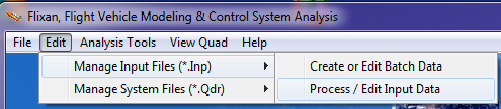
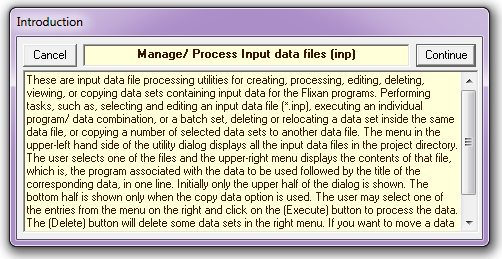
**Using the Flight Vehicle Modeling Program**

In the previous section we used spacecraft and reaction wheel non-linear models developed in Matlab and then we coupled them with state-space flexibility models that were developed using the Flixan Flex Spacecraft program. Now we will use the Flixan Flight Vehicle Modeling Program (FVP) to create similar models of the spacecraft coupled with four single gimbal CMGs, including structural flexibility, and hopefully the results will match with the results obtained from the previous section in folder “*(c) Flex 4SGCMG ACS w Gimbal*”*.* We will first show how to obtain the spacecraft state-space models by using the existing data files and running the FVP in batch mode, and then go into details to show how we create the spacecraft and flex data from scratch. The data for this analysis is in directory “*C:\Flixan\Examples\Flex Agile Spacecraft with SGCMG & RCS\CMG Control\(e) 4SGCMG using FVP* ". The input data file is "*FlexSc\_CMG\_FVP.Inp*" the systems file is “*FlexSc\_CMG\_FVP.Qdr*". The modal data files are the same as previously in the RCS analysis “*FlexSc\_FEM.Mod*" and “*FlexSc\_FEM.Nod*". The input data file contains data for two spacecraft with 4 SGCMGs, a rigid model and a flex model. A set of modal data consisting of 40 selected flex modes is included at the bottom of the input data file. Some unused states and outputs are eliminated using the Flixan truncation utility. The Matlab analysis is performed in the sub-directory "Matan".

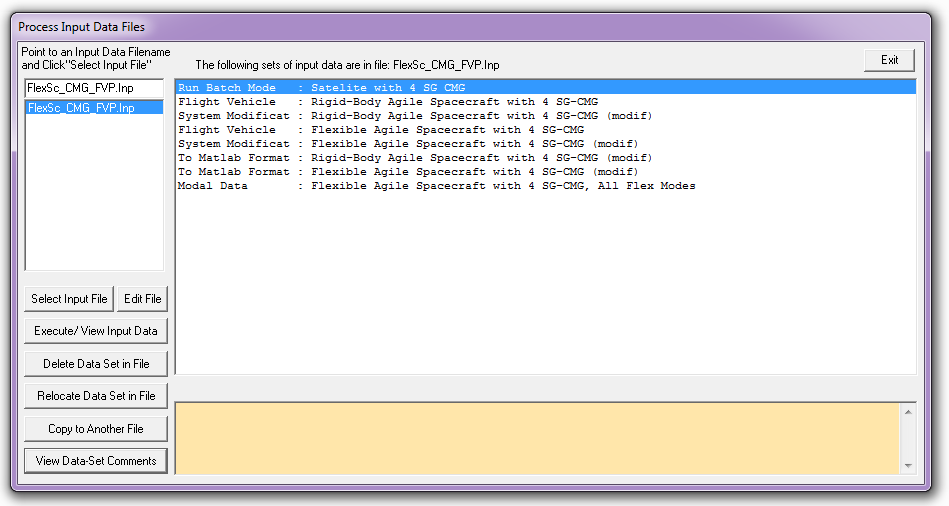
**Creating the Systems in Batch Mode**

On the top of the input data file there is a batch data-set “*Batch for Spacecraft with 4 SG CMG*”. It is a short script of commands that speeds up the generation of the spacecraft systems. To run the batch, first start the Flixan program, go to folder “…*Flex Agile Spacecraft with SGCMG & RCS\CMG Control\(e) 4SGCMG using FVP*”. Go to “*Edit*”, “*Manage Input Files*”, and then “*Process/ Edit Input Data*”. 

When the following dialog appears, click "Continue".



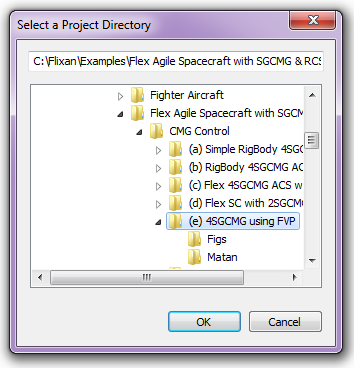
From the following dialog select the input file “*FlexSc\_CMG\_FVP.Inp*” and press the “*Select Input File*” button. The menu on the right shows all the data-sets that are saved inside the input file. Select the top batch set: “*Batch for Spacecraft with 4 SG CMG*”, and click on “*Execute/ View Input Data*”.

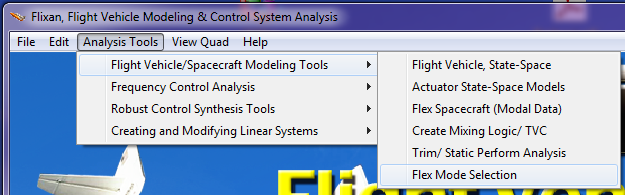


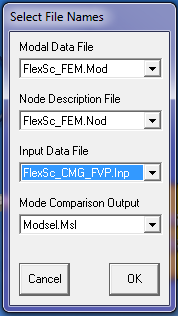
The Flixan program executes all the data-sets which are called by the batch and saves the spacecraft systems in file “*FlexSc\_CMG\_FVP.Qdr*”. It also creates two Matlab state-space m-files for the spacecraft with four CMGs that can be loaded into Matlab: a rigid-body model in file "*sc\_4cmg\_rb.m*" and a flex spacecraft model "*sc\_4cmg\_flex.m*". Click “Exit” to end the Flixan program. The two files are sent to subfolder "Matan" for analysis.

**Creating Set of Selected Modal Data**

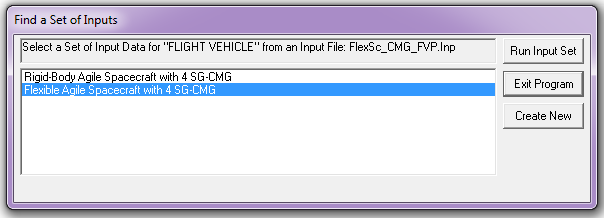
The flex model requires a set of selected modes reformatted and compatible to be processed with the spacecraft data. From the original modal data in file "*FlexSc\_FEM.Mod*" we must select a set of modes, scale them to match the units of the spacecraft data, and save the selected set in file "*FlexSc\_CMG\_FVP.Inp* ". We must first start the Flixan program and go to folder “…*Flex Agile Spacecraft with SGCMG & RCS\CMG Control\(e) 4SGCMG using FVP*”. Then go to “*Analysis Tools*”, “*Flight Vehicle/ Spacecraft Modeling Tools*”, and then to “*Flex Mode Selection*”, as shown below.



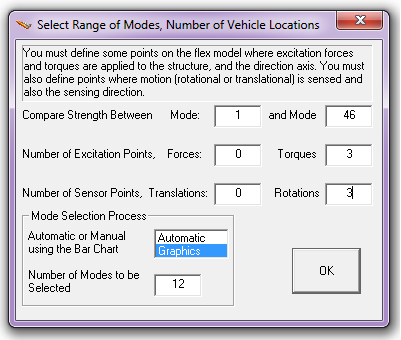


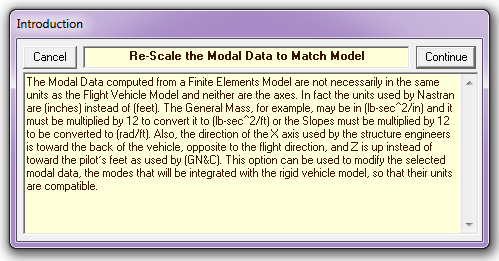
Using the filenames menu on the right we select the modal data filename which has an extension (.Mod), the nodes file (.Nod), the flight vehicle input data file (.Inp), and an output filename (Modsel.Msl), where the program will save the relative mode strength at the completion of mode selection. The modal data and nodes map files were used earlier in the RCS analysis. The input data file “*FlexSc\_CMG\_FVP.Inp*” is needed because the mode selection program needs the spacecraft data to match actuator and sensor locations with node points from the finite elements model. The nodes map is also used to facilitate this purpose.

Using the menu below select the spacecraft title “*Flexible Agile Spacecraft with 4 SG-CMG*” and click the “*Run Input Set*” button.

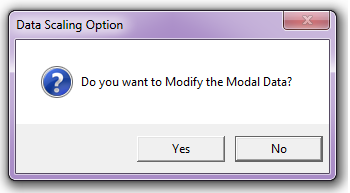


The dialog below is used to define the number of excitation, and the number of sensor points to be used for mode selection. These numbers do not have to be equal to the number of actual vehicle effectors and sensors used in the spacecraft model. It is only used for mode selection purposes. We must also define the range of modes to be evaluated (1 to 46 modes in this case). We will ignore the first 6 modes because they are rigid body modes and we should only include structural modes in the flex mode set. We do not define any forces excitations, but we define 3 torque excitations. Similarly, we do not select any translational sensors but 3 rotational sensors. These locations are only for mode selection. We will also select the graphic mode selection option where the user selects the modes from a bar chart using the mouse. The number of modes to be selected does not apply in this case. We click “OK” to continue.

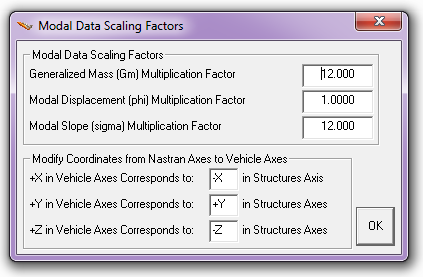




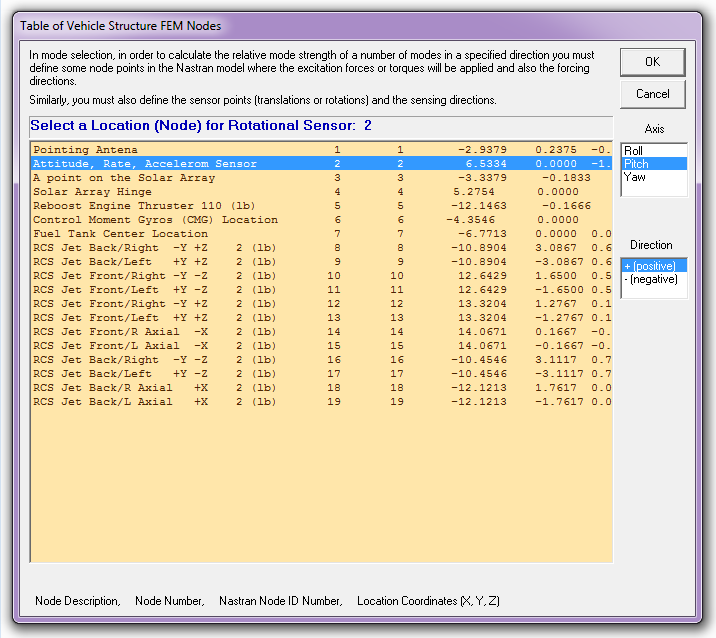
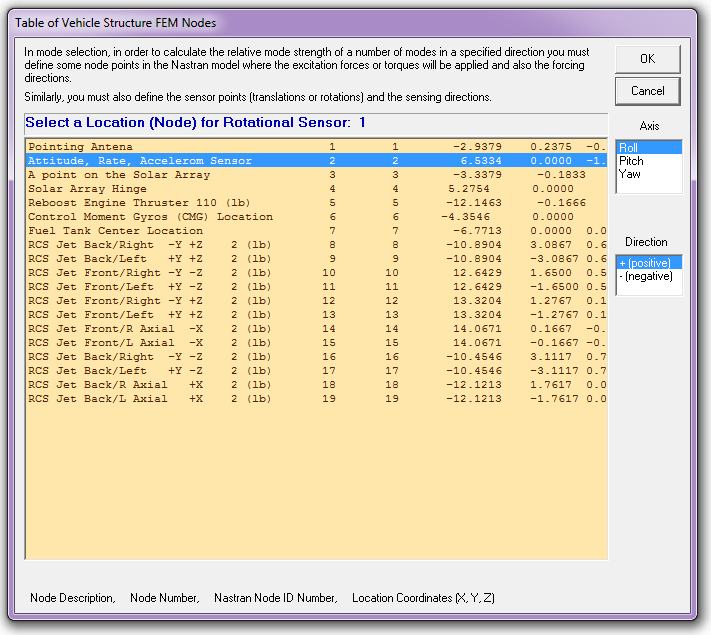
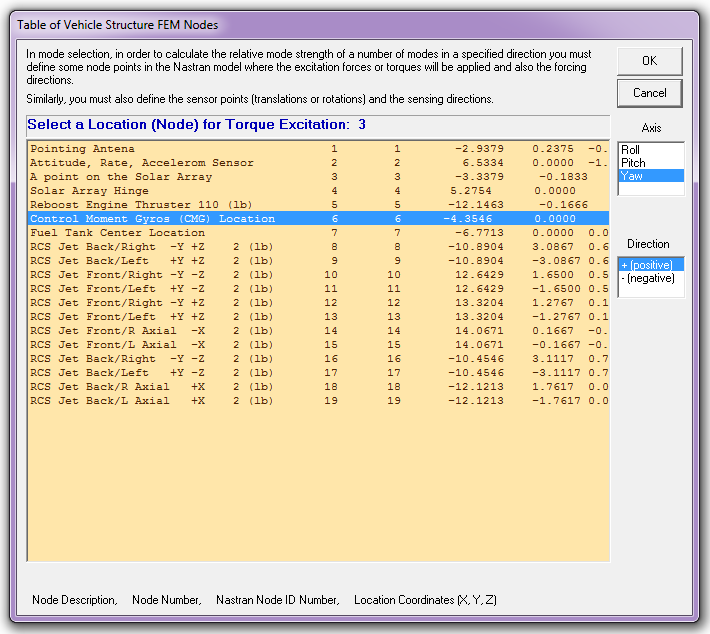
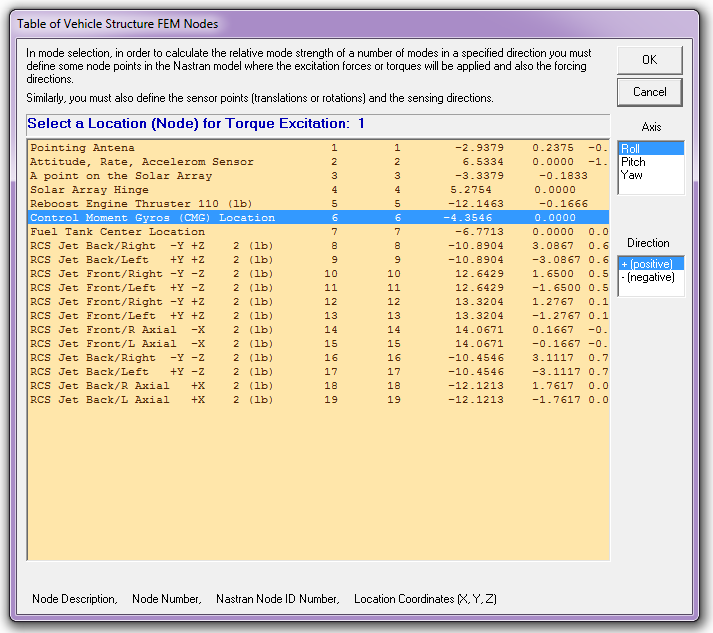
The following dialog allows you to convert the units of the modal data or to switch the direction of the coordinate axes of the finite elements model to match the rigid-body model. We click "Yes" because the modal data are in typical Nastran units and the x and z directions are reversed.



The following dialog defines the scaling factors that will be used to modify the modal shapes, slopes, generalized mass, and it will also reverse some of the directions.

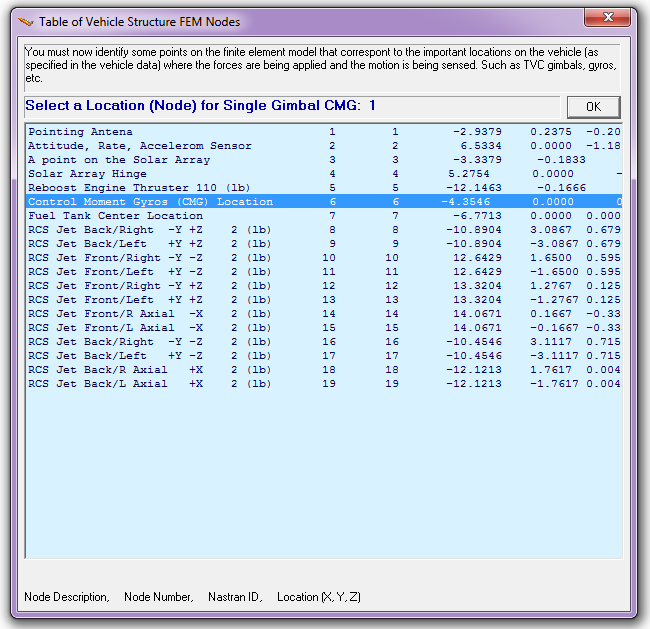


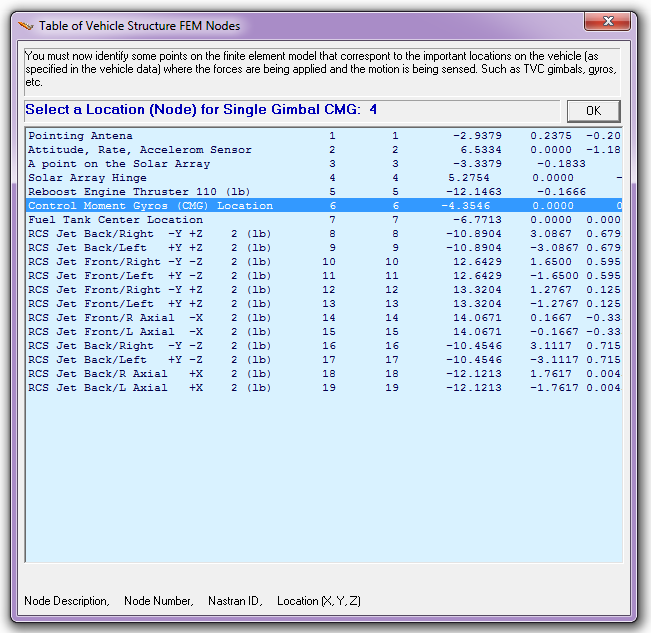
The next step is to identify locations from the finite elements model (nodes) for the 3 torque excitation points and the 3 rotational sensors points that will be used in mode selection. The nodes mapping file “*FlexSc\_FEM.Nod*” will be used as a reference in the process. It is included in node selection menu that helps the user to pick excitation and sensor nodes from the modal data file for mode strength comparison. For the 3 torque excitation points we select node #6, which is the CMG location, to apply torques in roll, pitch, and yaw. For the 3 rotational sensor points we select node #2, which is the location of the spacecraft gyros, to measure roll, pitch, and yaw rotations.

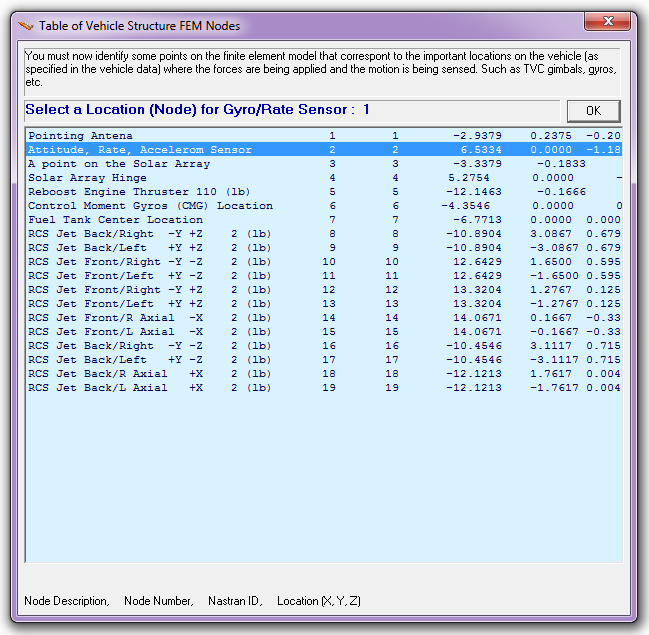


At this point the excitation and sensor points and directions for the mode selection process have been defined. The modal strength for each mode is calculated based on the values of the modal slopes at the torque locations and at the rotational measurements. When the mode shape magnitudes at the excitation and sensor points are high at a mode frequency it implies that this mode has a strong contribution to the overall structure flexibility. The mode selection program computes the mode strength at each mode frequency and saves it in file “*Modsel.Msl*”.

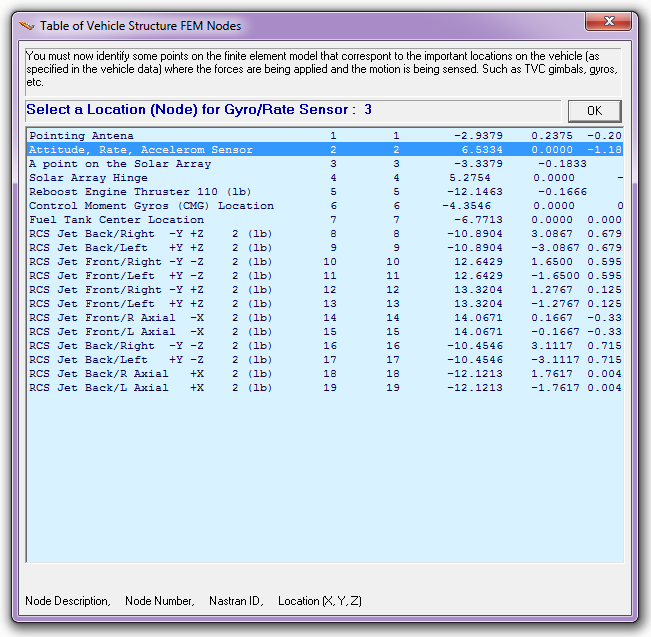
The mode selection process, however, is not finished yet because the program needs additional info before allowing the user to select which modes to retain from the big modal data file. Using similar menus that display the nodes table (different light-blue color), the user must select four nodes from the finite element model that correspond to the four CMGs which are defined in the vehicle input data. Node #6 is selected for all four CMGs.

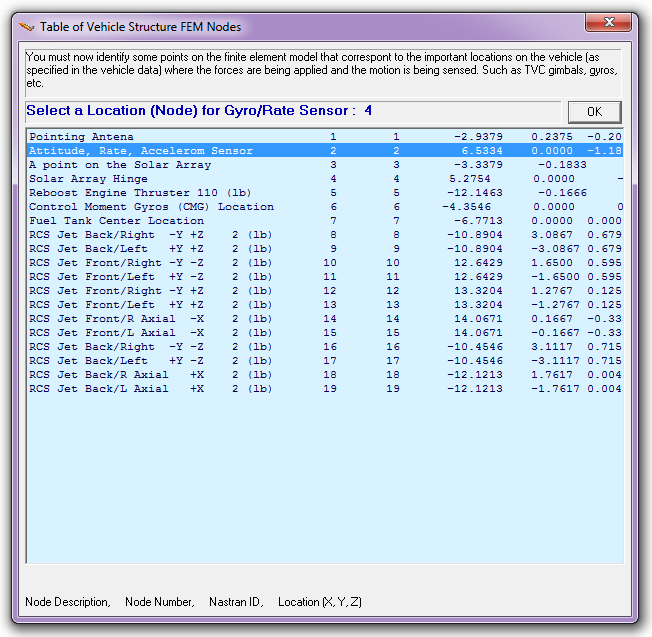


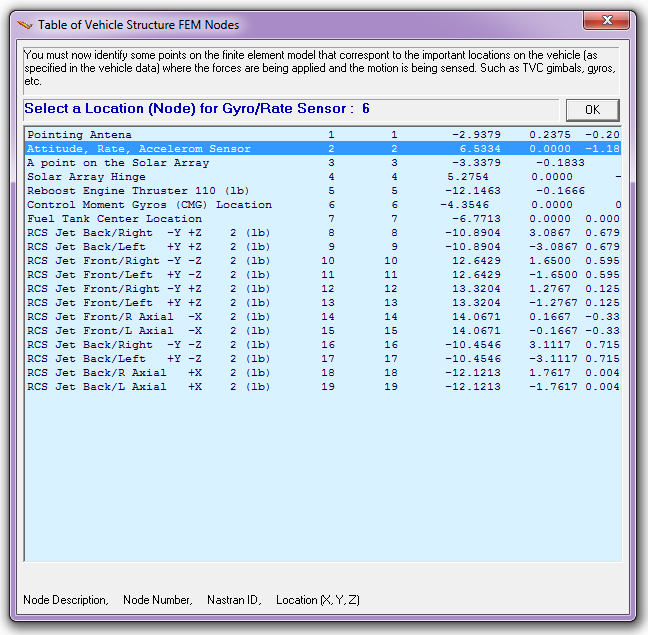


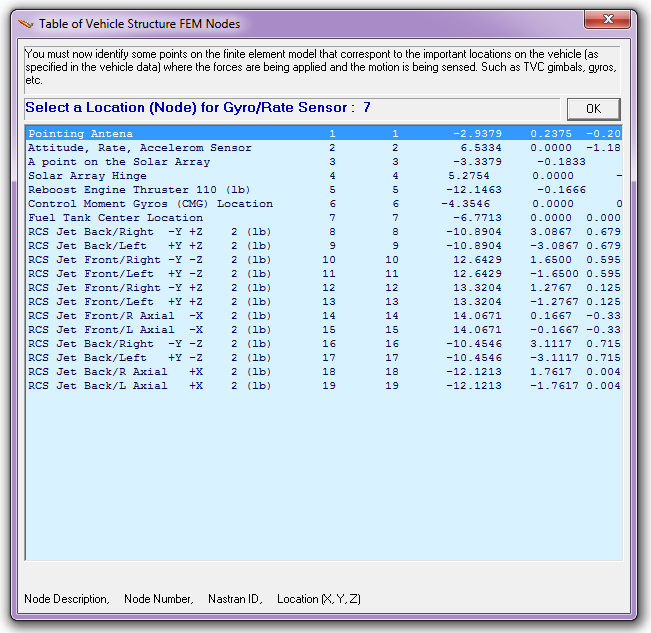


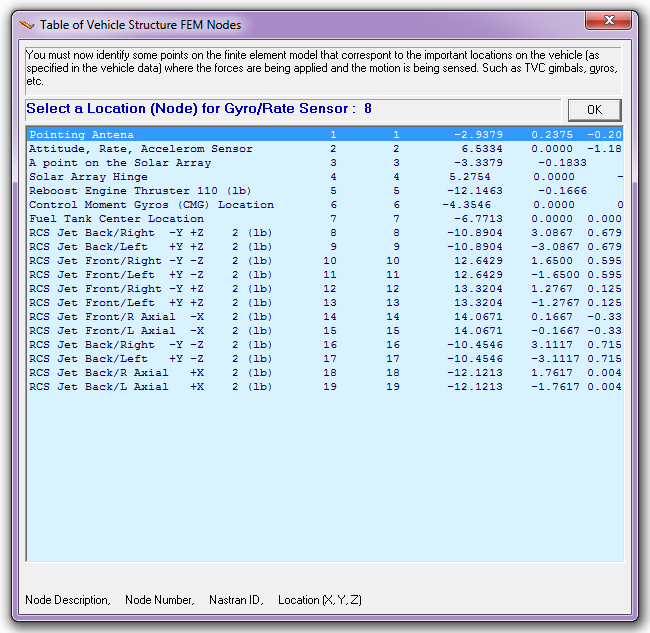
The user also selects 9 nodes (locations) for the 9 rotational sensors which are defined in the vehicle data, title "*Flexible Agile Spacecraft with 4 SG-CMG*". That is, three rotations at node #2, three rotational rates at node #2, and three rotational rates at node #1.



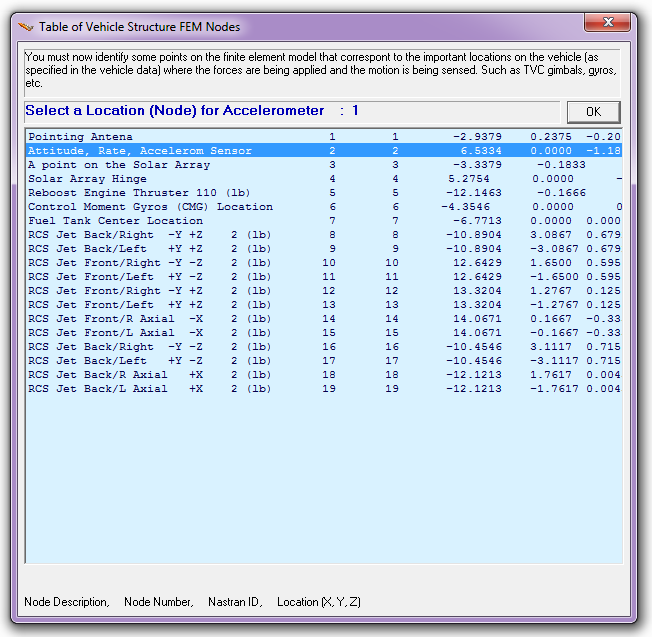


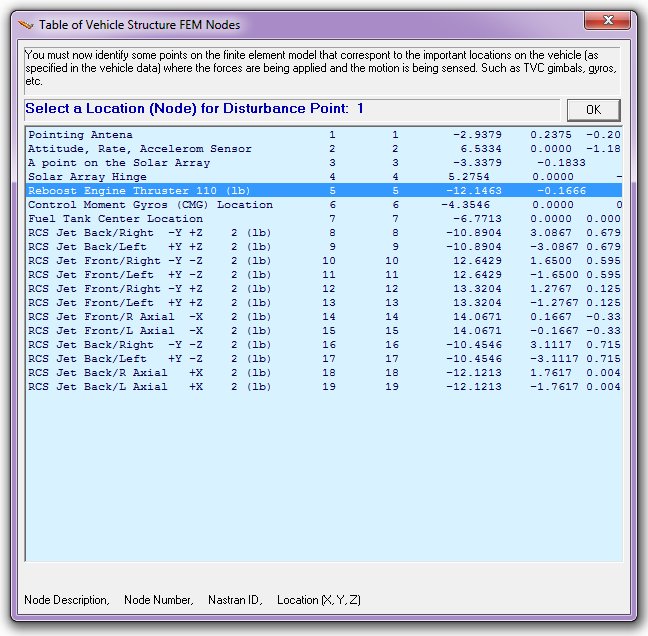
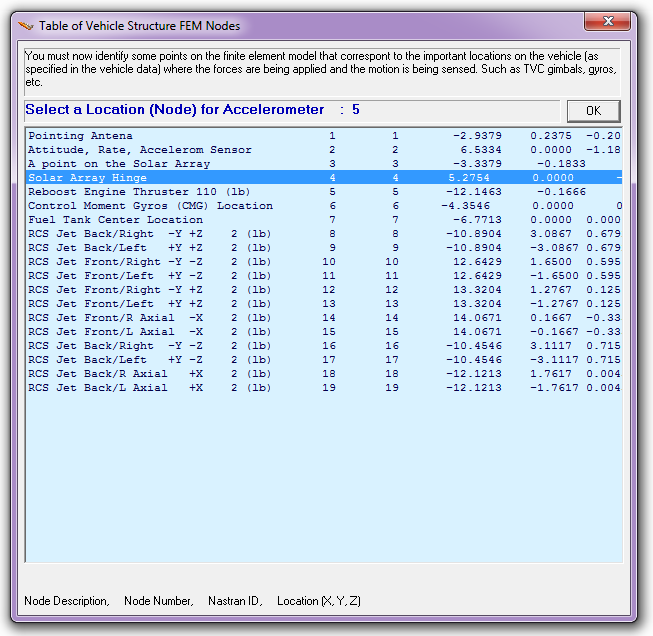






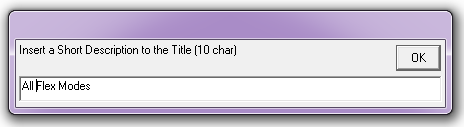
Similarly, nodes for the 6 accelerometers are selected. The first 3 accelerometers are at node #2, the nav base, and the next 3 are at node #4, the solar array.





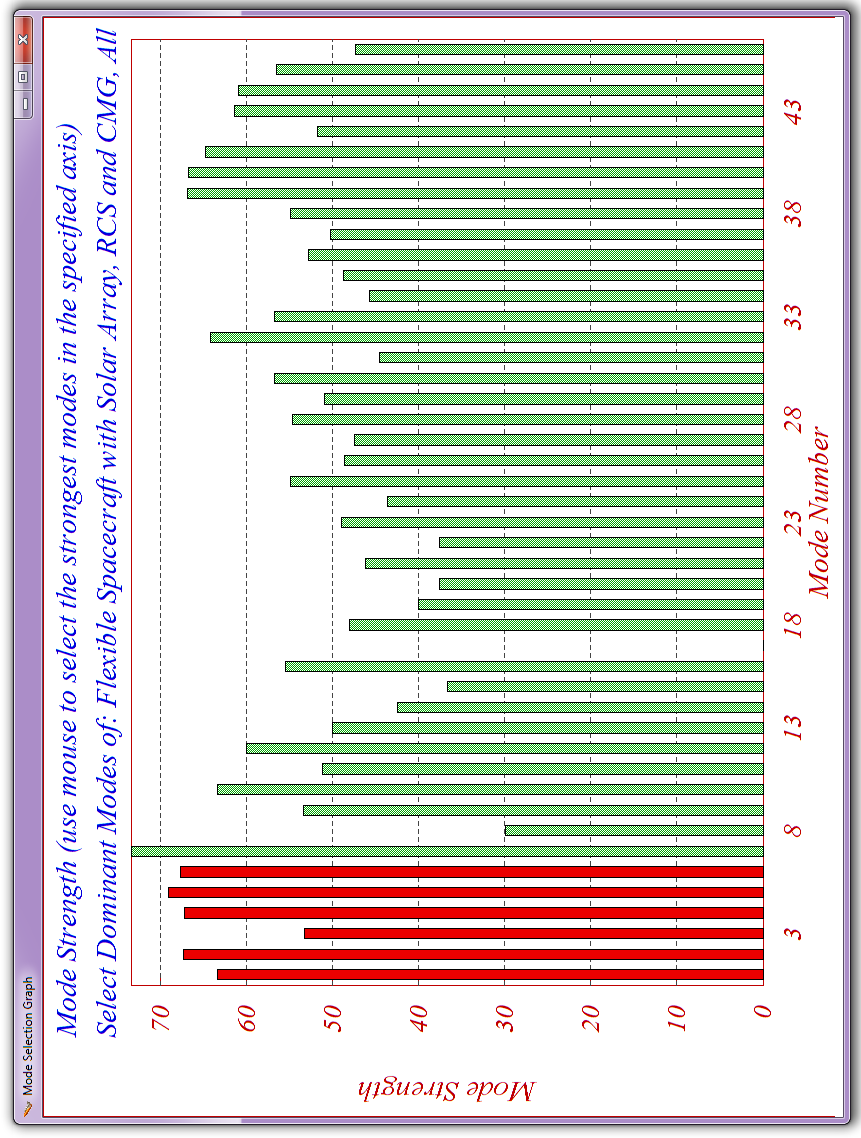
We also select a point where we can apply a disturbance.

The program will create a smaller subset of the original modal data set and will save it at the bottom of the input data file "*FlexSc\_CMG\_FVP.Inp*". At the end of this process the selected set of modal data will contain only the dominant modes (between the excitation and sensor points defined), and mode shapes only at the locations which are required by the flexible spacecraft model, such as: the CMG locations, the gyros, and the accelerometers. A title will be created for the selected and rescaled set of modal data. The selected modes title is "*Flexible Agile Spacecraft with 4 SG-CMG, All Flex Modes*", similar to the original vehicle title plus a short attachment inserted at the end by means of the following dialog.



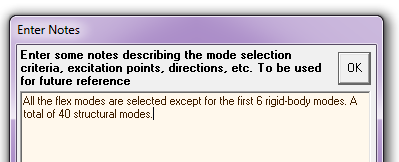
At this point the mode selection program saves the list of relative mode strengths (computed between the excitation points and directions and the sensor points and directions) in file “Modsel.Dat”. It also displays a bar-chart plot (shown in the next page) that shows the relative mode strength for each mode as a vertical bar, versus the mode number. All bars are initially red before selection. The height of each bar is logarithmically proportional to the relative mode strength. The strong modes are tall and the weak modes are short. The modal strength is a relative number adjusted with respect to the minimum and maximum modal strengths. The user selects some of the strongest modes from the chart by pointing the mouse cursor at the bar and clicking the mouse to select it. The modes change color from red to green when they are selected.

Notice that the first six modes must not be selected because they are rigid-body modes, and the rigid-body dynamics are already included in the vehicle model. We select all of the remaining flex modes from mode #7 to mode #46, a total of 40 flex modes, and press the "enter" button to complete the mode selection. They are the same flex modes that we selected in previous sections using the Flex Spacecraft Modeling program.



The final step before exiting mode selection is to complete the dialog below where the user enters some reference notes regarding the mode selection process. Describing, for example, what type of modes were selected, and the conditions of mode selection, excitation points, measurement points, directions, etc. This information will be included as comments below the title in the selected modes set, which is saved in the input data file “*FlexSc\_CMG\_FVP.Inp*”.

The title of the selected modes set is “*Flexible Agile Spacecraft with 4 SG-CMG, All Flex Modes*”. It contains the frequencies and the rescaled mode shapes of the selected modes at specific spacecraft locations. This title should also appear at the bottom of the spacecraft input data set “*Flexible Agile Spacecraft with 4 SG-CMG*”, below the number of flex modes. This will associate the selected modes with the spacecraft input data when the VFP processes the data.



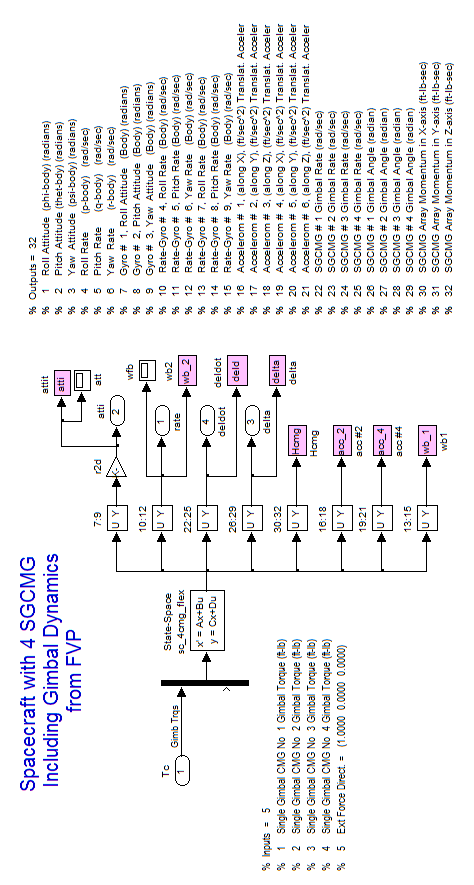
**The Simulation Model**

The simulation model is similar to the non-linear model presented in the previous section but simpler. It is missing all the non-linearities in the attitude control system and in the spacecraft dynamics. Its Simulink model is "*Lin\_Flex\_Sim.mdl*" shown in Figure (3). It is not intended to demonstrate large angle maneuvers but it is used for analyzing stability and performance at nominal operating conditions, such as, the initial condition when the gimbal angles are at zero and the CMG array momentum is zero.



Figure

The spacecraft plus CMG dynamics (green block) contains the state-space system from file "*sc\_4cmg\_flex.m*", title: “*Flexible Agile Spacecraft with 4 SG-CMG*”, which was created using the Flixan FVP. The state-space system is loaded into Matlab workspace by the initialization file "start.m". It implements the linearized equations described in Section (2.2) Dynamic Equations of Spacecraft with SGCMG. It is shown in detail in Figure (2). The inputs are four gimbal torques provided by the gimbal control system designed to control the CMG gimbal rates. The gimbal servo system and the steering were described earlier. The outputs are: spacecraft attitude, rates, and accelerations at different locations, including flexibility. There is also gimbal rates, gimbal angles, and CMG array momentum in body axis. The initialization file "start.m" is also loading the gimbal control system gains, the mass properties, the CMG orientation angles, gimbal directions, and momentum reference directions which are used by the steering logic.

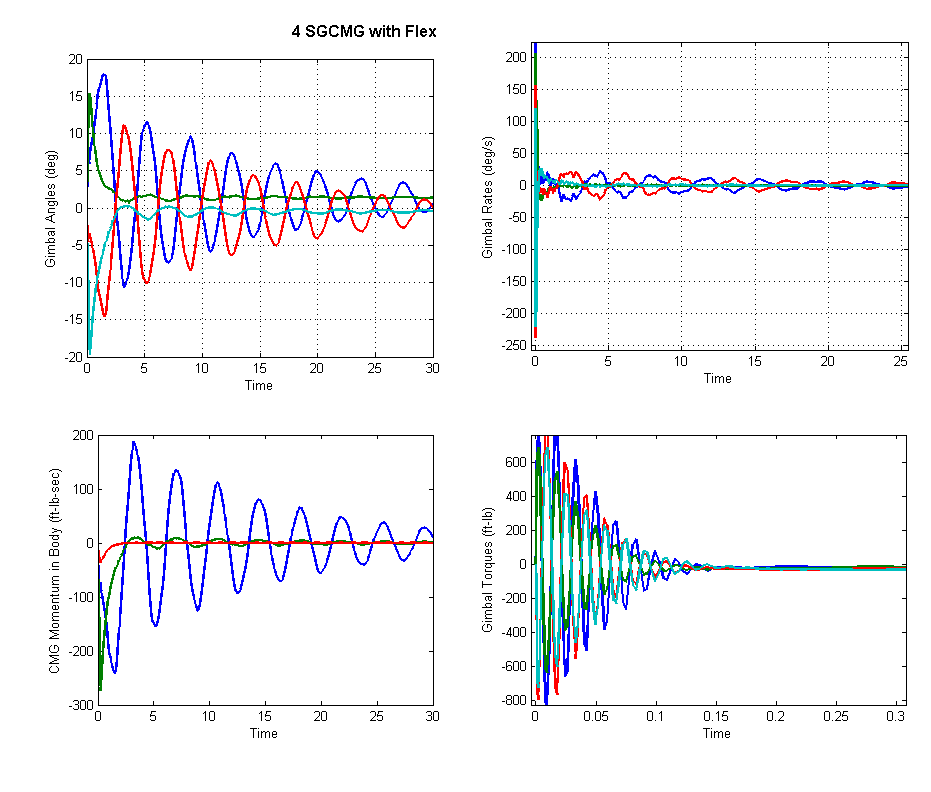
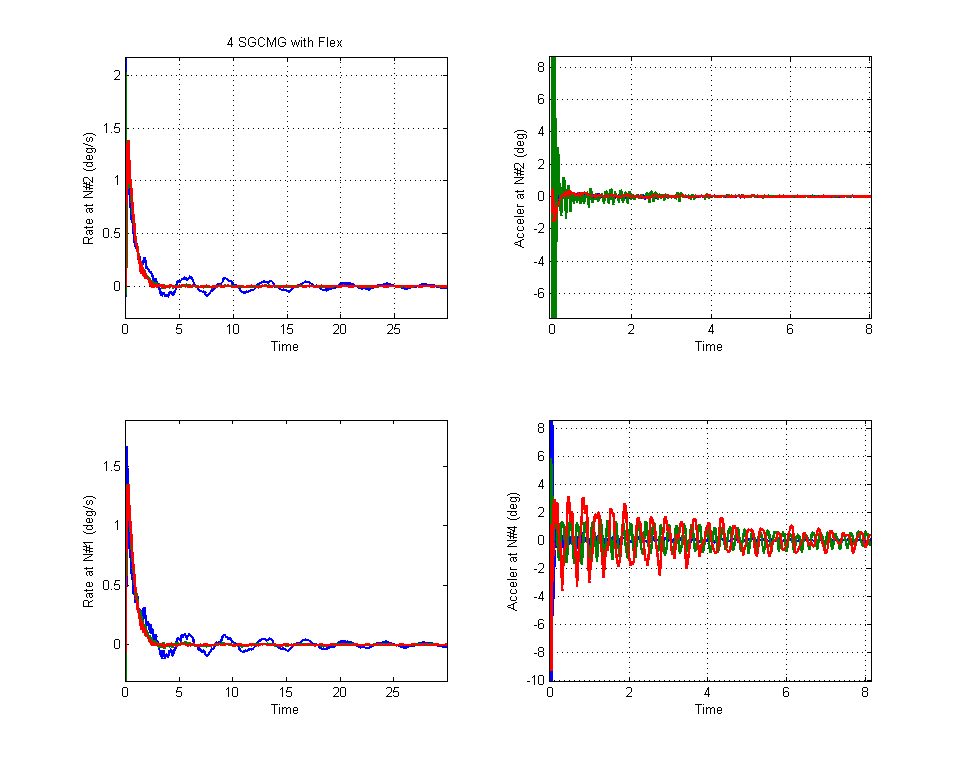
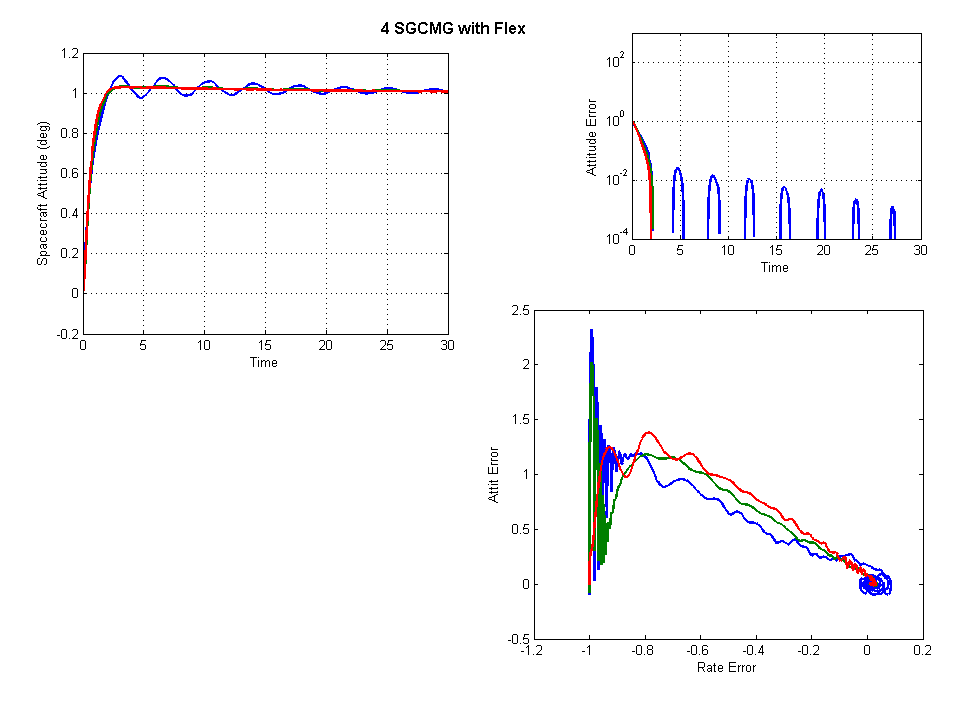


The attitude controller was simplified to a PID because we are only interested in small angles. The rate and energy limiting non-linearities were taken out. The PI section of the PID controller is shown in Figure (2). The rate feedback loop of the PID controller is in the steering.



Figure PI Attitude Control System

**Simulation Results**



**Stability Analysis**

