Satellite with CMG ACS Simulation

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Cmg4sim.mdl is a Simulink program that models the motion a LEO satellite whose attitude is controlled by four control moment gyros (CMG). It has six jets to manage momentum excesses above a magnitude threshold. A simulation is presented with the satellite flying in a near circular 35 degree inclined orbit and with some user set arbitrary initial angular rate. The CMG ACS is enabled throughout the simulation to control the satellite attitude to the LVLH orientation. After 2000 seconds into the simulation, the angular momentum management function is enabled to fire jet thrusters to bring down the system angular momentum down to under 0.5 ft-lb-sec magnitude. The simulation runs for 1 orbit period of 6000 seconds.

The topics covered here are:

1. Cmg4sim Simulink Program
2. Cmg4sim Simulation Result
3. Cmg4sim Model Data

The Cmg4sim model configuration is:

```
b1(B)+-b2(A)+-w[1]
      |
      +-b3(A)+-w[2]
      |
      +-b4(A)+-w[3]
      |
      +-b5(A)+-w[4]
      |
      +-xf[1:6]
```

where b1 = satellite bus (B= 3dof rotational motion)
b2:5 = four CMG joints (A= 1 dof rotation)
w = wheels

1. Cmg4sim Simulink Program

The Cmg4sim Simulink Program is Cmg4sim.mdl as shown in figure 1. Its four processors are:

1) xsim1_150715.dll simulation engine
2) cmd_sig.m command signal generator
3) contrl.m CMG control signal generator
4) fmgr.m momentum management function for firing jets

The signal flow and the functionality of the these processors are summarized in the next table.

processor	input	output	function
xsim1	- model file=cmg4sim.txt - cmg 1:4 input torque - xf 1:6 jet on/off switches	- plot file=z.1 - cmg 1:4 angles - cmg 1:4 rates - w1= b1 ang rate - rpy=attd errors	- reads model file to setup the eom configuration, and integrates the eom - sends plot data to z.1 file - actuates cmg 1:4 and jets 1:6 per input signals
cmd_sig	- w1= b1 ang rate - rpy=attd error	- td = desired torque to null rpy	- computes a PD error signal td for cmg control
contrl	- cmg 1:4 angle - cmg 1:4 rates - w1= b1 ang rate - td = command torque	- htqax 2:5= cmg 1:4 input torque	- computes the cmg 1:4 input torque per td from cmd_sig
fmgr	- enable switch (t=2000) - 20 second clock - 25 ms clock - syshb1=sys ang momentum in b1 coord	-firing signals for jets 1:6 0=off 1=on	- when enabled, jets are fired at 20 sec increment. - Each firing is a three 25 ms pulses along one of six principle axes, i.e. +/-x,y,z.

Table 1. Signal Flow and Functionality of Cmg4sim.mdl Processors

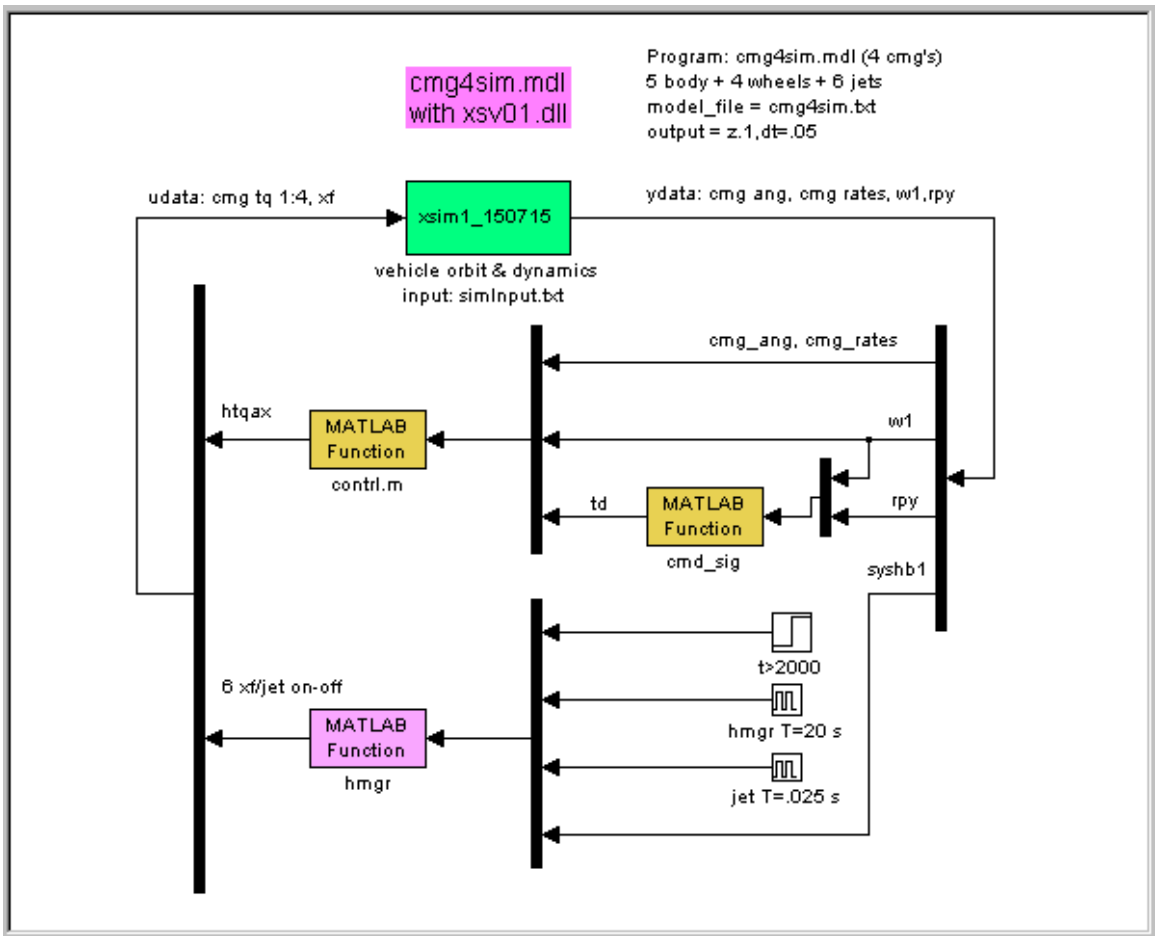
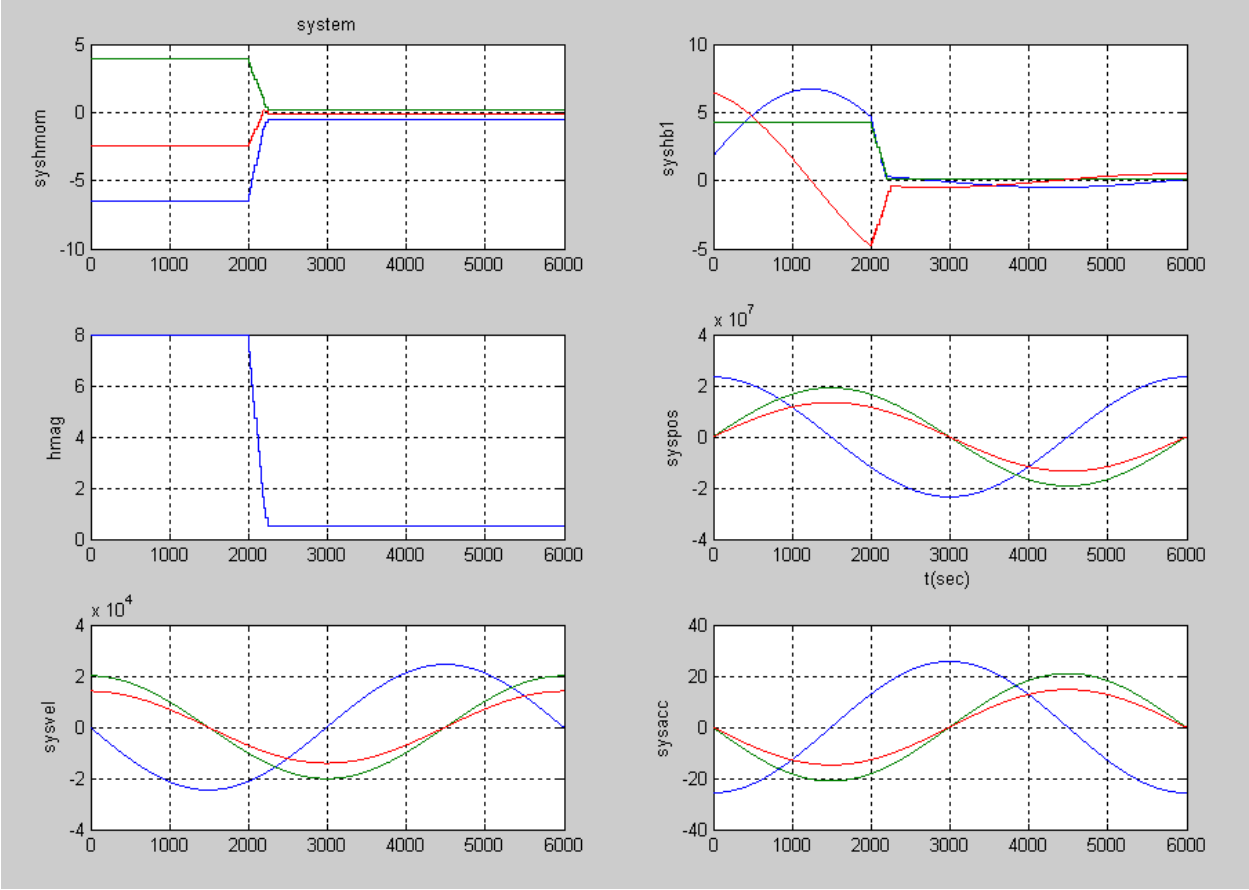


Figure 1 Simulink Program of Cmg4sim

2. Cmg4sim Simulation Result

Simulation scenario:
CMG rotors are set to 6000 rpm
Orbit: circular, 35 deg inclined, 100 minutes period.
Satellite angular vector is initialized to a non-orbital rate
CMG ACS is enabled to control vehicle attitude to LVLH orientation
The four CMG joint angles are set to the zero momentum position but they would move away from it to absorb excess angular momentum to maintain LVLH attitude
The momentum management function is enabled for t > 2000 sec to bring system angular momentum to under .5 ft-lbf-sec magnitude
Simulation runs for 1 orbit period of 6000 seconds.

Observations from the charts below: The system angular momentum, syshmom, is near constant for t < 2000 with an 8 ft-lb-sec magnitude because of a very small gravity gradient torque present. The momentum management jets start to fire from t=2000 once every 20 seconds and each time three 25 msec pulses to reduce the syshmom magnitude to under 0.5 ft-lbs. Once that goal is achieved, the firing essentially stops. The CMG maintains the satellite attitude at LVLH orientation throughout the simulation as the 2nd chart below shows.

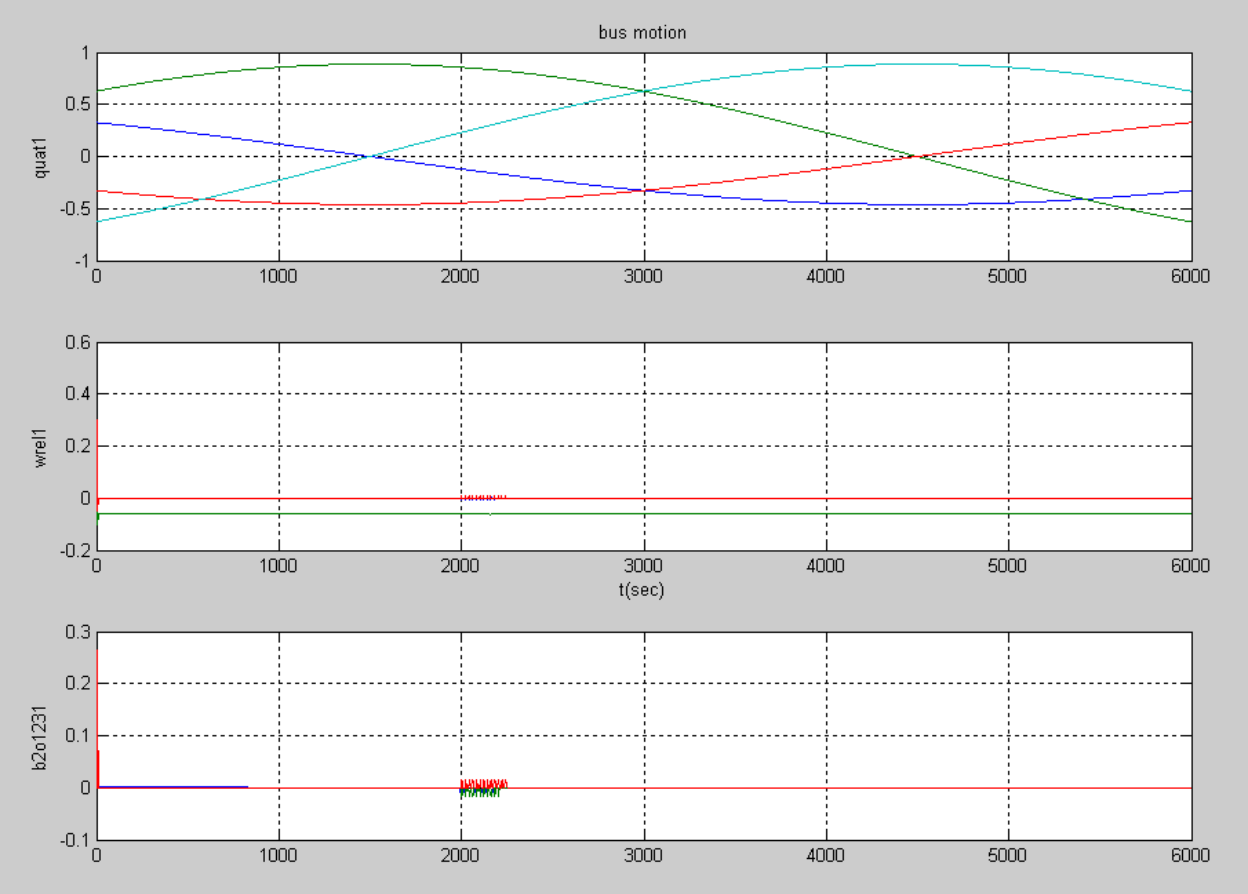


System Data

syshmom = system angular momentum in inertial coordinates

syshb1 = syshmom in b1 coordinates
hmag = magnitude of syshmom
syspos = system cm inertial position
sysvel = system cm inertial velocity
sysacc = system cm inertial acceleration

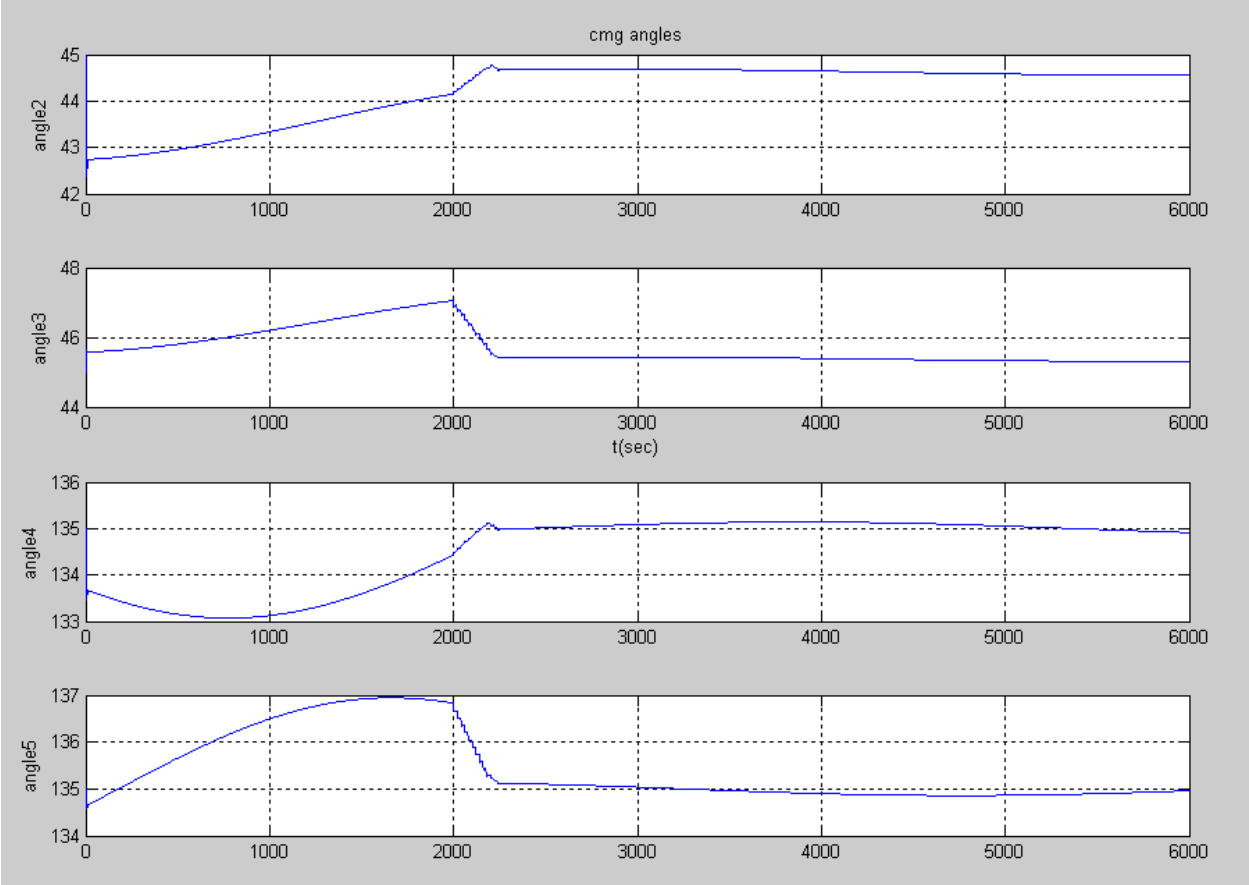
The next graphs are attitude and angular rate of the satellite. Note that the attitude disturbance for about 300 seconds after t=2000 are due to the momentum management jet firings.



Satellite Attitude and Angular Rate Vecotr

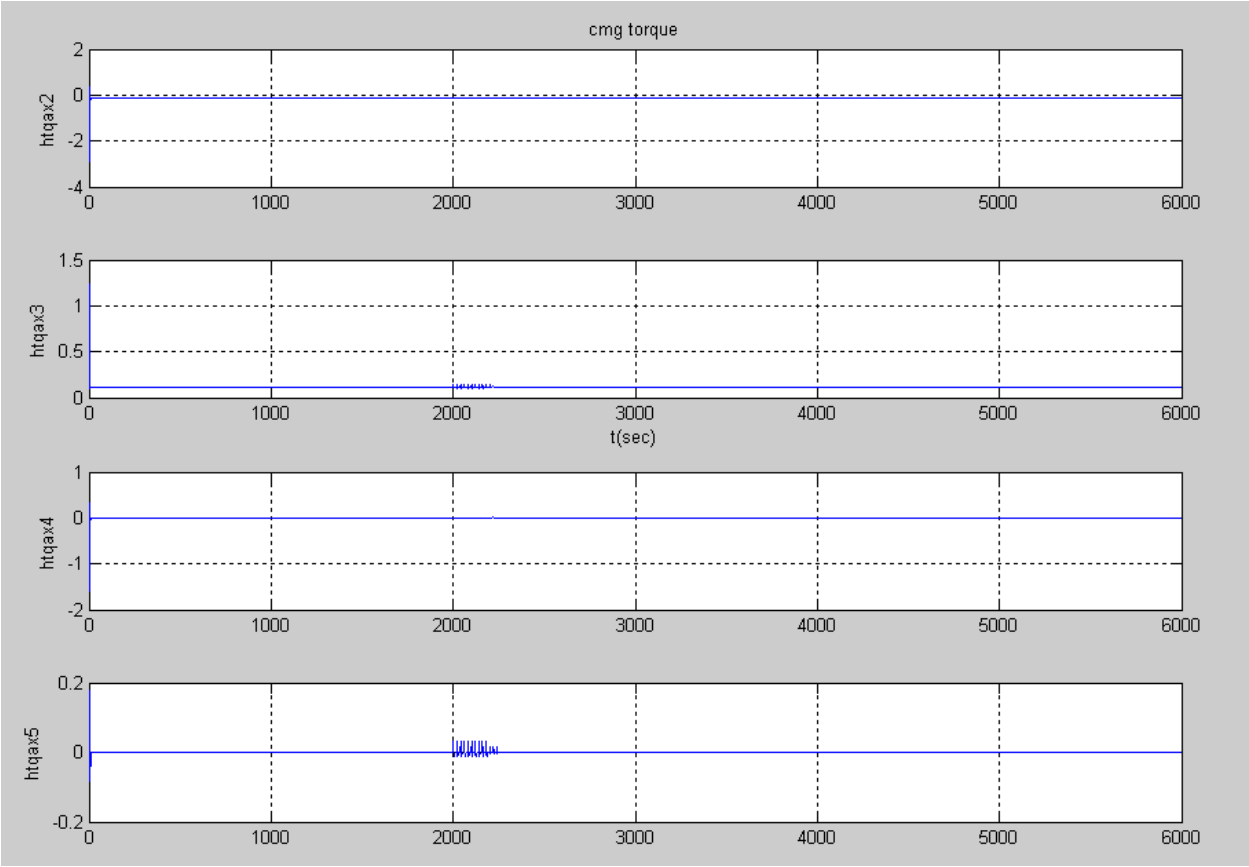
quat1= satellite inertial attitude quaternion
wrel1= satellite angular rate vector
b2o1231=satellite's roll pitch yaw angles wrt LVLH frame

The next graphs are the CMG 1:4 angles for the cmg4sat satellite. Note that the momentum management jets are fired to keep the CMG angles close to the [45, 45, 135, 135] configuration. That puts the system angular momentum to within +/- 0.5 ft-lbs of zero.



CMG 1:4 Angles

The next graphs are the input torque to CMG 1:4. Note the disturbance torque due to jet firings are small but not insignificant on the input torque to the CMG's after t=2000.



CMG 1:4 Input Torque

htqax2 = CMG1 input torque
htqax3 = CMG2 input torque
htqax4 = CMG3 input torque
htqax5 = CMG4 input torque

3. Model File

The model file for this program defines the construction and the computation of the equations of motion underlying Cmg4sim.mdl. It includes the mass property of the vehicle, the connectivity and dof's of bodies in the vehicle model. It defines the orbit this vehicle flies in. It sets the initial attitude and rate condition of the simulation. It defines the input/output signals of XSIM1.dll as well as the plot data sent to z.1 during run time.

The model data in cmg4sim.txt are divided into the following groups of information.

A. Configuration of the model
B. Mass property of the model
C. Initial relative angular rates
D. Static Orientations
E. Ephemeris of the orbit
F. Reaction wheel elements
G. Force elements
H. Simulation engine input
I. Simulation engine output
J. Simulation plot data

The memo will show what the data are and how to modify them using the Buildx.exe program.

A. Model Configuration

The Cmg4sim has the model configuration

```
b1(B)+-b2(A)+-w[1]
      |
      +-b3(A)+-w[2]
      |
      +-b4(A)+-w[3]
      |
      +-b5(A)+-w[4]
      |
      +-xf[1:6]
```

where b1 = satellite bus (B= 3dof rotational motion)
b2:5 = four CMG joints (A= 1 dof rotation)
w = wheels

This configuration is defined by the parent indices of the model objects. Note that one wheel is attached to each single axis CMG.

B. Mass Property

The mass column of next figure shows the mass of b1:b5 taken from the 'body' menu of Buildx.exe. The axis of motion, 'ax', for the CMG's are along the local 'x' axis. The 'ax' parameter does not apply to b1 because it's a 3 dof rotational joint. Local frame for b2:b5 means the static orientation of the CMG 1:4 bodies wrt the parent b1 frame. The 'pa' of b2:b5 are set to 1 because b1 is their parent body. The inboard joints of b2 to b5 are all one dof rotation joints with 'tp' set to 'A'. The motion type, 'tp', of b1 is set to B meaning that it has a 3 dof rotation w.r.t. the inertial reference frame. The data in the fl, vm, del_x columns are irrelevant for this simulation. The values under the 'angle' column means the initial rotation of the CMG frames from their static position in their respective local x-axis. These angles are chosen so that the plane formed from one pair of wheel axes (w1,w2) is orthogonal to the plane formed by the other pair (w3,w4) of wheel spin axes in the b1 frame.

	idx	name	pa	u	fl	vm	tp	ax	-- angle -	-- del_x -	----mass----
=>	1	b1	0	FPS	0	-	B	x	.000	.000	.100000E+03
	2	cmg1	1	FPS	0	-	A	x	45.000	.000	.100000E+01
	3	cmg2	1	FPS	0	-	A	x	45.000	.000	.100000E+01
	4	cmg3	1	FPS	0	-	A	x	135.000	.000	.100000E+01
	5	cmg4	1	FPS	0	-	A	x	135.000	.000	.100000E+01

Figure 2. Body Data from Body Menu

The next table displays the moment of inertia of b1:b3 in the order of ixx,iyy,izz,ixy,ixz and iyz. These are moi in local body coordinates.

	idx	name	- ixx -	- iyy -	- izz -
			---- ixy ---	---- ixz ---	---- iyz ---
=>	1	b1	.100000E+04	.120000E+04	.120000E+04
			.000000E+00	.000000E+00	.000000E+00
	2	cmg1	.500000E+01	.500000E+01	.500000E+01
			.000000E+00	.000000E+00	.000000E+00
	3	cmg2	.500000E+01	.500000E+01	.500000E+01
			.000000E+00	.000000E+00	.000000E+00
	4	cmg3	.500000E+01	.500000E+01	.500000E+01
			.000000E+00	.000000E+00	.000000E+00
	5	cmg4	.500000E+01	.500000E+01	.500000E+01
			.000000E+00	.000000E+00	.000000E+00

Figure 3. MOI Data from Moment of Inertia Menu

The next two are the svec and dvec definitions for b1:b3. The svec's are the positions of the body cm wrt to the inboard hinge in the local body coordinates, i.e. b2 to b5 frames.

	idx	name	u	----------	----svec----	----------
=>	1	b1	FPS	.000000E+00	.000000E+00	.000000E+00
	2	cmg1	FPS	.500000E+00	.000000E+00	.000000E+00
	3	cmg2	FPS	.500000E+00	.000000E+00	.000000E+00
	4	cmg3	FPS	.500000E+00	.000000E+00	.000000E+00
	5	cmg4	FPS	.500000E+00	.000000E+00	.000000E+00

Figure 4. Svec Data from Svec Menu

The dvec's are the joint position wrt to the inboard joint of the parent body in the parent body coordinates. In this case, dvec 2:5 are in b1 coordinates.

```
idx name        u ------------ ----dvec---- ------------
  1 b1        FPS  .000000E+00  .000000E+00  .000000E+00
  2 cmg1      FPS  .150000E+01  .000000E+00  .000000E+00
  3 cmg2      FPS -.150000E+01  .000000E+00  .000000E+00
  4 cmg3      FPS  .000000E+00  .150000E+01  .000000E+00
  5 cmg4      FPS  .000000E+00 -.150000E+01  .000000E+00
```

Figure 5. Dvec Data from Dvec Menu

The values of the body mass property can be changed using the instructions below.

Edit Mass Property

1. Start Buildx.exe and see Main Menu as in Figure 6.

```
*******************************************************
*          BBBB  U    U  I   L     DDDD   X    X      *
*          B   B U    U  I   L     D    D  X  X       *
*          BBBB  U    U  I   L     D    D   X         *
*          B   B U    U  I   L     D    D  X  X       *
*          BBBB   UUU    I   LLLL DDDD   X    X       *
*          ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~          *
*                  xsv version 1.0                    *
*                  copyright 2014                     *
*         concurrent dynamics international           *
*******************************************************


 simInputFile: sim1files.txt        < ENTERPRISE

  Model file < cmg4sim.txt
   Plot file > z.1
Summary file > sim1_summary.txt
Message file > sim1_message.txt
      plotDt = .10000E+01
```

Figure 6. Main Menu

Note that the model file is Cmg4sim.txt and the plot data are sent to the plot file, z.1.

2. Choose 'xsv' command at the Main Menu prompt to open Model_Menu page as shown in Figure 7.

3. Select 'body' command from Model Menu page (Fig. 6) to open Body_Menu. See Figure 2
   -use 'mass' command to edit mass of the bodies: follow the prompts

4. Select 'inr' command from Body_Menu to open MOI_Menu. See Figure 3.
   -use 'inr' command to edit moment of inertia of bodies: follow the prompts

5. Select 'svec' command from Body_Menu to open SVEC_Menu. See Figure 4.
   -use 'svec' command to edit svec of bodies: follow the prompts

6. Select ‘dvec’ command from Body_Menu to open DVEC_Menu. See Figure 5.
   -use ‘dvec’ command to edit dvec of bodies: follow the prompts

Select the ‘x’ command to exit the current menu. Select the ‘save’ command from the Model Menus page to save the current model data. Always follow the prompted instructions.

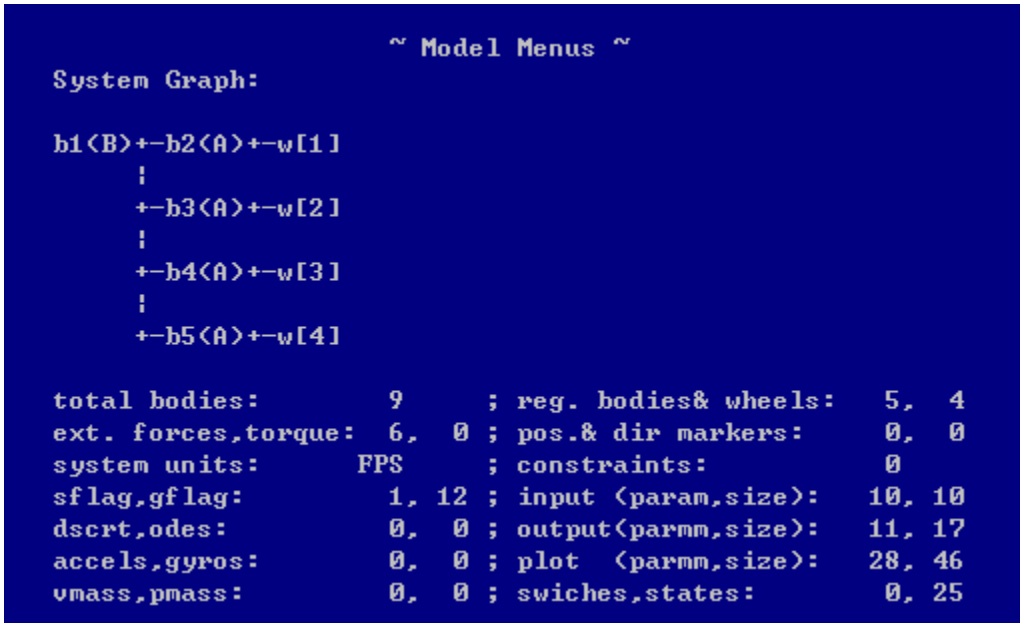


Figure 7. Model Menus

C. Initial Relative Rates

Go to the Relative Angular Rate Menu to set the initial angular rates of bodies relative to their parents. This applies to A and B type bodies. Figure 7 is that menu for Cmg4sim. Tp=B means the joint has 3 rotational dof relative to its parent. Tp=A means that the joint has 1 rotational dof relative to its parent. The initial angular rate of b1 for this case is set to an arbitrary [.1, .2, .3] deg/sec. Initial angular rates of all CMG's are zero for this simulation, wrel(2:5)=0.

	idx	name	tp	ax	----------	--wrel(d/s)-	----------
=>	1	b1	B	x	.100000E+00	.200000E+00	.300000E+00
	2	cmg1	A	x	.000000E+00	.000000E+00	.000000E+00
	3	cmg2	A	x	.000000E+00	.000000E+00	.000000E+00
	4	cmg3	A	x	.000000E+00	.000000E+00	.000000E+00
	5	cmg4	A	x	.000000E+00	.000000E+00	.000000E+00

Figure 8 Relative Angular Rate Menu for Cmg4sim

Edit Initial Relative Body Rates
Select the 'wrel' command from Body Menu page to open the Relative Angular Rate Menu. See Figure 8.

change body bi's rate relative to its parent in bi coordinates:

- use 'wrel<i>' command to change the inboard joint relative rate of bi: follow prompt instructions

Select the 'x' command to exit the menu. Select the 'save' command from the Model Menus page to save the current model data. Always follow the prompted instructions.

D. Static Orientations

The static orientations of each of the CMG's relative to their parent, the satellite, are set in the Body Menus of b2 to b5. These are shown next.

```
> dcm0          =    1.000000      .000000      .000000
                       .000000     1.000000      .000000
                       .000000      .000000     1.000000
```

Figure 9a Static Attitude of b2 (CMG1) wrt b1

```
> dcm0          =   -1.000000      .000000      .000000
                       .000000    -1.000000      .000000
                       .000000      .000000     1.000000
```

Figure 9b Static Attitude of b3 (CMG2) wrt b1

```
> dcm0          =     .000000    -1.000000      .000000
                      1.000000      .000000      .000000
                       .000000      .000000     1.000000
```

Figure 9c Static Attitude of b4 (CMG3) wrt b1

```
> dcm0          =     .000000     1.000000      .000000
                     -1.000000      .000000      .000000
                       .000000      .000000     1.000000
```

Figure 9d Static Attitude of b5 (CMG4) wrt b1

Since the free axis of b2:b5 are all local x-axis, that means the first column of each of the four figures 9a:9d are the g_i axis of the respective bodies in b1 coordinates.

Edit Static Orientation of bodies relative to their respective parents

Select the 'edit<j>' command from Body Menu page to open the Body Menu of bj. For example, type 'edit2' form Body Menu to see figure 9a in b2 Body Menu. Type 'edit3' to see figure 9b in b3 Body Menu and so forth.

change body bi's static orientation relative to its parent:

- use 'dcm' command to change the static orientation of bi relative to its parent: follow prompt instructions

Select the 'x' command to exit the menu. Select the 'save' command from the Model Menus page to save the current model data. Always follow the prompted instructions.

E. Ephemeris

The orbit is specified by the 'grav' menu in Buildx.exe. The Cmg4sim has the following orbit information.

```
                    ~ gravity Menu ~

> units      (U)=  FPS
> syspos        =    23414159.748          33.301          23.317
> sysvel        =            -.043       20084.993       14063.663

> refpos        =    23414159.748          33.301          23.317
> refvel        =            -.043       20084.993       14063.663

  gravity:
> gx gy gz      =  -25.6764946431    -.0000365183    -.0000255704
  mu            =  .140764418E+17

  ephemeris:
> semimajor (U)=    23414159.748
> ecc           =      .000000
> incl    (deg)=    35.000000
> rasc    (deg)=      .000000
> argp    (deg)=      .000000
> t_anom  (deg)=      .000099
  e_anom  (deg)=      .000099
  m_anom  (deg)=      .000099
  m_motion(d/s)=    .05999999

> LST_ang (deg)=  268.694913    ; sun_beta(deg)=     .000
> LST(h:m:s)    = 17:54:46.8

> period  (min)=         100.000; revs/day=  14.400
> period  (sec)=        6000.001
  range      (U)=    23414159.748
  equ. radius   =    20925646.325; J2=  .108263E-02
  prg.altitude  =     2488513.423; apg.altitude=     2488513.423
  we  (d/s,r/s)=       .00417807       .00007292

> sysacc flag   =  1
> gravity flag  = 12
```

Figure 10. Gravity Menu

This orbit specification shows that the Cmg4sim is in a 35 degree inclined circular orbit (ecc= 0) with a period of 100 minutes. The gravity flag of 12 means that the gravity model for the simulation is the aspherical earth gravity model with J2, J3 and J4 terms and with gravity gradient between the bodies.

The orbit parameters in the gravity menu can be changed using the following instructions.

Edit Ephemeris
Select ‘grav’ command from the Models Menu page to open the Gravity Menu. See Figure 10.

change ephemeris data:
- use ‘semi’ command to change the semi-major axis
- use ‘ecc’ command to change the eccentricity
- and so forth to modify ephemeris data
- note: other variables, i.e. syspos, sysvel, refpos, refvel, are automatically changed with changed ephemeris data

change orbit period:
- use ‘perm’ command to change orbit period in minutes
- use ‘pers’ command to change orbit period in seconds
- note: all other affected ephemeris data are automatically changed

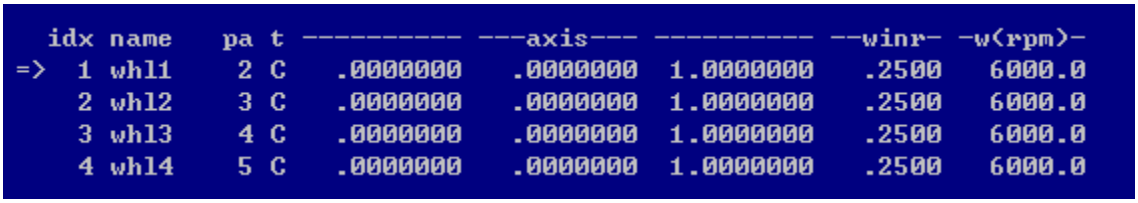
change syspos, sysvel, refpos, refvel:
- use ‘spos’ command to change syspos
- use ‘svel’ command to change sysvel
- use ‘rpos’ command to change refpos
- use ‘rvel’ command to change refvel
- note: all other affected ephemeris data are automatically changed

change gravity model:
- use ‘gflag’ command to select gravity model
  - gflag= 10 means spherical earth gravity (seg)
    11 means seg with gravity gradient (gg)
    12 means seg with gg and gg torque
    20 means oblate earth gravity with J2 effect (gJ2)
    21 means gJ2 with gg
    22 maans gJ2 with gg and gg torque
    30 means oblate earth gravity with J2, J3 and J4 effects
    31 means gJ234 with gg
    32 means gJ234 with gg and gg torque

Select the ‘x’ command to exit the menu. Select the ‘save’ command from this page to save the current model data. Always follow the prompted instructions.

F. Reaction Wheels

The Cmg4sim here has 4 wheels each attached to a single axis CMG. The wheel spin axis is oriented orthogonally with respect to the control axis of the CMG. All wheel speeds are set to 6000 rpm. These CMG's are used to control the satellite attitude.



	idx	name	pa	t	---axis---			--winr-	-w(rpm)-
=>	1	whl1	2	C	.0000000	.0000000	1.0000000	.2500	6000.0
	2	whl2	3	C	.0000000	.0000000	1.0000000	.2500	6000.0
	3	whl3	4	C	.0000000	.0000000	1.0000000	.2500	6000.0
	4	whl4	5	C	.0000000	.0000000	1.0000000	.2500	6000.0

Figure 11. Wheel Data from Wheel Menu

This figure shows that wheels 1 is attached to b2 (pa=2). Wheels 2 is attached to b3 (pa=3), and so forth. Their types are all 'C' meaning that they constrained to the set value of 6000 rpm in this example. The axis column shows the spinning axes of the wheels in the attached body coordinates in the local parent body frame. 'winr' column is the wheel spinning axis moment of inertia. The 'rpm' column are the initial spinning speed of the wheels.

The values of the wheel parameters in the Wheel Menu can be changed using the following instructions.

Edit Reaction Wheel Parameters
Select the 'whl' command from Model Menus page to open the Wheel Menu. See Figure 11.

change wheel functionality type:
- use 'type' command to change the wheel axis: follow prompt instructions
  type=A means that torque to the wheel is expected from xsim1.dll-input
  type=C means that the wheel speed is fixed or constrained

change wheel axis on the attached body:
- use 'axis' command to change the wheel axis: follow prompt instructions

change wheel inertia about wheel axis:
- use 'winr' command to change the wheel axis inertia: follow prompt instructions

change wheel spin rate:
- use 'rpm' command to change the wheel spin rate in rpm: follow prompt instructions

Select the 'x' command to exit the menu. Select the 'save' command from the Model Menus page to save the current model data. Always follow the prompted instructions.

G. Jet Forces

Cmg4sim here has six jets forces implemented. Their purpose is to manage excess angular momentum that can cause CMG singularities. In this example, the 6 jets are positioned and angled so that each jet firing produces a torque along one of the 6 principle axes, {±x-axis, ±y-axis, ±z-axis}. See figure 12.

	idx	name	p	t	c	---fmag---	----fx----	----fy----	----fz----
=>	1	f1	1	1	1	2.000	2.000	.000	.000
	2	f2	1	1	1	2.000	2.000	.000	.000
	3	f3	1	1	1	2.000	2.000	.000	.000
	4	f4	1	1	1	2.000	2.000	.000	.000
	5	f5	1	1	1	2.000	.000	-2.000	.000
	6	f6	1	1	1	2.000	.000	-2.000	.000

Figure 12 Jet Force Data from Force Menu

The location of the jets are shown in the next figure.

	idx	name	p	t	c	---fmag---	---posx---	---posy---	---posz---
=>	1	f1	1	1	1	2.000	-5.000	-5.000	.000
	2	f2	1	1	1	2.000	-5.000	5.000	.000
	3	f3	1	1	1	2.000	-5.000	.000	5.000
	4	f4	1	1	1	2.000	-5.000	.000	-5.000
	5	f5	1	1	1	2.000	.000	5.000	5.000
	6	f6	1	1	1	2.000	.000	5.000	-5.000

Figure 13 Jet Locations on b1

The next figure shows the torque produced by the 2 lbf jets when fired.

	idx	name	---tqmag--	---tqx----	---tqy----	---tqz----
=>	1	f1	10.000	.000	.000	10.000
	2	f2	10.000	.000	.000	-10.000
	3	f3	10.000	.000	10.000	.000
	4	f4	10.000	.000	-10.000	.000
	5	f5	10.000	10.000	.000	.000
	6	f6	10.000	-10.000	.000	.000

Figure 14 Torque by each jet

Use the following instructions to add and edit force parameters.

Edit Force Parameters
Select the 'force' command from Model Menus page to open the Force Menu. See Figure 12.

change force vectors in the list:
- use 'fvec' command to change the force vector: follow prompt instructions

change force magnitudes in the list:

- use ‘fmag’ command to change the force vector: follow prompt instructions

change force positions in the list:

- use ‘fpos’ command to change the force position: follow prompt instructions

display force vectors:

- use ‘vec’ command to display force vectors. See figure 12

display force positions:

- use ‘pos’ command to display force positions. See figure 13.

display torque vectors:

- use ‘rxf’ command to display force positions. See figure 14.

add forces:

- use ‘add’ command: flow promt instructions

remove forces:

- use ‘rem’ command: flow promt instructions

Select the ‘x’ command to exit the menu. Select the ‘save’ command from this page or the Model Menus page to save the current model data. Always follow the prompted instructions.

H. Simulation Engine Input

The signals required by xsim1.dll (simulation engine) for the Cmg4sim are in the next table.

```
Udata list:

 1) htqax,2          ¦ 2) htqax,3          ¦ 3) htqax,4
 4) htqax,5          ¦ 5) xf,1             ¦ 6) xf,2
 7) xf,3             ¦ 8) xf,4             ¦ 9) xf,5
10) xf,6
```

Figure 15 Udata List from the Input Data Menu for Cmg4sim

where htqax,2:5 = CMG input torque to b2:b5
xf,1:6 = jet 1:6 on/off switches

The size of each of these signals are as follows.

```
> len
  #   uDef        Len Loc   #   uDef        Len Loc
  1. htqax,2       1   1¦   2. htqax,3       1   2
  3. htqax,4       1   3¦   4. htqax,5       1   4
  5. xf,1          1   5¦   6. xf,2          1   6
  7. xf,3          1   7¦   8. xf,4          1   8
  9. xf,5          1   9¦  10. xf,6          1  10
```

Figure 16 Length of Udata Elements for Cmg4sim

Use the following instructions to change or edit the xsim input list.

Edit XSIM Inut Data
Select the 'input' command from Model Menus page to open the (XSIM) Input Menu. See Figure 15.

append new data to the input list:
- use 'add' command to add data to the list
  > this opens a data selection menu
- use 'sel<k>' to add selected kth parameter to the list
- use 'x' to exit the selection

insert new data to the input list:
- use 'add<j>' command to insert data before the j-th data in the list
  > this opens a data selection menu
- use 'sel<k>' to add selected kth parameter to the list
- use 'x' to exit the selection

change data in the input list:
- use 'chg<j>' command to change the j-th data in the list
  > this opens a data selection menu
- use 'sel<k>' to add selected kth parameter to the list
- use 'x' to exit the selection

remove data from the list:

- use ‘rem’ command to remove one or more data in the list: follow prompt instructions

see data length or dimensions of data in the list as shown in Figure 16:

- use ‘len’ command to see size of data in the list

Select the ‘x’ command to exit the menu. Select the ‘save’ command from the Model Menus page to save the current model data. Always follow the prompted instructions.

I. Simulation Engine Output

These are the signals that xsim1.dll (simulation engine) output to the Simulink workspace for control purposes. Cmg4sim's output data are in the next table.

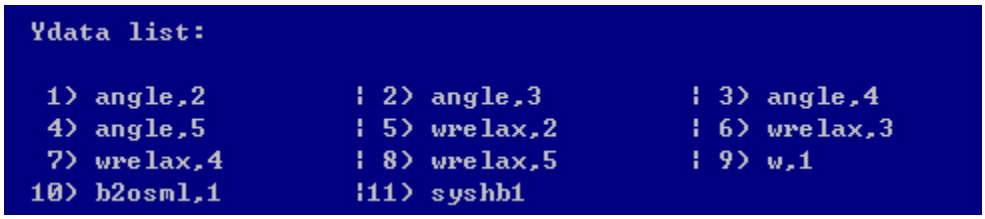


Figure 17 XSIM Output Data from Output Menu for Cmg4sim

where angle, 2:5 = cmg 1:4 input joint angles
wrel,2:5 = cmg 1:4 input joint rates
w,1 = satellite (b1) angular rate vector in b1 coordinates
hvelr,2 = tether displacement rate vector
b2osml,1 = satellite's (b1) roll, pitch and yaw attitude errors
syshb1 = total system angular momentum in b1 coordinates

The size of each of these signals are shown under the 'len' column next.

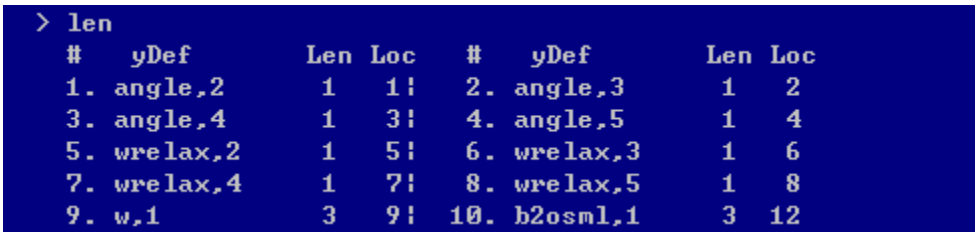


Figure 18 XSIM Output Data Size for Cmg4sim

The parameters in the Xsim output list can be changed using the following instructions.

Edit XSIM Output Data
Select the 'output' command from Model Menus page to open the (XSIM) Output Menu. See Figure 17.

append new data to the input list:
- use 'add' command to add data to the list: follow prompt instructions
  > this opens a data selection menu
- use 'sel<k>' to add selected kth parameter to the list
- use 'x' to exit the selection

insert new data to the input list:
- use 'add<j>' command to insert data before the j-th data in the list
  > this opens a data selection menu
- use 'sel<k>' to add selected kth parameter to the list
- use 'x' to exit the selection

change data in the input list:
- use 'chg<j>' command to change the j-th data in the list

> this opens a data selection menu
- use ‘sel<k>’ to add selected kth parameter to the list
- use ‘x’ to exit the selection

remove data from the list:
- use ‘rem’ command to remove one or more data in the list: follow prompt instructions

see data length or dimensions of data in the list as shown in Figure 18:
- use ‘len’ command to see size of data in the list

Select the ‘x’ command to exit the menu. Select the ‘save’ command from the Model Menus page to save the current model data. Always follow the prompted instructions.

J. Simulation Plot Data

The time response of signals selected for performance evaluation are saved in the plot_file=z.1. These signals are listed in the next table.

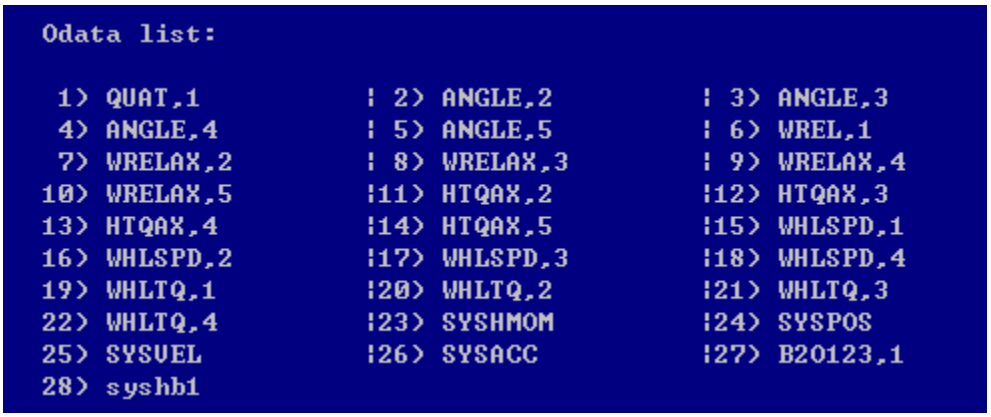


Figure 19 XSIM Plot Data List from Plot Menu for Cmg4sim

where, quat,1 = attitude quaternion of b1
angle, 2:5 = cmg 1:4 input angles
wrel,2:5 = cmg 1:4 input angular rates
htqax,2:5 = cmg 1:4 input joint torque
whlspd, 1:4 = cmg 1:4 rotor speed
whltq, 1:4 = cmg 1:4 rotor input torque (0 for cmg4sim)
syshmom = Cmg4sim total angular momentum about system cm
syspos = composite tether cm position in inertial frame
sysvel = composite tether cm velocity in inertial frame
sysacc = system cm acceleration vector in inertial coordinates
b2osml,1 = b1 roll-pitch-yaw relative to orbit frame
syshb1 = syshmom in b1 coordinates

The size of each of these signals are shown under the ‘len’ column next.

```
> len
  #   oDef        Len Loc    #   oDef        Len Loc
  1. QUAT,1        4   2¦   2. ANGLE,2       1   6
  3. ANGLE,3       1   7¦   4. ANGLE,4       1   8
  5. ANGLE,5       1   9¦   6. WREL,1        3  10
  7. WRELAX,2      1  13¦   8. WRELAX,3      1  14
  9. WRELAX,4      1  15¦  10. WRELAX,5      1  16
 11. HTQAX,2       1  17¦  12. HTQAX,3       1  18
 13. HTQAX,4       1  19¦  14. HTQAX,5       1  20
 15. WHLSPD,1      1  21¦  16. WHLSPD,2      1  22
 17. WHLSPD,3      1  23¦  18. WHLSPD,4      1  24
 19. WHLTQ,1       1  25¦  20. WHLTQ,2       1  26
 21. WHLTQ,3       1  27¦  22. WHLTQ,4       1  28
 23. SYSHMOM       3  29¦  24. SYSPOS        3  32
 25. SYSVEL        3  35¦  26. SYSACC        3  38
 27. B20123,1      3  41¦  28. syshb1        3  44
```

Figure 20 Data Size of Plot Data for Cmg4sim

The parameters in the Xsim plot data list can be changed using the following instructions.

Edit XSIM Plot Data

Select the ‘plot’ command from Model Menus page to open the (XSIM) Plot Menu. See Figure 19.

append new data to the input list:

- use ‘add’ command to add data to the list
  > this opens a data selection menu
- use ‘sel<k>’ to add selected kth parameter to the list
- use ‘x’ to exit the selection

insert new data to the input list:

- use ‘add<j>’ command to insert data before the j-th data in the list
  > this opens a data selection menu
- use ‘sel<k>’ to add selected kth parameter to the list
- use ‘x’ to exit the selection

change data in the input list:

- use ‘chg<j>’ command to change the j-th data in the list
  > this opens a data selection menu
- use ‘sel<k>’ to add selected kth parameter to the list
- use ‘x’ to exit the selection

remove data from the list:

- use ‘rem’ command to remove one or more data in the list: follow prompt instructions

see size of data in the list as shown in Figure 20:

- use ‘len’ command to see size of data in the list

Select the ‘x’ command to exit the menu. Select the ‘save’ command from the Model Menus page to save the current model data. Always follow the prompted instructions.