Tethersim with RWA ACS

Concurrent Dynamics International

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Tethersim.mdl is a Simulink program that simulates the motion a LEO satellite being deployed from a mothership with a 100 ft tether. The mothership mass is ten times that of the satellite. The motion of the involved bodies happen in a 40 degree inclined near circular LEO orbit. The satellite separates from the mothership at the very start of the simulation. Both the satellite and the mothership have their own RWA ACS to stabilize their respective attitudes to the LVLH orientation. The separation between the two vehicles is caused by an initial separation velocity of .5 f/s, the gravity gradient force and the difference in orbital motion between them. The simulation runs for 5 orbit periods of 60000 seconds.

The topics covered here are:

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

The Tethersim model configuration is:

```
b1(B)+-b2(F)+-b3(B)+-w[4,5,6]
     |
     +-w[1,2,3]
```

where b1 = mothership (B= 3dof rotational motion)
b2 = 3 dof translational joint (F= 3 relative translational dof)
b3 = 3 dof translational joint (B= 3 relative rotational dof)
w = wheels

1. Tethersim Simulink Program

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

1. xsim1_161003.dll simulation engine
2. tForce.m tether force processor
3. b1wtq.m ACS torque to wheels 1:3 on mothership (b1)
4. b3wtq.m ACS torque to wheels 4:6 on deployed satellite (b3)

The signal flow between the processors of tethersim.mdl and their functionality are summarized in the next table.

processor	input	output	function
xsim1	- model file=tethersim.txt - hf 2 = tether force - wtq1:3= b1 ACS torque - wtq4:6= b3 ACS torque	- plot file=z.1 - hposr2= sat pos wrt b1 - hvelr2= sat vel wrt b1 - w1= b1 ang rate - w3= b3 ang rate - rpy1= b1 attd errors - rpy3= b3 attd errors - wspd1:6 = whl 1:6 spd	- reads model file to setup the eom config., and integrates the eom - sends plot data to z.1 file - actuates reaction wheels 1:6 per input signals - apply internal force to satellite motion due to tether force
tForce	- hposr2= sat pos wrt b1 - hvelr2=sat vel wrt b1	- hf2 = tether force	- computes a PD force after tether length exceeds 100 ft - else computes a damp force only see figure 2
b1wtq	- w1= b1 ang rate - rpy1= b1 attd errors - wspd1:3 = whl 1:3 spd	- wtq1:3= b1 ACS torque	- computes the cmg 1:4 input torque per td from cmd_sig
b3wtq	- w3= b3 ang rate - rpy3= b3 attd errors - wspd4:6 = whl 4:6 spd	- wtq4:6= b3 ACS torque	- 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 Functionality and Signal Flow of the processors in Tethersim.mdl

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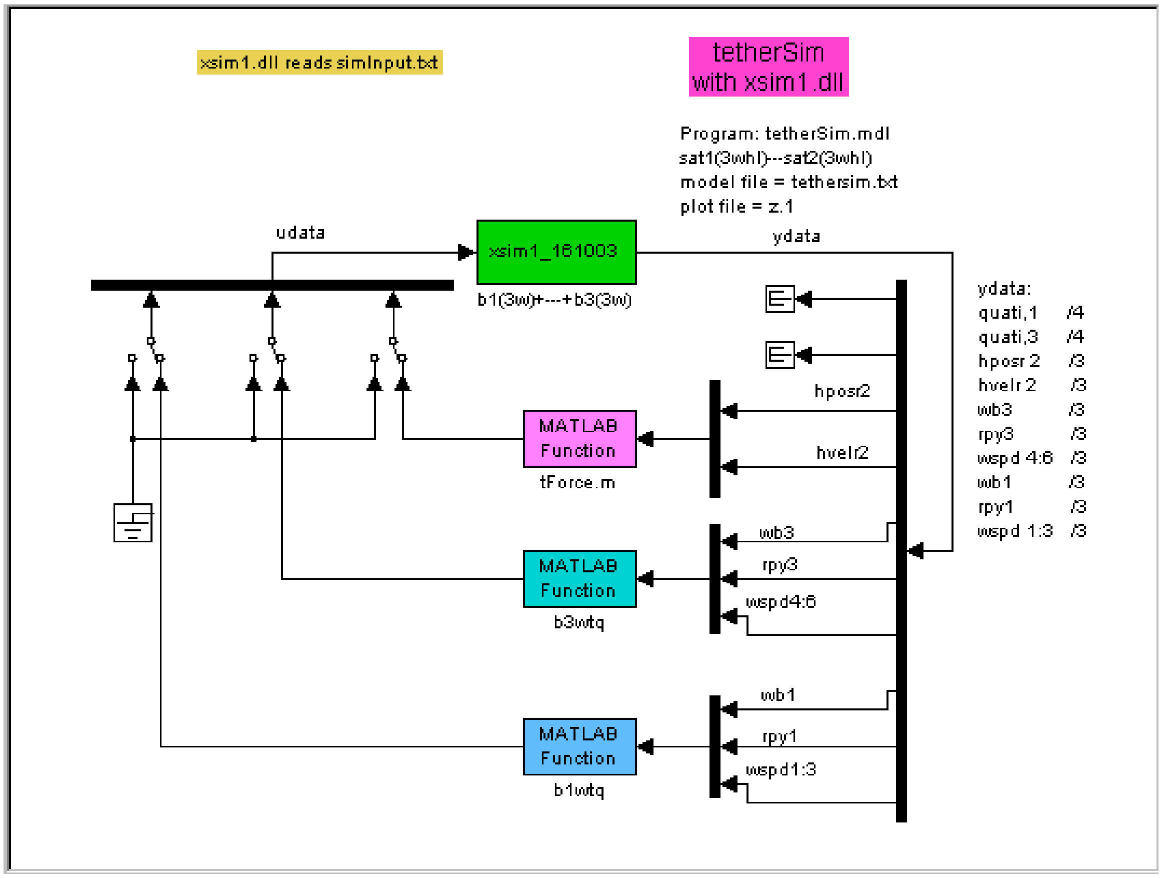

Figure 1 Simulink Program of Tethersim

The next table shows the tForce calculations that's used in figure 1.

```
function z=tForce(u)
global maxL

pos= u(1:3); % sat2 pos wrt sat1
vel= u(4:6); % sat2 vel wrt sat1

len= norm(pos);

if( len > 1.0 )
    unitv= (1/len)*pos;
else
    unitv= [0 0 0]';
end

velr= unitv'*vel;

if( len > maxL )
  z= (.005*(maxL-len)-.447*velr)*unitv;  % tether force for len > 100
else
  if( velr > 0 )
      z=-.447*velr*unitv;
  else
      z= 0.*unitv;
  end
end
```

Figure 2 tForce.m Listing

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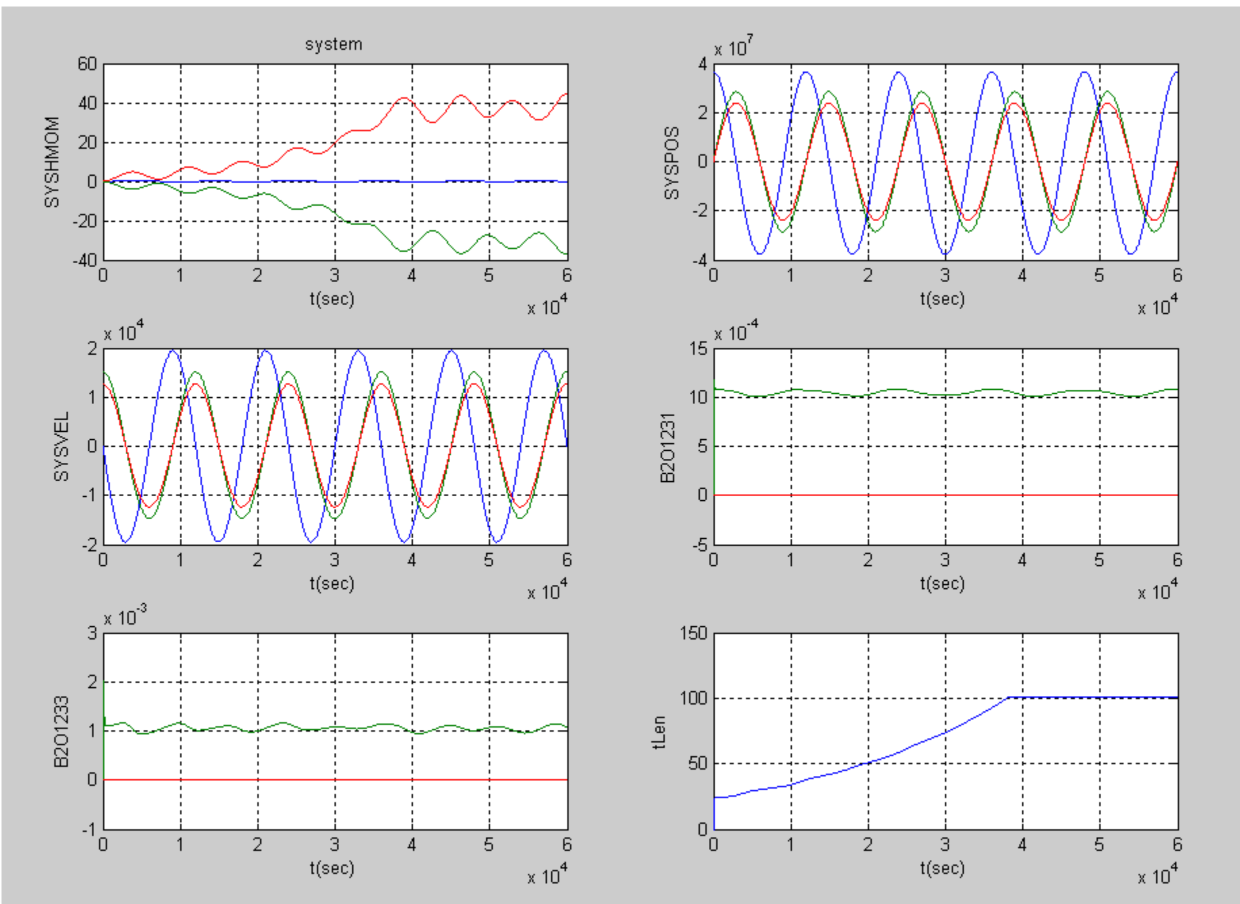
2. Tethersim Simulation Result

Simulation scenario summary:
Orbit: near circular, 40 deg inclined, 200 min (12000 sec) period
Satellite to payload mass ratio is 10:1.
Payload is attached to the satellite at t=0, tether length is zero
Initial angular rate=[0, 0.03, 0] d/s in body frame; this is the orbit rate
Gravity model: non-spherical with J2, J3, and J4 effects
gflag=12, meaning the satellite+payload experiences gravity gradient torque
Tether length grows until reaches 100 feet and stays that way until the end of simulation, t=60000 sec.
Throughout, satellite attitude is maintained by 4 RWA's at LVLH orientation.

Observations of the following charts: The system angular momentum, syshmom, increases proportionally to the length of the tether due to the large labration angle and the gravity gradient between the mothership and the satellite. The system momentum levels off with a sinusoidal modulation after the tether has reached 100 ft. The attitude of the mothership (b2o1231) and that of the satellite (b2o1233) are held to a small attitude error relative to the LVLH orientation. The simulation is run for 5 orbits, i.e. sim time=60000 sec.

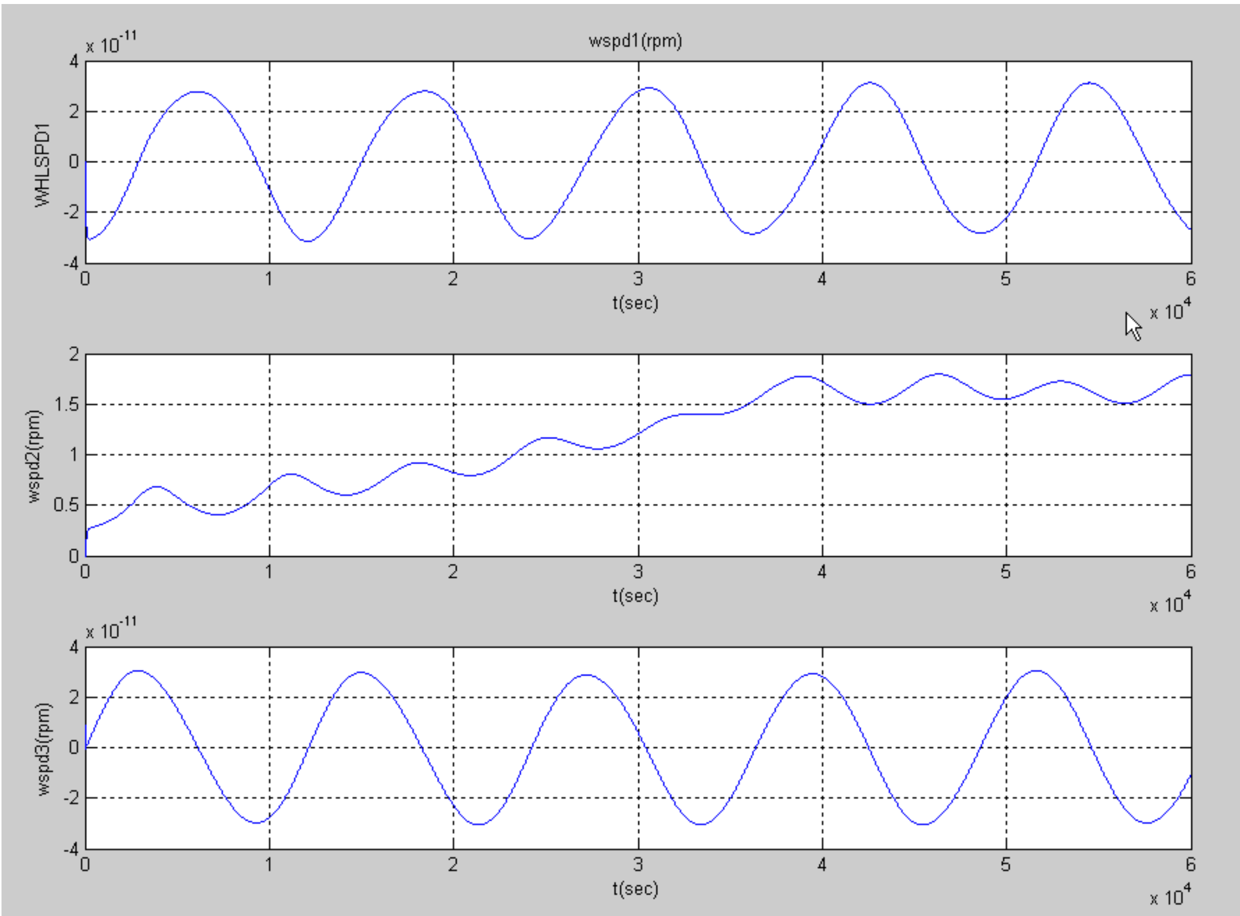


System Data

syshmom = system angular momentum in inertial coordinates

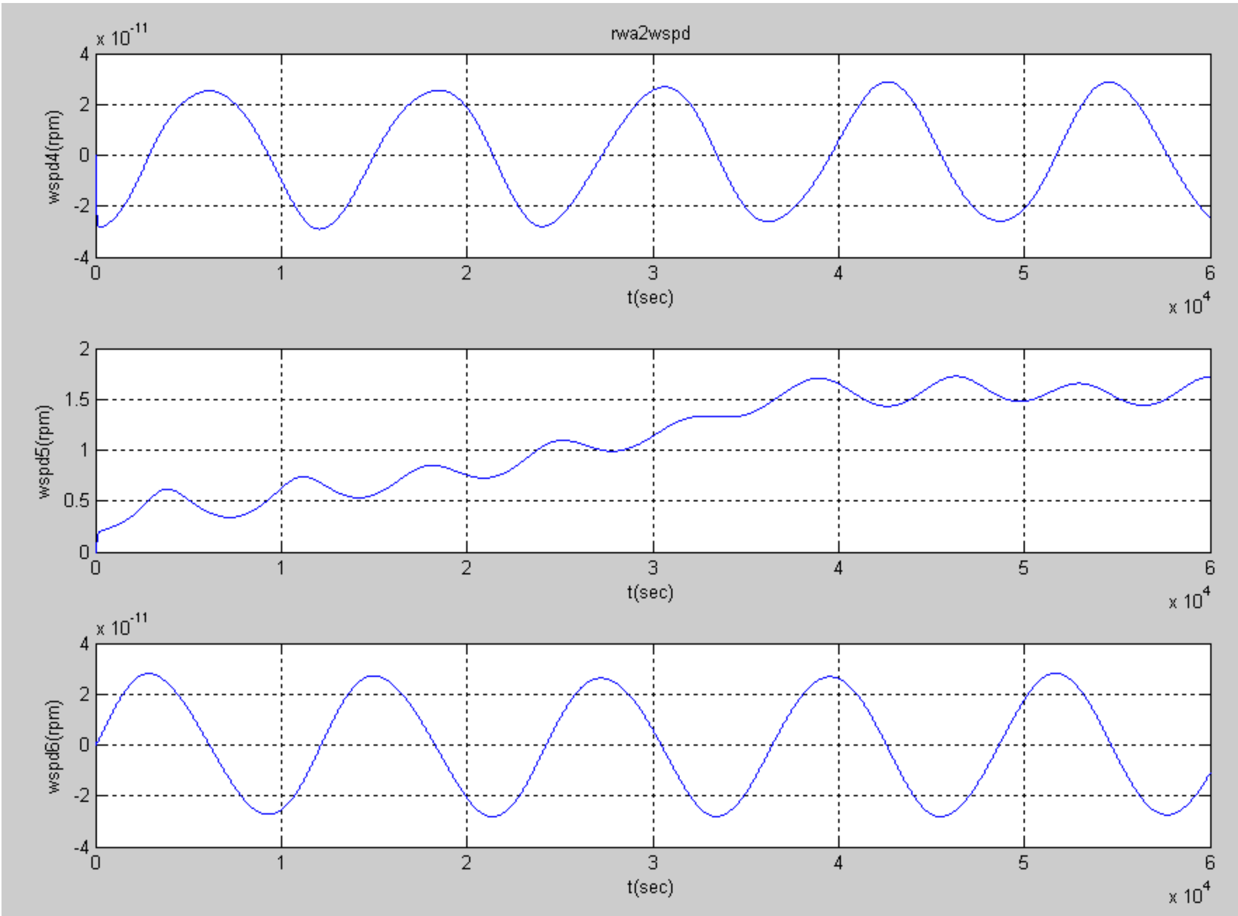
syshb1 = syshmom in b1 coordinates
syspos = system cm inertial position
b2o1231= b1 attitude roll, pitch (green), yaw relative to LVLH attitude
b2o1233= b3 attitude roll, pitch (green), yaw relative to LVLH attitude
tLen = tether length

The next graphs are the wheels speed for the mothership. Wheel2 is the only active wheel and its rpm is proportional to the system angular momentum shown above.



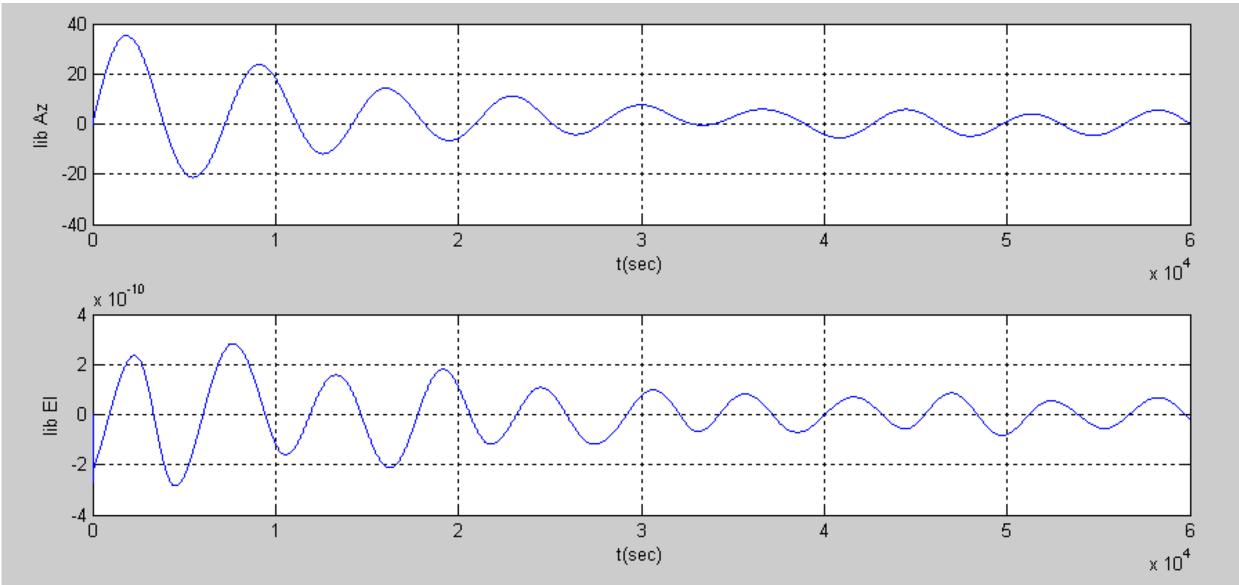
B1 Wheel 1:3 Speeds (rpm)

The next graphs are the wheels speed for the satellite. Wheel2 is the only active wheel and its rpm is proportional to the system angular momentum shown above.



B1 Wheel 1:3 Speeds (rpm)

The next graphs are the in-plane and out-of-plane libration angles of the mothership to satellite line. The in-plane angle has an initial peak of 35 degrees and it decays to +/-5 degrees after the tether has settled to 100 ft. The out-of-plane angle is negligible.



libration angles

lib Az = in-plane libration angle (deg)
lib El = out-plane libration angle (deg)

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 tethersim.txt can be divided into the following groups of information.

A. Configuration of the model
B. Mass property of the model
C. Initial relative angular rates
D. Ephemeris of the orbit
E. Reaction wheel elements
F. Constraints
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 through the Buildx.exe program.

A. Model Configuration

The Tethersim model configuration is:

```
b1(B)+-b2(F)+-b3(B)+-w[4,5,6]
      |
      +-w[1,2,3]
```

where b1 = mothership (B= 3dof rotational motion)
b2 = 3 dof translational joint (F= 3 relative translational dof)
b3 = 3 dof translational joint (B= 3 relative rotational dof)
w = wheels

This configuration is defined by the parent indices of the model objects. Note that b2 and b3 are co-located and b2 is massless.

B. Mass Property

The mass column of next figure shows the mass of b1:b3 taken from the 'body' submenus of Buildx.exe. The axis of motion, 'ax', for the array panels are along the 'z'. The 'pa' of b2 is set to 1 because b1 is their parent body and 'pa' of b3 is 2. The inboard joint of b2 and b3 are co-located, and b2 (tether) is purposely massless for simplicity. 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 type 'tp' of b2 is F meaning that it has a 3 translational dof relative to b1 and that of b3 is set to 'B' meaning that it has a 3 rotational dof relative to b2. In this case, entries in the fl, vm, ax, angle, del_x columns are irrelevant.

	idx	name	pa	u	fl	vm	tp	ax	-- angle -	-- del_x -	----mass----
=>	1	sat1	0	FPS	0	-	B	x	.000	.000	.100000E+03
	2	tether	1	FPS	0	-	F	x	.000	.000	.000000E+00
	3	sat2	2	FPS	0	-	B	x	.000	.000	.100000E+02

Figure 3. 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. They are defined in local body coordinates. Note that the moi of b2 is zero.

	idx	name	- ixx -	- iyy -	- izz -
			---- ixy ---	---- ixz ---	---- iyz ---
=>	1	sat1	.100000E+02	.200000E+02	.300000E+02
			.000000E+00	.000000E+00	.000000E+00
	2	tether	.000000E+00	.000000E+00	.000000E+00
			.000000E+00	.000000E+00	.000000E+00
	3	sat2	.100000E+01	.200000E+01	.300000E+01
			.000000E+00	.000000E+00	.000000E+00

Figure 4. 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.

	idx	name	u	------------	----svec----	------------
=>	1	sat1	FPS	.000000E+00	.000000E+00	.000000E+00
	2	tether	FPS	.000000E+00	.000000E+00	.000000E+00
	3	sat2	FPS	.000000E+00	.000000E+00	.500000E+00

Figure 5. 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. Note that dvec(3) is [0 0 0], meaning that inboard joint of b3 is co-located with that of b2.

idx	name	u	------------	----dvec----	------------
1	sat1	FPS	.000000E+00	.000000E+00	.000000E+00
2	tether	FPS	.000000E+00	.000000E+00	.500000E+00
3	sat2	FPS	.000000E+00	.000000E+00	.000000E+00

Figure 6. 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 7.

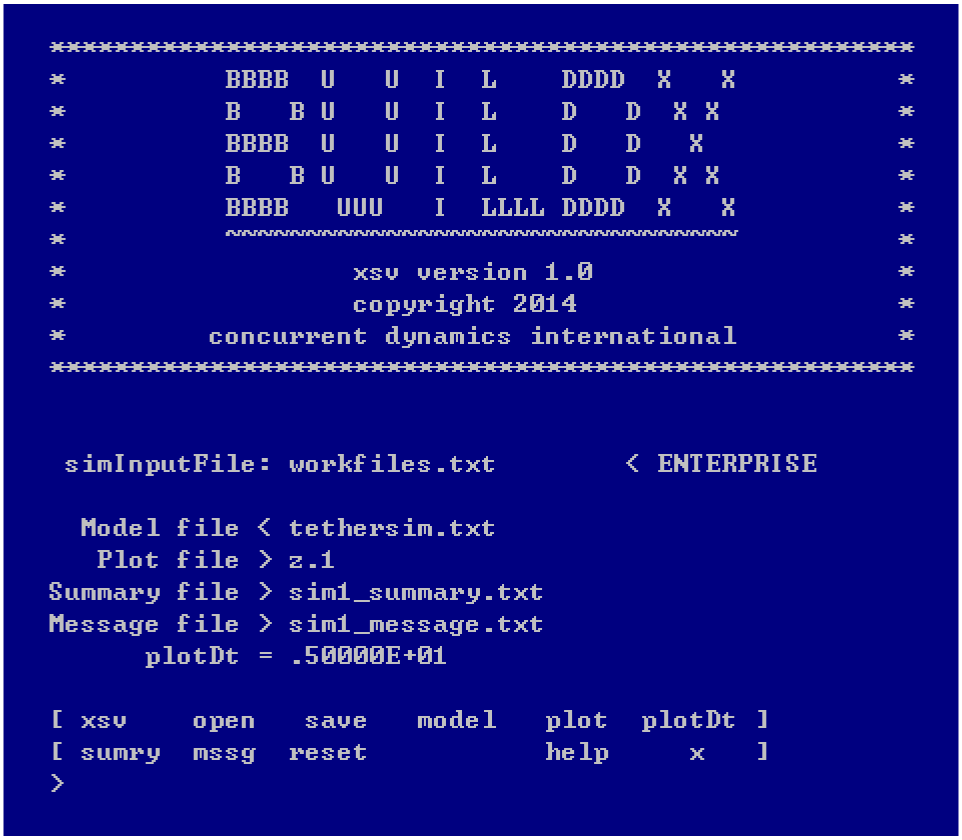


Figure 7. Main Menu

Note that the model file is Tethersim.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 8.

3. Select ‘body’ command from Model Menu page (Fig. 6) to open Body_Menu. See Figure 3
   -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 4.
   -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 5.
   -use ‘svec’ command to edit svec of bodies: follow the prompts

6. Select ‘dvec’ command from Body_Menu to open DVEC_Menu. See Figure 6.
   -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.

```
                      ~ Model Menus ~
System Graph:

b1(B)+-b2(F)+-b3(B)+-w[4,5,6]
     |
     +-w[1,2,3]

total bodies:         9     ; reg. bodies& wheels:   3,  6
ext. forces,torque:  0,  2 ; pos.& dir markers:     2,  3
system units:       FPS     ; constraints:           0
sflag,gflag:          1, 12 ; input (param,size):    7,  9
dscrt,odes:           0,  0 ; output(parmm,size):   14, 32
accels,gyros:         0,  0 ; plot  (parmm,size):   25, 60
vmass,pmass:          0,  0 ; swiches,states:        0, 32
```

Figure 8. Model Menus

C. Initial Relative Rates

Go to the Relative Angular Rate Menu to set the initial angular or displacement rates of bodies relative to their parents. Figure 9a is that menu for Tethersim. Tp=B means the joint has 3 rotational dof relative to its parent. Tp=F means that the joint has 3 translational dof relative to its parent. The initial rate of sat1 is the orbital angular rate. (Same as mean motion in ‘grav’ menu.)

```
  idx name      tp  ax ------------ --wrel(d/s)- ------------
=>  1 sat1       B   x  .000000E+00  .300000E-01  .000000E+00
    2 tether     F   x  .000000E+00  .000000E+00  .000000E+00
    3 sat2       B   x  .000000E+00  .000000E+00  .000000E+00
```

Figure 9a Relative Angular Rate Menu for Tethersim

Go to the Relative Displacement Rate Menu to set the initial separation rate of the satellite (sat2) from the mothership (sat1) to 0.5 f/s as shown in the next figure.

```
  idx name      tp ax ---------- ---dvel--- ----------
=>  1 sat1       B  x       .000       .000       .000
    2 tether     F  x       .000       .000       .500
    3 sat2       B  x       .000       .000       .000
```

Figure 9b Relative Displacement Rate Menu for Tethersim

Edit Initial Relative Body Angular Rates
Select the ‘wrel’ command from Body Menu page to open the Relative Angular Rate Menu. See Figure 9a.

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

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

Edit Initial Relative Body Displacement Rates
Select the ‘dvel’ command from Body Menu page to open the Relative Displacement Rate Menu. See Figure 9b.

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

- use ‘dvel<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. Ephemeris

The orbit is specified by the ‘grav’ menu in Buildx.exe. The Tethersim as the following orbit information.

```
                      ~ gravity Menu ~

 > units      (U)=  FPS
 > syspos       =    36606426.892         48.688          40.854
 > sysvel       =           -.034      15134.782       12699.590

 > refpos       =    36606426.983         48.688          40.854
 > refvel       =            .011      15134.782       12699.590

   gravity:
 > gx gy gz     =  -10.5045682646    -.0000139715    -.0000117235
   mu           =  .140764418E+17

   ephemeris:
 > semimajor (U)=    37167659.547
 > ecc          =      .015100
 > incl    (deg)=   40.000000
 > rasc    (deg)=      .000000
 > argp    (deg)=      .000099
 > t_anom  (deg)=      .000000
   e_anom  (deg)=      .000000
   m_anom  (deg)=      .000000
   m_motion(d/s)=    .03000000

 > LST_ang (deg)=  268.666060    ; sun_beta(deg)=  16.558
 > LST(h:m:s)   = 17:54:39.9

 > period  (min)=         200.000; revs/day=   7.200
 > period  (sec)=       12000.000
   range     (U)=    36606426.892
   equ. radius  =    20925646.325; J2=  .108263E-02
   prg.altitude =    15680780.567; apg.altitude=    16803245.876
   we   (d/s,r/s)=       .00417807        .00007292

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

Figure 10. Gravity Menu

This orbit specification shows that the Tethersim is in a 40 degree inclined near circular orbit (ecc=0.0151) with a period of 200 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. The gravity forces exerted on the two bodies are different due to gravity gradient between them.

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.

E. Reaction Wheels

The Tethersim here has 3 wheels attached to b1 and 3 wheels attached to b3 for ACS. The wheels attributes are displayed below.

	idx	name	pa	t	axis			winr	w(rpm)
=>	1	whl1a	1	A	1.0000000	.0000000	.0000000	.0500	.0
	2	whl1b	1	A	.0000000	1.0000000	.0000000	.0500	.0
	3	whl1c	1	A	.0000000	.0000000	1.0000000	.0500	.0
	4	whl4a	3	A	1.0000000	.0000000	.0000000	.0500	.0
	5	whl4b	3	A	.0000000	1.0000000	.0000000	.0500	.0
	6	whl4c	3	A	.0000000	.0000000	1.0000000	.0500	.0

Figure 11. Wheel Data from Wheel Menu

This table shows that wheels 1-3 are attached to b1 (pa=1). Wheels 4-6 are attached to b3 (pa=3). Their types are all ‘A’ meaning that they require actuation torque from Simulink workspace to the simulation engine xsim1.dll. The axis column shows the spinning axes of the wheels in the attached body coordinates. ‘winr’ 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 10.

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.

F. Jet Forces

The next display shows the force menu reflecting that the Tethersim here has no jet forces implemented.

Figure 12 Jet Force Data from Force Menu

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

display force positions:
- use ‘pos’ command to display force positions

display torque vectors:
- use ‘rxf’ command to display force positions

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.

G. Constraint Signals

The Constraint Menu displayed reflects that Tethersim has no constraint signals.

```
                        ~ Constraint Menu ~

no. of constraints  :  0
cn rowSize          :  0
cn index            :  1

cn gama             : .00000E+00  .00000E+00  .00000E+00
cn err              : .00000E+00  .00000E+00  .00000E+00
cn k1, k2           : .00000E+00  .00000E+00
cn pgain,vgain      : .00000E+00  .00000E+00
```

Figure 13 Constraint Signals Summary from CN Menu for Tethersim

Use the following procedure to add and edit constraints applicable to the simulation.

Edit CN Parameters
Select the ‘cn’ command from Model Menus page to open the Constraint Menu. See Figure 13.

change the parameters of a cn signal:
- use ‘edit<j>’ command to change the j-th cn signal: follow prompt instructions

add a lock constraint:
- use ‘lock’ command to create a lock constraint: follow prompt instructions

add a constraints:
- use ‘add’ command: flow promt instructions

remove constraints:
- use ‘rem<j>’ command to remove j-th cn signal

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 Tethersim are in the next table.

```
Udata list:

 1> WHLTQ,1           | 2> WHLTQ,2           | 3> WHLTQ,3
 4> WHLTQ,4           | 5> WHLTQ,5           | 6> WHLTQ,6
 7> HF,2
```

Figure 14 Udata List from the Input Data Menu

where whltq,1:3 = b1 wheel torque
whltq,4:6 = b3 wheel torque
hf,2 = tether force

The size of each of these signals are as follows.

```
> len
  #   uDef         Len  Loc    #   uDef         Len  Loc
  1. WHLTQ,1         1    1|   2. WHLTQ,2         1    2
  3. WHLTQ,3         1    3|   4. WHLTQ,4         1    4
  5. WHLTQ,5         1    5|   6. WHLTQ,6         1    6
  7. HF,2            3    7
```

Figure 15 Length of Udata Elements

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 14.

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 15:

- 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 signal computation purposes. Tethersim's output data are in the next table.

```
Ydata list:

 1> QUATI,1          | 2> QUATI,3          | 3> HPOSR,2
 4> HVELR,2          | 5> WB,3             | 6> B2OSML,3
 7> WHLSPD,4         | 8> WHLSPD,5         | 9> WHLSPD,6
10> WB,1             |11> B2OSML,1         |12> WHLSPD,1
13> WHLSPD,2         |14> WHLSPD,3
```

Figure 16 XSIM Output Data from Output Menu

where quati,1 = b1 inertial attitude quaternion (not used)
quati,3 = b3 inertial attitude quaternion (not used)
hposr,2 = tether displacement vector
hvelr,2 = tether displacement rate vector
wb3 = b3 total angular rate in b3 coordinates
b2osml,3 = b3's roll, pitch and yaw attitude errors
whlspd,4:6= b3 wheel speeds
wb,1 = b1 angular rate vector in b1 coordinates
b2osml,1 = small angle roll-pitch-yaw error of b1 wrt orbit frame
whlspd,1:3= b1 wheel speeds

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

```
> len
  #   yDef         Len  Loc    #   yDef         Len  Loc
  1. QUATI,1        4    1|   2. QUATI,3        4    5
  3. HPOSR,2        3    9|   4. HVELR,2        3   12
  5. WB,3           3   15|   6. B2OSML,3       3   18
  7. WHLSPD,4       1   21|   8. WHLSPD,5       1   22
  9. WHLSPD,6       1   23|  10. WB,1           3   24
 11. B2OSML,1       3   27|  12. WHLSPD,1       1   30
 13. WHLSPD,2       1   31|  14. WHLSPD,3       1   32
```

Figure 17 XSIM Output Data Size

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 16.

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 17:

- 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.

```
Odata list:

 1) QUAT,1          | 2) HPOSR,2          | 3) QUAT,3
 4) WB,1            | 5) HVELR,2          | 6) WB,3
 7) HFRC,2          | 8) WHLSPD,1         | 9) WHLSPD,2
10) WHLSPD,3        |11) WHLSPD,4         |12) WHLSPD,5
13) WHLSPD,6        |14) WHLTQ,1          |15) WHLTQ,2
16) WHLTQ,3         |17) WHLTQ,4          |18) WHLTQ,5
19) WHLTQ,6         |20) SYSHMOM          |21) SYSPOS
22) SYSVEL          |23) B2OSML,1         |24) B2OSML,3
25) B2O,1
```

Figure 18 XSIM Plot Data List from Plot Menu

where,	quat,1	= attitude quaternion of b1
	quat,3	= inertial attitude quaternion of b3
	hfrc,2	= tether force vector
	hposr,2	= tether displacement vector
	hvelr,2	= tether displacement rate vector
	wb,1	= b1 angular rate vector in b1 coordinates
	wb,3	= b3 angular rate vector in b1 coordinates
	whlspd,1:3	= b1 wheel spinning speed in d/s
	whlspd,4:6	= b3wheel spinning speed in d/s
	whltq,1:3	= b1 wheel torque
	whltq,4:6	= b3wheel torque
	syshmom	= Tethersim angular momentum about system cm
	syspos	= composite tether cm position in inertial frame
	sysvel	= composite tether cm velocity in inertial frame
	b2osml,1	= b1 roll-pitch-yaw relative to orbit frame
	b2osml,3	= b3 roll-pitch-yaw relative to orbit frame
	b2o,1	= b1 to orbit frame dcm

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. HPOSR,2          3    6
  3. QUAT,3           4    9|   4. WB,1             3   13
  5. HVELR,2          3   16|   6. WB,3             3   19
  7. HFRC,2           3   22|   8. WHLSPD,1         1   25
  9. WHLSPD,2         1   26|  10. WHLSPD,3         1   27
 11. WHLSPD,4         1   28|  12. WHLSPD,5         1   29
 13. WHLSPD,6         1   30|  14. WHLTQ,1          1   31
 15. WHLTQ,2          1   32|  16. WHLTQ,3          1   33
 17. WHLTQ,4          1   34|  18. WHLTQ,5          1   35
 19. WHLTQ,6          1   36|  20. SYSHMOM          3   37
 21. SYSPOS           3   40|  22. SYSVE            3   43
 23. B2OSML,1         3   46|  24. B2OSML,3         3   49
 25. B2O,1            9   52
```

Figure 19 Data Size of Plot Data

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 18.

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 19:

- 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.