological Organization (WMO), 1999, chap. 12)

The AIM science traceability matrix giving the flow down from science questions to instrument requirements, system capabilities and mission requirements is provided in **Table E-1** and in the figures on FO-F1.

To the extent possible, we will also take advantage of ground-based lidar and wide-field imagery data and use them in conjunction with CIPS images to determine additional PMC characteristics including PMC heights and thicknesses, PMC tilt angles, and the presence of multiple cloud layers. The 2001 Asilomar working group meeting on layered phenomenon pointed out differences between ground-based and satellite PMC observations and noted unexplained differences in ground-based data themselves. The unprecedented suite of AIM satellite measurements may help resolve some of these issues.

E.1.5 Relationship to Past, Present and Future Investigations and Missions

PMCs have been observed many times from satellites (e.g., SME, HALOE, MAHRSI, WINDII, SNOE, POAM II and SAGE II); but never as the primary objective. Thus these satellites have lacked the complement of instruments and spatial and temporal coverage needed to address the AIM science goals. The upcoming Thermosphere, Ionosphere, Mesosphere, Energetics and Dynamics Satellite Mission (TIMED) mission will include some synergistic measurements (e.g., solar fluxes, T, H_2O, and O_3). However, no TIMED experiment has PMCs as a science objective, and the 74 deg TIMED orbit inclination is not as favorable for polar soundings as is the AIM sun-synchronous orbit. Also, the AIM measurement techniques of absorption and scattering for T, H_2O, and O_3 offer considerable advantage over the TIMED approach of emission radiometry since thermal emission is minimal in the cold summer mesopause region. Other satellites collecting mesospheric data in the next decade include Earth Observing Satellite (EOS)-AURA, to be launched in 2004, and ODIN, which was launched in Spring, 2001. The EOS-AURA focus is on lower stratospheric ozone and tropospheric phenomena. ODIN will make UV/VIS/NIR and submillimeter wave limb measurements of T, H_2O, O_3, N_2O, chlorine dioxide (OClO) and aerosols in the stratosphere and mesosphere with about 4 km vertical resolution. However, ODIN will view exclusively in the limb with no imaging

Table E-1. AIM Science Traceability Matrix

Science Question	Required Geophysical Information	Measurements: Observable†	Measurements: Alt Range (km)‡	Measurements: Mission Requirements	Analysis	Science Results
1. What is the global morphology of PMCs, particle size, occurrence frequency and dependence upon H_2O and temperature? (see E.1.4.1)	PMC morphology PMC particle sizes Temperature H_2O density profiles	Scattered sunlight[1, 3], extinction[2] Mie scattered sunlight[1] CO_2 absorption[2], OH line ratios[3] H_2O absorption[2], OH fluorescent scattering[3]	80 – 85 80 – 85 15 – 110 70 – 82 15 – 95 55 – 85	Space-based mission; Low Earth polar orbit; Three PMC season life (in the same hemisphere); Ability to point at sun, nadir, and at the limb; See Table F-4 on FO-F1 for a list of resource requirements for each instrument	Correlate PMC occurrence frequencies with H_2O densities and temperature measurements	Understand the importance of H_2O and temperature in driving PMC variability
2. Do GW enhance PMC formation by perturbing the required temperature for condensation and nucleation? (see E.1.4.2)	PMC morphology GW activity	Scattered sunlight[1, 3], extinction[2] Amplitude and frequency of GW at two altitudes from scattered sunlight1	80 – 85 50, 82		Use CARMA* model with measured GW properties; compare calculated and measured PMC properties	Quantitative determination of the effect of GW induced changes in temperature on PMC formation
3. How does dynamical variability control the length of the cold summer mesopause season, its latitudinal extent, and observed inter-hemispheric asymmetry? (see E.1.4.3)	PMC morphology GW activity Global circulation (long-lived tracer density profiles) Temperature	Scattered sunlight[1, 3], extinction[2] See above CH_4 absorption[2], H_2O absorption[2], and CO_2 absorption[2] CO_2 absorption[2], OH line ratios[3]	80 – 85 50, 82 15 – 80 15– 95 80 – 110 15 – 110 70 – 82		Use NRL CHEM 2-D model constrained by measurements of inferred tracer upwelling, wave activity, and global temperature; compare to PMC observations	Validate model as a basis for global change studies
4. What are the relative roles of gas phase chemistry, surface chemistry, condensation /sublimation, and dynamics in governing the variability of H_2O in the polar mesosphere? (see E.1.4.4)	PMC morphology HO_x compounds O_x compounds Vertical diffusion Vertical advection (long lived tracers) Temperature OH density	Scattered sunlight[1], extinction[2] H_2O absorption[2] O_3 absorption[2] Difference of 50, 82 km GW activity[1] CH_4 absorption[2], H_2O absorption[2], and CO_2 absorption[2] CO_2 absorption[2], OH, OH line ratios[3]	80 – 85 15 – 95, 15 – 95 50, 82 15 – 80 15 – 95 80 – 110 15 – 110 55 – 85		Use detailed 1-D photochemical model with parameterized heterogeneous processes to compare with observed H_2O, O_3, OH, and clouds	Developed complete model of H_2O variability for use in 2-D model; transition to global change studies with 2-D model
5. Is PMC formation controlled solely by changes in the frost point or do extraterrestrial forcings such as cosmic dust influx or ionization sources play a role? (see E.1.4.5)	PMC morphology Cosmic dust input Ionization (NO as proxy) Temperature	Scattered sunlight[1, 3], extinction[2] Cosmic dust influx[4] NO absorption[2] CO_2 absorption[2], OH line ratios[3]	80 – 85 S/C alt. 15 – 140 15 – 110 70 – 82		Correlate PMC occurrence frequencies with cosmic dust input and NO measurements	Understand the relative roles of frost point changes and extraterrestrial forcings in driving PMC variability

†Superscripts 1,2,3,4 refer to measurements made by the CIPS, SOFIE, SHIMMER, and CDE instruments respectively. See Section E.2.1.

‡Altitude ranges are AIM capabilities and include significant margin over requirements. Simulated data precisions also exceed requirements (Fig. E-9, **FO-E1** and Section F.4).

*Community Aerosol and Radiation Model for Atmospheres (CARMA), Jensen et al. 1989; Summers et al. 1997a; Siskind et al. 1997.

measurements to correct for cloud non-uniformity. In addition, the mission will not provide continuous observations of the mesosphere, as it must time-share between its stratospheric aeronomy and astronomy objectives. While TIMED, EOS, and ODIN do not have the comprehensive focus on the polar mesosphere that AIM has, they will allow for cross-validation of several important parameters such as O_3 and H_2O. The uniqueness of the AIM mission is that it will combine high vertical and spatial resolution, selectivity to water-ice, unprecedented limb transmission sensitivity, nearly-simultaneous PMC imaging, atmospheric measurements and dust data needed to bring closure to key issues regarding PMC formation.

E.1.6 Value to the Sun-Earth Connection Theme

The overall goal of NASA's SEC program is to understand the coupling between the heliosphere and the Earth's atmosphere. AIM deals with Quest #4 of the SEC Roadmap (http://www.Lmsal.com/sec/), "How does solar variability affect life and society" which is a key element of the new "Living with a Star" initiative. The key to this quest is an improved understanding of the upper atmospheric regions that shield the planet and its biosphere from harmful solar radiation and particles. The study of anthropogenic influences on the upper atmosphere is an important aspect of Quest #4. PMCs are of special interest as they are sensitive to both global change and solar/terrestrial influences. A recent NRC book entitled *The Atmospheric Sciences Entering the 21st Century* notes the "need to closely monitor the occurrence and latitudinal extent of PMCs as a marker of global change".

As part of Quest #4, the SEC Roadmap has identified a candidate mission, the Global Mesospheric Water Cycle Probe, to quantify and interpret the long-term evolution of atmospheric water vapor, including the role of PMCs. The scope of that mission is broader than we can address here. However AIM addresses that part of the problem necessary to establish the physical basis for study of global change in the mesosphere. By using the AIM data with coupled multi-dimensional atmospheric models, we will begin developing a theoretical capability to predict future changes in the Ionosphere/Thermosphere/Mesosphere (ITM) climate. PMCs are perhaps the most obvious manifestation of solar terrestrial forcing interacting with global change. Indeed, the first-ever sighting of NLCs over the continental United States last summer makes this a propitious time for NASA to embark on a comprehensive study of the phenomenon of mesospheric clouds.

E.2 SCIENCE IMPLEMENTATION

E.2.1 Instrumentation

The AIM science objectives will be achieved by remotely sensing atmospheric parameters that are critical components of PMC microphysical models. Observation of these parameters will provide a foundation for deriving trends and signatures of global change. The suite of observations is summarized in Table F-4 on FO-F1. Simulated performance results for SOFIE, SHIMMER and CIPS are shown later in **Section F.4.**

SOFIE is an infrared radiometer experiment that uses a differential absorption technique in solar occultation (sunrise and set). SOFIE measures in eight spectral regions between 2.25 and 10.0 μm.

SHIMMER is an imaging UV interferometer that uses the SHS technique. The instrument measures a spectral image of the limb in a 0.33 nm passband near 308 nm with high spectral resolution (0.0058 nm).

CIPS is a UV panoramic imager that uses six identical intensified CCD cameras to image an 80 deg x 120 deg field of regard in the nadir in a 10 nm spectral passband centered near 265 nm.

CDE is a dust particle impact detector that uses the technique of detecting a depolarization signal in a thin (28 micron) permanently polarized PVDF film. The device provides an estimate of the incoming dust flux below a mass threshold of approximately 5×10^{-12} g.

SOFIE combines IR solar occultation, gas filter correlation radiometry (GFCR) and broadband differential absorption radiometry (DAR) in eight IR channels to measure profiles of T, H_2O, ice, aerosol extinction, NO (GFCR), CH_4, O_3 and CO_2. Aerosol extinction profiles will be retrieved for all eight spectral channels. Measurements will extend from 10 to 120 km with 1.3 km altitude resolution at the mesopause. The 15 orbits per day produce 30 occultations per day, 15 in each hemisphere (see **Fig. E-5**).

SOFIE particle measurements will be used to infer PMC volume densities and effective particle sizes. For PMC particle radii (r) and ice refractive indices, the SOFIE signal is dominated by absorption at wavelengths greater than 2.7 μm, while scattering dominates the measurement at 2.3 μm. Because particle absorption varies as r^3, it is directly proportional to the particle volume density. This relationship is nearly independent of particle size distribution and thus allows accurate

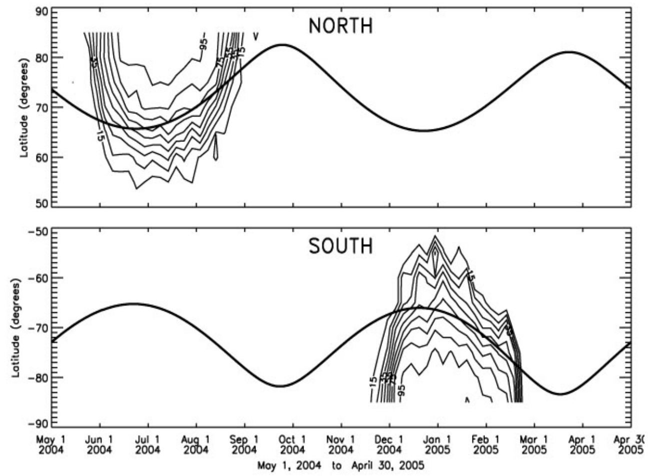


Figure E-5. Locations of coincident measurements by SOFIE, SHIMMER and CIPS (1 year). Contours show SME observations of PMC occurrence frequencies (avg. of 1982-1985).

and straightforward determination of volume from SOFIE measurements. In contrast to absorption, scattering varies as r^6 and this difference provides information concerning particle size. Model calculations reveal an empirical relationship between effective radius (r_e) and the ratio of SOFIE measurements in different channels [e.g., β(3.1μm)/β(2.3μm)], one dominated by absorption and the other by scattering. This relationship is characterized by uncertainties of less than ±20%, and thus reliable estimates of r_e will be possible.

The DAR approach involves electronically differencing the measurements from two spectral bandpasses, one that contains absorption by the target gas and one that does not (or is much weaker; see **Fig. E-6**, **FO-E1**). The ratio of this difference signal to the sum of the full signals (ΔV/V) provides several measurement advantages. First, noise from tracking jitter of the field of view (FOV) on the solar image is nearly eliminated. Second, the ratio greatly reduces sensitivity to absorbers that are somewhat spectrally flat or equal over the respective DAR bandpasses, such as aerosol. Finally, the difference signal can be nulled at high altitudes and measured with a high gain, allowing measurement precision to approach the noise limit. The approach is analogous to gas correlation measurements, like those by HALOE (Russell et al. 1993). Instead of using a gas cell to create a second bandpass, an additional bandpass filter is used. This approach is possible because at mesospheric altitudes the SOFIE target gas absorbers dominate the absorption features of the respective bandpasses. Once the target gas is retrieved using the DAR (ΔV/V) measurement, the results are used in the V signal model for retrieving aerosol extinction, resulting in aerosol extinction profiles for each DAR channel. Similar to the ΔV measurement, the V measurements will be offset, given a high gain, over-sampled, averaged in time and digitized with 16 bits to achieve part-per-million (ppm) precision of the transmission measurements. The upper mesosphere, with typical sub 1% absorption over most AIM bandpasses, is ideal for these techniques.

The DAR approach has been fully validated using flight data from a pair of HALOE channels to retrieve H_2O in the presence of PMCs (Fig. E-3a). Unlike HALOE, the SOFIE instrument is designed to optimize this measurement technique. Conservative estimates show precision and accuracy for ΔV signals equal to or better than the HALOE measurements and V measurements at least a factor of 30 better. The uncertainty of ΔV/V and V/Vo (Vo is V measured above the atmosphere) are both predicted to be $< 10^{-5}$ for the O_3 channel and $< 10^{-6}$ for all other SOFIE channels with the shorter wavelength channels approaching 10^{-7}. The 3.1 μm channel may go well beyond our goals, possibly providing continuous particulate extinction profiles from the stratosphere into the upper mesosphere.

The measurement precision stated above translates to water vapor measurement precision at 90 km of <40 parts per billion by volume (PPBV) and O_3 <50 ppbv. Fig. F-19 shown later displays predicted precision curves as a function of altitude for T, PMCs, H_2O, CO_2, CH_4, NO, OH (SHIMMER), and O_3. In contrast, our HALOE T, O_3 and H_2O retrievals only extend to ~80 km. We have chosen the SOFIE particle channels to coincide with sulfate aerosol features, thus allowing ice measurements near the mesopause and sulfate aerosol aerosol from the stratosphere through the lower mesosphere.

By using two CO_2 DAR channels, variation in optical depth and thermal dependence (through hydrostatics) allows retrieval of kinetic T and CO_2 simultaneously to 110 km and higher (Fig. F-19), removing the need for a-priori profiles of CO_2 mixing ratio. All retrievals (including the combination CO_2 and T) have been rigorously simulated with extensions of our HALOE algorithms, which have been developed and refined in over 15 years of occultation retrieval research for application to HALOE data.

The SOFIE differential measurement approach will not be implemented using the polarization modulation technique as described in the Step-1 proposal. The Phase A study revealed that the

PEM proposed is not a wide bandwidth device and would not produce useable modulation over the total SOFIE bandwidth of 2.25 µm to 10.00 µm. By eliminating the losses in the polarization elements the optical throughput is actually improved. In addition, the PEM high voltage and need for space qualification of the PEM are eliminated decreasing risk and cost. Beam modulation will be provided by a hysteresis synchronous motor driven chopper disk (as done in HALOE) located by the initial field stop. Thus SOFIE has become much more similar to the HALOE instrument that has been functioning perfectly in orbit aboard the UARS satellite since launch on September 12, 1991.

SOFIE consists of a steering mirror and associated control system, a collection telescope, collimation optics, differential absorption filter modules, focusing optics, field lenses, detectors, preamplifiers, a 16-channel lock-in amplifier, a controller/data formatter and power conditioning electronics. Although each component has flight heritage, the channel layout and filtering configuration are unique and were conceived specifically for AIM.

A telescope and optical system for solar imaging has been designed that provides a 1.8 arc-minute vertical (1.3 km at an 85 km tangent point) by 6 arc-minute horizontal instantaneous FOV. SOFIE will acquire the necessary pointing knowledge of ten times the spatial resolution, or <10 arc-seconds, by solar image tracking. The Cassegrain-type collection telescope has a diameter of 15.24 cm and a focal length of 40 cm focal ratio (f/) of 3.

Eight long wave pass filters divide the beam spectrally by band pairs:

- Ice/Aerosols: 2.25 µm to 2.400 µm and 2.400 µm to 2.500 µm;
- CO_2: 2.77-2.83 µm, 2.83-2.9 µm;
- Ice/Aerosols: 2.90-2.99 µm, 2.99-3.08 µm;
- CH_4: 3.4-3.46 µm, 3.47-3.53 µm;
- CO_2: 4.18-4.35 µm, 4.35-4.52 µm;
- NO: 5.18–5.32 µm;
- H_2O: 6.17-6.33 µm, 6.45-6.62 µm;
- O_3: 8.85-9.35 µm, 9.43-10.0 µm

while maximizing signal flux. (Note that NO will use the gas correlation method, that requires only one bandpass, as opposed to the DAR method. This reduces interference from CO_2 at lower mesosphere altitude.) Two channel separation modules divide the absorbing and non-absorbing bands for each constituent species. Each module uses a beamsplitter to split the modulated beam. The beam on one side of each module passes through a bandpass filter centered on the gaseous absorption band. The beam on the other side of the module passes through another bandpass filter centered on a weak absorption region. (For NO, one of the two paths will contain a gas cell containing NO, and only one bandpass filter will be used, coming before the beam is split). This allows each channel to be measured simultaneously using 16 separate detectors, preamplifiers, and balance circuits.

The average signals are sampled and the modulated signals are processed using lock-in amplifiers. The key to achieving high differential absorption sensitivity is the signal balance between the absorbing and non-absorbing components. The radiometric flux levels of the two components are closely balanced using the filter bandpasses. Fine balancing is achieved electronically in orbit prior to each sunset occultation event. Since this system is not an imaging system, but a radiometer, the aperture stop is imaged onto the detector. This creates an inverse Kohler illumination system, producing uniform irradiance across the detector, and minimizing any detector and far field non-uniformity effects (verified by HALOE). Furthermore, all channels have the identical field-of-view at all times. This is a major benefit to data interpretation for studies dependent on channel-to-channel differences, such as particle extinction wavelength dependencies. The detectors for the ten longer wavelengths are photovoltaic mercury cadmium telluride, specifically doped to operate at the appropriate wavelength and T. The detectors for the six shorter wavelength channels are photovoltaic indium arsenide. Each detector is thermoelectrically cooled to stabilize the response and decrease the noise.

SHIMMER will provide UV multispectral limb images of OH solar resonance fluorescence and Rayleigh and Mie scattered sunlight, each extending from an altitude of 30 to100 km. These images allow the direct retrieval of T and OH from which we will infer H_2O (Summers et. al 2001). The instrument will provide continuous coverage of the sunlit summertime hemisphere and produce 130 images per orbit with 2.2 km altitude sampling that will comprise 4.7 Mbytes/orbit. The precision of the SHIMMER data products is discussed in Section F.4.3.

SHIMMER uses the innovative SHS interferometry technique developed at the University of Wisconsin (Harlander et al. 1992, 2001) to make precise multi-spectral images of the UV dayglow at 308 nm with high spectral resolution. The passband has been narrowed from 2.0 nm in the

Step-1 proposal to 0.33 nm in order to improve the temperature measurements. The new pass-band also relaxes the requirement for sampling the interferograms which can now be reduced from 1024 to 512 elements without impacting the spectral resolution. The reduced sampling is achieved by binning of CCD pixels and reduces the data rate by about a factor of two.

SHS is a Fourier transform spectroscopy (FTS) technique, but unlike a conventional FTS instrument, it requires no moving optics. The use of fixed gratings instead of moving mirrors produces a wavelength-dependent path difference, referenced to the Littrow wavelength of the gratings. Moreover, the ability to use fixed field-widening prisms provides sensitivity gains of 10^4 over grating instruments (Harlander et al. 1992). The algorithms for fringe distortion correction and Fourier transform of the SHIMMER interferograms have been developed by Harlander et al. (1994) and successfully tested at the NRL with an instrument scheduled for flight on the Space Shuttle in 2002. The OH, and Mie/ Rayleigh scattering radiance retrieval and inversion algorithms for SHIMMER, including the scatter ratio calculation for the detection of PMCs, have been developed and tested on the MAHRSI flight data (Conway et al. 1996 and 1999; **Fig. E-7, FO-E1**). The OH inversion algorithm uses a Twomey regularization scheme that constrains the smoothness of the returned profile but requires no a-priori constraint. When inverted, each image will produce a single OH density profile and a single scatter ratio profile. The retrieval technique is not compromised by the bright spectrum of Mie scattered sunlight observed when PMCs are present so that simultaneous detection of PMCs and OH is possible. MAHRSI, a conventional grating spectrograph, required 153 sec to measure a single limb profile of 308 nm OH emission at 0.02 nm spectral resolution. SHIMMER requires less than 10 sec for one profile, achieves higher precision than MAHRSI at a spectral resolution of 0.0058 nm and is only 1/6th the size and mass of MAHRSI. Since the OH and PMC emissions are excited by sunlight, no measurements are made during orbit night.

SHIMMER's OH measurements (Fig.E-3b, FO-E1) will be used to infer H_2O profiles using NRL's CHEM 1-D photochemical model, which has been extensively validated (Jucks, et al. 1998). In the mesosphere OH is in photochemical equilibrium with H_2O whose chemical lifetime is more than a month. However the mapping of the OH distribution to H_2O is complicated by the diurnal variation of OH. The model will be used to simulate this variation and deduce a relationship of the form $[OH] = C[H_2O]^X$ where C and X are functions of local time, altitude and O_3 (validated by SOFIE twice each orbit). Fig. E-3a shows the striking agreement between the results of this technique and HALOE observation during the 1997 northern PMC season.

The SHIMMER high precision and spectral resolution allows retrieval of atmospheric temperature profiles between 50-85 km. Each transformed interferogram produces an OH spectrum at every altitude. As shown in Fig. E-7, the SHIMMER spectra separate individual rotational lines in the fluorescence band. By measuring the relative intensity of these lines, which are described by Boltzmann statistics (Stevens and Conway, 1999), T at each altitude can be retrieved. This technique is not compromised by the presence of a PMC. Testing with MAHRSI observations at 82 km indicates a nominal precision of about ± 5 K can be achieved for a zonally-averaged mean at 82 km. This uncertainty will be decreased at locations where there is more OH. and the microprocessor based instrument.

The instrument consists of the sensor assembly and the microprocessor based controller that provides the command and data-handling interface to the S/C and to the CCD camera, controls the sensor shutter, and provides power distribution to the sensor assembly. The sensor assembly is discussed in Section F.4.3. It includes the telescope that defines the instrument FOV (1.6 deg x 3.2 deg) and excludes out-of-band and off-axis light, the interferometer that spatially encodes the wavelength composition of the irradiance at every altitude, the imaging optics that image the interferogram on the CCD, and the CCD camera that converts interferograms to digital signals. The spatial resolution of the interferogram is 1 km at the tangent point and the spectral resolving power is 53,000. The CCD is a 1024 x 1024 frame transfer device. Following each 10 sec integration the active frame of the CCD is transferred to the storage frame. As the next integration proceeds, the image is collapsed and converted to 32 x 512 pixel interferograms by the 16-bit A to D converter. This compression reduces the altitude sampling to 2.2 km. Stored frame readout requires 2.5 sec. The CCD is cooled to –30 ºC by a combination of active control and a passive radiator to minimize power consumption. Using a shutter and diffusing filter in the optical path will facilitate periodic measurements of the CCD dark field, instrument flat field and long-term changes in spectral responsitivity.

SHIMMER was developed with NSF support. The interferometer has been extensively tested in the laboratory and its performance is near the theoretical predictions of fringe contrast, line shape, resolving power, and passband. It has also been vibration tested at flight levels for a proof-of-concept space flight aboard the Space Shuttle to occur in 2002. This flight will rigorously test our instrument and analysis techniques.

CIPS will produce on each orbit 34 panoramic high-resolution views of PMCs beneath the S/C. The scene recorded by CIPS during each 0.24 sec integration will include Rayleigh scattered sunlight from altitudes near 50 km and Mie scattered sunlight by PMC particles near 82 km. The primary purposes of CIPS measurements are to provide a morphology of PMCs; to provide measurements of GW activity in the presence of PMCs and globally in the upper stratosphere; and to measure particle size information over the spatial and temporal evolution of PMC's.

The instrument consists of a 2x3 array of cameras operating in a 10 nm passband centered at 265 nm, each with an overlapping FOV, and a resolution (at the nadir) of 2 km. The total FOV is 80 deg x 120 deg, centered at the sub-satellite point, with the 120 deg axis along the orbit track. Because of slant viewing at the edges of the FOV, the worst spatial resolution is about 17 km, adequate for identifying the larger-scale NLC "bands." The near-polar orbit will cause the observation swaths to overlap at latitudes higher than about 70 deg, so that nearly the entire polar cap will be mapped with 15-orbit per day coverage. For the first time a synoptic morphology of cloud evolution throughout the entire season, and in both hemispheres will be achieved.

PMC Morphology and Gravity Wave Activity. PMCs are identified as small enhancements of brightness against the bright Rayleigh-scattered background coming from the lower atmosphere. To minimize the background intensity, CIPS employs an interference filter, which is centered on the spectral "hole" produced by atmospheric ozone. Thomas et al. (1991) proved the feasibility of this detection method using 273.5 nm data from the SBUV nadir-viewing spectrometer on board of NIMBUS 7. They showed that the brighter PMCs could be distinguished against the background, despite their underfilling the 200 x 200 km FOV (see **Fig. E-8**) that fails to resolve small intense features. Thus CIPS takes advantage of the very wide range of contrasts exhibited by PMCs (see cover) through a hundred-fold higher spatial resolution and three-fold better sensitivity (1% of background) than SBUV. Scaling of visible lidar data (von Zahn et al. 1998) indicates that PMCs identified by CIPS will have a S/N up to 250.

In addition AIM observations at SZA from 87 deg to about 94 deg (the shadow band) experience a reduction in background signal of as much as a factor of 10 or greater. Yet PMCs remain 95% illuminated relative to an overhead sun condition. This results in greatly enhanced PMC contrast in this band that is roughly 700 km wide and centered on SOFIE and SHIMMER coincident observations. In addition, cloud-free regions can be used to confidently characterize gravity wave signatures inside and outside the shadow band. This ability to observe scenes with and without clouds in high and low background, combined with tracking clouds into and out of the low background regions, leads to analysis advantages unique to satellite observations.

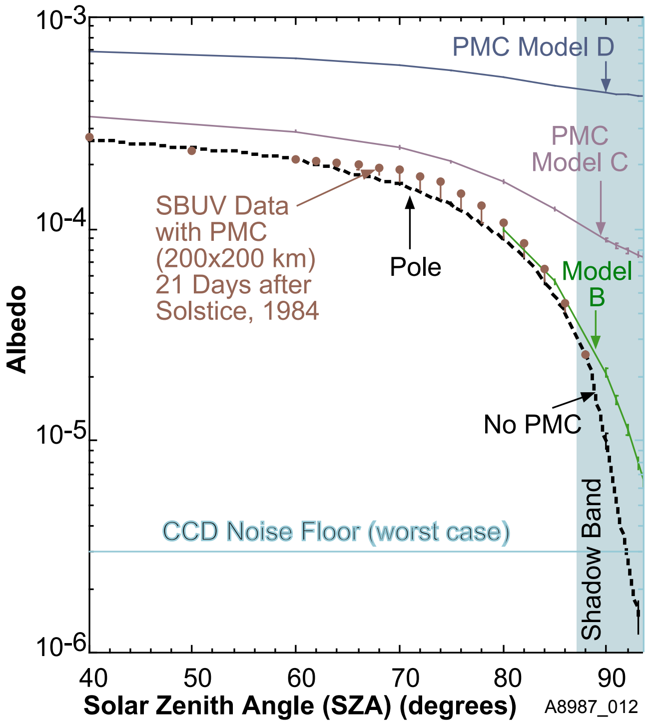


Figure E-8. Simulated UV albedos (for 2 x 2 km pixel) as a function of SZA show high CIPS S/N in the shadow-band region. The dotted line represents the UV albedo when NO PMCs are present. The solid curves represent cases where PMC are present at optical depths observed by SME. The difference between the solid curves and dotted line represent the CIPS PMC signals above the background. Note the large PMC minus background signal difference in the shadowband. The filled red circles are SBUV PMC data where the FOV is underfilled.

Nearly all the AIM science objectives can be accomplished with measurements in the low background shadow band. However, these observations also provide a natural and powerful validation aid for observations at higher Sun conditions where gravity wave signals in the background will be emphasized. Gravity wave effects on CIPS signals come from the dependence of O_3 photochemistry on T. The effect on the UV albedo in the Hartley bands is easily found from a single-scattering calculation (multiple scattering is negligible at 265 nm) to be linearly dependent upon the O_3 perturbation. Waves as small as 1-2 K at 50 km will cause a 3% perturbation in background signal, readily detectable by CIPS.

Another method of cloud identification, important for distinguishing against the sometimes-variable background, relies upon the Mie scattering-angle signature, now a well-established property of PMC (Von Cossart et al. 1999). Any brightness enhancement that shows forward-scattering behavior (more pronounced for brighter clouds, Thomas and McKay, 1985) can be identified as a PMC, and not an underlying background irregularity. This leads to separation of the gravity wave signature on the cloud albedo from that of the underlying background.

Cloud Particle Size, Mass and Surface Area. CIPS will measure the particle size distribution, f(r), at multiple locations along the thin flat layers of PMCs. This analysis will concentrate on the common volumes, in low background, observed by SOFIE and SHIMMER. The f(r) function is critical for the determination of column mass and surface area, quantities that are needed for study of the cloud microphysics and surface-induced heterogeneous chemistry. The method uses the cloud particle's Mie scattering-angle signature. For the brighter clouds that exhibit forward-scattering behavior, and that lie significantly above the noise level (see **Fig. E-9, FO-E1**), we will derive the particle concentration, the mean particle size, and the width of the size distribution, assuming the log-normal size distribution (Thomas and McKay, 1985). Thus, given the water-ice composition (verifiable from SOFIE IR extinction versus wavelength measurements), least-squares analysis of CIPS angular distributions at a single wavelength will yield column mass and surface area. This will allow correlation of PMC size with PMC extinction, T, H_2O and other atmospheric parameters.

We have demonstrated in the Phase A study that the particle size distribution can be determined better by combining CIPS and SOFIE measurements of PMC optical depths in the common volume observed by the two instruments in the shadow band zone, rather than using one instrument alone. This approach provides sufficient accuracy to accomplish the microphysics science objective requirement with margin (Science Objective 1, see Table E-1).

Given S/C pointing capabilities, image resolution and the typical large horizontal extent of thin layered PMCs, it will not be difficult to identify distinct clouds or cloud features in successive images (41 sec apart). Lifetimes are of order hours to several days (Thomas, 1991). Zalcik (1997) reported NLCs to vary appreciably over a 30-minute period, a notable result given the observed fact that most NLCs undergo no obvious changes over the several hours they are visible in the night sky (Fogle and Haurwitz, 1996). It is known that the small-scale (5-10 km) "billows" (probably secondary effects of gravity wave breaking; Fritts et al. 1993) can disappear in about 5 minutes, and appear to track the mean wind (Witt, 1962). Klostermeyer (1998) has recently proposed that ice crystals may nucleate and grow within a single gravity wave period of the order of one-three hours. The important point for CIPS is that GW are limited to periods larger than the Brunt-Vaissala value (about 5 min. at the mesopause). Furthermore, these high-frequency waves are minor contributors to the T variance, compared to the longer-period waves responsible for the prominent "bands" that occur in NLCs. In effect, successive images by CIPS on a given overpass will "freeze" all but the most rapidly varying waves which have little effect on the environment of PMCs, such as T and H_2O. The detailed dependence of the gravity wave-induced structure of PMCs on these variables will be defined at the low background points of intersection of the SOFIE, SHIMMER and CIPS fields of regard.

The CIPS optical elements are sized to permit a 5% measurement precision of the background sunlit Earth, meeting the requirements from Section E.1 with margin. Each camera has a focal ratio of 1.4, focal length of 35 mm, and 25 mm lens diameter. Each includes an interference filter and CCD detector system. The filters are Acton F255W UV filters centered at 265 nm with approximately 10 nm bandwidths. The CCD detectors are coupled with Hamamatsu V2697U-03 image intensifiers and have 1024 x 1024 pixels that are electronically binned in 3 x 3 combinations for effective 341 x 341 pixel images. Each pixel is digitized to 12-bit resolution. The FOV of an effective picture element (individual pixel sizes are 75 µm) is 1.1 km projected distance at a cloud height of 83 km. On average, 34 images are produced per orbit in the summer polar region. At least four exposures of the same cloud are made during a satellite overpass, at a rate of one every 41 sec. Each CCD is equipped with a DSP interface that incorporates a Huffman compression algorithm reducing each image by an estimated factor of two. Therefore each image (including all six cameras) will produce approximately 523 kbytes of data yielding approximately 18 Mbytes per orbit.

Detailed calculations (see Section F.4.4) have shown that the UV filter in conjunction with the image intensifier and CCD response characteristics accomplish the rejection of near-UV and visible radiation sufficiently to achieve the requirement of measuring contrast down to 5% of the typical background. We will demonstrate the CCD red light rejection properties using a lab prototype before the Spring, 2002 site visit. The image intensifier also has sufficient gain to allow the CCDs to be operated at ~20 ºC. With a nadir-pointed instrument, imaging is achieved with a body-fixed camera assembly. An effective exposure time of 0.24 seconds is matched to the required resolution of 2 km.

CDE will provide measurements of the variability of the cosmic dust influx for particles entering the atmosphere. This is a proxy measurement at the S/C altitude to estimate the deposition rate of cosmic material into the mesosphere. There are two principles to link CDE measurements to the density of cosmic dust supplied cloud nuclei: 1) immediate transport from Low Earth Orbit (LEO) to the mesosphere, where "smoke" particles have moderate lifetimes; and 2) the assumption that by measuring the small end of the size distribution, the entire dust influx can be monitored. These dust particles pass through the region of the S/C altitude to the mesosphere in less than a minute and without any significant changes in their velocity vector or mass until they reach an altitude of ~100 km. Entering the mesosphere, the particles ablate in approximately 0.2 s and deposit most of their mass in the altitude region of 80-100 km. The ablated material quickly (minutes) recondenses into nm-sized smoke particles (Hunten et al. 1980) that can serve as nuclei for water condensation and hence could control the efficiency of PMC formation. The lifetime of nm-sized smoke particles against coagulation and subsequent removal from the mesopause region is short (~1 week) compared with a PMC season. Thus, the availability of smoke particles as nucleation sites in the mesosphere can be monitored in LEO and correlated to PMC appearances.

The cosmic dust input into our atmosphere is about 100 metric tons per day (Love and Brownlee, 1993). Much of the mass is delivered in the form of 100 µm radius "Zodiacal light" grains. The average flux of these particles as measured on the Long Duration Exposure Facility (Love and Brownlee, 1993) is on the order of $100/m^2/yr$; however, the flux of smaller grains is expected to be significantly higher. The expected impact rate of 1 µm radius grains is between 10-100 a day. LASP is currently developing new low noise electronics to lower the size threshold of CDE to well below its current threshold of approximately 10^{-11}g. During the Phase A period, a preliminary version of one segment of CDE, complete with a rigidly mounted PVDF sensor and front-end electronics was taken to the Heidelberg dust accelerator to verify its performance. These tests demonstrated at least a factor of two improvement in our electronic noise, lowering the expected mass threshold to be on the order of 5×10^{-12}g. This could theoretically increase the impact rate by another factor of three or more. We assume that during periods of high dust input rates the fluxes are elevated for all sizes, so that by monitoring the lowest end of the dust size distribution we will monitor the total dust influx as well. The scale-height of the Zodiacal dust cloud is many orders of magnitude larger than the radius of the Earth. During periods of high dust influx an entire hemisphere will be exposed and daily averages of the impact rates can be used to increase statistics.

The CDE detection principle is based on the depolarization signal a dust particle generates penetrating a permanently polarized thin PVDF film (Simpson and Tuzzolino, 1985; Tuzzolino, 1992). Dust grains penetrating the thin film remove dipoles along their trajectory producing a fast electric charge pulse without requiring bias voltages. The produced signal is a function of the particle's mass and velocity. PVDF sensors provide the simplest possible dust detection with minimum compromise of the goals of the present mission. At an impact speed of >> 1 km/s, the PVDF mass threshold is 10^{-11} g. The initial plan for CDE was a time of flight system to provide both mass and velocity measurements for cosmic dust particles. The motivation for the velocity measurement was to discriminate between orbital debris (with impact speeds (<< 10 km/s) and cosmic dust (with impact speeds > 10 km/s). However, we have determined in this Phase A study that lowering the mass threshold for impacting dust will provide greater science return than retaining the time-of-flight system that has difficulties with low mass thresholds. This is because an incoming particle has to penetrate the front film and reach the back film to achieve a time-of-flight measurement. The problem of discrimination against orbital debris will be solved by the use of a "bumper" that eliminates particles with low eccentricity orbits; these constitute the bulk of the orbital debris.

Lowering the mass threshold will allow measurements of weekly, and perhaps daily, variations in cosmic dust influx. Similarly, larger detector surface area is desired. The current CDE design uses nine single layered PVDF segments.

At the small expense of giving up the TOF system, we have:

1) reduced the mass detection threshold from 10^{-9}g to 5 x 10^{-12}g; 2) doubled the detector surface area; and 3) reduced weight, power, and complexity, and thus risk.

The issue of discriminating slow but large (10 - 100 micron) debris from fast and small cosmic dust will be addressed during calibration.

E.2.2 Mission Description and Observing Strategy

AIM measurement objectives are achieved by using orbit selection, pointing strategy, signal characteristics and instrument design in a well-choreographed experiment. This starts with the occultation instrument, which provides excellent sensitivity to key state, PMC and chemistry parameters, but only 15 observations per day per hemisphere, all located at the terminator (90 deg SZA). The imager and limb scatter instruments provide near global coverage per day, but depend on the occultation instrument for the parameter fields necessary to interpret the PMC data. These issues are at the heart of the following strategy.

E.2.2.1 Orbit Selection

The goal is to maximize the number of PMC observations by the occultation instrument, SOFIE, and have identical latitude coverage for North and South summers. Adding the requirements of Earth sunset observations (to reduce modeling complexity) in the north, and inter-instrument coincident observations with fixed alignment, dictates a sun-synchronous orbit with midnight crossing for the ascending node. The resulting coverage by occultation events is depicted in Fig. E-5, which includes PMC probability contours derived from SME data. These data show that our orbit will encounter at least 700 PMC coincident observations by the AIM instrument suite per PMC season, and many more non-coincident measurements.

E.2.2.2 Coincident Measurements

The data analysis objectives require that all three remote sensors view the same air mass only minutes apart for every occultation event. This creates a large statistical set of coincident measurements, essentially eliminating error due to cloud (or other fields) non-uniformity when inferring mean characteristics. **Fig. E-10** depicts three positions of the AIM platform along the orbit, and the FOV alignment that allows all three instruments to view the same PMCs within six minutes of imager overpass; this is well under the 20-30 minutes time scale of PMC variability. This is achieved by sun pointing the S/C with SOFIE looking forward (or aft), SHIMMER looking aft (or forward) and CIPS looking in the nadir. A 180 deg yaw is performed twice per orbit to accommodate sunrise and sunset. This orientation also allows the three sensors to view though the same 2-D plane, with the imager viewing multiple angles as it passes over the occultation tangent point. Earth rotation (~1°, typically < 50 km) will prevent perfectly coincident planar viewing, but this is unimportant considering the natural horizontal resolution of the limb viewers (~200 km).

In addition to measurements used to characterize the cloud particulates, the imager will provide cloud extent information for added interpretation of limb measurements. At a minimum, statistical sets can be selected using events with the best cloud uniformity along the limb-viewing track. The 700+ coincident observations per season will permit precise and accurate inference of mean characteristics, such as mean scattering phase

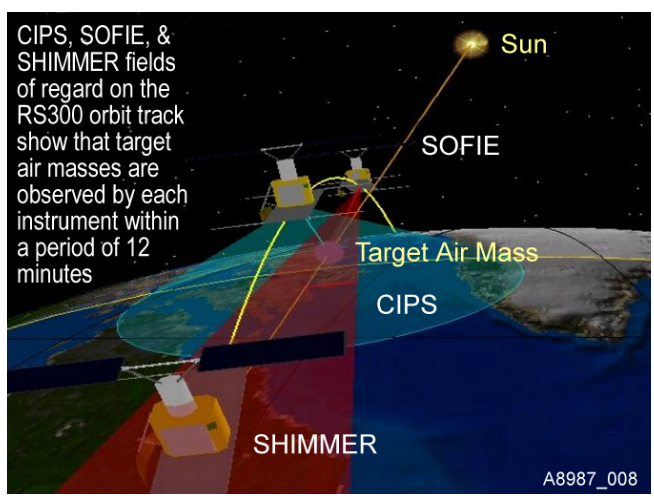


Figure E-10. AIM Observation Strategy

functions, extinction wavelength dependence, and correlated atmospheric conditions.

E.2.2.3 Intercomparisons

The coincident measurements permit a variety of validation opportunities. Retrieved temperature, ozone and methane profiles can validate imager identification and quantification of gravity wave activity. H_2O and OH retrievals can be compared using models. Altitude registration consistency between limb sensors can be compared using PMC cloud top signatures. Achieving good intercomparisons allows confident extension of imager and limb scatter analyses to non-coincident locations, essential for mapping of cloud fields by the imager. The very high sensitivity of the limb viewers will also allow accurate quantification of the imager's cloud size threshold.

E.2.2.4 Shadow Band

A key factor allowing high quality coincident measurements and a strategy for refining and validating the imager results is observation of what we call the "shadow band" (**Fig. E-8**). This is between about 87 deg and 94 deg SZA, where the increased optical depth of ozone thoroughly blocks (shadows) solar radiation from being Rayleigh scattered at lower altitudes, while clouds near 80 km stay fully illuminated. **Fig. E-8** shows the effect. PMCs go from being a small fraction of the signal for SZAs less than 87 deg to being the dominant source of albedo in this "shadow band". Since this band will be observed through all 120 deg of CIPS viewing angles, and with cloud S/N up to 100, and higher for signal integrated over many pixels, excellent scattering phase functions can be derived, especially when statistical sets are used to remove gravity wave effects. With phase functions determined, cloud signature can be more easily detected and reliably modeled at smaller SZA. This approximately 7 deg wide band, parallel to the terminator, will provide excellent observations for a variety of uses by CIPS, SHIMMER, and SOFIE.

E.2.2.5 Other Measurement Characteristics

The identical volume of air is measured simultaneously by each SOFIE channel. As a result, cloud irregularities have an identical effect in each channel, so that spectral PMC signatures deduced from SOFIE are still accurate. Consequently, cloud properties that depend only on the wavelength dependence of extinction, such as particle composition and size, can be reliably determined regardless of cloud non-uniformities. Also, the limb geometry greatly emphasizes tangent layers (a factor of 100 versus nadir). Therefore, even for broken cloud conditions in the instantaneous field of view (IFOV), these thin-cloud signals will peak for observations that pass close to the tangent altitudes corresponding to the cloud heights. This allows good discrimination of multiple cloud layers, and even better results for measurements that can be statistically aggregated. Furthermore, the CIPS imager data will be used by SOFIE to aid in interpreting measurements under non-uniform cloud conditions.

The small optical depths of PMCs determines that the cloud integrated CIPS signal is directly proportional to the total particulate scatter by the cloud (the entire cloud mass). Therefore, identifying the same cloud, or cloud subset, within an imager FOV, and integrating over that same cloud feature for integrating over that same cloud feature for various angular observations during the orbit crossing, gives excellent scattering phase data if background is not a problem, which is exactly the situation in the shadow band.

Nature provides some key observational opportunities, e.g., shadow bands, optically thin environments, cloudy and cloudless scenes, multiple solar angles, thin layers and limb geometry. Full exploitation of these opportunities is best achieved with orbiting sensors.

E.2.3 The Minimum Mission

The baseline mission consists of the AIM four-instrument complement flying on the RS300 S/C for 23 months (two PMC seasons in each hemisphere). It will completely address all six science objectives outlined in Section E.1.4. The minimum mission, documented in the AIM Phase A Science Requirements Document (SRD), will still produce compelling AIM science by addressing all six objectives, but less comprehensively than the baseline mission (see **Table E-2**). While the strength of the conclusions will be reduced, it will provide most of the needed database to constrain PMC microphysical models. The minimum mission will include two of the four instruments, either CIPS and SOFIE or CIPS and SHIMMER, flying on the RS300 S/C for one year (1 PMC season in each hemisphere).

Compared to the baseline, the minimum mission will require a trade-off between geographic coverage (SHIMMER) and measurement accuracy (SOFIE). Also statistical results will have higher uncertainty due to the decreased mission length.

Should unforeseen circumstances call for a reduction in the scope of the mission, the AIM

Table E-2. Minimum Mission Science

Science Objective	Science Change	Science Retained (%)
Obj. 1: PMC Microphysics	Fully addressed but no SOFIE / SHIMMER redundancy	100
Obj. 2: GW Effects	Fully addressed but no SOFIE / SHIMMER redundancy	100
Obj. 3: Temperature Variability	If SOFIE: Limited geographic regions; If SHIMMER: fully	85
Obj. 4: Hydrogen Chemistry	Focus on the role of condensation/ sublimation plus dynamics(if SOFIE) or plus HO_x (if SHIMMER)	70
Obj. 5: PMC Nucleation Environ.	Focus on relative roles of frost-point changes and ionization sources	50
Obj. 6: Long-term Mesospheric Change	More limited data for model validation but significant step forward will occur	80

* SOFIE versus SHIMMER decision will be made during the development if need arises

descope philosophy will be to reduce mission lifetime first, and then to reduce the instrument complement, as discussed in Section G. All possible descopes will allow the minimum mission to be satisfied

E.2.4 Data Analysis Plan

Experience with 20+ orbiting instruments and their data processing efforts has shown that algorithm design and validation demands cross-disciplinary expertise in instrument modeling, signal processing, retrieval theory, atmospheric radiative transfer, software engineering, and computer systems design. The AIM Data Analysis Plan is based upon well-organized systems that connect and induce strong interactions among a team of experts. GATS has devoted much of the last 12 years to developing software and systems that address these goals. Experience with past orbiting sensors plus many planned and proposed experiments has prepared the AIM Data Analysis team to guide the implementation of data processing and data management systems for the AIM project. The following sections discuss the plans for the creation and implementation of the AIM data processing system.

E.2.4.1 Approach and Organizational Responsibilities

Our data analysis approach will leverage facilities and talent through virtual data sites, keep the data analysis decisions with the appropriate instrument teams, take advantage of the unique capabilities of CU in mission operations and GATS in operational data processing and create a unified picture of the AIM mission both internally and externally.

Each instrument team will be responsible for Level 0 through Level 3 processing and their own data management. GATS will set up a Project Data Center (PDC) at HU to provide search and access functions for all data sets. The actual data will reside on storage systems at the individual Payload Operations Center-Data Processing Center (POC-DPC) sites (See Section F.7). GATS will work with the instrument teams to define common database access interfaces, naming conventions and file formats. As the data files are created at the individual sites, the PDC will update metadata and catalogue information that allows search and downloads by the public and science community. The PDC will also serve as the center for project information, linking to remote files maintained by other AIM organizations as needed.

GATS will be responsible for the overall AIM data flow architecture and the SOFIE POC-DPC which will be based on similar systems developed by GATS for the HALOE and SABER projects. The activities of the Mission Operations Center (MOC) will be handled by CU. CU has an extensive and successful record for performing S/C operations, which includes a software system known as Operations And Science Instrument Support (OASIS-RT). OASIS-RT is a robust S/C and instrument operations system with a solid pedigree from years of use and development. Fig. F-46, depicts the data flow plan and responsibilities of AIM organizations.

Finally, our plan must result in successful and timely data processing. We believe this demands close attention to five critical issues: Facilities, Instrument, Access, Rapid Solutions/Validation and Quality Assurance (QA).

E.2.4.2 Facilities

AIM facilities will use commercial off-the-shelf (COTS) software and computing hardware. Computational requirements for AIM are minimal. Modern desktop PCs are adequate for all phases of processing. Calculation of UV and IR absorption in the mesosphere can be done quickly and accurately. At mesospheric altitudes, only single scattering models are necessary, which are also very fast.

Data rates are also moderate, even for the panoramic imager CIPS. Therefore, the DPC for CIPS will be co-located at the CU MOC facility. The CIPS daily global maps of clouds and GW will be much smaller and more easily downloaded to other sites.

The available software is extensive. In addition to the CU OASIS-RT system, each instrument team has codes from past missions that can be configured for AIM processing. GATS, in addition to code for SOFIE processing, has a variety of tools to facilitate real-time problem diagnosis, post processing analysis and Internet access to complex databases. Some of these codes are discussed in following sections.

E.2.4.3 Instrument Characterization

Instrument performance issues usually dominate the problems encountered during the validation and data improvement effort. Therefore, data processing team staff will participate in instrument development, test and calibration. They will also mentor students from HU, CU, and NRL.

A related strategy is used to develop and test POC software. A S/C interface emulator code will be developed for use by the instrument teams during test and calibration. This results in tested POC, Level 0 and Level 1 processing code by the end of instrument development (having been used during these activities), guaranteeing a smooth integration and test (I&T) activity. The strategy is currently being used on the TIMED project with great success. A valuable additional benefit is software personnel that are thoroughly familiar with instrument characteristics (well prepared for the post launch analysis), and who double as calibration and I&T staff.

Between CU and GATS, nearly all the necessary communication codes (including Consultative Committee for Space Data Systems (CCSDS) protocol systems) are available and easily configured to accommodate each AIM instrument. Only the S/C emulator need be developed.

E.2.4.4 Access

The AIM project considers data access, including a suite of operational visual products, critical to team performance. Project proficiency depends on the speed and flexibility of data manipulation. Data access systems at each Data Processing Center (DPC) and the PDC will be established at the beginning of the project and eventually maintained by students.

These AIM systems will promote and facilitate science team, student and user community involvement by including project news, status, recent results, publication references and project descriptions. Utilities for collaborative and correlative investigators include graphical search and compare functions. A variety of data displays in the form of cross sections, profiles and trends will be maintained on-line for downloading by researchers and the public. AIM members currently maintain such web sites for several projects (haloedata.larc.nasa.gov developed and maintained by GATS and LASP.colorado.edu (SME and SNOE) developed and maintained by CU).

The web access systems will include metadata and science data in NETCDF format with read/write and downloading utilities. We note that multiple copies of HALOE data are maintained on systems around the world, obtainable without assistance by downloading from the HALOE web site. The delivery of AIM data to an archive center will be a simple activity, with the capability in place before launch.

E.2.4.5 Problem Solving/Validation

Data validation is an inadequate term for describing the difficult post-launch data improvement process. It implicitly presumes everything goes smoothly and we simply validate that fact. In reality, the validation uncovers problems leading to months (usually years) of repeating the following cycle:

- Detect a problem
- Diagnose a cause
- Code a solution
- Test the solution.

Comparing results to other data sets, though essential and well planned, only accomplishes step 1. Steps 2, 3 and 4 are often left to ad hoc procedures taking years. Processing systems in place for the HALOE, LIMS and SABER projects specifically address and expedite Steps 2, 3 and 4. Fast, simple and comprehensive web access to many forms of the data quickly brings Co-Is into the diagnostic step. An available suite of post processing routines for graphical rendering and statistical comparisons will aid the processing teams with Steps 1 and 2. This includes tools for correlative data management.

Also used for the HALOE, LIMS and SABER projects is an executive module control code called S3 that can be used to assemble C and/or Fortran routines into organized processing systems allowing rapid and reliable module changes and large team efforts. In addition, the system provides processing control and visual monitoring of variables using a Graphical User Interface (GUI). In effect, a complete variable monitoring capability is designed into the processing software, accelerating problem diagnosis, reliable change and testing (i.e., Steps 2, 3 and 4). These tools will provide the AIM team with a built-in comprehensive visual algorithm monitoring capability. Additionally, they will be controllable and can be monitored over the web. In summary, the AIM data system will be designed to accelerate the post-launch algorithm improvement process, of which validation is an essential but minor component. The GATS codes and utilities, written primarily to expedite post-launch efforts, will be available to all the AIM instrument teams. They also will enable the set-up of a wide variety of operational preliminary quick look schemes and data consistency checks.

E.2.4.6 Quality Assurance

Software and data will be under flexible but complete configuration control. We will use a three-tier QA system where the bottom tier permits uncontrolled development, the next tier manages code being tested and readied for the next release, and the top tier controls operational/released versions requiring formal tests and reviews (per ISO 9000 Standards) before being updated. This is analogous to a lab-prototype-production procedure. Operational code resides only at the top level.

In addition, the DPC teams will meet quarterly to review progress and data interface issues and share development experiences. Meetings will include schedule and status review by the PI or his representative. The PDC will maintain copies of schedules and development status of each instrument for continuous review by project management and oversight institutes.

E.2.4.7 Processing Flow

Figure F-46 depicts the data processing flow. Telemetered raw data will be received at the ground station and sent post-pass by high-speed link to the CU MOC. The MOC will transmit the instrument science data to the POC facilities via Goddard Space Flight Center (GSFC) within two hours of the pass, where the data will be stored and cataloged. When requested by a POC, the data will be decommutated from the total data and sent to the POC facility by CCSDS encapsulated packets. The MOC will also maintain data such as National Center for Environmental Predictions (NCEP) analysis and lunar ephemeris for use by DPC teams. The POCs are responsible for processing from decommutated Level 0 data through Level 3 and for storing data and data products by a project defined format and filing convention, which permits access through a web server. A catalogue is updated with the latest processing status for use by the PDC. The PDC then maintains a catalogue of data validation status and availability for user queries and searches that are handled by a PDC server. Our goal, within six months of launch, is to be producing research ready Level 2 & 3 products 78 hours after measurements. POC commanding will go from POC to MOC via Internet and CCSDS packets. Real-time contact capabilities will be defined during Phase B. To facilitate down-link data rate, there will be two contacts per day.

E.2.4.8 Schedule

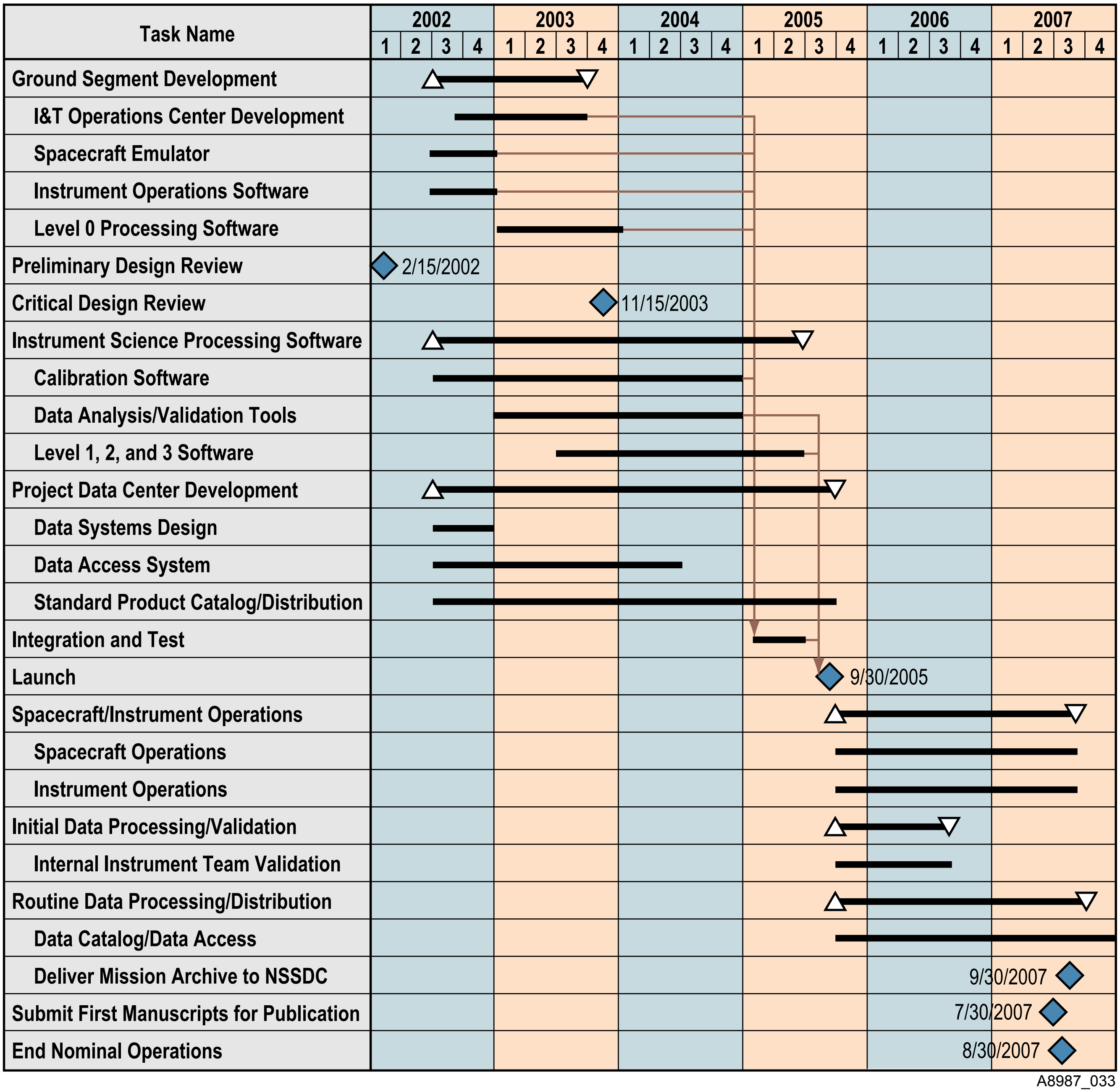
The data plan schedule is provided in **Table E-3**. Note that systems with archive capabilities are established before launch.

E.2.5 Science Team Member Roles and Responsibilities

The AIM science team is comprised of members from leading space research institutions who bring a broad range of experience and expertise in satellite remote sensing, instrumentation, data retrieval and analysis, and science investigations necessary to achieve AIM's objectives. Please refer to the vita for team members, which clearly indicate qualifications for their roles on AIM.

Table E-4 lists team members, primary responsibilities, and primary data products. AIM PI, James Russell, will have overall responsibility for the management and success of the mission. He will be assisted by the Co-PI, Scott Bailey, who additionally will be the lead HU faculty member for the implementation of the HU PDC. David Rusch will lead the CU portion of the science team in PMC investigations and, in particular, CIPS observations. Gary Thomas and Cora Randall will assist Rusch in CIPS algorithm development and data analysis. Mihály Horányi will analyze CDE data. Larry Gordley will lead the design and implementation of SOFIE including the calibration strategy and data processing system. He will also lead the design of the AIM data system and guide the implementation of the HU PDC. Robert Meier, assisted by Christoph Englert, will lead the design and implementation of SHIMMER and the reduction of its data. Michael Stevens and John Harlander will assist him in the data reduction and analysis. Mike Taylor and Patrick Espy will assist in the analysis of data from each of the experiments. David Siskind and Michael Summers will contribute 1-D and 2-D modeling and will participate in all data analysis activities.

Table E-3. Data Plan Schedule



E.2.6 Guest Investigator Program

The AIM team fully recognizes that the AIM suite of measurements, especially those measurements made outside the PMC region, have significant value in other studies regarding the upper atmosphere in addition to the focussed AIM objectives. Therefore a guest investigator program will be included as part of the AIM science. Funding has been allocated to this program to permit three one-year studies at a level of approximately $75K per year.

Table E-4. AIM Team Members Roles and Responsibilities				
Role	**Member**	**Support**	**Responsibilities***	**Products**
PI	James M. Russell III, HU	NASA/HU	Lead all phases of AIM mission from Instrument Development to Data Dissemination and Scientific Reporting, SOFIE Data Analysis; Obj. 1.4.1 and 1.4.4	PMC occurrence frequency, correlations with T and H_2O
Co-PI	Scott Bailey, HU	NASA	Lead HU PDC activities, CIPS Data Analysis, Obj. 1.4.5; E/PO Lead	Daily average ionization rate
Co-I	Gary Thomas, CU	LASP	CIPS data analysis and PMC research, Obj. 1.4.1, 1.4.2 and 1.4.3	Daily global maps of PMCs, size distribution and gravity waves
Co-I	David Rusch, CU	NASA	CIPS development, data analysis and POC-DP activities, research, Obj 1.4.1,1.4.2,1.4.3	
Co-I	Cora Randall, CU	NASA		
Co-I	Larry Gordley, GATS	NASA	SOFIE development; POC-DP and PDC software installation. AIM Data Plan Design and Implementation, Obj. 1.4.1	T, P, H_2O, O_3, CH_4, CO_2, PMC and Aerosol Extinction
	Robert Meier, NRL	NASA/NRL	SHIMMER development and data analysis, Obj. 1.4.1 and 1.4.4	Profiles, Daily Global coverage, OH, T, and inferred H_2O
Co-I	John Harlander, St. Cloud University	NASA		
Co-I	Michael Stevens, NRL	NASA/NRL	SHIMMER data analysis and POC-DP activities, Obj. 1.4.1 and 1.4.4	
Co-I	Mihály Horányi, CU	NASA	CDE development and POC-DP activities, Obj. 1.4.5	Extraterrestrial dust influx
Co-I	David Siskind, NRL	NASA/NRL	Research, Atmospheric Modeling, Obj. 1.4.2, 1.4.3 and 1.4.4	Advanced Analysis Products
Co-I	Michael Summers, GMU	NASA/GMU		
Co-I	Patrick Espy, BAS	BAS	Research, data analysis, Obj. 1.4.3	
Co-I	Mike Taylor, SDL	NASA	Research, data analysis, Obj. 1.4.2	
Co-I	Steven Eckermann	NASA/NRL	Research, data analysis, Obj. 1.4.2	Gravity wave analysis
Co-I	Christoph Englert, NRL	NASA/NRL	SHIMMER instrument design, development, data analysis	OH, H_2O analyses

*All Science Team members will be responsible for E/PO contributions.

AIM traceability provides a clear path from science objectives to instrument, spacecraft and mission requirements.

Table F-3. Science Objectives Traceability to Instruments

Science Objectives Determine the Required Geophysical Parameters to be Measured
Required Geophysical Parameters Dictate the Necessary Observations which then Define the Required Instruments

1. What is the global morphology of PMC particle size, occurrence frequency and dependence upon H_2O and Temperature?	2. Do GW enhance PMC formation by perturbing the required temperature for condensation and nucleation?	3. How does dynamical variability control the length of the cold summer mesopause season, its latitudinal extent and possible interhemispheric asymmetry?	4. What are the relative roles of gas phase chemistry, surface chemistry, condensation, sublimation and dynamics in determining the variability of H_2O in the polar mesosphere?	5. Is PMC formation controlled solely by changes in the frost point or do extraterrestrial forcings such as cosmic dust influx or ionization sources play a role?	6. What is needed to establish a physical basis for the study of mesospheric climate change and its relationship to global change?		Instruments
Geophysical Parameters Needed to Address the AIM Science Objectives						Observables	
PMC Morphology Particle Sizes	PMC Morphology	PMC Morphology	PMC Morphology	PMC Morphology	Objective 6 is addressed through the results of the previous objectives.	Cloud Extinction	SOFIE
Temperature Profile		T, CO_2 Profiles Circulation	Temperature Profile	Temperature Profile		CO_2 Absorption	SOFIE
H_2O Profile		H_2O Profile Circulation	H_2O Profile	H_2O Profile		H_2O Absorption	SOFIE
			O_3 Profile			O_3 Absorption	SOFIE
		CH_4 Profile Circulation	CH_4 Profile Circulation			CH_4 Absorption	SOFIE
				Ionization NO Profile		NO Absorption	SOFIE
PMC Presence H_2O Profile		H_2O Profile	OH Profile H_2O Profile	H_2O Profile		OH Fluorescent Scattering	SHIMMER
Temperature Profile		Temperature Profile	Temperature Profile	Temperature Profile		OH Line Ratios	SHIMMER
PMC Morphology	PMC Morphology.	PMC Morphology	PMC Morphology	PMC Morphology		Mie scattered sunlight	SHIMMER
PMC Morphology, Global Images PMC Particle Sizes	PMC Morphology, Global Images GW Activity	PMC Morphology, Global Images GW Activity	PMC Morphology, Global Images	PMC Morphology, Global Images		Scattered Sunlight	CIPS
				Cosmic Dust Influx		Cosmic Dust Influx	CDE

SOFIE = ▢ SHIMMER = ▢ CIPS = ▢ CDE = ▢

Requirements Flowdown Process Legend

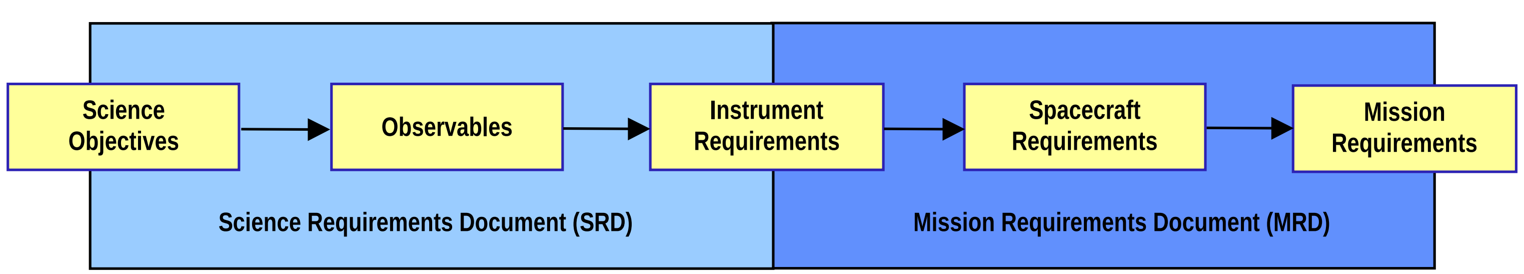


Table F-4. Requirements on Observables Place Requirements on S/C and Mission

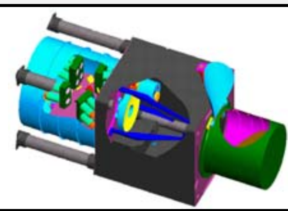
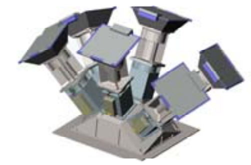
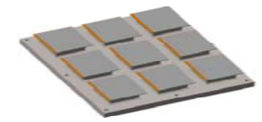
Instrument	Observables	Geophysical Parameters	SRD Instrument (Observation) Requirements[1]		Projected Performance[1]	Spacecraft Requirements Based on Obs./Instrument Requirements[2]	Mission Requirements Based on Obs./Instrument Requirements[2]
SOFIE	Cloud Extinction	PMC Morphology Part Sizes	Alt. Range (km)	78 - 85	50 - 85	Mass=42 kg Power=40.1 W Volume: 38 x 38 x 106 cm^3 Data Rate: 0.5 Mby per orbit Temp Range: ±50 non-op ±30 op Pointing: Control: ±0.5º Knowledge: ±0.5º Stability: <0.06º/sec	Four Different Obs. Strategies: solar (SOFIE) limb (SHIMMER) nadir (CIPS) zenith (CDE) Requires S/C yaw Total Inst Mass= 76.0 kg Total Inst Power[2]= 88.7 W Total Inst Data Rate=23.25 Mby per orbit Need 2 N and 2 S seasons, to see seasonal variability: thus need 22 months of observation time.
			Vert. Resolution	3 km	1.5 km		
			Horiz. Resolution	At common vol.	At common vol.		
			Temp. Resolution	1 min.@ com. vol.	1 min.		
			Precision	$5x10^{-6}$ km^{-1}	5×10^{-9} km^{-1}		
	CO_2 Absorption	Temperature	Alt. Range	70 - 90	15 - 120		
			Vert. Resolution	3 km	2.5 km		
			Horiz. Resolution	5 deg x 24 deg lat x lon	5 deg x 24 deg lat x lon		
			Temp. Resolution	1 min.@ com. vol.	1 min.		
			Precision	5 K	1.5K per profile		
	H_2O, O_3, CH_4, CO_2, NO Abs.	Mixing Ratio Profiles, Circulation	Alt. Range (km)	78-90, 78-90, 30-90, 80-100,80-95	15-95,15-100,15-95,80-110,15-150		
			Vert. Resolution	3, 3, 3, 3, 5 km	2 km for all		
			Horiz. Resolution	5 deg x 24 deg lat x lon	5 deg x 24 deg lat x lon		
			Temp. Resolution	1 day (1 min O_3)	1 min.		
			Precision (ppmv)	0.6, 0 .1, 0.05, 10.0, 1×10^7 cm^{-3}	0.15, 0.1, 0.05, 7.0, 3×10^6 cm^{-3}		
SHIMMER	OH Fluoresc. Scattering	OH, PMC[4] Presence	Alt. Range (km)	78 - 85	55 - 84	Mass=24 kg Power=22.1 W Volume: 51 x 13 x 61 cm^3 23 x 25 x 32 cm^3 Data Rate: 4.7 Mby per orbit Temp Range: -40 to 65 non-op -25 to 55 op Pointing: Control: ±0.1º Knowledge: ±0.020º Stab.:<0.007º/sec	22 months obs. time drives 500 km orbit to provide adequate orbit lifetime. To cover both poles need polar orbit. Local time of noon/ midnight optimizes SOFIE observations. **BATC RS300 on Pegasus meets all mission and S/C requirements.**
			Vert. Resolution	3 km	2.2 km		
			Horiz. Resolution	5 deg x 24 deg lat x lon	5 deg x 24 deg lat x lon		
			Temp. Resolution	1 min.@ com. vol.	10 sec		
			Precision	22% (OH)	9% (OH)		
	OH Line Ratios	Temperature	Alt. Range (km)	70 – 82	70 - 82		
			Vert. Resolution	3	2.2		
			Horiz. Resolution	5 deg x 360 deg lat x lon	5 deg x 360 deg lat x lon		
			Temp. Resolution	4 days	1 day		
			Precision	5 K	2.5 K		
	Mie Scattered Sunlight	PMC Morphology	Alt. Range (km)	81 – 85	Cloud heights		
			Vert. Resolution	3 km	2.2 km		
			Horiz. Resolution	5 deg x 24 deg lat x lon	5 deg x 24 deg lat x lon		
			Temp. Resolution	1 min.@ com. vol.	10 sec		
			Precision	56%	1.6%		
CIPS[3]	Scattered Sunlight	PMC Morph. Particle Sizes	Alt. Range (km)	Cloud heights	Cloud heights	Mass=11.3 kg Power=24 W Vol: 24 x 30 x 25 18 Mby per orbit -20 - +50 C	Inst. data rate requires two passes per day of 8.5 min. duration with 11 m antenna.
			Vert. Resolution	N/A	N/A		
			Horiz. Resolution	0.5 deg x 1 deg lat x lon	.02 deg x .02 deg lat xlon		
			Temp. Resolution	1 min	0.2 sec		
			Precision	16%, 50%	6%, 10%		
CDE[3]	Cosmic Dust Influx	Cosmic Dust Influx	Alt. Range (km)	Cloud alt	See F.4.4	Mass=1.3 kg Power = 2.5 W Vol: 40 x 40 x 3 cm^3 0.1 Mby per orbit -40 - +50 C	NORAD TLE + NSC data meet ephemerid requirements
			Vert. Resolution	N/A	N/A		
			Size range	$r < 0.7$ µm	$r < 0.7$ µm		
			Temp. Resolution	1 week	1 week		
			Precision	10%	10%		

[1]Precisions are quoted at cloud height.
[2]Power is orbit average.
[3]CIPS, CDE do not drive pointing requirements.
[4]PMC presence is a threshold detection.

Foldout F1. The AIM Suite of Instruments and RS300 Spacecraft Meet or Exceed All Requirements

Table F-1. AIM Instrument Summary

End-to-End Studies of Instrument Designs, Test Plans, and Retrieval Algorithms Verify That All AIM Objectives Will Be Met

	SOFIE	SHIMMER	CIPS	CDE
Instrument				
System Overview	7 channel differential absorption radiometer 1 gas correlation cell, 1 part in 106 absorption precision 2.25 – 10 µm	Spatial Heterodyne Hyperspectral Imager, 308.42±0.16 nm Spectral resolution: 0.006 nm, FOV: 30-100 km	265 nm Nadir Imager six individual CCD / Intensifier pairs Solar blind 80º x 120º FOV	Cosmic dust influx monitor, nine indiv. PVDF patches (10 cm x 10 cm) 2 pi FOV
System Heritage	Uses HALOE technique and involves several HALOE key personnel including the PI	Observational concept from MAHRSI SHS instrument for Space Shuttle Middeck instrument ready for flight	CCD , Filter heritage: Rosetta	VEGA 1 & 2, CASSINI, STARDUST, ARGOS
Observables and Deliverables (See FO-F1 & Table F-21)	T, H_2O, CH_4, O_3, NO Absorption Particulate extinction 1.6 km vertical resolution	OH, T, H_2O, Rayleigh and Mie scattered radiance 3 km vertical resolution	PMC presence PMC frequency of occurrence Particle size distribution 2 km res. at nadir	Cosmic dust influx at S/C and PMC altitude, min. threshold at 0.7 µ radius
Calibration and Testing	FOV, tracker perform., temporal/spectral response (in/out of band) thermal stability, S/N cell content, gain set	Radiometric Calibration Flat and Dark Field Internal Scattering Phase Correction	Sensitivity, field of view, off axis rejection, out of band response, flat field, linearity	Cross calibration with lasers (U. Chicago & LASP) and dust particles (Heidelberg, Germany)
Retrieval Algorithm Overview	Limb transmission profile inversion, HALOE heritage, line-by-line forward model	OH heritage from MAHRSI, H_2O from Summers et al. (2001), T from Stevens and Conway (1999)	PMC brightness relative to Rayleigh background; particle size from multiple viewing angles and distribution compared to Mie theory	Impact signal frequency and amplitude is used to determine flux based upon calibration results
Sections, figures where retrievals are demonstrated.	Sec. F.4.1 Fig. F-19	Sec. F.4.2 Fig. F-24	Sec. F.4.3	Sec. F.4.4

TRL levels by subsystem (TRL Level 1–9 grid; level marked for each subsystem):

Instrument	Subsystem	TRL Level
SOFIE	Steering Mirror	8
SOFIE	Telescope	9
SOFIE	Channel Separation	8
SOFIE	Detectors	9
SOFIE	TE Coolers	9
SOFIE	Preamps	9
SOFIE	Signal Processing	8
SOFIE	SOFIE Controller	8
SOFIE	ADCS	8
SOFIE	Telemetry Formatting	9
SOFIE	Sun Sensor	9
SOFIE	Housekeeping Monitor	9
SOFIE	RS-422 Transceivers	9
SHIMMER	Instrument Controller	9
SHIMMER	Camera Controller	8
SHIMMER	Camera	9
SHIMMER	Monolithic Interferometer	7
SHIMMER	Imaging Optics	9
SHIMMER	Mechanical Design	7
SHIMMER	Dust Door	9
SHIMMER	Shutter	8
CIPS	CCD Camera	7
CIPS	Image Intensifier	8
CIPS	Telescope	8
CIPS	HVPS	8
CIPS	I/F Electronics	7
CIPS	Cover	7
CIPS	Thermal Control	8
CIPS	Structure	7
CDE	Detector	6
CDE	Amplifier	8
CDE	I/F Electronics	8
CDE	Mechanical Structure	8

See FO-F1 for instrument resource requirements.

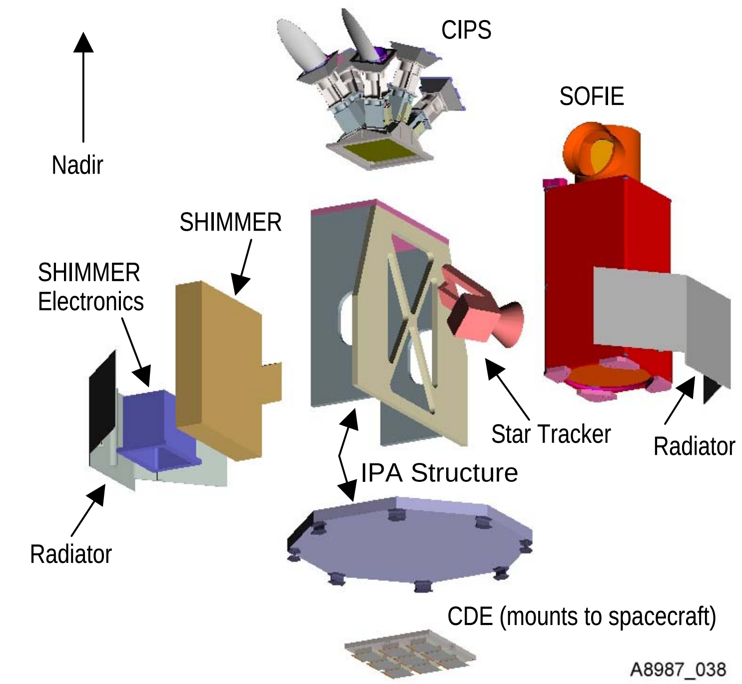


Figure F-2. Exploded View of Instruments on IPA

Table F–4b. Instrument Component List with Vendor and Heritage

	Component	#	Vendor	TRL	Basis of Estimate / Heritage
SOFIE	Steering Mirror	1	BATC	8	Quote, ACE
	Telescope	1	SDL	9	WIRE, HALOE
	Detectors	16	Judson	9	Quote, HALOE
	Sun Sensor	1	Adcole	9	Quote
	Electronics parts	-	SDL	8-9	WIRE, HALOE
	Optics components	-	Various	8	Quotes, WIRE, HALOE, RAMOS
SHIMMER	Instrument Controller	1	NRL	9	MAHRSI
	Camera / Controller	1	MPIA	8-9	MPIA Mars Missions
	Monolithic Inerferometer	1	NRL	7	SHIMMER Middeck
	Imaging Optics	1	NRL	9	SHIMMER Middeck
	Mechanical Design	1	NRL	7	SHIMMER Middeck
	Dust Door	6	NRL	9	MAHRSI
	Shutter	6	NRL	8	TRACE, SXI
CIPS	CCD Camera	6	DLR	7	Rosetta
	Image Intensifier	6	Hamamatsu	8	Rockets
	Telescope	6	Latkin	8	Simple common optical system
	HVPS	6	LASP	8	Cassini, rockets, Battel
	I/F Electronics	1	LASP	7	TIMED, SORCE
	Cover	6	LASP	7	SNOE, TIMED
	Thermal Control	1	LASP	8	SNOE
	Structure	1	LASP	7	Cassini
CDE	Detector	1	LASP	6	Vega, Cassini, Stardust, Argos
	Amplifier	1	LASP	8	Cassini, rockets
	I/F Electronics	1	LASP	8	Cassini
	Structure	1	LASP	8	SORCE, TIMED
IPA	Inteface plate, flexures	1	LASP	8	SORCE, TIMED
	Vertical plate, top plate	1	LASP	8	SORCE, TIMED
	Gussets	2	LASP	8	SORCE, TIMED
	Harness	1	LASP	8	SORCE, TIMED
	MLI	1	LASP	8	SORCE, TIMED
	Tracker Mount	1	LASP	8	SORCE, TIMED

Foldout F2. Instruments and IPA Summary

Table F 6. AIM Mass Budget

Subsystem/Item	Estimated Mass (kg)	Mass Growth Res. (%)	Mature Mass (KG)	Heritage/Comments
Structure	22.8	14.3	26.0	Conventional aluminum honeycomb construction
Electrical power	34.1	21.6	41.4	Li ion, triple jct GaAs
Avionics	11.9	21.9	14.4	PPC750 based; 256 Mbyte mass memory
Communications	9.59	10.5	10.59	RADARSAT derivative; STDN compatible
Thermal control	5.2	25.0	6.5	SME derived; mostly passive
ADCS	15.5	2.0	15.8	LOSAT-X derived 3-axis zero-net-momentum
Total RS300 bus mass	99.0	16.0	114.8	Maximum
AIM payload (total)	110.6	20.4	133.0	P/L estimate with pallet and electronics
Total AIM S/C @ separation	209.7	18.3	247.8	
Pegasus XL throw weight to mission orbit			252.0	500 km circular @ 97.4 degrees inclination, w/HAPS
Reserve (kg)		42.3		
% Reserve and margin		20.2%		

Table F-12. AIM Link Margins

AIM/RS300 Link Budget Summary

Link Description	Alt=500 km 11 Meter Ground Station (Typical Case)
Downlinks	
16 kbps housekeeping data (no payload data)	30.9 dB
4 Mbps payload data (housekeeping data packets interwoven within data stream	10.1 dB
16 kbps housekeeping data plus 2 Mbps payload data (typical case)	11.2 dB (PL data) 9.4 dB (HK data)
Uplinks	
2 kbps command uplink (with ranging	35.6 dB (CMD channel) 13.6 (ranging channel)

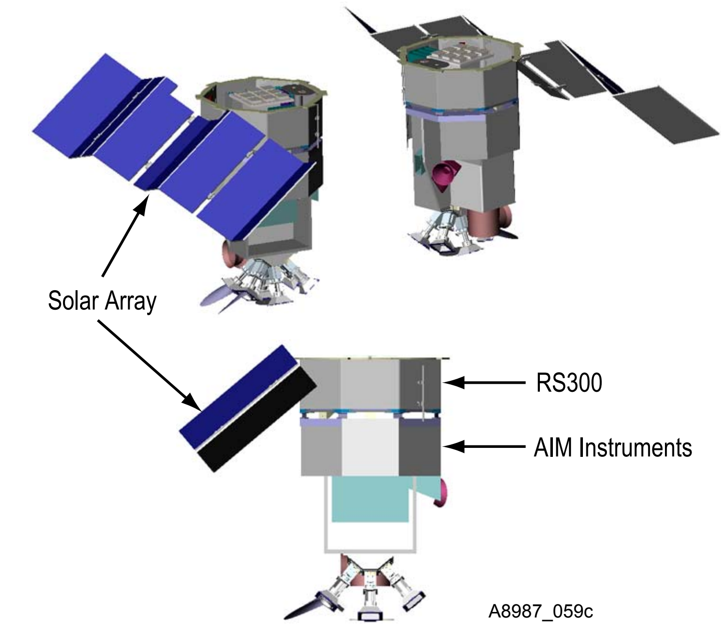


Figure F-11. AIM Deployed Configuration

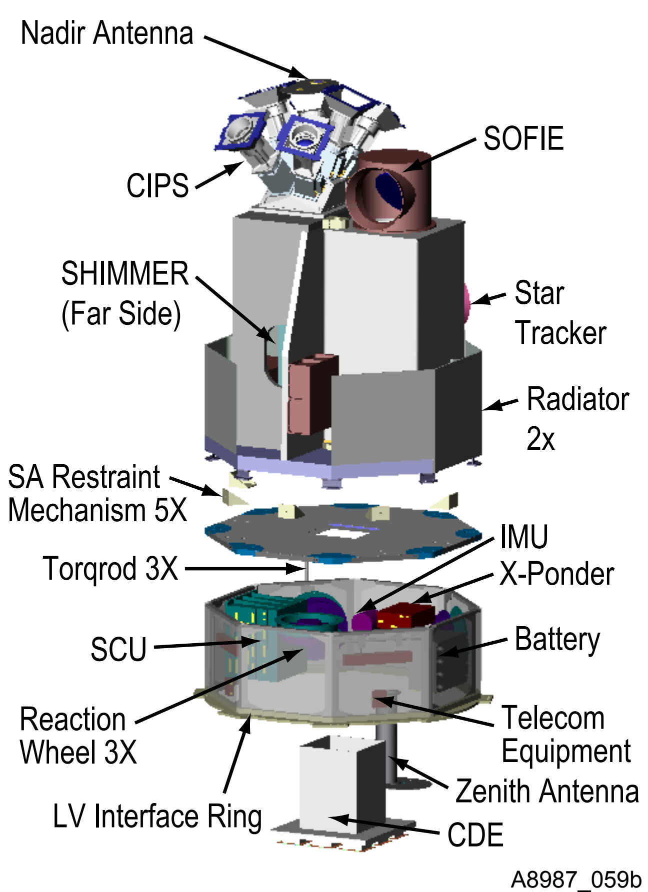


Figure F-12. AIM Exploded View

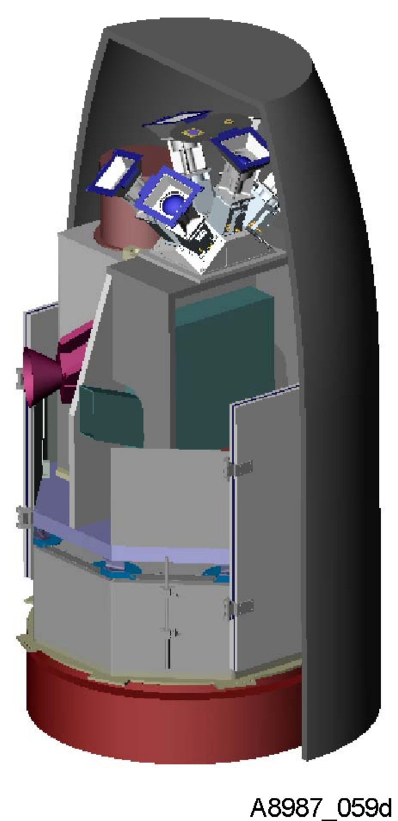


Figure F-4. AIM Stowed Configuration with HAPS in Fairing

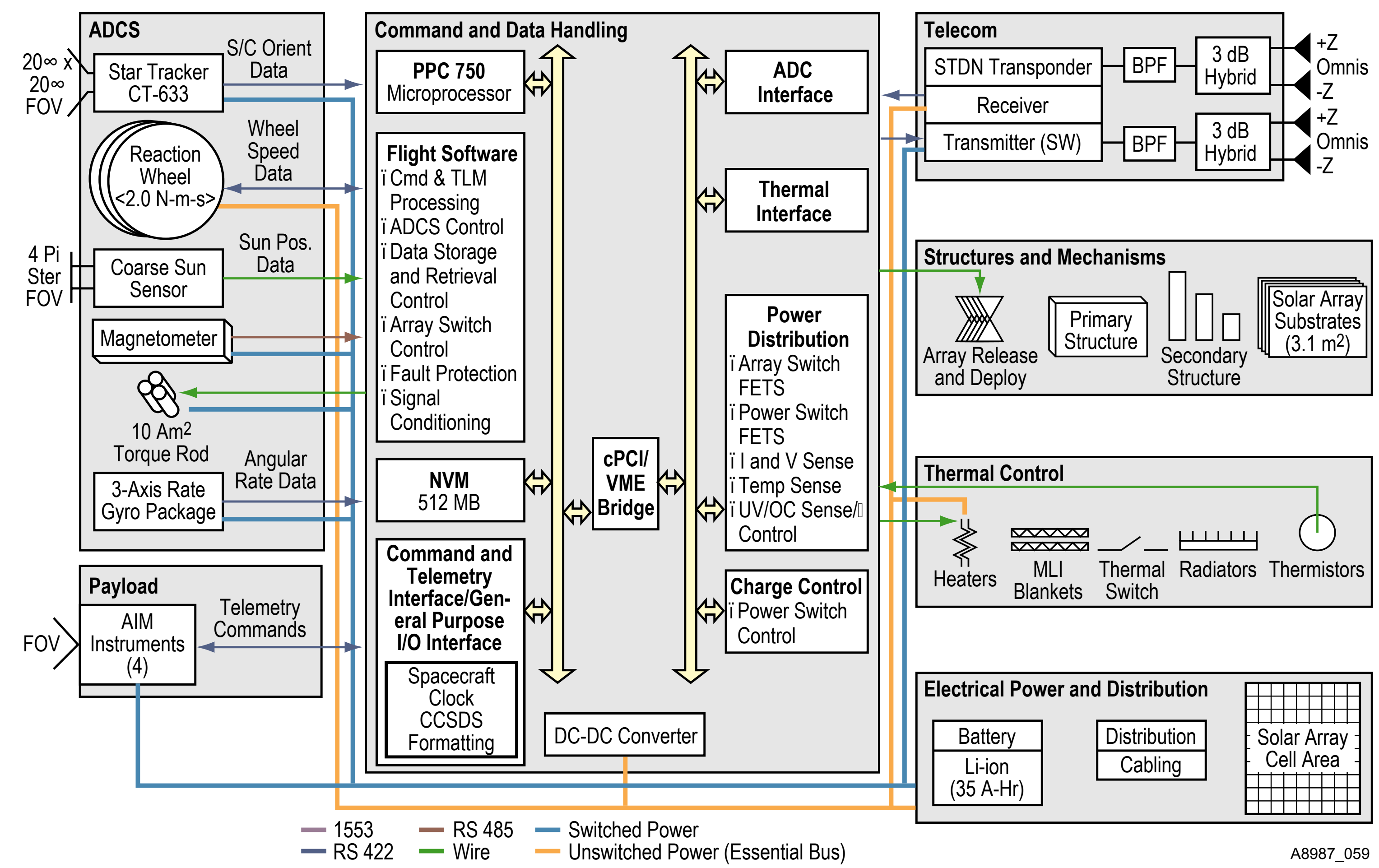
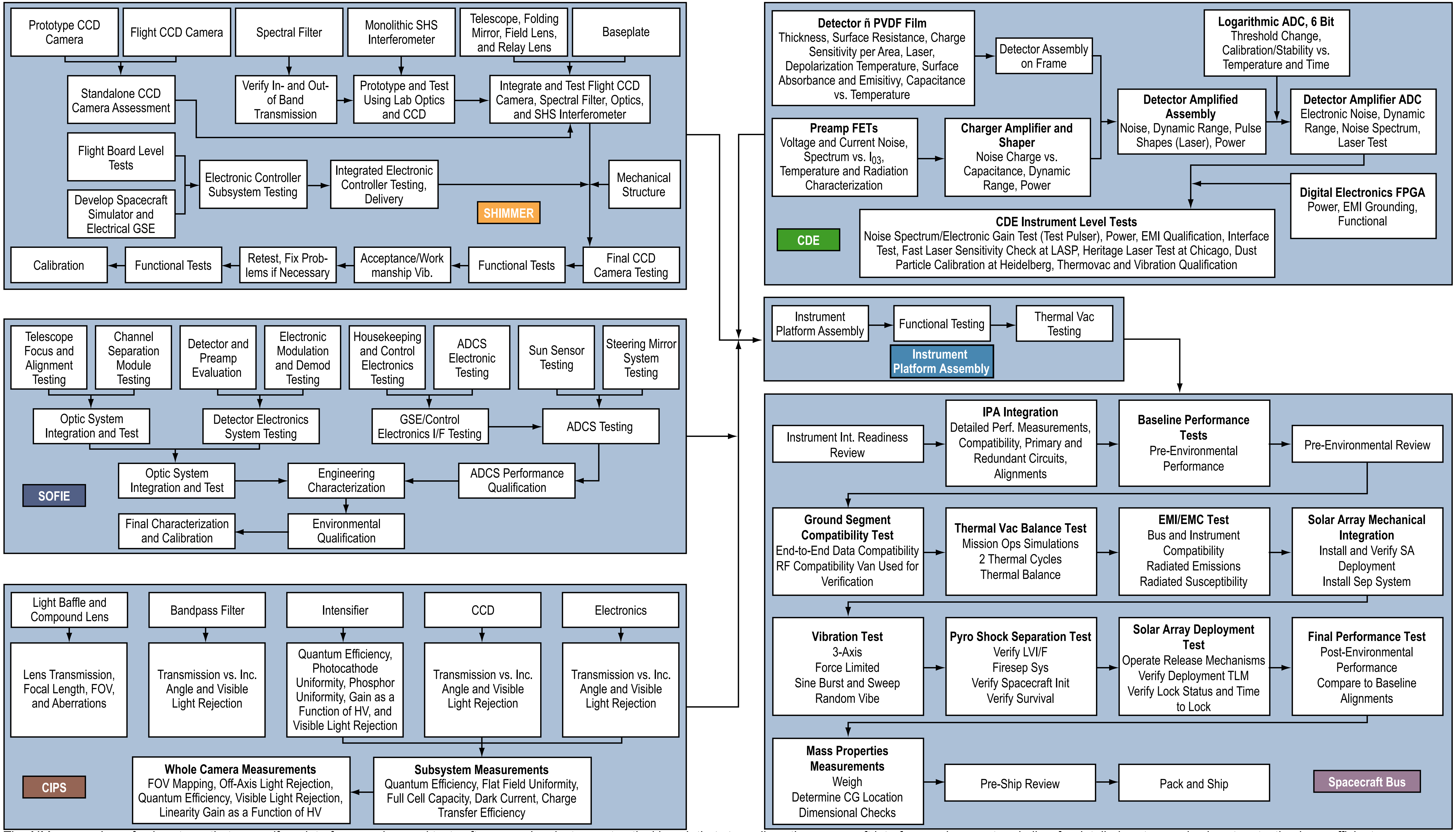


Figure F-3. The AIM – RS300 Functional Block Diagram

Foldout FO-F3. Spacecraft Overview



The AIM approaches of subsystems that use uniform interfaces and ground test software, and an instrument optical bench that streamlines the spacecraft interface, reduce cost and allow for detailed system and subsystem testing in an efficient integration process that ensures full capacity of achieving the AIM objectives.

Figure F-44. AIM Instrument Assembly Integration and Test Flow

Foldout F4. AIM Instrument Assembly Integration and Test Flow

F. Technical Approach

F.1 Overview

The AIM observatory consists of two principal subsystems: 1) the spacecraft (S/C) bus and 2) the instrument platform assembly (IPA). See **Fig. F-1**. The spacecraft bus is BATC's RS300, modified to accommodate the requirements of the AIM mission. These requirements are described in Section F.3. The IPA consists of the four instruments (SHIMMER (UV); CIPS (UV); SOFIE (IR); and CDE (dust)), the Star Tracker and the platform structure. See **Fig. F-2 on FO-F2**. Though mounted to the spacecraft, CDE is considered part of the platform as it shares the common electrical interface to the spacecraft. CDE requires a zenith view with minimal pointing requirements—easily within the pointing requirements of the remaining three instruments. SHIMMER, CIPS and SOFIE require co-spatial observations.

Simple Interface. The electrical interface between the IPA and the spacecraft bus is a simple power and serial bus connection using standard connector pairs. The physical interface to the spacecraft is accomplished using titanium flexures between the two structures. The instrument platform and the spacecraft bus are thermally isolated from each other. On the platform side each instrument controls its internal thermal environment. Thermal control of the IPA uses strategically placed heaters, controlled by the spacecraft. This design minimizes the interface complexity (see Fig. F-43).

Instrument Platform. Developing an instrument platform enables integration and test of the instruments in parallel with the spacecraft. The instruments and IPA are assembled and checked out at the instrument platform level to assure a fully functional instrument package when delivered to the spacecraft for final integration. LASP has used this approach on two prior missions (SME and SORCE) to reduce cost and schedule risk to the spacecraft bus vendor.

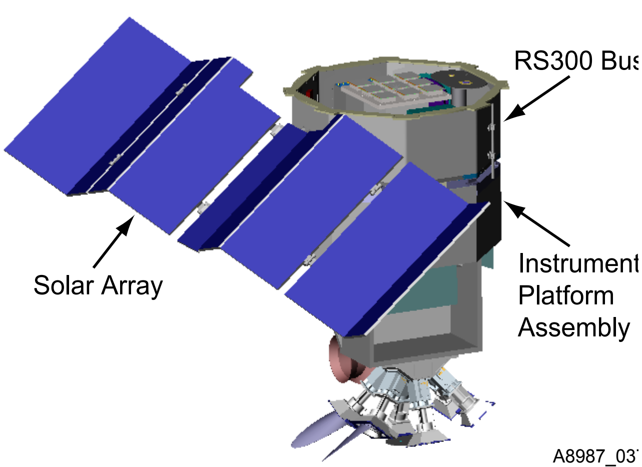


Figure F-1. AIM Spacecraft Deployed Configuration

Requirements Definition. This study has fully captured the science goals of the combined payload, distilled those goals into measurement requirements that meet the science objectives, and then allocated the measurement requirements in the form of instrument and spacecraft specifications. We confirmed that the selected instrument packages met the science requirements, and further assessed the instrument measurement capability to perform above the floor—providing a metric on the observational margin (Table F-4). Likewise, we carried out the same examination of the proposed spacecraft performance to assure that all science measurements can be accommodated at all points in the observing year, and again assessed the margin above the floor (Table G-4). We proceeded to study the risk issues for both the instruments and spacecraft.

Heritage and Technology Readiness Level. Each of the four instruments has successful heritage, with many technology readiness levels of TRL-8 and better and all of TRL-6 or better.[1] Each of the institutions—NRL, LASP, and SDL—are experienced in the design, development, assembly, test, calibration, integration, flight delivery and operation of instrument systems. **Table F-1 on Foldout (FO)-F2** lists the TRL levels for each instrument.

Spacecraft and Launch Vehicle. BATC's RS300 spacecraft meets the requirements of the mission. This spacecraft is comprised of heritage components, and provides a low-risk approach to the mission. The systems on the spacecraft bus are TRL-6 or higher (Table F-10). The spacecraft system launches on a Pegasus modified with a HAPS system to improve accuracy of the required orbit. An initial Interface Control Document (ICD) has been submitted to NASA Kennedy Space Center (KSC) describing the interface requirements between the spacecraft system and the launch vehicle. LASP and BATC both have interface control, design, integration and launch experience with Pegasus, and both fully understand the issues and requirements associated with the launch system.

Safety and Contamination Control. The IPA and spacecraft bus are passive elements without propulsion or expendables. Proven and reliable existing systems have been chosen for the satel-

[1] Refer to SMEX library for TRL definitions.

lite bus and instrument systems. Personnel working on the project are seasoned with many previous mission experiences similar to AIM. Contamination and control procedures for all wavelength ranges are the standard processes of all of the instruments and spacecraft providers.

Concept Study Risk Reduction Activities. Work has progressed on each of the instruments to evaluate the key risk items in the design. Effort was placed on evaluating risk, and closing out risk areas where possible. **Table F-2** lists the key studies performed during Phase A. These studies were carried out using funding provided by each of the participating institutions. The spacecraft has undergone internal IR&D work at BATC to move the designs closer to the Preliminary Design Review (PDR) level. Initial interfaces have been developed between the IPA and spacecraft bus and an engineering development unit bus structure has been built. At this point in the program the high-risk issues have been addressed and are well understood.

F.2. Mission Design

The AIM mission is designed to address all of its science objectives with the lowest possible risk and cost. The instrument suite and observation strategy have been carefully designed for summer polar mesospheric observations, using a reliable, low-cost launch vehicle, judicious choice of launch date, tailored orbit, length of mission, and required data down links. The AIM science objectives have been clearly defined in Section E.1.4. In this section we describe the approach for answering those objectives as well as provide an overview of the mission.

F.2.1 Science Traceability

FO-F1 provides two tables that trace the science objectives (see Section E.1.4) through to instrument requirements, spacecraft requirements, and mission design. The observables required to answer the AIM objectives and the requirements placed on those observations are listed in **Table F-3**. The requirements that the instruments place on the spacecraft and the mission are shown in **Table F-4**. We have determined that these objectives can be answered by a suite of four instruments. These instruments, shown in **FO-F2** are:

SOFIE (Solar Occultation For Ice Experiment) is an infrared radiometer experiment that uses a differential absorption technique in solar occultation (sunrise and set). SOFIE measures in eight spectral regions between 2.25 and 10.0 μm.

SHIMMER (Spatial Heterodyne IMager for Mesospheric Radicals) is an imaging UV interferometer that uses the SHS technique. The instrument measures a spectral image of the limb in a 0.33 nm passband near 308 nm with high spectral resolution (0.0058 nm).

CIPS (Cloud Imaging and Particle Size) is a UV panoramic imager that uses 6 identical intensified CCD cameras to image an 80 deg x 120 deg field of regard in the nadir in a 10 nm spectral passband centered near 265 nm.

CDE (Cosmic Dust Experiment) is a dust particle detector that uses the technique of depolarization detection in thin films.

The chosen AIM observables stem from challenges in observing the PMC phenomena. These tenuous clouds emit very little radiation because they occur in the coldest region of Earth's atmosphere. Therefore, sensing PMCs using emission requires expensive devices cooled to cryogenic temperatures. Like PMCs, signatures from other geophysical parameters (e.g., temperature, water, ozone and a tracer) suffer similar problems plus complicated non-equilibrium physics. Gaseous emission can be used only if elevated states can be found at short wavelengths that can be economically measured. Thus the obvious physical process observables are solar attenuation, resonance fluorescence and solar scattering.

Excellent PMC vertical profile extinction information can be acquired using solar occultation measurements with limited geographic coverage (SOFIE). Multiple angle solar scatter observations from limb viewers can achieve particulate scattering ratio information with broader coverage (SHIMMER). Global particle mapping and morphology requires a nadir imager that can isolate and measure the PMC scatter signature over wide viewing angles other than the limb (CIPS).

The SOFIE solar occultation signals are large enough to detect the very small molecular attenuation of a variety of key constituents that have no scatter signature. In fact, differential techniques using occultation can measure extinction with extraordinary precision and accuracy. These methods, used by the HALOE instrument on UARS, are enhanced and employed by SOFIE to infer CO_2 (and therefore temperature) as well as key gases and particulate extinction. Although occultation coverage is limited, the tremendous statistics from a satellite mission and the inherent high accuracy will allow atmospheric model calculations to extend to regions beyond where SOFIE measures. It also provides excellent calibration of SHIMMER temperatures that have wider geographical coverage.

Table F-2. Phase A Studies

#	Phase A Study	Result	CSR Sec.
1	Examine power system effects for yaw maneuver at equator vs. sub-solar point	Adequate power margin found	F.3.3
2	Evaluate spacecraft timeline and stability for instrument pointing to accommodate constant yaw motion, followed by repointing SOFIE for occultation measurements	All pointing requirements are met with adequate margin	F.2.4
3	Model AIM spacecraft and instrument lines of site in STK	Observation model is complete	F.2.4
4	Perform studies comparing LASP mission operations and SOMO	Moved to Phase B	F.7
5	What is the requirement for the min yaw motion rate required for common volume observations?	Yaw maneuver of 9 deg over 40 deg lat optimizes observations	F.2.4
6	Evaluate yaw-pitch-roll coupling during maneuvers	Cross coupling nulled by ADCS system	F.3.3
7	Evaluate thermal snap during day/night transitions	Effect is small	F.3.3
8	Evaluate relocating Star Tracker to instrument pallet	No complications	F.3.3
9	Provide power profile of instrument during orbit	Power profiles are complete	F.2.4,F.3.3
10	What is the co-alignment requirement for the star camera and SHIMMER?	Complete; see Table F-15	F.2.4,F.4.2, F.3.3
11	Determine savings (if any) on removing ranging capability from transponder	No savings, built-in feature	F.3.3
12	Determine testing requirements, equipment and support for instrument-to-pallet assembly and test	Requirements list complete	F.4.5,F.6
13	Evaluate effects of increasing BER from 10^{-7} to 10^{-6} on the downlink rate	Determined to be unacceptable	F.3.3,F.7
14	Create and distribute electrical interface diagram.	Complete, shown in Section F.4	F.3.3,F.4.5
15	Develop pallet design to include Phase A instrument new information, electrical interface box and instrument radiators	Complete, shown in Section F.4	F.4.5
16	Create initial thermal model of pallet and instruments	Complete, shown in Section F.4	F.4.5
17	Make plan for mass margin management	Complete, described in Section G	G.4
18	Determine thermal control method for pallet	Passive, described in Section G	F.4.5
19	Determine CDE interface	Complete, shown in Section F.4	F.4.4
20	Determine power switch location: S/C or Pallet	Spacecraft will provide	F.3.3
21	Perform launch vehicle injection errors study	Drives decision to use HAPS	F.2.3
22	Do trade study of altitude knowledge vs. pointing	Drives use of NSC data	F.4.2
23	Can CIPS download a raw image?	Yes	F.4.3
24	Study reaction wheel/CDE interaction	Moved to Phase B	F.4.4
25	Study pallet interface (mechanism thermal, power)	Preliminary design complete	F.4.5
26	Determine stowed array location and instrument FOV	Stowed configuration is acceptable; all FOV satisfied	F.3.3
27	Study CIPS flat field measurements in flight	Low lat, off season data can be used	F.4.3
28	Study CIPS data inversion algorithm	Algorithm is defined	F.4.3
29	Study instrument integration onto pallet	Integration plan is complete	F.4.5,F.6
30	Perform mass, CG and coupled loads analysis for pallet	All studies complete	F.4.5
31	Perform SHIMMER noise/bandwidth study	SHIMMER SNR meets all objectives	F.4.2
32	Test monolithic interferometer	One unit complete, meets all reqs.	F.4.2, H.1.3
33	Perform SHIMMER retrieval study	All requirements met with margin	Fig. F-24, F.4.2

SHIMMER uses observations of solar pumped resonant lines at short wavelengths to provide HOx chemistry data. It furthers the use of OH emission with a novel static measurement system that achieves high spectral resolution, providing spectral line intensity ratios that are used for temperature inferral. Observation of resonance fluorescence also allows viewing in multiple directions for better global coverage.

The CIPS measurement strategy described later

Foldout F1. The AIM Suite of Instruments

Foldout F2. End to End Phase A Studies of Instrument Designs and Test Plans Including Simulated Retrievals Verify that All AIM Objectives will be Met

in this section, is perhaps the only viable approach for global PMC mapping. It relies on shielding the underlying scattering media by using wavelengths that have ozone absorption and focusing on times when the underlying atmosphere below PMC altitudes is in the earth shadow.

The AIM observables include a suite of solar signals that allow altitude profiling of key parameters at specific coincident locations, mapping of HOx chemistry and determination of cloud morphology. AIM makes use of solar extinction, solar pumped emission and solar scattering; all vital components to the mission objectives. The AIM observables are the obvious choice for PMC analysis, and the AIM instrument suite is the logical low cost/low risk (high heritage) choice for accurate measurement of those observables.

Section F.4 provides details of the instruments and tabulates their data products.

The AIM spacecraft bus uses BATC's RS300 as shown in Functional Block Diagram in **FO-F3, Fig. F-3**, built from high-heritage components. Its functional architecture is processor-based and simple. The bus design capitalizes on ongoing IR&D activities, on parallel efforts, and on BATC's 40-year experience base in space systems. The RS300 is capable of providing the required instrument accommodation with adequate margins.

This suite of measurements incorporating different observation strategies is ideal for accomplishing the AIM objectives. The instruments are all low risk and low cost, and combined they comprise the minimal suite of instrumentation needed while maximizing the information gained. SOFIE and SHIMMER overlap in their measurement of Temperature (T), clouds, and H_2O (inferred from SHIMMER OH). This combination was chosen not for the added benefit of redundancy but rather to satisfy the requirements of obtaining very precise measurements of H_2O and T over the entire range of latitudes that PMCs form. The combination of the two techniques represents the most effective and efficient method to obtain the data required to meet the AIM objectives. We chose the well-proven low-risk and high precision method of solar occultation with limited spatial coverage and combined it with a limb scattering method that has better spatial coverage. The limb scattering measurements can be calibrated each orbit against the solar occultation measurement at the common volume location to validate measurements of H_2O and T throughout the sun lit portion of the summer hemisphere.

While SOFIE and SHIMMER provide information about the environment in which PMCs form (as well as some cloud properties), CIPS determines properties of the clouds themselves, in particular, cloud particles sizes. CIPS aids analysis of SOFIE and SHIMMER measurements by determining cloud extent in common FOVs. Finally, the CDE measures the cosmic dust input, providing knowledge of potential nucleation sites for cloud particles. The required geographical coverage for answering the AIM objectives clearly necessitated a space-based mission. With the instrument suite chosen, spacecraft requirements were generated. Those requirements are listed in Table F-4, FO-F1. The instrument mass, power, volumes, and data rate fit very well with a BATC RS300 spacecraft bus. The RS300 solar array design is flexible allowing for an implementation where the nominal angle relative to the sun is maintained by yaw maneuvers near the sub-solar and anti-solar points. The flexibility allows SOFIE to face the sun both as the spacecraft enters and exits shadow and SHIMMER to face towards the Earth's limb, but away from the sun (which could cause high background signals) as it observes PMCs. Neither CIPS which faces the nadir, nor CDE, which faces the zenith, are affected by this yaw maneuver.

The science objectives require measurements over the full range of latitudes where PMCs form, demanding a polar orbit. A local time of noon for the descending node equator crossing optimizes the coverage by SOFIE and permits coincident measurements with SHIMMER and CIPS at the SOFIE occultation point. A mission duration of four PMC seasons, two in each hemisphere, is sufficient to answer the objectives and ensure that the results are not obscured by seasonal variability.

Table F-5 provides a summary of all the design drivers for the AIM mission including those that drive cost and schedule**.** There are no cases where design margins are cost drivers; however, Table F-5 lists all margins in design also.

F.2.2 Launch Considerations

A launch date of September 30, 2005 provides for a schedule with minimal risk, appropriate margins, and for science observations to begin at an optimal time relative to the Southern 2005-2006 PMC season. There is, however, some flexibility in the launch date. For a launch significantly later than September 30, we may miss part of the first PMC season impacting science. An earlier launch would add development risk. The impacts of changing the launch date are addressed

Table F-5. AIM Design Drivers. *AIM design drivers have been addressed completely resulting in a design with adequate margins.*

		Design Parameter	Design Drivers	Current Margin, Comments	Driver
Spacecraft		Mass	Instruments, IPA, SOFIE	20% reserve and margin (See Section G.4)	C
Spacecraft		Power	Instruments, SOFIE (TECs)	14%	
Spacecraft		Data storage	CIPS, SHIMMER data volume	124%	
Spacecraft		Link margin	CIPS, SHIMMER data volume	>9 dB	
Spacecraft		Pointing, ADCS	SHIMMER limb viewing	80%	
Spacecraft		CPU MIPS	No major drivers from observatory	>600%	
Instruments / Observatory	SOFIE	Sensitivity	Required precision	**See FO-F1**, drives detector choice, optics	S,C
Instruments / Observatory	SOFIE	Spatial Res., FOV	Required alternate resolution	No margin, can trade with sensitivity	
Instruments / Observatory	SOFIE	Coverage, FOR	Limited by technique	N/A	
Instruments / Observatory	SOFIE	Spectral Resolution	Broadband measurement	N/A	
Instruments / Observatory	SOFIE	Pointing	Need to fix on sun during occultation	Planned options have margin, see F.4.1	
Instruments / Observatory	SOFIE	Structure/Mechanisms	Pointing mechanism, Pegasus launch, chopper	Planned options have margin, see F.4.1	
Instruments / Observatory	SOFIE	Lifetime	23-month mission lifetime (22 month Phase E)	>x2, Parts selection approp. for 2-year mission	
Instruments / Observatory	SOFIE	Signal processing	No on-board signal processing	N/A	
Instruments / Observatory	SOFIE	Data storage	Minimal data generation	N/A	
Instruments / Observatory	SHIMMER	Sensitivity	Required precision	**See FO-F1**, drives detector choice, optics	S
Instruments / Observatory	SHIMMER	Spatial Res., FOV	Required altitude resolution	No margin, can trade with sensitivity	
Instruments / Observatory	SHIMMER	Coverage, FOR	Required geographical coverage	Full lat. coverage of PMC region	
Instruments / Observatory	SHIMMER	Spectral Res.	Needed to measure OH, T	x3	C
Instruments / Observatory	SHIMMER	Pointing	Needed to image limb	x3, RS300 capability	
Instruments / Observatory	SHIMMER	Structure / Mech.	Pegasus launch	x2 factor of safety in structure	
Instruments / Observatory	SHIMMER	Lifetime	23-month mission lifetime (22 month Phase E)	>x2, Parts selection approp. for 2-year mission	
Instruments / Observatory	SHIMMER	Signal processing	No signal processing	N/A	
Instruments / Observatory	SHIMMER	Data storage	Spatial, spectral resolution	10% for 2 8-minute passes per day	
Instruments / Observatory	CIPS	Sensitivity	Required precision	See **FO-F1**, drives detector choice, optics	S,C
Instruments / Observatory	CIPS	Spatial Res., FOV	Structure in clouds	x2 in FOV	
Instruments / Observatory	CIPS	Coverage, FOR	Required geograph. coverage	X% overlap, multiple cameras, s/c motion	
Instruments / Observatory	CIPS	Spectral Res.	Broadband measurement	N/A	
Instruments / Observatory	CIPS	Pointing	Need to be point in nadir	>x10 from RS300 capability	
Instruments / Observatory	CIPS	Structure / Mech.	Mechanism dust cover, Pegasus launch	1 use mech., x2 factor of safety in structure	
Instruments / Observatory	CIPS	Lifetime	23-month mission lifetime (22 month Phase E)	>x2, Parts selection approp. for 2-year mission	
Instruments / Observatory	CIPS	Signal processing	On-board compression	>x2 capability from CIPS microcontroller	
Instruments / Observatory	CIPS	Data storage	Required spatial resolution	10% for 2 8-minute passes per day	
Instruments / Observatory	CDE	Sensitivity	Required precision	See **FO-F1**, Difficult to asses, particle influx not known	
Instruments / Observatory	CDE	Spatial Res., FOV	N/A	N/A	
Instruments / Observatory	CDE	Coverage, FOR	Observes full zenith hemisphere	N/A	
Instruments / Observatory	CDE	Spectral Res.	N/A	N/A	
Instruments / Observatory	CDE	Pointing	Needs to be pointed in zenith	>x10, RS300 capability	
Instruments / Observatory	CDE	Structure/Mechanism	No mechanism, vibration sensitive	Vibration studies to be done in Phase B	
Instruments / Observatory	CDE	Lifetime	23-month mission lifetime (22 month Phase E)	>x2, Parts selection approp. for 2-year mission	
Instruments / Observatory	CDE	Signal processing	No signal processing	N/A	
Instruments / Observatory	CDE	Data storage	Minimal data generation	N/A	
Instruments / Observatory	**IPA**		Mass may need to be reduced	Switch to composite materials	

* C=Key Cost Driver, S=Key Schedule Driver

Table F-5. AIM Design Drivers. *AIM design drivers have been addressed completely resulting in a design with adequate margins. (continued)*

	Design Parameter	Design Drivers	Current Margin, Comments	Driver
Mission	E/PO	Involve AIM science, minorities	Alaska workshops (NLCs), HBCU leadership	
	Mission ops	CIPS, SHIMMER, data volume	2 8-min. passes per day sufficient	
	Launch date	PMCs are a seasonal phenomenon	Flexible launch date, 2 PMC seasons per year	
	Orbit	PMCs are a polar phenomenon	Polar, sun synch. orbit is ideal	
	Mission lifetime	PMC seasons vary year to year	Four season mission is adequate	
	Launch vehicle	Payload mass, required orbit	Pegasus is adequate	
	Observations	Four different observing geometries	Equatorial yaw maneuvers allow common volume observations	

* C=Key Cost Driver, S=Key Schedule Driver

in Section L.

Because we are using the Pegasus XL launch vehicle and have chosen a polar orbit, Vandenberg Air Force Base is the logical choice for launch facility. A constraint is placed on the local time of the launch by optimizing the overlap of the CIPS and SHIMMER observations. The number of observations of the same volume of air (which are separated by six minutes in time) begins to be reduced if the the local time of the orbit is more than seven minutes away from noon/midnight. We have calculated the orbital (β angle) as a function of time (equation of time). We have found that using the HAPS option on the Pegasus will optimize the overlap of SHIMMER and CIPS observations.

The Pegasus XL has the ability to place AIM into its desired orbit of 500 km. The nominal orbital altitude provides more than the desired mission lifetime of 23 months as the expected orbit lifetime at 500 km is 4.5 years. Therefore, no propulsion systems are required for the AIM spacecraft and orbit maneuvers, and orbit maintenance is not required.

The Pegasus launch mass margin for a 500 km orbit using HAPS for orbital injection accuracy, is detailed in **FO-F3, Table F-6.** After HAPS orbit adjustments the AIM spacecraft is separated from the Pegasus booster, which is moved to a position which will ensure no recontact with the spacecraft.

The AIM spacecraft has adequate fairing clearance with the HAPS upper stage as shown in **Fig. F-4 on FO-F3**.

F.2.3 The AIM Orbit

The AIM orbit is a 500 km circular, sun-synchronous orbit at a local time of noon/ midnight (descending/ascending) with an inclination of 97.40 deg. This orbit is designed to provide the required geographical coverage, optimal overlap of measurements from instruments with different observation strategies, Earth (as opposed to spacecraft) sunset observations by SOFIE in the north, and nominal mission lifetime. In addition, the noon/midnight orbit is optimal for SHIMMER measurements because the OH concentration peaks at noon at most latitudes.

We have studied the radiation dose environment for the AIM orbit and lifetime. **Figure F-5** represents the results of that analysis. The AIM spacecraft will survive the environment represented by the 2X curve.

F.2.4 Mission Timeline

AIM Nominal Orbit Profile. A nominal AIM orbit is shown schematically in **Fig. F-6** for a southern summer. For the northern summer case, an analogous scenario is performed but in the northern hemisphere.

SOFIE will make two occultation measurements per orbit, a sunrise and a sunset. The sunrise occultation will occur just as the spacecraft reaches the terminator crossing into the dayside portion of the orbit and will last about one minute. SOFIE will scan across the disk of the sun for about three minutes after the occultation is complete to maximize the precision of the exoatmospheric offset and source measurements. The sunset occultation will occur as the spacecraft reaches the terminator crossing into the nightside portion of the orbit. The occultation will again last about one minute. For about four minutes prior to the occultation, SOFIE will scan across the disk of the sun. There are no special operating modes or special observations for SOFIE.

CIPS is a nadir viewing imager. It will take data in the summer hemisphere during that portion of the orbit where the atmosphere (100 km and below) is illuminated by the sun. The first CIPS observations are made at 30 deg latitude in the summer hemisphere. The observations continue

Foldout F3. Aeronomy of Ice in the Mesosphere (AIM)

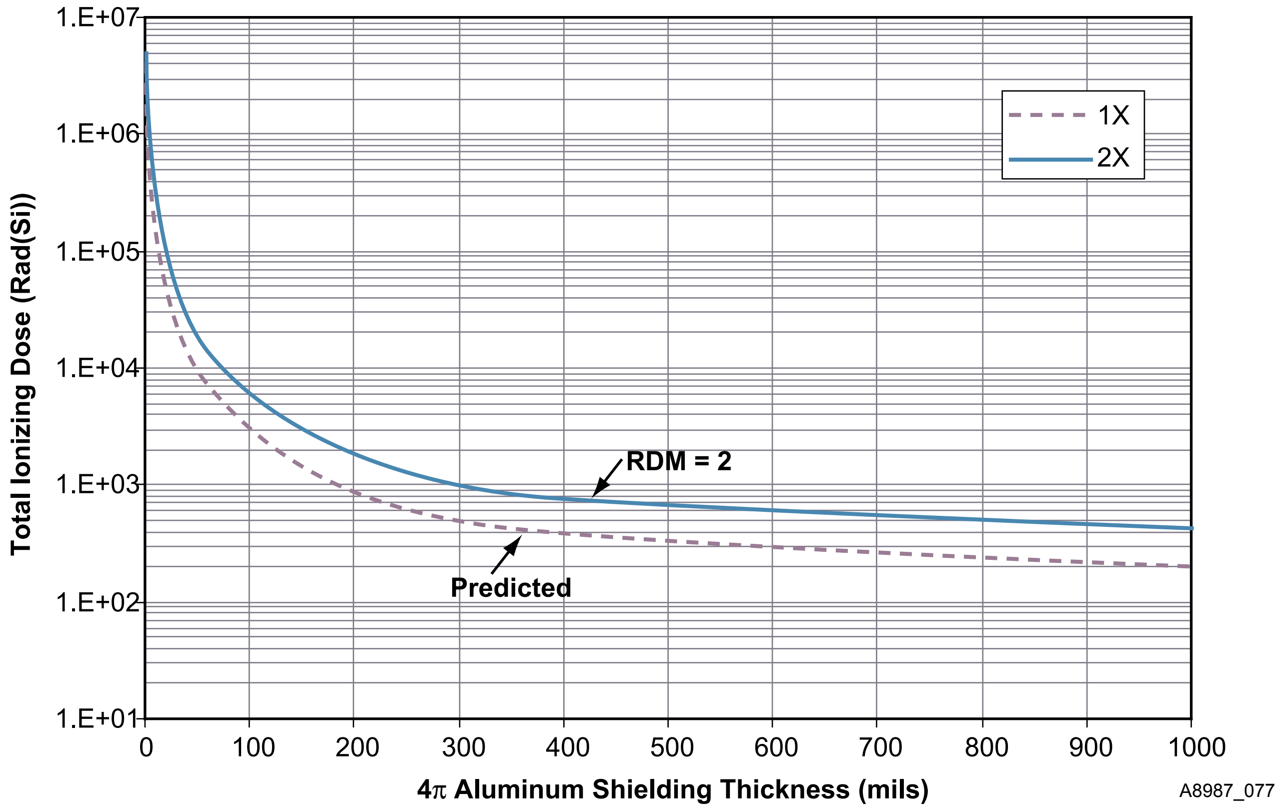


Figure F-5. AIM Total Ionizing Dose Curve

until CIPS has observed the terminator crossing. The terminator crossing is the common volume where CIPS, SOFIE, and SHIMMER observe the same volume of space. Observation of this volume is the most important. CIPS observes over a field of regard ±60 deg from the nadir and so it will continue to take observations until the spacecraft position is 8.5 deg in latitude past the terminator. During the period of the orbit where data is being stored, an image will be produced each 41 seconds. There are no other CIPS events during a nominal orbit. It is possible that during planned special campaign modes the sampling rate may increase but the plan described above will be nominal. Times and locations that are free of PMCs will be sampled to characterize the PMC free atmosphere and may also be customized to facilitate or optimize the guest investigator science. This sampling scheme will be chosen at a later time.

SHIMMER, a limb-imaging instrument, will observe the illuminated portion of the summer hemisphere each orbit. The first image will be taken when the spacecraft is at a latitude of about 17 deg in the PMC hemisphere so that the first SHIMMER image will be no lower than 40 deg in latitude. SHIMMER, a limb viewing experiment viewing along the orbit track, observes a volume of air approximately 23 deg along the orbit track away from the spacecraft. The spacecraft yaw maneuver must be complete in time for SHIMMER to see any low latitude PMCs. The last image will be taken about 23 deg along the orbit track before the terminator crossing into the nightside portion of the orbit. This is the common volume measurement. A SHIMMER image will be produced about every 12 seconds.

SHIMMER has one special mode that will be used about once every month. During the umbra part of one orbit, the spacecraft will point the SHIMMER FOV at the moon. A transmissive diffuser in front of the telescope will ensure the illumination of the entire FOV by the moon. This orientation is needed for approximately five minutes. The purpose is to measure the spectral structure of the reflected solar light so that sunlight scattered from the atmosphere can be distinguished from OH emissions in the SHIMMER data. Lunar observations are preferred over direct solar observations for this measurement because the lunar albedo is constant over the narrow SHIMMER bandpass and because the lunar spectrum will have an intensity closer in brightness to the Earth spectrum. These data will also be used to assess the performance of the instrument and check for any long-term changes in in-

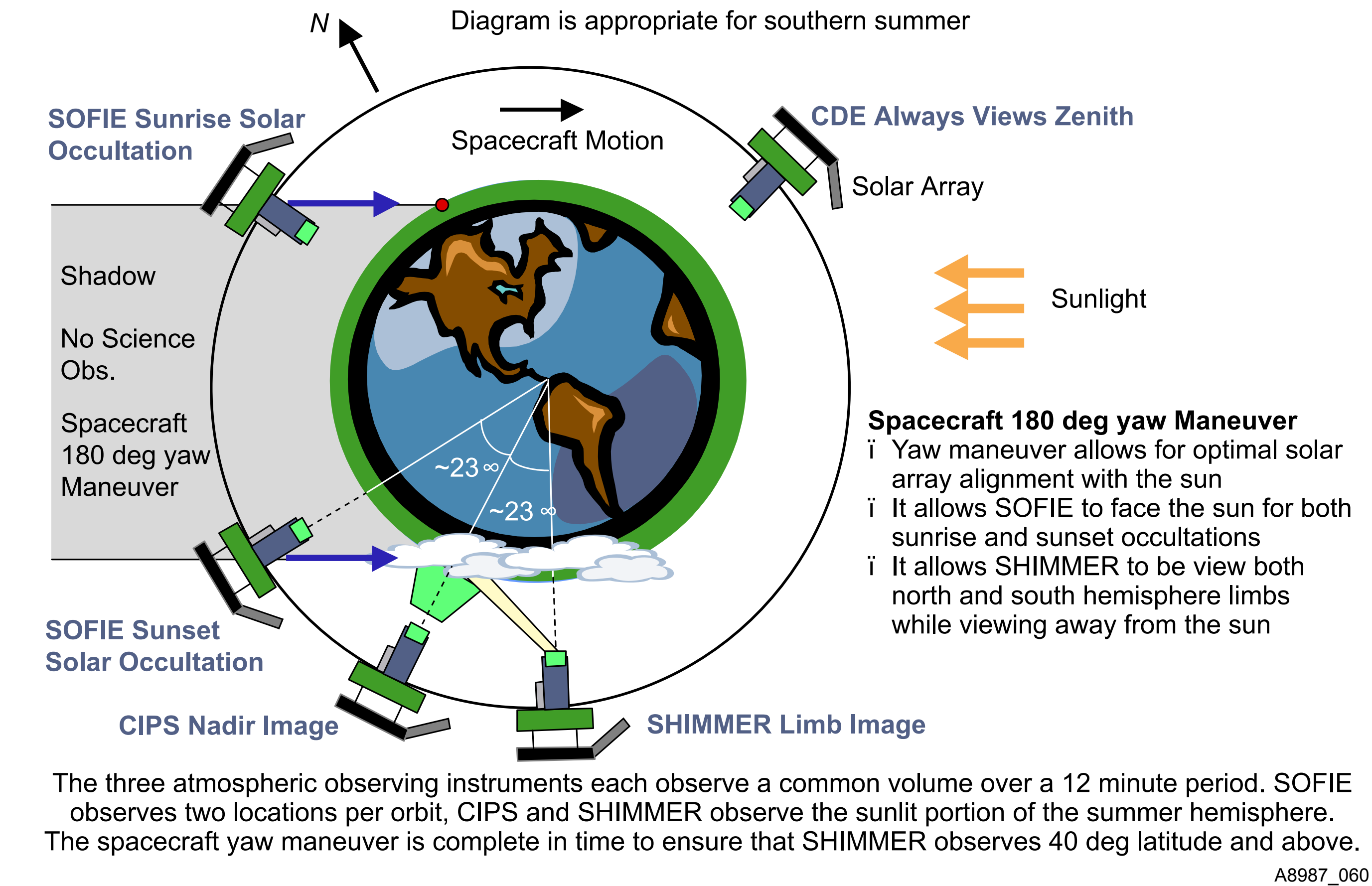


Figure F-6. AIM Observation Strategy. *The AIM observation strategy provides viewing of clouds with three techniques within 12 minutes during each orbit. The three techniques plus the cosmic dust collection allow all of the AIM objectives to be well addressed.*

strument function and spectral responsivity.

CDE, a particle counting experiment, observes in the zenith throughout the orbit. The CDE is always collecting data and there are no special operating modes.

The spacecraft will execute a 180 deg yaw maneuver twice an orbit for solar array and instrument pointing. This maneuver will require about 3.5 minutes, including settling time, and will be completed before the spacecraft reaches a latitude of 17 deg in the PMC hemisphere to accomodate SHIMMER observations as described earlier (see **Fig. F-7**). During this time, the spacecraft will travel through approximately 13 deg of latitude. Note that for optimal power considerations the maneuver would be centered over the subsolar point, which would be at about 23 deg latitude on the summer solstice. A detailed power analysis has shown that performing the maneuver before reaching the subsolar point maintains adequate power margins.

As the spacecraft moves toward the pole, aditional small yaw maneuvers are made. As mentioned above the common volume observa-

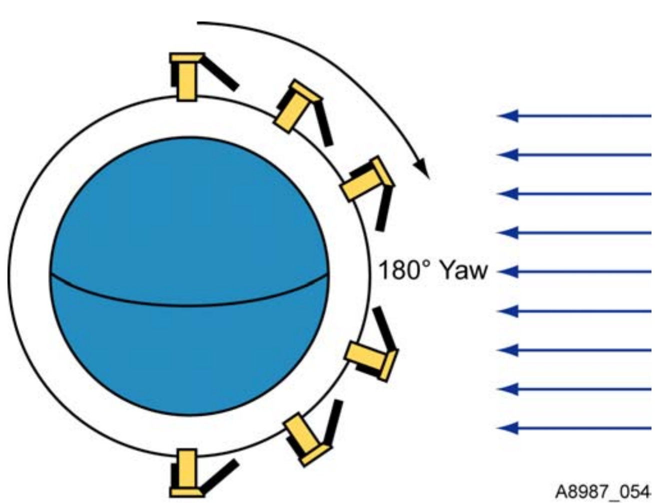


Figure F-7. AIM Yaw Maneuver

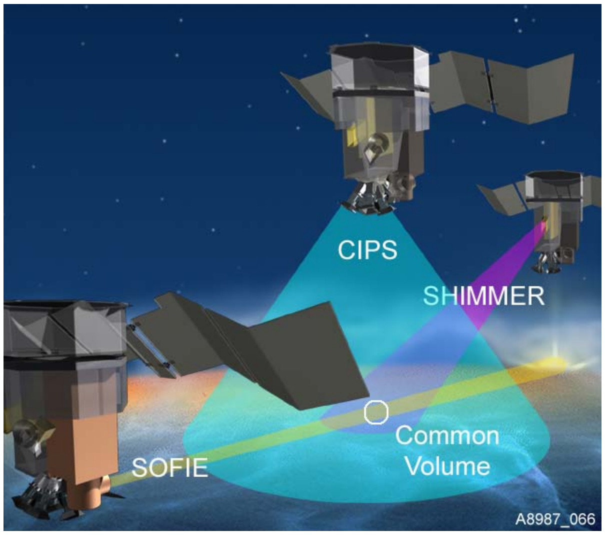


Figure F-8. Common Volume and Instrument Fields of View

tions (**Fig. F-8)** are the most important and occur over a period of 12 minutes. These small yaw adjustments are needed for two reasons. First, the orbital beta angle (the angle between the orbital plane and the sun) will vary throughout the year and affect the number of observations for which CIPS and SHIMMER will overlap. The beta angle effect combined with the spin of the Earth will also affect the ability of SOFIE and SHIMMER to observe the same volume of space 12 minutes apart. The beta angle variations are caused by the elliptical orbit of the Earth around the sun (the Earth speeds up and slows down) and the obliquity of the Earth's axis. Similar affects may be caused by orbit injection errors leading to a non-nominal precession rate. Detailed simulations of these effects have been performed which include the range of injection errors of the Pegasus XL. We have found that, at the time when the orbit local time is farthest from noon/midnight due to the equation of time, a yaw maneuver of only 9 deg is required to ensure common volume measurements by the three instruments. At all other times the maximum yaw required is less than 9 deg. Smaller yaw maneuvers earlier in the orbit (for southern observations, later in the orbit for northern observations), provides common volume observations by CIPS and SHIMMER over the entire science part of the orbit. Further studies during Phase B will determine the nominal number of maneuvers to make.

On a monthly basis, a 45 deg pitchover maneuver will be integrated into the yaw maneuver on the sunlit side of the orbit. This will be executed as a wind/unwind maneuver to minimize momentum management. This maneuver will extend the total orbit adjustment period to ~ seven minutes.

Once every 15 orbits, the reaction wheels will be desaturated via use of the magnetic torque rods. This 10-minute operation will occur over the hemisphere that is not under observation, during the nightside of the orbit. This operation will require 10 minutes.

Twice per day, an S-band communication pass will be executed for up to 11 minutes duration. Passes will be scheduled approximately one week ahead of time with one of the antenna facilities listed in Section F.7.

The selection of the four AIM experiments was made on the basis of their multiple synergistic aspects. The combination of the three remote sensing experiments (CIPS, SOFIE and SHIMMER) provides complementary information on PMC properties, all within a common volume.

For example, accurate ice particle size distribution information requires the combined CIPS and SOFIE radiances (Section F.4.3). CDE provides the input cosmic dust flux (see Section F.4.4), whose end result is a meteoric "smoke" layer (we now believe to be measurable by the SOFIE experiment), of critical importance to the microphysical goal of studying ice particle nucleation (Science Goals and Objectives E.1.4.5). Thus, in addition to having new data sets from four instruments, the combination of the data yields a wealth of unprecedented results on PMC ice particle sizes, densities and composition. Since these may be associated directly with common volume measurements of atmospheric water vapor, temperature, etc., they afford a closure of information vital for answering the science questions of what causes PMC, and why they vary in space and time. Indeed the combined information approaches the ideal of simultaneity, usually associated with "snapshot" *in situ* rocket probing. In addition, the ionized component (not directly measured by AIM) will be modeled (by CHEM 2-D), using additional input on solar and particulate fluxes from other NASA experiments. The global aspects of AIM will provide unprecedented detail on PMC microphysics over several thousand orbits in four PMC seasons, under varying atmospheric and solar conditions, both north and south, a feat only possible from orbit. The statistical ensemble of AIM measurements will provide the necessary data base to dissect and understand the variety of physical mechanisms affecting PMC.

AIM Operation Phase. PMC are a seasonal phenomenon. These clouds appear only in the summer hemisphere and only from about 45 days prior to solstice through 60 days post solstice. The nominal launch date of September 30, 2005 allows for a two-week checkout of the spacecraft while the instruments are allowed to outgas. The instruments can then be turned on and adjusted into their nominal observing modes over a second two-week period. This initial phase will then leave several weeks for the PMC-free atmosphere to be characterized and the beginning of the PMC season to be observed.

The operation phase is shown in **Fig. F-9**. Within about two to four weeks of AIM going into its nominal observation mode on about November 15, 2005, the Southern PMC season will begin. AIM will observe PMCs for the following three to four months. Note that AIM will provide the most sensitive detection system for PMCs ever implemented and may observe dim clouds at the beginning and end of each season that were previously not observable. For this reason, it is difficult to state definitively the length of the PMC season.

Approximately three months after the end of the 2005-2006 southern PMC season, the 2006 northern season will begin. Again for three to four months AIM will observe PMCs. The process is repeated as AIM observes the 2006-2007 southern PMC season and the 2007 northern season. The nominal AIM mission comes to an end on September 30, 2007.

During the 23-month AIM nominal mission, AIM will observe four PMC seasons. There will be approximately nine months of observations of the PMC-free atmosphere. These observations serve as a baseline for characterizing the environment in which PMCs do not form so that it can be compared and contrasted with the environment(s) in which PMCs do form. In addition, the data from the PMC-free portions of the mission may be valuable to a variety of guest investigator studies.

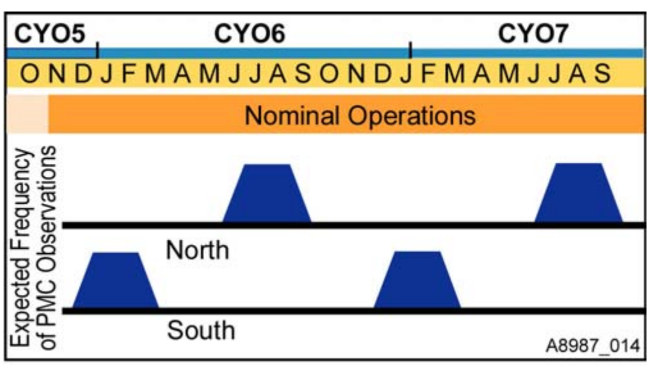


Figure F-9. Overview of the Nominal AIM Operational Phase. *Launch is September 30, 2005. A one-month period of spacecraft and then instrument check-out is shown before the 22 months of nominal –operation. Shown are the four seasons during which PMCs are expected to be observed.*

Communications Network. The AIM mission operations will be conducted by LASP, currently operating two spacecraft, SNOE and QuikSCAT, and is preparing to operate two more, ICESat and SORCE. The chief AIM ground stations will be located at Poker Flat, Alaska and Svalbard, Norway. LASP currently uses these 11-meter systems for the QuikSCAT spacecraft and plans to use them for ICESat also. We expect that AIM will be able to use the existing data links to these facilities. The White Sands Scheduling Office (WSO) will be used for ground station scheduling, which is the same as for SNOE and QuikSCAT. The GSFC Flight Dynamics Facility will be used for approximately two weeks after launch to process tracking data from NASA ground stations and provide ephemeris information to the MOC. Thereafter tracking data from the GS will be provided directly to the MOC and processed by the MOC to provide AIM ephemeredes for routine operations.

The AIM mission will require that two contacts per day of 8.5 minutes average duration be scheduled from a possible 12 to 16 opportunities available. Since the 3.5 Gb of on-board data memory allows for storage of 32 hours of AIM data, there are no hard requirements for the two daily passes to be scheduled at any particular time. This allows maximum flexibility for WSO to resolve scheduling conflicts between AIM and other users of the shared commercial ground resources. Current loading studies for these resources during the AIM mission time frame confirm that there will be no resource conflicts under normal circumstances. AIM, following the lead of previous SMEX missions, has imposed a 90% data capture requirement. This requirement should be more than sufficient to allow for any outage caused by resources becoming unavailable due to equipment failures or higher priority uses. Such lack of availability may ultimately result in the loss of data, however the number of views per day combined with sufficient on-board data storage memory should minimize loss due to lack of availability of other resources and still allow AIM to easily meet it's 90% data capture requirement.

F.3 Spacecraft Bus

BATC will use its RS300 spacecraft bus for the AIM program. The RS300 is a low-cost bus, specifically designed for Pegasus Class missions. Approximately 85% of the bus components have direct traceability to flight heritage. It maximizes the use of high-heritage components and leverages successful bus designs from previous BATC programs—DARPASAT, GFO, and the BCP-2000 spacecraft series (used on ICESat and QuikSCAT)—as well as current programs such as DEEP IMPACT. The RS300 meets all of AIM's requirements (see FO-F1) with adequate margin discussed in Section F.3.5.

F.3.1 Systems Overview

The AIM spacecraft characteristics are summarized in **Table F-7**. **Fig. F-10,** and **Fig. F-11 on FO-F3,** provide a view of the integrated RS300/ AIM IPA in the deployed configuration. The 3.1 m^2 solar array is fixed at its 50 deg fully deployed position. The CDE instrument can be seen at the top of the figure mounted to the centerline of the bus and pointing zenith. The CIPS instrument is at the bottom and points nadir. The stowed configuraton is shown on FO-F3 Fig. F-4. The Pegasus HAPS is also shown at the bottom of the figure and has been accounted for in determining the AIM spacecraft clearence with the Pegasus XL fairing. **Fig. F-12 on FO-F3** provides an exploded view of the spacecraft and the location of the spacecraft components. As can be seen, most of the bus components mount to the inside of the bus structure. This allows for maximizing the effective diameter of the primary structure to maximize its structural rigidity and payload capability. It also allows for the sidewalls to serve as radiators for the bus components. The Instrument Pallet Assembly mounts to eight attach fittings on the top deck. The multiple attach fittings allow the instrument loads to be evenly distributed over the interface allowing for a lighter structure and higher margins of safety. A flush interface design allows for easy integration of the instrument assembly. The star tracker is mounted to the IPA to increase pointing accuracy by minimizing thermal distortions between the tracker and instruments.

Table F-7. AIM Spacecraft Bus Characteristics

Design Life	24 months
Orbit	500 km polar sun-synch AM/PM
Launch Vehicle	Pegasus XL / HAPS
Launch Mass	252 kg (includes 20% reserve)
Redundancy Approach	Single string
Control System	3-axis stabilized, zero net momentum, stellar-inertial
Navigation	Transponder ranging
Available Power	290 (W) (orbital average, EOL)
Solar Array Size/Type	3.1 (sq m), deployable, non-articulating, triple-junction GaAs cells
Onboard Data Storage	3.0 Gbit (science); 1.0 Gbit (S/C)
Communication Approach	TT&C: S-band (STDN) Xpndrs Instrument : Same
Thermal Control	Primarily passive with some active heater control

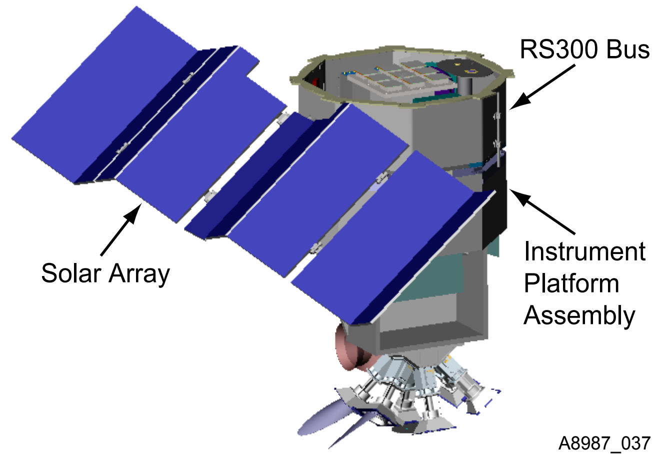


Figure F-10. AIM spacecraft deployed configuration

The RS300 spacecraft is single-string architecture and is consistent with other two-year spacecraft BATC has designed. In developing the design of the RS300, we have looked at HW and SW functions and made the decision to allocate many –functions to SW. This design minimizes the number of components to cause potential problems on orbit. Software modifications can be made on-orbit if necessary.

The RS300 is similar to other single-string spacecraft BATC has built—MTI, and DARPASAT, for example—that have been fully successful and reliable on orbit. Use of a redundant architecture would have significantly increased cost and mass. As a result, the single-string RS300 architecture was selected.

The structural, mechanical, power supply, electrical, thermal control, and communications subsystems meet all of AIM's requirements without modification. A functional block diagram of the flight system design, including flight subsystems and their interfaces, is provided in Fig. F-3.

BATC has developed the RS300 design to a Phase B level, and it has successfully passed a PDR design review (absent the payload). Once on contract, the design will undergo additional reliability analyses, including failure modes and effects analysis, derating analysis, worst case analysis (critical circuits), reliability predictions, extensive parts selection programs (including radiation hardness), fault tree analysis, and limited life analysis.

Design Process. The Design Process for the AIM spacecraft draws on BATC's 35-year history of designing and manufacturing scientific spacecraft. Our design is inherently conservative as design analyses and performance margins are based on worst-case mission scenarios.

Trade Studies. BATC used a system level design process based on trade studies. Prioritization was on establishing a cost-effective design maximizing reliability through the use of flight proven hardware while minimizing mass. A list of the key trades performed are included in **Table F-9**.

Simulations. BATC has conducted MATLAB simulations of the attitude control and temperature control systems to predict system performance. The results validated that the ADCS components and solar array configuration will meet all AIM requirements. A detailed NASTRAN computer model of the bus structure has also been created. Simulated flight loading conditions, placed on this model, have verified that the structure has robust mechanical margins. SINDA thermal analysis has been performed. STK has been used to conduct orbit analysis.

Engineering Models and Prototypes. RS300 program will use a software test bench to pre-integrate and test subsystem components before spacecraft bus I&T. This reduces schedule risk by validating component performance on the test bench before integration. The software test bench remains intact for the life of the program allowing software updates and anomaly resolutions to be tested on a hardware configuration almost identical to the flight system. An engineering development bus structure has been built and is being readied for vibration testing. This unit will then be used for wire harness and thermal blanket development and as a ground-handling pathfinder.

Table F-9. Key RS300 Trade Studies

Trade Area	Selected Option	Alternative Considered	Rationale for Selection
Solar Array	Fixed	Articulating	Lower cost, mass
Solar Cells	Triple Jct Ga As	Dual Jct. Ga As, Silicon	Lower cost, mass
Battery Type	Li Ion	Nickel Hydrogen	Lower cost, mass
Star Tracker	CT-633	CT-601	Lower cost, mass
Bus Design	Octagon, Al Honeycomb	Cylindrical Monocoque	Lower cost, mass

F.3.2 Flight Heritage

Over 85% of the RS300's components are either exact duplicates or minor modifications of flight-proven hardware. The Master Equipment List in **Table F-10** shows the heritage of all subsystems.

Over 55% of the RS300 hardware are flight-proven and identical to units flown on other spacecraft. An additional 30% of the equipment uses strictly conventional materials and design approaches but is tailored to mission-specific requirements. These include the solar array and structure, wire harnesses, coax cables, and MLI blankets. Each is a standard build and represents no schedule or development risk. This adds up to 85% of the spacecraft having traceability to flight heritage.

The only RS300 hardware without spaceflight heritage are the Spacecraft Control Unit (SCU), our one-box Command and Data Handling (C&DH) subsystem, and the bus structure. These comprise the other 15% of the hardware design. BATC is currently assembling a breadboard to assist in developing the SCU and has completed an Engineering Development Unit (EDU) of the structure.

The baseline RS300 spacecraft requires no new technology validation programs. Several new technologies planned for use—notably, Lithium-ion batteries and thermal switches—will have flight heritage on the STENTOR and PROSEDS missions when they fly in 2002.

F.3.3 Subsystems

The RS300 spacecraft is comprised of six subsystems: Structures and Mechanisms, Electrical Power, C&DH, Telecom, Thermal, and ADCS. Each of these subsystems is described in detail below.

Structures and Mechanisms Subsystem. The RS300 bus is designed to accommodate up to 150 kg payloads on Pegasus, Taurus, or Athena launch vehicles with factors of safety of 1.25. Since the AIM payload mass is only 110 kg, there is significant margin built into the design.

The RS300's primary structure is a simple aluminum honeycomb octagon. The sidewalls are 19 mm (0.75") thick, with an aluminum honeycomb core and 0.7 mm (0.03") aluminum facesheet. The fabrication of the octagonal structure involves an innovative technique that forms the primary load path from a single honeycomb panel. The resulting continuous outer facesheet provides highly efficient load carrying structure to minimize mass. Heat rejection requirements

Table F-10. AIM RS300 Master Equipment List

Description	Qnty F (#)	Mass: W ea (kg)	Mass: Total CBE (kg)	Mass: Reserve (%)	Mass: Total Mature (kg)	Power: Per Unit (Avg) (W)	Power: Total CBE (W)	Power: Reserve (%)	Power: Total Mature (W)	Supplier	TRL Level	Heritage
Attitude Determination and Control			**15.45**		**15.76**		**39.70**		**42.48**			
Reaction Wheel, Type A	3	2.55	7.65	1%	7.73	5.0	15.00	7%	16.05	Ithaco	9	NEAR, STEP, MSTI
RWE	3	0.91	2.73	3%	2.81	0.0	0.0	7%	0.00	Ithaco	9	NEAR, STEP, MSTI
Torque Rod, TR10CFR	3	0.5	1.50	3%	1.55	0.9	2.70	7%	2.89	Ithaco	9	SAGE, NIMBUS, LandSat
Magnetometer, IM103	1	0.227	0.23	4%	0.24	0.0	0.00	7%	0.00	Ithaco	9	Iridium
Star Tracker, CT-633	1	2.49	2.49	3%	2.56	10.0	10.00	7%	10.70	BATC	9	NEAR, Coriolis, GALEX
Coarse Sun Sensor	7	0.015	0.11	3%	0.11	0.0	0.00	7%	0.00	Adcole	9	QuickBird, QuickSCAT
LN-200S Rate Sensor	1	0.75	0.75	3%	0.77	12.0	12.00	7%	12.84	Litton	9	DS-1, Clementine BATSat
Electrical Power Subsystem			**34.09**		**41.44**		**10.00**		**12.50**			
Battery	1	11.70	11.70	25%	14.63					Eagle Picher	6	STENTOR
Solar Array	2	7.47	18.29		21.28					SpectroLab	9	
SA Cells	1	3.75	3.75	20%	4.50					SpectroLab	9	CloudSat, Icesat
S/A Hinge	8	0.2	1.60	2%	1.63					Starsys	9	SWIFT
S/A Root Hinge	1	2.1	2.10	2%	2.14					Starsys	9	SWIFT
S/A Restraint Mechanism + Bracket	4	0.13	0.52	20%	0.62					TiNi	9	ICESat
S/A Substrate (3.16 m^2)	8	1.29	10.32	20%	12.38					BATC	9	CloudSat
Cabling and connectors	1	4.1	4.10	35%	5.54		10.00		12.50	BATC	9	QuickBird
Command and Data Handling			**11.85**		**14.44**		**43.60**		**54.23**			
Spacecraft Control Unit	1	11.45	11.85		14.44	0	43.60		54.23			
PPC750 Processor	1	0.30	0.30	1%	0.30	12.0	12.00	7%	12.84	DY4	9	STS
256 MB NVM (PCI)	2	0.40	0.80	12%	0.90	3.0	6.00	15%	6.90	TBD	7	Deep Impact, X2000
Command and Telemetry Board/GPIO	1	0.90	0.90	20%	1.08	4.0	4.00	20%	4.80	SwRI	7	New Development
ADCS Interface Board	1	0.70	0.70	25%	0.88	2.0	2.00	25%	2.50	BATC	6	New Development
Power Distribution Board	1	0.90	0.90	35%	1.22	2.5	2.50	75%	4.38	BATC	6	New Development
Charge Control Board	1	0.70	0.70	35%	0.95	2.0	2.00	75%	3.50	BATC	6	New Development
cPCI/VME Bridge	1	0.25	0.25	12%	0.28	0.1	0.10	15%	0.12	SwRI	8	New Development
Thermal Interface Board	1	0.90	0.90	25%	1.13	2.0	2.00	25%	2.50	BATC	6	New Development
DC-DC Converter	1	1.00	1.00	20%	1.20	8.0	8.00	20%	9.60	SwRI	9	IMAGE, SWIFT
Hybrid cPCI/VME chassis w/ backplane	1	4.50	4.50	20%	5.40	3.0	3.00	20%	3.60	SwRI	7	New Development
Spare/Special Circuits	1	0.90	0.90	25%	1.13	2.0	2.00	75%	3.50	BATC	6	New Development

Table F-10. AIM RS300 Master Equipment List (continued)

		Mass				Power						
Description	Qnty F (#)	W ea (kg)	Total CBE (kg)	Reserve (%)	Total Mature (kg)	Per Unit (Avg) (W)	Total CBE (W)	Reserve (%)	Total Mature (W)	Supplier	TRL Level	Heritage
Structure			**22.76**		**26.02**		**0.00**		**0.00**			
Folded Honeycomb Assembly	1	6.60	6.60	12%	7.39					HexCell	7	Al Honeycomb
Top Deck	1	3.38	3.38	12%	3.79					HexCell	7	Al Honeycomb
Payload Attach Structure	8	0.31	2.48	12%	2.78					BATC	7	Al Honeycomb
Launch Vehicle Interface Ring	1	6.00	6.00	12%	6.72					BATC	7	Al Honeycomb
Brackets:	1	1.14	1.14	12%	1.28					BATC	7	6061-T6 Al Plate
Fasteners	1	2	2.00	25%	2.50					BATC	7	Flight Spec. Fasteners
S/A Deployment Panel	1	0.8	0.80	35%	1.08					BATC	9	Al Honeycomb
S/A Attach Flange	2	0.13	0.26	35%	0.35					BATC	9	6061-T6 Al Plate
S/A Boom Restraint Flange	1	0.1	0.10	35%	0.14					BATC	9	6061-T6 Al Plate
Mechanisms			**0.00**		**0.00**		**0.00**		**0.00**			
See EPS for Solar Array Mechanisms												
Thermal Control Subsystem			**5.23**		**6.54**		**17.00**		**20.40**			
Heaters/Wiring	11	0.025	0.28	25%	0.34	3	17.00	20%	20.40	Minco	9	QuickBird, CloudSat
Thermistors	25	0.01	0.25	25%	0.31	0	0.00	20%	0.00	YSI	9	QuickBird, CloudSat
MLI Blankets/Blanket Support**	12	0.15	1.80	25%	2.25	0	0.00	20%	0.00	BATC	9	QuickBird, CloudSat
Interface Materials	1	0.25	0.25	25%	0.31	0	0.00	20%	0.00	BATC, Berquist	9	QuickBird, CloudSat
Paint/Radiator Finishes	1		0.00	25%	0.00	0	0.00	20%	0.00	BATC/ Sheldahl	9	QuickBird, CloudSat
Thermal Switch Washers	16	0.008	0.13	25%	0.16	0	0.00	15%	0.00	Starsys	8	PROSEDS, Summer 2002
Thermal Switches	3	0.842	2.53	25%	3.16	0	0.00	15%	0.00	Starsys	8	PROSEDS, Summer 2002
Telecomm			**9.59**		**10.59**		**7.50**		**8.63**			
Transponder, STDN	1	5	5.00	12%	5.60			15%		L3 Comm.	9	GEO Lite, CloudSat
Receive						4	4.00	15%	4.60		9	GEO Lite, CloudSat
Transmit						4	3.50	15%	4.03		9	GEO Lite, CloudSat
Hybrid Coupler	2	0.11	0.22	12%	0.25	0	0.00	15%		Sage Laboratories	9	QuickBird, LOSAT-X
Antenna Ass'y (Rx/TX S-band)	2	0.56	1.12	25%	1.40	0	0.00	15%		BATC	9	QuickBird, LOSAT-X
Bandpass Filters	2	0.625	1.25	3%	1.29	0	0.00	12%		Delta Microwave	9	QuickBird, LOSAT-X
Coaxial Cable	1	2	2.00	3%	2.06	0	0.00	12%		Storm Products	9	QuickBird, LOSAT-X
Total Bus			98.97		114.80		117.8		138.24			

determined the minimum wall thickness, resulting in enhanced structural rigidity. The top deck is a 19-mm-thick (0.75”) aluminum honeycomb core/aluminum facesheet. Secondary structural elements, such as brackets and retainers, are machined from aluminum plate or bar stock or formed from aluminum alloy sheet.

The structural design minimizes cost, mass, and assembly time. The design has passed a peer review, and an engineering model of the structure has been constructed.

Preliminary finite-element analysis shows that the solar arrays and bus structure meets all design and structural requirements, including the Pegasus launch vehicle drop transient load case.

The RS300 has a first bending mode that exceeds 50 Hz with a 150 kg payload attached. In order to maintain the combined stiffness of the RS300 and payload above the Pegasus minimum required frequency of 20 Hz, BATC requires the payload minimum frequency be above 34 Hz. The IPA is estimated to be above 75 Hz, exceeding the requirement by 114%.

Solar Array. The solar array substrates are each fabricated in one piece from graphite facesheets bonded to an aluminum honeycomb core. This provides maximum stiffness, minimum inertia, and lessens succeptability to thermal-elastic shock.

The array is designed to be deployed to a fixed 50 deg angle relative to the spacecraft body and remain so for the duration of the mission. This saves the mass and cost of an actuated solar array drive.

The array deploys in two steps. After release from the launch locks, the array panels open and latch, with the center portion facing sun-normal and each of the four panels at 22.5 deg from normal. Then the entire array deploys to a fixed position 50 deg from nadir.

Mechanisms. The AIM spacecraft bus has two mechanisms, both used to deploy the solar arrays. Flight-proven Frangibolt actuators retain the arrays in stowed position during launch and release them after separation from the launch system. Frangibolts were selected for their high reliability, low pyro-shock properties, and good value. Flight-proven spring-powered hinge sets are used to deploy the two array wings.

The retention/release devices and hinge sets are made by Starsys Corp. and are identical to those used on BATC’s ICESat spacecraft.

Electrical Power Subsystem. Power is provided by a direct energy transfer system chosen for its low weight and maximum design heritage from our GFO spacecraft. The functional arrangement of the subsystem is shown in the functional diagram of FO-F3, Fig. F-3.

Electrical power is generated by a solar array assembly populated with 49 circuits of 26.8%-efficiency triple-junction solar cells, with a total cell active area of 2.35 m^2, shielded by 100 μm (0.004 in.) CMG cover glass. Triple-junction ($GaInP_2$/GaAs/Ge) cells provide high efficiency and radiation-hard performance. The solar array design accounts for losses associated with UV degradation, radiation, contamination, micrometeoroids, and array system losses (i.e., cell mismatch, cover glass transmission, and thermal cycling).

The Electrical Power Distribution System (EPDS) system uses a single 35 amp-hr lithium-ion battery for energy storage during eclipse and high-power-consumption periods. The battery consists of eight cells with circuitry to provide individual cell telemetry (voltage, temperature), balancing, and bypassing. To ensure extended battery life, its state of charge is maintained between 75% and 90%. Maximum depth of discharge expected during normal operations is 15%. Battery charge control and current and voltage sensing are provided by a power control card in the SCU, which is controlled by software hosted in the C&DH processor.

Power Profile. The AIM summer solstice power profile is shown in **Figure F-13**. Since summer solstice is near aphelion, it is the power-limiting case. The AIM power profile is affected by where in the orbit the spacecraft performs its yaw maneuver. The optimum point from a power collection standpoint occurs at the sub-solar point. However, for science collection reasons the yaw must be performed earlier (or later) depending on the time of year. The following two paragraphs provide a more detailed explanation of this

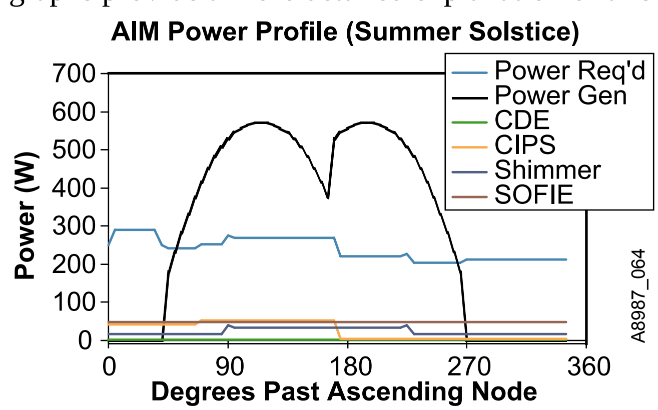


Figure F-13. AIM Power Profile

constraint and its effect on the AIM power profile.

The science package includes both forward- and backward-looking instruments. Of particular relevance to power generation, the SHIMMER instrument looks backwards 23 deg in the southern hemisphere. The SHIMMER instrument is implemented to observe NLCs in the summer hemisphere from polar regions down to 40 deg latitude. This imposes constraints on power generation at either solstice. For summer solstice (northern hemisphere summer), the spacecraft must delay its 180 deg yaw maneuver until after local noon. For observations at 40 deg N, the spacecraft must complete its yaw by 17 deg N (whereas local noon is 23.44 deg N). This delay decreases the integrated energy generated by the spacecraft per orbit. For winter solstice (southern hemisphere summer), the spacecraft must complete the yaw maneuver 6.4 deg before local noon so as to be in position and stabilized for observations at 40 deg S. The yaw maneuver must be initiated 17.7 deg before solar noon, as the spacecraft is stabilized three minutes after initiating the yaw and the orbital rate of rotation is 3.764 deg/minute.

C&DH Subsystem. The functional arrangement of the subsystem is shown in the functional diagram on FO-F3, Fig. F-3. The RS300's C&DH subsystem acquires, conditions, processes, formats, and stores housekeeping and instrument data at rates up to 8 Mbps on each of its four RS-422 data buses. It receives, validates, and issues both stored and real-time commands to the spacecraft subsystem and the AIM science instruments. It provides all spacecraft and instrument timing and clock functions; monitors, controls, and interfaces to all other spacecraft subsystems. It distributes power and conditions the batteries.

Running in the SCU, RS300 software applications perform fault protection, handle all ADCS computations, control battery charge, and control the spacecraft heaters. The spacecraft's Power PC-750 single board computer hosts all of these software-implemented functions. This approach minimizes mass by offloading hardware functions to software.

C&DH-to-subsystem interfaces are simplified by use of RS-422 and RS-485 asynchronous serial data links as shown in the functional diagram (FO-F3, Fig. F-3). In addition, the science instruments are provided four RS-422 data links. Science and other data will be CCSDS formatted prior to downlink.

The AIM processor has available 4.0 Gbit of non-volatile memory on a dedicated mass memory card, 1.0 Gbit of which is reserved for housekeeping and margin, leaving 3.0 Gbit allocated to store spacecraft, instrument, and science data between downloads. Spacecraft processor and storage margins are summarized in **Table F-11**.

Telecom Subsystem. AIM's telecom requirements are driven by the 4.0 Mbps downlink rate and the need to avoid oversubscription of the 11 m class ground station (see **FO-F3, Table F-12**). The system also accommodates a 2 kbps uplink and a 4 or 16 kbps downlink option to cover contingency operations. These requirements are met using a flight-proven STDN transponder, which works with two sets of omni patch antennas. The arrangement of these and the subsystem's passive components are shown in the functional diagram. Antenna mounting locations are shown in FO-F3, Fig. F-12 and are designed to provide spherical coverage for all uplinks and downlinks.

The subsystem communicates with the baseline 11 m ground station to achieve up to 4 Mbps telemetry downlink rate. It achieves this with greater than 9 dB minimum link margin using the omni antennas and the 5 W output of the transponder. Commands are uplinked at S-band at 2 Kbps with over 35 dB of margin using the omni's for all mission modes.

Thermal Subsystem. The thermal control system will maintain subsystem element temperatures within their allowable temperature ranges, as shown in **Table F-13**. These conditions will be satisfied for designated vehicle attitudes, operational modes, and mission phases.

Thermal requirements are met using a primarily passive approach. Electronic unit temperatures are maintained with internal power dissipation supplemented with heaters in safe and survival modes. To reduce the required heater power in cold-biased attitudes and low-power optional modes, the majority of the bus-mounted electronics use thermal switches for temperature con-

Table F-11. AIM Processor Margins

RS300 Processor Utilization			
	CPU (MIPS)	RAM (MB)	NVM (Gb)
Nominal capacity	327	64	4.00
Flight SW	28	17	0.44
Telemetry			0.08
Instrument Data			1.33
Total	**28**	**17**	**1.85**
Margin %	>10x	276%	116%

Table F-13. AIM Temperature Limits

	Operating Limits [°C]		Non Operating Limits [°C]	
Component	Minimum	Maximum	Minimum	Maximum
Battery, Li Ion	0	25	-20	50
Star Tracker	-25	45	-34	71
Transponder (SGLS)	-14	51	-34	71
Rate Sensor	-14	51	-34	71
SCU	-14	51	-34	71
Reaction Wheel	-14	51	-34	71
Magnetometer	-30	51	-40	60
Solar Array Mechanisms	-40	66	-65	93
Solar Array (GaAs)	-80	110	-120	150

trol with resistive heaters for redundancy. The elements not mounted with thermal switches use resistive heaters to maintain their temperatures within specified limits.

To further reduce thermal control power requirements, the nominal heater activation setpoints are cold-biased (set 5 °C above the minimum allowable electronics temperature). Heater set points can be modified by ground command to conserve power or optimize sensor performance during critical operations.

The internal RS300 bus geometric math model is shown in **Fig. F-14**. The sidewall radiators provide sufficient heat rejection capability over the full range of spacecraft power dissipations and attitudes. The external areas of the spacecraft bus not used as radiator surfaces are covered in MLI. Externally mounted vehicle elements (antennae, etc.) are painted white.

Attitude Determination & Control Subsystem (ADCS). AIM's requirements are driven by a need for accurate attitude knowledge for SHIMMER measurements. The attitude determination and control subsystem (ADCS) provides attitude knowledge of 40 arcsec (as), 3σ and attitude control of 40 as, 3σ. Key pointing requirements and AIM's performance can be seen in **Table F-14**.

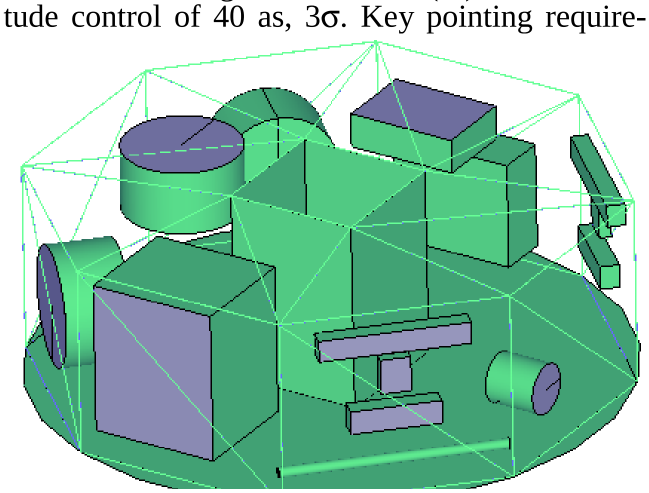


Figure F-14. AIM Bus Thermal Model

Pointing requirements are met with seven coarse sun sensors, a magnetometer, an inertial measurement unit (IMU), and a star tracker. The star tracker is the primary attitude reference. Working with the IMU, it provides attitude knowledge in yaw and pitch axes at a 5 Hz rate. Radiometric ranging, performed on the ground, is used to determine orbital position. Attitude control is provided by three 2 N-m-s reaction wheels in a zero-net-momentum mode. Three 10 A-m^2 magnetic torquers with the magnetometer allow reaction wheel momentum dumping. The coarse sun sensors are used for sun vector reference to point the spacecraft solar arrays at the sun in safe mode. **Table F-15** provides the budget for the ADCS pointing.

All ADCS computations, sequencing, and magnet control are performed in software run by the C&DH processor. The RS300 uses control algorithms proven on our BCP-2000 QuikSCAT, MTI, and QuickBird spacecraft.

Flight Software Subsystem. The allocation of many hardware functions to software is made possible by BATC's ASPEN flight software. See **Fig. F-15**. ASPEN flight software modules are in place for attitude determination and control, magnet and reaction wheel control, command and telemetry processing, and Central Processing Unit (CPU) management. These modules run under

Table F-14. Key ADCS Requirements for AIM

Parameter	Requirement	Performance
Pointing Control	360 as	**40** as
Pointing Knowledge	72 as	**40** as
Stability	25 as/sec	<15 as/sec
Position Knowledge (in-track)	1000 m	900 m
Position Knowledge (cross-track)	250 m	200 m

Table F-15. Pointing and Knowledge Requirements for AIM ADCS

Parameter	as, 3σ	Comment
CT-633 correlated errors	36	Matlab simulation
Star Catalog Noise	36	QuickBird analysis
Catalog Precession	2	Star Precession
Nadir Model Errors	2	QuickBird analysis
Jitter	3.3	QuickBird analysis
RSS Att. Est. Errors	36	
Total Align. Meas. Errors	11	ST to SHIMMER allocated 3 as, + other
Pallet Distortions	4	Pallet temp changes ground to on-orbit
1 g release	7	Worst case
Tracker boresight shift	7	Launch effects, thermal effects
Alignment Errors	15	
Att. Know. Accuracy	**40**	RSS of estimation and alignment (0.011 deg)
Requirement	72	(0.020 deg)
Margin	80%	
Control Sys. Errors	2	ICESat analysis
Spacecraft Drift	3	Budgeted
Att. Ctrl Accuracy	**40**	RSS of know and ADCS errors (0.011 deg)
Requirement	360	(0.10 deg)
Margin	800%	

Vx-Works Real-Time Operating System (RTOS) and require only database updates (rather than recoding) to meet AIM-specific requirements. The RS300 flight software requirements and margins are shown in Table F-11.

The AIM flight software will provide two safe modes for protection of the flight hardware in the event of anomalous conditions. A sun oriented Safe Mode will be run out of the normal processor of the SCU. An Emergency Mode is also available and provides the same capabilities run from the Command and Telemetry Processor Board in the SCU.

The C&DH subsystem has 64 MB RAM, 4 Gb NVM, and an effective processor speed of 327 MIPS. This provides ample margins for the flight software and the capability of using the spacecraft processor for some or all of the instrument processing requirements. This software is currently being developed for the Deep Impact program. We estimate that 80% of the ASPEN software will be directly re-used on the AIM program. This

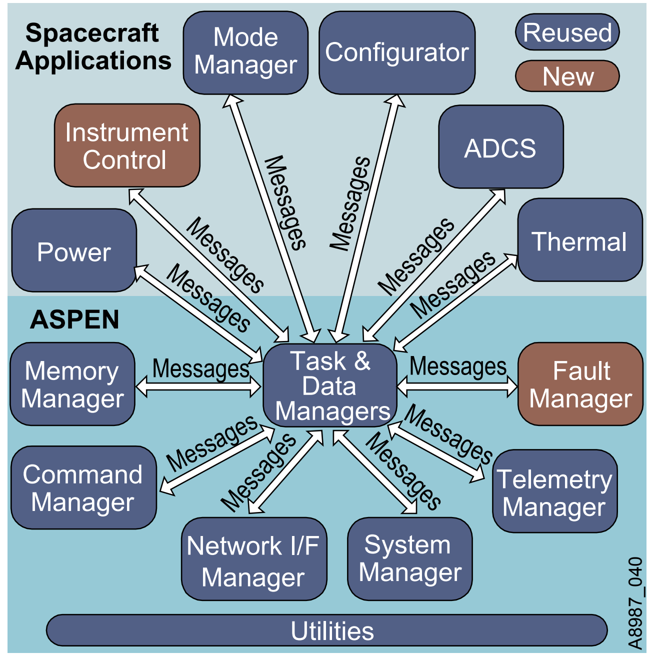


Figure F-15. RS300 Flight Software Functional Architecture

software will have been fully tested and qualified by the time AIM requires its use. Re-use of the ASPEN software has the effect of reducing development risk, lowering cost, and improving schedule performance.

The flight SW development process begins with SW requirements definition. Early requirement definition is supported by SW systems engineering involvement during Phase A/B to ensure the flowdown of solid, allocated requirements to be used for the SW preliminary design phase. During the design process, as code is developed, SW test benches reduce integration schedule risk and increase SW reliability. An independent group of flight SW engineers develop test procedures to be used for final verification and qualification of the flight SW before release as a product for bus integration. The process culminates with the Computer SW Configuration Item (CSCI) testing phase which consists of testing the completed CSCI using a full complement of hardware simulators and emulators.

This approach enables simultaneous development of both flight and ground SW through the iterative buildup of increasingly higher fidelity databases and simulations. It provides clean transitions from simulators to processor-in-the-loop, hardware-in-the-loop, and finally system level testing using flight hardware and flight operations procedures. Integrating and testing early and often minimizes implementation risk. An AIM SW management plan, finalized by SRR, describes the team's product assurance approach, including quality assurance, configuration management, project planning and tracking metrics, documents, and reviews. BATC has successfully used an earlier version of this process on the recent GFO and QuikSCAT spacecraft and it is in use currently on BATC's DI and Starlight spacecraft development programs.

F.3.4 Design Features Incorporated to Effect Cost Savings

The RS300's design achieves cost savings through use of 85% flight-proven hardware and software components, and by drawing on previous BATC mission designs wherever possible. Trade studies completed to date indicate that no significant changes need to be made to the baseline RS300 design in order to meet AIM's requirements. This early determination provides significant cost savings in Phase B. Additionally, an engineering model of the baseline bus structure has already been completed, reducing Phase B expenditures for AIM.

AIM will realize additional cost savings from the flight software simulator that is already in use on the ASPEN effort on Deep Impact.

The processor-based architecture drives cost savings by minimizing hardware needs. Other design features that offer cost benefits include:

- Lithium-ion battery technology—simple design lowers cost (and mass)
- Aluminum honeycomb construction—simple design lowers cost (and mass and risk)
- Thermal switch technology—design lowers cost (and power needs)
- Full test bench (including flight hardware, software, and harness)—early and complete testing lowers long-term cost (and risk)
- Engineering model—early development lowers cost (and schedule risk)
- 85% heritage components—re-use of flight-proven components lowers cost (and risk)

F.3.5 Margin Allocations Summarized

Key margins for the RS300 are shown in FO-F3, and discussed below.

Mass. The Pegasus XL with HAPS performance has a payload capacity of 252 kg into the nominal AIM mission orbit. This provides 43 kg of total reserve against the combination of a 99 kg RS300 spacecraft and 111 kg instrument platform assembly. A detailed breakout of spacecraft bus component mass estimates and reserves based on maturity is provided in Table F-10. The mass values represent the best estimate of the subsystem masses of all components. We have placed particular emphasis on those items that sometimes are overlooked or underestimated such as cabling, tiedowns, fasteners, nuts and bolts, and radiation requirements. As a result, we are confident that the mass will not increase beyond the allocated estimation uncertainty.

Associated with the mass is a computation of the uncertainty in the value. The uncertainty is a percentage of the best estimate. Its magnitude is based on the degree of component design maturity.

The AIM team recognizes that mass margin is a critical program issue. The AIM System Engineer will carefully monitor both the Pegasus performance and the AIM satellite's mass.

Power. The spacecraft bus power requirement of 117 W orbit-averaged is a current best estimate. The total power generated by the baseline solar arrays is 290 W orbit-averaged for the AIM mission profile and orbit. The remaining power 173 W is available for the instrument.

A summary of the AIM spacecraft power budget is shown in **Table F-16**.

Communication Link. Link margin performance for all RS300 telecom links is shown in Table F-12 on FO-F3 and includes the link data rate. The primary usage for the link for each antenna type and coverage is also shown. The performance of the nominal 11 m ground station provides margins greater than 9 dB. The link budget analysis for the science data link is shown in **Table F-17**.

Pointing Accuracy. The most stringent requirement for pointing on the AIM mission comes from the SHIMMER instrument 0.1 deg control and 0.02 deg knowledge. The RS300 control capability of 40 arcsec or 0.011 deg and knowledge accuracy of 40 arcsec meets these requirements with greater than 80% margin.

Data Throughput*. *And Memory. **Tables F-18 and F-19** provide the RS300 capabilities when the instrument and spacecraft data are stored and downlinked twice a day at 4.0 Mbps. At an orbit average science data rate of 31 kbps, the AIM system provides >49% margin on daily throughput and >124% margin on science data storage (also see **Table F-20**).

Computer Processor Utilization. Table F-11 provides a breakdown of the processor utilization for the AIM mission. The PPC 750 degraded performance value based on Deep Space –1 actuals is 327 MIPS. The bus software requires 28 MIPS.

Table F-16. AIM Power Budget

Subsystem/Item	Orbit Avg Power (W)	% Reserve	Orbit AvgPower (W) W/res	Heritage/ Comments
Electrical power and distribution	10.00	25	12.50	35 A-h battery; multijuntion array @ 27%
Command, control and data handling	43.60	24	54.34	100% duty cycle on processor
Communications	7.50	15	8.63	5 W RF @5% duty cycle; rcvr 4 W @ 100% duty cycle
Thermal control	17.00	20	20.40	Bus heaters
Attitude determination and control	39.70	7	42.48	Sensors, magnets, wheels
Subtotal, spacecraft bus	117.80	17	138.34	
Total, AIM IPA	98.70	20	118.27	
Total, orbit avg power draw, AIM S/C	216.50	19	256.61	
Total energy required/orbit (W-h)			408.01	
Total energy generated/orbit (W-h)			463.30	Triple jct solar array, 50 deg cant. angle, 5 deg off subsolar yaw
Margin on S/C electrical energy (W-h)			55.29	
Margin on S/C electrical energy (%)			14%	Worst case @ max shadow period, EOL

Table F-17. AIM Link Budget Analysis

Parameter	Symbol	Value	Unit	Source
Frequency	f	2.3	GHz	Input Parameter
Transmitter Power	p	5	Watt	
Total Transmit Power	P	37.0	dBm	P = 10 log(p)
Passive Loss	Li	-3.7	dB	
S/C Antenna Gain	Gt	-3.0	dBi	
Equiv. Isotropic Radiated Power	EIRP	30.3	dBm	EIRP = P+Gt+Li
Propagation Path Length	S	2077.9	km	500 km max input parameter (5° elevation angle)
Free Space Dispersion Loss	Ls	-166.0	dB	Ls = 92.44 – 20log(S) – 20log(f)
Atmospheric Loss	La	-0.4	dB	
11 Meter Ground Station G/T	Grp	22.8	dB/K	Typical at 5 deg elevation with atmospheric losses
Total Received Power/T		-113.3	dBm/K	
Boltzmann's Constant	K	-198.6	dBm/Hz/K	K = 10log(1.38*10^{-23})
Total Received Power/KT		85.3		
Data Channel (BPSK)				
Data Power/KT		85.3	dBm/Hz/KT	NRZ-M with R/S coding
Information Rate		66.0	dB-Hz	4 Mbps (4571 Msymbols/sec)
Available S/N		19.3	dB	
Required Eb/No 10E^{-7} BER w/coding		6.2		Required Eb/No plus coding gain
Implementation Loss		-3.0		Estimated from typical performance
Available Signal Margin		10.1	dB	

Equation from: Space Mission Analysis and Design by Wertz and Larson, Telemetry Applications Handbook by Eugene Law, Deep Space Telecommunications Engineering by J.H. Yuen.

Table F-18. AIM Throughput Margins

Contacts/ Day	Length of Contact (minutes)	Data Down-linked/Day (Gbits)	Data Collected/ Day+ OH	Margin (%)
1	8	1.92	2.73	-29
1	10	2.4	2.73	-12
2	8.5	4.08	2.73	49
2	10	4.8	2.73	75
3	8	5.76	2.73	110
3	10	7.2	2.73	163

Table F-19. AIM Instrument Data Requirements

Instrument	Data Rate (Mbytes/orbit)	Average Data Rate (kbps)
SOFIE	0.45	0.60
SHIMMER	4.7	6.26
CIPS	18	24.00
CDE	0.1	0.13
Total	**23.25**	**31.00**

Table F-20. AIM Computer Memory Margins

Contacts/ Day	Data Collected Between Contacts (Gbits)	Storage Allocation (Gbits)	Margin (%)
1	2.67	3.00	12
2	1.33	3.00	124
3	1.00	3.00	197

This leaves 299 MIPS (or >10x) of margin. No payload processing is required by the RS300.

F.4. Science Payload

As discussed above, the AIM instrument complement has been specifically designed to meet the AIM objectives including obtaining the required precision and geographical coverage. **Table F-21** overviews the instruments. The instruments are then described in detail in Sections F.4.1-F.4.4.

Table F-4 on FO-F1 describes the spacecraft and mission resources required by the instruments.

F.4.1 SOFIE

SOFIE uses differential absorption radiometry to measure profiles of T, H_2O, ice extinction, CH_4, O_3, CO_2, and particulate extinction and also uses gas filter correlation radiometry to measure the NO density profile. Aerosol extinction profiles will be retrieved for all eight spectral channels. SOFIE makes measurements in solar occultation for both sunrise and sunset for each orbit. **Fig. F-16** shows a pictorial layout of the critical elements of the SOFIE implementation. This

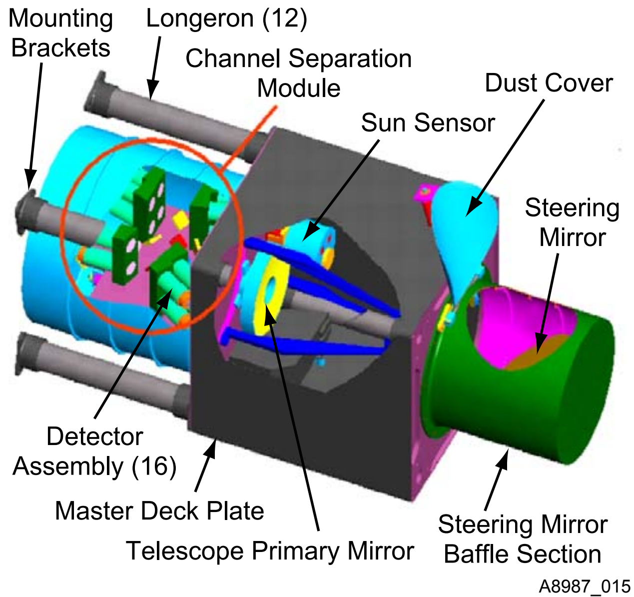


Figure F-16. Pictorial Layout of Critical Elements of The SOFIE Instrument

figure can best be understood in conjunction with the SOFIE Functional Block Diagram in **Fig. F-17.**

The telescope is a Cassegrain type and has a diameter of 15.24 cm and a focal length of 40 cm. This diameter was reduced from 20 cm in the Step 1 proposal in order to accommodate sizes of existing steering mirror designs. The higher optical transmissions of the new design without the polarization elements allowed the decrease in di-

Table F-21. Instrument Complement

Instrument, Technique, Heritage, AIM Coverage	Observable	Data Product	Altitude Range (km)	Precision (at PMC altitudes)
SOFIE IR Solar Occultation with differential absorption; radiometry at 2.4 – 9.4 µm, HALOE, 1 lat. and long. per orbit, 15 orbits per day	CO_2 Absorption	Temperature	15 – 110	1.5 K
		CO_2	80 – 110	1 ppmv (0.3%)
	H_2O Absorption	H_2O	15 – 95	0.15 ppmv (4%)
	CH_4 Absorption	CH_4	15 – 80	0.02 ppmv (12%)
	O_3 Absorption	O_3	15 – 95	0.06 ppmv (16%)
	NO Absorption	NO	15 – 140	3×10^6 cm^{-3} (25%)*
	Particle Absorption	Particle Extinction	PMC height	5×10^{-9} km^{-1} (1%)
SHIMMER UV limb Emission at 308 nm, MAHRSI, Shuttle, all summer latitudes each orbit	OH Solar Resonance Fluorescence	OH	55 – 81	9%
		H_2O	55 – 85	1.5 ppmv (19%)
	OH emission line ratio	Temperature	70 - 82	2.5 K**
	Scattered Sunlight	PMC Presence	PMC Height	1.6%
CIPS UV Nadir Emission at 265 nm, SBUV, Rosetta images entire polar region	UV Image of PMC	PMC Brightness	PMC Altitudes	5% brightness precision
		PMC Structure		
		PMC Particle Size***		
CDE Dust Sensor, Vega, Cassini, Stardust, Global coverage	Cosmic dust particles	Cosmic Dust Influx	Satellite altitude	10% per day

* 9 profile average; ** daily zonal mean; ***In combination with SOFIE and SHIMMER

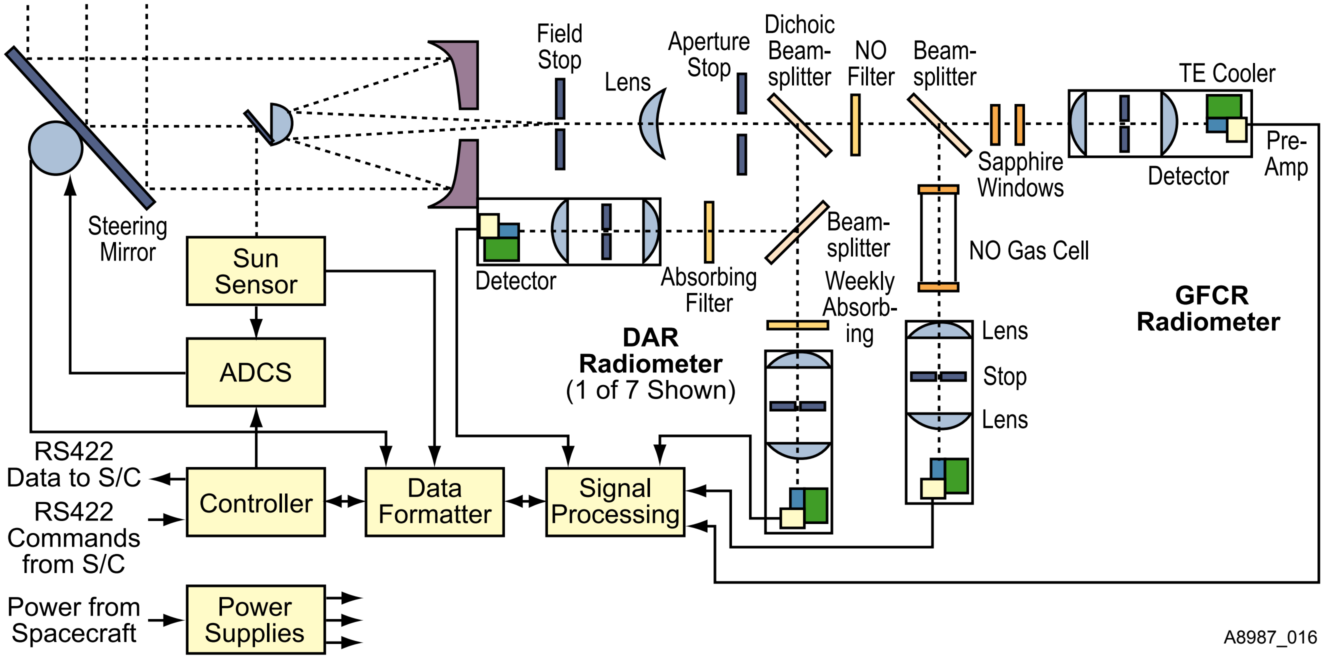


Figure F-17. SOFIE Functional Block Diagram

ameter without loss in signal levels. The telescope instantaneous field of view (IFOV) of 1.8 arc minutes vertical (1.3 km at 83 km tangent height) by 6.0 arc minutes horizontal (4.36 km) is determined by a field stop in the converging beam from the secondary mirror. This beam is recollimated, and an aperture stop in the collimated beam determines the effective aperture of the telescope. A spring-loaded dust cover, which is opened (but retained) after appropriate outgassing time on orbit prevents contamination of the mirrors.

After passing through the aperture stop, the input energy then enters the channel separation module shown in schematic form in **Fig. F-17.** See also Fig. F-18). A dichroic beam splitter reflects the energy at wavelengths shorter than 3.540 μm to a second beam splitter, which divides the energy equally between two beams. One beam illuminates the non-absorbing bandwidths of the four shorter constituent bands. The other beam illuminates the absorbing bandwidths of these four constituent bands. These two beams are parallel to each other and the absorbing and non-absorbing band-pass filters are also stacked to simplify the mechanical structure. At each filter, the energy within the defined band pass is transmitted to the detector cell and the energy outside the defined pass is reflected on to the remaining filters. The band-pass filters are positioned at 15 degrees normal to the collimated beam. Each “detector cell” contains two lenses, a stop, a detector with a thermo-electric cooler and a preamp. All these detector cells will be nearly identical, with the only exception being wavelength dependencies.

The energy transmitted by the first dichroic beam splitter impinges on a wide band pass filter, which transmits the band-limited energy to the nitric oxide (NO) band-defining filter. A third beam splitter divides the transmitted energy equally between two beams, one of which passes through a NO absorption cell, and the other passes only through identical cell windows, before both are incident upon (stacked) detector cells. The energy reflected by the wide band-pass filter is equally split between two beams by a fourth beam splitter. These two beams are the absorbing and non-absorbing beams of the 3 long-wavelength constituent bands, again stacked. In each case, the energy outside the desired band pass is reflected on to the other constituent bands while the energy within the desired bandwidth is transmitted to the detector cells. This layout has been carefully engineered to minimize the requirements on the individual filters, (and thus the filter costs), while maximizing the channel separation performance. This channel separation module is a realistic and practical implementation of the concept shown in the proposal, but it allows a significant reduction in individually mounted elements from about 70 for seven bands to about 40 for eight bands.

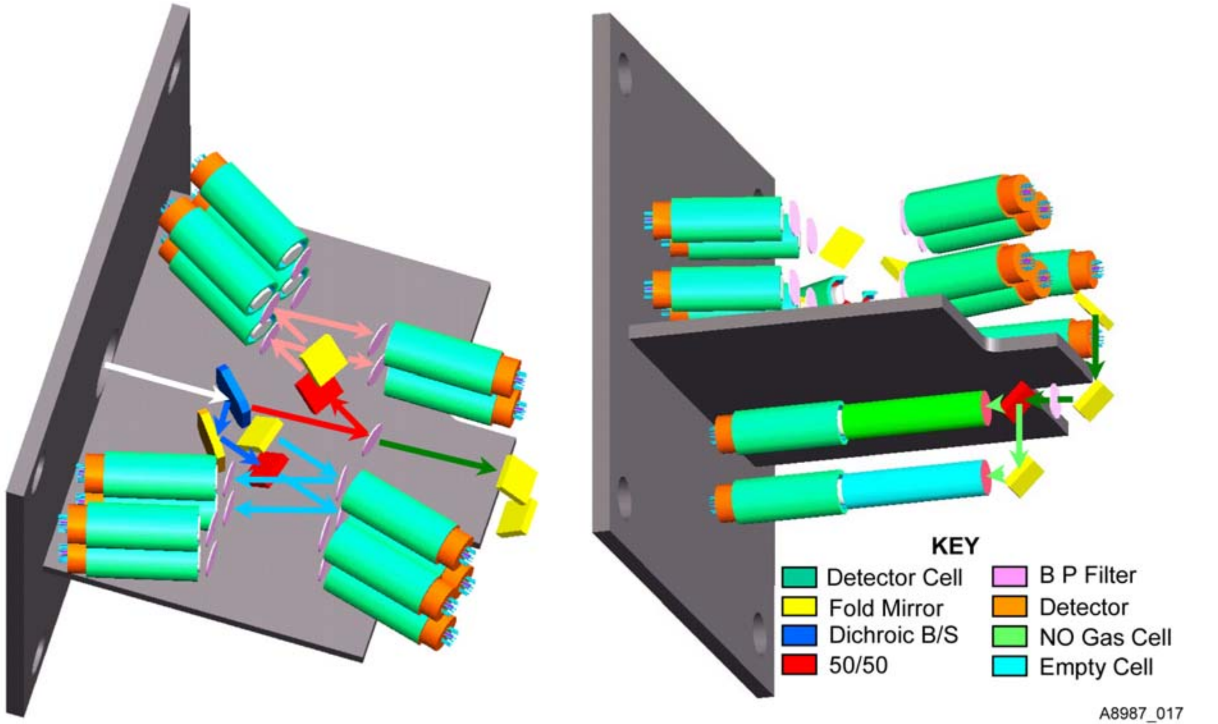


Figure F-18. Two views of SOFIE channel separation module

Changes Since the Proposal. A short wavelength channel was added for enhanced sensitivity to PMCs and mesospheric aerosols giving a total of eight channel pairs as opposed to seven single detectors described in the original proposal. The photoelastic modulator (PEM) was dropped due to technical risk. A simpler design is now used and is based on the highly successful UARS HALOE instrument. Like HALOE, a mechanical chopper, driven by a hysteresis synchronous motor, is used to modulate the signal in place of the PEM. The number of detectors and thermoelectric coolers increased from 7 to 16. The telescope diameter was reduced from 20 cm to 15.24 cm and the focal length form 60 cm to 40 cm. See Section E.2.1. None of these changes impact science.

Subsystems. The SOFIE implementation proposed as a result of the Phase A concept study is now very similar to the HALOE instrument, currently performing without flaw after ten years on orbit as part of the UARS mission. SDL will take advantage of this heritage and use the expertise of the HALOE team to decrease risk with SOFIE development. Some of the HALOE personnel, including the AIM PI who is the PI on HALOE and an AIM Co-I, Larry Gordley, have worked closely with SDL in the Phase A study. All of the SOFIE elements are judged to be at Technology Readiness Level 8 or 9, indicating that the elements are similar to designs that have been flown or have been through test and demonstration. No major new developments are needed. The current SOFIE design shows a mass of 42 kg, a power requirement of 40.1 W and physical dimensions of 38 by 38 by 106 cm. Actual measurement time of 360 seconds per orbit gives a data rate of 0.45 Mbytes per orbit.

Detectors. To obtain detectors with flight heritage, SDL has decided to purchase detectors from Judson Technologies Incorporated, which SDL and LaRC have previously used to supply space-qualified detectors for the SABER and HALOE instruments. Judson routinely delivers HgCdTe photovoltaic detectors for the wavelengths required by SOFIE.

Photovoltaic detectors are preferable to photoconductive units because of uniformity, shape characteristics, and low frequency noise considerations. However, these proven detectors do not have the high D* values achieved by the less reliable immersed detectors originally specified. As shown later in this section, the system S/N is still adequate for providing science measurements to the required accuracies needed to meet the AIM science objectives. During Phase B, SDL will implement the use of cone concentrator mirrors, i.e., Winston cones, to restore the high D* values. Void of wavelength dependence, these parabolic concentrator mirrors can be integrated into the “detector cells” as identical units. Judson Technologies already has experience in mating HgCdTe detectors to Winston cones.

Electronics Subsystem. The SOFIE instrument is self-contained, requiring no external electronics. The electronics elements are mounted inside SOFIE's envelope, but were not shown in Fig. F-16 to maintain clarity in the figure. Channel detector pairs will be electronically differenced, producing a delta signal at high gain. Lock-in amplifiers will be used to demodulate the data from the 16 detectors. Delta and base level signals for each detector pair will be passed to the spacecraft for transmission to the ground.

As noted in Section E.2.1, beam modulation will be provided by a hysteresis synchronous motor driven chopper disk (as done in HALOE) and will be located by the initial field stop. During Phase B, SDL will investigate a new technique of electronic modulation in the preamps to be used in place of the mechanical chopper. This would eliminate the moving mechanical devices in SOFIE other than the dust cover and the steering mirror. The effectiveness of the electronic chopping method has been demonstrated (Lockwood and Parrish, 1987). For HgCdTe detectors, the electronic chopping provides the option of eliminating the detector bias voltage and thus eliminates the 1/f noise (Tobin et al. 1980).

Mechanical Subsystem. SOFIE employs a proven physical construction, using longerons and deckplates common in rocket payloads. This construction is lightweight while maintaining rigidity. All of the structural elements and the mirrors are made of 6061-T6 aluminum, to give uniform expansion and contraction with temperature, eliminating the need for precise regulation of the structural temperatures. All of the optical elements requiring careful co-alignment are: the primary mirror with secondary mirror support, the field stop, collimating lens and aperture stop, and the channel separation module are common to and mounted off from the second deckplate, thus maintaining rigidity without excess mass. The cylindrical tube forming the baffles in the steering mirror section with its top plate and the dust cover seals off this section. Only the middle section requires a shell specifically for dust sealing, and because this section also does not require evacuation, the shell can be light weight, thin aluminum. Passive radiators used for instrument cooling and removal of the rejected heat from the TE coolers will be mounted to the sides of this middle section. Heat pipes will be used to transport the thermal energy to the IPA radiators.

The channel separation module including all the detector cells will be located in an evacuated enclosure vacuum-sealed by the collimating lens so that the detectors can be cooled without condensation problems during any pre-launch or other ground testing phase. The vacuum-tight enclosure will also be insulated to minimize the power inputs to the TE coolers required to bring the detectors to their required operating temperatures. Note that the passive radiators and heat pipes are not shown in Fig. F-16.

Pointing. The pointer tracker is a COTS system manufactured by Adcole Corporation. The Adcole Sun Sensor uses a Periodic Pattern Reticle with four photocells and two reticle patterns, one with nine line pairs and a second with 73 line space pairs, to form a 4-phase filter for each axis. A processor combines the four signals into two currents that are then solved mathematically to obtain a fractional period number that is converted into a 12-bit fractional binary number. Each bit represents 1.67 arc seconds. The sun sensor is sampled at 62.5 Hz to allow statistical processing to improve the precision. The steering mirror keeps SOFIE pointed at the same region of the sun during an occultation event with the position on the sun selectable by ground command. The nominal track position will be the sun center to minimize noise induced by tracker precision. The pointing system will provide knowledge of the mean position of one measurement sample relative to another to better than 1 arcsec over a 0.5 second time interval. This will give knowledge of the mean relative altitude measurement position to ~ 12 meters during the time it takes for the sun to sink or rise by ~ one IFOV. Note that the 1 arcsec is a statistical mean uncertainty based on a 62.5 Hz sample rate for the sun sensor. The steering mirror is guided by the SOFIE attitude determination and control system (ADCS) with input from the precision sun sensor co-aligned with the collection telescope. The sun sensor field of view (FOV) is ±0.95 degrees. The SOFIE sun sensor capability limits the spacecraft control requirements during SOFIE measurements to only about ±0.5 degrees.

Cleanliness. SOFIE will be assembled and tested at SDL in a minimum class 10,000 clean room environment. All elements within the vacuum enclosure will be assembled in a class 100 clean room environment. During spacecraft integration and test SOFIE will be maintained in class 100,000 conditions with the dust cover closed. Short periods of exposure to environments exceeding class 100,000 may be permitted provided the dust cover remains closed. In order to minimize contamination, in particular to organics, all non-sealed spacecraft components shall be low outgassing, defined as materials that have less than 1% Total Material Loss (TML) and less than 0.1% Collected Volatile Condensable Materials (CVCM). SDL will use only low outgassing materials in the fabrication of SOFIE. At the integration and launch pad sites and in the launch vehicle fairing, SOFIE will be bagged (covered) and purged with dry nitrogen such that excess pressure is maintained within the bag environment. The bag or cover may be removed for integrated system test for short durations. Prior to fairing closeout the covers shall be removed and a final cleaning of the area and the instrument will be performed.

Calibration. SDL will calibrate SOFIE under two conditions, with and without atmospheric absorption. SDL will first characterize the detector response to blackbody sources with no atmospheric absorption. This will be done by mating SOFIE to one of the SDL Multifunction Infrared Calibrators (MICs) under vacuum conditions by locating SOFIE within a special antechamber that is part of the MIC vacuum. SDL has sources that go as high as 1100 °C which can be coupled into the MIC. LaRC has a 2800 K solar simulator used for the HALOE testing that would be a better simulation of the orbital measurement and we will investigate use of that source in Phase B. The MIC can be cooled if desired, and SOFIE can be cooled independently to its expected on-orbit operating temperature. SDL has extensive experience with the MIC facilities that can provide multiple source configurations to characterize instrument optical and radiometric performance. A similar setup was used to calibrate the SABER instrument. During this portion of the calibration, SDL will characterize detector responsivity verses detector temperature, optoelectronic linearity verses signal level, spectral response, noise characteristics, offset correction, and estimated errors.

In the second calibration condition, SDL will test the tracking system from the ground at rates similar to orbit by placing SOFIE on a rotating platform. Overhead atmospheric opacity will be low enough to allow high transmission at the tracker bandpass. Viewing the sun through the atmosphere will characterize instrument performance in solar occultation conditions and will allow verification of the sun sensor, attitude determination and correction system, and steering mirror performance without interaction from the spacecraft attitude control system. This type of calibration will be repeated in depth during early orbit activities. Also, two full sun disk calibration scans will be performed during each measurement sequence.

During Phase B, SDL will develop a preliminary calibration plan. SDL will also determine if there is real value in taking SOFIE to a high altitude observatory location for the solar tracking calibrations.

Retrieval Study. The S/N levels shown in **Table F-22** were applied in detailed retrieval studies using the HALOE retrieval software. This al-

Table F-22. Predicted Specific Detectivities and Signal-to-Noise Values for the Various Constituent Bands Measured by SOFIE

Atmospheric Absorber	Lower λ (μm)	Upper λ (μm)	D* [$cmHz^{1/2}W$]	NEP [W]	S/N	Requirement
O3 (abs)	8.85	9.346	1.50E +09	9.43E-11	1.73E+04	1.0E+04
O3 (non-abs)	9.434	10	1.40E +09	1.01E-10	1.41E+04	1.0E+04
H2O (abs)	6.173	6.329	7.00E+09	20.2E-11	8.44E+04	2.5E+04
H2O (non-abs)	6.452	6.623	7.00E +09	2.02E-11	7.66E+04	2.5E+04
NO	5.18	5.32	2.50E+10	5.66E-12	6.27E+05	3.0E+05
CO2 (abs)	4.184	4.348	5.00E +10	5.66E-12	2.60E+06	4.0E+05
CO2 (non-abs)	4.348	4.525	5.00E +10	5.66E-12	2.44E+06	4.0E+05
CH4 (abs)	3.39	3.46	4.60E+10	6.15E-12	4.44E+06	4.0E+05
CH4 (non-abs)	3.47	3.54	4.60E +10	6.15E-12	4.00E+06	4.0E+05
Ice/Aer (abs)	2.9	2.99	1.00E +11	1.41E-12	1.71E+07	1.0E+06
Ice/Aer (non-abs)	2.99	3.08	1.00E +11	1.41E-12	1.50E+07	1.0E+06
CO2 (abs)	2.77	2.833	8.50E+10	1.66E-12	9.69E+06	3.0E+05
CO2 (non-abs)	2.833	2.899	8.50E+10	1.66E-12	9.18E+06	3.0E+05
new band	2.25	2.4	3.40E+10	4.16E-12	1.41E+07	1.0E+06
new band	2.4	2.5	3.40E +10	4.16E-12	7.69E+06	1.0E+06

lowed complete simulation of occultation measurements from a proven processing code. Precision errors are shown in **Fig. F-19**. The S/N value assumed for all channels except H_2O and O_3 was 10^6. This is known to be achievable at these wavelengths from the HALOE gas correlation difference signals. The higher S/N values actually predicted for these shorter wavelength channels were not used in the simulations because it is not known with certainty wether tracking jitter effects coupled to source non-uniformity will allow those values. Therefore we consider our performance estimates very conservative, especially for the shorter wavelengths.

The water and ozone channel results have been updated using the indicated levels in the table. These values are less than the values predicted in the Step 1 proposal, but still provide ample margin for our science requirements. Fig. F-19 displays the updated results and Table F-4 on FO-F1 contains requirements vs. predicted performance near mesopause altitudes.

F.4.2 SHIMMER

SHIMMER is a high spectral resolution UV spectrometer (Harlander et al. 2001). It uses the innovative optical technique known as Spatial Heterodyne Spectroscopy, which allows the design of a rugged, high throughput limb imager that is significantly smaller and lighter than comparable conventional spectrographs. The instrument has no moving optical components and consists of a dust door/diffuser combination, a telescope, an interference filter, a spatial heterodyne interferometer, exit optics, a shutter, a CCD camera, and the necessary controller electronics to operate the instrument and communicate with the spacecraft. The telescope images the vertical (altitude) dimension of the earth's limb onto the gratings of the spatial heterodyne interferometer. The horizontal dimension is deliberately defocused in this plane to avoid any contamination of the spectral information by horizontal atmospheric structures (like clouds). The interferometer superimposes a wavelength-dependent fringe pattern onto the limb image to obtain a spectral resolving power of 53,000. The exit optics between the interferometer and the CCD array image the grating plane onto the CCD chip where the spectral information is encoded as an interferogram in one dimension, and the altitude information is represented in the perpendicular dimension. The SHIMMER FOV is 1.6 deg x 3.2 deg which corresponds to an altitude range of 70 km on the limb, from 30 km to 100 km. The image on the CCD is collapsed to yield 32 altitude rows resulting in an altitude sampling of about 2.2 km on the limb. Periodically, SHIMMER will be pointed at the moon during the umbra part of the orbit to measure the spectral shape of the solar radiation utilizing a transmissive diffuser in front of the telescope to illuminate the whole FOV. This data will be used to verify the instrument's performance and the solar spectral shape that is used in the data reduction to separate the solar radiation scattered in the atmosphere from the OH resonance fluorescence. The data reduction technique is similar to the MAHRSI data processing described by Conway et al. (1999). The OH resonance fluorescence intensity is used to determine the OH vertical profile. Temperature profiles will be retrieved using the temperature dependent OH line strengths, and PMC information will be obtained by the background signal that originate from scattering in the atmosphere. Water vapor concentrations can be inferred from OH using a photochemical model as described by Summers et al. (2001).

The design of the SHIMMER instrument was driven by the measurement and mission requirements necessary to meet the AIM science objectives. Included in the design is protection of the CCD detector from radiation damage. After a brief description of the instrument changes since the proposal, the Subsystem Requirements and Characteristics section will discuss the individual instrument components and the rational for their selection. Pointing requirements of SHIMMER as well as calibration and cleanliness considerations are discussed. An instrument model including these subsystem characteristics was used to simulate measurements yielding estimated uncertainties. With a modified MAHRSI retrieval algorithm, the simulated measurements were analyzed confirming that the SHIMMER instrument meets the AIM measurement requirements with appropriate margin. These results are shown in the Retrieval Study section.

Changes Since the Proposal. The only significant change in the SHIMMER design since the proposal is to narrow the bandpass from 2.0 nm to about 0.33 nm to improve the temperature measurements. The physical reason for this improved sensitivity lies in the multiplex noise of Fourier transform devices like SHIMMER. The spectral noise depends on the average signal per spectral resolution element, and on the total num ber of spectral resolution elements within the bandpass. In the case where the desired informa-

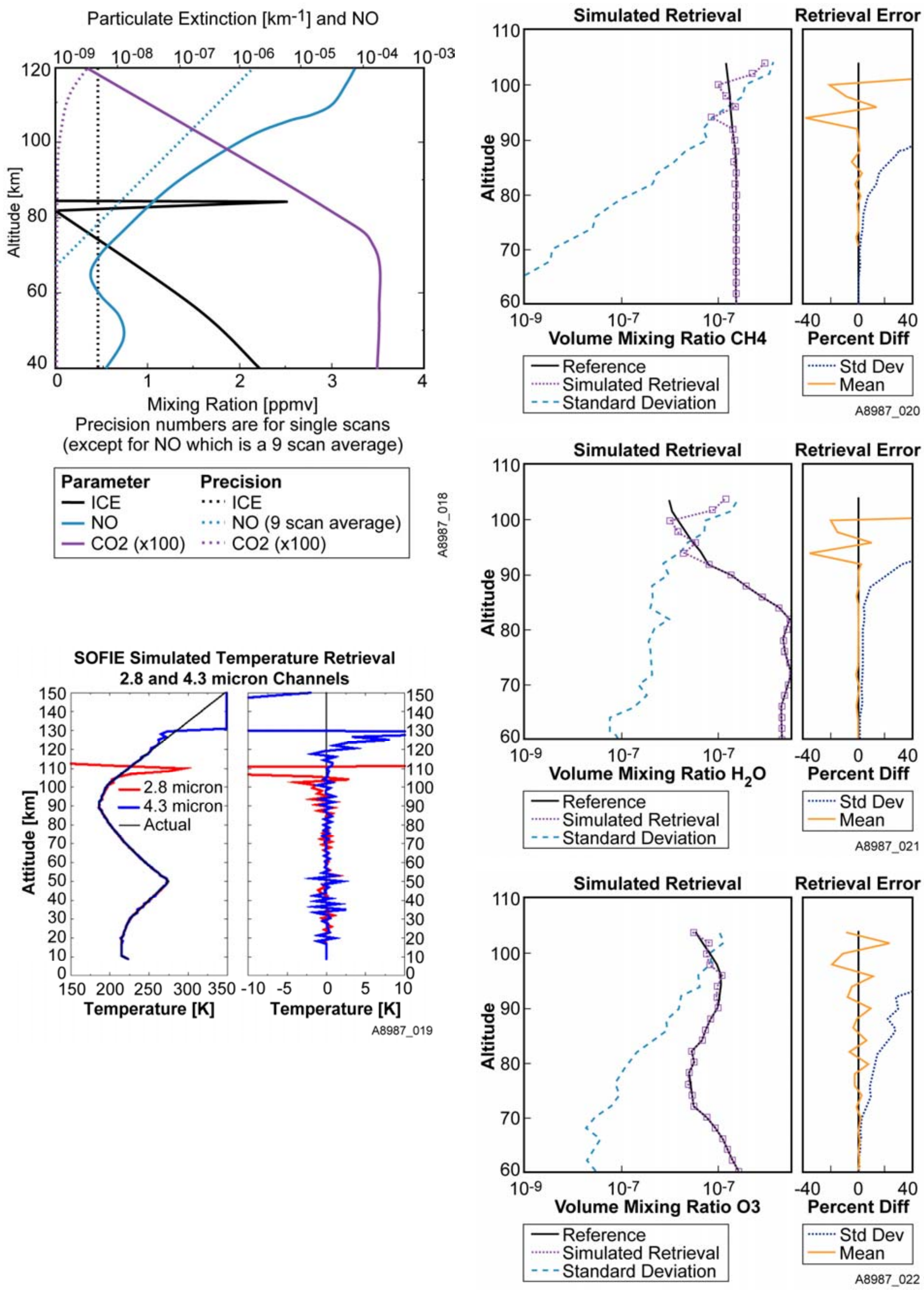


Figure F-19. Results of SOFIE Retrieval Simulations

tion is contained in a narrow portion of the spectrum, a suppression of the rest of the spectral signal results in an overall increase in signal to noise. We selected the new bandpass to include one bright OH resonance fluorescence feature as well as a nearby temperature dependent OH feature to retrieve the atmospheric temperature. The narrower bandpass does not compromise the separation of the OH signal from the background and has no impact on the OH density measurement itself. The narrower bandpass allows us to reduce the sampling of the interferograms from 1024 elements per interferogram to 512 without any impact on the spectral resolution or sensitivity. The new bandpass and improvements in the instrument model result in an integration time of less than 10s.

The FOV has been changed to 1.6 deg x 3.2 deg (perpendicular x parallel to the limb) to increase the etendue and sensitivity of the instrument. The FOV is equivalent to 70 km x 140 km on the limb. Data allocation of 4.7 Mbytes/orbit allows SHIMMER to take measurements throughout the entire summer polar region down to 30 deg latitude (130 images per orbit), thus fully addressing the AIM measurement requirements.

***Subsystem Requirements and Characteristics*.** The SHIMMER optical subsystem, including the detector, has been designed so that the number of photons detected in a given measurement time is large enough to meet the AIM measurement requirements, while not violating mass, volume, and power constraints. Careful analyses of the noise sources contributing to the SHIMMER measurements show that the system is primarily photon shot noise limited.

Optical Subsystem. The instrument subsystem characteristics that primarily determine the rate of photons detected are the etendue of the optical system, the transmittance of the optics and the interferometer, the transmittance of the interference filter, and the quantum efficiency of the detector. We selected a state of the art CCD detector chip (Marconi CCD47-20 1024 x 1024 13 μm pixels, frame transfer). This backthinned, UV anti-reflection coated detector array has a quantum efficiency of about 60% around 308 nm, which eliminates the need for an image intensifier. The CCD chip will be cooled to about –30 °C or lower with a TEC/radiator combination to keep dark current and noise contributions at a minimum. All transmitting optics are fused silica with multilayer dielectric antireflection coatings. The exit optics are designed to have sufficient image quality (MTF of 0.9 at 20 lines mm^{-1}) to recover the highest spatial frequency fringe pattern with adequate margin. The aperture and field widening of the interferometer have been chosen to match the AIM measurement requirements. The spectral resolution provided by the interferometer is 0.0058 nm—over three times higher than MAHRSI. Even though the bandpass of SHIMMER is significantly smaller than the MAHRSI bandpass, our simulations show that the OH resonance fluorescence and the solar background can readily be separated with the higher spectral resolution. All the optical elements of the monolithic interferometer are optically contacted. Optically contacting the interferometer components to form a single piece of fused silica (monolith) allows for the positioning of the optical components to interferometric tolerances without an elaborate fixture. Risk is significantly reduced, as the monolith is virtually impervious to misalignment due to vibration or shock. This development and its proven flight worthiness is discussed in more detail in New Technology, Section H.2.2. The FOV of the telescope was designed to match the etendue of the interferometer (1.25 x 10^{-5} m^2sr) and to image a 70 km altitude region on the limb. The input aperture of the telescope measures 6.35 x 12.7 cm^2. Out-of-band rejection is accomplished by an interference filter of bandpass 0.33 nm (available custom-made by Barr Associates) prior to the telescope and narrowband dielectric coatings on the three plane reflecting mirrors. The SHIMMER optical subsystem is shown schematically in **Fig. F-20**.

Mechanical Subsystem. A block diagram of SHIMMER including optical, mechanical, and electronic subsystems is shown in **Fig. F-21**. The instrument baseplate serves as an optical bench for the Spectrograph. The assembly is comprised of the telescope, filter, monolithic interferometer, exit optics assembly, shutter, and CCD camera. The mechanical interfaces of the optical elements to the instrument base plate are similar to the SHS instrument built and qualified for the Space Shuttle mid-deck. The SHS monolithic interferometer (**Fig. F-22** and Section H) serves as a prototype for the SHIMMER instrument. Light-tight walls and a lid will surround these optical assemblies to minimize stray light inside the instrument and to provide protection from contamination. The Spectrograph Assembly will have a mass of 12 kg, a volume of 61 x 51 x 12 cm^3 (excluding baffle), and a footprint on the IPA of 61 x 51 cm^2. The heatpipe and radiator used to remove heat from the CCD will have a mass of 2 kg. The mechanical housing of the SHIMMER electronics is

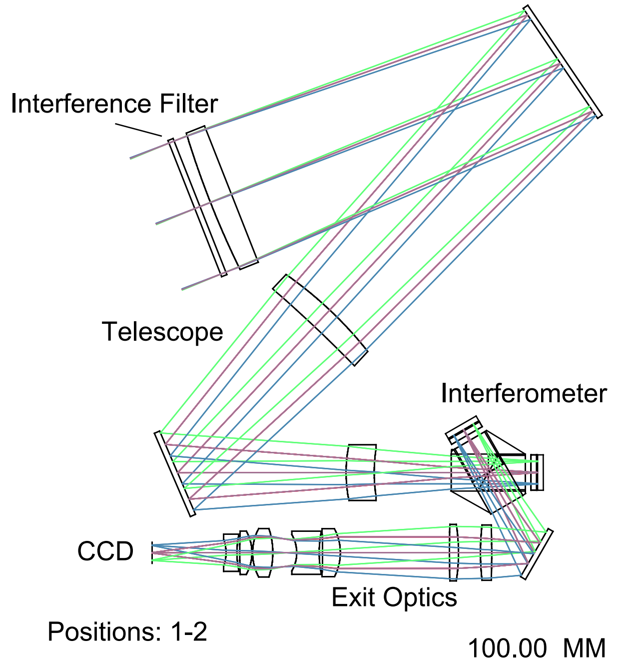


Figure F-20. SHIMMER Optical Subsystem

Figure F-19. Optical Subsystem of SHIMMER

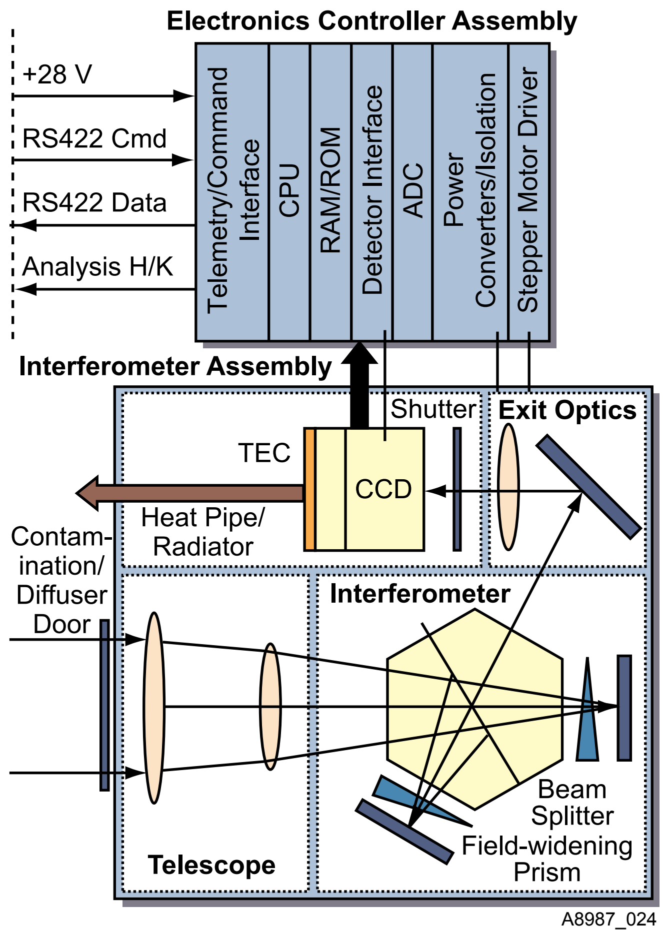


Figure F-21. SHIMMER Block Diagram

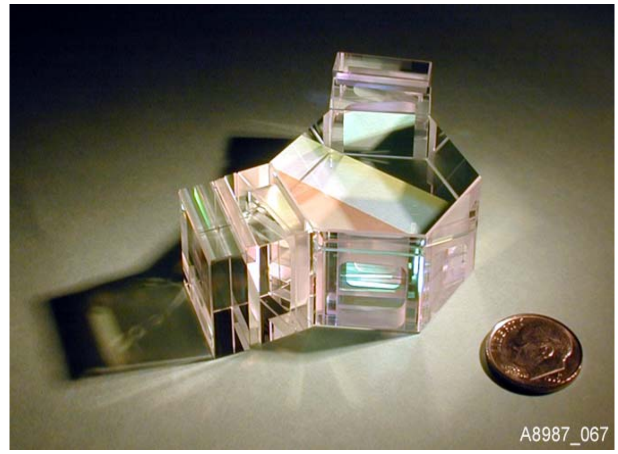


Figure F-22. The SHS Monolithic Interferometer

similar to a MAHRSI design. The SHIMMER Electronics Control Assembly (SECA) has a mass of 10 kg, a volume of 23 x 24.5 x 30.5 cm^3 (with connectors), and a footprint on the IPA pallet 23 x 24.5 cm^2.

Electronics Subsystem. The SHIMMER electronics control assembly (SECA) has been designed to process the science and housekeeping data from the instrument, control and operate the instrument, and to communicate with the spacecraft to meet the AIM specific requirements. The SECA contains six electronics modules: CPU, detector and telemetry control interface (DTI/TCI), CCD camera interface (CCI), analog to digital converter (ADC), motor control interface (MCI), and power distribution and conditioning (PDC). The SECA functional block diagram is shown in **Fig. F-23**. The CPU module comprises a HARRIS HS-80C86-RH microprocessor in minimum mode configuration with all memory and support chips, clock generator running at 5 MHz, eight input prioritized interrupt controller, on board real time clock, watch dog timer, and fully buffered bus interface. The DTI/TCI provides command and science data interface to the spacecraft and payload, and contains both a science telemetry RS-422 interface, and a command reception RS-422 interface. CCD data will be transferred over the science telemetry interface at the average rate of 512 x 32 pixels every 12 seconds (22,016 bps, inc. H/K). All functions and timing are controlled by a Field Programmable Gate Array (FPGA) under CPU direction, and the module contains static RAM for full image buffering.

The CCI module provides the command interface to the camera electronics, handshakes with the camera during data transfers, interfaces the thermoelectric cooler to the CCD and the tem-

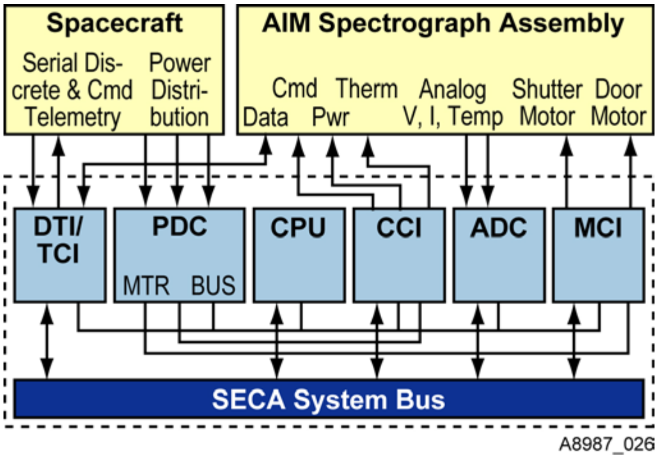


Figure F-23. SHIMMER Electronics Control Assembly (SECA) Functional Block Diagram

perature control servo loop circuits, and receives commands from the CPU via the bus. The ADC module uses a "true 14-bit" A/D converter, providing up to 15 differential analog signal inputs. The ADC module measures a precision reference and ground to allow for self calibration and offset compensation, has interfaces for up to 15 AD590M temperature sensors, and has 16-bit digital input/output capability.

The MCI module interfaces to variable reluctance, permanent magnet stepper motors, and uses a variable duty cycle to control torque and average power. This provides full directional control that includes optical sensor interface for position and limit sensing, and motor current and motor temperature monitors.

The PDC module utilizes a number of relevant design features, such as: discrete design surrounding Interpoint converter modules, precise high side current limiting with adjustable set-point, dedicated common mode input and output filter configuration for each converter, EMI filters customized to converter topology, soft-start over and under voltage protection, and input and output power bus voltage and current monitoring. The normal operational power for SECA/CCD (used for Limb, Background, Fringe and Dark observations) is 30 W, and the standby power is 15 W.

Software. The SHIMMER instrument software provides the command and control of the instrument, and interfaces with the spacecraft. During nominal operations, the primary function of the software and SECA is to control the CCD camera shutter, and to read out the CCD data. The software packetizes the CCD data along with system health information and transfers it to the spacecraft. During periodic moon observations the software commands the dust/diffuser door into the closed position for solar background spectrum measurements. SHIMMER only requires a relatively slow controller of modest capability for commanding the simple and straightforward basic operations of the instrument.

The flight software is correspondingly straightforward. The software is partitioned into two major parts, flight software and ground software. The flight software executes onboard the SHIMMER CPU module. The ground software supports the Controller Development GSE (CD-GSE), the spacecraft interface Simulator GSE (SCIS-GSE), and the Flight GSE (FL-GSE). The software development effort will utilize a series of incremental software builds, each leading to a product with more functional capability. The code effort starts with a stripped down real time operating system developed in house and used on other programs. The operating system consists of a Scheduler, an Executive, a Command Handler, and Interrupt Handlers coded in high level C. Simplicity is the overarching design philosophy. The operating system responds to synchronous and unscheduled asynchronous events in real time, and can also operate autonomously by scheduling events based on Greenwich Mean Time (GMT) tagged commands stored in memory. Importantly, the controller must have the hardware and software mechanisms available to allow for uploading code patches. The development of SHIMMER software will parallel the development of software for NRL's successful MAHRSI instrument. That operating system was developed in house and used for the two flights of MAHRSI on the Space Shuttle in 1994 and 1997. Major portions of the operating system (Scheduler and Executive) will be used for SHIMMER with little or no modification. The SHIMMER ground support equipment (GSE) software is written in Visual C++ along with Quinn-Curtis real time graphic utilities. The GSE software is developed and runs on a Pentium PC. Portions of the user interface and command generator that were developed for MAHRSI will also be used for SHIMMER.

Calibration. The SHIMMER instrument will be characterized and calibrated in six stages, beginning with assessment of the standalone CCD camera performance. Measurements will include darkfield and dark noise as a function of temperature, pixel response nonuniformity, quantum efficiency, photon transfer, response linearity, and corrupted pixel or column identification. Coincident with these measurements, the general performance of the standalone monolithic SHS interferometer will be determined using laboratory optics and Zn, MnNe, and halogen lamps feeding a large integrating sphere. These measurements include the verification of fringe contrast, fringe orientation, Littrow wavelength, and phase distortion.

Once flight telescope and imaging optics have been fabricated, detailed optical characterization and optimization will proceed. This includes setting telescope focus, verifying one-dimensional imaging, aligning relay lens, measuring fringe contrast at all spatial frequencies of interest, measuring instrument function, verifying bandpass, measuring flat field, and determining the phase correction matrix. Once fabrication of the flight electronics and mechanical structure are complete, final CCD camera characterization and testing will include darkfield and noise vs. temperature, photon transfer, bias and read noise, response linearity, and temperature control.

After functional test and final integration of the instrument subsystems, final radiometric calibration will be performed. These measurements include absolute radiometric calibration, wavelength calibration, and characterization of off-axis rejection, internal scattering, and out-of-band leakage. Careful alignment of SHIMMER on the spacecraft will be performed during spacecraft integration.

Operations. SHIMMER has four operating modes: Limb, Dark, Fringe and Background. The Limb (limb-viewing) Mode is the nominal mode where every 12 sec a full limb image will be acquired. This mode will be active throughout the sunlit summer hemisphere. In Dark Mode the CCD is not illuminated so the dark current and noise can be measured. Fringe Mode is used periodically for diagnostic purposes. An image taken in Fringe Mode will not be collapsed to 32 x 512 data points. The entire CCD image will be transferred to the ground. Background Mode will be used about once a month for the moon observations. For these measurements, the diffuser will be moved into the FOV and the instrument will be pointed toward the moon. If necessary, SHIMMER daytime observations preceeding the moon observations can be cancelled in preparation for this special maneuver.

Pointing. SHIMMER is hard mounted to the IPA without autonomous pointing capabilities. Therefore, pointing control and the knowledge of the spacecraft altitude is essential for the SHIMMER measurements. These properties are needed to accurately register the measured image to an altitude scale. The AIM requirement for 1 km altitude registration uncertainty is met with a pointing knowledge of 72 arcsec (900 m on the limb) and spacecraft altitude knowledge of 300 m. Altitude knowledge will be provided by the NSC (see also Section G). The spacecraft attitude knowledge requirement from SHIMMER is well within the RS300 capabilities. The RS300 is required to adjust the pointing to accommodate the oblatness of the Earth and changes in altitude due to orbit decay or orbit eccentricity. Pointing control is less critical, with a requirement of 0.1 deg (5 km on the limb) due to the fact that altitude coverage of SHIMMER exceeds the AIM requirements. Because the SOFIE FOV points toward the sun for orbit sunset and sunrise, SHIMMER is precluded from pointing directly at the sun, which would require closing the dust door in order to prevent any damage to the optics and the detector.

Cleanliness. SHIMMER will be maintained in a minimum class 100,000 environment. Short periods of exposure to environments exceeding class 100,000 may be permitted. In order to minimize contamination, in particular to organics, all non-sealed spacecraft components will be low outgassing, defined as materials that have less than 1% TML and less than 0.1% CVCM. At the integration and launch pad sites and in the launch vehicle fairing, the SHIMMER optical instrument will be bagged and purged with dry nitrogen such that excess pressure is maintained within the bag environment. The bag may be removed for integrated system test for short durations. Prior to fairing closeout the bag will be removed and a final cleaning of the area and instrument performed.

Retrieval Study. For the simulation of a typical SHIMMER data retrieval, theoretical noise calculations assuming the above described instrument subsystems and the MAHRSI retrieval code (Conway et al. 1999) have been used with the following input data:

- MAHRSI high latitude OH profile (~70 deg N, mid August)
- Solar zenith angle ~56 deg (noon local time)
- Theoretical SHIMMER instrument performance including photon shot noise, detector dark current noise, detector read noise and quantization noise
- Hanning apodization of interferograms
- Unless stated otherwise a single limb image is assumed (Image frequency = 1 per 12 sec)

We find that the results of this retrieval study satisfy the AIM science requirements.

Hydroxyl. The combined intensity of the $P_{11}(1)$, $Q_{11}(3)$, and ${}^{Q}P_{21}(3)$ lines in the OH resonance spectrum (Stevens and Conway, 1999) were used to retrieve the OH density profile shown in **Fig. F-24a** together with the estimated measurement precision.

Water Vapor. A water vapor profile was inferred in **Fig. F-24c** using the photochemical technique of Summers et al. (2001). The estimated absolute measurement precision is displayed separately and as an envelope of the profile.

Scattering (Cloud Brightness). To estimate the measurement precision of the radiance scattered by the clear atmosphere, an average MAHRSI high latitude scattering profile was used. This average was compiled without regard to the presence of ice particles along the line of sight. The estimated measurement precision is given **in Fig. F-24d**. Note that the additional scattering due to PMCs around 82 km increases the measurement precision at these altitudes.

Temperature. The temperature information in the SHIMMER spectra is retrieved using the temperature dependent intensity of the $Q_{11}(4)$ and ${}^{Q}P_{21}(4)$ lines. The expected precision of a 24 hour, 5 deg latitude interval, zonally averaged temperature measurement, was determined using a high latitude HALOE temperature profile and the g-factor temperature dependence from Stevens and Conway (1999). The result is shown in **Fig. F-24b**.

Performance Margin. SHIMMER was designed to meet the science requirements with appropriate margin. The desired performance is achieved primarily by choosing an appropriate etendue, altitude sampling, spectral bandpass and spectral resolution. All of the SHIMMER measurement requirements have been considered in the instrument design. No single requirement is a major cost driver. The measurement requirements for temperature and OH are the main drivers for the instrument development.

In summary, the estimated precision of the four SHIMMER data products (OH, T, Scatter Ratio and H_2O) compares to the AIM requirements (see also FO-F1) as follows:

OH. The AIM requirement calls for an uncertainty of 14% in OH concentration for concentrations higher than 2 x $10^{6}cm^{-3}$ with an altitude resolution of 3 km between 55 and 81 km every 5 deg in latitude (every minute). The estimated precision for this measurement is better than 9% with a 3 km altitude resolution.

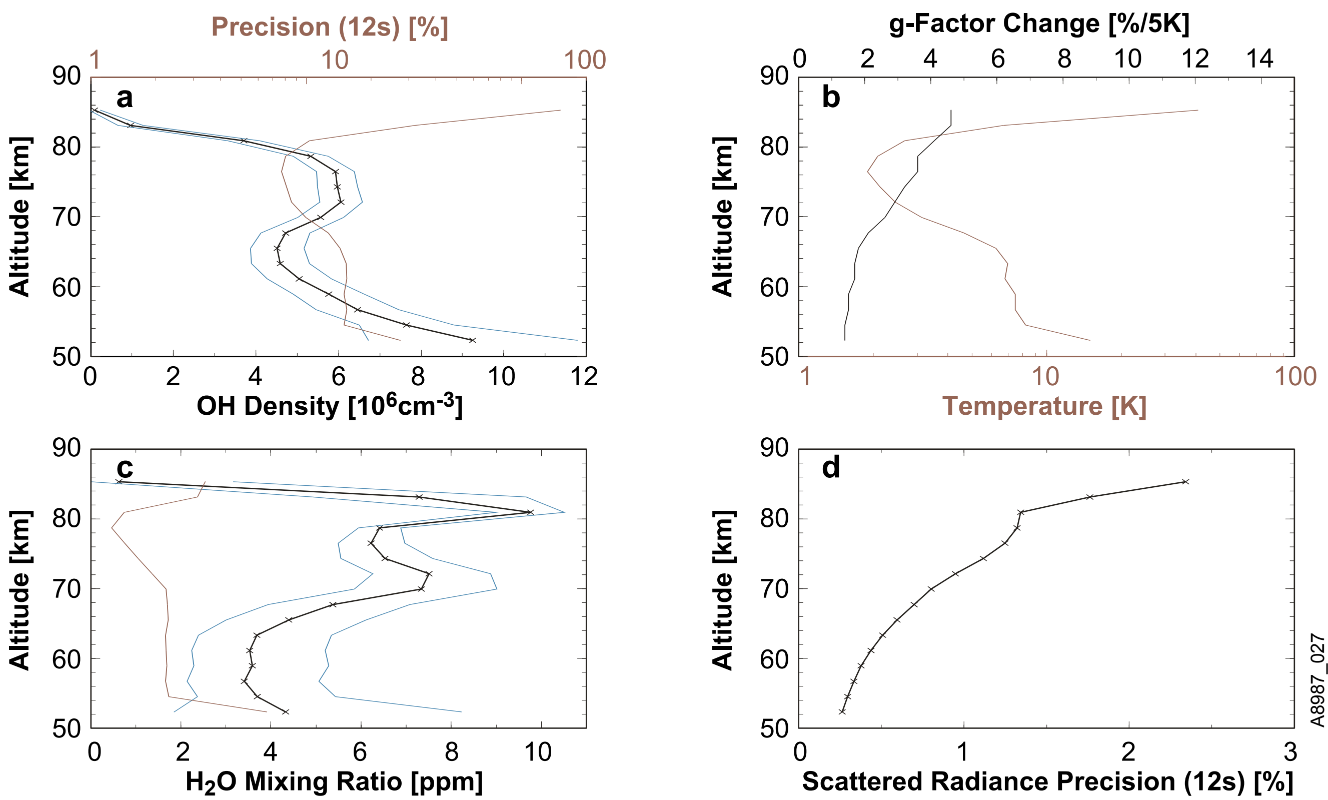


Figure F-24. SHIMMER Retrieval Study Results

T. SHIMMER is required to measure the zonal average of temperature in 5 deg latitude bins with 3 km altitude resolution every four days between 70 and 82 km with an uncertainty of 5 K. The estimated precision for this measurement is better than 2.5 K with a 3 km altitude resolution.

Scatter ratio. The SHIMMER measurements of scattering ratios requires an uncertainty of 54% over 5 deg in latitude (every minute) with a 3 km altitude resolution between 75 and 90 km. The estimated precision for this measurement is better than 1.6%.

H_2O. The water vapor measurement requirement for minimum science is met by the SOFIE instrument. However, SHIMMER data allows the inference of water vapor mixing ratios from the measured OH profiles. The estimated precision for this derived data product is better than 1.5 ppm with an altitude resolution of 3 km over 5 deg in latitude (every minute) between 55 and 85 km.

SHIMMER therefore exceeds all of the minimum science requirements with appropriate margin.

Data Management. SHIMMER will collect 75 Mbytes of data/day, which translates to 50 Gbytes of data during the 22 months of normal mission operations. The data will be managed with the wealth of computational resources available at NRL. The data of highest priority to AIM science are limited to the common volume measurements during the PMC seasons in each hemisphere, reducing the total amount of data by about 75%. A 12-minute orbital pass over the SHIMMER/CIPS column volume region will yield 60 limb images of OH(0,0) solar resonance fluorescence which will be reduced and inverted to local OH density profiles individually. Water vapor will be inferred from each profile using a separate algorithm that employs the relevant photochemistry relating the two (Summers et al. 1997a). OH(0,0) spectra will be co-averaged daily in 5 deg latitude bins to infer temperatures from line ratios and the OH density profile inferred from this average will be used to help validate individual profiles.

F.4.3 CIPS

The Cloud Imaging and Particle Size (CIPS) instrument will produce 34 panoramic high-resolution views of PMCs beneath the spacecraft on each orbit. The scene recorded by CIPS during each 0.24s integration will include Rayleigh scattered sunlight from altitudes near 50 km and Mie scattered sunlight by PMC particles near 82 km. The primary purposes of CIPS measurements are to provide the morphology of PMCs; to measure particle size information over the spatial and temporal evolution of PMC's; and to provide measurements of gravity wave activity in the presence of PMCs and globally in the upper stratosphere.

The CIPS instrument was designed to achieve the requirements of mapping the global morphology of PMC's and determining the ice particle sizes and concentrations within the common volumes observed by SOFIE and SHIMMER. The instrument, shown in **Fig. F-25**, consists of a 2 x 3 array of cameras each with a 40 deg x 40 deg FOV, operating in a 10 nm passband centered at 265 nm, with overlapping FOV's and a resolution (at the nadir) of 2 km. The total FOV is 80 deg (cross track) x 120 deg (along track), centered at the sub-satellite point. Because of slant viewing at the edges of the FOV, the worst spatial resolution is about 17 km, adequate for identifying the larger-scale PMC "bands".

Because the instrument will obtain multiple exposures of the same cloud element, CIPS will measure the scattering phase function at multiple locations along the thin flat layers of PMCs. The primary analysis will concentrate on the common volumes, in low background, observed by SOFIE and SHIMMER. The phase function is critical for the determination of column mass and surface area, quantities that are needed for study of the cloud microphysics and surface-induced heterogeneous chemistry. The method uses the cloud particle's Mie scattering-angle signature. For the brighter clouds that exhibit forward-scattering behavior, and that lie significantly above the noise level (see Fig. E-9, FO-E1), we will combine CIPS and SOFIE data (Section F.4.3) to derive the particle concentration, the mean particle

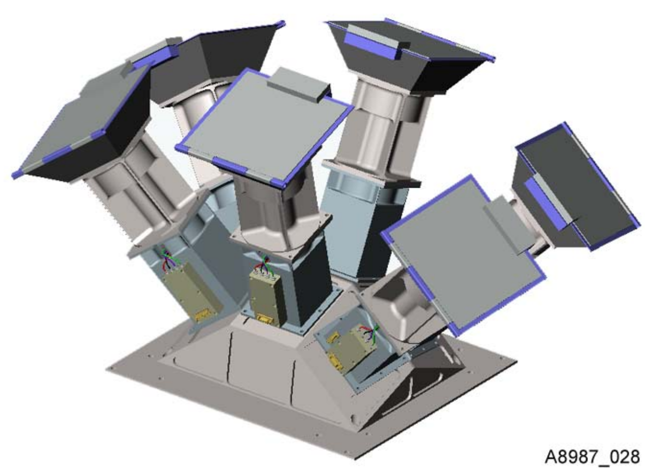


Figure F-25. CIPS Instrument

size, and the width of the size distribution, assuming the log-normal size distribution (Thomas and McKay, 1985). The water-ice composition (verifiable from SOFIE IR extinction versus wavelength measurements), the CIPS angular distributions at a single wavelength, and the CIPS and SOFIE optical depths, will yield ice column mass, concentration, and surface area. This will allow correlation of PMC size with PMC extinction, T, H_2O and other atmospheric parameters.

The CIPS optical elements (see **Fig. F-26**) are sized to permit a ±5% measurement precision of the background sunlit Earth, which is meeting with margin the requirements from Section E. Each camera has a focal ratio of 1.4, focal length of 35 mm, and 25 mm lens diameter. Each includes an interference filter and CCD detector system. The custom UV filters are manufactured by Barr associates and centered at 265 nm with approximately 10 nm bandwidths. The CCD detectors are coupled with Hamamatsu V5181U-03 image intensifiers (40 mm diameter active area) and have 1024 x 1024 useful pixels that are electronically binned in 3 x 3 combinations for effective 341 x 341 pixel images. The intensity of each pixel is digitized to 12 bit resolution. The instantaneous field-of-view of an effective picture element (individual pixel sizes are 22.5 μm) is 1.0 km projected distance at a cloud height of 83 km.

Imaging is achieved with this body-fixed camera assembly using an exposure time of 0.24 seconds, which is matched to the required nadir resolution of 2 km. Between four and six exposures of the same cloud are made during a satellite overpass, at a rate of one every 41 sec. Each CCD is equipped with a DSP interface that incorporates a lossless Huffman compression algorithm, reducing data volume by an estimated factor of two. Therefore each image (including all six cameras) will produce approximately 523 kbytes of data yielding approximately 18 Mbytes per orbit.

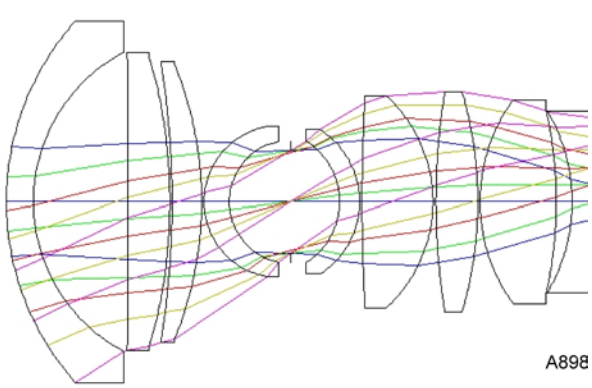


Figure F-26. CIPS Camera Optical Design

Changes Since the Proposal. A custom interference filter manufactured by Barr Associates has replaced the originally proposed Acton F225W interference filter. The new filter provides both a factor of 100 improvement in long wavelength light rejection and a factor of two increase in instrument sensitivity (filter transmission). The radiometric performance for CIPS is discussed below.

Subsystem Requirements and Characteristics. CIPS measures reflectance from PMCs against a bright visible light background with high radiometric precision and over a wide angular FOV. The implementation requires an instrument with maximum sensitivity in the 265±5 nm wavelength range and maximum rejection of visible and near infrared wavelengths. These requirements determine the performance characteristics of the cameras as described below. CIPS is also designed to meet the AIM mission requirements and in particular has been designed to protect the CCD detectors from radiation damage.

Optical and Detector Subsystem. Fig. F-26 shows an optical layout of the CIPS camera designed by Latkin Optical Corporation. It consists of a nine-element lens system with spherical surfaces, a 5 mm thick interference filter, and the output focal plane. The design is telecentric (the chief rays for all image points across the focal plane are normal to the input face of the interference filter), insuring that the wavelength response of the interference filter is independent of image position. Each lens, which is made from fused silica and calcium fluoride for negligible volume absorption, is anti-reflection coated to limit reflection losses to 0.5% per surface. At f/1.4, the lens-filter system produces point source images that have focal plane radii less that 70 μm over a 40 deg field. Spot radii increase to 140 μm at the corners of the CCD detector (28 deg off axis).

The camera-filter system images the nadir scene onto the input surface (backside of the input window) of the image intensifier, which has a CsTe photocathode that converts incident photons into electrons with a 12-15% absolute efficiency. Photoelectrons output from the photocathode are multiplied in a single stage microchannel plate (**Fig. F-27**) and accelerated into a P-20 phosphor, which is coupled through a fiber optics faceplate to the input of the CCD, producing a luminous gain of 2×10^3 with a decay time (to less than 1%) of 10^{-3} sec at the CCD. Thus, each photoelectron conversion at the photocathode produces a

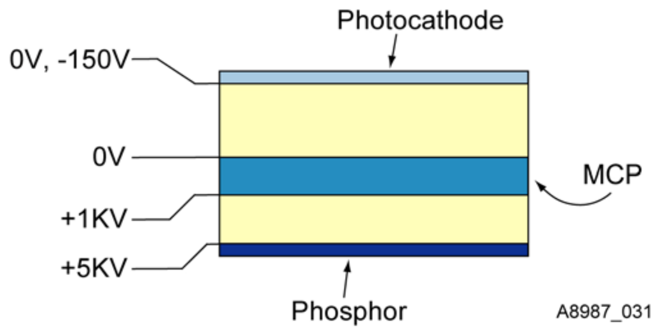


Figure F-27. Schematic of CIPS Image Intensifier

pulse of ~600 signal electrons in the CCD. The image intensifier performs four important functions in the CIPS system:

1. It converts ultraviolet photons into visible photons that can be sensed with a standard CCD.
2. Because the CsTe photocathode is very insensitive to visible light (See Fig. F-26), it acts as an essential additional filter for eliminating red leaks in the interference filter, providing additional long wavelength blocking.
3. Its luminous gain is large compared to CCD read noise and dark current noise (10 and 50 electrons respectively); therefore, the CIPS measurements are photon shot noise limited when the detector is operated at room temperature with a 0.24 second integration period.
4. It provides an electronic shutter that is enabled by switching the –130 volt bias at the photocathode. This eliminates image smear during the 2.05 second readout time (**Table F-23**)

Fig. F-28 summarizes detailed calculations showing that the UV filter in conjunction with the image intensifier and CCD response characteristics accomplish the rejection of near-UV and visible radiation sufficiently to achieve the requirement of measuring contrast ratios and cloud brightness. The upper two panels show the response of the intensifier CsTe photocathode and the interference filter transmission. The solid line in the lower left panel shows the radiance (product of the solar flux and the atmosphere albedo, A) assuming $A=10^4$ at 265 nm. The dotted and dashed lines show the effects of spectral transmissions of the photocathode and the filter on the incident radiance. The ratio of in-band transmitted light (265±5 nm) to the out-of-band transmitted light (>270 nm) is 10^4:1. Testing is underway to demonstrate the red light rejection properties with a lab prototype.

The CIPS baseline detector is a Marconi CCD55-30 Inverted Mode scientific sensor. This

Table F-23. CCD Camera Specifications

Detector	Marconi55-30 or equivalent	Full-frame CCD with anti-blooming control
Pixel size	22.5 x 22.5	μm^2
Number of pixels	1252 x 1152	total data volume
Number of useful pixels	1024 x 1024	active pixels
Readout frequency	625 kHz	
Image shift time 6 ms		
Total readout time	2.05 sec	
System Gain	~12 e^- per DN	TBC
Total noise in darkness	70 e	@ room temperature
Linearity error	1 %	
Power consumption	~2 W	per camera head (measurement 1.9 W)
Resolution	14 bit	
Full well capacity	164 ... 245	K-electrons
Temperature range	-20 deg C to +40 deg C	

device has 30% quantum efficiency at the peak wavelength (550 nm) of the P-20 phosphor. Its 22.5 µm square pixels will be binned in hardware to produce a 67.5 µm effective pixel footprint. Table F-23 summarizes its electrical characteristics. CIPS radiometric performance and margin is described below.

Mechanical Subsystem. Fig. F-25 shows the CIPS mechanical design. The six cameras are mounted on a single optical bench. Each camera is equipped with a single stage baffle that eliminates glints from adjacent cameras. A baffle, which is mounted on the sunward side of the instrument, shields the camera apertures from direct solar illumination at sunrise and sunset. Since the spacecraft must yaw around twice per obit to point SOFIE only a single baffle is required for sunrise and sunset (see Cover Photo). **Table F-24** summarizes the mass and volume for a single camera head, which includes baffle, optics, image intensifier, high voltage power supply, and camera electronics. The CIPS assembly, including,

Table F-24. Camera Head Mechanical Specifications

Parameter	Design Goal	Maximum
Total mass (per CH)	700 g	900 g
Size (envelope), W x H x L	64 x 78 x 104 mm^3	68 x 82 x 115 mm^3
Volume	450 cm^3	550 cm^3
Material	Aluminum	N/A

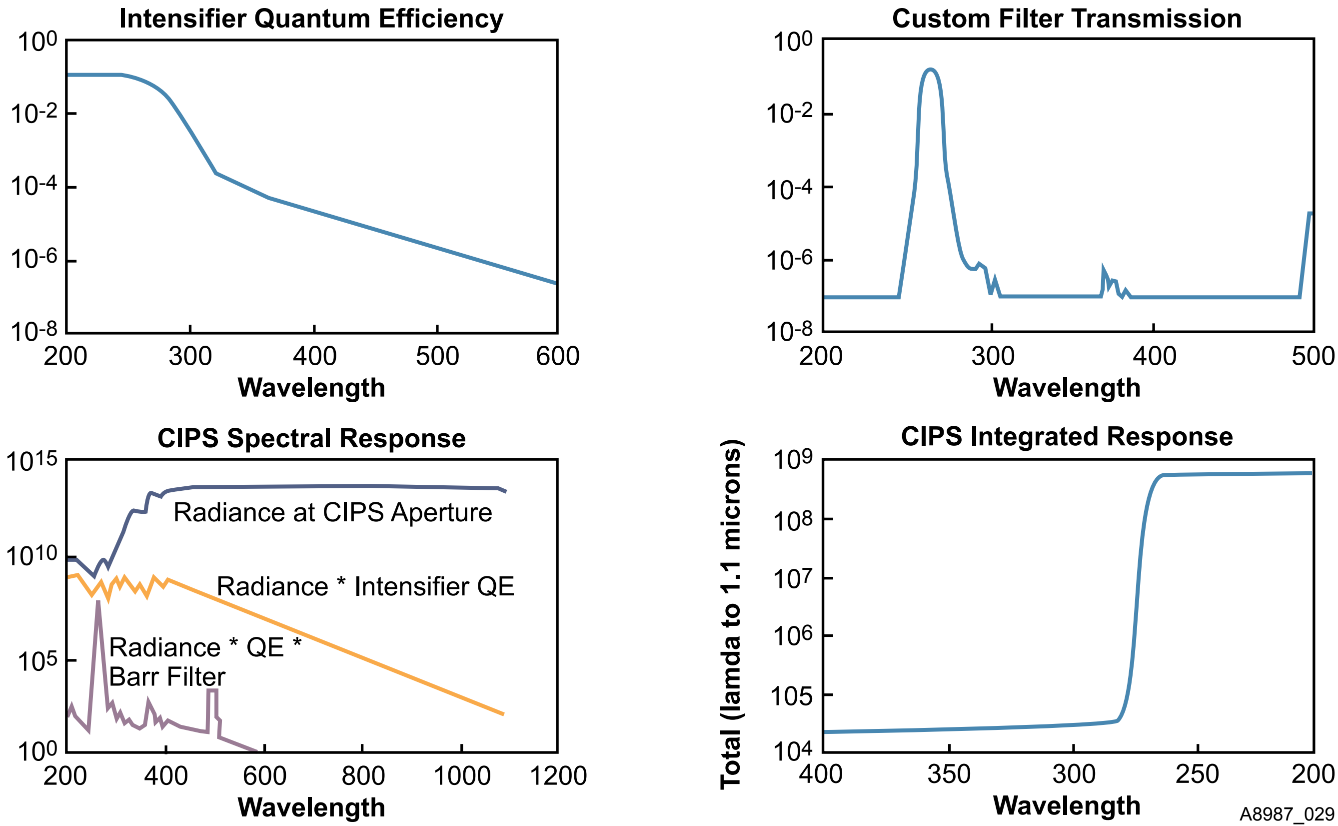


Figure F-28. CIPS Filter and Intensifier Spectral Response Reject Unwanted Long Wavelength Light

mounting structure, cameras with their associated electronics, and CIPS interface electronics, has a mass of 11.3 kg, a volume of 24 x 30 x 25 cm^3, and a footprint on the spacecraft mounting plate of 24 x 30 cm. The dust covers will be used during ground I&T and will be removed prior to fairing closeout.

Camera Electronics Subsystem. The cameras and their electronics are purchased from the DLR (German Institute of Space Sensor Technology & Planetary Exploration in Berlin). These Modular Sensor Electronics System (MOSES) cameras were developed for the Rosetta program.

The CIPS cameras contain the detector electronics subunit that has been developed for the ROLIS camera on Rosetta. The detector electronics combines a 1024 x 1024 active pixel, a full-frame CCD (Marconi 55-30), an FPGA with the signal chain, a clock driver, and a controller board. The latter incorporates the complete detector electronics from the image sensor and the image digitization to the data interface (I/F) with the CIPS interface. The cameras are controlled by command words transferred from the interface electronics to the camera head. The camera electronics are optimized for low-power dissipation and low readout noise.

Figs. F-29 and **F-30** show MOSES in its two-dimensional test configuration before and after folding-up.

The concept for the camera fabrication is based on a rigid-flex interconnection between the functional electronic boards (CCD head/focal plane assembly, clock driver, signal chain, and interface controller (see Fig. F-30).

Associated with each camera head is a microcontroller (M8051WARP embedded in FPGA—

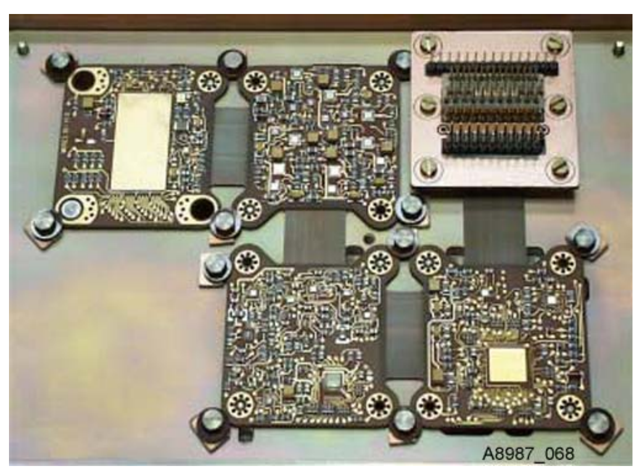


Figure F-29. Unfolded Camera Electronics

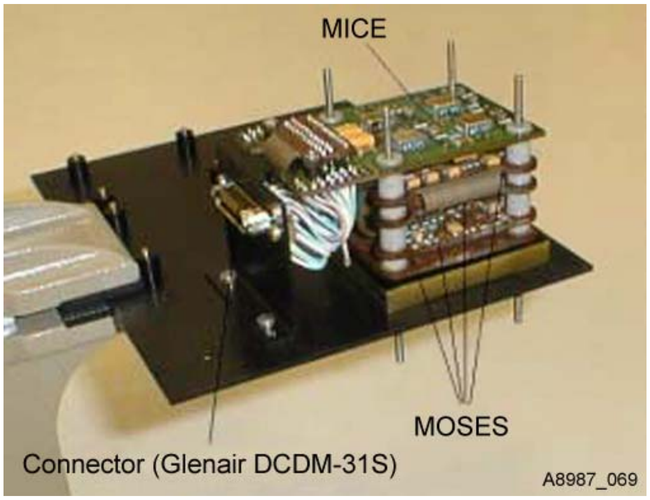


Figure F-30. Folded Camera Electronics

see discussion in interface electronics section) that controls the camera and performs 3 x 3 pixel binning that reduces the CCD image from 1024 x 1024 pixels to 340 x 340 pixels. The binning operation, computed real time during CCD readout, is performed on the 12 most significant bits of the 14-bit camera data resulting in a 16 bit data number for each of the 340 by 340 image pixels. The 340 x 340 pixel, 16-bit image data is buffered locally in the camera and transferred via the interface electronics to the RS300 C&DH computer during the 41 sec between images. The throughput rate for each camera is 5 KB/sec. Image compression is performed by a task running in the CIPS microcontroller. After compression, the images are stored in RS300 C&DH system solid-state memory prior to download.

Each camera also has a Hammatsu image intensifier that is electronically shuttered by a switched high voltage power supply. The high voltage power supplies are designed by Battel Engineering and manufactured, tested and qualified at LASP. Fig. F-27 is a schematic diagram of the image intensifier that shows the required voltages. Switching the –130 volt accelerating potential at the photocathode performs electronic shuttering. The electronic shuttering is implemented using a HV opto-coupler from Amptek.

Interface Electronics Subsystem. The Instrument Interface Electronics provides the interface pathway between the RS300 spacecraft C&DH system and the six camera heads. The electronics are designed around an intellectual property (IP) microcontroller core (8051 architecture) that is imbedded in a 54S x 72 FPGA. The microcontroller uses roughly 30% of the FPGA gate modules leaving significant programmable logic resources available to incorporate the remainder of the interface logic functions. **Fig. F-31** is a block diagram of the CIPS instrument interface electronics.

The intellectual property core used for the microcontroller design is the Mentor Graphics M8051Warp 8-Bit Microcontroller. The IP core is procured as a netlist module that is designed into the target FPGA. This core is a very high performance version of the common 8051 microcontroller. Performance optimization of the M8051 includes reduction of the number of clock cycles per machine cycle over the industry standard device. This results in a microcontroller that performs at an average rate significantly greater than 10 MIPS when clocked at 40 MHz. As an example, slow arithmetic operations (multiplies and divides) are performed at 5 MIPS while most other one and two byte arithmetic operations are performed at 20 MIPS.

Communications with the RS300 C&DH system are implemented via synchronous, serial (RS422 standard electrical signals) command and telemetry interfaces. The command interface can operate up to 1 Mbps while the telemetry interface operates up to 8 Mbps. Combined data rate for all six cameras, including housekeeping, peaks at 250 Kbps, and is therefore easily accommodated by the C&DH telemetry channel interface. The use of synchronous interfaces minimizes the hardware complexity in the Instrument Interface Electronics.

The Instrument Interface Electronics accepts commands, consisting of simple data taking, engineering and housekeeping configuration from the C&DH system. These commands are parsed by the microcontroller and sent to the appropriate subsystem including instrument electronics and any of the six camera heads.

Camera data is acquired as a stream of two byte parallel data from each camera. The data is transferred via direct memory access (DMA) into local buffer memory in the interface electronics prior to transmitting to the RS300 C&DH system. The telemetry transfers are initiated and synchronized by the instrument interface electronics.

The instrument interface electronics receive unregulated spacecraft +28V power that it filters, converts and distributes to the interface electronics and cameras. The CIPS instruments require 24 watts orbit average power with 46 watts needed during data taking. From a power perspective, there are three instrument operating modes; data taking at 46 watts peak, idle at 4 watts, and warm

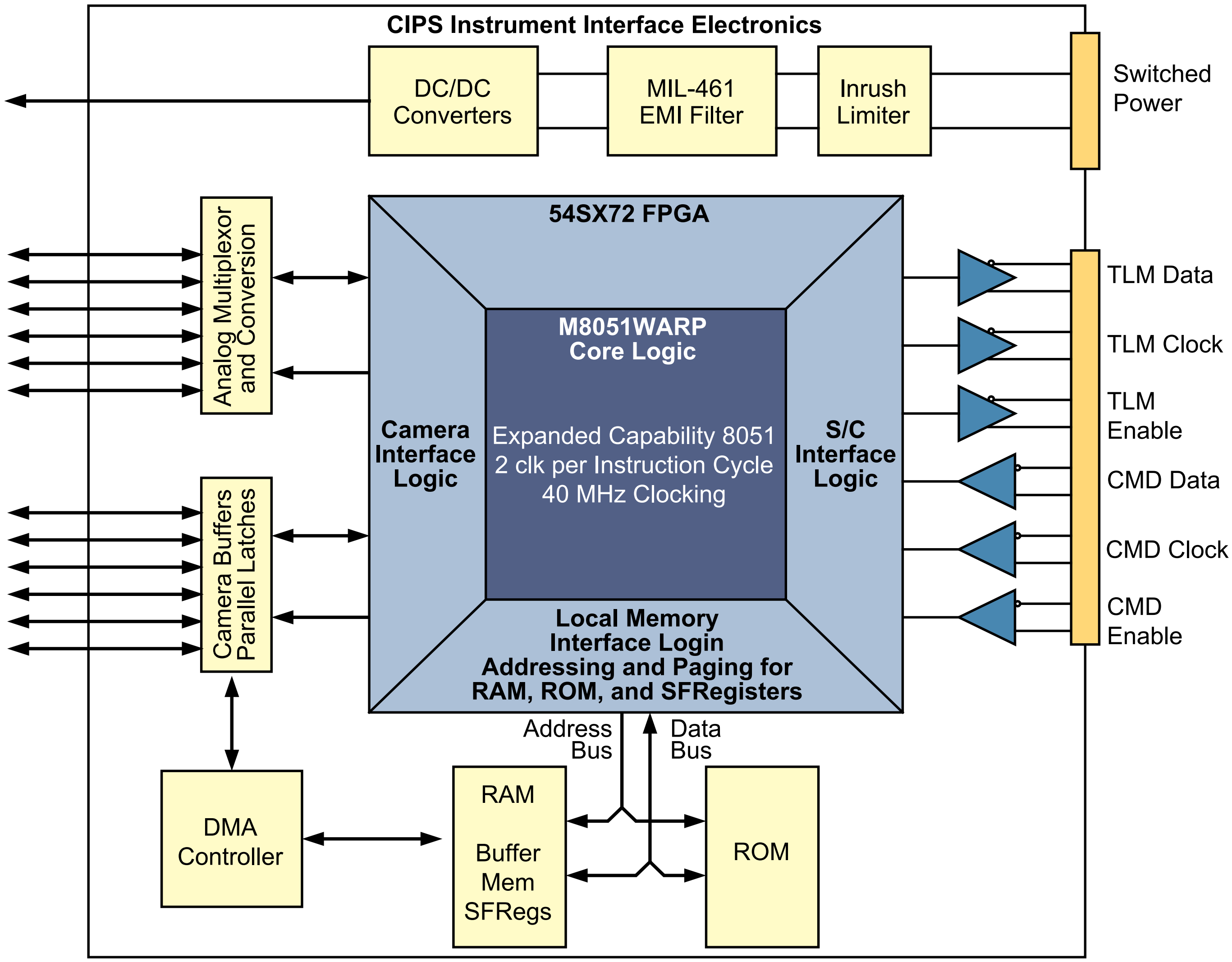


Figure F-31. CIPS Instrument Interface Electronics

Table F-25. Summary of CIPS Power Modes

Subsystem	Data Taking	Idle	Warm-up
Total for six Cameras	31.50	1.50	25.50
Total for Interface Logic	2.85	1.60	1.60
Total Interface Power (75%)	45.80	4.13	36.13
Orbit Average Power	**23.95**		

up at 36 watts. **Table F-25** summarizes the CIPS power modes and durations.

Calibration. Both component level and system level calibrations will be performed during CIPS qualification and test. Component level tests include stand-alone CCD performance. Measurements will include dark-field and dark noise as a function of temperature, pixel response nonuniformity, quantum efficiency, photon transfer, response linearity, and bad pixel and column identification. The intensifier will be characterized for quantum efficiency, luminous gain as a function of high voltage, decay time, and spatial response. Filter red transmission, band pass, and red leak (including a pinhole search) will be measured both at Barr Associates and at LASP. Once flight telescope and imaging optics have been fabricated, camera optical characterization will proceed. This includes setting telescope focus, measuring instrument function, verifying bandpass, and measuring flat field. Once fabrication of the flight electronics and mechanical structure is complete, final CCD camera characterization and testing can proceed. These measurements include dark-field and noise vs. temperature, photon transfer, bias and read noise, response linearity, and temperature control. After functional test and final integration of the instrument subsystems, final radiometric calibration will be performed. The measurements include absolute radiometric calibration, characterization of off-axis rejection, internal scattering, and out-of-band leakage. Alignment will be performed during IPA integration.

Qualification. CIPS will be functionally and environmentally tested and fully calibrated before delivery for IPA integration. The majority of the qualification activities will occur at LASP with vibration and EMI/EMC testing at BATC and BAC. Our approach is to thermal-vacuum cycle critical sub-assemblies. After the instrument is assembled we begin the formal instrument test and qualification cycle with a complete calibration. Initial calibration is followed by vibration testing and a subset of the calibration measurements, and then by thermal-vacuum qualification. A final complete calibration follows the thermal-vacuum test. The CIPS development schedule provides eight weeks for these activities. We expect that this will allow us to accumulate a minimum of 200 hours of operating time before delivery. Vibration levels and thermal-vacuum cycle requirements will be established by the AIM Project and will be incorporated in the CIPS Acceptance Test Plan (ATP).

During calibration and qualification we will routinely perform standard written functional test procedures (The CIPS Long Form Functional Test (LFFT) and the CIPS Short Form Functional Test (SFFT)) and keep a logbook to monitor the status of the instrument. We will track anomalies and problems by generating Problem Failure Reports (PFRs) within 24 hours of any incident.

Operations and Pointing. CIPS is body mounted and nadir pointed. It acquires a series of six full frame images using an exposure time of 0.24 seconds, which is matched to the required resolution of 2 km. Images are spaced 41 sec apart allowing the CIPS FOV to move 280 km along the spacecraft track. The spacecraft latitude at which an image sequence begins is seasonally dependent. For example, at solstice the initial sunlit latitude is 30 deg and the final latitude is 57 deg on the night side. On average, 34 images are produced per orbit. At least four, and as many as six exposures of the same cloud are made during a satellite overpass.

Requirements on boresighting with SHIMMER and SOFIE should be accurate to 1 deg Knowledge of CIPS alignment must exceed 0.1 deg.

Cleanliness and Contamination Control. CIPS will be assembled and tested at LASP in a minimum class 10,000 clean room. During spacecraft integration and test it will be maintained in class 100,000 conditions. Short periods of exposure to environments exceeding class 100,000 may be permitted. In order to minimize contamination by organic materials, all non-sealed SC components will be low outgassing, defined as materials that have less than 1% TML and less than 0.1% CVCM. At the integration and launch pad sites and in the launch vehicle fairing, CIPS will have red tag covers and be purged with dry nitrogen. Covers may be removed for integrated system test for short durations. Prior to fairing closeout the covers will be removed and a final cleaning of the area and the instrument will be performed.

***Radiometric Performance and Margin*. Fig. F-32** shows a simulated (1024 x 682 pixels) CIPS image, constructed from a ground-based photograph of an NLC (G. Witt, private communication). The grid represents the edges of the fields of view of the six separate cameras. There will actually be sufficient overlap between adjacent fields of view to be able to combine the images into a single "super image". There will be four to six sub-images of the same cloud, permitting the scattering phase function to be evaluated, after appropriate subtraction of the background scattering from the lower atmosphere.

The radiometric sensitivity (photoevents per integration period) of CIPS is the product of the input radiance, instrument etendue, filter bandpass, filter and lens transmission, and intensifier quantum efficiency: The noise in an integration

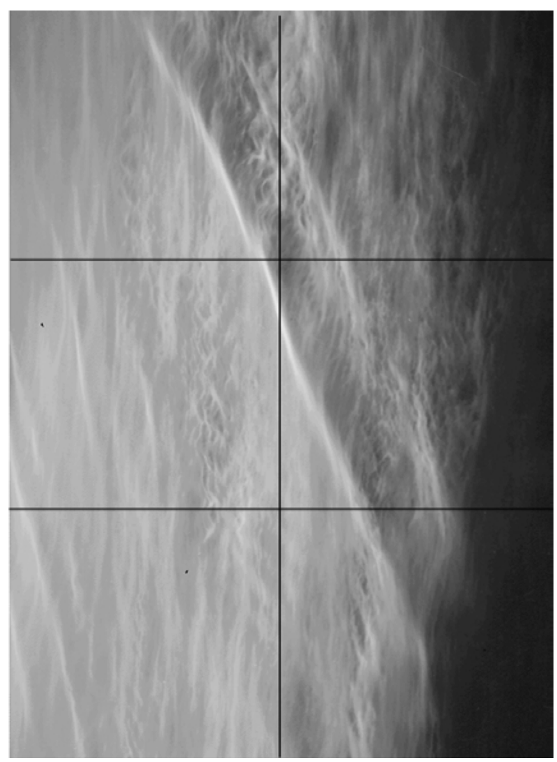


Figure F-32. Simulated CIPS Image

that produces N photoevents is square root (N) because each intensifier photoevent produces 600 electrons at the CCD, which is significantly greater than the CCD device noise (70 electrons per integration period).

Based on manufacturer measured data for existing lenses (transmission), filters (central transmission and bandpass function) intensifiers (quantum efficiency), the count rate for a single spatial pixel (67.5 μm square), C, for an albedo at 265 nm A, is given by C=2.35 x 10^7A. Typical values of A for the background of the sunlit Earth in the shadow-band are 1 x10^{-5} (see Fig. E-8), for which the signal and shot-noise for a single pixel are 235 and 15 counts respectively, yielding a measurement with a Signal-to-Noise Ratio (SNR) = 15. Integrating over a 13 x 13 km cloud element yields 40,000 counts and SNR = 200 (i.e., a .5% measurement). Our experience is that fully fabricated instruments may have sensitivities that are 25% lower than the values calculated from manufacturers data adding an additional 25% margin to this estimate (i.e., assuming that the sensitivity will be only 0.5 the value calculated from the manufacturing specifications) implies that the SNR for a single pixel will be reduced by 30%. Thus, we have achieved measuring the background in the shadow-band with a SNR resulting in SNR = 140 for a cloud element small compared with the volume sensed by the SOFIE and SHIMMER limb sensing experiments (~ 200 km x 30 km) with 50% margin.

Algorithm for Determining Ice Particle Size, Distribution, and Other Cloud Parameters. The CIPS Experiment on the AIM mission will image the same cloud element at multiple angles. Here, we describe a method for using multiple exposures of the same cloud element to determine the cloud phase function, and accurate constraints on the particle size distribution. Next, we describe a method whereby CIPS and SOFIE measurements may be combined to yield both the particle size, and the size distribution width, σ. The respective radiances yield the particle density, water-ice mass and particle area.

Given a measurement of the cloud radiance, E_1, the determination of r_m (the median radius of the ice particles), and the particle size distribution width parameter, σ, we can derive three microphysical quantities, the average ice particle number in a unit column, N (cm^{-2}); the average ice-water content in a column, (IWC) of the ice particles (in units of μg – m^{-2} or the equivalent number of water molecules-cm^{-2}); and the mean surface area of the ice particles in a column (cm^2 – cm^{-3}), A. In order to derive volumetric quantities, we need to divide the columnar quantities by the thickness h of the PMC. According to lidar measurements, h ≅ 1 km.

The ratio of the two separate cloud excess radiances at angles θ_1 and θ_2 is

$$E_1 / E_2 = p(\theta_1) / p(\theta_2) \quad (1)$$

where p the scattering phase function depends upon scattering angle θ, r_m, and σ. This is the basic equation for determining the relationship between the median particle radius, r_m and the width parameter σ. We now consider the relationship between r_m and σ by first defining the UV optical depth, which is a ratio of CIPS radiance (E) to the solar flux (F),

$$\tau(\Theta) = \frac{E}{F} = N\kappa_e(UV)\,p(\Theta)/(4\pi)$$

where κ_e is the extinction cross section and N is the ice particle column density. The SOFIE measurement of extinction optical depth in the IR is

$$\tau_e(IR, r_m, \sigma) = N\kappa_e(IR, r_m, \sigma)M$$

M is the equivalent number of air masses of ice particles along the line of sight. M will be determined accurately by integrating the spatially-resolved CIPS cloud radiance along the line of sight of SOFIE. The ratio of CIPS to SOFIE optical depths is

$$R = (\kappa_e(UV, r_m, \sigma)\,p(r_m, \sigma, \Theta)/(4\pi)) \, /(\kappa_e(IR, r_m, \sigma)M) \quad (2)$$

which is independent of N. The method consists of using the constraint, σ(r), determined from the CIPS measurements, to eliminate the dependence on σ in the Equation (2). We then have a unique relationship between R and r_m for a given scattering angle, θ. We calculated R, r_m, and σ through an inversion method using forward calculations based on (2). Figure F-33 demonstrates this approach for combining CIPS and SOFIE measurements to infer r_m.

Five values of R are shown for scattering angles 30, 45, 65, 90 and 120°. The relationship between σ and r_m is determined from the CIPS measurements (shown as data points *) and Mie scattering theory using Eqn. (1). Knowing this relationship from a measurement of two CIPS radiances, for example at 30 and 150°, we place σ(r_m) into Eqn.

(2) and obtain a function of the single variable, r_m. Figure F-33 shows five sets of curves of R as a function of r_m. The measurement errors are assumed to be 5% for the 30 degree measurement and 10% for the remaining angles. These errors combine to produce the error bands for each scattering angle in **Figure F-33**. *Each measurement of R provides an independent determination of r_m*. The slopes of the R-curves determine the sensitivity to particle radius.

Figure F-34 shows R vs r_m for the 90° curve and includes an estimated error (shaded area) on R of 10% to illustrate the corresponding error on the determination of r_m from this single measurement set. Given r_m, σ may be determined from **Figure F-35**. The relationship between σ and r_m (solid line) is calculated from Mie theory and from the measured CIPS radiances (30 and 150°). Errors in the determination of σ follow directly from errors in r_m. For an estimated error of 10% in R, r_m and σ are determined to an accuracy of ~22% and 9% respectively (see error bands in Figure F-35). Three other sets of angles are available from the sequence of six CIPS images (the 30° and 45° cases are not useful because of their flat character).

This analysis may be repeated, and the quantities r_m and σ may be determined to higher accuracy. *In this exercise, the resultant errors in r_m and σ are 18% and 8% respectively*. These errors can be reduced further by summing together more pixels (i.e., averaging over a larger cloud area). The water ice particle number density and the ice content follow immediately from the determination of r_m and σ. We can further reduce the errors by requiring that the SHIMMER PMC scattered radiance be consistent with the CIPS-SOFIE determination of cloud optical properties and Mie theory. In conclusion, this approach, using the coordinated measurements on AIM, will provide an unprecedented accuracy for determination of PMC properties.

Data Management. CIPS will collect 270 Mbytes of data/day (18 Mbytes per orbit for 15 orbits per day), which translates to approximately 180 Gbytes of data during the 22 months of normal mission operations. The data will be managed at LASP. A CIPS image is defined as a combination of the six individual "sub" images. Each sub-image consists of 1024 x 1024 pixels that will be electronically binned on orbit to yield an effective image size of 241 x 341 pixels (2 x 2 km) at 12-bit resolution. On-board 50% compression results in 87 Kbyte sub-images, for a total CIPS image size of 523 Kbytes. At 34 images per

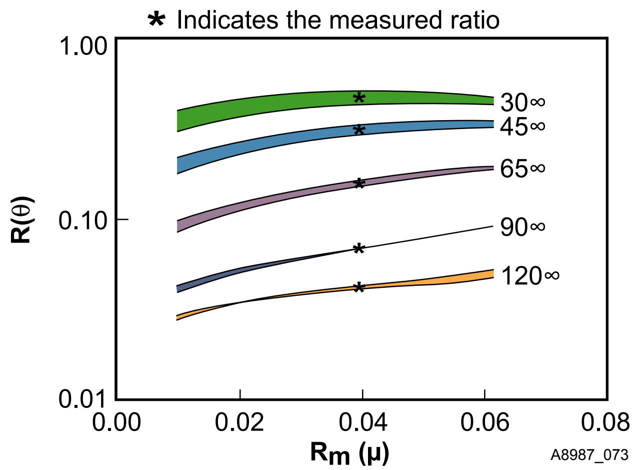


Figure F-33. R as a Function of r_m for Several Scattering Angles

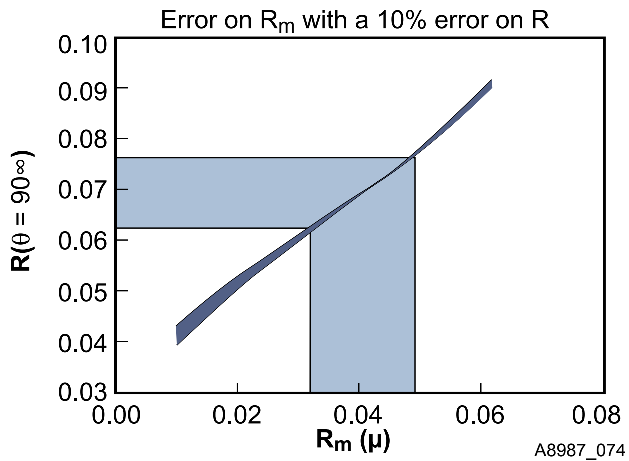


Figure F-34. R as a Function of r_m for a Scattering Angle of 90 deg

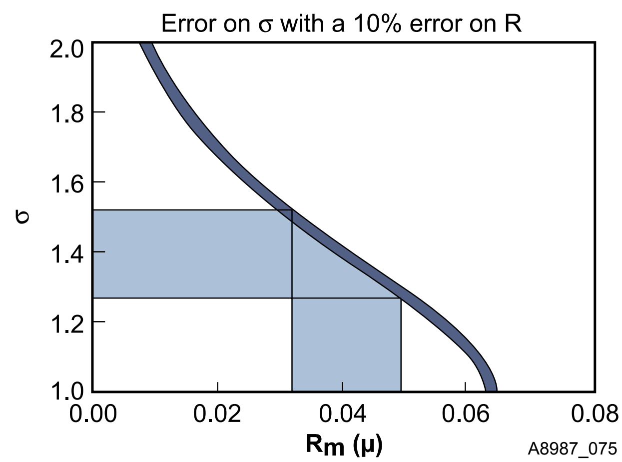


Figure F-35. Sigma vs r_m Showing the Error on Sigma as a Result of the error on r_m.

orbit, one orbit of CIPS data will comprise 18 Mbytes. All sub-images will be stored on-line individually. Each 2 x 2 km pixel will be tagged by its time, latitude, and longitude, overlapping segments at the edges of the sub-pixels will be removed, and the sub-images will be combined to form a CIPS image. Rayleigh scattering will be removed from these images to isolate PMC signatures. After identifying repetitive images of the same cloud, the scattering phase function, intensity and geographical extent will be defined from the sequence of measurements. The emphasis on cloud analysis will be weighted to the shadow-band region, but all clouds observed in 4 or more images will be analyzed for their particle properties. Cloud morphology will comprise the largest data requirement. It is expected that the amount of data required for this task will be reduced by more than a factor of 100 from the original images.

F4.4 CDE

The science goal of CDE is to monitor the flux of dust particles entering the atmosphere allowing for cross-correlation studies between the dust deposition rate and PMC brightness/frequency. CDE will measure dust impacts using a Polyvinylidene Fluoride (PVDF) film. This is a simple yet powerful approach with a high degree of heritage on Vega 1 and 2, Cassini, Stardust and Argos. PVDF sensors require no bias voltage. They are simple, inexpensive, reliable, electrically and thermally stable, mechanically rugged, radiation resistant, and not responsive to energetic ions or electrons.

Changes In The CDE Design Made During The Phase A Study. The proposed concept for CDE was a time of flight system to provide both mass and velocity measurements for cosmic dust particles. The motivation for the velocity measurement was to discriminate between orbital debris (with impact speeds (< 10 km/sec) and cosmic dust (with impact speeds > 10 km/sec). However, we have determined that lowering the mass threshold for impacting dust will provide greater science return than retaining the time-of-flight system. The latter has difficulties with low-mass thresholds because an incoming particle must penetrate the front film and still reach the back film to achieve a time-of-flight measurement. The problem of the latter discrimination against orbital debris will be largely eliminated by the use of the spacecraft structure as a "bumper" that will eliminate particles in a circular orbit, which constitute the bulk of the orbital debris. Lowering the mass threshold will allow us to measure weekly (perhaps daily) variations in cosmic dust influx. Similarly, larger detector surface area is desired. In the latest CDE design we use nine single layered PVDF segments.

At the small expense of giving up the TOF system, we have: 1) greatly reduced mass detection threshold (from a few microns, 10^{-9} g to sub-micron radius, few x 10^{-12} g, particles; the exact value will be determined in Phase B) depending upon the final noise level in our electronics; 2) doubled the surface collector area; and 3) gained highly reduced weight, power, and complexity, and thus reduced risk.

CDE Technical Description. The CDE is divided into three sections: the detector, the front end analog electronics, and the digital interface electronics. Each of these is described below.

Detector. The CDE detection principle is based on the depolarization signal a dust particle generates by penetrating a permanently polarized thin PVDF film (Simpson and Tuzzolino, 1985; Tuzzolino, 1992) Dust grains penetrating the thin film remove dipoles along their trajectory producing a fast electric charge pulse without requiring bias voltages. The produced signal is a function of particle mass and velocity. The physical construction of the detector is shown below. The PVDF film is mounted on a G4 board with a conductive adhesive connecting the positive electrode of the film to the top copper carrier. The second electrode is connected to the opposite copper carrier and ultimately to an electrical ground, **Fig. F-36.** The detector has an active area of 91.6 cm^2 and a capacitance of 34.8nf. A suite of nine detectors provides us a total area of 824.5 cm^2. The detector suite will be mounted on an aluminum back plate, **Fig. F-37.** Overall volume of the CDE will be 4800 cm^3 not including the volume encompassed by the structure that the CDE rests upon). Initial thermal analysis shows that this configuration has better heat dissipation

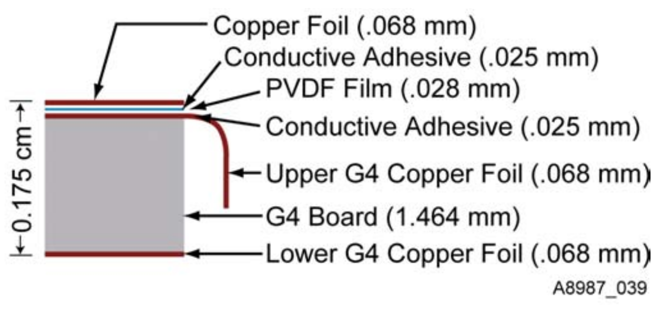


Figure F-36. CDE Elements

characteristics than PVDF detectors used previously. The PVDF film is available from Measurement Specialties.

Front End Analog Electronics. The front-end electronics consist of an analog preamplifier and a shaping circuit. Each detector requires its own preamplifier and shaping circuit that will be located directly below the detector. The preamplifier is charge sensitive (AMP TEK A250) with the ability to use an external field effect transistor (FET). An external FET allows us to match detector capacitance with the FET thereby optimizing the A250 for use with our detector. The dual channel IF3602 manufactured by InterFET Corporation will serve as the external FET. The A250 was developed for aerospace, nuclear physics, nuclear monitoring, particle, gamma, and x-ray imaging.

The shaping circuit is a band-pass circuit with corner frequency set to the point where the noise in the circuit is at a minimum. This can be represented by $\tau_{shaper} = E_n * C_{Detector} / I_n$. A four stage nonlinear shaping circuit is used to allow the detection of more divisions for smaller particles than larger ones. After signal shaping, the pulse height detector (AMP TEK PH300) will hold the signal and alert the digital interface. The PH300 was developed for Aerospace, nuclear monitoring, particle, gamma, and x-ray imaging.

Digital Interface Electronics. The digital interface electronics provide the interface between the spacecraft C&DH system and the CDE. Each of the nine analog signals from the peak hold detectors are digitized and sent to the 54SX FPGA. The FPGA records event time, patch location, and signal amplitude. The 54SX signals the spacecraft computer and forwards the data over an RS422 interface. The majority of FPGA logic designs have significant heritage on two previous programs, Cassini and EOS Source. In both of these cases, data were integrated and binned in a similar manner to the dust detector data.

Software. There are no software requirements for the CDE. All its functionality is contained in the FPGA.

Operations. CDE is designed to monitor dust influx at all times and thus CDE does not require commands beyond on and off. (See **Fig. F-38**).

Calibration. PVDF dust detectors have been extensively tested and calibrated in laboratory experiments (Simpson et al. 1989b) at the Munich and Heidelberg dust accelerators. The available calibration data for 28μm PVDF films are available from A. J. Tuzzolino (1996). PVDF films can also be tested using short duration (<μs) laser pulses (λ=337nm). During the Phase A study period, we were able to perform preliminary testing on the 28 μm PVDF film to verify the performance and correct operation of electronics and characterize the overall noise of detector and electronics. During Phase B, we will mount a single patch of the detector on a prototype structure identical to the spacecraft where CDE will be located, using the same methodology employed for flight. This will be taken to the Heidelberg (MPI-Kernphysik, Germany) dust accelerator for final testing and calibration. In Heidelberg the calibration will be preformed using both dust impacts and laser pulses. Cross calibrating using both methods enables us to test and calibrate the compliment of flight detectors at LASP with laser

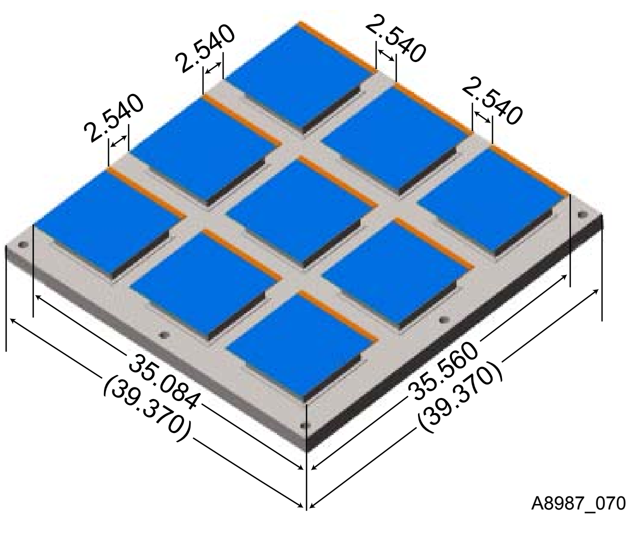


Figure F-37. CDE Layout

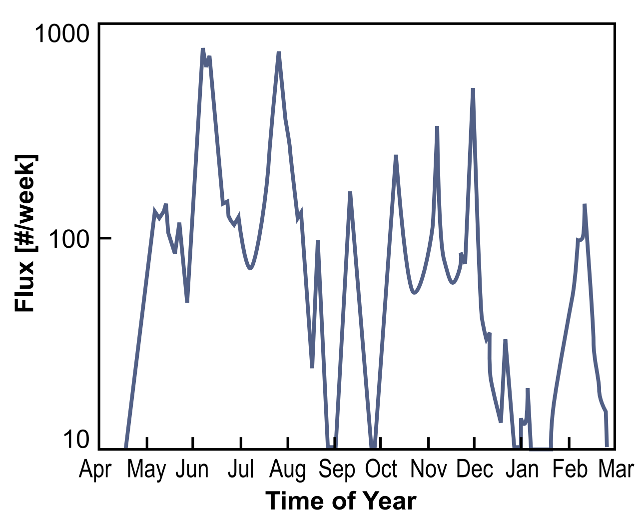


Figure F-38. CDE Predicted Fluxes

pulses only.

Pointing. CDE will point in the zenith direction at all times. There are no pointing accuracy constraints; only knowledge is required.

Cleanliness. Fabrication of the detector will require a minimum class 100,000 environment. Short periods of exposure to environments exceeding class 100,000 may be permitted for testing and calibration.

Data Analysis. Raw data is comprised of three pieces of information: 1) time of event, 2) patch ID, and 3) signal amplitude. This information combined with calibration data will be used to establish the temporal and spatial variability of the dust influx. The patch ID will be used to verify that each and all of the patches are working and show similar impact statistics.

Performance Margin. The minimum science requirement is to measure on average 100 impacts per week, so that a 10% variation of dust influx can be noticed. Based on existing measurements and theoretical models, this translates into a minimum measurement requirement of having a mass threshold of ~1×10^{-11}g for the given maximum available area of ~900 cm^2. We estimate the mass threshold of the current design to be at least a factor of two below the minimum measurement requirement. This is achieved by using smaller segments of PVDF detectors and minimizing the electric noise in the front-end electronics. Because the fluxes of these small grains have never been measured, it is difficult to predict the gain in impact rates. However it is clear that CDE comfortably exceeds all of the AIM minimum science requirements.

F.4.5 Instrument Platform Assembly

The IPA consists of a base, two vertical gussets, a backplate and top. It is shown in Fig. 2, FO-F2 and in **Fig. F-39**. All these are made of aluminum honeycomb. Radiators are attached to the base, and serve as the primary thermal control path. The exact configuration of the radiators will be tailored to meet the thermal requirements of the instruments and platform assembly. The platform interfaces to the spacecraft through eight titanium flexures.

The mass estimate for the platform components and the instruments is shown in **Table F-26**. Preliminary analysis shows that the inertial axes adjustment can be accomplished by adjusting component locations, and strategically lightweighting structure as necessary.

Finite Element Model. An initial Modal analysis has been performed assuming fixed constraints at the spacecraft/platform interface. See **Table F-27**. The results have conservatively been de-rated by 30% to account for anticipated joint losses in a finalized design. The model details and

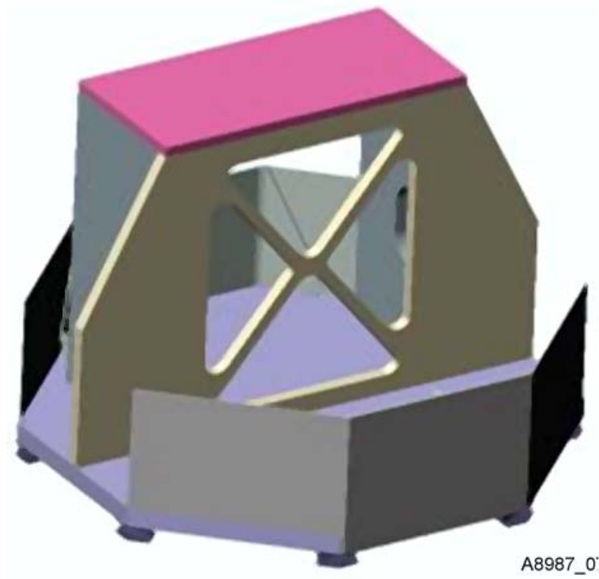


Figure F-39. Instrument Platform Assembly

Table F-26 Instrument Platform CBE Mass and Power

Instrument Platform	Mass (Kg)	Power (W)
Interface Plate	9.1	0
Interface Plate Flexures	1.3	0
Vertical Plate	6.5	0
Gussets	5.5	0
Interface Connector Bracket	0.2	0
Top Plate	3.0	0
Harness and Heaters	2.0	10
Misc. Fasteners and Hardware	1.5	0
MLI	1.0	0
MLI Attachment Hardware	0.5	0
Balance Weights	0.5	0
Tracker Mount	0.5	0
Instruments		
SOFIE	40.0	40.1
SOFIE Heat Pipe and Radiator	2.0	0
CIPS	11.3	24.0
Startracker (Carried in S/C Est)	0.0	0
CDE	1.3	2.5
CDE Support Posts	0.3	0
SHIMMER	12.2	0
SHIMMER Electronics	10.0	22.1
SHIMMER Heat Pipe and Radiator	2.0	0
Total (kg)	**110.6**	**98.7**

mass assumption at the time of analysis are shown, along with greatly exaggerated mode shapes one, two and three. The smooth transition mesh is also shown.

Thermal Model Description. A simplified thermal model was constructed of the spacecraft. Using a nominal environment (Earth I.R., Albedo, Solar Flux at 500 km), beta 0, and arrays pointed at sun (180 degree yaw near subsolar point)—a study of radiator size was performed. Initial thermal analyses indicate that the temperature of the spacecraft can be maintained using a band of radiators around the platform periphery. See **Figs. F-40, F-41**, and **F-42**.

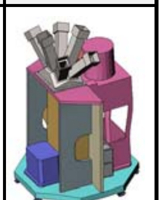
Electrical Interface. An electrical interface diagram for the IPA is shown in **Fig. F-43**.

F.5. Payload Integration

Instruments will be delivered to LASP for integration to the IPA structure. Final assembly will include attachment of the instruments, final cabling and harnessing, installation of heaters, mounting of radiators and other supporting structures, and prefit of the thermal blankets. During harness connections, safe to mate testing will be performed.

Once the instruments are integrated, a final set of functional tests will be performed to assure operational and functional compatibility. Initial testing will be done using instrument GSE. Eventually the AIM mission operations system will be introduced, and the instruments will be operated using a spacecraft simulator to validate the performance at the IPA level. The first set of tests will be run at room temperature. Upon successful completion of these tests the assembled IPA will be put into thermal vacuum testing to assure operation at environmental limits.

Table F-27 IPA Modal Analysis Summary

	Mode # 1	Mode # 2	Mode # 3
Initial modal survey	107 Hz	172 Hz	190 Hz
Estimated flight modes (70%)	75 Hz	130 Hz	143 Hz
Mode shape/ direction	Cantilever Y-Z Plane	Cantilever X-Y Plane	Torsion Z-X Plane
			

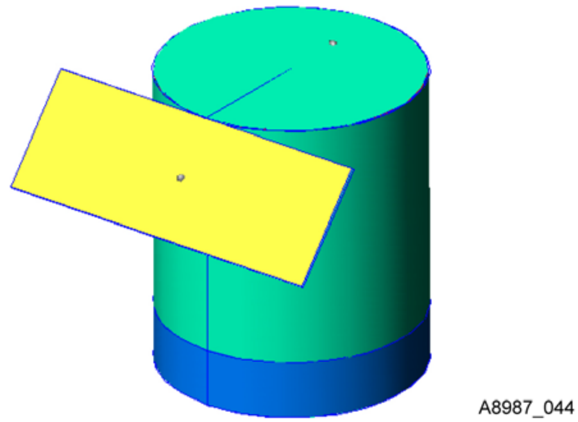


Figure F-40. AIM Reduce Node Thermal Model on Spacecraft

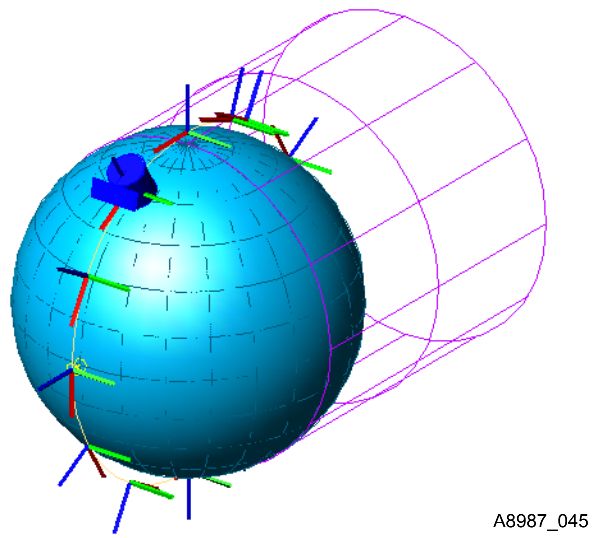


Figure F-41. Thermal Model of Spacecraft in Orbit

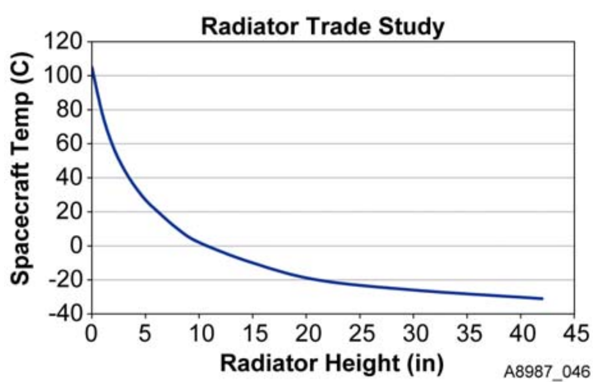


Figure F-42. Radiator Trade Study

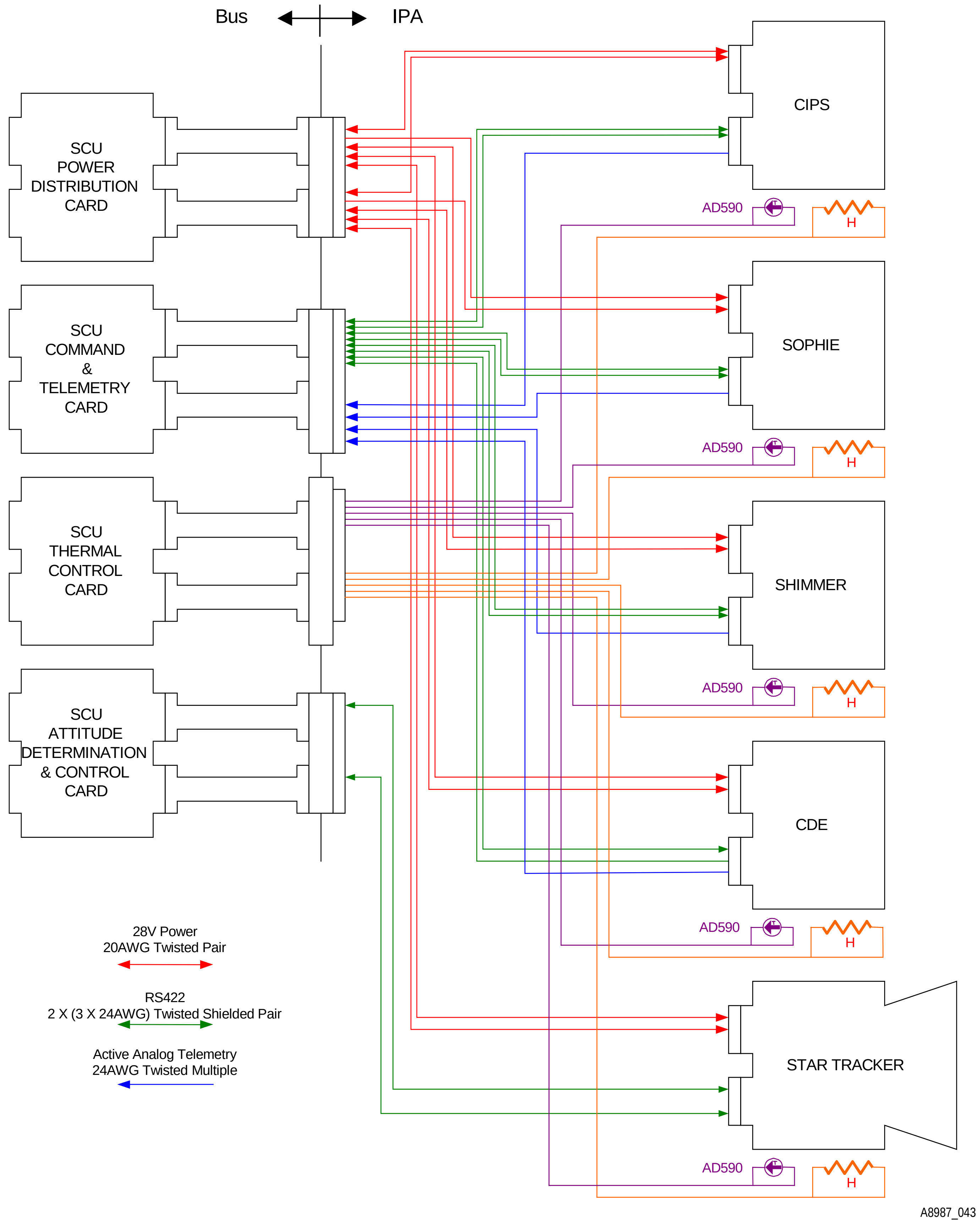


Figure F-43. AIM Spacecraft to Instrument Electrical Interface

Functional tests will be performed, using OASIS-CC and automated procedures, after each environmental test to reduce risk and help pinpoint the cause of any test failures or anomalies.

Integrated system testing is run with controlled automated procedures providing functional baselines that allow performance tracking throughout system testing up through launch operations. Thermal blankets will be installed prior to thermal vacuum testing. See **Fig. F-44 on FO-F4**.

F.6. Manufacturing, Integration and Test

Manufacturing of all components will take place at each of the team locations for their respective part of the project. Instrument, IPA bench, spacecraft and the AIM observatory integration and test will be modeled after SME and SNOE using established facilities. Each of the instruments will be assembled at the PI institution. Full testing will be performed in their facilities. The instruments will be integrated to the IPA at LASP, where full testing will take place with mission operations in the loop. Final integration of the IPA with the spacecraft will be done in a class 100,000 clean room located at BATC. The AIM Spacecraft I&T Manager or his designee(s) will plan, direct and oversee these efforts, ensuring that the latest test procedures are used. A MI&T schedule is included in Section G.

Instrument Level Testing. Instrument level testing will occur at the component, subsystem and full instrument level. A comprehensive protoflight test program will be used to ensure that each instrument meets its performance requirements over the expected environmental conditions. The generic planned test flow for each of the instrument is shown in on FO4. Ultimately, environmental testing, including voltage/temperature thermal, thermal vacuum and vibration, will be performed to assure that the spacecraft and instruments meet the functional requirements. On a limited basis, EMI/EMC testing will be performed to assure self-compatibility between instrument and spacecraft subsystems.

Spacecraft Bus Level Testing. The spacecraft bus will be integrated as shown in **Fig. F-45** and each of the subsystems will be checked out and tested according to the following flow. Specific testing of spacecraft subsystems and functional checkout of the system with mission operations in the loop will be accomplished at this level.

System Testing. Following a successful completion of the instrument bench tests, the bench assembly will be delivered to BATC for integration to the spacecraft. The primary set of tests include functional tests, alignments, special performance tests, orbit simulations and integrated system testing. Following is a discussion of these tests.

Functional Test. The functional test is a fully automated command/response test using only external stimuli and OASIS-CC running CSTOL test scripts. The scripts are run using a SPARC workstation automatically stepping through the procedure, verifying limits and providing breakpoints for out of limit conditions. All spacecraft subsystem and instrument commands are sent and verified via telemetry.

Integrated Systems Test. The integrated systems test is the complete suite of tests performed prior to environmental testing to establish a baseline and after all environmental tests for comparison against the established baseline. This test is also performed at the launch site.

Alignment Tests. After initial alignment of the star tracker, magnetometer, and instruments, the alignment tests verify that the alignments have not shifted out of tolerance following any of the environmental testing.

Special Performance Tests. Due to the extra time and specialized equipment required, the special performance tests are run less frequently. These tests include battery capacity, receiver sensitivity, transmitter output characteristics (power and frequency), RF compatibility with NASA ground stations, solar panel output and special instrument testing.

Plugs Out Test. All Electronic GSE (EGSE) is disconnected and communications are accomplished solely through RF transmission and reception.

Environmental Tests. The planned environmental tests for AIM include limited EMI/EMC

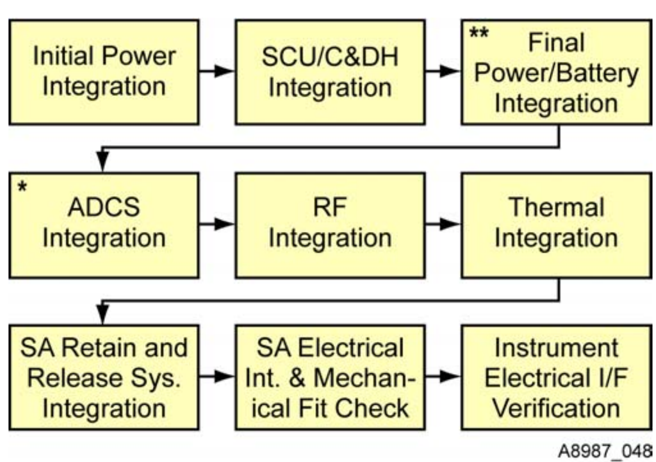


Figure F-45. Spacecraft Test Flow

Foldout F-4

F.7. Mission Operations, Ground and Data System

The AIM ground system is divided into two parts: mission operations and science payload operations and data processing. The key mission operations components are:

- Ground Stations (GS)—The Honeywell Datalynx PF1 11-m antenna at Poker Flat Alaska and the Kongsberg 11-m SKS antenna in Svalbard, Norway are used for space-to-ground communications.
- Mission Operations Center (MOC) at LASP controls the spacecraft and receives and processes telemetry data.
- White Sands Scheduling Office (WSO) at NASA's White Sands Complex schedules ground station contacts.
- Flight Dynamics Facility (FDF) at GSFC provides orbit determination during launch and early orbit operations.

These same components are currently used to operate the QuikSCAT satellite. AIM leverages this heritage to provide a low risk, low cost approach to mission operations.

The payload operations and data processing components are developed by and co-located with the instrument teams and the PI:

- Payload Operations Centers-Data Processing Centers (POC-DPC) monitor instrument health, generate non-routine command sequences, and perform science data processing.
- Project Data Center (PDC) catalogs the project's science data, produces integrated science products, and provides information to the public.

Space-to-Ground Communications. AIM typically downlinks 2.73 Gb per day at 4 Mb/s, which requires 12.5 minutes of link time. GS contacts are typically 8.5-10 minutes, so two contacts per day are scheduled for routine operations. Outside the PMC season, only one contact per day will be required.

Data are downlinked in Consultative Committee for Space Data Systems (CCSDS) frames with Reed-Solomon (R-S) encoding applied. The spacecraft's 5-watt transmitter and the 11-m GS antennas yield a 10^{-7} bit error rate. Three virtual channels are used:

- Real time health and status at 16 kb/s
- Playback health and status
- Playback science data

Only the first of these data streams is sent to the MOC in real-time. Playback frames are collected at the GS and transferred (minus the R-S check bits) to the MOC post pass. This transfer averages 167 Mbytes per pass. Playback data are required to reach the MOC within two hours of the end of a pass, which means that the average data rate on the link between the GS and the MOC must be at least 210 kb/s, which can easily be achieved with the lines currently in place.

Commanding of AIM uses a NASA standard uplink at 2000 b/s. 11-m antennas transmitting at 200 W power give a 10^{-6} bit error rate before error correction. Commands are in CCSDS format. The bulk of the uplink contains stored commands for the science instruments, along with the attitude quaternions that specify the pointing of the spacecraft for science observations. This requires about 60,000 bytes of command data per day, which requires about four minutes of uplink time. During routine operations commanding is done on only one of the two daily GS contacts.

S-band frequency allocation for the AIM mission will be coordinated through the Radio Frequency Management office at GSFC.

Ground Data System. A diagram of the AIM Ground System is shown in **Fig. F-46**. The PF1 station will be the primary GS for AIM, with the SKS station as backup. Both stations can contact AIM on almost every orbit.

The MOC is connected to the GS control facilities (in Columbia, MD for PF1 and Tromso Norway for SKS) via NASA's Internet Protocol Operations Network (IONet). These links are already in place and are used on QuikSCAT and other missions. The WSO will be used for ground station scheduling, which is the same as for SNOE and QuikSCAT. The FDF will process launch data and will be used for two weeks after launch to process tracking data and provide ephemeris information to the ground stations and the MOC. Thereafter tracking data from the GS will be provided directly to the MOC and processed by the MOC to determine AIM's orbit. **Table F-28** shows the entire data value transferred per day for AIM and including the tracking data.

The AIM MOC will be located within LASP's existing multi-mission satellite operations facility (see **Fig. F-47**) and will use hardware, software, procedures, and personnel that are already in place to operate the SNOE, QuikSCAT, ICESat, and SORCE satellites. The LASP facility, the information systems within it, and the flight team personnel meet the same stringent security standards that apply to NASA's own satellite operations centers at GSFC and the Jet Propulsion Laboratory. (Documentation on LASP security—including Risk Assessment, Security Plan, and

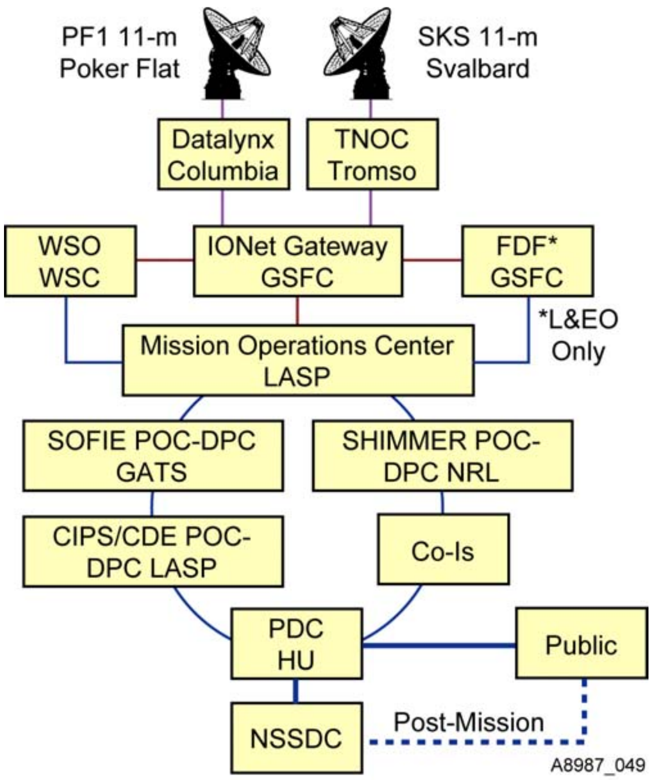


Figure F-46. AIM Ground System Elements and Data Flows

Table F-28. AIM Data Volume

Data Type	From	To	Volume	Network
R/ T Command	MOC	GS	0.012	IONet
R/T Telemetry	GS	MOC	2.4	IONet
PBK Telemetry	GS	MOC	375	IONet
Tracking Data	GS	FDF	0.15	IONet
Ephemerides	FDF	GS	0.001	IONet
Ephemerides	FDF	MOC	0.001	Internet
Schedules	WSO	GS	0.001	IONet
Sched Requests	MOC	WSO	0.001	Internet
Level 0 Data	MOC	DPC	350	Internet
Cmd Requests	POC	MOC	0.002	Internet
Level 1 Data	MOC	CO-Is	1000	Internet
Outreach	PDC	Public	1	Internet
Documentation	PDC	All	0.1	Internet
Data Catalog	PDC	All	0.1	Internet

Volume is in Mbytes per day

Rules of Behavior—will be made available for review during the site visit).

The operations team for AIM is made of up LASP professionals and students. There are currently 11 professional and 19 student members of the LASP flight team spread across several missions. Students undergo an extensive summer-long training program before becoming members

Figure F-47. LASP Operations Center

of the team. Once certified, they are involved in all aspects of operations, including planning, scheduling, real-time contacts, data processing, attitude and orbit analysis, and engineering data analysis. LASP will appoint a Mission Operations Manager (MOM) to head the flight team for AIM. The MOM oversees preparation of the MOC to support the AIM mission, pre-launch tests and rehearsals, operations during launch and early orbit, and routine operations. The MOM reports to the project manager during the development phases and directly to the PI during Phase E.

The software used in the MOC for the AIM mission will be the same as for QuikSCAT, ICE-Sat, SNOE, and SORCE. This includes the Oasis-Command and Control (OASIS-CC) software for real-time monitor and control; the Oasis-Planning and Scheduling (OASIS-PS) software for planning, scheduling, and command sequence generation; commercial Satellite Tool Kit and MicroCosm software for orbit prediction and determination; and other existing LASP-built software packages for data processing, data management, and spacecraft engineering data analysis. Only about 10 work-months of effort and 2500 lines of new code are required to tailor this software suite for use on AIM. The OASIS-CC software will also be used for instrument level and spacecraft level integration and testing. This means that operations software, databases, procedures, and displays will all have been used extensively on the ground prior to launch and the entire mission team will be familiar with them prior to on-orbit operations, which greatly reduces risk.

Project Operations and Control Center (POCC)/MOC Communications. The MOC monitors the status of AIM's science instruments but detailed analysis of instrument performance, along with the generation of non-routine instrument command sequences and the processing of instrument science data, is performed at the three POC-DPCs. All CIPS and CDE downlinked science data is sent from the MOC to the POC-DPC at LASP over a local area network. The MOC transmits the SOFIE and SHIMMER downlinked science data to the two remote POC-DPCs over dedicated data lines. At a data rate of 256 kb/s, it takes less than two hours to transfer a typical day's worth of downlink science data. The POC-DPCs communicate with the PDC and with the co-investigators over existing Internet paths. Staffing at POC-DPCs is small, with 20-30 hours per week of effort needed at each site for command request generation and data processing.

Mission Operations Plan. **Fig. F-48** below depicts the initial weeks of the AIM mission, showing the steps through which the mission must progress to achieve routine operations. The number of GS contacts needed for each step are indicated by the width of the bar. For the first three days after launch, all GS contacts over eight minutes in duration are used. Thereafter, the number of passes is rapidly reduced, reaching two contacts per day during routine operations. The plans for spacecraft commissioning will be based upon LASP's experience with the BCP-2000.

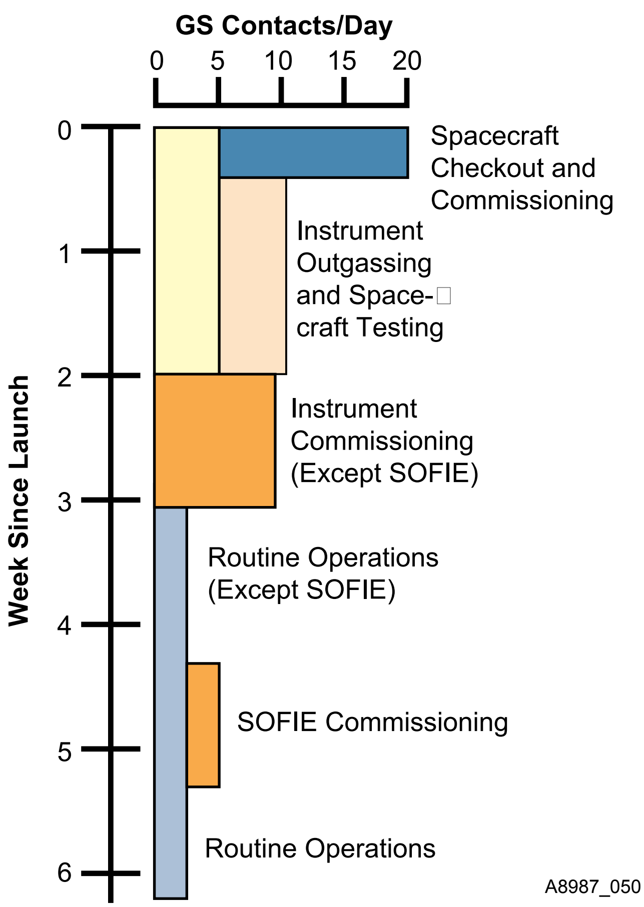


Figure F-48. AIM Operations Timeline

During spacecraft commissioning the MOC is staffed around the clock. During instrument commissioning there are two shifts per day. During routine operations, flight team personnel are typically on site for the prime shift only. All command passes are staffed by professional and student flight team members. Downlink-only passes need not be attended—software automation that is already in use for QuikSCAT and other missions will be used for AIM to monitor the contacts and immediately alert flight team members by pager if a problem arises.

Mission planning and scheduling are done on weekly intervals. GS schedule requests are prepared in the MOC and transferred to the WSO, which returns confirmed schedules to the MOC. The MOC generates a schedule of spacecraft activities, plans the nominal science observations, and generates attitude quaternions needed to make the observations. This process is very similar to the scheduling process for ICESat and SORCE. The instrument teams, through their POC-DPCs, generate non-routine instrument command or spacecraft maneuver requests and transfer them to the MOC for incorporation into the spacecraft schedule. From the integrated schedule, the MOC generates a command sequence every day for uploading to the spacecraft.

The MOC processes the raw telemetry data from the spacecraft and generates a Level 0 database of packets separated by source and arranged in time order, with duplicates removed and bad packets replaced with good ones where possible. Spacecraft housekeeping data are archived at the MOC and analyzed by the flight team. Packets containing instrument housekeeping and science data are sent to the appropriate POC-DPC for Level 1 and higher data processing by the investigator teams.

LASP has submitted a Project Service Level Agreement (PSLA) to NASA's Space Operations Management Office (SOMO) to initiate a trade study on the use of SOMO-provided services versus any proposed alternatives. LASP will continue to track the results of this study, with the results anticipated no later than the start of Phase B.

F.8. Facilities

The AIM team possesses all of the required facilities to develop, manufacture, and operate the AIM instruments and spacecraft. Each of the institutes contributing flight hardware have at least 40 years experience in developing space flight hardware. There are no new facilities required for

AIM. Further information and pictures of existing facilities can be found in Appendix M2.

No new GSE are required for AIM. The PDC at HU will be new to HU but will based upon designs and experience at GATS. Only the computers (Sun workstations) will be new purchases.

F.9 Product Assurance, Mission Assurance, and Safety

The PI will delegate planning and implementation of the Safety, Reliability of Quality Assurance (SR&QA) plan to LASP. LASP will maintain, oversee and direct an effective, focused SR&QA program for the SMEX/AIM Project that will include oversight of all subcontracts and suppliers. This program will provide the necessary traceability and record keeping. The SR&QA plan will be detailed in the AIM Performance Assurance and Implementation Plan (PAIP). The AIM PAIP will be patterned after the LASP SORCE project PAIP that has been reviewed and approved by NASA/GSFC. The predominant assurance objective is that AIM will operate in a safe and environmentally sound manner, and will meet the science objectives and corresponding measurement requirements specified in the science requirements document and traceability matrix.

In meeting the financial and performance goals of the AIM project, it is planned to embrace the techniques, methods and controls already in place at each of the participating organizations. The SR&QA plan will draw from each of the teams current plans, and only in the case of identified deficiencies will new requirements be developed and applied. AIM will use the established practices and procedures of LASP, BATC, SDL, GATS and NRL where possible. Each of the team members has institutional performance assurance standards and oversight organizations in place, and each of the organizations has proven performance capability in spacecraft and spacecraft hardware development.

AIM SR&QA Manager. The AIM Performance Assurance Manager at LASP will ensure that Performance Assurance requirements are determined and satisfied throughout all phases of the project, and that those requirements are continuously maintained during trade studies, risk assessment, flight system design, procurement, fabrication, assembly, calibration and test, shipment, launch vehicle integration and launch. The plan will also apply to deliverable GSE, ground checkout and flight software, sponsor-furnished property (SFP), and spares.

NIAT Report. We have studied the NASA Integrated Action Team (NIAT) recommendations extensively and are implementing the recommendations toward AIM. NIAT embraces these themes:

- Developing and Supporting Exceptional People and Teams
- Delivering Advanced Technology
- Understanding and Controlling Risk
- Ensuring Formulation Rigor
- Implementation Discipline
- Improving Communication

In examining these themes we have determined that the key elements that apply to AIM are contained in all 17 NIAT recommendedations.

To implement support toward these points, AIM will augment the project management plan in the following areas: a) 1) Red Team and peer review activities, b) Risk Assessment, and 3) Independent Verification and Validation. Additionally we will implement a number of the other recommendations detailed throughout the report.

Formal Review Team (Red Team) and Review Activities. AIM intends to hold a combination of peer and project level reviews to maximize visibility into designs and plans of the instrument and spacecraft systems and, if necessary, guide the direction of these efforts in the most economical, reliable and safe direction. These reviews will serve two purposes. First, they will provide for information transfer between the AIM Team and NASA in order that NASA can evaluate and apprise the AIM project. Second, these reviews will evaluate subsystem and system designs to assure their successful performance in meeting requirements under operating and environmental conditions during qualification testing and flight. The reviews will also be used to assess the quality assurance and verification plans, and to aid in the refinement of the I&T plans and mission operations.

Reviews. We anticipate that the Formal Review Team (Red Team) will be a combination of NASA/GSFC staff and independent reviewers who will remain with the project over its lifetime. In budgeting for these reviews we have allocated significant resources to two multi-day Red Team reviews with full project team participation at the CDR and FRR. We anticipate that the other formal reviews will involve a subset of the Red Team, with reduced participation on the part of the AIM teams. The resources allocated to this effort can be seen in Appendix M12.

While we understand the importance of the larger formal reviews, the AIM project is placing emphasis on the peer reviews. In our experience peer reviews enable the earliest visibility into the project elements, and leverage input over a longer period of time—maximizing the return on the invested review dollars and time. We would expect that Red Team representation would be present at these peer reviews.

Peer design reviews at the subsystem and system level will be held for the instruments and spacecraft for subsystem electronic circuit and packaging design, mechanical design, and ground system design. System level assessments will also be part of these reviews, as will risk assessment and tracking. Formal actions will be assigned and tracked on a project-wide tracking system to assure that issues are addressed, resolved and closed out. Software development will be reviewed in a similar fashion, with four reviews required of each team at specified stages of the software development.

Risk Management Methodology. The AIM project will implement a Continuous Risk Management methodology for all flight hardware, software, GSE and mission operations. The plan identifies an individual at LASP who will oversee and manage this activity for AIM. This individual will be supported by Risk Engineers in budgeted positions at each of the team institutions to lead risk management for their organization. NIAT funds will support this effort. Additionally funding has been allocated to acquire an independent assessment of the project through Failure Modes and Effects Analysis (FMEA), Probabilistic Risk Assessment (PRA) Fault Tree analysis and other processes as required. Further aspects of the risk program are detailed in the management plan (Section G.4). The resources allocated to this effort can be seen in Appendix M12.

Independent Validation and Verification (IV&V). The AIM project has performed a preliminary assessment of the software to be used in the project. Independent assessment of software will be undertaken during Phase B, at which time an IV&V plan will be fully defined. $700K is budgeted for this effort.

Product Assurance Plan. The Product Assurance Plan will cover product quality, parts selection, plans for resolving test anomalies, problem/failure reporting, inspections, quality control, parts selection and control, reliability, safety assurance, and software validation. The LASP documents from which the PAIP will be derived have been recently revised to meet the requirements of the NASA/SORCE program and meet the intent of ISO 9000 series, American National Standard, “Quality Systems - Model for Quality Assurance in Design, Development, Production, Installation, and Servicing,” ANSI/ASQC Q9001-1994.

Safety Plan. The AIM Safety Program will provide for hazard identification and control to personnel, facilities, support equipment and the flight system during all stages of the mission development, launch and operations. Included is a safety risk assessment for affected parts, processes and procedures on the program, including hazards in the flight hardware, software, GSE and support facilities.

The AIM safety program will meet the system safety requirements stated in the applicable launch range safety regulation for EWR 127-1, “Eastern and Western Range Safety Requirements”. AIM launches on a Pegasus from the WTR to obtain a sun-synchronous orbit.

AIM will submit, in accordance with an agreed to schedule, all ground operations procedures to be used at NASA integration facilities, or the launch site, for review and approval by NASA. All hazardous operations, as well as the procedures to control them, will be identified and highlighted. All launch site procedures will comply with the applicable launch site safety regulations.

Parts, Material and Processes Selection. An Electrical, Electronic, and Electromechanical (EEE) Parts Control Program will be implemented to assure that all parts selected for use in flight hardware meet mission objectives for quality and reliability. This program will facilitate the management, selection, standardization, and control of parts and associated documentation. The primary mechanism to accomplish this will be the Program Approved Parts List (PAPL). The PAPL will be developed and maintained to assure that only parts whose performance and reliability have been proven, or that have demonstrated acceptance for the application, are used. The foundation for the Parts Control Program will be GSFC 311-INST-001, “Instructions for EEE Parts Selection, Screening and Qualification.” For each EEE part that is a candidate for the PAPL, an appropriate parts quality level (as defined in 311-INST-001) will be assigned, based on system redundancy or criticality. Parts selected from the PPL, or NASA EEE Parts Selection List (NPSL) are considered to have met all criteria of 311-INST-001, and will be considered for approval for the PAPL. Custom or advanced technology devices such as custom hybrid microcircuits, detectors, ASIC’s, and Multi-Chip Modules (MCM) will also be subject to parts control appropriate for the individual technology.

Materials and Process Controls. Materials and processes used to fabricate flight hardware will be reviewed by AIM Mission Assurance for acceptability and compatibility. Nonmetallic materials selected for use will be reviewed for previous in-orbit experience and for conformance to outgassing properties using NASA Ref. Pub. 1124, "Outgassing Data for Selecting Spacecraft Materials" and/or the MSFC Materials and Processes Technical Information System (MAPTIS). All materials lists and EEE parts lists will be reviewed. Printed circuit boards shall be compliant to MIL-PRF-55110F.

Recommended parts and materials for AIM flight hardware are identified by MIL-STD-975, the GSFC Preferred Parts List (PPL), QML-38534, QML-38535 and the MSFC MAPTIS. Each subsystem or system design engineer will identify the initial specific part selections and evaluate these selections for reliability and any known deficiencies. An AIM EEE Parts List will be maintained as a deliverable document.

EEE parts will be selected in accordance with the order of acceptance as stated in the Performance Assurance Plan. Parts will be procured to comply with the AIM radiation hardness requirement. In some cases, radiation susceptibility testing, analysis and part shielding (i.e., CCDs) may be required to assure proper performance. Part derating for radiation will be specified.

Parts will be stored is a controlled environment area with limited access and electro-static discharge (ESD) protection. EEE parts are put into ESD protective bags or containers and stored in grounded cabinets.

Contamination Control. AIM will implement a contamination control program consistent with the requirements of the mission. The plan will address all aspects of contamination control throughout the mission, including transportation and launch site processing. The contamination control plan will be made available to the Explorer Program Office if requested. All assembly of flight electronic hardware will be performed in clean, air-conditioned areas. In addition, assembly and testing at the End Item level and for certain critical components will be performed in controlled access Class 10,000 areas per either LASP Contamination Control Plan, 20560-T6-0002, or contamination control plans of the participating institutions.

Reliability Assurance. Reliability assurance programs will also be required of all team members. As determined by the AIM Project Manager or designee, other subcontractors or suppliers of flight parts, materials, or components may be contractually obligated to comply with reliability requirements equivalent to those defined and specified by the Product Assurance Implementation Plan.

An evaluation of alternatives for achieving the stated reliability specification will be made using system reliability requirements. Items to be considered include design modifications, use of more reliable parts, design simplification, components derating, and component or subsystem redundancy.

As deemed appropriate by the AIM Systems Engineer or designee, a FMEA will be performed at the piece-part level for each system after the system design definition has been finalized. This analysis will identify reliability-critical items and single point failures.

Electronic circuits and electromechanical and mechanical items will be designed using a worst-case design philosophy, in which the engineer considers all parameters set at maximum and minimum levels as well as environmental effects and aging. Where necessary, worst-case design margins will be verified by simulation or test. The results will be reviewed at subsystem-level design reviews and will be considered in FMEAs.

Trend analysis will identify performance parameters for critical components, subsystems, and systems that can be tracked from nominal ambient performance after first successful functional checkout.

Baseline data and subsequent recording of trend data, the associated hardware, configuration, test setup, and other factors that might affect component operation will be recorded by the System Engineer or designee in the system test log during the complete system test program.

Throughout the program the AIM system engineer will give careful consideration to the maintainability of the system and to the elimination of failures due to human error. Efforts will be directed toward providing access and other design features to facilitate performance of all checkout, repair, and maintenance tasks. Features intended to eliminate potential failures due to human error, to minimize hazards to life and equipment, and to enhance maintainability will be given careful consideration at all design reviews.

Reliability, maintainability, and safety issues will be addressed and satisfactorily resolved at design reviews.

As part of the design review effort, each electronic/electrical design engineer will apply EEE parts derating criteria and will be responsible for ensuring that the applicable criteria are applied to all parts of the design. Necessary deviations will be reviewed and, if acceptable, approved by AIM project on a case-by-case basis. In general, EEE parts derating will be in accordance with the current GSFC PPL. For designs requiring radiation hardening there will be additional derating criteria. Parts not meeting the derating criteria must be identified and their application justified as part of the design review activity for that electronic assembly.

All flight hardware will be required to operated for several hundred hours of error-free operation of the integrated spacecraft and instrument(s) prior to the start of environmental testing.

Software. AIM will employ a structured program for the development of flight and ground software, and will implement software quality assurance controls and reviews in order to meet project requirements. Following the independent assessment, IV&V activities will be integrated to assure that assessment will be done in an appropriate way. The software plan will address the development life cycle phases such as requirement analysis, design, code, unit tests, integration and build test, performance verification, and maintenance. All code produced will be structured, error-free, properly documented, and maintainable.

Quality Assurance Plan. The Quality Assurance Plan will address quality program management, design and document review, parts and materials control, procurement, fabrication, Fabrication and Assembly Instructions (FAIs), processes control, contamination, controlled inventory and workmanship standards. Inspection includes in-process inspection, end item inspection and test, and control of inspection records. Other areas include non-conforming articles, material control, metrology and approvals. **Table F-29** provides a summary of the LASP developed hardware Product Assurance requirements for the AIM Project.

Performance Verification Requirements. All components of the flight hardware will be tested to levels necessary to ensure the capability of the design to perform its intended function, in accordance with an Integration and Test Plan. Test plans will identify testing to be conducted, facilities to be used, and specific operations, methods, and documentation required for testing the hardware. The test program, including the test plans and procedures, will be in accordance with, and will satisfy, the applicable portions of the Test Verification Matrix.

Identification Methods. Materials, processes, and design parameters will be identified in the design documentation so that the engineering features to be evaluated may be associated with the particular articles. Each article, including piece parts and components, will be identified by a unique part number. Certain EEE (semiconductors, other active devices) parts will be identified by a lot number and/or serial number. Assemblies will be identified by a serial number, starting at the first assembly level.

Material Control. Materials under assembly will be identified by drawing number and serial number (if appropriate) and will maintain this identity on the documentation.

Production tooling, jigs, fixtures, and other pieces of equipment which control critical dimensions, contours, or location of machine operations will be controlled to ensure initial accuracy and repeatability during use. The cognizant fabrication supervisor is responsible for establishing and maintaining the necessary controls and calibrations for the applicable equipment.

Raw material certification for the deliverable item will provide traceability of materials through inspection records to the purchase order.

Each organization is responsible for ensuring that all persons working on high-reliability hardware are made aware of the importance of reliability and high quality workmanship, and are properly trained to perform the tasks assigned to them. Training will be in several basic areas as follows:

- Soldering—All solderers are certified per NASA NHB 5300.4(3A-2) by a qualified instructor.
- Potting and Conformal Coating—All personnel involved in potting or the application of conformal coating are trained to the specific standard fabrication process by a qualified instructor.
- Quality Assurance inspectors will be certified per NASA NHB 5300.4(3A-2) by a qualified instructor.

PFR and Corrective Action. If a malfunction occurs during the formal acceptance testing of the contract end item a PFR will be opened and executed.

Failures or malfunctions occurring at subcontractor facilities will be documented on their standard forms and submitted to the LASP Product Assurance (PA) Manager as required. The PA

Table F-29. AIM Product Assurance Requirements

Program Component	AIM Product Assurance Plan
Flight HW	Flight hardware shall be fabricated in accordance with the appropriate plan at each participating organization.
Parts	Electrical, electronic, and electromechanical (EEE) parts shall be procured to high reliability Military Specifications, high reliability manufacturer's part number or design specifications (i.e., Grade 3 parts or better). Special purchase instructions shall be reviewed by cognizant Product Assurance staff at each organization.
Suppliers	Suppliers of deliverable flight hardware shall be reviewed as part of the Performance Assurance Program.
Product Assurance	LASP shall monitor each organization's Product Assurance activities. Source inspection for critical flight parts will be undertaken when necessary.
Flight Parts and Materials	All EEE flight parts and materials purchased by each organization shall be issued under the control of parts control organization within each organization.
Flight Part Tests	LASP shall require that each organization perform, or designate a vendor to perform, evaluation studies on EEE flight parts that have not demonstrated high reliability.
Parts Procurements	Electronic parts that cannot be procured in an already screened condition shall be screened or otherwise verified as acceptable prior to use in flight hardware.
Parts Grade	Grade Levels 1, 2 and 3 EEE parts are approved for flight use on the AIM Project. All other EEE parts require LASP approval of a Nonstandard Part Approval Request (NSPAR).
Radiation	Radiation hardness requirements for the AIM Project hardware are as defined in the Phase B plan.
Parts Controls	EEE part type identification and controls shall be maintained on flight hardware.
Parts Failure	Failure analysis and corrective action shall be conducted for parts and components, as required.
Configuration	The as-built configuration for the flight model shall be maintained and verified during fabrication.
Reliability Assessment	Reliability assessment studies shall be performed on the flight hardware designs. These reliability assessment shall meet the intent of the NIAT recommendations and include FMEA and probabilistic risk assessment. It is the current plan to employ an independent organization to undertake these studies for the project.
Final Delivery	An end-of-program physical configuration verification audit shall be performed in accordance with LASP procedures for deliverable hardware.
MRB	The disposition of nonconforming parts and materials shall be in accordance with LASP Material Review Board procedures.
Reviews	Designs for flight hardware shall be reviewed in formal peer design reviews with tracking and closeout of action items. Teams will also attend formal project reviews as outlined in the Management Plan.
Safety	A Safety Plan based on the requirements of the AIM Project shall be developed.
ICDs	Subcontractor control shall be through Interface Control Drawings or other standard purchasing specifications subject to review by LASP.

Manager will ensure that proper analysis has been made and that adequate corrective action has been taken by the subcontractor.

The LASP Product Assurance Manager is an active representative in the Government Industry Data Exchange Program (GIDEP). GIDEP is utilized in searching history fits for relevant data and information with regard to parts and materials used in flight hardware. As a function of failure analysis, the Marshall Space Flight Center (MSFC) "ALERT" system is scanned for similar occurrences.

The AIM PA Manager, as necessary, will issue alerts when problems are disclosed in flight parts. In addition, pertinent alerts received through the GIDEP system will be reviewed by all appropriate personnel for impact upon the flight parts and materials used in flight hardware.

Inspection and Tests. Inspection and tests will be performed on all assemblies, mechanical and electrical, in order to eliminate workmanship and process defects. The controlling documents for inspection and test include:

- FAIs, Engineering Change Orders (ECOs), Material Review Board (MR) forms, and PFRS
- Acceptance Test Procedures
- I&T Plans
- Approved Drawings
- Test Procedures

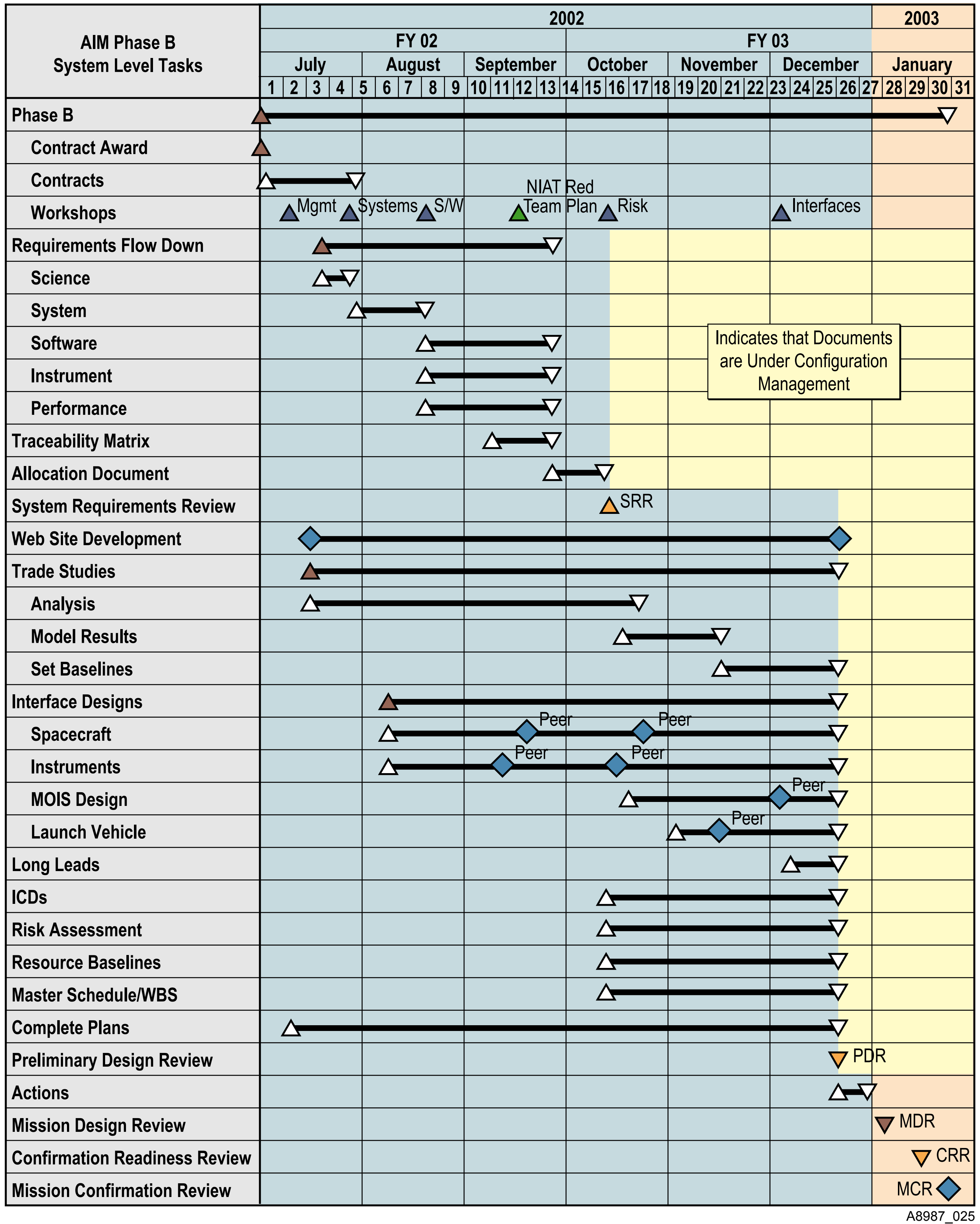


Figure G-7. AIM Phase B Schedule

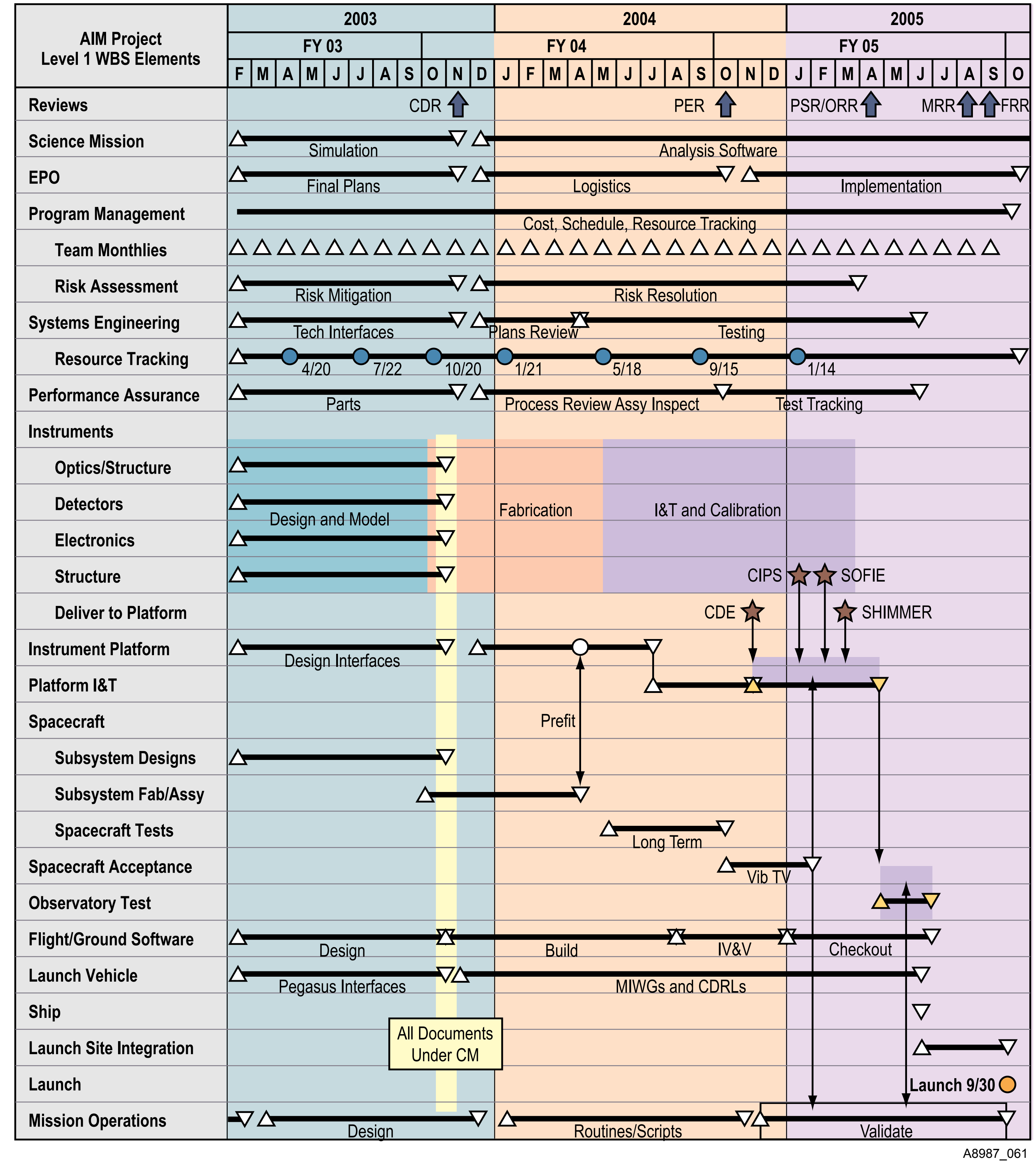


Figure G-8. AIM Phase C/D Schedule

Foldout G-1. AIM Schedules for Phase B and C/D

G. Management Plan

The AIM management plan establishes an efficient organizational structure for multi-institutional interaction, clear lines of authority, clean interfaces, managers and team members experienced in space hardware development and implementation, proven cost control mechanisms, and clearly defined roles, responsibilities and decision making.

The AIM Team includes Hampton University (HU), the University of Colorado Laboratory for Atmospheric and Space Physics (LASP), the Utah State University Space Dynamics Laboratory (SDL), the Naval Research Laboratory (NRL), Ball Aerospace & Technologies Corp. (BATC), and Gordley and Associates Technical Software, Inc. (GATS).

G.1 Team Member Responsibilities

HU, the PI institution, is the prime contractor and manages the programmatic aspects of the project, including the NASA interface, the subcontract to LASP, project reporting to NASA and other administrative efforts as required. HU will provide Science Team and E/PO leadership.

LASP provides overall project management, including management of subcontracts to BATC and SDL, the CIPS and CDE instruments, the IPA, mission flight operations and coordinates all project IV&V activities. Each organization brings complementary strengths and collectively they provide the management and leadership experience needed to coordinate the multi-institutional team. Both institutions build on years of successful experience in these areas.

SDL provides the SOFIE instrument, NRL the SHIMMER instrument and BATC the RS300 spacecraft bus. LASP integrates SOFIE, SHIMMER and CIPS with the instrument platform assembly (IPA) structure at LASP and validates IPA performance prior to integration with the spacecraft bus. LASP and BATC integrate the IPA to the spacecraft bus, and mount the CDE instrument directly to the spacecraft at the BATC facility.

GATS coordinates the development and operation of all instrument DPCs; leads the design, development and implementation of the SOFIE data retrieval and processing software and the SOFIE Payload Operations Center-Data Processing Center (POC-DPC) center; and coordinates and assists HU with the development of the AIM PDC.

G.1.1 Organizational Structure

The AIM team brings together the broad expertise, talent and commitment to excellence that will ensure successful implementation of the AIM mission.

Organization Description. The AIM organizational structure is shown in **Fig. G-1**. The AIM team has developed a close working relationship as a result of past proposal efforts by the same team, and work accomplished during the extended Concept Development phase. A firm working foundation is in place and the AIM Management Team is prepared to move forward with this project. The management model we are using is derived from years of successful hardware efforts developed at the partner institutions, with much of this experience coming from recent programs.

The PI, Dr. James M. Russell III, is the program's single point of contact with NASA. He maintains overall responsibility and decision-making authority for all aspects of the program. He ensures the technical and scientific success of the mission, the integrity of the investigation and the successful implementation of the E/PO program. The Co-PI, Dr. Scott M. Bailey assists the PI in managing the science activities and also provides oversight of E/PO effort. The HU Program Coordinator (PC), James L. Raper, is a seasoned ex-NASA flight project manager who reports directly to the PI. He assists in managing the LASP subcontract, schedule and cost control, and program reporting. The E/PO effort is directed by Dr. Dianne robinson, head of the HU Interdisciplinary Science Center. Dr. Robinson reports directly to the Co-PI. This management team arrangement provides both the PI and Co-PI with the rapid and current information needed to make clear and timely decisions.

The PM at LASP, Michael T. McGrath, reports directly to the PI. Locating the project management function at LASP logically flows from the fact that most of the AIM hardware development, including the IPA, two of the four AIM instruments, and mission operations occur there. The decision is also driven by LASP experience in project management, their share of project activity and their geographic location with respect to the team and the nearby spacecraft contractor BATC. BATC and SDL report to the PM and are managed as a part of the overall team. The PM oversees instrument activities, the spacecraft development, flight operations system development and implementation, mission assurance and safety, IV&V activities and launch vehicle interface. He leads NIAT activities for the project. Note that the AIM PM is the current Director for

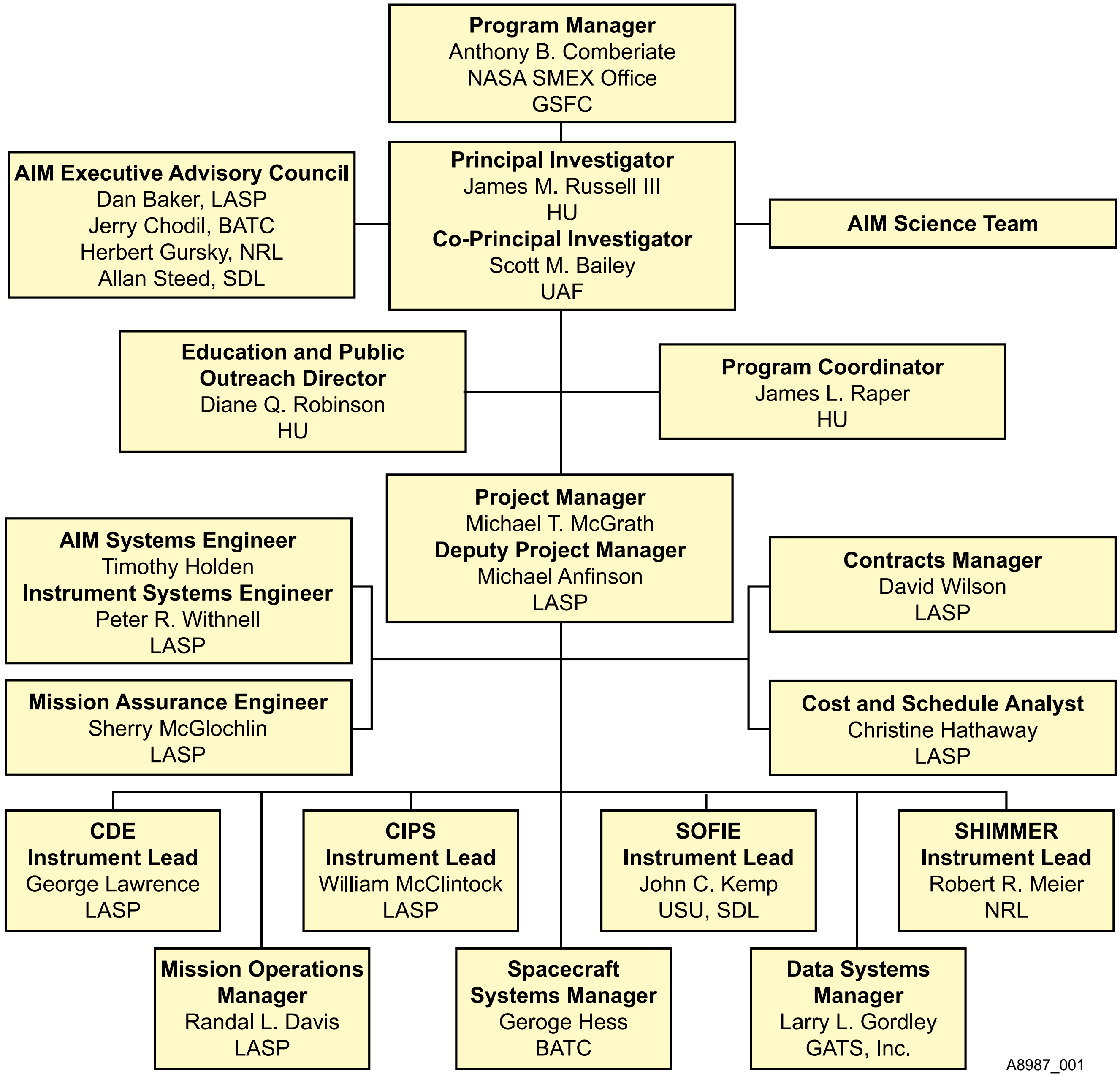


Figure G-1. AIM Organizational Structure

Engineering at LASP. The LASP engineering director oversees all the hardware projects at LASP. As LASP is organized into a project structure it is the case that the Engineering Director is intimately involved with all projects irrespective of the number of projects in the lab. LASP funds a significant portion of this position from internal funds to accomplish this. It is currently the case, given LASP's projected work load, that AIM will be the only hardware program in LASP during Phase B, C, and into D. With one project, the Engineering Director would focus full time (with the exception a minimum of administrative work) on this project. The role of AIM project manager thus fits well with this position.

Organizational Implementation Responsibilities and Experience. A detailed project WBS is included in Section K, Costs. **Table G-1** shows WBS Levels 1 and 2 for all phases of the project including team institutional roles and responsibilities.

Key Positions, Roles and Responsibilities. *AIM team members collectively have broad experience in science team leadership, space missions management, remote sensing instrumentation and techniques, testing, calibration, space system en-*

Table G-1. WBS Area and Responsibility

WBS Level	Program Component	Responsibility
1	**Science**	
1.1	Mission Planning	HU/UAF
1.2	Mission Simulation	HU/LASP/GATS
1.3	Data Analysis	GATS, Inc. / HU, LASP, NRL, SDL
1.4	Data Archival	HU
1.5	E/PO	HU
2	**Management**	
2.1	Program Coordination	HU/UAF
2.2	Project Management	LASP
2.3	Systems Engineering	LASP, Distributed*
2.4	Mission Assurance	LASP/ Distributed*
2.5	Risk Mitigation (NIAT)	LASP/ Distributed*
2.6	Documentation	HU / LASP
2.7	Red Team Reviews	LASP
3	**Spaceflight Segment**	
3.1	Instrumentation	LASP, SDL, NRL
3.2	Spacecraft Bus	BATC
3.6	Launch Vehicle	KSC / LASP
4	**Ground Segment**	
4.3	Telemetry Station	LASP
4.4	Mission Control Center	LASP
4.5	Mission Ops Planning and Training	LASP
4.6	Mission Operations	LASP
4.7	Software IV&V	LASP
4.8	Data Processing	GATS, Inc. / HU, LASP, NRL, SDL

* SDL,NRL,BATC

gineering and implementation, and E/PO methods and approaches.

The key AIM positions, required qualifications, relevant experience and time commitments are discussed in **Table G-2**. Personnel changes (should they occur) will be handled by drawing on the strong expertise pool at partner institutions and if required by open solicitations. Whenever possible, a period of work overlap for both persons will be planned.

Unique or Proprietary Capabilities. LASP's Mission Operations and Information Systems Division (MOIS) is in a unique position to economically manage and implement mission operations economically because of its existing ground station (Fig. F-47) and experience in operating a number of other space missions including e.g. SME, Quick Scatterometer (QuikSCAT) and SNOE. MOIS also has developed and maintains OASIS-CC software for managing, scheduling and operating spacecraft. OASIS-CC is currently used by a broad user base within industry. LASP tailors this software for use at the I&T phase of projects. A key advantage of a collocated operations team at the time of hardware integration is the ability to operate the AIM IPA using flight scripts and procedures. Co-development of hardware and software creates a significant test bed to assess the performance of the entire system prior to integration with the spacecraft. Issues located during this time are corrected quickly, and retests can be run in an expeditious manner. Once complete, these same scripts and software are carried forward into the overall spacecraft testing. BATC will use OASIS-CC during the full up spacecraft testing effort, drawing on procedures created and validated in previous project stages. Testing in this way provides a stepwise approach to closing the loop with mission operations during final checkouts, and carries forward previously validated tests and results.

SDL has background and experience in the development, test, calibration and implementation of space-borne and rocket-borne IR detection systems for both commercial and military customers—rare in a university. This includes state-of-the-art facilities for building, testing and calibrating IR systems and a broad base of in-house expertise in the development and implementation of IR detector array systems.

NRL brings a unique capability for spacecraft altitude determination to AIM. This will be provided at no cost because of the NRL role in the mission. SHIMMER requires post-observation spacecraft altitude knowledge of ±300 m that is beyond the accuracy obtainable by the daily North American Aerospace Defense (NORAD) two-line elements. AIM will receive data routinely with an accuracy of ~100-200 m through the Naval Space Command (NSC). This will be provided at no cost because of the NRL role in the mission.

The BATC RS300 bus for AIM uses tested systems previously flown and currently flying on commercial and NASA missions. The approach of providing a "generic" spacecraft bus with a simple interface to the payload creates economy in cost and schedule at significantly reduced risk. GATS has a unique capability to provide SOFIE data retrieval and analysis software as a result of its software role on the HALOE mission. Much of the software has been previously developed by GATS, is current, operational and unique thereby greatly minimizing risk inherent in new software development.

Table G-2. Key Personnel, Required Qualifications, Relevant Experience and Time Commitment

Key Position, Name and Org.	Required Qualifications	Relevant Experience	Time
PI J. Russell HU	Scientific and technical management expertise; decision making and team leadership ability; satellite remote sensing instrument test, calibration and data analysis experience; satellite experiment implementation experience; data validation and analysis expertise	NASA line manager 22 years; PI or Co-PI on three satellite missions (LIMS, HALOE, SABER); Co-I on ATMOS Shuttle Solar occultation mission and ISAMS UARS experiment; 25 years experience in satellite data validation, science data analysis and investigations; > 250 journ. art.	B: 70%* C: 70%* D: 70%* E: 70%*
Co-PI S. Bailey UAF	Mission development experience; science to instrument requirements flow-down expertise; science team management capability; satellite data validation, analysis, interpretation and investigation experience; E/PO knowledge and creativity	Co-led SNOE instrument student effort; Co-I on two satellite missions (SNOE, SEE); data validation analysis and application of data from SNOE and sounding rockets; 10 years experience in remote sensing; E/PO experience SNOE, HU	B: 65%* C: 65%* D: 65%* E: 65%*
PM M. McGrath LASP	Space hardware technical development management expertise; decision making ability; team leadership capability; flight instrument and spacecraft engineering expertise; cost tracking and control experience; risk mitigation expertise	LASP Director of Engineering; 21 years in engineering management; key engineer roles in numerous successful space experiments including PV, SME, SMM, and SNOE	B:100% C:100% D:100% E: 2%
Deputy PM M. Anfinson LASP	Ability to track details; experience in integration and test of satellite instruments and systems; expertise in tracking schedules, schedule slack, costs and earned value system changes; hands on experience in S/C projects from design to flight. Experience in NASA hardware projects.	Major engineering development and management roles in space hardware and implementation for AE, PV, SME, Pathfinder, Cassini, TIMED and SORCE. 25 years experience in instrument design, management and spacecraft systems interaction.	B: 70% C:100% D:100% E: 2%
Program Coordinator J. Raper HU	Expertise in space mission project management, schedule design, control and tracking; engineering management experience; experience in cost tracking and control, space project implementation, engineering reviews and NASA reporting	NASA project management 32 years; Project Manager for the highly successful HALOE experiment operating perfectly on UARS after 10 years; broad experience and knowledge in NASA technical review and reporting req.	B: 50% C: 50% D: 50% E: 0%
S/C Project Manager G. Hess BATC	Spacecraft development and program management experience; schedule and cost tracking expertise; familiarity with earned value system and application; expertise in mission assurance; team leadership ability	Space systems acquisition and development 32 years. Chief Engineer on Lockheed Martin's Brilliant Eyes program (1991-92). Phase A PM for the Discovery 2000 Kepler Mission (2001).	B:100% C:100% D:100% E: 0%
Systems Eng. T. Holden LASP	Broad experience in space system and hardware design, test, calibration, application, system trades and interface management; team leadership ability; expert in cataloging system level requirements, tracking performance and managing technical resources; deep knowledge of current methods.	10 years management and development roles in space HW and SW applications. SE and PM for SORCE, ICD & requirements mgmt., CDRL and contract waiver review. Extensive NASA / subcontractor interactions.	B:100% C:100% D:100% E: 0%
Mission Assur. Engineer S. McGlochlin LASP	Experience establishing and overseeing mission Product Assurance plans, with safety and reliability assurance; familiarity with parts program design and implementation; ability to apply standards across institutions; expertise in configuration mgmt.	Mission assurance roles on FUSE, SNOE and SORCE satellite missions; 10 years experience in satellite mission assurance engineering	B: 50% C: 50% D: 50% E: 0%
Data Systems Manager L. Gordley GATS, Inc.	Expert in state-of-the-art data systems, formats, processing systems, and retrieval of remotely sensed data; intimately familiar with data display needs, validation and methods for satellite mission implementation; deep knowledge of AIM science	Broad experience in data systems gained from deep involvement in LIMS, HALOE, CLAES and SABER satellite experiments. 28 years experience in satellite remote sensing, data validation, analysis and interpretation	B: 20%* C: 20%* D: 20%* E: 20%*
Mission Ops. Manager R. Davis LASP	Experience in design and execution of mission ops. command and control systems; knowledge of ops. requirements, down and uplink antenna capabilities, data transfer methods and space system health and safety tracking; expert in mission ops. management	Deep experience in managing mission operations for SME, STRVa, STRVb, SNOE and QuikSCAT satellite missions; broad experience in design and checkout of seamless ground /flight software systems; 29 years experience in mission ops.	B: 50% C: 70% D: 70% E: 70%
E/PO Director D. Robinson HU	Expert in E/PO requirements, methods, and applications and evaluations for K-14 and public outreach; experience in teaching; experience working with satellite science teams; track record reaching out to underserved minorities/native Americans	University educator; 20 years experience in E/PO for NSF and NASA; Leads E/PO for the ESSP-3 and SABER satellite missions; serves as reviewer of E/PO programs for NASA	B: 20%* C: 50%* D: 50%* E: 70%*

*AIM budgeted amounts augmented by institutions

Contractual and Financial Relationships. The AIM team consists of universities, government institutions and private industry. All NASA funds flow to HU except for the launch vehicle and NRL. NRL is a government institution and NASA supplies funds directly to them. HU issues subcontracts to LASP, GATS, University of Alaska, Fairbanks (UAF) and George Mason University (GMU) for mission and science implementation activities. LASP issues subcontracts to BATC and SDL for hardware and science activities and work closely with the NASA SMEX Office in managing the NRL and ELV efforts. Contractual agreements and incentive plans for cost, schedule and performance are in place and described in Appendices M5 and M8. British Antarctic Survey (BAS) is a foreign institution and no funds are sent to them.

Relevant Institutional Experience. *The team's breadth of expertise and experience in instrument development, integration and test, satellite bus design and program implementation, mission operations and science data analysis will assure the success of the AIM mission.*

The HU Center for Atmospheric Sciences faculty have extensive experience in leading science teams, guiding space hardware development, validating satellite data and conducting scientific investigations.

LASP has broad experience in project management, and instrument/small satellite development. Recent project management experience has been on a scale similar to AIM. The LASP SORCE program, for example, functions in the PI mode and involves a satellite procurement, development of four instruments, parallel I&T of an observatory module, launch vehicle interface management and conduct of mission operations from its proven facility.

BATC has 40 years experience in managing space-based programs and a breadth of experience in developing spacecraft supporting science observations. The RS300 spacecraft bus derives significant heritage from ongoing flight projects.

SDL is broadly experienced in spacecraft and instrument applications and has a long record of developing many successful sounding rocket and satellite instruments. The SOFIE instrument subsystems e.g. derive strong heritage from the SDL SABER instrument soon to fly on the TIMED satellite, from other SDL space instruments and HALOE.

NRL brings a breadth of instrument and spaceflight experience including implementation of a forerunner science instrument, MAHRSI, that flew on the CRISTA SPAS mission and the SHIMMER instrument forerunner already built, that will fly on the Space Shuttle in CY02.

GATS has broad experience in test and flight data processing and analysis for numerous space missions including UARS HALOE. AIM data analysis efforts will build on systems already in place at GATS. Additional information about the team member organizations and responsibilities is included in Appendix M2.

G.1.2 Experience and Commitment of Key Personnel

Principal Investigator and Project Manager. The experience and time commitment of the AIM PI and PM are described in Table G-2. They may be reached at:

Dr. James M. Russell III
Center for Atmospheric Sciences
Hampton University
23 Tyler Street
Hampton, Virginia 23668
757-728-6893(V);757-727-5090(Fax)
james.russell@hamptonu.edu

Mr. Michael T. McGrath
LASP Space Technology Building
University of Colorado
1234 Innovation Drive
Boulder, Colorado 80309
303-492-8482(V);303-492-6444(Fax)
mcgrath@lasp.colorado.edu

Other Key Personnel. Other key personnel are described in **Table G-2** and **Table G-3**. L. Gordley listed as Data Systems Manager in **Table G-2** will also serve as the SOFIE PI.

G.2 Management Processes and Plans

AIM uses proven management processes, unique tools and innovative methods established by team partners in past highly successful space hardware efforts to ensure that the AIM science goals and objectives will be met.

AIM Management Approach. The management of the AIM program relies on the AIM Project Work Breakdown Structure (APWBS) and the AIM Integrated Project Schedule (AIPS) shown later in Section G.3. Together these two elements provide a means to develop the baseline schedule at the work package level, to allocate resources to each of the teams, to assess progress at various detailed levels of the project, assess earned value, and, where necessary, to adjust resources to mitigate risk and keep the project on schedule and within budget. Work packages and schedules are developed for each of the participating institu-

Table G-3. Other Key Personnel, Responsibilities, Relevant Experience, and Availability

Team Member	Institution	Responsibilities	Relevant Mission Experience	Support	Time (%)
S. Lane	CU	NIAT Engineer	SOLSTICE, GFFC, CASSINI, 15 yrs exp. Mech. Eng.	NASA	50*
S. Eckermann	NRL	Co-I	CRISTA science team affiliate	NASA/NRL	55**
C. Englert	NRL	Co-I	THOMAS, MAHRSI, 5 yrs. exp. in space /air flt HW.	NASA/NRL	87
P. Espy	BAS	Co-I	SABER, UARS (correlative), rockets and grnd.-based	BAS	10
J. Harlander	SCU	Co-I	Co-Inventor of and more than 15 years exp. with SHS	NASA	7
M. Horányi	CU	Co-I, PI CDE	Ulysses, Galileo, Cassini, 20 yrs. theory and analysis	NASA	10
R. Meier	NRL	Co-I, SHIMMER PI and Inst. Lead	Rockets, OGO, OSO, SURE, HIRAAS, SSULI, GUVI	NASA/NRL	35
C. Randall	CU	Co-I	HST, POAM, SAGE, HIRDLS, 19 yrs. data analysis	NASA	15
D. Rusch	CU	Co-I, PI CIPS	Rockets, PIDDP, SME, POAM	NASA	44
D. Siskind	NRL	Co-I	SABER Co-I, UARS/HALOE Guest Investigator	NASA/NRL	50**
M. Stevens	NRL	Co-I	MAHRSI, 12 years exp. in space-based remote sensing	NASA/NRL	87**
M. Summers	GMU	Co-I	MAHRSI, 15 yrs mesospheric science studies	NASA/GMU	25**
M. Taylor	SDL	Co-I	25-years of ground-based aeronomy	NASA	19
G. Thomas	CU	Co-I	Rockets, SME	NASA/CU	15
M. Hervig	GATS	SOFIE Sci. Lead	HALOE, AVHRR, SAGE, balloons, 10 yrs. remt. sens.	NASA	50
J. Kemp	SDL	SOFIE Inst. Lead and PM	CIRRIS-1A, WIRE, 30 yrs. exp. space remote sensing	NASA	90*
G. Lawrence	CU	CDE Inst. Lead	Cassini, SORCE, 34 yrs. exp. in flt. hdw. design/devel.	NASA	10*
W. McClintock	CU	CIPS Inst. Lead	Cassini, SORCE, 20 yrs. inst. design at LASP	NASA	15*
S. Myers	NRL	SHIMMER Inst. PM	Program Management for RPI, EIS, SECCHI	NASA/NRL	15*
J. Cardon	NRL	SHIMMER Inst. Lead	MAHRSI, UVPI, ISO, SHIMMER MIDDECK, 15 yrs exp. space remote sensing	NASA/NRL	85*
D. Purmort	BATC	S/C SE	20 years aerospace technical experience.	NASA	100*
D. Welch	CU	MOM Dep.	SME, SAMPEX, FAST, SNOE, QuikSCAT, 18 yrs ops	NASA	40
B. Maggi	HU	E/PO Dir. Assistant	ESSP-3 and SABER E/PO, 10 yrs exp. consulting	NASA	25

No stars means average effort throughout the program; * Phases B/C/D; ** Phase E

tions. Within these institutional work packages, specific WBS elements are created that correspond to the lowest tracking level of work to be performed. The performance of each institutional WBS element corresponds to a WBS task schedule within the institutional project schedule. These schedules flow up to the AIPS. Changes within any level of the WBS are immediately reflected in the AIPS.

Authority and responsibility for control and oversight of each of the WBS elements as related to cost, schedule and requirements are as follows.

Level 1 WBS. Decisions flow from NASA directives to the AIM PI, to the AIM PM and then to the Project. The PI, with responsibility for the overall AIM mission, approves the top level resource allocation at Level 1 of the WBS. The PI is responsibe for science, cost, schedule and technical performance, and authority over decisions involving the Level 1 WBS.

Level 2 WBS. The PM is responsible for allocating resources, schedules and requirements defined in Level 1 down to Levels 2 and 3. System and subsystem specifications, ICDs, WBS budgets and schedules define the scope of each Level 2 and Level 3 effort – these generally relate to the resources and budgets allocated to each of the institutions.

Level 3 WBS. Each institutional manager (Level 3 manager) is responsible for overseeing their respective Level 3 WBS. The AIM PM and his management group will work with the Level 3 managers to establish cost, schedule and requirements specifications.

The Level 3 managers allocate resources, requirements, specifications, funding resources and schedule to Level 4 and below, and have decision making authority as long as these decisions do not a) impact the AIPS Critical Path, b) increase costs above the Level 3 budget allocation, c) impact requirements as defined in the requirements flow-down matrix, or d) alter the specific subsystem end-item specification or deliverable.

Level 4 WBS. The Level 3 manager establishes and controls the scope of the Level 4 work packages and schedules. Oversight responsibility for Level 4 efforts will be under the oversight of Level 4 managers. During the course of the AIM project, changes and adjustments will be required at Level 4 including the shifting of resources across work packages. The authorized Level 3 manager makes these decisions without need for approval as long as the rules discussed in Level 3 are not violated.

All changes made in work packages at Level 3 and 4 flow up to the AIM Project WBS Levels 1 and 2, and schedule adjustments are automatically reflected in the AIPS. As described, the AIM Management System fully captures any changes made. The APWBS and the AIPS are reviewed at a minimum on a weekly basis by the AIM PM, and are a principal focus of the AIM management team.

AIM Integrated Product Development Teams. The day-to-day project implementation at the working level is guided by three Integrated Product Development Teams (IPDTs): Science, Systems and Management.

- The Science Team, led by the PI, includes the Co-PI and Co-Investigators. This team assesses science and measurement requirements versus systems performance. It bears the fundamental responsibility to insure that the instrument and spacecraft systems provide the measurements needed to meet the six AIM scientific objectives.
- The Systems IPDT, led by the AIM System Engineer (ASE) includes the spacecraft SE, the AIM Instrument System Engineer (AISE), SEs for each of the four instruments and the launch vehicle, the AIM Mission Assurance Engineer (AMAE), and the AIM Mission Operations Manager (AMOM). This team allocates technical resources and controls the overall systems configuration. This responsibility includes the technical issues relating to the spacecraft bus and the IPA configuration, electrical, thermal and mechanical interfaces, mass, power and data rate allocation, and any uncompensated momentum transfers between the individual instruments and the spacecraft. The ASE, when directed by the PM, has responsibility to flow down technical directives to the spacecraft and instrument systems engineers.
- The Project Management IPDT, led by the AIM Project Manager, includes the spacecraft and instrument PMs, the AIM Deputy Project Manager (ADPM), the ASE, the AISE, and the AMAE. This IPDT has the primary responsibility to address programmatic and unresolved resource issues and to develop solutions where decisions are straightforward.

AIM Integrated Product Teams and Councils. In some instances it may be more advantageous to convene a broader grouping of experienced personnel and technical resources. This can be done in two ways: 1) through Integrated Product Teams (IPTs), and 2) through councils. IPDTs can be combined into integrated product teams to solve broader issues. These groups meet when technical and programmatic issues require broader technical input to arrive at potential solutions to issues that emerge. Should a solution not be possible after convening IPTs, the issue is refered to one of four councils.

AIM Councils. The four councils include: 1) the PI Council, 2) the Management Council, 3) the Executive Advisory Council, and 4) the E/PO council. These councils deal with top level issues.

- The PI Council (PIC) consisting of the PI, Co-PI, PM and PC will address most project-level actions and decisions.
- The Management Council (MC) includes all members of the PIC plus lead representatives from CU, SDL, BATC, NRL and GATS. This council deals with unresolved “cross cutting” issues, i.e. issues or decisions affecting more than one experiment. The MC has monthly telecons and in-person meetings as needed.
- The Executive Advisory Council (EAC) includes the PIC and higher management representatives from each of the major AIM institutions. The EAC convenes if major problems are encountered requiring senior management action in any one of the AIM team member organizations. This council assists the PM in resolving problems to ensure the close, smooth management of the mission. Occasional, no more frequent than annual, EAC meetings will be held to brief and review progress, and advise on future plans
- The E/PO council (E/POC) is chaired by the AIM Co-PI and includes the PI and E/PO director. This council meets monthly to review the status of the E/PO program, assess prog-

ress and evaluate future plans and directions.

The AIM team has operated informally in the manner just described during the Concept Study. Consequently, transition to the formal WBS and Schedule tracking system will proceed smoothly when the system is formally implemented during Phase B.

Systems Engineering and Integration. The AIM Systems Engineer is responsible for ensuring that the delivered hardware meets performance verification requirements at integration. This requires that a series of systems engineering tasks take place over the term of the project. These are described by phase as follows.

Phase B. The AIM Systems Engineer, with support and input from the AIM Systems IPDT, AIM Management IPDT and the AIM Science IPDT, is responsible for developing the AIM Project System Specifications. The activities to be undertaken by the ASE and the Systems IPDT for Phase B are shown later in Section G.3 and **Fig. G-7**, **FO-G1**. The processes involved in this work include:

- Taking the flow-down of the science and measurement requirements in the Science Requirements Document (SRD) developed in Phase A and allocating those requirements to the instruments and spacecraft in the form of end item specifications, resource allocations (power, mass and data) and performance metrics.
- Formalizing these requirements and specifications in the form of ICDs, requirements and specifications that are traceable and verifiable back to the SRD. This work builds on the Phase A concept study preliminary design identifiying the mechanical, electrical, thermal, and data interfaces between the instrument platform assembly, the CDE, and the spacecraft. This interface parallels the interface developed between LASP and BATC for the SME spacecraft. According to senior BATC staff, this approach was one of the most successful that BATC has implemented between a spacecraft and science payload.
- Identifying key trades to optimize the science return from the AIM hardware system, and to work these trades during the Preliminary Analysis (Phase B) phase.
- Placing the products and processes needed to assure delivery of hardware and subsystems under configuration control in the Preliminary Analysis (Phase B) phase.
- Tracking these items using the AIM requirements traceability software tool to assure that all requirements are met and traceable through the life of the AIM mission.

Phase C and D. The ASE is the principal technical interface between the AIM project, BATC (spacecraft) and the instrument teams on issues relating to requirements and specification development and interface control documentation. The ASE coordinates the technical relationships during instrument and spacecraft development to meet the required performance metrics during instrument bench testing, spacecraft integration and launch vehicle integration and operations. The ASE and the Systems IPDT activities for Phase C/D are shown in the top level AIPS, and in more detail on the Phase C/D schedule shown later in Section G.3, and **Fig. G-8, FO-G1**.

Having established the mass, power, and data budgets for the AIM system, the ASE tracks and monitors the system-wide status of these resources. The ASE holds the mass, power and data reserve for the Level 3 efforts, and is delegated the decision making on allocation of the reserve within an agreed-upon allocation schedule.

The ASE and his team assure integrity and operation at integration, including definition of all interfaces (power, data, ground, mechanical and thermal) between the instrument platform and the spacecraft, and all interfaces (power, data, ground, mechanical and thermal) between each of the instruments and the IPA. The ASE and his team support the IPA during LASP mission simulation tests, integrate the IPA with the spacecraft, and participate in the fully integrated spacecraft performance testing at BATC. Processes and procedures for all of the testing are approved and reviewed by the ASE.

The Systems IPDT is actively involved in the optimization and implementation of the project-wide systems engineering effort. This IPDT (with its makeup of all subsystem and system-level managers) directs hardware, software, or integration responsibilities. They broadly trade on decisions with input from across the system. In doing this the ASE will be responsible for assuring closure of all technical and implementation issues.

The ASE and the Systems IPDT serve as the primary means by which conflicting issues and subsystem problems are identified and resolved. The Systems IPDT holds weekly telecons during the Preliminary Analysis Phase. Action items from these meetings are recorded, maintained, and distributed to the project. Implicit in the work undertaken by the ASE is minimizing risk and development uncertainty, conserving resources and minimizing costs. Techniques to be used include:

- Concluding the Preliminary Analysis Phase with the design baseline specified and maintained under configuration control.
- Designing to cost using the WBS.
- Emphasizing re-use of existing proven designs. In designs that are new, early and repeated testing at critical levels of the design process will be coordinated.
- Emphasizing testing at all levels of the hardware development process.
- Developing an engineering model spare to avoid conflict where two disciplines are required to share the same hardware.
- Undertaking appropriate levels of computer analysis validated by order of magnitude back-of-the-envelope calculations.

Requirements Development. Detailed Science and Mission Requirements Documents developed in the Phase A study drove development of all other requirements including requirements for the ground, launch and space segments (see **Fig. G-2**). Science requirements were converted to measurement goals (desires) and requirements (science floor), and captured in the mission requirements. Measurement requirements were allocated to each AIM instrument. These requirements led to development of specifications for the IPA, the spacecraft bus and preliminary ICDs.

Derived requirements have been distilled down through the levels of the WBS. In developing final requirements in Phase B the ASE will ensure that they are: 1) complete and specific; 2) appropriately and accurately allocated to the AIM subsystem elements; 3) verified, thoroughly documented, and rigidly controlled by configuration management techniques, and 4) correctly interpreted through discussion between the ASE and team members. All requirements will be documented on-line using the previously mentioned software system, and made accessible to all team members from their institutional locations.

The minimum measurement requirements are captured in the Requirements Traceability Matricies as allocated to the instruments and spacecraft bus (Section F.2.1, FO-F1). Phase B design trades will be conducted to optimize the system design so that each science goal correlates to a HW/SW performance target that meets the minimum science requirement. Additionally, any reserve above the minimum has been determined, and is carried as science measurement reserve. Because changes to requirements or the introduction of new requirements are a project wide concern, any change requests after the baseline is placed under CM control will be scrutinized by

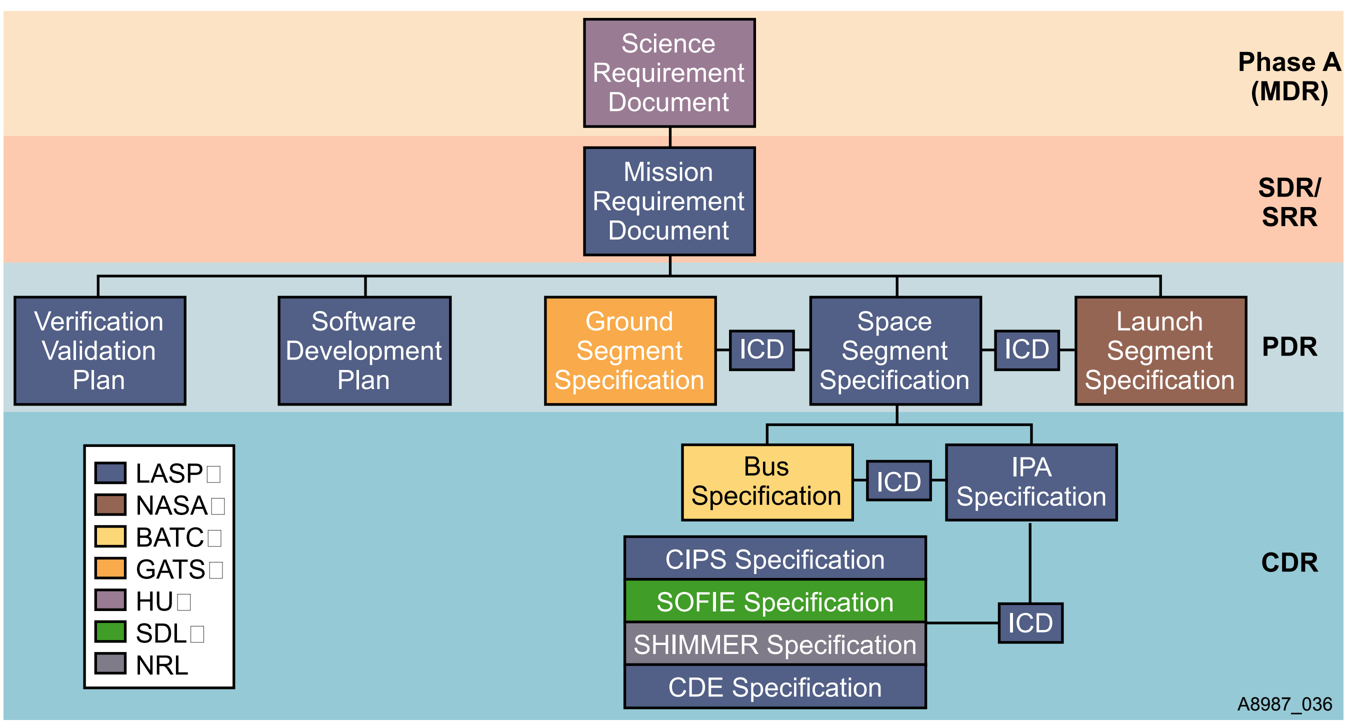


Figure G-2. AIM Specification Tree

the Management and Systems IPDTs and evaluated by a Change Control Board as part of the Configuration Management process described in the next section.

AIM Configuration Management. The AIM configuration is managed using a documented approach to change control. The AIM PM and his staff implement the on-line Configuration Management (CM) database, providing a central focus for control of all changes to documentation supporting the HW and SW designs. The AIM CM Plan controls the spacecraft and instrument functional (performance metrics and measurement requirements) and physical (mass, volume, interface, power, thermal, operating margins, etc) characteristics over the life of the project. The CM Plan provides the mechanism by which changes are controlled and communicated to the project. The AIM CM system enables traceability of the history of changes. **Fig. G-3** shows the configuration management and change control process.

The AIM Configuration Management and Control Plan will adopt, where possible, the plans currently in use from each of the participating institutions. The policies, practices, and organization to be proposed will comply with the relevant standards. All key drawings, documents and records will be available on the web, accessible by an internet browser. Interface designs will undergo review and approval, and design compatibility and margins will be analyzed to assure that the hardware interfaces are compatible, that the electrical interfaces are well understood, and that the assembly of the hardware proceeds without issues. Design for accessibility and test is stressed. All system level assembly is done under a formal Fabrication and Assembly Instructions (FAI) process with full inspection and signoff. All testing proceeds under the direction of the respective I&T Manager. The AIM team has minimized the interfaces between the major subsystems and simplicity has been stressed.

Four fundamental systems engineering documents will be generated and maintained at the project level:

- AIM Mission Plan
- AIM Science or Requirements Document
- AIM Spacecraft/Instrument Bench Interface Control Document
- AIM I&T Plan

AIM project science requirements and interfaces will be placed under configuration control by the time of SRR. The baseline hardware configuration is managed within the AMAE's task with configuration control at the time of CDR.

Change requests are categorized as Level 1, 2 or 3 changes. Level 1 changes impact the science, mission, cost and/or schedule performance. These

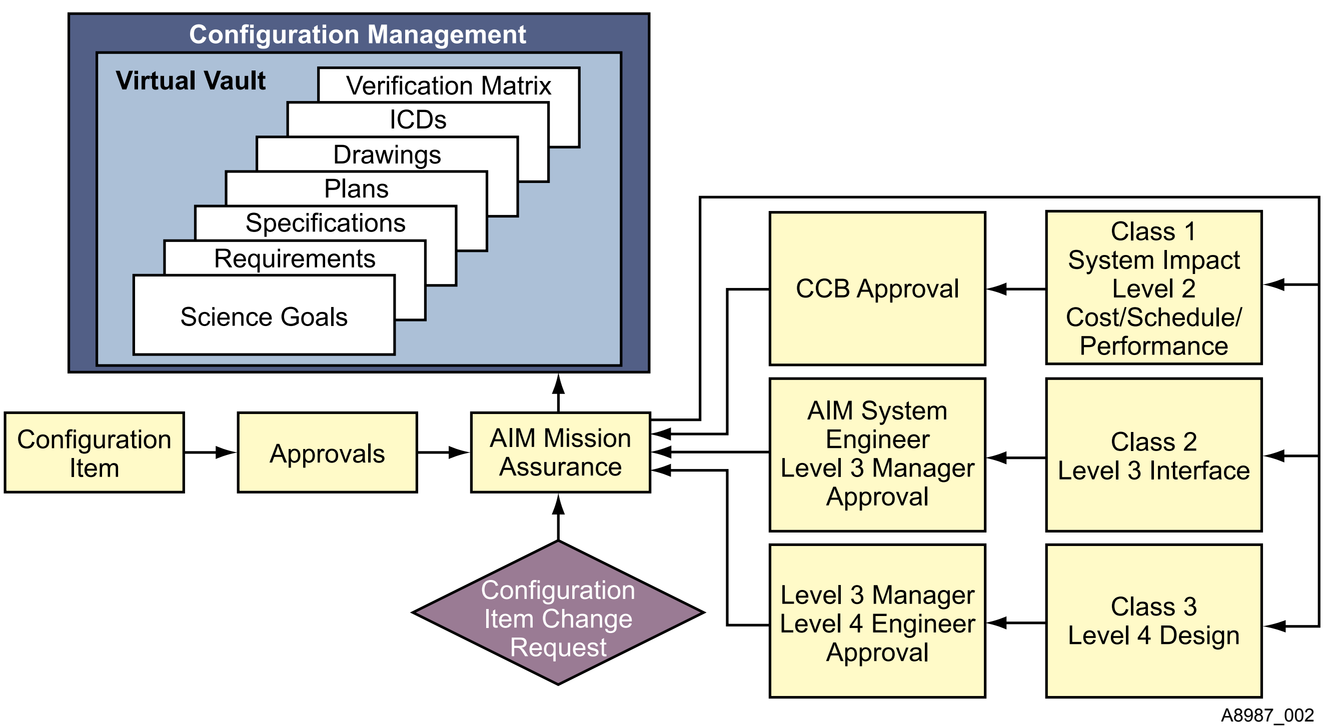


Figure G-3. AIM Configuration Management and Change Control Process

requests are routed to the Change Control Board (CCB) comprised the PI, PM, ADPM, AMAE, ASE and representatives from the Science, Systems and Management IPDTs. All proposed changes, including addition of science and measurement requirements, scope changes, cost and schedule changes, interface modifications and any miscellaneous modifications with project-wide resource impact are reviewed and authorized by the CCB. In general, once the baseline is placed under configuration management, any proposed Level 1 changes will be strongly resisted unless it can be demonstrated that it reduces cost, schedule and/or performance risk without impact or modification to the baseline mission.

Level 2 change requests are those that do not have impact on resources but involve technical interfaces at the Level 3 WBS. These are handled by the ASE and the Level 3 manager. Level 3 change requests have no impact on resources above Level 3. The Level 3 and Level 4 managers will act on these requests.

All approved requests are passed back to the AMAE. Her staff records the changes, updates the baseline configuration and places the revised configuration under CM control. Monthly reports are generated detailing all requests and dispositions.

During the Concept Study, the AIM team focused on science requirements, measurement requirements and instrument specifications development. These key instrument and spacecraft requirements, along with supporting documents, will be re-examined in the early part of Phase B, and placed under CM at the System Requirements Review (SRR).

The AMAE coordinates all activities pertaining to the CM system. She convenes the CCB to review Level 1 change requests, assuring that the change requests are complete. The CCB has the sole responsibility and authority to manage and act on Level 1 requests. All Level 1 request decisions ultimately rest with the AIM PI for final approval. The CCB meets as required to disposition requests quickly and efficiently. Decisions will be communicated to all affected team members across the project through the AIM PM.

Schedule Management. The AIM Project Management Control System (APMCS) is implemented around the WBS. Microsoft Project is used to coordinate, track and manage the overall AIM schedule, system effort and major project milestones. Critical paths are identified, tracked and updated no less frequently than monthly. A top-level AIPS links to each team member institution's schedule. Instrument and spacecraft schedule milestones are incorporated into the overall schedule, but tracked in detail at each of the respective institutions. Strong emphasis is placed on tracking near-term milestones and tasks.

Negative slack is managed and mitigated through appropriate use of the existing resource pool. If mitigation is not possible within available resources, additional labor and/or funding resources are brought into the project to resolve the slack condition.

Team Member Coordination and Communications. C*ommunication methods and activities have been tailored to effectively manage, focus and motivate the AIM project's distributed team, and to keep the team member institutions fully informed of project issues.*

Our methods for team communications are shown in **Fig. G-4**. Weekly telecons and the project FTP site were highly effective in Phase A. PI, PM and team member sites will be linked via the web to the AIM secure web site and project server at LASP. The web site will contain information on costs, schedule, requirements, specifications, action items and the events calendar. Existing web broadcasting capability at LASP will be used as needed. Quarterly science team meetings, major technical reviews, instrument peer reviews and IPDT/instrument team meetings will also serve as key times for information exchange. A CAD-enabled common web space environment will be used to review designs.

Progress Reporting Processes. AIM managers and key staff convey project accomplishments, concerns, actions, milestone tracking and schedule status to the PM. This is assembled and reported to the PI. Schedule updates are discussed, along with Material Review Board (MRB) and Deviation/Waiver events, Engineering Change Request/Engineering Change Order (ECR/ECOs), and notice of problems or issues. Formal documentation is archived at LASP and will be available for review by request.

Each month the Level 3 managers update their Level 3 WBS project schedules. These revisions are reflected in the AIPS by way of links between the AIPS and the institutional Level 3 schedules. Expenditures for the month by WBS element will be updated by the Level 3 managers, and these updates roll up into the AIM Project WBS. Earned value analysis is performed by comparing the AIPS and APWBS as-spent resources to the baselines. The PM and his staff maintain the

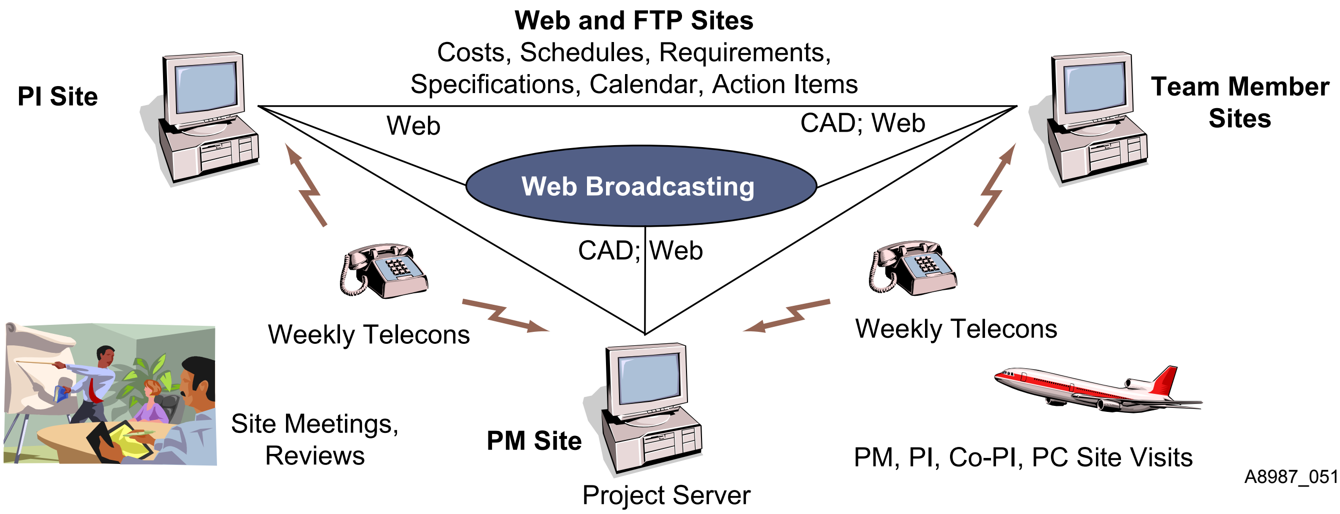


Figure G-4. Team Member Coordination and Communications

costs, schedule and performance baselines online for access by all of the project staff. Progress reporting on schedule and cost status is reviewable online at the LASP site.

All project related documents and configured items are controlled on a protected web site within a Virtual Vault at LASP. Actions, action items and receipts/deliverables (Rec/Dels) will be tracked using commercially-available software package linking all institutions. Two such packages, OPTIX and Teamshare, are under AIM review.

Performance Measurement. Earned value assessment and variable analysis will establish a metrics to evaluate manpower loading scheduling and reserve decisions. This assessment is augmented by periodic re-forecasting of manpower requirements. Subcontract performance measurement is evaluated by reviewing milestone completion, schedule and task progress. **Fig. G-5** illustrates the flow of schedule and cost information necessary for assessing progress and making decisions about project direction and changes.

Technical performance metrics for the instrument and spacecraft developments will be finalized during Phase B. Initially this list will include mass, power and data estimates, reserve allocations and not-to-exceed values. These baseline values will be reviewed at the SRR, formalized and placed under configuration control at completion of the Preliminary Design Review (PDR). These parameters, either directly measured or derived from instrument design models, represent key performance requirements that must be met to ensure that mission objectives are met. Additional metrics will be incorporated if an out-of-tolerance condition will adversely impact mission goals, performance and/or resources.

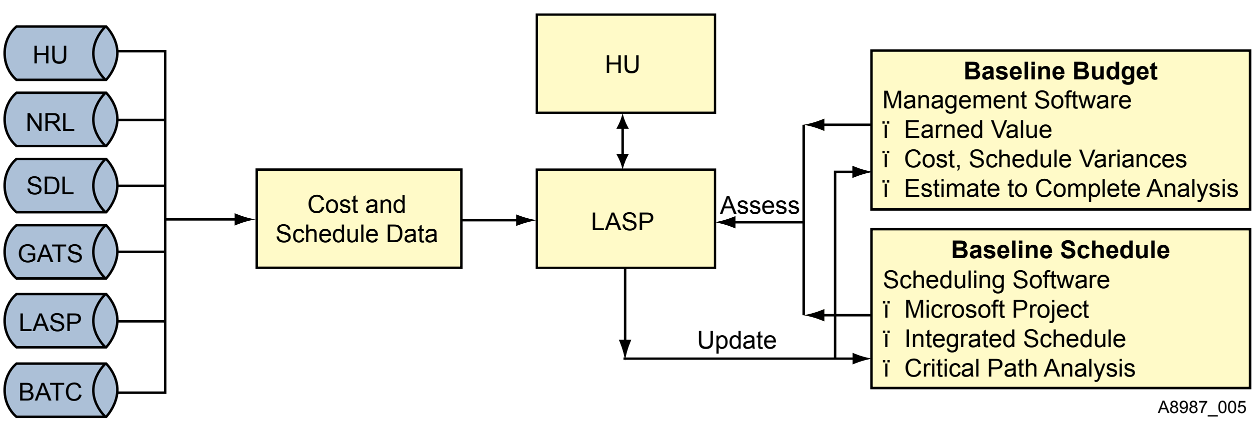


Figure G-5. Schedule and Cost Information Flow for Assessing Progress and Updating Baseline

Resource Management*. The resources and reserves required for successful space implementation are in place and clear lines of authority for management of these resources are established.*

Table G-4 shows system level resources at CSR submission, maximum resource value, reserves and margins and review threshold levels.

Measured values falling below the base line create a red flag, and are brought to the attention of the AIM PI. The AIM PM, with PI oversight, will work with the staff, IPDTs, and management councils to resolve and/or mitigate these issues. These system-level metrics are flowed down and budgeted to the subsystems by the ASE and his staff. All subsystem metric budgets are analyzed monthly, to ensure that any subsystem problems are quickly identified and appropriate corrective actions are developed with the subsystem manager. The ASE documents changes to those characteristics, and provides information on the state of change action.

Process to Develop Project Baseline. Overall project goals, budgets, schedules and system-level program requirements are developed and established at the first level of the WBS. The PI and the PM are directly involved in this effort. The final configuration of this WBS level is reviewed and approved by the PI. This establishes the general resource allocation across the project, and establishes the goals and requirements for science, management, systems, spacecraft, instruments, ground and flight software, GSE, I&T, mission operations and science data analysis. Further development beyond Level 1 has been previously described.

E/PO Processes and Plans. E/PO processes and plans parallel those for the technical part of the effort. Management is governed by the E/POC led by the AIM Co-PI. As indicated in Section G.2, this council meets monthly. The E/PO Director reports to the AIM Co-PI who oversees the program to ensure that all program objectives are met, that the effort is focused on AIM science and that there is substantial in-

Table G-4. AIM Resource Management

	Resource	CSR Estimate	Maximum Resource value	Reserves and Margins	Review Threshold
Spacecraft and Instrument Resources and Metrics	Mass	209.5 kg	252 kg	Reserve and Margin: 42 kg; 20%	238kg See Sec. G.4
	Power (orbital avg.)	216.5 w	290 w	Reserve: 40 W; 19% Margin: 35 W; 14%	240 w See Sec. G.4
	ADCS Pointing Knowledge	±40arcsec (3σ)	±72 arcsec (3σ)	80% Margin	±60 arcsec (3σ)
	Microprocessor Utilization	28 MIPS	327 MIPS	Margin: >10x	100 MIPS
	CPU Memory	17 MB RAM	64 MB RAM	Margin: 276%	32 MB
	Data Storage Memory	1.33 Gbits	3.0 Gbits NVM (Science Allocated)	Margin: 2.7 Gbits, 124%	2.0 Gbits
	Link Margin	>9 dB	>3 dB min	>6 dB	3 dB
	Data Downlink Volume	2.73 Gbits / day	3.84 Gbits / day	Margin: 40 %	3.0 Gbits / day
	IPA C.G. offset from LV Axis	0.2 in.	0.5 in.	0.3 in.	0.4 in.
	Lowest Res. Frequency	75 Hz	> 35 Hz	114%	45 Hz
Program	Schedule	See Sec L	See Sec L	18.5 weeks Reserve: 11%	9 weeks
	Launch Date	Flexible	See Section L		
	Budget	$ 74.1M	$ 81.22M	20% on phases C/D	Reviews are held if spending is 15% over resource use plan (Fig. G-9)
Institute	Facilities	All of the AIM team institutes providing flight hardware have significant experience in programs of the scope of AIM. Their participation in AIM is not large compared to other recent programs and therefore does not pose any risk in terms of lack of available facilities or personnel. See Appendix M2.			
	Human Resources				

volvement by the AIM Science Team. The HU PC monitors the budget and schedule. AIM E/PO is unique in its focus on underserved populations. HU, the PI institution, is an HBCU and because of this and the AIM E/PO Director's more than 20 years E/PO experience working with needs, educational approaches, cultural sensitivities, and teachers from schools serving minority students, the AIM E/PO team has a great advantage in knowing how to reach the underserved minority population.

Unique Tools, Processes, or Methods. No unique management tools, processes or methods are needed or used to develop and implement AIM. Tried and proven methods resident among the team members will be employed.

G.3 Schedules

The AIM schedule, workflow and mission life-cycle is clearly defined because of a highly productive Phase A study. Methods for internal review, cost control and management direction are in place.

Schedules. The AIPS (**Fig. G-6**) is the "integration" of the WBS Level 2 and Level 3 schedules, as developed for each phase by the respective team members. A total of 18.5 weeks of funded schedule reserve is included (see reserve use approach in Fig. G-9). Detailed Phase B, C and D schedules are shown in **Fig. G-7** and **G-8 on FO-G1.**

Scheduling is done with consideration of the work and corresponding budget estimates. During Phase B, attention will focus on leveling personnel loading across the WBS to ensure time commitments are less than or equal to full time. Schedules will be fit to the funding profile to assure that adequate fiscal resources will be available to complete work packages on schedule within the AIM budget.

The mission-level milestones are shown at the top on the AIM Integrated Project Schedule, with supporting instrument milestones detailed below. Instrument and spacecraft peer reviews are indicated on the schedule (also Fig. G-7), with the detailed order of reviews tracked on the Level 3 schedules. Engineering model development for the key systems will be complete by the PDR. It is anticipated that all development risk for subsystems currently below Technical Readiness Level-7 (TRL-7) will be retired by the end of Phase B.

Instrument Schedule. As noted in Section G.2, systems engineering starts with establishing the system-level architecture, then flowing requirements down to the subsystem level, and establishing ICD's. Verification planning then begins, followed by execution of the test and verification procedures. This cycle is duplicated for the quality assurance planning and implementation. Subsystem testing is mandated at the component, subsystem and instrument level. Consistent testing in this fashion has been shown to eliminate many of the small issues early permitting concentration on the key system issues at higher levels of integration. Our instrument schedules allow for instrument performances to be well characterized and calibrated prior to delivery to the IPA. Instrument schedule lengths up to delivery to IPA are: CDE–29 months; CIPS–31 months; SOFIE–32 months, and SHIMMER–33 months. IPA testing occurs at LASP with time to debug issues at the platform level prior to proceeding to BATC for full spacecraft integration and testing. Seventeen days of funded slack are in the IPA I&T phase.

Subsystem Schedules

IPA Schedule. Five months are scheduled for IPA integration. Instruments arrive at least one month apart to allow individual instrument tests on the IPA. Three and a half weeks of fully funded schedule reserve is available if needed.

Spacecraft Schedule. The spacecraft schedule is currently 24 months from spacecraft start to the integration with the IPA. There is currently 7 months of slack created by the 24-month schedule matching with the instrument 31-month schedule. The 7-month period is currently funded as a level of effort activity for BATC. BATC has developed the details of its schedule to meet the required reviews and milestones in Phase B.

IPA Integration with the Spacecraft. Once testing of the IPA is completed at LASP, the IPA assembly will be delivered for integration to the spacecraft. Three months of schedule time is allocated to this activity including three weeks of funded slack.

Delivery to the Launch Site. Delivery to the launch site is currently scheduled for July 5, 2005 with launch scheduled for September 30, 2005, providing about 60 days of additional slack—again funded. Should issues arise precluding the September 30th launch date, it's possible to slip the launch to the end of October and observe the first PMC season. This could be considered as slack reserve as it provides an additional four weeks of slack, albeit unfunded.

Critical Path. The critical path for AIM runs through the instrument development, integration

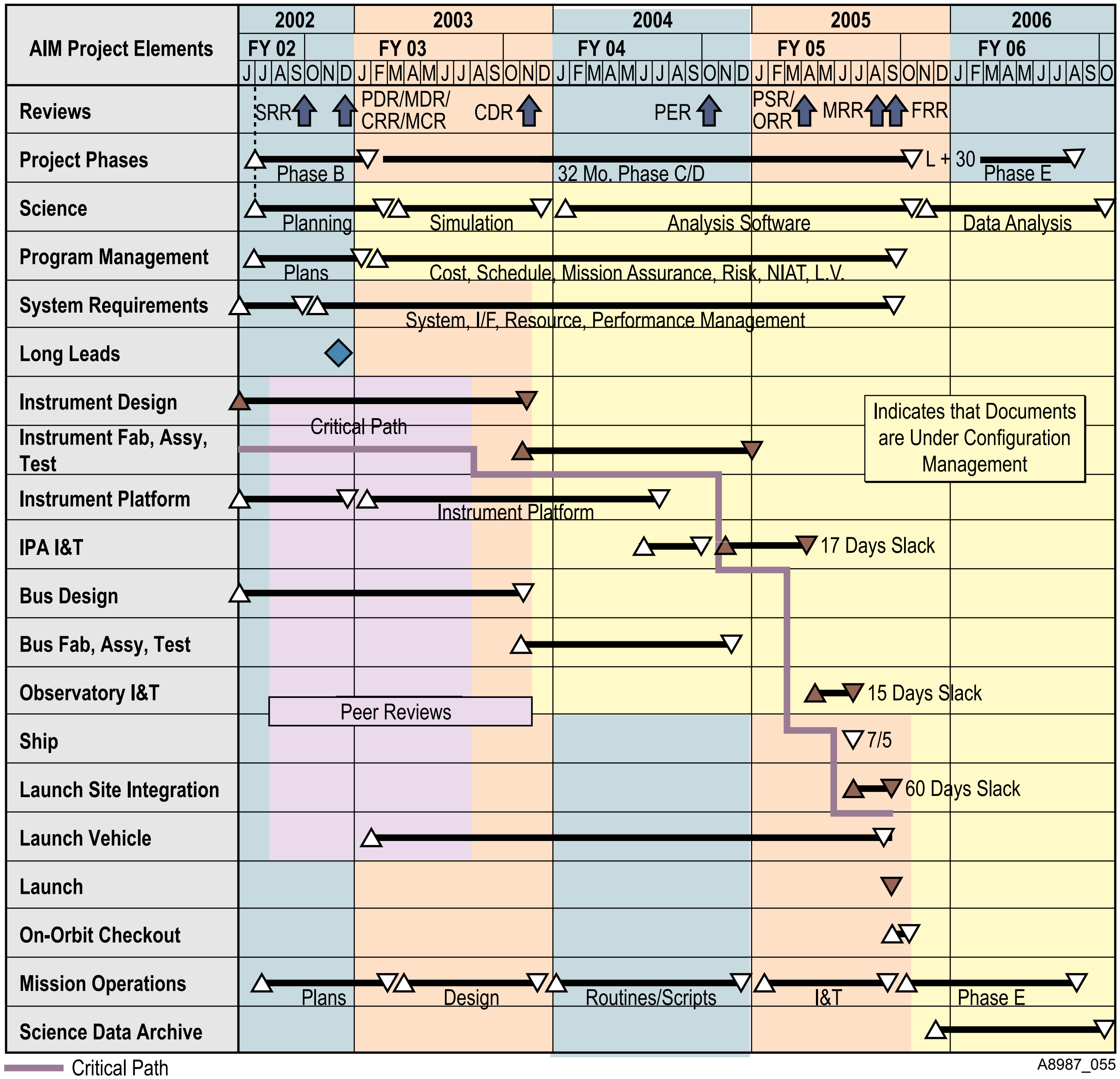


Figure G-6. AIM Integrated Project Schedule

and test of the IPA and final integration with the spacecraft (red line in Fig. G-6).

Long-Lead Procurements. Long lead procurements include the following:

- CIPS and SHIMMER detectors
- SOFIE detectors with Winston cones
- SOFIE infrared filter design and pointing system
- SHIMMER monolithic interferometer

Control and Direction. Control and direction comes from the PM with oversight by the PI, input by the IPDTs, and the advice (as needed) of the AIM councils described in Section G.2. Action on any major milestone changes (e.g. instrument assembly, start of a performance or calibration test) that affect only one AIM system will be decided by the PM with PI notification. The PM and systems IPDT will provide advice, establish new guidelines for that system and monitor future progress. A major milestone change that occurs within an AIM system that will affect other systems (such as a domino schedule effect) will trigger a MC council to develop options, establish work around approaches, and give guidance to.

Foldout G1

the institutional partner regarding extra resources needed at his or her institution. When required, the EAC will be consulted. If no mitigation efforts are possible, the PM uses reserve with the concurrence of the PI to resolve major schedule issues. More information on schedule management is included in G.4, ***Reserves and Reserve Management***

G.4 AIM Risk Management

AIM risk management plans and approaches build on methods established by AIM team partners in past highly successful mission developments.

The overall objective of Risk Management and Risk Assessment for AIM is to apply a project-wide structure for assessing risk to understand the probability and impact of such risk, and proactively managing the risk by making appropriate decisions based on 1) the likelihood that an undesired event will occur, and 2) the severity of the consequence should the event occur.

The AIM PM will develop a risk assessment approach for the project, and document the risk for the PI and NASA visibility. The LASP Project Office will have an overall Risk Manager and each partner will devote at least one-half full time equivalent (FTE) to risk identification and mitigation for their effort. A risk analysis in Phase B will culminate in documented risk list, mitigation plans and assessments of the success probability of each plan. Mitigation plans will address the near- and long-term activities required to offset the risk, including the potential effects of those activities on other program elements. LASP, the PI and NASA will jointly evaluate the mitigation options, with the PI deciding the appropriate action.

AIM Risk Management Approach, Top 3 Risks and Mitigation Approaches. The AIM anticipated risk areas shown in **Table G-5** were identified and the planned mitigation approaches discussed and agreed upon. **Table G-6** describes the AIM top three risks, mitigations, outcomes and actions required.

Mass is identified as the top risk. We have very carefully indentified flight hardware down to the subsystem level, and in places down to the component level, its maturity and any changes needed in the existing hardware. We have taken account of the hardware current status and estimated the maximum likely mass growth (1 to 35%) according to the guidelines described in ANSI/AIAA G-020-1992. The result is a current 20% reserve + margin total. We note that 25% is often allocated to less mature system components. During the project, mass tracking will be a principle focus of the ASE and his staff. In Phase B a fully-detailed AIM MEL will be developed down to the component level. Monthly tracking of mass is performed to assure that growth will not occur beyond the present allocation.

There are two mitigation strategies for handling unforeseen mass issues. The first involves modifying the IPA structure. Initial FEM models of the IPA indicate a very comfortable 75Hz first mode —significantly above the 34 Hz required by the spacecraft. One approach to "creating" additional mass reserve is to further lightweight the structure. Currently the IPA structural mass fraction is ~30%. Typical spacecraft primary structures can be expected to be 15% (ref. Spacecraft Mission Analysis and Design). A second alternative is to change out the aluminum honeycomb structure in favor of a composite structure. We estimate that these changes would result in a 3 to 7 kg (respectively) increase in mass reserve. A SMF of 15% would yield 15 kg of savings resulting in overall-reserves and margins of 30%.

The second strategy involves the Pegasus

Table G-5. Anticipated AIM Risk Areas and Planned Mitigation Approach

Risk Area	Mitigation
Changing requirements	The AIM systems engineer documents measurement requirements, and flow down to hardware subsystems. Requirements configuration is actively managed.
Procurement risk	Key long lead and critical procurements will be tracked by the respective organization
Development and technical risk.	Use of appropriate technology, heritage designs, computer models and early testing at the component level and at each subsequent level of integration.
Cost and schedule risk	Adequate reserves across project. Slack in schedule. Cost and Schedule Status Reviews. Earned value metrics. Parallel production of spacecraft and instruments. Parallel testing of instrument complement and spacecraft bus.
Facility risk	Management systems in place at all organizations to schedule facility use.
Manufacturing risk	Identified manufacturing facilities.
Organization and staffing risk	Key experienced staff identified. Staffing plan identified.

Table G-6. AIM Top Three Risks and Mitigation Plans

Item	Risk	Mitigation	Outcome	Action Required
Mass Reserve	Reserve and margin = 20%	Described in text	Described in text	• Assess in Phase B • Aluminum or composit decision point early in Phase C
CCD Detectors For CIPS	Detector fabrication quality	Procure eng. model	• Validate assembly quality	• Implemented in Concept Study • LASP PA will oversee assembly on-site if necessary
	Flight delivery delays	Procure eng. model	Remove delivery uncertainty	• Implemented in Concept study • Place long lead contract to vendor
	Detector performance	Procure eng. model	• Validate performance	• In process • Back-up CCD identified if required
SOFIE HgCdTe detectors	Detector fabrication quality	Procure eng. model	• Validate assembly quality	• Planned activity for Phase B
	Flight delivery delays	Procure eng. model	• Remove delivery uncertainty • Develop vendor relationship	• Planned activity for Phase B
	Detector performance	Procure eng. model	• Validate performance	• Planned activity for Phase B

launch vehicle. Preliminary discussions with Pegasus indicate there are several potential ELV changes that could result in increased payload mass to the 500 km orbit. Examples are: 1) use of the planned upgraded rocket motor; 2) off-load of some of the HAPS hydrazine; 3) decrease the number of batteries; and 4) release the payload fairing earlier. These changes would increase the lift capability to 500 km by about 12 kg. This second strategy alone would add an additional 7% to the current reserve if all were selected. Of course the AIM team and NASA would need to evaluate such changes and determine their impact on flight success.

Table G-7 discusses the mitigation techniques to be used throughout the project. AIM incorporates risk management approaches used for past instrument and spacecraft efforts by the respective AIM organizations and the PM will, in implementation, formalize this process. As part of this effort the AIM Project will contract out the Failure Mode and Effects Analysis (FMEA), Fault Tree Analysis (FTA) and Probabilistic Risk Assessment efforts to an independent group. This independent assessment of the AIM system design, and results from this study, will be incorporated to minimize the probability of failure.

A TRL assessment was done in the Phase A concept study on all instruments and the spacecraft (on FO-F2). From this exercise, trade studies were identified and have proceeded through the CSR phase to further reduce risk and advance the TRL level of the trade area.

Reserves and Reserve Management. *The AIM project has adequate technical and programmatic reserves (cost, schedule, mass, power, and data) budgeted into the project baseline.*

Reserves in Cost, Schedule and Technical Resources by Phase, Project Element and Year. Cost, schedule, mass and power reserves, their permissible use by project phase and major element and planned total cost expenditures are shown in **Fig. G-9**. The plan is to hold the maximum amount of reserves throughout the development but experience shows that portions of the reserve will have to be used at times due to unforeseen issues. AIM resources will be managed to the green area of Fig. G-9**.** Any planned uses that would move into the yellow area will be considered serious triggering (IPDT) or Management Council interaction.

It is planned that no more than 5% of cost reserve will be used in Phase B since preliminary designs are in process. No more than 45% may be used in Phase C as designs proceed to CDR and systems are defined in more detail. No more than 45 % may be used in Phase D to handle unforeseen material and labor issues associated with build, test and calibration. The remaining 5% will be held for Phase E. One and a half weeks schedule reserve use is allocated in Phase B to handle minor unforeseen problems. Three additional weeks may be used for Phase C leading up to CDR with most of the schedule reserve (~ 8 weeks) being held for Phase D to cover build, test and calibration issues. The use of as much as 75% of the mass reserve will be permitted up to CDR when the designs are firmed up with the remaining held in Phase D to cover growth occurring during build. Power reserve use of as much as 60% will be permitted up to CDR with the remaining 40% available for use in the build phase

Table G-7. Activities Included in the Risk Mitigation Process

Process	Focus	Attributes
1. Peer Reviews	- HW and SW - Action Items - Formalized tracking - Closeout by systems IPDT	- Earliest review point for HW and SW levels for S/C, instruments, stages of programs, launch vehicle interface, operations, etc. - Experienced in-house reviewers. Outside participation by expert(s). Invitation to Red Team to attend.
2 System Reviews	- HW and SW - Action Items - Formalized tracking - Closeout by Systems IPDT	- Full set of reviews - Experienced review team from NASA, industry, and academia. Invitation to Red Team to attend.
3 I&T Plan	Verification and validation of performance at unit, instrument, spacecraft, observatory, and mission levels for hardware and software.	- Test plans at the unit level, S/C and integrated mission level. Verification plans for each. - Test Flow Plan and certified I&T facilities - Contamination Control Plan - Test Anomaly Tracking - Software development facilities and test approaches
4 Mission Assurance	AIM Product Assurance and Implementation Plan (PAIP)	- Quality, reliability, and safety plans (adopt existing policies - Parts selection and derating plan - Workmanship standards - SW assurance processes - Waivers and deviations requests
5 Systems Management	Mission Systems, Instrument System, and Spacecraft Systems Engineering Process	- Experienced project systems engineer - Systems engineers for S/C and instruments - System engineering IPDT - Formalized requirements tracking process - Mass, power and margin tracking and control - Configuration Management - Documentation and records control - Risk management and metrics (dedicated person) - Requirements verification matrix
6 Staffing and Experience	Organization chart(s) for Project Office, Instrument(s), Spacecraft, and Mission Ops	- Responsive management structure - Experienced managers and lead technical staff - Established business systems
7 I&T	System level testing, issues, problems, and resolution for HW and SW from earliest assembly though mission systems testing.	- Focus on testing at earliest levels - I&T schedule protection with contingency plans - Formalization of results tracking - Formal anomaly resolution - System engineering IPDT disposition - Common test software
8 Long term test	Failure-free and total operating hours for all hardware and software.	- Minimum failure free run time
9 Technical Review of Results	Tracking, closeout and reporting	- TAWS and RFA formal tracking systems - Origination processes - Close out processes - Reporting plans to NASA and Red Team
10 Training for Mission Simulations, Launch, and Operations,	Amount, level, and fidelity of training plans for the flight operations team on launch and on-orbit operations including contingency operations.	- Flight ops training plans for launch and operations - Contingency plans - Mission timeline critical events - Standards for training - Certification
11 Subsystem FMEA, FTA, PRA	Required FMEAs, FTAs, and PRAs for the mission - Probability of occurrence - Criticality assessment - Failure mitigation plans	- Independent assessment by outside contractor - FMEA of critical systems - Fault tree analyses - Probabilistic risk assessment - Single point failure analyses

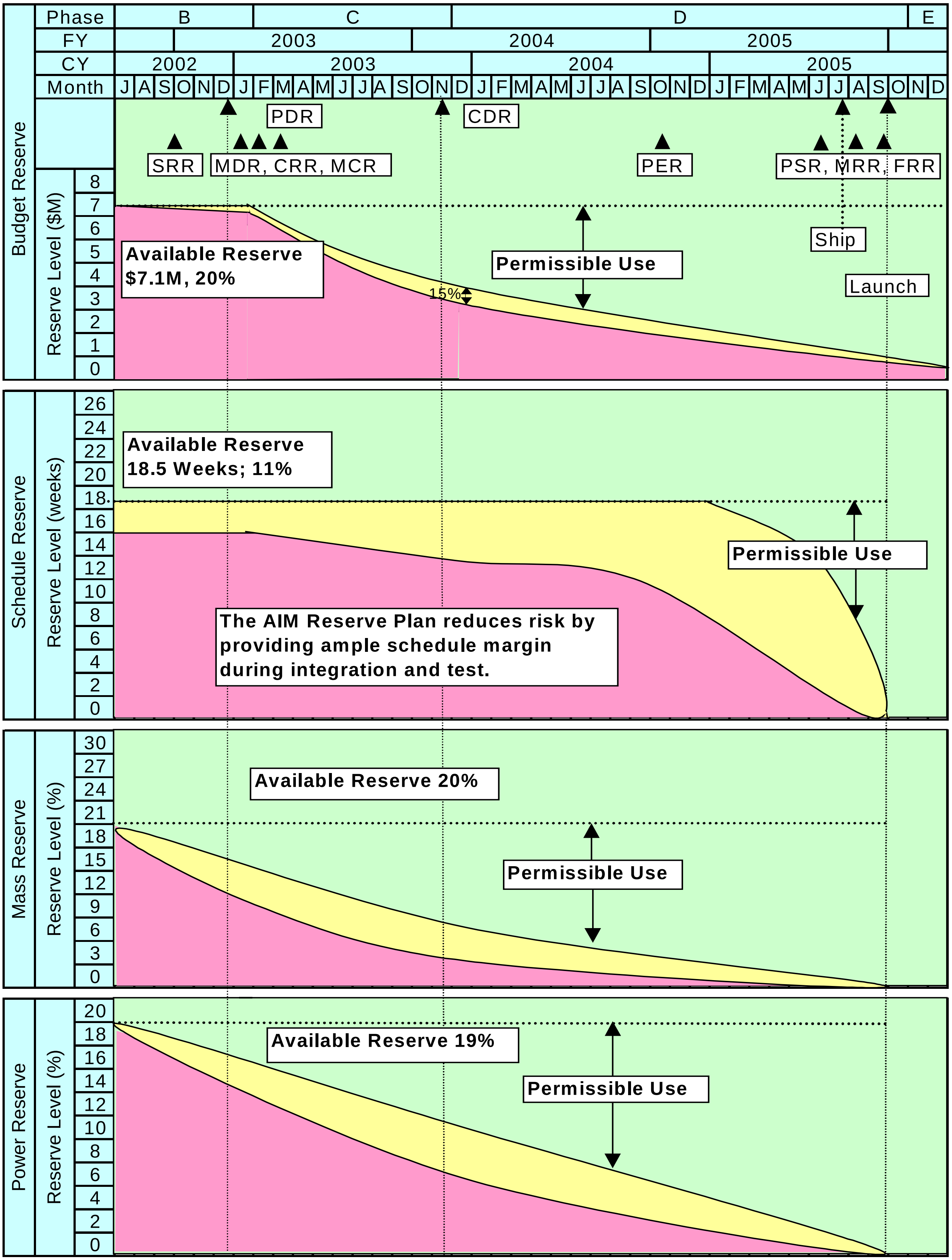


Figure G-9. Cost, Schedule, Mass and Power Reserve Permissible Use when reality sets in as actual circuits are built and components are purchased.

Reserve Management. The AIM team has developed an ordered, methodical, and efficient approach for reserve management decision-making (Section G.2). The final authority on the AIM team is the PI who has overall responsibility for all aspects of the AIM Project. In carrying out the day-to-day activities, specific decision making authority is delegated to the PM who further delegates to the lowest level, with decision making guided by a set of project rules discussed below. Issues regarding E/PO will be decided by the Co-PI, with PI concurrence, after discussion in the E/POC. Compartmentalizing schedule and costs and tracking these with the WBS is the central focus of the reserve management plan. These resources will be managed at the WBS Level 4. Decision approaches to technical, schedule and cost resource management are discussed below and summarized in **Table G-8**. Schedule management was also discussed in Sec. G.2 and G.3.

Spacecraft and Instrument Mass and Power and Data Rate. Data rate capability of the RS300 and downlink sites far exceeds AIM requirements, leaving the focus on mass and power. Use is tracked by the systems engineer, made available to the PM when changes occur, and requests to allocate reserve are evaluated in the Systems IPDT using the guidelines in Fig. G-9. The ASE may use mass and power reserve if the requested change uses reserve in the green area and the concurrence of the PM is obtained prior to implementation. If the change results in reserve use into the yellow area, the systems IPDT will discuss it, the PM will make the decision and inform the PI. If the change would result in reserve use in the red area, the issue is brought to the MC for discussion, problem solving and allocation adjustment consideration and the PM makes the decision with PI concurrence.

Schedule. All schedule reserves are funded. If the change affects only one instrument or is in the green area, the PM decides and informs the PI. If it affects more than one instrument or is in the yellow area, a MC council is held and the PM decides; if more than one and in the red area, a MC is held and the PM decides with PI concurrence.

Costs. Budgets and costs for the project work packages, both projected and as-spent, will be tracked in the AIM Integrated Budget (AIB) created in Microsoft Excel. The AIB will be linked to each team member institution's budget. Earned value, progress and milestone tracking will be performed by the AIM Management Team using schedule and cost performance metrics derived from these tools. The PM decides cost reserves use in the green area and informs the PI. If the request results in reserve use in the yellow area, the PIC will discuss all issues and the PM decides cost reserve use in the green area. If costs during the year exceed the earned value expectation, this will trigger a PIC discussion resulting in suggestions, plans and approaches for detailed evalua-

Table G-8. Decision Making Approach for Reserve Allocations

How are resource management decisions made?									
Mass and Power			Schedule			Cost			
Does the change result in the parameter being in the green, yellow or red area of the reserve allocation curves?			Does the change in milestone affect one or more instruments? Green, yellow or red area?			Is the reserve request in the green, yellow or red area of the allocation curves?			
Within use plan	Exceeds 1st tier use plan	Exceeds 2nd tier use plan	One or within use plan	More than one or exceeds 1st tier use plan	More than one or exceeds 2nd tier use plan	Within use plan	Exceeds 1st tier reserve use plan	Exceeds 2nd tier reserve use plan	Exceeds earned value expectation
ASE Decision PM Concurrence	Sys. IPDT Discussion PM Decision PI Notification	MC Discussion PM Decision PI Concurrence	PM Decision PI Notification	MC Discussion PM Decision	MC Discussion PM Decision PI Concurrence	PM Decision PI Notification	PIC Discussion PM Decision	MC Discussion PI Decision	MC Discussion PI Decision

tion of the system in question to determine the problems and to assist in developing solutions that will guide PM action. If a request results in reserve use in the red area, a MC will be held to assess the problems and discuss solutions to guide the PI decision on actions that facilitate a recovery at a selected point downstream. The management and systems IPDTs will be called on to advise the MC and where deemed necessary by the PI, the EAC will be called on in this situation.

Reserves, Potential Descope Options and Their Effect on Cost, Schedule and Performance. **Table G-9** shows a series of reserve recovery options and their impact on budget, schedule, mass and power reserves. Some of these options are science descopes and their effect on science is indicated along with the latest point in the program development when the decision can be made. The minimum mission and effects on science are described in the Science Section E.2.3. The baseline mission consists of the four AIM instruments flying on the RS300 S/C for 23 months (2 PMC seasons in each hemisphere). The minimum mission with the descopes discussed below still allow 85% of the science objectives to be met. Only five options have an important impact on science objectives, i.e. reduction of mission lifetime to one year, removal of CDE, SOFIE or SHIMMER and reduction of CIPS to three cameras instead of six. Should descopes be required, the first option will be to reduce mission lifetime for a savings of $3M. Beyond that, if CDE is removed, it still may be possible to get some information on cosmic dust changes using the SOFIE low wavelength channel thereby addressing Science Objective 5 concerning nucleation sites for PMC formation. Thus CDE would be the first instrument to be removed. Reduction of CIPS to three cameras would be next because only spatial coverage is diminished still allowing all objectives to be met. Removal of SHIMMER would be next because it has a smaller science impact (three science objectives) than removal of SOFIE (four objectives). The other options in Table G-9 offer ways to manage reserves without science impact. The strategy for maintaining reserves as a function of cost-to-completion was described earlier in this section.

G.5 Government Furnished Property, Services, Facilities

No new facilities or equipment are required. AIM does require funding of a launch opportunity on Pegasus and the services of NRL for the SHIMMER instrument.

A draft Payload Interface Control Document was submitted to NASA/KSC to assure that costs budgeted for the Pegasus launch vehicle are sufficient to support the required services. This was confirmed in an e-mail message from Mr. Darrell Foster of the Kennedy Space Center (KSC) that is included in Appendix M1. The real year costs presented in the AIM proposal were adjusted to reflect an approximate later launch date.

Orbit tracking and data transmittal support will be purchased through the NASA Consolidated Space Operations Contract (CSOC) and thus is not considered to be Government Furnished Equipment (GFE). NSC altitude data is obtained by internal NRL arrangement as part of the SHIMMER effort is also not considered GFE.

G.6 Reviews

The AIM plan includes major reviews proven by experience among AIM team partners to be essential for successful space hardware development and implementation. The plan establishes a new system for E/PO program review.

AIM will use formal and informal review processes.

Scientific and Technical Reviews. The required reviews for Earth Explorers projects/missions are the System Requirements Review (SRR), Preliminary Design Review (PDR), Mission Design Review (MDR), Confirmation Readiness Review (CRR), Mission Confirmation Review (MCR), Critical Design Review (CDR), Pre- Environmental Review (PER), Pre-Ship/Operational Readiness Review (PSR/ORR), Mission Readiness Review (MRR), and Flight Readiness Review (FRR). The scope and function of these required reviews are described in **Table G-10**. Review processes for each of the instruments and spacecraft are discussed briefly next.

Instrument and Spacecraft Reviews. Reviews for the spacecraft, instruments and ground systems will be those listed in Table G-10. BATC, SDL, NRL, LASP and GATS will participate in each review. Less formal peer reviews will be used in advance of these reviews by the performing organization to provide time for understanding details of the component systems and the degree to which requirements are fulfilled. Periodic internal progress and status reviews will be presented to higher organizational management.

E/PO Reviews. The E/PO program will be reviewed at the time of the SRR, PDR, CRR and CDR major program reviews. Approximately at the time of the CDR, the E/PO Program Evaluation and Research Group will begin activities and

Table G-9. Reserve Recovery Options by Mission Development Phase and Science Impacts

Reserve Recovery Options	Budget Reserve		Schedule Reserve		Mass Reserve		Power Reserve		Science Impact	Latest Decision (weeks)	Comments
	Total ($M)	Ph C-D (%)	Ph C/D (wks)	Ph C/D (%)	Total (kg)	Total (%)	Total (W)	Total (%)			
Current Status	7.1	20	18.5	12	43	20%	50	9%			
Extra shifts, weekends	0	0	<8-13	+ <5-8	-	-	-	-	-	Any time	Depends on time of decision
Reduce reviews for NIAT	+ <0.7	+ <1.9	+ 6	+ 32	-	-	-	-	None	PDR	Increases risk
Use lighter materials in IPA	- 0.25	- 0.7	-	-	+ 7.5	+ 3.5	-	-	None	CDR minus 10 wks	More costly material
Remove star tracker	+0.25	+0.7	-	-	2.5	1.6	10	-	Perf. Loss	CDR	SHIMMER alt reg to 1 deg
Reduce mission lifetime to one year	+ 3	+ 8.3	-	-	-	-	-	-	Perf. Loss	CDR	See Section L
Reduce CIPS to three cameras	+ 0.6	+ <.6	-	-	+ 4.8	+ 2.2	+ 6	+ 2.3	Perf. Loss	CDR	Reduced spatial coverage
Reduce number of SOFIE channels (each)	+<.2	+<.6	-	-	+ ~ 1	+ ~0.5	+ 5	+ 1.9	Descope	CDR	Insignificant help
Remove CDE	+1.0	+2.8	0	0	+ 1.5	+ .7	+ 2.5	+ 1	Descope	CDR	Affects objective 5
Fly only SOFIE and CIPS **	+3.9	+10.8	+6	+ 4	+ 25.5	+ 12	+ 24.6	+ 9.3	Perf. Loss	CDR	Impacts three science objectives(1,3, and 4)
Fly only SHIMMER and CIPS **	+4.7	+13.1	+6	+ 4	+ 40	+ 19	+ 43.5	+ 17	Perf. Loss	CDR	Impacts four science objectives (1, 3, 4 and 5)
Reduce function of PDC	+0.9	+1.11	-	-	-	-	-	-	Perf. Loss	Launch	Data access reduced
Remove Guest Investigator Program	+ 0.25	+ 0.7	-	-	-	-	-	-	None	Launch	Reduces science return
Increase T of SHIMMER CCD	-	-	-	-	-	-	+ 2	0.8	Perf. Loss	On-orbit	Reduces meas. Precision
SHIMMER powered in 1 hemisphere	-	-	-	-	-	-	+ 4	+ 1.5	None	On-orbit	Offers some power reserve
Reduce observations in off seasons	+ 1	+ 2.8	-	-	-	-	-	-	Perf. Loss	On orbit	May miss some clouds

*+X refers to the amount of resource gained by the action; e.g. removing CDE adds 1.5 kg to the available mass reserve or 0.7% to the total reserve. **Can only descope SHIMMER or SOFIE but not both in order to meet objectives.

provide ongoing review of the program throughout its life.

G.7 Reporting

The AIM plan establishes clear reporting methods and processes that will be implemented by a management team with extensive experience in space hardware management and space flight implementation.

Reporting Process. HU is the sole contracting point with NASA and issues and manages subcontracts with LASP and GATS. Launch vehicle and NRL funds come directly from NASA to the individual institutions. LASP manages sub-

Table G-10. Review, Purpose Timing and Chair of AIM Reviews			
Review	**Objectives**	**Timing after start**	**Chair**
SRR	1st major review. ***Formally examine agreed-to*** science, operations and technical requirements including requirements traceability.	3 months	GSFC System Review Off. Code 301
PDR	Examine preliminary subsystem and system component designs for technical feasibility with respect to mission requirements; assess mission design at the subsystem and system levels	5.5 months (after def. of science/tech. requirements)	GSFC System Review Off. Code 301
MDR	***Confirm***: final design, fabrication and test plans for each subsystem; final ICDs; mission integration and verification plans; full programmatic plan through launch; requirements flow-down traceability; risk identification and mitigation plans including descopes; complete cost, schedule and resource plans; complete ground and systems architecture; final science requirements definition; complete definition of roles /responsibilities of all team members	7 months	GSFC System Review Off. Code 301
CRR	Earth Explorers ***gate for mission approval*** to move to Phase C. MDR findings presented to GSFC GPMC for mission confirmation. Outcome is confirmation or conditional confirmation pending action item closure	After MDR	GPMC Chair
MCR	GPMC and Explorers Program Office present results and recommendations of the CRR to NASA OSS for final approval to proceed into Phase C/D	After CRR	OSS AA
CDR	***Gateway to approval*** to start flight HW manufacturing and flight SW coding. ***Review***: implementations of design approaches, mission ops. Planning and test planning for all systems. Manufacturing may begin for long-lead items prior to CDR as needed to meet schedule, with Explorers Program Office approval.	16 months	Red Team GSFC System Review Off. Code 301
PER	Purpose is to ***assess readiness*** of flight hardware, SW, and required environmental test facilities for acceptance testing. ***Review***: changes since CDR; status of non-conformities; test documentation (plans, procedures, waivers) and facilities readiness; HW and SW configuration; mission operations status	27 months (prior to full sys. integ. and func. test)	GSFC System Review Off. Code 301
PSR	***Verify***: all elements meet mission requirements and are ready to proceed to final launch preparations including: flight hardware and SW testing complete with no open issues; system requirements; final hardware and SW configuration; disposition of waivers, deviations, open issues; test results showing S/C and ground support equipment compatibility; results of end-to-end system testing; orbital operations plans; mission operations ground system and data processing system readiness; launch system readiness (interfaces); evaluation of acceptance data packages	35 months	GSFC System Review Off. Code 301
ORR	Assess readiness and documentation of final details of the approach to be used for flight operations	Part of PSR	GSFC System Review Off. Code 301
MRR	Review all components of mission readiness including: project status; science objectives, mission performance, and readiness of: instruments, spacecraft, ground systems and launch service; launch site assessment; resolution of open items, liens, and waivers; public affairs plan. Result is certification to proceed towards launch.	37 months	GPMC Chair OSS AA
FRR	***Purpose***: to certify final flight readiness of all mission elements. All open issues from the MRR must be resolved before the FRR. Review takes place at the launch site.	39 months	Red Team GSFC System Review Off. Code 301
Peer Reviews	***Purpose***: Evaluate all designs at various stages with the help of outside, NASA and Red Team reviewers. Critique and input given while design is in progress to reduce redesign and significant changes. Formal actions recorded, assigned and tracked.	Throughout development	AIM PM and Instrument and S/C PMs
Weekly Management Reviews	***Review***: top level management issues including schedule, cost, problem solving, reserve allocation and general high level status. Accomplished using tele- video- and webcast conferencing as needed. PIC, ASE and invited staff participate.	Throughout development	PM

contracts with BATC and SDL. The PI maintains authority over the flow of funds to the launch vehicle provider and NRL and receives schedule, cost, status, progress and problem reports directly. HU is responsible for overall AIM cost reporting requiring Level-2 cost/schedule status report (C/SSR) cost reporting from subcontractors aimed at identifying problems early in their development through the identification of spending anomalies. Status Reports and Financial Reports are critical to keeping the SMEX management team apprised of project status, accomplishments and issues. Reports are provided to the NASA SMEX program office by HU on a periodic basis. AIM managers and key staff convey the project's accomplishments, areas of concern, actions, milestone tracking and schedule status. Schedule updates are discussed, along with MRB and Deviation/Waiver events, ECR/ECOs, and notice of problems or issues. A top ten list of problems/issues/tall poles and the "Fever Chart" is reviewed. This information will be conveyed in either telecon, written or in-person presentation format. Formal documentation will be archived at LASP and available for review by request. HU will submit a financial report on Government Forms 533M and/or 533Q. General progress will be reported to NASA as described below by the AIM PI and the AIM PM. Additional team members will participate as required. Topics to be discussed include:

- Top 10 Watchlist of problems, issues, "tall poles"
- "Fever Chart"
- Current Risk Issues and Mitigation Plans
- Instrument and Spacecraft Progress
- Staffing and Programmatic Review
- Review of Work Package Progress
- Review of Schedule Progress
- Problems and Issues
- Plans for the upcoming month

Types and Frequencies of Reports. AIM reporting will include:

- Quarterly PM report
- Written Monthly Report to SMEX Office
- Telecon Monthly Report to SMEX Office
- Weekly Web-based Progress Summary (after CDR)
- Monthly Progress Reviews

Quarterly Program Management Council (PMC) Report. This report will be presented by the PI at the GSFC. Status, progress, problems and cost for all AIM participants will be covered. Top-level summaries of all the subjects listed above will be included.

Written Monthly Report to SMEX Office. All AIM participants will provide a standard set of charts (developed around topics listed above) with explanatory narrative to the PC at HU for assembly into the written report which will be forwarded to the SMEX Office over the PI's signature.

Telecon Monthly Report to SMEX Office. The Co-PI will develop and coordinate the telecon agenda and the telecon will be led by the PI. Subjects to be covered will always include schedule and cost and others will be selected from the list above as appropriate to current status. Where a specific topic is not covered in a monthly report, its omission is for time streamlining and means that the planned baseline has not changed.

Weekly Web-based Progress Summary. All participants will submit weekly technical progress reports to the PC at HU weekly for submission to the NASA web site. These reports will have the form of short write-ups about recent activities. They are not intended to come from every participant every week.

Monthly Progress Reviews. These reviews will be organized by the PM and nominally conducted by teleconference. As appropriate, a review may be a presentation at one of the partners' sites. The frequency of the reviews may be adjusted if the monthly frequency appears to be too often for the stage of development. Primary emphasis will be on technical progress with only summary inclusion of cost and schedule information. Attendance at these progress reviews may include interested SMEX Office personnel.

G.8 Software Independent Verification and Validation (IV&V)

AIM team members have experience and knowledge in software IV&V and other NIAT requirements derived from a number of highly successful space missions.

The NIAT recommendations applicable to the AIM effort are implemented throughout the AIM project and member institution efforts. The AIM team supports a breadth of peer and project reviews, Red Team Reviews, project and independent risk and reliability assessment efforts, and Software IV&V efforts. Funding for staff specifically identified to support the NIAT efforts has been developed separately from the institutional and project budgets. Guidelines for reviews and team participation have been developed, and will be iterated with NASA following selection to assure an optimal fit to the AIM and NASA goals (Appendix M2). Initial analyses of maturity and risk have been conducted.

Contact has been made with the IV&V facility. NASA's software IV&V process is new, but LASP already has significant experience working with the Fairmont facility on other projects; for example the SORCE mission (very similar in scope to AIM).

An analysis of the consequences of software failure has been made for the AIM project, along with an assessment of failure probability for each of the following components:

- Spacecraft bus flight SW
- Science instrument SW and firmware
- MOC SW at LASP
- POC-DPC SW

Results of these analyses are summarized in **Table G-11** (for the science instruments, the worst ranking is used). The overall ranking of consequence is given in the second to last row of the table, with possible values of Grave (G), Substantial (S), Marginal (M), or Insignificant (I). The last row of the table gives the numeric result of the failure probability analysis for each component.

The results of these two analyses are combined to create **Fig. G-10**, which shows where AIM fits in the IV&V process. The red area indicates that a full IV&V analysis is appropriate. There are no components of AIM that fall into this category. The yellow area indicates where an Independent Assessment of software is appropriate. Bus flight software does fall into this category. We expect therefore that a key part of the AIM IV&V process will be to work with Fairmont on an independent assessment of bus flight software.

Table G-11. Software Failure Consequences

	S/C	Insts	MOC	POC-DPC, PDC
Loss of Life	No	No	No	No
Serious Injury	No	No	No	No
Catastrophic Failure	Yes	No	No	No
Partial Failure	Yes	Yes	Yes	Yes
Equipment Loss	$0	$0	$0	$0
Investment Wasted	8 Yr	3 Yr	3 Yr	3 Yr
Adverse Visibility	Agency	Local	Agency	Local
Operations Effect	Project	Project	Project	Project
Consequence	**S**	**M**	**M**	**M**
Failure Probability	**46**	**39**	**52**	**37**

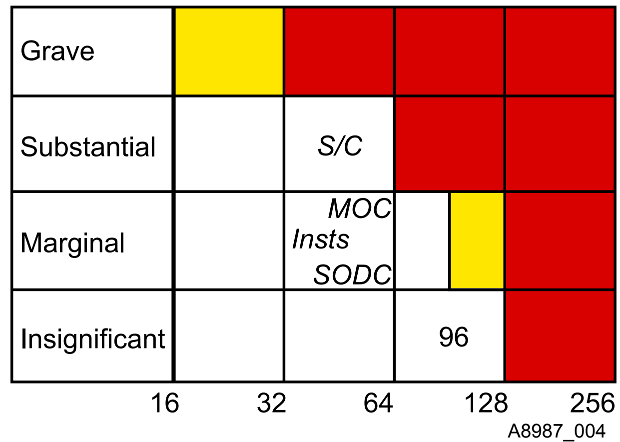


Figure G-10. AIM Software Risk Table

An independent assessment of the all of the AIM mission SW will be undertaken during Phase B, at which time an IV&V Plan will be fully defined and the Memorandum of Agreement (MOA) between the AIM mission and the IV&V facility will be completed. The AIM mission has been in contact with the IV&V facility in West Virginia and has begun work on the generation of a draft MOA for the AIM Mission.

RS300 Bus Flight Software. Refer to Sections F.3, Spacecraft Systems; C&DH; and, Flight Software for a description of the RS300 flight software package. See also **Table G-12** for flight software heritage information.

The RS300 uses standard BATC flight software that utilizes the VxWorks RTOS. Existing software modules from the Deep Impact mission will be used for attitude determination and control, reaction wheel control, command and telemetry processing, and CPU management. Also, the existing module from the BCP2000, used for QuikSCAT, ICESat and other missions, will be used for control of the torque rods. These modules require only database updates, rather than re-

Table G-12. RS300 Flight Software

Component	Provider	Heritage
RTOS	VxWorks	Many missions
ADCS	BATC	Deep Impact
Torque Rod Control	BATC	BCP2000
Reaction Wheel Control	BATC	Deep Impact
Cmd/Tlm Processing	BATC	Deep Impact
CPU Management	BATC	Deep Impact
ASPEN Simulator	BATC	Deep Impact

coding, for mission-unique requirements.

AIM will inherit the ASPEN flight software simulation system that will have been utilized previously for the Deep Impact mission.

Risk Mitigation. The RS300 spacecraft builds on heritage spacecraft software, especially the ASPEN development. Eighty percent of software lines of code (SLOC) will be directly ported to the AIM mission, and will adhere to rigorous reliability analysis, including FMEA, Derating Analysis, and Worst Case Analysis. Additionally, the flight software will be used extensively during AIM's integration and test.

Potential for Catastrophic/Partial Mission Failure. Failure of bus flight software might result in full mission failure and therefore the consequence of failure could be catastrophic to the mission. Likewise, failure of parts of the flight software, such as the ADCS software, could result in the loss of science data.

AIM Payload Flight Software. The AIM payload consists of four instruments, SHIMMER, SOFIE, CIPS, and CDE. We have based our ranking of the payload flight software on the SHIMMER instrument. See **Table G-13** for software/firmware components and heritage.

SHIMMER contains a microprocessor based instrument controller and internal instrument software. The SHIMMER software is derived from a previous NRL Space Science Division project, MAHRSI. See Section F.4.2 ***Software*** for more description of the SHIMMER flight software.

SOFIE and CIPS do not contain any flight software, but since firmware is considered software per the "Software Safety NASA Technical Standard" (NASA-STD-8719.13A), we also performed an evaluation for SOFIE and CIPS. The SOFIE firmware builds upon the heritage of the successful HALOE instrument flying aboard UARS. The CIPS firmware builds upon LASP’s heritage in developing instruments for UARS, Galileo, CASSINI, and SORCE. CDE does not contain any software or firmware.

Risk Mitigation. Risk will be minimized through heritage, testing and design simplicity. Three levels of software testing, functional, component level and system level, will be used for the AIM instrumentation.

Table G-13. AIM Payload Flight Software

Component	Provider	Heritage
SHIMMER Flt SW	NRL	MAHRSI
SOFIE firmware	SDL	UARS/HALOE
CIPS firmware	LASP	UARS, Galileo, Cassini, SORCE, & many others

Potential for Partial Mission Failure. Failure of the SHIMMER flight software will result in loss of science data. SOFIE and CIPS do not present any risk of even partial mission failure due to a firmware problem.

Mission Operations Ground Software. Much of the hardware, software procedures and people involved in the AIM mission operations are currently being used for QuikSCAT. See **Table G-14** for more information on the Mission Operations Software.

Performance of this software has been excellent on QuikSCAT. All project requirements are being met and no QuikSCAT pass has been missed or data lost because of failures within the MOC.

Risk Mitigation. Risk is minimized through substantial use of off-the-shelf software with a long history of success on similar missions, use of the same software during AIM integration and test, extensive testing, and procedural safeguards; e.g. real time command and control software prevents critical commands from being issued without full operator oversight and most spacecraft commands are generated offline and checked before being sent.

Potential for Partial Mission Failure. Because of the safeguards built into the spacecraft, no catastrophic mission failure can occur due to incorrect commands sent from the ground. The only conceivable operational problems would be some loss of science data.

Science Operations Ground Software. The science operations ground software (**Table G-15**) will be distributed between NRL, GATS, LASP (POC-DPCs) and HU (PDC). The POC-DPC's will provide Level 1 and above science data processing, access to retrieved data products, moni-

Table G-14. Mission Operations Software

Component	Provider	Heritage
OASIS-CC	LASP	Over 150 licensed users
OASIS-PS	LASP	SNOE,STRV, QuikSCAT
Tablemaster	BATC	GFO, QuickBird, QuikSCAT
TDP	LASP	ARGOS, Gravity Probe-B (GP-B), SNOE, QuikSCAT
TCAD	LASP	ARGOS, GP-B, SNOE, QuikSCAT
STK	Analytical Graphics	Industry leading software
Attitude Maneuver Planning	CCAR	ICESat
MicroCosm	VanMartin Systems	COTS Version of NASA GeoDyne II

Table G-15. Science Operations Software		
Software	**Provider**	**Heritage**
NRL POC-DPC	NRL	Shuttle mid-deck experiment
GATS POC-DPC	GATS	HALOE, SABER
LASP POC-DPC	CU/LASP	UARS, Galileo, Cassini, SORCE, and many others
HU PDC	GATS	

toring of instrument performance, command requests to the MOC for upload to the spacecraft, and, in the case of NRL, provide instrument flight software maintenance. The PDC will provide search and access functions for all data sets.

Risk Mitigation. POC-DPC software, at all sites, is thoroughly tested with a spacecraft simulator, the actual spacecraft, and all other ground system elements. The software will also go through rigorous testing with simulated data sets from prior, similar instrumentation.

Potential for Partial Mission Failure. The only potential for partial mission failure from the science operations centers would be the upload of erroneous SHIMMER flight software. No other command sequences generated by any of the centers could impact the mission.

H. New Technology; Small Disadvantaged Business Plan

H.1 Small Disadvantaged Business Plan

The AIM Team is committed to and will meet or exceed NASA's SDB contracting goal of 8% of the total available funds (about $50M, exclusive of ELV costs) directed toward Small, Small Disadvantaged and Women-Owned Businesses, HBCUs, and minority educational institutions. HU, an HBCU, alone will receive about 6% of the contract funds which nearly meets the total NASA mandated goal. The combination of this funding and assuming at least 8% of subcontract funds for all AIM partners will bring the total estimated SDB funding to 10%, which exceeds the NASA goal.

H.1.1 Hampton University

HU funding for GATS, a small business, is expected to be about $1.5M. HU is committed to SDB goals contracting and will pursue other possibilities for increasing SDB subcontracting.

H.1.2 LASP—University of Colorado

LASP is committed to support of the SDB program and as on past projects, it will develop an AIM Master Subcontracting Plan in partnership with the university to satisfy the applicable requirements of public laws in this area. Individual goals will be established that include percentages, dollars and a description of products and/or services to be obtained from concerns that fall under the SDB provision.

LASP will receive about $13 M of AIM funding and it will need to devote special efforts to SDB contracting to achieve the 8% goal. LASP currently books its airfares through Boulder Travel, a Small Business. SDB Travel Agents are inconveniently located in Denver, but an effort will be made to book at least one trip through a SDB. Other SB vendors used by LASP are for copies, miscellaneous supplies and hardware, small electronics, photo processing and equipment repair and calibration.

H.1.3 Ball Aerospace & Technologies Corp.

BATC has met or exceeded its SDB goals on all NASA contracts completed in the last three years because of its aggressive, proactive outreach program and commitment to the program. BATC's excellent record of using SDB concerns has led to several recognitions including: "Outstanding" ratings recently received from Defence Contract Management Command (DCMC), a distinction shared by only two other companies in the south central US region; the Small Business Administration's Award of Distinction in 1992; the first DOD mentor-protégé agreement in the space program with Vista Computer Services; finalist among only six companies chosen nationally to compete for the GSFC Contractor Excellence Award, that includes the Small Business Program in the selection criteria. Finally, BATC is a founder and principal supporter of the Boulder Technology Incubator—a nonprofit corporation that nurtures technically based start-up companies in the Denver area.

SDB contracting results at BATC from 1997 through 1999 indicates from 2.5 to 6% per year for all contracts and 2 to 5% for NASA contracts. BATC will receive about $16M of funding for AIM and will need to devote more effort than usual to SDB contracting to achieve the 8% goal.

H.1.4 Space Dynamics Laboratory

SDL's program for SB/SDB is managed through the Utah State University Research Foundation (USURF) contracting office. A "Use of SB and SDB" clause is placed by the contracting office into subcontracts as applicable given the size and nature of each effort. USURF/SDL's traditional and proven approaches for using SDB for subcontracts and purchases are employed wherever possible and the list of potential contractors and suppliers is expanded at every opportunity. SDL, as an instrument lead on AIM, will enthusiastically promote the continued utilization and expansion of SDBs among all of its subcontracts.

Recent SDL SDB contracting on NASA Projects has regularly exceeded mandated goals and varied from 3 to 80% for 5 different contracts. SDL will receive about $7M of funding for AIM and has the potential to far exceed an 8% SDB contracting goal.

H.1.5 NRL Small Business Plan

Established NRL programs provide assistance for socially and economically disadvantaged firms to conduct business with NRL. Through these programs, NRL will pursue SB/SDB/WOSB firms that can furnish goods and services for the SHIMMER investigation.

The PI will be responsible to assess and supervise the SHIMMER acquisition program and to establish SB/SDB/WOSB subcontracting goals. Detailed subcontracting records will be maintained be available for AIM Project Office review. It should be noted that while sources are not yet totally identified to meet the requested goal, as the program progresses, NRL will identify suppliers and subcontracts during Phase B. NRL will further opportunities for SB/SDB/WOSB to the maximum extent practicable.

During FY00, NRL achieved a total of 27.5% for SD/SDB/WOSB funding. NRL will receive about $7M of AIM funding and has the potential to far exceed the 8% goal.

H.2 New Technology

H.2.1 Spacecraft New Technologies

1. Li-ion Batteries. An industry-wide intensive development program has been underway for the past several years to develop Li-ion batteries for aerospace applications. There are four primary aerospace battery vendors, each of which has been developing and demonstrating their technologies through extensive testing. In addition, NASA, Jet Propulsion Laboratory, USAF, Department of Defense (DOD), and the large prime contractors have been testing and qualifying the technology for near-term insertion. Li-ion batteries are baselined for hundreds of proposed missions.

The first flight of a Li-ion battery will take place in 2002 on an experimental European Space Agency spacecraft called STENTOR. The fully qualified battery has been manufactured and delivered by SAFT and is designed for a nine-year mission life in geo-stationary orbit.

Li-ion batteries differ from other battery chemistries in that they are sensitive to overcharging. They also show cycle life and calendar life degradation effects.

Since the technology has not fully matured, the RS300 spacecraft is implementing the Li-ion battery in a very robust fashion. The primary risk areas are addressed explicitly through the battery design. Since calendar life is not a driving issue for SMEX missions, the primary risk areas are cycle life and overcharge protection. The cycle life effects have been shown to be a function of the depth of discharge of the cycles that the battery experiences. By lowering the depth of discharge, the battery capacity degradation is minimized. The RS300 sizes the battery such that the depth of discharge is never greater than 15%. Experimental data have demonstrated the functional life of the battery over 12,000 cycles at this depth of discharge. To protect against overcharge, various charge control methods have been suggested.

To maintain a simple, robust design, the RS300 monitors the voltage of each cell to prevent overcharging any individual cell, while charging the cells at the battery level. To prevent capacity limitations due to varying cell performance over life, an additional cell will be added to the battery so that the maximum charge voltage limit per cell can be maintained at a lower value. This technique reduces the “stress” on the anode and eliminates the possibility of oxidizing the electrolyte. A qualification battery will be procured and tested to flight-like conditions to verify performance for the AIM mission.

Thus, the viability of the use of a Li-ion battery will be guaranteed by a robust design that explicitly addresses degradation mechanisms, and it will be further demonstrated by test.

2. cPCI-VME Bridge Chip. The highest risk item in the SCU is the cPCI-VME bridge chip being designed by Southwest Research Institute (SwRI). According to the latest schedule, the bridge would be completed on radiation tolerant FPGAs by the end of 2000 with the goal of migrating the design to an application specific integrated circuit (ASIC) in 2001. The FPGA design has the vast majority of the functionality of the final ASIC design and would most likely be acceptable for the RS300, if for some reason the ASIC design was not available when we needed it.

If the bridge is not available for our first build, we would make some modifications to the avionics architecture. Several possibilities exist, such as changing to an all VME or all cPCI design. Switching to an all VME design would be the easiest and have the least of impact. There are currently three boards on the cPCI bus—Power PC 750 processor, 512 MB non-volatile memory, and command and telemetry board. The cPCI processor we have baselined is also available in a VME design as are a variety of memory boards. The final board on the cPCI bus is the command and telemetry board. SwRI currently offers a VME command and telemetry module that probably does not have the same functionality as the board we baselined, however, we could add an additional board to recover the required functionality. In this case the overall SCU would be larger, with higher mass and most likely higher power consumption.

3. Heat Switch. The Starsys thin plate heat switch has undergone extensive testing (thermal vacuum, thermal cycling, endurance cycling and random vibration). The Starsys switch has its first flight in July 2002 aboard the NASA PROSEDS spacecraft. Since it contains no "moving" parts the switch is expected to have an unlimited life cycle (currently tested to 100,000 cycles). The first switch fabricated for the RS300 spacecraft will undergo qualification level testing and additional units will undergo acceptance testing. Additionally, the thin plate switch does not experience drift in its activation temperature (the activation temperature is the temperature at which the paraffin melts, resulting in an expansion of volume and forcing contact between two metal surfaces, hence, completing the thermal circuit).

H.2.2 SHIMMER New Technology

The monolithic interferometer is the only new technology in SHIMMER. A prototype funded by NASA's PIDDIP program was shown earlier in Fig. F-22. The first optical test measurements were performed on the prototype using a breadboard experimental setup. These tests included the determination of the Littrow frequency, the angular acceptance of the interferometer and the first assessment of scattered light from the gratings. It's near theoretical performance indicates the maturity of the technology and demonstrates the low-risk nature of SHIMMER. This new technology provides an elegant solution to the demanding requirement that optical elements in the interferometer (beamsplitter, gratings and prisms) be held to arcsec angular and one-twentieth micron linear tolerances. Instead of using a complex, massive mechanical structure to hold the optics individually, they are optically contacted using fused silica spacers between them. As a result the critical alignment between elements is maintained by the parts themselves instead of by an external mechanical assembly. Great care must be taken in the fabrication and assembly of the elements and spacers to achieve the required interferometric alignment, however, once successfully assembled the monolithic interferometer is extremely robust, nearly impossible to misalign, much less massive and smaller than a system employing mechanical mounts.

Due to the robustness of the optically contacted interferometer it is a risk mitigating technology particularly with respect to misalignments during vibration. Once successfully assembled the only risk is in maintaining the integrity of the optical contacts. Studies have shown (Karow 1993) that both the tensile and shear strength of such contacts exceed our requirements. To empirically test the strength of an optical contact we performed successful qualification-level vibration and thermal tests on an optically contacted part with size and mass similar to the SHIMMER interferometer (**Fig. H-1**). During Phase B we plan to perform qualification testing on the prototype interferometer shown in Fig. F-22. If testing indicates

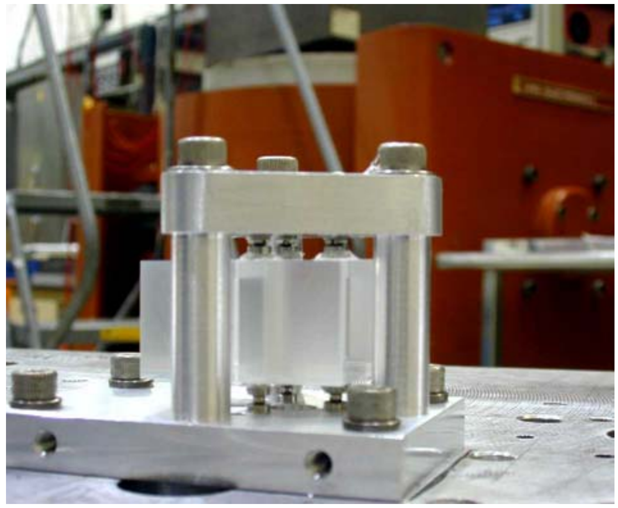


Figure H-1. Demonstration of SHS Optical Contact Flight Worthiness

that the contacts are not strong enough, the design of the AIM interferometer will include reinforcing bars bonded across the optical contacts.

H.2.3 New Technology Status, Risk and Mitigation

Table H-1 summarizes the status, risk and mitigation plans for the AIM new technologies. Note that two of the four items will be flight proven by the time of the AIM application.

Table H-1. New Technology Status, Risks and Mitigations

Item	Status	Risk	Mitigation
S/C Li-ion batteries	Baselined for 100+ flights; space qualified; 1st flight, 9/01	Cycle life; over charging	Reduce depth of discharge application design
S/C VME bridge chip	Design migrated to ASIC in 2001	Availability; radiation tolerance	Use FPGA Design
S/C Starsys heat switch	Extensive testing; 1st flight in 2002	Not space qualified now	Conduct qual. and acceptance level testing
SHIMMER monolithic inteferometer	Part qual. level vibration and thermal tests complete	Integrity of optical contacts	Qual. level test on protoflight interferometer

I Technical Definition (Phase B) Plan

I.1. Overview

Phase will accomplish the requisite project planning and mission systems analysis and trade studies necessary to solidify the AIM preliminary design. These analyses and trades will encompass all elements of the AIM mission including development, launch, mission operations, science operations, and E/PO. Phase B includes the SRR, and shall culminate in a PDR. Due to limited space in this section, combine tasks in Appendix M4 with the below tasks to understand the complete Phase B scope.

I.2. Phase B Plans for Management

The Phase B period from project initiation through the PDR will define and document the baseline design, the minimum mission design, and the implementation plan for all segments of the AIM project.

Hampton University: The PI at HU will provide the overall leadership of the AIM project. HU will (see M4.2.1.1 for other tasks):

- Begin procurement of the Pegasus ELV and NRL with GSFC
- Lead the science team in analyzing and confirming the project requirements definition
- Complete the draft E/PO plan

LASP:

The AIM PM and staff will further establish the management framework for the project, including cost/schedule, risk, mission assurance and all project plans. The activities involved in this work include (see M4.2.1.2 for other tasks):

- Complete the Project Management, Mission Assurance, Risk Management and preliminary I&T plans
- Provide management to cost, schedule, and technical resources as described in the AIM management plan
- Develop the ICD between the spacecraft and IPA, and vice versa
- Support periodic meetings, SRR, and PDR
- Further develop the NIAT program elements within AIM
- Review and complete the WBS and construct the architecture and implement the earned value tracking system
- Implement the requirements tracking system
- Establish the Red Team activities and technical interfaces with NASA
- Interview prospective organizations to perform FMEA, PRA and Fault Tree Analysis
- Create a top ten list of project-wide risks. Formulate tracking process. Coordinate team.
- Conduct workshops where necessary to educate all team members on the management approach, processes and reporting requirements.
- Prepare financial and progress tracking reports as required.
- Provide management of the spacecraft contractor and SDL hardware efforts
- Establish the IPDTs and the IPTs.
- Formalize the resource allocation schedules, and delegate management and tracking of resources to the appropriate WBS levels.
- Implement all SW systems across the project
- Update current schedules to include all instrument efforts at the Level 5 WBS.
- Develop the implementation plan for mission assurance and implementation.

The AIM SE, with support and input from the AIM Systems IPDT, AIM Project Management IPDT and the AIM Science IPDT, will develop the AIM Project System Specifications during this phase. The processes involved in this work include:

- Taking the flowdown of the science and measurement requirements and allocating those requirements to the instruments and spacecraft in the form of end item specifications, resource allocations (power, mass and data) and performance metrics.
- Formalizing these requirements and specifications in the form of ICDs, requirements and specifications that are traceable and verifiable back to the SRD.
- Placing configuration control on products and processes needed to assure delivery of HW and subsystems that meet specifications within cost as defined in the Phase B schedule.
- Implementing and tracking these items using the AIM requirements traceability SW tool to assure that all requirements are met and traceable through the life of the AIM mission.

I.3. Phase B Plans for Flight Systems

SOFIE. The initial Phase B effort is to derive the detailed SOFIE optical, mechanical, electronic and radiometric instrument specifications from the AIM system requirements. These will be presented in the SRR.

After SRR, SDL will issue a contract to a filter vendor for initial design work to complete preliminary band pass filter and beam splitter designs and to predict the performance of each element. This will refine the spectral performance expected in the various bands and will enable a more precise end-to-end simulation of SOFIE performance for the design reviews. This study may indicate that specific filter specifications will have to be iterated in order to achieve the desired performance

SDL will procure prototype InAs and photo voltaic HgCeTe detectors and evaluate them with prototype preamp circuitry, to verify that advertised detector sensitivity numbers are realized. These sensitivity numbers will be used with the predicted filter responses to predict SOFIE's atmospheric constituent sensitivities. SDL, with Judson Technologies, will also perform detailed design integrating parabolic cone concentrators to the HgCdTe detectors to increase the effective D*. The reflective element would be wavelength independent and identical elements could be used in each HgCdTe detector cell. (InfraRed Associates have reported a factor of six to eight improvement in their HgCdTe detector sensitivity by this technique).

SDL will also test the prototype detectors to verify that the 1/f noise is eliminated by SDL proposed electronic modulation circuit designs. If the 1/f noise is eliminated by the electronic modulation as expected, the mechanical chopper and tuned lock-in amplifiers will be removed. SDL will also determine the data transmission method to best preserve the high SNR achieved by the solar occultation measurement. It is expected that transmitting the difference signal and the sum of the absorbing- and non-absorbing signals for each constituent band will be superior to transmitting the absorbing- and non-absorbing signals directly. SDL will evaluate potential use of a 24 bit analog-to-digital converter in place of the planned 16-bit converter.

During Phase B, SDL will evaluate which specific vendor (from three competitors) will be used to provide the SOFIE steering mirror. A decision will be made whether to use the Adcole Sun Sensor, or whether alternative sun sensors might better meet the SOFIE requirements. One idea under consideration is use of ATA rate sensors to maintain precise pointing on the solar disk with a less precise sun sensor. SDL will also generate a sun sensor calibration plan.

The key products of the SOFIE technical definition phase are: a detailed set of SOFIE specifications; detailed preliminary specifications and design for each filter and beam splitter; an end-to-end simulation of the eight atmospheric constituent sensitivities; detailed preliminary mechanical design of the integration of Winston cones with HgCdTe detectors complete with integrated TE coolers; detailed preliminary electronic design to eliminate detector 1/f noise without a mechanical chopper; detailed preliminary electronic design to optimize signal-to-noise ratio in the transmitted/received data; a preliminary radiometric calibration plan; detailed schedule and cost projection for Phase C/D; and, a self-consistent design for the PDR. Each of the above activities will be completed during Phase B and the results will be incorporated into the design presented at the PDR. (See M4.2.1.4 for other tasks.)

SHIMMER. There are several major issues associated with SHIMMER instrument design that must be thoroughly investigated during Phase B with regard to required instrument performance (as derived in the traceability matrix), scheduling, and cost. Since off-axis and internally scattered light must be minimized in order to achieve SHIMMER objectives, instrument models will be refined and laboratory measurements made to determine the effectiveness of initial optical designs, and to determine the extent to which optical subsystems must be baffled or modified. The ramifications for mechanical design, schedule, and cost will be assessed. Detailed design specifications for monolithic SHS interferometer development and fabrication must be completed, since the interferometer will very likely be a long lead time item that must be procured during Phase B. A detailed detector and instrument controller electronics study will be conducted to produce block diagrams and interface control specifications that can be refined and implemented in later program phases. The CCD camera electrical, optical, thermal, and mechanical specifications will be finalized, since the camera will very likely be a long lead time item that must be procured during this phase. Initial mechanical designs for the contamination/diffuser door and shutter will be investigated, and provisions for mounting of corner cubes for precise optical alignment of SHIMMER on the spacecraft will be integrated into the preliminary mechanical design.

Primary tradeoff issues for SHIMMER will be to minimize scattered light, both internal to the interferometer, and in the telescope, without violating mass and volume constraints; minimizing baseplate and chassis mass without compromising structural and thermal stability; optimizing detector and instrument control complexity and power consumption while maintaining full functionality; and upgrading instrument radiometric models by incorporating preliminary design updates and refined subsystem and component specifications.

As with all limb viewing instruments, off-axis and internally scattered light is an issue of primary importance. Scattered light can be reduced at the expense of design complexity, mass, volume, and cost. Decisions will be made during Phase B to balance the costs and benefits, with the goal of meeting SHIMMER performance requirements with great certainty. The SHS interferometer, while not a new technology, is, nonetheless, a complex optical unit requiring very careful design and testing, and unique, long-lead-time, manufacturing processes.

The studies and preliminary design activities described above will be carried out in order of criticality during Phase B. The long lead time units, SHS interferometer and CCD camera, will be addressed first. Much of the other work will then proceed concurrently as electrical and software engineers focus on electronics design, instrument scientists proceed with optics and radiometric studies and experimentation, and technical managers and systems engineers develop system specifications, derive manpower estimates, and refine the WBS. The mechanical design can parallel concurrently with other subsystem preliminary design, but cannot be completed until the optical design is finalized in Phase C. (See M4.2.1.5 for other tasks.)

CIPS. During Phase B, LASP will assemble the full management, systems and design team for the CIPS instrument. That team will develop a detailed budget and schedule; assess key risk items, and review and verify the flowdown of requirements from science to the instruments.

The CCD camera and electronic systems designs will be advanced. Reevaluated designs will be modeled, breadboarded and tested. The CIPS camera microcontroller design will be advanced, and the existing prototype will be further upgraded for performance and software evaluation. The designs in the instrument with focus on optical, mechanical, electrical and thermal interfaces. The interface to the IPA will be developed. Scattered light studies will be undertaken on the optical baffles and covers.

A specific area of focus will be the CCD camera procurement. The DLR's capability to produce high reliability space flight HW will be evaluated. Their design, assembly and review processes, facilities and institutional and component heritages will be evaluated. If necessary, LASP will work with DLR on either having them adopt acceptable processes or to develop a collaborative plan for using acceptable processes (i.e., have LASP or acceptable manufacturer build some parts) or develop qualification plan for components that may have more risk.

Underway since August, 2001 is the development of a CCD camera prototype to validate the advertised performance of the camera, and to assure that the camera will meet the requirements of the AIM mission. The LASP team will complete the prototype camera evaluation system including lens, image intensifier, HVPS, camera, camera microcontroller, and GSE computer with test data acquisition software. They will evaluate this camera and compare its performance with the requirements. They will verify camera thermal performance (stability) under the switched power conditions that will be required to meet the orbit average power requirements. Candidate compression algorithms will be evaluated and using data produced with the prototype camera system, the team will verify that orbit average compression requirements can be met. LASP will evaluate the possibility of developing a light source that is somewhat representative of the image the camera will see. Although not required, this source would produce realistic data for analysis of camera and compression algorithm performance, and would simplify the calibration process. (See M4.2.1.2 CIPS for other tasks.)

CDE.

- Complete trade study to define effect of reaction wheel on CDE; complete other trade studies as needed.

LASP will assemble the full management, systems and design team for the CDE instrument. That team will develop a detailed budget and schedule, assess key risk items, and review and verify the flowdown of requirements from science to the instruments.

The CDE team will continue to develop the instrument designs with focus on mechanical, electrical and thermal interfaces. Refinement of the breadboard circuits and detector elements, and testing of these circuits and detectors in environments that are similar to those that will be seen in flight will proceed. Susceptibility to microphonic and external electrical noise sources will be evaluated. Lessons learned from the recent calibration experience in Heidelberg will be incorporated into the current design. The interface definition and design will proceed.

With these results from the prototype tests in hand, mechanical or electrical trades will be explored, e.g., isolation mounts on the spacecraft wheels versus filters in the electronics. The CDE team will complete the design of the pulse height to digital conversion circuits and reinvestigate nonlinear (logarithmic) compression of the data prior to conversion, modifying circuit designs as required. Finally, the packaging of the system will be refined. (See M4.2.1.2 CDE for other tasks.)

Instrument Platform Assembly. The design of the instrument pallet assembly will be further developed. The interfaces between the IPA and spacecraft will be defined in the spacecraft/IPA ICD. This ICD will be placed under configuration control at the PDR. Additionally ICDs will be developed for each of the instruments. These will define the electrical, thermal, mechanical, proximity and coalignment requirements for the instruments, tracker and electronics systems. Particular attention will be focused on the placement and interconnect of the thermal radiators for the SHIMMER and SOFIE detectors.

Further study will be undertaken of the structural design of the IPA. A full coupled loads analysis will be completed. Additional design details will be added to the IPM including modeling the cable harness and full accounting of all fasteners and ancillary HW. These details will be added to the mass list to ensure that full tracking of mass is in place.

The details of the structural design will proceed, including developing a preliminary fabrication and assembly plan to assure ease of fabrication and servicing. A more-detailed thermal model will be studied including view factors between the IPA and the spacecraft, and accommodation of the radiators

Spacecraft Bus. During Phase B, BATC will perform the preliminary design and trade studies to formalize the AIM flight spacecraft. To accomplish this, BATC will perform tasks listed in M4.2.1.3.

During Phase B, BATC will contribute to a number of activities in support of the spacecraft and the mission SRR and PDR. Because the baseline bus design is near PDR level, BATC engineering and design work will focus on clearly developing system requirements and working with the other team members to define the interface requirements between the spacecraft and the instruments.

In preparation for the PDR, BATC will concentrate particularly on the development of the spacecraft portion of the project plan, cost estimate, acquisition plan, project implementation plan, and the spacecraft preliminary design.

The spacecraft preliminary design includes defining requirements at the subsystems and systems level (to the PDR level), detailing the procurement specifications for major spacecraft elements, and detailing the spacecraft subcontracting plan.

Also, BATC will develop its risk management plan, system integration and test plans, mission integration and test plans, configuration control plan, safety, mission success, and environmental management plans.

I.4. Ground System

Mission Operations

- Review plans and cost for operation plan

Data Processing. During Phase B, GATS will

- Complete preliminary design of the ground system
- Support periodic meetings, SRR, and PDR
- Support SDL in developing SOFIE instrument interface control specifications

I.5. Phase B Milestones and Schedule

Fig. G-7 on **FO-G1** shows the **A**IM Phase B schedule including all milestones.

J. Education and Public Outreach

Polar mesospheric clouds may well be the only truly visible phenomena associated with global atmospheric change. The AIM mission is dedicated to providing a scientific basis for understanding these changes. The visible manifestation of PMCs, as Noctilucent Clouds (NLCs), observed from the ground, provides unprecedented opportunities for public outreach and K-14 education. Indeed, recent sightings of these "clouds on the edge of space" over populated regions of the United States compels us to bridge the scientific and technical aspects of the AIM mission to education and public communities nationwide.

The AIM Education and Public Outreach (E/PO) plan targets K-14 Formal Education, Informal Education, and Public Awareness. Each of these is addressed in a program of national scope, capitalizing on AIM's opportunities for student research and for enhancing scientific awareness in the general public. HU, a Historically Black University, will manage all aspects of the AIM E/PO. Select science education leaders, classroom teachers, and AIM scientists will serve on an Advisory Board for all activities (see **FO-J1**).

E/PO Objectives

- Enhance the quality of science, mathematics, and technology for the K-14 curriculum, while meeting national education standards, by incorporating current AIM research data into formal education.
- Assist with creating a scientifically literate workforce by developing education materials that utilize AIM data and the environmental implications of the data, for informal education organizations.
- Aid in developing a citizenry capable of making educated decisions related to environmental policies and laws by producing multimedia products, which share the excitement of the AIM mission with the public.

J.1. Educational Program Activities

J.1.1 Formal Education for K-14

Needs Assessment. An education needs assessment was conducted via audio conference with leaders involved in science education for rural Alaska students and urban African American students. It was determined that educator workshops pairing urban educators serving a large African American population with rural Alaska educators would be highly beneficial. In preparation for these workshops, the E/PO staff will attend the Old Minto Cultural Heritage Camp designed to sensitize and integrate educators into the native community. This training is key to local acceptance of the E/PO staff and the successful integration of AIM into the local and state curriculum. Jackie Colander and Daryl Baynes are educators who work with schools with high concentrations of minorities. They will act in a support capacity and serve on the E/PO advisory board.

Lead Educator Workshops. Two professional development workshops will be held during consecutive summers for Lead Educators nationwide who will also function as regional workshop leaders in their home states. Lead educator workshops will focus on AIM science, data collection, national standards, and web-based NLC lessons. The workshops will be held in Anchorage AK because Alaska is an optimal location for viewing NLCs. Each workshop will host ten teams of educators composed of a science teacher, a teacher skilled in technology and an administrator. Five teams will be selected from rural Alaska areas where NLCs are most likely to be sighted, and paired with five teams from urban areas in the United States. The E/PO Director, Dianne Q. Robinson, will coordinate efforts with the five NASA broker facilitators in selecting the teams from a national pool, emphasizing participation by urban educators working with underserved students. Participants will be fully supported and have the opportunity to receive graduate credit from Hampton University. Lead Educator workshops will familiarize participants with science related to the AIM mission. The AIM E/PO Director, Dianne Q. Robinson, will develop and lead the Lead Educator Workshops (see FO-J1) assisted by AIM scientists Bailey, Englert, Stevens, Taylor, and Randall. WHRO-TV will provide a two-way videoconference between scientists representing each of the mission partners and teachers in the workshops, allowing teachers an opportunity to directly interact with AIM scientists. A special attempt will be made to have teachers make direct observations of NLCs. Experience indicates that teachers are more likely to return to their classrooms with an excitement for continued study with their students if they have had first hand experiences. American Association for the Advancement of Science's (AAAS) Project 2061, will lead a workshop session to assist teachers in developing lessons that align AIM science with National Standards. Dr. Bernie Dodge, originator of WebQuests, will lead a session focused on the development of AIM WebQuests. The educator teams will be asked to design grade WebQuests that align to national standards. WebQuests developed in the workshop will be posted on the E/PO website to share the web-based instruction on a global level. Teachers will field test the lessons they develop during the workshop with students from local schools.

Lead teams from Alaska will be provided with cameras to photograph NLCs for distribution on the E/PO website. Since NLCs are observable in pre-dawn and evening hours, after school science clubs will be encouraged to assist with data collection. The NLC images will be posted online, allowing them to be utilized by students on a global level. Teachers from rural Alaska schools will be paired with teachers from urban schools with underserved populations for the development of cooperative student projects. Digital webcams used for two-way videoconferencing between rural and urban students will be distributed, giving the teams an opportunity to participate in cross-cultural projects to study NLCs.

Regional Educator Workshops. Following the Lead Educator workshops, each Lead Team will be required to host a workshop for twenty teachers in their home state. They will host a multimedia presentation on their experience in the Alaska workshops. AIM scientist Mike Taylor and NLC amateur observer Mark Zalcik will be available as advisors for accessing web-based information on NLC data. Graduate credit in science will be made available through HU to teachers attending the regional workshops. Lead teachers will receive a stipend to assist with materials needed for implementation of the regional workshops. The Regional Educator workshops will expand the second tier of staff development to impact an additional 200 educators nationally each year for two years. Each of these 200 educators and each Lead Educator Teams have the potential to impact 150 students for a total of 31,500 students each year of the project.

NASA CONNECT Video. The AIM E/PO will partner with NASA LaRC Education to produce a NASA CONNECT video focusing on PMCs/NLCs and the AIM mission. NASA CONNECT is an award winning video series that targets grades 4-8 and reaches eight million students in the U.S. and 32 other countries. Scientists and E/PO staff from the AIM mission will serve as content advisors for the video. Included in the video will be footage highlighting the teamwork of urban students and rural Alaska students as they collaborate on AIM projects.

J.1.2 Informal Education

Science Centers. The E/PO staff will partner with Richard Byles PhD, Education Director at the Virginia Air and Space Center (VASC), to develop education packets and exhibit materials on the AIM mission. This information will be made available to science center directors at a reception hosted by VASC and the AIM E/PO at the annual Association for Science and Technology Centers Conference.

After School Science Clubs. AIM E/PO staff will distribute cameras to rural Alaska after school science clubs and centers. In exchange for the cameras, the groups will agree to collect images of NLCs for the E/PO website. Urban teachers who participated in the Alaska workshops will be encouraged to sponsor after school science clubs with the Alaska NLC observer clubs.

E/PO Website. Educators, students, and the public will find images, lessons, WebQuests, and flash animation activities at the AIM E/PO website that will facilitate a better understanding of the AIM mission. The AIM E/PO program will also partner with the National Center for Atmospheric Research (NCAR), E/PO director Roberta Johnson, in utilizing the website "Windows to the Universe". This website will host a section specific to the AIM mission, and will include NLC background information for students and educators. It will link to the AIM E/PO website.

NASA OSS Sun-Earth Connection Forum. Jim Thieman, Co-Manager of the OSS Sun-Earth Connection Education Forum, will partner with the AIM E/PO in developing public outreach materials. The Forum is a part of NASA's Space Science Public Outreach program relevant to the AIM mission. AIM E/PO staff will also work directly with the Forum in providing information on NLCs for their website. Included will be AIM E/PO education materials developed in collaboration with the Alaska Native Ways of Knowing Project. These materials will incorporate traditional native knowledge related to the sky.

National Parks. The AIM E/PO staff will partner with Wyndeth Davis, at the National Parks Headquarters, to develop AIM education packets and web-based materials. These materials will be distributed to US parks for their Junior Ranger and Parks as Classrooms programs. These packets will also assist park rangers north of 40 deg with incorporating NLC observations in their night hikes. This will have a long-term impact reaching out to parents and children in an informal setting.

J.1.3 Public Awareness

Larry Crum, VP of WHRO-TV, has agreed to produce and broadcast nationally a video that highlights the AIM mission. The video will familiarize the public with AIM research and global implications for climatic change. Also, AIM will provide National Public Radio (NPR) with guest speakers from the AIM science team for public broadcasts.

J.1.4 Management

Dianne Q. Robinson of HU will serve as the E/PO Director, responsible for the development and implementation of the E/PO. Dr. Robinson will work closely under the direction of the PI and Co-PI, both of who will participate actively, along with the science team. The Co-PI will be responsible for leading the science team in its participation and ensuring that AIM research and related science are fully integrated into E/PO. An E/PO manager will be hired to assist Dr. Robinson with the implementation activities. FO-J1 shows an organizational chart. E/PO management processes and plans are described in Section G.

E/PO Assessment and Evaluation. The Program Evaluation and Research Group (PERG) at Lesley University, Cambridge, MA will conduct the evaluation of the AIM E/PO program. Using both quantitative and qualitative methods, such as questionnaires, surveys, interviews, document review and observations of program activities, PERG staff will develop a matrix that will match program components and goals with appropriate data sources. Staff, evaluators will develop sets of indicators or types of evidence, drawn from the particular program objectives, appropriate for each program component. Using those indicators evaluators will measure/assess the program components to determine what is working in the program, what needs to be improved and whether the program is meeting its own goals.

The E/PO evaluation (see below) will consist of three phases. In phase one, evaluators will conduct a needs assessment to ensure that the program will be focused on meeting the real needs of the rural and diverse education community the program will serve. In phase two, evaluators will conduct a formative evaluation of the program in operation, providing verbal and written formative evaluation feedback to program staff at scheduled intervals for the purposes of strengthening the program and increasing its effectiveness. In phase three, evaluators will conduct a summative evaluation that will analyze the program's effectiveness in relation to its goals.

E/PO Budget. See FO-J1 and Section K.

EPO Evaluation

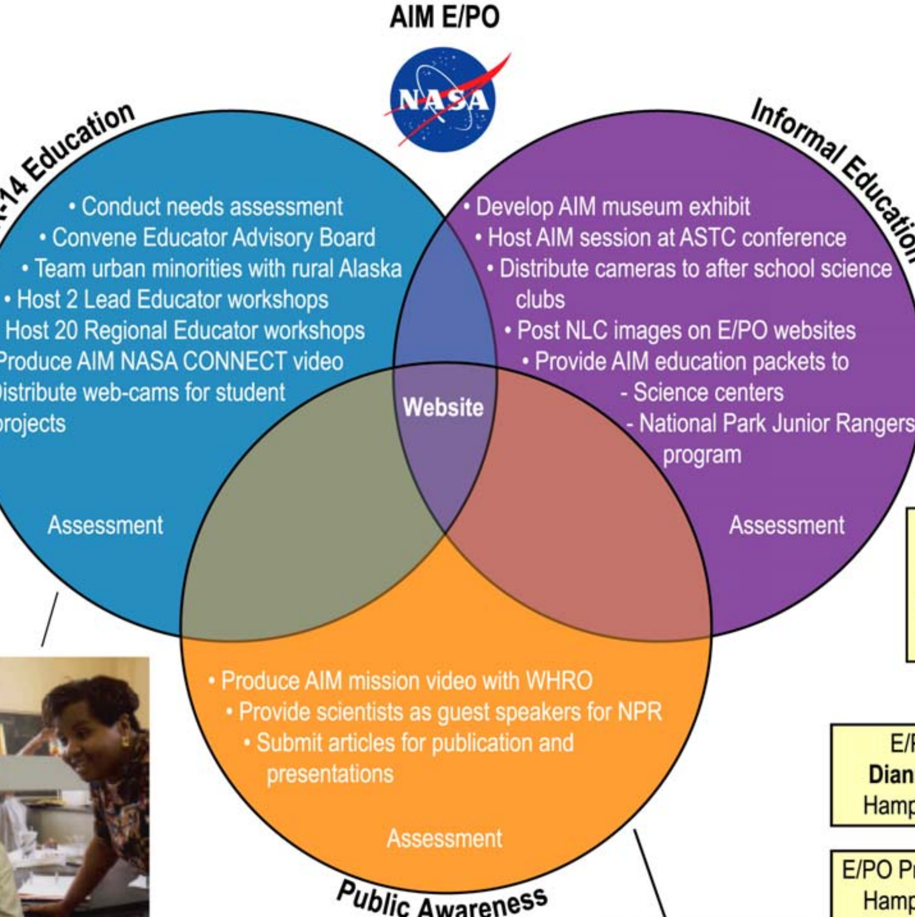
Program Goals	Review Needs Assessment Data	Review Curriculum Materials	Observe All Student Materials Use	Interview Selected Educators	Survey All Participating Educators	Review Diversity Of K-14 Students	Analyze Student Products	Conduct Student Focus Groups	Interview Informal Orgs, Staff Re: Use	Observe Data Use In Informal Orgs.	Interview Participating Scientists	Review Public Access Materials	Focus Groups Of Public Viewers	Interview AIM E/PO Staff
1. GOAL: Incorporate AIM NLC research data into formal education														
Does the AIM E/PO program incorporate the AIM NLC research data into formal education?	X	X		X	X						X			X
How is the AIM NSL research data used by K-14 teachers and students?	X		X	X	X		X	X						X
2. GOAL: Develop AIM NLC education materials that utilize AIM data and demonstrate the environmental implications of the data for informal education organizations														
Do the materials developed by the AIM E/PO utilize AIM data?		X									X			X
Do those materials address the environmental implications of the data in a manner accessible to information education organizations?		X									X			X
How are the materials used by the information education organizations and do they relate to the organization's needs?									X	X				X
3. GOAL: Produce multi-media products that share the purpose and excitement of AIM with the public														
How are the multi-media products accessed by the public?						X						X	X	X
What are the effects of the mutli-media products on those who use them?						X						X	X	X

Section J Foldout

E/PO Overview

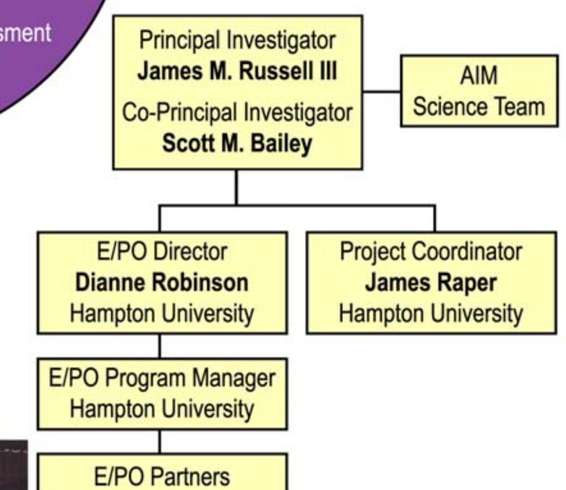
E/PO Components	Hampton University	AIM Science Team	NASA Sun-Earth Connection	NASA LaRC Education Department	Space Dynamics Lab/USU	NCAR "Windows to the Universe"	Amateur NLC Network	Virginia Air and Space Center	National Parks	WHRO Public Broadcasting Network	Alaska Space Grant Consortium	Minority University-Space Interdisciplinary Network	NASA NOVA Program	NSF Rural Systemic Initiative	NSF Local Systemic Change	Alaska Native Knowledge Network	AAAS Project 2061	WebQuest Project	FY02	FY03	FY04	FY05	FY06	FY07	Cost
HU Faculty	L																								$294K
University Overhead	L																								$173K
Travel, Supplies, etc.																									$122K
Evaluation by PERG																									$75K
Formal K-14 Education	Incorporating AIM research and data into the classroom																								
Lead & Regional Workshops	L	L					P				P	P	P	P	P	P	P	P							$151K
NASA CONNECT	P	P		L																					$25K
Informal Education	Developing AIM educational materials that utilize AIM data and teach the environmental implications of that data																								
E/PO Website	L	P																							
Online NLC Images and Lessons	P	P			L	L	P																		$38K
Museum Packets	P	P						L																	$8K
Parks as Classrooms	P	P							L																$3K
Cameras-After School Science Clubs	L										P														$3K
Public Outreach	Producing multimedia products which share the excitement of the AIM mission with the public																								
Mission Video & Radio Broadcasts	P	P								L															$30K
Legends of the Night-Sky Materials	P		L														P								$3K
Total Cost																									$925K

Legend: L = Lead Organization ■ = Design Phase P = Partner Organization ■ = Implementation Phase



NLC Observations Utilized for Informal Education Packets and Programs

Lead and Regional Educator Workshops Incorporate AIM Research and Data for Rural Alaska and Urban Under Served Students



Organizational Structure

Mission Video Shares the Excitement of AIM Research with the General Public

A8987_062

E/PO Partner Organizations	Contact
Hampton University	Dianne Q. Robinson Scott Bailey
AIM Science Team	Chris Englert
NASA Sun-Earth Connection	Jim Thieman
UCAR – University Corporation for Atmospheric Research	Roberta Johnson
NASA CONNECT (NASA LaRC Education Department)	Bill Williams
Space Dynamics Lab/USU	Gayle Bowen
Amateur NLC Network	Mark Zalcik
Virginia Air & Space Center	Richard Byles
National Park Service	Wyndeth Davis
WHRO Public Broadcasting Network	Larry Crum
Alaska Space Grant Consortium	Joe Hawkins
Minority University-Space Interdisciplinary Network	James Harrington
NASA NOVA Program	Mike Freeman
AAAS Project 2061	George Nelson
WebQuest Project	Bernie Dodge
Alaska - Rural Systemic Initiative (RSI) & Center for Cross Cultural Studies	Ray Barnhardt

E/PO Advisory Board Members

Name	Title and Organization
Emma Walton	Past President, National Science Teachers Association (NSTA)
MacGregor Kinsley	Professor, NSF Local Systemic Change-Rhode Island College
Jackie Colander	Principal, Norfolk City Public Schools, Virginia
Ted Munsch	Professor, Alaska Pacific University, Alaska
Darryl L. Baynes	Director, Minority Aviation Education Association
Bob Yager	Professor & Past NSTA President, University of Iowa
Pete Money	Director, Museum of Natural History, Harvard University
Gail Raymond	Science Program Director, Alaska Public Schools
Paul Adams	Physics Professor, Fort Hays State University, Kansas
Lori Gillam	Secondary Science Expert, Alaska Public Schools
Elena Sparrow	Professor & NSF Global Change Project, University of Alaska at Fairbanks

Lead Educator Workshops

Agenda	AIM Science Team	WHRO Public TV	NLC Observers Network	AAAS - Project 2061	Web-Quest Program	NCAR/UCAR	Alaska Space Grant Consortium	Virginia Air & Space Center	NASA CONNECT Video	Hampton University	Alaska Rural Systemic Initiative Center for Cross-Cultural	National Parks	SDL-Space Development Lab	NASA Sun-Earth Connection
The focus of the two Lead Educator workshops will be to familiarize the participants with the science related to the AIM mission and provide support for incorporating it into the curriculum.														
AIM scientists will provide science instruction and incorporate two-way video with the mission partners.	**X**	**X**								**X**				
NLC images-observe, analyze & photograph	**X**		**X**										**X**	
Aligning AIM to national standards				X										
Developing AIM WebQuests					X								X	
Field testing lessons							X		X		X			
Culturally Responsive Science Curriculum										X	X			
Additional resources	X		X			X		X	X			X		X
Designing regional workshops	X	X								X	X			

Foldout J1. AIM E/PO Overview

K. Cost

The AIM Phase A study included a detailed assessment of mission costs. The results are a robust cost estimate with adequate reserves. We have drawn on the significant experience of the AIM team with spaceflight hardware as well as cost models to validate these costs. All AIM cost estimates are presented in this section. The costs use rates and procedures in accordance with FAR 15.401. The total cost to NASA for AIM is $81.22M in FY2000 dollars including resources requested to implement the recommendations from the NIAT report and the increase in cost of the ELV since the release of the SMEX AO.

K.1 Introduction

The AIM Mission is requesting $74.96M (FY00), which includes prudent reserves, against the Explorer conforming cap of $75M (FY00). To implement the NIAT recommendations, AIM is requesting $5.0M (FY00) in nonconforming true costs. Further we note the increase in Launch Vehicle cost of $1.26M, which is not counted against the cap. This gives a total cost to NASA for the AIM mission of $81.22M (FY00).

In this Concept study we performed new efforts to define and cost every aspect of the AIM mission to a greater detail than was performed for the step 1 proposal.

The HU and UAF budgets cover costs for:

- AIM Science Team leadership, meetings and workshops
- Analysis and reporting of flight measurements by PI and Co-PI
- Implementation of the E/PO efforts
- Developing and monitoring contracts with LASP, E/PO partners, GATS, and two Co-Is
- Data archival and dissemination
- Program Coordination, which includes periodic reviews and reporting to NASA, working with KSC and GSFC to develop and monitor contracts with NRL for SHIMMER and KSC for the Pegasus XL, respectively.

HU uses a grass roots approach to costing. A detailed WBS is used to identify cost elements. Estimates were developed based on allocations and actuals from past and on-going projects. Vendor quotes were used when appropriate and available.

The CU/LASP budget covers costs for:

- Project management and systems engineering including mission assurance, safety, and implementation of NIAT recommendations
- Support for program red teams, independent assessments of faults, failure modes and probabilistic risk, as well as the implementation of a full risk assessment program.
- Management and development of both CIPS and CDE
- Administration and monitoring of the SDL and NRL (with GSFC) instrument subcontracts through delivery to LASP for integration on to the IPA.
- Development, integration and test of the IPA
- Management of spacecraft bus development subcontract with BATC including launch-vehicle integration.
- Science algorithm development, science data processing, and mission operations
- Mission operations
- CIPS and CDE data processing, analysis, and reporting by Co-Is.

LASP uses a grassroots approach to costing. This process has evolved from lessons learned on past projects, and is routinely examined and refined to assure that all elements of a project are adequately accounted for. All elements of the LASP costs were developed using an internal LASP-developed Level 4 WBS that correlates to the AIM WBS. Estimating was done using actuals from past and on-going projects (Cassini, TIMED, SNOE and SORCE); using quotes from vendors for the principal subcontracts, parts and components; and using bottoms-up costing for the remaining components of the budget. Quotes obtained from subcontractors and hardware providers, and the hardware they will build is from their standard and space qualified line of systems. Hardware subsystems with flight heritage are preferentially selected to minimize development costs and risk, and significant heritage will be utilzed from recently completed projects—reducing the uncertainty and risk in these efforts.

All LASP budgets are reviewed independently for completeness and accuracy by the LASP Administrator and the LASP Engineering Director, accompanied by a final review by the University of Colorado's Office of Budget and Planning.

The budget for BATC/Civil Space Systems covers costs for:

- The management, design, development, qualification, test, and delivery of the AIM spacecraft
- Integration of the IPA with the AIM spacecraft
- Launch site support

BATC delivers over $120M of flight hardware per year for NASA and similar science-related customers. This productivity provides a significant source of cost experience for producing developmental scientific missions complying with NASA's requirements. BATC has developed detailed guidelines for managers and engineers in each discipline to use when developing grassroots Basis of Estimates (BOE). These guidelines capture BATC's ISO-certified way of doing business. The responsible engineers and managers determine the scope of work, and using these guidelines (e.g., typical inspection hours per drawing), generate a most probable grassroots estimate based on a WBS level 5 for the cost of the effort. BATC also uses two cost models to cross-check their grassroots estimates including their own Cost Estimating Relationship (CER) model that reflects more than 10-years of historical experience in developing and operating spacecraft systems and payloads. The other, commercially available, model used is the Small Spacecraft Cost Model (SSCM), v.1998 and v.2000.

SDL, who provides the SOFIE instrument, provides over $55 M of spaceflight hardware per year to NASA and the DoD and has a proven ability to control costs and schedule on state-of-the-art spaceflight instrument systems. Over SDL's 43 year history, numerous instrument development programs have demonstrated the company's ability to develop cutting-edge instruments and space flight systems within cost constraints while maintaining an overall cost control variance better than 3.4%. SDL has achieved this control using small, focused, Integrated Product Development (IPD) teams with involved program management that balances the amount of oversight, documentation and quality control with the program's cost requirements. By having a small and active team that is involved in the system from beginning to end, interface issues, documentation requirements, and lengthy procedures are minimized. Additionally, SDL is registered to the ISO 9001 standard and uses standardized costing procedures.

The SDL budget covers costs for:

- Development of SOFIE
- Co-I support

SDL's AIM costs are estimated based on WBS level 4 or better grass roots estimating techniques for labor and parts. Parts and major subsystems are all based on vendor quotes and catalog prices while labor estimates are based on prior programs of similar complexity. These cost estimates are then validated with SDL's proprietary IR instrument cost model that yields cost numbers based on key instrument parameters including aperture size, mass, lifetime and operating temperature. SDL's cost model, based on prior actual costs for SDL's 412 instruments that have flown, is uniquely adapted to their mode of business. Cost model results are used only to flag anomalous results and to validate the basic grassroots estimate.

The NRL budget covers costs for:

- Development of SHIMMER
- SHIMMER data processing, analysis, and reporting by Co-Is.

The GATS budget covers costs for:

- Coordination of all data processing activities
- SOFIE data processing
- SOFIE science measurement capability, development, and verification
- Leading the development of the PDC.

NRL and GATS follow similar costing procedures as LASP. A grassroots process is followed that is based upon an internally developed WBS that directly correlates to the AIM WBS. NRL and GATS, like LASP, BATC, and SDL, possess significant experience in spaceflight hardware. This experience is heavily drawn upon in deriving costs. Actual costs from past and ongoing projects are incorporated.

We are confident of our cost estimates because of the work accomplished over the past year in design work, laboratory tests and demonstrations, and extensive computer modeling and simulation of the AIM design. Prototypes for CDE and SHIMMER have been developed. Engineering model detectors for CIPS have been purchased and are undergoing testing. The IPA has been simulated. The spacecraft bus study extended into Phase B in some areas. The entire mission observation scenario including operations command sequences have also been simulated. These are but a sampling of the many activities that have occurred during Phase A in order to provide an accurate cost breakdown. We have also included adequate margins for all engineering resources to reduce the need to use cost reserves. Section F details the applied reserve and margins and Section G.4 describes how they will be managed. Adequate reserves with a good management plan serve to reduce the likelihood that cost reserves will be needed.

We have read the NIAT report and the other Lessons-Learned reports and understand the need for using the Faster, Better, Cheaper philosophy prudently. We do include significant reserves and control their release for carefully reviewed and approved specific needs to assure that adequate resources exist, especially during the test phase of the project. We use proven, effective control methods, such as Earned Value systems and incentive contracts, to ensure the as-delivered cost meets the proposed cost. Incentive plans are covered in Appendix M8.

K.2 Heritage

The AIM Team builds upon a strong heritage. Heritage is a major strength of the AIM program. Many of our designs are based upon similar hardware built for other recent missions. This heritage provides high-confidence estimates of labor hours and materials. In addition, AIM has a high percentage of purchased parts, having a recent cost history based on catalog prices or purchases on other programs. Furthermore we have gathered new or recent ROMs for major subsystem elements. These ROMs compare well with ROMs gathered during the Step 1 proposal for the same materials.

By taking advantage of high heritage designs and components, the AIM project offers high-performance hardware with estimated savings in proposed costs of $16M over the entire AIM project (all phases). **Table K-1** overviews all of the areas where heritage has provided significant cost savings.

K.3 Costing Strategy & Methodology

Consistent with the project element structure and adoption of concurrent engineering practices, AIM costs are constructed and organized by the WBS. Each subsystem or activity is independently priced, including the resources necessary to specify, design, fabricate, test, and deliver each article. These costs include the requisite technical management, systems engineering, mission assurance, test equipment, and software unique to each activity. Each subsystem technical lead has generated and signed up to the cost and will operate in what is essentially a fixed-cost mode.

Table K-1. Cost Savings Due to Heritage

AREA	Cost Savings ($FY2000)	Heritage and How Heritage Provided a Cost Savings
SOFIE	0.9	HALOE heritage simplified design process, using same chopper mechanisim
SOFIE S/W	1	HALOE software is reapplied
SHIMMER	1.3	SHIMMER experiment for the shuttle provided significant preliminary design
SHIMMER S/W	.2	MAHRSI software (some) is applied to SHIMMER
CIPS	.5	Rosseta detectors needed only to be refabriacted, little new design
CDE	.1	Electronics for CDE have been used on LASP rocket experiments
S/C Software	4	Deep Impact, 74% reuse of software
S/C C& DH	2	Deep Impact, reuse of component specifications, algorithms, designs, analyses
S/C ADCS	4	Deep Impact, GFO, MTI: 1 work-years savings each, QuickBird: 6 work-years, ASPEN IR&D: 5 work-years
S/C Structure	1	GFO and QuickBird heritage savings
S/C GSE & Test	1	Deep Impact – based on modifications of DI test procedures, use of DI RF console
Total	16.0M	

A WBS element total cost was developed for all AIM elements from a grassroots assessment based on the WBS and other salient information. Quotes were obtained from each team member for work to be performed. Multiple estimates were developed for the flight segment cost. Many vendors provided written quotes used in determining total cost. Mission and management factors were also considered in determining cost and cost validity. The following factors require recognition when considering the integrity of the proposed cost:

- The AIM team consists of experienced institutions in instrument and spacecraft development: LASP, SDL, NRL, and BATC all have at least 40 years experience in space-flight hardware.
- BATC's recent successful cost history with NASA averages as-delivered cost within 7.4% of target cost.
- Substantial scientific margins exist between the baseline and the performance floor.
- Graceful descope options that retain scientific value have been studied.
- Extensive use of off-the-shelf systems and components with flight heritage have been selected.
- Adequate funded margin has been included into the schedule (See Section G.3).

K.4 AIM Cost

The AIM mission proposes a total cost to NASA of $81.22M (FY2000). The AIM costs are broken out in detail in **Fig. K-1, K-2a. b, c ,K-3, and K-4** as required by the SMEX Concept Study Report Guidelines dated April 25, 2001.

Fig. K-1 displays the AIM costs by phase and by institution for each year of the AIM mission. The costs are presented in real year dollars with sums also shown in FY2000 dollars. Contributions by the AIM team institutions are also shown. Fig. K-2 shows the AIM costs by WBS element for each fiscal year of the AIM mission in real year dollars and with sums in FY2000 dollars. Fig. K-3 shows AIM costs by major element and mission phase for each fiscal year of the AIM mission in real year dollars with sums in FY2000 dollars.

Fig. K-4 shows the AIM elements costs for Phases C and D broken out in terms of recurring and nonrecurring costs. The determination of recurring versus nonrecurring costs was calculated by a grass roots estimate supplemented with comparisons to previous projects described in the next section.

K.5 Confidence in AIM Costing

The AIM costs displayed in Figs. K-1 through K-3 are the result of careful costing activities during Phase A. The costing exercises relied heavily on the strong AIM team member experiences. As described above, the spacecraft costs are validated through cost models. The AIM team members providing the instruments have in the past used cost models for validating instrument costs. Past experience suggests however that the most popular cost models tend to overpredict costs, sometimes by as much as a factor of two, especially for instruments with high heritage or instruments developed by universities where student involvement may lower some costs. Validations or model comparisons that were performed for AIM elements are described below.

SOFIE: The SOFIE instrument has strong heritage from the HALOE experiment and shares the same PI. Accordingly, related costs on HALOE were considered during a grass roots cost estimate for the SOFIE instrument.

In addition to the grass roots cost estimate, SDL modeled the SOFIE instrument cost based on an in-house proprietary cost model developed from over 400 space flight experiments conceived and delivered by SDL over the last 40 years. This modeling validated the grass roots calculation. The model predicted a FY2000 cost of $4.6M versus the estimated cost of $4.8M. **Fig. K-8** compares the estimated SOFIE cost with the costs of previous instrument built by SDL. The validity of this model and SDL cost performance are borne out by the excellent record of conformity to target costs, the most recent being the SABER instrument that will launch on the TIMED satellite in December 2001.

The SOFIE data processing software will be developed by GATS who developed the software for HALOE. Much (about 50%) of the AIM software will be heritage from HALOE. The on-going HALOE processing provided GATS with significant experience from which to draw upon in costing AIM.

SHIMMER: The SHIMMER costs were developed based upon knowledge of the recurring costs, experience in building a previous instrument, and NRL's 50 years of experience in developing space-flight hardware. A SHIMMER instrument currently being built for the Space Shuttle also contributed critical costing data.

Figure K-1 Total Mission Cost Funding Profile Template

Item	FY1	FY2	FY3	FY4	FY5	FY6	FY7	Total (Real Yr.)	Total (FY 2000)
	7/01 - 09/01	10/01 - 9/02	10/02 - 9/03	10/03 - 9/04	10/04 - 9/05	10/05 - 9/06	10/06 - 9/07		
Phase A									
-HU	35614							35,614	34,644
Award base FEE								-	-
-GATS	20,405.80	13,984.42						34,390	33,083
-LASP	47,748	87,252						135,000	135,000
-NRL	105,765.78							105,766	102,885
-BALL	46667	23333						70,000	67,475
-GMU	3,504							3,504	3,408
-SDL	32,410	33,317						65,727	63,054
Phase B									
-HU		87,423.18	66,742.85					154,166	144,162
-UAF		38,838.58	32,493.39					71,332	66,662
Award base FEE		5,882.02	9,574.32					15,456	14,379
-GATS		15,196.55	20,829.05					36,026	33,553
-LASP		917,522.00	2,284,244.00					3,201,766	2,931,490
-NRL		438,846.46	1,202,637.69					1,641,484	1,522,286
-BALL			2964917					2,964,917	2,729,186
BALL FEE			146542					146,542	134,891
-GMU		9,069.06	3,664.14					12,733	11,955
-SDL		278,904.63	457,887.03					736,792	685,400
-SDL/USU		10,173.22	13,526.47					23,700	22,078
RESERVE		261,908.02	968,637.74					1,230,546	1,139,460
Phase C/D									
-HU			133,485.69	203,322.15	334,228.63			671,036	596,056
-UAF			64,986.78	97,138.44	153,249.25			315,374	280,285
Award base FEE			40,588.68	43,973.60	12,305.75			96,868	87,455
-GATS			54,761.94	108,478.52	176,134.62			339,375	300,961
-LASP			2,869,791.97	4,401,906.91	1,769,892.48			9,041,591	7,649,515
-NRL			1,278,612.17	1,199,078.81	408,011.12			2,885,702	2,606,026
-BALL			6278307	4938617	1692903			12,909,827	11,675,858
BALL FEE			311568.06	244432.315	83649.835			639,650	578,528
-GMU			5,610.84	9,486.62	48,110.51			63,208	55,565
-SDL			1,974,672.10	2,090,201.33	439,153.10			4,504,027	4,071,801
-SDL/USU			27,105.56	44,906.24	49,452.33			121,464	108,235
RESERVE			2,594,580.04	2,516,817.67	985,072.34			6,096,470	5,499,937

Figure K-1 Total Mission Cost Funding Profile Template (continued)

Item	FY1	FY2	FY3	FY4	FY5	FY6	FY7	Total (Real Yr.)	Total (FY 2000)
	7/01 - 09/01	10/01 - 9/02	10/02 - 9/03	10/03 - 9/04	10/04 - 9/05	10/05 - 9/06	10/06 - 9/07		
Phase E									
-HU						311,736.81	276,229.36	587,966	491,814
-UAF						140,156.13	127,080.23	267,236	223,499
Award base FEE						4,234.63	1,213.25	5,448	4,588
-GATS						211,731.74	60,662.71	272,394	229,402
-LASP						22,875.02	-	22,875	17,669
-NRL						515,957.59	530,404.40	1,046,362	874,350
-BALL						153854		153,854	130,362
BALL FEE						7605.28		7,605	6,444
-GMU						104,468.35	107,345.05	211,813	176,994
-SDL/USU						80,312.33	71,140.74	151,453	126,686
Launch Services				15,000,000	5,000,000	8,000,000		28,000,000	24,564,950
RESERVE								-	-
Ground Data System Dev									
-HU		12,696.95	38,065.52	33,547.40	303,649.29	279,695.74	281,784.83	949,440	810,825
Award base FEE		257.56	1,526.94	3,261.15	9,729.42	9,258.40	598.40	24,632	21,382
-GATS		12,877.97	76,347.10	163,057.28	486,470.87	462,920.21	29,920.06	1,231,593	1,069,097
-LASP		22,689	319,397	710,036	1,123,363	1,095,100	536,454	3,807,039	3,133,392
-NRL		2,565.87	27,245.17	119,569.38	184,898.93	470,493.60	483,667.43	1,288,440	1,092,931
-BALL								-	-
E/PO		-	94,137.87	301,322.17	309,027.30	280,307.50	75,289.42	1,060,084	925,199
RESERVE						382736.1064	236338.9175	619,075	519,093
Other (NIAT)		301,071	1,248,072	1,158,063	1,071,260	63,252	-	3,841,718	3,419,515
NASA OSS Mission Cost	$292,114	$2,573,808	$25,610,558	$33,387,216	$14,640,562	$12,596,696	$2,818,129	91,919,082	$81,223,462
Contributions by Organization (Non-U.S. or U.S.) to:									
Phase A								-	-
-HU	50,000							50,000	48,638
-GATS								-	-
-LASP								-	-
-NRL								-	-
-BALL								-	-
-GMU								-	-

Figure K-1 Total Mission Cost Funding Profile Template (concluded)									
Item	**FY1**	**FY2**	**FY3**	**FY4**	**FY5**	**FY6**	**FY7**	**Total (Real Yr.)**	**Total (FY 2000)**
	7/01 - 09/01	10/01 - 9/02	10/02 - 9/03	10/03 - 9/04	10/04 - 9/05	10/05 - 9/06	10/06 - 9/07		
-SDL								-	-
Phase B								-	-
Phase C/D								-	-
-HU								-	-
"NRL" US Airforce STP			116,242.01	303,097.46	585,201.95			1,004,541	888,130
-BALL								-	-
-GMU								-	-
-SDL								-	-
Other (specify)								-	-
Contributed Costs (Total)	$50,000		$116,242	$303,097	$585,202			1,054,541	936,768
						Mission Totals			$82,160,229.86

Figure K-2a Time Phased Cost Breakdown by WBS and Major Cost Category for Hampton University (Phase B)

(Phased costs in Real Year Dollars, Totals in Real Year and GY2000 Dollars)

WBS/Cost Category Description	FY1	FY2	FY3	Total (RY$)	Total (FY2000$)
	7/01 - 09/01	10/01 - 9/02	10/02 - 9/03		
Total Direct Labor Cost		**808,496**	**1,767,066**	**2,575,562**	**2,368,361**
WBS 1.0 Science					
WBS 1.1 Mission Planning		36,126	27,432	63,559	59,436
WBS 1.2 Simulation		15,197	20,829	36,026	33,553
WBS 1.3 Data Analysis		25,647	36,947	62,594	57,359
WBS 2.0 Management					
WBS 2.1 Program Coordination		19,129	26,220	45,349	42,236
WBS 2.2 Project Management		78,742	79,294	158,036	142,912
WBS 2.3 Systems Engineering		37,116	38,211	75,327	68,104
WBS 2.4 Mission Assurance		26,611	31,208	57,819	52,228
WBS 3.0 Spaceflight Segment					
WBS 3.1 Instrumentation		547,603	693,124	1,240,727	1,142,934
WBS 3.2 Spacecraft Bus			796,087	796,087	732,793
WBS 3.4 Ship/Integration					
WBS 3.5 Integration and Test					
WBS 3.6 Launch Vehicle					
WBS 4 Ground Segment					
WBS 4.3 Telemetry Station					
WBS 4.4 Mission Control Center		14,578	7,094	21,672	19,699
WBS 4.5 Operations planning and training					
WBS 4.8 Data Processing		2,566	3,518	6,084	5,666
WBS 1.4 Data Archival		5,182	7,102	12,284	11,441
Total Subcontract Costs		**473,654**	**1,601,786**	**2,075,440**	**1,949,737**
WBS 1.0 Science					
WBS 1.1 Mission Planning					
WBS 1.2 Simulation					
WBS 1.3 Data Analysis		26,420		26,420	25,000
WBS 2.0 Management+B68					
WBS 2.2 Project Management					
WBS 2.3 Systems Engineering					
WBS 2.4 Mission Assurance					
WBS 3.0 Spaceflight Segment					
WBS 3.1 Instrumentation					
WBS 3.1.1 SOFIE		17,014	34,981	51,995	48,300
WBS 3.1.2 CIPS		166,947	880,314	1,047,262	995,400
WBS 3.1.3 SHIMMER		250,395	343,208	593,603	552,862
WBS 3.1.4 CDE					
WBS 3.1.5 IPA					
WBS 3.2 Spacecraft			331,166	331,166	304,836
WBS 3.5 Integration & Test					
WBS 3.6 Launch Vehicle					

Figure K-2a Time Phased Cost Breakdown by WBS and Major Cost Category for Hampton University (Phase B) – concluded					
(Phased costs in Real Year Dollars, Totals in Real Year and GY2000 Dollars)					
WBS/Cost Category Description	FY1	FY2	FY3	Total (RY$)	Total (FY2000$)
	7/01 - 09/01	10/01 - 9/02	10/02 - 9/03		
WBS 4 Ground Segment					
WBS 4.3 Telemetry Station					
WBS 4.4 Mission Control Centert					
WBS 4.5 Operations planning and training					
WBS 4.8 Data Processing		12,878	12,116	24,994	23,339
Total Materials & Equipment Cost		**88,274**	**1,151,581**	**1,239,855**	**1,120,721**
WBS 1.0 Science					
WBS 1.3 Data Analysis			7,965	7,965	7,000
WBS 2.0 Management					
WBS 2.2 Project Management			18,206	18,206	16,000
WBS 2.3 Systems Engineering		13,624	42,671	56,295	50,000
WBS 3.0 Spaceflight Segment					
WBS 3.1 Instrumentation		74,650	1,064,228	1,138,878	1,030,683
WBS 3.2 Spacecraft			18,510	18,510	17,038
Total Reserves					
		261,908	968,638	1,230,546	1,139,460
Total Other Costs		**482,511**	**2,900,147**	**3,382,657**	**3,104,812**
Fee		6,624	10,461	17,084	15,897
Ball Fee			293,084	293,084	269,782
E/PO			31,379	31,379	28,884
Other (Specify)		475,887	2,565,223	3,041,110	2,790,249
Total Contract Cost		1,852,935	7,420,580	9,273,515	8,543,631
Total Other Costs to NASA OSS					
Launch Services (WBS 3.4.1)					
Ground Segment					
E/PO					
Other (NIAT)		301,071	313,302	614,373	577,843
Total Contributions(Non-U.S. or U.S.)					
TOTAL COST FOR PHASE		**2,154,006**	**7,733,882**	**9,887,888**	**9,121,474**

Figure K-2b Time Phased Cost Breakdown by WBS and Major Cost Category for Hampton University (Phase C/D)					
(Phased costs in Real Year Dollars, Totals in Real Year and GY2000 Dollars)					
WBS/Cost Category Description	FY3--C	FY4	FY5	Total (RY$)	Total(FY2000$)
	2/03 - 9/03	10/03 - 9/04	10/04 - 9/05		
Total Direct Labor Cost	**3,858,621**	**5,414,296**	**2,985,314**	**12,258,231**	**10,673,966**
WBS 1.0 Science					
WBS 1.1 Mission Planning	54,865	84,602	153,099	292,566	259,611
WBS 1.2 Simulation	54,762	108,479	176,135	339,375	300,961
WBS 1.3 Data Analysis	126,660	197,830	293,910	618,400	523,064
WBS 2.0 Management				-	
WBS 2.1 Program Coordination	52,439	80,861	73,602	206,903	184,785
WBS 2.2 Project Management	281,948	392,479	317,454	991,881	834,119
WBS 2.3 Systems Engineering	116,246	161,817	168,929	446,992	374,577
WBS 2.4 Mission Assurance	94,942	132,162	65,569	292,673	247,551
WBS 3.0 Spaceflight Segment				-	
WBS 3.1 Instrumentation	1,992,706	2,743,142	507,204	5,243,052	4,567,386
WBS 3.2 Spacecraft Bus	997,198	1,239,971	528,485	2,765,654	2,488,539
WBS 3.4 Ship/Integration				-	
WBS 3.5 Integration and Test	-	61,444	182,764	244,208	204,115
WBS 3.6 Launch Vehicle				-	
WBS 4 Ground Segment				-	
WBS 4.3 Telemetry Station				-	
WBS 4.4 Mission Control Center	63,589	168,873	291,374	523,836	432,125
WBS 4.5 Operations planning and training				-	
WBS 4.8 Data Processing	9,061	20,733	19,578	49,373	43,959
WBS 1.4 Data Archival	14,204	21,903	207,211	243,318	213,175
				-	
Total Subcontract Costs	**4,007,032**	**3,266,927**	**1,511,338**	**8,785,297**	**7,930,124**
WBS 1.0 Science				-	
WBS 1.2 Simulation				-	
WBS 1.3 Data Analysis			95,672	95,672	83,333
WBS 2.0 Project Management				-	
WBS 2.2 Project Management				-	
WBS 2.3 Systems Engineering				-	
WBS 2.4 Mission Assurance				-	
WBS 2.5 Risk Mitigation (NIAT)				-	
WBS 2.6 Documentation				-	
WBS 2.7 Red Team Reviews				-	
				-	
WBS 3.0 Spaceflight Segment				-	
WBS 3.1 Instrumentation	1,162,792	1,726,440	138,074	3,027,307	2,736,501
WBS 3.2 Spacecraft (BALL)	2,590,629	922,836		3,513,465	3,210,984
WBS 3.3 Integration & test				-	
WBS 3.5 Integration and Test			32,277	32,277	28,114
WBS 3.6 Launch Vehicle				-	

Figure K-2b Time Phased Cost Breakdown by WBS and Major Cost Category for Hampton University (Phase C/D) – concluded

(Phased costs in Real Year Dollars, Totals in Real Year and GY2000 Dollars)

WBS/Cost Category Description	FY3--C	FY4	FY5	Total (RY$)	Total(FY2000$)
	2/03 - 9/03	10/03 - 9/04	10/04 - 9/05		
WBS 4 Ground Segment				-	
WBS 4.3 Telemetry Station				-	
WBS 4.4 Mission Control Centert	33,830	104,331	147,760	285,922	253,260
WBS 4.5 Operations planning and training	140,884	259,801	471,594	872,279	773,070
WBS 4.8 Data Processing	78,897	253,517	625,960	958,375	844,861
Total Materials & Equipment Cost	**809,109**	**301,491**	**55,541**	**1,166,141**	**1,053,222**
WBS 1.3 Data Analysis			12,495	12,495	10,000
WBS 3.0 Spaceflight Segment				-	
WBS 3.1 Instrumentation				-	
WBS 3.1.1 SOFIE	392,042	106,095		498,137	455,872
WBS 3.1.2 CIPS		94,547		94,547	79,000
WBS 3.1.3 SHIMMER	269,602	37,413	7,749	314,764	288,417
WBS 3.1.4 CDE				-	
WBS 3.1.5 IPA				-	
WBS 3.2 Spacecraft	147,465	4,794		152,259	140,033
WBS 3.5 Integration and Test		11,968	4,592	16,560	14,000
WBS 4.4 Mission Control Center		38,298	4,873	43,171	35,900
WBS 4.8 Data Processing		8,376	25,831	34,207	30,000
Total Reserves					
	2,594,580	2,516,818	985,072	6,096,470	5,499,937
Total Other Costs	**5,162,030**	**5,974,044**	**3,115,684**	**14,251,758**	**12,623,702**
Fee	43,164	49,373	24,390	116,927	105,186
Ball Fee	623,136	488,865	167,300	1,279,301	1,157,056
E/PO	62,759	301,322	309,027	673,108	596,752
Other (Specify)	4,432,972	5,134,484	2,614,967	12,182,422	10,764,707
Total Contract Cost	**13,836,793**	**14,956,757**	**7,667,877**	**36,461,426**	**32,281,014**
Total Other Costs to NASA OSS	**934,769**	**16,158,063**	**6,071,260**	**23,164,092**	**20,574,814**
Launch Services (WBS 3.4.1)		15,000,000	5,000,000	20,000,000	17,786,486
Other (NIAT)	934,769	1,158,063	1,071,260	3,164,092	2,788,327
Total Contributions (Non-U.S. or U.S.)					
-US Air Force STP	116,242	303,097	585,202	1,004,541	888,130
TOTAL COST FOR PHASE	14,887,804	31,417,917	14,324,338	60,630,060	53,743,958

Figure K-2c Time Phased Cost Breakdown by WBS and Major Cost Category for Hampton University (Phase E)					
(Phased costs in Real Year Dollars, Totals in Real Year and GY2000 Dollars)					
WBS/Cost Category Description		FY6	FY7	Total (RY$)	Total(FY2000$)
		10/05 - 9/06	10/06 - 9/07		
Total Direct Labor Cost		**2,248,336**	**1,777,106**	**4,025,442**	**3,298,772**
WBS 1.0 Science					
WBS 1.1 Mission Planning		157,386	142,545	299,931	250,844
WBS 1.2 Simulation					
WBS 1.3 Data Analysis		800,680	659,492	1,460,172	1,221,996
WBS 2.0 Management					
WBS 2.1 Program Coordination		65,873	46,979	112,852	94,536
WBS 2.2 Project Management					
WBS 2.3 Systems Engineering		14,697		14,697	11,352
WBS 2.4 Mission Assurance					
WBS 3.0 Spaceflight Segment					
WBS 3.1 Instrumentation		13,348	13,722	27,070	22,620
WBS 3.2 Spacecraft Bus		51445		51,445	43590
WBS 3.4 Ship/Integration					
WBS 3.5 Integration and Test					
WBS 3.6 Launch Vehicle					
WBS 4 Ground Segment					
WBS 4.3 Telemetry Station					
WBS 4.4 Mission Control Center		273,018	118,367	391,385	297,957
WBS 4.5 Operations planning and training					
WBS 4.8 Data Processing		658,876	579,007	1,237,882	996,536
WBS 1.4 Data Archival		213,013	216,994	430,007	359,341
Total Subcontract Costs		**859,555**	**239,920**	**1,099,474**	**926,058**
WBS 1.0 Science					
WBS 1.2 Simulation					
WBS 1.3 Data Analysis		116,054	119,303	235,357	196,667
WBS 2.0 Program Management					
WBS 3.0 Spaceflight Segment					
WBS 3.1 Instrumentation					
WBS 3.2 Spacecraft					
WBS 3.5 Integration & Test					
WBS 3.4 Launch Vehicle					
WBS 4 Ground Segment					
WBS 4.3 Telemetry Station					
WBS 4.4 Mission Control Center		42,877		42,877	36,330
WBS 4.5 Operations planning and training		149,478		149,478	126,655
WBS 4.8 Data Processing		551,146	120,616	671,762	566,406
Total Materials & Equipment Cost		**1770.31255**	**1819.8813**	**3590.19384**	**3000**

Figure K-2c Time Phased Cost Breakdown by WBS and Major Cost Category for Hampton University (Phase E) – concluded					
(Phased costs in Real Year Dollars, Totals in Real Year and GY2000 Dollars)					
WBS/Cost Category Description		FY6	FY7	Total (RY$)	Total(FY2000$)
		10/05 - 9/06	10/06 - 9/07		
WBS 3.0 Spaceflight Segment					
WBS 3.1 Instrumentation					
WBS 3.1.1 SOFIE					
WBS 3.1.2 CIPS					
WBS 3.1.3 SHIMMER		1,770	1,820	3,590	3000
WBS 3.1.4 CDE					
WBS 3.1.5 IPA					
WBS 3.2 Spacecraft					
Total Reserves					
		382,736	236,339	619,075	519,093
Total Other Costs		**1,048,651**	**562,944**	**1,611,595**	**1,308,321**
Fee		17,317	5,199	22,516	18,958
Ball Fee		15,211		15,211	12,888
E/PO		280,307	75,289	355,597	299,563
Travel, Misc Other Direct Costs, and Indirect Costs		735,815	482,455	1,218,271	976,912
Total Contract Cost		**4,158,312**	**2,581,789**	**6,740,101**	**5,536,150**
Total Other Costs to NASA OSS		**8,063,252**	**-**	**8,063,252**	**6,832,886**
Launch Services (WBS 3.4.1)		8,000,000		8,000,000	6,778,464
Other (NIAT)		63,252		63,252	54,422
Total Contributions (Non-U.S. or U.S.)					
TOTAL COST FOR PHASE	0	**12,221,564**	**2,581,789**	**14,803,353**	**12,369,036**

Figure K-3 Fiscal Year Costs in Real Dollars (to nearest thousand)

(Totals in Real Year and Fiscal Year 2000 Dollars)

Cost Element	FY1	FY2	FY3	FY4	FY5	FY6	FY7	Total (RY$)	Total (FY2000$)
	7/01 - 09/01	10/01 - 9/02	10/02 - 9/03	10/03 - 9/04	10/04 - 9/05	10/05 - 9/06	10/06 - 9/07		
Phase A	292,114	157,887						450,000	439,549
Reserves									
Total Phase A								**450,000**	**439,549**
Phase B		1,852,943	4,162,585					6,015,528	5,544,676
Ball Phase B			2,964,917					2,964,917	2,729,186
Ball Phase B Fee			146,542					146,542	134,891
Reserves		261,908	968,638					1,230,546	1,139,460
Total Phase B								**10,357,533**	**9,548,213**
Phase C/D									
SOFIE			2,135,538	1,642,120	738,977			4,516,635	4,079,811
CIPS			1,348,021	1,822,003	252,752			3,422,777	2,919,485
SHIMMER			1,265,541	1,100,803	269,124			2,635,468	2,385,021
IPA			305,428	570,290	33,119			908,837	774,803
CDE			285,148	577,937	67,575			930,660	791,093
Instr Integ, Assy & Test			-	959,233	490,762			1,449,995	1,267,699
Subtotal - Instruments								***13,864,372***	***12,217,912***
Spacecraft Bus			6,136,468	4,129,199	376,783			10,642,450	9,674,142
Spacecraft Bus Fee			304566.565	204492.45	18628.155			527,687	479,684
Spacecraft Integ, Assy & Test					97,415			97,415	84,852
Spacecraft Integ, Assy & Test (BALL)			141,839	809,418	959,757			1,911,014	1,691,312
Spacecraft Integ, Assy & Test Fee			7001.495	39939.865	47388.77			94,330	83,485
Other Hardware Elements								-	
Launch Ops					356,362	11,868		368,230	320,459
Launch Ops Fee					17632.905	586.175		18,219	15,856
Subtotal - Spacecraft								***13,659,346***	***12,349,789***
Proj Mgmt/Miss Analysis/Sys Eng			852,352	1,197,109	961,266			3,010,727	2,548,657
Science Team Support			323,103	495,317	865,876			1,684,296	1,450,214
Prelaunch GDS/MOS Development			357,460	863,153	1,721,780			2,942,393	2,549,724
E/PO, Other			62,759	301,322	309,027			673,108	596,752
Subtotal Phase C/D before Reserves								***8,310,524***	***7,145,348***
Reserves			2,594,580	2,516,818	985,072			6,096,470	5,499,937
Total Phase C/D								**41,930,712**	**37,212,986**

Figure K-3 Fiscal Year Costs in Real Dollars (to nearest thousand) – concluded

(Totals in Real Year and Fiscal Year 2000 Dollars)

Cost Element	FY1	FY2	FY3	FY4	FY5	FY6	FY7	Total (RY$)	Total (FY2000$)
	7/01 - 09/01	10/01 - 9/02	10/02 - 9/03	10/03 - 9/04	10/04 - 9/05	10/05 - 9/06	10/06 - 9/07		
Phase E									
MO&DA						2,952,313	1,874,225	4,826,537	3,996,571
MO&DA (BALL)						141,986		141,986	120,306
MO&DA (Ball Fee)						7019.105		7,019	5,947
Tracking Services						279,696	281,785	561,481	469,244
E/PO						280,307	75,289	355,597	299,563
Other (Management)						476,932	350,491	827,423	627,524
Subtotal Phase E before Reserves								***6,720,043***	***5,519,154***
Reserves						382,736	236,339	619,075	519,093
Total Phase E								**7,339,118**	**6,038,247**
NIAT		301,071	1,248,072	1,158,063	1,071,260	63,252	-	3,841,718	3,419,515
Launch Services				15,000,000	5,000,000	8,000,000		28,000,000	24,564,950
Total NASA Cost	292,114	2,573,808	25,610,559	33,387,216	14,640,560	12,596,696	2,581,790	$91,919,081	$ 81,223,459
Contributions	50,000		116,242	303,097	585,202			1,004,541	$936,768
Total Contributions								1,004,541	936,768
				Total Mission Cost					$ 82,160,227

Figure K-4. Phase C/D Development Costs In Real Year Dollars (to nearest thousand)				
Cost Element	**Non-Recurring**	**Recurring**	**Total (RY$)**	**Total (FY2000$)**
SOFIE	3,152,819	1,351,208	4,504,027	4,071,801
CIPS	1,751,400	1,167,600	2,919,000	2,919,000
SHIMMER	3,064,000	766,000	3,830,000	3,830,000
IPA	774,881	136,744	911,625	774,803
CDE	834,682	278,227	1,112,910	943,590
Subtotal - Instruments	**9,577,782**	**3,699,779**	**13,277,561**	**12,539,194**
S/C Bus Prog Mgmt	616,464	652,680	1,269,144	1,143,176
S/C Bus Prog Mgmt Fee	30,520	32,345	62,865	56,624
S/C Bus Miss Assur	748,654	382,746	1,131,400	1,031,333
S/C Bus Miss Assur Fee	36,950	18,889	55,839	50,900
S/C Bus Sys Eng	541,860	435,185	977,045	883,319
S/C Bus Sys Eng Fee	26,743	21,491	48,234	43,606
S/C Bus Struct and Mech	675,971	520468	1196439	1,095,801
S/C Bus Struct and Mech Fee	33,370	25,706	59,076	54,106
S/C Bus EPS	539,056	1449044	1988100	1,818,799
S/C Bus EPS Fee	26,603	72,218	98,821	90,405
S/C Bus C&DH	774,054	809111	1583165	1,448,972
S/C Bus C&DH Fee	38,203	40,229	78,431	71,784
S/C Bus Telecomm	268,411	1107900	1376311	1,258,071
S/C Bus Telecomm Fee	13,248	55,301	68,549	62,660
S/C Bus Thermal	307,590	124012	431602	393,268
S/C Bus Thermal Fee	15,183	6,123	21,306	19,414
S/C Bus ADCS	387,556	1330489	1718045	1,568,016
S/C Bus ADCS Fee	19,132	66,437	85,569	78,098
S/C Bus Flight Software	1,661,436		1661436	1,501,689
S/C Bus Flight Software Fee	82,031	-	82,031	74,144
S/C Bus I&T	965,580	973041	1938621	1,719,010
S/C Bus I&T Fee	47,681	48,002	95,683	84,843
S/C Bus GSE	274,683	139277	413960	377,231
S/C Bus GSE Fee	13,556	6,865	20,421	18,609
S/C Bus Launch Ops	-	343331	343331	296,722
S/C Bus Launch Ops Fee	-	16,977	16,977	14,673
Subtotal - Spacecraft Bus	**8,144,533**	**8,677,864**	**16,822,397**	**15,255,270**
Any other elements (specify)				-
Program Management	153,201	1,378,806	1,532,007	1,283,637
Systems Engineering	71,400	642,597	713,996	596,323
Quality Assurance	91,445	365,778	457,223	385,299
Integration & Test	30,517	274,651	305,168	249,019
Mission Control Center	314,451	943,353	1,257,805	1,036,508
Operations planning and training	126,032	1,134,287	1,260,319	1,035,160
Subtotal - Other elements	**787,045**	**4,739,473**	**5,526,517**	**4,585,946**
Total NASA OSS Development Cost	18,509,359	17,117,116	35,626,475	32,380,410

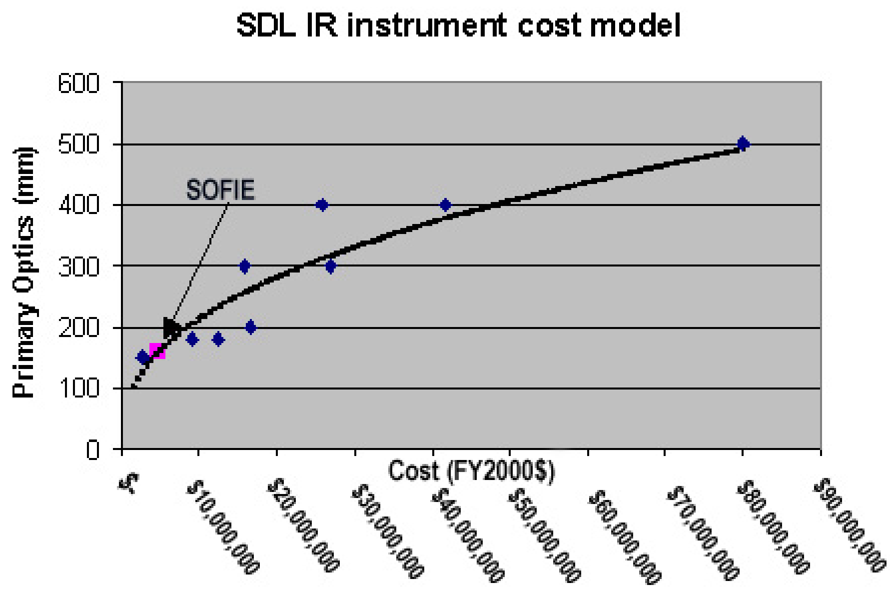


Figure K-8. SDL Comparison of SOFIE Estimate to Past Performance

The SHIMMER data processing software strongly follows that from the MAHRSI experiment, again providing an important source of information, basis of comparison, and aid in estimating SHIMMER costs.

CDE: The CDE costing process was based on the breadboard development of this instrument, the evaluation of the status of designs, and the detailed assessment of costs to produce those designs in flight hardware. The full process began with the conceptual design, followed by the generation of the WBS. Each of the engineering managers (electrical, mechanical, software, systems, project management, I&T and mission assurance) developed independent manpower and hardware budgets for their respective areas of expertise. These budgets were then iterated and evaluated for consistency and completeness by this group, and by all key engineering and administrative staff. The construction and processes involved in producing a flight version of the CDE are standard approaches within LASP. The CDE is new to LASP but the detection method has strong heritage with the University of Chicago with whom LASP is partnering for AIM. Further, the CDE electronics are based upon earlier LASP designs.

CIPS: The CIPS costing process was based on instrument designs and comparisons of the proposed hardware systems to those that have been previously built. The process used is identical to that performed for the CDE.

One very clear and stable aspect of the CIPS budget is that the detector subcontracts represent a significant fraction of the total instrument cost. The CIPS instrument is a new development at LASP; however, the CCD's are being purchased directly. The CCD's have flight heritage (Rosetta) and require no new development. The CIPS elements beyond the CCD's are not complex and fall well within LASP's 50 years of experience in developing space flight hardware.

The CIPS data processing software strongly mimics analysis of SBUV data, which has been performed by one of the LASP CIPS investigators (Thomas). All of the CIPS costing is based upon experience in similar efforts.

IPA: Costing of the IPA was performed using comparisons to the electrical, structural and thermal designs for the SNOE spacecraft and the TIMED pointing platform, including the lessons learned from the costs involved in the development of the SORCE optical bench, and the issues related to developing multiple instrument and electrical interfaces with that assembly.

LASP Management: Management and systems engineering costs were estimated using experiences from past projects as a guide. Mission Operations costs derive directly from ongoing operations, with updated information on ground systems and networks. Mission assurance costs were developed using the current SORCE project-wide mission assurance plan that is currently being implemented by LASP. NIAT costs have been estimated using the experiences gained from the SORCE project, with modifications to meet our expectations of the needs of NASA.

Project management at LASP follows closely the project management for LASP's SORCE mission and includes some of the same personnel. Also, SORCE is a similar model, having four instruments and a spacecraft provider (Orbital) outside LASP. Thus the costing for program management is based upon experience with a similar program.

LASP Mission Operations: LASP has performed and led mission operations for several NASA missions, including spacecraft developed by BATC. The costing for mission operations is therefore strongly based upon experience with similar missions (QuikSCAT).

BATC: A three-way cost methodology for developing Phase B-E cost of BATC deliverables was pursued and is summarized in Fig. K-3. Where a method produced only Phase C/D costs, grass-roots cost for Phases B and E were added to produce the final estimate. The estimates include fee. The methods used were:

1. Grassroots: a bottoms up approach based upon the evaluations from cognizant engineers.
2. BATC Cost Estimating Relationship (CER): cost relationships derived from a large number of projects completed at BATC.
4. Small Spacecraft Cost Model (SSCM2000)

The modeling results are expressed in real year (RY) dollars and do not include reserve.

All of the cost approaches show consistency in the predicted cost of BATC products (all flight hardware and mission support operations) and provide confidence in the detailed grassroots mission cost (Table K-4).

Method 1: BATC (Grassroots). This is the preferred method and is the basis for the spacecraft WBS element costs. The engineering team developed a large number of parameters that describe the spacecraft bus. These include a detailed drawing tree, drawing counts, electronic board counts, board area estimates, parts lists, connector counts, weights, power, volume, computer software configuration items (CSCI), source lines of code, and other parameters. Relevant parameters and historical basis of estimates (BOEs) were used to generate most probable labor hours. Costs were compared to, or derived from, recent missions such as Deep Impact and SIRTF, to make the estimates more specific to recent missions. Finally, ratios of WBS cost elements were compared to ratios of recent missions for reasonableness. Statements of work (SOW) and specifications were developed and vendors provided written quotes for spacecraft subsystem components including ADCS, C&DH, EPS, and Telecomm. This results in a grassroots estimate for the spacecraft and mission operations support of $17.6M (RY) including fee.

Method 2: BATC (CER). BATC has invested significantly during the past four and a half years in a project intended to capture and parameterize the costs from the past 10 years of NASA flight instruments and spacecraft. BATC has defined a set of parameters that accurately reproduce the costs of those missions, and have been captured in a Cost Estimating Relationship (CER) model.

The CER model is a function-oriented model. It is used to estimate labor hours in a functional organization format. There are over 30 cost estimating relationships used to estimate design, systems engineering, product assurance, test, and production. This modeling approach better quantifies the tasks performed at BATC on a project. The labor hours produced by the CERs are dollarized using historical skill mixes by function and current labor rates and burdens. Subcontract, material, and other direct costs (ODCs) are added based on the values used in our engineering estimate. The CER model covers all labor from ATP to the delivery of the hardware. It does not include any effort associated with launch operations or mission support. These costs, estimated from pervious missions, were added to the model results and are based on our engineering estimate.

The total AIM spacecraft and mission operations costs for the CER model is $18.2M (RY), again without reserves, but with fee. This is extremely close to the $17.6M (RY) generated by the grass-roots method.

Method 3: Small Spacecraft Cost Model (SSCM2000). This model is an updated version of the SSCM98 model and is designed specifically to estimate small spacecraft. The SSCM2000 model includes spacecraft that are more representative in size of the AIM spacecraft. The SSCM2000 costs represent engineering, manufacturing, and development for Phases C/D. Concept development (Phase B) and operations (Phase E) are not included. The relationships used in the model are based on performance parameters e.g. spacecraft and subsystem weight, power, solar array cells type, and three different mission classes: planetary (mass range of 105Kg to 772Kg), earth orbiting small satellite (mass range of 102Kg to 376Kg) and microsatellite (mass range of 4Kg to 95Kg). The mass of the AIM RS300 is 100Kg.

This model produced a $24.9M (RY) estimate for the earth-orbiting small satellite; $22.9M (RY) estimate for the planetary; and a $10.6M (RY) estimate for the earth-orbiting micro satellite spacecraft. These estimates were adjusted by factoring in a grass roots estimate for Phases B and E. The BATC in-house grass roots and CER estimates fall in between the small and micro satellite estimates. This would be expected because the RS300 bus parameters fall within (or very close to) the parameter values of these two spacecraft classes.

It is impossible to perform a detailed reconciliation between the BATC CER estimates and the SSCM2000 model, as the cost data used to develop the SSCM model is proprietary and not available for review. However it is reasonable to assume that if the database used to construct the SSCM model was aligned so that the median mass was closer to 100Kg, an adjusted cost in the range of $17M to $19M could be realized.

K.6 Fees and Fee Awards

Three AIM team members are awarded fees for their contributions. BATC and GATS are for-profit companies and SDL is a not for profit university affiliated research center. As detailed in Appendix M8, each of these team members has agreed in principle to incentive plans, which will be finalized in Phase B. The details of the incentive plans may be obtained in Appendix M8. Fees are awarded according to in-flight performance, schedule performance, and cost performance. During Phase B, BATC, GATS, and SDL are each awarded fixed 5% fees. In Phases C, D, E, the incentive-based fees are awarded. Fees based on in-flight and schedule performance are budgeted explicitly in Figs. K-1 through K-4. Cost incentive fees, because they are awarded on the basis of minimizing need for using cost reserves, are contained within the reserve budget. The reserve budget is described in the following section.

K.7 AIM Reserve Strategy

The AIM Reserve Strategy is detailed in Section G.4. The reserve is controlled by the PM (with PI concurrence) who establishes a formal process for the release of these funds. Reserve is not applied to the ELV, science (data analysis), guest investigator, E/PO, or mission operations costs during any phase of the mission. For the rest of the AIM mission elements, the reserves going into Phases C, D, and E are 20%. In Phase B, a 20% reserve is applied to the spacecraft while 15% is applied to all other AIM elements. **Fig. K-9** shows the breakout of reserve as a function of FY and phase. Fig. K-9 also shows the cost of each AIM major elements as a function of FY and phase. The reserves are also shown in Figs. K-1 through K-4. The above values are determined through experience with other missions and are strongly based on the NIAT recommendations. A portion of the reserve allocation, approximately $1.5M (FY2000) is taekn from the non-conforming NIAT allowance in order to reach the NIAT recommend value of 20% reserve at Phases C/D. The NIAT contribution is detailed in Appendix M12. The breakdown of other NIAT costs are shown in **Fig. K-7**.

K.8 Cost Management

Section G.2 of the AIM CSR details the management processes and plans that will be incorporated on the AIM mission, as well as the AIM approach to releasing cost reserves and a detailed discussion of the AIM project descope strategy. As discussed earlier, the management team has determined a set of descope options with minor mission impact and ease of implementation.

An Earned Value system run by LASP will be implemented for the AIM Project. The goal is to provide tracking and reporting consistency while allowing flexibility and discretion as to how it is implemented. The primary elements are a work breakdown structure (WBS), a master schedule, a PERT-type logic network, a current contract baseline value, and budgets for each major WBS subsystem element. Assessing performance against milestones and funds expended (earned value) and displaying the data in a meaningful manner (performance charts) are the basic elements of this system. The objective is to communicate cost and schedule performance relative to a baseline. It is designed to identify problems and to anticipate future problems by projecting from current earned value data. Details are found in Section G.

In order to identify and prepare for the potential long lead-time purchases and to further solidify the AIM cost, the AIM team wrote specifications and RFPs for all major instrument and spacecraft components. Firm Fixed Price quotations were received from major subcontractors adding credibility to the cost roll-up.

Figure K-9 Major Element Cost Review

BUDGET BROKEN DOWN INTO SPENDING AREAS			Phase B		Phase C/D			Phase E		TOTAL
			7/1/02-9/30/02	10/1/02-1/31/03	2/1/03-9/30/03	10/1/03-9/30/04	10/1/04- 9/30/05	10/1/05-9/30/06	10/1/06-9/30/07	
	Line Item		FY2002	FY2003	FY2003	FY2004	FY2005	FY2006	FY2007	FY 2000 $
Science										
	Science									-
	HU		66,821	54,382	108,763	158,146	242,700	215,919	190,442	1,037,174
	LASP		14,771	39,898	139,635	205,343	304,878			704,525
	NRL		4,512	6,016	12,032	18,048	13,536	437,175	437,175	928,494
	SDL		9,627	12,451	24,950	40,210	43,075	68,049	58,636	256,998
	GMU		8,582	3,373	5,165	8,495	41,906	88,517	88,477	244,514
	GATS		14,380	19,173	50,408	97,134	153,419	179,402	50,000	563,916
	GATS FEE		288	383	1,008	1,943	3,068	3,588	1,000	11,278
	Total Science									
	GI Program					83,333	83,333	83,333		250,000
	Ed & Outreach			28,884	57,769	269,810	269,173	237,507	62,056	925,199
Program Management										-
	Project Coordi-nation	(HU)	52,656	36,965	73,929	110,893	98,576	83,640	58,644	515,303
	Project Man-agement	(LASP)	259,030	286,719	678,267	903,225	683,767	17,669		2,828,677
	NIAT	(ALL)	284,893	287,210	861,631	1,036,954	933,103	53,594		3,457,386
Payload										-
	SOFIE		263,918	421,482	1,817,673	1,871,611	382,517			4,757,200
	SOFIE Fee		5,278	8,430	36,353	37,432	7,650			95,144
	SHIMMER		410,753	1,101,005	1,164,922	1,055,633	341,854			4,074,167
	CIPS		464,287	1,549,459	1,183,448	1,628,343	356,713			5,182,250
	CDE		59,722	121,717	250,435	486,179	54,479			972,532
	Instrument Pallette		56,418	79,469	268,298	479,756	26,749			910,690
	Spacecraft			2,232,503	6,697,512	4,641,013	1,557,998	140,917		15,269,943
	Launch Vehicle					13,431,323	4,355,163	6,778,464		24,564,950

Figure K-9 Major Element Cost Review (concluded)

BUDGET BROKEN DOWN INTO SPENDING AREAS			Phase B		Phase C/D			Phase E		TOTAL
			7/1/02-9/30/02	10/1/02-1/31/03	2/1/03-9/30/03	10/1/03-9/30/04	10/1/04- 9/30/05	10/1/05-9/30/06	10/1/06-9/30/07	
	Line Item		FY2002	FY2003	FY2003	FY2004	FY2005	FY2006	FY2007	FY 2000 $
Ground Segment										-
	Mission Ops		20,819	9,842	281,311	618,592	946,275	508,985	137,713	2,523,537
	Data Process-ing									-
		SOFIE DPC + GATS	12,186	11,153	59,124	146,005	423,732	392,236	24,661	1,069,097
		GAT'S Fee	244	223	1,182	2,920	8,475	7,845	493	21,382
		SHIMMER DPC	2,428	3,238	21,841	107,065	161,053	398,653	398,653	1,092,931
		CIPS+CDE DPC						350,574	259,281	609,855
		PDC	12,015	11,680	23,359	30,039	264,488	236,988	232,255	810,825
	Total		2,023,628	6,325,655	13,819,017	27,469,446	11,757,680	10,283,056	1,999,487	73,627,230
								Phase A Cost		437,743
	Reserve		247,835	891,625	2,388,294	2,253,613	858,030	324,295	194,798	7,158,489
								Total Mission Cost		81,223,462
				B			C/D		E	
	Cost by phase			8,349,282			53,046,142		12,282,543	73,677,968
				1,139,460			5,499,937		519,093	7,158,489
	Reserve in $RY		261,908	968,638	2,594,580	2,516,818	985,072	382,736	236,339	7,946,091

Figure K-7 Funding Profile Template For NIAT Activities									
(FY costs in Real Year Dollars, Totals in Real Year and FY 2000 Dollars)									
Item	**FY1**	**FY2**	**FY3**	**FY4**	**FY5**	**FY6**	**FY7**	**Total (Real Yr.)**	**Total (FY 2000)**
	7/01 - 09/01	10/01 - 9/02	10/02 - 9/03	10/03 - 9/04	10/04 - 9/05	10/05 - 9/06	10/06 - 9/07		
FMEA, etc.									
-NRL		$ 15,059	$ 116,633	$ 168,278	$ 98,814	$ -		$ 398,784	$ 358,360
-SDL		$ -	$ 152,894	$ 79,862	$ -	$ -		$ 232,757	$ 212,249
-LASP		$132,770	$ 601,248	$ 548,144	$ 335,050	$ 5,422	$ -	$1,622,634	$1,428,463
-IV&V		$ 22,192	$ 114,069	$ 273,614	$ 321,458	$ 57,830		$ 789,164	$ 700,000
- BALL		$131,049	$ 263,227	$ 88,164	$ 315,939			$ 798,379	$ 720,443
Additions to the OSS Cost Cap		$301,071	$1,248,072	$1,158,063	$1,071,260	$ 63,252	$ -	$3,841,718	$3,419,515

Note that in addition to the $3.42M (FY2000) allocated above to NIAT activities, an additional $1.58M (FY2000) is added to the project reserves in order to reach the NIAT recommended 20% allocation at Phases C/D.

K.9 Co-Investigator Commitments and Costs

Fig. K-5 displays the Co-Investigator commitments and costs for each phase of the AIM mission. Reserves are not applied to investigator costs. Note that in some cases, investigators costs are supplemented by their home institutions. For example the PI is supported by NASA for only one month per year while HU supports the remainder of his contribution. **Fig. K-6** shows that there are no NASA civil servant costs required for the AIM mission.

K.10 Conclusion

We believe that the proposed funds are adequate to carry out this mission, and the reserves are adequate to deal with any unexpected problems. We have carefully evaluated the project cost factors and are confident that our price provides the best value for the project.

We have been especially sensitive with regard to cost and risk mitigation in our trade studies. Our approach toward cost is designed to achieve a low-risk, affordable product with high-quality performance. Our significant margins and reserves throughout the project for mass, power, schedule, and all other performance parameters provide formidable protection to the cost reserves. The current cost estimates were developed with an extensive disciplined grass roots approach, and are supported by cost modeling and comparisons to similar missions and mission elements. We have allocated cost reserves that are sufficient to cover unforeseen cost increases and we have developed a carefully considered detailed cost reserve use plan.

For the above reasons, we are confident that our estimated costs are real, reasonable, complete, and credible and protected by reserves and reserve management strategies.

Figure K-5. Co-Investigation Commitment and Cost Funding Profile Template
(FY costs in Real Year Dollars, Total in Real Year and FY2000 Dollars)

	Phase B	Phase C/D	Phase E	Total (Real Year)	Total (FY 2000)
NASA OSS Cost					
Co-I #1 James Russell/ HU					
Percent Time					-
Cost	33,513	70,600	56,531	160,645	141,715
Co-I #2 Scott Bailey/ UAF					
Percent Time	50.00%	50.00%	50.00%		
Cost	71,332	315,374	267,236	653,943	570,445
Co-I #3 David Rusch, LASP					
Percent Time	25.00%	31.82%	72.50%		
Cost	14,475	110,244	166,793	291,512	231,214
Co-I #4 Mihaly Horanyi, LASP					
Percent Time		9.09%	5.00%		
Cost		26,467	9,602	36,069	29,444
Co-I #5 Cora Randall, LASP					
Percent Time	16.67%	12.12%	25.00%		
Cost	7,314	31,993	42,940	82,247	65,178
Co-I #6 Michael Summers/ GMU					
Percent Time	5.1%	10.9%	41%		
Cost	12,733	51,995	154,616	219,345	173,968
Co-I #7 Eckermann/NRL					
Percent Time			55%		
Cost			151,716.00	181,563	151,716
Co-I #8 Siskind/NRL					
Percent Time			55%		
Cost			181,563.28	181,563	151,716
Co-I #9 Stevens/NRL					
Percent Time			50%		
Cost			184,679.57	184,680	154,320
Co-I #10 Meier/NRL					
Percent Time	11%	6%	87%		
Cost	11,878.27	29,394.02	287,844.99	329,117	277,992
Co-I #11 Englert/NRL					
Percent Time	18%	17%	69%		
Cost	22,960.92	102,868.59	284,477.39	410,307	351,127
Co-I #12 Harlander/ St.Cloud State Univ.					
Percent Time	88%	79%	100%		
Cost	93,664.64	381,626.81	300,786.44	776,078	644,687
Co-I #13 Mike Taylor/ SDL-USU					
Percent Time	8%	10%	2%		
Cost	12,527	76,536	17,951	107,013	95,000
Total NASA OSS Co-I Cost	280,398	1,197,099	2,106,738	3,614,082	3,038,522
Contributions					
Co-I #1 Name/Organization					
Percent Time					
Cost					
Co-I #2 Name/Organization					
Percent Time					
Cost					
Co-I #n Name/Organization					
Percent Time					
Cost					
Total Contributed Co-I Cost					

Item	FY01	FY02	FY03	FY04	FY05	FY06	FY07	Total (Real Yr.)	Total (FY 2001)
Workforce	0	0	0	0	0	0	0	0	0
Facilities	0	0	0	0	0	0	0	0	0
E/PO	0	0	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0	0
NASA Civil Service Costs included in NASA OSS cost	0	0	0	0	0	0	0	0	0
Contributions by NASA Centers									
Workforce	0	0	0	0	0	0	0	0	0
Facilities	0	0	0	0	0	0	0	0	0
E/PO	0	0	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0	0
Contributed NASA Civil Service Costs	0	0	0	0	0	0	0	0	0

Figure K-6. NASA Civil Service Costs Funding Profile Template

Mission Total= 0

K.11 Phases B/C/D/E Supplemental Information

Supplemental information is provided in order to help the reviewer understand how the costs were derived. **Fig. K-10** shows the major components of the instruments which served as a basis of estimate. In that table, the TRL levels and the heritage of the component are shown. The BATC and SDL proprietary packages include further details.

Fig. K-11a through **K-11h** list the work force staffing plans for each institution. The costs in these tables cover the staffing that is paid for by NASA OSS and does not include support from the institutions.

Figs. K-12, K-13, and the attached proprietary packages from SDL and BATC provide information on the various elements of the cost breakdown. Included is costs for materials, subcontracts, travel, computers, consultant charges as well as indirect rates and costs.

Figure K-10 Basis of Estimate

See Table F-10 for Spacecraft MEL / Basis of Estimate

	Component	#	Vendor	TRL	Basis of Estimate / Heritage
SOFIE	Steering Mirror	1	BATC	8	Quote, ACE
	Telescope	1	SDL	9	WIRE, HALOE
	Detectors	16	Judson	9	Quote, HALOE
	Sun Sensor	1	Adcole	9	Quote
	Electronics parts	-	SDL	8-9	WIRE, HALOE
	Optics components	-	-	8	Quotes, WIRE, HALOE, RAMOS
SHIMMER	Instrument Controller	1	NRL	9	MAHRSI
	Camera / Controller	1	MPIA	8-9	MPIA Mars Missions
	Monolithic Inerferometer	1	NRL	7	SHIMMER Middeck
	Imaging Optics	1	NRL	9	SHIMMER Middeck
	Mechanical Design	1	NRL	7	SHIMMER Middeck
	Dust Door	6	NRL	9	MAHRSI
CIPS	Shutter	6	NRL	8	TRACE, SXI
	CCD Camera	6	DLR	7	Rosetta
	Image Intensifier	6	Hamamatsu	8	Rockets
	Telescope	6	Latkin	8	Simple common optical system
	HVPS	6	LASP	8	Cassini, rockets (Battel)
	I/F Electronics	1	LASP	7	TIMED, SORCE
	Cover	6	LASP	7	SNOE, TIMED
	Thermal Control	1	LASP	8	SNOE
CDE	Structure	1	LASP	7	Cassini
	Detector	1	LASP	6	Vega, Cassini, Stardust, Argos
	Amplifier	1	LASP	8	Cassini, rockets
	I/F Electronics	1	LASP	8	Cassini
IPA	Structure	1	LASP	8	SORCE, TIMED
	Intefrace plate, flexures	1	LASP	8	SORCE, TIMED
	Vertical plate, top plate	1	LASP	8	SORCE, TIMED
	Gussets	2	LASP	8	SORCE, TIMED
	Harness	1	LASP	8	SORCE, TIMED
	MLI	1	LASP	8	SORCE, TIMED
	Tracker Mount	1	LASP	8	SORCE, TIMED
Spacecraft	Management	-	BATC	-	Historical % based on H/W cost
	Mission Assurance	-	BATC	-	Historical % based on H/W cost
	Systems Engineering	-	BATC	-	Historical % based on H/W cost
	Structures and Mechanisms	-	BATC	8	GFO, QuickBird, Vendor quote
	Electrical Power Subsystem	-	BATC	9	QuickBird, Vendor quotes, HST Instrument
	Command and Data Handling	-	BATC	8	Deep Impact, Vendor quotes
	Telecommunications	-	BATC	9	QuickBird, Vendor quotes
	Thermal Control	-	BATC	9	QuickBird, QuikSCAT
	ADCS	-	BATC	9	Deep Impact, GFO, MTI, QuikSCAT, Vendor quotes
	Flight Software	-	BATC	7-8	Deep Impact
	S/C I&T	-	BATC	9	Deep Impact, QuickBird
	Ground Support Equip.	-	BATC	9	Deep Impact, QuickBird
	Launch checkout / Orbital Ops	-	BATC	-	Historical % based on H/W cost
	Mission Ops / Data Analysis	-	BATC	-	Historical % based on H/W cost

Figure K-11a Work Force Staffing Plan

HU Work Force Staffing Plan	2002	2003	2004	2005	2006	2007
PI Faculty (Jim Russell)	0.1	0.1	0.1	0.1	0.1	0.1
Project Coordinator (Jim Raper)	0.125	0.5	0.5	0.375	0.25	0.05
DPC Director				1	1	1
Admin. Ast.	0.25	1	1	1	1	0.91
Secretarial/Clerical	0.25	1	1	1	1	0.91
Undergraduate Students				1.5	1.5	1.365
Graduate Students				1.5	1.5	1.5

Fiogure K-11b Work Force Staffing Plan

UAF Work Force Staffing Plan	2002	2003	2004	2005	2006	2007
Co-I (Scott Bailey)	0.167	0.5	0.5	0.5	0.5	0.33
Graduate Students				1	1	1

Figure K-11c Work Force Staffing Plan

SDL Work Force Staffing Plan	2002	2003	2004	2005	2006	2007
Co-I Dr. Mike Taylor (Science)	0.05	0.19	0.19	0.19	0.19	0.17
John Kemp (PM/Lead)	0.25	1.00	1.00	0.46		
Senior Engineer/Scientist	0.50	1.67	1.66	0.46		
Engineer Scientist	0.44	1.58	1.34	0.29		
Senior Designer	0.25	0.83	0.40	-		
Senior Technologist	0.13	0.67	0.90	0.46		
Technologist	-	0.50	0.90	0.29		
Technician	-	-	0.02	-		
Sr. Support Staff/Tech Writer	0.13	0.50	0.50	0.42		
Graduate Student	0.16	0.47	0.46	0.06	0.63	0.46

Figure K-11d Work Force Staffing Plan

GMU Work Force Staffing Plan	2002	2003	2004	2005	2006	2007
Michael Summers (PM/Lead)	0.05	0.05	0.05	0.21	0.41	0.41
Student GRA - Doctoral				1	2	2

Figure K-11e Work Force Staffing Plan

GATS Work Force Staffing Plan	2002	2003	2004	2005	2006	2007
Data Analyst	0.42	0.44	0.25	1.00	0.7	
Data Manager	0.22	0.22	0.22		0.25	0.5
Data Systems Engineer	0.3	0.31	0.3	1.3	1.3	1
Flight Ops Engineer			0.12	0.88		
Flight Ops Software				0.5		
Sr. Scientific Programmer				1	0.67	0.33
Scientific Programmer				1	0.83	0.67

Figure K-11f Work Force Staffing Plan

NRL Work Force Staffing Plan	2002	2003	2004	2005	2006	2007
Prin.Investigator R. Meier	0.04	0.18	0.19	0.13	0.58	0.58
Project Scientist - C. Englert	0.25	0.99	0.96	0.64	1.03	1.03
Instrument Scientist - J. Cardon	0.25	0.94	0.71	0.60	0.88	0.88
Res. Physicist - C. Brown	0.18	0.71	0.62	0.45	0.05	0.05
Mechanical Tech - L. Marlin	0.21	0.79	0.50	0.26	0.00	0.00
QA/Reliability Engineer	0.03	0.13	0.20	0.08	0.00	0.00
Business Manger	0.05	0.20	0.18	0.08	0.08	0.08
Res. Physicist - M. Stevens	0.03	0.10	0.06	0.04	0.72	0.72
Res. Physicist - D. Siskind	0.00	0.00	0.00	0.00	0.42	0.42
Res. Physicist - S. Eckermann	0.00	0.00	0.00	0.00	0.46	0.46

Figure K-11g Work Force Staffing Plan

LASP Work Force Staffing Plan	2002	2003	2004	2005	2006	2007
RUSCH, David W.- PRINCIPAL INVESTIGATOR	0.06	0.25	0.25	0.44	0.71	0.50
CALLAN, Michael- DATA/SOFTWARE MANAGER	0.00	0.50	0.75	0.83	0.87	0.59
MCGRATH, Michael T.- AIM PROJECT MGR	0.13	0.58	0.50	0.45	0	0.00
ANFINSON, Michael D.- INSTRUMENT MGR	0.06	0.25	0.25	0.25	0.02	0.00
RANDALL, Cora E.- CO-INVESTIGATOR	0.00	0.08	0.08	0.25	0.25	0.17
McClintock, William E.- INSTRUMENT SCIENTIST	0.05	0.20	0.20	0.03	0	0.00
DAVIS, Randal L.- OPERATIONS SYSTEM MANAGER	0.03	0.07	0.07	0.07	0.07	0.03
HORANYI, Mihaly- CO-INVESTIGATOR	0.00	0.08	0.08	0.08	0.08	0.00
JOUCHOUX, Alain J.- SOFTWARE	0.03	0.07	0.10	0.07	0	0.00
LAWRENCE, George M.- INSTRUMENT SCIENTIST	0.00	0.07	0.03	0.00	0	0.00
Administrative (incl. Project) Support	0.38	1.58	1.50	0.95	0	0.00
Contract Administration	0.25	1.38	1.50	1.27	0	0.00
Drafting	0.11	1.19	1.20	0.00	0	0.00
Electrical Engineers	0.91	5.40	4.71	1.06	0.03	0.00
Electrical Technicians	0.00	1.72	2.05	0.38	0	0.00
Ground Software Engineers	0.00	0.07	0.20	0.13	0	0.00
Graduate Assistants	0.44	1.63	1.63	1.60	0.5	0.21
Instrument Makers	0.00	0.24	2.45	0.08	0	0.00
Instrument Engineers	0.25	1.88	2.63	1.04	0.04	0.00
Mechanical Engineers	0.87	4.02	3.35	1.44	0.07	0.00
Operations Engineers	0.03	0.33	0.73	1.40	1.47	0.60
PostDoctorates	0.00	0.00	0.00	0.00	0	0.00
Purchasing Support	0.18	0.71	0.90	0.23	0	0.00
Quality Assurance Personnel	0.37	1.76	1.76	0.66	0	0.00
Software Engineers	0.11	0.62	0.91	0.68	0	0.00
Systems Engineering	0.00	0.74	1.13	0	0	0
Undergraduate Assistants	0.83	4.19	5.81	2.58	2	0.83

Figure K-11h. BATC Work Force Staffing Plan						
SBU	**Lab Cat**	**FY 2003**	**FY 2004**	**FY 2005**	**FY 2006**	**Total Hrs**
CD	E07 SR MGR (George Hess)	0.81	1.00	0.53	0.08	2.43
CD	E08 SR AD/SPVR	0.81	0.56	0.14	0.02	1.54
CD	N13 SR CLER	0.38	0.50	0.21	0.04	1.13
CD	**SubTotal**	**2.00**	**2.07**	**0.88**	**0.15**	**5.10**
ETP	E02 PR ENG	2.34	1.06	0.42	0.17	4.00
ETP	E03 SR ENG	7.27	3.28	2.03	0.13	12.70
ETP	E04 ENG/TS2	10.30	8.17	1.66	0.08	20.22
ETP	E05 ENG/TS1	1.74	1.84	0.97	0.08	4.64
ETP	E06 AD/SPVR2	0.36	0.25	0.04	0.00	0.65
ETP	E09 AD/SPVR1	0.01	0.00	0.00	0.00	0.02
ETP	N01 TECH	0.00	0.00	0.75	0.00	0.75
ETP	N02 SR TECH	0.10	0.01	0.51	0.00	0.62
ETP	N11 SR DFT/GPH	0.15	0.02	0.00	0.00	0.17
ETP	N12 SR PLNR	0.38	0.50	0.08	0.00	0.96
ETP	N13 SR CLER	0.02	0.00	0.00	0.00	0.02
ETP	**SubTotal**	**22.66**	**15.15**	**6.48**	**0.46**	**44.74**
PT	E05 ENG/TS1	0.00	0.00	0.00	0.00	0.00
PT	N01 TECH	0.09	0.31	0.03	0.00	0.43
PT	N02 SR TECH	1.30	0.96	0.32	0.00	2.58
PT	N10 SR INSP	0.19	0.06	0.00	0.00	0.24
PT	N14 SR MACH	0.91	0.08	0.00	0.00	0.99
PT	**SubTotal**	**2.49**	**1.42**	**0.35**	**0.00**	**4.25**
	Grand Total	**27.15**	**18.63**	**7.71**	**0.60**	**54.09**

Figure K-12a Cost Elements Overview

COST ELEMENTS	FY1	FY2	FY3	FY4	FY5	FY6	FY7	Total (Real Yr.)	Total (FY 2000)
DIRECT LABOR COSTS	7/01 - 09/01	10/01 - 9/02	10/02 - 9/03	10/03 - 9/04	10/04 - 9/05	10/05 - 9/06	10/06 - 9/07		
Direct Labor Hours									
-HU + UAF		60,437	182,263	187,366	433,912	436,272	406,518	1,706,768	62,570
-GATS		434	1,801	1,665	10,451	6,898	4,601	25,850	25,850
-LASP		10,602	61,482	72,326	33,317	12,716	6,091	196,534	196,534
-NRL		1,863	7,278	6,131	4,119	7,568	7,568	34,526	35,029
-BALL									
-GMU		80	80	80	320	640	640	1,840	1,840
-SDL		3,339	13,031	12,982	4,341	-	-	33,694	33,694
-SDL/USU		84	334	334	464	1,634	1,260	4,111	4,111
Total		76,838	266,269	280,885	486,925	465,728	426,677	2,003,323	359,628
Direct Labor Costs									
-HU + UAF		60,437	182,263	187,366	433,912	436,272	406,518	1,706,768	1,475,405
-GATS		13,659	58,070	65,701	301,170	216,648	1,314,357	1,969,605	1,654,437
-LASP		422,172	2,534,013	3,029,534	1,550,840	582,925	319,945	8,439,429	7,102,832
-NRL		198,679	853,236	805,506	545,980	862,229	886,371	4,152,000	3,631,381
-BALL									
-GMU		5,142	5,286	5,434	29,857	66,537	68,399	181,905	154,573
-SDL		102,139	405,863	409,801	153,909	-	-	1,071,712	971,249
-SDL/USU		5,395	22,186	22,807	25,058	40,681	35,210	151,337	131,266
Total	$ -	807,623	4,060,917	4,526,148	3,040,726	2,205,292	3,030,801	17,672,756	15,121,143

Figure K-12b HU and UAF Cost Elements

COST ELEMENTS	FY1	FY2	FY3	FY4	FY5	FY6	FY7	Total (Real Yr.)	Total (FY 2000)
DIRECT LABOR COSTS	7/01 - 09/01	10/01 - 9/02	10/02 - 9/03	10/03 - 9/04	10/04 - 9/05	10/05 - 9/06	10/06 - 9/07		
Direct Labor Hours									
HU + UAF		1,855	6,448	6,448	16,588	16,328	14,903	62,570	62,570
Total									
Direct Labor Costs									
HU +UAF		60,437	182,263	187,366	433,912	436,272	406,518	1,706,768	1,475,405
Total									

Other Direct Costs

Travel	Destination	Purpose	# Trips	# Days per Trip	Travel Costs	Relocation Costs
Travel (Faculty)					165,000	
Travel (Student, No Overhead Charged)					15,000	

Computer Related costs	Qty	Unit Cost	Total Cost
Computer Equipment			75000

Other misc.	Total Cost
Materials and Supplies	$ 5,500
Toll Calls	$ 5,350
Publications	$ 31,000
Equipment Maintenance	$ 6,000
Other Equipment	$ 10,000

Figure K-12c LASP Cost Elements									
COST ELEMENTS	FY1	FY2	FY3	FY4	FY5	FY6	FY7	Total (Real Yr.)	Total(FY 2000)
DIRECT LABOR COSTS	7/01 - 09/01	10/01 - 9/02	10/02 - 9/03	10/03 - 9/04	10/04 - 9/05	10/05 - 9/06	10/06 - 9/07		
Direct Labor Hours									
-Lasp		10,602	61,482	72,326	33,317	12,716	6,091	196,534	196,534
Total									
Direct Labor Costs									
-Lasp		422,172	2,534,013	3,029,534	1,550,840	582,925	319,945	$ 8,439,429.00	$ 7,102,832.00
Total									
Direct Materials									
Parts & Materials	Qty	Unit Cost	Total Cost (FY00 $'s)	Total Cost (Real Yr $'s)	Fiscal Yr				
Printed circuit boards (3.1.2.1)	a/r	25000	$25,000.00	$28,447.50	2003				
Printed circuit boards (3.1.4.1)	a/r	4000	$4,000.00	$4,551.60	2003				
Camera Electronics (3.1.2.1)	8	12000	$96,000.00	$109,238.40	2003				
8051 Core IP (3.1.2.1)	1	10000	$10,000.00	$11,379.00	2003				
misc electronics (3.1.4.1)	a/r	12000	$12,000.00	$13,654.80	2003				
misc electronics (3.1.2.1)	a/r	15000	$15,000.00	$17,068.50	2003				
connectors & wire (3.1.4.1)	a/r	2000	$2,000.00	$2,275.80	2003				
connectors & wire (3.1.2.1)	a/r	5000	$5,000.00	$5,689.50	2003				
connectors & wire (3.1.5.1)	a/r	15000	$15,000.00	$17,068.50	2003				
HVPS parts (3.1.2.1)	8	6000	$48,000.00	$54,619.20	2003				
Low voltage power converters (3.1.2.1)	a/r	15000	$15,000.00	$17,068.50	2003				
Low voltage power converters (3.1.4.1)	a/r	12000	$12,000.00	$13,654.80	2003				
misc parts for GSE (3.1.2.1)	a/r	15000	$15,000.00	$17,068.50	2003				
misc parts for GSE (3.1.4.1)	a/r	4000	$4,000.00	$4,551.60	2003				
General Materials (3.1.2.1)		5000	$5,000.00	$5,689.50	2003				
General Materials (3.1.2.1)		5000	$5,000.00	$5,984.00	2004				
General Materials (3.1.4.1)		4000	$4,000.00	$4,551.60	2003				
General Materials (3.1.4.1)		4000	$4,000.00	$4,787.20	2004				
General Materials (3.1.5.1)		25000	$25,000.00	$29,920.00	2004				
Hepa Filters for clean room (3.5.2.1)	A/R	10000	$10,000.00	$11,968.00	2004				
Shipping container (3.1.2.1)		5000	$5,000.00	$5,689.50	2003				
Wide Angle UV lens (3.1.2.1)	8	5000	$40,000.00	$43,597.44	2002				
Bandpass filters (3.1.2.1)	8	2000	$16,000.00	$18,206.40	2003				
Fiber optics taper (3.1.2.1)	12	1000	$12,000.00	$13,079.23	2002				
camera head for CCD evaluation (3.1.2.1)	2	2500	$5,000.00	$5,689.50	2003				
Engineering Model CCDs (3.1.2.1)	3	800	$2,400.00	$2,615.85	2002				
lens design (3.1.2.1)	1	9000	$9,000.00	$9,809.42	2002				
Total			$420,400.00	$477,923.84					

Figure K-12c LASP Cost Elements (continued)

Other Direct Costs

Travel	Destination	Purpose	No. Trips	No. Days per Trip	Travel Costs (FY00 $'s)	Travel Costs (Real Yr $'s)
Davis	Goddard	Mission Ops	2	2	$2,776	
Davis	Goddard	Mission Ops	3	2	$4,164	
Davis	Goddard	Mission Ops	5	2	$6,940	
Davis	Goddard	Mission Ops	1	2	$1,388	
					$0	
Science Team	Washington, D.C.	Science Team	1	4	$5,768	
Science Team	Washington, D.C.	Science Team	1	3	$6,075	
Science Team	Washington, D.C.	Science Team	1	3	$6,210	
Science Team	Washington, D.C.	Science Team	1	3	$6,210	
Science Team	Washington, D.C.	Science Team	1	3	$6,210	
Science Team	Munich	Science Team	1	7	$5,487	
Management	Washington, D.C.	Meeting	1	2	$2,138	
Management	Washington, D.C.	Meeting	3	2	$6,414	
Management	Los Angeles	Meeting	2	2	$3,028	
Management	Washington, D.C.	Meeting	3	2	$6,414	
Management	Los Angeles	Meeting	2	2	$3,028	
Management	Washington, D.C.	Meeting	2	2	$4,276	
Systems	Washington, D.C.	Meeting	1	2	$2,138	
Systems	Washington, D.C.	Meeting	2	2	$4,276	
Systems	Washington, D.C.	Meeting	2	2	$4,276	
CCD Team	Munich	Meeting	2	7	$10,974	
CCD Team	Munich	Meeting	1	7	$5,487	
CDE Test Team	Munich	Testing	1	5	$4,397	
Launch Team	Los Angeles	Launch	1	14	$13,520	
Total Dollars (uninflated)					$121,594	$149,262

Figure K-12c LASP Cost Elements (continued)						
Other Direct Costs						
Computer Related costs	**Qty**	**Unit Cost**	**Total Cost (FY00 $'s)**	**Total Cost (Real Yr $'s)**	**Fiscal Yr**	
Computers (4.1 CIPS)	3	4000	$12,000.00	$13,654.80	2003	
Computers (4.2 CDE)	1	3200	$3,200.00	$3,641.28	2003	
maintenance for CAD S/W	1	2310	$2,310.00	$2,517.75	2002	
maintenance for CAD S/W	1	2310	$2,310.00	$2,628.55	2003	
maintenance for CAD S/W	1	2380	$2,380.00	$2,848.38	2004	
Computers (2.0 Mgmt)	4	4000	$16,000.00	$18,206.40	2003	
Computers (4.1 CIPS)	2	4000	$8,000.00	$9,103.20	2003	
Computers (5.1 FSW)	2	4000	$8,000.00	$9,103.20	2003	
Science computers	4	2500	$10,000.00	$12,495.00	2005	
Sun workstation for Science	1	7000	$7,000.00	$7,965.30	2003	
Mission Ops S/W- Sybase database	1	4850	$4,850.00	$6,060.08	2005	
Flight S/W	1	2000	$2,000.00	$2,393.60	2004	
Flight S/W	1	2000	$2,000.00	$2,499.00	2005	
compiler (4.1 CIPS)	1	2500	$2,500.00	$2,844.75	2003	
SunBlade 100 workstations (MODA)	3	1300	$3,900.00	$4,873.05	2005	
Design Software	1	1500	$1,500.00	$1,634.90	2002	
Design Software	1	1500	$1,500.00	$1,706.85	2003	
Design Software	1	1500	$1,500.00	$1,795.20	2004	
Design Software	1	1500	$1,500.00	$1,874.25	2005	
Sun, Sybase, MicroCosm (maintenance, MODA)	1	8320	$8,320.00	$9,957.38	2004	
Sun, Sybase, MicroCosm (maintenance, MODA)	1	8320	$8,320.00	$10,395.84	2005	
Sun, Sybase, MicroCosm (maintenance, MODA)	1	8320	$8,320.00	$10,853.44	2006	
Sun 450 server (MODA)	1	32000	$32,000.00	$38,297.60	2004	
Total			$149,410.00	$177,349.80		
Consultants (name)	Hours	Rate	Total Cost (FY00 $'s)	Total Cost (Real Yr $'s)	Fiscal Yr	
			$-			
Total			$-	$ -		

Figure K-12c LASP Cost Elements (concluded)						
Other Direct Costs						
Other Miscellaneous (specify)			**Total Cost (FY00 $'s)**	**Total Cost (Real Yr $'s)**	**Fiscal Yr**	
FPGA Programmer (4.1 CIPS)			$2,000.00	$2,275.80	2003	
FPGA Programming Head (4.1 CIPS)			$2,000.00	$2,275.80	2003	
electronics test equip (3.0 Sys Eng)			$12,500.00	$13,624.20	2002	
electronics test equip (3.0 Sys Eng)			$37,500.00	$42,671.25	2003	
Clean Room Equipment (4.4 Cal & Test)	1	25000	$25,000.00	$29,920.00	2004	
Other Lab Equipment (4.1 CIPS)		20000	$20,000.00	$22,758.00	2003	
Other Lab Equipment (4.1 CIPS)		20000	$20,000.00	$23,936.00	2004	
Supplies, communication, reproduction			$151,662.00	$179,848.00	various	
Miscellaneous supplies and hardware			$124,087.00	$147,146.00	various	
Equipment repair and calibration			$41,360.00	$49,048.00	various	
Tuition			$42,195.00	$46,806.00	various	
Total			$478,304.00	$560,309.05		

Figure K-12d SDL Cost Elements

COST ELEMENTS	FY1	FY2	FY3	FY4	FY5	FY6	FY7	Total (Real Yr.)	Total (FY 2000)
DIRECT LABOR COSTS	7/01 - 09/01	10/01 - 9/02	10/02 - 9/03	10/03 - 9/04	10/04 - 9/05	10/05 - 9/06	10/06 - 9/07		
Direct Labor Hours									
-SDL		3,339	13,031	12,982	4,341			33,694	33,694
-SDL/USU		84	334	334	464	1,634	1,260	4,111	4,111
Total									
Direct Labor Costs									
-SDL		$102,139.26	$ 405,863.12	$409,800.53	$153,908.69			$ 1,071,711.60	$ 971,249.05
-SDL/USU		$ 5,395.35	$ 22,185.66	$ 22,806.86	$ 25,058.17	40680.6417	35210.19	$ 151,336.86	$ 131,265.74
Total									
Direct Materials									
Parts & Materials (SOFIE)	Qty	Unit Cost	Total Cost FY00						
Parts & Materials									
Fold Mirrors (3.1.1.1)	7	1,000.00	7,000.00						
Collimating Lenses (3.1.1.1)	4	1,740.00	6,960.00						
Detectors Qualification Materials (3.1.1.2)	lot	30,000.00	30,000.00						
Preamps (3.1.1.2)	8	2,200.00	17,600.00						
De4tectors/TE Coolers (3.1.1.3)	14	2,808	39,312.00						
ADCS Electronics (3.1.1.3)	lot	100,000.00	100,000.00						
Computers, controls, electronics (3.1.1.3)	lot	100,000.00	100,000.00						
Power Conditioning (3.1.1.3	lot	60,000.00	60,000.00						
Aluminum (3.1.1.4)	lot	6,000.00	6,000.00						
Mechanical Housing (3.1.1.4)	1	25,000.00	25,000.00						
Testing Supplies (3.1.1.7)	lot	20,000.00	20,000.00						
Total			411,872.00						
Equipment									
GSE (3.1.1.7)	lot	50,000.00	50,000.00						
Calibration Equipment (3.1.1.7)	lot	25,000.00	25,000.00						
Total			75,000.00						
Total			$ 486,872.00						

Figure K-12d SDL Cost Elements (concluded)						
Other Direct Costs						
Travel	Destination	Purpose	# Trips	# Days per Trip	Travel Costs	Relocation Costs
Logan UT, SDL (SOFIE)	Norfolk, VA	Management Meeting	5	3	$ 8,028.00	NA
Logan UT, SDL (SOFIE)	Boulder Co	Management Meeting	12	4	$ 28,008.00	NA
Logan UT, SDL (SOFIE)	Santa Maria, CA	Intgration & Launch support	4	7	$ 15,545.00	NA
Logan UT, SDL (Science)	Boulder Co	Science Meetings	18	3	$ 13,176.00	NA
Logan UT, SDL (Science)	San Fransisco CA	Science Meetings	4	5	$ 6,484.00	NA
Total			43		$ 71,241.00	
Other misc. (Service Centers&General Services)	Hours	Rate	Total Cost			
Machine Shop (3.1.1.4) Phase C (SOFIE)	1,275.00	50.00	63,750.00			
Machine Shop (3.1.1.4) Phase D (SOFIE)	191.25	50.00	9,562.50			
General Services& Network Charges (SOFIE)			159,251.00			
General Services& Network Charges (Science)			19,047.00			
Total			$ 251,610.50			

Figure K-12e NRL Cost Elements									
COST ELEMENTS	FY1	FY2	FY3	FY4	FY5	FY6	FY7	Total (Real Yr.)	Total (FY 2000)
DIRECT LABOR COSTS	7/01 - 09/01	10/01 - 9/02	10/02 - 9/03	10/03 - 9/04	10/04 - 9/05	10/05 - 9/06	10/06 - 9/07		
Direct Labor Hours									
-NRL	503	1,863	7,278	6,131	4,119	7,568	7,568		35,029
Total									
Direct Labor Costs									
-NRL	$46,696	$198,679	$853,236	$805,506	$545,980	$862,229	$886,371	$4,152,000	$ 3,631,381.00
Total									
Direct Materials									
Parts & Materials	Qty	Unit Cost	Total Cost						
Interferometer			$165,000.00						
filters			$ 30,000.00						
imaging optics			$180,000.00						
CCD Camera System (Flight +backup)			$210,000.00						
Shutter			$ 10,000.00						
Baffel/Door Assy			$ 70,000.00						
Cold finger/heat pipes			$ 20,000.00						
Housing/optical bench Assy			$ 50,000.00						
Elect Fab			$ 10,000.00						
GSE computers			$ 30,000.00						
Mass Store			$ 10,000.00						
Harness			$ 10,000.00						
Misc.			$ 52,000.00						
Test fixturing, lamps, etc			$ 10,000.00						
Supplies			$ 6,500.00						
Data analysis tools			$ 30,000.00						
			$ -						
Total*			$893,500.00						
***Includes FY01 costs. All costs in $FY00.**									

Figure K-12e NRL Cost Elements (concluded)									
COST ELEMENTS	FY1	FY2	FY3	FY4	FY5	FY6	FY7	Total (Real Yr.)	Total (FY 2000)
DIRECT LABOR COSTS	7/01 - 09/01	10/01 - 9/02	10/02 - 9/03	10/03 - 9/04	10/04 - 9/05	10/05 - 9/06	10/06 - 9/07		
Other Direct Costs									
Travel	Destination	Purpose	No. Trips	No. Days per Trip	Travel Costs	Relocation Costs			
	Boulder, CO	Programmatics	30	2	$45,000				
	Boulder, CO	S/C integration	8	10	$20,000				
	Albuquerque, NM	Programmatics	6	2	$9,000				
	Boston, MA	Technical Inter-face	6	2	$9,000				
	Melbourne, FL	Launch Support	5	5	$10,000				
	Germany	Technical Inter-face	3	5	$12,000				
	West Coast	Science Meetings	4	5	$14,000				
	TBD	Science Meetings	4	5	$14,000				
	Local Travel	Misc.			$2,000				
Total*					$135,000.00				
***Includes FY01 costs. All costs in $FY00.**									

Figure K-12f GATS Cost Elements									
COST ELEMENTS	FY1	FY2	FY3	FY4	FY5	FY6	FY7	Total (Real Yr.)	Total (FY 2000)
DIRECT LABOR COSTS	7/01 – 09/01	10/01 – 9/02	10/02 – 9/03	10/03 – 9/04	10/04 – 9/05	10/05 – 9/06	10/06 – 9/07		
Direct Labor Hours									
-HU									
-GATS		434	1,801	1,665	10,451	6,898	4,601	25,850	25,850
Total									
Direct Labor Costs									
-HU									
-GATS		13,659	58,070	65,701	301,170	216,648	1,314,357	1,969,605	1,654,437
Total									
Other Direct Costs									
Travel	Destination	Purpose	No. Trips	No. Days per Trip	Travel Costs	Relocation Costs			
Science Team					50,000				
Total					$50,000.00				

Figure K-12g GMU Cost Elements									
COST ELEMENTS	FY1	FY2	FY3	FY4	FY5	FY6	FY7	Total (Real Yr.)	Total (FY 2000)
DIRECT LABOR COSTS	7/01 - 09/01	10/01 - 9/02	10/02 - 9/03	10/03 - 9/04	10/04 - 9/05	10/05 - 9/06	10/06 - 9/07		
Direct Labor Hours									
-GMU		80	80	80	320	640	640	1,840	1,840
-SDL								-	-
Total	-	80	80	80	320	640	640	1,840	1,840
Direct Labor Costs									
-GMU	1,250	5,142	5,286	5,434	29,857	66,537	68,399	181,905	154,573
-SDL								-	-
Total	1,250	5,142	5,286	5,434	29,857	66,537	68,399	181,905	154,573
Other Direct Costs									
Travel	Destination		Purpose	# Trips	# Days per Trip	Travel Costs	Relocation Costs		
Domestic Travel						7,200	NA		
Other misc.				Total Cost					
1. Tuition Doctoral GRA's									
- Out/State: 12 Credit Hrs @ $552/Hr				19,122					

Figure K-13. AIM Team Institution Rates Overview

Indirect Rates	Rates (%)	Comments
-HU		
General Administrative Expenses (G&A)	49%	
UAF		
General Administrative Expenses (G&A)	47%	
-GATS		
General Administrative Expenses (G&A)	19.03%	
Other (Fee)	7%	Gats is committed to an award base fee.
-LASP		
Labor Overhead	48.8%	
Materials Overhead	48.8%	
General Administrative Expenses (G&A)	48.8%	
Other (Tuition, equipment > $5,000, excess over $25,000 on subcontracts)	0.0%	
-NRL		
Labor Indirect	$24.89/hr	The Indirect costs funds a proportionate share of supervisory, management, secretarial and clerical costs, office supplies, etc. incurred in the Space Science Division. Rate is applied to each direct labor hour budgeted.
Materials Overhead	10%	Actual rate is dependent on the size of the procurement; 10% used as a budgetary value.
General Administrative Expenses (G&A)	$20.05/hr	The G&A costs funds a proportionate share of all general costs at NRL including utilities, facilities, shops, building and procurement services, comptrollers office, etc. Rate is applied to each direct labor hour budgeted.
Other (specify): Labor Fringe	45.00%	Fringe benefits cover annual and sick leave, government-paid portion of hospitilization and life insurance premiums, holidays and other costs directly attributed to government employment.
-BATC		
Labor Overhead		
Materials Overhead		
General Administrative Expenses (G&A)		Available with attached proprietary package.
Other (specify)		BATC is committed to an award base Fee.
Off-site Burden Rates (if used provide a copy of company policy)		
Fee		
-GMU		
General Administrative Expenses (G&A)	43%	
-SDL		
General Administrative Expenses (G&A)		Available with attached proprietary package.
Fee	7%	SDL is committed to an award base Fee.

Space Dynamics Laboratory Proprietary Costing Data for AIM

1. SOFIE Instrument:

Cost Summary: Costs in GFY-00 dollars

	GFY 02	GFY 03	GFY 04	GFY 05	TOTAL
Labor Hours					
Sr. Prog Mgr/Sr. Sys Eng	440	1,760	1,760	807	**4,767**
Senior Engineer/Scientist	880	2,933	2,915	807	**7,535**
Engineer Scientist	770	2,787	2,365	513	**6,435**
Senior Designer	440	1,467	708	0	**2,614**
Senior Technologist	220	1,173	1,588	807	**3,788**
Technologist	0	880	1,588	513	**2,981**
Technician	0	0	37	0	**37**
Sr. Support Staff/Tech Writer	220	880	880	748	**2,728**
Graduate Student	325	975	966	0	**2,266**
Total Labor Hours	**3,295**	**12,855**	**12,806**	**4,195**	**33,151**
Labor Dollars					
Sr. Prog Mgr/Sr. Sys Eng	23,162	92,646	92,646	42,463	**250,917**
Senior Engineer/Scientist	27,491	91,637	91,065	25,200	**235,393**
Engineer Scientist	19,004	68,775	58,368	12,669	**158,816**
Senior Designer	11,022	36,740	17,727	0	**65,489**
Senior Technologist	5,080	27,092	36,659	18,626	**87,457**
Technologist	0	16,509	29,785	9,630	**55,924**
Technician	0	0	590	0	**590**
Sr. Support Staff/Tech Writer	6,263	25,054	25,054	21,296	**77,666**
Graduate Student	3,377	10,130	10,040	0	**23,547**
Total Direct Labor Dollars	**95,398**	**368,584**	**361,934**	**129,884**	**955,799**
Paid Absences	16,563	64,524	63,340	23,379	**167,806**
Total Labor Dollars	**111,961**	**433,108**	**425,274**	**153,263**	**1,123,605**
Fringe Benefits					
Staff	37,729	146,966	144,276	53,252	**382,223**
Students	135	405	402	0	**942**
Total Fringe Benefits	**37,864**	**147,371**	**144,678**	**53,252**	**383,165**
Other Direct Cost					
Travel	1,373	4,119	15,997	31,573	**53,062**
Materials/Parts	0	391,872	20,000	0	**411,872**
Other Direct Costs	15,857	61,490	60,628	21,276	**159,251**
Service Centers	0	63,750	9,563	0	**73,313**
Equipment	0	0	75,000	0	**75,000**
Inflation	118	56,820	16,234	6,271	**79,444**
Total Other Direct Cost	**17,348**	**578,051**	**197,422**	**59,120**	**851,942**
Subtotal USURF Cost	**167,173**	**1,158,530**	**767,373**	**265,635**	**2,358,712**
Subcontracts, < $25,000	16,100	133,900	0	0	**150,000**
Subcontracts, > $25,000	0	378,050	799,583	0	**1,177,632**
Total Subcontracts	**16,100**	**511,949**	**799,583**	**0**	**1,327,632**
Total Direct Cost	**183,273**	**1,670,479**	**1,566,956**	**265,635**	**3,686,344**
MTDC-On Campus	183,273	1,292,430	692,373	265,635	**2,433,712**
Facilities & Administration-On	80,640	568,669	304,644	116,880	**1,070,833**
Total Base Cost	**263,914**	**2,239,148**	**1,871,600**	**382,515**	**4,757,177**
Fee	5,278	44,783	37,432	7,650	**95,144**
Total Cost Plus Fee	**269,192**	**2,283,931**	**1,909,032**	**390,165**	**4,852,321**

SOFIE BOE

BASIS OF ESTIMATE

[X] Parts & Materials
[X] Equipment Components
[X] Service Center
[X] Sub-Contracts

Nomenclature	Qty	Unit Cost	Total Cost	SOURCE: Written Quote	Verbal Quote	Catalog Price	Prior Purchase	Engineer Estimate
Parts & Materials								
Phase C								
Fold Mirrors (3.1.1.1)	7	1,000.00	7,000.00					X
Collimating Lenses (3.1.1.1)	4	1,740.00	6,960.00	X				
Detectors Qualification Materials (3.1.1.2)	lot	30,000.00	30,000.00					X
Preamps (3.1.1.2)	8	2,200.00	17,600.00	X				
De4tectors/TE Coolers (3.1.1.3)	14	2,808	39,312.00	X				
ADCS Electronics (3.1.1.3)	lot	100,000.00	100,000.00		X			
Computers, controls, electronics (3.1.1.3)	lot	100,000.00	100,000.00		X			
Power Conditioning (3.1.1.3	lot	60,000.00	60,000.00					X
Aluminum (3.1.1.4)	lot	6,000.00	6,000.00					X
Mechanical Housing (3.1.1.4)	1	25,000.00	25,000.00		X			
Testing Supplies (3.1.1.7)	lot	20,000.00	20,000.00					X
Total			411,872.00					
Equipment								
Phase C								
GSE (3.1.1.7)	lot	50,000.00	50,000.00					X
Calibration Equipment (3.1.1.7)	lot	25,000.00	25,000.00					X
Total			75,000.00					
Service Center								
Phase C								
Machine Shop (3.1.1.4)	1,275	50.00	63,750.00				X	
Total			63,750.00					
Phase D								
Machine Shop (3.1.1.4)	191	50.00	9,562.50				X	
Total			9,562.50					
Sub Contract								
Phase B								
Initial Filter Design Task (3.1.1.1)	lot	48,300.00	48,300.00	X				
Total			48,300.00					
Phase C								
Steering Mirror (3.1.1.1)	1	640,000.00	640,000.00	X				
Telescope (3.1.1.1)	2	25,000.00	50,000.00	X				
Band Pass Filters& Beam splitters (3.1.1.1)	20	12,065.00	241,300.00	X				
Focus Lenses (thick)(3.1.1.1)	36	896.00	32,256.00	X				
Focus Lenses (thin) (3.1.1.1)	36	716.00	25,776.00	X				
Sun Sensor (3.1.1.5)	1	290,000.00	290,000.00					
Total			1,279,332.00					
TOTAL			**1,887,816.50**					

SOFIE Travel

TRAVEL SUMMARY

Destination	Purpose	No. Trips	People per Trip	Air fare/ Trip	Days per trip	Daily Per Diem	Total Auto Days	Daily Auto Fuel	Daily Auto Rental	Misc. Other Costs[1]	SLC Airport Travel[2]	Total Air Fare	Total Per Diem	Total Auto Cost	Total Cost
Norfolk, VA	Meeting	4	1	598.00	3	165.00	12	10.00	45.00	180.00	280.00	2,392.00	1,980.00	660.00	5,492.00
Norfolk, VA	Meeting	1	2	598.00	3	165.00	3	10.00	45.00	45.00	140.00	1,196.00	990.00	165.00	2,536.00
Boulder Co	Meeting	2	1	104.00	2	132.00	4	10.00	45.00	60.00	140.00	208.00	528.00	220.00	1,156.00
Boulder Co	Meeting	1	1	104.00	3	132.00	3	10.00	45.00	45.00	70.00	104.00	396.00	165.00	780.00
Boulder Co	Meeting	2	2	104.00	2	132.00	4	10.00	45.00	60.00	280.00	416.00	1,056.00	220.00	2,032.00
Boulder Co	Meeting	1	2	104.00	8	132.00	8	10.00	45.00	120.00	140.00	208.00	2,112.00	440.00	3,020.00
Boulder Co	Meeting	1	3	104.00	3	132.00	3	10.00	45.00	45.00	210.00	312.00	1,188.00	165.00	1,920.00
Boulder Co	Meeting	1	3	104.00	8	132.00	8	10.00	45.00	120.00	210.00	312.00	3,168.00	440.00	4,250.00
Boulder Co	Meeting	1	3	104.00	16	132.00	16	10.00	45.00	240.00	210.00	312.00	6,336.00	880.00	7,978.00
Boulder Co	Meeting	1	4	104.00	2	132.00	2	10.00	45.00	30.00	280.00	416.00	1,056.00	110.00	1,892.00
Boulder Co	Meeting	2	4	104.00	3	132.00	6	10.00	45.00	90.00	560.00	832.00	3,168.00	330.00	4,980.00
Santa Maria, CA	Meeting	1	2	136.00	7	147.00	7	10.00	45.00	105.00	140.00	272.00	2,058.00	385.00	2,960.00
Santa Maria, CA	Meeting	1	3	136.00	7	147.00	7	10.00	45.00	105.00	210.00	408.00	3,087.00	385.00	4,195.00
Santa Maria, CA	Meeting	2	3	136.00	7	147.00	14	10.00	45.00	210.00	420.00	816.00	6,174.00	770.00	8,390.00
Ship to Pallet Integration site				Total Round Trip Miles											
Boulder Co		1	2	1,039.00	3	132.00		0.62		45.00			792.00	644.18	1,481.18
Total Travel															53,062.18

[1] Miscellaneous Other Costs estimated at $15 per day, to cover parking, tolls, telephone, and similar expenses not covered by per -diem.

[2] Logan is located approximately 170 miles(round trip) from the Salt Lake City International Airport; amount reflects $70 per person round trip charge for a shuttle service.

2. SDL Science Team Investigation Support

Cost Summary: Costs in GFY-00 dollars

	GFY 02	GFY 03	GFY 04	GFY 05	GFY 06	GFY 07	TOTAL
Labor Hours							
Program Mgr/Systems Eng	84	334	334	334	334	307	**1,728**
Graduate Student	0	0	0	130	1,300	953	**2,383**
Total Labor Hours	**84**	**334**	**334**	**464**	**1,634**	**1,260**	**4,111**
Labor Dollars							
Program Mgr/Systems Eng	3,210	12,841	12,841	12,841	12,841	11,771	**66,345**
Graduate Student	0	0	0	1,351	13,507	9,905	**24,763**
Total Direct Labor Dollars	**3,210**	**12,841**	**12,841**	**14,192**	**26,348**	**21,676**	**91,108**
Paid Absences	579	2,316	2,316	2,316	2,316	2,123	**11,966**
Total Labor Dollars	**3,789**	**15,157**	**15,157**	**16,508**	**28,664**	**23,799**	**103,074**
Fringe Benefits							
Staff	1,316	5,265	5,265	5,265	5,265	4,826	**27,201**
Students	0	0	0	54	540	396	**991**
Total Fringe Benefits	**1,316**	**5,265**	**5,265**	**5,319**	**5,805**	**5,222**	**28,192**
Other Direct Cost							
Travel	732	2,196	3,817	3,817	4,549	4,549	**19,660**
Other Direct Costs	499	1,994	1,994	2,309	5,138	4,134	**16,068**
Inflation	31	124	361	536	850	1,077	**2,979**
Total Other Direct Cost	**1,261**	**4,315**	**6,172**	**6,662**	**10,537**	**9,759**	**38,707**
Subtotal USURF Cost	**6,367**	**24,736**	**26,594**	**28,488**	**45,006**	**38,781**	**169,972**
Total Direct Cost	**6,367**	**24,736**	**26,594**	**28,488**	**45,006**	**38,781**	**169,972**
MTDC-On Campus	6,367	24,736	26,594	28,488	45,006	38,781	**169,972**
Facilities & Administration-On	2,801	10,884	11,701	12,535	19,803	17,063	**74,788**
Total Base Cost	**9,168**	**35,620**	**38,295**	**41,023**	**64,809**	**55,844**	**244,760**
Fee	458	1,781	1,915	2,051	3,240	2,792	**12,238**
Total Cost Plus Fee	**9,627**	**37,402**	**40,210**	**43,075**	**68,049**	**58,636**	**256,998**

SDL Science Investigation Support Travel:

TRAVEL SUMMARY

PROJECT: AIM
Task: Science Team Support
WBS No.

Destination	Purpose	No. Trips	People per Trip	Air fare/ Trip	Days per trip	Daily Per Diem	Total Auto Days	Daily Auto Fuel	Daily Auto Rental	Misc. Other Costs[1]	SLC Airport Travel[2]	Total Air Fare	Total Per Diem	Total Auto Cost	Total Cost
Boulder Co	Meetings	12	1	104.00	3	128.00	36	7.00	36.00	540.00	840.00	1,248.00	4,608.00	1,548.00	8,784.00
Boulder CO	Meeting	6	1	104.00	3	128.00	18	7.00	36.00	270.00	420.00	624.00	2,304.00	774.00	4,392.00
San Francisco CA		4	1	236.00	5	205.00	20	7.00	36.00	300.00	280.00	944.00	4,100.00	860.00	6,484.00
Total Travel															19,660.00

[1] Miscellaneous Other Costs estimated at $15 per day, to cover parking, tolls, telephone, and similar expenses not covered by per diem.
[2] Logan is located approximately 170 miles(round trip) from the Salt Lake City International Airport; amount reflects $70 per person round trip charge for a shuttle service.

3. USU Research Foundation Cost Assumptions

Utah State University Research Foundation (USURF) is primarily a contractor to the United States Government, and as such is subject to the cost principles contained in applicable government regulations and Office of Management and Budget (OMB) circulars. The information contained herein and our associated cost assumptions and practices may change periodically to reflect changing government requirements; these changes are applied consistently across all agreements. In addition, USURF may make periodic (usually quarterly) adjustments to rates to reflect changes in actual costs, and will revise these assumptions as those changes occur. The cost assumptions contained herein, in any case, are not fixed for the term of any agreement resulting from this proposal, but will be revised to ensure compliance with government regulations and use of current cost and pricing data. Rates listed herein are based upon the USURF fiscal year, which runs from July 1 to June 30.

Labor

Labor Mix

In developing this proposal, USURF has used a labor mix based upon recent and current experience in designing, developing, fabricating and deploying electro-optical instruments in ground- and space-based research programs, in developing software for and analyzing data from such research programs, and in directing and conducting university-cooperative research.

Labor Categories

USURF uses the following labor categories for persons working specifically on and chargeable as direct labor to a contract:

- *Senior Program Manager/Senior Systems Engineer:* Senior technical personnel (management level) with advanced degrees (typically Ph.D.) and a minimum of eighteen years' experience in areas related to the statement of work, dealing directly with the government and other customers in a management capacity, and management of major programs.
- *Program Manager/ Systems Engineer:* Senior technical personnel with advanced degrees and a minimum of twelve years' experience in areas related to the statement of work, dealing directly with the government and other customers, and management of programs.
- *Senior Engineer/Scientist:* Engineers, scientists, physicists, computer scientists, and software engineers holding a MS degree and having eight to twelve years' experience.
- *Engineer/Scientist:* Engineers, scientists, physicists, computer scientists, and software engineers holding a BS degree (or equivalent experience) and having four to eight years' experience.
- *Senior Designer:* Electrical, Mechanical, and other Designers with a minimum of twelve years' experience or equivalent education, including the design of major systems and subsystems.
- *Senior Technologist:* Technologists with a minimum of twelve years' experience or equivalent education, including experience with assembly, integration, and test of major systems and subsystems.
- *Technologist:* Technologists with applicable post-high school education and a minimum of four years' experience.
- *Technician:* Technicians with a high school diploma and a minimum of two years' experience.[1]
- *Senior Support Staff/Technical Writer:* Management-level support personnel, including program coordinators, project support managers, cost/schedule analysts, and technical writers. Requires an MS or equivalent experience and twelve or more years' experience working at the program management level.
- *Graduate Student:* Graduate students attending Utah State University. [1,2]

  1 Indicates personnel who are "non-exempt" and are subject to premium-time overtime compensation under the Fair Labor Standards Act. See section 1.1.4 and 1.10 below.

  2 Students are generally restricted to half-time employment (20 hours per week) during USU academic sessions.

Labor Rates

USURF has developed an average labor rate for each labor category identified above, using current actual labor rates for all personnel so categorized. USURF escalates these rates by 4.2% annually on July 1st as an estimated inflationary adjustment. Table I below lists these average labor rates for the USURF fiscal years identified.

Table I. USURF Labor Rates in Current Real Year Dollars & FY-00 Dollars Used for Proposal Purposes									
Labor Category	**FY00**		**FY 02**	**FY 03**	**FY 04**	**FY 05**	**FY 06**	**FY 07**	**FY 08**
Sr. Prog Mgr/Sr. Sys Eng	**52.64**		57.22	59.62	62.12	64.73	67.45	70.28	73.23
Program Mgr/Systems Eng	**38.4**		41.09	42.82	44.62	46.49	48.44	50.47	52.59
Senior Engineer/Scientist	**31.24**		33.58	34.99	36.46	37.99	39.59	41.25	42.98
Engineer Scientist	**24.68**		27.59	28.75	29.96	31.22	32.53	33.90	35.32
Senior Designer	**25.05**		27.16	28.30	29.49	30.73	32.02	33.36	34.76
Senior Technologist	**23.09**		24.98	26.03	27.12	28.26	29.45	30.69	31.98
Technologist	**18.76**		19.32	20.13	20.98	21.86	22.78	23.74	24.74
Technician	**16.08**		18.18	18.94	19.74	20.57	21.43	22.33	23.27
Sr. Support Staff/Tech Writer	**28.47**		27.61	28.77	29.98	31.24	32.55	33.92	35.34
Graduate Student	**10.39**		11.18	11.65	12.14	12.65	13.18	13.73	14.31

Overtime Premium

Overtime premium is the premium pay that must be made to all FLSA non-exempt employees that work more than 40 hours during a given work week. Such pay may be subject to the limitations of FAR 52.222-2, if applicable and/or restrictions under OMB Circular A-21. See section 11.1 below.

Labor Hour Definition

USURF allocates labor hours and labor charges in accordance with the requirements of Section J.8 of Office of Management and Budget (OMB) Circular A-21. USURF defines a labor hour as an hour of direct labor charged to a contract by means of the USURF payroll/labor distribution system. Labor hours are a portion of an employee’s total annual activity and salary, based upon the following formula:

40 hours per week x 52 weeks per year = 2,080 total compensated hours

Less: hours associated with paid absences (see 1.2.1 below) = 320 hours

Net Direct Productive Labor Hours (DPLH) per year: 1,760 hours.

Therefore, the total compensated hours for a month are 173.33, and the net DPLH hours per month average are 146.67 (on average). For salaried personnel, USURF identifies labor hours and the corresponding charges to each cost objective based upon percentage allocations. That calculation uses the monthly compensated hours and dollars as a base; from these numbers the hours identified to paid absences (and the associated labor dollars) are subtracted, and the remaining hours and dollars are charged to the cost objectives based on the percentages of the employees efforts allocable to the identified cost objectives.

USURF uses the same number of base hours to propose and estimate labor for students and other hourly employees, and charges actual hours based upon recorded time cards. These employees are not eligible for paid absences or other staff benefits (see 1.2.3).

Fringe Benefits

USURF has negotiated methodologies for charging fringe benefits as direct costs. While the rate is not a negotiated forward pricing rate, the calculation methodology has been thoroughly reviewed and approved by the government as a part of the indirect cost negotiation agreement. The cost of these benefits is calculated as a percentage of direct labor costs. The costs accrued in the various benefit pools are periodically reviewed to ensure that neither over- nor under-charging occurs.

1.2.1 Paid Absences

Paid absences for benefit-eligible employees include twelve holidays per year, annual leave, sick leave, and miscellaneous leave (jury, military, bereavement and other leave). The costs of paid absences are charged to cost objectives as a fringe benefit at the rates shown in Table II below. This amount is accrued/pooled and the actual costs of paid absences is charged against the pool as the leave is taken. Note that Students do not receive this benefit.

1.2.2 Staff Benefits and Payroll Taxes:

The costs of employer payroll taxes (FICA, etc.), insurance, retirement, and other employee benefits are pooled and charged to cost objectives as a fringe benefit at the rates shown in Table II below. As stated above, the various pools are reviewed periodically to ensure that neither over- nor under-charging occurs.

1.2.3 Student Payroll Taxes and Insurance:

The costs of employer payroll taxes (FICA, etc.) and required workers compensation and unemployment insurance, along with the associated labor costs, are included in the calculation of the rates for the applicable pools referenced above. Only the rates associated with these taxes and insurance are applied to student wages. Also, students who are enrolled full-time at Utah State University are exempt from payroll taxes during the academic term. Historically, approximately one-half of student labor is incurred while students are enrolled; therefore, only one-half of the full rate for these taxes and insurance is used in proposals to estimate the cost of student taxes and insurance.

Table II. USURF Fringe Benefit Rates by Government Fiscal Year

	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08
Paid Absences	18.00%	18.00%	18.00%	18.00%	18.00%	18.00%	18.00%
All Non-Part Time Labor	41.00%	41.00%	41.00%	41.00%	41.00%	41.00%	41.00%
Students	4.00%	4.00%	4.00%	4.00%	4.00%	4.00%	4.00%

Other Direct Costs

Travel

USURF summarizes travel by task, where applicable, and brings totals forward to the appropriate cost summary. The travel summary identifies individual destinations, man-trips, trip-days, car-days, airfares, etc., for ease in computation. USURF's source for travel costs is American Express/Morris Travel, Logan, Utah, which includes the State of Utah special discount travel rates with airlines and car rental agencies. In addition, where applicable, travel costs include a per-mile rate for chargeable travel using a vehicle from the vehicle service center (see Section 1.4.6 below). USURF calculates mileage reimbursement for use of personal vehicles in accordance with the current Federal Travel Regulation. Per diem rates come from the most recent update to the Federal Travel Regulation, Appendix A to Chapter 301. USURF's travel policy complies with the provisions of OMB Circular A-21. Also included is a charge for round trip shuttle service to the nearest airport, Salt Lake City International Airport.

Parts/Materials

USURF defines parts and materials as property, including equipment, that may be incorporated into or attached to a deliverable end item, or that may be consumed or expended in performing a contract. This category includes:

- electronic and mechanical assemblies,
- components,
- parts,
- raw and processed materials (including raw materials required for machining, the charge for which includes a 15% handling fee),
- small tools with an acquisition cost between $1,000 and $5,000, and
- supplies and equipment that may be consumed in normal use in performing the contract.

Materials, including components requiring further refinement or processing, are not end products until such processes are completed.

USURF also includes in this category certain special-purpose software (and maintenance agreements on such software) required for specific program needs. Determined on a case-by-case basis in developing proposals, this category would include (for example) data display software that was required by a program and became part of that program's end-item. It would not include (for example) spread-sheet software or other general purpose software that would be used on the program, but would also have other uses not specifically related to this program. Neither does it include software that is part of Computer Services (see Section 1.4.5 below).

General Services

For proposal purposes only, USURF has developed a rate for proposing certain charges that historically correlate very closely with direct labor. This rate, 10.15% of unburdened direct labor, includes charges for telecommunications, freight and postage, data processing charges from the Utah State University Computer Services, printing and copying, operating supplies, office supplies, small tools of less than $1,000 value, repairs and maintenance, non-auto rentals, general purpose software, and other current expenses. USURF reviews this rate periodically to assure neither over- nor under-pricing proposals.

This general services rate is for proposals only. In any agreement resulting from this proposal, USURF direct-charges any costs incurred in these categories.

Network Services are set up to handle the operations of our Information Technology department. The charge covers salaries, equipment upgrades, equipment maintenance, training and other miscellaneous charges. Each Employee will be charged a per month "Network Service" fee based on payroll charges. Preliminary calculation of the fee will be $200 per month per employee.

Service Centers

USURF operates several service centers within its organization. Both the proposed and charged costs for these centers are based upon calculated, established billing rates, which are reviewed periodically to ensure that the centers are operating on a break-even basis. All costs included within service centers are a part of the MTDC base when calculating Facilities and Administrative Costs (see Section 1.9 below). Cost estimates are detailed on a Basis of Estimate form for each Service Center included.

Machine Shop

USURF operates its own machine shop in order to control costs and provide quality control. The billing rate for machine shop services and labor is presently $40.00 per labor hour, excluding materials. Materials are priced separately at cost plus 15% materials handling fee (see Section 1.3.2 above).

Environmental Test Center

USURF operates its own environmental test center, which includes a vibration test facility and spin-balance table. The billing rate is presently $150.00 per operating hour, which includes both the usage of the center's equipment and center labor.

Thermal Vacuum Test Facility

USURF operates its own thermal vacuum test chamber for both space simulation testing and thermal cycle testing. The billing rate for this chamber is presently $19.00 per hour, for the facilities only. Because different programs' test requirements produce very different support requirements, set-up and operational labor costs are priced separately as direct labor. Bulk liquid nitrogen is charged through this center at the rate of $.62 for the first 5,000 liters per month, and $.55 per liter thereafter.

Advanced Research Transcripts (ART) Shop

USURF operates its own ART shop in order to control documentation costs. The ART Shop is responsible for all USURF publications, including report preparation, photography, artwork, editorial services and related efforts. The billing rate for services and labor is presently $20.00 per hour, plus actual material costs.

Computer Services

USURF operates computing facilities which provide computing services, access to equipment, and software programs. Charges for these services are billed on an hourly, daily, or monthly basis, consistent with the program's hardware, software, and processing requirements.

Collaborator Agreements

USURF typically engages in two types of collaborator agreements: subcontracts/subgrants and consulting agreements.

Subcontracts / Subgrants

USURF defines a subcontractor or subgrantee as an individual or organization providing a deliverable end product or significant component or service to USURF which meets a prime contract requirement. For USURF to consider a collaborator as a subcontractor or subgrantee, the individual or organization must meet certain tests:

- it must be responsible for performing a substantive portion of the program's Statement of Work as it appears in the prime contract,
- its performance must be measured against meeting the objectives stated in this portion of the Statement of Work,
- it is responsible for making programmatic decisions within the sphere defined by that portion of the Statement of Work,
- it is responsible for program compliance requirements as reflected in that portion of the Statement of Work, and

- its use of program funds is to complete a task defined in the Statement of Work rather than merely providing materials, goods or services.

Consulting Agreements

USURF defines a consultant as an individual or firm providing USURF and the prime contract the benefit of its specialized knowledge, experience, and expertise in disciplines including, but not limited to, science and engineering, management, personnel, finance, accounting, planning, and data processing. The individual or organization may:

- investigate assigned problems or projects,
- provide counsel and review,
- assist in design, development or analysis,
- provide advice in formulating or implementing programs or services or improvements in programs or services, or
- undertake specialized assignments and investigations in support of the program originating the funding.

USURF negotiates consulting agreements with entities customarily engaged in an independently established business as consultants, and considers the following criteria in defining a consultant:

- a consultant operates independently and has a separate place of business,
- a consultant has the necessary investment in tools, equipment, or facilities,
- a consultant has other clientele and relies upon consulting as its major source of income,
- a consultant has a profit or loss potential,
- a consultant engages in advertising its service,
- a consultant possesses business, trade, or professional licenses, and
- a consultant has filed tax returns reflecting independence.

Inflation

USURF applies an inflation factor to out-year travel, materials and parts, service centers, and any other out-year costs which do not already include an inflation allowance. This inflation factor of 4.2% per year, compounded, is based on uninflated current-year quotes from vendors.

Facilities and Administration (Indirect Cost)

The USURF facilities and administration (F&A) rate is a fixed rate with carry-forward that has been negotiated with the Office of Naval Research, the cognizant agency. The rate for the period July 1, 2001 through June 30, 2002 is 44% of modified total direct cost (MTDC); this rate is also applicable as a provisional rate for future years. The MTDC definition appearing in OMB Circular A-21 and USURF's F&A agreement is total direct cost (TDC) less the following:

- equipment,
- capital expenditures,
- charges for patient care and tuition remission,
- rental of brick-and-mortar-type facilities,
- scholarships and fellowships, and
- subcontracts and sub-grants in excess of the first $25,000 for each subagreement.

USURF, under the cost principles of OMB Circular A-21, is subject to a cap on the administration portion of its F&A rate; this capped rate of 38% is generally applicable to all non-DoD governmental agreements. However, USURF as a matter of course requests a waiver to this limitation because, unlike most educational institutions, USURF is solely dedicated to and funded by research. As a result, if a given contract or grant does not pay the full, uncapped F&A rate, there is not an alternate source of funding to cover the deficit created by the difference between the capped reimbursement rate and USURF's actual costs. Therefore, all proposals are submitted with the uncapped rate.

Fixed Fee

USURF has used a fixed fee of 2% of total cost in developing this proposal.

Fee is necessary in USURF contracts for several reasons. First, the foundation incurs necessary costs associated with being a research facility that may not be allowable as direct charges to government contracts (e.g., proposal preparation, independent research and development, etc.). Second, USURF incurs the cost of building and maintaining a capable research team (e.g., attracting and maintaining a qualified and stable labor force, special incentives to reward extraordinary performance, etc.). Finally, the foundation experiences costs associated with doing business that are not allowable as direct or indirect expenses but are nevertheless necessary for continued operation (e.g., costs related to the Board of Trustees, special advisory boards, bonding and insurance, hosting national and international conferences that promote interest in USURF and enhance its capability as a research organization, and marketing).

As an organization distinct from Utah State University, USURF does not have access to the State Education and General Purpose funding or other appropriated funding sources that typically cover expenditures of this nature for universities, and therefore fee is a necessary aspect of the foundation's doing business. The federal government has recognized the necessity of this type of funding as a means of stimulating and supporting unique research efforts and organizations (see FAR 48 C.F.R. 15.901 and FAR Supplement Part 215 subpart 215.9).

Extra-Contractual Pay

USURF may find it necessary to require staff to expend extraordinary effort to complete tasks under a given contract. The foundation treats extra compensation for its personnel in accordance with USURF policy and applicable regulations, particularly Section J.8 of OMB Circular A-21, the Fair Labor Standards Act (FLSA), and FAR 52.222-2. Treatment of extra compensation depends upon the individual's classification as faculty, exempt staff or non-exempt staff.

- Faculty members (individuals with university academic teaching appointments): USURF generally does not pay extra compensation to faculty members (identified under 1.1 above), except under exceptional circumstances:
  a. the work is made unavoidable by the requirements of the program in question,
  b. the work being compensated is separate from the normal academic departmental work assignment,
  c. the work being compensated is in addition to regular full-time workload, and
  d. the compensation is provided for in the agreement or approved in writing by the sponsoring agency.

Unless specifically disallowed during negotiations, USURF considers this disclosure and the agency's approval of this proposal to be the agency's approval of extra compensation payment to faculty. USURF will pay such extra compensation only if that work meets the criteria in (a), (b) and (c) above.

- Exempt staff: USURF may pay exempt staff members extra compensation in addition to their base salary when such compensation is commensurate with added, extraordinary workload requirements, and has the approval of program management and USURF administration. This compensation will be at the straight-time hourly rate for the individual employee.
- Non-exempt staff: In accordance with FLSA, USURF must pay extra compensation to any non-exempt staff member who works more than 40 hours in any given week. This compensation must be at a minimum of 1½ times the base hourly rate for the employee in question. Whenever the contract contains FAR 52.222-2, "Overtime Premium," the sponsoring agency must approve the premium portion of this compensation. As with exempt staff, extra compensation for non-exempt staff must have the approval of program management and the USURF administration.

Business System Approvals

USURF currently has approved contracting, purchasing, subcontract management, property, accounting, cost/schedule control, and EEO compliance systems. Cognizant government contacts are:

Administrative Contract Officer	**Auditor/Audit Agency**
Ronald P. Moody	Michael S. McConnell, Branch Manager
Office of Naval Research	Defense Contract Audit Agency
1107 NE 45th Street. Suite 350	Salt Lake Valley Office
Seattle, WA 98105-4631	1717 South Redwood Road, Suite 200
Telephone: (206) 526-3169	Salt Lake City, UT 84104-5110
Fax: (206) 526-3210	Telephone: (801) 975-3555 ext. 225

K.12 BATC Rates

On January 1, 2000, Ball Aerospace & Technologies Corp. (BATC) announced a realignment of its business segments, creating seven strategic business units (SBU) but not changing the underlying legal/contractual structure of BATC. Based on this realignment, indirect rates for years 2000–2004 and out-years along with the underlying cost and pricing data were submitted to the ACO and DCAA on April 17, 2000. On August 20, 2001, BATC submitted revised FY2001 bid rates only based on FY 2001 YTD actual cost and ETC cost information.

BATC notified the ACO on November 1, 2001, of rate structure changes to become effective January 1, 2002. These changes include implementing separate indirect rate structures for Civil Space Systems (CSS) and Defense Operations (DO), which were previously combined into a single rate structure. Additionally, an Engineering Matrix service center will be established to provide a centrally based core of high-quality engineering talent in support of BATC programs and projects within both CSS and DO.

We are currently evaluating the rate impacts due to these changes and anticipate submitting new Forward Pricing Rates in the near future. On November 1, 2001, we provided the ACO with revised disclosure statements reflecting all changes to be effective January 1, 2002. As such, we are currently coordinating these changes through the cognizant ACO (DCMC-Denver) and DCAA-Denver Branch offices. Any questions requiring clarification from the ACO should be coordinated through the following:

Ms. Renee Varin Potratz, ACO
DCMC-Denver
Orchard Place 2, Suite 200
5975 Greenwood Plaza Boulevard
Englewood, CO 80111-4715
Phone: (303) 220-4040

Please note that our ACO will not divulge any rate information directly to prime contractors. Therefore, prime contractors should request this information through their local ACO or the PCO administering the prime contract.

BATC's applicable forward pricing rates contained in this proposal are summarized in **Tables K12-2**, **K12-3,** and **K12-4** and are applied to the applicable bases (estimated hours or direct dollars) to derive proposal cost.

A salary increase allowance (SIA) is applied to the base labor rate, to reflect labor cost increases over the period of performance of the contract. This yearly allowance is part of our FPRP (see Table K-2). The total salary rate increase is applied during February to coincide with merit pay increases given to employees. The February rate remains unchanged until February of the following year. The monthly SIA factors are presented in Table K-5, Section K12.2.

The supporting cost and pricing data for BATC's forward pricing rates are located in the BATC Finance and Analysis Office, Building RA-5, 1600 Commerce Street, Boulder, CO, 80301.

K12.1 Labor Category Rates

The proposed direct labor cost consists of the sum of the direct labor cost for each labor category, plus an additional cost for salary escalation (reference Section K12.2, Salary Increase Allowance) at the proposed annual rate.

K12.1.1 Engineering Labor

Engineering labor costs consist of the estimated engineering labor hours, multiplied by the applicable average rate for each labor category used.

Direct labor hours are estimated using labor categories for the personnel proposed for this program. These categories are established in accordance with the labor classifications in the BATC Labor Administration Plan. Average labor rates are established for each category and are based on actual rates incurred for the months of March and April 2001 (see Table K12-3). These rates include the actual salary increase for calendar year 2001.

Table K-2 BATC proposed forward pricing rates (effective August 20, 2001)

	2001 (%)	2002 (%)	2003 (%)	2004 (%)
A. Annual Salary Increase Allowance (SIA)	N/A*	4.5	4.5	4.5
B. Overhead				
1. Civil/Defense Engineering Overhead	68.3	60.7	60.1	59.9
2. Engineering/Technology Products (ETP) Overhead	106.1	104.3	104.2	104.5
3. Commercial Space Operations (CSO) Overhead	N/A	N/A	N/A	N/A
4. Boulder Production & Test Overhead	185.3	189.9	183.9	183.7
5. Major Procurement Overhead	3.0	2.5	2.4	2.4
6. Material Handling Overhead	13.5	10.9	10.2	10.0
7. Off-Site Overhead	46.3	49.6	49.2	49.5
C. General and Administrative (G&A)				
1. Civil/Defense G&A Overhead	23.2	23.3	23.5	23.5
2. ETP G&A Overhead	38.8	44.8	44.8	44.5
3. CSO G&A Overhead	N/A	N/A	N/A	N/A
D. Facilities Capital Cost-of-Money (CMF)				
1a. Civil/Defense Engineering	1.4090	1.3530	1.3060	1.2520
b. ETP Engineering	2.3972	2.5810	2.4880	2.3850
c. CSO Engineering	N/A	N/A	N/A	N/A
2. Boulder Production & Test	7.0659	7.3080	7.0150	6.7170
3. Major Procurement	0.0099	0.0140	0.0140	0.0130
4. Material Handling	0.2699	0.1880	0.1820	0.1740
5a. Civil/Defense G&A	0.2375	0.1750	0.1690	0.1550
b. ETP G&A	0.4699	0.3080	0.2960	0.2560
c. CSO G&A	N/A	N/A	N/A	N/A
E. Other Factors				
1. Miscellaneous Other Direct Costs (ODC)	1.7	1.7	1.7	1.7
2. Freight-in on Material	1.5	1.5	1.5	1.5

Rate Application

A. Percent of direct labor dollars
- B.1. Percent of direct Civil/Defense and ETP engineering labor dollars in-plant (including SIA)
- B.2. Percent of direct ETP engineering labor dollars in-plant (including SIA)
- B.3 Percent of direct CSO engineering labor dollars in-plant (including SIA)
- B.4. Percent of direct production/test labor dollars in-plant (including SIA)
- B.5. Percent of direct material and procurement dollars (excluding interdivisional transfers) greater than $500,000
- B.6. Percent of direct material and procurement dollars (excluding interdivisional transfers) less than $500,000
- B.7. Percent of direct off-site labor dollars (including SIA)
- C.1. Percent of Civil/Defense value-added cost input (total cost input less materials, procurements, and interdivisional transfers).
- C.2. Percent of ETP product value-added cost input (total cost input less materials, procurements, and interdivisional transfers).
- C.3. Percent of CSO value-added cost input (total cost input less materials, procurements, and interdivisional transfers).
- D.1. Percent of direct engineering labor dollars in-plant (including SIA)
- D.2. Percent of direct production/test labor dollars in-plant (including SIA)
- D.3. Percent of direct material and procurement dollars (excluding interdivisional transfers) greater than $500,000
- D.4. Percent of direct material and procurement dollars (excluding interdivisional transfers) less than $500,000
- D.5. Percent of value-added cost input
- E.1. Percent of total direct labor dollars (including SIA)
- E.2. Percent of material dollars and subcontracts

*The SIA factor for 2001 is not applicable because the direct labor rates submitted 25 May 2001 to the government for 2001 have already been adjusted for the inflationary impacts associated with that year.

Table K-3 2001 Civil/Defense and Engineering/Technology Products direct labor rates

BATC Position Abbreviations, Labor Categories, and Labor Rates		
Abbreviations	**Labor Categories**	**2001 Proposed Rate ($)**
	Exempt	
SR MGR	Senior Manager	54.76
MGR	Manager	49.08
PR ENG	Principal/Staff Engineer	48.11
SR ENG	Senior Engineer	38.85
ENG/TS 2	Engineer/Technical Specialist 2	30.67
ENG/TS 1	Engineer/Technical Specialist 1	24.64
SR AD/SPVR	Senior Administrator/Supervisor	33.28
AD/SPVR 2	Administrator/Supervisor 2	24.59
AD/SPVR 1	Administrator/Supervisor 1	19.75
	Nonexempt	
SR TECH	Senior Technician	22.42
TECH	Technician	16.93
PR ASSY	Prototype Assembler	N/A*
ASSY	Assembler	N/A*
SR INSP	Senior Inspector	N/A*
INSP	Inspector	N/A*
SR DFT/GRPH	Senior Drafting/Graphics	21.08
DRFT/GRPH	Drafting/Graphics	13.00
SR PLNR	Senior Planner	19.39
PLNR	Planner	17.45
SR CLER	Senior Clerical	17.89
CLER	Clerical	N/A*
SR MACH	Senior Machinist	N/A*
MACH	Machinist	N/A*

* N/A signifies that no hours had been charged against this labor category when the rates were calculated; therefore, no rate was established. If it is required to estimate labor costs for this category in the future, a rate will be established, based on then current salaries or anticipated salaries for new hires.

Table K-4 2001 production and test direct labor rates

BATC Position Abbreviations, Labor Categories, and Labor Rates		
Abbreviations	**Labor Categories**	**2001 Proposed Rate ($)**
	Exempt	
SR MGR	Senior Manager	N/A*
MGR	Manager	35.17
PR ENG	Principal/Staff Engineer	44.78
SR ENG	Senior Engineer	N/A*
ENG/TS 2	Engineer/Technical Specialist 2	28.78
ENG/TS 1	Engineer/Technical Specialist 1	24.54
SR AD/SPVR	Senior Administrator/Supervisor	32.23
AD/SPVR 2	Administrator/Supervisor 2	24.53
AD/SPVR 1	Administrator/Supervisor 1	N/A*
	Nonexempt	
SR TECH	Senior Technician	22.34
TECH	Technician	17.84
PR ASSY	Prototype Assembler	N/A*
ASSY	Assembler	N/A*
SR INSP	Senior Inspector	21.02
INSP	Inspector	N/A*
SR DFT/GRPH	Senior Drafting/Graphics	N/A*
DRFT/GRPH	Drafting/Graphics	N/A*
SR PLNR	Senior Planner	N/A*
PLNR	Planner	N/A*
SR CLER	Senior Clerical	16.39
CLER	Clerical	N/A*
SR MACH	Senior Machinist	26.16
MACH	Machinist	18.14

* N/A signifies that no hours had been charged against this labor category when the rates were calculated; therefore, no rate was established. If it is required to estimate labor costs for this category in the future, a rate will be established, based on then current salaries or anticipated salaries for new hires.

The average labor rates for the engineering labor include only those personnel assigned to the Civil/Defense, Engineering/Technology Products (ETP), and Commercial Space Operations (CSO) engineering pools. This includes design engineers, drafters, program business analysts, program managers, program secretaries, quality assurance engineers, production engineers, test engineers, engineering technicians, and production planners. It does not include hands-on production and test personnel as described in the following section.

K12.1.2 Production and Test Labor

Production and test labor costs consist of the estimated production and test labor hours, multiplied by the applicable average rate for each labor category used.

Direct labor hours are estimated using labor categories for the personnel proposed for this program. These categories are established in accordance with the labor classifications in the BATC Salary Administration Plan. Average labor rates are established for each category and are based on actual rates incurred for the months of March and April 2001 (see Table K-4). These rates include the actual salary increase for calendar year 2001.

The average labor rates for the production and test labor include only those personnel assigned to the production and test pool. This consists of hands-on personnel involved in the fabrication, assembly, and testing of the program hardware. It includes environmental test, machine shop, and electronic assembly personnel.

K12.2 Salary Increase Allowance

A salary increase allowance (SIA) is applied to the base labor rate, to reflect labor cost inreases over the period of performance of the contract. This yearly allowance is part of our negotiated FPRP (see Table K-2). The total salary rate increase is applied during February because salary increases occur then. The February rate remains unchanged until February of the following year. **Table K-5** presents the monthly SIA factors.

Table K-5 BATC engineering and Boulder production and test labor SIA factors

Year	Month	SIA Factor	Year	Month	SIA Factor
2001	JAN	0.00000	2005	JAN	0.14117
	FEB	0.00000		FEB	0.19252
	MAR	0.00000		MAR	0.19252
	APR	0.00000		APR	0.19252
	MAY	0.00000		MAY	0.19252
	JUN	0.00000		JUN	0.19252
	JUL	0.00000		JUL	0.19252
	AUG	0.00000		AUG	0.19252
	SEP	0.00000		SEP	0.19252
	OCT	0.00000		OCT	0.19252
	NOV	0.00000		NOV	0.19252
	DEC	0.00000		DEC	0.19252
2002	JAN	0.00000	2006	JAN	0.19252
	FEB	0.04500		FEB	0.24618
	MAR	0.04500		MAR	0.24618
	APR	0.04500		APR	0.24618
	MAY	0.04500		MAY	0.24618
	JUN	0.04500		JUN	0.24618
	JUL	0.04500		JUL	0.24618
	AUG	0.04500		AUG	0.24618
	SEP	0.04500		SEP	0.24618
	OCT	0.04500		OCT	0.24618
	NOV	0.04500		NOV	0.24618
	DEC	0.04500		DEC	0.24618
2003	JAN	0.04500	2007	JAN	0.24618
	FEB	0.09203		FEB	0.30226
	MAR	0.09203		MAR	0.30226
	APR	0.09203		APR	0.30226
	MAY	0.09203		MAY	0.30226
	JUN	0.09203		JUN	0.30226
	JUL	0.09203		JUL	0.30226
	AUG	0.09203		AUG	0.30226
	SEP	0.09203		SEP	0.30226
	OCT	0.09203		OCT	0.30226
	NOV	0.09203		NOV	0.30226
	DEC	0.09203		DEC	0.30226
2004	JAN	0.09203	2008	JAN	0.30226
	FEB	0.14117		FEB	0.36086
	MAR	0.14117		MAR	0.36086
	APR	0.14117		APR	0.36086
	MAY	0.14117		MAY	0.36086
	JUN	0.14117		JUN	0.36086
	JUL	0.14117		JUL	0.36086
	AUG	0.14117		AUG	0.36086
	SEP	0.14117		SEP	0.36086
	OCT	0.14117		OCT	0.36086
	NOV	0.14117		NOV	0.36086
	DEC	0.14117		DEC	0.36086

K12.3 Overhead

The costs for Civil/Defense, ETP, and CSO engineering overhead, off-site overhead, production and test overhead, material handling overhead, and major procurement overhead are collected in separate pools. The overhead costs are applied based on a percentage of the applicable direct cost base.

Each year, the indirect costs and the base costs are estimated in detail for the upcoming year and in summary for subsequent years. For the current year, department operating costs, fringe, facility, and equipment costs are budgeted at the department level whereas allocated costs are budgeted at the account level. These budgets are based on current and projected activity levels, anticipated staffing changes, changes in business functions, and other factors. The direct cost base is estimated from individual project forecasts, marketing plans, and IR&D/B&P plans.

K12.3.1 Engineering Overhead

Engineering overhead rates for Civil/Defense, ETP, and CSO are determined by calculating allocated indirect costs as a percentage of the engineering direct labor base.

The engineering indirect costs are those required to support the engineering direct labor. These indirect costs include operating costs for the departments whose personnel make up the engineering direct labor pool and that directly support engineering labor, as well as facility costs, fringe, and allocations from intermediate cost pools.

The engineering overhead rate is applied to the total cost of engineering direct labor, including SIA.

K12.3.2 Production and Test Overhead

The production and test overhead rate is determined by calculating allocated indirect costs as a percentage of the production and test direct labor base.

The Boulder production and test indirect costs are those required to support the production and test direct labor. These indirect costs include operating costs for the departments whose personnel make up the production and test direct labor pool and that directly support production and test personnel in the fabrication, assembly, and testing of program hardware, as well as facility costs, fringe, and allocations from intermediate cost pools.

The production and test overhead rate is applied to the total cost of production and test direct labor, including SIA.

K12.3.3 Material Handling

The BATC material handling rate is determined by calculating the allocated indirect costs as a percentage of the cost base of direct material, procurements, and consulting dollars valued at less than $500,000.

The BATC material handling pool indirect costs are based on allocations from pertinent support organization pools whose activities are associated with the procurement of materials, procurements, and consulting agreements valued at less than $500,000. These include allocations from BATC Procurement, BATC Material Control, Procurement Systems and Compliance, Ball stock inspection, product and data management services, accounts payable, and Costpoint.

The material handling base consists of material, procurement, and consulting dollars charged to all projects, where the purchase order is expected to be less than $500,000.

The material handling rate is applied to the total cost of direct materials, procurements, and consulting agreements valued at less than $500,000, excluding interorganizational transfers.

K12.3.4 Major Procurement

The BATC major procurement rate is determined by calculating the indirect costs as a percentage of the cost base of direct material and procurements valued at $500,000 or more.

The BATC major procurement indirect costs are those required to support the processing of direct materials and procurements valued at $500,000 or more. These indirect costs include the costs for activities associated with material and procurement management and administrative support of these procurements, associated cost and pricing support, fringe costs for the personnel assigned to the pool, allocations from other procurement-related support departments such as BATC Material Control and Procurement Systems and Compliance, and allocations from other administrative support departments.

The major procurement base consists of material and procurement dollars charged to all programs where the purchase order is expected to be valued at $500,000 or more.

The major procurement rate is applied to the total cost of direct materials and procurements valued at $500,000 or more, excluding interorganizational transfers.

K12.4 General and Administrative (G&A)

The Civil/Defense, ETP, and/or CSO G&A rates are determined by calculating allocated G&A costs as a percentage of a value-added base. G&A costs consist of SBU management and administrative expenses, which are for the management of the SBU as a whole. The G&A pool includes the operating costs for the SBU's staff and the contracts, marketing, and division finance and planning organizations; fringe costs for these organizations; and allocations from intermediate cost pools. Allocations for BATC management staff, Ball Corporation staff, and applicable SBU IR&D and B&P recoverable costs are also included in the G&A pool.

The value-added base consists of all program costs (before cost of money), excluding direct material, freight, procurements, interorganizational transfers, and G&A.

Each year, the costs of G&A functions and the value-added base are estimated in detail for the upcoming year and at summary levels for subsequent years. G&A SBU management staff costs are estimated at the department level based on current and projected activity levels, anticipated staffing changes, changes in business functions, and other factors. The IR&D cost estimates are based on projections of the type and number of IR&D programs to be undertaken. The B&P cost estimates are based on the number and complexity of proposals to be submitted. Home office (Ball Corporation) and BATC allocations are estimated in accordance with CAS 403. The value-added base is estimated from individual program forecasts, marketing plans, and IR&D/B&P plans.

K12.5 Cost of Money

The cost of money is an imputed cost allocated to programs and proposals as specified by CAS 414. It represents the costs to the contractor of having facilities and equipment available for use in performance of Government contracts.

Cost of money factors (CMF) are revised semiannually to reflect the treasury interest rates that are published in January and July of each year and the current estimates of the book value of land, buildings, and equipment. CMFs correspond to the indirect rate pools (Civil/Defense, ETP, and/or CSO engineering overhead; Civil/Defense, ETP, and/or CSO G&A; and Boulder production and test, material handling, and major procurement). Each CMF is based on the book value of assets assigned to or allocated to its corresponding indirect rate pool. CMFs are applied to the same base as the corresponding overhead rate.

Pages K-70 through K-73 provide copies of documents relating to CMF (Forms CASB-CMF).

K12.5.1 Engineering Labor CMF

The engineering labor cost of facilities capital is based on the net book value of fixed assets employed in support of engineering direct labor. These assets include land, land improvements, buildings, leasehold improvements, machinery and equipment, and furniture and fixtures.

The engineering labor CMF rate is applied to the same base as the engineering overhead rate.

K12.5.2 Production and Test Labor CMF

The production and test labor cost of facilities capital is based on the net book value of fixed assets employed in support of production and test direct labor. These assets include land, land improvements, buildings, leasehold improvements, machinery and equipment, and furniture and fixtures.

The production and test labor CMF rate is applied to the same base as the production and test overhead rate.

K12.5.3 Material Handling CMF

The material handling cost of facilities capital is based on the net book value of fixed assets employed in support of the processing of direct materials, procurements, and consulting agreements where the purchase order is expected to be less than $500,000. These assets include land, land improvements, buildings, leasehold improvements, machinery and equipment, and furniture and fixtures.

The material handling CMF rate is applied to the same base as the material handling overhead rate.

K12.5.4 Major Procurement CMF

The major procurement cost of facilities capital is based on the net book value of fixed assets employed in support of the processing of direct materials and procurements where the purchase order is expected to be valued at $500,000 or more. These assets include land, land improvements, buildings, leasehold improvements, machinery and equipment, and furniture and fixtures.

The major procurement CMF rate is applied to the same base as the major procurement overhead rate.

K12.5.5 G&A CMF

The Civil/Defense, ETP, and/or CSO G&A cost of facilities capital is based on the net book value of fixed assets employed in support of the value-added cost base. These assets include land, land improvements, buildings, leasehold improvements, machinery and equipment, and furniture and fixtures.

The G&A CMF rate is applied to the same base as the G&A rate.

FORM CASB-CMF

FACILITIES CAPITAL

COST OF MONEY FACTORS COMPUTATION

($000)

CONTRACTOR: BALL AEROSPACE & TECHNOLOGIES CORP. BUSINESS UNIT: Civil/Defense and ETP	ADDRESS: P.O. BOX 1062 BOULDER, COLORADO 80306-1062

COST ACCOUNTING PERIOD Estimate for Year Ending: **2001**		1. APPLICABLE COST OF MONEY RATE 6.125%	2. ACCUMULATION AND DIRECT DISTRIBUTION OF N.B.V.	3. ALLOCATION OF UNDISTRIBUTED	4. TOTAL NET BOOK VALUE	5. COST OF MONEY FOR THE COST ACCOUNTING PERIOD	6. ALLOCATION BASE FOR THE PERIOD	7. FACILITIES CAPITAL COST OF MONEY FACTOR
BUSINESS UNIT FACILITIES CAPITAL	RECORDED		38,882.2	BASIS OF ALLOCATION	COLUMNS 2 + 3	COLUMNS 1 x 4	IN UNIT(S) OF MEASURE	COLUMNS 5 / 6
	LEASED PROPERTY							
	CORPORATE OR GROUP		1,326.8					
	TOTAL		40,209.1					
	UNDISTRIBUTED		26,151.7					
	DISTRIBUTED		14,057.3					
OVERHEAD POOLS	CIVIL/DEFENSE		1,397.2	7,468.6	8,865.8	543.0	38,539.1	1.4090%
	ENGINEERING/ TECHNOLOGY PRODUCTS		8,489.6	8,649.9	17,139.5	1,049.8	43,792.0	2.3972%
	PROD & TEST LABOR		4,062.1	4,832.0	8,894.2	544.8	7,709.8	7.0659%
	MATERIAL HANDLING		29.9	1,229.8	1,259.6	77.2	28,590.9	0.2699%
	MAJOR PROCUREMENTS		0.0	50.1	50.1	3.1	30,900.8	0.0099%
G&A EXPENSE POOLS	CIVIL/DEFENSE G&A		21.9	2,188.1	2,210.1	260.4	109,626.5	0.2375%
	ETP G&A		56.6	1,733.2	1,789.8	152.9	32,527.0	0.4699%
	TOTAL		14,057.3	26,151.7	40,209.1	2,631.0	\\\\\\\\\\\\\\\\	\\\\\\\\\\\\\\

FORM CASB-CMF

FACILITIES CAPITAL

COST OF MONEY FACTORS COMPUTATION

($000)

CONTRACTOR: BALL AEROSPACE & TECHNOLOGIES CORP.
BUSINESS UNIT: Civil/Defense, CSO and ETP

ADDRESS: P.O. BOX 1062
BOULDER, COLORADO 80306-1062

COST ACCOUNTING PERIOD Estimate for Year Ending: **2002**		1. APPLICABLE COST OF MONEY RATE 6.750%	2. ACCUMULATION AND DIRECT DISTRIBUTION OF N.B.V.	3. ALLOCATION OF UNDISTRIBUTED	4. TOTAL NET BOOK VALUE	5. COST OF MONEY FOR THE COST ACCOUNTING PERIOD	6. ALLOCATION BASE FOR THE PERIOD	7. FACILITIES CAPITAL COST OF MONEY FACTOR
BUSINESS UNIT FACILITIES CAPITAL	RECORDED		41,670.4	BASIS OF ALLOCATION	COLUMNS 2 + 3	COLUMNS 1 x 4	IN UNIT(S) OF MEASURE	COLUMNS 5 / 6
	LEASED PROPERTY							
	CORPORATE OR GROUP		2,406.2					
	TOTAL		44,076.6					
	UNDISTRIBUTED		27,809.7					
	DISTRIBUTED		16,266.9					
OVERHEAD POOLS	CIVIL/DEFENSE		833.5	7,866.1	8,699.6	587.2	43,406.0	1.3530%
	ENGINEERING/ TECHNOLOGY PRODUCTS		8,627.5	10,803.5	19,431.0	1,311.6	50,812.8	2.5810%
	PROD & TEST LABOR		5,445.0	5,603.5	11,048.5	745.8	10,204.6	7.3080%
	MATERIAL HANDLING		0.0	1,077.5	1,077.5	72.7	38,598.7	0.1880%
	MAJOR PROCUREMENTS		1.7	105.3	107.0	7.2	50,157.7	0.0140%
	COMMERCIAL SPACE OPS		1,319.5	1,027.1	2,346.6	158.4	7,052.7	N/A
G&A EXPENSE POOLS	CIVIL/DEFENSE G&A		19.8	188.5	208.3	218.9	125,179.9	0.1750%
	ETP G&A		11.2	754.4	765.6	89.8	29,202.7	0.3080%
	COMMERCIAL SPACE G&A		8.7	383.7	392.3	45.9	27,392.2	N/A
	TOTAL		16,266.9	27,809.7	44,076.6	3,237.6	\\\\\\\\\\\\\\\\	\\\\\\\\\\\\\\

FORM CASB-CMF

FACILITIES CAPITAL

COST OF MONEY FACTORS COMPUTATION

($000)

CONTRACTOR: BALL AEROSPACE & TECHNOLOGIES CORP.
BUSINESS UNIT: Civil/Defense, CSO and ETP

ADDRESS: P.O. BOX 1062
BOULDER, COLORADO 80306-1062

COST ACCOUNTING PERIOD Estimate for Year Ending: **2003**		1. APPLICABLE COST OF MONEY RATE 6.750%	2. ACCUMULATION AND DIRECT DISTRIBUTION OF N.B.V.	3. ALLOCATION OF UNDISTRIBUTED	4. TOTAL NET BOOK VALUE	5. COST OF MONEY FOR THE COST ACCOUNTING PERIOD	6. ALLOCATION BASE FOR THE PERIOD	7. FACILITIES CAPITAL COST OF MONEY FACTOR
BUSINESS UNIT FACILITIES CAPITAL	RECORDED		43,790.6	BASIS OF ALLOCATION	COLUMNS 2 + 3	COLUMNS 1 x 4	IN UNIT(S) OF MEASURE	COLUMNS 5 / 6
	LEASED PROPERTY							
	CORPORATE OR GROUP		2,464.0					
	TOTAL		46,254.5					
	UNDISTRIBUTED		29,163.9					
	DISTRIBUTED		17,090.6					
OVERHEAD POOLS	CIVIL/DEFENSE		875.7	8,259.7	9,135.5	616.6	47,199.3	1.3060%
	ENGINEERING/ TECHNOLOGY PRODUCTS		9,064.3	11,326.0	20,390.3	1,376.3	55,309.7	2.4880%
	PROD & TEST LABOR		5,720.7	5,881.0	11,601.8	783.1	11,163.2	7.0150%
	MATERIAL HANDLING		0.0	1,130.4	1,130.4	76.3	41,999.2	0.1820%
	MAJOR PROCUREMENTS		1.8	110.5	112.2	7.6	55,255.5	0.0140%
	COMMERCIAL SPACE OPS		1,386.3	1,078.2	2,464.5	166.4	7,933.2	N/A
G&A EXPENSE POOLS	CIVIL/DEFENSE G&A		20.8	197.5	218.3	228.9	135,220.7	0.1690%
	ETP G&A		11.8	772.9	784.7	92.8	31,332.5	0.2960%
	COMMERCIAL SPACE G&A		9.1	407.6	416.7	48.9	30,610.8	N/A
	TOTAL		17,090.6	29,163.9	46,254.5	3,397.0	\\\\\\\\\\\\\\\\	\\\\\\\\\\\\\\

FORM CASB-CMF

FACILITIES CAPITAL

COST OF MONEY FACTORS COMPUTATION

($000)

CONTRACTOR: BALL AEROSPACE & TECHNOLOGIES CORP. BUSINESS UNIT: Civil/Defense, CSO and ETP	ADDRESS: P.O. BOX 1062 BOULDER, COLORADO 80306-1062

COST ACCOUNTING PERIOD Estimate for Year Ending: **2004**		1. APPLICABLE COST OF MONEY RATE 6.750%	2. ACCUMULATION AND DIRECT DISTRIBUTION OF N.B.V.	3. ALLOCATION OF UNDISTRIBUTED	4. TOTAL NET BOOK VALUE	5. COST OF MONEY FOR THE COST ACCOUNTING PERIOD	6. ALLOCATION BASE FOR THE PERIOD	7. FACILITIES CAPITAL COST OF MONEY FACTOR
BUSINESS UNIT FACILITIES CAPITAL	RECORDED		45,662.5	BASIS OF ALLOCATION	COLUMNS 2 + 3	COLUMNS 1 x 4	IN UNIT(S) OF MEASURE	COLUMNS 5 / 6
	LEASED PROPERTY							
	CORPORATE OR GROUP		2,521.4					
	TOTAL		48,183.9					
	UNDISTRIBUTED		30,366.2					
	DISTRIBUTED		17,817.8					
OVERHEAD POOLS	CIVIL/DEFENSE		913.0	8,607.5	9,520.5	642.6	51,341.0	1.2520%
	ENGINEERING/ TECHNOLOGY PRODUCTS		9,450.0	11,787.8	21,237.8	1,433.6	60,116.9	2.3850%
	PROD & TEST LABOR		5,964.1	6,126.3	12,090.5	816.1	12,150.2	6.7170%
	MATERIAL HANDLING		0.0	1,177.2	1,177.2	79.5	45,698.7	0.1740%
	MAJOR PROCUREMENTS		1.8	115.0	116.8	7.9	60,321.9	0.0130%
	COMMERCIAL SPACE OPS		1,445.3	1,122.5	2,567.9	173.3	8,717.2	N/A
G&A EXPENSE POOLS	CIVIL/DEFENSE G&A		21.7	205.5	227.1	227.6	147,062.9	0.1550%
	ETP G&A		12.3	798.0	810.3	86.7	33,863.8	0.2560%
	COMMERCIAL SPACE G&A		9.5	426.4	435.9	50.5	33,655.9	N/A
	TOTAL		17,817.8	30,366.2	48,183.9	3,517.8	\\\\\\\\\\\\\\\	\\\\\\\\\\\\\

DD FORM 1861: CONTRACT FACILITIES CAPITAL COST OF MONEY

Date Prepared 8/20/01

CONTRACT FACILITIES CAPITAL COST OF MONEY **2002**			FORM APPROVED OMB NO. 0704-0267
1. Contractor Name: Ball Aerospace & Technologies Corp.		2. Contractor Address: P.O. Box 1062 Boulder, CO 80306-1062	
3. Business Unit: Civil/Defense, CSO and ETP			
4.		5. Performance Period: 07/01/01-10/30/05	
6. Distribution of Facilities Capital Cost of Money			
		Facilities Capital Cost of Money	
POOL	ALLOCATION BASE	FACTOR	AMOUNT
Civil/Defense	46,547	1.353%	630
CD/ETP	530,579	1.353%	7,179
Engineering/Technology Products	530,579	2.581%	13,694
Production and Test	9,512	7.308%	695
Material Handling	292	0.188%	1
Major Procurement Material Handling	600	0.014%	0
Civil/Defense G&A	76,348	0.175%	134
CD/ETP G&A	1,415,055	0.175%	2,476
PT G&A	27,737	0.175%	49
TOTAL	2,637,251		24,857
TREASURY RATE			6.125%
FACILITIES CAPITAL EMPLOYED (TOTAL/TREASURY RATE)			
7. DISTRIBUTION OF FACILITIES CAPITAL EMPLOYED			
		PERCENTAGE	AMOUNT
LAND		3.10%	$0
BUILDINGS		52.50%	$0
EQUIPMENT		44.40%	$0
FACILITIES CAPITAL EMPLOYED		100.00%	$0

DD Form 1861, AUG 87 *Supersedes all previous editions of DD forms 1861-1 and 1861-2, which are obsolete.*

DD FORM 1861: CONTRACT FACILITIES CAPITAL COST OF MONEY

Date Prepared 8/20/01

CONTRACT FACILITIES CAPITAL COST OF MONEY **2003**		FORM APPROVED OMB NO. 0704-0267	
1. Contractor Name: Ball Aerospace & Technologies Corp.		2. Contractor Address: P.O. Box 1062 Boulder, CO 80306-1062	
3. Business Unit: Civil/Defense, CSO and ETP			
4.		5. Performance Period: 07/01/01-10/30/05	
6. Distribution of Facilities Capital Cost of Money			
		Facilities Capital Cost of Money	
POOL	ALLOCATION BASE	FACTOR	AMOUNT
Civil/Defense	156,188	1.306%	2,040
CD/ETP	1,388,999	1.306%	18,140
Engineering/Technology Products	1,388,999	2.488%	34,558
Production and Test	140,955	7.015%	9,888
Material Handling	2,717,191	0.182%	4,945
Major Procurement Material Handling	659,400	0.014%	92
Civil/Defense G&A	577,271	0.169%	976
CD/ETP G&A	3,694,737	0.169%	6,244
PT G&A		0.169%	680
TOTAL	11,126,308		77,564
TREASURY RATE			6.125%
FACILITIES CAPITAL EMPLOYED (TOTAL/TREASURY RATE)			
7. DISTRIBUTION OF FACILITIES CAPITAL EMPLOYED			
		PERCENTAGE	AMOUNT
LAND		3.10%	$0
BUILDINGS		52.50%	$0
EQUIPMENT		44.40%	$0
FACILITIES CAPITAL EMPLOYED		100.00%	$0

DD Form 1861, AUG 87 *Supersedes all previous editions of DD forms 1861-1 and 1861-2, which are obsolete.*

DD FORM 1861: CONTRACT FACILITIES CAPITAL COST OF MONEY

Date Prepared 8/20/01

CONTRACT FACILITIES CAPITAL COST OF MONEY **2004**	FORM APPROVED OMB NO. 0704-0267

1. Contractor Name: Ball Aerospace & Technologies Corp.		2. Contractor Address: P.O. Box 1062 Boulder, CO 80306-1062	
3. Business Unit: Civil/Defense, CSO and ETP			
4.		5. Performance Period: 07/01/01-10/30/05	
6. Distribution of Facilities Capital Cost of Money			
		Facilities Capital Cost of Money	
POOL	ALLOCATION BASE	FACTOR	AMOUNT
Civil/Defense	159,195	1.252%	1,993
CD/ETP	776,736	1.252%	9,725
Engineering/Technology Products	776,736	2.385%	18,525
Production and Test	33,407	6.717%	2,244
Material Handling		0.174%	
Major Procurement Material Handling		0.013%	
Civil/Defense G&A	257,968	0.155%	400
CD/ETP G&A	2,066,894	0.155%	3,204
PT G&A	95,343	0.155%	148
TOTAL	4,166,280		36,238
TREASURY RATE			6.125%
FACILITIES CAPITAL EMPLOYED (TOTAL/TREASURY RATE)			
7. DISTRIBUTION OF FACILITIES CAPITAL EMPLOYED			
		PERCENTAGE	AMOUNT
LAND		3.10%	$0
BUILDINGS		52.50%	$0
EQUIPMENT		44.40%	$0
FACILITIES CAPITAL EMPLOYED		100.00%	$0

DD Form 1861, AUG 87 *Supersedes all previous editions of DD forms 1861-1 and 1861-2, which are obsolete.*

DD FORM 1861: CONTRACT FACILITIES CAPITAL COST OF MONEY

Date Prepared 8/20/01

CONTRACT FACILITIES CAPITAL COST OF MONEY **2005**			FORM APPROVED OMB NO. 0704-0267
1. Contractor Name: Ball Aerospace & Technologies Corp.		2. Contractor Address: P.O. Box 1062 Boulder, CO 80306-1062	
3. Business Unit: Civil/Defense, CSO and ETP			
4.		5. Performance Period: 07/01/01-10/30/05	
6. Distribution of Facilities Capital Cost of Money			
		Facilities Capital Cost of Money	
POOL	ALLOCATION BASE	FACTOR	AMOUNT
Civil/Defense	55,816	1.252%	699
CD/ETP	304,323	1.252%	3,810
Engineering/Technology Products	304,323	2.385%	7,258
Production and Test	10,928	6.717%	734
Material Handling		0.174%	
Major Procurement Material Handling		0.013%	
Civil/Defense G&A	118,712	0.155%	184
CD/ETP G&A	809,804	0.155%	1,255
PT G&A	31,188	0.155%	48
TOTAL	1,635,095		13,989
TREASURY RATE			6.125%
FACILITIES CAPITAL EMPLOYED (TOTAL/TREASURY RATE)			
7. DISTRIBUTION OF FACILITIES CAPITAL EMPLOYED			
		PERCENTAGE	AMOUNT
LAND		3.10%	$0
BUILDINGS		52.50%	$0
EQUIPMENT		44.40%	$0
FACILITIES CAPITAL EMPLOYED		100.00%	$0

DD Form 1861, AUG 87 *Supersedes all previous editions of DD forms 1861-1 and 1861-2, which are obsolete.*

K12.6 Miscellaneous Other Direct Costs

The miscellaneous ODC rate reflects the estimated value of those incidental and unpredictable costs that occur on programs. Examples of miscellaneous ODC charges are overtime premium, shift differential, standard hardware shipment costs, and special equipment charges (not including computer rentals). The total overtime premium historically approximates 1% of the total direct labor or 1 percentage point of the miscellaneous ODC factor. The base upon which the miscellaneous ODC rate is applied is the total cost of direct labor, including SIA.

This factor is calculated annually using an average of the last five years' proportion of miscellaneous ODC to direct labor. The resulting factor is then used for the current year and out-year estimates and is applied to direct labor.

K12.7 Freight-In

Freight-in is the estimated amount of transportation costs to be incurred when non-major procurements of direct materials and subcontracts are procured. The rate is determined annually, using an average of the last five years' proportion of total freight-in cost to total cost of non-major procurements. The resulting factor is then used for the current year and out-year estimates and is applied to the total cost of non-major procurements of direct materials and subcontracts.

K12.8 BATC Historical and Estimated Rate Structure

The BATC historical and estimated rate structure (**Table K-6**) is presented for the customer's use in evaluating BATC's actual rates for calendar years 1995-2000 and the basis for the estimated rates for calendar years 2001-2004.

Table K-6 BATC historical and estimated rate structure

	Actuals 1995	Actuals 1996	Actuals 1997	Actuals 1998	Actuals 1999	Actuals 2000	Est. 2001	Est. 2002	Est. 2003	Est. 2004
Civil/Defense Overhead										
Unallocated Expenses										
Indirect Labor						6,434	6,794	8,296	9,019	9,808
Nonlabor (1)						2,467	2,602	1,831	1,991	2,165
Depreciation						481	393	441	528	668
Plant/Property						326	344	477	519	564
Unallocated Total						9,707	10,134	11,046	12,057	13,206
Allocated Expenses										
Fringe Benefits (2)						3,647	3,523	4,594	4,948	5,417
Facilities (3)						3,885	4,758	4,512	4,644	4,846
Intermediate Pool Alloc (4)						1,742	3,836	2,370	2,582	2,788
Other (5)						2,374	4,090	3,815	4,120	4,501
Allocated Total						11,648	16,207	15,291	16,294	17,553
Total Indirect Expenses						21,355	26,341	26,337	28,351	30,759
Allocation Base										
Total Direct Labor						35,278	38,539	43,406	47,199	51,341
Overhead Rate						60.5%	68.3%	60.7%	60.1%	59.9%
Civil/Defense General & Administrative Overhead										
Unallocated Expenses										
Indirect Labor						1,605	1,813	2,408	2,617	2,847
Nonlabor (1)						479	700	682	742	807
Depreciation						18	15	21	27	33
Plant/Property						46	53	20	21	23
Unallocated Total						2,147	2,580	3,130	3,407	3,709
Allocated Expenses										
Fringe Benefits (2)						554	716	715	770	843
Facilities (3)						125	156	148	160	172
Intermediate Pool Alloc (4)						2,214	2,275	2,594	2,781	2,977
Other (5)						475	480	1,708	1,847	2,018
Group Allocation (6)						7,140	7,004	7,301	7,897	8,612
Corporate Allocation (7)						1,176	1,035	1,571	1,753	1,933
Allocated Total						11,684	11,666	14,037	15,208	16,555
IR&D/B&P						8,582	11,188	12,046	13,095	14,241
Total Indirect Expenses						22,413	25,434	29,213	31,710	34,505
Allocation Base										
G&A Value-Added Base						102,536	109,627	125,180	135,221	147,063
G&A Overhead Rate						21.9%	23.2%	23.3%	23.5%	23.5%

Note: There is no historical data prior to 2000 due to BATC reorganization in January 2000.

Table K-6 BATC historical and estimated rate structure (continued)

	Actuals 1995	Actuals 1996	Actuals 1997	Actuals 1998	Actuals 1999	Actuals 2000	Est. 2001	Est. 2002	Est. 2003	Est. 2004
Engineering/Technology Products Overhead										
Unallocated Expenses										
Indirect Labor						5,700	5,969	7,637	8,248	8,908
Nonlabor (1)						1,748	2,489	1,962	2,119	2,288
Depreciation						2,921	2,800	3,375	4,045	4,742
Plant/Property						724	742	1,016	1,097	1,185
Unallocated Total						11,094	12,000	13,989	15,509	17,123
Allocated Expenses										
Fringe Benefits (2)						18,637	22,050	23,721	25,541	27,913
Facilities (3)						5,458	6,222	7,588	8,180	8,748
Intermediate Pool Alloc (4)						7,743	7,962	9,684	10,566	11,394
Other (5)						(1,112)	(1,764)	(1,994)	(2,181)	(2,327)
Allocated Total						30,727	34,470	38,999	42,105	45,728
Total Indirect Expenses						41,821	46,470	52,988	57,614	62,851
Allocation Base										
Total Direct Labor						39,041	43,792	50,813	55,310	60,117
Overhead Rate						107.1%	106.1%	104.3%	104.2%	104.5%
Engineering/Technology Products General & Administrative Overhead										
Unallocated Expenses										
Indirect Labor						1,952	2,302	2,322	2,508	2,709
Nonlabor (1)						448	621	636	687	742
Depreciation						42	22	21	23	24
Plant/Property						14	5	8	8	9
Unallocated Total						2,455	2,950	2,987	3,226	3,484
Allocated Expenses										
Fringe Benefits (2)						1,270	1,363	582	623	677
Facilities (3)						356	297	130	141	152
Intermediate Pool Alloc (4)						968	2,066	927	992	1,060
Other (5)						25	(397)	1,093	1,172	1,275
Group Allocation (6)						1,979	2,777	2,889	3,059	3,321
Corporate Allocation (7)						310	430	607	657	720
Allocated Total						4,908	6,536	6,286	6,645	7,204
IR&D/B&P						2,278	3,150	3,863	4,172	4,505
Total Indirect Expenses						9,641	12,636	13,078	14,043	15,069
Allocation Base										
G&A Value-Added Base						19,137	32,527	29,203	31,332	33,864
G&A Overhead Rate						50.4%	38.8%	44.8%	44.8%	44.5%

Note: There is no historical data prior to 2000 due to BATC reorganization in January 2000.

Table K-6 BATC historical and estimated rate structure (continued)

	Actuals 1995	Actuals 1996	Actuals 1997	Actuals 1998	Actuals 1999	Actuals 2000	Est. 2001	Est. 2002	Est. 2003	Est. 2004
Production & Test Overhead										
Unallocated Expenses										
Indirect Labor	1,223	1,497	1,911	2,283	2,117	1,867	1,964	3,061	3,349	3,645
Nonlabor (1)	603	679	831	776	784	599	1,081	1,071	1,172	1,276
Depreciation	674	703	850	1,157	1,283	1,115	1,117	1,856	2,211	2,571
Plant/Property	222	302	377	412	444	362	342	529	578	629
Unallocated Total	2,722	3,180	3,968	4,628	4,628	3,943	4,504	6,518	7,310	8,121
Allocated Expenses										
Fringe Benefits (2)	2,717	3,669	3,925	4,077	4,047	3,789	4,146	5,116	5,545	6,077
Facilities (3)	2,582	2,584	2,853	4,272	3,846	3,272	3,220	4,528	4,732	4,954
Intermediate Pool Alloc (4)	2,486	2,419	2,427	2,412	2,412	2,353	2,411	3,868	4,212	4,538
Other (5)	168	(24)	112	(21)	(148)	(167)	6	(649)	(1,272)	(1,372)
Allocated Total	7,954	8,648	9,318	10,740	10,158	9,247	9,783	12,862	13,216	14,196
Total Indirect Expenses	10,676	11,828	13,286	15,368	14,786	13,190	14,287	19,380	20,526	22,317
Allocation Base										
Total Direct Labor Base	6,225	7,411	8,185	7,569	7,064	6,485	7,710	10,205	11,163	12,150
Prod/Test Overhead Rate	171.5%	159.6%	162.3%	203.0%	209.3%	203.4%	185.3%	189.9%	183.9%	183.7%
BATC Material Handling Overhead										
Unallocated Expenses										
Indirect Labor					65	128	989	187	196	205
Nonlabor (1)	0	2	1	(3)	(0)	102	70	4	4	4
Depreciation						0	9			
Plant/Property					5	4	45			
Unallocated Total	0	2	1	(3)	69	233	1,112	191	200	209
Allocated Expenses										
Fringe Benefits (2)						20	351	44	46	48
Facilities (3)						7	535	15	15	16
Intermediate Pool Alloc (4)	1,910	3,015	3,746	3,718	3,530	2,998	1,761	3,897	4,236	4,522
Other (5)	(36)	(20)	(1)	(10)	44	49	96	48	(208)	(221)
Allocated Total	1,874	2,996	3,745	3,708	3,573	3,075	2,742	4,004	4,089	4,365
Total Indirect Expenses	1,874	2,998	3,746	3,705	3,642	3,308	3,855	4,195	4,288	4,573
Allocation Base										
Total Material & Subcontract Base	20,824	28,701	35,169	33,662	32,043	25,464	28,591	35,599	41,999	45,699
BASD Material Handling Overhead Rate	9.0%	10.4%	10.7%	11.0%	11.4%	13.0%	13.5%	10.9%	10.2%	10.0%

Table K-6 BATC historical and estimated rate structure (concluded)

BATC Major Procurement Overhead	Actuals 1995	Actuals 1996	Actuals 1997	Actuals 1998	Actuals 1999	Actuals 2000	Est. 2001	Est. 2002	Est. 2003	Est. 2004
Unallocated Expenses										
Indirect Labor	313	387	492	333	388	402	502	681	711	780
Nonlabor (1)	78	202	217	43	54	29	47	88	92	101
Depreciation	4	9	6	7	2	2	0	0	0	0
Plant/Property	0	0	0	0	2	1	5	1	1	2
Unallocated Total	396	599	716	383	445	435	554	770	805	882
Allocated Expenses										
Fringe Benefits (2)	120	152	122	142	116	101	157	153	158	180
Facilities (3)	29	29	32	28	26	30	46	50	53	60
Intermediate Pool Alloc (4)	57	53	45	77	70	56	75	83	91	98
Other (5)	82	73	148	65	50	113	89	196	205	214
Allocated Total	288	306	347	312	262	300	367	483	506	552
Total Indirect Expenses	685	905	1,062	695	707	735	921	1,253	1,311	1,434
Allocation Base										
Total Material & Subcontract Base	44,920	69,208	66,335	38,941	36,302	23,930	30,901	50,158	55,256	60,322
Major Procurement Overhead Rate	1.5%	1.3%	1.6%	1.8%	2.0%	3.1%	3.0%	2.5%	2.4%	2.4%
BATC Miscellaneous ODC Rate										
Overtime Premium			721	561	486	376	512			
Other Direct Costs			550	413	396	352	441			
Total Misc ODC Costs			1,271	974	882	728	953			
Total Direct Labor			57,631	54,940	55,598	49,997	55,171			
Miscellaneous ODC Rate			2.2%	1.8%	1.6%	1.5%	1.7%	1.7%	1.7%	1.7%
BATC Freight-In Rate										
Total Freight-In Cost			389	428	408	360	379			
Total Cost of Purchased Material			30,435	27,793	26,476	18,663	25,477			
Freight-In Rate			1.3%	1.5%	1.5%	1.9%	1.5%	1.5%	1.5%	1.5%
Salary Increase Allowance (8)							N/A	4.5%	4.5%	4.5%

Notes:

1. Nonlabor includes materials, supplies, travel, data processing, and other indirect costs.
2. Fringe includes paid absence, holidays, vacation, and other employee benefits.
3. Facilities includes costs associated with buildings, utilities, management of facilities, facility related costs, and telecommunication costs.
4. Intermediate Pool Allocations includes costs allocated for Accounting, Human Resources, Purchasing, Classified Security, Clean Rooms, Metrology, and other intermediate pools.
5. Other includes costs such as credits/adjustments for interpool charging, state taxes (G&A only), special allocations, and reductions for expressly unallowable costs.
6. Group G&A allocation is based on the three-factor formula per CAS 403 and excludes expressly unallowable costs.
7. Corporate G&A allocation is based on the three-factor formula per CAS 403 and excludes expressly unallowable costs.
8. Salary Increase Allowance is based on the latest data from Human Resources.

K12.9 Rate Verification Table

The rate verification table (**Table K-7**) is enclosed for the customer's use in comparing rates applied in our annual accounting periods to those stated in our forward pricing rate tables.

Table K-7 Rate Verification Table

SBU	Year	SIA	Overhead	ODC	Freight	G&A	G&A CMF	CMF	Mat Hndl	Mat Hndl CMF	Major CMF	Major Proc
CD	1999		55.95	1.7	1.5	26.8	0.176	1.208	11.5	0.228	0.011	2.5
CD	2000		62.1	1.7	1.5	23.5	0.225	1.639	11.6	0.235	0.017	2.5
CD	2001		68.3	1.7	1.5	23.2	0.2375	1.409	13.5	0.2699	0.0099	3
CD	2002	4.5	60.7	1.7	1.5	23.3	0.175	1.353	10.9	0.188	0.014	2.5
CD	2003	4.5	60.1	1.7	1.5	23.5	0.169	1.306	10.2	0.182	0.014	2.4
CD	2004	4.5	59.9	1.7	1.5	23.5	0.155	1.252	10	0.174	0.013	2.4
CD	2005	4.5	59.9	1.7	1.5	23.5	0.155	1.252	10	0.174	0.013	2.4
CD	2006	4.5	59.9	1.7	1.5	23.5	0.155	1.252	10	0.174	0.013	2.4
CD	2007	4.5	59.9	1.7	1.5	23.5	0.155	1.252	10	0.174	0.013	2.4
CD	2008	4.5	59.9	1.7	1.5	23.5	0.155	1.252	10	0.174	0.013	2.4
ET	1999		116.53	1.7	1.5	54.3	0.874	3.121	11.5	0.228	0.011	2.5
ET	2000		108	1.7	1.5	46	0.381	3.130	11.6	0.235	0.017	2.5
ET	2001		106.1	1.7	1.5	38.8	0.4699	2.3972	13.5	0.2699	0.0099	3
ET	2002	4.5	104.3	1.7	1.5	44.8	0.308	2.581	10.9	0.188	0.014	2.5
ET	2003	4.5	104.2	1.7	1.5	44.8	0.296	2.488	10.2	0.182	0.014	2.4
ET	2004	4.5	104.5	1.7	1.5	44.5	0.256	2.385	10	0.174	0.013	2.4
ET	2005	4.5	104.5	1.7	1.5	44.5	0.256	2.385	10	0.174	0.013	2.4
ET	2006	4.5	104.5	1.7	1.5	44.5	0.256	2.385	10	0.174	0.013	2.4
ET	2007	4.5	104.5	1.7	1.5	44.5	0.256	2.385	10	0.174	0.013	2.4
ET	2008	4.5	104.5	1.7	1.5	44.5	0.256	2.385	10	0.174	0.013	2.4
PT	1999		198.8	1.7	1.5			9.222	11.5	0.228		
PT	2000		198.8	1.7	1.5			8.614	11.6	0.235		
PT	2001		185.3	1.7	1.5			7.0659	13.5	0.2699		
PT	2002	4.5	189.9	1.7	1.5			7.308	10.9	0.188		
PT	2003	4.5	183.9	1.7	1.5			7.015	10.2	0.182		
PT	2004	4.5	183.7	1.7	1.5			6.717	10	0.174		
PT	2005	4.5	183.7	1.7	1.5			6.717	10	0.174		
PT	2006	4.5	183.7	1.7	1.5			6.717	10	0.174		
PT	2007	4.5	183.7	1.7	1.5			6.717	10	0.174		
PT	2008	4.5	183.7	1.7	1.5			6.717	10	0.174		

K12.10 BATC Rate Application

The BATC Rate Application Example by Element of Cost (**Table K-8**) is presented for the customer's use in understanding the current BATC indirect rate structure and its application to the cost estimate prepared for this proposal. Table K-8 summarizes indirect rate application information previously contained in this section. It also provides additional background and supporting information for our current indirect rate structure.

Table K-8 BATC rate application example by element of cost (Example uses 2001 rates; assumes Civil/Defense (CD) owned project)

CD - Civil/Defense
ETP - Engineering/Technology Products
PT - Production & Test

	Rates %	$	Rates %	$	
LABOR	**ETP**		**PT**		**Rate Calculation**
Direct Labor w/SIA		**1.00**		**1.00**	
ETP or PT Labor O/H	106.1000	1.0610	185.3000	1.8530	Calc on ETP or PT Direct Labor
CD Labor O/H	68.3000	0.6830			Calc on ETP Direct Labor only
Direct Labor & O/H		2.7440		2.8530	
CD G&A	23.2000	0.6366	23.2000	0.6619	Calc on ETP or PT Direct Labor & OH
ETP or PT Labor CMF	2.3972	0.0240	7.0659	0.0707	Calc on ETP or PT Direct Labor
CD Labor CMF	1.4090	0.0141			Calc on ETP Direct Labor only
CD G&A CMF	0.2375	0.0065	0.2375	0.0068	Calc on ETP or PT Direct Labor & OH
Burdened Cost		**3.4252**		**3.5923**	
Burden Only		**2.4252**		**2.5923**	
LABOR	**CD**				
Direct Labor w/SIA		**1.00**			
CD Labor O/H	68.3000	0.6830			Calc on CD Direct Labor
Direct Labor & O/H		1.6830			
CD G&A	23.2000	0.3905			Calc on CD Direct Labor & OH
CD Labor CMF	1.4090	0.0141			Calc on CD Direct Labor
CD G&A CMF	0.2375	0.0040			Calc on CD Direct Labor & OH
Burdened Cost		**2.0915**			
Burden Only		**1.0915**			
MATERIAL	**MAT'L/SUBS**		**MAJ. PROC.**		
Mat'l/Sub or Maj Proc		**1.00**		**1.00**	
Mat'l or Maj Proc O/H	13.5000	0.1350	3.0000	0.0300	Calc on Mat'l & Freight or Maj Proc
CD G&A	23.2000	0.0313	23.2000	0.0070	Calc on Mat'l or Maj Proc O/H
Mat'l or Maj Proc CMF	0.2699	0.0027	0.0099	0.0001	Calc on Mat'l & Freight or Maj Proc
CD G&A CMF	0.2375	0.0003	0.2375	0.0001	Calc on Mat'l or Maj Proc O/H
Burdened Cost		**1.1693**		**1.0371**	
Burden Only		**0.1693**		**0.0371**	
ODC	**ODC**				
Direct ODC		**1.00**			
CD G&A	23.200	0.2320			Calc on Total ODC
CD G&A CMF	0.2375	0.0024			Calc on Total ODC
Burdened Cost		**1.2344**			
Burden Only		**0.2344**			
Interdivisional	**Interdivisional**				
Interdivisional		1.00			Interdivisional work is costed by the performing
					SBU and is proposed to CD fully burdened.
Burdened Cost		**1.00**			CD does not apply any additional burdening
Burden Only		**0.00**			to interdivisional work.

NOTES:
1) All elements of cost are applied with CD's G&A and CD's G&A CMF since CD is the owning SBU
2) Explanation of ETP and CD Overhead application:

BATC's use of multiple cost centers related to our business unit structure should not be mistaken as double counting. Our system is reviewed and monitored by our ACO for the development and application of rates to the appropriate cost input base. The overall philosophy of the BATC rate structure is to allow Civil and Defense (CD) business units to pursue and capture new business while Engineering/Technologies Products (ETP) provides engineering support for the execution of the captured programs. ETP OH contains management support for the matrix ETP direct labor base (approx. 800 engineers) that support all CD programs. It also includes non-labor costs (primarily depreciation, plant/equipment expenses) along with fringe, facility and intermediate pool allocations. The ETP OH rate methodology assumes that a portion of the ETP direct labor base is created from matrix support to CD programs and is therefore included in the ETP direct labor base for rate computation. This is due to the fact that the Civil and Defense business units do not maintain all of the personnel required to execute customer programs. The CD OH rate contains support for only the CD direct labor base (approx. 130 CD employees) that support the pursuit, capture and management of CD programs. The CD OH rate methodology assumes that direct labor for a CD program is a mix of CD personnel and ETP Matrix personnel, which are both included in the CD direct labor base for rate computation.

BALL PROPRIETARY DATA

K.13 Education/Public Outreach

The E/PO program has been described in detail in Section J. The E/PO costs are shown in E/PO **Fig. K-14** through **K-16**. Fig. K-14 shows all of the costs in detail. The E/PO program is based at Hampton University and all E/PO subcontracts are managed from there. The E/PO costing was performed in a grass roots manner as described earlier. The E/PO costs are divided into four general categories: direct costs, other direct costs, subcontract costs, and costs associated with the lead educator workshops. Direct costs include professional costs including salaries and benefits. HU waves indirect costs on student labor. Note also that the E/PO director is a faculty member and receives partial support from HU. The PI and Co-PI, who are also partially supported by their institutions, consider their contribution to the AIM E/PO activities as part of their science contribution and therefore do not charge their time to the E/PO budget.

Figure K-14. E/PO Template #1

Budget Category	FY2002	FY2003	FY2004	FY2005	FY2006	FY2007	Totals (RY$)	Totals (FY2000$)
Direct Labor								
Director, Dianne Q. Robinson	$ -	$ 6,567	$ 6,751	$ 6,940	$ 7,134	$ 3,667	$ 31,060	$ 27,202.50
Assistant Director, Barbara Maggi	$ -	$ 3,621	$ 7,445	$ 7,653	$ 7,868	$ 4,044	$ 30,631	$ 26,665.33
Program Manager		$ 21,727	$ 22,336	$ 22,961	$ 11,802	$ 4,044	$ 82,871	$ 73,333.33
Admin. Ast.	$ -	$ -	;	$ -	$ -	$ -	$ -	
Secretarial/Clerical	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
Total Direct Labor	$ -	$ 31,916	$ 36,531	$ 37,554	$ 26,804	$ 11,755	$ 144,561	$ 127,201.17
Fringe Benefits@18.5%	$ -	$ 5,904	$ 6,758	$ 6,948	$ 4,959	$ 2,175	$ 26,744	$ 23,532.22
Other Direct Labor (No Fringe or Over-head)								
Undergraduate Student	$ -	$ 10,429	$ 10,721	$ 11,021	$ 11,330	$ 10,677	$ 54,178	$ 47,200
Graduate Student	$ -	$ 13,036	$ 26,803	$ 27,554	$ 28,325	$ 14,559	$ 110,277	$ 96,000
Total Other Direct Labor	$ -	$ 23,466	$ 37,524	$ 38,575	$ 39,655	$ 25,236	$ 164,455	$ 143,200
Other Direct Costs								
Travel (Faculty)	$ -	$ 5,432	$ 10,051	$ 19,517	$ 20,064	$ 10,919	$ 65,983	$ 57,000
Travel (Student, No Overhead Charged)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Materials and Supplies	$ -	$ 1,086	$ 2,234	$ 3,444	$ 4,721	$ 2,427	$ 13,911	$ 12,000
Consultants	$ -	$ -	$ 3,350	$ 5,740	$ 5,901	$ 3,640	$ 18,631	$ 16,000
Toll Calls	$ -	$ 326	$ 335	$ 344	$ 354	$ 364	$ 1,723	$ 1,500
Publications	$ -	$ -	$ 1,117	$ 2,296	$ 4,721	$ 1,213	$ 9,347	$ 8,000
Equipment Maintenance	$ -	$ -	$ 1,675	$ 2,296	$ 2,360	$ 1,213	$ 7,545	$ 6,500
Computer Equipment	$ -	$ 4,345	$ 22,736	$ 2,107	$ 5,026	$ -	$ 34,214	$ 30,452
Other Equipment	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
Total Other Direct Costs	$ -	$ 11,190	$ 41,498	$ 35,745	$ 43,146	$ 19,776	$ 151,355	$ 131,452
Total Direct Cost	$ -	$ 72,476	$ 122,312	$ 118,821	$ 114,565	$ 58,942	$ 487,116	$ 425,385
Modified Total direct Cost (Excludes Student and Equiptment Costs)	$ -	$ 44,664	$ 62,052	$ 78,140	$ 69,884	$ 33,706	$ 288,447	$ 251,733
Indirect Cost @48.5% OF MTDC	$ -	$ 21,662	$ 30,095	$ 37,898	$ 33,894	$ 16,348	$ 139,897	$ 122,091

Figure K-14. E/PO Template #1 (continued)

Subcontracts	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
NASA Connect	$ -	$ -	$ 27,920	$ -	$ -	$ -	$ 27,920	$ 25,000
Windows on the Universe	$ -	$ -	$ 11,168	$ 11,481	$ 11,802	$ -	$ 34,451	$ 30,000
Virginia Air and Space Museum	$ -	$ -	$ 8,376	$ -	$ -	$ -	$ 8,376	$ 7,500
Space Development Laboratory			$ 4,467	$ 4,592			$ 9,059	$ 8,000
WHRO-TV	$ -	$ -	$ 22,336	$ 11,481	$ -	$ -	$ 33,816	$ 30,000
Evaluation	$ -	$ -	$ 27,920	$ 28,702	$ 29,505	$ -	$ 86,127	$ 75,000
Total Subcontracts	$ -	$ -	$ 102,187	$ 56,255	$ 41,307	$ -	$ 199,749	$ 175,500
Indirect Cost on Subcontracts	$ -	$ -	$ 46,728	$ 9,087	$ 1,140	$ -	$ 56,956	$ 50,723
Participant Costs								
Stipend, $1000 per group x 10 groups	$ -	$ -	$ -	$ 11,481	$ 11,802	$ -	$ 23,283	$ 20,000
Follow up stipend, $500 x 10 groups	$ -	$ -	$ -	$ 5,740	$ 5,901	$ -	$ 11,641	$ 10,000
Participant flights, $650 x 30	$ -	$ -	$ -	$ 22,387	$ 23,014	$ -	$ 45,401	$ 39,000
Participant Rooms, $75 x 10 days x 30	$ -	$ -	$ -	$ 25,831	$ 26,555	$ -	$ 52,386	$ 45,000
Participant food, $30 x 10 days x 30	$ -	$ -	$ -	$ 10,333	$ 10,622	$ -	$ 20,954	$ 18,000
Participant field trips, $150*30	$ -	$ -	$ -	$ 5,166	$ 5,311	$ -	$ 10,477	$ 9,000
Partipant materials allotment, $175*30	$ -	$ -	$ -	$ 6,027	$ 6,196	$ -	$ 12,223	$ 10,500
Total Participant Cost	$ -	$ -	$ -	$ 86,966	$ 89,401		$ 176,367	$ 151,500
Annual Total Cost (RY)	$ -	$ 94,138	$ 301,322	$ 309,028	$ 280,307	$ 75,289	$ 1,060,084	$ 925,199
Annual Total Cost (FY2000)	$ -	$ 86,653	$ 269,810	$ 269,173	$ 237,506	$ 62,056		$ 925,199
Running Cost	$ -	$ 94,138	$ 395,460	$ 704,488	$ 984,795	$ 1,060,084		

Figure K-15. E/PO Template #2

Budget Category	FY2002	FY2003	FY2004	FY2005	FY2006	FY2007	Totals (RY$)	Totals (FY2000$)
Lead Workshop Activities								
Stipend, $1000 per group x 10 groups	$ -	$ -	$ -	$ 11,481	$ 11,802	$ -	$ 23,283	$ 20,000
Follow up stipend, $500 x 10 groups	$ -	$ -	$ -	$ 5,740	$ 5,901	$ -	$ 11,641	$ 10,000
Participant flights, $650 x 30	$ -	$ -	$ -	$ 22,387	$ 23,014	$ -	$ 45,401	$ 39,000
Participant Rooms, $75 x 10 days x 30	$ -	$ -	$ -	$ 25,831	$ 26,555	$ -	$ 52,386	$ 45,000
Participant food, $30 x 10 days x 30	$ -	$ -	$ -	$ 10,333	$ 10,622	$ -	$ 20,954	$ 18,000
Participant field trips, $150*30	$ -	$ -	$ -	$ 5,166	$ 5,311	$ -	$ 10,477	$ 9,000
Partipant materials allotment, $175*30	$ -	$ -	$ -	$ 6,027	$ 6,196	$ -	$ 12,223	$ 10,500
Total Costs for Lead Workshops	$ -	$ -	$ -	$ 86,966	$ 89,401		$ 176,367	$ 151,500

Figure K-16. E/PO Template #3

		FY2002	FY2003	FY2004	FY2005	FY2006	FY2007	Totals (RY$)	Totals (FY2000$)
Hampton University									
PI: James M. Ruseell, III	(% Time)	0	5	5	5	5	5		
PI: James M. Ruseell, III	Direct cost	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Director: Dianne Q. Robinson	(% Time)	20	50	50	50	70	70		
Director: Dianne Q. Robinson	Direct cost	$ -	$ 7,782	$ 8,000	$ 8,224	$ 8,454	$ 4,345	$ 36,806	$ 32,235
University of Alaska									

K.14 Work Breakdown Structure and WBS

A complete AIM WBS has been developed during Phase A and is shown in **Fig. K-17**. As described earlier, the WBS is an important factor in developing the AIM mission costs. The WBS is based on the previous mission experience of the AIM team members and in particular on those heritage items listed in Fig.K-10. Following the WBS is a WBS dictionary with particular detail on the spacecraft elements of the WBS.

AIM Mission Work Breakdown Structure Dictionary

The WBS Dictionary for the AIM Mission is provided below, including activities for each WBS element.

1.0 Science

The science effort includes the definition of the science requirements and their traceability to the mission design. PI activities, all data analysis activities, the guest investigator program, and the E/PO program are contained within the science element. The science traceability and data analysis plans are described in Sections E.2 and F.2. The E/PO program is described in Section J.

2.0 Management

Project management includes all program coordination at HU as well as technical, cost, schedule, and resource management at LASP. System engineering, review processes, risk mitigation, and NIAT related activities are also included. All of these activities are described in Section G.

3.0 Spaceflight Segment

The AIM spaceflight segment includes the development of the AIM science instruments, the integrated platform assembly, and the spacecraft. Each of these is described in Sections F.3 and F.4. A WBS dictionary for the spacecraft is provided in the following section.

Ground Segment

The AIM ground segment includes all required GSE, mission operations, data processing, and the PDC activities, which include data dissemination and archiving. Each of these activities are described in Sections E.2.4 and F.7.

Figure K-17. AIM Work Breakdown Structure

WBS #	Category	Sub-Element 1	Sub-Element 2	Sub-Element 3	Sub-Element 4	Primary Organization
1	**Science**					HU
1.1		Mission Planning				HU
1.2		Simulation				GATS
1.3		Data Analysis				GATS
1.3.1			SOFIE Validation/Analysis			GATS, Gordley
1.3.2			CIPS Validation/Analysis			LASP, Rusch
1.3.3			SHIMMER Validation/Analysis			NRL, Englert
1.3.4			CDE Validation/Analysis			LASP, Horanyi
1.3.5			Objective 1. Microphysics			Randall, LASP
1.3.6			Objective 2. Gravity Waves			Taylor, SDL
1.3.7			Objective 3. Temp. Variability			Eckermann, NRL
1.3.8			Objective 4. H Chemistry			Summers, GMU
1.3.9			Objective 5. Nuc. Environment			Stevens, NRL
1.3.10			Objective 6. Long Term Change			Thomas, LASP
1.3.11			Data Product Contents			Siskind, NRL
1.4		Data Archival				HU/GATS
1.5		E/PO				HU
1.5.1			Teacher Workshops			HU
1.5.2			Public Outreach			HU
1.5.3			E/PO Product Production			HU
1.5.3.1				Video Production		HU
1.5.3.2				E/PO Material Production		HU
2	**Project Management**					
2.1		Program Coordination				HU
2.1.1			Business Management			HU
2.1.2			Subcontract Management			HU
2.2		Project Management				LASP
2.3		Systems Engineering				LASP
2.4		Mission Assurance				LASP
2.5		Risk Mitigation (NIAT)				LASP
2.5.1			Risk Mitigation (NIAT)			SDL, NRL, BATC
2.5.2			Software IV&V			LASP
2.6		Documentation				LASP
2.7		Red Team Reviews				LASP/ALL
3	**Spaceflight Segment**					
3.1		Instrumentation				
3.1.1			SOFIE			SDL
3.1.1.1				Optics		SDL
3.1.1.1.1					Pointing Mirror & Control	SDL
3.1.1.1.2					Telescope (Elements & Structure)	SDL
3.1.1.1.3					Polarization Elements	SDL
3.1.1.1.4					Filters	SDL

Figure K-17. AIM Work Breakdown Structure (continued)

3.1.1.1.5			Lenses & Mirrors	SDL
3.1.1.1.6			Precision Optical Structure	SDL
3.1.1.2		Detectors & Pre-amps		SDL
3.1.1.3		Electronics		SDL
3.1.1.3.1			Lock-in Amps	SDL
3.1.1.3.2			Balance & DC Sample Circuits	SDL
3.1.1.3.3			Power Condition-ing	SDL
3.1.1.3.4			Instrument Con-troller	SDL
3.1.1.3.5			Data Formatter	SDL
3.1.1.3.6			PEM Electronics	SDL
3.1.1.3.7			Housekeeping Electronics	SDL
3.1.1.3.8			Attitude Determi-nation & Control	SDL
3.1.1.4		Instrument Struc-ture		SDL
3.1.1.5		Sun Sensor		SDL
3.1.1.6		Interfaces		SDL
3.1.1.6.1			Electrical	SDL
3.1.1.6.2			Mechanical	SDL
3.1.1.7		Test		SDL
3.1.1.7.1			Instrument I&T	SDL
3.1.1.7.2			Calibration	SDL
3.1.2	CIPS			LASP
3.1.2.1		Optics		LASP
3.1.2.2		Detector		LASP
3.1.2.3		Interface		LASP
3.1.2.3.1			Electrical	LASP
3.1.2.3.2			Mechanical	LASP
3.1.2.4		Test		LASP
3.1.2.4.1			Instrument I&T	LASP
3.1.2.4.2			Calibration	LASP
3.1.3	SHIMMER			NRL
3.1.3.1		Optics		NRL
3.1.3.1.1			Imaging optics	NRL
3.1.3.1.2			Filters	NRL
3.1.3.1.3			Interferometer	NRL
3.1.3.1.4			Baffle/Door As-sembly	NRL
3.1.3.2		Detector		NRL
3.1.3.2.1			CCD Camera System	NRL
3.1.3.2.2			Shutter	NRL
3.1.3.2.3			CDD Cooling	NRL
3.1.3.3		Instrument Con-troler		NRL
3.1.3.4		Housing/Optical Bench/Mech		NRL
3.1.3.5		Instrument I&T		NRL
3.1.3.6		Calibration		NRL
3.1.4	CDE			LASP

Figure K-17. AIM Work Breakdown Structure (continued)

3.1.4.2			Detector		LASP
3.1.4.3			Interface		LASP
3.1.4.4			Test		LASP
3.1.4.4.1				Instrument I&T	LASP
3.1.4.4.2				Calibration	LASP
3.1.5		IPA			LASP
3.1.5.1			IPA		LASP
3.1.5.2			I&T		LASP/All
3.2	Spacecraft Bus				LASP
3.2.1		S/ C Bus System Management			Ball Aerospace
3.2.1.1			Program Management		Ball Aerospace
3.2.1.2			Business Management		Ball Aerospace
3.2.1.3			Production Eng. and Planning		Ball Aerospace
3.2.1.4			Configuration Control		Ball Aerospace
3.2.1.5			Data Management		Ball Aerospace
3.2.1.6			Travel		Ball Aerospace
3.2.2		Mission Assurance			Ball Aerospace
3.2.2.1			Mission Assurance Manager		Ball Aerospace
3.2.2.2			Product Assurance		Ball Aerospace
3.2.2.3			Reliability		Ball Aerospace
3.2.2.4			Parts – Radiation		Ball Aerospace
3.2.2.5			Safety		Ball Aerospace
3.2.2.6			Destructive Physical Analysis		Ball Aerospace
3.2.2.7			Software QA		Ball Aerospace
3.2.2.8			M&P Contamination		Ball Aerospace
3.2.3		S/C Bus Systems Engineering			Ball Aerospace
3.2.3.1			Systems Eng. Management		Ball Aerospace
3.2.3.2			Inertial Measurement Unit		Ball Aerospace
3.2.3.3			Systems Eng. Analysis		Ball Aerospace
3.2.3.4			Payload Accommodations		Ball Aerospace
3.2.3.5			LV Interf. and Launch Site Doc.		Ball Aerospace
3.2.3.6			Configuration Management		Ball Aerospace
3.2.4		Structures and Mechanisms Sys.			Ball Aerospace
3.2.4.1			Design		Ball Aerospace
3.2.4.2			Bus Structure		Ball Aerospace
3.2.4.3			Mechanisms		Ball Aerospace
3.2.4.4			Materials / Subcontracts		Ball Aerospace
3.2.5		Electrical Power and Signal Dist.			Ball Aerospace
3.2.5.1			Subsystem Design and Analysis		Ball Aerospace
3.2.5.2			Battery Assembly		Ball Aerospace

Figure K-17. AIM Work Breakdown Structure (continued)

3.2.5.3		Harness		Ball Aerospace
3.2.5.4		Solar Array / Structure		Ball Aerospace
3.2.6	Command and Data Handling Sys.			Ball Aerospace
3.2.6.1		Subsystem Design and Analysis		Ball Aerospace
3.2.6.2		S/C control unit		Ball Aerospace
3.2.6.3		Fab. and Assembly		Ball Aerospace
3.2.6.4		Integration and Test		Ball Aerospace
3.2.7	TT&C Sys.			Ball Aerospace
3.2.7.1		Design		Ball Aerospace
3.2.7.2		Procurement, Integration & Test		Ball Aerospace
3.2.8	Thermal Control Sys.			Ball Aerospace
3.2.8.1		Subsystem Design and Analysis		Ball Aerospace
3.2.8.2		Detailed Design		Ball Aerospace
3.2.8.3		Fab. and Assembly		Ball Aerospace
3.2.8.4		Test		Ball Aerospace
3.2.8.5		Quality Assurance		Ball Aerospace
3.2.9	AD&CS			Ball Aerospace
3.2.9.1		Subsystem Design and Analysis		Ball Aerospace
3.2.9.2		Inertial Measurement Unit		Ball Aerospace
3.2.9.3		Star Tracker		Ball Aerospace
3.2.9.4		Reaction Wheels		Ball Aerospace
3.2.9.5		Torque Rods		Ball Aerospace
3.2.9.6		Coarse Sun Sensor		Ball Aerospace
3.2.9.7		Magnetomoter		Ball Aerospace
3.2.10	Software			Ball Aerospace
3.2.10.1		Software Management		Ball Aerospace
3.2.10.2		Software Develop and Test		Ball Aerospace
3.2.10.3		Acceptance Test		Ball Aerospace
3.2.11	Spacecraft IA&T			Ball Aerospace
3.2.11.1		Management and Planning		Ball Aerospace
3.2.11.2		Assembly, Integration and Test		Ball Aerospace
3.2.11.2.1			Assembly	Ball Aerospace
3.2.11.2.2			Test	Ball Aerospace
3.2.11.3		Payload I&T		Ball Aerospace
3.2.11.4		System I&T:		Ball Aerospace
3.2.11.4.1			System Integration	Ball Aerospace
3.3.11.4.2			System Test	Ball Aerospace
3.2.11.4.3			Environmental Test	Ball Aerospace
3.2.11.4.4			Test Consumables	Ball Aerospace
3.2.11.4.5			Quality Assurance	Ball Aerospace
3.2.11.5	Pack and Ship			Ball Aerospace

Figure K-17. AIM Work Breakdown Structure (continued)

3.2.12		Ground Support Equipment			Ball Aerospace
3.2.12.1			Electrical GSE		Ball Aerospace
3.2.12.1.1				Engineering, Design, Analysis	Ball Aerospace
3.2.12.1.2				Fabrication and Assembly	Ball Aerospace
3.2.12.1.3				Test	Ball Aerospace
3.2.12.1.4				Quality Assurance	Ball Aerospace
3.2.12.1.5				Materials and Subcontracts	Ball Aerospace
3.2.12.1.6				S/W Development and Test	Ball Aerospace
3.2.12.2			Mechanical GSE		Ball Aerospace
3.2.12.2.1				Engineering, Design, Analysis	Ball Aerospace
3.2.12.2.2				Fabrication and Assembly	Ball Aerospace
3.2.12.2.3				Test	Ball Aerospace
3.2.12.2.4				Quality Assurance	Ball Aerospace
3.2.12.2.5				Materials and Subcontracts	Ball Aerospace
3.2.13		Launch Checkout and Operatios			Ball Aerospace
3.2.13.1			Launch site operations		Ball Aerospace
3.2.13.2			Post-Launch Commisioning		Ball Aerospace
3.2.14		Mission Ops and Data Analysys			Ball Aerospace
3.2.14.1			Mission Operations		Ball Aerospace
3.3	Integration & Test (S/C+Insts.)				
3.3.1		S/C I&T Management			All
3.3.2		System Integration & Test			All
3.3.2.1			Instrument Integration		All
3.3.2.2			System Test		All
3.3.2.3			Environmental testing		All
3.3.2.4			Consumables		All
3.3.2.5			GSE Design, Fab. and Test		All
3.3.2.6			Bus Critical Cleaning		All
3.3.3		S/c Integration & Test Support			All
3.4	Launch Vehicle				
3.4.1		Launch Vehicle			NASA Contract
3.4.2			Mechanical Interface		Ball Aerospace
3.4.3			Ejection System		Ball Aerospace
3.4.4			Integration and ground safety		Ball Aerospace
3.4.5			Safety Documentation		Ball Aerospace

Figure K-17. AIM Work Breakdown Structure (concluded)

4	**Ground Segment**				
4.3		Telemetry Station			LASP
4.4		Mission Control Center			LASP
4.5		Operations planning and training			LASP
4.8		Data Processing			NRL/LASP/GATS
4.8.1			SOFIE Processing		GATS
4.8.1.1				Level 0	GATS
4.8.1.2				Level 1	GATS
4.8.1.3				Level 2	GATS
4.8.2			CIPS Processing		LASP
4.8.2.1				Level 0	LASP
4.8.2.2				Level 1	LASP
4.8.2.3				Level 2	LASP
4.8.3			SHIMMER Processing		NRL
4.8.3.1				Level 0	NRL
4.8.3.2				Level 1	NRL
4.8.3.3				Level 2	NRL
4.8.3.4				Level 3	NRL
4.8.3.5				Level 4	NRL
4.8.4			CDE Processing		LASP
4.8.4.1				Level 0	LASP
4.8.4.2				Level 1	LASP
4.8.4.3				Level 2	LASP

AIM Spacecraft Bus Work Breakdown Structure (WBS) Dictionary

3.2 Spacecraft

3.2.1 Spacecraft Program Management

The spacecraft program manager, with administrative and business management support, will provide all effort required to integrate AIM RS-300 spacecraft management disciplines, functions, and systems to achieve cost-effective planning, organization, control, and reporting of management and technical approaches, schedules, and resources to attain project objectives.

3.2.1.1 Program Management

This work package contains the effort of the spacecraft program manager and the program administrative assistant. This effort provides the program management and direction to ensure that program objectives are achieved within cost, schedule, and performance goals. This work package also includes the budget for all miscellaneous other direct costs and materials to cover program supplies, mailings, and telephone charges for the staff charging directly to the program.

3.2.1.2 Business Management

This work package contains the effort of the business manager and assistant to provide the program with cost and schedule planning and control, financial analysis, and other general planning and reporting required for the program. This also includes the planning, implementation, and maintenance of the Ball earned value system (BEVS) for the program. Specific tasks within this work package include:

- Generation of BEVS reports
- Control account manager training and support
- Work order maintenance and support
- Program status reporting (other than BEVS reports)
- WBS and WBS dictionary maintenance
- Preparation of contract change proposals as required
- Develop and maintain master and detailed program schedules
- Integrate cost and schedule planning data within the BEVS

3.2.1.3 Production Engineering and Planning

Provide the production engineering and planning efforts associated with the in-house fabricated spacecraft hardware items. This effort includes the following tasks:

- Prepare and maintain production orders and certification logs
- Plan and manage the control account
- Prepare, track, and control program purchase requisitions of materials, subcontracts, and major procurements
- Prepare detailed production schedules
- Supervise the manufacturing process
- Coordinate program production and material requirements
- Review and approve all hardware material requirements

3.2.1.4 Configuration Control

Provide hardware and software configuration control throughout the program. Specific tasks include:

- Establishment and maintenance of the program drawing files
- Plan and manage the control account
- Setup and maintenance of the drawing records
- Generation and update of the drawing release tracking system
- Support to all design reviews
- Preparation and distribution of drawing lists
- Serve as chairperson of the program configuration change control board
- Release of engineering drawings through document control
- Reproduction and distribution of drawings and documents

3.2.1.5 Data Management

Provide data management support for all contract data requirements and internal documentation throughout the program. Specific tasks include:

- Establishment and maintenance of complete program documentation files
- Plan and manage the control account
- Setup and maintenance of contract data requirements schedules
- Setup and coordination of the contract data preparation and submittal schedules
- Maintenance of program electronic data web site (if applicable)
- Reproduction and distribution of program documents
- Maintain a database of engineering reports, meeting/review materials, and other applicable program documentation
- Coordination with the customer on specific format and/or submittal issues

3.2.1.6 Program Travel

Plan and accumulate the cost of all program travel (not including direct labor) in this work package.

3.2.2 Mission Assurance

3.2.2.1 Mission Assurance Manager/Product Assurance

Provide mission assurance management support to the Ball hardware and software portion of the mission. Provide control account management and planning for the entire mission assurance effort. Track program requirements and assure they are properly flowed down to the other mission assurance functions.

3.2.2.2 Product Assurance

Provide product assurance support to the Ball portion of the mission. This includes but is not necessarily limited to:

- Failure reporting and analysis
- Parts list review
- Quality engineering in accordance with internal Quality Work Instructions
- In-process inspection of parts and assemblies
- Inspection of raw materials and subcontracted assemblies according to program requirements

3.2.2.3 Reliability

Provide reliability prediction support as required for the Ball portion of the mission.

3.2.2.4 Parts – Radiation

Provide parts analysis and selection support as required for the Ball portion of the mission. In addition, perform radiation analysis and parts selection as required.

3.2.2.5 Safety

Perform safety analysis and engineering as required for the Ball portion of the mission.

3.2.2.6 Materials and Processes (Flight)

Provide materials and process analysis and engineering support for the Ball flight hardware portion of the mission.

3.2.2.7 Software QA

Provide software quality assurance support for the test and flight software development.

3.2.3 Spacecraft System Engineering

3.2.3.1 System Engineering Management

Provide spacecraft-level system engineering and technical management support required to ensure the spacecraft meets all customer requirements with sufficient margins. Tasks include:

- Prepare all required design documents
- Plan and manage the control account
- Perform technical risk analysis
- Manage all system-level trade studies and other special studies

- Maintain the specification tree
- Support resolution of discrepancies between subsystems
- Review/approve all allocated baseline documents
- Prepare and maintain all functional baseline documents
- Review program plans and test plans
- Manage specialty engineering and concurrent engineering activities
- Support interfaces with outside organizations by the other technical managers
- Support all program and design reviews

3.2.3.2 System Requirements

Manage the overall system requirements as they flow down to the spacecraft. Tasks include:

- Allocate system requirements to hardware configuration item and computer software configuration items (CSCI) via the system/segment
- Assure consistency of subsystem functions/requirements
- Maintain the requirements allocation data base

3.2.3.3 Analysis

Perform all subsystem and specialty analysis as required in support of the system engineering function.

3.2.3.4 Payload Accommodations

Perform the technical interface and requirements management function necessary for successful payload to spacecraft integration and operations.

3.2.3.5 Launch Vehicle Interface and Launch/Operations Documentation

Perform the technical interface and requirements management function required for successful spacecraft to launch vehicle integration and the Ball portion of launch and spacecraft operations. Prepare all documentation required for launch vehicle integration and launch/operations.

3.2.4 Structures and Mechanisms Subsystem

3.2.4.1 Subsystem Engineering, Design, and Analysis

Manage, analyze, and design the structures and mechanisms subsystem to meet the spacecraft requirements. Specific tasks include:

- Provide any non-recurring engineering and analysis required at the structures and mechanisms subsystem level
- Plan and manage the control account
- Prepare procurement packages and technically manage structures and mechanisms subsystem subcontracts
- Prepare contingency operations plans
- Provide technical input and support for all design reviews
- Produce all required structures and mechanisms subsystem design documentation
- Perform and/or supervise all structures and mechanisms subsystem design and specialty analysis
- Provide weekly and monthly subsystem status reports
- Monitor and status component fabrication, assembly, and test
- Prepare, update, and maintain structures and mechanisms drawings and specifications
- Prepare and maintain test documentation
- Support structures and mechanisms subsystem level testing
- Provide sustaining engineering support through delivery, launch, and on-orbit checkout of the spacecraft

3.2.4.2 Bus Structure

Design, document, specify, procure, and test the bus structure to meet the spacecraft requirements.

3.2.4.3 Mechanisms

Design, document, specify, procure, and test the mechanisms to meet the spacecraft requirements.

3.2.4.4 Subcontracts and materials

Specify and procure all materials and subcontracts necessary to fabricate, assemble, test, and deliver the structures and mechanisms subsystem according to the spacecraft integration and test schedule requirements.

3.2.5 Electrical Power Subsystem (EPS)

3.2.5.1 Subsystem Engineering, Design, and Analysis

Manage, analyze, and design the EPS to meet the spacecraft requirements. Specific tasks include:

- Provide any non-recurring engineering and analysis required at the EPS level
- Plan and manage the control account
- Prepare procurement packages and technically manage EPS subcontracts
- Prepare contingency operations plans
- Provide input and support for all design reviews
- Produce all required EPS subsystem design documentation
- Perform and/or supervise all EPS subsystem design and specialty analysis
- Provide weekly and monthly subsystem status reports
- Monitor and status component fabrication, assembly, and test
- Prepare, update, and maintain EPS subsystem drawings and specifications
- Prepare and maintain test documentation
- Support EPS subsystem and system level testing
- Provide sustaining engineering support through delivery, launch, and on-orbit checkout of the spacecraft

3.2.5.2 Battery Assembly

Design, document, specify, procure, and test the battery assembly to meet the spacecraft requirements.

3.2.5.3 Cabling and Terminal Boards

Design, document, specify, procure, and test the cabling and terminal boards to meet the spacecraft requirements.

3.2.5.4 Solar Array

Design, document, specify, procure, and test the solar arrays to meet the spacecraft requirements.

3.2.6 Command and Data Handling Subsystem (C&DH)

3.2.6.1 Subsystem Engineering, Design, and Analysis

Manage, analyze, and design the C&DH subsystem to meet the spacecraft requirements. Specific tasks include:

- Provide any non-recurring engineering and analysis required at the C&DH subsystem level
- Plan and manage the control account
- Prepare procurement packages and technically manage C&DH subsystem subcontracts
- Prepare contingency operations plans
- Provide input and support for all design reviews
- Produce all required C&DH subsystem design documentation
- Perform and/or supervise all C&DH subsystem design and specialty analysis
- Provide weekly and monthly subsystem status reports
- Monitor and status component fabrication, assembly, and test
- Prepare, update, and maintain C&DH subsystem drawings and specifications
- Prepare and maintain test documentation
- Support C&DH subsystem and system level testing
- Provide sustaining engineering support through delivery, launch, and on-orbit checkout of the spacecraft

3.2.6.2 Spacecraft Control Computer

Design, document, specify, procure, and test the control computer to meet the spacecraft requirements.

C&DH Subsystem Integration and Test

Provide all labor and other resources necessary to perform C&DH subsystem integration and test activities required prior to the subsystem delivery to bus level integration and test.

3.2.7 Telecommunications Subsystem

3.2.7.1 Subsystem Engineering, Design, and Analysis

Manage, analyze, and design the telecommunications subsystem to meet the spacecraft requirements. Specific tasks include:

- Provide any non-recurring engineering and analysis required at the telecommunications subsystem level
- Plan and manage the control account
- Prepare procurement packages and technically manage telecommunications subsystem subcontracts
- Prepare contingency operations plans
- Provide input and support for all design reviews
- Produce all required telecommunications subsystem design documentation
- Perform and/or supervise all telecommunications subsystem design and specialty analysis
- Provide weekly and monthly subsystem status reports
- Monitor and status component fabrication, assembly, and test
- Prepare, update, and maintain telecommunications drawings and specifications
- Prepare and maintain test documentation
- Support telecommunications subsystem and system level testing
- Provide sustaining engineering support through delivery, launch, and on-orbit checkout of the spacecraft

3.2.7.2 Subsystem Procurement, Test, and Integration

Design, document, specify, procure, and test the telecommunications subsystem to meet the spacecraft requirements.

3.2.8 Thermal Control Subsystem

3.2.8.1 Subsystem Engineering, Design, and Analysis

Manage, analyze, and design the thermal subsystem to meet the spacecraft requirements. Specific tasks include:

- Provide any non-recurring engineering and analysis required at the thermal subsystem level
- Plan and manage the control account
- Prepare procurement packages and technically manage thermal subsystem subcontracts
- Prepare contingency operations plans
- Provide input and support for all design reviews
- Produce all required thermal subsystem design documentation
- Perform and/or supervise all thermal subsystem design and specialty analysis
- Provide weekly and monthly subsystem status reports
- Monitor and status component fabrication, assembly and test
- Prepare, update, and maintain thermal drawings and specifications
- Prepare and maintain test documentation
- Support thermal subsystem and system level testing
- Provide sustaining engineering support through delivery, launch, and on-orbit checkout of the spacecraft

3.2.8.2 Fabrication and Assembly

Fabricate the thermal subsystem as specified and designed.

3.2.8.3 Test

N/A. Thermal subsystem testing performed during spacecraft system testing.

3.2.8.4 Quality Assurance

Provide in-process inspection of the thermal subsystem fabrication and assembly.

3.2.8.5 Materials and Subcontracts

Specify and procure all materials and subcontracts necessary to fabricate, assemble, test, and deliver the spacecraft thermal control subsystem to the spacecraft integration and test schedule.

3.2.9 Attitude Determination and Control Subsystem (ADCS)

3.2.9.1 Subsystem Engineering, Design, and Analysis

Manage, analyze, and design the ADCS to meet the spacecraft requirements. Specific tasks include:

- Provide any non-recurring engineering and analysis required at the ADCS level
- Plan and manage the control account
- Specify algorithms for flight software development
- Prepare procurement packages and technically manage ADCS subcontracts
- Prepare contingency operations plans
- Provide input and support for all design reviews
- Produce all required ADCS design documentation
- Perform and/or supervise all ADCS design and specialty analysis
- Provide weekly and monthly subsystem status reports
- Monitor and status component fabrication, assembly, and test
- Prepare, update, and maintain ADCS drawings and specifications
- Prepare and maintain test documentation
- Support ADCS subsystem and system level testing
- Provide sustaining engineering support through delivery, launch, and on-orbit checkout of the spacecraft

3.2.9.2 Inertial Measurement Unit (IMU)

Design, document, specify, procure, and test the IMU to meet the spacecraft requirements.

3.2.9.3 Star Tracker(s)

Design, document, specify, procure, and test the star tracker(s) to meet the spacecraft requirements.

3.2.9.4 Reaction Wheels

Design, document, specify, procure, and test the reaction wheels to meet the spacecraft requirements.

3.2.9.5 Torque Rods

Design, document, specify, procure, and test the torque rods to meet the spacecraft requirements.

3.2.9.6 Coarse Sun Sensors

Design, document, specify, procure, and test the course sun sensors to meet the spacecraft requirements.

3.2.9.7 Magnetometer

Design, document, specify, procure, and test the magnetometer to meet the spacecraft requirements.

3.2.10 Flight Software

3.2.10.1 Software Management

Perform the following tasks in support of the management of the development of flight software for the spacecraft:

- Planning
- Plan and manage the control account
- Input and support for all design reviews
- Tracking and oversight
- Subcontract management

3.2.10.2 Software Development and Test

Provide labor and hardware/software tools to perform flight software development and test. Perform the following tasks in this work package:

- Requirements analysis
- Architectural design

- Build development
- Component development
- Component test

3.2.10.3 Flight Software Acceptance Test

Perform the following tasks in support of the acceptance test of the flight software for the spacecraft:

- Test planning
- Test procedures
- Formal qualification

3.2.11 Spacecraft Integration, Assembly, and Test (IA&T)

3.2.11.1 Spacecraft IA&T Management and Planning

Perform the following tasks in support of the Spacecraft IA&T:

- Coordination of IA&T activities with other control account managers and subsystem engineers
- Daily supervision of IA&T activities
- Plan and manage the control account
- Generate electrical and mechanical GSE specifications
- Provide input and support for all design reviews
- Prepare and publish all spacecraft test reports
- Prepare the spacecraft test requirements documentation
- Prepare inputs to the payload requirements document

3.2.11.2 Bus Assembly, Integration, and Test (AI&T)

3.2.11.2.1 Assembly and Integration

Perform all effort necessary to assemble and integrate all of the bus subsystems into a spacecraft. Perform the following tests as part of subsystem assembly and integration:

- Modal survey and static loads testing of the integrated structure
- Electrical distribution component integration
- Power, telecommunications, ADCS, and C&DH subsystem integration

3.2.11.2.2 Test

Perform all of the effort necessary to test the fully integrated bus. Perform the following tasks as part of this work package:

- Performance and functional testing
- Compatibility test with ground segment
- Solar array compatibility test

3.2.11.3 Payload Integration and Test

Perform all of the effort necessary to perform interface integration and check out the performance of the payload(s). This includes all I&T team effort with the exception of the spacecraft subsystem engineers who are covered by their respective sustaining engineering tasks within their control accountss.

3.2.11.4 System Integration and Test

3.2.11.4.1 System Integration

Integrate the payload with the fully integrated and functionally tested spacecraft bus. This includes all I&T test team members (including quality assurance) but does not include the subsystem engineers who are covered in their respective subsystem engineering packages under sustaining engineering.

3.2.11.4.2 System Test

Perform system test and verification of the fully integrated spacecraft. This includes the effort of the entire I&T team in the performance of the following tests:

- Baseline performance test
- Mass properties and alignment verification
- Final performance test
- Note: Environmental testing and environmental support staff effort is covered under WBS element 2.4.3.

3.2.11.4.3 Environmental Test

Perform the following environmental tests on the spacecraft:
- Electromagnetic compatibility
- Pyro shock/separation test
- Acoustic test
- Thermal vacuum and thermal balance test

3.2.11.4.4 Test Consumables

This work package covers the cost of all materials consumed during the bus and spacecraft I&T phase.

3.2.11.4.5 Quality Assurance

Provide in-process inspection support for the system integration and test of the spacecraft bus.

3.2.11.5 Pack and Ship

Prepare the spacecraft and GSE for shipment to the launch site. Procure or otherwise provide and support the shipment of the spacecraft to the launch site.

3.2.12 Ground Support Equipment

3.2.12.1 Electrical GSE

3.2.12.1.1 Subsystem Engineering, Design, and Analysis

Manage, analyze, and design the electrical GSE to meet the spacecraft I&T requirements. Specific tasks include:
- Provide any non-recurring engineering and analysis required
- Plan and manage the control account
- Prepare procurement packages and technically manage electrical GSE subcontracts
- Prepare contingency operations plans
- Provide input and support for all design reviews
- Produce all required electrical GSE design documentation
- Perform and/or supervise all electrical GSE design and specialty analysis
- Provide weekly and monthly subsystem status reports
- Monitor and status component fabrication, assembly and test
- Prepare, update, and maintain drawings and specifications
- Prepare and maintain test documentation
- Support electrical GSE subsystem and system level testing

3.2.12.1.2 Fabrication and Assembly

Provide the direct labor necessary to fabricate and assemble the electrical GSE.

3.2.12.1.3 Test

Provide the direct labor necessary to test the electrical GSE.

3.2.12.1.4 Quality Assurance

Provide in-process inspection support for the fabrication, assembly, and test of the electrical GSE.

3.2.12.1.5 Materials and Subcontracts

Specify and procure all materials and subcontracts necessary to fabricate, assemble, test, and deliver the electrical GSE to the spacecraft integration and test schedule requirements. (Include the spacecraft shipping container)

3.2.12.1.6 GSE Software Development and Test

Provide the direct labor necessary to develop and test the GSE software.

3.2.12.2 Mechanical GSE

3.2.12.2.1 Subsystem Engineering, Design, and Analysis

Manage, analyze, and design the mechanical GSE to meet the spacecraft I&T requirements. Specific tasks include:
- Provide any non-recurring engineering and analysis required
- Plan and manage the control account
- Prepare procurement packages and technically manage mechanical GSE subcontracts
- Prepare contingency operations plans
- Provide input and support for all design reviews

- Produce all required mechanical GSE design documentation
- Perform and/or supervise all mechanical GSE design and specialty analysis
- Provide weekly and monthly status reports
- Monitor and status component fabrication, assembly and test
- Prepare, update, and maintain drawings and specifications
- Prepare and maintain test documentation
- Support mechanical GSE subsystem and system level testing

3.2.12.2.2 Fabrication and Assembly

Provide the direct labor necessary to fabricate and assemble the mechanical GSE.

3.2.12.2.3 Test

Provide the direct labor necessary to test the mechanical GSE.

3.2.12.2.4 Quality Assurance

Provide in-process inspection support for the fabrication, assembly, and test of the mechanical GSE.

3.2.12.2.5 Materials and Subcontracts

Specify and procure all materials and subcontracts necessary to fabricate, assemble, test, and deliver the mechanical GSE to the spacecraft integration and test schedule requirements.

3.2.13 Launch, Checkout and Orbital Operations

3.2.13.1 Launch Site Operations

After delivery to the launch site, perform all effort necessary to integrate the spacecraft to the launch vehicle and perform functional checkout prior to launch. After integration with the launch vehicle, verify the performance of the spacecraft during the pre-launch operations phase of the mission.

3.2.13.2 Post-launch Operations and Commissioning

Perform 30 days of post-launch spacecraft operations ending in the commissioning of the spacecraft for the on-orbit operations phase of the mission.

3.2.14 Mission Operations and Data Analysis (MO&DA)

3.2.14.1 Mission Operations

Provide technical and management support as required by the program mission operations plan.

L. Changes Required for and Implications of Being the Second SMEX Launched Under this AO

The optimal launch date for AIM is September 30, 2005 (See Section G.3 and Fig. F-9). This date was arrived at by carefully determining the appropriate schedule for the development of each instrument, the spacecraft, and the ground system including consideration of an appropriate level of reviews, long lead purchases, risk analysis, and appropriate schedule reserves. Budget was a factor in selecting the launch date but not a driver.

While the September 30, 2005 date was chosen because it presented the optimal, minimal risk implementation, it also proves to be optimal for scientific reasons. PMCs have been observed one month prior to summer solstice. Given AIM's superior sensitivity compared to previous observations, AIM may observe PMCs as early as November 15 in the SH. For a September 30 launch date, the instruments begin to make observations by October 15, so there will be about one month before the first observation of a PMC. This time period will allow us to fully test out all of the observational scenarios and data processing software and be fully prepared to observe PMCs before they form. We will be able to characterize very well the PMC-free atmosphere. AIM will certainly be able to observe the beginning of the PMC season and will be able to see the atmospheric conditions change from prohibiting PMC formation to promoting PMC formation.

L.1 Science Investigation Implications of Launching on a Different Launch Date

The possible science impacts due to a change in launch date range from no impact at all to a very mild impact. PMC are a seasonal phenomenon and a new season begins in one hemisphere or the other about each 180 days. We have determined that if AIM observes PMCs for four seasons, all of the science objectives can be answered fully without significant uncertainties arising from seasonal variability. We have budgeted for 23 months in space or effectively 22 months of Phase E operations.

If the AIM launch date were to slip in increments of 180 days, there would be no science impact whatsoever. The worst possible launch slip is a slip of 90 days or 90 days plus a multiple of 180 days. In this case, the launch would occur a few weeks after the PMC season has begun, routine observations would not begin until nearly a month later when the season is winding down, and our operations budget would be fully utilized just before AIM begins its fourth season of observations, 22 months later. Potentially, such a launch slip could reduce the AIM mission from observing four PMC seasons to observing only slightly more than three PMC seasons.

Reducing to three seasons would have a science impact, albeit a mild one as we discuss below. However, it may be that even for a 90-day launch slip, four PMC seasons can be observed.

The current mission operations plan for AIM calls for two contacts per day. Two contacts are absolutely needed during the PMC season to ensure that all of the required AIM data is downlinked reliably and completely each day. During the time periods when PMCs are not forming however, fewer contacts may be required. We may be able to reduce to one contact per day. The reduction in contact time, antenna time, and operations staff during the non PMC seasons may be enough that the cost saving may allow enough operations time to observe the fourth season if a worst case 90-day (or 90 plus an increment of 180 days) launch slip occurs. In Phase B we will study the minimum required satellite contact rate during the non PMC time periods to explore the possibility of using any cost savings to extend the mission into the fourth PMC season. This will be considered carefully because the duration and spatial extent of a PMC season are somewhat variable. It may be that there are dim PMCs that are formed earlier than thought but have not been observed because previous experiments lacked the sensitivity that AIM will achieve.

Should the launch date slip by 90 days or 90 days plus a multiple of 180 days, and should there not be any cost savings that would allow observations of a fourth season, there would be a science impact. Depending upon the specific objective this impact may, however, be a mild one. Two of our objectives (Objective 2 concerning GWs and Objective 4 concerning hydrogen chemistry) are physical-process-oriented. In other words, they seek to understand processes related to PMCs. Thus, the unique combination of AIM instruments should allow us to answer these objectives at a high level of confidence (95%) even if only one or two PMC seasons were observed. The other four objectives (1, 3, 5 and 6), dealing with morphology, temperature variability, nucleation, and climate change require several seasons for us to be highly confident in our conclusions. This is because interhemispheric and interannual variability can affect our conclusions. However, even if each of the four seasons were of equal importance, the maximum science impact would be no more than 25% for these three objectives. In practice, the first year (our minimum mission) is still the most important. Even without a fourth season, we estimate answering these four objectives at an 80-85% confidence level. When combined with the process-oriented Objectives 2 and 4, we estimate an 85-90% confidence in meeting all our objectives if we miss the fourth season entirely. Thus, the reduction from four seasons to three is a mild, but not negligible, impact.

We further point out that the cost of observing the fourth season is approximately 1.5% of the AIM budget. For that 1.5%, we gain a 15% increase in our science. Thus, that fourth season is well worth the cost and effort.

L.2 Implementation Plan Changes Due to Launching on a Different Date

The chosen launch date provides for appropriate levels of schedule reserves and provides for a low risk mission. To move the launch date earlier would therefore affect the risk involved with the flight systems.

The present launch date is based upon a 27-month instrument development schedule; the AIM team members are comfortable with developing the instruments within that schedule. Shortening of the instrument development schedule would require reduction of the phase B and phase C design periods, as integration and testing tasks are already scheduled to be completed in parallel fashion whenever possible. This would require larger design teams for shorter time periods, which are less efficient for instrument design. This presents some additional risk to program schedule and integrity because some elements must then be designed in parallel that would normally be addressed sequentially as predecessor tasks are completed. This spike in resource usage also presents a burden to resource management and may result in use of temporary personnel.

The spacecraft bus development, already at the PDR level, will operate on a compressed schedule relative to the instruments. The spacecraft bus development will ramp up more slowly so that the instrument requirements are fully developed and documented at the time when that information is needed for the spacecraft development. The AIM program is designed for a smooth path from science objectives to measurement requirements to instrument requirements and then to spacecraft requirements and so the schedule reflects that design. The spacecraft bus is therefore less affected by a schedule reduction than the instruments.

L.3 Cost Plan Changes Due to Launching on a Different Date

The cost implications for the instrument teams caused by a change of launch date are dominated by the cost connected with building and testing the instruments.

An earlier launch date would require the procurement of long lead items with shorter notice, which has the potential of significantly increasing the costs. This is particularly true for items that require special customization and/or development efforts such as the SHIMMER monolithic interferometer. Moreover, a tighter schedule requires increased staffing or increased hours for the existing staff. The proposed schedule allows our current staff to work full time on the instruments, so that a further increase in hours can only be achieved by allowing for overtime or perhaps the hiring of temporary personnel, which increases risk. The involvement of additional staff requires a proper training period causing an additional budget increase.

For a later launch date, no additional costs are incurred for building the instrument. While such a schedule slip mitigates schedule risks and allows for additional testing, a minimal cost increase necessarily follows as the testing team is maintained for a longer period of time.

Summary. The optimal launch date for AIM is September 30, 2005. Changing this launch date has the greatest impact if it is moved earlier. This is primarily due to shortening the instrument development time, which would lead to both increased cost and increased risk. Delaying the launching has little or no impact except in maintaining the testing team for a longer period of time. From the standpoint of science, changing the launch date impacts our ability to measure four complete PMC seasons. Since PMCs occur every 180 days, this risk is periodic and maximizes at about a 15% science loss for a 90-day change and zero for a 180-day change.