ArraySim with RWA and Jets

Concurrent Dynamics International

January 2017

Arraysim.mdl is a Simulink program that simulates the motion of a LEO satellite that has two solar arrays, four reaction wheels and six jets. The satellite is placed on a 10 degree inclined circular orbit. The gravity model for the simulation is that of a spherical earth. After the start of the simulation the two solar arrys would deploy from their stowed position. In parallel the ACS would control the satellite attitude to track the LVLH attitude using the jets initially and switches to RWA's later.

The topics covered in this memo are:

1. Arraysim Simulink Program
2. Arraysim Simulation 1 Result
3. Arraysim Simulation 2 Result
4. Arraysim Model Data

The model configuration of Arraysim is:

```
b1(B)+-b2(A)+-b3(A)+-b4(A)+-b5(A)+-b6(A)
     |
     +-b7(A)+-b8(A)+-b9(A)+-b10(A)+-b11(A)
     |
     +-w[1:4]
     |
     +-xf[1:8]
     |
     +-cn[1:8]
```

where b1= central body, or bus (B= 3 relative rotational dof)
b2:b6 = array1 (A= 1 relative rotational dof); b2 = array1 drive
b7:b11= array2 (A= 1 relative rotational dof); b7 = array2 drive
b3:b6= array1 panels
b8:b11= array2 panels
w = wheels
xf = jet forces (0/1 signals)
cn= constraint switches (0/1 signals)

1. Arraysim Simulink Program

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

1) xsim1_150715.dll simulation engine
2) acs_rwa.m RWA ACS
3) acs_jet.m Jet ACS
4) hinge_locks (subsystem) controls locking of solar arrays 1:2

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

processor	input	output	function
xsim1	- model file=cmg4sim.txt - wtq 1:4 = RWA torque - xf 1:6 = jet on/off signals - cn 1:2 = array locking signals	- plot file=z.1 - ang 3,8 for array drive - w1= b1 ang rate - rpy=attd errors - wspd 1:4= wheel speed	- reads model file to setup the eom config., and integrates the eom - sends plot data to z.1 file - actuates rwa 1:3 and jets 1:6 per input signals - locks arrays when stowed or deployed
acs_rwa	- ena= enable switch - 2 Hz pulse train - w1= b1 ang rate - rpy= attd error - wspd = whl speed	- wtq 1:4 = RWA torque	- computes RWA torque using a PD error signal based on input
acs_jet	- ena= enable switch - 20 Hz pulse train - clock for t - w1= b1 ang rate - rpy= attd error - wspd = whl speed (NA)	- xf 1:6= jet on/off signals	- issues a pulse width jet on/off signals to reduce the PD error signal based on input
hinge locks	- ang 3:8 = array 1:2 inner most array panel angles	-cn1= 1 if angle 2=0 cn2= 1 if angle 3=0 else cn 1:2= 0	- locks the array angles 3, 8 to 0 at end of array deployment - cn= 0 means unlocked cn= 1 means locked

Table 1. Description of Arraysim.mdl processors

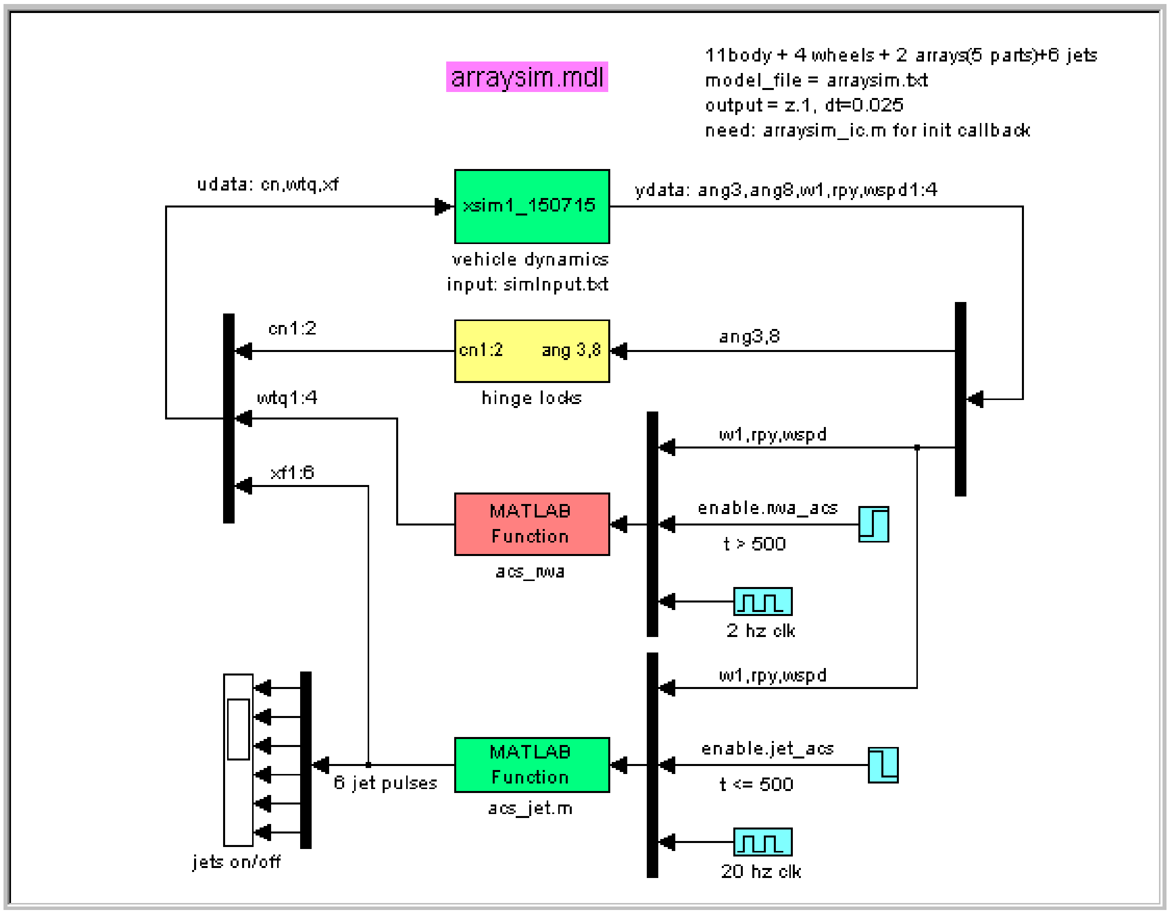
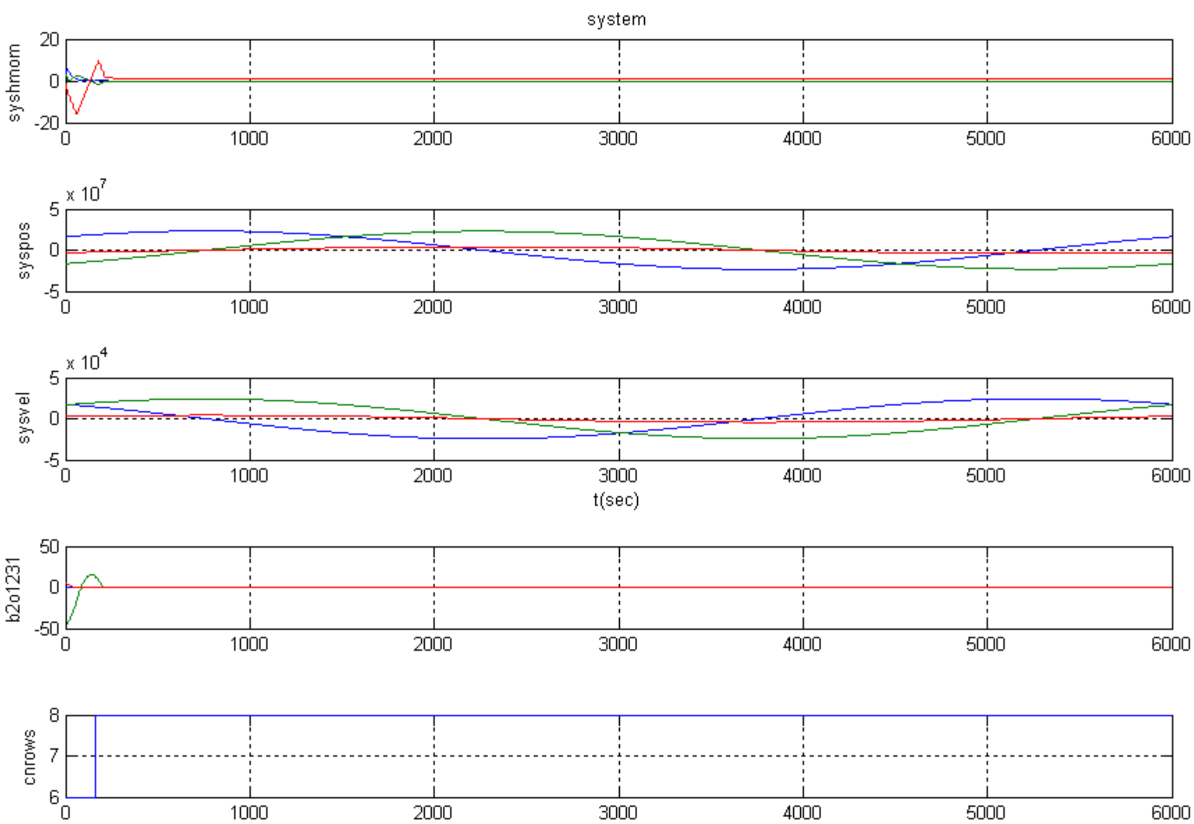


Figure 1 Simulink Program of ArraySim with RWA and Jet ACS

2. Arraysim Simulation 1 Result

Simulation scenario summary:
Orbit: circular, 10 deg inclined, 100 min period
Total time simulated is 6,000 sec = 1 orbit.
Arrays 1:2 start to deploy from stowed configuration at t=0
Arrays 1:2 fully deployed t~300 seec and array angles 3,8 are zero thereafter
ACS by 6 jets for t <=500
ACS by 3 RWA's for t>500.

Observations of Arraysim case 1 from following charts: the syshmom is controlled by jets from some non-zero initial value to near zero in the first 300 seconds. It stayed low and remained so and constant for t > 500 sec after transition to RWA ACS. The syspos shows one orbit of system cm motion. The b2o1231 showed that the attitude error was controlled by the jets in the first 300 seconds to near zero, and remained so for the rest of the simulation. The last chart, cnrows, showed that 6 constraints were in effect during the array deployment and 8 constraints were in effect for the rest of the simulation. The last 2 constraints are the locking of the arrays when they were fully deployed.

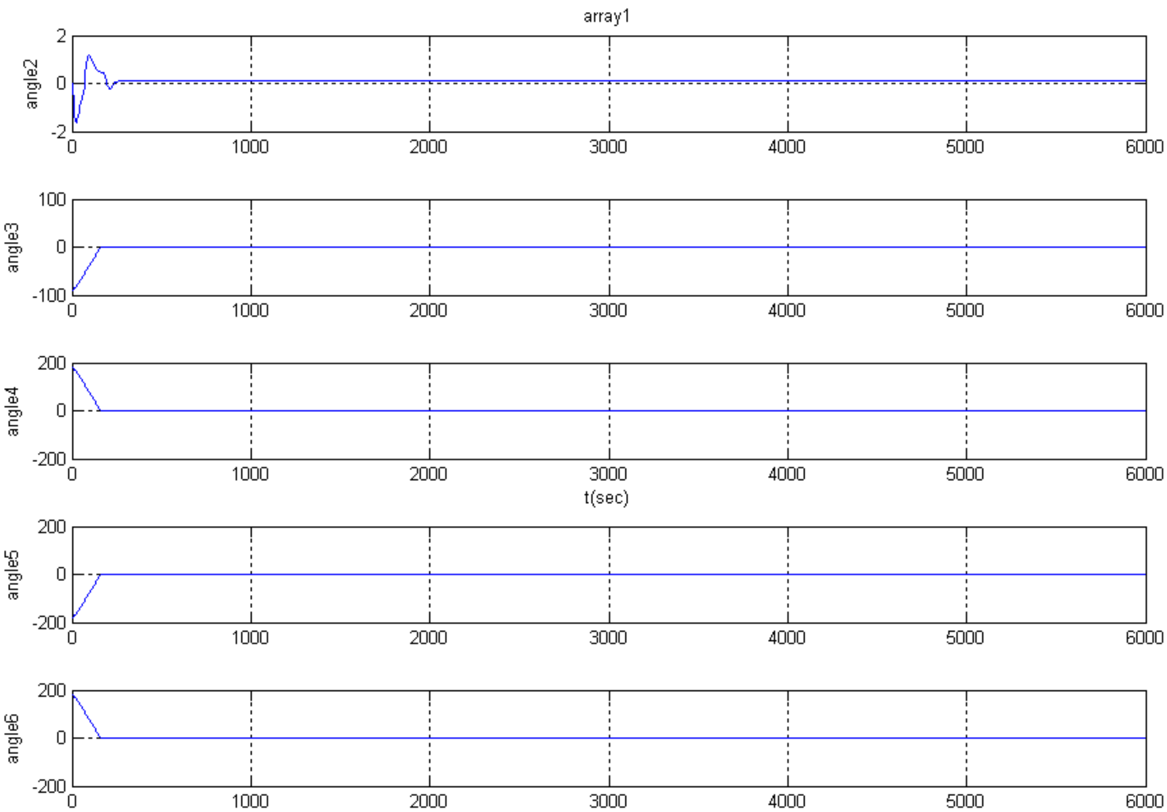


System Data (simulation1)

syshmom= system angular momentum in inertial coordinates
syspos= system cm inertial position
sysvel= system cm inertial velocity

b2o1231= bus attitude roll, pitch (green), yaw
cnrows= number of constraints in effect

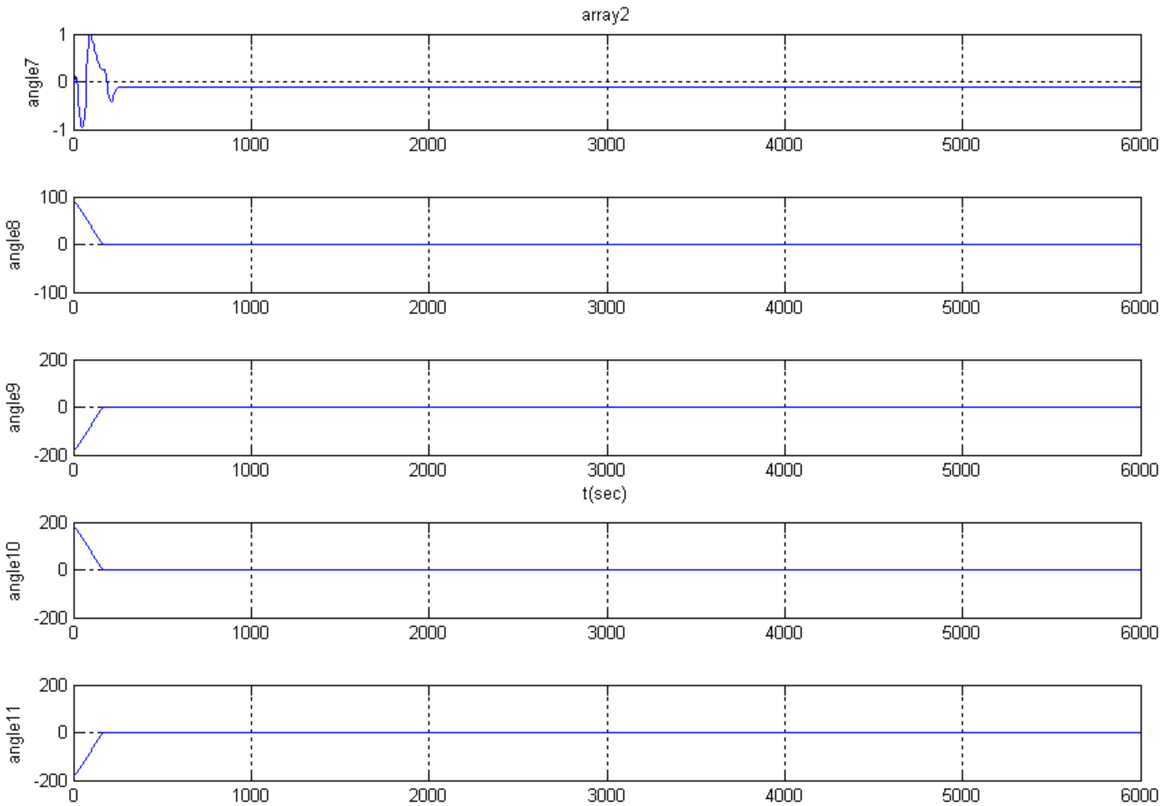
Angle2, the drive axis angle of array1, is controlled (per jnt2 instructions) to hold at 0.1 deg. The transient lasted 200 seconds and the angle is controlled to 0.1 deg afterwards. Angles 3:6 are the array panel angles, and they showed that they unfolded from the initial [-90,180,-180,180] positions to [0,0,0,0] in a coordinated manner due to the gear_constraints given in the model data. Once deployed the array angles remained at [0,0,0,0] until the end of simulation.



Array1 Angles (simulation 1)

angle2=array1 drive axis angle (deg)
array3:6=array1 panel angles(deg)

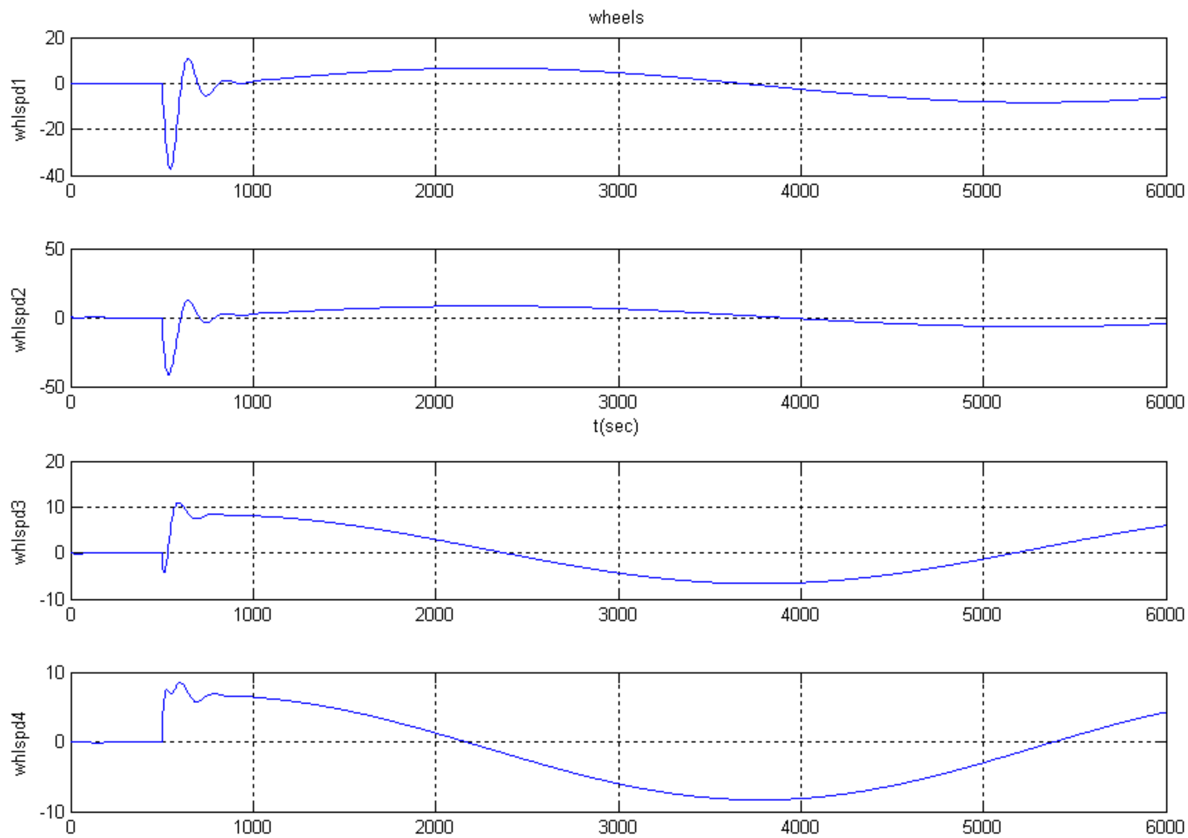
Angle7, the drive axis angle of array1, is controlled (per jnt7 instructions) to hold at -0.1 deg. It has a transient that lasted past the array deployment completion and it stayed at the controlled value of -0.1 deg until the end of simulation. Angles 8:11 are the array panel angles, and they showed that they unfolded from the initial [90,-180,180, -180] positions to [0,0,0,0] in a coordinated manner due to the gear_constraints given in the model data. Once deployed the array angles remained at [0,0,0,0] until the end of simulation.



Array2 Angles (simulation 1)

angle7=array2 drive axis angle (deg)
array8:11=array2 panel angles(deg)

Wheel speed is near zero while Jet ACS is on but not constant. Wheels speed has a transient for about 500 seconds after RWA ACS started at t=500 sec. From then on, the wheels are responsible to maintain the vehicle at the LVLH attitude.



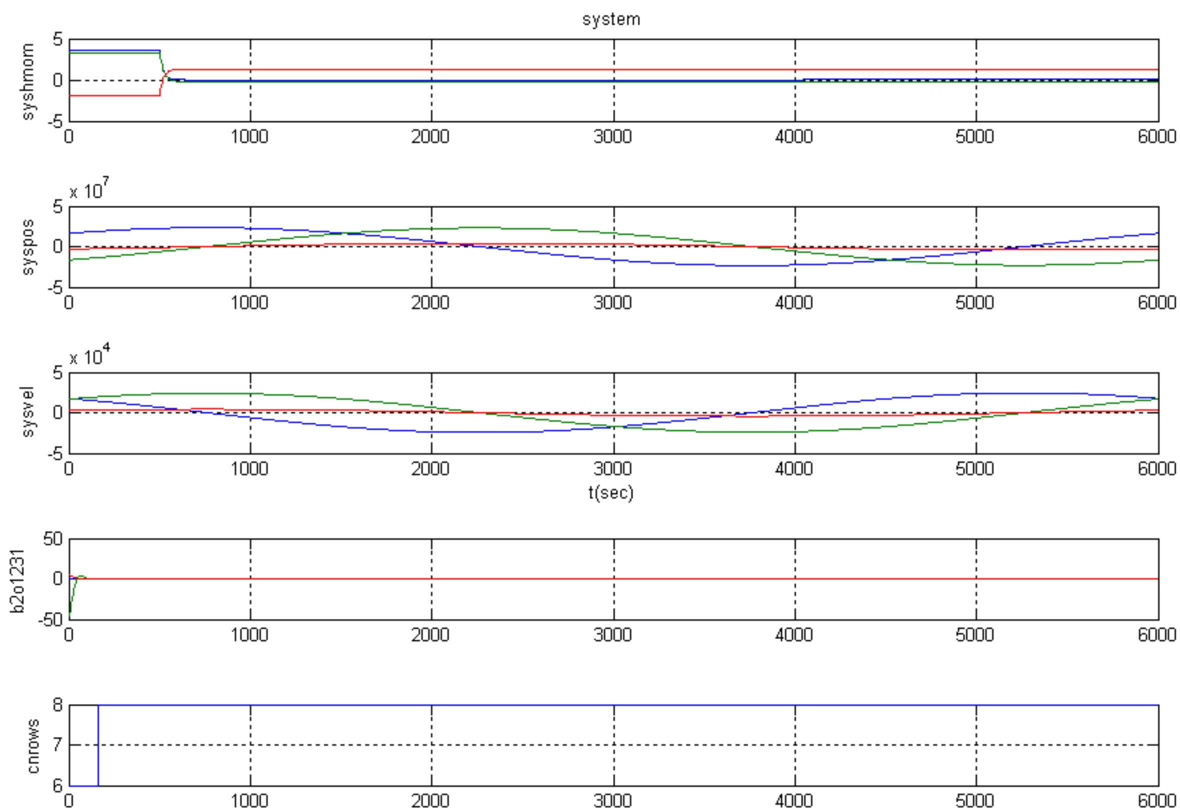
Wheel Speed (simulation 1)

whlspd1= wheel1 speed (rpm)
whlspd2= wheel2 speed (rpm)
whlspd3= wheel3 speed (rpm)
whlspd4= wheel4 speed (rpm)

3. Arraysim Simulation 2 Result

Simulation scenario summary:
Orbit: circular, 10 deg inclined, 100 min period
Total time simulated is 6,000 sec = 1 orbit.
Arrays 1:2 start to deploy from stowed configuration at t=0
Arrays 1:2 fully deployed t~300 seec and array angles 3,8 are zero thereafter
ACS by 3 RWA for t <=500
ACS by 6 Jets for t>500.

Observations of Arraysim case 2 from the following charts: the syshmom is constant for t < 500 due to RWA ACS. It is reduced to about 1.5 ft-lb-s due to Jet ACS after t=500. Syshmom stays near that low value until the end of the simulation. The LVLH attitude error was brought down from some 45 degrees to near zero within first 30 seconds of the simulation due to RWA ACS. The Jet ACS continued to hold that error to near zero after t >500. The cnrows chart shows that 6 gear constraints were active during the array deployment in the first 150 sec of the simulation. Two more constaints, the lock constraints, is enabled once the array deployment is complete. All eight constraints must be active to keep the arrays deployed at the [0,0,0,0] position for each array.

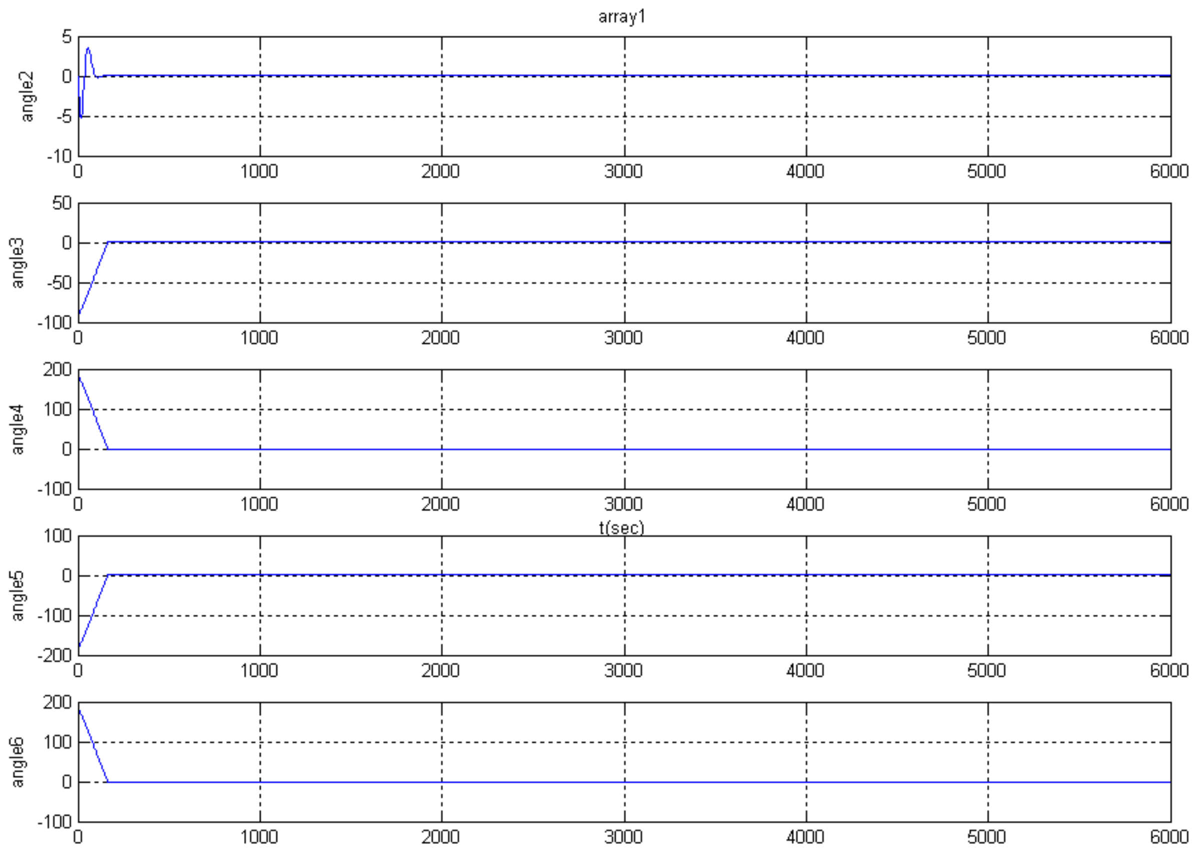


System Data (simulation 2)

syshmom= system angular momentum in inertial coordinates
syspos= system cm inertial position
sysvel= system cm inertial velocity

b2o1231= bus attitude error in roll(blue), pitch(green), yaw(red)
cnrows= number of constraints in effect

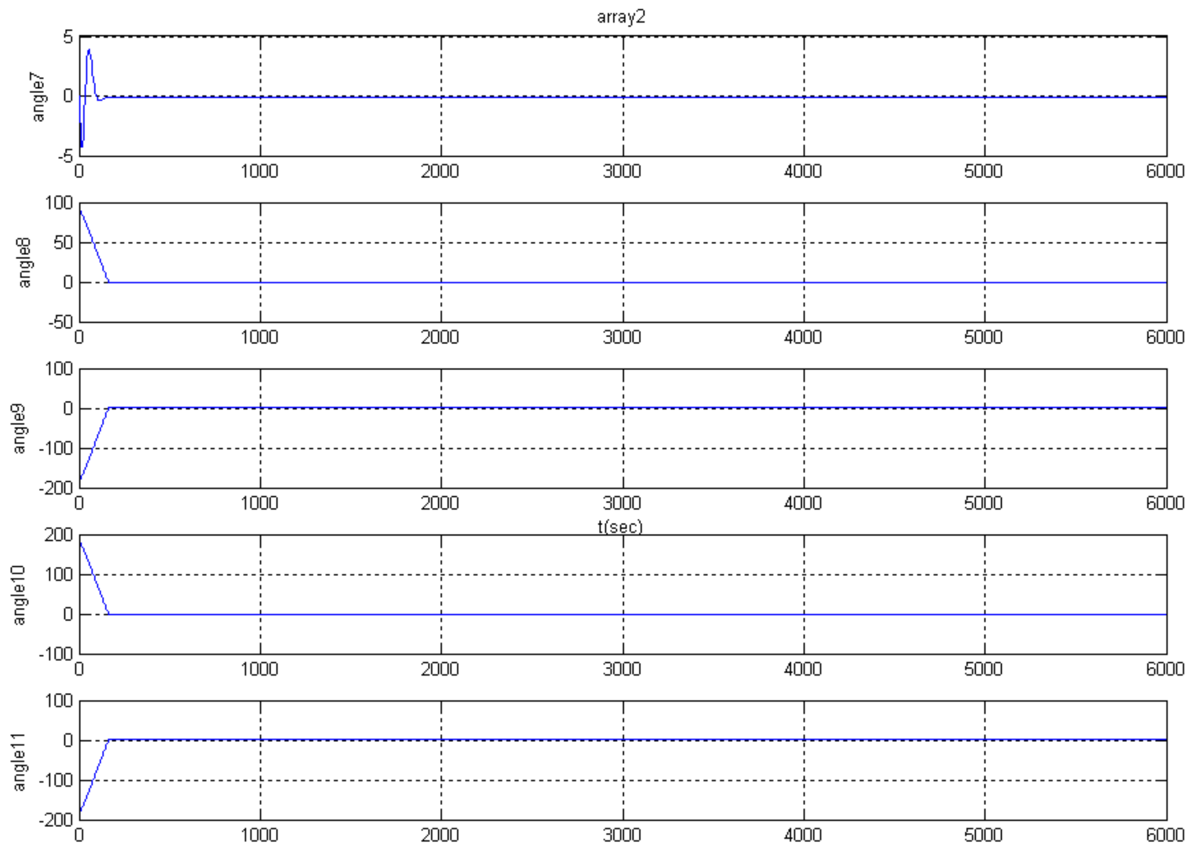
Angle2, the drive axis angle of array1, is controlled (per jnt2 instructions) to hold at 0.1 deg. The transient here is much shorter than example1. Angles 3:6 are the array panel angles, and they showed that they unfolded from the initial [-90,180,-180,180] positions to [0,0,0,0] in a coordinated manner due to the gear_constraints given in the model data. Once deployed the array angles remained at [0,0,0,0] until the end of simulation.



Array1 Angles (simulation 2)

angle2=array1 drive axis angle (deg)
array3:6=array1 panel angles(deg)

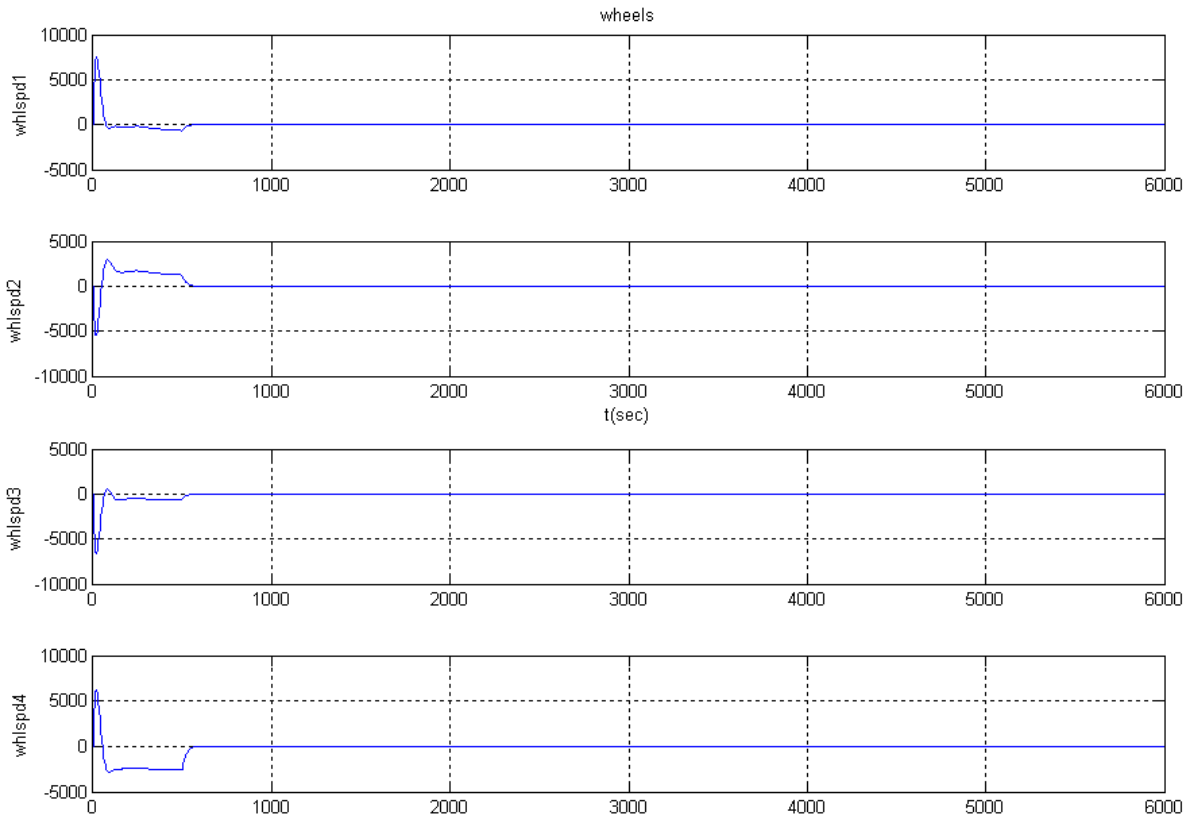
Angle7, the drive axis angle of array1, is controlled (per jnt7 instructions) to hold at -0.1 deg. It has a much shorter transient than in example1 and it stayed at the controlled value of -0.1 deg until the end of simulation. Angles 8:11 are the array panel angles, and they showed that they unfolded from the initial [90,-180,180, -180] positions to [0,0,0,0] in a coordinated manner due to the gear_constraints given in the model data. Once deployed the array angles remained at [0,0,0,0] until the end of simulation.



Array2 Angles (simulation 2)

angle7=array2 drive axis angle (deg)
array8:11=array2 panel angles(deg)

Wheels speed transient at the beginning are done to reduce the vehicle attitude to near zero during the RWA ACS period of t <500. Wheels speed kept near zero after Jet ACS started at t=500 sec.



Wheel Speed 1:4 (simulation 2)

whlspd1= wheel1 speed (rpm)
whlspd2= wheel2 speed (rpm)
whlspd3= wheel3 speed (rpm)
whlspd4= wheel4 speed (rpm)

4. Arraysim Model File

The model data in the Arraysim.txt are divided into the following groups:

A. Configuration of the model
B. Mass property of the model
C. Joint torque/force specifications
D. Ephemeris of the orbit
E. Reaction wheel elements
F. Force elements
G. Constraint Signals
H. Simulation engine input
I. Simulation engine output
J. Simulation plot data

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

A. Model Configuration

The model configuration of Arraysim is

```
b1(B)+-b2(A)+-b3(A)+-b4(A)+-b5(A)+-b6(A)
     |
     +-b7(A)+-b8(A)+-b9(A)+-b10(A)+-b11(A)
     |
     +-w[1:4]
     |
     +-xf[1:8]
     |
     +-cn[1:8]
```

where b1= central body, or bus (B= 3 relative rotational dof)
b2:b6 = array1 (A= 1 relative rotational dof); b2 = array1 drive
b7:b11= array2 (A= 1 relative rotational dof); b7 = array2 drive
b3:b6= array1 panels
b8:b11= array2 panels
w = wheels
xf = jet forces (0/1 signals)
cn= constraint switches (0/1 signals)

The parent-child relations between model objects define the connectivity of bodies in the model. They are represented by the parent indices of the objects.

B. Mass Property

The mass column of next figure shows the mass of b1:b11 taken from the 'body' submenus of Buildx.exe. The axis of motion, 'ax', for the array panels are along the 'z' and the drive axis (b2, b7) are along 'y' axis of the bus (b1). the 'pa' of b2 and b7 are set to 1 because b1 is their parent body. The parents of the panels are set according to the model configuration above. The motion type 'tp' of all bodies except b1 is set to 'A' meaning that they each have a 1 dof of rotation and torque at the xsim input is expected to move them. The bus has 'tp' set to B meaning it has a 3 dof rotation w.r.t. the inertial reference 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	drive1	1	FPS	0	-	A	y	.000	.000	.100000E+01
3	yoke1	2	FPS	0	-	A	z	-90.000	.000	.100000E+01
4	pnl1a	3	FPS	0	-	A	z	180.000	.000	.300000E+01
5	pnl1b	4	FPS	0	-	A	z	-180.000	.000	.300000E+01
6	pnl1c	5	FPS	0	-	A	z	180.000	.000	.300000E+01
7	drive2	1	FPS	0	-	A	y	.000	.000	.100000E+01
8	yoke2	7	FPS	0	-	A	z	90.000	.000	.100000E+01
9	pnl2a	8	FPS	0	-	A	z	-180.000	.000	.300000E+01
10	pnl2b	9	FPS	0	-	A	z	180.000	.000	.300000E+01
11	pnl2c	10	FPS	0	-	A	z	-180.000	.000	.300000E+01

Figure 2 Body Data from Body Menu

The next table displays the moment of inertia of b1:b11 in the order of ixx,iyy,izz,ixy,ixz and iyz.

idx	name	- ixx -	- iyy -	- izz -
		---- ixy ---	---- ixz ---	---- iyz ---
=> 1	b1	.100000E+04	.120000E+04	.120000E+04
		.000000E+00	.000000E+00	.000000E+00
2	drive1	.100000E+01	.100000E+01	.100000E+01
		.000000E+00	.000000E+00	.000000E+00
3	yoke1	.100000E+01	.100000E+01	.100000E+01
		.000000E+00	.000000E+00	.000000E+00
4	pnl1a	.100000E+02	.500000E+01	.100000E+02
		.000000E+00	.000000E+00	.000000E+00
5	pnl1b	.100000E+02	.500000E+01	.100000E+02
		.000000E+00	.000000E+00	.000000E+00
6	pnl1c	.100000E+02	.500000E+01	.100000E+02
		.000000E+00	.000000E+00	.000000E+00
7	drive2	.100000E+01	.100000E+01	.100000E+01
		.000000E+00	.000000E+00	.000000E+00
8	yoke2	.100000E+01	.100000E+01	.100000E+01
		.000000E+00	.000000E+00	.000000E+00
9	pnl2a	.100000E+02	.500000E+01	.100000E+02
		.000000E+00	.000000E+00	.000000E+00
10	pnl2b	.100000E+02	.500000E+01	.100000E+02
		.000000E+00	.000000E+00	.000000E+00
11	pnl2c	.100000E+02	.500000E+01	.100000E+02
		.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:b11. 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	b1	FPS	.000000E+00	.000000E+00	.000000E+00
2	drive1	FPS	.000000E+00	.150000E+01	.000000E+00
3	yoke1	FPS	.000000E+00	.150000E+01	.000000E+00
4	pnl1a	FPS	.000000E+00	.150000E+01	.000000E+00
5	pnl1b	FPS	.000000E+00	.150000E+01	.000000E+00
6	pnl1c	FPS	.000000E+00	.150000E+01	.000000E+00
7	drive2	FPS	.000000E+00	-.150000E+01	.000000E+00
8	yoke2	FPS	.000000E+00	-.150000E+01	.000000E+00
9	pnl2a	FPS	.000000E+00	-.150000E+01	.000000E+00
10	pnl2b	FPS	.000000E+00	-.150000E+01	.000000E+00
11	pnl2c	FPS	.000000E+00	-.150000E+01	.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.

idx	name	u	------------	----dvec----	------------
1	b1	FPS	.000000E+00	.000000E+00	.000000E+00
2	drive1	FPS	.000000E+00	.300000E+01	.000000E+00
3	yoke1	FPS	.000000E+00	.300000E+01	.000000E+00
4	pnl1a	FPS	.000000E+00	.300000E+01	.000000E+00
5	pnl1b	FPS	.000000E+00	.300000E+01	.000000E+00
6	pnl1c	FPS	.000000E+00	.300000E+01	.000000E+00
7	drive2	FPS	.000000E+00	-.300000E+01	.000000E+00
8	yoke2	FPS	.000000E+00	-.300000E+01	.000000E+00
9	pnl2a	FPS	.000000E+00	-.300000E+01	.000000E+00
10	pnl2b	FPS	.000000E+00	-.300000E+01	.000000E+00
11	pnl2c	FPS	.000000E+00	-.300000E+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: workfiles.txt        < ENTERPRISE

  Model file < arraysim.txt
   Plot file > z.1
Summary file > sim1_summary.txt
Message file > sim1_message.txt
      plotDt = .50000E+01

[ xsv    open   save   model   plot  plotDt ]
[ sumry  mssg   reset          help     x   ]
> _
```

Figure 6 Main Menu

Note that the model file is Arraysim.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.

```
                        ~ Model Menus ~
System Graph:

b1(B)+-b2(A)+-b3(A)+-b4(A)+-b5(A)+-b6(A)
     |
     +-b7(A)+-b8(A)+-b9(A)+-b10(A)+-b11(A)
     |
     +-w[1,2,3,4]

total bodies:       15     ; reg. bodies& wheels:  11,  4
ext. forces,torque:  8,  0 ; pos.& dir markers:     0,  0
system units:      FPS     ; constraints:           8
sflag,gflag:         1, 10 ; input (param,size):   12, 12
dscrt,odes:          0,  0 ; output(parmm,size):    8, 12
accels,gyros:        0,  0 ; plot  (parmm,size):   45, 67
vmass,pmass:         0,  0 ; swiches,states:        0, 37
```
Figure 7. Model Menus

C. Joint Actuation Specification

The ‘jnt’ Menu is a way to model the force/torque signals to all single axis joints without having to program that signals outside the xsim1.dll engine. Figure 7 shows the ‘jnt’ Menu display for arraysim shows the ‘jnt’ specifications for all 11 bodies. The values under the ‘tp’ column indicate the type of the joints, values under the ‘ax’ column are the free axis of the joints, the value of [0 0 0] under the ‘mode’ column means that the correspoinding joint is not actuate by the ‘jnt’ module in xsim1.dll. The mode value of [1 0 0] means that the joint in controlled by angle, and [2 0 0] means that the joint is controlled by rate. The values under ‘kp’ and ‘kv’ are the position gains and rate gains for the joint controller. The values under ‘pLoad’ are the constant force/torque or preload applied to the indicated joints.

	idx	name	tp	ax	mode	----kp----	----kv----	---pLoad--
=>	1	b1	B	x	0 0 0	.0000	.0000	.0000
	2	drive1	A	y	2 0 0	.0000	6.8000	.0000
	3	yoke1	A	z	1 0 0	.0000	50.0000	.5000
	4	pnl1a	A	z	0 0 0	.0000	.0000	.0000
	5	pnl1b	A	z	0 0 0	.0000	.0000	.0000
	6	pnl1c	A	z	0 0 0	.0000	.0000	.0000
	7	drive2	A	y	2 0 0	.0000	6.8000	.0000
	8	yoke2	A	z	1 0 0	.0000	50.0000	-.5000
	9	pnl2a	A	z	0 0 0	.0000	.0000	.0000
	10	pnl2b	A	z	0 0 0	.0000	.0000	.0000
	11	pnl2c	A	z	0 0 0	.0000	.0000	.0000

Figure 8 JNT Menu Display for ArraySim

On typing ‘show’ command, one can see the command angles/positions, and the Coulomb friction specified for the joints. The command is angle/position for a joint when its mode-value for is [1 - -]. The same command becomes the angular_rate/displacement_rate command when the mode-value for the joint is [2 - -].

	idx	name	--ang(d)--	----pos---	--j_coul--
=>	1	b1	.0000	.0000	.00000
	2	drive1	.1000	.0000	.00000
	3	yoke1	.0000	.0000	.00000
	4	pnl1a	.0000	.0000	.00000
	5	pnl1b	.0000	.0000	.00000
	6	pnl1c	.0000	.0000	.00000
	7	drive2	-.1000	.0000	.00000
	8	yoke2	.0000	.0000	.00000
	9	pnl2a	.0000	.0000	.00000
	10	pnl2b	.0000	.0000	.00000
	11	pnl2c	.0000	.0000	.00000

Figure 9 JNT angle/displacement commands and Coulomb friction settings for ArraySim

Edit JNT Parameters

Select the ‘jnt’ command from Model Menus page to open the Constraint Menu. See Figure 8.

change mode-value of a joint:

- use ‘mode<j>’ command to change the mode of j-th joint: follow prompt instructions

change joint position gain:
- use ‘kp<j>’ command to change the position gain of j-th joint: follow prompt instructions

change joint rate gain:
- use ‘kv<j>’ command to change the rate gain of j-th joint: follow prompt instructions

change angular position command:
- use ‘ang<j>’ command to change ang-command of j-th joint: follow prompt instructions

change displacement command:
- use ‘pos<j>’ command to change pos-command of j-th joint: follow prompt instructions

change preload command:
- use ‘pl<j>’ command to change preload of j-th joint: follow prompt instructions

change Coulomb friction command:
- use ‘coul<j>’ cmd to change Coulomb friction of j-th joint: 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 Arraysim as the following orbit information.

```
                      ~ gravity Menu ~

> units      (U)=  FPS
> syspos        =    16316730.971   -16537356.159    -2915982.080
> sysvel        =       17585.035       16827.253        2967.099

> refpos        =    16316730.971   -16537356.404    -2915982.102
> refvel        =       17585.035       16827.253        2967.098

  gravity:
> gx gy gz      =  -17.8932977559   18.1352403476    3.1977321749
  mu            =  .140764418E+17

  ephemeris:
> semimajor (U)=    23414158.319
> ecc          =      .000000
> incl    (deg)=   10.000000
> rasc    (deg)=      .000000
> argp    (deg)=      .000000
> t_anom  (deg)=  -45.823217
  e_anom  (deg)=  -45.823217
  m_anom  (deg)=  -45.823217
  m_motion(d/s)=    .06000000

> LST_ang (deg)=  222.862091    ; sun_beta(deg)=    .000
> LST(h:m:s)   = 14:51:26.9

> period  (min)=         100.000; revs/day=  14.400
> period  (sec)=        6000.000
  range      (U)=    23414158.319
  equ. radius  =    20925646.325; J2=  .108263E-02
  prg.altitude =     2488511.994; apg.altitude=     2488511.994
  we  (d/s,r/s)=       .00417807        .00007292

> sysacc flag  =  1
> gravity flag = 10
```

Figure 10 Gravity Menu

This orbit specification shows that the Arraysim is in a 10 deg inclined circular orbit with an orbit period of 100 minutes. The gravity flag of 10 means that the spherical earth gravity is chosen for the simulation.

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 Arraysim here has 4 wheels for ACS. The wheels attributes are displayed below.

```
  idx name    pa t ---------- ---axis--- ---------- --winr- -w(rpm)-
=>  1 whl1     1 A   .5773503  -.5773503   .5773503   .1000       .0
    2 whl2     1 A   .5773503   .5773503   .5773503   .1000       .0
    3 whl3     1 A  -.5773503   .5773503   .5773503   .1000       .0
    4 whl4     1 A  -.5773503  -.5773503   .5773503   .1000       .0
```

Figure 11   Wheel Data from Wheel Menu

This table shows that wheels 1-4 are attached to b1 (pa=1). 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 11.

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 Arraysim here has 8 jets. (Jets 7 and 8 are idle.) Their attributes are displayed in next two tables. All Jets are attached to b1 (p=1). All jets are type 1 (t=1) meaning that the simulation engine xsim1.dll expects on/off (0/1) signals to be in the sim-input channel to turn on and off these jets. 'fmag' is the force magnitude when jets are fired. 'fx,fy,fz' are the force vectors of the jets in the attached body coordinates.

	idx	name	p	t	c	---fmag---	----fx----	----fy----	----fz----
=>	1	f1	1	1	1	.200	.200	.000	.000
	2	f2	1	1	1	.200	.200	.000	.000
	3	f3	1	1	1	.200	.200	.000	.000
	4	f4	1	1	1	.200	.200	.000	.000
	5	f5	1	1	1	.200	.000	-.200	.000
	6	f6	1	1	1	.200	.000	-.200	.000
	7	f7	1	1	1	.000	.000	.000	.000
	8	f8	1	1	1	.000	.000	.000	.000

Figure12 Jet Force Data from Force Menu

The next table shows the position of the jet thrusters on their attached bodies that is b1 in this case.

	idx	name	p	t	c	---fmag---	---posx---	---posy---	---posz---
=>	1	f1	1	1	1	.200	-3.000	-3.000	.000
	2	f2	1	1	1	.200	-3.000	3.000	.000
	3	f3	1	1	1	.200	-3.000	.000	3.000
	4	f4	1	1	1	.200	-3.000	.000	-3.000
	5	f5	1	1	1	.200	.000	3.000	3.000
	6	f6	1	1	1	.200	.000	3.000	-3.000
	7	f7	1	1	1	.000	.000	.000	.000
	8	f8	1	1	1	.000	.000	.000	.000

Figure 13 Jet Impact Position Data from Force Menu

The values of the force parameters can be changed using the following instructions.

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 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 ArraySim here has 8 constraint signals that control the deployment of the two arraysim arrays. Constraints 1 and 2 switches lock the innermost panels (b3, b8) when their inboard joint angles (ang3, ang8) reaches 0. Gear constraints 3 to 5 controls the linear relations between the panel angles on the y+ face of the bus, and gear constraints 6 to 8 controls the same between panel angles on the y- face of the bus. The values under the ‘ic’ column in the cn Menu are the initial values of the cn switches (0-off, 1-on), indices under the ‘b1 b2’ columns indicate the joints for which the constraints apply.

	idx	type	ic	ln	ov	b1	b2	f1	f2	d1	d2	d3	p1	p2
=>	1	LOCK	0	1	0	3	0	0	0	0	0	0	0	0
	2	LOCK	0	1	0	8	0	0	0	0	0	0	0	0
	3	GEAR	1	1	0	3	4	0	0	0	0	0	0	0
	4	GEAR	1	1	0	4	5	0	0	0	0	0	0	0
	5	GEAR	1	1	0	5	6	0	0	0	0	0	0	0
	6	GEAR	1	1	0	8	9	0	0	0	0	0	0	0
	7	GEAR	1	1	0	9	10	0	0	0	0	0	0	0
	8	GEAR	1	1	0	10	11	0	0	0	0	0	0	0

Figure 14 Constraint Signals Summary from CN Menu

Edit CN Parameters
Select the ‘cn’ command from Model Menus page to open the Constraint Menu. See Figure 14.

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 gear constraint:
- use ‘gear’ command to create a gear 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 Arraysim are in the next table.

```
Udata list:

 1) cn,1                | 2) cn,2                | 3) whltq,1
 4) whltq,2             | 5) whltq,3             | 6) whltq,4
 7) xf,1                | 8) xf,2                | 9) xf,3
10) xf,4                |11) xf,5                |12) xf,6
```

Figure 15 Udata List from the Input Data Menu

where, cn,1:2   = array deployment constraint signals (1/0)
whltq,1:4=b1 wheel torque
xf ,1:6   = jet firing (1/0) commands

Note: no array torque input for arraysim, that's defined through menu.

The size of each of these signals are as follows.

```
> len
  #    uDef          Len  Loc    #    uDef          Len  Loc
  1.  cn,1            1    1|    2.  cn,2            1    2
  3.  whltq,1         1    3|    4.  whltq,2         1    4
  5.  whltq,3         1    5|    6.  whltq,4         1    6
  7.  xf,1            1    7|    8.  xf,2            1    8
  9.  xf,3            1    9|   10.  xf,4            1   10
 11.  xf,5            1   11|   12.  xf,6            1   12
```

Figure 16 Length of Udata Elements

Note that only 'xf1:6' (1/0) signals are defined to actuate the jets.

The parameters in the xsim input list can be changed using the following instructions.

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

```
Ydata list:

 1) angle,3            | 2) angle,8            | 3) w,1
 4) b2osml,1           | 5) whlspd,1           | 6) whlspd,2
 7) whlspd,3           | 8) whlspd,4
```

Figure 17 XSIM Output Data from Output Menu

where, agnle,(3,8)= solar array drive joint angles (b3,b8)
w,1 = total angular rate of b1 in b1 coordinates
b2osml,1= small angle roll-pitch-yaw of b1 wrt orbit frame
angle,2:3 = array1 and 2 joint angles
wspd,1:3= reaction wheels 1:4 speed in d/s

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

```
> len
  #   yDef          Len  Loc   #   yDef          Len  Loc
  1. angle,3         1    1|   2. angle,8         1    2
  3. w,1             3    3|   4. b2osml,1        3    6
  5. whlspd,1        1    9|   6. whlspd,2        1   10
  7. whlspd,3        1   11|   8. whlspd,4        1   12
```

Figure 18 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 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.

Odata list:

1) quat,1	2) wrel,1	3) whlspd,1
4) whlspd,2	5) whlspd,3	6) whlspd,4
7) whltq,1	8) whltq,2	9) whltq,3
10) whltq,4	11) syshmom	12) syspos
13) sysvel	14) syspmom	15) b2o123,1
16) angle,2	17) angle,3	18) angle,4
19) angle,5	20) angle,6	21) angle,7
22) angle,8	23) angle,9	24) angle,10
25) angle,11	26) wrelax,2	27) wrelax,3
28) wrelax,4	29) wrelax,5	30) wrelax,6
31) wrelax,7	32) wrelax,8	33) wrelax,9
34) wrelax,10	35) wrelax,11	36) htqax,2
37) htqax,3	38) htqax,7	39) htqax,8
40) syshb1	41) cnrows	42) sunb,1
43) sunorb	44) eclipse	45) lst

Figure 19 XSIM Plot Data List from Plot Menu

where, quat,1= attitude quaternion of b1
htqax,2:3= array1 and 2 joint torque
w,1:3 = total angular rate vector of b1:b3 in b1 coordinates
wrel,1 = angular rate vector of b1 in b1 coordinates
wrelax,2:11= array1 and 2 joint rates
htqax, 2:11 = array1 and 2 joint torque
whlspd,1:4= wheel spinning speed in d/s
whltq,1:4 = wheel torque
syspos = composite tether cm position in inertial frame
sysvel = composite tether cm velocity in inertial frame
sysacc = system cm acceleration in inertial frame
syshmom= Arraysim angular momentum about system cm
syshb1 = syshmom in b1 coordinates
b2osml,1 = small angle b1 attitude roll-pitch-yaw wrt orbit frame
sunorb = satellite-to-sun vector in orbit frame
eclipse = in-eclipse flag (1/0)
lst = local satellite time (0:2pi)
cnrows= nof constraint equations in use

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

#	oDef	Len	Loc	#	oDef	Len	Loc
1.	quat,1	4	2	2.	wrel,1	3	6
3.	whlspd,1	1	9	4.	whlspd,2	1	10
5.	whlspd,3	1	11	6.	whlspd,4	1	12
7.	whltq,1	1	13	8.	whltq,2	1	14
9.	whltq,3	1	15	10.	whltq,4	1	16
11.	syshmom	3	17	12.	syspos	3	20
13.	sysvel	3	23	14.	syspmom	3	26
15.	b2o123,1	3	29	16.	angle,2	1	32
17.	angle,3	1	33	18.	angle,4	1	34
19.	angle,5	1	35	20.	angle,6	1	36
21.	angle,7	1	37	22.	angle,8	1	38
23.	angle,9	1	39	24.	angle,10	1	40
25.	angle,11	1	41	26.	wrelax,2	1	42
27.	wrelax,3	1	43	28.	wrelax,4	1	44
29.	wrelax,5	1	45	30.	wrelax,6	1	46
31.	wrelax,7	1	47	32.	wrelax,8	1	48
33.	wrelax,9	1	49	34.	wrelax,10	1	50
35.	wrelax,11	1	51	36.	htqax,2	1	52
37.	htqax,3	1	53	38.	htqax,7	1	54
39.	htqax,8	1	55	40.	syshb1	3	56
41.	cnrows	1	59	42.	sunb,1	3	60
43.	sunorb	3	63	44.	eclipse	1	66
45.	lst	1	67				

Figure 20 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 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.