# TIMED

*Thermosphere • Ionosphere • Mesosphere • Energetics and Dynamics*

# G&C Analysis and Simulations

**Presented by Wayne Dellinger**

**December 4, 1997**

# G&C Modes

- **Operational**
  - **Full complement of hardware**
- **Nadir Pointing**
  - **Degraded performance**
  - **e.g., Single tracker**
- **Sun Safe**
  - **Lowest level of hardware availability**
  - **No trackers when in AIU only sun safe**
  - **During tip-off only torque rods and magnetometers**

# G&C General Functions

- **Momentum Management**
  - **Continuous torque rod commanding**
  - **Variable duty cycle**
- **Yaw Maneuver**
  - **Bang-bang control**
  - **Maximum torque about Z ~ 0.1 N-m**
  - **Maximum angular acceleration ~ 7.6E-05 r/s$^2$**
  - **Maneuver completion time ~ 6.8 minutes**

# Attitude Determination

- **Two trackers, boresights orthogonally mounted**
  - **~ 9 arcseconds 3-σ each axis at fiducial frame**
- **Single tracker**
  - **~ 72 arcseconds 3-σ about boresight, 9 arcseconds 3-σ off boresight**
- **Tracker boresights closely aligned with TIDI boresights**
- **Gradual degradation when one tracker blinded**

# Selected S/C Jitter Requirements

- **@ 0.5 Hz, 0.005 degrees p-p (87 μrads p-p)**
- **@ 0.004 Hz, 1.0 degree p-p (17453 μrads p-p)**
- **@ 0.001 Hz, 1.0 degree p-p (17453 μrads p-p)**

# Solar Panel Thermal Deformation

- "Twang" when going into/coming out of eclipse
- ~ 1.6 mN-m torque over ~ 68 seconds
- ~ 0.11 N-m-s increase in momentum
- Slow enough and small enough for wheels to compensate

# Tip-Off Scenario

- **Current rates from Boeing are 5 deg/sec about X, 2.5 deg/sec about Y and Z (27.1, 15.9, 7.9 N-m-s)**
- **With current inertia and maximum wheel momentum capability, maximum tolerable rates are : 1.9, 7.7, and 13.5 deg/sec, X, Y, and Z (10.3, 48.9, 42.9 N-m-s)**
- **This is a single axis analysis**

# Tip-Off Scenario Continued

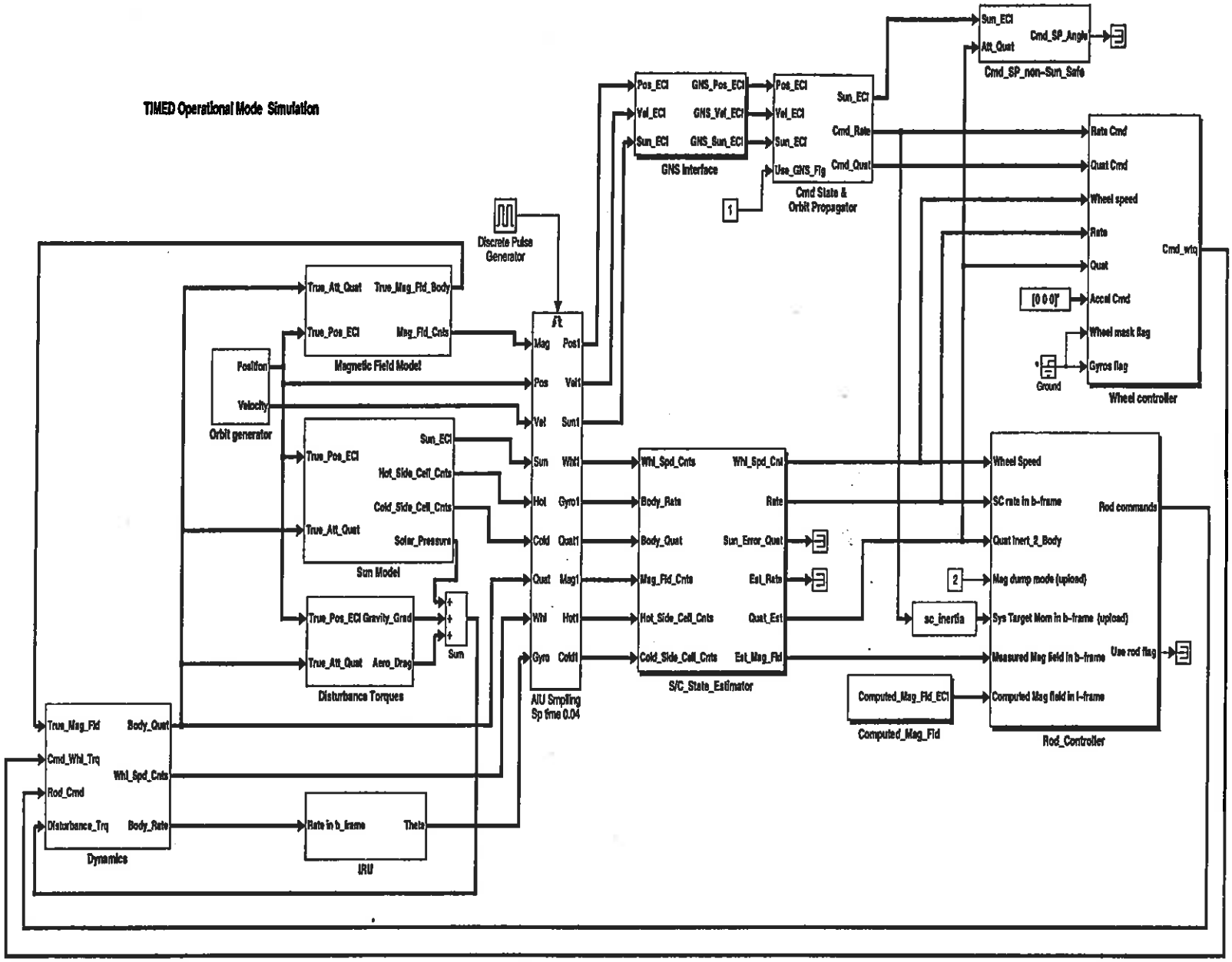
- **Initially use torque rods and magnetometers only to dump momentum**
  - **Analysis estimates ~ 20 N-m-s dumped per orbit**
  - **Simulation collaborates**
  - **Must estimate rates from magnetometer/sun sensor data since IRU is off**
- **Begin to command wheels one orbit after separation**
- **Use wheels to further reduce body rates, and**
- **Command to Sun**

# Anomalies Currently Considered

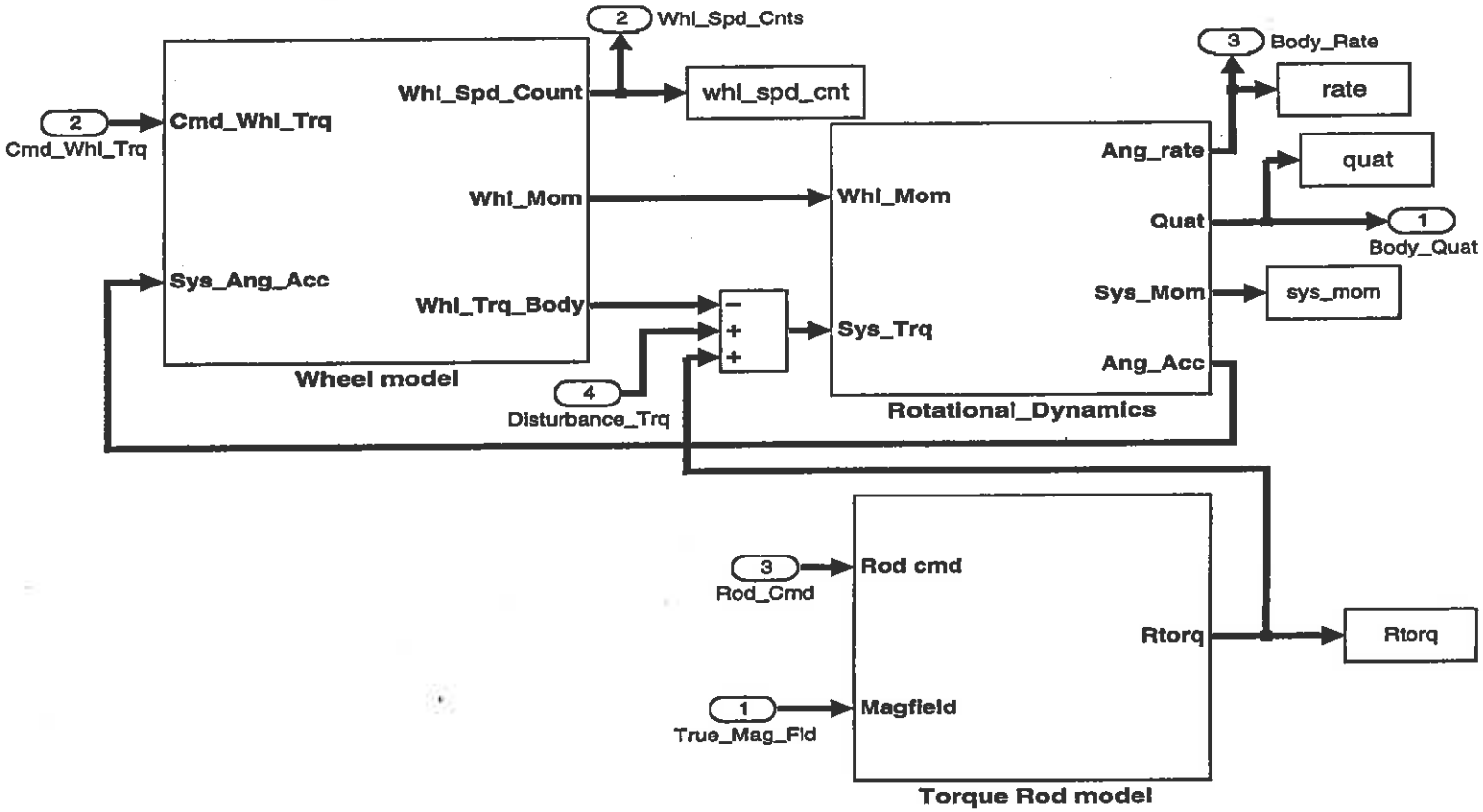
- **Failed wheel, spin up/down**
- **Failed torque rod**
  - **Redundant coils**
  - **Watch for momentum build-up**
- **Failed magnetometer**
  - **Cross-strapped**
- **Failed Sun sensor**
  - **Cross-strapped**
- **IRUs, star trackers**
  - **Components provide information concerning health**

# Stability

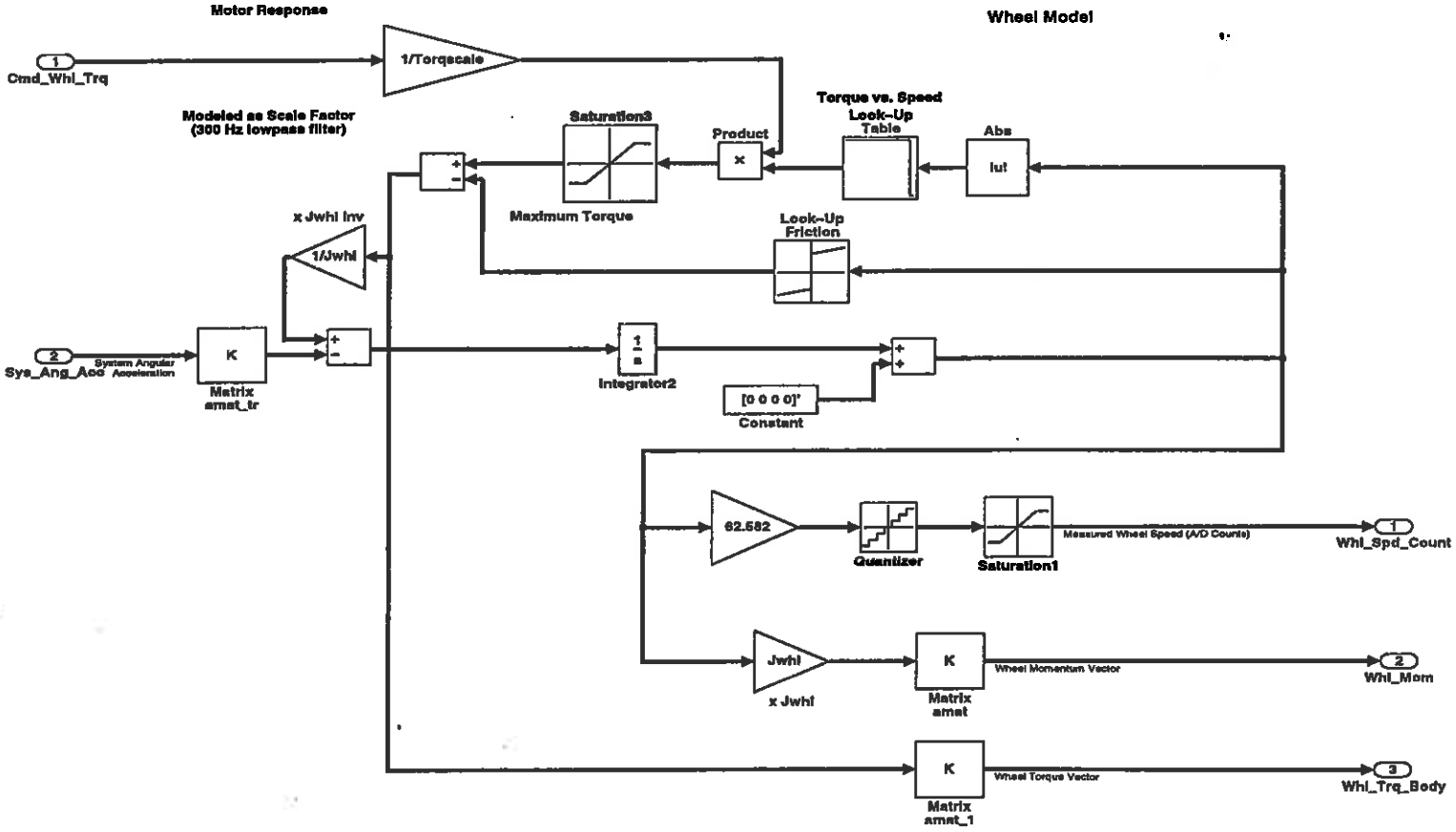
- **Linearized system**
- **Wheel controller only**
- **Current calculations show sufficient gain and phase margins**
- **More detailed analysis forthcoming**
  - **Structural modes**
  - **Discrete controller**


TIMED Operational Mode Simulation
Discrete Pulse Generator
GNS Interface
Pos_ECI
Vel_ECI
Sun_ECI
GNS_Pos_ECI
GNS_Vel_ECI
GNS_Sun_ECI
Cmd State & Orbit Propagator
Use_GNS_Flg
Cmd_Rate
Cmd_Quat
Cmd_SP_non-Sun_Safe
Att_Quat
Cmd_SP_Angle
Wheel controller
Rate Cmd
Quat Cmd
Wheel speed
Rate
Quat
Accel Cmd
Wheel mask flag
Gyros flag
Cmd_whl
Ground
Magnetic Field Model
True_Att_Quat
True_Mag_Fld_Body
True_Pos_ECI
Mag_Fld_Cnts
Orbit generator
Position
Velocity
Sun Model
Hot_Side_Cell_Cnts
Cold_Side_Cell_Cnts
Solar_Pressure
Disturbance Torques
Gravity_Grad
Aero_Drag
Sum
AIU Smpling
Sp time 0.04
Mag
Pos
Vel
Sun
Hot
Cold
Gyro
Mag1
Whl
Pos1
Vel1
Sun1
Whl1
Gyro1
Quat1
Mag1
Hot1
Cold1
S/C_State_Estimator
Whl_Spd_Cnts
Body_Rate
Body_Quat
Mag_Fld_Cnts
Hot_Side_Cell_Cnts
Cold_Side_Cell_Cnts
Whl_Spd_Cnt
Rate
Sun_Error_Quat
Est_Rate
Quat_Est
Est_Mag_Fld
sc_inertia
Computed_Mag_Fld_ECI
Computed_Mag_Fld
Rod_Controller
Wheel Speed
SC rate in b-frame
Quat Inert_2_Body
Mag dump mode (upload)
Sys Target Mom in b-frame (upload)
Measured Mag field in b-frame
Computed Mag field in I-frame
Rod commands
Use rod flag
Dynamics
True_Mag_Fld
Cmd_Whl_Trq
Rod_Cmd
Disturbance_Trq
Body_Quat
Whl_Spd_Cnts
Body_Rate
IRU
Rate in b_frame
Theta

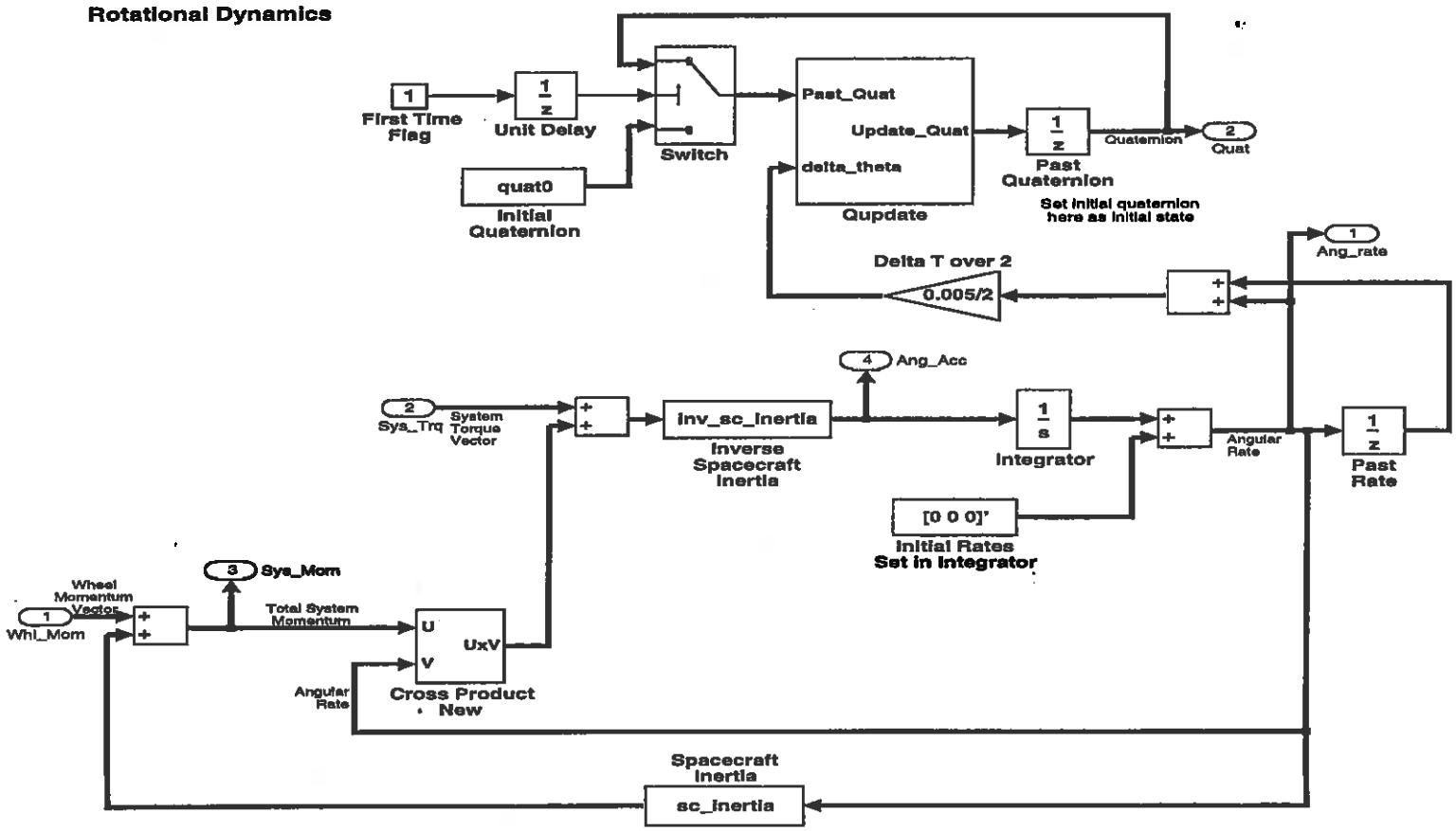
# Dynamics Truth Model



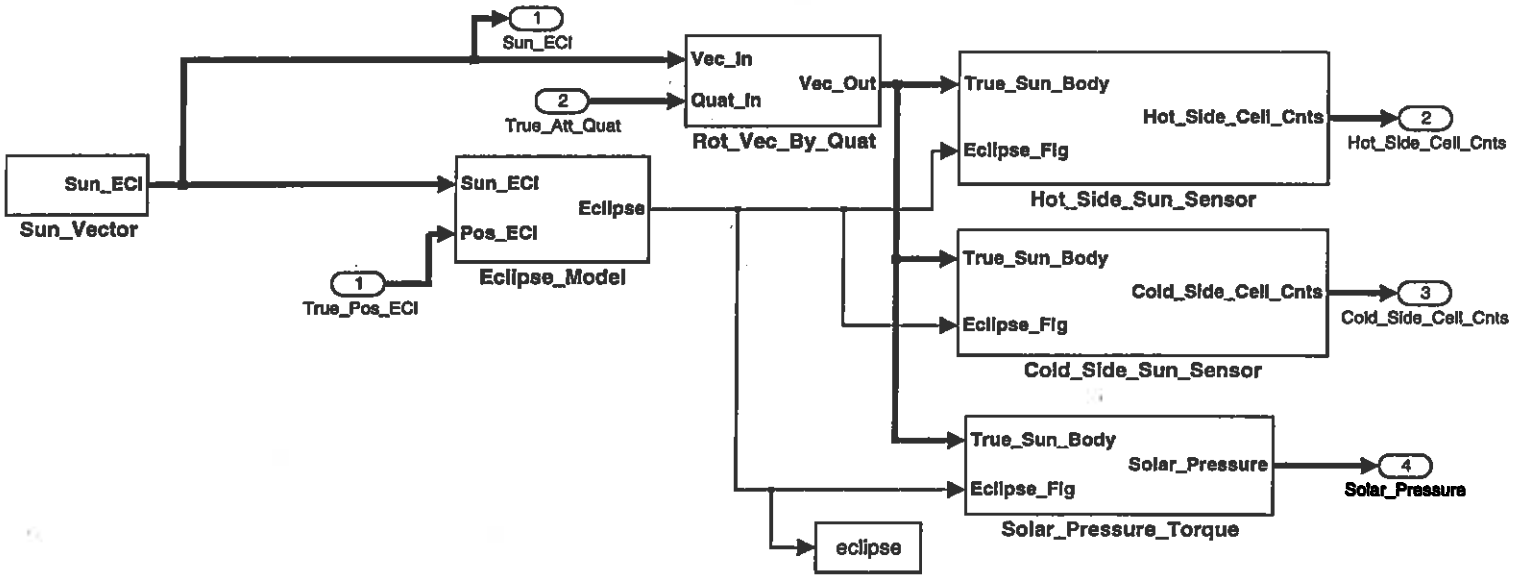
# Wheel Dynamics



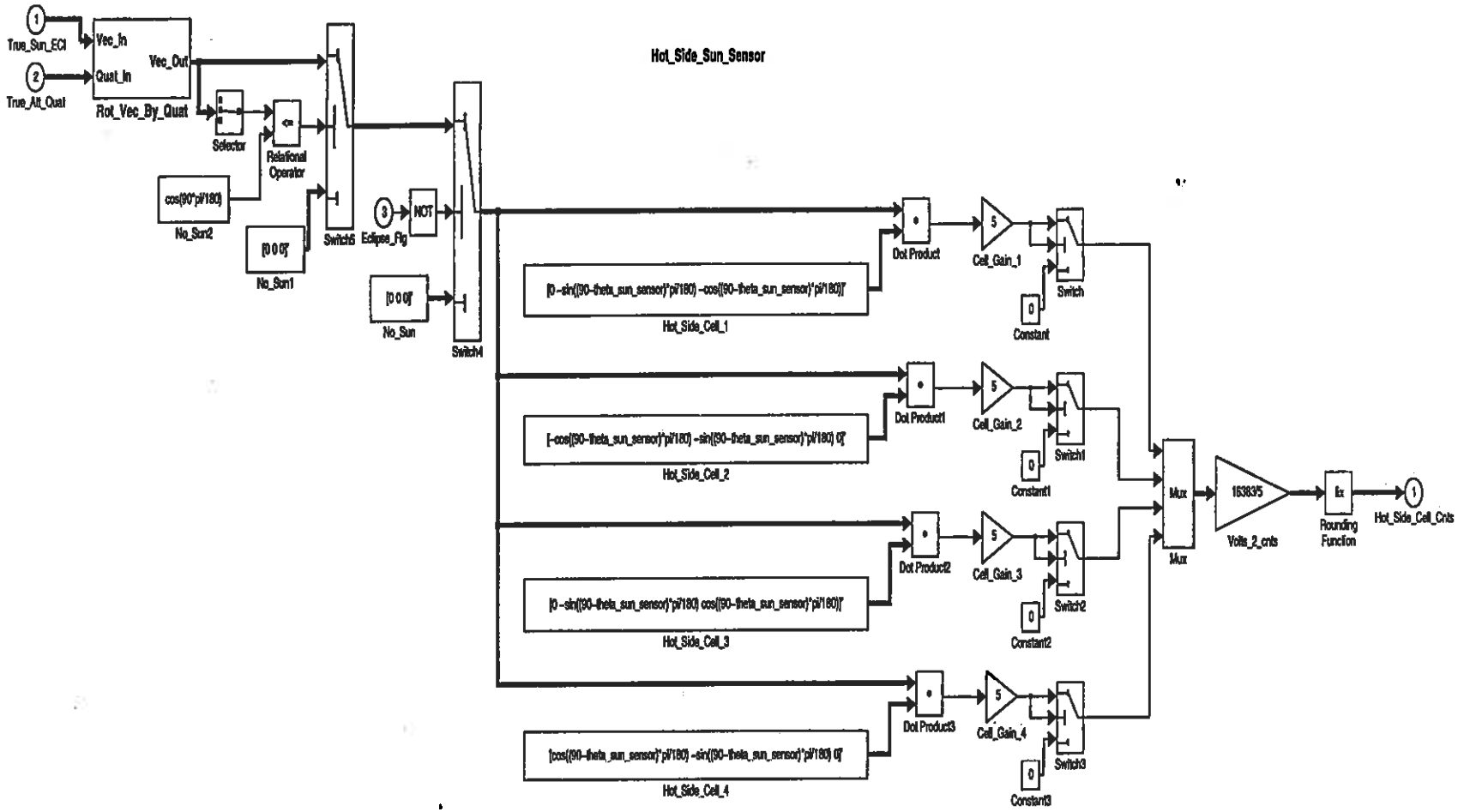
## Spacecraft Dynamics



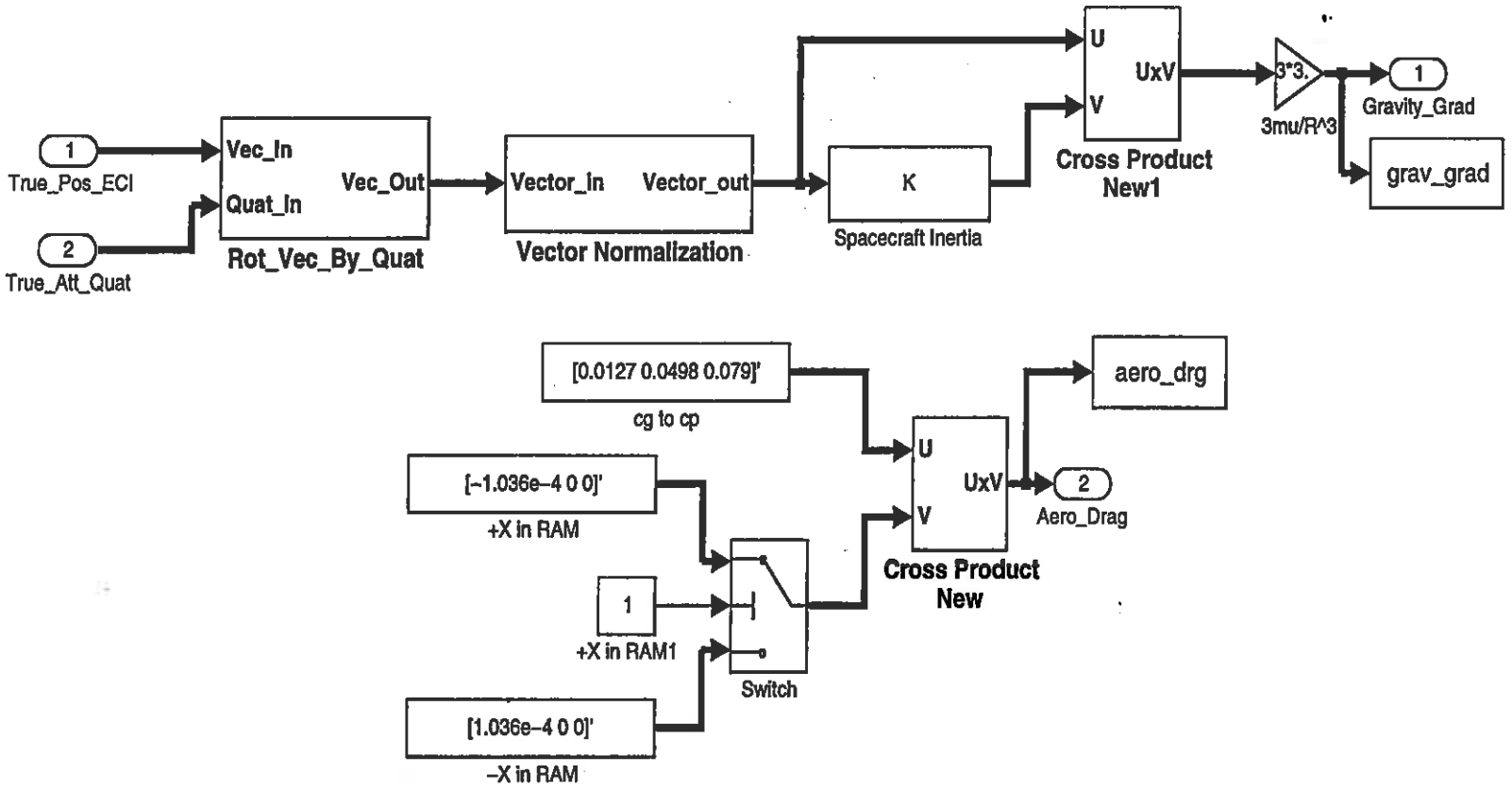
# Solar Models



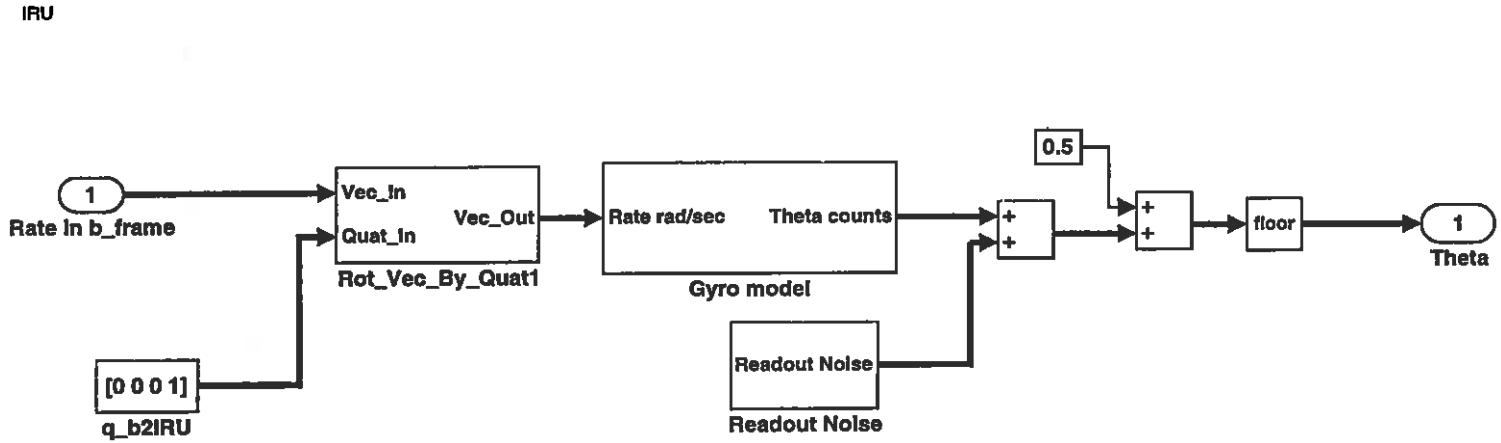
# TIMED


Hot_Side_Sun_Sensor
True_Sun_ECI
True_Alt_Quat
Vec_In
Quat_In
Vec_Out
Rot_Vec_By_Quat
Selector
Relational Operator
cos(90*pi/180)
No_Sun2
[0 0 0]'
No_Sun1
Switch5
Eclipse_Flg
NOT
[0 0 0]'
No_Sun
Switch4
[0 -sin((90-theta_sun_sensor)*pi/180) -cos((90-theta_sun_sensor)*pi/180)]'
Hot_Side_Cell_1
[-cos((90-theta_sun_sensor)*pi/180) -sin((90-theta_sun_sensor)*pi/180) 0]'
Hot_Side_Cell_2
[0 -sin((90-theta_sun_sensor)*pi/180) cos((90-theta_sun_sensor)*pi/180)]'
Hot_Side_Cell_3
[cos((90-theta_sun_sensor)*pi/180) -sin((90-theta_sun_sensor)*pi/180) 0]'
Hot_Side_Cell_4
Dot Product
Dot Product1
Dot Product2
Dot Product3
Cell_Gain_1
Cell_Gain_2
Cell_Gain_3
Cell_Gain_4
Switch
Switch1
Switch2
Switch3
Constant
Constant1
Constant2
Constant3
Mux
Mux
163835
Volts_2_cnts
fix
Rounding Function
Hot_Side_Cell_Cnts

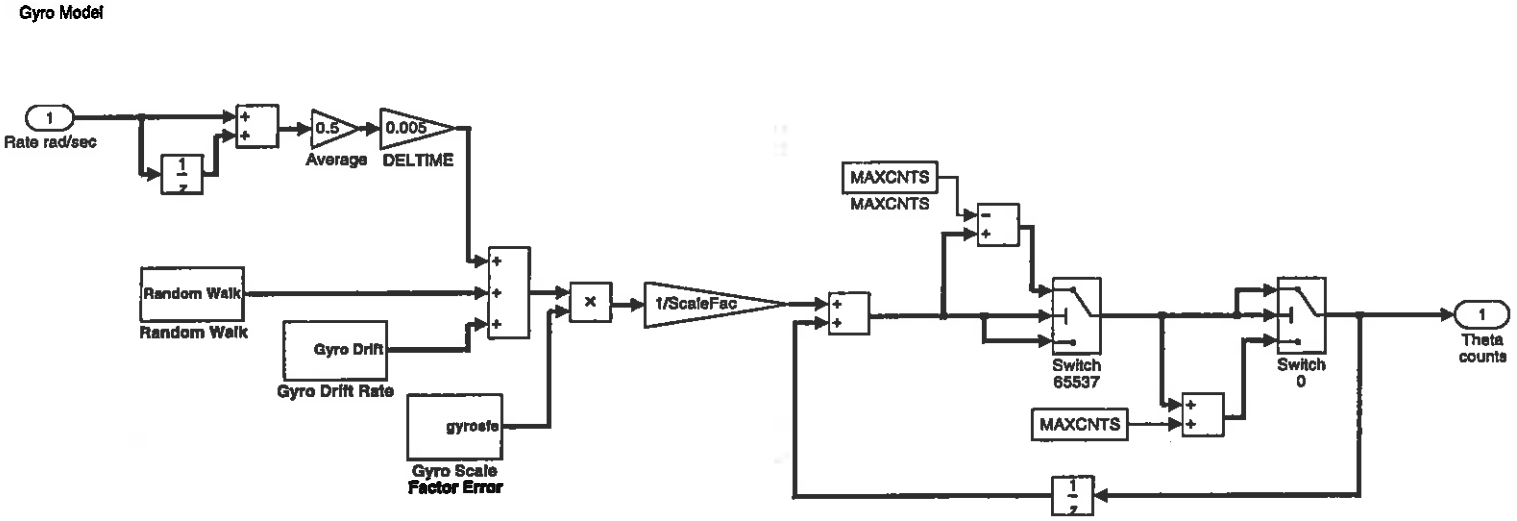
# Disturbance Torques



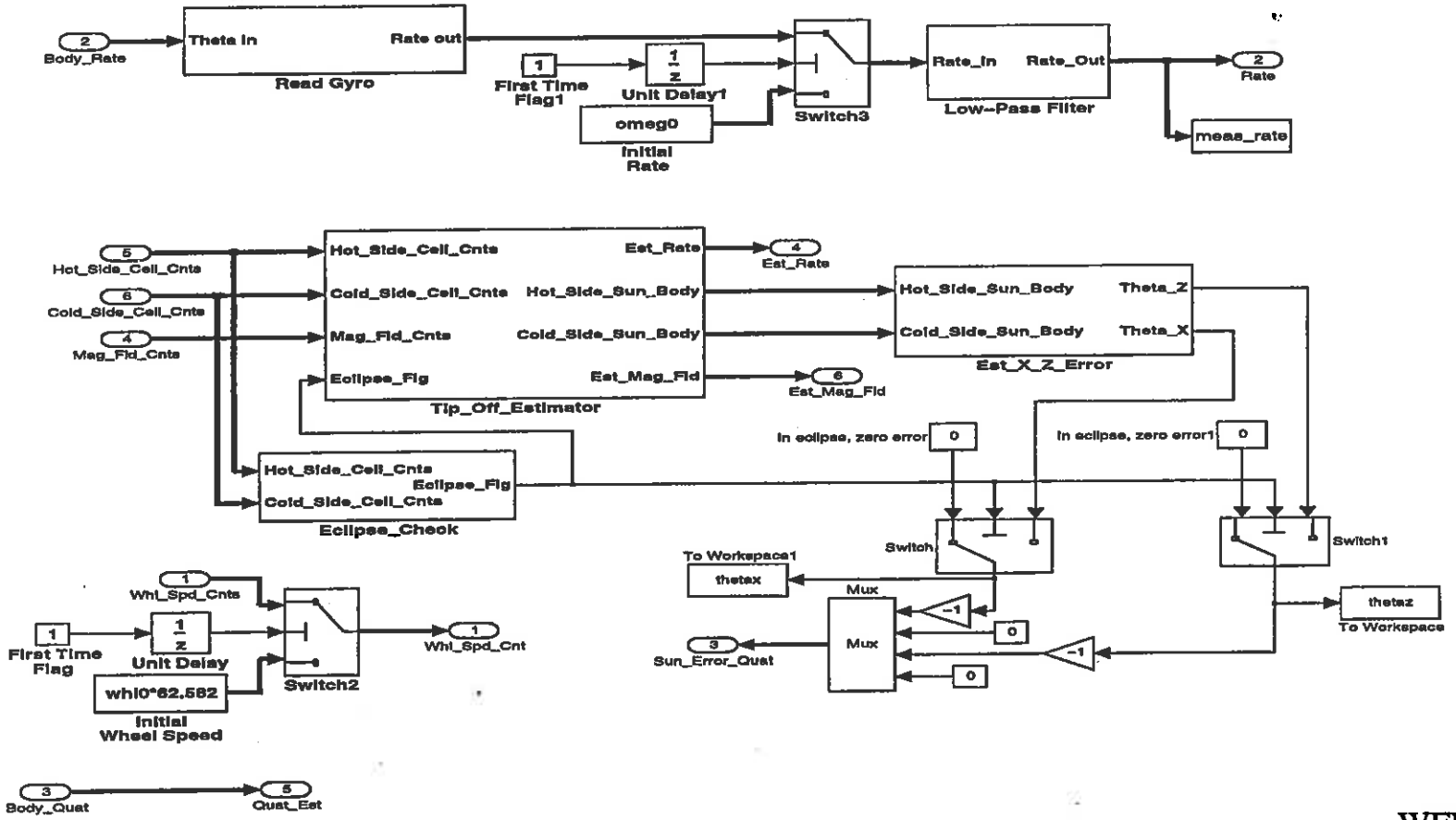
# IRU Model


IRU
1
Rate in b_frame
Vec_In
Quat_In
Vec_Out
Rot_Vec_By_Quat1
[0 0 0 1]
q_b2IRU
Rate rad/sec
Theta counts
Gyro model
Readout Noise
Readout Noise
0.5
+
+
+
+
floor
1
Theta

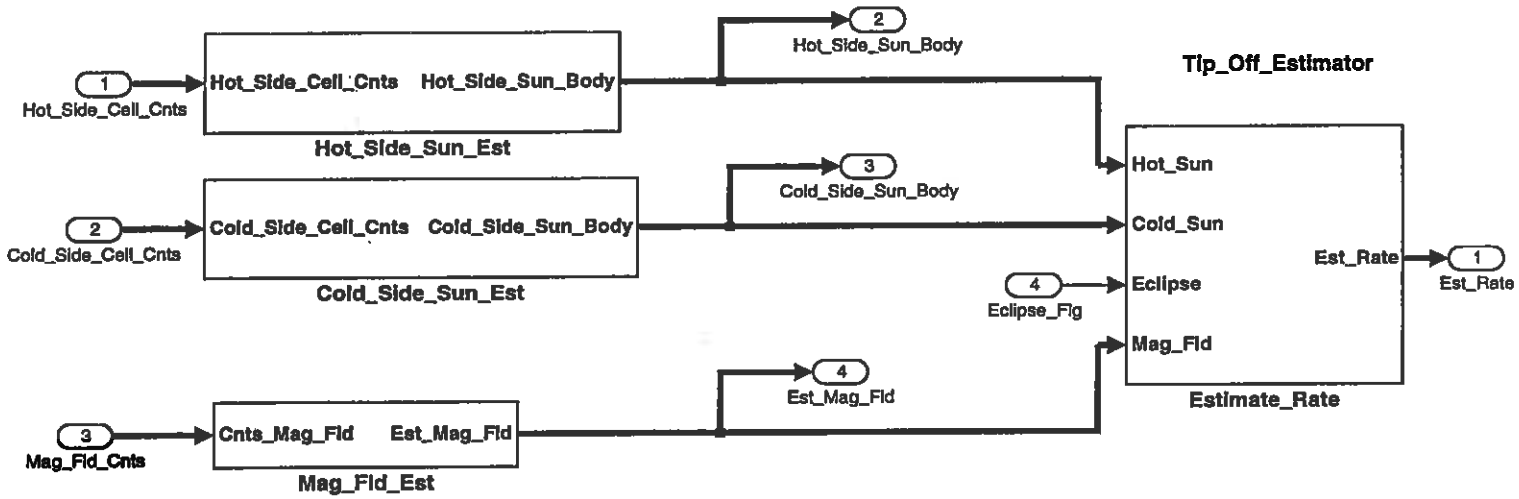
# IRU Model Continued



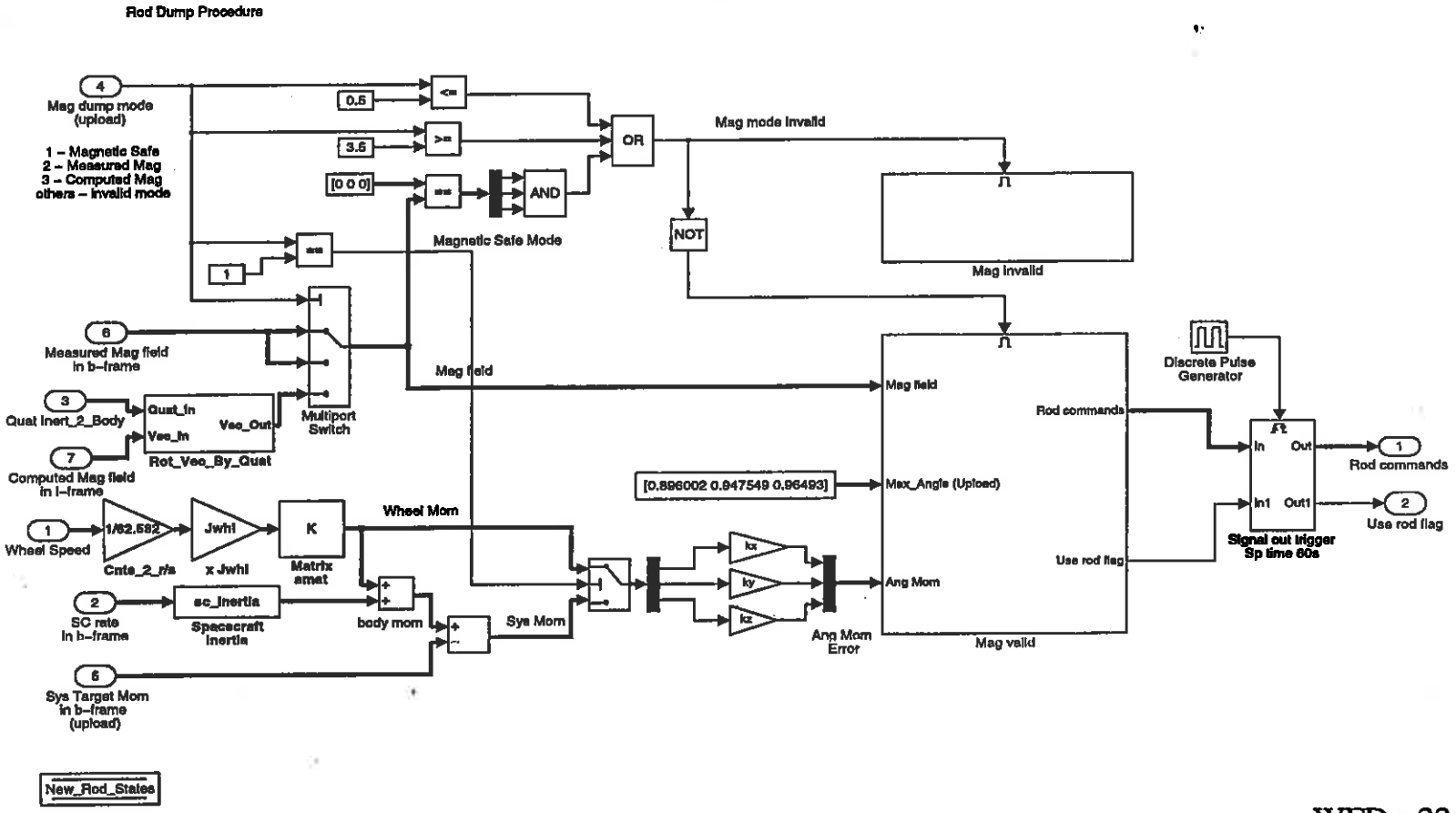
# Spacecraft State Estimator



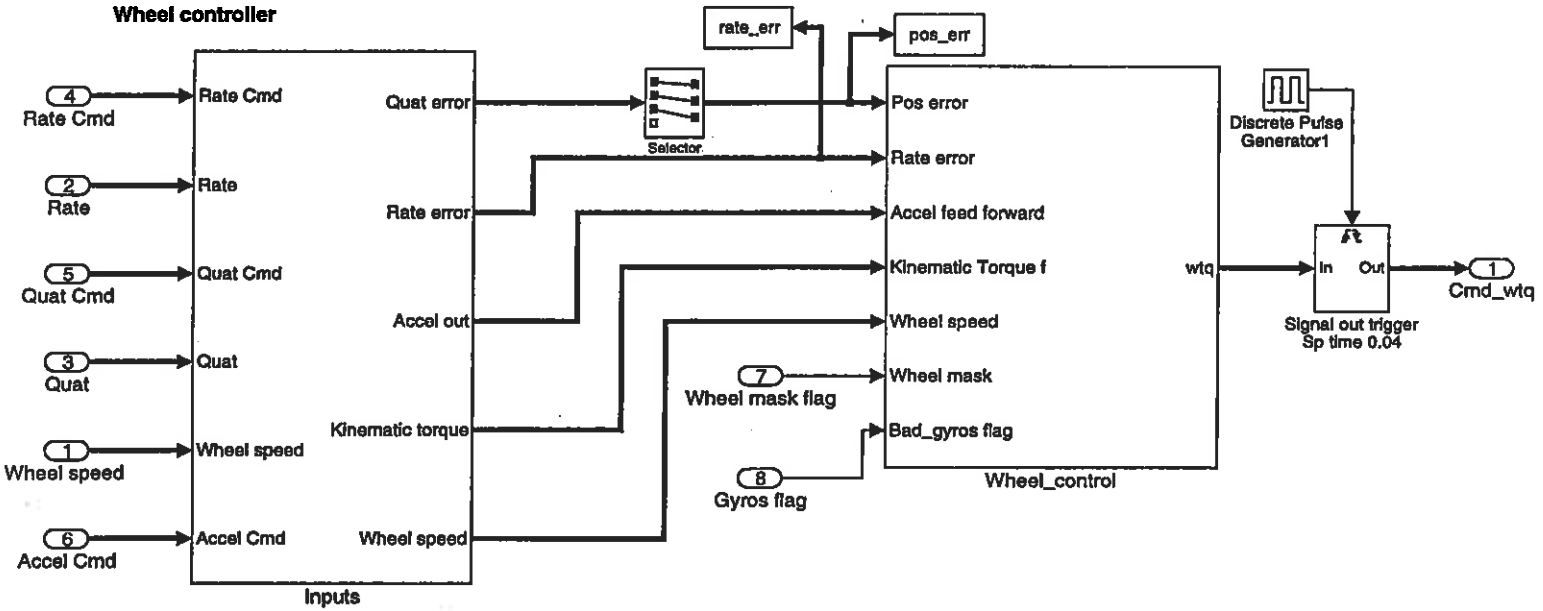
## Tip-Off Estimator



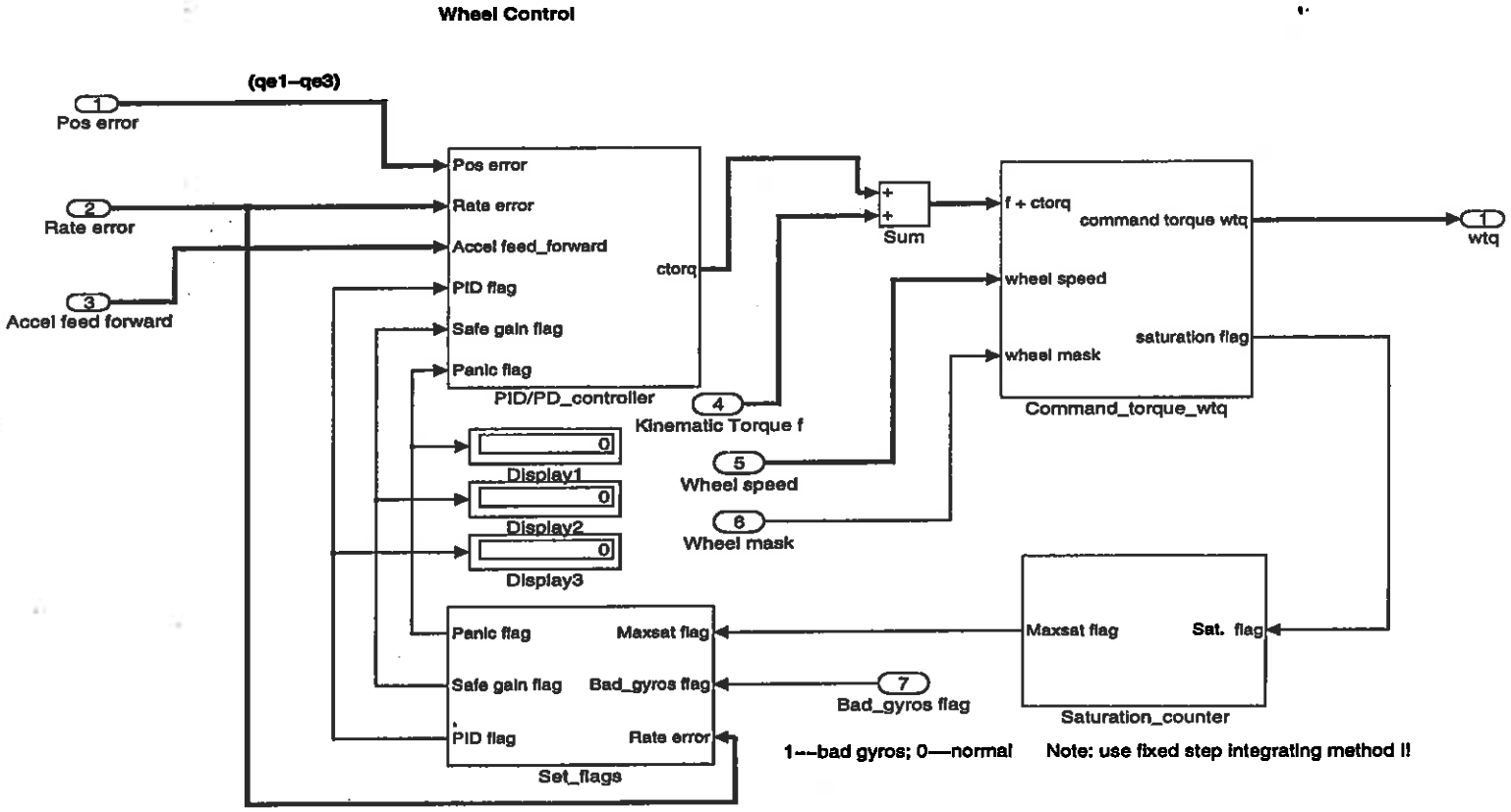
# Magnetic Torque Rod Momentum Dumping

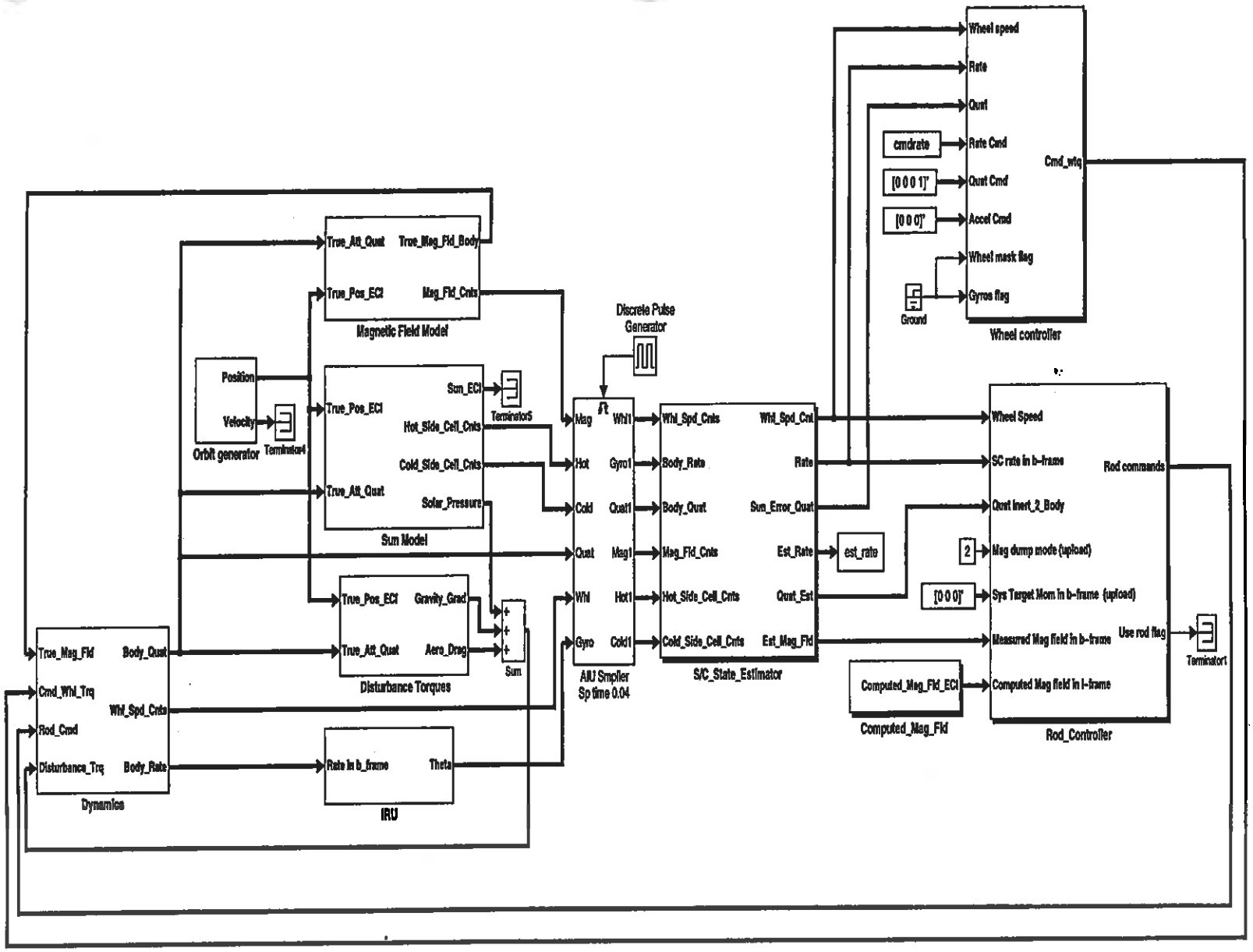


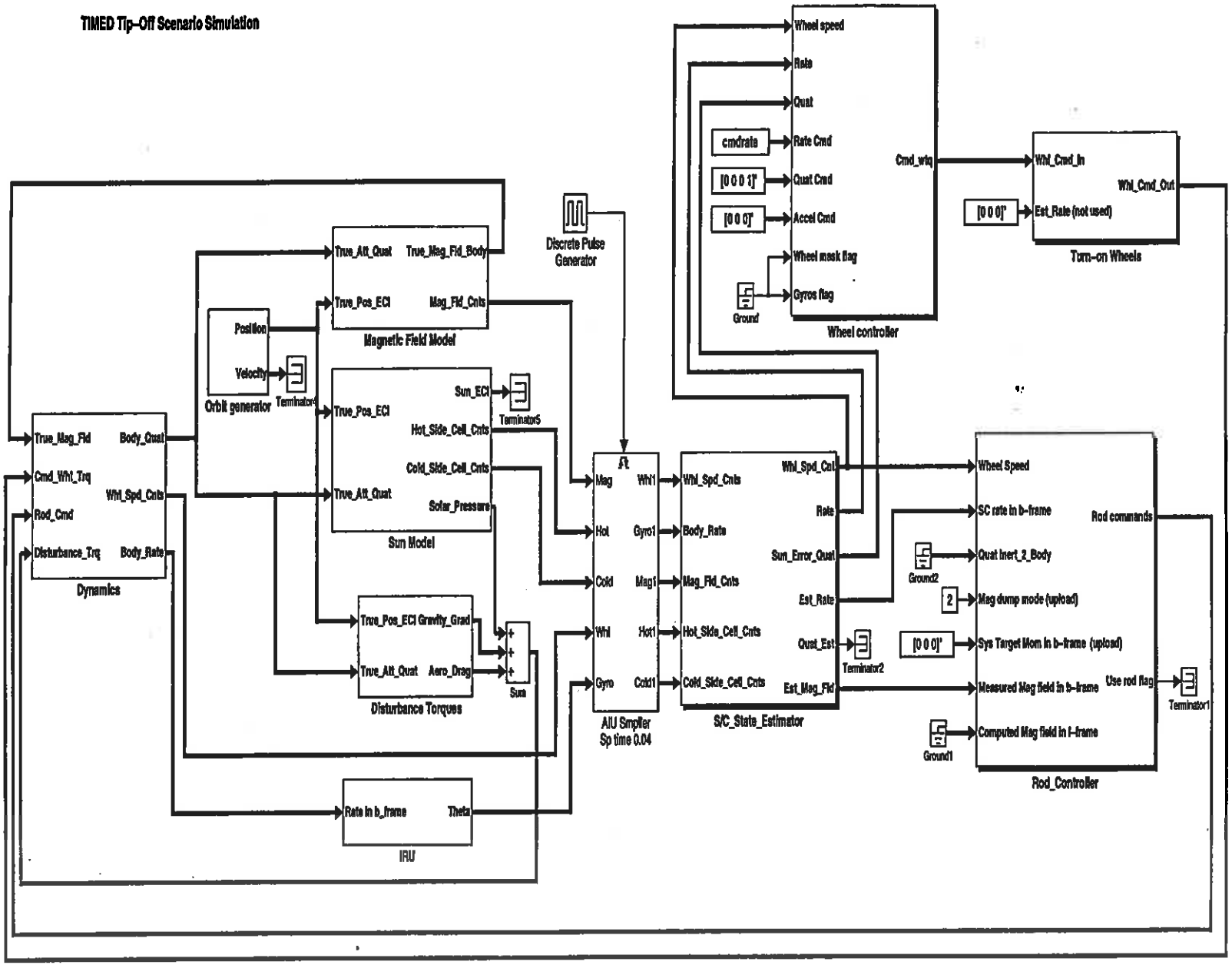
# Wheel Control



# Wheel Control Continued



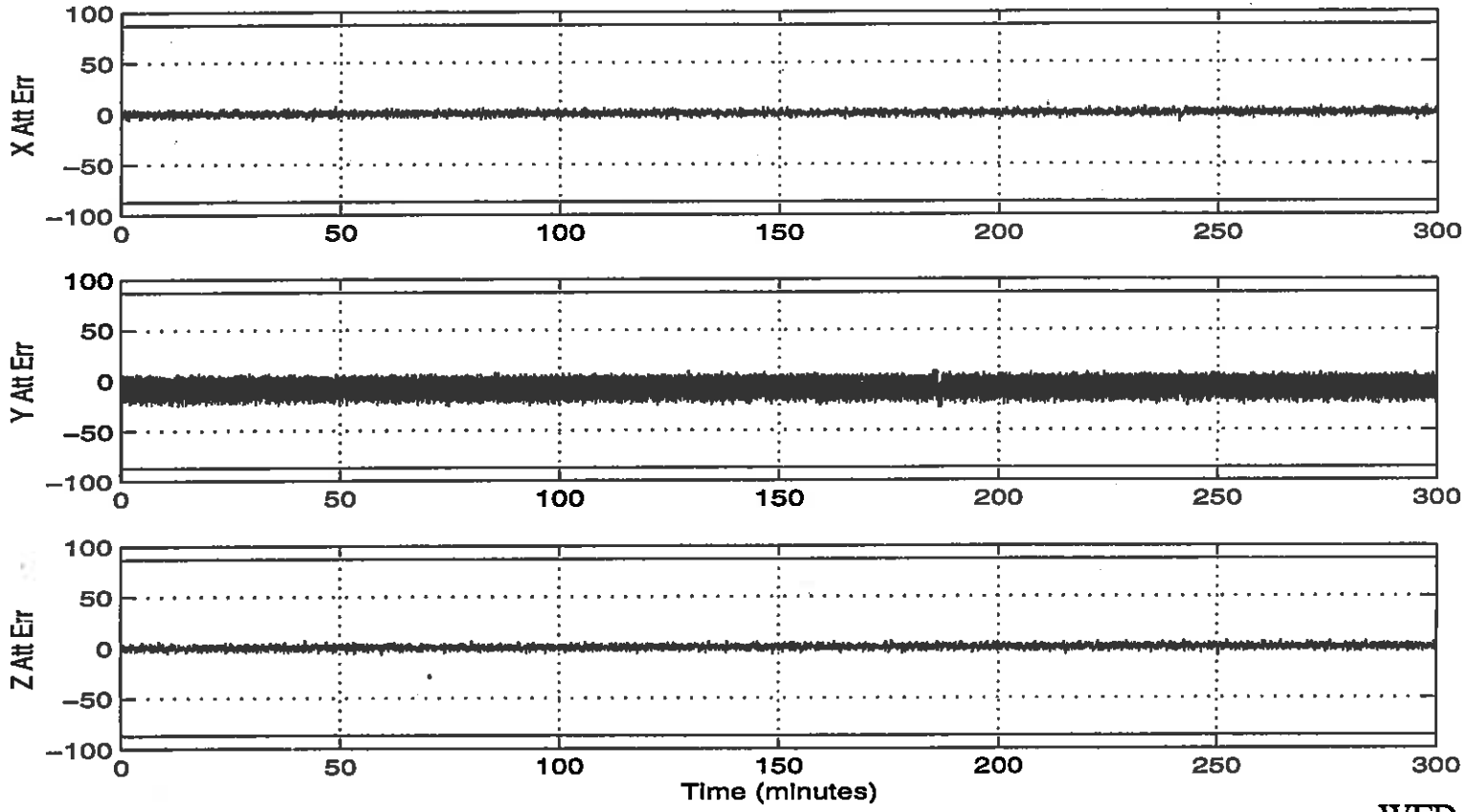

Wheel speed
Rate
Quat
cmdrate
Rate Cmd
[0 0 0 1]'
Quat Cmd
[0 0 0]'
Accel Cmd
Wheel mask flag
Gyros flag
Cmd_wtq
Ground
Wheel controller
True_Att_Quat
True_Mag_Fld_Body
True_Pos_ECI
Mag_Fld_Cnts
Magnetic Field Model
Discrete Pulse Generator
Position
Velocity
Orbit generator
Terminator4
Sun_ECI
Hot_Side_Cell_Cnts
Cold_Side_Cell_Cnts
Solar_Pressure
Terminator5
Sun Model
Mag
Hot
Cold
Quat
Whl
Gyro
Whl1
Gyro1
Quat1
Mag1
Hot1
Cold1
AIU Smpler
Sp time 0.04
Whl_Spd_Cnts
Body_Rate
Body_Quat
Mag_Fld_Cnts
Hot_Side_Cell_Cnts
Cold_Side_Cell_Cnts
SC_State_Estimator
Whl_Spd_Cmd
Rate
Sun_Error_Quat
Est_Rate
Quat_Est
Est_Mag_Fld
est_rate
Gravity_Grad
Aero_Drag
Disturbance Torques
Sum
True_Mag_Fld
Cmd_Whl_Trq
Rod_Cmd
Disturbance_Trq
Body_Quat
Whl_Spd_Cnts
Body_Rate
Dynamics
Rate in b_frame
Theta
IRU
Computed_Mag_Fld_ECI
Computed_Mag_Fld
Wheel Speed
SC rate in b-frame
Quat Inert_2_Body
2
Mag dump mode (upload)
[0 0 0]'
Sys Target Mom in b-frame (upload)
Measured Mag field in b-frame
Computed Mag field in I-frame
Rod commands
Use rod flag
Terminator1
Rod_Controller


TIMED Tip-Off Scenario Simulation
Wheel speed
Rate
Quat
cmdrate
Rate Cmd
[0 0 0 1]'
Quat Cmd
[0 0 0]'
Accel Cmd
Wheel mask flag
Gyros flag
Ground
Wheel controller
Cmd_wtq
Whl_Cmd_In
Whl_Cmd_Out
[0 0 0]'
Est_Rate (not used)
Turn-on Wheels
Discrete Pulse Generator
True_Att_Quat
True_Mag_Fld_Body
True_Pos_ECI
Mag_Fld_Cnts
Magnetic Field Model
Position
Velocity
Orbit generator
Terminator
Sun_ECI
Hot_Side_Cell_Cnts
Cold_Side_Cell_Cnts
Solar_Pressure
Terminator5
Sun Model
True_Mag_Fld
Body_Quat
Cmd_Whl_Trq
Whl_Spd_Cnts
Rod_Cmd
Disturbance_Trq
Body_Rate
Dynamics
True_Pos_ECI
Gravity_Grad
True_Att_Quat
Aero_Drag
Disturbance Torques
Sum
Rate in b_frame
Theta
IRU
AIU
Mag
Hot
Cold
Whl
Gyro
Whl1
Gyro1
Mag1
Hot1
Cold1
AIU Simpler
Sp time 0.04
Whl_Spd_Cnts
Body_Rate
Mag_Fld_Cnts
Hot_Side_Cell_Cnts
Cold_Side_Cell_Cnts
S/C_State_Estimator
Whl_Spd_Cnt
Rate
Sun_Error_Quat
Est_Rate
Quat_Est
Est_Mag_Fld
Terminator2
Ground2
2
[0 0 0]'
Ground1
Wheel Speed
SC rate in b-frame
Quat Inert_2_Body
Mag dump mode (upload)
Sys Target Mom in b-frame (upload)
Measured Mag field in b-frame
Computed Mag field in I-frame
Rod commands
Use rod flag
Terminator1
Rod_Controller

## Operational Mode Simulation

- Three orbit simulation
- 60 second command cycle for torque rods
- Includes environmental disturbances
- Includes gyro noise
- Does not include star trackers
- Does not include Kalman filter

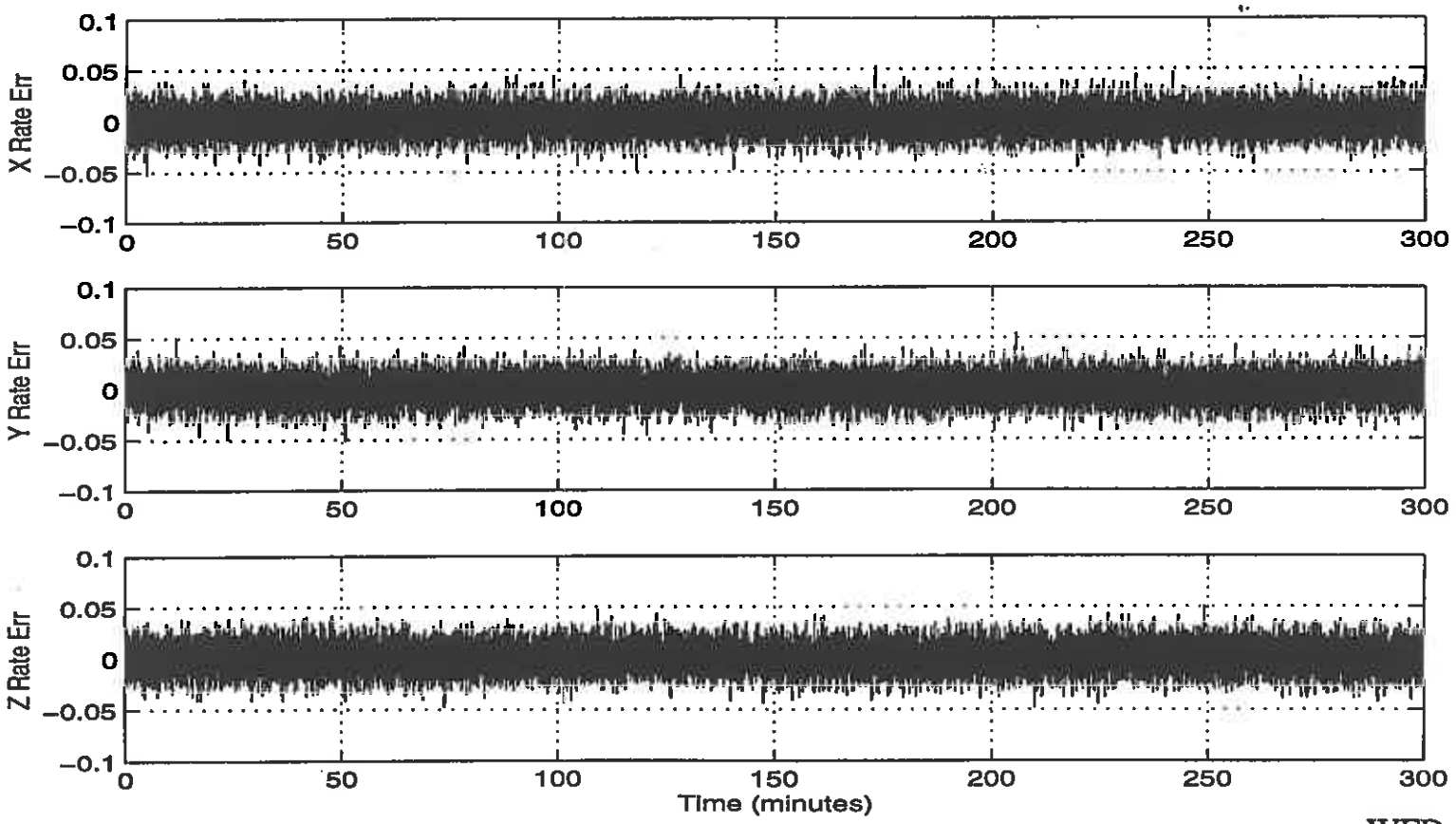
# Operational Mode S/C Attitude Error, μrads



# TIMED

*Thermosphere • Ionosphere • Mesosphere • Energetics and Dynamics*

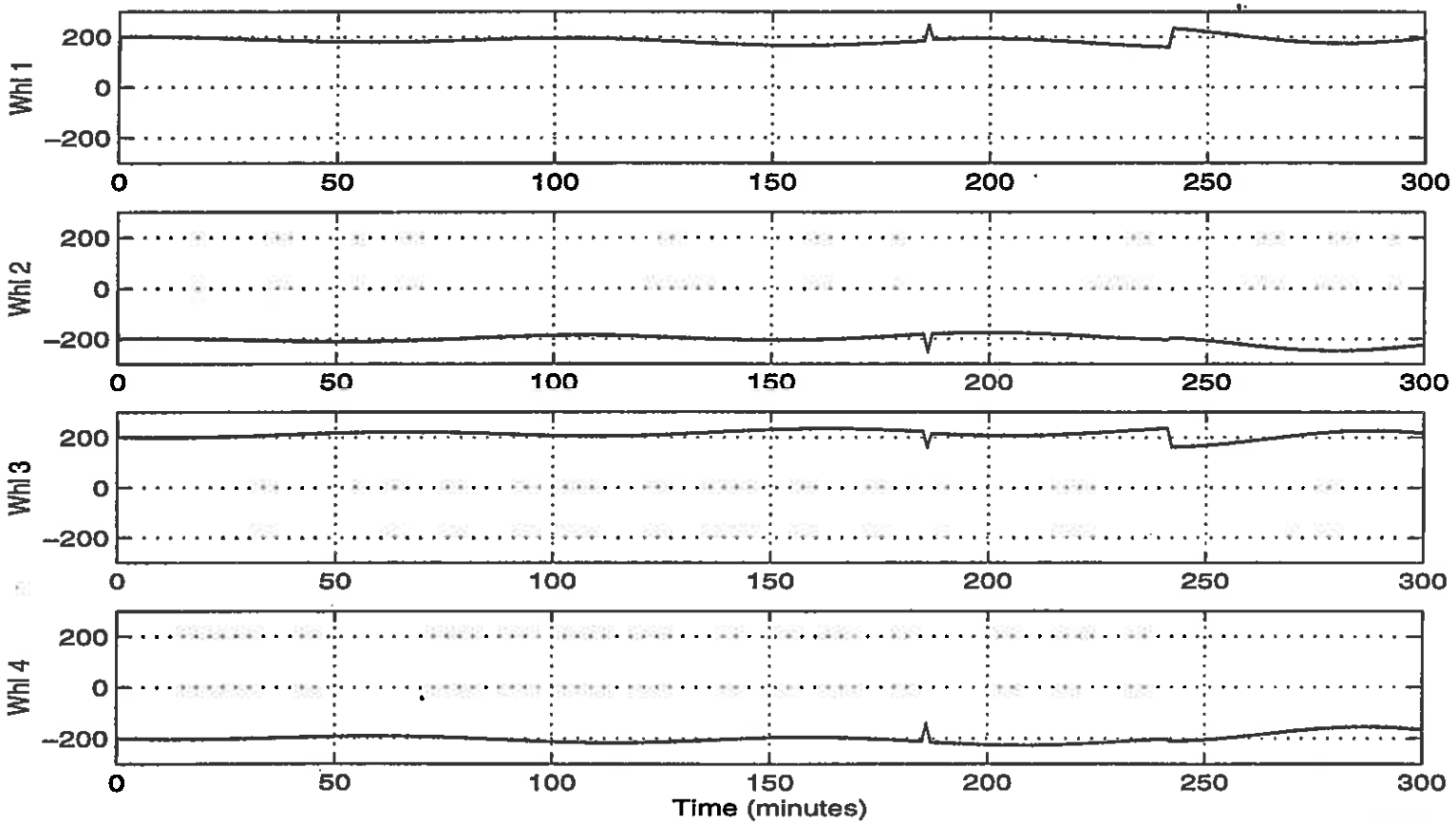
## Operational Mode S/C Rate Error, mrads/sec



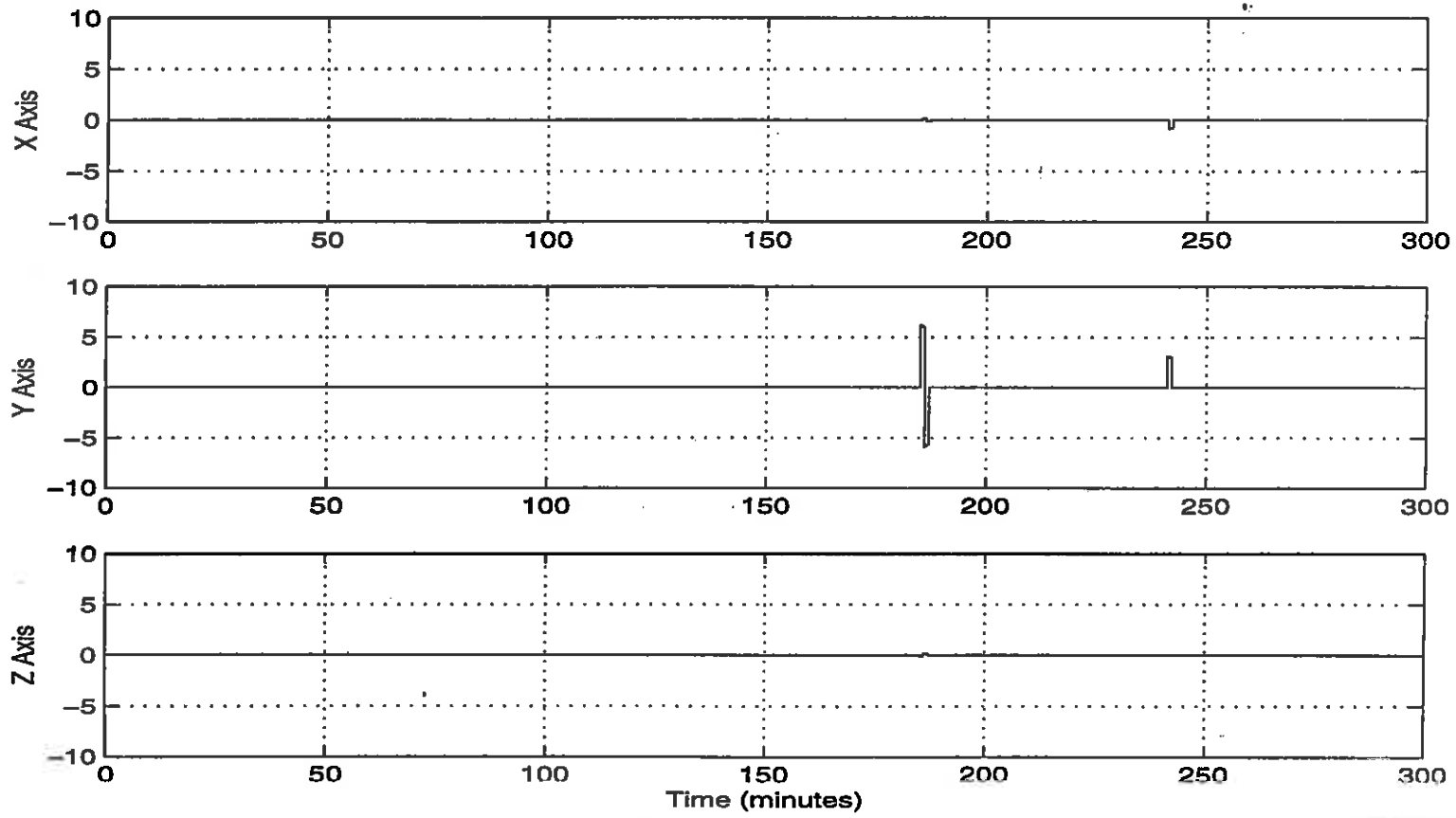
# TIMED

*Thermosphere • Ionosphere • Mesosphere • Energetics and Dynamics*

## Operational Mode Wheel Speed, rpm
## Maximum Speed 5100 rpm



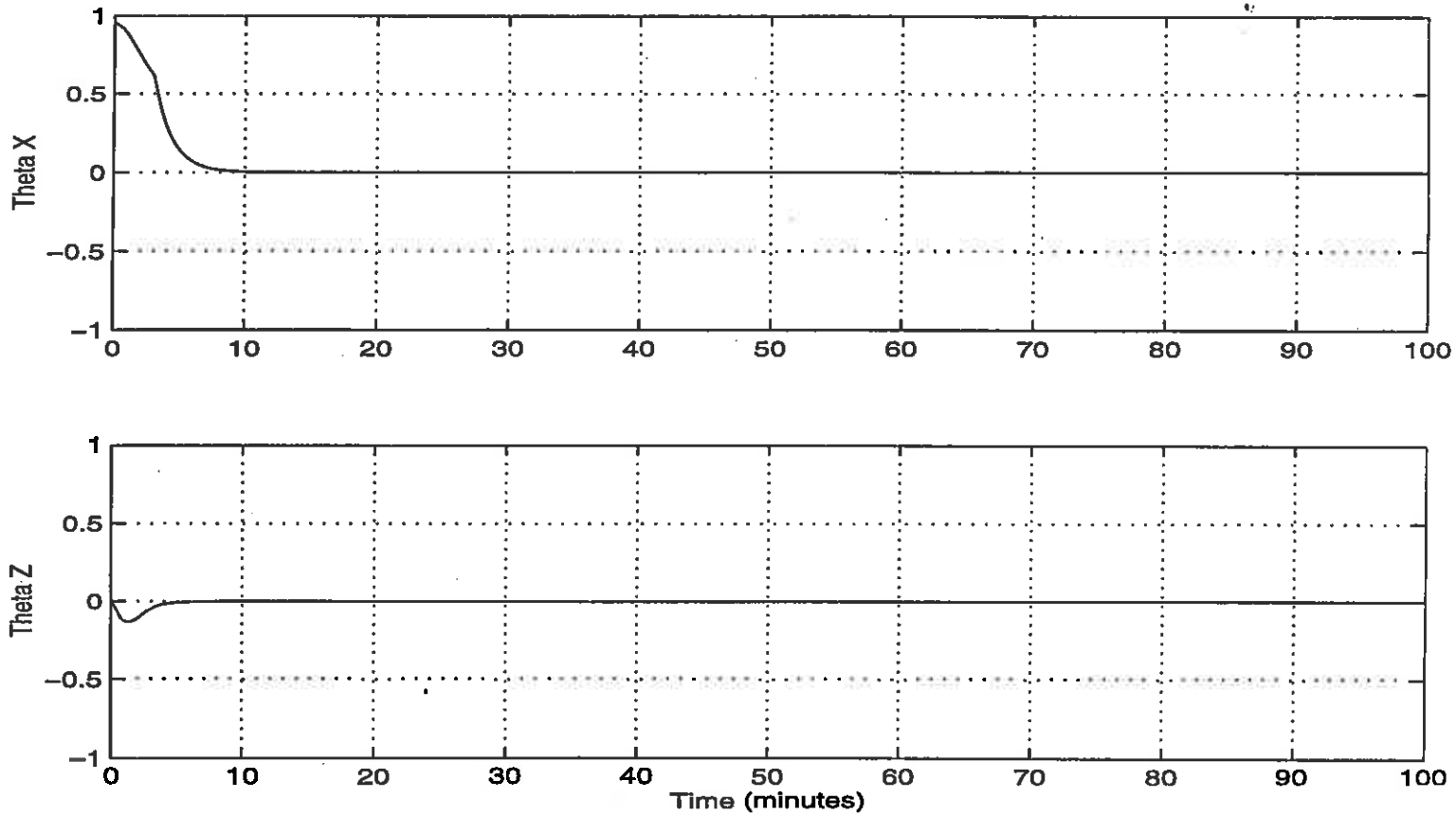
# Operational Mode Torque Rod Torque, mN-m



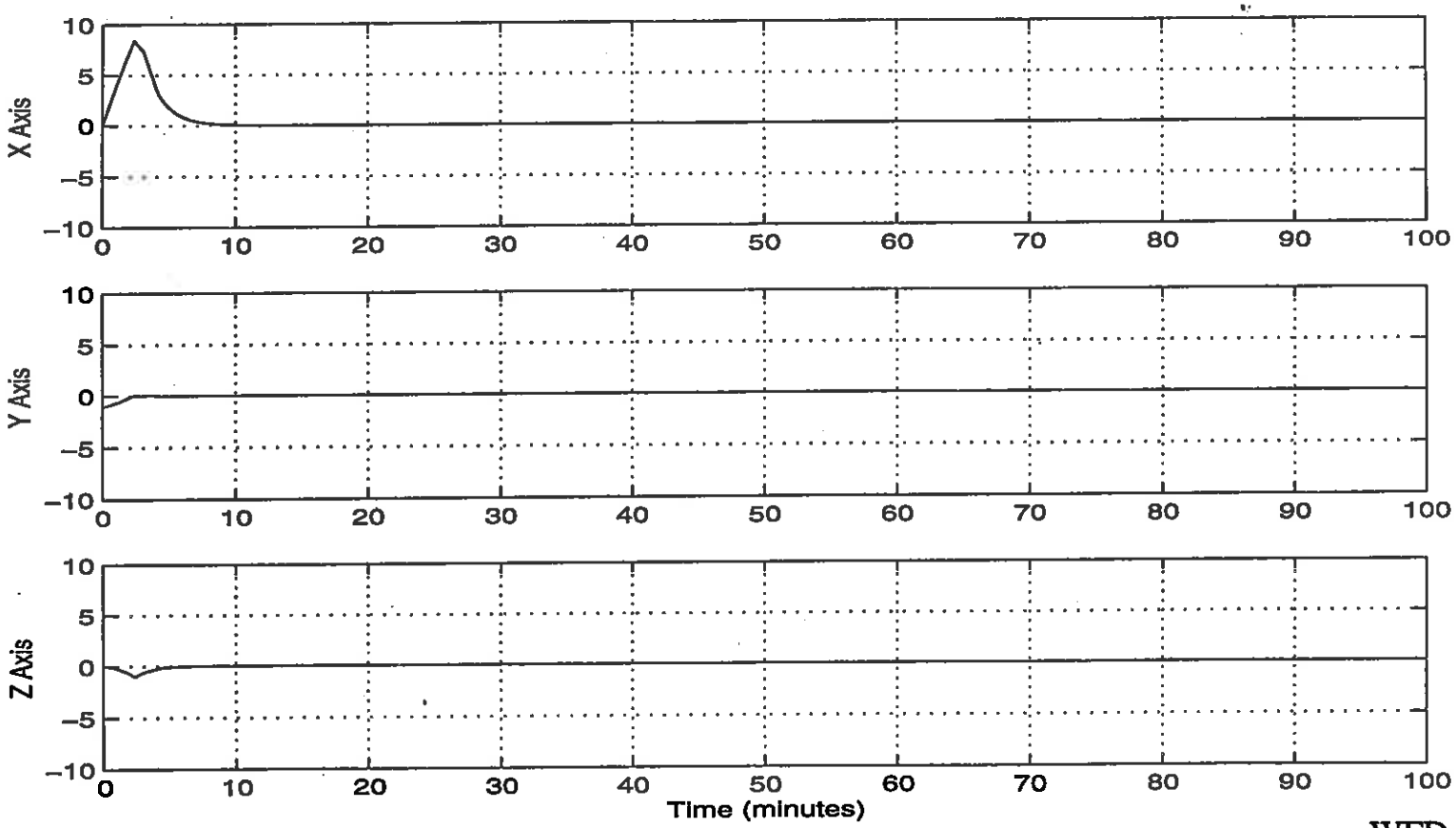
## Sun Safe Mode Simulation

- **Single orbit simulation**
- **Start with operational mode conditions**
- **Slew to attitude with -Y axis towards Sun**
- **Pointing control based on Sun sensors**
- **Rate control based on IRU**
- **Torque rod commanding every 60 seconds**

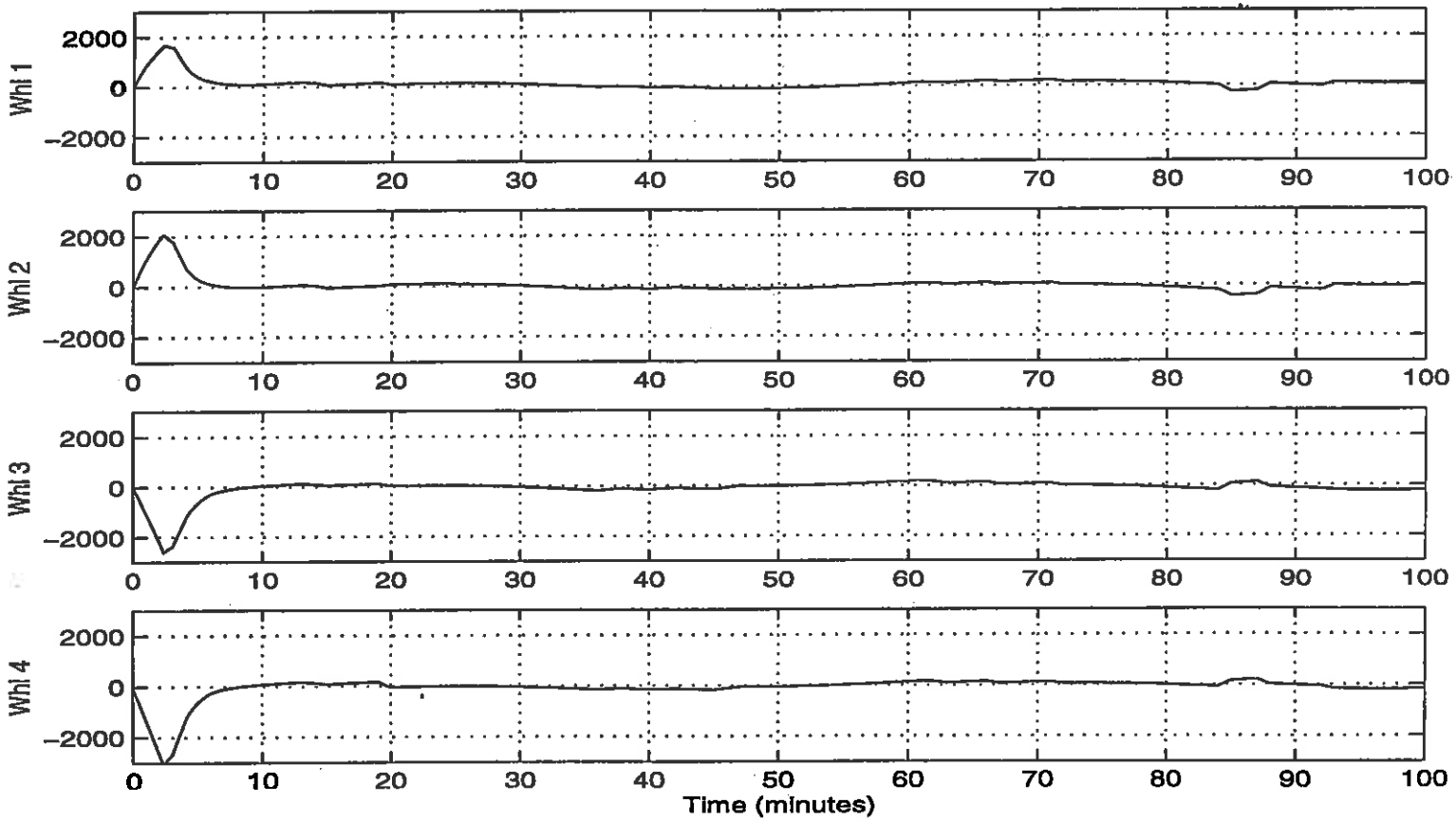
# Sun Safe Mode X and Z Axis Calculated Attitude Errors, rads



## Sun Safe Mode S/C Rate, mrads/sec



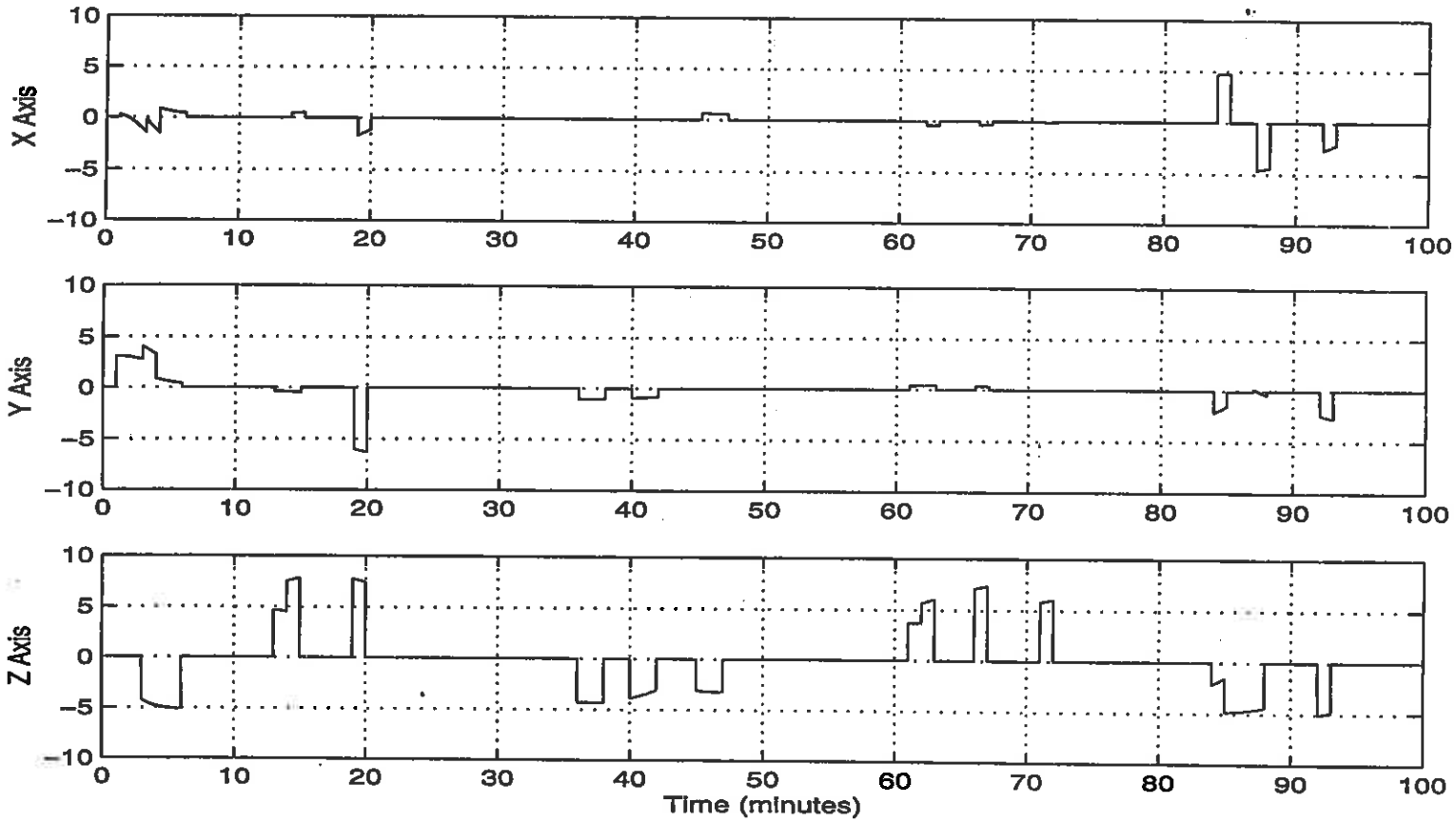
## Sun Safe Mode Wheel Speed, rpm
## Maximum Speed 5100 rpm



# TIMED

*Thermosphere • Ionosphere • Mesosphere • Energetics and Dynamics*

## Sun Safe Mode Torque Rod Torque, mN-m



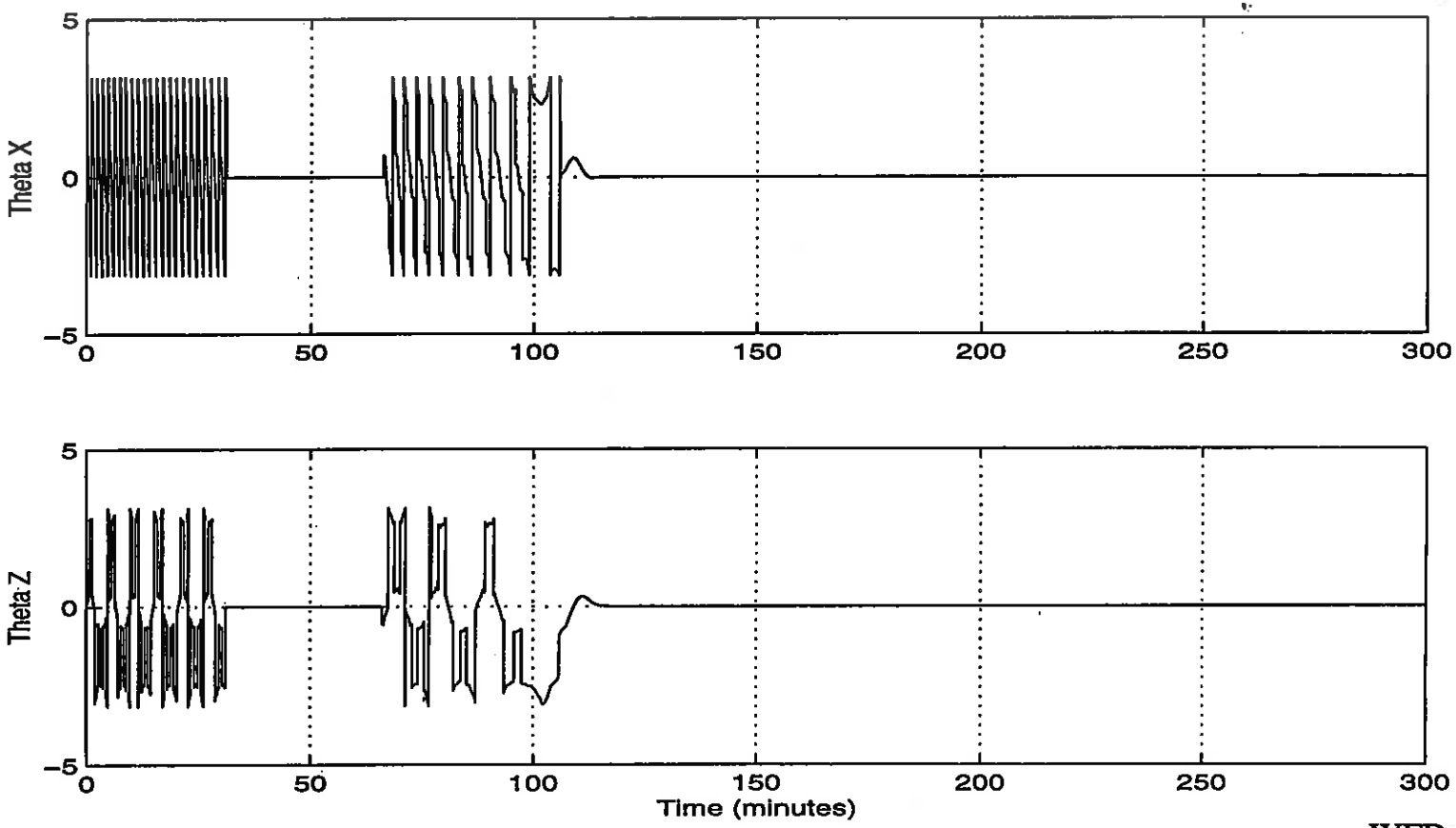
# *TIMED*


*Thermosphere • Ionosphere • Mesosphere • Energetics and Dynamics*

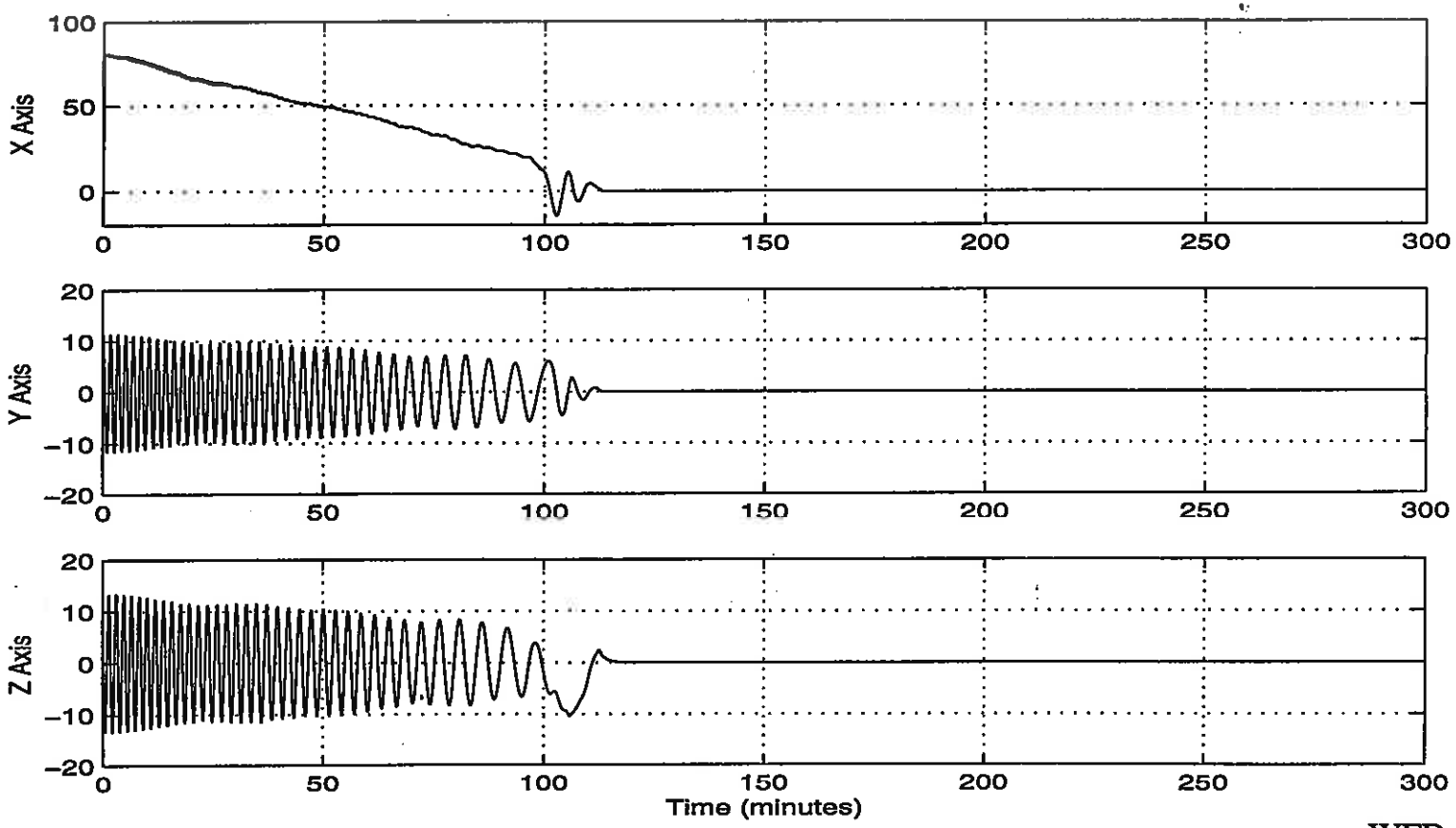
## Tip-Off Scenario Simulation

- **Three orbit simulation**
- **Initial rates of 4.65, 0.58, 0.33 deg/sec X-Y-Z in deployed configuration (corresponds to 5.0 deg/sec X and 2.5 deg/sec Y and Z tip-off rates)**
- **Use only torque rods, magnetometers, and Sun sensors during first orbit**
- **Command torque rods every second before wheels on, then every 60 seconds**
- **Command wheels after first orbit, ~97 minutes after separation**
- **Rate control always, angle control when wheels enabled and not in eclipse**

# Tip-Off Scenario X, Z Axis Calculated Attitude Errors, rads



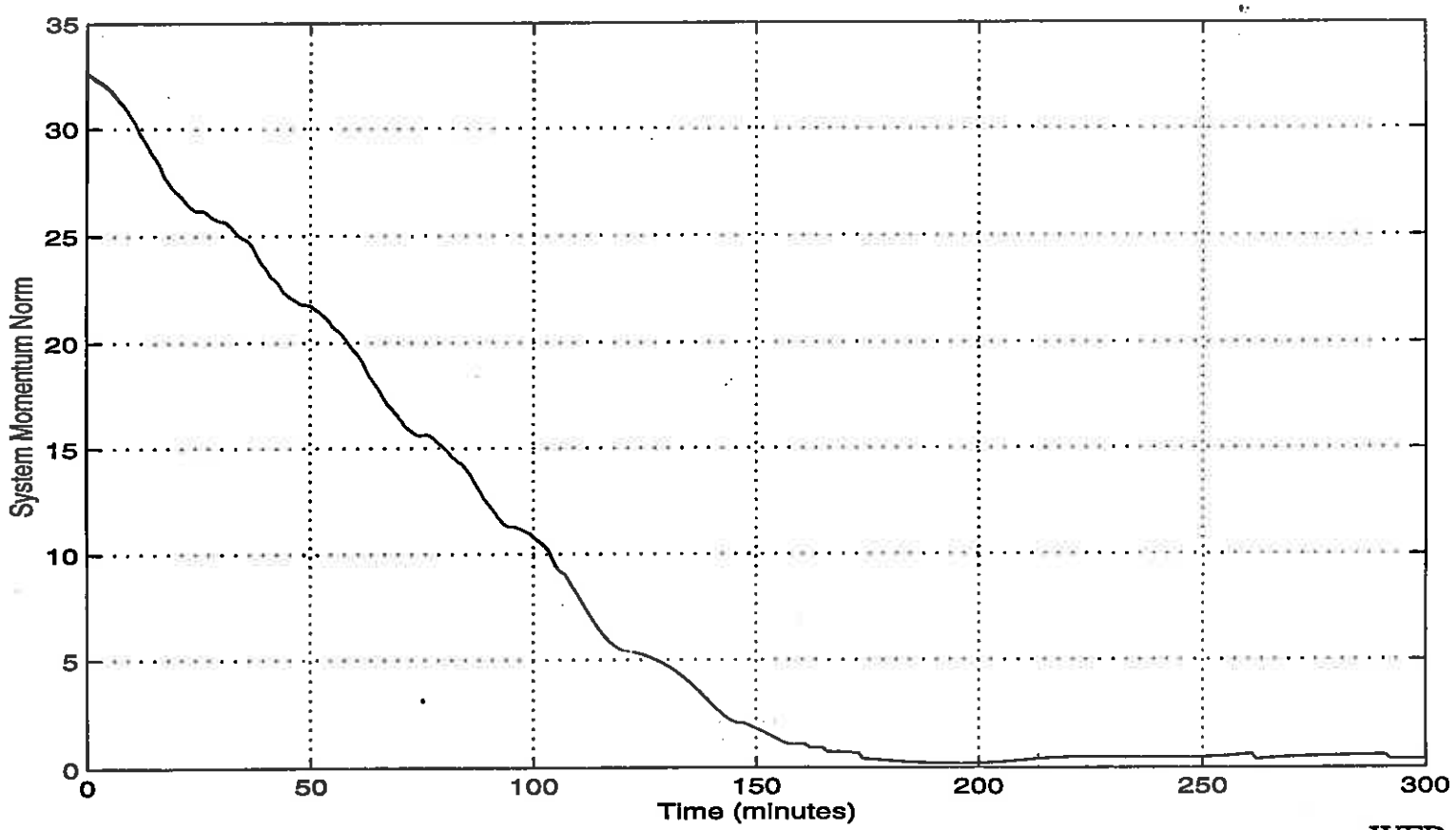
# Tip-Off Scenario S/C Rate, mrads/sec



# TIMED

*Thermosphere • Ionosphere • Mesosphere • Energetics and Dynamics*

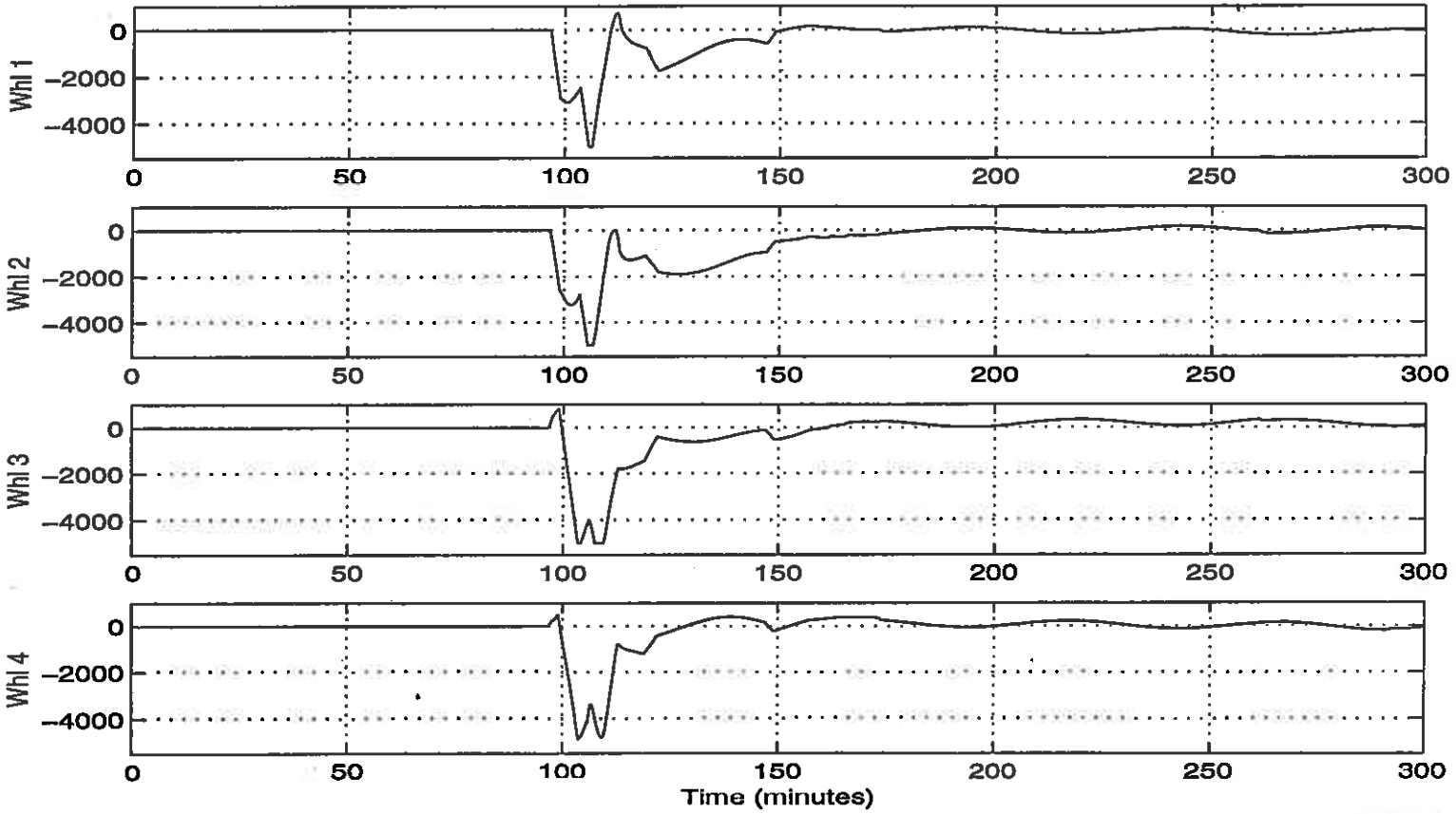
## Tip-Off Scenario System Momentum, N-m-s



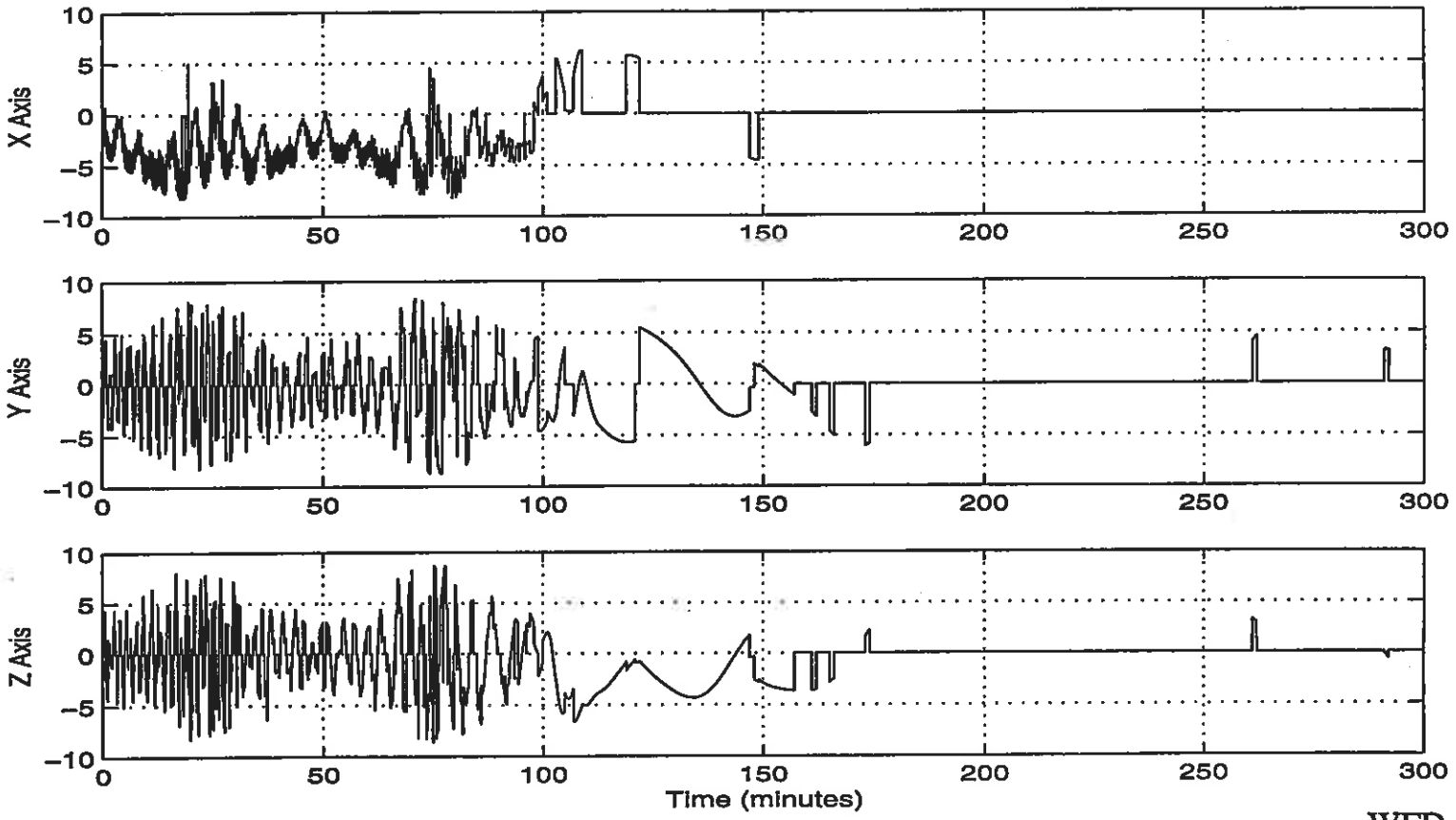
# TIMED


*Thermosphere • Ionosphere • Mesosphere • Energetics and Dynamics*

## Tip-Off Scenario Wheel Speed, rpm
## Maximum Speed 5100 rpm



# Tip-Off Scenario Torque Rod Torque, mN-m



# Continuing Work

- **Fine tuning of simulation models**
- **Attitude estimation filter**
- **Improve torque rod controller**
  - **Optimize duty cycle**
  - **Optimize hysteresis thresholds**
- **Tip-off scenario requires more study**
  - **Reduction in momentum directly related to quality of rate measurement**
  - **Improve rate estimation in absence of IRU**
- **Implement large simulation incorporating all modes**