TIMED SPACECRAFT ALIGNMENTS

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TIMED Alignment Plan

Spacecraft Coordinate System Definition:

- The X-Y Plane is defined by the Spacecraft/launch vehicle separation plane. (The plane is defined by measuring the bottom of the S/C separation flange.)
- The Z-axis is normal to this plane, with its origin at the center of the S/C adapter separation flange, and positive in a downward direction.
- The X-axis is parallel to the +Y side (SABER side) of the aft deck, and it lays in the XY plane.
- The Y-axis forms an orthogonal coordinate system.

Mapping of the Spacecraft Coordinate System:

- The coordinate system shall be measured by indicating the adapter flange surface to within 0.003" over its 38.81" bolt circle diameter, and mapping this surface into a Spacecraft Master optical cube.
- The +Y side of the aft deck shall be indicated to within 0.001" over its 30.50" length, This definition of the X-axis shall be mapped into the Spacecraft Master optical cube.
- This cube shall then become the Spacecraft coordinate system angular reference.

TIMED Alignment Plan (Continued)

Mapping of the Instrument Bench Coordinate System:

- The Instrument Bench shall have its coordinate system defined by the plane of its top surface, as defined by the star camera and TIDI telescope mounting pads and by the edge of its longest side.
- This coordinate system shall be mapped into a master optical cube mounted on the Instrument Bench, and the optical cube shall then become the Instrument Bench coordinate system angular reference.

Mapping of the Individual TIMED Instruments:

- Each instrument shall have an optical cube mounted on solid structure which can be used as a reference of the Instrument's coordinate system and boresight.
- If multiple boresights are part of the instrument, then each boresight shall be mapped into its respective optical cube. (i.e. TIDI telescopes shall each have an optical cube as a boresight reference.)

TIMED Components which Require Mapping:

- TIMED Spacecraft Master Cube
- Instrument Bench Master Cube
- TIDI - Four TIDI Telescopes
- SABER
- GUVI
- SEE
- Two Star Trackers
- Two Gyros
- Two GPS Antennas
- Four Reaction Wheels

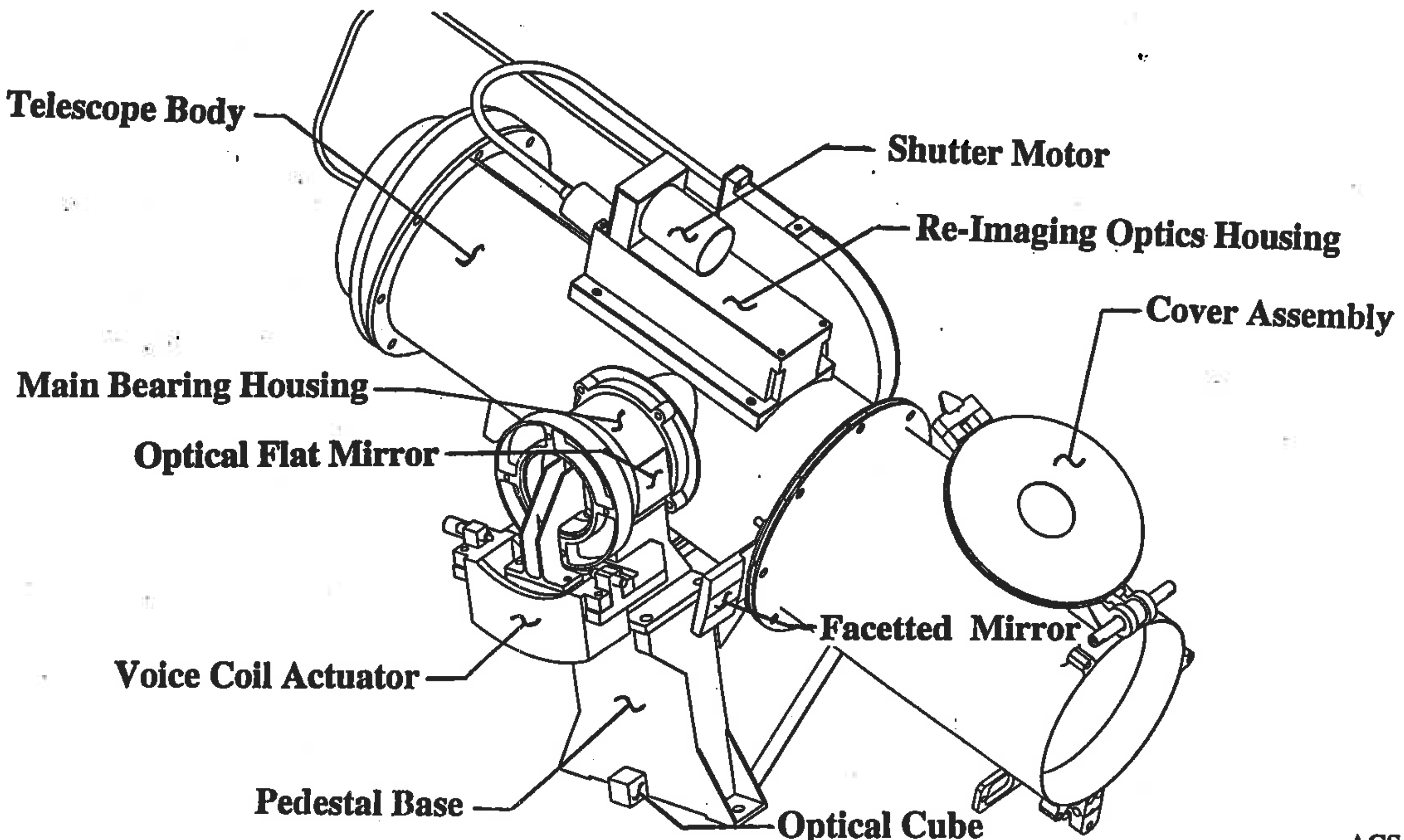
TIDI Telescope Optical Reference Surfaces

• A faceted mirror will be attached adjacent to the telescope body, with three optical flats on its forward face. The center flat is normal to the telescope boresight, and the top and bottom flats are +5° and –5° offset in elevation from the center one. A side surface of the faceted mirror will be used as a telescope roll reference.

• A 1.00" optical flat will be added to the main bearing assembly housing, and it will be aligned with the telescope nominal boresight (parallel to the center facet of the telescope mirror.)

• A 0.75" optical cube will be attached to the pedestal base, adjacent to the mounting surface of the telescope. This cube will be used as a telescope boresight reference for all optical mappings at the Instrument Bench and Spacecraft assembly levels.

TIDI Telescope Optical Reference Surfaces



TIMED Instrument Bench Optical Mappings

• A 1.00" optical cube will be attached to the center of the top surface of the optical bench, adjacent to the mounting brackets of the star trackers. This Bench Master Cube will be used as a reference for all optical mappings at the Instrument Bench and Spacecraft assembly levels. Two sides of the cube must be viewable to orient the Bench and all instruments on it.

•An optical cube will be attached to the top of each star tracker body. Two faces of this cube must be mapped to fix the star tracker boresight in Instrument Bench coordinates. A top surface and a side surface of the cube will be used as a tracker boresight azimuth, elevation, and roll reference.

• A 0.75" optical cube will be epoxied to the side of each TIDI telescope pedestal base, and it will be aligned nominally with the telescope base coordinate system. The front surface of the cube will be used as the azimuth and elevation reference, and a side face will be mapped to fix the roll of the telescope.

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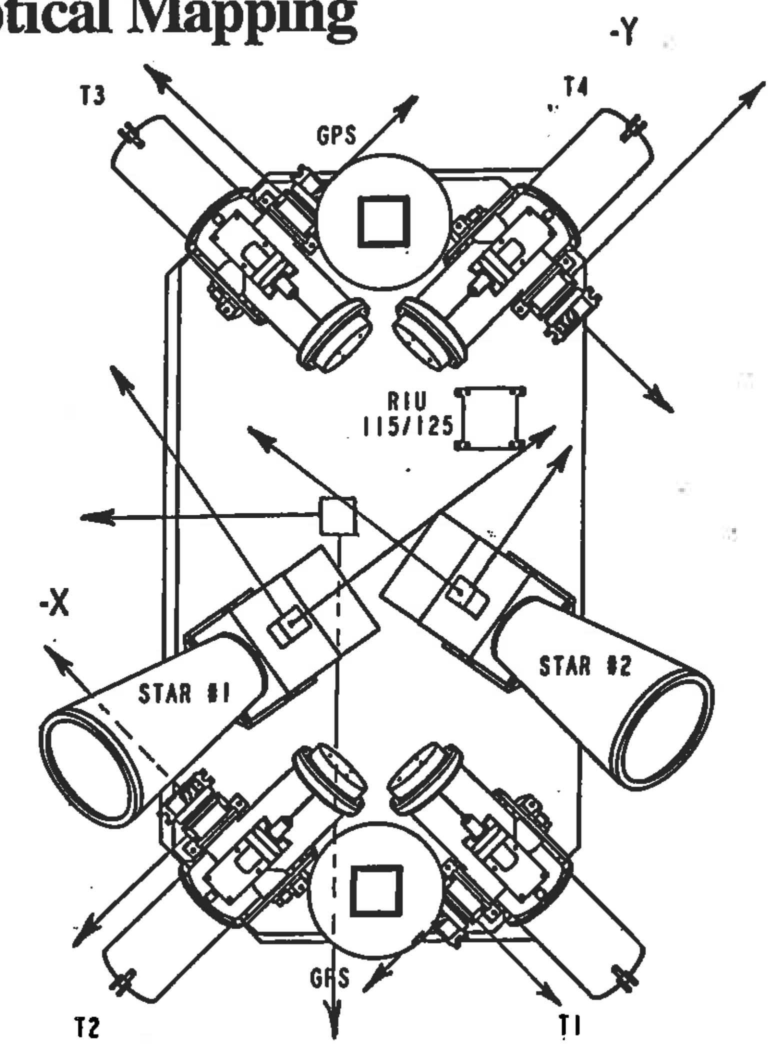
TIMED Instrument Bench Optical Mapping Lines-of-Sight

One Instrument Bench
Master optical cube
(in center of Bench)

Two Star Trackers

Four TIDI Telescopes

Two GPS Antennas



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TIMED Attitude Determination Errors

Alignment Knowledge Error Sources:	Alignment Errors (arc seconds)		
Star Camera Boresight Knowledge	Azimuth	Elevation	Rotation
using optical cube as Boresight reference;	2.8	2.8	31.9
Mapping Star Camera Optical Cube into Instrument Bench Master Cube;	2	1.5	1.5
Knowledge of (1) Star Camera Boresight in Instr. Bench Optical Cube;	3.4 rss	3.2 rss	32 rss
Using (2) Star Cameras to minimize Boresight rotation error;	1.8 rss	3.2 rss	3.2 rss
IMU Gyro Coordinate System Knowledge (Drift rate spec.<1 degree/hour)	unknown	unknown	unknown

(Absolute offsets not critical, only used as "flywheel" to smooth fixes and fly thru bad Star Camera data points.)

Attitude Determination Errors:	Roll	Pitch	Yaw
(1) Star Camera & Gyro System Attitude determination Errors (rss)	20.7	20.7	21.9
(2) Star Cameras & Gyro System Attitude determination Errors (rss)	4.1	4.1	3.7
Data Latency (10 millisec)	0	2	0
Instrument Bench + Star Camera mounting bracket Errors	[1.8+34.3]	[11.3+27.9]	[4.0+3.8]
Thermal distortion	= 36.1	= 39.2	= 7.8
1g Effect (Gravity effect can be reduced by using ±1g mapping)	27.4(3)	25.6(3)	2.2(1)
Spacecraft Top Deck Structural Distortion			
Thermal Distortion	5	5	2
1g Effect	5	10	2
Mapping Instrument Bench Cube into Spacecraft Master Cube	1.5	1.5	2
Total Attitude Determination Error at S/C Master Cube (rss) (2) Starcam.	46.0(37.1)	48.2(40.9)	9.7(9.5)

Using (2) Star cameras, Total Error = 67 (56) arc sec rss = 0.019° (.0156°) rss

(Bracketed values computed using ±1g mapping to reduce gravity effect)

Total Attitude Determination Error
Measured at TIMED Spacecraft Master Cube

Attitude Determination Errors (arc seconds rss)

Unbracketed Values summed without ±1g mappings

(Bracketed Values used ±1g Instrument Bench mapping to reduce gravity effect)

With Titanium Star Camera Mounting Bracket (Thermal Distortion caused by CTE);

	Roll	Pitch	Yaw	= Total Error	
(1) Star camera	50.3(42.3)	52.3(45.7)	23.7(23.6)	= 76 (67) arc sec rss	= 0.021°(.0185°) rss;
(2) Star cameras	46.0(37.1)	48.2(40.9)	9.7(9.5)	= 67 (56) arc sec rss	= 0.019° (.0156°) rss

If Star Camera Bracket had ≈0 CTE (No thermal distortion);

	Roll	Pitch	Yaw	= Total Error	
(1) Star camera	35.2(22.3)	36.6(26.4)	22.7(22.6)	= 56 (41) arc sec rss	= 0.015°(.011°) rss;
(2) Star cameras	28.7(9.1)	30.5(16.7)	6.8(6.5)	= 42 (20) arc sec rss	= 0.012°(.0056°) rss)

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TIMED TIDI Instrument Alignment Errors

Initial Alignment Error Sources:	Alignment Errors (arc seconds) Roll	Pitch	Yaw
Instrument Bench Structure as referenced in Instrument Master Cube	8	12	9
Instrument Bench Errors			
Geometric Toler. (0.005"/foot flatness, 0.002"/6.8" pinned bolt hole)	2.6 arc min	2.6 arc min	1 arc min
Thermal distortion	36.1	39.2	7.8
1g Effect	27.4	25.6	2.2
Mapping TIDI Telescopes Ref. Cubes into Instrument Bench Master Cube	2	2	3
Total Alignment Error from Spacecraft Sources (rss)	2.7 arc min	2.7 arc min	1 arc min
Mapping TIDI Telescope Boresight into Telescope cube	15	5	5
TIDI Instrument Internal Misalignment	<1 arc min	<1 arc min	<1 arc min
Total Initial Alignment Error (0.08 degrees rss)	3 arc min	3 arc min	<2 arc min

(Alignment Error Allocation = 0.50 deg. rss) (Yaw misalignment to be reduced by sighting cube & pinning feet.)

Boresight Knowledge (Pointing) Error Sources:	Roll	Pitch	Yaw
Instrument Bench/ Star Camera mounting bracket Errors			
Thermal distortion	36.1	39.2	7.8
1g Effect (Gravity effect can be reduced by using ±1g mapping)	27.4(3)	25.6(3)	2.2(1)
Mapping TIDI Telescope ref. cubes into Bench Master Cube	1.5	1.5	2
(2) Star Camera and Gyro System Attitude Determination Error	4.1 rss	4.1 rss	3.7 rss
Data Latency (10 millisec)		2	
Total Spacecraft Pointing Error (0.019° rss)	45.5 (36.5)	47.1 (39.6)	9.1 (8.9)
TIDI Instrument Structural Distortion;			
Telescope Housing Thermal Distortion	TBD	TBD	TBD
Telescope Pedestal Thermal Distortion	4.2	4.2	35
LVDT Thermal Transient/ Pre-Amp Sensitivity	23.3	23.3	0
1g-0g Transition and Launch Stress Effects	24	24	2
Mapping TIDI Telescope Boresights into TIDI Cubes	2	2	3
Total Boresight Knowledge (Pointing) Error using (2) Star cameras,	56.7 (49.7) rss	58 (52) rss	36.3 rss

Pointing Error Allocation = 0.05 °rss   Total Error = 88.9 (80.6) arc sec rss = 0.025° (0.022°) rss

(Bracketed values computed using ±1g mapping to reduce gravity effect)

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TIMED SEE Instrument Alignment Errors

	Alignment Errors (arc seconds)		
Initial Alignment Error Sources:	Roll	Pitch	Yaw
Spacecraft Structure as referenced in Spacecraft Master Cube	17	17	9
Mapping SEE Instrument Cube into Spacecraft Master Cube	1.5	1.5	2
Spacecraft Structure Errors	(0.010"/14.4")	(0.010"/19.4")	(0.004"/24.2")
Geometric Tolerancing	=143 (.040°)	=106 (.030°)	= 34 (.009°)
Thermal distortion	5	5	2
1g-0g Transition and Launch Stress Effects	15	15	2
Total Alignment Error from Spacecraft Sources (rss)	145 (.040°)	108 (.030°)	35 (.010°)
Mapping SEE Boresight(s) into SEE cube	TBD	TBD	TBD
SEE Instrument Internal Misalignment	TBD	TBD	TBD
Total Initial Alignment Error (0.05 + TBD degrees rss)	0.040°+TBD	0.030°+TBD	0.010°+TBD

(Alignment Error Allocation = 1.0 degrees rss) (Yaw misalignment to be reduced by min. clearance bolts in feet.)

Boresight Knowledge (Pointing) Error Sources:	Roll	Pitch	Yaw
(2) Star Camera and Gyro Attitude Determ. Error @ S/C master cube (rss)	46.0(37.1)	48.2(40.9)	9.7(9.5)
Mapping SEE Instrument cube into Spacecraft Master Cube	1.5	1.5	2
Total Spacecraft Pointing Error (0.019° (0.016°) rss)	46.0 (37.1)	48.2 (40.9)	9.9 (9.7)
Spacecraft Pointing Error Allocation (0.1° each axis)			
SEE Instrument Structural Distortion;			
Thermal Distortion	TBD	TBD	TBD
1g-0g Transition and Launch Stress Effects	TBD	TBD	TBD
Mapping SEE Instrument Boresight into SEE Cube	2	2	3
Total Boresight Knowledge (Pointing) Error using (2) Star cameras,	46.1 (37.2) rss	48.3 (41) rss	10.3 rss

Pointing Error Allocation = 0.10°rss Total Error = 67.6(56.3)+TBD arc sec rss = 0.019°(0.016°)+TBD rss

(Bracketed values computed using ±1g mapping to reduce gravity effect)

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TIMED SABER Instrument Alignment Errors

Initial Alignment Error Sources:	Alignment Errors (arc seconds) Roll	Pitch	Yaw
Spacecraft Structure as referenced in Spacecraft Master Cube	17	17	9
Mapping SABER Instrument Cube into Spacecraft Master Cube	1.5	1.5	2
Spacecraft Structure Errors	(0.010"/24.4")	(0.005"/30.5")	(0.010"/30.5")
Geometric Tolerancing	= 85	= 34	= 68
Thermal distortion (15°C x 24 μin/in/°C = 0.022"/62" ht.)	98 (46"w.)	83 (54.5"w.)	15
1g-0g Transition and Launch Stress Effects	30	30	10
Total Alignment Error from Spacecraft Sources (rss)	134 (.037°)	96 (.027°)	71(.020°)
Mapping SABER Boresight into SABER cube	TBD	TBD	TBD
SABER Instrument Internal Misalignment	TBD	TBD	TBD
Total Initial Alignment Error (0.050 + TBD degrees rss)	.037°+TBD	.027°+TBD	.020°+TBD
(Alignment Error Allocation = 0.10 degrees rss)			

Boresight Knowledge (Pointing) Error Sources:	Roll	Pitch	Yaw
Spacecraft Structural Distortion			
Thermal distortion	98	83	15
1g-0g Transition and Launch Stress Effects	30	30	10
Mapping SABER Instrument cube into Spacecraft Master Cube	1.5	1.5	2
(2) Star Camera and Gyro Attitude Determ. Error @ S/C master cube (rss)	46.0(37.1)	48.2(40.9)	9.7(9.5)
Total Pointing Error from Spacecraft Sources (0.041° rss)	112.3 (109)	100.6 (97)	20.6
SABER Instrument Structural Distortion;			
Thermal Distortion	TBD	TBD	TBD
1g-0g Transition and Launch Stress Effects	TBD	TBD	TBD
Mapping SABER Instrument Boresight into SABER Cube	2	2	3
Total Boresight Knowledge (Pointing) Error using (2) Star cameras,	109+TBD rss	97+TBD rss	20.8+TBD rss

Pointing Error Allocation = 0.10?°rss   Total Error = 147+TBD arc sec rss = 0.041° + TBD rss

TIMED GUVI Instrument Alignment Errors

Initial Alignment Error Sources:	Alignment Errors (arc seconds) Roll	Pitch	Yaw
Spacecraft Structure as referenced in Spacecraft Master Cube	17	17	9
Mapping GUVI Instrument Cube into Spacecraft Master Cube	1.5	1.5	2
Spacecraft Structure Errors	(0.015"/11.5")	(0.015"/4.5")	(0.028"/12.4")
Geometric Tolerancing Errors	= 0.075°	= 0.191°	= 0.130°
Thermal Distortion (15°C x 24 µin/in/°C = 0.022"/62" ht.)	0.028° (46"w.)	0.024° (54.5"w.)	0.004°
1g-0g Transition and Launch Stress Effects	30 (.008°)	30 (.008°)	10 (.003°)
Total Alignment Error from Spacecraft Sources (rss)	0.081°	0.193°	0.130°
Mapping GUVI Boresight(s) into GUVI cube	TBD	TBD	TBD
GUVI Instrument Internal Misalignment	TBD	TBD	TBD
Total Initial Alignment Error (0.25+ TBD degrees rss)	0.081°+TBD	0.193°+TBD	0.130°+TBD
(Alignment Error Allocation = 1.0 deg. rss)			

Boresight Knowledge (Pointing) Error Sources:	Roll	Pitch	Yaw
Spacecraft Structural Distortion			
Thermal distortion	103 (.028°)	87 (.024°)	15 (.004°)
1g-0g Transition and Launch Stress Effects	30	30	10
Mapping GUVI Instrument cube into Spacecraft Master Cube	1.5	1.5	2
(2) Star Camera and Gyro Attitude Determ. Error @ S/C master cube (rss)	46.0(37.1)	48.2(40.9)	9.7(9.5)
Total Pointing Error from Spacecraft Sources (0.043° rss)	116.7(113.5)	103.9(100.7)	20.6
GUVI Instrument Structural Distortion;			
Thermal Distortion	TBD	TBD	TBD
1g-0g Transition and Launch Stress Effects	TBD	TBD	TBD
Mapping GUVI Instrument Boresight into GUVI Cube	TBD	TBD	TBD
Total Boresight Knowledge (Pointing) Error using (2) Star cameras,	114+TBD rss	101+TBD rss	20.6+TBD rss

Pointing Error Allocation = 0.05 degrees rss Boresight alignment knowledge
(0.30 degrees rss on-orbit knowledge) Total Error = 154+TBD arc sec rss = 0.043°+TBD rss