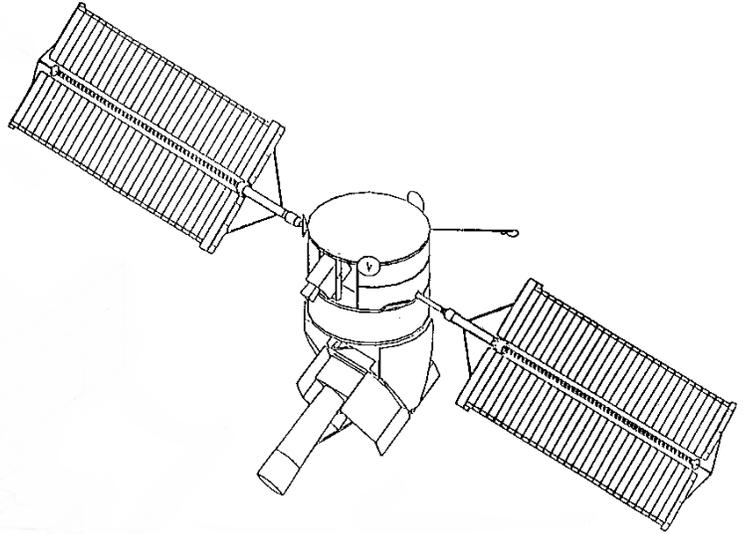


Rigid Body Spacecraft Equations

This section describes the equations of motion for a rigid body spacecraft that is controlled by reaction control jets (RCS), and also an array of momentum exchange devices, such as, reaction wheels (RWA), single-gimbal control moment gyros (SG-CMG), and double-gimbal control moment gyros (DG-CMG). Equations of a spacecraft with rotating appendages are also included. The Flixan program provides the capability to synthesize any spacecraft configuration consisting of: RCS, RWs, CMGs, and gimbaling appendages, or any combination of the above devices. Structural flexibility can also be included and implemented as a separate flex system coupled



with the rigid-body model. It requires using the flexible spacecraft modeling program and modal data with nodes at the actuator and sensor locations, as demonstrated in the examples.

1. Rigid Body Spacecraft with Reaction Wheels

Reaction wheels consist of a spinning rotor whose spin axis is fixed relative to the spacecraft and its spin rate is maintained close to zero. Its speed is increased or decreased to generate a reaction torque about the spin axis. They are inexpensive but their control torque capabilities are small and are typically used to control small 3-axes stabilized satellites. Figure 1a shows a typical reaction wheel (RW) with the control electronics. Its angular rate can be varied by applying a torque to the motor that rotates it about its spin axis. As the wheel accelerates it applies an equal and opposite reaction torque to the spacecraft that is used to control attitude. In general, a three axes stabilized spacecraft requires a RW array consisting of at least three reaction wheels.

Figure 1b represents a rigid-body spacecraft with a RW and an externally applied force F . The spacecraft origin is at the CG. The unit vector \underline{a}_i defines the spin direction of wheel (i). A force vector \underline{F}_j defines an external force (j), for example, due to an RCS jet firing. The displacement \underline{d}_j represents the distance between the force F_j application point, and the vehicle CG (assuming the mass properties include the wheels). By combining the reaction wheel assembly (RWA) spin column vectors \underline{a}_i together we can create a transformation matrix C_w^b that transforms the wheel momentum from individual wheel axis to spacecraft body axes (x, y, z). For example, if we are using four reaction wheels the transformation from wheel to body is shown in equation 1.1. The transformation from body to wheel is the pseudo-inverse of C_w^b .

$$C_w^b = \begin{bmatrix} \underline{a}_1 & \underline{a}_2 & \underline{a}_3 & \underline{a}_4 \end{bmatrix} \quad (1.1)$$

The following equations describe the non-linear dynamics of a spacecraft with reaction wheels and reaction control jets that can be used for large angle simulations. The rate of change of system momentum (total momentum of spacecraft plus wheels) is not affected by the internal wheel control torques but it is only affected by the external torques due to disturbances or the RCS jets torques.

$$\dot{\underline{H}}_{sys} = -\underline{\omega}_b \times \underline{H}_{sys} + \underline{T}_{ext} \quad \textit{System Angular Momentum Rate} \quad (1.2)$$

\underline{T}_{ext} is the sum of all external moments applied to the spacecraft. It consists of three terms: aerodynamic disturbance torques T_D , gravity gradient torques T_{GG} , and also the control torques generated by the reaction control jets $\underline{F}_{RCS(j)}$.

$$\underline{T}_{ext} = \underline{T}_D + T_{GG} + \sum_j^{nf} \underline{d}_j \times \underline{F}_{RCS(j)} \quad (1.3)$$



Figure 1a Typical Reaction Wheel with Control Electronics

When the spacecraft has an orbital rate ω_0 (rad/sec) the gravity gradient torque is a function of the LVLH Euler angles (ϕ, θ, ψ), as described in equation 1.4.

$$T_{GG} = 3\omega_o^2 (c \times J_v c) \quad , \quad c = \begin{bmatrix} -\sin \theta \cos \psi \\ \cos \phi \sin \theta \sin \psi + \sin \phi \cos \theta \\ -\sin \phi \sin \theta \sin \psi + \cos \phi \cos \theta \end{bmatrix} \quad (1.4)$$

The spacecraft with reaction wheels model can be implemented in two forms. In the simplest form the momentum of the reaction wheel array is calculated in the body frame. This model does not keep track of the individual wheel speeds and it does not calculate the torque produced by each individual wheel on the vehicle. Only the combined RWA torque is calculated, which is fine if the wheels are collocated. The following equation calculates the spacecraft rotational acceleration $\dot{\omega}$ as a function of the RWA internal torque vector T_w and also the external torques T_{ext} . The second equation calculates the rate of change in RW momentum as a function of the torque generated by the wheels, which is opposite to spacecraft torque.

$$\begin{aligned}
 J_v \dot{\omega} &= -\omega \times J_v \omega + T_{RW} + T_{ext} \\
 \dot{h}_b + \omega \times h_b &= -T_{RW}
 \end{aligned}
 \tag{1.5}$$

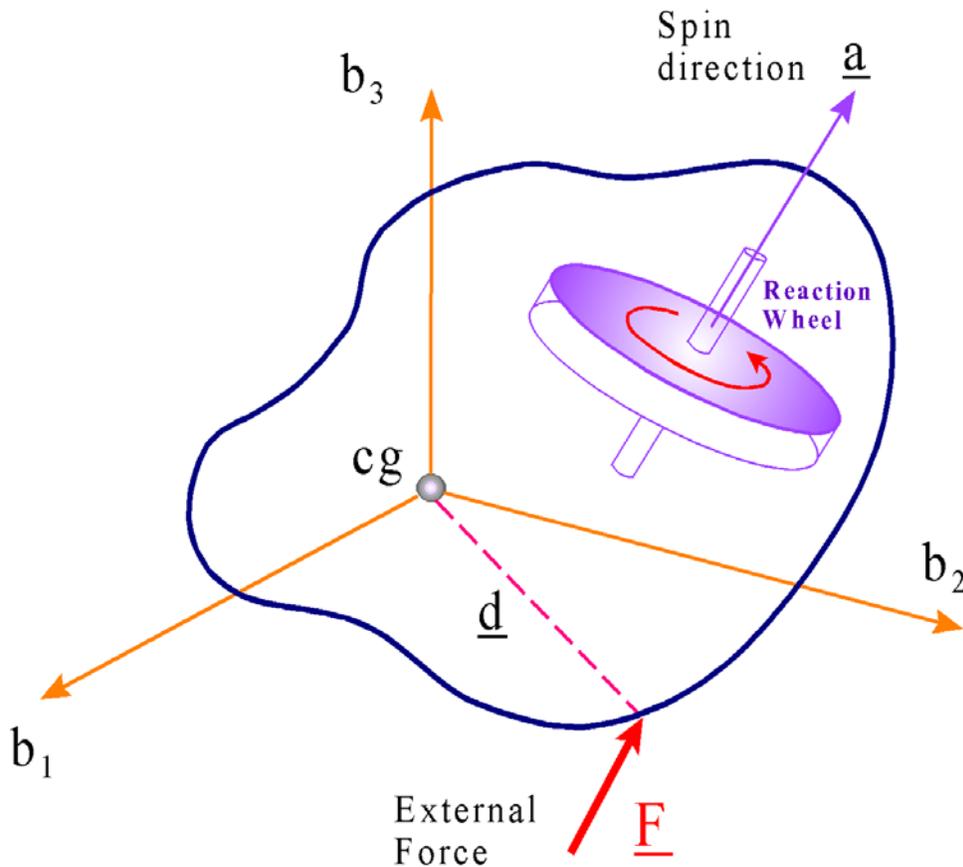


Figure 1b Spacecraft with a Reaction Wheel and an External Force

Where:

- \underline{h}_b is the RW array momentum in the spacecraft body frame.
- T_{RW} is a vector of RW torques in spacecraft body axes
- T_{ext} is the external torques applied to the spacecraft in body axes
- J_v is the spacecraft moment of inertial dyadic

2. Spacecraft with Single Gimbal CMGs

A single gimbal control moment gyroscope (SGCMG) is shown in Figure 2.1. It consists of a spinning rotor that is mounted on a structure that can be gimballed perpendicular to the rotor axis. The rotor spin rate is maintained at a constant speed by a small motor that produces a constant angular momentum h . It is the precession of this vector that produces a useful output torque that is substantially greater than a reaction wheel torque, and for this reason it is very attractive in applications that require high torque and in fast maneuvering or agile spacecraft. The direction of the spinning rotor and hence the flywheel momentum can be rotated relative to the spacecraft by a stronger motor and a gimbal. The gimbal motor controls the gimbaling rate, and hence the output torque. By commanding the gimbal to rotate, by means of a servo system that receives rate command from the steering logic, high precession torques are generated by changing the orientation of the angular momentum vector. The reaction torque on the spacecraft T is equal and opposite to the rate of change in momentum vector \dot{h} , which is orthogonal to the momentum vector h and also to the gimbaling vector according to the right hand rule. However, the torque direction at any instant is a function of the gimbal position. The SGCMG essentially acts as a torque amplification device because the output torque magnitude is equal to the CMG momentum multiplied by the gimbal rate. In addition, this does not require very much power, because, a small input torque from the gimbal actuator produces a much greater torque in a plane formed by the rotating momentum vector.

2.1 CMG Array Geometry

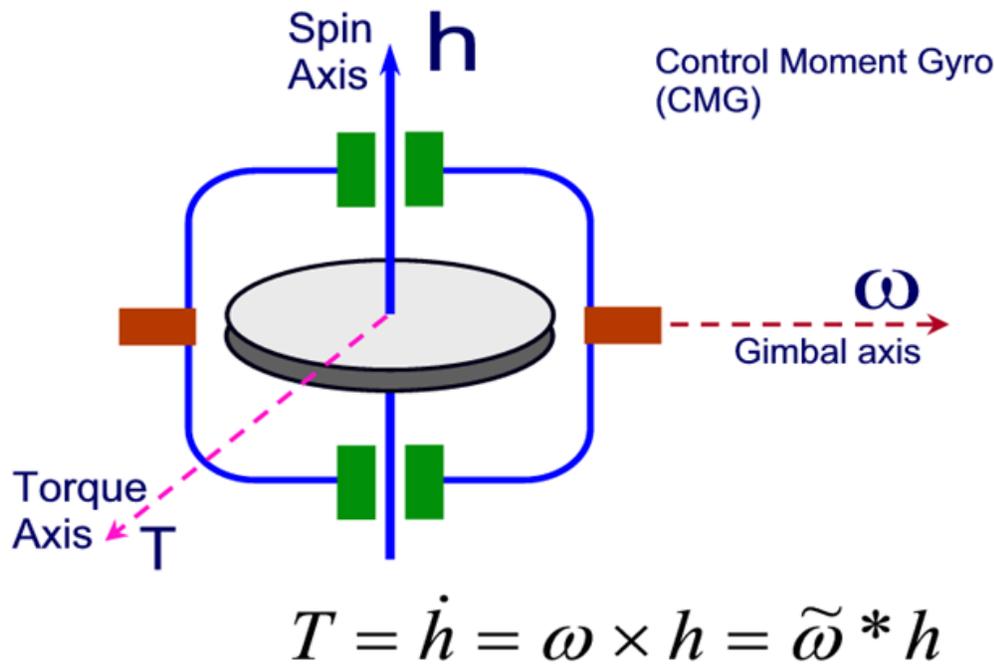


Figure 2.1a Single-Gimbal Control Moment Gyro

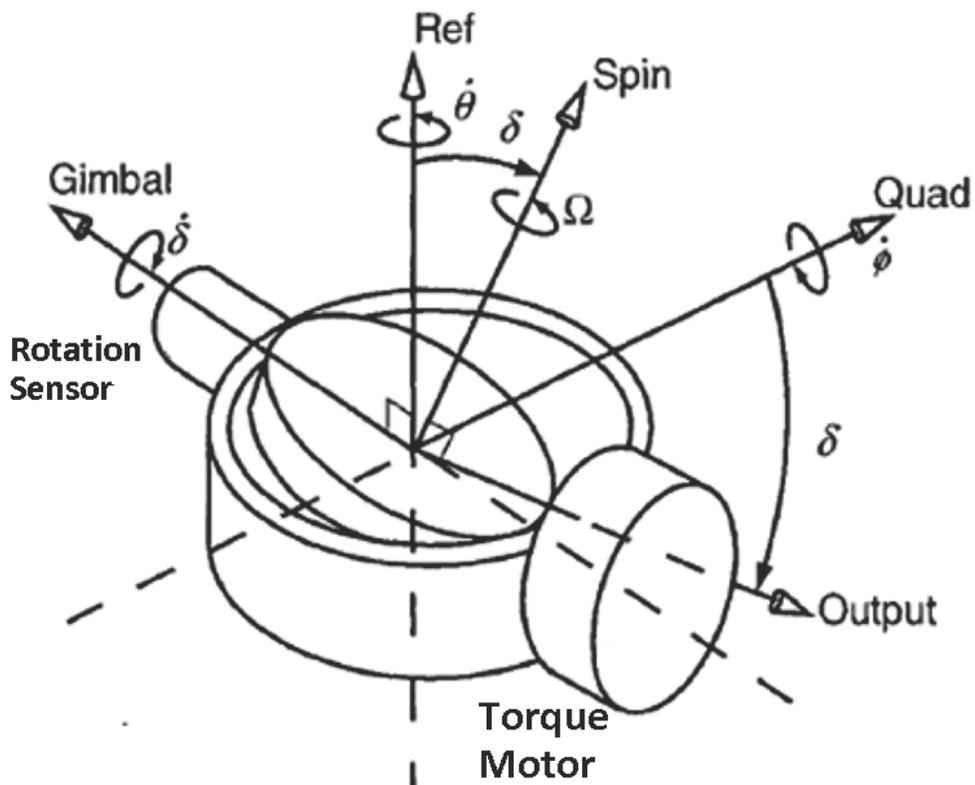
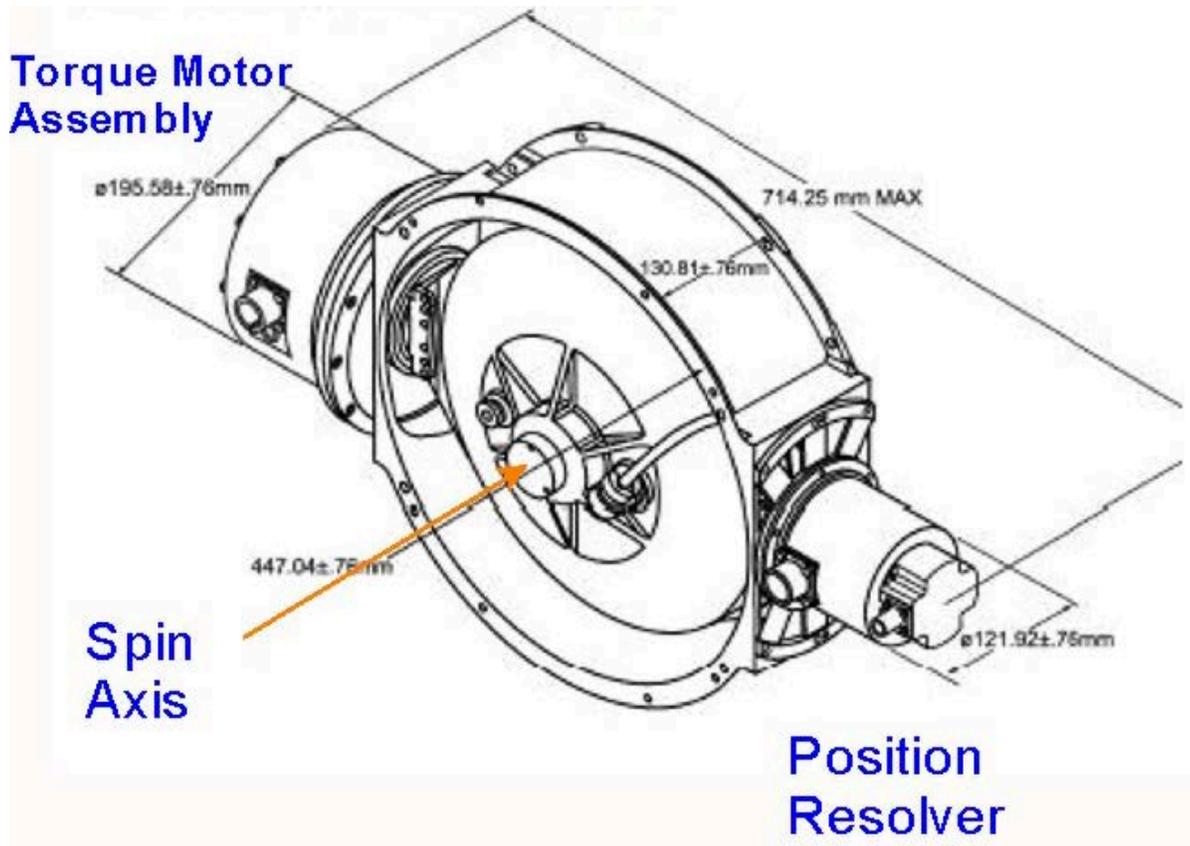


Figure 2.1b Single Gimbal Control Moment Gyro

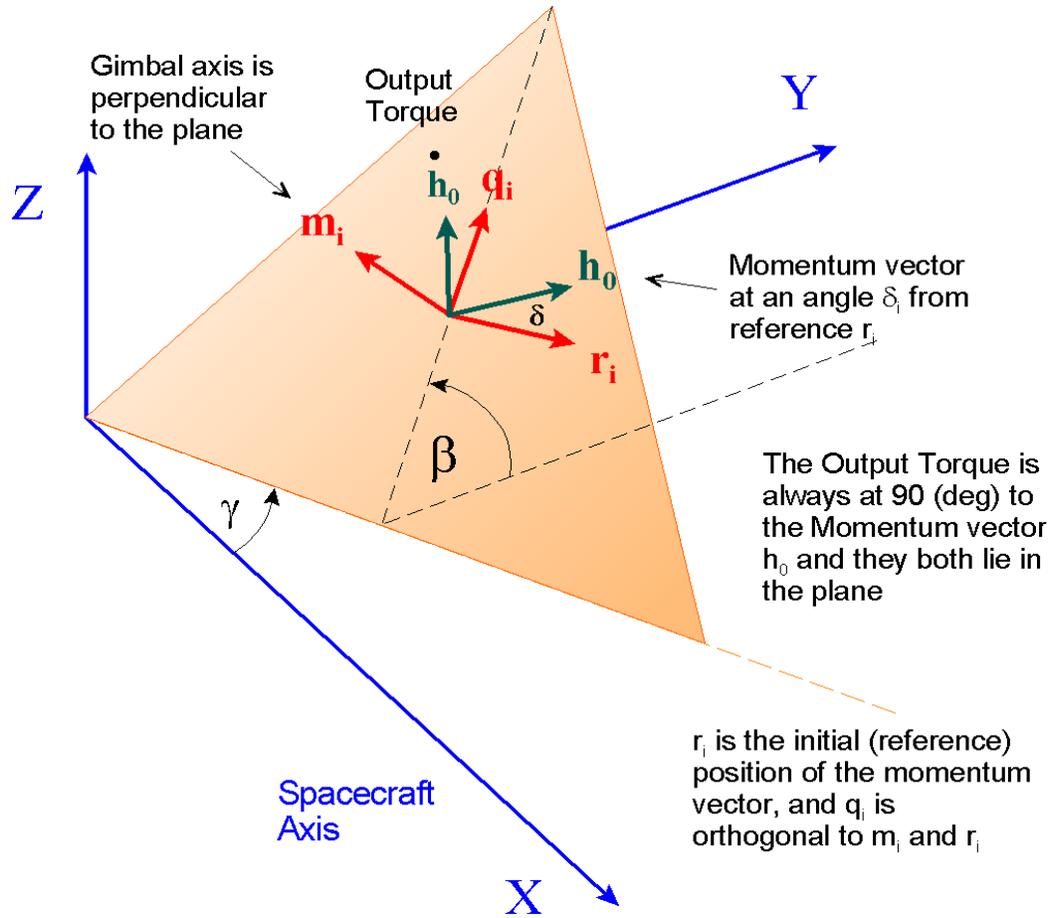
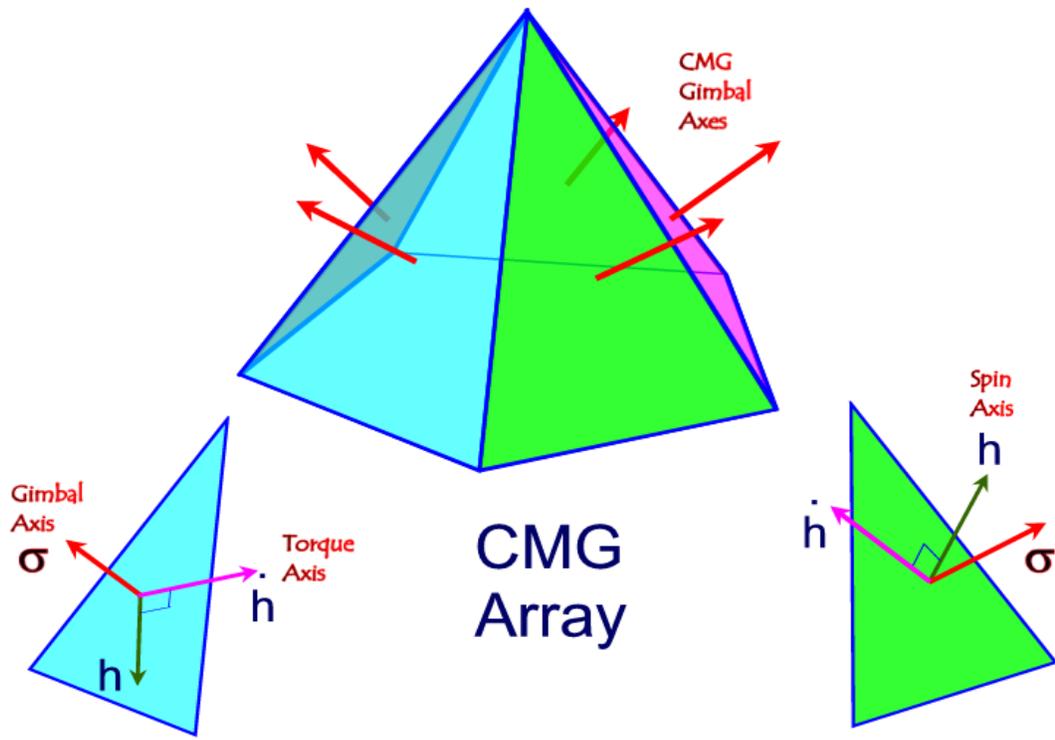


Figure 2.2 Orientation of a CMG in Spacecraft Coordinates

Let us consider a SGCMG pyramid arrangement shown in Figure 2.4b, where the spacecraft has four SGCMGs mounted onto the four faces of the four sided pyramid. All CMGs have the same constant angular momentum $h_0=1200$ (ft-lb-sec). Their CMG momentum vectors \underline{h}_i are initially (at zero gimbal, $\delta_{0i}=0$) parallel to the spacecraft X-Y plane producing zero total momentum. Their momentum vectors are constrained to lay parallel to the surface of the pyramid and they can be continuously rotated about the gimbal vectors $\underline{\delta}_i$, which are perpendicular to each surface. The orientation of each CMG relative to the spacecraft is shown in Figure 2.4b. The pyramid angle β is 68° , and the γ_i angles of the four surfaces according to Figure 2.2 are: 90° , 180° , 270° , and 0° . We can create the 3×4 gimbal to body transformation matrix M_g^b by stacking together the four gimbal direction column unit vectors \underline{m}_i as shown in equation 2.5.

$$M_g^b = [\underline{m}_1 \quad \underline{m}_2 \quad \underline{m}_3 \quad \underline{m}_4] \text{ where } : \underline{m}_i = \begin{bmatrix} \sin \beta_i \sin \gamma_i \\ -\sin \beta_i \cos \gamma_i \\ \cos \beta_i \end{bmatrix} \quad (2.5)$$

$$M_g^b = \begin{bmatrix} \sin \beta & 0 & -\sin \beta & 0 \\ 0 & \sin \beta & 0 & -\sin \beta \\ \cos \beta & \cos \beta & \cos \beta & \cos \beta \end{bmatrix} = \begin{bmatrix} 0.927 & 0 & -0.927 & 0 \\ 0 & 0.927 & 0 & -0.927 \\ 0.375 & 0.375 & 0.375 & 0.375 \end{bmatrix}$$



σ is the CMG gimbal axis direction
 h is the initial CMG momentum direction
 \dot{h} is the initial CMG torque direction

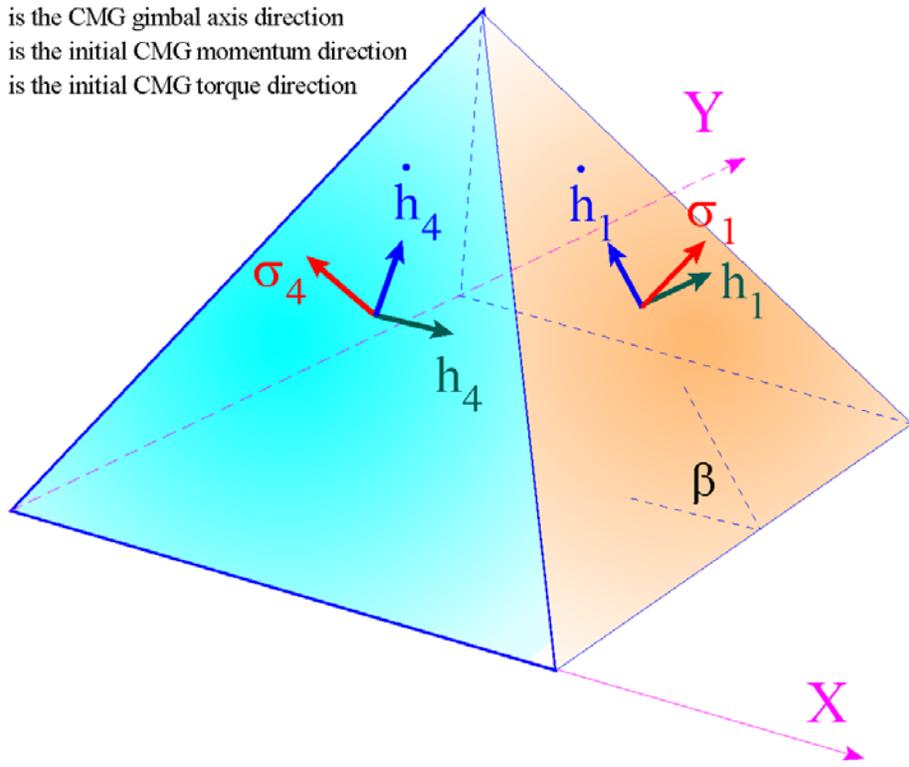


Figure 2.4 Arrays of five and four CMGs in Pyramid Configuration

Similarly, we create the 3x4 reference directions matrix R by stacking together the initial directions unit vectors \underline{r}_i of the momentum vectors \underline{h}_i when the gimbal angles are zero, $\delta_{0i}=0$. In this orientation the initial gimbal angles produce zero momentum bias.

$$R = [\underline{r}_1 \quad \underline{r}_2 \quad \underline{r}_3 \quad \underline{r}_4] \text{ where: } \underline{r}_i = \begin{bmatrix} \cos \gamma_i \\ \sin \gamma_i \\ 0 \end{bmatrix}; \quad R = \begin{bmatrix} 0 & -1 & 0 & 1 \\ 1 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \quad (2.6)$$

We must also define a third 3x4 Quad-matrix Q that contains column vectors of the cross product direction unit vectors \underline{q}_i .

$$Q = [\underline{q}_1 \quad \underline{q}_2 \quad \underline{q}_3 \quad \underline{q}_4]; \quad \underline{q}_i = (\underline{m}_i \times \underline{r}_i);$$

$$Q = \begin{bmatrix} -0.375 & 0 & 0.375 & 0 \\ 0 & -0.375 & 0 & 0.375 \\ 0.927 & 0.927 & 0.927 & 0.927 \end{bmatrix} \quad (2.7)$$

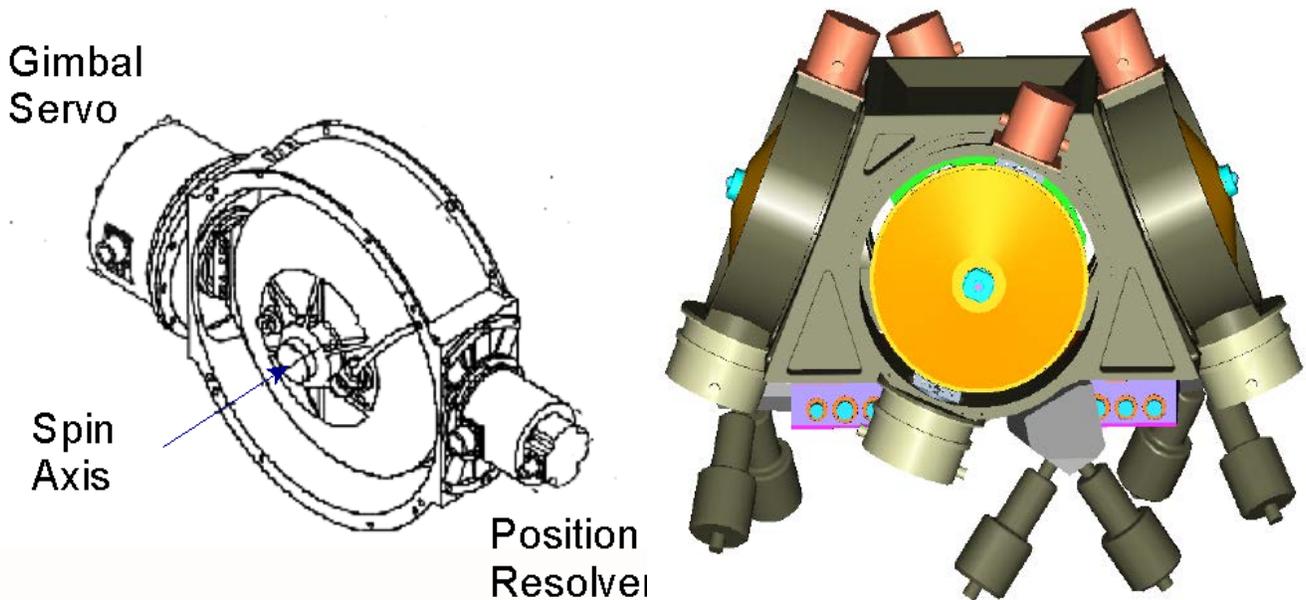


Figure 2.6 A Single-Gimbal Control Moment Gyro and a Cluster of four Single Gimbal CMGs mounted on a pyramid structure which is isolated from the spacecraft by means of disturbance isolation struts

Notice, that the pyramid structure is only used for visualization. The CMGs do not have to be physically mounted on the four surfaces of an actual pyramid, as in Figure 2.4, but they can be translated anywhere on the spacecraft as long as their gimbal axes (\underline{m}_i) and their reference momentum vectors (\underline{r}_i) are parallel to the directions shown in the pyramid. See, for example, the CMG cluster in Figure 2.6. The CMGs are typically mounted on a structure that it is mechanically isolated from the spacecraft by means of vibration isolation struts, as shown in Figure 2.6, that attenuate mechanical vibrations from the CMGs.

5. Generating Spacecraft Models with Flixan

In this section we will demonstrate how to generate linear spacecraft systems using the Flixan Flight Vehicle Modeling program. We begin with a Space Station model that is controlled by a centralized momentum control system. Then we will analyze a spacecraft that is controlled with an array of 4 Single Gimbal CMGs. Our third example is a spacecraft that is controlled by an array of 3 Reaction Wheels and it includes 4 gimbaling appendages.

5.1 Flexible Space Station Model with a Centralized Momentum Control System

The following “Flight Vehicle” dataset was created for Space Station model that is controlled by a 3-axis momentum control system such as a cluster of double-gimbal CMGs. In this case we will not model the detailed CMG steering but use the simple generic model described in Section 3. The Space Station Example is in folder “C:\Flixan\Examples\Large Space Station”, and the input file that contains the spacecraft data is in file “SpaceStation.Inp”. This file contains two data-set models, a rigid and a flexible model, to be processed by the flight vehicle modeling program. The file also includes a modal data set of 34 selected flex modes to be combined with the flex model, and Matlab conversion data-sets. The title of the flexible vehicle set is “Space Station with RCS and a Double-Gimbal CMG Array” and it includes 8 force inputs representing the reaction control thrusters, 3 external torques (roll, pitch, and yaw), a centralized momentum control system, 3-gyros, 3-rate-gyros, and 4-accelerometers. A set of 34 selected structural modes is included in the input file, and the modal data title also included at the bottom of the spacecraft dataset. The dataset for this configuration is shown below.

```
FLIGHT VEHICLE INPUT DATA .....
Space Station with RCS and a Double-Gimbal CMG Array
!
! The Space Station state-space model is now created using the vehicle modeling program.
! The model uses 8 RCS jets, an array of double-gimbal control moment gyros, 3 rate
! gyros, 3 attitude sensors, and 4 accelerometers. The Station is initialized at the
! Local Vertical Local Horizontal (LVLH) attitude and it has a negative pitch rate
! -0.063 radians/sec which is equal to the orbital rate. The vehicle rates are with
! respect to the LVLH frame. A constant bias torque 7.40153 (ft-lb) is applied
! in the direction (-0.1969, 0.5963, 0.7781) to represent the steady-state gyroscopic
! and gravity-gradient torques due to the constant pitch rate
Body Axes Output, LVLH Attitude

Vehicle Mass (lb-sec^2/ft), Gravity Accelerat. (g) (ft/sec^2), Earth Radius (Re) (ft) : 6200.0      32.174      0.20896E+08
Moments and products of Inertias Ixx, Iyy, Izz, Ixy, Ixz, Iyz, in (lb-sec^2-ft) : 0.119416e+9  0.40408e+8  0.110166e+9, 0.476e+7, 0.1216e+7,
CG location with respect to the Vehicle Reference Point, Xcg, Ycg, Zcg, in (feet) : 0.0      0.0      0.0
Vehicle Mach Number, Velocity Vo (ft/sec), Dynamic Pressure (psf), Altitude (feet) : 0.0      25500.0    0.0001      700000.0
Inertial Acceleration Vo_dot, Sensed Body Axes Accelerations Ax,Ay,Az (ft/sec^2) : 0.0      0.0      0.0      0.0
Angles of Attack and Sideslip (deg), alpha, beta rates (deg/sec) : 0.0      0.0      0.0      0.0
Vehicle Attitude Euler Angles, Phi_o,Thet_o,Psi_o (deg), Body Rates Po,Qo,Ro (deg/sec) : 0.0000    0.0000    0.0000    0.0000    -0.063
W-Gust Azim & Elev angles (deg), or Torque/Force direction (x,y,z), Force Locat (x,y,z) : Torque    0.196972   -0.596376   -0.778163
Surface Reference Area (feet^2), Mean Aerodynamic Chord (ft), Wing Span in (feet) : 0.0      1.0      1.0
Aero Moment Reference Center (Xmrc,Ymrc,Zmrc) Location in (ft), {Partial_rho/ Partial_H} : 0.0      0.0      0.0      -0.0
Aero Force Coeff/Deriv (1/deg), Along -X, {Cao,Ca_alf,PCa/PV,PCa/Ph,Ca_alfdot,Ca_q,Ca_bet} : 0.0      0.0      0.0      0.0      0.0
Aero Force Coeff/Derivat (1/deg), Along Y, {Cyo,Cy_bet,Cy_r,Cy_alf,Cy_p,Cy_betdot,Cy_V} : 0.0      -0.0      0.0000    0.0000    0.0000
Aero Force Coeff/Deriv (1/deg), Along Z, {Czo,Cz_alf,Cz_q,Cz_bet,PCz/Ph,Cz_alfdot,PCz/PV} : 0.0      -0.0      0.0000    0.0000    0.0000
Aero Moment Coeff/Derivat (1/deg), Roll: {Clo,Cl_beta,Cl_betdot,Cl_p,Cl_r,Cl_alfa} : 0.0      -0.0      0.0000    0.0000    0.0000
Aero Moment Coeff/Deriv (1/deg), Pitch: {Cmo,Cm_alfa,Cm_alfdot,Cm_bet,Cm_q,PCm/PV,PCm/Ph} : 0.0      -0.0      0.0000    0.0000    0.0000
Aero Moment Coeff/Derivat (1/deg), Yaw : {Cno,Cn_beta,Cn_betdot,Cn_p,Cn_r,Cn_alfa} : 0.0      0.0      0.0000    0.0000    0.0000
```

Number of Thruster Engines, Include or Not the Tail-Wags-Dog and Load-Torque Dynamics ? : 8

RCS Jet No: 1	Upper Right, +X (20 lb jet)	: UR+X Jet	Throttling	Node 25
Engine Nominal Thrust, and Maximum Thrust in (lb)	(for throttling)	: 0.0	20.0	
Mounting Angles wrt Vehicle (Dyn,Dzn), Maximum Deflections from Mount (Dymax,Dzmax) (deg):	0.0	0.0	0.0	0.0
Eng Mass (slug), Inertia about Gimbal (lb-sec ² -ft), Moment Arm, engine CG to gimbal (ft):	0.0	0.0	0.0	
Thruster location with respect to the Vehicle Reference Axes, Xjet, Yjet, Zjet, (ft)	: 0.0,	73.7,	-185.0	
RCS Jet No: 2	Upper Right, -Y (20 lb jet)	: UR-Y Jet	Throttling	Node 25
Engine Nominal Thrust, and Maximum Thrust in (lb)	(for throttling)	: 0.0	20.0	
Mounting Angles wrt Vehicle (Dyn,Dzn), Maximum Deflections from Mount (Dymax,Dzmax) (deg):	0.0	-90.0	0.0	0.0
Eng Mass (slug), Inertia about Gimbal (lb-sec ² -ft), Moment Arm, engine CG to gimbal (ft):	0.0	0.0	0.0	
Thruster location with respect to the Vehicle Reference Axes, Xjet, Yjet, Zjet, (ft)	: 0.0,	73.7,	-185.0	
RCS Jet No: 3	Upper Left, +X (20 lb jet)	: UL+X Jet	Throttling	Node 26
Engine Nominal Thrust, and Maximum Thrust in (lb)	(for throttling)	: 0.0	20.0	
Mounting Angles wrt Vehicle (Dyn,Dzn), Maximum Deflections from Mount (Dymax,Dzmax) (deg):	0.0	0.0	0.0	0.0
Eng Mass (slug), Inertia about Gimbal (lb-sec ² -ft), Moment Arm, engine CG to gimbal (ft):	0.0	0.0	0.0	
Thruster location with respect to the Vehicle Reference Axes, Xjet, Yjet, Zjet, (ft)	: 0.0,	-65.6,	-185.0	
RCS Jet No: 4	Upper Left, +Y (20 lb jet)	: UL+Y Jet	Throttling	Node 26
Engine Nominal Thrust, and Maximum Thrust in (lb)	(for throttling)	: 0.0	20.0	
Mounting Angles wrt Vehicle (Dyn,Dzn), Maximum Deflections from Mount (Dymax,Dzmax) (deg):	0.0	+90.0	0.0	0.0
Eng Mass (slug), Inertia about Gimbal (lb-sec ² -ft), Moment Arm, engine CG to gimbal (ft):	0.0	0.0	0.0	
Thruster location with respect to the Vehicle Reference Axes, Xjet, Yjet, Zjet, (ft)	: 0.0,	-65.6,	-185.0	

Number of External Torques on the Vehicle : 3

Torque No 1	Direction (x, y, z)	: 1.0	0.0	0.0
Torque No 2	Direction (x, y, z)	: 0.0	1.0	0.0
Torque No 3	Direction (x, y, z)	: 0.0	0.0	1.0

Double Gimbal Control Moment Gyro System (3-axes), Initial Momentum (x,y,z) (ft-lb-sec) : Yes 0.0 0.0 0.0

Number of Gyros, (Attitude and Rate) : 6

Gyro No 1	Axis:(Pitch,Yaw,Roll), (Attitude, Rate, Accelerat), Sensor Locat, Node 2	: Roll	Rate	0.0	82.0	0.0
Gyro No 2	Axis:(Pitch,Yaw,Roll), (Attitude, Rate, Accelerat), Sensor Locat, Node 2	: Pitch	Rate	0.0	82.0	0.0
Gyro No 3	Axis:(Pitch,Yaw,Roll), (Attitude, Rate, Accelerat), Sensor Locat, Node 2	: Yaw	Rate	0.0	82.0	0.0
Gyro No 1	Axis:(Pitch,Yaw,Roll), (Attitude, Rate, Accelerat), Sensor Locat, Node 2	: Roll	Attitude	0.0	82.0	0.0
Gyro No 2	Axis:(Pitch,Yaw,Roll), (Attitude, Rate, Accelerat), Sensor Locat, Node 2	: Pitch	Attitude	0.0	82.0	0.0
Gyro No 3	Axis:(Pitch,Yaw,Roll), (Attitude, Rate, Accelerat), Sensor Locat, Node 2	: Yaw	Attitude	0.0	82.0	0.0

Number of Accelerometers, Along Axes: (x,y,z) : 4

Acceleromet No 1	Axis:(X,Y,Z), (Position, Velocity, Acceleration), Sensor Loc, Node 2	: X-axis	Accelerat.	0.0	232.35	18.0
Acceleromet No 2	Axis:(X,Y,Z), (Position, Velocity, Acceleration), Sensor Loc, Node 2	: Z-axis	Accelerat.	0.0	232.35	18.0
Acceleromet No 3	Axis:(X,Y,Z), (Position, Velocity, Acceleration), Sensor Loc, Node 4	: X-axis	Accelerat.	0.0	-224.63	16.0
Acceleromet No 4	Axis:(X,Y,Z), (Position, Velocity, Acceleration), Sensor Loc, Node 4	: Z-axis	Accelerat.	0.0	-224.63	16.0

Number of Bending Modes : 34

Space Station with RCS and a Double-Gimbal CMG Array, 34 Modes

The flight vehicle modeling program will process the above spacecraft dataset, including the following dataset which is referenced by title and contains the selected modal data for the flexible space-station model. It is located in the same input file and includes frequencies (rad/sec), damping coefficients (ζ), modal mass, and mode shapes and slopes at selected locations. Only the first mode is shown. The locations correspond to the locations specified in the spacecraft dataset above.

To process this dataset using the flight vehicle modeling program start the Flixan program, select the project directory, then go to “*Program Functions*”, “*Flight Vehicle/ Spacecraft Modeling Tools*”, and then “*Flight Vehicle State-Space*”. From the following menu select the input and system filenames and click on “*Process Files*”.

SELECTED MODAL DATA AND LOCATIONS FOR : 34 Modes
 Space Station with RCS and a Double-Gimbal CMG Array, 34 Modes
 ! The same 34 modes were selected as in the previous examples from all directions

MODE#	1/ 7, Frequency (rad/sec), Damping (zeta), Generalized Mass=	1.0097	0.50000E-02	12.000			
DEFINITION OF LOCATIONS (NODES)	phi along X	phi along Y	phi along Z	sigm about X	sigm about Y	sigm about Z	
Modal Data at the 8 Engines, (x,y,z)...							
Top Right RCS Thruster Assembl	1050	0.59628D-02	-0.16325D-04	0.96510D-04	0.42971D-06	-0.33256D-04	0.10894D-04
Top Right RCS Thruster Assembl	1050	0.59628D-02	-0.16325D-04	0.96510D-04	0.42971D-06	-0.33256D-04	0.10894D-04
Top Left RCS Thrusters Assembl	2050	0.54261D-02	-0.62395D-05	0.74506D-04	-0.10905D-06	-0.31918D-04	-0.18344D-04
Top Left RCS Thrusters Assembl	2050	0.54261D-02	-0.62395D-05	0.74506D-04	-0.10905D-06	-0.31918D-04	-0.18344D-04
Bottom Right RCS Thruster Asse	1150	-0.35170D-02	-0.59190D-04	0.96566D-04	0.13160D-06	-0.31650D-04	0.15942D-04
Bottom Right RCS Thruster Asse	1150	-0.35170D-02	-0.59190D-04	0.96566D-04	0.13160D-06	-0.31650D-04	0.15942D-04
Bottom Left RCS Thrusters Asse	2150	-0.32580D-02	-0.58408D-04	0.74465D-04	0.21757D-06	-0.30306D-04	-0.12670D-04
Bottom Left RCS Thrusters Asse	2150	-0.32580D-02	-0.58408D-04	0.74465D-04	0.21757D-06	-0.30306D-04	-0.12670D-04
Modal Data at the Double Gimbal GMGs Cluster...							
Right Keel/Boom Intrsect, CMG	1000	0.11384D-02	-0.58736D-04	0.96470D-04	-0.23552D-06	-0.30827D-04	0.65746D-04
Modal Data at the 3 External Torque Points...							
Center Habitat Module	9007	0.29012D-02	-0.26348D-04	0.31307D-04	0.30160D-06	-0.43846D-05	-0.97127D-07
Center Habitat Module	9007	0.29012D-02	-0.26348D-04	0.31307D-04	0.30160D-06	-0.43846D-05	-0.97127D-07
Center Habitat Module	9007	0.29012D-02	-0.26348D-04	0.31307D-04	0.30160D-06	-0.43846D-05	-0.97127D-07
Modal Data at the 6 Gyros ...							
Right Boom (Sensor Assembly)	6001	-0.14682D-03	-0.65626D-04	0.90529D-04	-0.37958D-06	-0.33769D-04	0.86246D-04
Right Boom (Sensor Assembly)	6001	-0.14682D-03	-0.65626D-04	0.90529D-04	-0.37958D-06	-0.33769D-04	0.86246D-04
Right Boom (Sensor Assembly)	6001	-0.14682D-03	-0.65626D-04	0.90529D-04	-0.37958D-06	-0.33769D-04	0.86246D-04
Right Boom (Sensor Assembly)	6001	-0.14682D-03	-0.65626D-04	0.90529D-04	-0.37958D-06	-0.33769D-04	0.86246D-04
Right Boom (Sensor Assembly)	6001	-0.14682D-03	-0.65626D-04	0.90529D-04	-0.37958D-06	-0.33769D-04	0.86246D-04
Right Boom (Sensor Assembly)	6001	-0.14682D-03	-0.65626D-04	0.90529D-04	-0.37958D-06	-0.33769D-04	0.86246D-04
Modal Data at the 4 Accelerometers, along (x,y,z)...							
Right Solar Array Boom	6070	-0.25921D-01	-0.73995D-04	-0.57584D-04			
Right Solar Array Boom	6070	-0.25921D-01	-0.73995D-04	-0.57584D-04			
Left SA Boom, Extreme end	5070	-0.26691D-01	0.68332D-05	-0.15103D-03			
Left SA Boom, Extreme end	5070	-0.26691D-01	0.68332D-05	-0.15103D-03			
Modal Data at the Disturbance Point							
Module, (Front Dock)	9018	0.28820D-02	-0.73445D-04	0.35876D-03	0.49346D-06	-0.54146D-05	-0.28216D-06

Flixan, Flight Vehicle Modeling & Control System Analysis

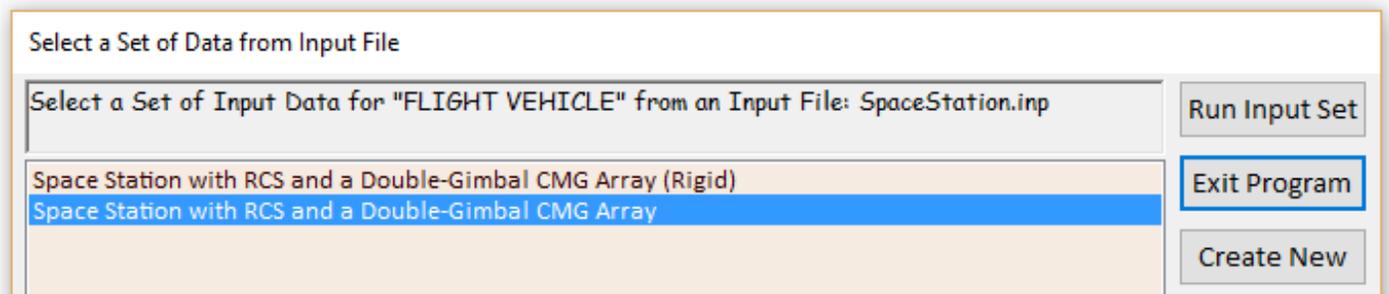
Utilities | File Management | **Program Functions** | View Quad | Help Files

- Flight Vehicle/Spacecraft Modeling Tools > Flight Vehicle, State-Space
- Frequency Control Analysis > Actuator State-Space Models
- Robust Control Synthesis Tools > Flex Spacecraft (Modal Data)
- Creating and Modifying Linear Systems > Create Mixing Logic/ TVC
- Trim/ Static Perform Analysis
- Flex Mode Selection

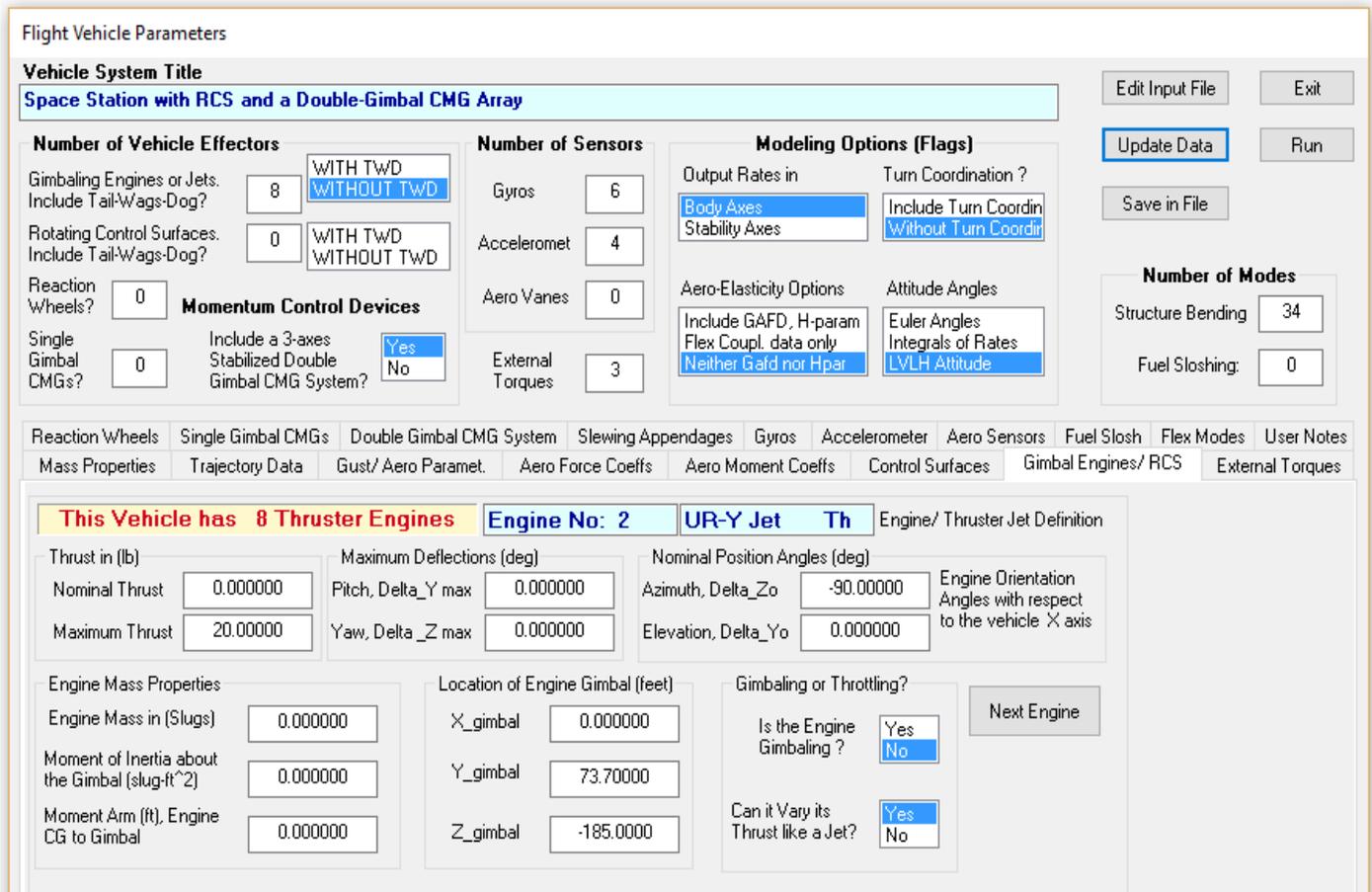
Select Input and System Filenames

Select a File Name containing the Input Data Set (x.Inp)	Select a File Name containing the State Systems (x.Qdr)
SpaceStation.Inp	SpaceStation.Qdr
SpaceStation.Inp	SpaceStation.Qdr
NewFile.Inp	NewFile.Qdr

The following menu shows the “Flight Vehicle” datasets which are in file “SpaceStation.Inp”. Select the second one and click on “Run Input Set” to process it.



The flight vehicle modeling program reads the data and presents the dialog below that shows the spacecraft parameters prior to processing in tabs. Click on “Run” to process the dataset and the program will create the spacecraft state-space system in file “SpaceStation.Qdr”.



Flight Vehicle Parameters

Vehicle System Title
Space Station with RCS and a Double-Gimbal CMG Array

Number of Vehicle Effectors
 Gimballing Engines or Jets. Include Tail-Wags-Dog? 8 WITH TWD WITHOUT TWD
 Rotating Control Surfaces. Include Tail-Wags-Dog? 0 WITH TWD WITHOUT TWD
 Reaction Wheels? 0
 Single Gimbal CMGs? 0

Momentum Control Devices
 Include a 3-axes Stabilized Double Gimbal CMG System? Yes No

Number of Sensors
 Gyros 6
 Acceleromet 4
 Aero Vanes 0
 External Torques 3

Modeling Options (Flags)
 Output Rates in: Body Axes Stability Axes
 Turn Coordination?: Include Turn Coordin Without Turn Coordin
 Aero-Elasticity Options: Include GAFD, H-param Flex Coupl. data only Neither Gafd nor Hpar
 Attitude Angles: Euler Angles Integrals of Rates LVLH Attitude

Number of Modes
 Structure Bending 34
 Fuel Sloshing: 0

Mass Properties | Trajectory Data | Gust/ Aero Paramet. | Aero Force Coeffs | Aero Moment Coeffs | Control Surfaces | Gimbal Engines/ RCS | External Torques
 Reaction Wheels | Single Gimbal CMGs | Double Gimbal CMG System | Slewing Appendages | Gyros | Accelerometer | Aero Sensors | Fuel Slosh | Flex Modes | User Notes

This Vehicle Uses A Double Gimbal CMG Array

Initial CMG Momentum Vector
 Hx 0.000000
 Hy 0.000000
 Hz 0.000000

The table below shows the Space Station system 15 inputs and 24 outputs. The system has 8 RCS jet force inputs providing forces in the directions defined in the input data. Actually, the inputs are defined as throttles rather than forces which are the ratios of “force divided by max force”. There are 3 control torques in roll, pitch and yaw, provided by the centralized CMG cluster. We have also included 3 external torques for disturbance analysis. The last input is an additional disturbance torque in the direction defined in the input data.

The system outputs are the standard flight vehicle model outputs. Some of them are not useful for this application and they can be removed from the model. The set includes 3 gyros, 3 rate gyros, and 4 accelerometers at the locations defined in the input data. The last 3 outputs are the CMG momentum in spacecraft roll, pitch, and yaw axes. Actually they are variations in the CMG momentum from nominal momentum because this model is linear.

Definition of System Variables

Inputs = 15

1	Throttle Input	dTh/Th for Engine No	1	(-)
2	Throttle Input	dTh/Th for Engine No	2	(-)
3	Throttle Input	dTh/Th for Engine No	3	(-)
4	Throttle Input	dTh/Th for Engine No	4	(-)
5	Throttle Input	dTh/Th for Engine No	5	(-)
6	Throttle Input	dTh/Th for Engine No	6	(-)
7	Throttle Input	dTh/Th for Engine No	7	(-)
8	Throttle Input	dTh/Th for Engine No	8	(-)
9	Double Gimbal CMG Torque	in the X-axis	(ft-lb)	
10	Double Gimbal CMG Torque	in the Y-axis	(ft-lb)	
11	Double Gimbal CMG Torque	in the Z-axis	(ft-lb)	
12	Ext Torque Input 1	(ft-lb), dir:	1.00 0.00 0.00	
13	Ext Torque Input 2	(ft-lb), dir:	0.00 1.00 0.00	
14	Ext Torque Input 3	(ft-lb), dir:	0.00 0.00 1.00	
15	Ext Torque Direct.=(0.1970 -0.5964 -0.7782)		

Outputs = 24

1	Roll Attitude	(phi-LVLH)	(radians)
2	Roll Rate	(p-body)	(rad/sec)
3	Pitch Attitude	(thet-LVLH)	(radians)
4	Pitch Rate	(q-body)	(rad/sec)
5	Yaw Attitude	(psi-LVLH)	(radians)
6	Yaw Rate	(r-body)	(rad/sec)
7	Angle of attack, alfa,	(radians)	
8	Angle of sideslip, beta,	(radian)	
9	Change in Altitude, delta-h,	(feet)	
10	Forward Acceleration (V-dot)	(ft/sec)	
11	Cross Range Velocity (Vcr)	(ft/sec)	
12	Rate-Gyro # 1, Roll Rate	(Body)	(rad/sec)
13	Rate-Gyro # 2, Pitch Rate	(Body)	(rad/sec)
14	Rate-Gyro # 3, Yaw Rate	(Body)	(rad/sec)
15	Gyro # 4, Roll Attitude	(Body)	(radians)
16	Gyro # 5, Pitch Attitude	(Body)	(radians)
17	Gyro # 6, Yaw Attitude	(Body)	(radians)
18	Accelerom # 1, (along X),	(ft/sec ²) Translat.	Accelerat.
19	Accelerom # 2, (along Z),	(ft/sec ²) Translat.	Accelerat.
20	Accelerom # 3, (along X),	(ft/sec ²) Translat.	Accelerat.
21	Accelerom # 4, (along Z),	(ft/sec ²) Translat.	Accelerat.
22	Double Gimbal CMG Momentum Change	in X-axis	(ft-lb-sec)
23	Double Gimbal CMG Momentum Change	in Y-axis	(ft-lb-sec)
24	Double Gimbal CMG Momentum Change	in Z-axis	(ft-lb-sec)