Flixan Utilities

The Flixan program includes additional utilities that perform other type of functions that further refine, modify, augment and reformat the flight vehicle models. There is a utility for combining systems and matrices together using an algorithm that is not vulnerable to algebraic looping. Matlab often causes algebraic loops errors when closing a loop around a system. There are also utilities for combining transfer-functions into systems, transforming continuous systems to discrete using (z) or Tustin transformations with variable delays, utilities for transforming systems and matrices from a system files (.Qdr) to formats that can be loaded into Matlab or converting Matlab generated data to system files. There are also utilities that modify or reduce already existing systems. Modifying the inputs and outputs, or reducing the variables of a system by selecting a smaller number of inputs, states, and outputs, or modifying the system units by rescaling some of the variables. Additional outputs can also be included from the states, state derivatives, or output derivatives. These utilities are useful for separating coupled systems to longitudinal and lateral subsystems. There are also utilities for processing the input data in batch mode. Batch instructions call multiple other utilities, process the entire input file, and generate systems without any interactive assistance from the user.

Each Flixan utility reads and processes a set of instructions data which are included in the input file (.Inp), in a similar fashion as the vehicle, the actuator and other Flixan programs. An input data file typically contains multiple data-sets to be processed by different utility programs. Each data-sets is processed by the corresponding utility program which typically creates a new system in the systems file according to the instructions and the data read from the set. The input data-sets are created either by using a text editor, copied from another file and modified, or more efficiently, each utility program itself is capable of generating its own input set interactively with the user, by means of menus and dialogs, as we shall see in the examples.

Initially the analyst must generate the desired dynamic models and matrices for his analysis and must prepare the input file by setting-up and testing each data-set, one set at a time. The dynamic models created may be rigid-body or high order models with flexibility, actuators, TWD, slosh, etc. They may include flight control or sensor dynamics. They may be coupled or decoupled, with pitch and lateral separated. They may be open-loop or closed-loop depending on the analysis required. When all the elements in the input file are prepared and tested for one flight condition, the modeling becomes easier and faster for the next run or case, because the same input file can be modified and be reused for a different situation or iteration. A batch can be included which can instantly processes the entire input file.

1.0 Systems Combination Program

The systems combination program is a Flixan utility that interconnects several state-space systems together and with matrices, which are read from a systems file (.Qdr). The combined system created is in state-space form and it is saved in the same systems file. The program uses two data files: an input data file (.Inp) and the systems file. The input file contains the titles of the systems to be combined, the interconnection instructions, and the definitions of input and output variables. The interconnection instructions describe how the various subsystems are combined together and how they connect to the big system inputs and outputs. There is also an interactive Graphics/ User interface (GUI) utility included that helps the user to enter the interconnection data in the input file or to read the interconnections from the file graphically without editing the file directly. Figure (1-1) shows the interaction between the systems combination program, the GUI, the user, and the data files.
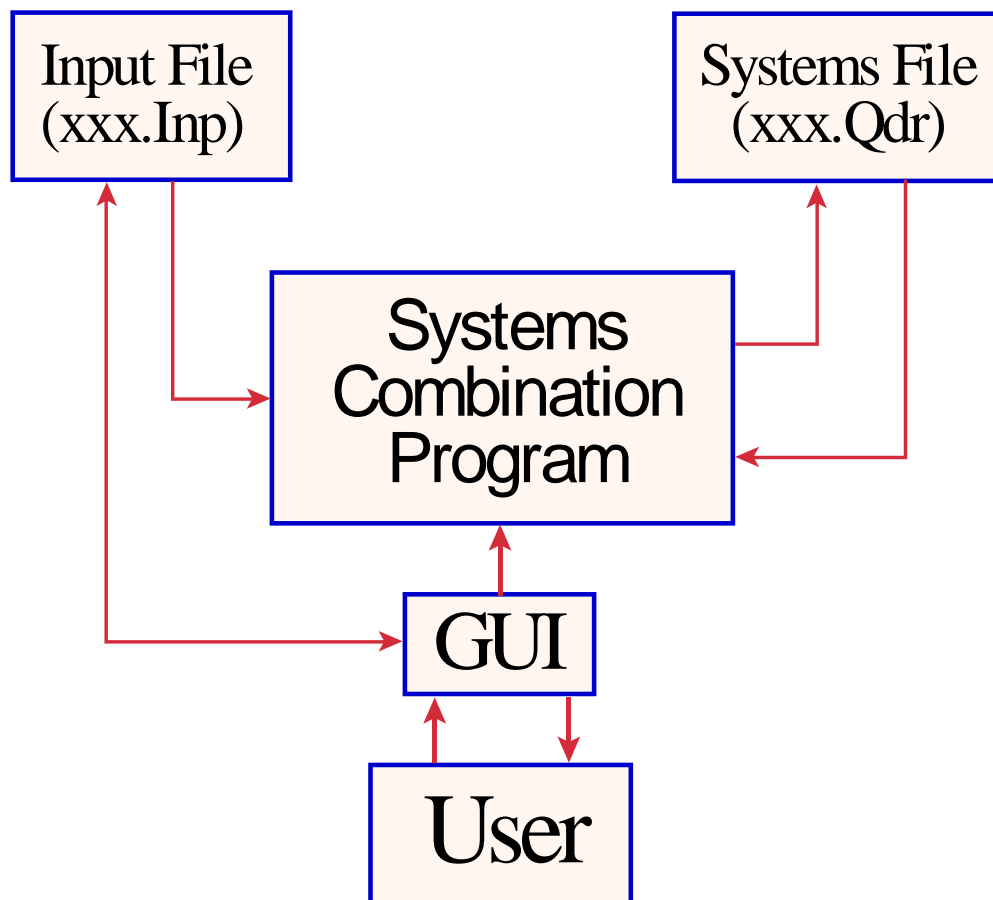

Figure (1.1) Diagram of the Systems Combination Utility Program showing its interaction with the User and the Input/ Output Files

1.1 Program and Input/ Output Files Selection

The systems combination program is selected from the Flixan main menu by clicking on the "*Program Functions*", select the "*Creating and Modifying Linear Systems*" group, and then click on "*Combine State-Space Systems and Matrices*". Then use the following file selection dialog to select the input data file and the systems file from the menus, as shown below.

Systems Interconnection data-set in the input file (.Inp)

System interconnection data-sets contain the system interconnection instructions and they are located in input files (.Inp). A typical data-set for combining two systems is shown below.

```
INTERCONNECTION OF SYSTEMS .....
RULV, Pitch Closed-Loop, Simple Model
! Combine the Simple Vehicle model with the Actuator model in Closed-Loop
! Form for Time-Domain Simulation and Check the Eigenvalues
Titles of Systems to be Combined
Title 1 RULV, Pitch Axis, Max_Q (T=85 sec)
Title 2 Main Engine Actuator
SYSTEM INPUTS TO SUBSYSTEM  2                                      Eng. Actuator
System Input  1 to Subsystem  2, Input  1, Gain=-1.8              Theta_command
.....................................................................
SYSTEM INPUTS TO SUBSYSTEM  1                                      Vehicl Distrb
System Input  2 to Subsystem  1, Input  7, Gain= 1.0             Gust Velocity
.....................................................................
SYSTEM OUTPUTS FROM SUBSYSTEM  1                                   From Vehicle
Via Matrix +I6
.....................................................................
SYSTEM OUTPUTS FROM SUBSYSTEM  2                                   From Actuator
System Output  7 from Subsystem  2, Output  1, Gain= 1.0         Delta_Engine
System Output  8 from Subsystem  2, Output  2, Gain= 1.0         Delta_Dot_Eng
.....................................................................
SUBSYSTEM NO  2 GOES TO SUBSYSTEM NO  1                            Actuat to Veh
Subsystem  2, Output  1 to Subsystem  1, Input  1, Gain= 0.4082   Eng.Defl # 1
Subsystem  2, Output  1 to Subsystem  1, Input  2, Gain= 0.4082   Eng.Defl # 2
Subsystem  2, Output  1 to Subsystem  1, Input  3, Gain= 0.4082   Eng.Defl # 3
Subsystem  2, Output  1 to Subsystem  1, Input  4, Gain= 0.4082   Eng.Defl # 4
Subsystem  2, Output  1 to Subsystem  1, Input  5, Gain= 0.4082   Eng.Defl # 5
Subsystem  2, Output  1 to Subsystem  1, Input  6, Gain= 0.4082   Eng.Defl # 6
.....................................................................
SUBSYSTEM NO  1 GOES TO SUBSYSTEM NO  2                            Vehi to Actu
Subsystem  1, Output  1 to Subsystem  2, Input  1, Gain= 1.8      Theta
Subsystem  1, Output  2 to Subsystem  2, Input  1, Gain= 2.3      q - rate
Subsystem  1, Output  6 to Subsystem  2, Input  1, Gain=-0.008    Nz Accelerat
.....................................................................
Definitions of Inputs  =   2
Attitude Theta Command    (radians)
Wind Gust Disturbance     (ft/sec)

Definitions of Outputs =   8
Pitch Attitude   (theta-rigid)  (radians)
Pitch Rate       (q -rigid)    (rad/sec)
Angle of attack   (alpha)    (radians)
Change in Altitude   (dh)        (feet)
Forward Acceleration  (V-dot)     (ft/sec)
Accelerometer #  1, (along z), (ft/sec^2)
Actuator Delta_Engine (radians)
Actuator Delta_Dot_Engine (rad/sec)
-------------------------------------------------------
```

The first line in the data-set "INTERCONNECTION OF SYSTEMS", defines the type of input data and the utility program that will process it. This is because the input file typically also contains data for other Flixan programs, such as, transfer function combination data, flight vehicle modeling data, etc. The second line contains the title of the new system to be created. Every system in Flixan is identified by a title which is less than 100 characters long. The following few lines, starting with (!), are comment lines. They provide a short description of the new system for documentation purposes and they are optional. The comment lines are also copied in the systems file below the new system title. The lines below the line "Titles of Systems to be Combined", contain the titles of systems to be combined together. These systems must already exist in the systems file (.Qdr), otherwise, an error will occur. Notice that each system is assigned a reference number, (1, 2, 3, ... max= 9). The program searches the systems file (*.Qdr), finds the subsystem titles, reads the quadruple data for each

subsystem and combines them together. The lines below the system titles define how the systems are to be connected together, and there are four types of interconnection groups.

1. Direct connections from the combined system inputs to the combined system outputs that define the direct feed-through matrix D.
2. Connections from the new system inputs to one of the subsystem inputs, followed with the detail connections to this subsystem.
3. Connections from one of the subsystem outputs to the combined system's outputs, followed with the detail connections from this subsystem.
4. Connections between one of the subsystem outputs to another subsystem inputs, followed with the detail interconnections between the two subsystems.

In the interconnections data, the sub-systems to be combined are referred to by their corresponding system numbers. Matrices can also be used in the interconnections. The matrices must already exist in the systems file and they are defined by their corresponding matrix name (not title). Identity matrices can also be used for interconnections and in this case they don't have to exist in the systems file. At the bottom of the data-set the user may include definition labels of the new system's inputs and outputs. The input and output definitions are optional. If they are not included the program creates default labels.

An experienced user can easily create by copying and pasting an interconnection data-set in the input file by using a standard text editor. There is, however, a GUI capability in the program that makes it easier for the user to create the interconnections set by using menus and dialogs. The GUI helps to enter the title, selecting the systems to be combined, defining the new system input and output labels, entering the user comments, and defining the interconnections. It also provides text editing capability to modify the input data. The GUI will also save the interconnections in the input data file, and run the program to create the combined system in file (.Qdr).

Systems File

The systems file (with an extension Qdr) contains state-space systems and matrices to be combined. The program reads the systems to be combined and the matrices from this file and when it finishes combining them together it saves the new system at the bottom of this file without destroying the already existing data. Interconnections between subsystems, inputs, and outputs are not always defined individually but they can be vectored interconnections defined by matrices. The gain matrices must already be saved in the systems file under a unique title and name. The matrix name is used in the interconnection, for example, "Via Matrix Kc". The program locates the interconnection matrix in the systems file and checks to make sure that its dimension is correct, or flags an error if it can't find it. A state-space system has the form shown in the following example.

```
STATE-SPACE SYSTEM ...
Main Engine Actuator
! Comments for the Actuator System
Number of Inputs, States, Outputs, Sample Time dT (for discrete)=  2   4   3   0.0
Quadruple Matrices: (A,B,C,D)

Matrix A                      Size =  4 X  4

          1-Column        2-Column        3-Column        4-Column
  1-Row -0.52100776E+02 -0.11670057E+02 -0.10960186E+02 -0.20318937E+01
  2-Row -0.53950001E+02 -0.14243727E+02 -0.13377304E+02  0.00000000E+00
  3-Row  0.00000000E+00  0.00000000E+00  0.00000000E+00  0.10000000E+01
  4-Row  0.00000000E+00  0.11136935E+04 -0.27679742E+04 -0.36536758E+01
--------------------------------------------------------------------------------

MATRIX B                      SIZE =  4 X  2

          1-Column        2-Column
  1-Row  0.40223714E+02  0.00000000E+00
  2-Row  0.49094502E+02  0.00000000E+00
  3-Row  0.00000000E+00  0.00000000E+00
  4-Row  0.00000000E+00  0.22143490E-03
--------------------------------------------------------------------------------

MATRIX C                      SIZE =  3 X  4

          1-Column        2-Column        3-Column        4-Column
  1-Row  0.00000000E+00  0.00000000E+00  0.10000000E+01  0.00000000E+00
  2-Row  0.00000000E+00  0.00000000E+00  0.00000000E+00  0.10000000E+01
  3-Row  0.00000000E+00  0.11136935E+04 -0.27679742E+04 -0.36536758E+01
--------------------------------------------------------------------------------

MATRIX D                      SIZE =  3 X  2

          1-Column        2-Column
  1-Row  0.00000000E+00  0.00000000E+00
  2-Row  0.00000000E+00  0.00000000E+00
  3-Row  0.00000000E+00  0.22143490E-03
--------------------------------------------------------------------------------
Definition of System Variables

Inputs  =   2
  1    Engine Deflection Command (delta-com) (radians)
  2    Load-Torque Feedback      (Tl)        (ft-lb)

Outputs =   3
  1    Engine Gimbal Rotation    (delta)     (radians)
  2    Engine Gimbal Rate      (delta-dot)   (rad/sec)
  3    Engine Gimbal Accelerat.(delta-d-dot) (rad/sec^2)

States  =   4
  1    Differ. Pressure Feedback (DPF)   (ft-lb)
  2    Piston Displacement       (Xr)    (feet)
  3    Engine Gimbal Rotation    (delta-dd) (radians)
  4    Engine Gimbal Rate  (delta-dot)   (rad/sec)
--------------------------------------------------------------------------
```

The first line indicates that the data which follow is a state-space system. The second line is the title of this system, same title as the data-set in (.Inp) file. The next lines starting with (!) are comment lines, same as the input data comments. The length of the title and length each comment line should be less than 100 characters long. The next line defines the system dimension and the sampling rate (0 for continuous system). The data at the bottom of the set below is the state-space system matrices (A, B, C, D) are definitions of the system inputs, states, and output variables, which are optional. The systems combination program will either process an already existing set of interconnection data or it can create a set of interconnection data interactively with the user, and then run it. Let us demonstrate in the following section an example of creating a systems interconnection set and then run it.

1.2 Creating a New Interconnection Set Interactively

In this example we have a systems file "*RULV.Qdr*" that contains two systems: a pitch vehicle model of a launch vehicle with 6 engines and an actuator. This example is located in folder "*C:\Flixan\Comb_Trfn\Examples*". We will combine the two systems together by generating the interconnections data-set in file "*RULV.Inp*" that will connects the two systems, as shown in Figure (1.2), and then process the set to create the closed-loop system.
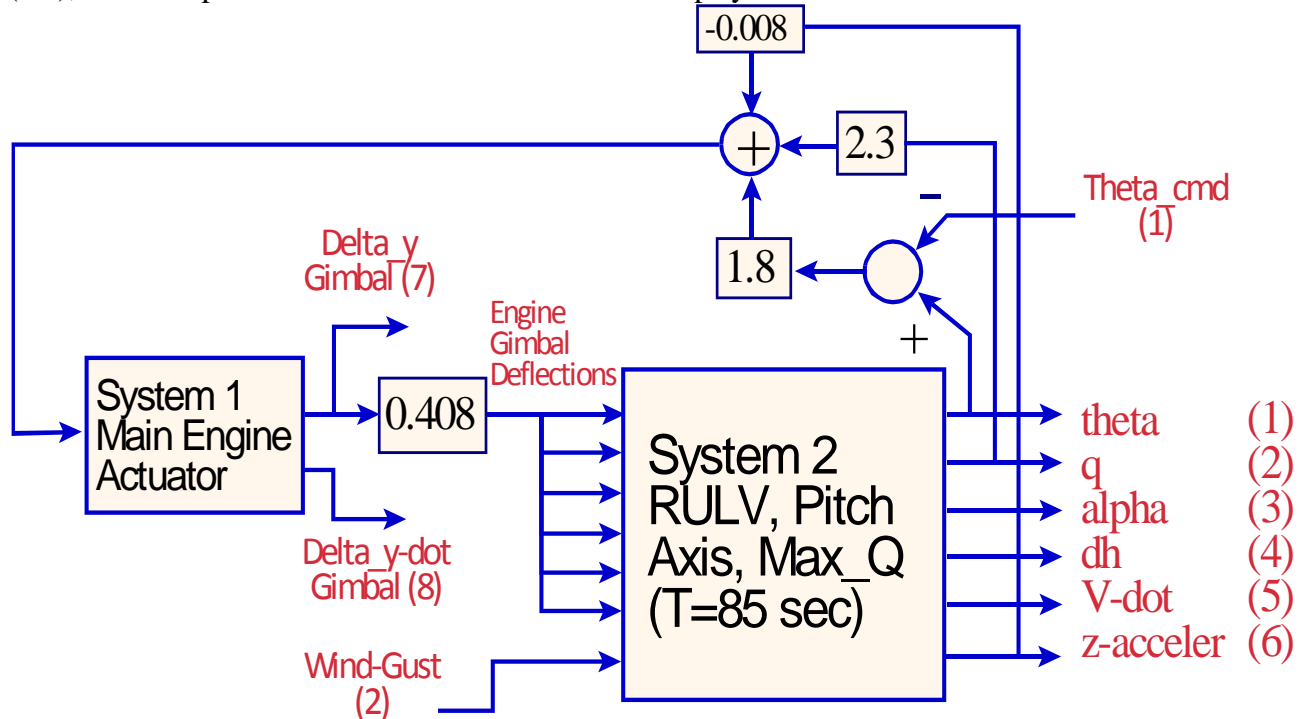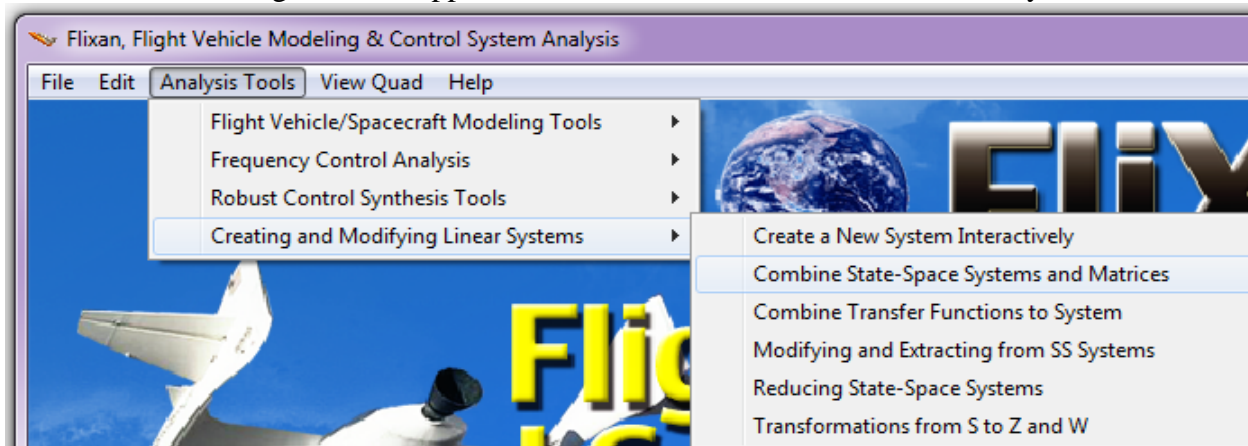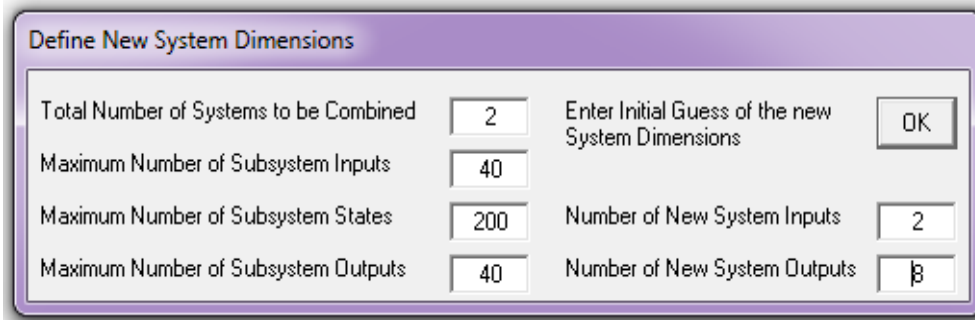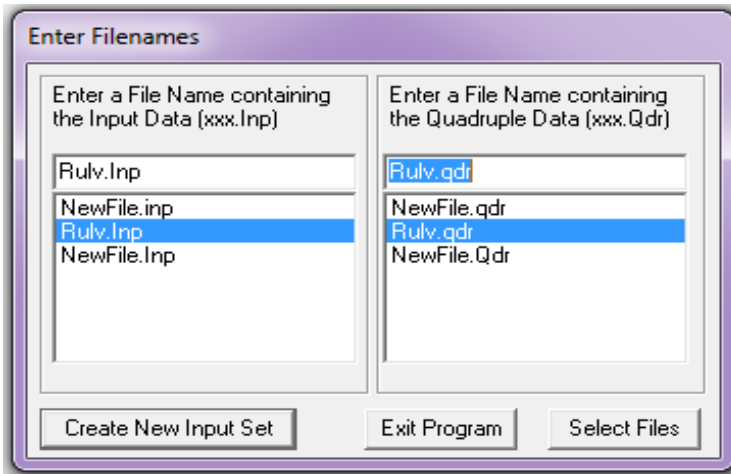

Figure (1.2) Two Subsystems in Closed-Loop Form Interconnection

So we begin the systems combination program from the Flixan main menu by clicking on "*Analysis Tools*", then "*Creating and Modifying Linear Systems*", and then on "*Combine State-Space Systems and Matrices*". Then from the following file selection menu select the input data file and the systems file, as shown below, and then click on "*Create a New Input Set*" to begin the interconnections interrogation session. In the systems dimension dialog you must enter the number of systems to be connected (2), the combined system inputs (2), and the combined system outputs (8). The systems interconnection dialog will then appear from where the user will enter the new system data.

Enter Filenames

Enter a File Name containing the Input Data (xxx.Inp)

Rulv.Inp

NewFile.inp
Rulv.Inp
NewFile.Inp

Enter a File Name containing the Quadruple Data (xxx.Qdr)

Rulv.qdr

NewFile.qdr
Rulv.qdr
NewFile.Qdr

[Create New Input Set] [Exit Program] [Select Files]

Define New System Dimensions

Total Number of Systems to be Combined	2	Enter Initial Guess of the new System Dimensions	[OK]
Maximum Number of Subsystem Inputs	40		
Maximum Number of Subsystem States	200	Number of New System Inputs	2
Maximum Number of Subsystem Outputs	40	Number of New System Outputs	3

Title: The systems interconnection GUI dialog is shown below used for entering the interconnection parameters for our example. You must first enter a title for the combined system "*RULV, Pitch Closed-Loop, Simple Model*", and click on the "Update Data" button. You must be updating the data every time you enter or modify the data in one of the tabs.

Direct Input to Output Connections Tab: The systems interconnection dialog has tabs for entering different types of data. The first tab on the left side is used for defining direct connections from the new system inputs to the new system outputs without connecting to any of the subsystems. This is used, of course, if there are any direct connections because in most cases, such as in this example, there aren't any direct connections from inputs to outputs. In essence you are defining the direct feed-through matrix (D) of the state-space representation. The dialog includes buttons for adding a new connection, deleting, or modifying an already existing connection. If you click on "*Add a Connection*" a couple of menus will appear on the right. The menu on the left shows the titles of the new system inputs and the menu on the right shows the titles of the new system outputs. Default titles are used if the inputs/ outputs have not been defined. The user may select a single "from" input and a single "to" output pair for a scalar connection between one of the system inputs to one of the system outputs, one at a time, enter the gain in the field below, and click on "OK" to continue. Vectored interconnections between new system inputs and outputs can also be defined. In this case the user must select a group of inputs and a group of outputs using the "from" and "to" menus, for example, 2 inputs and 3 outputs. In this case the program expects a matrix to define the interconnection between the new system inputs and outputs. In fact, it expects the name of a (3x2) matrix that already exists in the systems file. It also expects the sign of the interconnection, for example, +Kc2 or -Kmix . It is also possible to define vector interconnections using identity matrices. The sign and size of the identity matrix must be included, for example, +I3 or -I5 . In this case the identity matrix does not have to be saved in the systems file. You must make sure that you select the proper number of inputs and outputs that

correspond to the size of the identity matrix or the dimensions of any other interconnection matrix, and starting from the first input and the first output. You must also remember to click on "*Update Data*" between tabs.
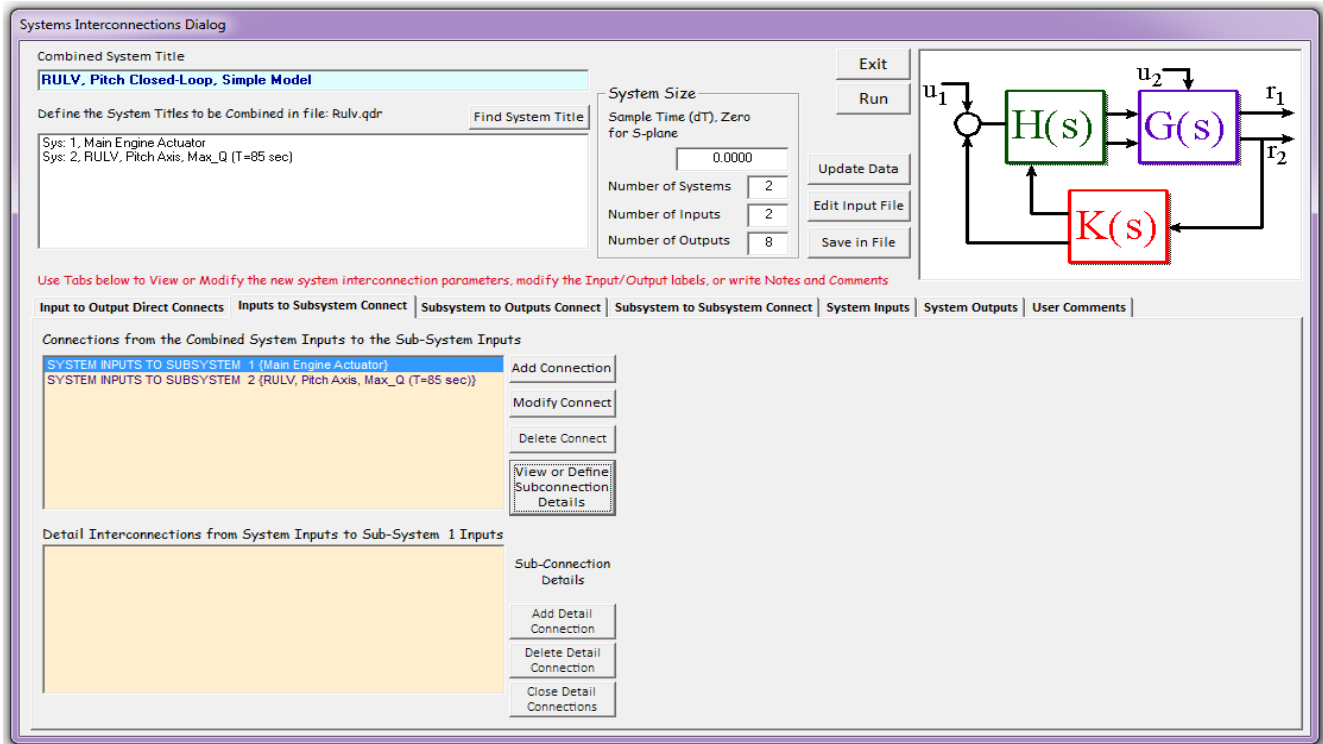
System Inputs to Subsystem Connections Tab: Select the second tab which is used for connecting system inputs to subsystem inputs and click on "*Add Connections*". It is similar to the first tab, except, it is more complex because there more than one set of connections to be defined from the combined system inputs to the subsystem inputs. For this reason, the system to subsystem input interconnections are defined in two levels, a top level and a detailed level. The top level interconnection defines which subsystems are connected to the combined system inputs without any specific details. The detailed level defines the actual interconnections between the combined system inputs and the subsystem's inputs. When you create a new interconnections set there aren't any connections defined yet. To begin an input to subsystem interconnection you must first click on the "*Add Connections*" button, and a menu appears on the upper-right showing the subsystems available to be connected. From the upper right menu select one of the subsystems at a time to be connected to the new system inputs. First select "*System 1, Main Engine Actuator*" and click on "*Add Connection*". A new high level connection appears in the upper-left menu "*System Inputs to Subsystem 1 {Main Engine Actuator}*". There are no details yet, the interconnection specifics will be added later.
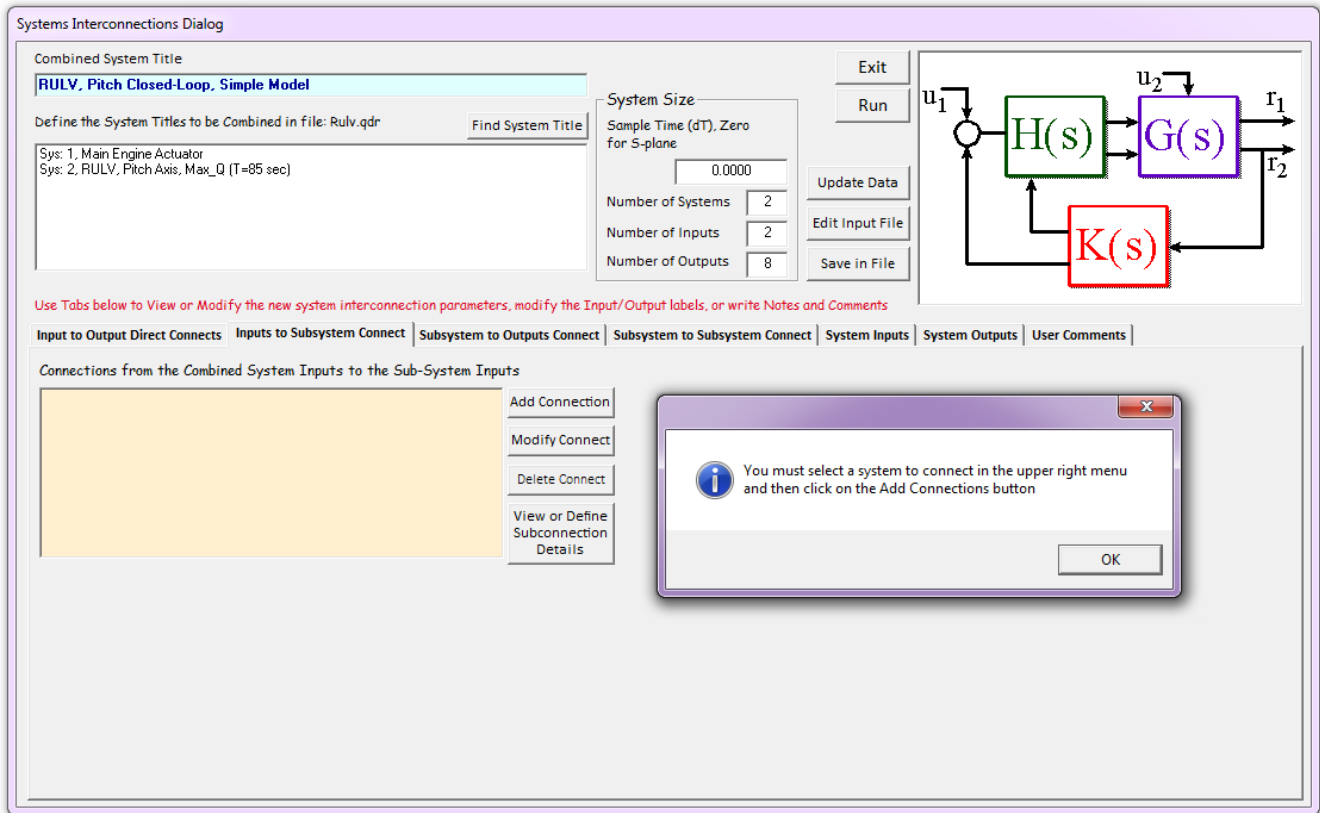

An additional top level connection is also defined. From the upper-right menu select "*System 2, RULV, Pitch Axis, Max_Q (T=85 sec)*" and click on "*Add Connection*". The two subsystems are now included in the upper-left display as recipients from the new system inputs. It means that both subsystems are receiving external inputs (in this case theta-command, and wind-gust). In case of error, you may also use the option buttons to modify or to delete some of the high level connections.

9
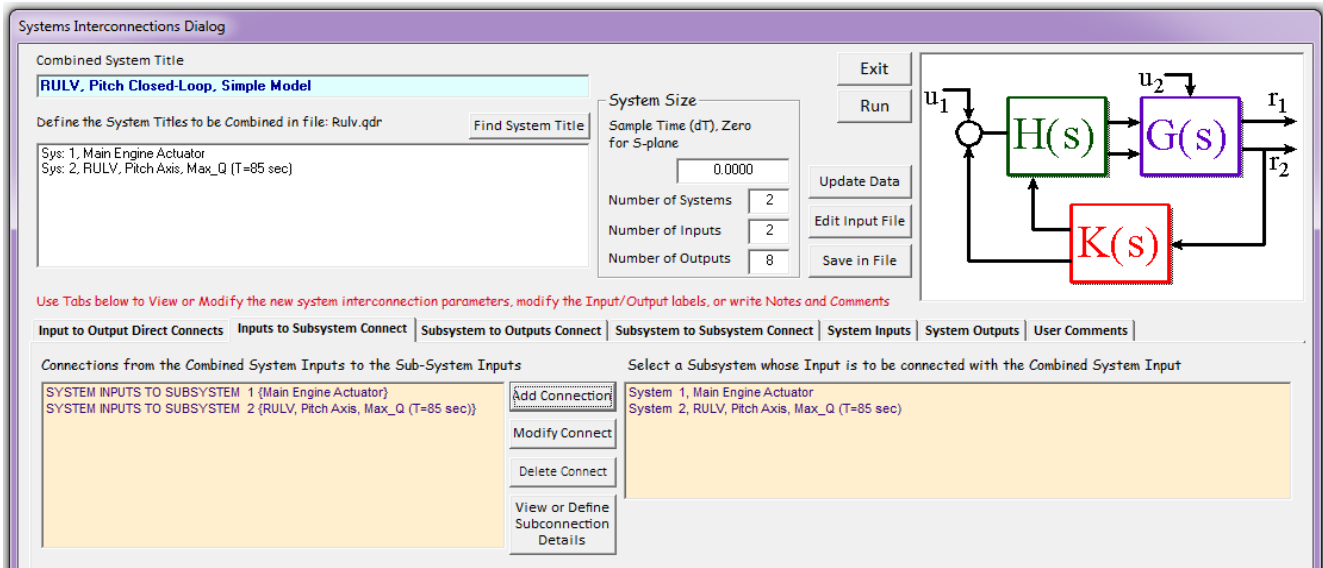
When the high level interconnection definitions are complete the next step is to enter the interconnection details between the combined system inputs and the individual inputs for each of the subsystems. From the upper-left menu select one of the high level connections, for example, "*System Inputs to Subsystem 1 {Main Engine Actuator}*" and click on "*View or Define Sub-Connection Details*" button to define the detail connections between the system inputs and subsystem #1. A detailed level interconnections display appears in the lower left side directly below the high level definitions menu with similar buttons on its right side as the high level menu. It is empty for now because the interconnections between the system inputs and the "*Subsystem 1 {Main Engine Actuator}*" inputs are not defined yet. They will later be included in this list. Click on "*Add Detail Connections*" to define the detail connections between the combined system inputs and subsystem #1.

Two white menus appear at the lower right and they are used to define the "from" and "to" connection details between the system inputs and the actuator subsystem #1 inputs. The left menu shows a list of the combined system 2 inputs (generic names because they haven't been defined yet), and the right menu shows a list of the actuator subsystem #1 inputs (as defined in the systems file). The second input "*Load-Torque*" will not be used in this example. The user selects variables to be connected from the two menus to define the interconnections. If you select only one item from each menu the program assumes that you are defining a scalar connection from one of the system inputs to one of the subsystem inputs and it expects a gain number in the gain field below the menus, and click "OK" to continue. Otherwise, if you select more than one system inputs or more than one subsystem inputs from the menus, for example, 1 system input and 2 subsystem inputs, the program expects a matrix interconnection. In such case it would expect the name of a (2x1) matrix and assume that it has been saved in the systems file. It also expects the sign of the interconnection, for example, -Kc or +H2 . In this case, however, the interconnection shown below is scalar and connects the first system input (theta_comd) to the first actuator input which is (engine deflection command), with a gain of (-1.8), see Figure (1.2). Click "OK" and the interconnection will appear in the lower-left display. Click on "*Close Detail Connections*", the lower menus disappear, and the dialog returns to the high level connections menu in the upper left hand corner of the tab.
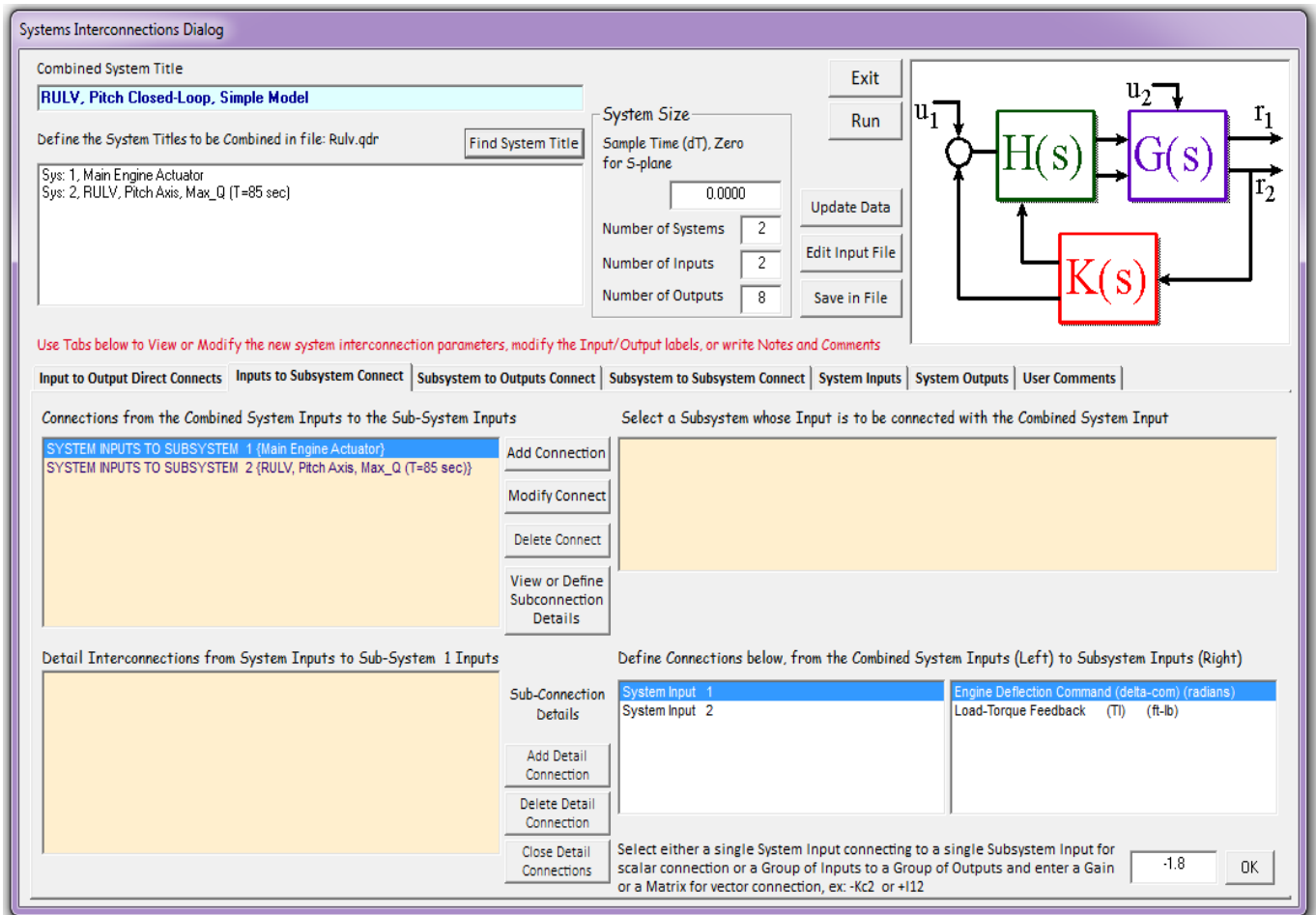
Similarly, from the upper-left menu select the second high level connection between "Combined System Inputs to Subsystem Inputs", which is, "*System Inputs to Subsystem 2 (Rulv ...)*", and click on: "*View or Define Sub-Connection Details*" button to define the detail connections between the system inputs and subsystem #2. The lower-left display becomes visible again and it is empty because the connections to system #2 have not been defined yet. Click on "*Add Detail Connections*" to define the detail connections between the combined system inputs and subsystem #2, which is the vehicle model. It has 6 engine deflection inputs and a wind-gust disturbance. The connections between the system inputs and the subsystem #2 inputs are defined using the menus in the lower-right. In this case we must connect the 2nd system input with input #7 of subsystem #2, which is the wind-gust disturbance, see Figure (1.2). Enter a gain of 1.0, click "OK", and the interconnection will appear in the lower-left display. Click on "*Close Detail Connections*" and the lower menus will disappear. Click on the "*Update Data*" button every time you complete a tab.
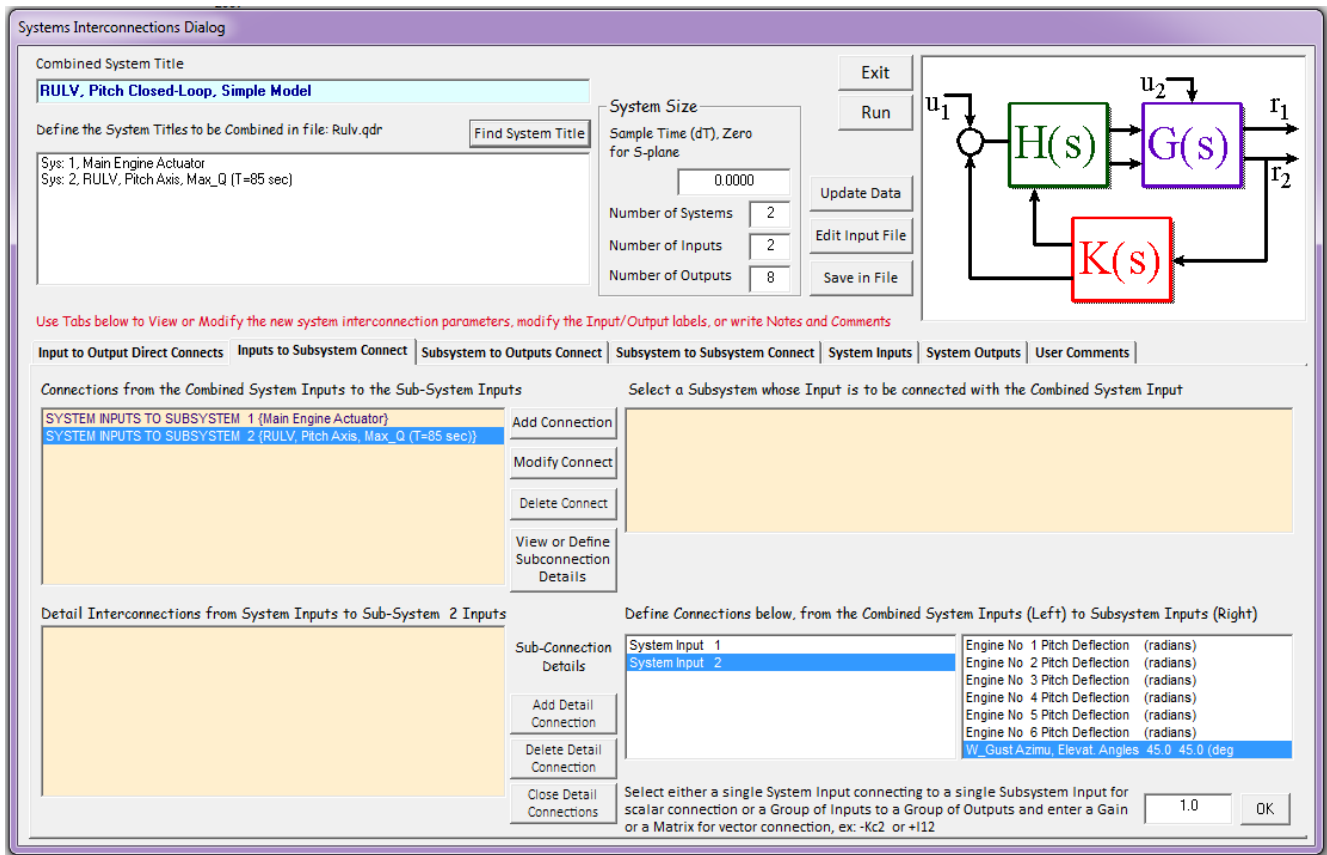
Subsystem Outputs to System Output Connections: You may now select the third tab from the left which is used for defining connections between a subsystem's outputs to the combined system outputs. It is very similar to the previous tab in the sense that the interconnections are defined in two levels. The high level interconnection defining which subsystems are connected to the combined system outputs, and the detailed level defining the exact interconnections from the subsystem outputs to the combined system outputs. To introduce a new subsystem to the output connection click on "*Add Connections*" and a menu appears on the upper-right showing the available subsystems. From that menu select one of the subsystems to be connected at a time to the combined system outputs. In this case select "*System 2, RULV, Pitch Axis, Max_Q (T=85 sec)*" and click on "*Add Connection*" button. Both subsystems will be included in the upper-left display because they are both connecting to the new system outputs. When you finish defining the high level connections the next thing to do is to enter the interconnection details between the selected subsystem outputs and the "combined system" outputs using the lower menus.
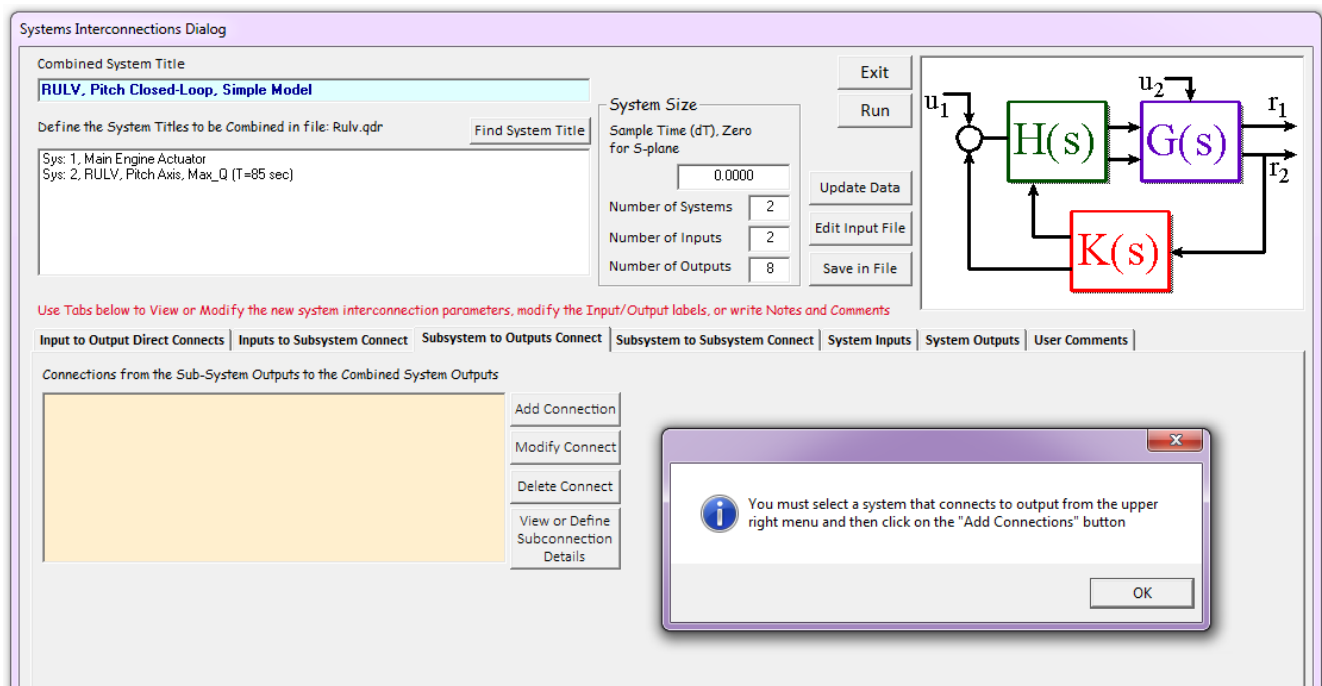
Let us first consider the subsystem #2 to system output connections by selecting the "*System Outputs from Subsystem 2 {Actuator}*" connection from the upper-left menu and clicking on "*View or Define Subconnection Details*" button to define the interconnection details. The lower-left display (showing the detail connections) opens up directly below the high level definitions menu but it is empty for now because the interconnections are not defined yet. It uses similar buttons on its right side as the high level menu. Click on "*Enter Detail Connections*" to define the detail connections between subsystem #2 and the combined system outputs using the "from" and "to" white menus in the lower-right. The left menu shows a list of subsystem #2 outputs as defined in the systems file and the right menu shows a list of the combined system outputs which are default names since they haven't been defined yet. In this case we must connect all 6 vehicle model outputs to the first 6 outputs of the combined system. The last two outputs will later be connected to subsystem #1 outputs. In this case the interconnections are not defined individually using scalar gains but in vector form using a (6x6) identity matrix. Enter the matrix (+I6) in the bottom right, as shown below, and click "OK". The matrix interconnection appears in the lower-left display as "*Via Matrix +I6*". Click on "*Close Detail Connections*" and the lower menus disappear.

We must now define the connections between the engine actuator (subsystem #1) and the combined system outputs. Using the upper-right menu select "*System #1 Main Engine Actuator*" and click on "*Add Connection*" button. The subsystem to output connection is then confirmed and included in the upper-left

14

hand display as "*System Outputs from Subsystem #1 (...)*". To define the detail sub-connections you must select it from the upper-left hand menu and click on "*View or Define Sub-Connection Details*" button. The lower-left display becomes visible but it is empty because the connections have not been defined yet. Click on "*Enter Detail Connections*" to define the detail connections between subsystem #1 and the combined system outputs using the "from" and "to" menus in the lower-right. In this case we must connect the engine gimbal rotation to system output #7 and the gimbal rate to output #8, with a gain of 1.0, one at a time, and click "OK". The two detailed interconnections are shown in the lower-left display. Click on "*Close Detail Connections*" and the lower menus will disappear. Remember to click on the "Update Data" button every time you complete one of the tabs.

Systems Interconnections Dialog

Combined System Title

RULV, Pitch Closed-Loop, Simple Model

Define the System Titles to be Combined in file: Rulv.qdr   [Find System Title]

Sys: 1, Main Engine Actuator
Sys: 2, RULV, Pitch Axis, Max_Q (T=85 sec)

System Size

Sample Time (dT), Zero for S-plane   0.0000

Number of Systems   2
Number of Inputs   2
Number of Outputs   8

[Exit] [Run] [Update Data] [Edit Input File] [Save in File]

Use Tabs below to View or Modify the new system interconnection parameters, modify the Input/Output labels, or write Notes and Comments

| Input to Output Direct Connects | Inputs to Subsystem Connect | **Subsystem to Outputs Connect** | Subsystem to Subsystem Connect | System Inputs | System Outputs | User Comments |

Connections from the Sub-System Outputs to the Combined System Outputs

SYSTEM OUTPUTS FROM SUBSYSTEM 2 {RULV, Pitch Axis, Max_Q (T=85 sec)}
SYSTEM OUTPUTS FROM SUBSYSTEM 1 {Main Engine Actuator}

[Add Connection] [Modify Connect] [Delete Connect] [View or Define Subconnection Details]

Select a Sub-System whose Output Connects to the Combined System Output

Detail Interconnections from Sub-System 1 Outputs to Combined System Outputs

Sub-Connection Details
[Enter Detail Connections] [Delete Detail Connections] [Close Detail Connections]

Define Connections from the Sub-system Outputs below

Engine Gimbal Rotation   (delta)   (radians)
Engine Gimbal Rate   (delta-dot) (rad/sec)
Engine Gimbal Accelerat.(delta-d-dot) (rad/sec^2)

to the Combined System Outputs below

System Output 2
System Output 3
System Output 4
System Output 5
System Output 6
System Output 7
System Output 8

Select either a single Subsystem Output connecting to a single System Output for Scalar connection and enter Gain, or connect a Group of Subsystem to System Outputs for Vectored connection and enter a Matrix. ex: -Kc2   1.0   [OK]

Systems Interconnections Dialog

Combined System Title

RULV, Pitch Closed-Loop, Simple Model

Define the System Titles to be Combined in file: Rulv.qdr   [Find System Title]

Sys: 1, Main Engine Actuator
Sys: 2, RULV, Pitch Axis, Max_Q (T=85 sec)

System Size

Sample Time (dT), Zero for S-plane   0.0000

Number of Systems   2
Number of Inputs   2
Number of Outputs   8

[Exit] [Run] [Update Data] [Edit Input File] [Save in File]

Use Tabs below to View or Modify the new system interconnection parameters, modify the Input/Output labels, or write Notes and Comments

| Input to Output Direct Connects | Inputs to Subsystem Connect | **Subsystem to Outputs Connect** | Subsystem to Subsystem Connect | System Inputs | System Outputs | User Comments |

Connections from the Sub-System Outputs to the Combined System Outputs

SYSTEM OUTPUTS FROM SUBSYSTEM 2 {RULV, Pitch Axis, Max_Q (T=85 sec)}
SYSTEM OUTPUTS FROM SUBSYSTEM 1 {Main Engine Actuator}

[Add Connection] [Modify Connect] [Delete Connect] [View or Define Subconnection Details]

Select a Sub-System whose Output Connects to the Combined System Output

Detail Interconnections from Sub-System 1 Outputs to Combined System Outputs

Output 7 from Subsystem 1 {Main Engine Actuator} Output 1, Gain=   1.0000

Sub-Connection Details
[Enter Detail Connections] [Delete Detail Connections] [Close Detail Connections]

Define Connections from the Sub-system Outputs below

Engine Gimbal Rotation   (delta)   (radians)
Engine Gimbal Rate   (delta-dot) (rad/sec)
Engine Gimbal Accelerat.(delta-d-dot) (rad/sec^2)

to the Combined System Outputs below

System Output 2
System Output 3
System Output 4
System Output 5
System Output 6
System Output 7
System Output 8

Select either a single Subsystem Output connecting to a single System Output for Scalar connection and enter Gain, or connect a Group of Subsystem to System Outputs for Vectored connection and enter a Matrix. ex: -Kc2   1.0   [OK]

Subsystem Outputs to Subsystem Input Connections: The fourth tab from the left is used for defining scalar or matrix connections between subsystem outputs and other subsystem inputs or an algebraic feedback loop around the same subsystem. This interconnection algorithm does not cause "algebraic loop" errors like those appearing in Matlab/ Simulink. This type is very similar to the previous two tabs and the interconnections are defined in two levels. The high level interconnection defines which subsystem's output and input connect without specific details, using the two menus in the upper-right, and the lower level defines the exact interconnections between the "from" subsystem outputs and the "to" subsystem inputs using the lower level menus, as before. To introduce a new connection between subsystems click on "*Add Connections*" and two smaller menus appear in the upper right hand side of the tab. They are both identical and each menu contains the subsystem titles to be combined. There is a label above the two upper-right menus: "*Select a System from the Left whose output connects to one of the system inputs on the Right*". Select a subsystem title from each menu to indicate that some of the outputs of the subsystem from the left will be connected to some of the inputs of the subsystem on the right. First select a combination "*from System #1 {Actuator} Output to System #2 {Vehicle}*" and click on "*Add Connection*" button. Then using the same two menus select a combination "*from System #2 {Vehicle} Output to System #1 {Actuator}*" and click on "*Add Connection*" button again. This defines two top level interconnections between the two subsystems which are also included in the upper-left display. You can also modify or delete some of the existing high level connections using the appropriate buttons. When you finish defining the high level connections the next step is to enter the subsystem to subsystem interconnection details.

17

Systems Interconnections Dialog

Combined System Title

RULV, Pitch Closed-Loop, Simple Model

Define the System Titles to be Combined in file: Rulv.qdr   Find System Title

Sys: 1, Main Engine Actuator
Sys: 2, RULV, Pitch Axis, Max_Q (T=85 sec)

Exit
Run

System Size
Sample Time (dT), Zero for S-plane
0.0000

Number of Systems   2
Number of Inputs   2
Number of Outputs   8

Update Data
Edit Input File
Save in File

Use Tabs below to View or Modify the new system interconnection parameters, modify the Input/Output labels, or write Notes and Comments

Input to Output Direct Connects | Inputs to Subsystem Connect | Subsystem to Outputs Connect | **Subsystem to Subsystem Connect** | System Inputs | System Outputs | User Comments

Inter-Connections from Sub-System Outputs to Sub-System Inputs

Add Connection
Modify Connect
Delete Connect
View or Define Subconnection Details

From the Left Menu on the right hand side you must select a Subsystem whose Output is to be connected to the Input of a Subsystem selected from the Right Menu. Then Click on "Add Connections" button

OK

Systems Interconnections Dialog

Combined System Title

RULV, Pitch Closed-Loop, Simple Model

Define the System Titles to be Combined in file: Rulv.qdr   Find System Title

Sys: 1, Main Engine Actuator
Sys: 2, RULV, Pitch Axis, Max_Q (T=85 sec)

Exit
Run

System Size
Sample Time (dT), Zero for S-plane
0.0000

Number of Systems   2
Number of Inputs   2
Number of Outputs   8

Update Data
Edit Input File
Save in File

Use Tabs below to View or Modify the new system interconnection parameters, modify the Input/Output labels, or write Notes and Comments

Input to Output Direct Connects | Inputs to Subsystem Connect | Subsystem to Outputs Connect | **Subsystem to Subsystem Connect** | System Inputs | System Outputs | User Comments

Inter-Connections from Sub-System Outputs to Sub-System Inputs

System 1 {Main Engine Actuator} Output To System 2 {RULV, Pitch Axis, Ma}
System 2 {RULV, Pitch Axis, Ma} Output To System 1 {Main Engine Actuator}

Add Connection
Modify Connect
Delete Connect
View or Define Subconnection Details

Select a System from Left whose Output connects to one of the following Systems Inputs on the Right

System 1, Main Engine Actuator
System 2, RULV, Pitch Axis, Max_Q (T=85 sec)

System 1, Main Engine Actuator
System 2, RULV, Pitch Axis, Max_Q (T=85 sec)

From the upper-left menu select one of the top level connections, for example, "*System 1 {Actuator} Output to System 2 {Rulv} Input*" and click on "*View or Define Subconnection Details*" button. The lower-left display that will include the connection details, directly below the high level definitions menu, becomes visible but it is empty because the connections have not been defined yet. Click on "*Add Detail Connections*" and two white menus appear in the lower right hand corner labeled "*Define the Detailed Connections below from Subsystem Outputs to Subsystem Inputs*" to define the exact connections between the subsystems. The left menu shows a list of subsystem #1 outputs and the right menu a list of subsystem #2 inputs for the user to select the detailed interconnections. In fact, the first output of subsystem #1 which is "engine deflection" must be connected to the first 6 inputs of the "vehicle model" which is subsystem #2 with a gain of 0.408, one scalar connection at a time. Click "OK" after defining each connection, and the connections will gradually appear in the lower-left display, as shown below. When you have finished entering the detailed connections press the "*Close Detailed Connections*" button, the lower level menus close, and the dialog will return to the top level menu in the upper left hand side. From this menu you can either select another "*Subsystem to*

Subsystem" connection or select to another tab. You must remember to "*Update Data*" before changing tabs.

Systems Interconnections Dialog

Combined System Title
RULV, Pitch Closed-Loop, Simple Model

Define the System Titles to be Combined in file: Rulv.qdr   Find System Title

Sys: 1, Main Engine Actuator
Sys: 2, RULV, Pitch Axis, Max_Q (T=85 sec)

System Size
Sample Time (dT), Zero for S-plane
0.0000
Number of Systems   2
Number of Inputs   2
Number of Outputs   8

Exit
Run
Update Data
Edit Input File
Save in File

Use Tabs below to View or Modify the new system interconnection parameters, modify the Input/Output labels, or write Notes and Comments

Input to Output Direct Connects | Inputs to Subsystem Connect | Subsystem to Outputs Connect | **Subsystem to Subsystem Connect** | System Inputs | System Outputs | User Comments

Inter-Connections from Sub-System Outputs to Sub-System Inputs

System 1 {Main Engine Actuator} Output To System 2 {RULV, Pitch Axis, Ma}
System 2 {RULV, Pitch Axis, Ma} Output To System 1 {Main Engine Actuator}

Add Connection
Modify Connect
Delete Connect
View or Define Subconnection Details

Select a System from Left whose Output connects to one of the following Systems Inputs on the Right

Detail Interconnections from Sub-System 1 Outputs to Sub-System 2 Inputs

Sub-Connection Details
Add Detailed Connections
Delete Detailed Connections
Close Detailed Connections

Define the detailed connections below, from the Subsystem Outputs to the Subsystem Inputs

Engine Gimbal Rotation   (delta)   (radians)
Engine Gimbal Rate   (delta-dot) (rad/sec)
Engine Gimbal Accelerat.(delta-d-dot) (rad/sec^2)

Engine No 1 Pitch Deflection   (radians)
Engine No 2 Pitch Deflection   (radians)
Engine No 3 Pitch Deflection   (radians)
Engine No 4 Pitch Deflection   (radians)
Engine No 5 Pitch Deflection   (radians)
Engine No 6 Pitch Deflection   (radians)
W_Gust Azimu, Elevat. Angles 45.0 45.0 (deg)

Select either a single System Output going to a single System Input for scalar connection or a Group of Outputs to a Group of Inputs for Vector connection and enter a Gain or Matrix, ex: +I3 or -Km
0.4082   OK

Systems Interconnections Dialog

Combined System Title
RULV, Pitch Closed-Loop, Simple Model

Define the System Titles to be Combined in file: Rulv.qdr   Find System Title

Sys: 1, Main Engine Actuator
Sys: 2, RULV, Pitch Axis, Max_Q (T=85 sec)

System Size
Sample Time (dT), Zero for S-plane
0.0000
Number of Systems   2
Number of Inputs   2
Number of Outputs   8

Exit
Run
Update Data
Edit Input File
Save in File

Use Tabs below to View or Modify the new system interconnection parameters, modify the Input/Output labels, or write Notes and Comments

Input to Output Direct Connects | Inputs to Subsystem Connect | Subsystem to Outputs Connect | **Subsystem to Subsystem Connect** | System Inputs | System Outputs | User Comments

Inter-Connections from Sub-System Outputs to Sub-System Inputs

System 1 {Main Engine Actuator} Output To System 2 {RULV, Pitch Axis, Ma}
System 2 {RULV, Pitch Axis, Ma} Output To System 1 {Main Engine Actuator}

Add Connection
Modify Connect
Delete Connect
View or Define Subconnection Details

Select a System from Left whose Output connects to one of the following Systems Inputs on the Right

Detail Interconnections from Sub-System 1 Outputs to Sub-System 2 Inputs

Subsystem 1, Output 1 to Subsystem 2, Input 1, Gain= 0.40820
Subsystem 1, Output 1 to Subsystem 2, Input 2, Gain= 0.40820
Subsystem 1, Output 1 to Subsystem 2, Input 3, Gain= 0.40820
Subsystem 1, Output 1 to Subsystem 2, Input 4, Gain= 0.40820
Subsystem 1, Output 1 to Subsystem 2, Input 5, Gain= 0.40820

Sub-Connection Details
Add Detailed Connections
Delete Detailed Connections
Close Detailed Connections

Define the detailed connections below, from the Subsystem Outputs to the Subsystem Inputs

Engine Gimbal Rotation   (delta)   (radians)
Engine Gimbal Rate   (delta-dot) (rad/sec)
Engine Gimbal Accelerat.(delta-d-dot) (rad/sec^2)

Engine No 1 Pitch Deflection   (radians)
Engine No 2 Pitch Deflection   (radians)
Engine No 3 Pitch Deflection   (radians)
Engine No 4 Pitch Deflection   (radians)
Engine No 5 Pitch Deflection   (radians)
Engine No 6 Pitch Deflection   (radians)
W_Gust Azimu, Elevat. Angles 45.0 45.0 (deg)

Select either a single System Output going to a single System Input for scalar connection or a Group of Outputs to a Group of Inputs for Vector connection and enter a Gain or Matrix, ex: +I3 or -Km
0.4082   OK
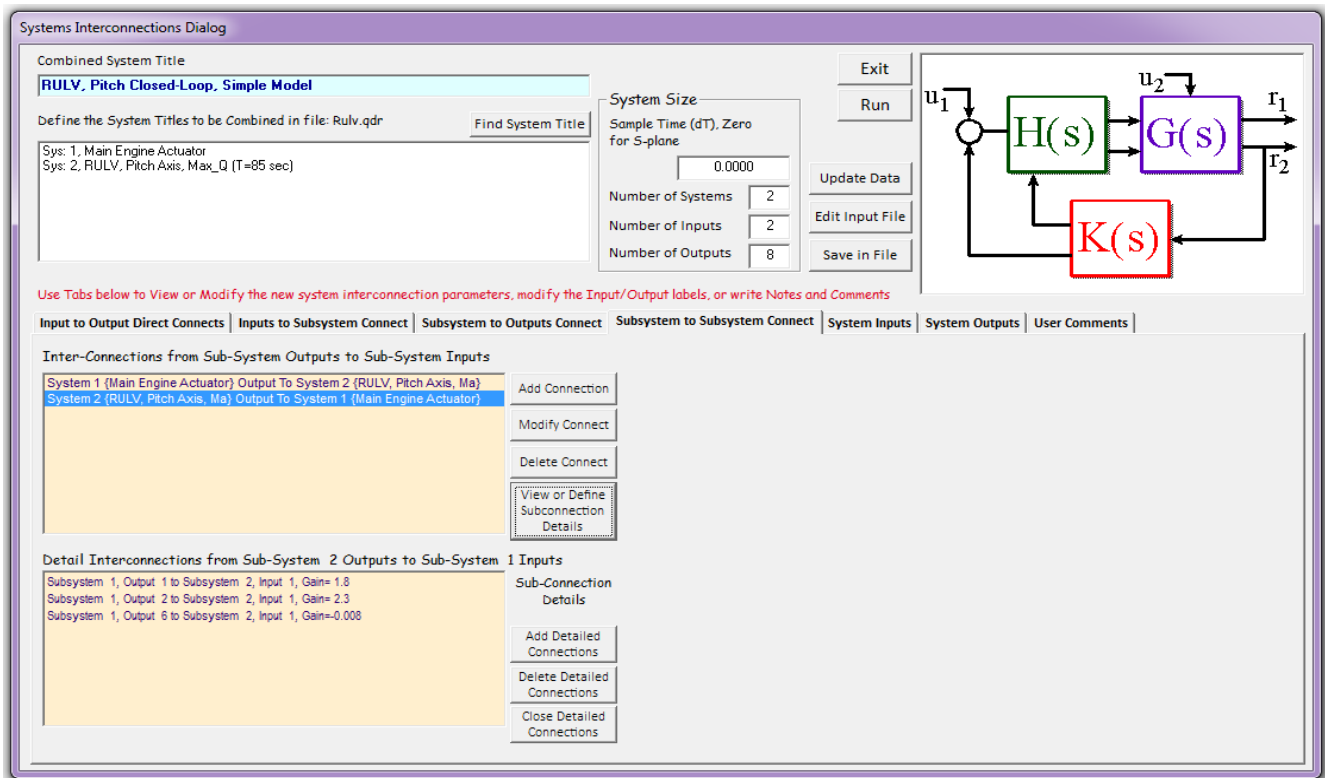
Using the Top Buttons "Run", "Exit", "Update Data", "Edit Input", "Save in File"

When the system interconnections are all defined the user must press the "*Update Data*" button, and then "*Save in File*" to save the new set of interconnections in the input data file. If you made a mistake or forgot to include a detail you can always edit the input data file by clicking on "*Edit Input File*". A text editor comes up where the user may edit the input data file (.Inp) and save it before running it. At this point you may run the new set of system interconnections by clicking on the "*Run*" button. The utility will process the input data and will create a new state-space system that will be saved at the bottom of the selected systems file. The new system will have the same title and the same comments included as those in the interconnection data-set. If for some reason you do not wish to process the data and would like to exit the program without running it, use the "*Exit*" button to return to the Flixan main menu. The systems interconnections set will remain in the input file and you can modify it and run it at some later time.

Matrix Interconnections:

In some cases the interconnections between system inputs and outputs are not defined by scalar connections but vectored connections by means of matrices. The interconnection matrices must be saved in the systems file together with the systems to be connected. Furthermore, if all of the outputs of one system are directly connected to the inputs of another system the interconnection between the two subsystems can be defined with an identity matrix connection. In this case the identity matrix does not have to be saved in systems file but only defined in the interconnections together with its size and sign, for example, -I8 . Only the gain matrices, other than identity matrices, must already exist in the systems file (*.Qdr). A typical gain matrix is shown below. It has a title in the 2nd line and a matrix name "Kmix1" in this case that must be less than 20 characters long. Comment lines beginning with "!" may be included below the title. The definitions of the matrix inputs and outputs are included below the matrix, and they are optional. The Flixan program locates the matrix in a systems file from its name. The interconnection between two subsystems in the interconnection data is defined as follows, for example:

System # 1 goes to System # 2;
Via Matrix -I3 or
Via Matrix +Kc1

The matrix sign, either (+ or -) must be included in front of the matrix title to indicate positive or negative connections. Matrix -I3 signifies an identity matrix of size (3x3) with a negative sign in front of it. Matrix +Kc1 means that the interconnection between subsystem #1 and subsystem #2 will be implemented via matrix Kc1 and the matrix Kc1 should be saved in file and the user must make sure that the number of output and input connections match the matrix size, otherwise, an error will occur.

```
Gain Matrix for ...
Mixing Logic for RUV Rocket Plane, Max-Q, TVC Only
! This is a TVC Matrix for a Flight Vehicle that uses 6 TVC engines
! It converts the roll, pitch, and yaw demands to pitch and yaw engine deflections
Matrix Kmix1                Size = 12 X  3
           1-Column              2-Column              3-Column
   1-Row -0.421476571158E-01 -0.696887052969E+00 -0.189849954035E-01
   2-Row -0.842953142316E-01 -0.696887052969E+00 -0.379699908071E-01
   3-Row -0.421476571158E-01 -0.696887052969E+00 -0.189849954035E-01
   4-Row  0.421476571158E-01 -0.696887052969E+00  0.189849954035E-01
   5-Row  0.842953142316E-01 -0.696887052969E+00  0.379699908071E-01
   6-Row  0.421476571158E-01 -0.696887052969E+00  0.189849954035E-01
   7-Row  0.701454508604E-01  0.560429840605E-17 -0.665455594906E+00
   8-Row -0.285868827862E-02 -0.463518776671E-18 -0.698339587537E+00
   9-Row -0.758628274177E-01 -0.653133595940E-17 -0.731223580168E+00
  10-Row -0.758628274177E-01 -0.653133595940E-17 -0.731223580168E+00
  11-Row -0.285868827862E-02 -0.463518776671E-18 -0.698339587537E+00
  12-Row  0.701454508604E-01  0.560429840605E-17 -0.665455594906E+00
-----------------------------------------------------------------
Definitions of Matrix Inputs (Columns):     3
P-dot Roll  Acceleration About X Axis
Q-dot Pitch Acceleration About Y Axis
R-dot Yaw   Acceleration About Z Axis

Definitions of Matrix Outputs (Rows):     12
Output:  1 Dy(engine):  1 Pitch Deflection
Output:  2 Dy(engine):  2 Pitch Deflection
Output:  3 Dy(engine):  3 Pitch Deflection
Output:  4 Dy(engine):  4 Pitch Deflection
Output:  5 Dy(engine):  5 Pitch Deflection
Output:  6 Dy(engine):  6 Pitch Deflection
Output:  7 Dz(engine):  1 Yaw  Deflection
Output:  8 Dz(engine):  2 Yaw  Deflection
Output:  9 Dz(engine):  3 Yaw  Deflection
Output: 10 Dz(engine):  4 Yaw  Deflection
Output: 11 Dz(engine):  5 Yaw  Deflection
Output: 12 Dz(engine):  6 Yaw  Deflection
---------------------------------------------------------------------
```

User Comments Tab:

This tab is used for viewing system comments already entered in the systems interconnections data-set. These are comments and user notes regarding the system for documentation purposes. The comment lines begin with (!) and they are below the system title. The comments from the input data are also copied and inserted in the systems data below the title. When starting with a new system this display/ tab is also used for entering the system notes interactively.

System Input and System Output Definition Tabs:

These tabs are used for viewing the system input and output definitions. The system inputs and outputs are defined in the input file, at the bottom of the data-set, below the systems interconnections data. They are also copied to the systems file below the quadruple matrices. Initially, when we define a new set of interconnections interactively the utility assigns default titles for the system inputs and outputs, such as, "*System Input 1*". The tabs may be used to redefine the default input and output names and the user may replace them with more descriptive labels. For example, to change one of the inputs from the menu, select the default label, ex. "*System Input 2*", click on "*Edit*" button at the bottom, and the default label appears in the field below the menu. Then you can modify the default label in that field to more descriptive name, such as for example: "*Wind-Gust Disturbance in (ft/sec)*", and press the "*Edit*" button again. The default label will then be changed to the new name. You may then select other inputs and repeat. You must also remember to click "*Update Data*" before changing tabs.

Systems Interconnections Dialog

Combined System Title

RULV, Pitch Closed-Loop, Simple Model

Define the System Titles to be Combined in file: Rulv.qdr   [Find System Title]

Sys: 1, Main Engine Actuator
Sys: 2, RULV, Pitch Axis, Max_Q (T=85 sec)

[Exit]
[Run]

System Size

Sample Time (dT), Zero for S-plane

0.0000

Number of Systems   2
Number of Inputs   2
Number of Outputs   8

[Update Data]
[Edit Input File]
[Save in File]

Use Tabs below to View or Modify the new system interconnection parameters, modify the Input/Output labels, or write Notes and Comments

| Input to Output Direct Connects | Inputs to Subsystem Connect | Subsystem to Outputs Connect | Subsystem to Subsystem Connect | System Inputs | System Outputs | User Comments |

System Output 1
System Output 2
System Output 3
System Output 4
System Output 5
System Output 6
System Output 7
System Output 8

Select an Output from menu and press Edit to modify the Output title at the bottom. Repeat to change other Outputs.

System Output 1   [Edit]

Systems Interconnections Dialog

Combined System Title

RULV, Pitch Closed-Loop, Simple Model

Define the System Titles to be Combined in file: Rulv.qdr   [Find System Title]

Sys: 1, Main Engine Actuator
Sys: 2, RULV, Pitch Axis, Max_Q (T=85 sec)

[Exit]
[Run]

System Size

Sample Time (dT), Zero for S-plane

0.0000

Number of Systems   2
Number of Inputs   2
Number of Outputs   8

[Update Data]
[Edit Input File]
[Save in File]

Use Tabs below to View or Modify the new system interconnection parameters, modify the Input/Output labels, or write Notes and Comments

| Input to Output Direct Connects | Inputs to Subsystem Connect | Subsystem to Outputs Connect | Subsystem to Subsystem Connect | System Inputs | System Outputs | User Comments |

Pitch Atiittude (theta) in (rad)
Pitch Rate (q) in (rad/s)
Angle of Attack (alpha) in (rad)
Delta Altitude (dh) in (feet)
Forward Acceleration (V-dot) in (ft/sec2)
Accelerometer along Z in (ft/sec^2)
Pitch Engine Actuator Deflection (rad)
Engine Deflection Rate (rad/sec)

Select an Output from menu and press Edit to modify the Output title at the bottom. Repeat to change other Outputs.

System Output 8   [Edit]

24

1.3 Running an Already Existing Interconnection Set

It is obviously a lot easier to modify an already existing interconnection set using a typical text editor and then process it using the interconnection utility. In this case the interconnection data are already saved in the input file "*Rulv.Inp*" and the systems to be combined are already saved in file "*Rulv.Qdr*". This example is located in folder "*C:\Flixan\Comb_Trfn\Examples*". From the Flixan main menu the user selects the systems combination utility by clicking on the "*Analysis Tools*", then "*Creating and Modifying Linear Systems*", and then clicking on "*Combine State-Space Systems and Matrices*". Using the filename selection menu, select the input and system filenames and click on "*Select Files*" to process the already existing data. In this case the input data file contains four sets of interconnection data. The following menu shows the titles of the four interconnection sets in file "*Rulv.Inp*". The user selects the second set "*RULV, Pitch Closed-Loop, Simple Model*", and clicks on "*Run Input Set*".

Enter Filenames

Enter a File Name containing the Input Data (xxx.Inp)

```
Rulv.Inp
```
NewFile.inp
Rulv.Inp
NewFile.Inp

Enter a File Name containing the Quadruple Data (xxx.Qdr)

```
Rulv.qdr
```
NewFile.qdr
Rulv.qdr
NewFile.Qdr

[Create New Input Set]   [Exit Program]   [Select Files]

Find a Set of Inputs

Select a Set of Input Data for "INTERCONNECTION" from an Input File: Rulv.inp

RULV, Pitch Forward Loop, T=85, Simple Model
RULV, Pitch Closed-Loop, Simple Model
RULV, Pitch Closed Loop, (with TWD/ DWT/ Slosh)
RULV, Pitch Open-Loop System, (with TWD/ DWT/ Slosh/ Flex)

[Run Input Set]

[Exit Program]

[Create New]

The following dialog shows the interconnection details of the closed-loop system already described in Figure (1.2). The interconnections are obtained from the input data set. The combined system's title is shown at the top and the two systems to be combined are shown in the white display below. This system has 2 inputs and 8 outputs. The sampling time is zero for continuous system. The interconnection details, input/ output definitions and user comments are shown by selecting in the corresponding tabs. To process the data and to generate the new system you must click on "*Run*". The dialog also provides the capability to edit the input file before processing it by clicking on "*Edit Input File*". The "*Exit*" button will return to the Flixan main menu without running the program.
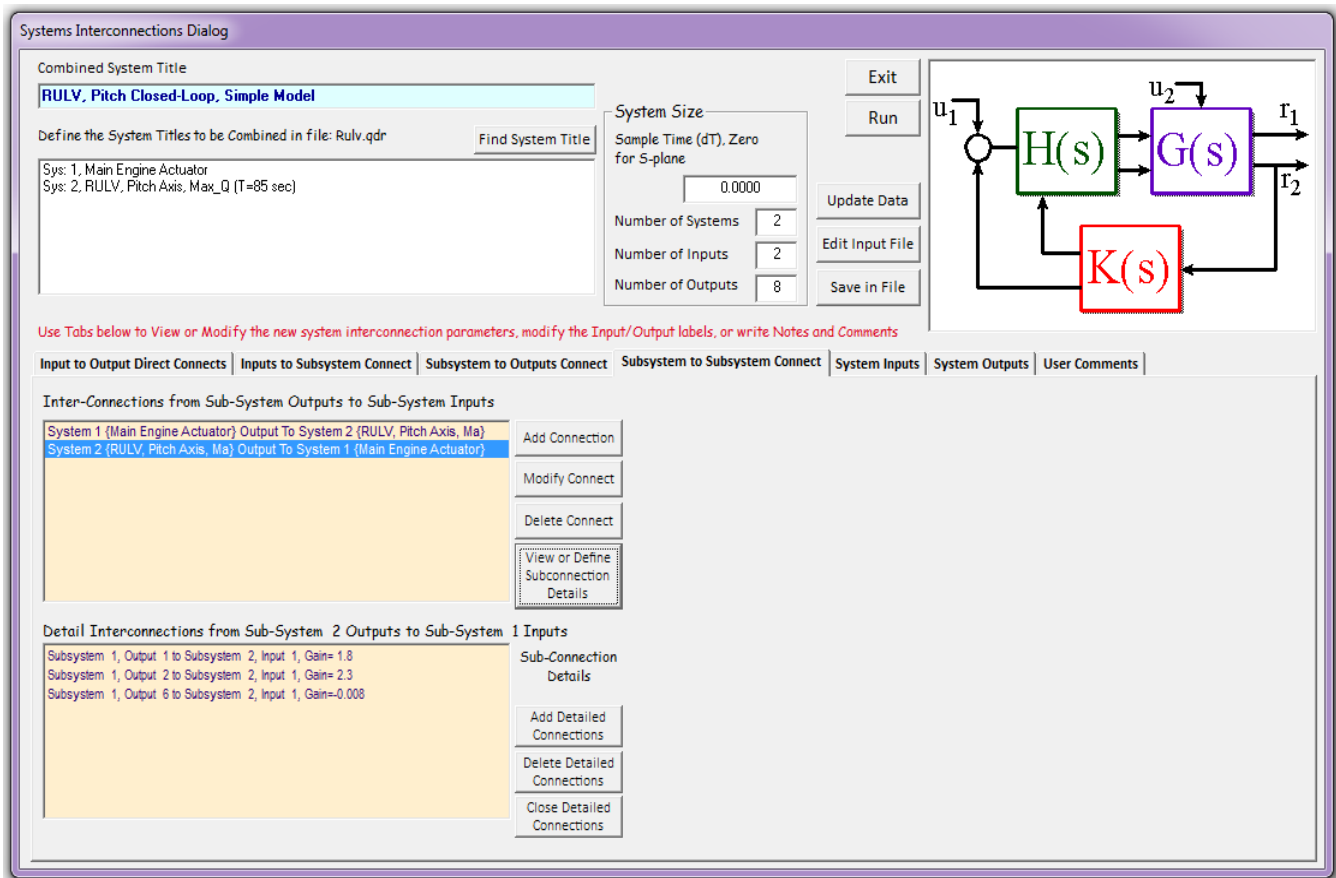
This example can also be processed in batch mode by running the batch set which is located on the top of the input file "*Rulv.Inp*". More system combination examples are located in folder: "*C:\Flixan\ Comb_Trfn\Examples*".

1.4 Processing Interconnection Sets in Batch Mode

In this example we have an input file "*Comb_tst.Inp*" consisting entirely of system and transfer-function interconnections, and it is located in directory "*C:\Flixan\Comb_Trfn\Examples*". This input file, shown below, includes many data-sets, and it is a lot easier and faster to process it in batch mode. It also includes a batch set on the top that can process the entire file. There are user notes in the batch below the title that describe the processes. The generated systems are saved in file "*Comb_tst.Qdr*".

26

BATCH MODE INSTRUCTIONS ....
Systems Interconnection Testing Batch
! A Batch Set used for generating and connecting systems together for demo purposes.
! It first retains two matrices in the systems file that will be used later in the connections.
! Then it generates two second order systems from Transf-Functions. Then a second order with
! 1 sec delay. Then it combines the two 2nd order systems together to create a 4th order system.
! Then it combines two identical 4th order systems in series to create an 8th order system.
! Then it combines four of these 8th order systems in parallel to create a 32nd order system.
! Then it creates a 14th order system by combining 3 of the above systems (2nd, 4th, and 8th).
! Then we create a system by combining two different 2nd order Transf-Functions in parallel.
! We also create a big system of 116 states, 5 inputs and 5 outputs by combining seven of the
! above systems together. We also combine the 14th order with the 8th order systems via gain
! matrix connections to create a 22nd order system. We finally create a 5th order system using
! transf-functions and combine the 5th order with a 4th order and also an 8th order systems to
! create another system.
Retain Matrix   : (3x2) Gain Connection matrix
Retain Matrix   : (2x2) Gain Connection matrix
Transf-Functions : (s^2 +2s +16)/(s^2 +5s +25)
Transf-Functions : 4/(s^2 +2s +4)
Transf-Functions : 4/(s^2 +2s +4)*exp(-sT)
System Connection: Fourth Order System
System Connection: Eighth Order System
System Connection: 32nd Order
System Connection: Fourteenth Order System (3 Systems Combined)
System Connection: Two Second Order Transfer Functions Connected in Parallel
System Connection: Two Systems in Series (12th Order)
System Connection: A Big System
System Connection: Two Systems Connected with a Gain Matrix
Transf-Functions : 4/(s^2 +2s +4)*exp(-sT) (b)
Transf-Functions : Fifth Order System of 3 Transfer Functions
System Connection: Another System Combination

SYSTEM OF TRANSFER FUNCTIONS ...
(s^2 +2s +16)/(s^2 +5s +25)
! A simple 2nd order numerator 2nd order denominator transfer function
Continuous
TF. Block # 1 Second order, (2 zeros/2 poles)   Order of Numer, Denom= 2 2
Numer 1.00000   2.00000   16.0000
Denom 1.00000   5.00000   25.0000

Block #, from Input #, Gain
  1 1   1.00000
....
Outpt #, from Block #, Gain
  1 1   1.00000
....
Definitions of Inputs =   1
Transf. Function (s^2 +2s +16)/(s^2 +5s +25) Input #1

Definitions of Outputs =   1
Transf. Function (s^2 +2s +16)/(s^2 +5s +25) Output #1

SYSTEM OF TRANSFER FUNCTIONS ...
4/(s^2 +2s +4)
! Another second order denominator transfer function
Continuous
TF. Block # 1 Low Pass Filter (2 rad/sec bandwidth)   Order of Numer, Denom= 0 2
Numer 0.0   0.0   4.0
Denom 1.00000   2.00000   4.00000

Block #, from Input #, Gain
  1 1   1.00000
....
Outpt #, from Block #, Gain
  1 1   1.00000
....
Definitions of Inputs =   1
Transf. Function 4/(s^2 +2s +4) Input # 1

Definitions of Outputs =   1
Transf. Function 4/(s^2 +2s +4) Output # 1

SYSTEM OF TRANSFER FUNCTIONS ...
4/(s^2 +2s +4)*exp(-sT)
! Another second order denominator transfer function
Continuous
TF. Block # 1 Low Pass Filter (2 rad/sec bandwidth)   Order of Numer, Denom= 0 2
Numer 0.0   0.0   4.0
Denom 1.00000   2.00000   4.00000
TF. Block # 2 Delay (sec)= 1.00000   Order of Numer, Denom= 1 1

Block #, from Input #, Gain
  1 1   1.00000
....
Block #, from Block #, Gain
  2 1   1.00000
....
Outpt #, from Block #, Gain
  1 2   1.00000
....
Outpt #, from Input #, Gain
  1 1   0.10000
....
Definitions of Inputs =   1
Low Pass Filter Input 1

Definitions of Outputs =   1
Delay Output 1

INTERCONNECTION OF SYSTEMS .....
Fourth Order System
! Combine the two transfer functions in parallel in a single fourth order system
Titles of Systems to be Combined   (Found in File Comb_tst.Qdr)
Title 1 (s^2 +2s +16)/(s^2 +5s +25)
Title 2 4/(s^2 +2s +4)
SYSTEM INPUTS DIRECT TO SYSTEM OUTPUTS
System Input 2 to System Outpt 1, Gain=0.156250
System Input 2 to System Outpt 2, Gain=0.500000
....
SYSTEM INPUTS TO SUBSYSTEM 1
System Input 1 to Subsystem 1, Input 1, Gain= 1.00000
....
SYSTEM INPUTS TO SUBSYSTEM 2
System Input 2 to Subsystem 2, Input 1, Gain= 1.00000
....
SYSTEM OUTPUTS FROM SUBSYSTEM 1
System Output 1 from Subsystem 1, Output 1, Gain= 1.56250
....
SYSTEM OUTPUTS FROM SUBSYSTEM 2
System Output 2 from Subsystem 2, Output 1, Gain=0.500000
....
Definitions of Inputs =   2
Transfer Function 1 Input 1
Transfer Function 2 Input 2

Definitions of Outputs =   2
Transfer Function 1 Output 1
Transfer Function 2 Output 2

INTERCONNECTION OF SYSTEMS .....
Eighth Order System
! Combine the fourth order system with an identical 4th order in series to create
! an 8th order system
Titles of Systems to be Combined   (Found in File CMBT.QDR)
Title 1 Fourth Order System
Title 2 Fourth Order System
SYSTEM INPUTS TO SUBSYSTEM 1
Via Matrix +I2
....
SYSTEM OUTPUTS FROM SUBSYSTEM 2
Via Matrix +I2
....
SUBSYSTEM NO 1 GOES TO SUBSYSTEM NO 2
Via Matrix +I2
....
Definitions of Inputs = 2
System 1 Input 1
System 1 Input 2

Definitions of Outputs = 2
System 2 Output 1
System 2 Output 2

INTERCONNECTION OF SYSTEMS .....
32nd Order
! This Interconnection set combines four identical Eighth order systems
! in parallel to create a 32nd order system.
```
Titles of Systems to be Combined        (Found in File CMBT.QDR)
Title 1 Eighth Order System
Title 2 Eighth Order System
Title 3 Eighth Order System
Title 4 Eighth Order System
SYSTEM INPUTS TO SUBSYSTEM  1
Via Matrix +I2
.................................................................................
SYSTEM INPUTS TO SUBSYSTEM  2
System Input  3 to Subsystem  2, Input  1, Gain= 1.00000
System Input  4 to Subsystem  2, Input  2, Gain= 1.00000
.................................................................................
SYSTEM INPUTS TO SUBSYSTEM  3
System Input  5 to Subsystem  3, Input  1, Gain= 1.00000
System Input  6 to Subsystem  3, Input  2, Gain= 1.00000
.................................................................................
SYSTEM INPUTS TO SUBSYSTEM  4
System Input  7 to Subsystem  4, Input  1, Gain= 1.00000
System Input  8 to Subsystem  4, Input  2, Gain= 1.00000
.................................................................................
SYSTEM OUTPUTS FROM SUBSYSTEM  1
Via Matrix +I2
.................................................................................
SYSTEM OUTPUTS FROM SUBSYSTEM  2
System Output  3 from Subsystem  2, Output  1, Gain= 1.00000
System Output  4 from Subsystem  2, Output  2, Gain= 1.00000
.................................................................................
SYSTEM OUTPUTS FROM SUBSYSTEM  3
System Output  5 from Subsystem  3, Output  1, Gain= 1.00000
System Output  6 from Subsystem  3, Output  2, Gain= 1.00000
.................................................................................
SYSTEM OUTPUTS FROM SUBSYSTEM  4
System Output  7 from Subsystem  4, Output  1, Gain= 1.00000
System Output  8 from Subsystem  4, Output  2, Gain= 1.00000
.................................................................................
Definitions of Inputs  =  8
System 1 Input 1
System 1 Input 2
System 2 Input 3
System 2 Input 4
System 3 Input 5
System 3 Input 6
System 4 Input 7
System 4 Input 8

Definitions of Outputs =  8
System 1 Output 1
System 1 Output 2
System 2 Output 3
System 2 Output 4
System 3 Output 5
System 3 Output 6
System 4 Output 7
System 4 Output 8
---------------------------------------------------------------------------------------------
```

INTERCONNECTION OF SYSTEMS .....
Fourteenth Order System (3 Systems Combined)
! Combine a second order system with a fourth order system and an eighth order system to create a
! fourteenth order system
Titles of Systems to be Combined
Title 1 (s^2 +2s +16)/(s^2 +5s +25)
Title 2 Fourth Order System
Title 3 Eighth Order System
SYSTEM INPUTS DIRECT TO SYSTEM OUTPUTS
System Input 1 to System Outpt 1, Gain= 0.10000
System Input 3 to System Outpt 2, Gain= 0.20000
....
SYSTEM INPUTS TO SUBSYSTEM 1   (s^2 +2s +16)/(s^2 +5s +25)
System Input 1 to Subsystem 1, Input 1, Gain=   1.0000
....
SYSTEM INPUTS TO SUBSYSTEM 2   Fourth Order System
System Input 2 to Subsystem 2, Input 1, Gain=   2.0000
System Input 3 to Subsystem 2, Input 2, Gain=   3.0000
....
SYSTEM OUTPUTS FROM SUBSYSTEM 3   Eighth Order System
Via Matrix -I2   Size (2 x 2)
....
SUBSYSTEM NO 1 GOES TO SUBSYSTEM NO 3
Subsystem 1, Output 1 to Subsystem 3, Input 1, Gain=   1.0000
Subsystem 1, Output 1 to Subsystem 3, Input 2, Gain= 0.50000
....
SUBSYSTEM NO 2 GOES TO SUBSYSTEM NO 3
Subsystem 2, Output 1 to Subsystem 3, Input 2, Gain=   1.0000
Subsystem 2, Output 2 to Subsystem 3, Input 1, Gain= 0.60000
....
Definitions of Inputs =   3
New System Input 1
New System Input 2
New System Input 3

Definitions of Outputs =   2
New System Output 1
New System Output 2

INTERCONNECTION OF SYSTEMS .....
Two Second Order Transfer Functions Connected in Parallel
! A simple 2nd order numerator 2nd order denominator transfer function
Titles of Systems to be Combined
Title 1 (s^2 +2s +16)/(s^2 +5s +25)
Title 2 4/(s^2 +2s +4)
SYSTEM INPUTS DIRECT TO SYSTEM OUTPUTS
System Input 1 to System Outpt 1, Gain= 0.10000
System Input 2 to System Outpt 2, Gain= 0.20000
....
SYSTEM INPUTS TO SUBSYSTEM 1   (s^2 +2s +16)/(s^2 +5s +25)
System Input 1 to Subsystem 1, Input 1, Gain=   1.0000
....
SYSTEM INPUTS TO SUBSYSTEM 2   4/(s^2 +2s +4)
System Input 2 to Subsystem 2, Input 1, Gain=   1.0000
....
SYSTEM OUTPUTS FROM SUBSYSTEM 1   (s^2 +2s +16)/(s^2 +5s +25)
System Output 1 from Subsystem 1, Output 1, Gain=   1.0000
....
SYSTEM OUTPUTS FROM SUBSYSTEM 2   4/(s^2 +2s +4)
System Output 2 from Subsystem 2, Output 1, Gain=   1.0000
....
Definitions of Inputs =   2
System Input   1
System Input   2

Definitions of Outputs =   2
System Output 1
System Output 2

INTERCONNECTION OF SYSTEMS .....
Two Systems in Series (12th Order)
! Connect the Fourth Order System in Series with the Eighth Order System
Titles of Systems to be Combined
Title 1 Fourth Order System
Title 2 Eighth Order System
SYSTEM INPUTS TO SUBSYSTEM 1   Fourth Order System
Via Matrix +I2   Size (2 x 2)
....
SYSTEM OUTPUTS FROM SUBSYSTEM 2   Eighth Order System
Via Matrix -I2   Size (2 x 2)
....
SUBSYSTEM NO 1 GOES TO SUBSYSTEM NO 2
Via Matrix +I2   Size (2 x 2)
....
Definitions of Inputs =   2
Fourth Order, Input 1
Fourth Order, Input 2

Definitions of Outputs =   2
Eighth Order, Output 1
Eighth Order, Output 2

INTERCONNECTION OF SYSTEMS .....
A Big System
! Randomly Connect seven Systems together
Titles of Systems to be Combined
Title 1 Fourth Order System
Title 2 Eighth Order System
Title 3 Fourteenth Order System (3 Systems Combined)
Title 4 Two Systems in Series (12th Order)
Title 5 32nd Order
Title 6 32nd Order
Title 7 Fourteenth Order System (3 Systems Combined)
SYSTEM INPUTS DIRECT TO SYSTEM OUTPUTS
System Input 1 to System Outpt 3, Gain=   2.0000
System Input 2 to System Outpt 1, Gain=   1.0000
....
SYSTEM INPUTS TO SUBSYSTEM 1   FOURTH ORDER SYSTEM
System Input 5 to Subsystem 1, Input 2, Gain=   1.0000
System Input 3 to Subsystem 1, Input 1, Gain=   2.0000
System Input 1 to Subsystem 1, Input 2, Gain=   1.0000
....
SYSTEM INPUTS TO SUBSYSTEM 7   Fourteenth Order System (3 Systems Combined)
Via Matrix +I2   Size (2 x 2)
....
SYSTEM INPUTS TO SUBSYSTEM 2   EIGHTH ORDER SYSTEM
System Input 2 to Subsystem 2, Input 1, Gain=   2.0000
System Input 3 to Subsystem 2, Input 2, Gain=   2.0000
System Input 5 to Subsystem 2, Input 2, Gain=   2.0000
....
SYSTEM INPUTS TO SUBSYSTEM 4   TWO SYSTEMS IN SERIES (12TH ORDER)
System Input 4 to Subsystem 4, Input 1, Gain=   2.0000
System Input 5 to Subsystem 4, Input 2, Gain=   2.0000
System Input 2 to Subsystem 4, Input 1, Gain=   2.0000
....
SYSTEM INPUTS TO SUBSYSTEM 5   32ND ORDER
System Input 1 to Subsystem 5, Input 4, Gain=   2.0000
System Input 5 to Subsystem 5, Input 8, Gain=   2.0000
System Input 3 to Subsystem 5, Input 2, Gain=   2.0000
....
SYSTEM INPUTS TO SUBSYSTEM 6   32ND ORDER
System Input 2 to Subsystem 6, Input 6, Gain=   1.0000
System Input 3 to Subsystem 6, Input 7, Gain=   2.0000
System Input 4 to Subsystem 6, Input 3, Gain=   3.0000
....
SYSTEM OUTPUTS FROM SUBSYSTEM 3   FOURTEENTH ORDER SYSTEM (3 SYSTEMS COMBINED)
System Output 5 from Subsystem 3, Output 2, Gain=   2.0000
System Output 2 from Subsystem 3, Output 1, Gain=   1.0000
System Output 4 from Subsystem 3, Output 2, Gain=   5.0000
System Output 1 from Subsystem 3, Output 1, Gain=   2.0000
....

31

```
SYSTEM OUTPUTS FROM SUBSYSTEM  5   32ND ORDER
System Output  3 from Subsystem  5, Output  6, Gain=   1.0000
System Output  5 from Subsystem  5, Output  8, Gain=   1.0000
System Output  4 from Subsystem  5, Output  3, Gain=   1.0000
.................................................................
SYSTEM OUTPUTS FROM SUBSYSTEM  6   32ND ORDER
System Output  1 from Subsystem  6, Output  7, Gain=   1.0000
System Output  2 from Subsystem  6, Output  5, Gain=   1.0000
System Output  5 from Subsystem  6, Output  2, Gain=   1.0000
.................................................................
SUBSYSTEM NO  1 GOES TO SUBSYSTEM NO  3
Subsystem  1, Output  1 to Subsystem  3, Input  1, Gain=   1.0000
Subsystem  1, Output  2 to Subsystem  3, Input  3, Gain=   1.0000
.................................................................
SUBSYSTEM NO  7 GOES TO SUBSYSTEM NO  5
Subsystem  7, Output  1 to Subsystem  5, Input  1, Gain=   1.0000
Subsystem  7, Output  2 to Subsystem  5, Input  2, Gain=  -1.0000
.................................................................
SUBSYSTEM NO  2 GOES TO SUBSYSTEM NO  5
Subsystem  2, Output  1 to Subsystem  5, Input  2, Gain=   2.0000
Subsystem  2, Output  2 to Subsystem  5, Input  7, Gain=   3.0000
.................................................................
SUBSYSTEM NO  2 GOES TO SUBSYSTEM NO  6
Subsystem  2, Output  1 to Subsystem  6, Input  4, Gain=   1.0000
Subsystem  2, Output  2 to Subsystem  6, Input  8, Gain=   2.0000
.................................................................
SUBSYSTEM NO  3 GOES TO SUBSYSTEM NO  2
Via Matrix -I2                         Size (  2 x  2)
.................................................................
SUBSYSTEM NO  5 GOES TO SUBSYSTEM NO  1
Via Matrix +I2                         Size (  2 x  2)
.................................................................
```

INTERCONNECTION OF SYSTEMS .....
Two Systems Connected with a Gain Matrix
! Combine an eighth order system in series with a fourteenth order system and synthesize
! twenty second order system

```
Titles of Systems to be Combined
Title 1 Eighth Order System
Title 2 Fourteenth Order System (3 Systems Combined)
SYSTEM INPUTS DIRECT TO SYSTEM OUTPUTS
Via Matrix +K2                         Size (  2 x  2)
.................................................................
SYSTEM INPUTS TO SUBSYSTEM  1      Fourth Order System
Via Matrix -I2                         Size (  2 x  2)
.................................................................
SYSTEM OUTPUTS FROM SUBSYSTEM  2   Fourteenth Order System (3 Systems Combined)
Via Matrix -K2                         Size (  2 x  2)
.................................................................
SUBSYSTEM NO  1 GOES TO SUBSYSTEM NO  2
Via Matrix -Kg                         Size (  3 x  2)
.................................................................
```

32

SYSTEM OF TRANSFER FUNCTIONS ...
4/(s^2 +2s +4)*exp(-sT) (b)
! This is a second order low pass filter with a cut-off frequency of 2 (rad/sec) in series with a
! one second Pade delay approximation.
Continuous
TF. Block # 1 Low Pass Filter (2 rad/sec bandwidth)   Order of Numer, Denom= 0 2
Numer 0.0   0.0   4.0
Denom 1.00000   2.00000   4.00000
TF. Block # 2 Delay (sec)= 1.00000   Order of Numer, Denom= 1 1
....
Outpt #, from Input #, Gain
     1   1   0.1000000   {Combined System Outp} from {Low Pass Filter Inpu}
....
Block #, from Input #, Gain
     1   1   1.000000   {TF: 1, Low Pass Fil} from {Low Pass Filter Inpu}
....
Outpt #, from Block #, Gain
     1   2   1.000000   {Combined System Outp} from {TF: 2, Delay (sec)=}
....
Block #, from Block #, Gain
     2   1   1.000000   {TF: 2, Delay (sec)=} from {TF: 1, Low Pass Fil}
....
Definitions of Inputs =   1
Low Pass Filter Input

Definitions of Outputs =   1
Combined System Output

SYSTEM OF TRANSFER FUNCTIONS ...
Fifth Order System of 3 Transfer Functions
! This System consists of three transfer functions in feedback configuration
Continuous
TF. Block # 1 Second Order (a)   Order of Numer, Denom=   2 2
Numer 1.0   1.0   3.0
Denom 1.0   2.0   5.0
TF. Block # 2 Second Order (b)   Order of Numer, Denom=   2 2
Numer 1.0   0.5   2.0
Denom 1.0   4.0   6.0
TF. Block # 3 First Order   Order of Numer, Denom=   1 1
Numer 1.0   1.0
Denom 1.0   4.0
....
Block #, from Input #, Gain
   1   1   1.000000   {TF: 1, Second Order} from {Combined System Inpu}
   2   2   1.000000   {TF: 2, Second Order} from {Combined System Inpu}
....
Outpt #, from Block #, Gain
   1   2   1.000000   {Combined System Outp} from {TF: 2, Second Order}
   2   3   1.000000   {Combined System Outp} from {TF: 3, First Order }
....
Block #, from Block #, Gain
   2   1   1.000000   {TF: 2, Second Order} from {TF: 1, Second Order}
   3   2   1.000000   {TF: 3, First Order } from {TF: 2, Second Order}
   1   3 -4.000000   {TF: 1, Second Order} from {TF: 3, First Order }
....
Definitions of Inputs =   2
Combined System Input 1
Combined System Input 2

Definitions of Outputs =   2
Combined System Output 1
Combined System Output 2


```
INTERCONNECTION OF SYSTEMS .....
Another System Combination
! Combine three systems together from above
!
Titles of Systems to be Combined
Title 1 Fourth Order System
Title 2 Eighth Order System
Title 3 Fifth Order System of 3 Transfer Functions
SYSTEM INPUTS DIRECT TO SYSTEM OUTPUTS
System Input  1 to System Outpt  2, Gain=  0.10000
System Input  2 to System Outpt  1, Gain=  0.20000
...................................................................
SYSTEM INPUTS TO SUBSYSTEM  1     Fourth Order System
System Input  1 to Subsystem  1, Input  2, Gain=   1.0000
System Input  2 to Subsystem  1, Input  1, Gain=   1.3400
...................................................................
SYSTEM INPUTS TO SUBSYSTEM  2     Eighth Order System
Via Matrix +I2                         Size (  2 x  2)
...................................................................
SYSTEM OUTPUTS FROM SUBSYSTEM  2   Eighth Order System
System Output  2 from Subsystem  2, Output  1, Gain=   2.0000
System Output  1 from Subsystem  2, Output  2, Gain=   1.5670
...................................................................
SUBSYSTEM NO  1 GOES TO SUBSYSTEM NO  2
Subsystem  1, Output  1 to Subsystem  2, Input  1, Gain=   2.0000
Subsystem  1, Output  1 to Subsystem  2, Input  2, Gain=   2.3456
Subsystem  1, Output  2 to Subsystem  2, Input  2, Gain=   1.2345
...................................................................
SUBSYSTEM NO  2 GOES TO SUBSYSTEM NO  3
Via Matrix -I2                         Size (  2 x  2)
...................................................................
SUBSYSTEM NO  3 GOES TO SUBSYSTEM NO  1
Via Matrix -I2                         Size (  2 x  2)
...................................................................
Definitions of Inputs  =   2
Combined System Input 1
Combined System Input 2

Definitions of Outputs =   2
Combined System Output  1
Combined System Output  2
------------------------------------------------------------------------------------------
```

Let us now process this file by running the batch set which is located on the top of the input file. First select the directory, and from the Flixan main menu select "*File Management*", then "*Manage Input Files*", and then "*Edit/ Process Input Data Files*", as shown.
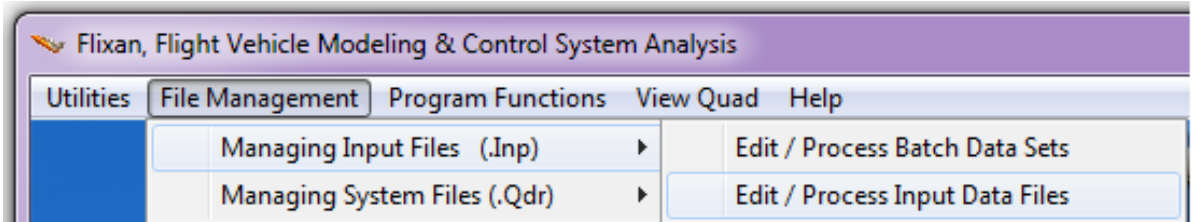
The input data file manager dialog comes up that has two menus. From the left menu select the input file "*Comb_tst.Inp*" and click on "Select Input File". The menu on the right side shows the titles of the data-sets located in this file, also the program that will process each set. They are mainly system and transfer-function interconnection sets. Select the first title which is the batch set and it will process the remaining data-sets in batch (non-interactively). Click on "*Process Input Data*", and the batch set will process the input file and save the systems in file " *Comb_tst.Qdr*".

Managing Input Data Files

To Manage an Input Data File, Point to the
Filename and Click on "Select Input File"

Comb_tst.Inp

- Comb_tst.Inp
- CTST.INP
- ROCK.INP
- Rulv.Inp
- TF-Test.Inp

Select Input File
Edit Input File
Process Input Data
Delete Data Sets in File
Relocate Data Set in File
Copy Set to Another File
View Data-Set Comments

Exit

The following Input Data Sets are in File: Comb_tst.Inp

```
Run Batch Mode    : Systems Interconnection Testing Batch
Transf-Functions : (s^2 +2s +16)/(s^2 +5s +25)
Transf-Functions : 4/(s^2 +2s +4)
Transf-Functions : 4/(s^2 +2s +4)*exp(-sT)
System Connection: Fourth Order System
System Connection: Eighth Order System
System Connection: 32nd Order
System Connection: Fourteenth Order System (3 Systems Combined)
System Connection: Two Second Order Transfer Functions Connected in Parallel
System Connection: Two Systems in Series (12th Order)
System Connection: A Big System
System Connection: Two Systems Connected with a Gain Matrix
Transf-Functions : 4/(s^2 +2s +4)*exp(-sT) (b)
Transf-Functions : Fifth Order System of 3 Transfer Functions
System Connection: Another System Combination
```

Replace Systems File?

The systems filename: Comb_tst.Qdr
already exists. Do you want to create it again?

Yes   No

Comments, Data-Set User Notes

A Batch Set used for generating and connecting systems together for demo purposes. It first retains two matrices in the systems file that will be used later in the connections. Then it generates two second order systems from Transf-Functions. Then a second order with 1 sec delay. Then it combines the two 2nd order systems together to create a 4th order system. Then it combines two identical 4th order systems in series to create an 8th order system. Then it combines four of these 8th order systems in parallel to create a 32nd order system. Then it creates a 14th order system by combining 3 of the above systems (2nd, 4th, and 8th). Then we create a system by combining two different 2nd order Transf-Functions in parallel. We also create a big system of 116 states, 5 inputs and 5 outputs by combining seven of the above systems together. We also combine the 14th order with the 8th order systems via gain matrix

Managing Input Data Files

To Manage an Input Data File, Point to the
Filename and Click on "Select Input File"

Comb_tst.Inp

- Comb_tst.Inp
- CTST.INP
- ROCK.INP
- Rulv.Inp
- TF-Test.Inp

Select Input File

Exit

The following Input Data Sets are in File: Comb_tst.Inp

```
Run Batch Mode    : Systems Interconnection Testing Batch
```

Batch Mode Execution

```
Retain Matrix    : (3x2) Gain Connection matrix
Retain Matrix    : (2x2) Gain Connection matrix
Transf-Functions : (s^2 +2s +16)/(s^2 +5s +25)
Transf-Functions : 4/(s^2 +2s +4)
Transf-Functions : 4/(s^2 +2s +4)*exp(-sT)
System Connection: Fourth Order System
System Connection: Eighth Order System
System Connection: 32nd Order
System Connection: Fourteenth Order System (3 Systems Combined)
System Connection: Two Second Order Transfer Functions Connected in Parallel
System Connection: Two Systems in Series (12th Order)
System Connection: A Big System
System Connection: Two Systems Connected with a Gain Matrix
Transf-Functions : 4/(s^2 +2s +4)*exp(-sT) (b)
Transf-Functions : Fifth Order System of 3 Transfer Functions
System Connection: Another System Combination
```

Comments, Data-Set User Not

A Batch Set used for genera... ...ons. Then it
generates two second order s... ...system. Then
it combines two identical 4th order systems in series to create an 8th order system. Then it combines four of these 8th order systems in parallel to create a 32nd order system. Then it creates a 14th order system by combining 3 of the above systems (2nd, 4th, and 8th). Then we create a system by combining two different 2nd order Transf-Functions in parallel. We also create a big system of 116 states, 5 inputs and 5 outputs by combining seven of the above systems together. We also combine the 14th order with the 8th order systems via gain matrix

A display pops up temporarily while the batch is executing that shows the batch commands, as shown above. The currently executing command is highlighted for debugging purposes in case of errors. Notice that the batch includes two commands to retain and copy two matrices from the original file to the new file because the matrices are used in the interconnections. Otherwise, the old data in the systems file are erased and replaced with new data.

2.0 Transfer Functions Combination Program

The transfer functions combination program is a Flixan utility that can be used to combine several transfer function blocks together in a state-space system form. The combined state-space system is saved in a systems file. The program uses two data files, an input data file (.Inp) and a systems file (.Qdr). The input data file includes the transfer functions to be combined, the transfer function interconnections, and the definitions of the combined system's input and output variables. The interconnection instructions describe how the transfer functions are to be connected together by the program, and to the system inputs and outputs. The combined TF system is saved in the systems file. There is also an interactive Graphics/ User interface (GUI) utility included that helps the user to enter the transfer-function interconnection data in the input file or to read the interconnections from the file graphically without editing the file directly. Figure (2.1) shows the interaction between the transfer functions combination program, the GUI, the user, and the data files.
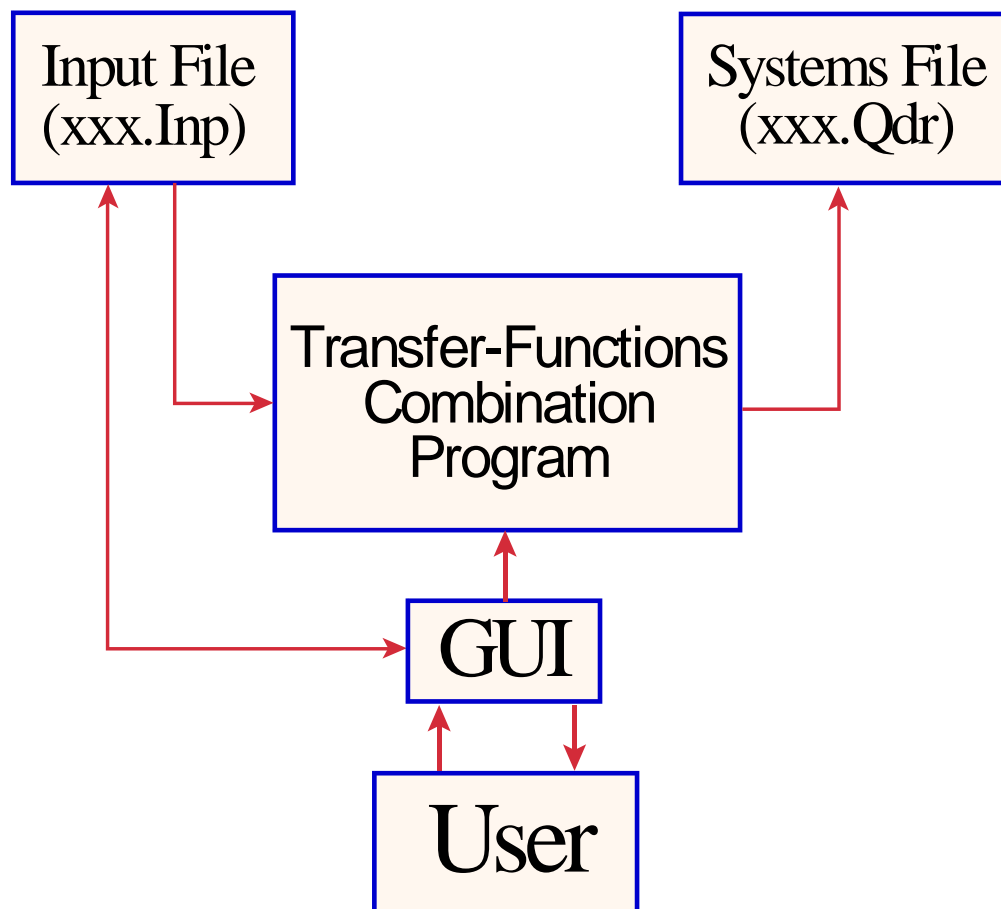
Figure (2.1) Diagram of the Transfer-Functions Interconnection Utility Program showing its interaction with the User and the Input/ Output Files

36

2.1 Program and Input/ Output Files Selection

The transfer functions combination program can be selected from the Flixan main menu by clicking on the "*Program Functions*", select the "*Creating and Modifying Linear Systems*" group, and then click on "*Combine Transfer-Functions to State Systems*". Then use the following file selection dialog to select the input data file and the systems file from the menus, as shown below. The two files are selected from a filenames selection menu.

Transfer Functions Interconnection data-set in the input file (.Inp)

TF interconnection data-sets contain the transfer functions interconnection instructions and they are located in input files (.Inp). A typical data-set for interconnecting three transfer function blocks together is shown below.

```
SYSTEM OF TRANSFER FUNCTIONS ...
3 Blocks Interconnection Test
! Comment lines for the new system
! This system is obtained by combining 3 TF blocks
!
Continuous
TF. Block #  1 (s2+3s=2)/(s2+2s+0.75)                    Order of Numer, Denom=  2  2
Numer 1.00000     3.00000     2.00000
Denom 1.00000     2.00000     0.750000
TF. Block #  2 1/(s+5)                                    Order of Numer, Denom=  0  1
Numer 0.00000     1.00000
Denom 1.00000     5.00000
TF. Block #  3 (s3+5s2+6.75s+2.25)/(s3+3.4s2+3.2s+0.8)   Order of Numer, Denom=  3  3
Numer 1.00000     5.00000     6.75000     2.25000
Denom 1.00000     3.40000     3.20000     0.800000
--------------------------------------------------------------------------
Block #, from Input #, Gain
     1             2         1.00000
     2             1         1.00000
     3             3         1.00000
..........................
Block #, from Block #, Gain
     2             1         0.37500
..........................
Outpt #, from Block #, Gain
     1             2         5.00000
     2             3         0.35555
     2             1         0.133333
..........................
Outpt #, from Input #, Gain
     1             1         0.001
     2             1         0.355555
..........................
Definitions of Inputs  =   3
System Input 1 to Block 2
System Input 2 to Block 1
System Input 3 to Block 3

Definitions of Outputs =   2
System Output 1 from Block 2
System Output 2 from Blocks 1 and 3
-----------------------------------------------------------------------------
```

At the top of the data-set there is a line describing the type of data following in order to identify the program that will process the data. In this case it is a system of transfer-functions interconnection. This is because the input file does not only contain transfer functions combination data for this program but it may also contain data-set for other Flixan programs (such as, for example, systems combination data, flight vehicle modeling, actuator, etc). In the second line we have the title for the new system to be created. It will not be a transfer function but it will be in state-space form. The next few lines below the title beginning with (!) are comment lines for documentation purposes which describe the new system and they are optional. The comment lines will be copied in the systems file below the new system title.

The next line defines if the transfer functions and subsequently the new system to be created are "Continuous" (s-plane), or "Discrete" (z-plane). If the TF are discrete the sampling period is also included in (seconds). For example, "*Discrete, dT= 0.04*". The following lines define the transfer function blocks. Each block is assigned a TF block number and a short description title. The numerator and denominator orders of each TF are shown at the right end of the line. Below each TF title, in the

next two lines, the numerator and denominator coefficients are included in descending order. The order of each transfer function should not exceed 5. To include higher order TFs you must combine smaller blocks in series. The lines below the transfer functions define the interconnections. That is, how the TF blocks are connected together and with the system inputs and outputs. Similar to the systems interconnection utility there are four types of interconnection instructions.

1. Direct connections from the system inputs to the system outputs which define the direct feed-through matrix D, (*Output #, from Input #, Gain*), followed with the detailed direct connections and gains between system inputs to system outputs.
2. Connections between the system inputs to TF blocks, (*Block #, from Input #, Gain*), followed with detailed connections and gains between inputs and blocks.
3. Connections between transfer function outputs and the system outputs, (*Output #, from Block #, Gain*), followed with detailed connections and gains between TF blocks and outputs.
4. Connections between the TF blocks, (*Block #, from Block #, Gain*), followed with detailed connections and gains.

In the TF interconnections data, the blocks to be combined are referred to by their block numbers. At the bottom of the data set the user may include definition labels of the new system's inputs and outputs. The input and output definitions are optional. If they are not included the program assigns default labels, such as, "*System Input 1*", etc. An experienced user can easily create by copying and pasting a TF interconnections data-set in the input file by using a standard text editor. There is, however, a GUI capability in the program that makes it easier for the user to generate the interconnections set by using menus and dialogs. The GUI helps entering the title, selecting and defining the transfer-functions to be combined, entering the TF interconnections, the new system input and output labels, and the user comments. It also provides text editing capability to modify the input data. The GUI will also save the TF interconnections in the input data file, and run the TF program to create the combined system in file (.Qdr).

Systems File

The systems file (with an extension Qdr) contains state-space systems and matrices generated by Flixan. The program reads the transfer function interconnection data, combines them together, saves the combined system at the bottom of the systems file without destroying the already existing data. The system title is the same as in the TF interconnections data in the input file. The lines below the title starting with (!) are comments copied from the TF set. The length of the title and length each comment line should be less than 100 characters long. The following line defines the system dimension and sample rate (0 if continuous).

2.2 Creating a New Transfer-Functions Interconnection Set Interactively

If the transfer function interconnection data have not been created yet in the input file the program will obtain the interconnections from the user interactively using a GUI dialog. In the example that follows we will use the TF program to combine a system of transfer-function blocks together and to create a TF interconnections set in file "*TF-Test.Inp*". Then we will process this data-set using the transfer-functions interconnection program to generate a state-space system that will be saved in systems file "*TF-Test.Qdr*". This TF system is a Shuttle lateral flight control system, shown in Figure (2.2), and the example files are located in folder "*C:\Flixan\Comb_Trfn\Examples*".
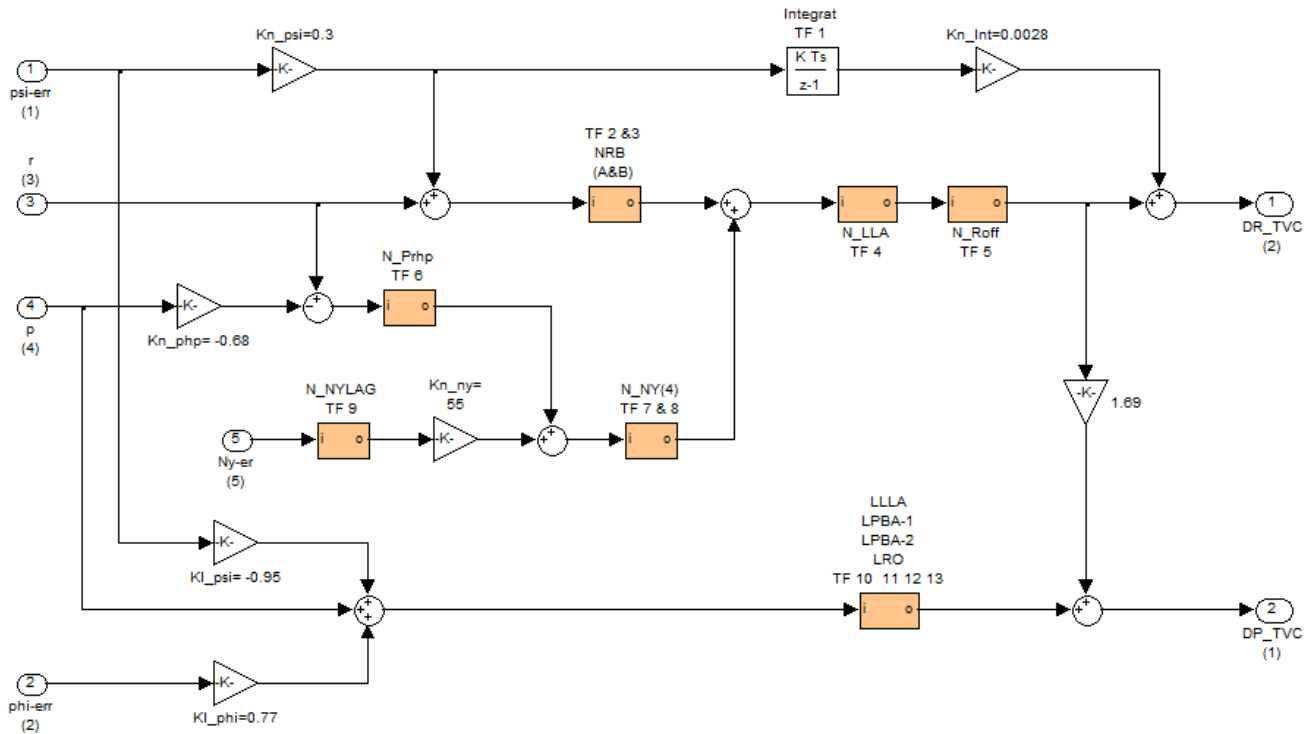
Figure (2.2) Shuttle Ascent Lateral Flight Control System

So let us begin the transfer-functions combination program starting from the Flixan main menu, click on "*Program Functions*", select "*Creating and Modifying Linear Systems*", and then "*Combine Transfer-Functions to State Systems*". From the following file selection menu select an input data file and the systems file, as shown below, and then click on "*Create a New Input Set*" to begin the interactive TF interconnections process.
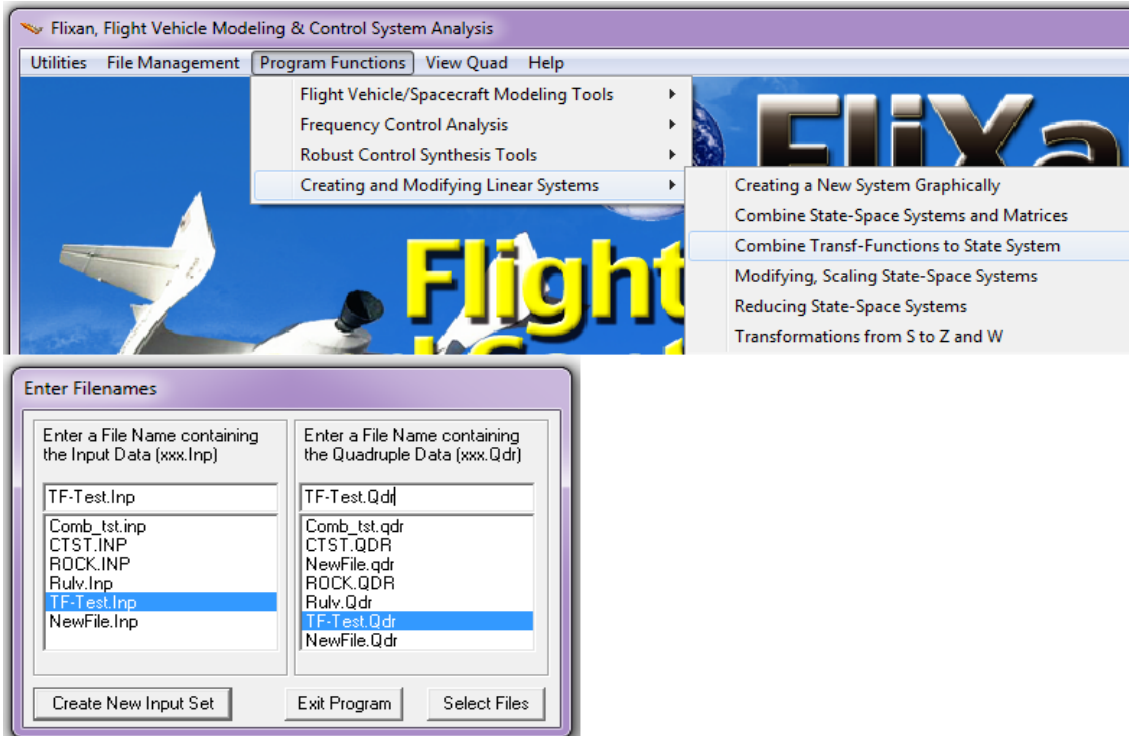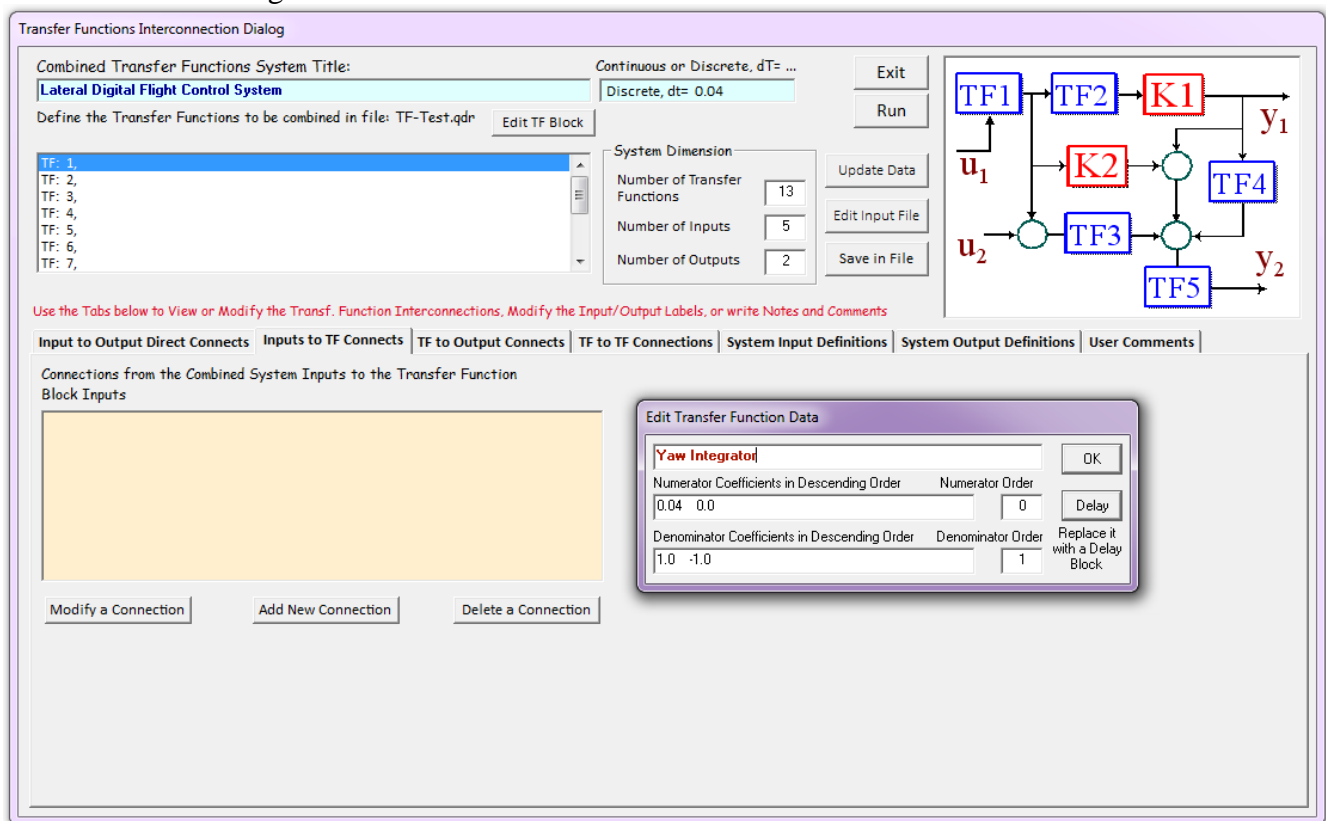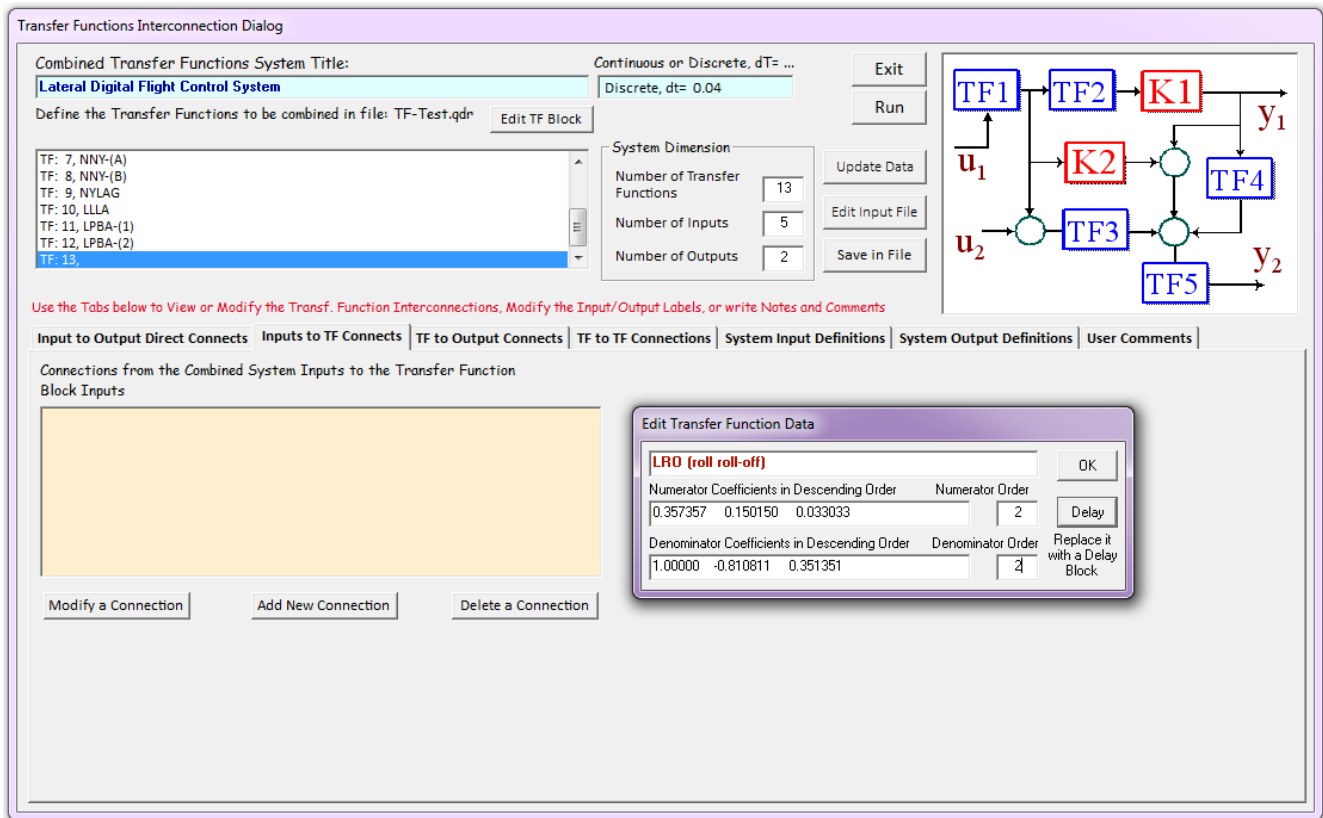
The transfer functions interconnection GUI dialog will then appear where the user will enter the TF data for this example. You must first enter a title for the combined system "*Lateral Digital Flight Control System*", the number of transfer functions to be combined (13), the sampling time (sec) if the transfer-functions are defined in the z-plane, in this case enter: "*Discrete, dT= 0.04*", otherwise "*Continuous*" if the transfer-functions are in the s-plane. Then enter the number of inputs (2) and the number of outputs (2) in the new system. Each TF is automatically assigned a number used for interconnection referencing. After entering the top level data click on the "*Update Data*" button to update the data internally. You must update the data every time you change tabs. Do not save the data in file yet, you must save it at the end.
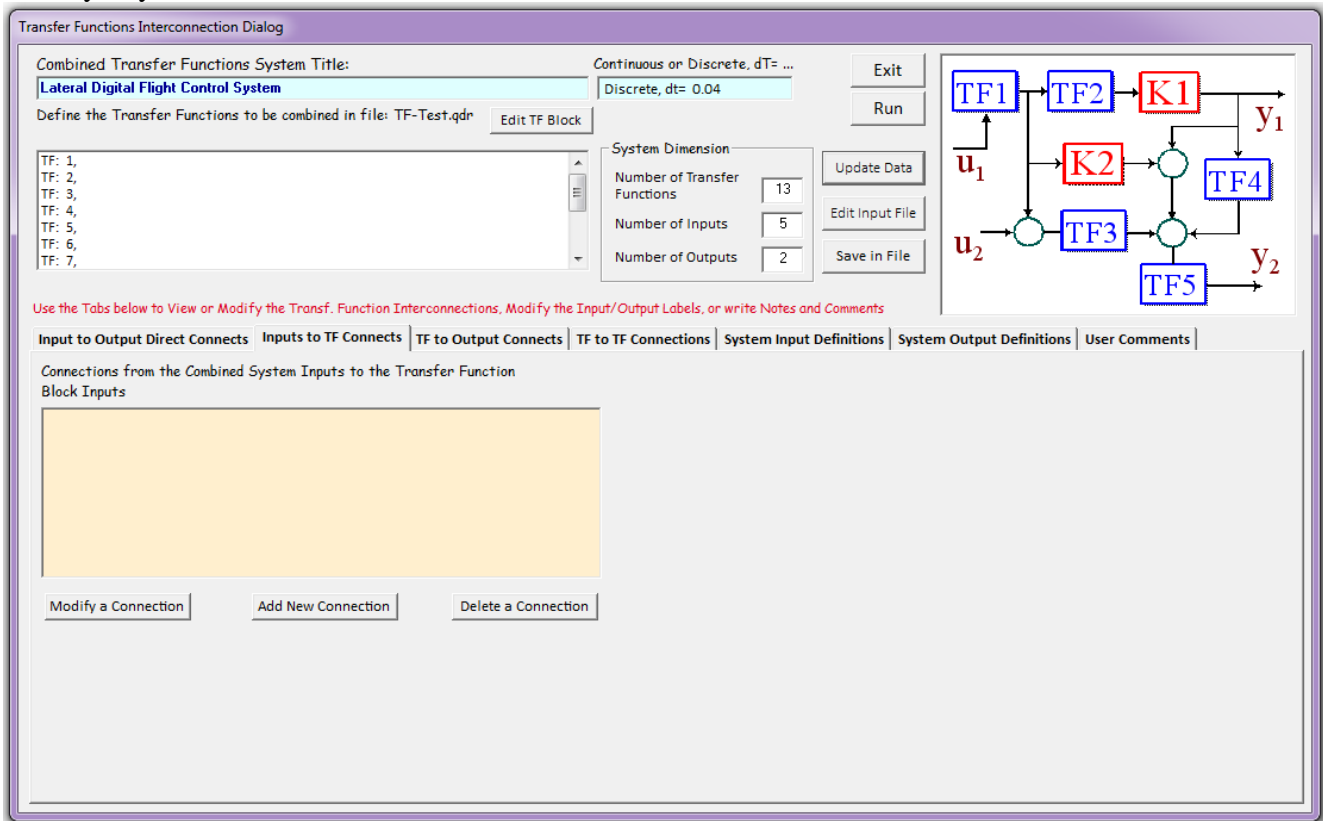
The dialog has several tabs for entering the four different groups of interconnection data between inputs, outputs, and transfer-functions, already discussed, definitions of the new system inputs and outputs, and user notes/ comments about this TF system. The TF interconnections are not shown in block diagram form like in Simulink. It is assumed that the user has already a block diagram drawing of the combined system to implement. The TF block diagram is defined by individual connections between the TF, the inputs, and outputs. The connections are defined using the first four tabs by the "from" and "to" numbers of the: TF, inputs, and outputs, and by the "Gain" in between, as already seen in the input data-set. Once the interconnection set is "saved in file" the user may either process the data set by clicking on "Run", or modify some of the info and save it under a different title in the same input data file and run the modified version. It is also possible to edit the data directly from the GUI dialog by clicking on "*Edit Input File*". A text editor comes up where the user can edit the input data file (.Inp) and save it before running it.

Defining the TF blocks: The next thing to do is to enter the data for the 13 TF blocks defined above. The transfer function blocks are listed in the white menu below the title and they are initially blank. When starting with a new system this window is empty and the user must define the transfer function data and titles. Up to 40 transfer functions blocks may be included in that list and each transfer function must be 5th order or less. At this point the dialog expects us to define the 13 TF coefficients and to identify each one with a short label. Let us select the first TF from the menu and click on "*Edit TF Block*" to define the transfer function data and title. A transfer function data entry form comes up and the user defines the transfer function title and its coefficients. The TF may also be defined as a Pade delay approximation by entering the delay time in (sec) and the order of the Pade approximation. In this case we enter an integrator for the first TF and click OK. We also enter a short title "yaw Integrator". Similarly we define the remaining of the TF blocks, one at a time. The last one shown is TF:13, "*LRO (roll axis roll-off)*". The transfer-function titles are gradually appearing in the white menu as they get updated. We may now begin entering the interconnections. Click on the "Update Data" button before entering the tabs.

42

Transfer Functions Interconnection Dialog

Combined Transfer Functions System Title:
Lateral Digital Flight Control System

Continuous or Discrete, dT= ...
Discrete, dt= 0.04

Exit
Run

Define the Transfer Functions to be combined in file: TF-Test.qdr   Edit TF Block

TF: 7, NNY-(A)
TF: 8, NNY-(B)
TF: 9, NYLAG
TF: 10, LLLA
TF: 11, LPBA-(1)
TF: 12, LPBA-(2)
TF: 13,

System Dimension
Number of Transfer Functions   13
Number of Inputs   5
Number of Outputs   2

Update Data
Edit Input File
Save in File

TF1 → TF2 → K1
u₁   K2   TF4
u₂   TF3
TF5
y₁
y₂

Use the Tabs below to View or Modify the Transf. Function Interconnections, Modify the Input/Output Labels, or write Notes and Comments

Input to Output Direct Connects | Inputs to TF Connects | TF to Output Connects | TF to TF Connections | System Input Definitions | System Output Definitions | User Comments

Connections from the Combined System Inputs to the Transfer Function
Block Inputs

Edit Transfer Function Data

LRO (roll roll-off)   OK

Numerator Coefficients in Descending Order   Numerator Order
0.357357   0.150150   0.033033   2   Delay

Denominator Coefficients in Descending Order   Denominator Order   Replace it with a Delay Block
1.00000   -0.810811   0.351351   2

Modify a Connection   Add New Connection   Delete a Connection

Direct Connections from System Inputs to System Outputs: The first tab on the left is for defining direct connections from the system inputs to the system outputs without connecting to the TF blocks. It defines the direct feed-through matrix (D) in the state-space representation. In this example we do not have any direct connections between the system inputs and outputs. However, the tab includes a menu on the left side that has a title "*Direct Connections from the Combined System Inputs to the Combined System Outputs*". The buttons below the menu are used for adding a new connection, deleting, or modifying an already existing connection. If you click on the "*Add a Connection*" button a couple of white menus appear on the right used for defining the interconnection. The menu on the left shows the titles of the combined system inputs and the menu on the right shows the combined system outputs. Default names are used, such as "*System Input 1*", if descriptive names have not yet been defined. Connections must be defined one at a time by selecting one item from each menu, entering the gain, and clicking "OK". No matrix interconnections. The two white menus on the right disappear, and interconnection defined appears in the left menu, one at a time, for example, "*Input 1 goes to Output 2, Gain=5.2*". We may now go to the second tab.

Connections from System Inputs to Transfer Function Blocks: The second tab is for defining connections from the system inputs to the TF block inputs, and it is very similar to the first tab. There is a menu on the left that has a title "*Connections from the Combined System Inputs to the Transfer Function Inputs*". The interconnections are eventually included in this menu, for example, "*Input 1 {Command} goes to T.F. #2 {Integrator}, Gain=3.2*", but initially when there are no connections defined this menu is blank. There are buttons below the menu for adding a new connection, deleting, or modifying an already existing connection. You may click on "*Add a Connection*" and a couple of menus appear on the right having a title "*Define Connections from the Combined System Inputs to Transfer Function Inputs*". The menu on the left shows the titles of the combined system inputs, and the menu on the right shows the titles and numbers of the transfer function blocks. The TF data and

43

titles are already defined. You can only select one item from each menu which defines a scalar connection between one of the system inputs to one of the transfer functions. Begin by selecting "*System Input 1*" from the left menu and "*TF: 1, Yaw Integrator*" from the right menu. Enter a gain of 0.3 below, and click on "OK" to submit it. The two white menus on the right disappear and the interconnection that you defined appears in the left menu as follows: "*Input 1 {system input 1} goes to T.F. #1 {yaw integrator}, Gain=0.3*". Click on "*Add a Connection*" button again to define more connections between system inputs and TF blocks, as shown below. The menu on the left gradually begins to fill with input to TF connections as shown. When you finish with the connections click on the "*Update Data*" button and go to the next tab.

System Inputs to Transfer-Function Connections

Connections from Transfer Function Blocks to System Outputs: The third tab is for defining connections from TF block outputs to the combined system outputs and it is very similar to the previous tabs. There is a menu on the left that has a title "*Connections from Transfer Function Outputs to the Combined System Outputs*". The interconnections are eventually included in this menu, for example, "*T.F. #2 {low-pass} goes to Output #3 {Gimbal Command}, Gain=5.2*", but initially when there are no connections defined this menu is blank. There are buttons below the menu for adding new connections, and for deleting, or modifying already existing connections. You may click on "*Add a Connection*" and a couple of white menus appear on the right having a title "*Define Connections from Transfer Function Outputs to the Combined System Outputs*". The menu on the left shows the titles and numbers of the "from" transfer function blocks and the menu on the right shows the titles and numbers of the system outputs. The TF data and titles are already defined. You can only select one item from each menu which defines a scalar connection between one of the transfer functions to one of the system outputs. Begin by selecting "*TF: 1, Yaw Integrator*" from the left menu and "*System Output 2*" from the right menu. Enter a gain of 0.00028 below, and click on "OK" to accept it. The two white menus on the right disappear and the interconnection that you defined appears in the left menu as follows: "*T.F. #1 {yaw integrator} goes to Output #2 {system output 2}, Gain=0.28e-3*". Click on "*Add a Connection*" button again to define more connections between TF blocks and system outputs, as shown below. You may also use the "*Modify a Connection*" or "*Delete a Connection*" buttons in case of errors. The menu on the left gradually begins to fill with TF to output connections, as shown below. When you finish with the connections click on the "*Update Data*" button and go to the next tab.

Connections between Transfer Function Blocks: The fourth tab is also similar to the previous tabs and it is used for defining connections from TF block outputs to other TF blocks, or a feedback loop around the same TF block. There is a menu on the left side with a title "*Connections from Transfer Function Outputs to Transfer Function Inputs*". The interconnections between TF's are eventually included in this menu, for example, "*T.F. #1 {low-pass} goes to T.F. #2 {Integrator}, Gain=1.5*", but initially when there are no connections defined, this menu is blank. There are buttons below the menu for adding new connections, and for deleting, or modifying an already existing connection. You may click on "*Add a Connection*" and a couple of white menus appear on the right having a title "*Define Connections from Transfer Function Outputs Connecting to Transfer Function Inputs*". Both menus show the titles and numbers of the transfer function blocks as they are already defined. You can only select one item from each menu which defines a scalar connection between the two transfer functions. Begin by selecting "*TF: 2, NRB-(A)*" from the left menu and "*TF: 3, NRB-(B)*" from the right menu, enter a gain of 1.0 below, and click on "OK" to accept it. The two white menus on the right disappear and the interconnection that you defined appears in the left menu as follows: "*T.F. #2 {NRBB-(A)} goes to T.F. #3 {NRBB-(B)}, Gain=1.0*". Click on "*Add a Connection*" again to define more connections between the TF blocks, as shown below. You may also use the "*Modify a Connection*" or "*Delete a Connection*" buttons in case of an error. The menu on the left gradually begins to fill with TF to TF connections, as shown below. When you finish with this type of interconnections click on the "*Update Data*" button and go to the next tab.

Transfer Functions Interconnection Dialog

Combined Transfer Functions System Title:
Lateral Digital Flight Control System

Continuous or Discrete, dT= ...
Discrete, dt= 0.04

Exit

Run

Define the Transfer Functions to be combined in file: TF-Test.qdr   Edit TF Block

```
TF: 6, NPRHP
TF: 7, NNY-(A)
TF: 8, NNY-(B)
TF: 9, NYLAG
TF: 10, LLLA
TF: 11, LPBA-(1)
TF: 12, LPBA-(2)
```

System Dimension

Number of Transfer Functions   13

Number of Inputs   5

Number of Outputs   2

Update Data

Edit Input File

Save in File

Use the Tabs below to View or Modify the Transf. Function Interconnections, Modify the Input/Output Labels, or write Notes and Comments

| Input to Output Direct Connects | Inputs to TF Connects | TF to Output Connects | TF to TF Connections | System Input Definitions | System Output Definitions | User Comments |

Connections from Transfer Function Block Outputs to the Combined System Outputs

```
T.F. # 1 { Yaw Integrator   } goes to Outp: 2 {System Output 2   }, Gain= 0.2800000E-03
```

Define connections from Transfer Function Outputs

Connecting to the Conbined System Outputs

```
TF: 1, Yaw Integrator
TF: 2, NRB- (A)
TF: 3, NRB-(B)
TF: 4, NLLA
TF: 5, NROFF (yaw roll-off)
TF: 6, NPRHP
TF: 7, NNY-(A)
```

```
System Output 1
System Output 2
```

Select a "From" Transfer Function Block and a System Output that it connects to. Enter also the scalar gain   1.0   OK

Modify a Connection   Add New Connection   Delete a Connection

---

Transfer Functions Interconnection Dialog

Combined Transfer Functions System Title:
Lateral Digital Flight Control System

Continuous or Discrete, dT= ...
Discrete, dt= 0.04

Exit

Run

Define the Transfer Functions to be combined in file: TF-Test.qdr   Edit TF Block

```
TF: 1, Yaw Integrator
TF: 2, NRB- (A)
TF: 3, NRB-(B)
TF: 4, NLLA
TF: 5, NROFF (yaw roll-off)
TF: 6, NPRHP
TF: 7, NNY-(A)
```

System Dimension

Number of Transfer Functions   13

Number of Inputs   5

Number of Outputs   2

Update Data

Edit Input File

Save in File

Use the Tabs below to View or Modify the Transf. Function Interconnections, Modify the Input/Output Labels, or write Notes and Comments

| Input to Output Direct Connects | Inputs to TF Connects | TF to Output Connects | TF to TF Connections | System Input Definitions | System Output Definitions | User Comments |

Connections from Transfer Function Block Outputs to the Combined System Outputs

```
T.F. # 1 { Yaw Integrator   } goes to Outp: 2 {Yaw FCS Demand to TV}, Gain= 0.2800000E-03
T.F. # 5 { NROFF (yaw roll-off} goes to Outp: 2 {Yaw FCS Demand to TV}, Gain=  1.000000
T.F. # 5 { NROFF (yaw roll-off} goes to Outp: 1 {Roll FCS Demand to T}, Gain=  1.690000
```

Define connections from Transfer Function Outputs

Connecting to the Conbined System Outputs

```
TF: 7, NNY-(A)
TF: 8, NNY-(B)
TF: 9, NYLAG
TF: 10, LLLA
TF: 11, LPBA-(1)
TF: 12, LPBA-(2)
TF: 13, LRO (roll roll-off)
```

```
Roll FCS Demand to TVC
Yaw FCS Demand to TVC
```

Select from one of the Transfer-Function Blocks and the System Output that it connects to, Enter also the Gain   1.0   OK

Modify a Connection   Add New Connection   Delete a Connection

Transfer-Function to System Output Connections

Transfer-Function to Transfer-Function Connections

User Comments Tab:

This tab is used for viewing the system comments already entered in the transfer-function interconnections data-set. These are comments and user notes regarding the TF system for documentation purposes. The comment lines begin with (!) and they are below the system title. The comments from the input data are also copied and inserted in the systems data below the title. When starting with a new TF system this display/ tab is also used for entering the new system notes interactively.

System Input and System Output Definition Tabs:

These tabs are used for viewing the system input and output definitions. The system inputs and outputs are defined at the bottom of the TF data-set, in the input file below the TF interconnections data, and they are also copied to the systems file below the quadruple matrices. Initially, when we define a new TF interconnection system interactively the utility assigns default titles for the system inputs and outputs, such as, "*System Output 1*". The tabs may be used to redefine the default input and output names and the user may replace them with more descriptive labels. For example, to change one of the outputs from the menu, select the default label, ex. "*System Output 2*", click on "Edit" button at the bottom, and the default label appears in the field below the menu. Then you can modify the default label in that field to more descriptive name, such as for example: "*Pitch Rate in (deg)*", and press the "*Edit*" button again. The default label will then be changed to the new name. You may then select other variables and repeat. You must also remember to click "*Update Data*" before changing tabs.

Using the Top Buttons "Run", "Exit", "Update Data", "Edit Input", "Save in File"

When the TF interconnections are all defined the user must press the "*Update Data*" button, and then "*Save in File*" to save the new set of TF interconnections in the input data file. If you made a mistake or forgot to include a detail you can always edit the input data file by clicking on "*Edit Input File*". A text editor comes up where the user may edit the input data file (.Inp) and save it before running it. At this point you may run the new set of system interconnections by clicking on the "*Run*" button. The utility will process the TF data and it will create a new state-space system that will be saved at the bottom of the selected systems file. The new system will have the same title and the same comments included as those in the TF interconnection data-set. If for some reason you do not wish to process the data and would like to exit the program without running it, use the "*Exit*" button to return to the Flixan main menu. The TF interconnections set will remain in the input file and you can modify it and run it at some later time.

Transfer Functions Interconnection Dialog

Combined Transfer Functions System Title:

Lateral Digital Flight Control System

Continuous or Discrete, dT= ...

Discrete, dt= 0.04

Exit

Run

Define the Transfer Functions to be combined in file: TF-Test.qdr

Edit TF Block

TF: 6, NPRHP
TF: 7, NNY-(A)
TF: 8, NNY-(B)
TF: 9, NYLAG
TF: 10, LLLA
TF: 11, LPBA-(1)
TF: 12, LPBA-(2)

System Dimension

Number of Transfer Functions — 13

Number of Inputs — 5

Number of Outputs — 2

Update Data

Edit Input File

Save in File

Use the Tabs below to View or Modify the Transf. Function Interconnections, Modify the Input/Output Labels, or write Notes and Comments

Input to Output Direct Connects | Inputs to TF Connects | TF to Output Connects | TF to TF Connections | **System Input Definitions** | System Output Definitions | User Comments

Yaw Attitude Error
Roll Attitude Error
Yaw Rate Error
Roll Rate Error
Lateral Accelerometer

Select an Input from menu and press Edit to modify the Input title at the bottom. Repeat to change other Inputs.

Lateral Accelerometer

Edit

Transfer Functions Interconnection Dialog

Combined Transfer Functions System Title:

Lateral Digital Flight Control System

Continuous or Discrete, dT= ...

Discrete, dt= 0.04

Exit

Run

Define the Transfer Functions to be combined in file: TF-Test.qdr

Edit TF Block

TF: 6, NPRHP
TF: 7, NNY-(A)
TF: 8, NNY-(B)
TF: 9, NYLAG
TF: 10, LLLA
TF: 11, LPBA-(1)
TF: 12, LPBA-(2)

System Dimension

Number of Transfer Functions — 13

Number of Inputs — 5

Number of Outputs — 2

Update Data

Edit Input File

Save in File

Use the Tabs below to View or Modify the Transf. Function Interconnections, Modify the Input/Output Labels, or write Notes and Comments

Input to Output Direct Connects | Inputs to TF Connects | TF to Output Connects | TF to TF Connections | System Input Definitions | **System Output Definitions** | User Comments

Roll FCS Demand to TVC
Yaw FCS Demand to TVC

Select an Output from menu and press Edit to modify the Output title at the bottom. Repeat to change other Outputs.

Roll FCS Demand to TVC

Edit

2.3 Running an Already Existing TF Interconnection Set

It is obviously a lot easier to modify an already existing TF interconnection set using a typical text editor and then process it using the interconnection utility. In this case the transfer-function data are already saved in the input file "*TF-Test.Inp*" and the new system will be saved in file "*TF-Test.Qdr*". This example is located in folder "*C:\Flixan\Comb_Trfn\Examples*". The transfer-functions interconnection program is selected from the Flixan main menu by clicking on the "*Program Functions*", then "*Creating and Modifying Linear Systems*", and then "*Combine Transfer-Functions to State Systems*". Using the filename selection menu, select the input and system filenames and click on "*Select Files*" to process the already existing data. In this case the input data file contains three sets of TF data. The following menu shows the titles of the three interconnection sets in file "*TF-Test.Inp*". The user selects the second set "*Lateral Digital Flight Control System*", and clicks on "*Run Input Set*".
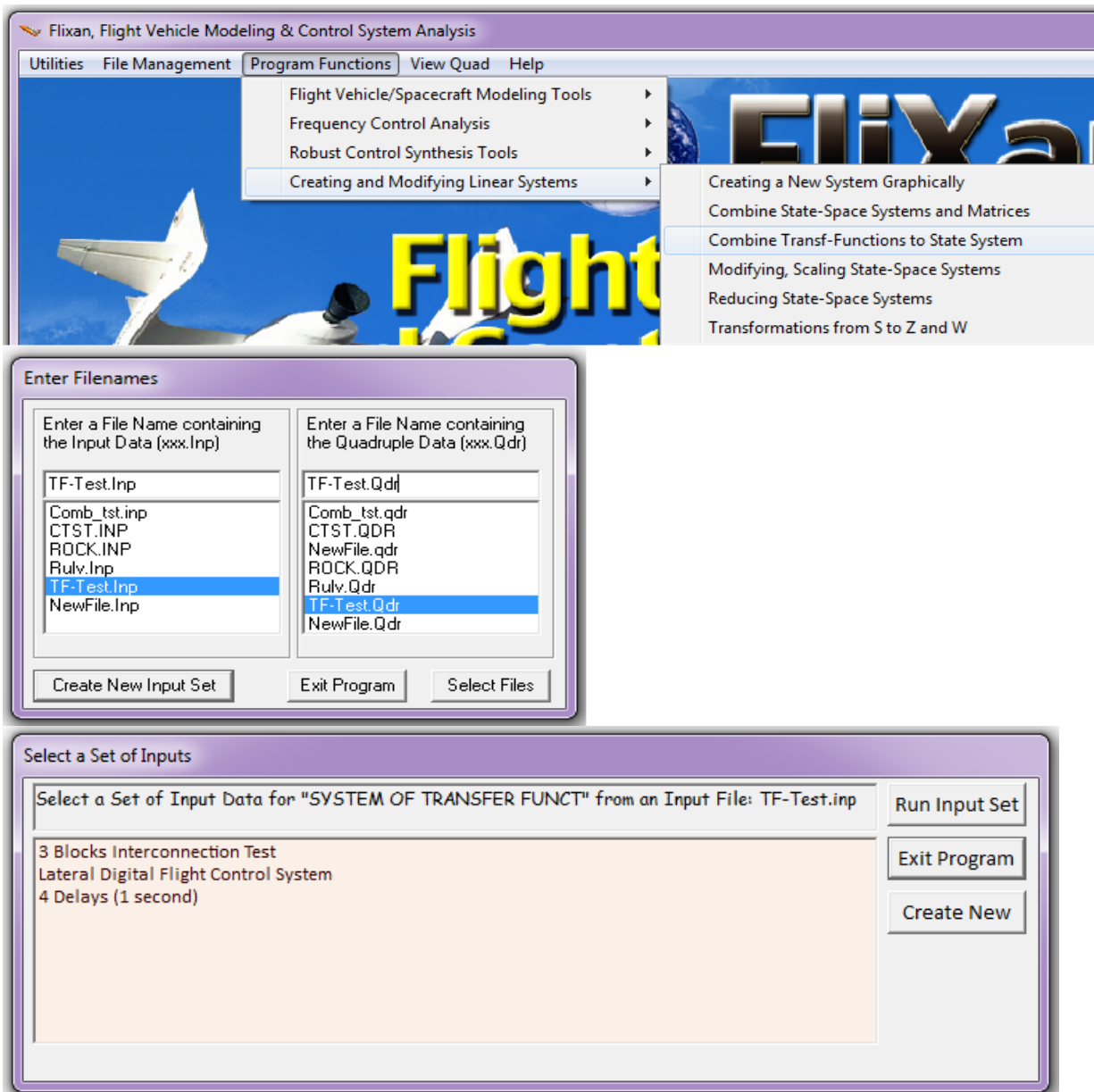
The TF utility dialog below shows the TF interconnection details of the flight-control system as described in Figure (2.2). The interconnections are obtained from the input data set. The system's title is shown at the top and the titles of the 13 transfer-function to be combined are shown in the white menu below the title. This system has 5 inputs and 2 outputs. The transfer functions are defined in the z-domain with 0.04 (sec) sampling time. The interconnection details, input/ output definitions and user comments are shown by selecting in the corresponding tabs. To process the data and to generate the new system you must click on "*Run*". The dialog also provides the capability to edit the input file before processing it by clicking on "*Edit Input File*". The "*Exit*" button will return to the Flixan main menu without processing the data.

The remaining two TF interconnection sets in file "*TF-Test.Inp*" can also be processed in a similar manner, as shown below. To read or edit the transfer functions, select one TF at a time from the menu, and click on "*Edit TF Block*". A small dialog opens up that shows the TF title and the numerator/ denominator coefficients from where they can be modified.

52

Transfer Functions Interconnection Dialog

Combined Transfer Functions System Title:

3 Blocks Interconnection Test

Continuous or Discrete, dT= ...

Continuous

Define the Transfer Functions to be combined in file: NewFile.qdr   **Edit TF Block**

| Exit |
| Run |

```
TF: 1, (s2+3s=2)/(s2+2s+0.75)
TF: 2, 1/(s+5)
TF: 3, (s3+5s2+6.75s+2.25)/(s3+3.4s2+3.2s+0.8)
```

System Dimension

Number of Transfer Functions   3

Number of Inputs   3

Number of Outputs   2
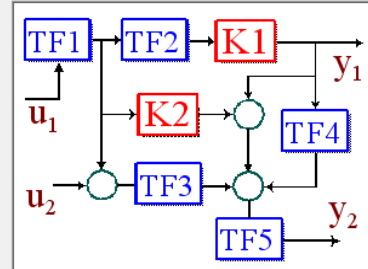
| Update Data |
| Edit Input File |
| Save in File |

Use the Tabs below to View or Modify the Transf. Function Interconnections, Modify the Input/Output Labels, or write Notes and Comments

| Input to Output Direct Connects | Inputs to TF Connects | TF to Output Connects | TF to TF Connections | System Input Definitions | System Output Definitions | User Comments |

Direct Connections from the Combined System Inputs to the Combined System Outputs

```
Input: 1 {System Input 1 to BI} goes to Outp: 1 {System Output 1 from}, Gain= 0.1000000E-02
Input: 1 {System Input 1 to BI} goes to Outp: 2 {System Output 2 from}, Gain= 0.3555550
```

Edit Transfer Function Data

(s3+5s2+6.75s+2.25)/(s3+3.4s2+3.2s+0.8) | OK |

Numerator Coefficients in Descending Order   Numerator Order

1.00000   5.00000   6.75000   2.25000   3 | Delay |

Denominator Coefficients in Descending Order   Denominator Order

1.00000   3.40000   3.20000   0.800000   3   Replace it with a Delay Block

| Modify a Connection | Add New Connection | Delete a Connection |

Transfer Functions Interconnection Dialog

Combined Transfer Functions System Title:

4 Delays (1 second)

Continuous or Discrete, dT= ...

Continuous

Define the Transfer Functions to be combined in file: NewFile.qdr   **Edit TF Block**

| Exit |
| Run |

```
TF: 1, Delay (sec)= 1.00000
TF: 2, Delay (sec)= 1.00000
TF: 3, Delay (sec)= 1.00000
TF: 4, Delay (sec)= 1.00000
```

System Dimension

Number of Transfer Functions   4

Number of Inputs   4

Number of Outputs   4

| Update Data |
| Edit Input File |
| Save in File |
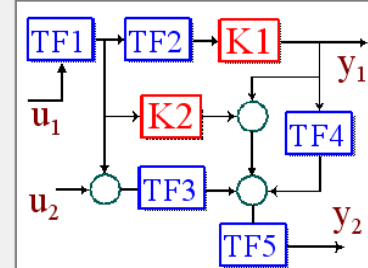
Use the Tabs below to View or Modify the Transf. Function Interconnections, Modify the Input/Output Labels, or write Notes and Comments

| Input to Output Direct Connects | Inputs to TF Connects | TF to Output Connects | TF to TF Connections | System Input Definitions | System Output Definitions | User Comments |

Connections from the Combined System Inputs to the Transfer Function Block Inputs

```
Input: 1 {System Input  1  } goes to T.F.# 1 { Delay (sec)= 1.0000}, Gain= 1.000000
Input: 2 {System Input  2  } goes to T.F.# 2 { Delay (sec)= 1.0000}, Gain= 1.000000
Input: 3 {System Input  3  } goes to T.F.# 3 { Delay (sec)= 1.0000}, Gain= 1.000000
Input: 4 {System Input  4  } goes to T.F.# 4 { Delay (sec)= 1.0000}, Gain= 1.000000
```

Numerator Order   2   Delay in (seconds),

Denominator Order   3   Enter zero for TF   1.00000 | OK |

| Modify a Connection | Add New Connection | Delete a Connection |

This example file can also be processed in batch mode by running the batch set which is located on the top of the input file "*TF-Test.Inp*", as shown below. From the Flixan main menu select "*Edit*", then "*Manage Input Files*" and then "*Process/ Edit Input Data*". The following dialog is used for managing and processing input files. Use the left menu to select the input file "*TF-Test.Inp*" and click on "*Select Input File*". The menu on the right side shows the titles of the data-sets located in this file, also the program that will process each set. The top set is a batch file that will process the remaining three TF sets together in batch, and not interactively. Click on "*Process or View Input Data*", and the batch set will process the data, and save the three systems in file "*TF-Test.Qdr*". The previous systems in this file will be replaced. More transfer-function and system combination examples are located in folder: "*C:\Flixan\Comb_Trfn\Examples*".
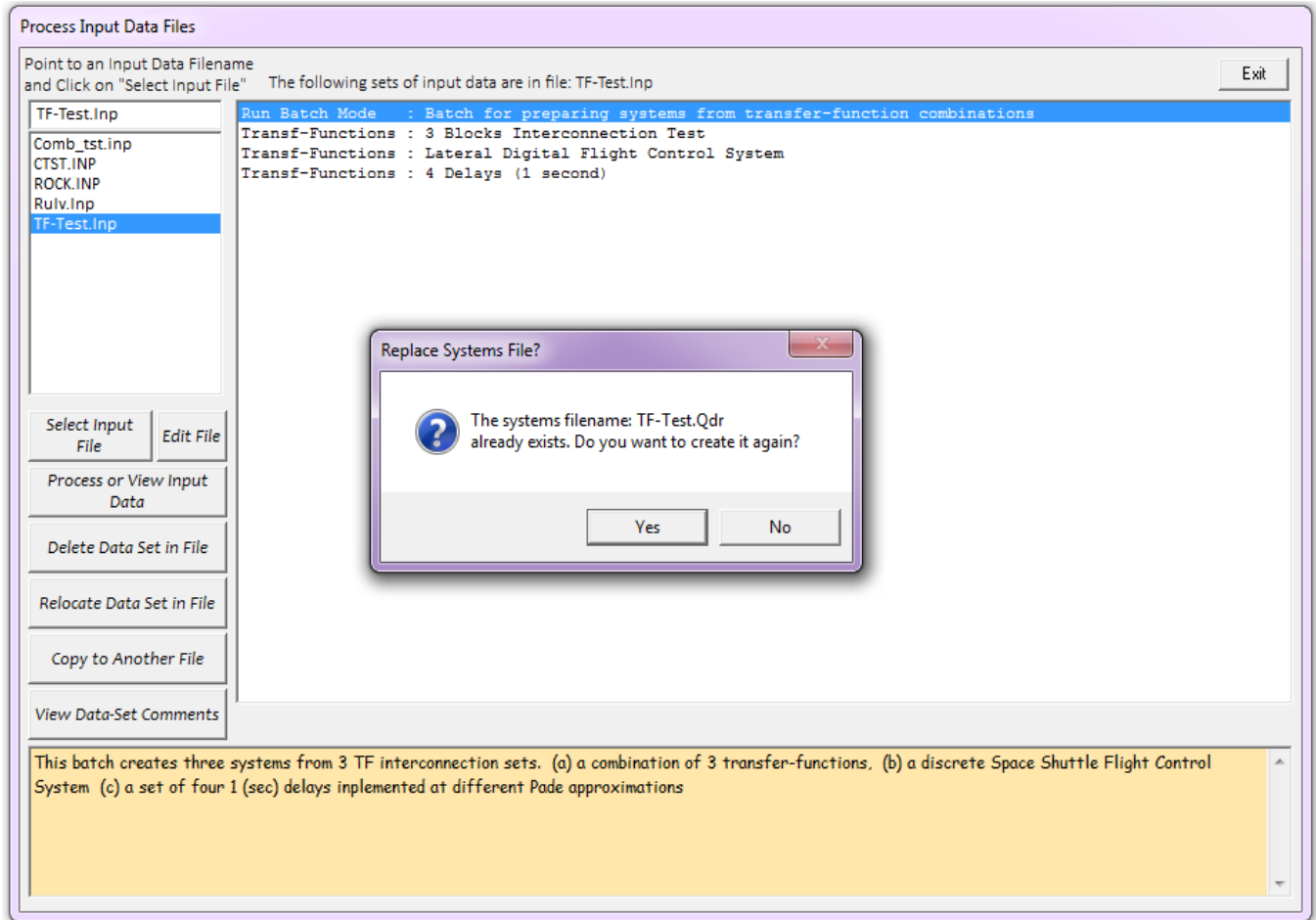
3.0 Systems Reconstruction Program

This is a utility program used to modify, reduce, simplify, separate or reconstruct an existing state-space system. For example, the analyst may wish to replace the system outputs with a new set of outputs, or change the units of the system variables, or to eliminate some unnecessary inputs, states, or outputs, or to separate pitch and lateral dynamics. The System Modification program reads the state-space system to be modified from a systems file ".Qdr" and creates new systems by modifying the original system's variables or may perform some of the following operations:

- Rescale the original system variables by converting the units of the old system's inputs, state, and output variables into different units. The conversion is defined by a constant scaling factor (S), where the old units = (S) times the new units.
- The utility can also create a new system by replacing the old system outputs with a new set of outputs which are made up from a combination of some of the old system's outputs, the states, and the derivatives of the old system outputs and states. This option is useful for extracting derivatives of outputs which are often needed when constructing control design models for LQG or H-infinity synthesis, where state or output derivatives are often included in the criteria optimization vector.
- It is also used to simplify a system by eliminating some of the unused old system's inputs, states, or outputs. It can also be used to decouple a state-space system. Separating, for example, a coupled flight vehicle model into pitch and a lateral subsystems. This option can also be used to change the sequence of the system's variables.
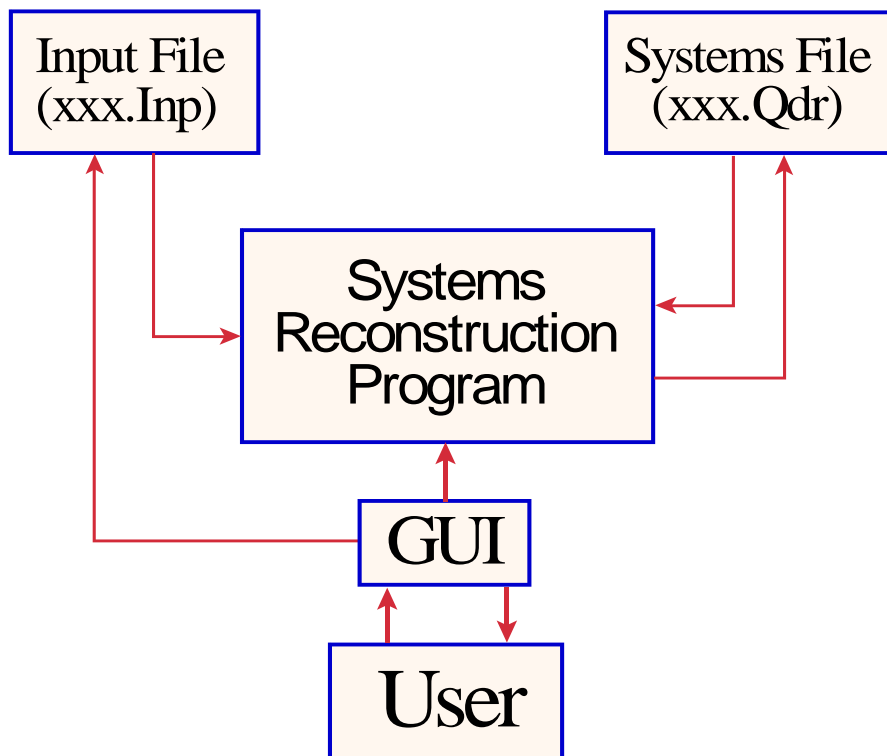
Figure (3.1) Diagram of the Systems Reconstruction Program used to Modify/ Rescale existing systems. It shows the interaction between with the User, Program, and Input/ Output Files

3.1 Program and Files Selection

The example files presented in this section are located in folder "*C:\Flixan\Modify\Examples*". The Systems Reconstruction/ Modification program can be selected from the Flixan main menu by clicking on "*Program Functions*", then select the "*Creating and Modifying Linear Systems*" group, and then click on "*Modifying & Scaling State-Space Systems*". Then using the following file selection dialog select the input data file and the systems file from the menus, as shown below. The input file contains the system reconstruction instructions, that is, when the instructions set has already been saved there from a previous run. Otherwise, the user must define the system modification instructions interactively which will be saved in file ".Inp" for a later use. The systems file originally contains the state-space system that will be modified by the program according to the instructions in the input set, such as, rescaling, selecting variables, creating new outputs, etc. The modified system will also be placed in the same systems file. After selecting the two filenames the user must click on "*Process Files*" to run the program, or if the instructions are not in file click on "*Create New Input Set*" to enter the system modification instructions interactively.
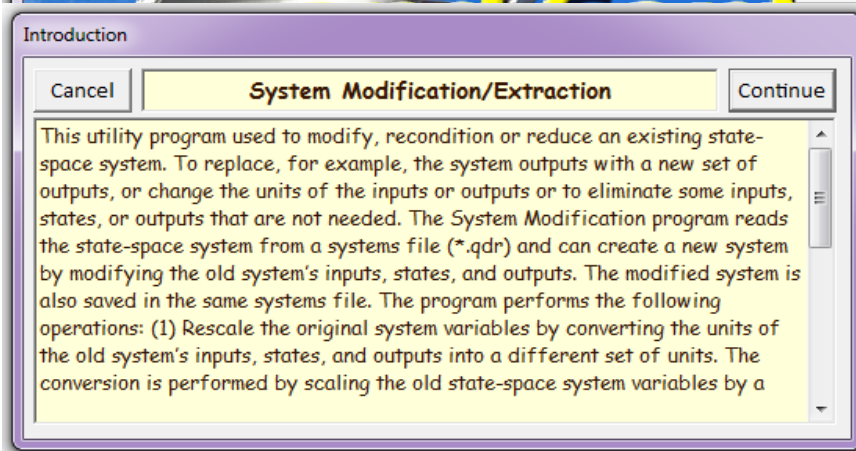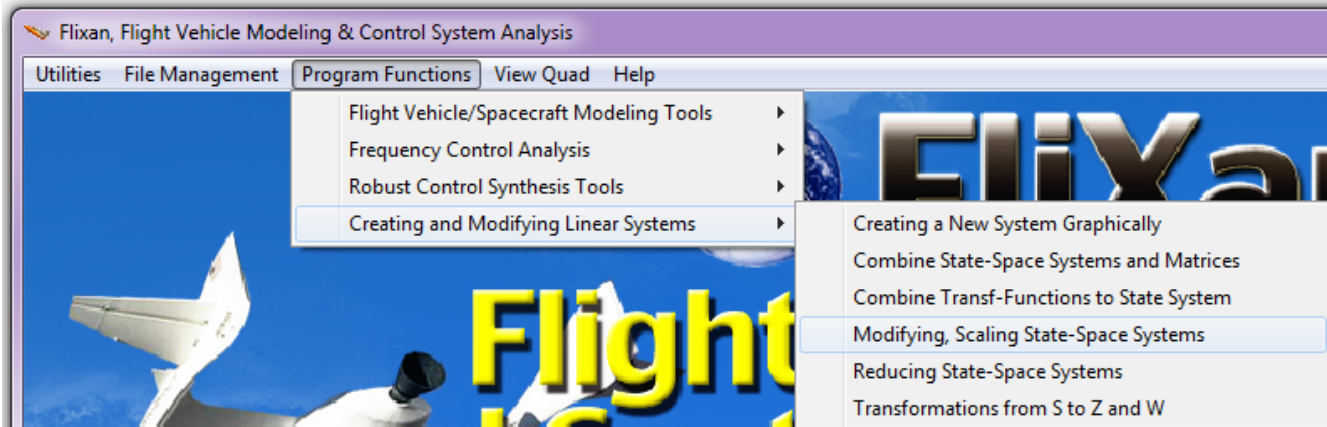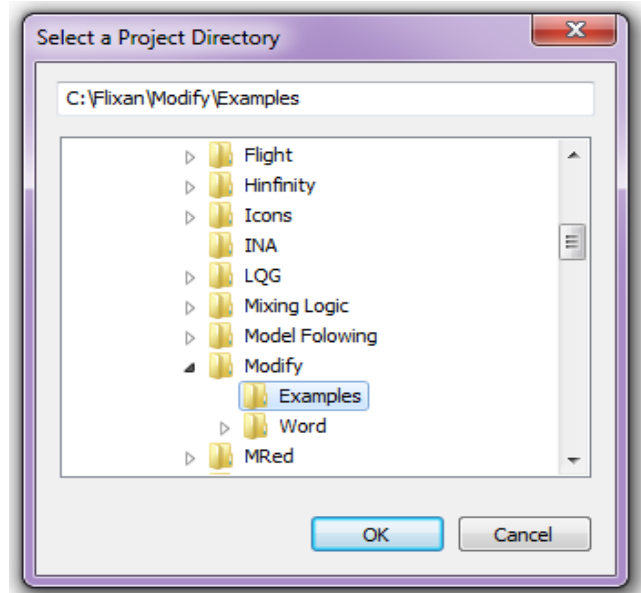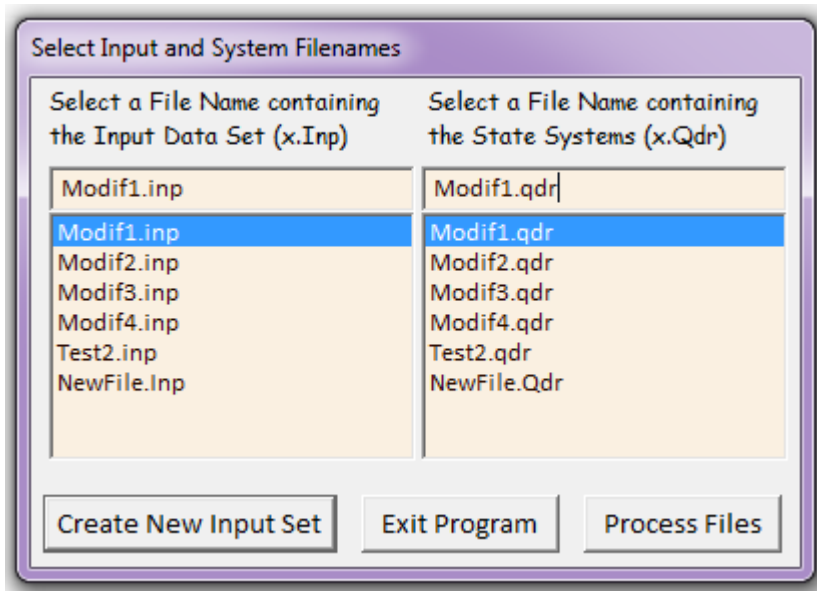
3.2 Instructions Already Saved in Input Data File

When the system modification data is already defined in the input file, the user selects the input and systems filenames from the menu above and clicks on "*Process Files*". The input file typically contains several sets of system modification instructions. Three typical system modification data-sets from file "*Modif4.Inp*" are shown below. They all begin with the line: "CREATE A NEW SYSTEM FROM AN OLD SYSTEM" which identifies the type of data and process, followed by system titles and instructions. There are two system titles: (a) the title of the modified new system to be created, and (b) the original system title before the modifications.

```
-----------------------------------------------------------------------------------------
CREATE A NEW SYSTEM FROM AN OLD SYSTEM... (Titles of the New and Old Systems)
X-45 Descent at Qbar=250, Mach=0.4 (Lateral Outputs)
X-45 Descent at Qbar=250, Mach=0.4
! From the original system, create a new set of outputs only for the lateral axis
NEW SYSTEM OUTPUTS FROM PREVIOUS SYSTEM OUTPUTS/ STATES/ DERIVATIVES
From Old System Output:    1                    Roll Attitude    (phi-Stabil)  (radians)
From Old System Output:    2                    Roll Rate        ( p -Stabil)  (rad/sec)
From Old System State :    5                    Yaw  Attitude    (psi-rigid)   (radians)
From Old System State :    6                    Yaw  Rate        ( r -rigid)   (rad/sec)
From Old System Output:    8                    Angle of sideslip (beta-rigid)  (radians)
From State Derivative :    8                    Angle of sideslip (beta-rigid)  (radians) /Rate
From Old System Output:    12                   CG Acceleration along Y axis, (ft/sec^2)
From Output Derivative:    2                    Roll Rate        ( p -Stabil)  (rad/sec) /Rate
From Output Derivative:    6                    Yaw  Rate        ( r -Stabil)  (rad/sec) /Rate
-----------------------------------------------------------------------------------------
CREATE A NEW SYSTEM FROM AN OLD SYSTEM... (Titles of the New and Old Systems)
X-45 Descent at Qbar=250, Mach=0.4 (Pitch Dynamics)
X-45 Descent at Qbar=250, Mach=0.4
! Extract the Pitch Dynamic Model from system: " X-45 Descent at Qbar=250, Mach=0.4"
TRUNCATE OR REORDER THE SYSTEM INPUTS, STATES, AND OUTPUTS
Extract Inputs :   1    4    5
Extract States :   3    4
Extract Outputs:   3    4
-----------------------------------------------------------------------------------------
CREATE A NEW SYSTEM FROM AN OLD SYSTEM... (Titles of the New and Old Systems)
X-45 Descent at Qbar=250, Mach=0.4 (Lateral Dynamics)
X-45 Descent at Qbar=250, Mach=0.4
! Extract the Lateral Dynamic Model from system: " X-45 Descent at Qbar=250, Mach=0.4"
TRUNCATE OR REORDER THE SYSTEM INPUTS, STATES, AND OUTPUTS
Extract Inputs :   2    3    5
Extract States :   1    2    5    6    8
Extract Outputs:   1    2    5    6    8   12
-----------------------------------------------------------------------------------------
```

The program searches through the input data file "Modif4.Inp" looking for system modification data-sets. When it finds them it displays their titles in a menu, shown below, and in this case it found many system modification sets in this file. These are the first titles that define the new system to be created and not the original system titles. The user selects one of the new system titles from this menu and clicks on "Run Input Set" to process it. The program reads the input instructions and calculates the modified state-space system from the original system. Then it saves the new system in the systems file "Modif4.Qdr" using the new system title selected from the menu.

Select a Set of Data from Input File

Select a Set of Input Data for "CREATE A NEW SYSTEM" from an Input File: Modif4.inp

Run Input Set

Exit Program

Create New

X-45 Descent, Pitch Axis at Qbar=250, Mach=0.4
X-45 Descent, Lateral Axes at Qbar=250, Mach=0.4
X-45 Descent, Lateral Axes at Qbar=250, Mach=0.4, Modification-1
X-45 Descent, Lateral Axes at Qbar=250, Mach=0.4, Modification-2
X-45 Descent at Qbar=250, Mach=0.4 (Pitch Outputs)
X-45 Descent at Qbar=250, Mach=0.4 (Lateral Outputs)
X-45 Descent at Qbar=250, Mach=0.4 (Pitch Dynamics)
X-45 Descent at Qbar=250, Mach=0.4 (Lateral Dynamics)
X-45 Descent at Qbar=250, Mach=0.4 (Reorder System)

3.3 Creating a New Set of System Modification Instructions

If the system modification instructions are not in file (.Inp) the program will create the instructions set interactively, save it in file (.Inp), and then process it. After selecting the input and system files from the filename selection menu the user must click on "*Create a New Input Set*" instead of "*Process Files*" as in the previous section. If the input filename does not exist the user may enter a new name with an extension (.Inp). The program will receive the system modifications interactively, save them as a data-set in the input file and process the set. The following menu shows the titles of the systems included in file "*Modif4.Qdr*". Select the first one to be modified. It is a vehicle model that includes both pitch and lateral dynamics.

Select a State-Space System from Quad File

Select a State-Space Model for System Modification, From Systems File: Modif4.qdr

X-45 Descent at Qbar=250, Mach=0.4
X-45 Descent, Pitch Axis at Qbar=250, Mach=0.4
X-45 Descent, Lateral Axes at Qbar=250, Mach=0.4
X-45 Descent, Lateral Axes at Qbar=250, Mach=0.4, Modification-1
X-45 Descent, Lateral Axes at Qbar=250, Mach=0.4, Modification-2
X-45 Descent at Qbar=250, Mach=0.4 (Pitch Outputs)
X-45 Descent at Qbar=250, Mach=0.4 (Lateral Outputs)
X-45 Descent at Qbar=250, Mach=0.4 (Pitch Dynamics)
X-45 Descent at Qbar=250, Mach=0.4 (Lateral Dynamics)
X-45 Descent at Qbar=250, Mach=0.4 (Reorder System)
X-45 Descent at Qbar=250, Mach=0.4-Modified

Choose a System Title and then click "Select"   Cancel   View System   Select

58

In this example we will create a new system by extracting only the pitch variables from the original system. Using the following dialog enter the new system's title "*X-45 Descent at Qbar=250, Mach=0.4 (Pitch Axis)*". From the menu select the third option "*Extract or Reorder some of the System Variables*", enter some comments below describing the new system, and click on "*Select Option*" to continue. The following dialog shows the definitions of the original system's inputs, states, and outputs in three separate menu tabs. From the menus the user selects the variables to be retained in the new system. Click on "Save Changes" every time you modify the choices. Then click on "Continue" to save and process the new set of system modification data.
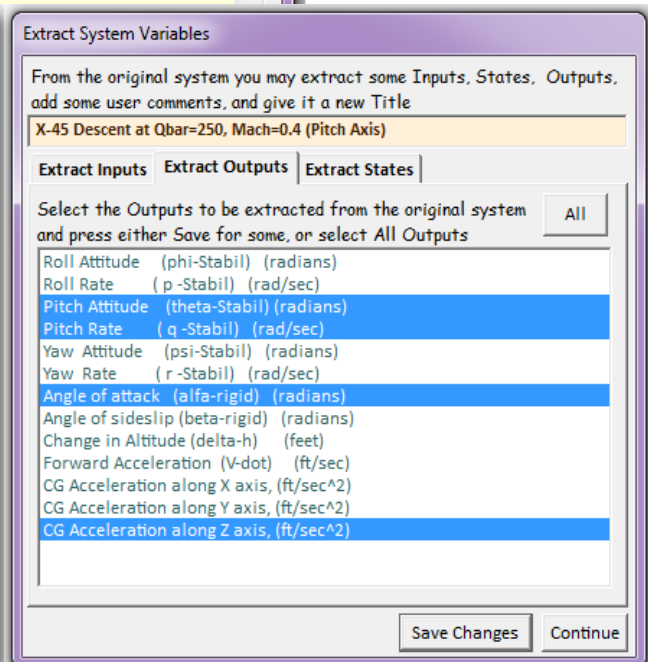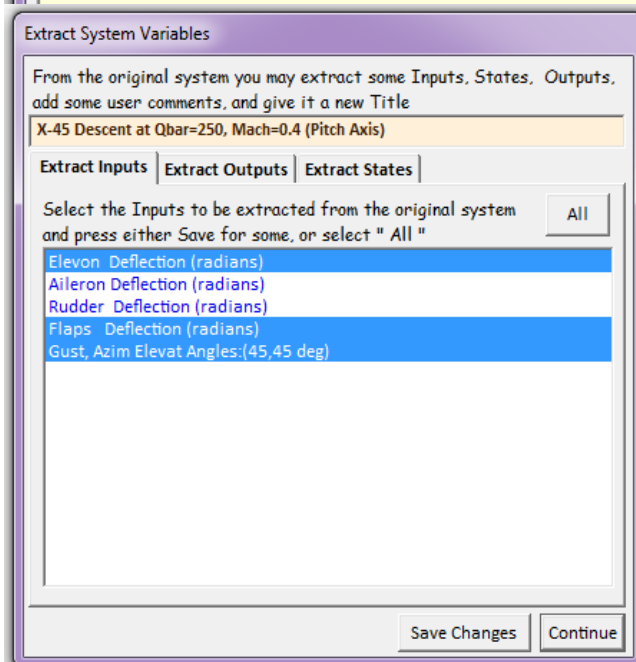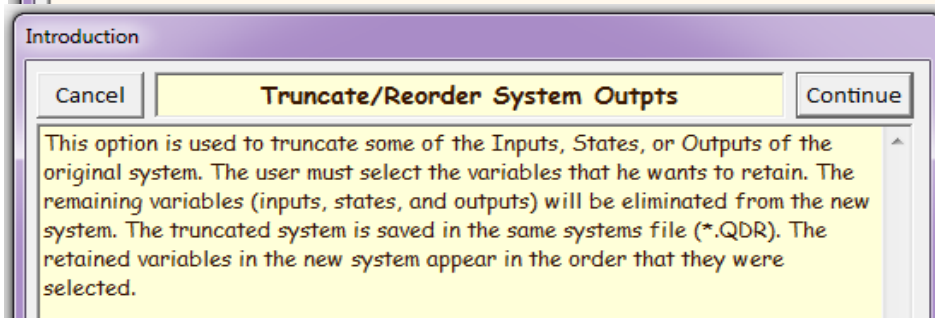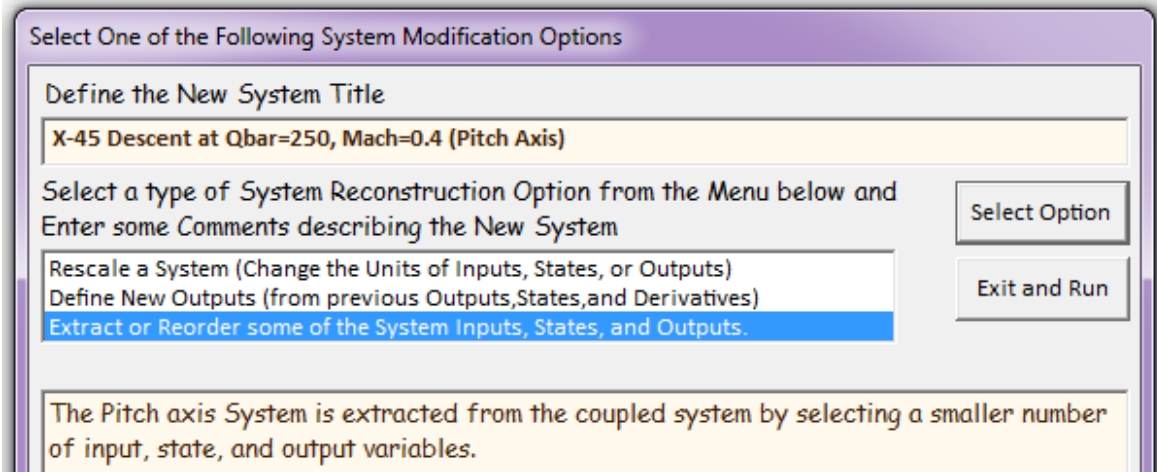
3.4 Creating a New Set of System Rescaling Instructions

This option is used for converting the units of some of the system inputs, states, or output variables from one type of units to another. Converting, for example, a system whose inputs are defined in pounds and its outputs in feet to a dynamically equivalent system whose inputs are defined in kilograms and its outputs are in meters. It is used, for example, to transform a plant model in order to combine it with a controller or an actuator systems that is defined in different units. In order to scale a state-space variable from one set of units to another the user must define the conversion factor "S". This scaling factor is defined as: one old unit is equal to "S" times the new unit.

Let us consider, for example, a simple second order system that models the response of a spring to an applied force. The force is applied at one end of a spring and the other side is fixed. The input to this model is the force applied in pounds. The two states are position and velocity at one end of the spring in feet and (feet/sec) respectively. The two outputs are: (1) spring position in feet, and (2) a direct feed-through term that measures the applied force. The state-space representation of this system is in file: Modif1.Qdr. The force in the original system input is defined in (lb) and it must be converted to (oz), the scaling factor S=16. The system output is in (feet) and it must be converted to (inches), the scaling factor S=12.

The diagram in Figure (3.1) shows both: the original and the scaled system in parallel. Both systems are equivalent. The original system is shown on the top. Its input is in (lb) and its two outputs are in (feet) and (lb). This system was transformed, as we shall see, to a new set of units, shown below. Its input is in (ounces) and its outputs are in (inches) and (ounces). The equivalence of the two systems is demonstrated by including unit conversion gains to rescale the inputs and the outputs of the modified system to match the original. The two systems are excited together in parallel and they respond identically, as expected.
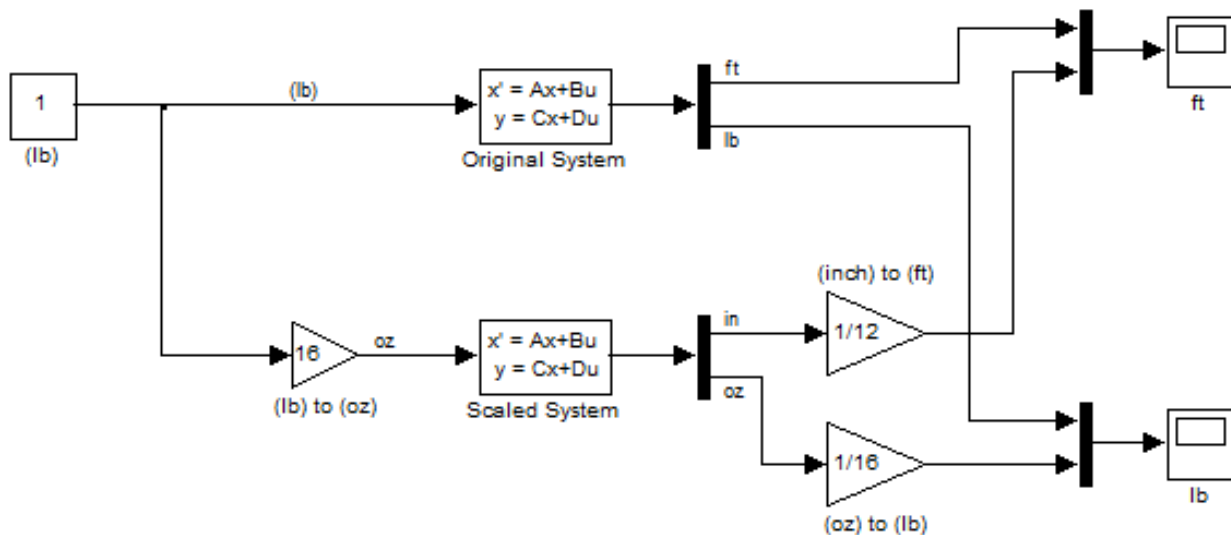
Figure (3.1) Comparison between the Original and the Scaled Systems

Re-scaling a system's input is performed by dividing with the scaling factor (S) the corresponding column in matrices B and D. Similarly, rescaling a system's output is performed by multiplying with the scaling factor (S) the corresponding row in matrices C and D. Rescaling the states affects only matrices A, B, and C. Notice, that it is not necessary to rescale the states in order to combine two

60

systems together. Rescaling a system's inputs and outputs is not only used for the purpose of changing its units. It is also a good practice to rescale a system when the magnitudes of matrices B, C, or D are either too small or too large. This may avoid numerical problems associated with some control algorithms.

So let us begin by scaling the original system "*Spring Model*" which is in file "*Modif1.Qdr*". We will assume again that the system modification instructions are not in file and the program will create a new set of scaling instructions interactively, save the set in file "*Modif1.Inp*". and process it. The input and systems files "*Modif1.Inp*" and "*Modif1.Qdr*" are located in directory "*C:\Flixan\ Modify\ Examples*". The user must select the two files from the menus and click on "*Create New Input Set*" to create the system rescaling instructions set, and from the following menu one of the systems from file "*Modif1.Qdr*" is chosen to be rescaled. It is the original "*Spring Model*".
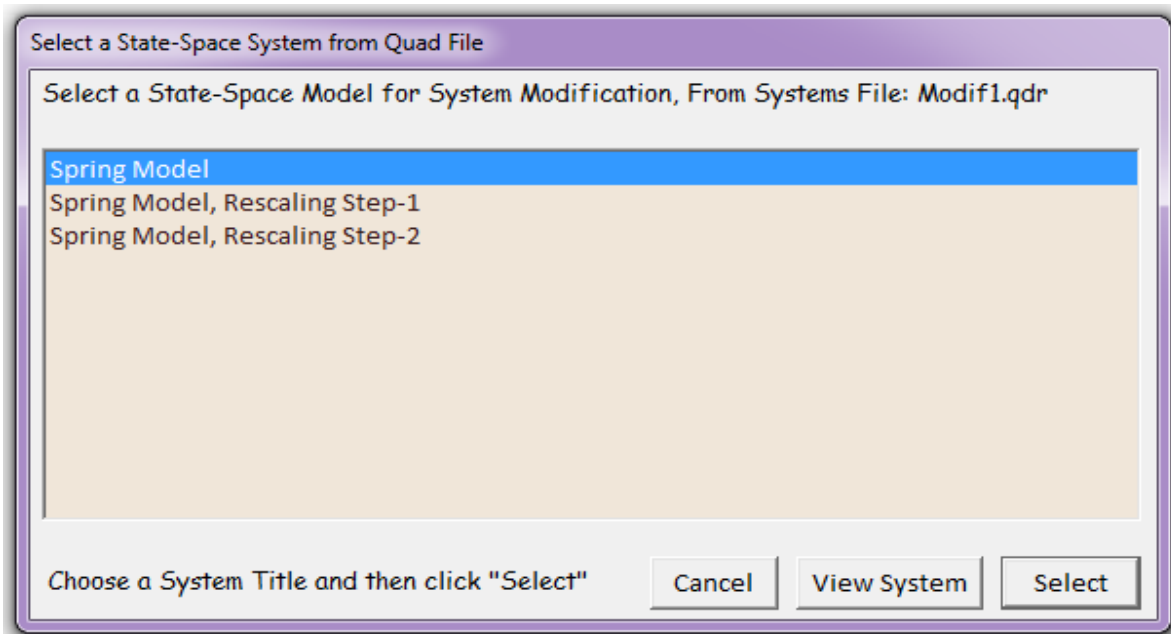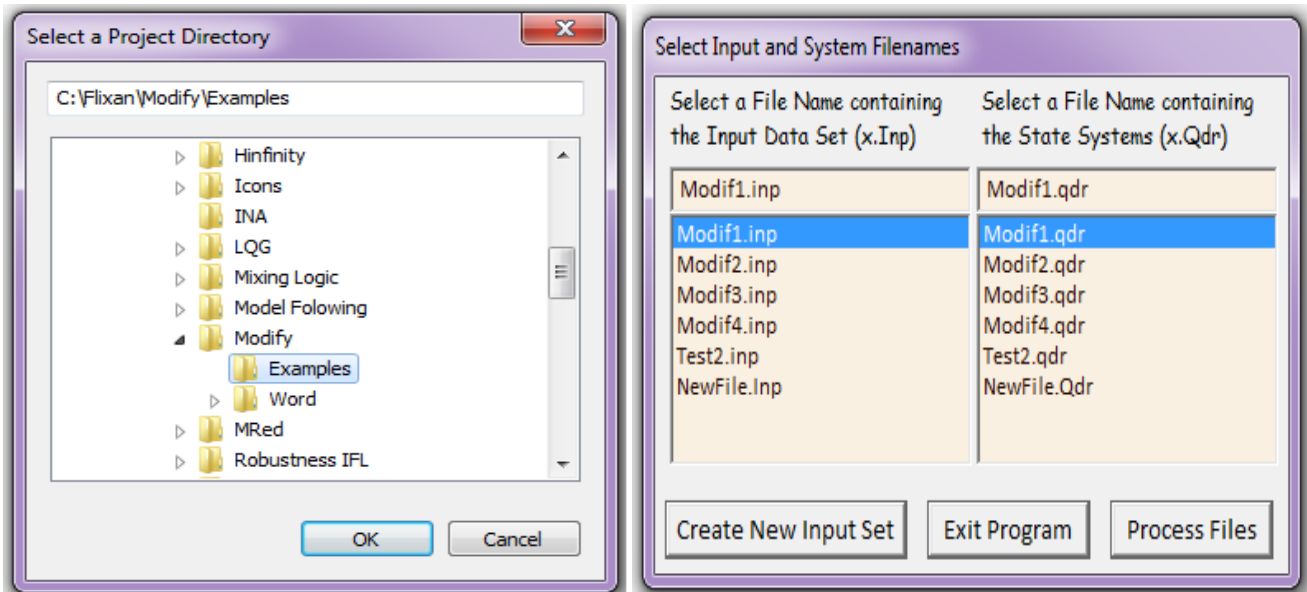
The program reads the state-space system and opens the following dialog used for selecting system modification options. The user replaces the default title on the top with a new system title: "*Spring Model, Rescaling Step-3*". From the system modifications menu we select the first option to rescale the system variables. In the field below the user enters some comments describing the system modifications, and click on "*Select Option*". The notes are helpful in describing the new system, its characteristics, and how it was derived from the original system. The user notes will also be included as comments in the data files and become available to other utility programs.
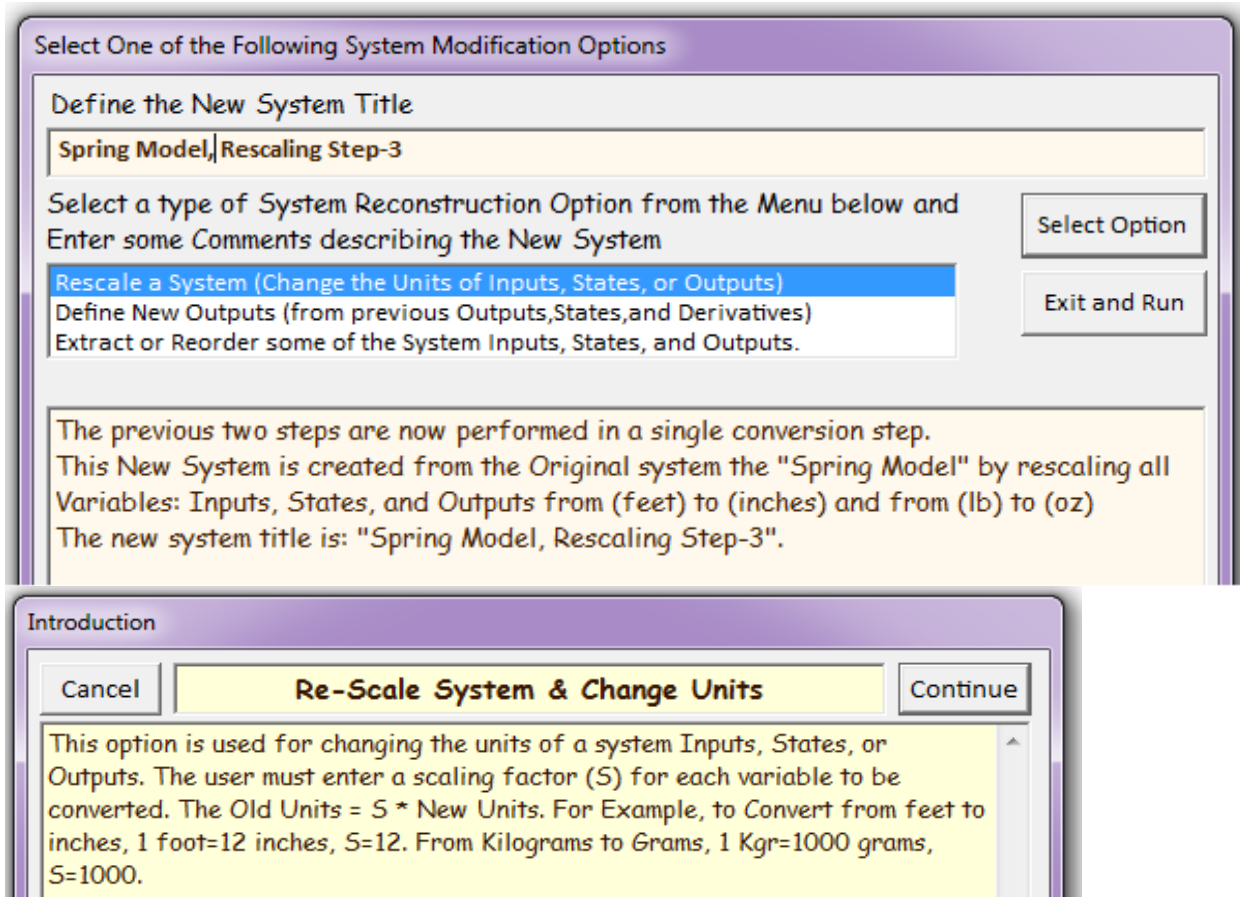
The next step is for the user to select some of the system variable to be scaled. The variables are selected from the dialog below that has three menus in separate tabs for selecting and scaling inputs, states, and outputs. The user selects one of the menu tabs, for example, "*Scale Outputs*", from the menu selects one of the outputs, for example, "*Position (ft)*", and enters at the bottom the scaling factor (s) that converts the old units to the new units. $Old\,Units=(s)*NewUnits$. For example, select the inputs menu tab and then the "*Applied Force in (lb)*". Enter a scaling factor of 16 at the bottom to convert pounds to ounces. Click on "OK" every time you select and scale a variable. The title of the variable changes because scaling factor is included on its right side. When you finish scaling the variables click on "*Continue*", and the program returns to the previous dialog.

It is also possible to include more than one type of modifications in the same data set under one title, as it will be shown in other examples. For this reason the interactive utility does not terminate after completing one option, but it returns to the menu and waits for additional options to be included in the

set before creating the final system. To save and run the new instructions and to create the new system the user must click on the "*Exit and Run*" button. The new set of instructions, shown below, will finally be saved in the input file and be processed to create the modified system in file "*Modif1.Qdr*" under the new title.
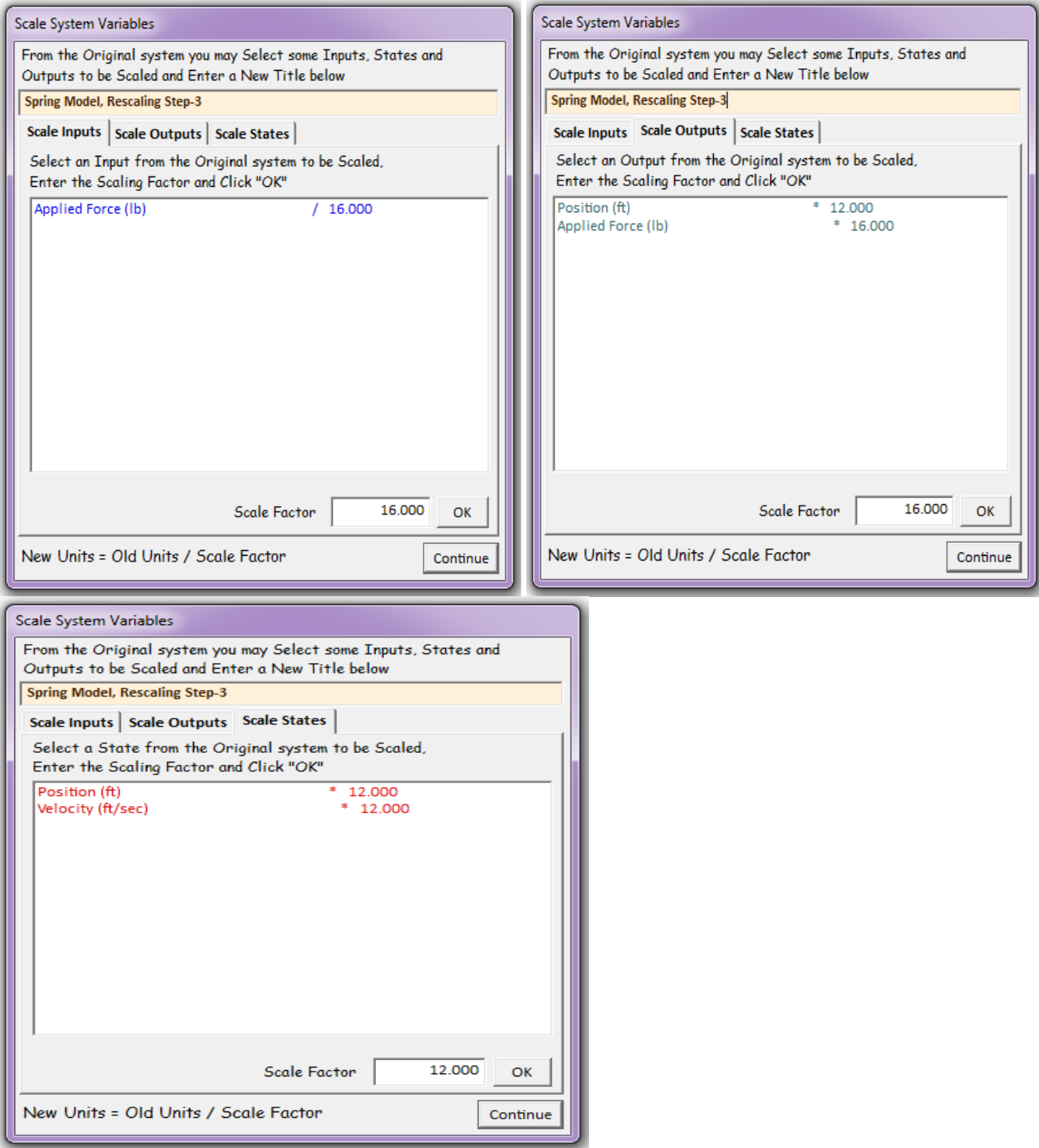
Click on "*Continue*" and the interactive utility returns to the previous dialog with the three options. From there click on "*Exit and Run*" to process the modification data. Notice that the name-list of the rescaled system variables, printed at the bottom of the system in the ".Qdr" file, includes the scaling

factors (S) on the right side of each variable. The input file "*Modif1.Inp*" is shown below. We just demonstrated and processed the third system modification set "*Spring Model, Rescaling Step-3*". Notice that the system scaling can also be performed in two steps for demo purposes, step-1 and step-2. There is also a batch set on the top for fast processing of the entire file.

```
-------------------------------------------------------------------------------------------
STATE-SPACE SYSTEM RE-SCALING EXAMPLES
-------------------------------------------------------------------------------------------
BATCH MODE INSTRUCTIONS ...............
Batch for rescaling a system inputs, states, and outputs
! In step-1 we rescale the system inputs and outputs from pounds to ounces, and from feet to inches.
! In step-2 we rescale the states of the system created in step-2 from feet to inches.
! In step-3 we do the rescalings performed in steps 1 and 2 in one set.
Retain System    : Spring Model
System Modificat : Spring Model, Rescaling Step-1
System Modificat : Spring Model, Rescaling Step-2
System Modificat : Spring Model, Rescaling Step-3
To Matlab Format : Spring Model
To Matlab Format : Spring Model, Rescaling Step-3
-------------------------------------------------------------------------------------------
CREATE A NEW SYSTEM FROM AN OLD SYSTEM... (Titles of the New and Old Systems)
Spring Model, Rescaling Step-1
Spring Model
! Example: 1,
! A New System is created from the "Spring Model" by having Input #1 converted
! from pounds to ounces (1 lb = 16 oz) and Output #1 converted from feet to inches
! (1 ft = 12 in). The new system title is: "Spring Model, Rescaling Step-1".
RESCALE A SYSTEM, CHANGE THE UNITS OF INPUTS/STATES/OUTPUTS
Rescale Inputs : 1
Scaling Values : 16.00
Rescale Outputs:  1        2
Scaling Values : 12.00     16.00
-------------------------------------------------------------------------------------------
CREATE A NEW SYSTEM FROM AN OLD SYSTEM... (Titles of the New and Old Systems)
Spring Model, Rescaling Step-2
Spring Model, Rescaling Step-1
! Example: 2,
! This New System is created from the previous one "Spring Model, Rescaling Step-1"
! by rescaling its states from (feet) to (inches), a factor of 12. The new system title
! is: "Spring Model, Rescaling Step-2".
RESCALE A SYSTEM, CHANGE THE UNITS OF INPUTS/STATES/OUTPUTS
Rescale States :  1        2
Scaling Values : 12.00     12.00
-------------------------------------------------------------------------------------------
CREATE A NEW SYSTEM FROM AN OLD SYSTEM... (Titles of the New and Old Systems)
Spring Model, Rescaling Step-3
Spring Model
! Example: 3, The previous two steps are now performed in a single conversion step.
! This New System is created from the Original system the "Spring Model"
! by rescaling all Variables: Inputs, States, and Outputs
! from (feet) to (inches) and from (lb) to (oz)
! The new system title is: "Spring Model, Rescaling Step-3".
RESCALE A SYSTEM, CHANGE THE UNITS OF INPUTS/STATES/OUTPUTS
Rescale Inputs :  1
Scaling Values : 16.00
Rescale States :  1        2
Scaling Values : 12.00     12.00
Rescale Outputs:  1        2
Scaling Values : 12.00     16.00
-------------------------------------------------------------------------------------------
CONVERT TO MATLAB FORMAT ........      (Title, System/Matrix, m-filename)
Spring Model
System
Original_Sys.m
-------------------------------------------------------------------------------------------
CONVERT TO MATLAB FORMAT ........      (Title, System/Matrix, m-filename)
Spring Model, Rescaling Step-3
System
Scaled_Sys.m
-------------------------------------------------------------------------------------------
```

3.5 Creating a New Set of Outputs Interactively

Sometimes a system's output does not include sufficient variables. Some required states or derivatives do not appear in the output vector and the analyst would like to modify the output vector to include them. This option is used to replace a system's outputs with a new set of outputs from a combination of the original system variables. The new outputs can be selected from: (a) the original system outputs, (b) its output derivatives, (c) the old system states, and (d) the derivatives of the states. This utility is particularly useful in preparing synthesis models for control system design because design models often require additional output criteria to be optimized that may not necessarily appear in the original output. The original system to be modified in this example is "*Shuttle Entry Lateral model with beta-integral*" located in file "*Modif2.Qdr*". The output reconstruction data-set is not available yet so we will create it interactively and place it in file "*Modif2.Inp*". So we begin the program, as in previous examples, by selecting the two files from the filenames selection menu, and click on "*Create a New Input Set*" to begin the interactive data collection process. From the next menu select the original system from file "*Modif2.Qdr*", and click on "Select".

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)

Modif2.inp

Modif2.qdr

Modif1.inp	Modif1.Qdr
Modif2.inp	Modif2.qdr
Modif3.inp	Modif3.qdr
Modif4.inp	Modif4.Qdr
Test2.inp	Test2.qdr
NewFile.Inp	NewFile.Qdr

Create New Input Set   Exit Program   Process Files

Select a State-Space System from Quad File

Select a State-Space Model for System Modification, From Systems File: Modif2.qdr

Shuttle Entry Lateral model with beta-integral
Shuttle Entry Lateral model with beta-integral (New System)

Choose a System Title and then click "Select"   Cancel   View System   Select

The program opens the following dialog for selecting type of system modification. The new system title is entered on the top, and from the menu select the second option to define a new set of outputs. Some comments may also be included in the field below, and click on "*Select Option*", as shown.

Select One of the Following System Modification Options

Define the New System Title

Shuttle Entry Lateral model with beta-integral (New System)

Select a type of System Reconstruction Option from the Menu below and
Enter some Comments describing the New System

| Select Option |

Rescale a System (Change the Units of Inputs, States, or Outputs)
Define New Outputs (from previous Outputs,States,and Derivatives)
Extract or Reorder some of the System Inputs, States, and Outputs.

| Exit and Run |
| Edit Input File |

This System was obtained from the previous one by performing a combibed (NEW OUTPUTS) and (TRUNCATE) operation. The following modifications are performed: (a) Keep the previous system Outputs 2,3, and 4 (Roll rate, Yaw rate, and beta, (b) Include State 4, the angle of sideslip (beta) in the Outputs, (c) Include the roll and yaw accelerations p_dot, r_dot in the Outputs, (d) Include the derivative of state 4, (beta_dot) in the Outputs, (e) Eliminate state 1 (roll attitude) from the states and from the outputs.

Introduction

| Cancel | | Create New System Outputs | Continue |

This option can be used to create a new system from an already existing system by changing its outputs. The new system has the same inputs and states as the old, but its outputs can be selected from the old system's outputs, its output derivatives, the old system's states, and the state derivatives. The modified system can also be saved in the same systems file (*.Qdr). This option is useful for creating control design models that require derivatives of certain variables in the performance criteria.

The following dialog is introduced to help the user select the new system outputs. It has a menu that includes four groups of variables from where the user may choose the new outputs: (a) from the original system outputs, (b) from the derivatives of the outputs, (c) from the old system states, and (d) from the derivatives of the states. The new system outputs are selected one at a time from the four groups of variables using this dialog. Select one of the four types of variables from the menu, "*old system states*" in this case, and click on "*Choose an Output Type*". The display below the menu is initially empty. It will eventually contain the selected output variables. The menu at the bottom of the dialog contains the variable titles of the selected group. The user selects one variable at a time from this menu and clicks on "*Include Variable to Outputs*". The selected variable titles are gradually included in the outputs list at the top. Variables from other groups can also be selected, such as, in this case from "*old system state derivatives*". The first four outputs in this demo (roll rate, yaw rate, etc), were selected from the original system states. The last three outputs (p-dot, r-dot, and β-dot) was selected from the state derivatives.
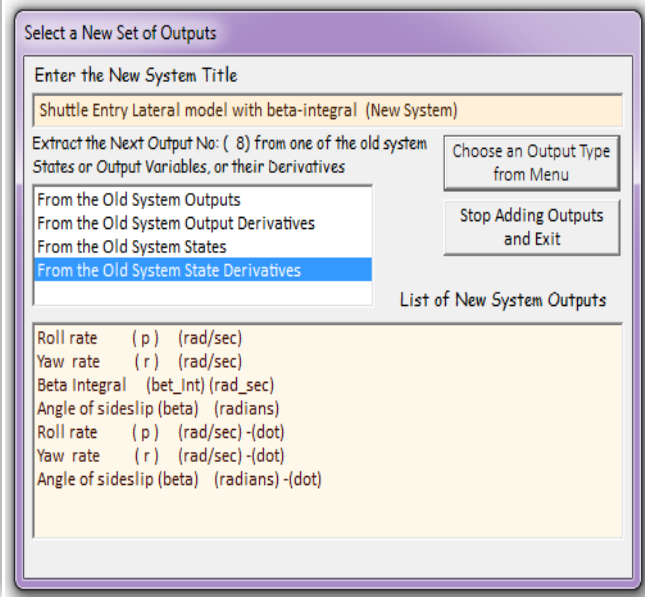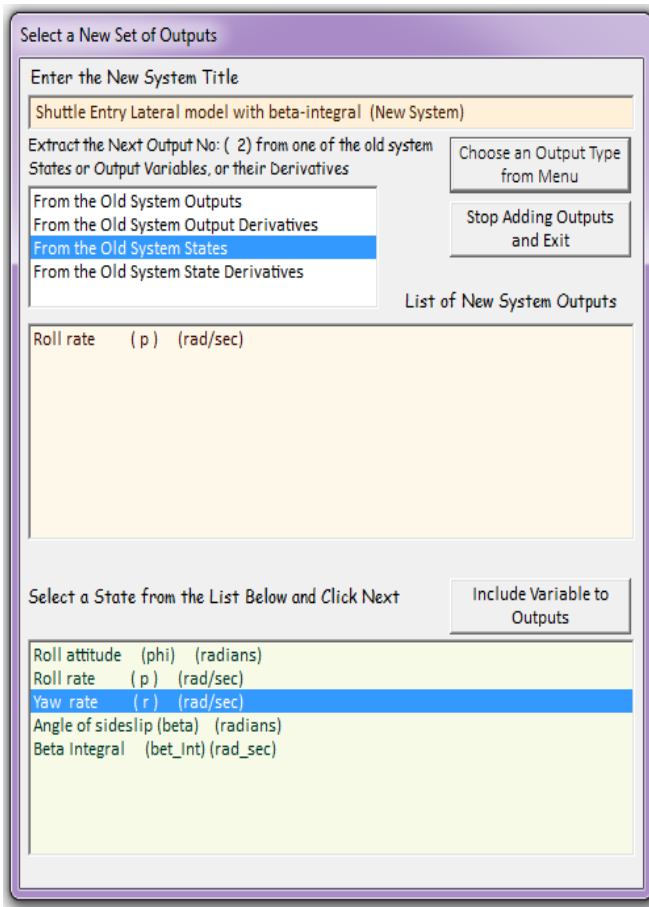
This process of selecting one variable at a time from different groups is repeated multiple times. When a variable from the derivative groups is selected, a short label "-dot" is included at the end of its title. When the outputs list is complete the user clicks on "*Stop Adding Outputs and Exit*", and the utility returns to the previous dialog in case the user wants to include additional modification options for the same system under the same title. In this case we want to eliminate one of the states, the roll attitude, and we select the third option for truncating some of the original system variables, and click on "*Select Option*". The dialog of this option includes three menu tabs for selecting the system inputs, states, and outputs to be retained from the original system. From the menu we select to retain all inputs and all outputs. From the states we truncate the first state (roll attitude). This variable was also excluded from the outputs.

Select One of the Following System Modification Options

Define the New System Title

Shuttle Entry Lateral model with beta-integral (New System)|

Select a type of System Reconstruction Option from the Menu below and
Enter some Comments describing the New System

Rescale a System (Change the Units of Inputs, States, or Outputs)	**Select Option**
Define New Outputs (from previous Outputs,States,and Derivatives)	**Exit and Run**
Extract or Reorder some of the System Inputs, States, and Outputs.	**Edit Input File**

This System was obtained from the previous one by performing a combibed (NEW
OUTPUTS) and (TRUNCATE) operation. The following modifications are performed: (a)
Keep the previous system Outputs 2,3, and 4 (Roll rate, Yaw rate, and beta, (b) Include
State 4, the angle of sideslip (beta) in the Outputs, (c) Include the roll and yaw
accelerations p_dot, r_dot in the Outputs, (d) Include the derivative of state 4, (beta_dot)
in the Outputs, (e) Eliminate state 1 (roll attitude) from the states and from the outputs.

Introduction

Cancel	**Truncate/Reorder System Outpts**	Continue

This option is used to truncate some of the Inputs, States, or Outputs of the
original system. The user must select the variables that he wants to retain. The
remaining variables (inputs, states, and outputs) will be eliminated from the new
system. The truncated system is saved in the same systems file (*.QDR). The
retained variables in the new system appear in the order that they were
selected.
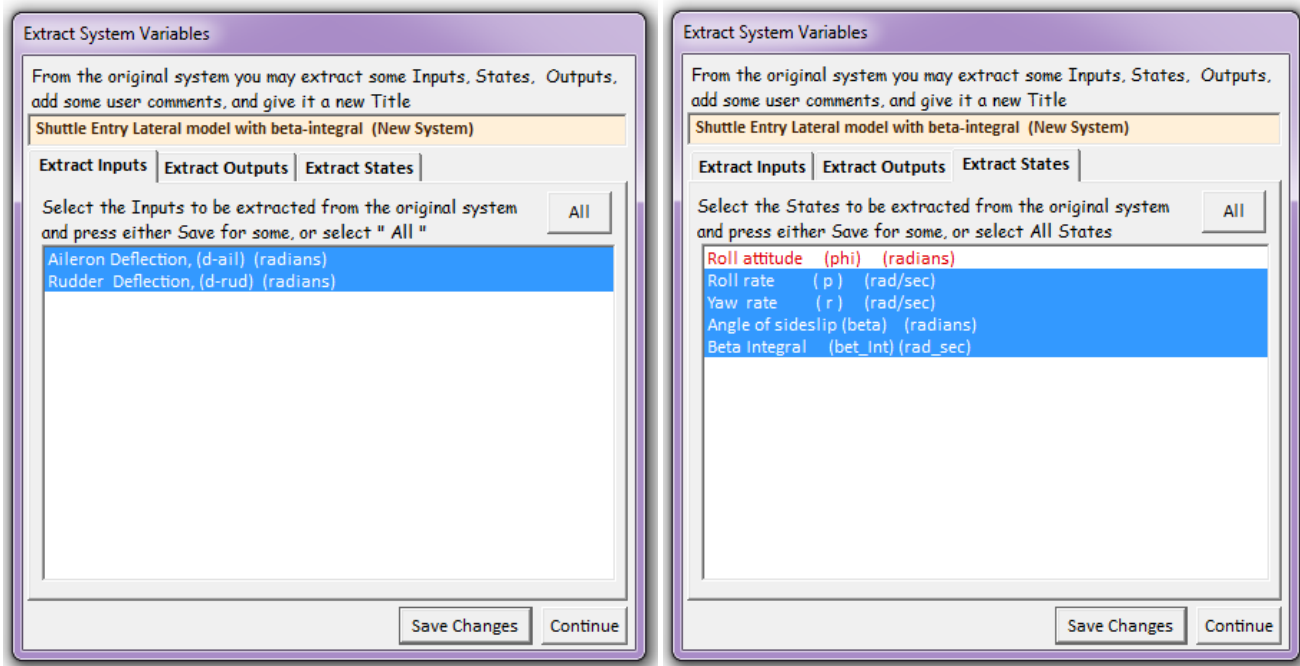
The system modification instructions set is now saved in file "*Modif2.Inp*" and processed. The new system is saved in file "*Modif2.Qdr*" and its title is "*Shuttle Entry Lateral model with beta-integral (New System)".* The system modification data-set is shown below and it consists of two parts: (a) the new outputs reconstruction, and (b) the states extraction and the elimination of roll attitude state.

```
CREATE A NEW SYSTEM FROM AN OLD SYSTEM... (Titles of the New and Old Systems)
Shuttle Entry Lateral model with beta-integral (New System)
Shuttle Entry Lateral model with beta-integral
! This System was obtained from the previous one by performing a combibed (NEW OUTPUTS)
! and (TRUNCATE) operation. The following modifications are performed:
! (a) Keep the previous system Outputs 2,3, and 4 (Roll rate, Yaw rate, and beta
! (b) Include State 4, the angle of sideslip (beta) in the Outputs
! (c) Include the roll and yaw accelerations p_dot, r_dot in the Outputs
! (d) Include the derivative of state 4, (beta_dot) in the Outputs
! (e) Eliminate state 1 (roll attitude) from the states and from the outputs.
NEW SYSTEM OUTPUTS FROM PREVIOUS SYSTEM OUTPUTS/ STATES/ DERIVATIVES
From Old System State :    2               Roll rate        ( p )     (rad/sec)
From Old System State :    3               Yaw  rate        ( r )     (rad/sec)
From Old System State :    5               Beta Integral    (bet_Int) (rad_sec)
From Old System State :    4               Angle of sideslip (beta)   (radians)
From State Derivative :    2               Roll rate        ( p )     (rad/sec) -(dot)
From State Derivative :    3               Yaw  rate        ( r )     (rad/sec) -(dot)
From State Derivative :    4               Angle of sideslip (beta)   (radians) -(dot)
TRUNCATE OR REORDER THE SYSTEM INPUTS, STATES, AND OUTPUTS
Extract States :    2    3    4    5
----------------------------------------------------------------------------------------
```

3.6 Example 3 Separating a Coupled Vehicle Model

In this example we will demonstrate how to separate a coupled flight vehicle model into separate subsystems. The original state-space system represents a reentry vehicle near landing and it was generated by the flight vehicle modeling program. The system title is *"Re-entry Vehicle, Landing Model (Coupled Pitch and Lateral Axes)"* and it is included in file "*Modif3.Qdr*". This example files are also located in "*C:\Flixan\Modify\ Examples*". The pitch and lateral dynamics are both included and are coupled in this dynamic model. We will use the systems truncation option to split the original system and to create two separate pitch and a lateral subsystems. We will also use the scaling option to rescale the output angles from radian to degrees. Two sets of system modification instructions are created: one set for pitch and one for lateral system extractions. Each set performs two functions: scaling and truncating. In the pitch system the pitch variables are extracted from the original inputs, states, and outputs. The same for the lateral system. Initially we assume that the input file is empty so we will create the system modifications interactively and save them in file "*Modif3.Inp*".

So we begin the program as in previous examples by selecting the two files "*Modif3.Qdr*" and "*Modif3.Inp*" from the filenames selection menu, and click on "*Create a New Input Set*" to begin the interactive data collection process. From the systems selection menu chose the original system title *"Re-entry Vehicle, Landing Model (Coupled Pitch and Lateral Axes)"*, and click on "Select".
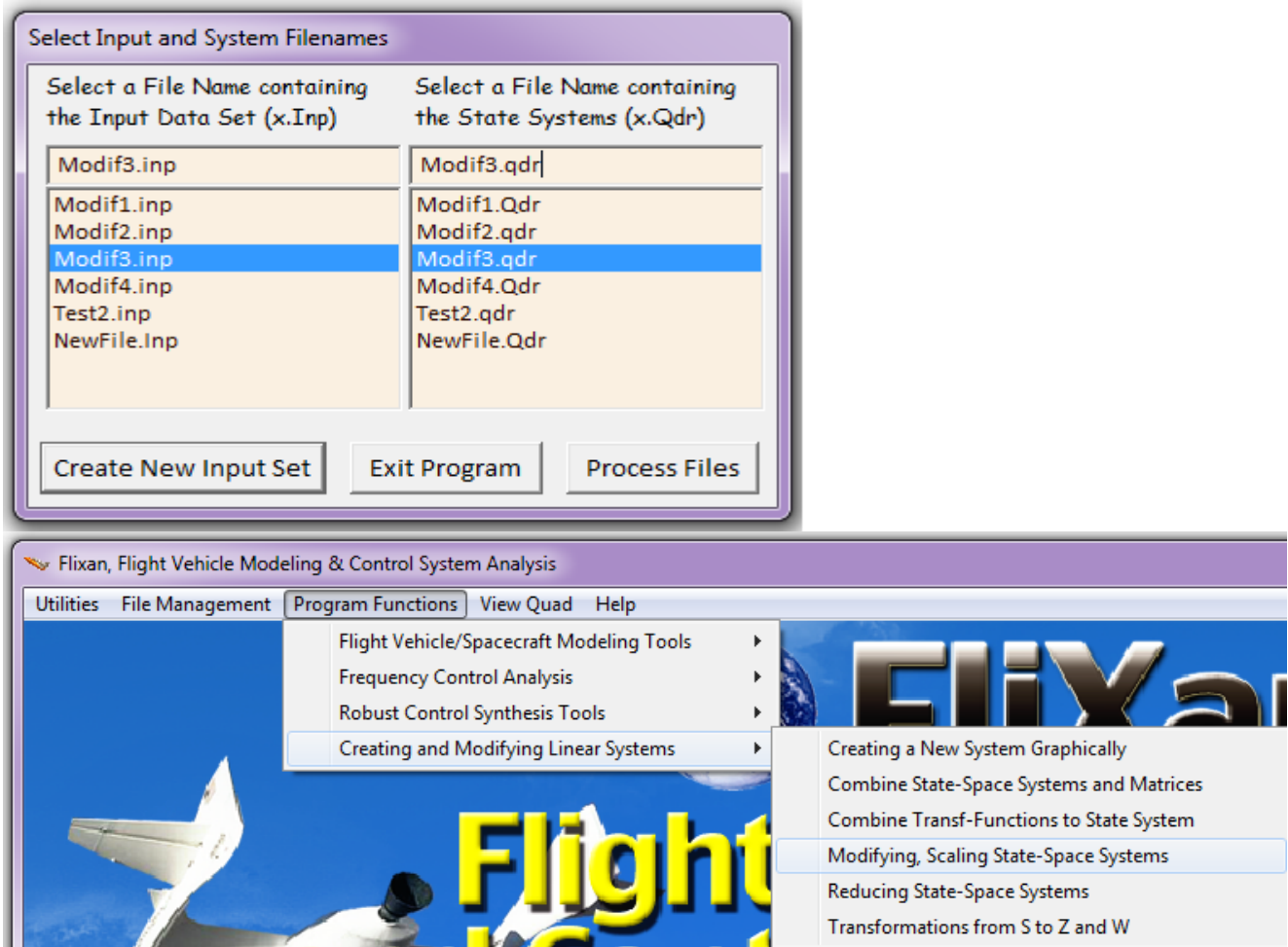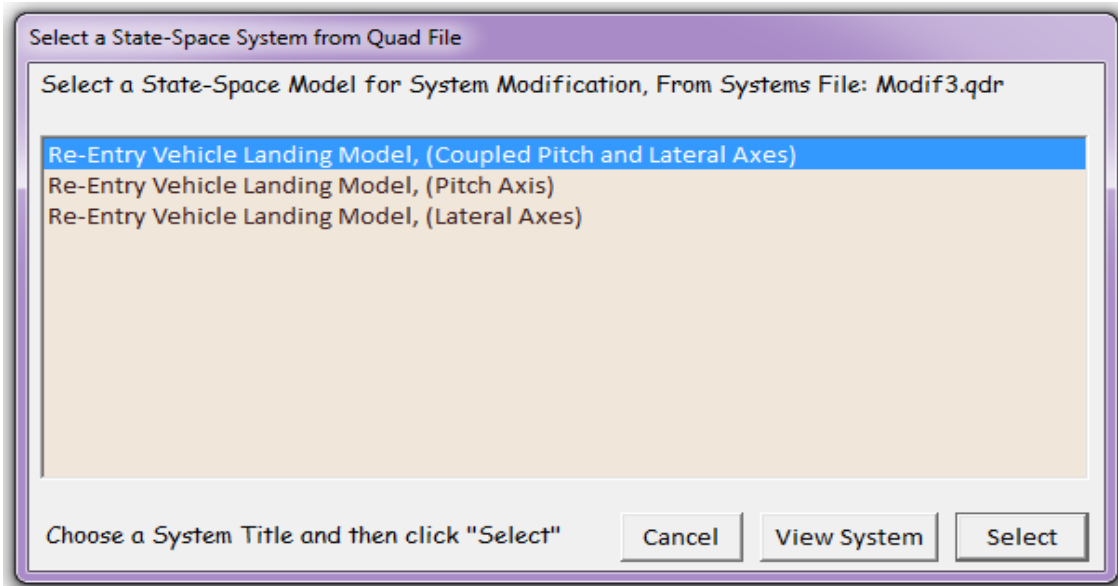
The program opens the following dialog where the user selects the type of system modification and enters the new system title, which is: *"Re-entry Vehicle, Landing Model (Pitch Axis)"*. From the menu select the first option to rescale the new system outputs. Some comments are also included in the field below, and click on "*Select Option*", as shown
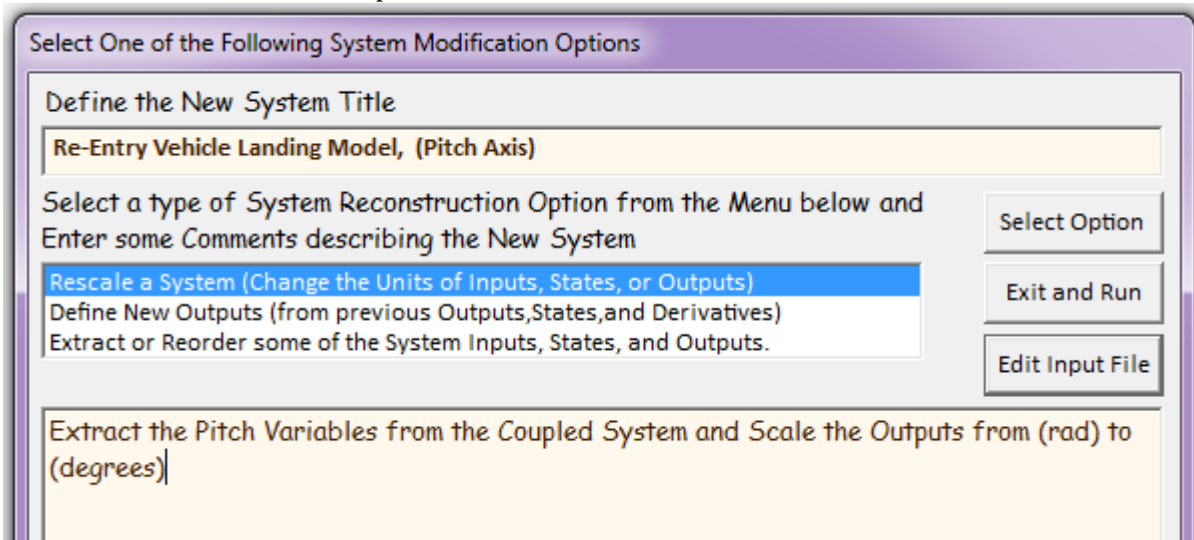
The next step is to scale the output angles. Another dialog comes up that includes three menu tabs for selecting and scaling the original system variables. Select the outputs menu tab and from there select three outputs: (#3) the pitch attitude, (#4) the pitch rate, and (#7) the angle of attack, and enter a scaling factor of 57.3 to convert them to degrees, because 1 (radian) = 57.3 (degrees). Click on "OK" every time you select and scale a variable. The variable title changes because scaling factor is included on the title right side. When you finish scaling the outputs click on "*Continue*", and the program returns to the previous dialog.

Scale System Variables

From the Original system you may Select some Inputs, States and
Outputs to be Scaled and Enter a New Title below

Re-Entry Vehicle Landing Model, (Pitch Axis)

| Scale Inputs | Scale Outputs | Scale States |

Select an Output from the Original system to be Scaled,
Enter the Scaling Factor and Click "OK"

```
Roll attitude (phi) (rads)
Roll rate (p)    (rad/sec)
Pitch attitud (thet) (rads)                    /  57.300
Pitch rate (q)   (rad/sec)                     /  57.300
Yaw attitude (psi)  (rads)
Yaw rate (r)    (rad/sec)
Angle of Attack (alpha) rads                   /  57.300
Angle of Sidesl (beta)  rads
Change in Altitude (ëh)    (feet)
Accelerat. along V (V-dot)  (ft/s^2)
CG Acceleration along x axis (ft/s^2)
CG Acceleration along y axis (ft/s^2)
CG Acceleration along z axis (ft/s^2)
```

Scale Factor   57.300   OK

New Units = Old Units / Scale Factor   Continue

From the systems modification options menu, this time we choose the third option "*Extract or Reorder*" to extract the variables that we want to retain in the new pitch system, and click on "Select Option". A new dialog comes up that includes three menu tabs for extracting from the original system inputs, states, and outputs.

Select One of the Following System Modification Options

Define the New System Title

Re-Entry Vehicle Landing Model, (Pitch Axis)

Select a type of System Reconstruction Option from the Menu below and
Enter some Comments describing the New System   Select Option

Rescale a System (Change the Units of Inputs, States, or Outputs)   Exit and Run
Define New Outputs (from previous Outputs,States,and Derivatives)
Extract or Reorder some of the System Inputs, States, and Outputs.   Edit Input File

Extract the Pitch Variables from the Coupled System and Scale the Outputs from (rad) to
(degrees)

Using this system variables dialog and by selecting the appropriate menu tabs, we can extract the desired inputs, states and outputs for the pitch model, from the original system variables. From the 5 original system inputs we select 3: the elevon deflection, the body flap deflection, and the wind gust velocity. From the 10 original states we select 5: pitch attitude and rate, angle of attack (α), change in altitude (dh), and change in velocity (dV). From the 13 original outputs we select 7: pitch attitude and rate, angle of attack (α), change in altitude (dh), acceleration (V-dot), CG acceleration along x axis, and CG acceleration along z axis. Click on "Continue" and the program will save the system modification instructions in file "*Modif3.Inp*", process it, create the pitch system and save it in file "*Modif3.Qdr*".
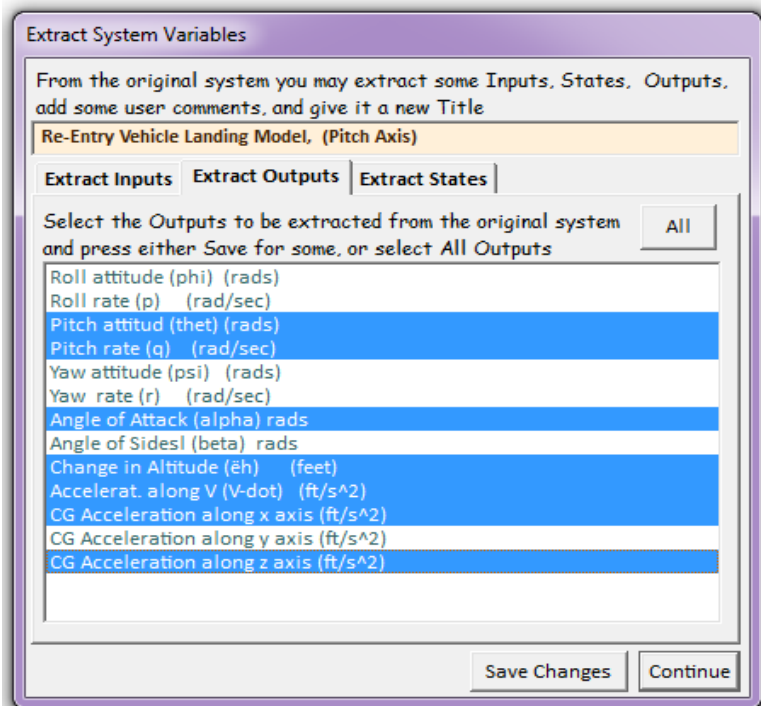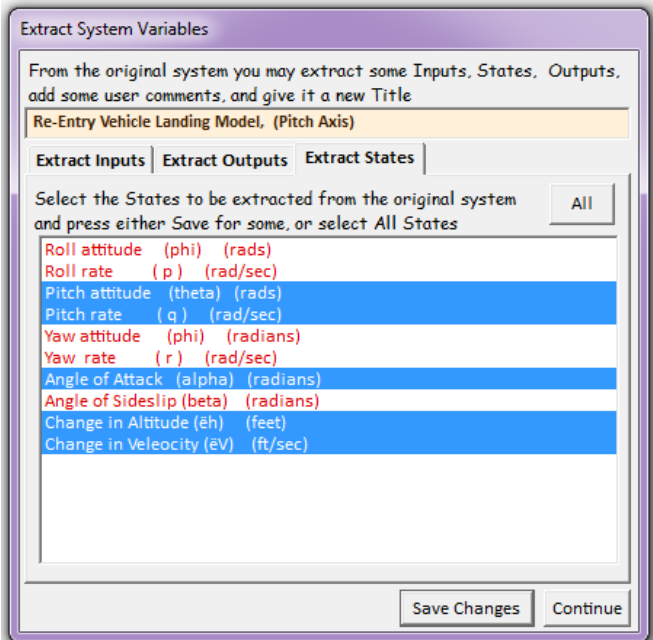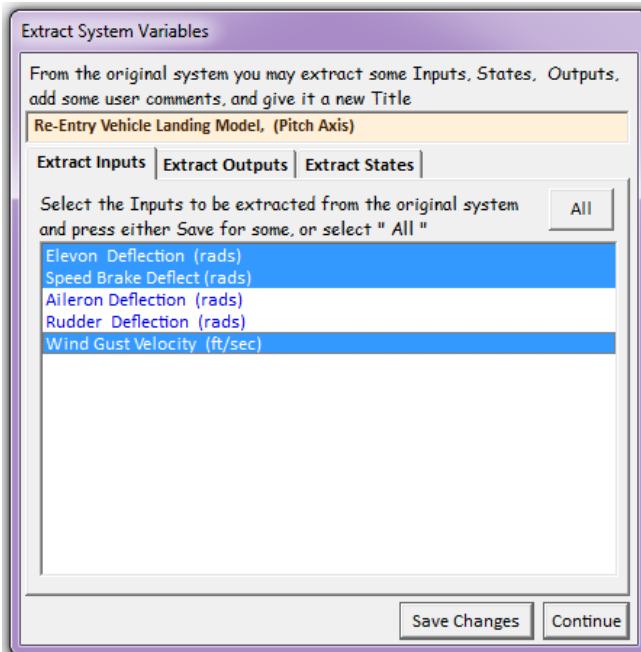
The extraction of the lateral system from the original system is very similar with the pitch axis. The lateral system consists of 2 Inputs, 5 States, and 6 Outputs. The inputs are the aileron and rudder deflections in (radian). For outputs we select roll and pitch attitude and rates, the angle of sideslip (beta), and the Ny acceleration. The output angles are converted from radians to degrees. This time we will not construct the modification instructions from scratch but we will process the data-set already saved in file "*Modif3.Inp*". Its title is "*Re-Entry Vehicle Landing Model, (Lateral Axes)"*. When the program gets to the point of selecting the filenames, this time click on "*Process Files*". The following menu shows the titles of the system modification sets in file "*Modif3.Inp*". Select the title of the second set which extracts the lateral model and click on "*Run Input Set*" to process the data. The extracted lateral system with the scaled outputs will be saved in file "*Modif3.Qdr*".
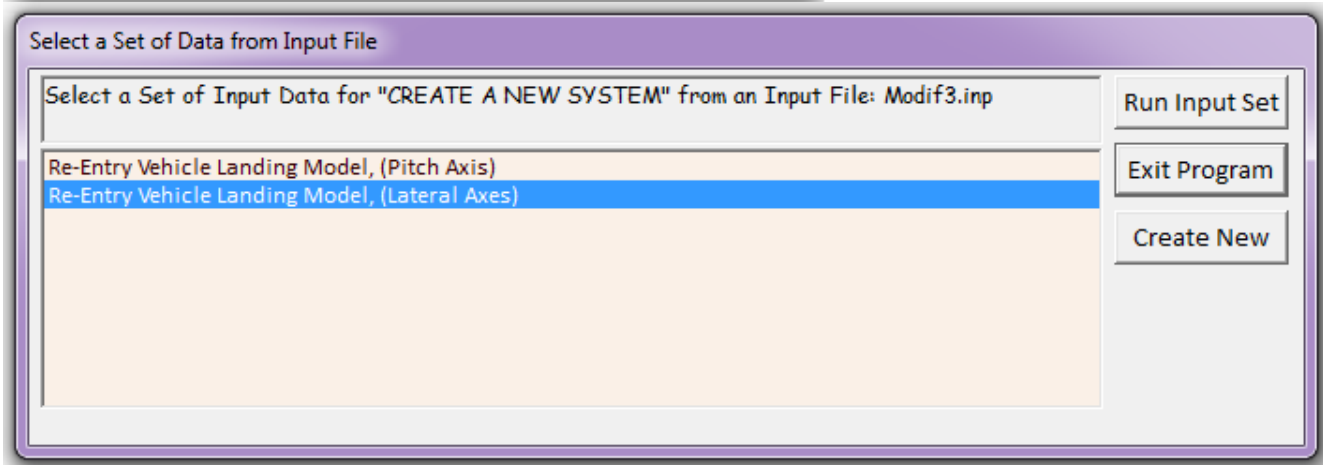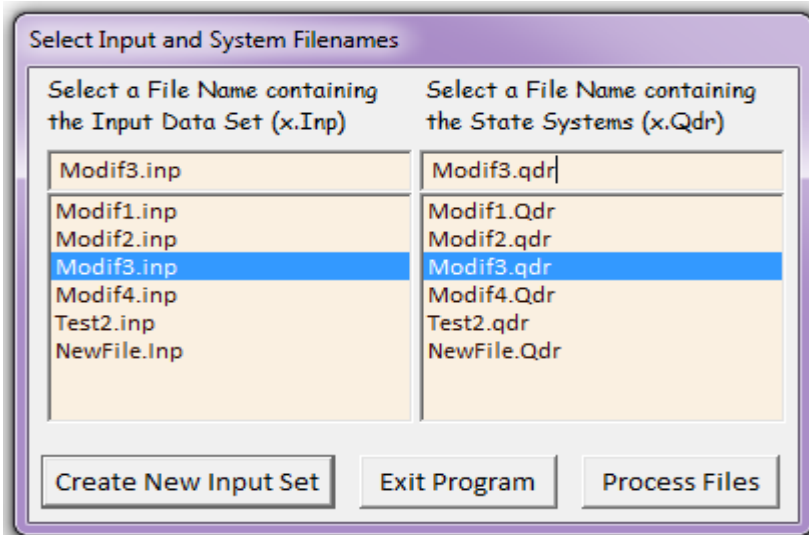
The input file "*Modif3.Inp*" is shown below. It includes the two pitch and lateral subsystem extraction data-sets. There is also a batch set included for processing the file in batch.

```
--------------------------------------------------------------------------------
      Flight Vehicle Landing Model
      Pitch and Lateral Decoupling Example
--------------------------------------------------------------------------------
BATCH MODE INSTRUCTIONS ...............
Batch for separating a flight vehicle model to Pitch and Lateral
! The original system is a Shuttle Landing model that includes both pitch and lateral
! dynamics. This system will be separated to two subsystems: a pitch subsystem and a
! lateral subsystem. The subsystem outputs are scaled from (radians) to (degrees)
!
Retain System    : Re-Entry Vehicle Landing Model, (Coupled Pitch and Lateral Axes)
System Modificat : Re-Entry Vehicle Landing Model, (Pitch Axis)
System Modificat : Re-Entry Vehicle Landing Model, (Lateral Axes)
-----------------------------------------------------------------------------------------
CREATE A NEW SYSTEM FROM AN OLD SYSTEM (Titles of the New and Old Systems)
Re-Entry Vehicle Landing Model, (Pitch Axis)
Re-Entry Vehicle Landing Model, (Coupled Pitch and Lateral Axes)
! The original system consists of the coupled (pitch and lateral)
! dynamics of a flight vehicle. We will use the system extraction
! program to extract the pitch variables in a separate pitch systems
! The Pitch System consists of: Inputs: (1, 2, &  5),
! States: (3, 4, 7, 9, & 10), and Outputs:(3, 4, 7, 9, 10, 11, & 13)
! The output angles must first be converted from radian to degrees
RESCALE A SYSTEM, CHANGE THE UNITS OF INPUTS/STATES/OUTPUTS
Rescale Outputs:  3     4      7
Scaling Values :  57.3  57.3  57.3
TRUNCATE OR REORDER THE SYSTEM INPUTS, STATES, AND OUTPUTS
Extract Inputs :  1,   2,   5
Extract States :  3,   4,   7,   9, 10
Extract Outputs:  3,   4,   7,   9, 10, 11, 13
-----------------------------------------------------------------------------------------
CREATE A NEW SYSTEM FROM AN OLD SYSTEM (Titles of the New and Old Systems)
Re-Entry Vehicle Landing Model, (Lateral Axes)
Re-Entry Vehicle Landing Model, (Coupled Pitch and Lateral Axes)
! We will use the system extraction program to extract the lateral variables
! The Lateral System consists of: Inputs: (3, 4),
! States: (1, 2, 5, 6, & 8), and Outputs:(1, 2, 5, 6, 8, & 12)
! The output angles must first be converted from radian to degrees
RESCALE A SYSTEM, CHANGE THE UNITS OF INPUTS/STATES/OUTPUTS
Rescale Outputs:  1     2     5     6     8
Scaling Values :  57.3  57.3  57.3  57.3  57.3
TRUNCATE OR REORDER THE SYSTEM INPUTS, STATES, AND OUTPUTS
Extract Inputs :  3,   4
Extract States :  1,   2,   5,   6,   8
Extract Outputs:  1,   2,   5,   6,   8, 12
-----------------------------------------------------------------------------------------
```

4.0 Utilities for Exporting data to Matlab and Importing data from Matlab

The Flixan program includes utility functions that convert Flixan data to Matlab format and also read data from Matlab generated files. The "Matlab exporting" utility reads matrices or state-space systems from systems files (.Qdr) and converts them into Matlab "ascii" matrices (.Mat) or m-file functions (.m), where they can be loaded into Matlab. The "from Matlab " importing utility reads Matlab "ascii" matrices (.Mat) and saves them in a systems file (.Qdr), either as a state-space system or as individual matrices using names other than [A,B,C,D], which identify a system. The Matlab data are not necessarily located in the same directory folder as the Flixan data. The user is prompted to specify separate directories, one for the data files used for the Flixan analysis, and a separate directory for the Matlab analysis containing the Simulink files (.Mdl), m-files (.m), and Matlab matrices (.Mat). The Flixan project directory is selected first. Then go to the Flixan main menu and click on "*Utilities*" to select the Matlab conversion utilities, as shown.
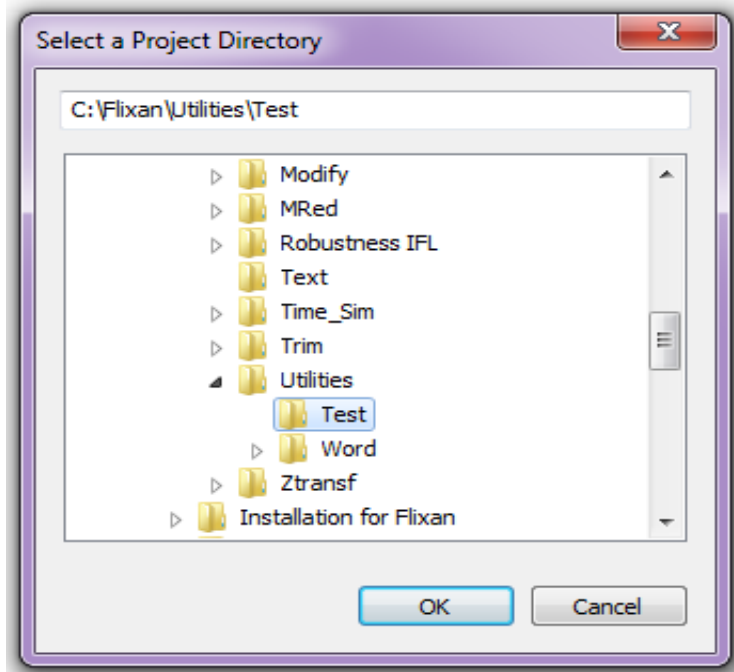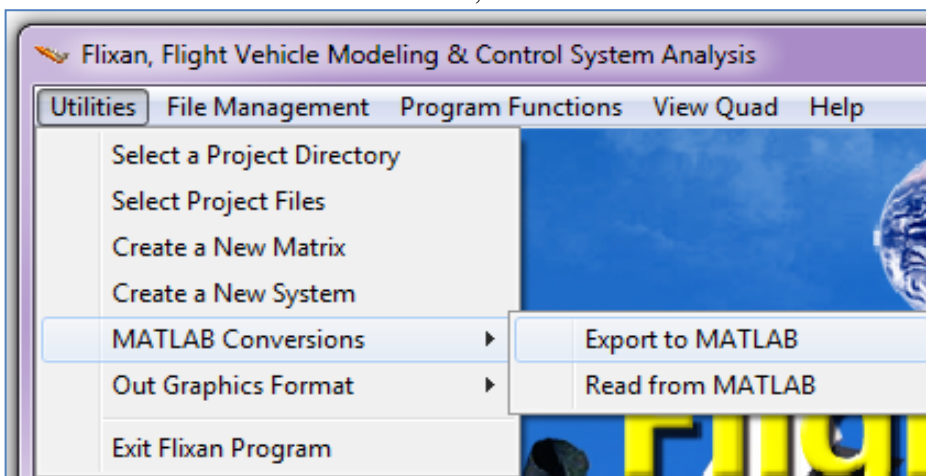
4.1 Exporting Data from Flixan to Matlab

To convert systems or single matrices from Flixan files to Matlab format, go to "*Matlab Conversions*" and select "*Export to Matlab*". This will open a systems filename (.Qdr) selection menu where the user selects a systems file. This file contains the data to be exported to Matlab. The program also asks the user to select the Matlab destination directory which may be different from the location of the systems file.
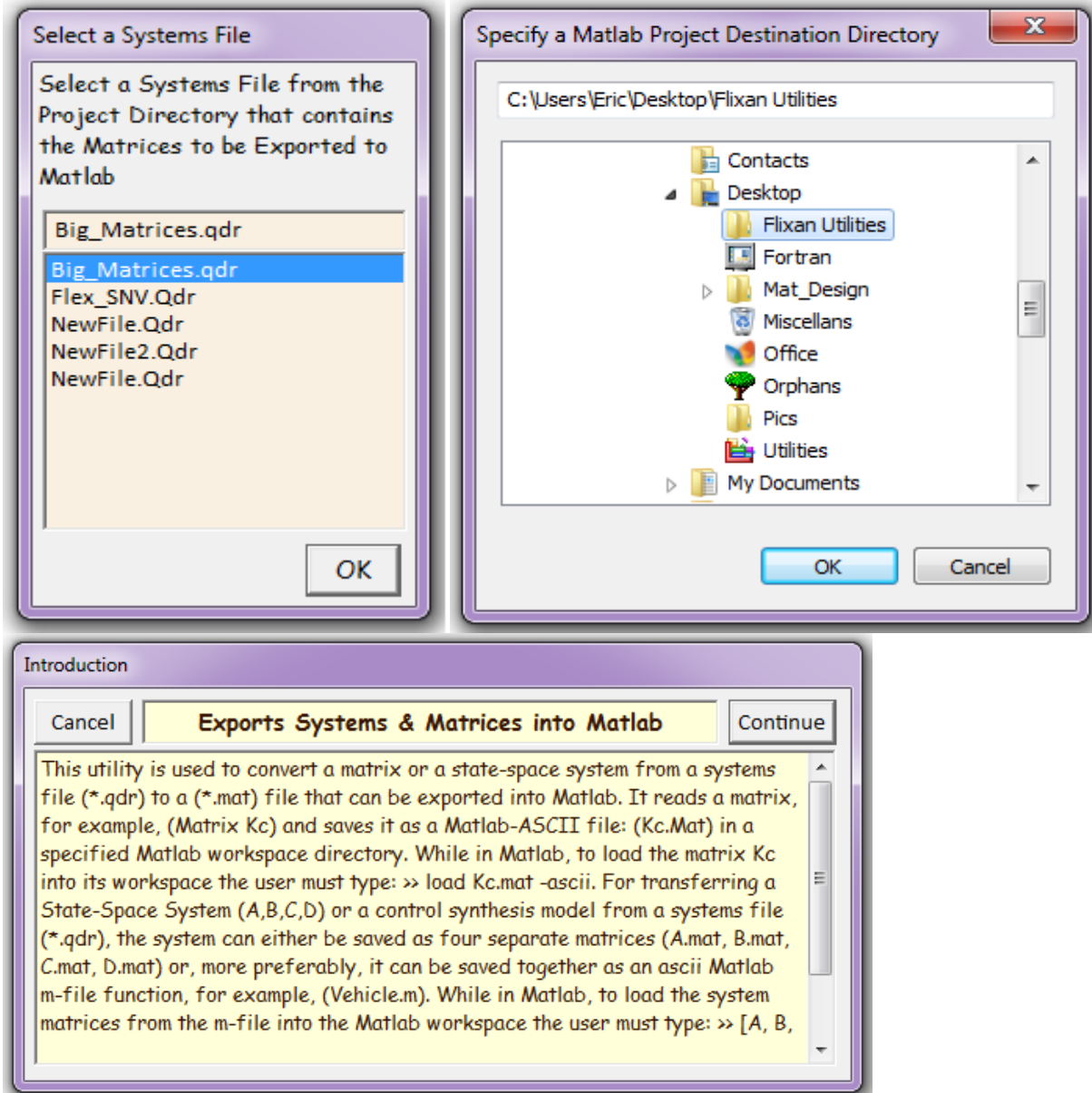
A Matlab exporting dialog comes up from where the user has a choice to select between three different types of data to be transferred from the systems file to Matlab format: (a) a single gain matrix (other than A, B, C, D), (b) a state-space system [A, B, C, D], and (c) a synthesis model for H-infinity control design [A, B1, B2, C1, C2, D11, D12, D21, D22]. The user can also select the Matlab output format: either as "ascii" matrix files (.mat), or as function that includes several matrices in a single function m-file (.m). There is a third choice where the user may wish to save the "To Matlab" instructions data-set in the input file. This data-set can be used for reprocessing the input file in batch mode.

Exporting a Matrix

If the input data is a single matrix it will be converted into a Matlab (.mat) ascii file. The filename is the same as the matrix name in the (.Qdr) file. For example, if the matrix name was "Kmix2" in the systems file it will be saved as "Kmix2.mat" in the Matlab folder. The matrix to be transferred is selected from a menu that includes all the individual matrices, other than (A, B, C, D), which are saved in the selected systems file. The matrix name, a short description, and its size appear in the menu.
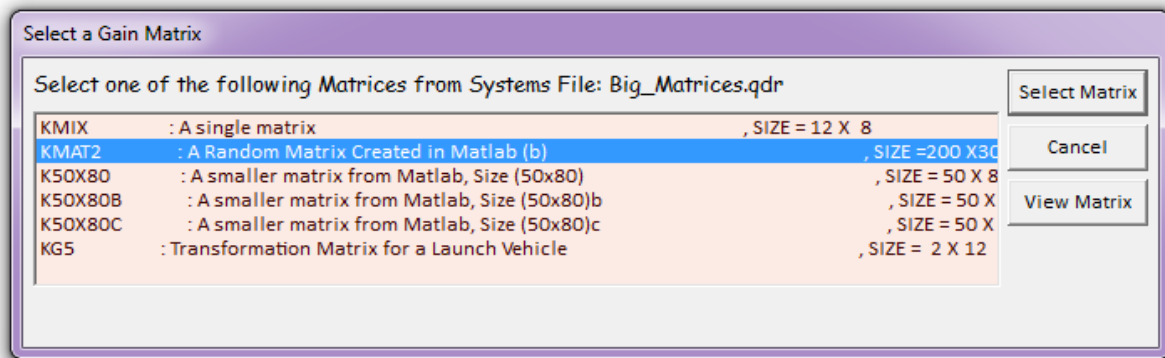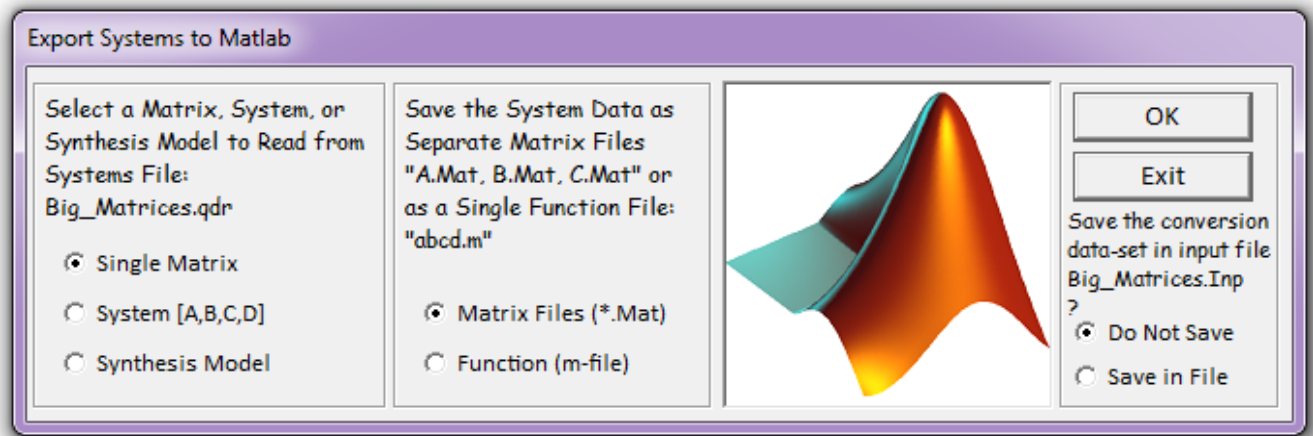
Exporting a System

From the Matlab exporting dialog we have the choice to save the four state-space matrices either as individual matrices (A.mat, B.mat, C.mat, D.mat) or as a system function (m-file). In this example we select to save them as a function m-file, and click on "OK".
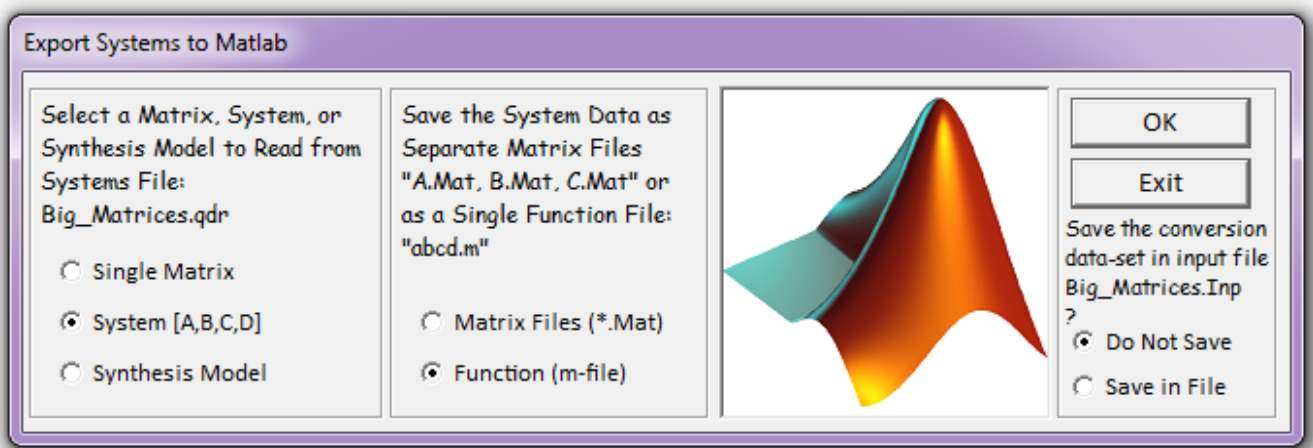
The following systems menu comes up showing the systems already saved in the selected file. From this menu we must select one of the systems to be converted. The utility reads the four system matrices and the system title from the (.Qdr) file. The exported data will be saved as an m-file in this case. We must also enter a name for the function m-file that will receive the system data, for example, "Control_System" or "Flight_Vehicle". The extension ".m" is added at the of the name, for example, "Control_System.m". The m-file will be saved in the selected Matlab directory. In case of a control synthesis model the process is similar to the quadruple state-space model except that there are nine matrices being defined there instead of four. The m-file function in this case contains all nine matrices.
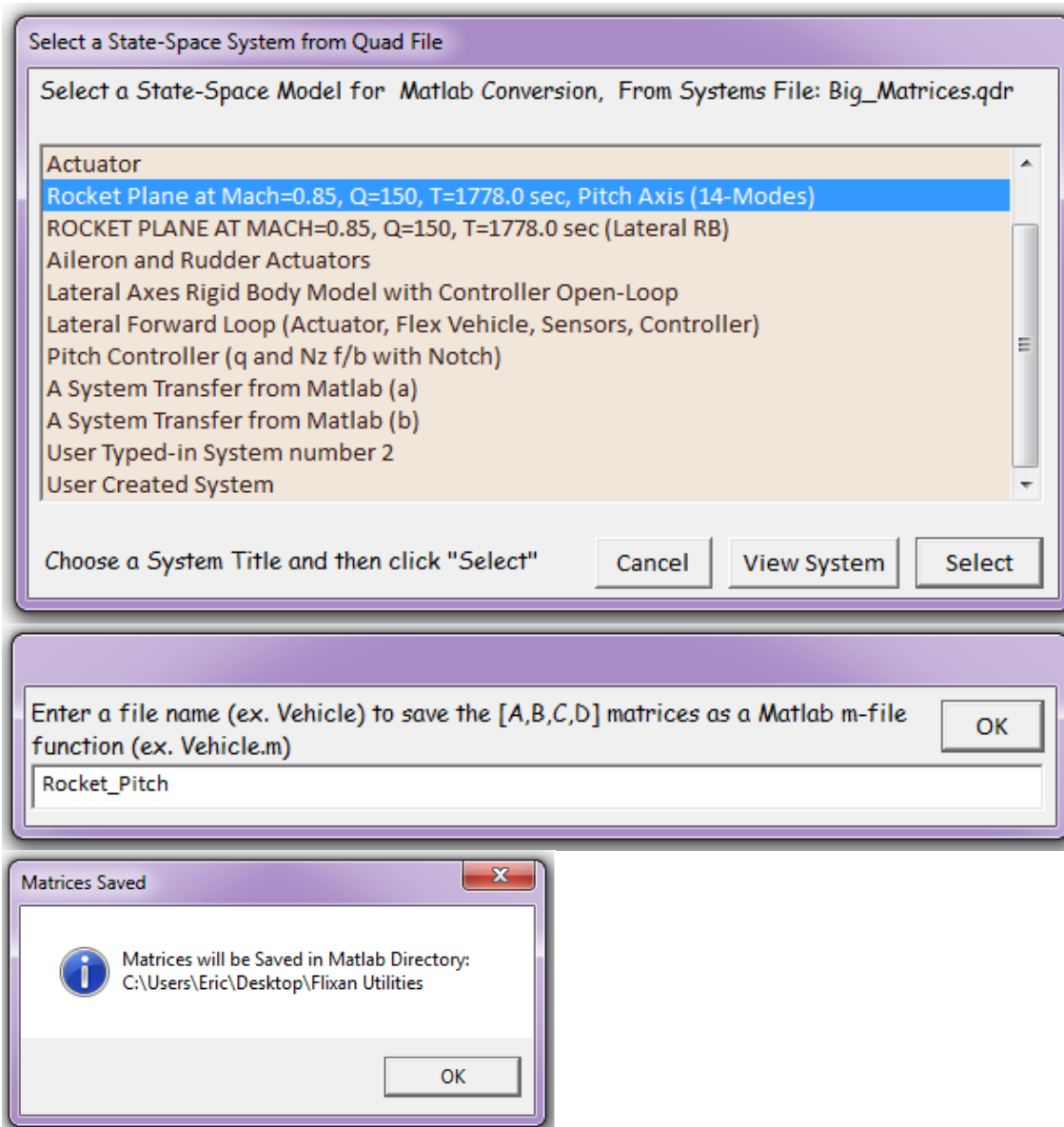
4.2 Loading the Flixan Data in Matlab Workspace

The next step is to load the matrix or system to Matlab workspace. Start Matlab, change directory and go to the folder that contains the Matlab matrices or m-files. To load a ascii matrix file, for example "Kc2.mat", from the Matlab command prompt you must type the following command

>> load Kc2.mat -ascii

and the matrix Kc2 will be added in the Matlab workspace. If the data is a state-space system described by four separate ascii matrix files [A.mat, B.mat, etc], you may load each matrix separately, as follows:

```
>>load A.mat -ascii    % will become matrix A in Matlab workspace
>>load B.mat -ascii    % will become matrix B in Matlab workspace
>>load C.mat -ascii    % will become matrix C in Matlab workspace
>>load D.mat -ascii    % will become matrix D in Matlab workspace
```

If the system or synthesis model were saved as function m-files all matrices are in the same file. The m-file has a name (for example: pitch.m, as shown below). The same name appears inside the file and defines the Matlab function. The definitions of the state-variables, inputs, and outputs are also included in the Matlab function file. Also the system title and its comments are transferred to the function file.

```
function [Api, Bpi, Cpi, Dpi]= pitch
% X-45 Descent, Pitch Axis at Qbar=250, Mach=0.4
% The Pitch axis System is extracted from the coupled system by selecting a smaller number of
% input, state, and output variables
Api= [
   0.00000000E+00    0.10000000E+01    0.00000000E+00
   0.00000000E+00    0.00000000E+00    0.17443050E+01
   0.00000000E+00    0.10000000E+01   -0.81841860E+00];

Bpi= [
   0.00000000E+00    0.00000000E+00    0.00000000E+00
  -0.18048657E+02   -0.18430048E+01    0.24435920E-02
  -0.14332058E+00   -0.12162023E+00   -0.11790709E-02];

Cpi= [
   0.10000000E+01    0.00000000E+00    0.00000000E+00
   0.00000000E+00    0.10000000E+01    0.00000000E+00
   0.00000000E+00    0.00000000E+00    0.10000000E+01
   0.00000000E+00    0.00000000E+00   -0.44052295E+03];

Dpi= [
   0.00000000E+00    0.00000000E+00    0.00000000E+00
   0.00000000E+00    0.00000000E+00    0.00000000E+00
   0.00000000E+00    0.00000000E+00    0.13047952E-02
  -0.72512183E+02   -0.62899919E+02   -0.60757972E+00];

%  Definition of State-Space System Variables
%  Inputs  =   3
%    1     Elevon  Deflection (radians)
%    2     Flaps   Deflection (radians)
%    3     Gust, Azim Elevat Angles:(45,45 deg)

%  States  =   3
%    1     Pitch Attitude    (theta-rigid)  (radians)
%    2     Pitch Rate        ( q -rigid)    (rad/sec)
%    3     Angle of attack   (alfa-rigid)   (radians)

%  Outputs =   4
%    1     Pitch Attitude    (theta-Stabil) (radians)
%    2     Pitch Rate        ( q -Stabil)   (rad/sec)
%    3     Angle of attack   (alfa-rigid)   (radians)
%    4     CG Acceleration along Z axis, (ft/sec^2)
```

To load the state-space or synthesis model matrices the user must execute the function, as follows:

>> [Ap, Bp, Cp, Dp]= Pitch   % for a state-space system
>> [A, B1, B2, C1, C2, D11,D12,D21,D22]= Synthesis_Model   % for a SM

4.3 Saving Matlab data to Matrix Files to be Uploaded to Flixan

The systems or individual matrices created in Matlab can be uploaded and saved in Flixan. They must first be saved in Matlab as ascii (.mat) files. Then they can be converted and included in Flixan system files using the "From Matlab" utility. To save, for example, a single matrix Kmix from Matlab, as an ascii file, the user must type

save Kmix.mat Kmix -ascii   % Save it as a single file

In case of a system the four matrices can be saved from the Matlab workspace as separate matrix files (for example, A1.mat, B1.mat, etc)

save A1.mat a -ascii   % Save system in 4 separate [A,B,C,D] files
save B1.mat b -ascii
save C1.mat c -ascii
save D1.mat d -ascii

To make things more compact a system of four matrices can be exported from Matlab as a single file containing the four matrices with an additional line on the top. The first line is a single row vector with four elements containing the system dimensions. The number of inputs, states, and outputs, and also the sampling frequency if the system is discrete (zero for a continuous system). For example, the following Matlab script file generates a random system and saves it in a single file "system.mat"

```
% Program to create a random system and save it in an ascii Matlab file
Nu=8;                                % Inputs
Nx=56;                               % States
No=11;                               % Outputs
dT=0.02;                             % System Sampling Period
e=[Nu, Nx, No, dT];                  % Row vector with system dimension
a=rand(Nx,Nx)-0.6;                   % A matrix
b=rand(Nx,Nu)-0.5;                   % B matrix
c=rand(No,Nx)-0.4;                   % C matrix
d=zeros(No,Nu);                      % D matrix = 0
save System.mat e a b c d -ascii     % Save it as a single ascii file
```

The "From Matlab" utility is also capable to read control synthesis models in this format. Synthesis models consist of 9 matrices.

4.4 Transferring Matlab Generated Data to Flixan System Files

The process of reading Matlab data into Flixan system files (.Qdr) is similar. First, select the directory where the Flixan files are located and from Flixan main menu select "*Utilities*", "*Matlab Conversions*", and "*Read from Matlab*". You must also select the Matlab directory that contains the Matlab generated matrix files to be transferred. In this case shown both directories are the same. From the system filename selection menu select a systems file to save the imported matrices or systems.
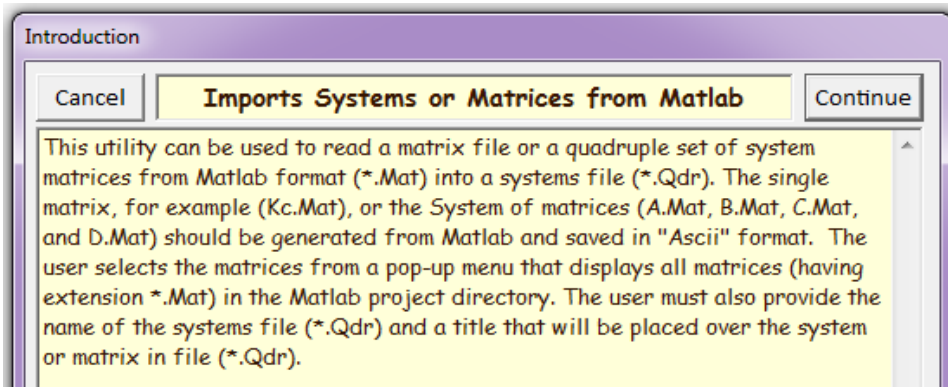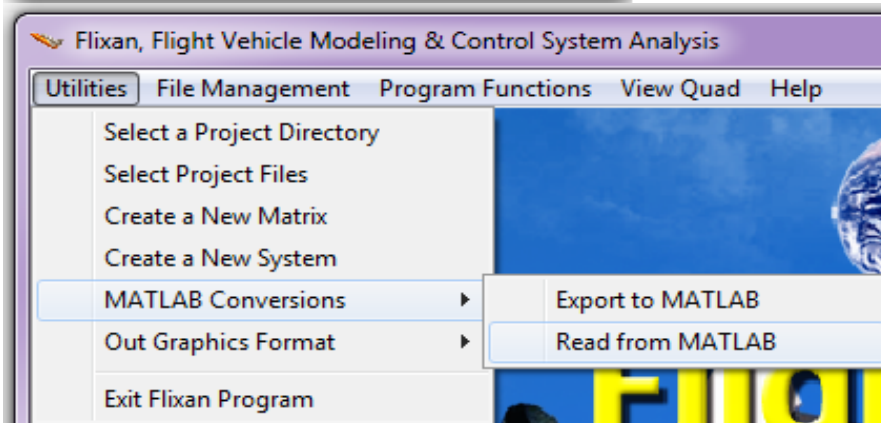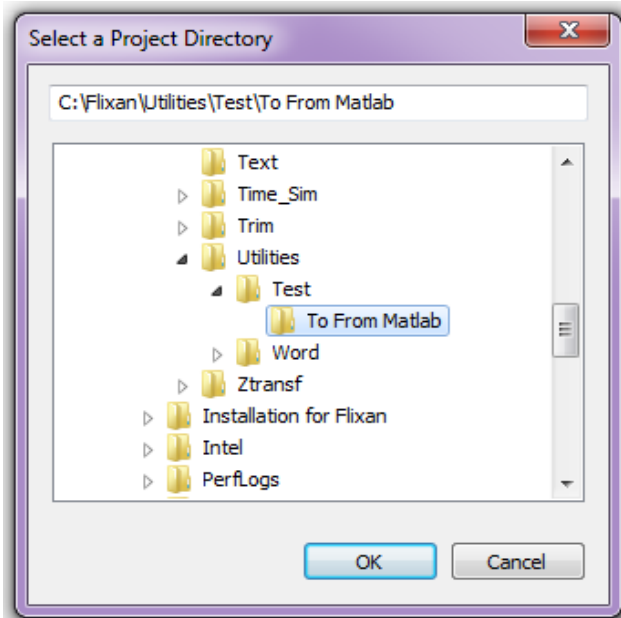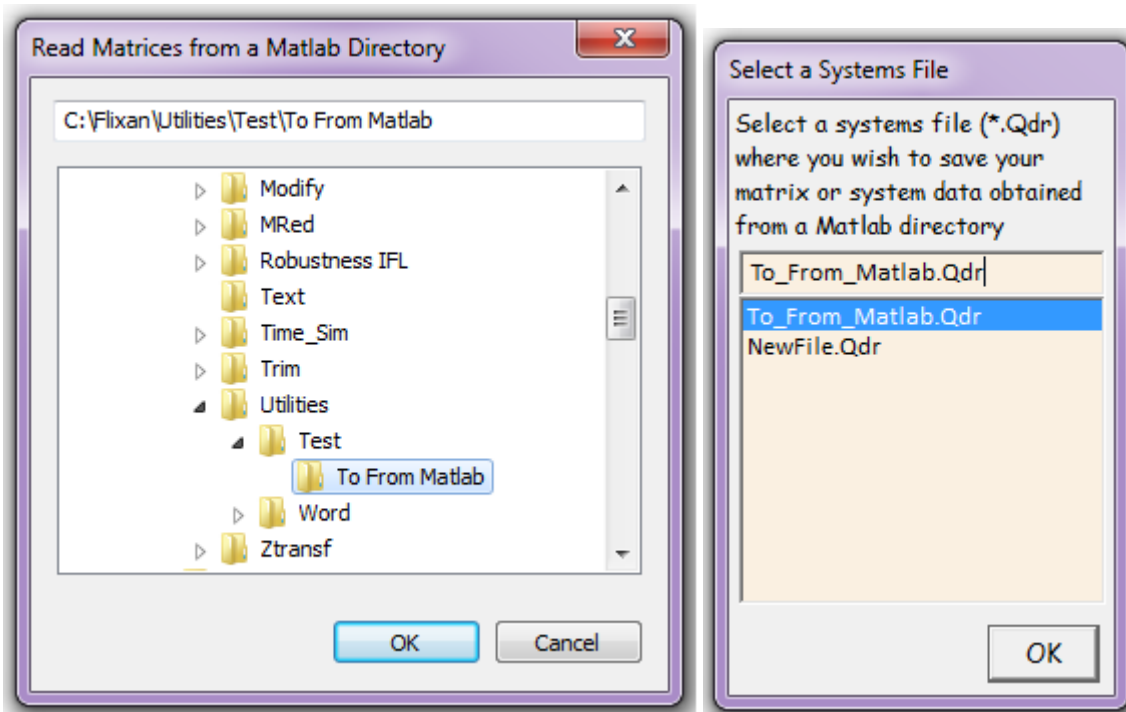
The following dialog is used to select if you want to read an individual matrix (other than A,B,C,D) or a state-space system. You must also enter a title for this system or matrix different from other elements in the systems file, and click OK. The user may also save the "From Matlab" instructions data-set in the input file. This data-set can be used for reprocessing the input file in batch mode at a later time.

Reading a Matrix from Matlab

When the input is a matrix the user clicks on "*Single Matrix*", enters its new title, and clicks on "OK". The Matlab generated matrix is expected to be a (.Mat) file in ascii format. The following menu shows all (.Mat) files located the selected Matlab folder. The user selects one of the files "Kmat.mat" in this case, which is a single matrix, and clicks on "Select File". The other two (.Mat) files are systems containing quadruple matrices. The matrix will then be saved in the selected systems file as "Matrix Kmat", under the title entered: "New Matrix Kmat Title".
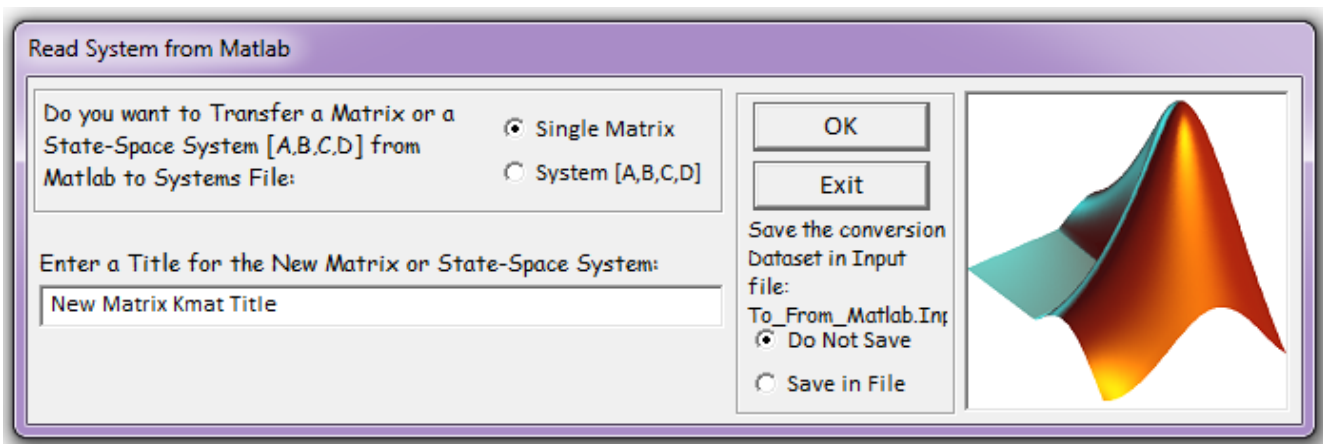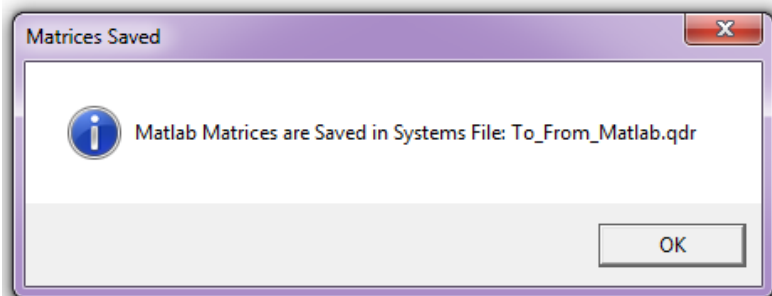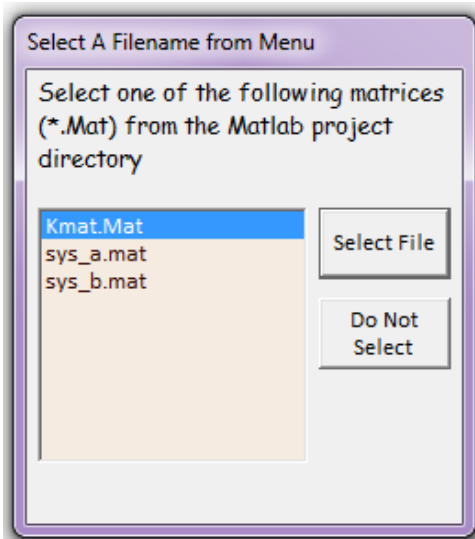
Reading a System from Matlab

When the input from Matlab is a system, the user selects "*System [A,B,C,D]*" in the read from Matlab dialog, enters its new title, and clicks on "OK". The Matlab generated system is expected to be in (.Mat) ascii format, either as four separate (.Mat) files, or as a single (.Mat) file containing all four matrices, the system inputs, states, and output dimensions, and the sampling period. The single file formatting of the four matrices was described in section 4.3. The selection between the two options is defined in the next dialog where the system's sampling period is also entered in seconds (zero for a continuous system), click OK.

From the following filename selection menu the user must select the proper Matlab generated matrix filenames (.Mat) from the Matlab folder. If the system is defined in a single file only one filename (containing all four matrices) will be selected. If the system is defined in separate matrices then four matrix filenames must be selected. In this example we have selected a single file "sys_a.mat". If the matrix dimensions are defined correctly a new system will be created in the (.Qdr) file. Otherwise, an error will occur "Matrix dimensions do not match for a system" and the program returns to the main menu. The title and the system dimensions are also included in the system data.
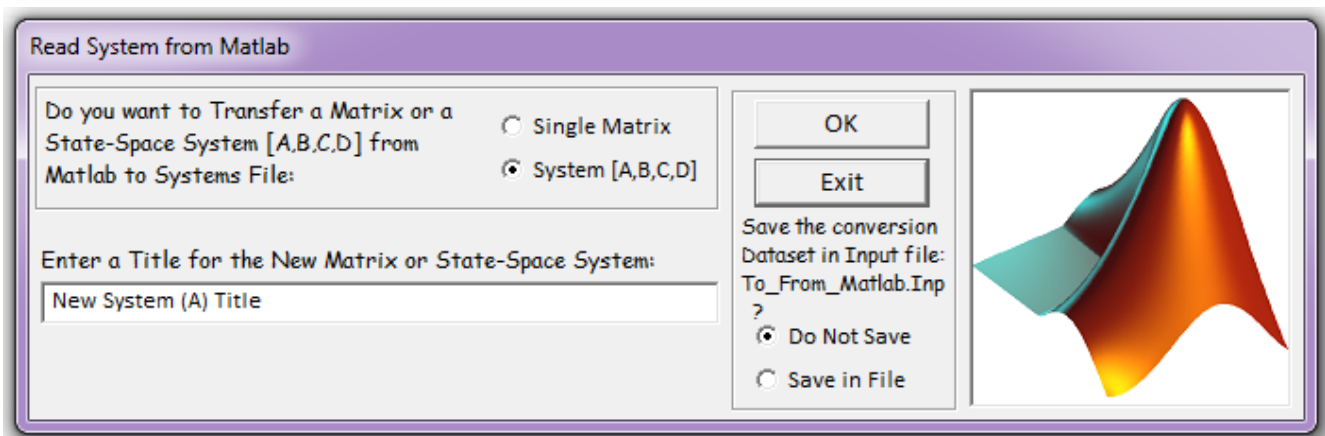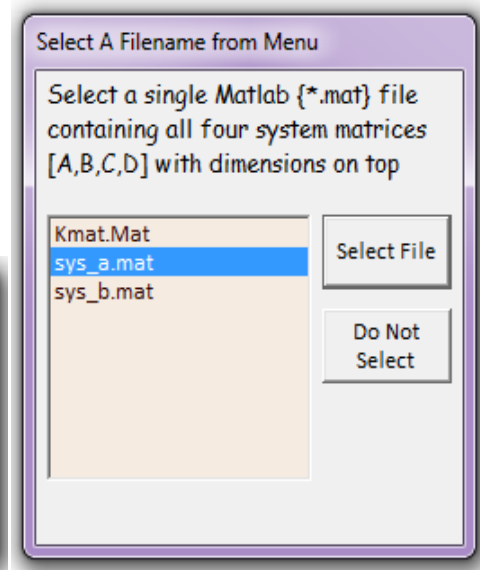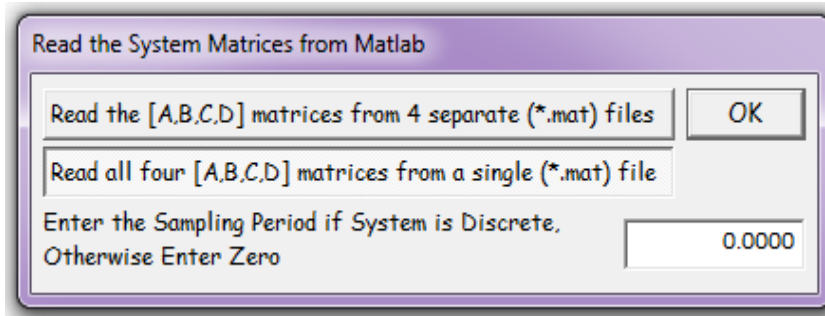
Transferring Data in Batch Mode

It is a lot easier, however, to transfer data between Flixan and Matlab programs in batch mode. In this case the transfer information is defined in an input file (.Inp) and a batch set processes the input file, as shown in the example below which is located in "*C:\Flixan\Utilities\Test\To From Matlab*". In this example we will transfer two systems and a matrix from a systems file "*To_From_Matlab.Qdr*" and load them into Matlab. Then from Matlab we will transfer them back to Flixan and save them in the same systems file under different titles. The input file "*To_From_Matlab.Inp*", is shown below. It contains data conversion sets and a batch set that processes them. The first two sets below the batch convert the two systems "*System (A)*" and "*System (B)*" from the systems file to two function m-files "sys_a.m" and "sys_b.m" that canbe loaded into Matlab. The third set converts the matrix Kmat, title: "*Matrix Kmat Title*" from the systems file to matrix "Kmat.mat" that can also be loaded to Matlab. When in Matlab the system quadruple matrices are compacted into single ascii matrices (.mat), and saved as following:

```
% Load the two systems and convert them to single matrices
[a1,b1,c1,d1]= sys_a;                  % load system (a)
[nx,nx]= size(a1);
[nr,nu]= size(d1);
e1=[nu, nx, nr, 0.0];                  % Row vector with system dimension
save sys_a.mat e1 a1 b1 c1 d1 -ascii   % Save it as a single ascii file

[a2,b2,c2,d2]= sys_b;
[nx,nx]= size(a2);
[nr,nu]= size(d2);
e2=[nu, nx, nr, 0.0];                  % Row vector with system dimension
save sys_b.mat e2 a2 b2 c2 d2 -ascii   % Save it as a single ascii file
```

The last three data conversion sets in the input file read the two systems and matrix from files "sys_a.mat", "sys_b.mat", and "Kmat.mat" and transfer them back in the systems file "*To_From-Matlab.Qdr* " using different titles.

```
BATCH MODE INSTRUCTIONS ...............
Batch for Converting Systems To and From Matlab
! Convert systems (A) and (B) to Matlab System Functions: sys_a.m, sys_b.m
! Convert Matrix Kmat from Systems file to Kmat.Mat
! Convert Matlab system of matrices sys_a.mat to a new system "New System (A)" in Flixan .Qdr file
! Convert Matlab system of matrices sys_b.mat to a new system "New System (B)" in Flixan .Qdr file
! Convert Matlab matrix Kmat.mat to a matrix title: "New Matrix Kmat", name Kmat in Flixan Qdr file
!
Retain System     : System (A)
Retain System     : System (B)
Retain Matrix     : Matrix Kmat Title
!
To Matlab Format : System (A)
To Matlab Format : System (B)
To Matlab Format : Matrix Kmat Title
!
From Matlab Form : New System (A)
From Matlab Form : New System (B)
From Matlab Form : New Matrix Kmat
-------------------------------------------------------------------------------------
CONVERT TO MATLAB FORMAT ........      (Title, System/Matrix, m-filename)
System (A)
! Convert the system "System (A)" from .Qdr file ...
! to a Matlab system function "sys_a.m"
System
Sys_A.m
-------------------------------------------------------------------------------------
CONVERT TO MATLAB FORMAT ........      (Title, System/Matrix, m-filename)
System (B)
! Convert the system "System (B)" from .Qdr file ...
! to a Matlab system function "sys_b.m"
System
Sys_B.m
-------------------------------------------------------------------------------------
CONVERT TO MATLAB FORMAT ........      (Title, System/Matrix, m-filename)
Matrix Kmat Title
! Convert the Matrix "Matrix Kmat Title from .Qdr file ...
! to a Matlab ascii matrix "Kmat.mat"
Matrix Kmat.mat
-------------------------------------------------------------------------------------
CONVERT FROM MATLAB FORMAT ......  (Title, System/Matrix, Mat filename)
New System (A)
! Converts System "sys_a.mat" from Matlab matrix file ...
! to a Flixan System "New System (A)" in .qdr file
System sys_a.mat
-------------------------------------------------------------------------------------
CONVERT FROM MATLAB FORMAT ......  (Title, System/Matrix, Mat filename)
New System (B)
! Converts System "sys_b.mat" from Matlab matrix file ...
! to a Flixan System "New System (B)" in .qdr file
System sys_b.mat
-------------------------------------------------------------------------------------
CONVERT FROM MATLAB FORMAT ......  (Title, System/Matrix, Mat filename)
New Matrix Kmat
! Converts the Matrix from Matlab file "Kmat.mat" ...
! to a Flixan Matrix Kmat, titled "New Matrix Kmat" in (.qdr) file
Matrix Kmat.mat
-------------------------------------------------------------------------------------
```

This input file can now processed in batch mode by running the batch set located on the top of the file. From the Flixan main menu select "*Edit*", then "*Manage Input Files*" and then "*Process/ Edit Input Data*". From the next dialog use the left menu to select the input file "*To_From_Matlab.Inp*" and click on "*Select Input File*". The menu on the right shows the titles of the data-sets located in this file, also the program that will process each set. Select the first title which is the batch set and click on "*Process or View Input Data*", and the batch set will process the data. The Matlab generated systems and matrix are saved in file *To_From_Matlab.Qdr*". Notice that the original systems and matrix are retained in the systems file after reprocessing. A display pos-up highlighting the batch statements as they are executing.
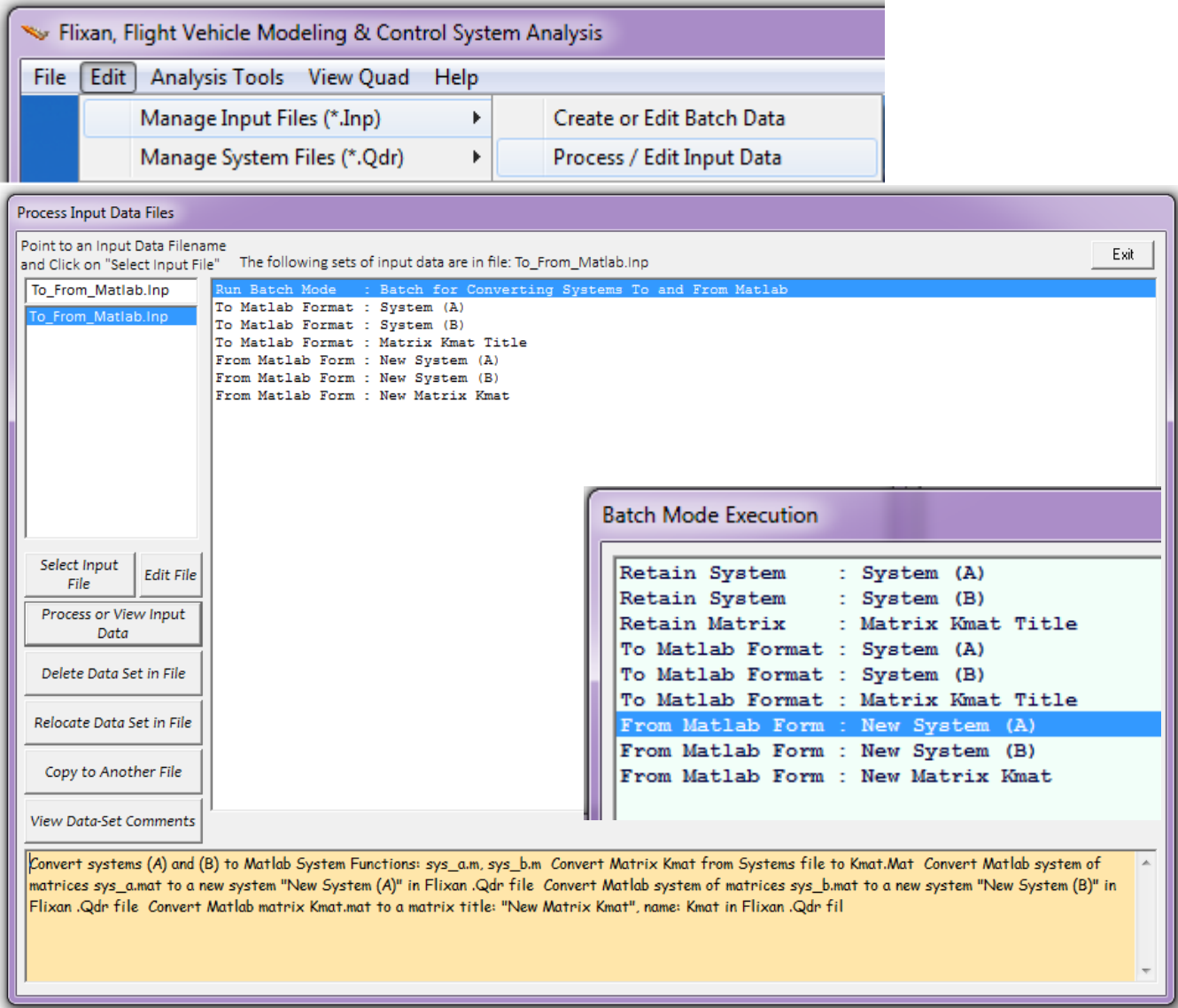
5.0 Continuous to Discrete System Transformations

This program is mainly used for transforming continuous state-space systems to discrete systems described by a set of state difference equations.

$x(k + 1) = Fx(k) + Gu(k);$

$y(k) = Hx(k) + Eu(k)$

It is also used for transforming a discrete system from the z-plane to the w-plane, and from the w-plane back to the z-plane. The program reads the state-space system data of the system to be converted from a systems file ".Qdr", the transformation instructions from an input file ".Inp", and can perform the following transforms:

- Transform a continuous system to a discrete system using the Z-transform.
- Transform a continuous system to a discrete system using the Tustin transform.
- Transform a continuous system with delays at its inputs to a discrete system using the Z-transform. The delays at the system inputs are (from 0 to δT), where δT is the sampling period.
- Transform a discrete system defined in the z-plane to a discrete system in the w-plane, and
- Transform a discrete system in the defined w-plane to a discrete system in the z-plane.
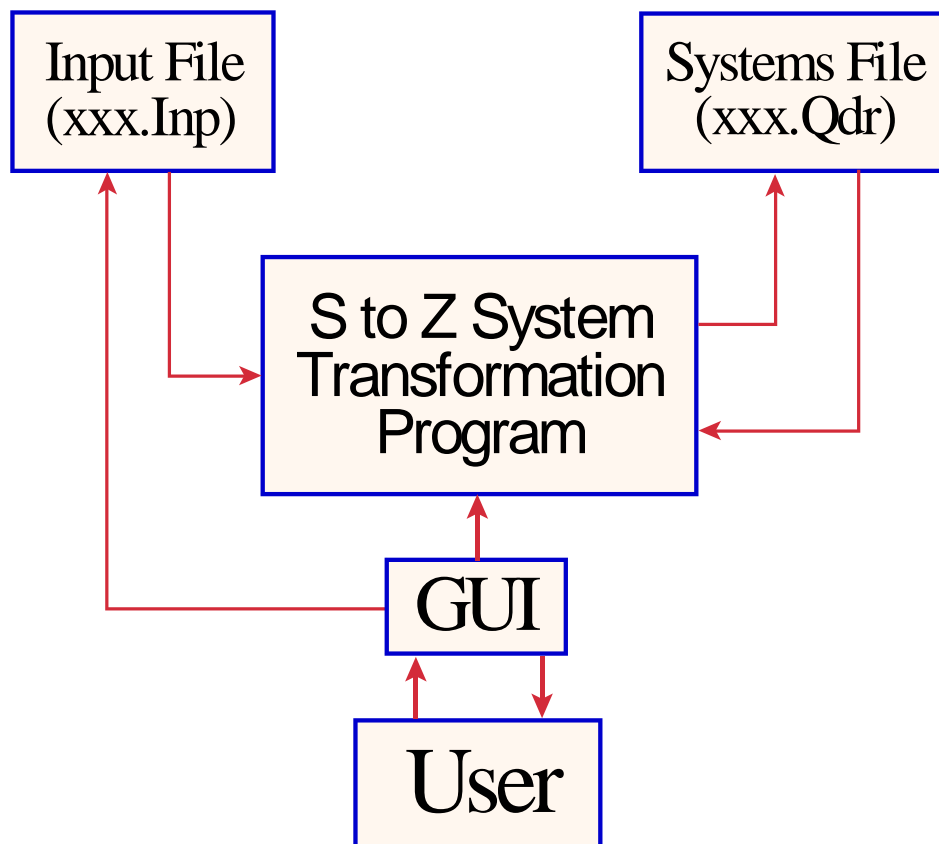
Figure (5.1) Systems S to Z to W Transformation Program

5.1 Running the Z-Transform Program

The Z-Transformation program like most Flixan programs requires two files: an input data file ".Inp" and a systems file ".Qdr". The systems file initially contains the state-space system to be transformed by the program. The transformed system will also be saved in this file by the z-transformation program. The input file contains a set of instructions defining the process, such as the one shown below. The data set first contains a line that identifies the data process: "TRANSFORM A SYSTEM (S-Z-W)". The next line is the title of the transformed new system (blue). Some comment lines (shown in green) may be included below the title. Next line is the title of the original system to be transformed (blue). The last line (black) shows the type of transformation to be performed and the sampling period (δT) of the transformed system, for example:

```
TRANSFORM A SYSTEM (S-Z-W) .... (Titles of the New and Old Systems)
Flexible System (7-Modes) (Z-Transform)
! This data-set discretizes the system "Flexible System (7-Modes)"
! The new discrete system title is "Flexible System (7-Modes) (Z-Transform)"
Flexible System (7-Modes)
From S-plane to Z-plane using the Z-Transform, dT= 0.002
-----------------------------------------------------------------
```

To run the z-transform program start from the Flixan main menu, click on "*Program Functions*", select "*Creating and Modifying Linear Systems*", and then click on "*Transformations from S to Z and W*". Then use the following filename selection dialog to select the input data and the systems files from the menus, as shown below, and click on "*Process Files*". The input file contains the system transformation instructions previously created such as the ones above. If not, they must be defined them interactively by clicking on "*Create New Input Set*".
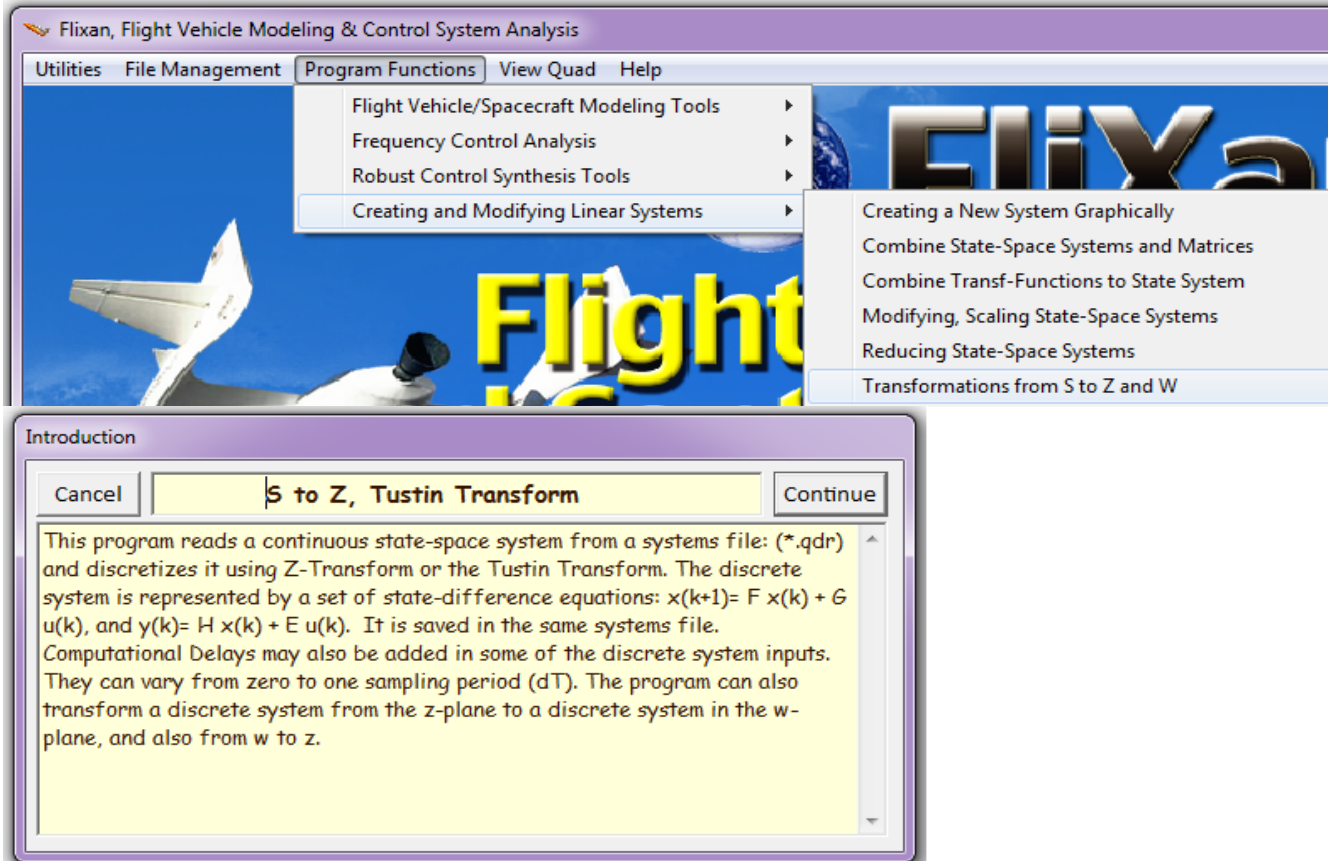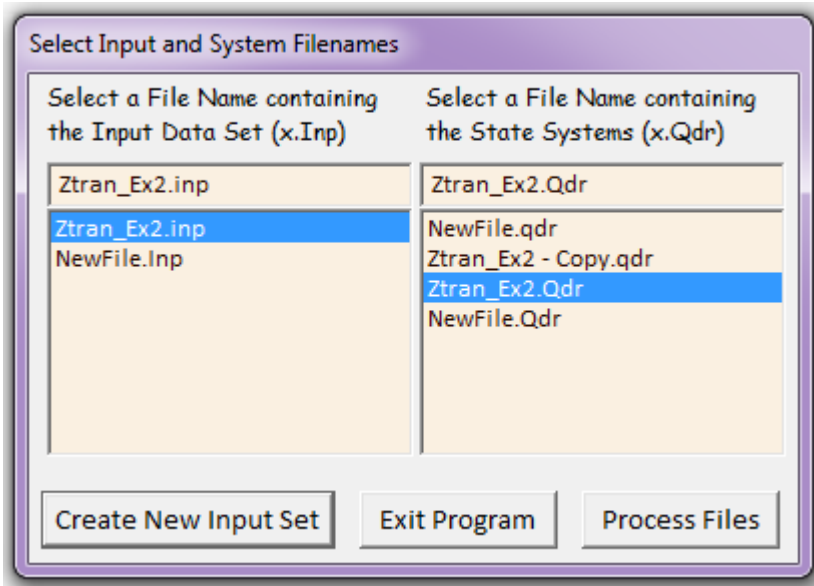
5.2 Transformation Data-Set is already Saved in the Input File

When you click on "*Process Files*" in the above menu, the program searches the input file, "*Ztran-Ex2.Inp*" in this case, and looks for data-sets containing (S-Z-W) transformation instructions, which begin with: "TRANSFORM A SYSTEM (S-Z-W)" in the top line. In this case it finds five transform sets and their titles appear in the menu below, from where the user selects one of the transform titles and clicks on "*Run Input Set*". The program reads the system to be transformed from the systems file "*Ztran-Ex2*.qdr", discretizes it at the sampling rate defined in the input set and saves the z-transformed system in the same systems file under the new title.
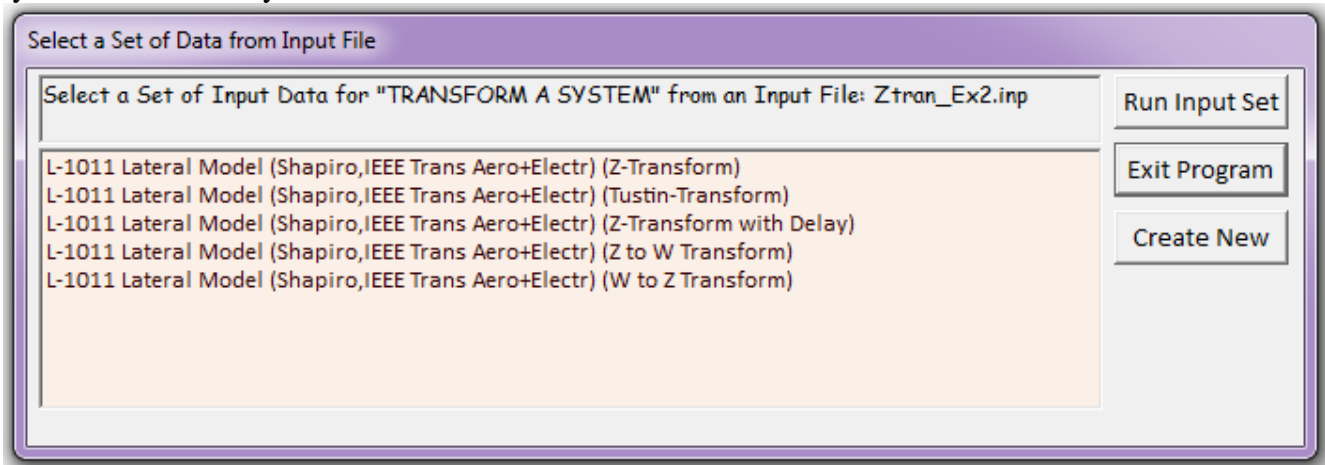
5.3 Transformation Data-Set Not Included in Input File

If the transformation data-set does not exist in the input file the user must create it interactively by entering the information and then process it. In the filenames selection menu instead of processing the files the user must click on "*Create a New Input Set*" button. At this point the program wants to know the state-space system that must be transformed from s to z. The following menu shows the titles of the systems which are already saved in file "*Ztran_Ex2.Qdr*". Most of them are already discrete, but select the first one which is a continuous s-plane system to discretize. Do not choose a discrete system unless

you want a "z to w" transformation. The program reads the state-space matrices of the selected system and it attempts to create a title for the transformed new system. Its title is similar to the original system title with a short extension at the end describing the type of transformation. The user can modify the new title as desired and click "OK".

Select a State-Space System from Quad File

Select a State-Space Model for (S-W-Z) Transformat. From Systems File: Ztran_Ex2.Qdr

L-1011 Lateral Model (Shapiro,IEEE Trans Aero+Electr)
L-1011 Lateral Model (Shapiro,IEEE Trans Aero+Electr) (Z-Transform)
L-1011 Lateral Model (Shapiro,IEEE Trans Aero+Electr) (Tustin-Transform)
L-1011 Lateral Model (Shapiro,IEEE Trans Aero+Electr) (Z-Transform with Delay)
L-1011 Lateral Model (Shapiro,IEEE Trans Aero+Electr) (Z to W Transform)
L-1011 Lateral Model (Shapiro,IEEE Trans Aero+Electr) (W to Z Transform)

Choose a System Title and then click "Select"   Cancel   View System   Select

Enter Title

Enter the Title of the Transformed System in the Field Below.   OK
It should be different from the Old Title.

L-1011 Lateral Model (Shapiro,IEEE Trans Aero+Electr) (Z-Transformed)

Select one of the Following (S - Z - W) System Transformation Options

From S-plane to Z-plane Using the Z-Transform
From S-plane to Z-plane Using the Tustin-Transform
From S-plane to Z-plane Using the Z-Transform (with Delays at the Inputs)
Transform a Discrete System from Z-plane to W-plane
Transform a Discrete System from W-plane to Z-plane

Discrete System Sampling Period (dT) in seconds   0.01   OK

Finally, the program wants to know what type of transformation to perform on the selected continuous system. The above menu shows the transform options. Choose the first option which is a "*from s to z transformation*", enter a 10 msec sampling period (δT), as shown, and click "OK". The new set is then added to file "*Ztran_Ex2.Inp*", and the transformed new system is added at the bottom of file "*Ztran_Ex2.Qdr*" using the new title. The new system's title is the same as the original title with a short extension at the end of the title which identifies the transformation.

91

5.4 Types of Transformations

The program basically uses two methods to discretize a continuous system. The z-transform and the Tustin transformation methods. A third option that ads delays at the system inputs is also included.

S to Z via the Z-Transform

A continuous state-space system (A, B, C, D) can be transformed to a discrete system described by a set of state difference matrices (F, G, H, E) using the following z-transformation.

$$F = e^{At} \; ; \qquad G = \left(e^{At} - I\right)A^{-1}B \; ; \qquad H = C \; ; \qquad E = D$$

The program uses the following equation to calculate the matrix exponential $\{ e^{AT} \}$.

$$e^{At} = \left(I + e^{-At}\right)^{-1}\left(I + e^{At}\right)$$

$$e^{At} = \left(I - \frac{AT}{2} + \frac{(AT)^2}{4} - \frac{(AT)^3}{12}\right)^{-1}\left(I + \frac{AT}{2} + \frac{(AT)^2}{4} + \frac{(AT)^3}{12}\right)$$

S to Z via the Tustin-Transform

The second method used for transforming a continuous state-space system (A, B, C, D) to a discrete system described in terms of state difference matrices (F, G, H, E) is the Tustin transformation described by the following equations.

$$F = F_1^{-1}F_2 \; ; \qquad\qquad G = 2F_1^{-2}\left(\frac{BT}{2}\right)$$

$$H = C; \qquad\qquad E = D + CF_1^{-1}\left(\frac{BT}{2}\right) \; where$$

$$F_1 = \left(I - \frac{AT}{2}\right) \qquad\qquad F_2 = \left(I + \frac{AT}{2}\right)$$

Z-Transform of a System with an Input Delay

This option is used for including additional delays (δ) sec at the inputs of a system, where the delays are less than one sampling period ($\delta < T$). It requires that the system be z-transformed at two different rates. Figure (5-2) is a timing diagram showing an input/output sequence of a discrete system with a delay (δ). The system's output and state equations are shown below. The state vector propagation is described in two steps:

$$y(n) = \qquad C\,x(n) \qquad\qquad +D\,u(n-1)$$
$$x(n+\delta) = \qquad \Phi(\delta)\,x(n) \qquad\qquad +\Gamma(\delta)\,u(n-1)$$
$$x(n+1) = \qquad \Phi(T-\delta)\,x(n+\delta) \qquad +\Gamma(T-\delta)\,u(n)$$

The matrices $\Phi(.)$ and $\Gamma(.)$ are the discrete system's state transition matrix and input matrix. This approach is implemented by z-transforming the continuous system at two different sampling rates: at (δ), and at (T-δ) seconds. By combining the state difference equations and augmenting the state vector, the discrete system with the computational delay can be expressed by the following augmented state-space representation.

$$\begin{bmatrix} x(n+1) \\ u(n) \end{bmatrix} = \begin{bmatrix} \Phi(T) & \Gamma(T) \\ 0 & 0 \end{bmatrix} \begin{bmatrix} x(n) \\ u(n-1) \end{bmatrix} + \begin{bmatrix} \Gamma(T-d) \\ I \end{bmatrix} u(n)$$

$$y(n) = \begin{bmatrix} C & D \end{bmatrix} \begin{bmatrix} x(n) \\ u(n-1) \end{bmatrix} \quad where$$

$$\Phi(T) = \Phi(T-\delta)\Phi(d) \quad and \quad \Gamma(T) = \Phi(T-\delta)\Gamma(d)$$

When the z-transform option with delay is selected the program opens the following dialog and asks for the transport delay (δ), in addition to the sampling period (T). The delay (δ) must be less than (T). Note, that for delays which are multiple to one sampling period (nT) they can be implemented using discrete transfer functions { z^{-n} } in series with the z-transformed system, see example 1 below.
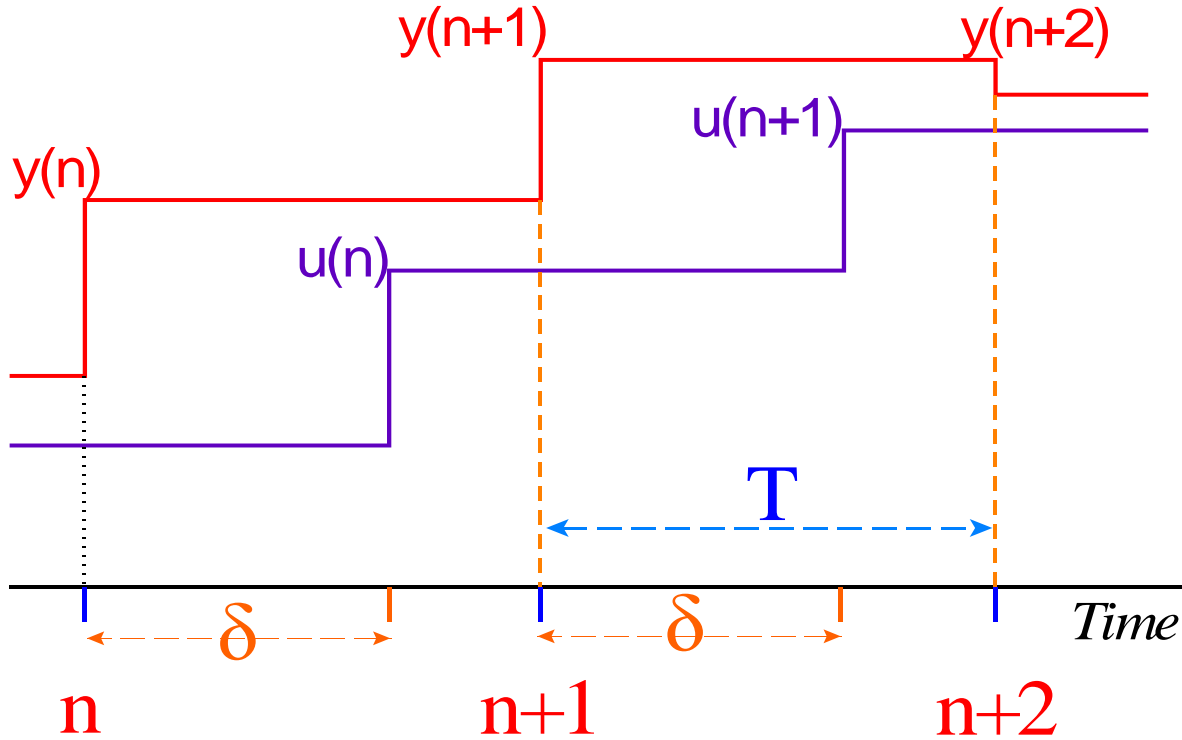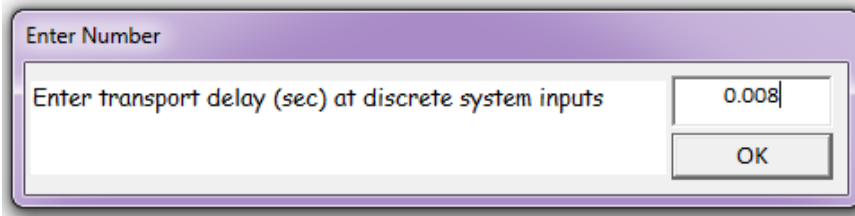
Figure (5.2) Input/ Output Timing Diagram

93

5.5 More Z-Transform Examples

The following examples demonstrate some more applications of the Z-transform program. The first example uses a model of a lightly damped structure. The second example is a lateral model of a Lockheed 1011 aircraft. The third example is a model of the Shuttle vehicle during ascent which includes structural flexibility and fuel sloshing.

Flexible Plate

The first example is a SISO model of a flexible plate consisting of seven flex resonances. The input to this model is force at a certain location perpendicular to the surface and the output is acceleration at a different location. This system is in file:*"Ztran_Ex1.Qdr"*, located in folder "*C:\Flixan\Ztransf\ Examples\Ex-1*", and its title is: *"Flexible System (7-Modes)"*. The transformations to be performed are already defined in the input file*"Ztran_Ex1.Inp"*, shown below. The z-transform program will be used to discretize this system using the three options: (a) Z-Transform, (b) Tustin Transform, and (c) Z-Transform with delay. An additional system is created by combining the z-transformed system with one sample delay in series. We will then analyze the three discrete systems by comparing their frequency responses against those of the continuous system. Similar transformations are performed for TVC engine actuator model located in the same files. The input file for this example is shown below and it will be processed in batch mode. The transformed new systems are also converted into Matlab format for further analysis.

```
BATCH MODE INSTRUCTIONS ...............
Batch for discretizing two continuous systems with various delays
! This batch discretizes a continuous system with flex modes and introduces a delay
! of one sampling period at its input. It discretizes also the system using the Tustin
! transform, and also using the z-tansform with a delay of 3/4 (dT). The discretized
! systems are then compared using frequency response analysis.
!
! This batch also calculates three types of discretizations for an actuator model using a
! sampling period of 2 msec.
!
Retain System    : Flexible System (7-Modes)
Retain System    : TVC Engine Actuator Example ...
!
!               FLEXIBLE PLATE EXAMPLE
!
Transf-Function  : One Sample Delay, z^{-1}, dT=0.0002
S-Z-Transform    : Flexible System (7-Modes) (Z-Transformed at 0.0002 sec)
S-Z-Transform    : Flexible System (7-Modes) (Tustin-Transformed at 0.0002 sec)
S-Z-Transform    : Flexible System (7-Modes) (Z-Transformed with 0.00015 sec Delay)
System Connection: Z-Transformed Flexible System with One Sample Delay at the Input
To Matlab Format : Flexible System (7-Modes)
To Matlab Format : Z-Transformed Flexible System with One Sample Delay at the Input
To Matlab Format : Flexible System (7-Modes) (Z-Transformed at 0.0002 sec)
To Matlab Format : Flexible System (7-Modes) (Tustin-Transformed at 0.0002 sec)
To Matlab Format : Flexible System (7-Modes) (Z-Transformed with 0.00015 sec Delay)
!
!               ACTUATOR EXAMPLE
!
S-Z-Transform    : TVC Engine Actuator Example ... (Z-Transformed at 2 msec)
S-Z-Transform    : TVC Engine Actuator Example ... (Tustin-Transformed at 2 msec)
S-Z-Transform    : TVC Engine Actuator Example ... (Z-Transformed at 2 msec with 1.5 msec delay)
To Matlab Format : TVC Engine Actuator Example ...
To Matlab Format : TVC Engine Actuator Example ... (Z-Transformed at 2 msec)
To Matlab Format : TVC Engine Actuator Example ... (Tustin-Transformed at 2 msec)
To Matlab Format : TVC Engine Actuator Example ... (Z-Transformed at 2 msec with 1.5 msec delay)
--------------------------------------------------------------------------------------------
```

```
--------------------------------------------------------------------------------------------------
                               FLEX PLATE EXAMPLE
--------------------------------------------------------------------------------------------------
SYSTEM OF TRANSFER FUNCTIONS ...
One Sample Delay, z^{-1}, dT=0.0002
! Delay implemented as discrete transfer function
Discrete, dt=  0.20000E-03
TF. Block #  1 0.0002 sec Delay                              Order of Numer, Denom=  1  1
Numer 0.00000    1.00000
Denom 1.00000    0.00000
------------------------------------------------------------------------------
Block #, from Input #, Gain:
  1  1   1.00000
.........................
Outpt #, from Block #, Gain:
  1  1   1.00000
.........................
------------------------------------------------------------------------------
INTERCONNECTION OF SYSTEMS .....
Z-Transformed Flexible System with One Sample Delay at the Input
!
! This system is obtained by combining the "(Z-Transform)" system in
! series with the "One Sample Delay {z^-1}" system.
!
Titles of the Systems to be Connected ...
Title 1 One Sample Delay, z^{-1}, dT=0.0002
Title 2 Flexible System (7-Modes) (Z-Transformed at 0.0002 sec)
...........................................................................
SYSTEM INPUTS TO SUBSYSTEM  1
System Input  1 to Subsystem  1, Input  1, Gain= 1.00000
...........................................................................
SYSTEM OUTPUTS FROM SUBSYSTEM  2
System Output  1 from Subsystem  2, Output  1, Gain= 1.00000
...........................................................................
SUBSYSTEM NO  1 GOES TO SUBSYSTEM NO  2
Subsystem  1, Output  1 to Subsystem  2, Input  1, Gain= 1.00000
...........................................................................
Definitions of Inputs  =   1
One Sample Delay

Definitions of Outputs =   1
Flexible System (7-Modes)
------------------------------------------------------------------------------
TRANSFORM A SYSTEM (S-Z-W) ..... (New system title, Comments, Old System title, Transform)
Flexible System (7-Modes) (Z-Transformed at 0.0002 sec)
! Continuous System Model:  Acceleration of a Flexible Plate at a point in response to a Force
! Input  which is applied at a different point. Z-Transformed at 0.0002 sec
Flexible System (7-Modes)
From S-plane to Z-plane using the Z-Transform, dT=  0.20000E-03
--------------------------------------------------------------------------------------------------
TRANSFORM A SYSTEM (S-Z-W) ..... (New system title, Comments, Old System title, Transform)
Flexible System (7-Modes) (Tustin-Transformed at 0.0002 sec)
! Continuous System Model:  Acceleration of a Flexible Plate at a point in response to a Force
! Input  which is applied at a different point. Discretized using Tustin Transform, dT=0.0002 sec
Flexible System (7-Modes)
From S-plane to Z-plane using the Tustin-Transform, dT=  0.20000E-03
--------------------------------------------------------------------------------------------------
TRANSFORM A SYSTEM (S-Z-W) ..... (New system title, Comments, Old System title, Transform)
Flexible System (7-Modes) (Z-Transformed with 0.00015 sec Delay)
! Continuous System Model: Acceleration of a Flexible Plate at a point in response to a Force
! input which is applied at a different point. Z-Transformed at 0.0002 sec with 0.00015 sec Delay
Flexible System (7-Modes)
From S-plane to Z-plane using the Z-Transform with Delay, dT, Delay=  0.20000E-03 0.15000E-03
--------------------------------------------------------------------------------------------------
CONVERT TO MATLAB FORMAT ........     (Title, System/Matrix, m-filename)
Flexible System (7-Modes)
System
Flex7_s.m
--------------------------------------------------------------------------------------------------
CONVERT TO MATLAB FORMAT ........     (Title, System/Matrix, m-filename)
Z-Transformed Flexible System with One Sample Delay at the Input
System
Flex7_z1.m
--------------------------------------------------------------------------------------------------
```

```
CONVERT TO MATLAB FORMAT ........       (Title, System/Matrix, m-filename)
Flexible System (7-Modes) (Z-Transformed at 0.0002 sec)
System
Flex7_z.m
-----------------------------------------------------------------------------------------------
CONVERT TO MATLAB FORMAT ........       (Title, System/Matrix, m-filename)
Flexible System (7-Modes) (Tustin-Transformed at 0.0002 sec)
System
Flex7_zt.m
-----------------------------------------------------------------------------------------------
CONVERT TO MATLAB FORMAT ........       (Title, System/Matrix, m-filename)
Flexible System (7-Modes) (Z-Transformed with 0.00015 sec Delay)
System
Flex7_zd.m
-----------------------------------------------------------------------------------------------
                             ACTUATOR EXAMPLE
-----------------------------------------------------------------------------------------------
TRANSFORM A SYSTEM (S-Z-W) ..... (New system title, Comments, Old System title, Transform)
TVC Engine Actuator Example ... (Z-Transformed at 2 msec)
! The following system is an actuator model for the Space Shuttle main engine operating during
! nominal conditions. It must be discretized with a sample period of 0.002 seconds
TVC Engine Actuator Example ...
From S-plane to Z-plane using the Z-Transform, dT=  0.002
-----------------------------------------------------------------------------------------------
TRANSFORM A SYSTEM (S-Z-W) ..... (New system title, Comments, Old System title, Transform)
TVC Engine Actuator Example ... (Tustin-Transformed at 2 msec)
! The following system is an actuator model for the Space Shuttle main engine operating during
! nominal conditions. It must be discretized with a sample period of 0.002 seconds
TVC Engine Actuator Example ...
From S-plane to Z-plane using the Tustin-Transform, dT=  0.002
-----------------------------------------------------------------------------------------------
TRANSFORM A SYSTEM (S-Z-W) ..... (New system title, Comments, Old System title, Transform)
TVC Engine Actuator Example ... (Z-Transformed at 2 msec with 1.5 msec delay)
! The following system is an actuator model for the Space Shuttle main engine operating during
! nominal conditions. It must be discretized with a sample period of 0.002 seconds
TVC Engine Actuator Example ...
From S-plane to Z-plane using the Z-Transform with Delay, dT, Delay=  0.20000E-02 0.15000E-02
-----------------------------------------------------------------------------------------------
CONVERT TO MATLAB FORMAT ........       (Title, System/Matrix, m-filename)
TVC Engine Actuator Example ...
System
Actuat_s.m
-----------------------------------------------------------------------------------------------
CONVERT TO MATLAB FORMAT ........       (Title, System/Matrix, m-filename)
TVC Engine Actuator Example ... (Z-Transformed at 2 msec)
System
Actuat_z.m
-----------------------------------------------------------------------------------------------
CONVERT TO MATLAB FORMAT ........       (Title, System/Matrix, m-filename)
TVC Engine Actuator Example ... (Tustin-Transformed at 2 msec)
System
Actuat_zt.m
-----------------------------------------------------------------------------------------------
CONVERT TO MATLAB FORMAT ........       (Title, System/Matrix, m-filename)
TVC Engine Actuator Example ... (Z-Transformed at 2 msec with 1.5 msec delay)
System
Actuat_zd.m
-----------------------------------------------------------------------------------------------
```

The above input file is now processed in batch mode by running the batch set located on the top of the file. From the Flixan main menu select "*Edit*", then "*Manage Input Files*" and then "*Process/ Edit Input Data*". From the following dialog use the left menu to select the input file "*Ztran_Ex1.Inp*" and click on "*Select Input File*". The menu on the right shows the titles of the data-sets located in this file, also the program that will process each set. Select the first title which is the batch set, click on "*Process or View Input Data*", and the batch set will process the data, and save the transformed systems in file "*Ztran_Ex1.Qdr*". Notice that the two original continuous systems are retained in the systems file after reprocessing. A display shows the batch statements as they are executing. A Matlab script "run_flx.m", located in the same folder, loads the systems and calculates their frequency responses, as shown below.

Process Input Data Files

Point to an Input Data Filename
and Click on "Select Input File"   The following sets of input data are in file: Ztran_Ex1.inp

Exit

Ztran_Ex1.inp

Ztran_Ex1.inp

```
Run Batch Mode   : Batch for discretizing two continuous systemS with various delays
Transf-Functions : One Sample Delay, z^{-1}, dT=0.0002
System Connection: Z-Transformed Flexible System with One Sample Delay at the Input
S-Z-Transform    : Flexible System (7-Modes) (Z-Transformed at 0.0002 sec)
S-Z-Transform    : Flexible System (7-Modes) (Tustin-Transformed at 0.0002 sec)
S-Z-Transform    : Flexible System (7-Modes) (Z-Transformed with 0.00015 sec Delay)
To Matlab Format : Flexible System (7-Modes)
To Matlab Format : Z-Transformed Flexible System with One Sample Delay at the Input
To Matlab Format : Flexible System (7-Modes) (Z-Transformed at 0.0002 sec)
To Matlab Format : Flexible System (7-Modes) (Tustin-Transformed at 0.0002 sec)
To Matlab Format : Flexible System (7-Modes) (Z-Transformed with 0.00015 sec Delay)
S-Z-Transform    : TVC Engine Actuator Example ... (Z-Transformed at 2 msec)
S-Z-Transform    : TVC Engine Actuator Example ... (Tustin-Transformed at 2 msec)
S-Z-Transform    : TVC Engine Actuator Example ... (Z-Transformed at 2 msec with 1.5 msec delay)
To Matlab Format : TVC Engine Actuator Example ...
To Matlab Format : TVC Engine Actuator Example ... (Z-Transformed at 2 msec)
To Matlab Format : TVC Engine Actuator Example ... (Tustin-Transformed at 2 msec)
To Matlab Format : TVC Engine Actuator Example ... (Z-Transformed at 2 msec with 1.5 msec delay)
```

Select Input File   Edit File

Process or View Input Data

Delete Data Set in File

Relocate Data Set in File

Copy to Another File

View Data-Set Comments

Replace Systems File?

The systems filename: Ztran_Ex1.Qdr
already exists. Do you want to create it again?

Yes   No

This batch discretizes a continuous system with flex modes and introduces a delay of one sampling period at its input. It discretizes also the system using the Tustin transform, and also using the z-transform with a delay of 3/4 (dT). The discretized systems are then compared using frequency response analysis. This batch also calculates three types of discretizations for an actuator model using a sampling period of 2 msec.

Process Input Data Files

Point to an Input Data Filename
and Click on "Select Input File"   The following sets of input data are in file: Ztran_Ex1.inp

Exit

Ztran_Ex1.inp

Ztran_Ex1.inp

```
Run Batch Mode   : Batch for discretizing two continuous systemS with various delays
Transf-Functions : One Sample Delay, z^{-1}, dT=0.0002
System Connection: Z-Transformed Flexible System with One Sample Delay at the Input
```

Batch Mode Execution

```
Retain System     : Flexible System (7-Modes)
Retain System     : TVC Engine Actuator Example ...
Transf-Function   : One Sample Delay, z^{-1}, dT=0.0002
S-Z-Transform     : Flexible System (7-Modes) (Z-Transformed at 0.0002 sec)
S-Z-Transform     : Flexible System (7-Modes) (Tustin-Transformed at 0.0002 sec)
S-Z-Transform     : Flexible System (7-Modes) (Z-Transformed with 0.00015 sec Delay)
System Connection: Z-Transformed Flexible System with One Sample Delay at the Input
To Matlab Format : Flexible System (7-Modes)                                             ec delay)
To Matlab Format : Z-Transformed Flexible System with One Sample Delay at the Input
To Matlab Format : Flexible System (7-Modes) (Z-Transformed at 0.0002 sec)
To Matlab Format : Flexible System (7-Modes) (Tustin-Transformed at 0.0002 sec)
To Matlab Format : Flexible System (7-Modes) (Z-Transformed with 0.00015 sec Delay)
S-Z-Transform     : TVC Engine Actuator Example ... (Z-Transformed at 2 msec)          ec delay)
S-Z-Transform     : TVC Engine Actuator Example ... (Tustin-Transformed at 2 msec)
S-Z-Transform     : TVC Engine Actuator Example ... (Z-Transformed at 2 msec with 1.5 msec delay)
To Matlab Format : TVC Engine Actuator Example ...
To Matlab Format : TVC Engine Actuator Example ... (Z-Transformed at 2 msec)
To Matlab Format : TVC Engine Actuator Example ... (Tustin-Transformed at 2 msec)
To Matlab Format : TVC Engine Actuator Example ... (Z-Transformed at 2 msec with 1.5 msec delay)
```

View Data-Set Comments

This batch discretizes a continuous system with flex modes and introduces a delay of one sampling period at its input. It discretizes also the system using the Tustin transform, and also using the z-transform with a delay of 3/4 (dT). The discretized systems are then compared using frequency response analysis. This batch also calculates three types of discretizations for an actuator model using a sampling period of 2 msec.

Figure (5.3) Frequency Response comparison between the continuous, the z-transformed, and the Tustin-transformed systems. The Tustin transform is a closer match to the continuous system. It causes less phase lag but it creates a slight shift at the high frequency resonance.
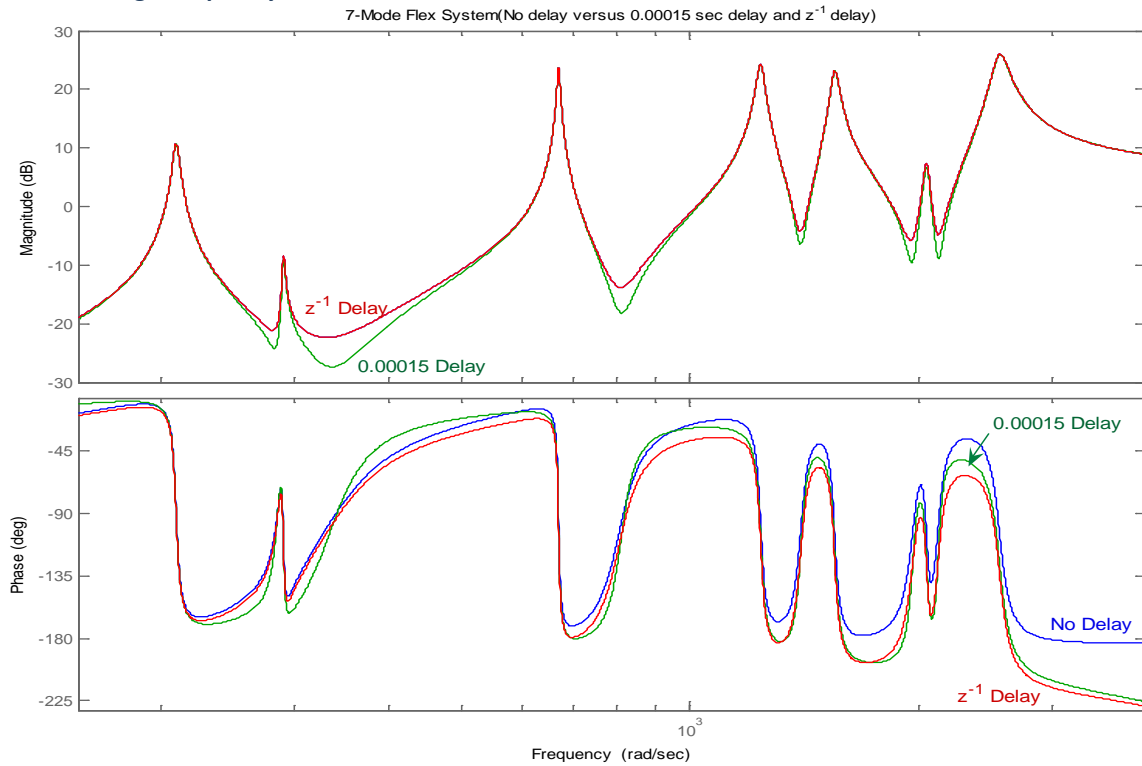
Figure (5.4) Frequency Response comparison between three z-transformed systems, (a) the z-transformed system without delays, (b) the system with the 0.00015 sec input delay, and (c) the system with the (z^{-1}) delay at its input. Notice that the z-transformed systems with the delays have significantly more phase lag at high frequencies than the z-transformed system without delay, and the system with the one sampling period (T) delay has more phase lag than the system with (0.75T) delay, as expected.

Lockheed-1011 Aircraft Lateral Model

In this example we have a lateral model of a Lockheed-1011 aircraft. Its title is *"L-1011 Lateral Model (Shapiro, IEEE Trans Aero+Electr)"*. It is located in systems file "*Ztran-Ex2.Qdr*", in directory "*\Flixan\Ztransf\ Examples\Ex-2*". We will discretize this system using (a) the z-transform, (b) the Tustin transform, and (c) the z-transform with delay. The transformation instructions are in input file "*Ztran_Ex2.Inp*", below. We will calculate and compare the frequency responses of the continuous and discrete-time systems. We will also demonstrate the z to w domain transformation capability by transforming a discrete system from the z-plane to the w-plane using the (z to w) transformation option in the program. We will also use the w-plane to z-plane transformation option to change it back from the w-plane to the z-plane.

```
BATCH MODE INSTRUCTIONS ...............
Batch set for calculating the open and closed loop models
! This batch creates discrete models from the continuous state-system
! "L-1011 Lateral Model (Shapiro,IEEE Trans Aero+Electr)". It discretizes it
! using (Z) and Tustin transforms. It also creates a z-transform model with
! computational delay at the system's inputs. The original continuous system
! is retained after processing the data. It also converts the z-plane model
! into W, and then the W back into Z.
!
Retain System    : L-1011 Lateral Model (Shapiro,IEEE Trans Aero+Electr)
S-Z-Transform    : L-1011 Lateral Model (Shapiro,IEEE Trans Aero+Electr) (Z-Transform)
S-Z-Transform    : L-1011 Lateral Model (Shapiro,IEEE Trans Aero+Electr) (Tustin-Transform)
S-Z-Transform    : L-1011 Lateral Model (Shapiro,IEEE Trans Aero+Electr) (Z-Transform with Delay)
S-Z-Transform    : L-1011 Lateral Model (Shapiro,IEEE Trans Aero+Electr) (Z to W Transform)
S-Z-Transform    : L-1011 Lateral Model (Shapiro,IEEE Trans Aero+Electr) (W to Z Transform)
-------------------------------------------------------------------------
TRANSFORM A SYSTEM (S-Z-W) ..... (New system title, Old System title, Transform)
L-1011 Lateral Model (Shapiro,IEEE Trans Aero+Electr) (Z-Transform)
! This data-set discretizes the following s-plane system from s to z using
! the Z-transformation. The sample time is 0.01 sec. The new system title is
! L-1011 Lateral Model (Shapiro,IEEE Trans Aero+Electr) (Z-Transform)
!
L-1011 Lateral Model (Shapiro,IEEE Trans Aero+Electr)
From S-plane to Z-plane using the Z-Transform, dT= 0.01
-------------------------------------------------------------------------
TRANSFORM A SYSTEM (S-Z-W) ..... (New system title, Old System title, Transform)
L-1011 Lateral Model (Shapiro,IEEE Trans Aero+Electr) (Tustin-Transform)
! This data-set discretizes the following s-plane system from s to z using
! the Tustin-transformation. The sample time is 0.01 sec. The new system title is
! L-1011 Lateral Model (Shapiro,IEEE Trans Aero+Electr) (Tustin-Transform)
!
L-1011 Lateral Model (Shapiro,IEEE Trans Aero+Electr)
From S-plane to Z-plane using the Tustin-Transform, dT= 0.01
-------------------------------------------------------------------------
TRANSFORM A SYSTEM (S-Z-W) ..... (New system title, Old System title, Transform)
L-1011 Lateral Model (Shapiro,IEEE Trans Aero+Electr) (Z-Transform with Delay)
! This data-set discretizes the following s-plane system from s to z using
! the Z-transformation. An additional 0.008 sec delay is included at the system input
! The sample time is 0.01 sec. The new system title is
! L-1011 Lateral Model (Shapiro,IEEE Trans Aero+Electr) (Z-Transform with Delay)
!
L-1011 Lateral Model (Shapiro,IEEE Trans Aero+Electr)
From S-plane to Z-plane using the Z-Transform with Delay, dT, Delay= 0.01, 0.008
-------------------------------------------------------------------
TRANSFORM A SYSTEM (S-Z-W) ..... (New system title, Old System title, Transform)
L-1011 Lateral Model (Shapiro,IEEE Trans Aero+Electr) (Z to W Transform)
L-1011 Lateral Model (Shapiro,IEEE Trans Aero+Electr) (Z-Transform)
From Z-plane to W-plane Transform
-------------------------------------------------------------------
TRANSFORM A SYSTEM (S-Z-W) ..... (New system title, Old System title, Transform)
L-1011 Lateral Model (Shapiro,IEEE Trans Aero+Electr) (W to Z Transform)
L-1011 Lateral Model (Shapiro,IEEE Trans Aero+Electr) (Z to W Transform)
From W-plane to Z-plane Transform
------------------------------------------------------------------------------------
```

This input file can be processed in batch mode by running the batch set located on the top of this file. From the Flixan main menu select "*Edit*", then "*Manage Input Files*" and then "*Process/ Edit Input Data*". From the following dialog use the left menu to select the input file "*Ztran_Ex2.Inp*" and click on "*Select Input File*". The menu on the right shows the titles of the data-sets located in this file, also the program that will process each set. The batch comments are shown at the bottom. Click on "*Process or View Input Data*", and the batch set will process the data and save the transformed systems in file "*Ztran_Ex2.Qdr*". Notice that the original continuous system is retained in the systems file after reprocessing.
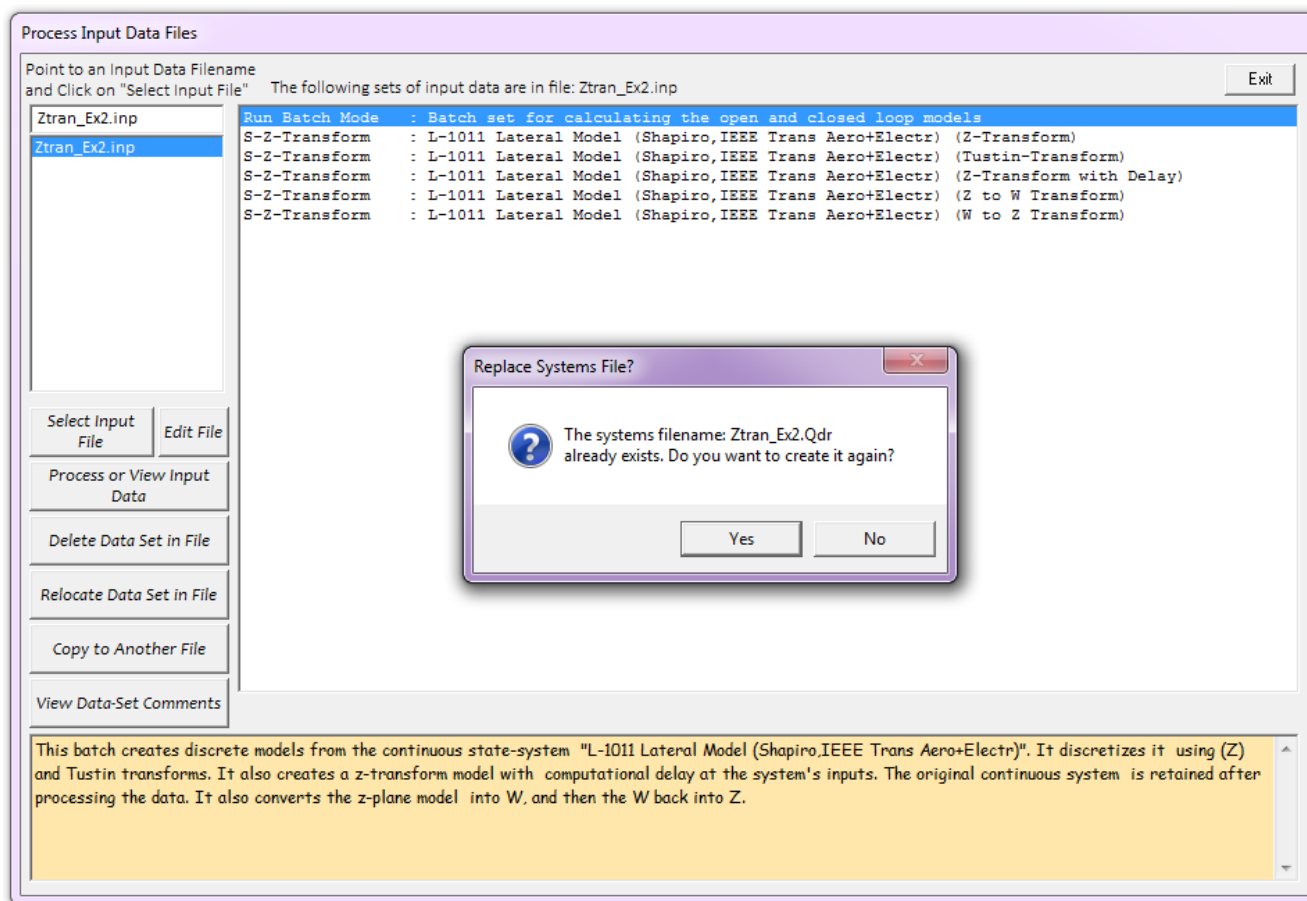
Flexible Launch Vehicle Model

The third example uses a lateral axes model of the Space Shuttle during ascent. The input and system files are "*Ztran_Ex3.Inp*" and "*Ztran_Ex3.Qdr*" located in "*C:\Flixan\Ztransf\EXAMPLES\Ex-3*". The title of the continuous system to be transformed is: *"Flex Vehicle(Max-Q), Aero, Slosh, TWD, Actuators, TVC"*. It has 3 inputs and 12 outputs and contains several low damped flexible modes. The first resonance is fuel sloshing in the external tank. We will use the Z-transform program to discretize this system and to create three transformations using: (a) the standard Z-transform, (b) the Tustin Transform, and (c) the Z-transform with a 0.02 seconds delay at the inputs. The sampling period is 0.04 seconds in all three cases. The discrete systems are also saved in systems file *"Ztran_Ex3.Qdr"*.

```
BATCH MODE INSTRUCTIONS ...............
Batch for preparing the Shuttle Ascent, First Stage Max-Q, Longitudinal Axis Models
! This batch set creates four different types of discretizations for a continuous system
! "Flex Vehicle(Max-Q), Aero, Slosh, TWD, Actuators, TVC" which is in file "Ztran_Ex3.Qdr"
! (a) Z-transform using 20 msec sampling period,
! (b) Z-transform using 40 msec sampling period,
! (c) Tustin-transform using 40 msec sampling period,
! (d) Z-transform using 40 msec sampling period plus 20 msec delay at the 3 inputs inputs.
! The models are then compared using frequency response analysis.
!
Retain System    : Flex Vehicle(Max-Q), Aero, Slosh, TWD, Actuators, TVC
S-Z-Transform    : Flex Vehicle(Max-Q), Aero, Slosh, TWD, Actuators, TVC (Z-Transform 0.02)
S-Z-Transform    : Flex Vehicle(Max-Q), Aero, Slosh, TWD, Actuators, TVC (Z-Transform 0.04)
S-Z-Transform    : Flex Vehicle(Max-Q), Aero, Slosh, TWD, Actuators, TVC (Tustin-Transform)
S-Z-Transform    : Flex Vehicle(Max-Q), Aero, Slosh, TWD, Actuators, TVC (Z-Transform+Delay)
!
To Matlab Format : Flex Vehicle(Max-Q), Aero, Slosh, TWD, Actuators, TVC
To Matlab Format : Flex Vehicle(Max-Q), Aero, Slosh, TWD, Actuators, TVC (Z-Transform 0.04)
To Matlab Format : Flex Vehicle(Max-Q), Aero, Slosh, TWD, Actuators, TVC (Z-Transform 0.02)
To Matlab Format : Flex Vehicle(Max-Q), Aero, Slosh, TWD, Actuators, TVC (Tustin-Transform)
To Matlab Format : Flex Vehicle(Max-Q), Aero, Slosh, TWD, Actuators, TVC (Z-Transform+Delay)
----------------------------------------------------------------------------------------
TRANSFORM A SYSTEM (S-Z-W) ..... (Titles of the New and Old Systems)
Flex Vehicle(Max-Q), Aero, Slosh, TWD, Actuators, TVC (Z-Transform 0.02)
Flex Vehicle(Max-Q), Aero, Slosh, TWD, Actuators, TVC
From S-plane to Z-plane using the Z-Transform, dT=  0.02
----------------------------------------------------------------------------------------
TRANSFORM A SYSTEM (S-Z-W) ..... (Titles of the New and Old Systems)
Flex Vehicle(Max-Q), Aero, Slosh, TWD, Actuators, TVC (Z-Transform 0.04)
!
! Transform the Continuous Vehicle Model to Discrete with a
! Sample Period dT=0.04 seconds Using the Z-Transform
!
Flex Vehicle(Max-Q), Aero, Slosh, TWD, Actuators, TVC
From S-plane to Z-plane using the Z-Transform, dT= 0.04
----------------------------------------------------------------------------
TRANSFORM A SYSTEM (S-Z-W) ..... (Titles of the New and Old Systems)
Flex Vehicle(Max-Q), Aero, Slosh, TWD, Actuators, TVC (Tustin-Transform)
!
! Transform the Continuous Vehicle Model to Discrete with a
! Sample Period dT=0.04 seconds Using the Tustin-Transform
!
Flex Vehicle(Max-Q), Aero, Slosh, TWD, Actuators, TVC
From S-plane to Z-plane using the Tustin-Transform, dT= 0.04
----------------------------------------------------------------------------
TRANSFORM A SYSTEM (S-Z-W) ..... (Titles of the New and Old Systems)
Flex Vehicle(Max-Q), Aero, Slosh, TWD, Actuators, TVC (Z-Transform+Delay)
!
! Transform the Continuous Vehicle Model to Discrete with a
! Sample Period dT=0.04 seconds Using the Z-Transform
! Add a 0.02 seconds Computational Delay at the (3) Plant Inputs
!
Flex Vehicle(Max-Q), Aero, Slosh, TWD, Actuators, TVC
From S-plane to Z-plane using the Z-Transform with Delay, dT, Delay= 0.04, 0.02
----------------------------------------------------------------------------
```

This input file is processed in batch mode by running the batch set located on the top of the file, as before and shown below. Click on "*Process or View Input Data*", and the batch set will process the data and save the transformed systems in file "*Ztran_Ex3.Qdr*". The original continuou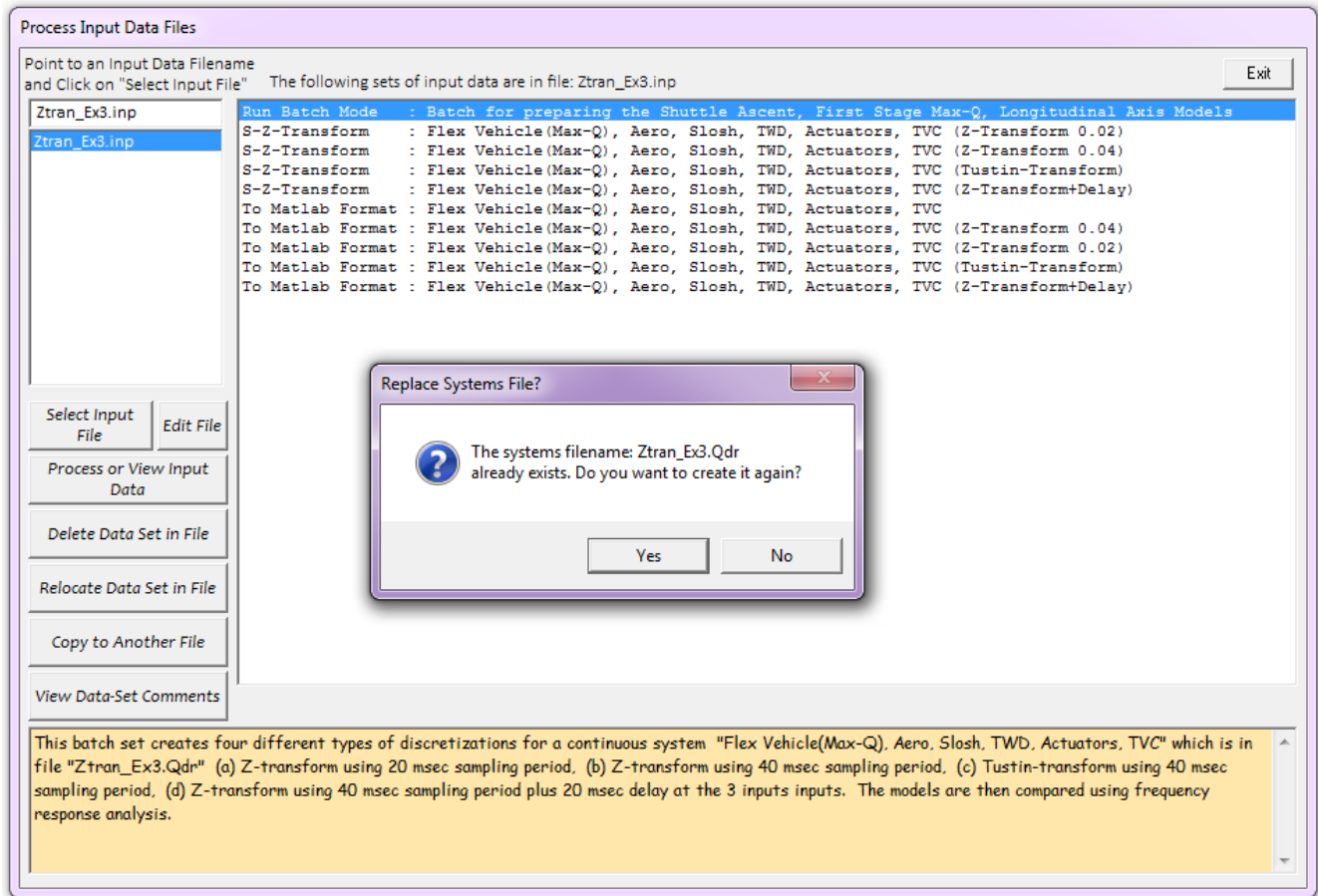s system is retained in the systems file after reprocessing. The continuous and the four discrete systems are also converted to Matlab format for further analysis.

We will now calculate the frequency responses of the four systems and compare them with each other. There is a Matlab script "*run_vehi.m*" included in this folder that loads the four systems and plots their frequency response. In this case between yaw TVC deflection (input 2) to the yaw gyro response (output 7), shown below. The Figure compares: (a) the continuous system response, against (b) the responses of the Z-Transform, (c) the Tustin Transform, and (d) the Z-transform with delay. The results are shown in Figure (5.6). The zero-order-hold is not included. The frequency response obtained from the Tustin transform does not match the resonance amplitudes of the flex mode frequencies as well as the z-transformations match. The magnitudes of the continuous system, the z-transformed system, and the z-transform system with input delays are almost identical. The Tustin-transform causes almost the same amount of phase lag at high frequencies as the z-transform. The z-transform with delay (red) has a considerably more phase lag and a little more attenuation near the Nyquist frequency.
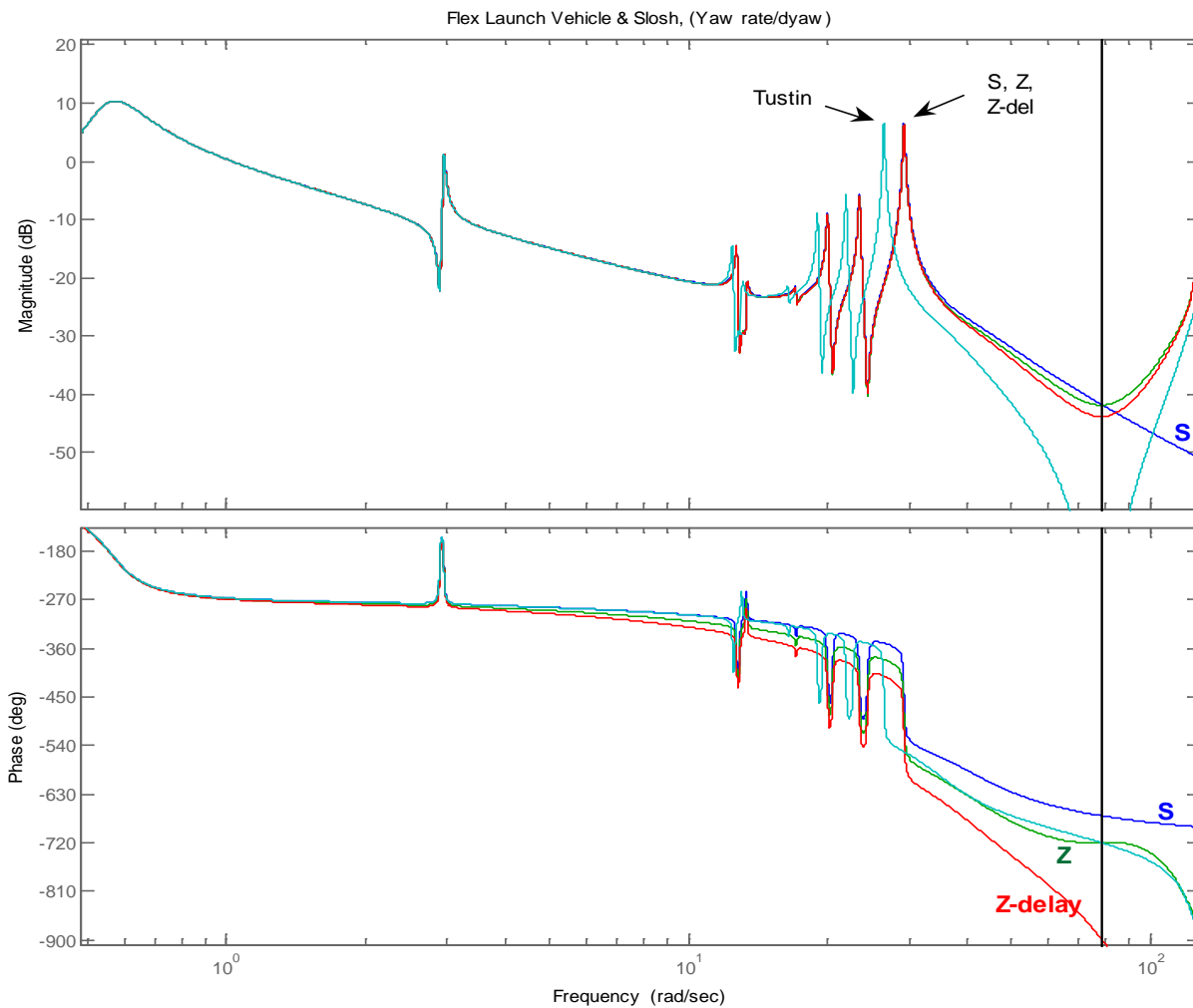
Figure (5.6) Open-Loop Frequency Response between gimbal deflection and yaw rate showing the comparison between four systems: (a) the continuous system (blue), (b) the z-transformed system (green), (c) the Tustin transformed system (cyan), and (d) the z-transformed system with 20 msec delay (red). This system has a lot of flex resonances and the first resonance is fuel sloshing. The discrete systems are sampled at 40 msec. The Tustin transform causes significantly more frequency shift. The magnitudes of the other two systems are very close to the continuous system. The 20 msec input delay, however, causes additional phase lag at high frequencies, as expected.

6.0 Managing Input/Output Files

The Flixan program includes several utility programs for managing the input data and systems files. The input files (.Inp) contain sets of data or instructions which are processed by various Flixan programs generating matrices and state-space systems in (.Qdr) files for system analysis. Input data files typically contain multiple sets of data and system files may also contain several systems and single matrices related to a particular vehicle or project. All files associated with the same project are located in the same directory which is typically named after the vehicle name or flight condition. The purpose of the file management utilities is to organize the files and process the input data. They perform functions, such as: cleaning the files from unused data, viewing and editing user comments, reordering the sequence of some functions, editing the files, and for creating and editing batch sets for fast processing. The file management utilities are user friendly and fully interactive by means of window menus and dialogs.

6.1 Input Data files (*.Inp)

The input data files are typically created interactively by the various Flixan utilities and programs. They can also be created by the user, by copying, pasting and modifying previously generated data sets using a text editor. Each input file contains multiple sets of input data that correspond to various Flixan programs, such as: flight vehicle or actuator modeling, system or transfer function interconnections, system discretization or restructuring, effector mixing logic, etc. Each program processes its corresponding data and creates a system or a matrix. The data sets in an input file can either be processed interactively by selecting the corresponding utility through the Flixan menus or they can be processed through the file manager utility. They can also be processed much faster by running a batch data-set, again through the file manager utility. The first line of a data-set (red) identifies the type of data and the utility that will process it. For example, FLIGHT VEHICLE INPUT DATA, INTERCONNECTION OF SYSTEMS, ACTUATOR INPUT DATA, MIXING LOGIC, BATCH MODE INSTRUCTIONS, etc. The second line is a unique title for the data-set (blue) and it should be less than 100 characters long. The same title is also used to identify the system or the matrix that will be created by the program or utility and it is saved in a systems file. The lines below the title, starting with an exclamation mark (!) are user comments (green) which are inserted there, either directly by editing the input data file, or transferred there by another utility. Each comment line should be less than 100 characters long and they should be limited to 10 lines. A sample input data file is shown below.

```
BATCH MODE INSTRUCTIONS ...............
Batch for calculating the Closed-Loop model for a Zulu Rocket
! This batch set creates a state-space model for a rigid Zulu rocket during first stage
! at Max-Q and then extracts the longitudinal subsystem. It creates also a flex vehicle
! model with fuel sloshing and extracts also the longitudinal flex subsystem.
! It creates also state-space systems for the angle of attack estimator, the flight
! control system, and the closed-loop system. The state-space systems are converted to
! Matlab format.
Flight Vehicle   : Zulu, Stage-1, Max-Q, Rigid Body
System Modificat : Zulu, Stage-1, Max-Q, Rigid Body, Pitch Axis
Flight Vehicle   : Zulu, Stage-1, Max-Q, 8 Flex Modes with Slosh
System Modificat : Zulu, Stage-1, Max-Q, 8 Flex Modes with Slosh, Pitch Axis
Transf-Function  : Alpha Estimator
Transf-Function  : Pitch Flight Control System
System Connection: Pitch Closed-Loop System
To Matlab Format : Zulu, Stage-1, Max-Q, Rigid Body, Pitch Axis
--------------------------------------------------------------------------------
```

Zulu, Stage-1, Max-Q, Rigid Body
! This is a Launch Vehicle during First Stage at Maximum Dynamic Pressure. It is launched from
! a high altitude to maximize orbit performance. At Max-Q and while flying at 2.5 Mach it
! experiences a strong wind shear that causes 4 deg of angle of attack. The vehicle has two side
! liquid oxygen rockets that can provide 320,000 (lb) of thrust each. The two fuel tanks, one
! on each side cause a significant amount of slosh disturbance.
!
Body Axes Output,Attitude=Euler Angles,Without GAFD, No Turn Coordination

```
Vehicle Mass (lb-sec^2/ft), Gravity Accelerat. (g) (ft/sec^2), Earth Radius (Re) (ft)   :   8878.0      32.174      0.20896E+08
Moments and products of Inertias Ixx, Iyy, Izz, Ixy, Ixz, Iyz, in (lb-sec^2-ft)         :   519500.0    1671000.0   2110000.0  0.0000
CG location with respect to the Vehicle Reference Point, Xcg, Ycg, Zcg, in (feet)       :   -126.05     0.0000      0.007
Vehicle Mach Number, Velocity Vo (ft/sec), Dynamic Pressure (psf), Altitude (feet)      :   2.5         2000.0      220.00     83000.
Inertial Acceleration Vo_dot, Sensed Body Axes Accelerations Ax,Ay,Az (ft/sec^2)        :   62.000      54.000      0.0000     21.000
Angles of Attack and Sideslip (deg), alpha, beta rates (deg/sec)                        :   4.0000      0.0000      0.0000     0.0000
Vehicle Attitude Euler Angles, Phi_o,Thet_o,Psi_o (deg), Body Rates Po,Qo,Ro (deg/sec)  :   0.0000      44.000      0.0000     0.0000
Wind Gust Vel wrt Vehi (Azim & Elev) angles (deg), or Force(lb), Torque(ft-lb), locat:xyz:  Gust        45.0        45.0
Surface Reference Area (feet^2), Mean Aerodynamic Chord (ft), Wing Span in (feet)       :   47.3        7.7000      7.7000
Aero Moment Reference Center (Xmrc,Ymrc,Zmrc) Location in (ft), {Partial_rho/ Partial_H}:  -127.2       0.0000      0.0000     0.0000
Aero Force Coef/Deriv (1/deg), Along -X, {Cao,Ca_alf,PCa/PV,PCa/Ph,Ca_alfdot,Ca_q,Ca_bet}: 0.63        0.001       0.0000     0.0000
Aero Force Coeffic/Derivat (1/deg), Along Y, {Cyo,Cy_bet,Cy_r,Cy_alf,Cy_p,Cy_betdot,Cy_V}: 0.0         -0.06       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}: -1.1        -0.31       0.0000     0.0000
Aero Moment Coeffic/Derivat (1/deg), Roll: {Clo, Cl_beta, Cl_betdot, Cl_p, Cl_r, Cl_alfa}: 0.0         -0.005      0.0000     0.0000
Aero Moment Coeff/Deriv (1/deg), Pitch: {Cmo,Cm_alfa,Cm_alfdot,Cm_bet,Cm_q,PCm/PV,PCm/Ph}: 2.3         0.6         0.0000     0.0000
Aero Moment Coeffic/Derivat (1/deg), Yaw : {Cno, Cn_beta, Cn_betdot, Cn_p, Cn_r, Cn_alfa}: 0.0         -0.26       0.0000     0.0000
```

```
Number of Control Surfaces, With or No TWD (Tail-Wags-Dog and Hinge Moment Dynamics) ?  :  0    NO TWD
Number of Thruster Engines, Include or Not the Tail-Wags-Dog and Load-Torque Dynamics ? :  2    NO TWD
```

```
TVC Engine No: 1                                 (Gimbaling  Throttling   Single_Gimbal) : Left TVC       Gimbaling
Engine Nominal Thrust, and Maximum Thrust in (lb)   (for throttling)                     : 320000.0       320000.0
Mounting Angles wrt Vehicle (Dyn,Dzn), Maximum Deflections from Mount (Dymax,Dzmax) (deg): 0.5            0.0         5.0          5.0
Eng Mass (slug), Inertia about Gimbal (lb-sec^2-ft), Moment Arm, engine CG to gimbal (ft): 47.0           260.00      0.2
Gimbal location with respect to the Vehicle Reference Axes, Xgimb, Ygimb, Zgimb, in (ft) : -144.6         -8.7        0.0
TVC Engine No: 2                                 (Gimbaling  Throttling   Single_Gimbal) : Right TVC      Gimbaling
Engine Nominal Thrust, and Maximum Thrust in (lb)   (for throttling)                     : 320000.0       320000.0
Mounting Angles wrt Vehicle (Dyn,Dzn), Maximum Deflections from Mount (Dymax,Dzmax) (deg): 0.5            0.0         5.0          5.0
Eng Mass (slug), Inertia about Gimbal (lb-sec^2-ft), Moment Arm, engine CG to gimbal (ft): 47.0           260.00      0.2
Gimbal location with respect to the Vehicle Reference Axes, Xgimb, Ygimb, Zgimb, in (ft) : -144.6         8.7         0.0
```

```
Number of Gyros, (Attitude and Rate)                                            :  0
Number of Accelerometers, Along Axis: (x,y,z)                                   :  0
Number of Vane Sensors, (Measuring Alpha or Beta)                               :  0
Number of Slosh Modes                                                           :  0
Number of Bending Modes                                                         :  0
```

CREATE A NEW SYSTEM FROM AN OLD SYSTEM... (Titles of the New and Old Systems)
Zulu, Stage-1, Max-Q, Rigid Body, Pitch Axis
Zulu, Stage-1, Max-Q, Rigid Body
! Pitch rigid system is extracted from the coupled rigid system above
TRUNCATE OR REORDER THE SYSTEM INPUTS, STATES, AND OUTPUTS
Extract Inputs :   1   2   5
Extract States :   3   4   7
Extract Outputs: 3   4   7 14

FLIGHT VEHICLE INPUT DATA ......
Zulu, Stage-1, Max-Q, 8 Flex Modes with Slosh
! This is a Launch Vehicle during First Stage at Maximum Dynamic Pressure. It is launched from
! a high altitude to maximize orbit performance. At Max-Q and while flying at 2.5 Mach it
! experiences a strong wind shear that causes 4 deg of angle of attack. The vehicle has two side
! liquid oxygen rockets that can provide 320,000 (lb) of thrust each. The two fuel tanks, one
! on each side cause a significant amount of slosh disturbance.
!
Body Axes Output,Attitude=Euler Angles,Without GAFD, No Turn Coordination

```
Vehicle Mass (lb-sec^2/ft), Gravity Accelerat. (g) (ft/sec^2), Earth Radius (Re) (ft)   :   8878.0      32.174      0.20896E+08
Moments and products of Inertias Ixx, Iyy, Izz, Ixy, Ixz, Iyz, in (lb-sec^2-ft)         :   519500.0    1671000.0   2110000.0  0.0000
CG location with respect to the Vehicle Reference Point, Xcg, Ycg, Zcg, in (feet)       :   -126.05     0.0000      0.007
Vehicle Mach Number, Velocity Vo (ft/sec), Dynamic Pressure (psf), Altitude (feet)      :   2.5         2000.0      220.00     83000.
Inertial Acceleration Vo_dot, Sensed Body Axes Accelerations Ax,Ay,Az (ft/sec^2)        :   62.000      54.000      0.0000     21.000
Angles of Attack and Sideslip (deg), alpha, beta rates (deg/sec)                        :   4.0000      0.0000      0.0000     0.0000
Vehicle Attitude Euler Angles, Phi_o,Thet_o,Psi_o (deg), Body Rates Po,Qo,Ro (deg/sec)  :   0.0000      44.000      0.0000     0.0000
Wind Gust Vel wrt Vehi (Azim & Elev) angles (deg), or Force(lb), Torque(ft-lb), locat:xyz:  Gust        45.0        45.0
Surface Reference Area (feet^2), Mean Aerodynamic Chord (ft), Wing Span in (feet)       :   47.3        7.7000      7.7000
Aero Moment Reference Center (Xmrc,Ymrc,Zmrc) Location in (ft), {Partial_rho/ Partial_H}:  -127.2       0.0000      0.0000     0.0000
Aero Force Coef/Deriv (1/deg), Along -X, {Cao,Ca_alf,PCa/PV,PCa/Ph,Ca_alfdot,Ca_q,Ca_bet}: 0.63        0.001       0.0000     0.0000
Aero Force Coeffic/Derivat (1/deg), Along Y, {Cyo,Cy_bet,Cy_r,Cy_alf,Cy_p,Cy_betdot,Cy_V}: 0.0         -0.06       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}: -1.1        -0.31       0.0000     0.0000
Aero Moment Coeffic/Derivat (1/deg), Roll: {Clo, Cl_beta, Cl_betdot, Cl_p, Cl_r, Cl_alfa}: 0.0         -0.005      0.0000     0.0000
Aero Moment Coeff/Deriv (1/deg), Pitch: {Cmo,Cm_alfa,Cm_alfdot,Cm_bet,Cm_q,PCm/PV,PCm/Ph}: 2.3         0.6         0.0000     0.0000
Aero Moment Coeffic/Derivat (1/deg), Yaw : {Cno, Cn_beta, Cn_betdot, Cn_p, Cn_r, Cn_alfa}: 0.0         -0.26       0.0000     0.0000
```

```
Number of Control Surfaces, With or No TWD (Tail-Wags-Dog and Hinge Moment Dynamics) ?  :  0    NO TWD
Number of Thruster Engines, Include or Not the Tail-Wags-Dog and Load-Torque Dynamics ? :  2    WITH TWD
```

```
TVC Engine No: 1                                 (Gimbaling  Throttling   Single_Gimbal) : Left TVC       Gimbaling
Engine Nominal Thrust, and Maximum Thrust in (lb)   (for throttling)                     : 320000.0       320000.0
Mounting Angles wrt Vehicle (Dyn,Dzn), Maximum Deflections from Mount (Dymax,Dzmax) (deg): 0.5            0.0         5.0          5.0
Eng Mass (slug), Inertia about Gimbal (lb-sec^2-ft), Moment Arm, engine CG to gimbal (ft): 47.0           260.00      0.2
Gimbal location with respect to the Vehicle Reference Axes, Xgimb, Ygimb, Zgimb, in (ft) : -144.6         -8.7        0.0
TVC Engine No: 2                                 (Gimbaling  Throttling   Single_Gimbal) : Right TVC      Gimbaling
Engine Nominal Thrust, and Maximum Thrust in (lb)   (for throttling)                     : 320000.0       320000.0
Mounting Angles wrt Vehicle (Dyn,Dzn), Maximum Deflections from Mount (Dymax,Dzmax) (deg): 0.5            0.0         5.0          5.0
Eng Mass (slug), Inertia about Gimbal (lb-sec^2-ft), Moment Arm, engine CG to gimbal (ft): 47.0           260.00      0.2
Gimbal location with respect to the Vehicle Reference Axes, Xgimb, Ygimb, Zgimb, in (ft) : -144.6         8.7         0.0
```

```
Number of Gyros, (Attitude and Rate)                                          : 3
Gyro No  1 Axis:(Pitch,Yaw,Roll), (Attitude, Rate, Accelerat), Sensor Location in (feet) : Roll   Rate    -102.00      0.00       0.00
Gyro No  2 Axis:(Pitch,Yaw,Roll), (Attitude, Rate, Accelerat), Sensor Location in (feet) : Pitch  Rate    -102.00      0.00       0.00
Gyro No  3 Axis:(Pitch,Yaw,Roll), (Attitude, Rate, Accelerat), Sensor Location in (feet) : Yaw    Rate    -102.00      0.00       0.00

Number of Accelerometers, Along Axis: (x,y,z)                                 : 2
Acceleromet No  1 Axis:(X,Y,Z), (Position, Velocity, Acceleration), Sensor Location (ft) : Y-axis Accelerat.   -102.00  0.00       0.00
Acceleromet No  2 Axis:(X,Y,Z), (Position, Velocity, Acceleration), Sensor Location (ft) : Z-axis Accelerat.   -102.00  0.00       0.00

Number of Vane Sensors, (Measuring Alpha or Beta)                             : 0

Number of Slosh Modes                                                         : 2
Left Tank (slug), Frequ Wy,Wz at 1g (rad/s), Damping (zeta-y-z), Locat {Xsl,Ysl,Zsl} (ft): 350.0  2.31 2.31  0.001 0.001 -135.00  -8.7
Rght Tank (slug), Frequ Wy,Wz at 1g (rad/s), Damping (zeta-y-z), Locat {Xsl,Ysl,Zsl} (ft): 350.0  2.31 2.31  0.001 0.001 -135.00   8.7

Number of Bending Modes                                                       : 8
Zulu, Stage-1, Max-Q, 8 Flex Modes, Pitch Modes
-------------------------------------------------------------------------------------------------------------------
SELECTED MODAL DATA AND LOCATIONS FOR THE PITCH MODES
Zulu, Stage-1, Max-Q, 8 Flex Modes, Pitch Modes
! The pitch modes were selected by applying +Z forces at the two gimbals, (same direction at the
! left and right TVC). The pitch rotation was sensed at the IMU node. We included also modal data
! at the two TVC gimbals, the 3 roll, pitch, and yaw gyros, and the two (Ny and Nz) acceleromet.
! The modal data were scaled from the original Nastran output in (*.mod) file. We reverse the
! directions in the X and Z axes. The modal slopes were multiplied by 12 to be converted from
! (rad/inch) to (radians/foot). The modal masses were multiplied by 12 to be converted from
! (snails) to (slugs). Standard Nastran to GN&C units transformation (Default).

MODE # 1/  1, Frequency (rad/sec), Damping (zeta), Generalized Mass=    20.449      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

                              Node ID#   Modal Data at the  2 Engines, (x,y,z)...
Left  (-y) Boster Gimbal Locat   35701   -0.25060D-01   0.10089D-01  -0.48000D-03   0.23400D-04  -0.24816D-04  -0.12228D-02
Right (+y) Boster Gimbal Locat   45701    0.25080D-01   0.10093D-01  -0.98000D-04   0.22764D-04  -0.21000D-04  -0.12233D-02

                              Node ID#   Modal Data at the  3 Gyros ...
Nav Base (IMU , Accelerom)       95602   -0.13080D-05   0.23100D-01   0.18520D-03  -0.60120D-04   0.17244D-04   0.36600D-02
Nav Base (IMU , Accelerom)       95602   -0.13080D-05   0.23100D-01   0.18520D-03  -0.60120D-04   0.17244D-04   0.36600D-02
Nav Base (IMU , Accelerom)       95602   -0.13080D-05   0.23100D-01   0.18520D-03  -0.60120D-04   0.17244D-04   0.36600D-02

                              Node ID#    Modal Data at the  2 Accelerometers, along (x,y,z)...
Nav Base (IMU , Accelerom)       95602   -0.13080D-05   0.23100D-01   0.18520D-03
Nav Base (IMU , Accelerom)       95602   -0.13080D-05   0.23100D-01   0.18520D-03

                              Node ID#    Modal Data at the  2 Slosh Masses...
Left  Booster Liquid Oxygen Sl   81602   -0.90090D-02   0.51000D-02   0.26000D-03  -0.33480D-05   0.24360D-04   0.26904D-02
Right Booster Liquid Oxygen Sl   88603    0.90170D-02   0.50960D-02   0.34470D-03  -0.40680D-05  -0.83160D-05   0.26904D-02

                              Node ID#    Modal Data at the Disturbance Point
Nav Base (IMU , Accelerom)       95602   -0.13080D-05   0.23100D-01   0.18520D-03  -0.60120D-04   0.17244D-04   0.36600D-02

MODE # 2/  2, Frequency (rad/sec), Damping (zeta), Generalized Mass=    22.271      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

                              Node ID#    Modal Data at the  2 Engines, (x,y,z)...
Left  (-y) Boster Gimbal Locat   35701   -0.26580D-03   0.57370D-04   0.25310D-01   0.12300D-03  -0.19884D-02  -0.15852D-04
Right (+y) Boster Gimbal Locat   45701    0.41850D-03   0.88360D-04   0.25260D-01   0.11760D-03  -0.19872D-02  -0.18912D-04

                              Node ID#    Modal Data at the  3 Gyros ...
Nav Base (IMU , Accelerom)       95602    0.43500D-03   0.45400D-03  -0.10500D-01   0.43200D-05  -0.23088D-02   0.54600D-04
Nav Base (IMU , Accelerom)       95602    0.43500D-03   0.45400D-03  -0.10500D-01   0.43200D-05  -0.23088D-02   0.54600D-04
Nav Base (IMU , Accelerom)       95602    0.43500D-03   0.45400D-03  -0.10500D-01   0.43200D-05  -0.23088D-02   0.54600D-04

                              Node ID#    Modal Data at the  2 Accelerometers, along (x,y,z)...
Nav Base (IMU , Accelerom)       95602    0.43500D-03   0.45400D-03  -0.10500D-01
Nav Base (IMU , Accelerom)       95602    0.43500D-03   0.45400D-03  -0.10500D-01

                              Node ID#    Modal Data at the  2 Slosh Masses...
Left  Booster Liquid Oxygen Sl   81602   -0.12800D-03   0.12550D-03  -0.24500D-01  -0.32760D-04  -0.11892D-02   0.13236D-04
Right Booster Liquid Oxygen Sl   88603    0.15130D-03   0.28260D-03  -0.24510D-01   0.37200D-04  -0.81360D-03   0.70200D-04

                              Node ID#    Modal Data at the Disturbance Point
Nav Base (IMU , Accelerom)       95602    0.43500D-03   0.45400D-03  -0.10500D-01   0.43200D-05  -0.23088D-02   0.54600D-04
-------------------------------------------------------------------------------------------------------------------
CREATE A NEW SYSTEM FROM AN OLD SYSTEM... (Titles of the New and Old Systems)
Zulu, Stage-1, Max-Q, 8 Flex Modes with Slosh, Pitch Axis
Zulu, Stage-1, Max-Q, 8 Flex Modes with Slosh
! Pitch flexible system is extracted from the coupled system above
! to be used in Matlab/Simulink Simulations
TRUNCATE OR REORDER THE SYSTEM INPUTS, STATES, AND OUTPUTS
Extract Inputs :   1   2   3   4   9
Extract States :   3   4   7  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26  27  29  31  33
Extract Outputs:   3   4   7  13  16  17  18
-------------------------------------------------------------------------------------------------------------------
```

SYSTEM OF TRANSFER FUNCTIONS ...
Alpha Estimator
! This filter estimates the angle of attack in (radians) from the accelerometer measurement and
! the gimbal deflection angle. It basically solves the normal force equation for alpha. The
! inputs are (a) Nz measurement from the accelerometer, (b) Pitch rate to counteract against the
! rotational component picked up by the accelerometer, (c) gimbal deflection to estimate the
! normal component of thrust. The washout filter differentiates the rate gyro signal at low
! frequencies.
Continuous
TF. Block # 1 Integrator   Order of Numer, Denom=   0 1
Numer 0.0   1.0
Denom 1.0   0.0
TF. Block # 2 Washout Filter   Order of Numer, Denom=   1 1
Numer 280.0   0.0
Denom 1.0   10.0
....
Block #, from Input #, Gain
    1   1   -8878.000   {TF: 1, Integrator } from {Nz Acceleration}
    1   2   -464000.0   {TF: 1, Integrator } from {Gimbal Deflection}
    2   3   1.0   {TF: 2, Washout Filt} from {Pitch Rate Gyro}
....
Outpt #, from Block #, Gain
    1   1   0.1745000E-01   {System Output 1   } from {TF: 1, Integrator }
....
Block #, from Block #, Gain
    1   1   -3225.860   {TF: 1, Integrator } from {TF: 1, Integrator }
    1   2   -8878.0   {TF: 1, Integrator } from {TF: 2, Washout Filt}
....
Definitions of Inputs =   3
Nz Acceleration (ft/sec^2)
Gimbal Deflection, Delta (rad)
Pitch Rate Gyro, q-flex (rad/sec)

Definitions of Outputs =   1
Alpha Estimate in (radians)

SYSTEM OF TRANSFER FUNCTIONS ...
Pitch Flight Control System
! This is the state-feedback pitch FCS with filters and actuator combined
! The attitude, pitch rate and gamma come from the vehicle subsystem. The
! angle of attack comes from the alpha estimator. The output goes to the
! vehicle gimbal deflection input.
Continuous
TF. Block # 1 Gamma Integrat   Order of Numer, Denom=   0 1
Numer 0.0   1.0
Denom 1.0   0.0
TF. Block # 2 Low-Pass Filter   Order of Numer, Denom=   0 2
Numer 0.0   0.0   324.0
Denom 1.0   19.8   324.0
TF. Block # 3 Actuator   Order of Numer, Denom=   0 1
Numer 0.0   63.0
Denom 1.0   63.0
....
Block #, from Input #, Gain
    2   1   0.85   {TF: 2, Filter} from {Theta Error}
    2   2   0.5   {TF: 2, Filter} from {Pitch Rate Gyro}
    2   3   0.0125   {TF: 2, Filter} from {Alpha}
    1   4   1.0   {TF: 1, Integrator} from {Gamma Error}
....
Outpt #, from Block #, Gain
    1   3   1.0   {Gimbal Deflect} from {TF: 3, Actuator}
....
Block #, from Block #, Gain
    3   2   1.0   {TF: 3, Actuator} from {TF: 2, Filter}
    2   1   0.04375   {TF: 2, Filter} from {TF: 1, Gamma Integral}
....
Definitions of Inputs =   4
Theta error (Theta-Thetcom) (rad)
Pitch rate gyro (rad/sec)
Alpha (rad)
Gamma error (Gamma-Gamcom) (rad)

Definitions of Outputs =   1
Gimbal Deflection (radians)

```
INTERCONNECTION OF SYSTEMS .....
Pitch Closed-Loop System
! Closed-Loop System obtained using the Flixan system building utilities
! to be used for Simulations
Titles of Systems to be Combined
Title 1 Zulu, Stage-1, Max-Q, 8 Flex Modes with Slosh, Pitch Axis
Title 2 Alpha Estimator
Title 3 Pitch Flight Control System
SYSTEM INPUTS TO SUBSYSTEM  3      Pitch Flight Control System
System Input  1 to Subsystem  3, Input  1, Gain= -1.0000          Theta Command
System Input  2 to Subsystem  3, Input  4, Gain= -1.0000          Gamma Command
.....................................................................
SYSTEM INPUTS TO SUBSYSTEM  1      Zulu, Stage-1, Max-Q, 8 Flex Modes with Slos
System Input  3 to Subsystem  1, Input  5, Gain=  1.0000          Wind Gust (ft/sec)
.....................................................................
SYSTEM OUTPUTS FROM SUBSYSTEM  1   Zulu, Stage-1, Max-Q, 8 Flex Modes with Slosh
System Output  1 from Subsystem  1, Output  1, Gain=  1.0000      Theta
System Output  2 from Subsystem  1, Output  4, Gain=  1.0000      q-flex (rate gyro)
System Output  3 from Subsystem  1, Output  3, Gain=  1.0000      Alpha
System Output  5 from Subsystem  1, Output  1, Gain=  1.0000      Gamma= Theta
System Output  5 from Subsystem  1, Output  3, Gain= -1.0000          -Alpha
System Output  6 from Subsystem  1, Output  5, Gain=  1.0000      Nz accelerom
.....................................................................
SYSTEM OUTPUTS FROM SUBSYSTEM  2   Alpha Estimator
System Output  4 from Subsystem  2, Output  1, Gain=  1.0000      Alpha-Hat
.....................................................................
SYSTEM OUTPUTS FROM SUBSYSTEM  3   Pitch Flight Control System
System Output  7 from Subsystem  3, Output  1, Gain=  1.0000      Gimbal deflect (rad)
.....................................................................
SUBSYSTEM NO  1 GOES TO SUBSYSTEM NO  3                           Vehicle to Controller
Subsystem  1, Output  1 to Subsystem  3, Input  1, Gain=  1.0000  Attitude Theta
Subsystem  1, Output  4 to Subsystem  3, Input  2, Gain=  1.0000  q-flex
Subsystem  1, Output  1 to Subsystem  3, Input  4, Gain=  1.0000  Gamma= Theta
Subsystem  1, Output  3 to Subsystem  3, Input  4, Gain= -1.0000      -Alpha
.....................................................................
SUBSYSTEM NO  1 GOES TO SUBSYSTEM NO  2                           Vehicle to Estimator
Subsystem  1, Output  4 to Subsystem  2, Input  3, Gain=  1.0000  q-flex
Subsystem  1, Output  5 to Subsystem  2, Input  1, Gain=  1.0000  Nz
.....................................................................
SUBSYSTEM NO  2 GOES TO SUBSYSTEM NO  3                           Estimator to Controller
Subsystem  2, Output  1 to Subsystem  3, Input  3, Gain=  1.0000  Alpha-Estimate
.....................................................................
SUBSYSTEM NO  3 GOES TO SUBSYSTEM NO  1                           Gimbal to Vehicle
Subsystem  3, Output  1 to Subsystem  1, Input  1, Gain=  1.0000  Pitch Gimbal-1
Subsystem  3, Output  1 to Subsystem  1, Input  2, Gain=  1.0000  Pitch Gimbal-2
.....................................................................
SUBSYSTEM NO  3 GOES TO SUBSYSTEM NO  2                           Gimbal to Estimator
Subsystem  3, Output  1 to Subsystem  2, Input  2, Gain=  1.0000  Pitch Gimbal
.....................................................................
Definitions of Inputs  =   3
Theta Command (rad)
Gamma Command (rad)
Wind Gust Veloc. (ft/sec)

Definitions of Outputs =   7
Theta (rad)
Pitch Rate (rad/sec)
Alpha (rad)
Alpha Estimate (rad)
Gamma (rad)
Normal Accelerometer, Nz (ft/sec^2)
Gimbal Deflection (rad)
-----------------------------------------------------------------------------------------------------------
CONVERT TO MATLAB FORMAT ........     (Title, System/Matrix, m-filename)
Zulu, Stage-1, Max-Q, Rigid Body, Pitch Axis
System
Vehi_Pitch_rb
-----------------------------------------------------------------------------------------------------------
CONVERT TO MATLAB FORMAT ........     (Title, System/Matrix, m-filename)
Zulu, Stage-1, Max-Q, 8 Flex Modes with Slosh, Pitch Axis
System
Vehi_Pitch_SFlx
-----------------------------------------------------------------------------------------------------------
CONVERT TO MATLAB FORMAT ........     (Title, System/Matrix, m-filename)
Alpha Estimator
System
Estimator
-----------------------------------------------------------------------------------------------------------
CONVERT TO MATLAB FORMAT ........     (Title, System/Matrix, m-filename)
Pitch Flight Control System
System
pitch_fcs
-----------------------------------------------------------------------------------------------------------
```

Flixan uses two separate utility programs for managing input data files: a utility for managing the sets within an input file, and a utility for creating, editing, and processing batch sets in an input file.

6.1.1 Input File Manager Utility

The input file manager utility is used for preparing and processing input files that have an extension (.Inp). For example, editing, deleting or relocating data-sets inside the file, or copying data-sets to another file. Editing or viewing user comments. Individual data-sets and batch sets can also be processed from the file manager utility. Batch sets are useful for fast processing of the entire input file instead of interactively. Initially interactive processing is useful when setting up the modeling structure and the functions to be performed. When the process is debugged, a batch data-set can be created for the next reprocessing, which may be another flight condition or a parameter modification, etc. To run the input file managing utility you must first start Flixan and select a project directory. From the Flixan main menu select "*File Management*", then "*Manage Input Files*" and then "*Edit/ Process Input Data*".
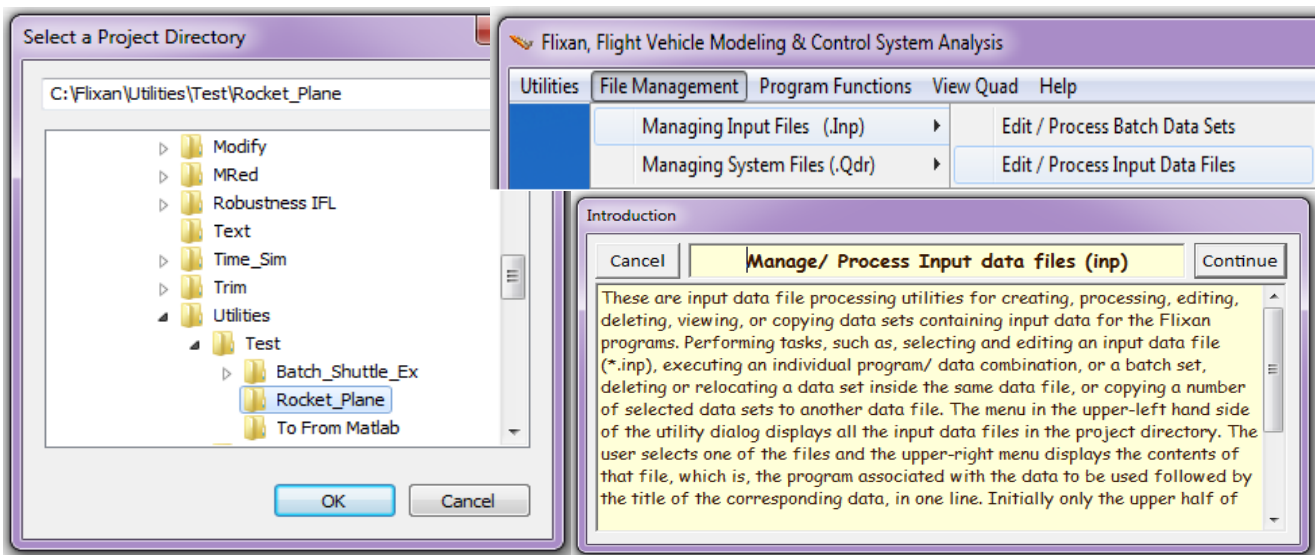

The file manager utility dialog is shown below. You must first select the input file to be processed. The menu on the left side of this dialog shows all the input filenames having extension (.Inp) located in the selected folder: "*C:\Flixan\Utilities\Test\Rocket_Plane*". In this case choose the file "*RocketPlane-RB.Inp*" and click on "*Select Input File*". The menu on the right will then show the titles of all data-sets located in this file. The type of the data-set also appears on the left side of each title to identify the Flixan utility that will process each set. For example: "Flight Vehicle", "Actuator", "Mixing Logic", "Transfer Function Data", "Batch Data", etc. The utility performs several file management functions, such as, deleting unused sets or relocating them to other positions inside this file, processing the data-sets by running the corresponding Flixan program or copying a number of selected data-sets to another input file. The user can also edit the selected input file. The user defined comments associated with each set appear in the beige field below the menus. These are the user comment lines that begin with an (!). The data-set title must first be selected in the menu and then click on "*View Data-Set Comments*" button which displays the user comments. They can also be edited or new comments be entered in this field if the original set did not include any.
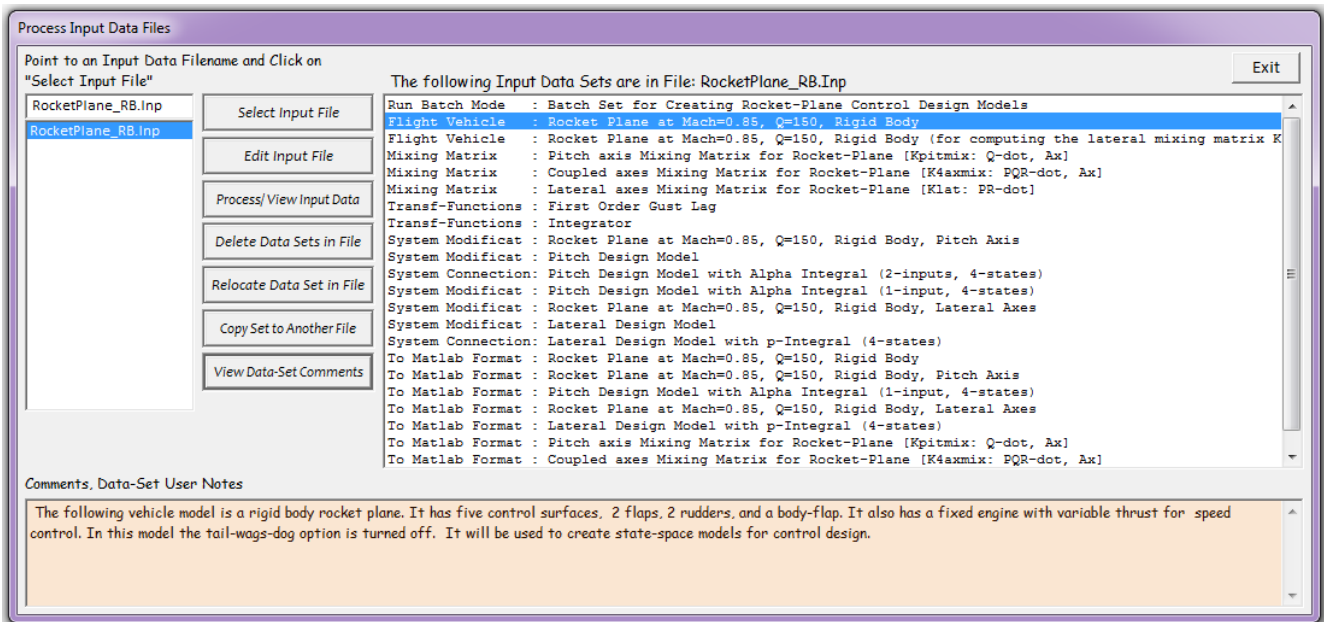
To process, for example, one of the data sets highlighted on the right menu, which in this case we select a rigid-body rocket-plane flight vehicle model. Click on "*View Comments*" to see the user notes in the comments field below, and then click on "*Process/ View Input Data*" to process the set. The flight vehicle program dialog comes up where the user can view or modify the data, and then click on "Run" to process the vehicle data. In this case the system already exists in the systems file and we cancel the processing.
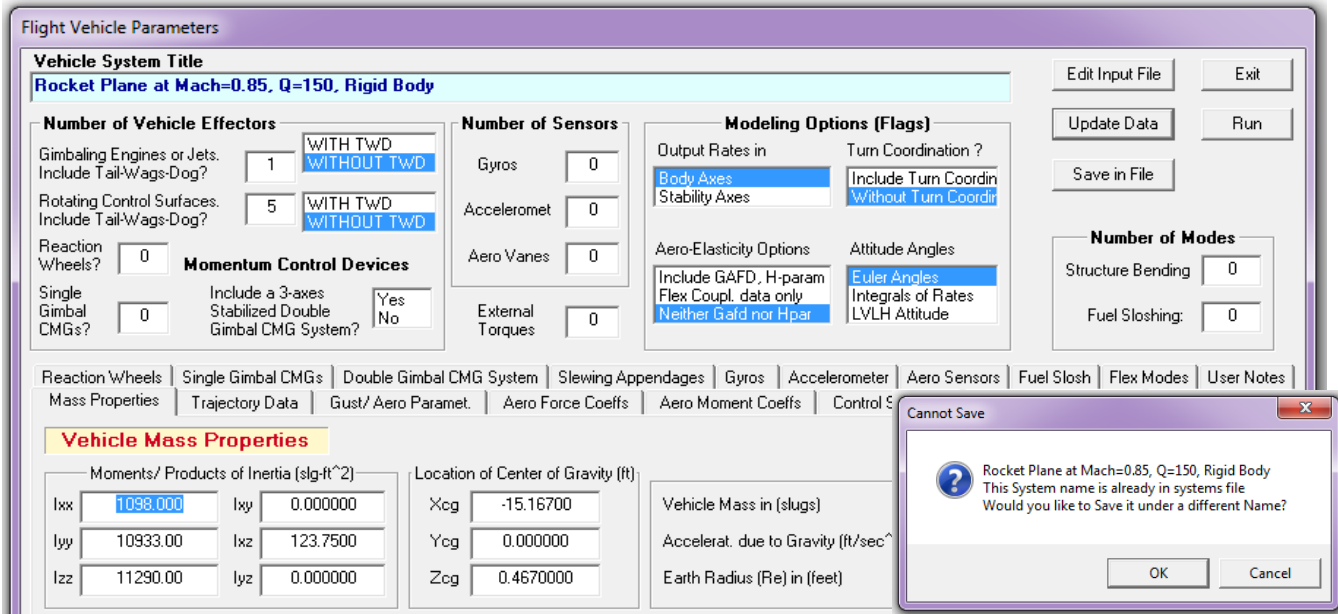
This example also includes a batch set on the top for processing the entire file in batch mode rather than interactively. Batch is a much faster way of processing the already created input files. Return to the file manager dialog and select the first title which is the batch set, and click on "*Process / View Input Data*", to process the batch data. Say "Yes" to recreate the already existing systems file "*RocketPlane-RB.Qdr*". The batch processes the individual data-sets located in the input file. A display comes up showing the individual set titles highlighted as they are being processed. It is used for monitoring the batch process in case of errors.

110
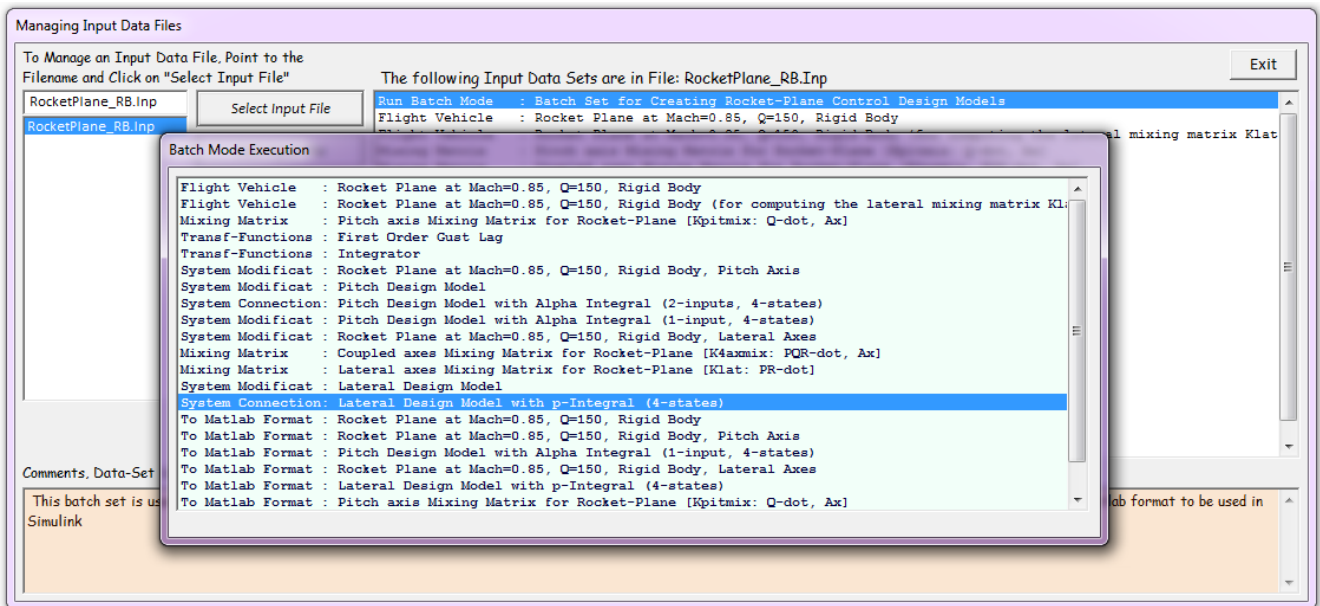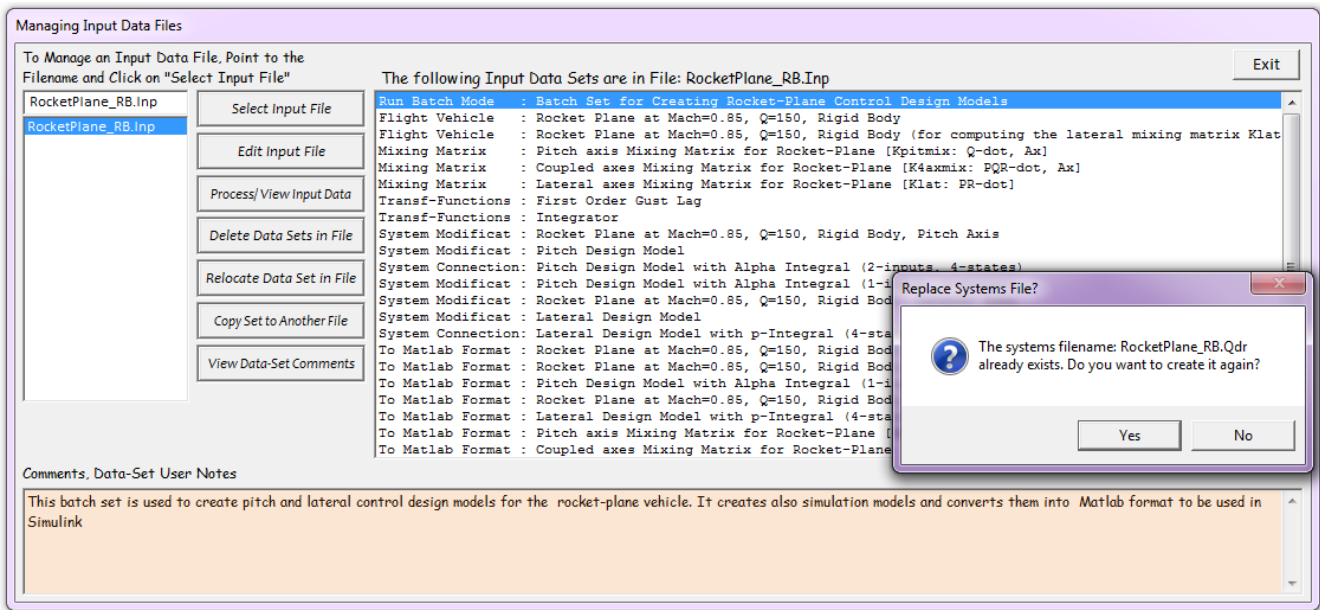
The "*Delete Data Sets in File*" button is used to delete selected items from the right menu in case you want to remove some older and unused data sets. You may also relocate some the data-sets to a different position inside the input data file by using the "*Relocate Data Set in File*" button. The file manager utility can also be used to copy selected data-sets from one input file to another. Return to the utility dialog and reselect the input filename. Initially only the upper half of the dialog is visible. The lower half appears only when you click on "*Copy Set to Another File*". This button allows you to copy the highlighted data sets from the original file to another input data file that is defined in the lower left menu. After highlighting the data sets to be copied from the original file using the upper-right menu, click on the "*Copy to Another File*" button and the dialog displays two additional menus at the bottom. Use the lower-left menu to enter or to select a destination filename in a similar manner as the original filename from the upper-left menu.
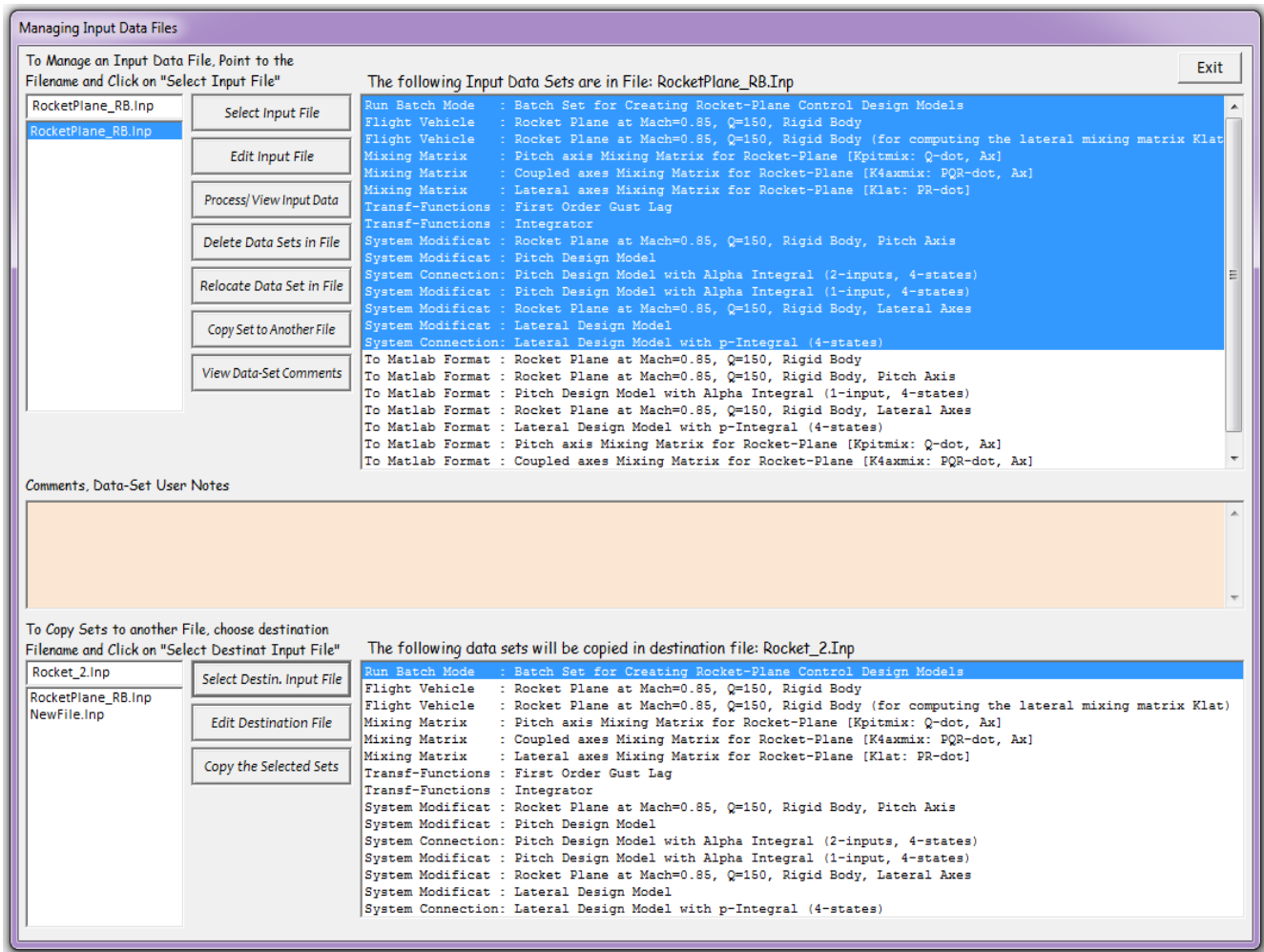
In this case we type-in a new filename: "*Rocket_2.Inp*" in the field above the menu and click on "*Select Destination Input File*". The display on the bottom right shows the titles of the data-sets that will be copied from the original file to the new file. Click on the "*Copy the Selected Sets*" and the new data will be copied to the second file. The total contents of the second file are now shown in the lower-right display. Click on any button and the file managing dialog returns to its original size. Now the newly created filename "*Rocket_2.Inp*" is included in the left menu. You may select it and process it using the batch, the same way as the original file.

Managing Input Data Files

To Manage an Input Data File, Point to the
Filename and Click on "Select Input File"

RocketPlane_RB.Inp
RocketPlane_RB.Inp

| Select Input File |
| Edit Input File |
| Process/View Input Data |
| Delete Data Sets in File |
| Relocate Data Set in File |
| Copy Set to Another File |
| View Data-Set Comments |

Exit

The following Input Data Sets are in File: RocketPlane_RB.Inp

```
Run Batch Mode    : Batch Set for Creating Rocket-Plane Control Design Models
Flight Vehicle    : Rocket Plane at Mach=0.85, Q=150, Rigid Body
Flight Vehicle    : Rocket Plane at Mach=0.85, Q=150, Rigid Body (for computing the lateral mixing matrix Klat
Mixing Matrix     : Pitch axis Mixing Matrix for Rocket-Plane [Kpitmix: Q-dot, Ax]
Mixing Matrix     : Coupled axes Mixing Matrix for Rocket-Plane [K4axmix: PQR-dot, Ax]
Mixing Matrix     : Lateral axes Mixing Matrix for Rocket-Plane [Klat: PR-dot]
Transf-Functions  : First Order Gust Lag
Transf-Functions  : Integrator
System Modificat  : Rocket Plane at Mach=0.85, Q=150, Rigid Body, Pitch Axis
System Modificat  : Pitch Design Model
System Connection : Pitch Design Model with Alpha Integral (2-inputs, 4-states)
System Modificat  : Pitch Design Model with Alpha Integral (1-input, 4-states)
System Modificat  : Rocket Plane at Mach=0.85, Q=150, Rigid Body, Lateral Axes
System Modificat  : Lateral Design Model
System Connection : Lateral Design Model with p-Integral (4-states)
To Matlab Format  : Rocket Plane at Mach=0.85, Q=150, Rigid Body
To Matlab Format  : Rocket Plane at Mach=0.85, Q=150, Rigid Body, Pitch Axis
To Matlab Format  : Pitch Design Model with Alpha Integral (1-input, 4-states)
To Matlab Format  : Rocket Plane at Mach=0.85, Q=150, Rigid Body, Lateral Axes
To Matlab Format  : Lateral Design Model with p-Integral (4-states)
To Matlab Format  : Pitch axis Mixing Matrix for Rocket-Plane [Kpitmix: Q-dot, Ax]
To Matlab Format  : Coupled axes Mixing Matrix for Rocket-Plane [K4axmix: PQR-dot, Ax]
```

Comments, Data-Set User Notes

To Copy Sets to another File, choose destination
Filename and Click on "Select Destinat Input File"

Rocket_2.Inp

RocketPlane_RB.Inp
NewFile.Inp

| Select Destin. Input File |
| Edit Destination File |
| Copy the Selected Sets |

The following data sets are now in destination file: Rocket_2.Inp

```
Run Batch Mode    : Batch Set for Creating Rocket-Plane Control Design Models
Flight Vehicle    : Rocket Plane at Mach=0.85, Q=150, Rigid Body
Flight Vehicle    : Rocket Plane at Mach=0.85, Q=150, Rigid Body (for computing the lateral mixing matrix Klat
Mixing Matrix     : Pitch axis Mixing Matrix for Rocket-Plane [Kpitmix: Q-dot, Ax]
Mixing Matrix     : Coupled axes Mixing Matrix for Rocket-Plane [K4axmix: PQR-dot, Ax]
Mixing Matrix     : Lateral axes Mixing Matrix for Rocket-Plane [Klat: PR-dot]
Transf-Functions  : First Order Gust Lag
Transf-Functions  : Integrator
System Modificat  : Rocket Plane at Mach=0.85, Q=150, Rigid Body, Pitch Axis
System Modificat  : Pitch Design Model
System Connection : Pitch Design Model with Alpha Integral (2-inputs, 4-states)
System Modificat  : Pitch Design Model with Alpha Integral (1-input, 4-states)
System Modificat  : Rocket Plane at Mach=0.85, Q=150, Rigid Body, Lateral Axes
System Modificat  : Lateral Design Model
System Connection : Lateral Design Model with p-Integral (4-states)
```

Managing Input Data Files

To Manage an Input Data File, Point to the
Filename and Click on "Select Input File"

Rocket_2.Inp

RocketPlane_RB.Inp
Rocket_2.Inp

Select Input File

Exit

The following Input Data Sets are in File: Rocket_2.Inp

```
Run Batch Mode    : Batch Set for Creating Rocket-Plane Control Design Models
Flight Vehicle    : Rocket Plane at Mach=0.85, Q=150, Rigid Body
```

Batch Mode Execution

```
Flight Vehicle    : Rocket Plane at Mach=0.85, Q=150, Rigid Body
Flight Vehicle    : Rocket Plane at Mach=0.85, Q=150, Rigid Body (for computing the lateral mixing matrix Kl
Mixing Matrix     : Pitch axis Mixing Matrix for Rocket-Plane [Kpitmix: Q-dot, Ax]
Transf-Functions  : First Order Gust Lag
Transf-Functions  : Integrator
System Modificat  : Rocket Plane at Mach=0.85, Q=150, Rigid Body, Pitch Axis
System Modificat  : Pitch Design Model
System Connection : Pitch Design Model with Alpha Integral (2-inputs, 4-states)
System Modificat  : Pitch Design Model with Alpha Integral (1-input, 4-states)
System Modificat  : Rocket Plane at Mach=0.85, Q=150, Rigid Body, Lateral Axes
Mixing Matrix     : Coupled axes Mixing Matrix for Rocket-Plane [K4axmix: PQR-dot, Ax]
Mixing Matrix     : Lateral axes Mixing Matrix for Rocket-Plane [Klat: PR-dot]
System Modificat  : Lateral Design Model
System Connection : Lateral Design Model with p-Integral (4-states)
To Matlab Format  : Rocket Plane at Mach=0.85, Q=150, Rigid Body
To Matlab Format  : Rocket Plane at Mach=0.85, Q=150, Rigid Body, Pitch Axis
To Matlab Format  : Pitch Design Model with Alpha Integral (1-input, 4-states)
To Matlab Format  : Rocket Plane at Mach=0.85, Q=150, Rigid Body, Lateral Axes
To Matlab Format  : Lateral Design Model with p-Integral (4-states)
To Matlab Format  : Pitch axis Mixing Matrix for Rocket-Plane [Kpitmix: Q-dot, Ax]
```

Comments, Data

This batch set
Simulink

Matlab format to be used in

113

6.1.2 Utility for Creating, Editing and Managing Batch Data-Sets

Batch sets are important for quickly processing input data files and a batch set utility is included in Flixan for creating and managing batch sets. A batch is a set of input instructions that coordinate non-interactive processing of data-sets within an input file by Flixan utilities. This is in contrast with the interactive processing that uses menus, dialogs, and graphics. The batch manager is a utility that is not only used to create new batch sets but also to modify existing data-sets and to save them under a different title in the input data file (.Inp). Batch sets are typically created for future applications after the modeling process has already been debugged interactively. To create a set of batch commands you must first plan the data processing sequence and debug one process at a time by running each data-set/ utility combination interactively, to make sure that they can be processed successfully without any errors caused by erroneous input data. When the individual steps are successfully tested, then you can use the batch utility to create a batch that will process the individual steps faster. The following is an example of creating and running a batch using the batch editor. You must first select the directory that includes at least one input data file (.Inp). In this case choose folder: "*C:\Flixan\Utilities\Test\Batch_Shuttle_Ex*". Then go to Flixan main menu, click on "*File Management*", then "*Manage Input Files*", and "*Edit/ Process Batch Data Sets*".
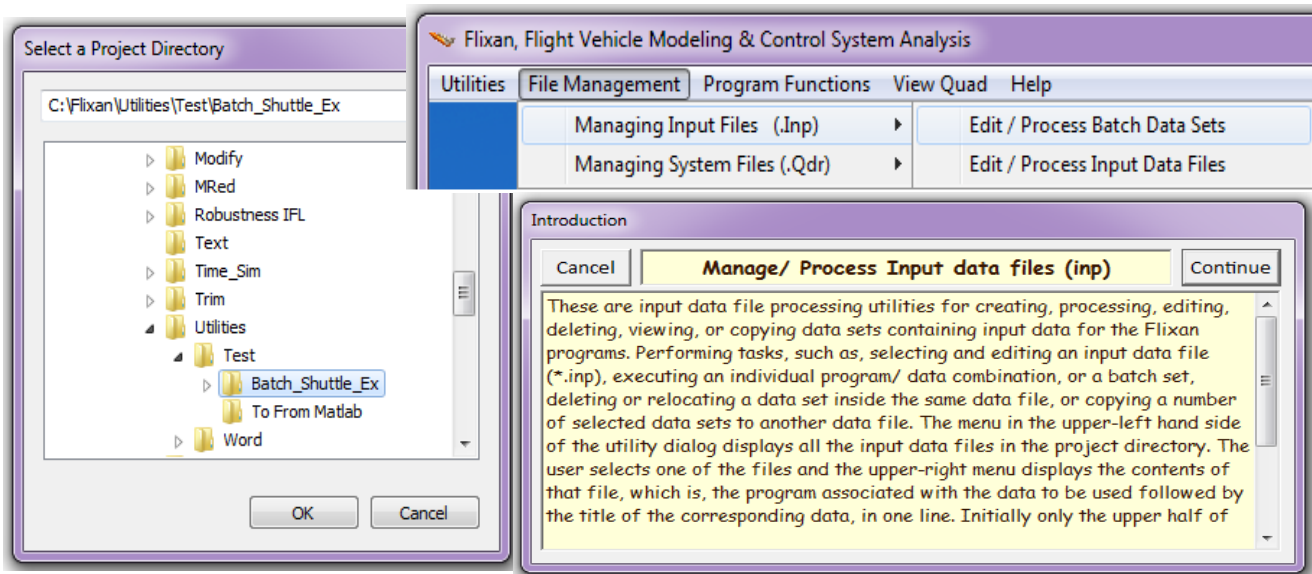
This will open the batch editor dialog shown below. From the filename selection menu on the left side select the input file "*Shuttle_Stg1_T55.Inp*" and click "*Select Input File*". This input file already includes previously created data-sets ready to be processed by Flixan programs. The individual sets are either created interactively by Flixan or copied from other input files using a text editor. The menu at the bottom of this dialog shows the titles of all the data sets which are included in this file. The corresponding utility program is also shown on the left side of each title. At this point the program expects the user to either create a new batch or to modify an already existing batch. In this case the file already contains a batch set and the editor prompts the user to either select the existing batch title from a menu or to create a new batch. In this case we respond with "*Create New*" batch. We must then enter a new title for the new batch to be created: "*New Batch for the Shuttle Ascent Example*". The light blue menu at the top of the dialog will eventually show the accumulated batch commands that will be included in this batch and processed by the batch processor. Titles from the yellow menu at the bottom are gradually selected and included in the batch, one or more items at a time by clicking on "*Include Title in Batch Set*".
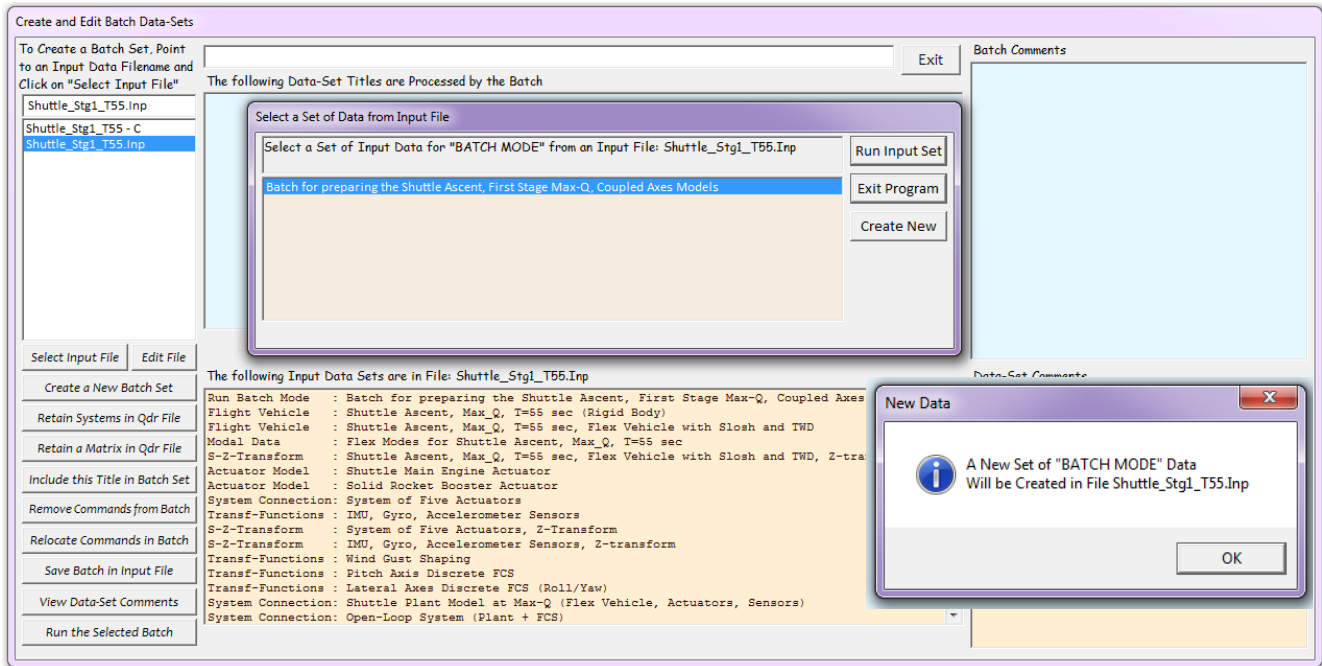
The light blue display on the upper right shows the user comments for the selected batch set. When starting a new batch the user must type-in the batch notes in this field, describing the function and the purpose of this batch. The notes will appear as comment lines in the new batch set in the (.Inp) file after saving it. The buttons in the lower left corner are for various editing functions. When you click on "*Retain a System in Qdr File*" or "*Retain a Matrix in Qdr*", as shown below, the program will save some of the systems and matrices from the old systems file to the new systems file. The systems filename is typically the same as the input file but with a different extension (.Qdr). The file is recreated every time you process the batch, so in order to preserve some of the old systems and matrices you must include "*Retain*" statements in the batch.

Create and Edit Batch Data-Sets

To Create a Batch Set, Point to an Input Data Filename and Click on "Select Input File"

Shuttle_Stg1_T55.Inp
Shuttle_Stg1_T55 - C
Shuttle_Stg1_T55.Inp

New Batch for Shuttle Ascent Example

Exit

The following Data-Set Titles are Processed by the Batch

```
Retain System   : Shuttle Main Engine Actuator
Retain System   : Solid Rocket Booster Actuator
```

Select a Gain Matrix

Select one of the following Matrices from Systems File: Shuttle_Stg1_T55.Qdr

```
TVC             : Shuttle Stage-1 TVC Matrix at Max-Q
```

Select Matrix
Cancel
View Matrix

Batch Comments

This batch set creates Space Shuttle Ascent models at Max Dynamic Pressure which occurs 55 seconds after lift-off. A rigid-body model is created and a flexible model with 29 mixed symmetric and anti-symmetric flex modes. Fuel sloshing for the External Tank is also included in the flex model and the tail-wags-dog option is turned on. Two actuator models are created,

The following Data-Sets are in Input File: Shuttle_Stg1_T55.Inp

Data-Set Comments

```
Run Batch Mode    : Batch for preparing the Shuttle Ascent, First Stage Max-Q, Coupled Axes Models
Flight Vehicle    : Shuttle Ascent, Max_Q, T=55 sec (Rigid Body)
Flight Vehicle    : Shuttle Ascent, Max_Q, T=55 sec, Flex Vehicle with Slosh and TWD
Modal Data        : Flex Modes for Shuttle Ascent, Max_Q, T=55 sec
S-Z-Transform     : Shuttle Ascent, Max_Q, T=55 sec, Flex Vehicle with Slosh and TWD, Z-transform
Actuator Model    : Shuttle Main Engine Actuator
Actuator Model    : Solid Rocket Booster Actuator
System Connection: System of Five Actuators
Transf-Functions : IMU, Gyro, Accelerometer Sensors
S-Z-Transform     : System of Five Actuators, Z-Transform
S-Z-Transform     : IMU, Gyro, Accelerometer Sensors, Z-transform
Transf-Functions : Wind Gust Shaping
Transf-Functions : Pitch Axis Discrete FCS
Transf-Functions : Lateral Axes Discrete FCS (Roll/Yaw)
System Connection: Shuttle Plant Model at Max-Q (Flex Vehicle, Actuators, Sensors)
System Connection: Open-Loop System (Plant + FCS)
```

Select Input File | Edit File
Create a New Batch Set
Retain Systems in Qdr File
Retain a Matrix in Qdr File
Include this Title in Batch Set
Remove Commands from Batch
Relocate Commands in Batch
Save Batch in Input File
View Data-Set Comments
Run the Selected Batch

When you click on "*Retain Systems*.." or "*Retain a Matrix*.." buttons, selection menus come up showing the existing systems or matrices in the old systems file. From the menus, the user selects some of the systems or matrices to be retained in the new systems file. Obviously, only a few of them are needed. Most of them are re-created. The corresponding statements will be added in the light blue batch commands list on the top. There are also buttons for deleting some of the already existing batch commands and for relocating them within the batch. There is also a "*Run the Selected Batch*" button for testing the batch while editing, and either before or after saving it. You may start, for example, with a few commands in the batch and test them, add some more and test them again, and so on until the batch set is complete. In the following dialog we select four data-set titles from the lower menu and include them in the batch set.


Create and Edit Batch Data-Sets

To Create a Batch Set, Point to an Input Data Filename and Click on "Select Input File"

Shuttle_Stg1_T55.Inp
Shuttle_Stg1_T55 - C
Shuttle_Stg1_T55.Inp

New Batch for Shuttle Ascent Example

Exit

The following Data-Set Titles are Processed by the Batch

```
Retain System   : Shuttle Main Engine Actuator
Retain System   : Solid Rocket Booster Actuator
Retain Matrix   : Shuttle Stage-1 TVC Matrix at Max-Q
```

Batch Comments

This batch set creates Space Shuttle Ascent models at Max Dynamic Pressure which occurs 55 seconds after lift-off. A rigid-body model is created and a flexible model with 29 mixed symmetric and anti-symmetric flex modes. Fuel sloshing for the External Tank is also included in the flex model and the tail-wags-dog option is turned on. Two actuator models are created,

The following Data-Sets are in Input File: Shuttle_Stg1_T55.Inp

Data-Set Comments

```
Run Batch Mode    : Batch for preparing the Shuttle Ascent, First Stage Max-Q, Coupled Axes Models
Flight Vehicle    : Shuttle Ascent, Max_Q, T=55 sec (Rigid Body)
Flight Vehicle    : Shuttle Ascent, Max_Q, T=55 sec, Flex Vehicle with Slosh and TWD
Modal Data        : Flex Modes for Shuttle Ascent, Max_Q, T=55 sec
S-Z-Transform     : Shuttle Ascent, Max_Q, T=55 sec, Flex Vehicle with Slosh and TWD, Z-transform
Actuator Model    : Shuttle Main Engine Actuator
Actuator Model    : Solid Rocket Booster Actuator
System Connection: System of Five Actuators
Transf-Functions : IMU, Gyro, Accelerometer Sensors
S-Z-Transform     : System of Five Actuators, Z-Transform
S-Z-Transform     : IMU, Gyro, Accelerometer Sensors, Z-transform
Transf-Functions : Wind Gust Shaping
Transf-Functions : Pitch Axis Discrete FCS
Transf-Functions : Lateral Axes Discrete FCS (Roll/Yaw)
System Connection: Shuttle Plant Model at Max-Q (Flex Vehicle, Actuators, Sensors)
System Connection: Open-Loop System (Plant + FCS)
```

Select Input File | Edit File
Create a New Batch Set
Retain Systems in Qdr File
Retain a Matrix in Qdr File
Include this Title in Batch Set
Remove Commands from Batch
Relocate Commands in Batch
Save Batch in Input File
View Data-Set Comments
Run the Selected Batch

When the batch is tested successfully you may save it in the data file by clicking on the "*Save Batch in Input File*". The new set of instructions will be saved at the bottom of the input data file under the new title and the new comments. The lower-left yellow menu shows the titles and processes of the data-sets located in the input file (.Inp). The user comments of the individual data-sets can also be displayed and modified using the yellow display located in the lower-right corner of the dialog. You must first select the title of the data-set from the lower-left yellow menu and the corresponding comment lines (!) will appear in the yellow field on the lower-right. This is useful when the analyst is checking the various sets of data included in the input data file. The "Edit File" button us used for editing the entire input file, as shown below.
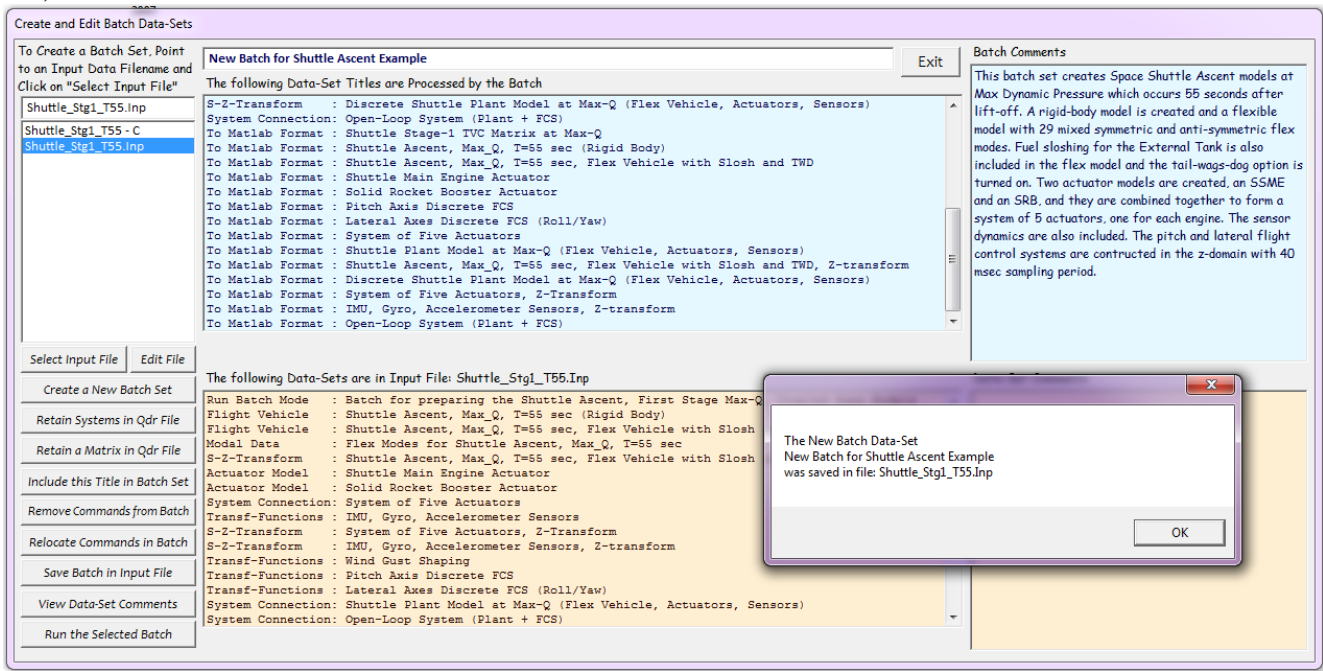

```
BATCH MODE INSTRUCTIONS ...............
New Batch for Shuttle Ascent Example
! This batch set creates Space Shuttle Ascent models at Max Dynamic Pressure which occurs 55
! seconds after lift-off. A rigid-body model is created and a flexible model with 29 mixed
! symmetric and anti-symmetric flex modes. Fuel sloshing for the External Tank is also included in
! the flex model and the tail-wags-dog option is turned on. Two actuator models are created, an
! SSME and an SRB, and they are combined together to form a system of 5 actuators, one for each
! engine. The sensor dynamics are also included. The pitch and lateral flight control systems are
! contructed in the z-domain with 40 msec sampling period.
Retain System      : Shuttle Main Engine Actuator
Retain System      : Solid Rocket Booster Actuator
Retain Matrix      : Shuttle Stage-1 TVC Matrix at Max-Q
Flight Vehicle     : Shuttle Ascent, Max_Q, T=55 sec (Rigid Body)
Flight Vehicle     : Shuttle Ascent, Max_Q, T=55 sec, Flex Vehicle with Slosh and TWD
Transf-Functions : Pitch Axis Discrete FCS
Transf-Functions : Lateral Axes Discrete FCS (Roll/Yaw)
System Connection: System of Five Actuators
Transf-Functions : IMU, Gyro, Accelerometer Sensors
Transf-Functions : Wind Gust Shaping
System Connection: Shuttle Plant Model at Max-Q (Flex Vehicle, Actuators, Sensors)
S-Z-Transform      : System of Five Actuators, Z-Transform
S-Z-Transform      : IMU, Gyro, Accelerometer Sensors, Z-transform
S-Z-Transform      : Shuttle Ascent, Max_Q, T=55 sec, Flex Vehicle with Slosh and TWD, Z-transform
S-Z-Transform      : Discrete Shuttle Plant Model at Max-Q (Flex Vehicle, Actuators, Sensors)
System Connection: Open-Loop System (Plant + FCS)
To Matlab Format : Shuttle Stage-1 TVC Matrix at Max-Q
To Matlab Format : Shuttle Ascent, Max_Q, T=55 sec (Rigid Body)
To Matlab Format : Shuttle Ascent, Max_Q, T=55 sec, Flex Vehicle with Slosh and TWD
To Matlab Format : Shuttle Main Engine Actuator
To Matlab Format : Solid Rocket Booster Actuator
To Matlab Format : Pitch Axis Discrete FCS
To Matlab Format : Lateral Axes Discrete FCS (Roll/Yaw)
To Matlab Format : System of Five Actuators
To Matlab Format : Shuttle Plant Model at Max-Q (Flex Vehicle, Actuators, Sensors)
To Matlab Format : Shuttle Ascent, Max_Q, T=55 sec, Flex Vehicle with Slosh and TWD, Z-transform
To Matlab Format : Discrete Shuttle Plant Model at Max-Q (Flex Vehicle, Actuators, Sensors)
To Matlab Format : System of Five Actuators, Z-Transform
To Matlab Format : IMU, Gyro, Accelerometer Sensors, Z-transform
To Matlab Format : Open-Loop System (Plant + FCS)
-----------------------------------------------------------------------------------------------
```

117
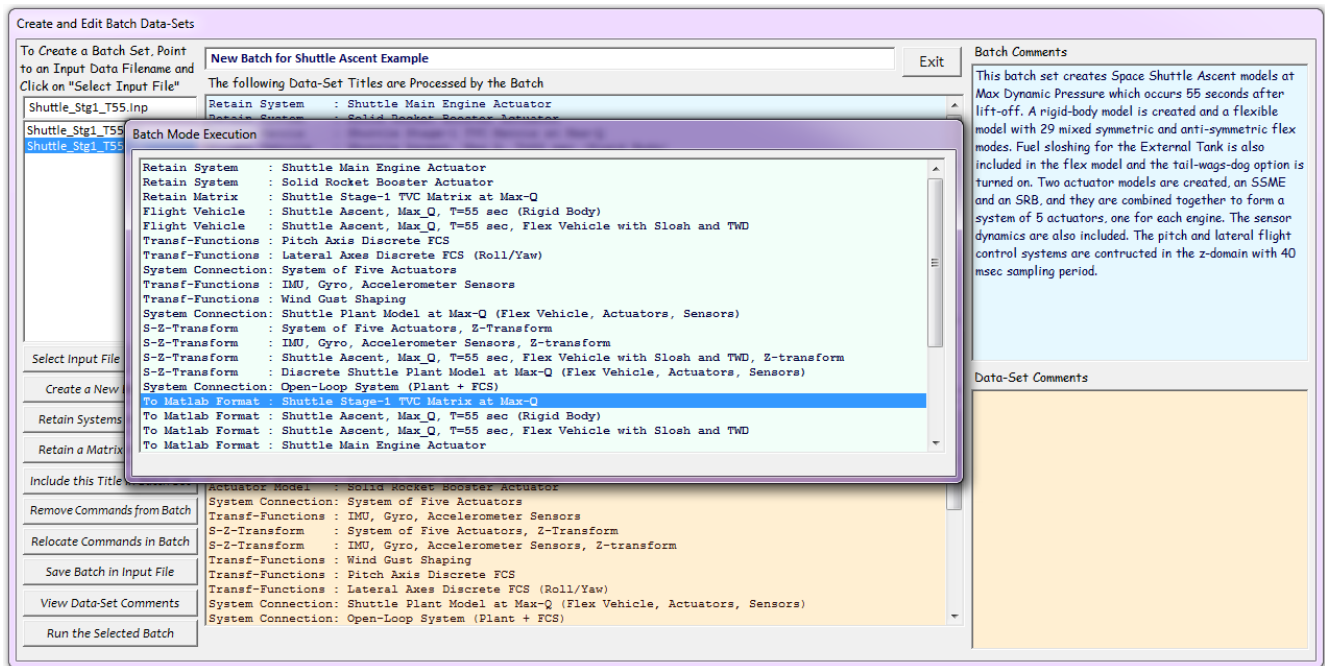
When you click on "*Run the Selected Batch*" the program will process the selected batch set, create new systems and matrices, and save them in systems file "*Shuttle_Stg1_T55.Qdr*". A display momentarily pop-up, while the program is processing the input file, showing the set that is currently being processed. This is mainly for debugging purposes and for locating the problem in case of an error.

6.1.3 Processing the new Batch Using the File Manager

This newly created batch can also be processed via the file manager utility. From the Flixan main menu select "*Edit/ Process Input Data*", then from the file manager dialog select the input file "*Shuttle_Stg1_T55.Inp*", and find the newly created batch set "*New Batch for Shuttle Ascent Example*" which is originally located at the bottom of the file. Highlight this batch set and relocate it closer to the top, right below the original batch, as shown.
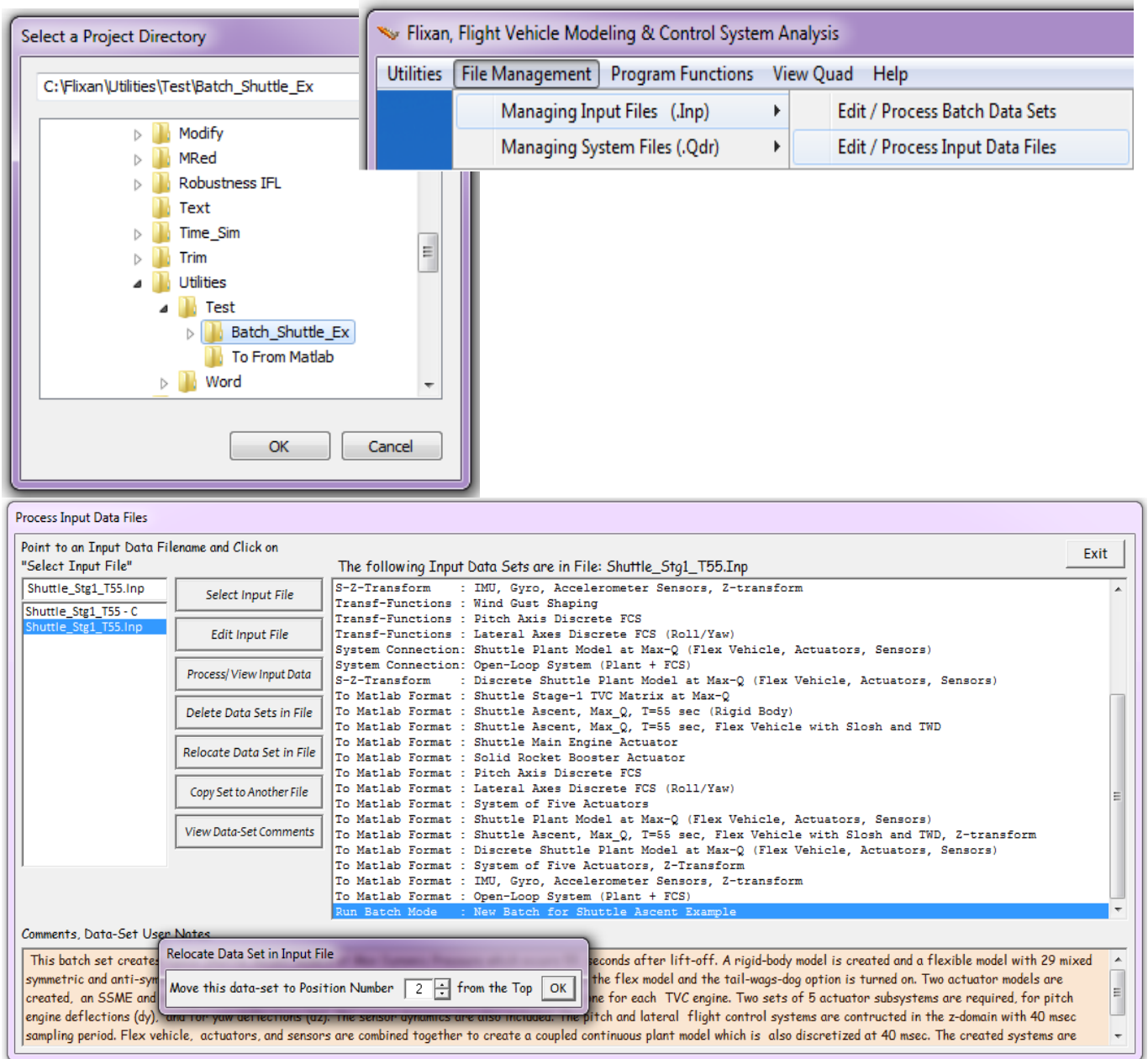
Then go to the menu on the right and select the new batch title, as shown below. Also click on "*View Data-Set Comments*" to be able to read the batch comments at the bottom of the dialog. Then click on "*Process/ View Input Data*" to process the batch.
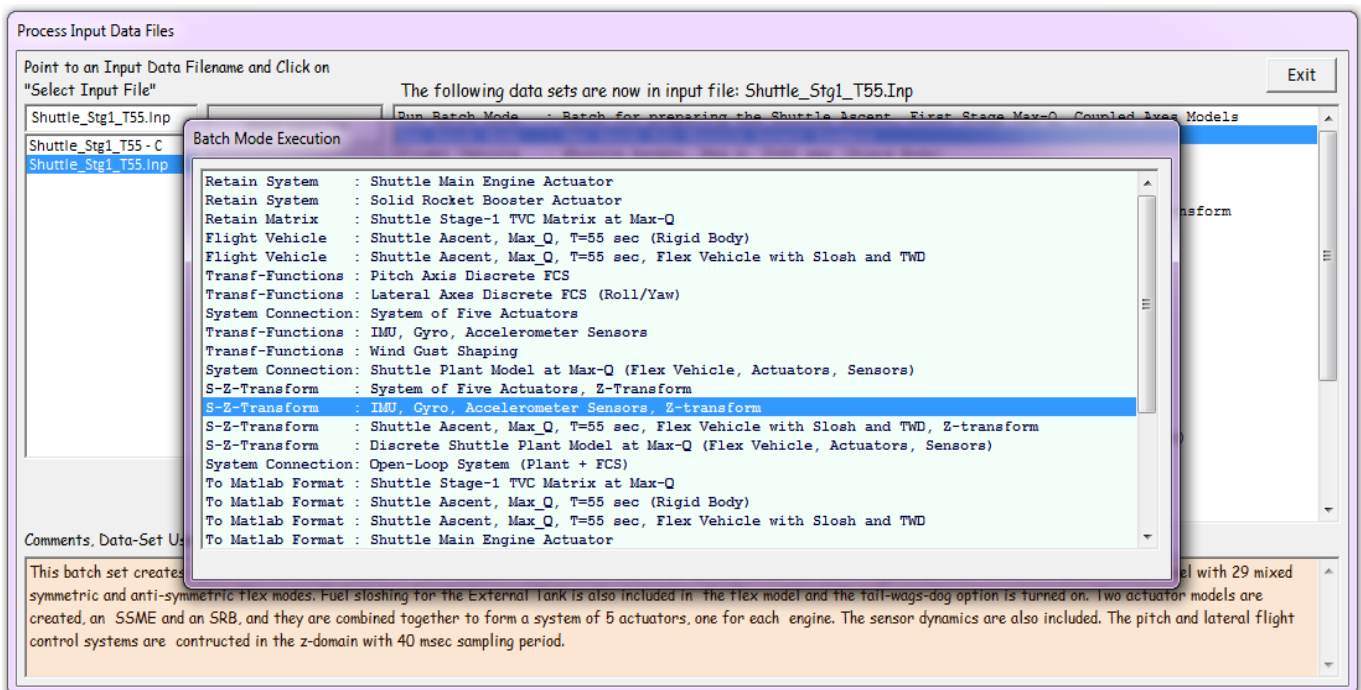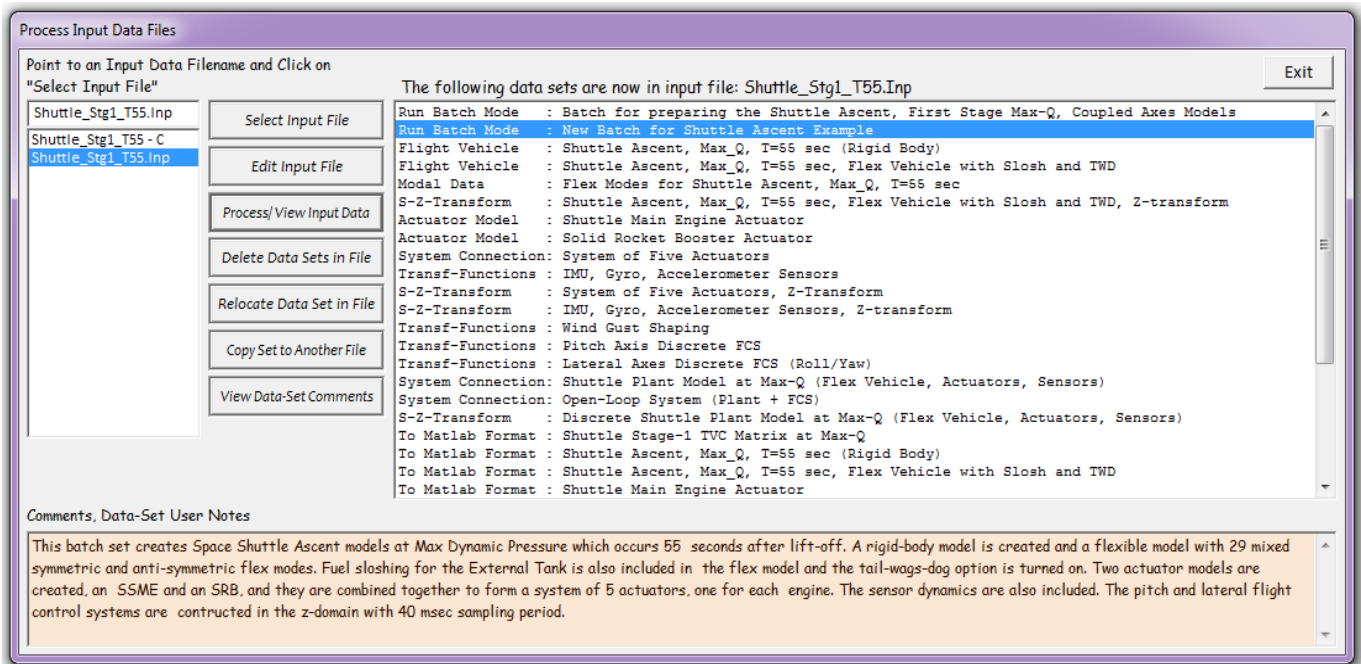
The new batch is then processed by Flixan and the new systems are saved in file: "*Shuttle_Stg1-T55.Inp*".

6.2 System Files (.Qdr)

A systems file consists of state-space systems and single matrices which are generated by Flixan programs and utilities, similar to the file below. Each system or matrix has a title followed by comment lines below the title. Single matrices also have a short name in addition to the title. You must avoid using: A, B, C, D, for single matrix names because they are reserved for state-space system matrices. Input and output definitions are also included below the matrix or system data.

```
GAIN MATRIX FOR ...
Shuttle Stage-1 TVC Matrix at Max-Q
! Converts the Roll, Pitch, and Yaw FCS Demands to Pitch and Yaw Engine Deflections
!
Matrix TVC                    Size = 10 X  3
           1-Roll             2-Pitch             3-Yaw
   1-dy1  0.0                 1.28                0.0
   2-dy2 -0.2518              1.28                0.0
   3-dy3  0.2518              1.28                0.0
   4-dy4 -0.35                0.6                 0.0
   5-dy5  0.35                0.6                 0.0
   6-dz1 -0.189               0.0                 0.61
   7-dz2  0.0                 0.0                 0.61
   8-dz3  0.0                 0.0                 0.61
   9-dz4  0.0                 0.0                 0.43
  10-dz5  0.0                 0.0                 0.43
-----------------------------------------------------------------------------------------
Definitions of Matrix Inputs (Columns):    3
DP_TVC Roll  FCS Demand About X Axis
DQ_TVC Pitch FCS Demand About Y Axis
DR_TVC Yaw   FCS Demand About Z Axis

Definitions of Matrix Outputs (Rows):     10
Dy_engine 1 Centr SSME Pitch Deflection (rad)
Dy_engine 2 Left  SSME Pitch Deflection (rad)
Dy_engine 3 Right SSME Pitch Deflection (rad)
Dy_engine 4 Left  SRB  Pitch Deflection (rad)
Dy_engine 5 Right SRB  Pitch Deflection (rad)
Dz_engine 1 Centr SSME Yaw   Deflection (rad)
Dz_engine 2 Left  SSME Yaw   Deflection (rad)
Dz_engine 3 Right SSME Yaw   Deflection (rad)
Dz_engine 4 Left  SRB  Yaw   Deflection (rad)
Dz_engine 5 Right SRB  Yaw   Deflection (rad)
-----------------------------------------------------------------------------------------
STATE-SPACE SYSTEM ...
Shuttle Main Engine Actuator
! Shuttle Main Engine Actuator Without Compensator  Using the Hydraulic Actuator Model Type (B)
Number of Inputs, States, Outputs, Sample Time dT (for discrete)=    2    4    3    0.0000
Matrices: (A,B,C,D)
Matrix A                    Size =  4 X  4
           1-Column             2-Column             3-Column             4-Column
   1-Row -0.521007765548E+02 -0.116700557842E+02 -0.109601849353E+02 -0.203189376000E+01
   2-Row -0.539500000000E+02 -0.142437261803E+02 -0.133773030730E+02  0.000000000000E+00
   3-Row  0.000000000000E+00  0.000000000000E+00  0.000000000000E+00  0.100000000000E+01
   4-Row  0.000000000000E+00  0.111369353410E+04 -0.276797413640E+04 -0.365367581931E+01
-----------------------------------------------------------------------------------------
Matrix B                    Size =  4 X  2
           1-Column             2-Column
   1-Row  0.402237129840E+02  0.000000000000E+00
   2-Row  0.490945000000E+02  0.000000000000E+00
   3-Row  0.000000000000E+00  0.000000000000E+00
   4-Row  0.000000000000E+00  0.221434898140E-03
-----------------------------------------------------------------------------------------
Matrix C                    Size =  3 X  4
           1-Column             2-Column             3-Column             4-Column
   1-Row  0.000000000000E+00  0.000000000000E+00  0.100000000000E+01  0.000000000000E+00
   2-Row  0.000000000000E+00  0.000000000000E+00  0.000000000000E+00  0.100000000000E+01
   3-Row  0.000000000000E+00  0.111369353410E+04 -0.276797413640E+04 -0.365367581931E+01
-----------------------------------------------------------------------------------------
Matrix D                    Size =  3 X  2
           1-Column             2-Column
   1-Row  0.000000000000E+00  0.000000000000E+00
   2-Row  0.000000000000E+00  0.000000000000E+00
   3-Row  0.000000000000E+00  0.221434898140E-03
-----------------------------------------------------------------------------------------
```

Definition of System Variables

Inputs =   2
        Nozzle Deflection Command (Delta_com) (rad)
        Load-Torque at the Gimbal, (Tl) (ft-lb)

Outputs =   3
        Nozzle Gimbal Rotation (Delta)   (rad)
        Nozzle Gimbal Rate   (Delta-dot) (rad/sec)
        Gimbal Accelerat. (Delta-dot-dot) (rad/sec^2)

States =   4
        Differ. Pressure Feedback (DPF)   (ft-lb)
        Piston Displacement   (Xr)   (feet)
        Engine Gimbal Rotation (Delta)   (rad)
        Engine Gimbal Rate   (Delta-dot) (rad/sec)

Gain Matrix for ...
Pitch axis Mixing Matrix for Rocket-Plane [Kpitmix: Q-dot, Ax]
! Mixing Logic Matrix for the rocket-plane in the pitch axis. It converts the pitch and
! axial acceleration demands to five aero-surface deflections and engine thrust variation
Matrix Kpitmix   Size = 6 X 2
           1-Column   2-Column
   1-Row -0.488779040922E-01 0.982582014775E-01
   2-Row -0.291806701836E-01 -0.310962189063E-02
   3-Row -0.291806701836E-01 -0.310962189063E-02
   4-Row -0.127295123699E+00 0.117463289448E-03
   5-Row -0.127295123699E+00 0.117463289448E-03
   6-Row -0.370557557847E-01 0.137897247667E-02

Definitions of Matrix Inputs (Columns):   2
Q-dot Pitch Accel Demand About Y Axis
Ax Forward Accel Demand Along X Axis

Definitions of Matrix Outputs (Rows):   6
Output: 1 Delta(throttle) of Engine No: 1
Output: 2 Control Surface: 1 Deflection (radians)
Output: 3 Control Surface: 2 Deflection (radians)
Output: 4 Control Surface: 3 Deflection (radians)
Output: 5 Control Surface: 4 Deflection (radians)
Output: 6 Control Surface: 5 Deflection (radians)

STATE-SPACE SYSTEM ...
First Order Gust Lag
! A low-pass filter 0.5 (rad/sec) to smooth out the input gust
Number of Inputs, States, Outputs, Sample Time dT (for discrete)=   1   1   1   0.0000
Matrices: (A,B,C,D)
Matrix A   Size = 1 X 1
           1-Column
   1-Row -0.500000000000E+00

Matrix B   Size = 1 X 1
           1-Column
   1-Row 0.100000000000E+01

Matrix C   Size = 1 X 1
           1-Column
   1-Row 0.500000000000E+00

Matrix D   Size = 1 X 1
           1-Column
   1-Row 0.000000000000E+00

Definition of System Variables

Inputs =   1
   1   Input No: 1

States =   1
   1   State No: 1

Outputs =   1
   1   Output No: 1

STATE-SPACE SYSTEM ...
Pitch Design Model
! The pitch axis control design model is extracted from the coupled rigid-body model. The
! wind-gust input is not used. The states and outputs are: (theta, q, and alpha)
Number of Inputs, States, Outputs, Sample Time dT (for discrete)=   6   3   3   0.0000
Matrices: (A,B,C,D)
Matrix A   Size = 3 X 3
            1-Column   2-Column   3-Column
   1-Row 0.000000000000E+00 0.999996066093E+00 0.000000000000E+00
   2-Row 0.000000000000E+00 -0.301385824515E+00 -0.398388623235E+01
   3-Row 0.533570410077E-08 0.997318761156E+00 -0.303460356762E+00

Matrix B   Size = 3 X 6
            1-Column   2-Column   3-Column   4-Column   5-Column
6-Column
   1-Row 0.000000000000E+00 0.000000000000E+00 0.000000000000E+00 0.000000000000E+00
   2-Row -0.383726824856E-01 -0.873361046148E+00 -0.873361046148E+00 -0.363483208593E+01 -
   3-Row -0.149738604708E-03 -0.251044848966E-01 -0.251044848966E-01 -0.214350479379E-01 -
----
Matrix C   Size = 3 X 3
            1-Column   2-Column   3-Column
   1-Row 0.100000000000E+01 0.000000000000E+00 0.000000000000E+00
   2-Row 0.000000000000E+00 0.100000000000E+01 0.000000000000E+00
   3-Row 0.000000000000E+00 0.000000000000E+00 0.100000000000E+01

Matrix D   Size = 3 X 6
            1-Column   2-Column   3-Column   4-Column   5-Column
6-Column
   1-Row 0.000000000000E+00 0.000000000000E+00 0.000000000000E+00 0.000000000000E+00
   2-Row 0.000000000000E+00 0.000000000000E+00 0.000000000000E+00 0.000000000000E+00
   3-Row 0.000000000000E+00 0.000000000000E+00 0.000000000000E+00 0.000000000000E+00

Definition of System Variables

Inputs =   6
   1   Throttle Input dTh/Th for Engine No 1 (-)
   2   Aero Surface No 1 Deflection   (radians)
   3   Aero Surface No 2 Deflection   (radians)
   4   Aero Surface No 3 Deflection   (radians)
   5   Aero Surface No 4 Deflection   (radians)
   6   Aero Surface No 5 Deflection   (radians)

States =   3
   1   Pitch Attitude   (theta-rigid) (radians)
   2   Pitch Rate   (q -rigid)   (rad/sec)
   3   Angle of attack   (alfa-rigid)   (radians)

Outputs =   3
   1   Pitch Attitude (thet-123) (radians)
   2   Pitch Rate   (q-body)   (rad/sec)
   3   Angle of attack, alfa, (radians)

STATE-SPACE SYSTEM ...
Pitch Design Model with Alpha Integral (2-inputs, 4-states)
! The pitch axis control design model is augmented with the integral of the angle of attack for
! H-infinity design. The states and outputs are: (theta, q, alpha, and alpha-integral). The
! inputs to the design model are reduced to two by pre-multiplying it with the mixing matrix
! (Kpitmix)
Number of Inputs, States, Outputs, Sample Time dT (for discrete)=   2   4   4   0.0000
Matrices: (A,B,C,D)
Matrix A   Size = 4 X 4
            1-Column   2-Column   3-Column   4-Column
   1-Row 0.000000000000E+00 0.999996066093E+00 0.000000000000E+00 0.000000000000E+00
   2-Row 0.000000000000E+00 -0.301385824515E+00 -0.398388623235E+01 0.000000000000E+00
   3-Row 0.533570410077E-08 0.997318761156E+00 -0.303460356762E+00 0.000000000000E+00
   4-Row 0.000000000000E+00 0.000000000000E+00 0.100000000000E+01 0.000000000000E+00

Matrix B   Size = 4 X 2
            1-Column   2-Column
   1-Row 0.000000000000E+00 0.000000000000E+00
   2-Row 0.999912364254E+00 0.751375398850E-06
   3-Row 0.702100385268E-02 0.132980916263E-03
   4-Row 0.000000000000E+00 0.000000000000E+00

123

```
Matrix C                      Size =   4 X  4
           1-Column              2-Column              3-Column              4-Column
   1-Row  0.100000000000E+01  0.000000000000E+00  0.000000000000E+00  0.000000000000E+00
   2-Row  0.000000000000E+00  0.100000000000E+01  0.000000000000E+00  0.000000000000E+00
   3-Row  0.000000000000E+00  0.000000000000E+00  0.100000000000E+01  0.000000000000E+00
   4-Row  0.000000000000E+00  0.000000000000E+00  0.000000000000E+00  0.100000000000E+01
-----------------------------------------------------------------------------------------------
Matrix D                      Size =   4 X  2
           1-Column              2-Column
   1-Row  0.000000000000E+00  0.000000000000E+00
   2-Row  0.000000000000E+00  0.000000000000E+00
   3-Row  0.000000000000E+00  0.000000000000E+00
   4-Row  0.000000000000E+00  0.000000000000E+00
-----------------------------------------------------------------------------------------------
Definition of System Variables

Inputs  =   2
   1   Pitch Acceleration
   2   Axial Acceleration

States  =   4
   1   State No:  1
   2   State No:  2
   3   State No:  3
   4   State No:  4

Outputs =   4
   1   Pitch Attitude    (theta-rigid)  (radians)
   2   Pitch Rate        ( q -rigid)    (rad/sec)
   3   Angle of attack   (alpha)        (radians)
   4   Alpha Integral                   (rad-sec)
-----------------------------------------------------------------------------------------------
STATE-SPACE SYSTEM ...
Pitch Design Model with Alpha Integral (1-input, 4-states)
! Eliminate the second input (Ax acceleration) from the pitch design model
Number of Inputs, States, Outputs, Sample Time dT (for discrete)=    1    4    4    0.0000
Matrices: (A,B,C,D)
Matrix A                      Size =   4 X  4
           1-Column              2-Column              3-Column              4-Column
   1-Row  0.000000000000E+00  0.999996066093E+00  0.000000000000E+00  0.000000000000E+00
   2-Row  0.000000000000E+00 -0.301385824515E+00 -0.398388623235E+01  0.000000000000E+00
   3-Row  0.533570410077E-08  0.997318761156E+00 -0.303460356762E+00  0.000000000000E+00
   4-Row  0.000000000000E+00  0.000000000000E+00  0.100000000000E+01  0.000000000000E+00
-----------------------------------------------------------------------------------------------
Matrix B                      Size =   4 X  1
           1-Column
   1-Row  0.000000000000E+00
   2-Row  0.999912364254E+00
   3-Row  0.702100385268E-02
   4-Row  0.000000000000E+00
-----------------------------------------------------------------------------------------------
Matrix C                      Size =   4 X  4
           1-Column              2-Column              3-Column              4-Column
   1-Row  0.100000000000E+01  0.000000000000E+00  0.000000000000E+00  0.000000000000E+00
   2-Row  0.000000000000E+00  0.100000000000E+01  0.000000000000E+00  0.000000000000E+00
   3-Row  0.000000000000E+00  0.000000000000E+00  0.100000000000E+01  0.000000000000E+00
   4-Row  0.000000000000E+00  0.000000000000E+00  0.000000000000E+00  0.100000000000E+01
-----------------------------------------------------------------------------------------------
Matrix D                      Size =   4 X  1
           1-Column
   1-Row  0.000000000000E+00
   2-Row  0.000000000000E+00
   3-Row  0.000000000000E+00
   4-Row  0.000000000000E+00
-----------------------------------------------------------------------------------------------
Definition of System Variables

Inputs  =   1
   1   Pitch Acceleration

States  =   4
   1   State No:  1
   2   State No:  2
   3   State No:  3
```

```
   4   State No:  4

Outputs =   4
   1   Pitch Attitude    (theta-rigid)  (radians)
   2   Pitch Rate        ( q -rigid)    (rad/sec)
   3   Angle of attack   (alpha)        (radians)
   4   Alpha Integral                   (rad-sec)
-------------------------------------------------------------------------------------------
Gain Matrix for ...
Coupled axes Mixing Matrix for Rocket-Plane [K4axmix: PQR-dot, Ax]
! This mixing logic uses all five control surfaces and the variable throttling engine  to achieve
! roll, pitch, yaw attitude control plus axial (Ax) acceleration control
Matrix K4axmix              Size =  6 X  4
            1-Column           2-Column           3-Column           4-Column
   1-Row  0.000000000000E+00 -0.488779040922E-01  0.000000000000E+00  0.982582014775E-01
   2-Row  0.321285869960E-01 -0.291806701836E-01  0.176524775014E+00 -0.310962189063E-02
   3-Row -0.321285869960E-01 -0.291806701836E-01 -0.176524775014E+00 -0.310962189063E-02
   4-Row  0.878975586914E-02 -0.127295123699E+00 -0.123043886641E+00  0.117463289448E-03
   5-Row -0.878975586914E-02 -0.127295123699E+00  0.123043886641E+00  0.117463289448E-03
   6-Row  0.000000000000E+00 -0.370557557847E-01  0.000000000000E+00  0.137897247667E-02
-------------------------------------------------------------------------------------------
Definitions of Matrix Inputs (Columns):    4
P-dot Roll  Accel Demand About X Axis
Q-dot Pitch Accel Demand About Y Axis
R-dot Yaw   Accel Demand About Z Axis
Ax  Forward Accel Demand Along X Axis

Definitions of Matrix Outputs (Rows):     6
Output:  1 Delta(throttle) of Engine No:  1
Output:  2 Control Surface:  1 Deflection (radians)
Output:  3 Control Surface:  2 Deflection (radians)
Output:  4 Control Surface:  3 Deflection (radians)
Output:  5 Control Surface:  4 Deflection (radians)
Output:  6 Control Surface:  5 Deflection (radians)
-------------------------------------------------------------------------------------------
Gain Matrix for ...
Lateral axes Mixing Matrix for Rocket-Plane [Klat: PR-dot]
! This mixing logic uses only four control surfaces for lateral (roll and yaw)  control. It is
! based on a separate vehicle model which does not use the engine  and the body-flap
Matrix Klat                 Size =  4 X  2
            1-Column           2-Column
   1-Row  0.321285869960E-01  0.176524775014E+00
   2-Row -0.321285869960E-01 -0.176524775014E+00
   3-Row  0.878975586914E-02 -0.123043886641E+00
   4-Row -0.878975586914E-02  0.123043886641E+00
-------------------------------------------------------------------------------------------
Definitions of Matrix Inputs (Columns):    2
P-dot Roll  Accel Demand About X Axis
R-dot Yaw   Accel Demand About Z Axis

Definitions of Matrix Outputs (Rows):     4
Output:  1 Control Surface:  1 Deflection (radians)
Output:  2 Control Surface:  2 Deflection (radians)
Output:  3 Control Surface:  3 Deflection (radians)
Output:  4 Control Surface:  4 Deflection (radians)
-------------------------------------------------------------------------------------------
STATE-SPACE SYSTEM ...
Lateral Design Model
! A further simplified lateral axes rigid-body model is extracted from the coupled  rigid-body
! model to be used for LQR control design. It consists of  three states: (p, r, and beta)
Number of Inputs, States, Outputs, Sample Time dT (for discrete)=   4    3    3    0.0000
Matrices: (A,B,C,D)
Matrix A                    Size =  3 X  3
            1-Column           2-Column           3-Column
   1-Row -0.571243257881E+00  0.588055221219E+00 -0.184398767835E+02
   2-Row  0.198513239863E-01 -0.198692970677E+00  0.142318779813E+00
   3-Row  0.349050142074E-01 -0.998225203528E+00 -0.101044964581E+00
-------------------------------------------------------------------------------------------
Matrix B                    Size =  3 X  4
            1-Column           2-Column           3-Column           4-Column
   1-Row  0.111759819563E+02 -0.111759819563E+02  0.160336238937E+02 -0.160336238937E+02
   2-Row  0.798367964709E+00 -0.798367964709E+00 -0.291807761069E+01  0.291807761069E+01
   3-Row -0.102729036961E-01  0.102729036961E-01  0.197449806024E-01 -0.197449806024E-01
-------------------------------------------------------------------------------------------
```

```
Matrix C                    Size =  3 X  3
          1-Column              2-Column            3-Column
   1-Row  0.100000000000E+01  0.000000000000E+00  0.000000000000E+00
   2-Row  0.000000000000E+00  0.100000000000E+01  0.000000000000E+00
   3-Row  0.000000000000E+00  0.000000000000E+00  0.100000000000E+01
------------------------------------------------------------------------------------------------
Matrix D                    Size =  3 X  4
          1-Column              2-Column            3-Column            4-Column
   1-Row  0.000000000000E+00  0.000000000000E+00  0.000000000000E+00  0.000000000000E+00
   2-Row  0.000000000000E+00  0.000000000000E+00  0.000000000000E+00  0.000000000000E+00
   3-Row  0.000000000000E+00  0.000000000000E+00  0.000000000000E+00  0.000000000000E+00
------------------------------------------------------------------------------------------------
Definition of System Variables

Inputs  =   4
   1   Aero Surface No  1 Deflection    (radians)
   2   Aero Surface No  2 Deflection    (radians)
   3   Aero Surface No  3 Deflection    (radians)
   4   Aero Surface No  4 Deflection    (radians)

States  =   3
   1   Roll Rate         ( p -rigid)    (rad/sec)
   2   Yaw  Rate         ( r -rigid)    (rad/sec)
   3   Angle of sideslip (beta-rigid)   (radians)

Outputs =   3
   1   Roll Rate     (p-body)    (rad/sec)
   2   Yaw  Rate     (r-body)    (rad/sec)
   3   Angle of sideslip, beta, (radian)
------------------------------------------------------------------------------------------------
STATE-SPACE SYSTEM ...
Lateral Design Model with p-Integral (4-states)
! The Lateral Axes control design model is augmented with the integral of roll rate.  The states
! for LQR design are: (p,r, beta, and p-Integral)
Number of Inputs, States, Outputs, Sample Time dT (for discrete)=    2    4    4    0.0000
Matrices: (A,B,C,D)
Matrix A                    Size =  4 X  4
          1-Column              2-Column              3-Column            4-Column
   1-Row -0.571243257881E+00  0.588055221219E+00  -0.184398767835E+02  0.000000000000E+00
   2-Row  0.198513239863E-01 -0.198692970677E+00   0.142318779813E+00  0.000000000000E+00
   3-Row  0.349050142074E-01 -0.998225203528E+00  -0.101044964581E+00  0.000000000000E+00
   4-Row  0.100000000000E+01  0.000000000000E+00   0.000000000000E+00  0.000000000000E+00
------------------------------------------------------------------------------------------------
Matrix B                    Size =  4 X  2
          1-Column              2-Column
   1-Row  0.100000029654E+01 -0.340084894157E-05
   2-Row  0.248960760822E-05  0.999966672176E+00
   3-Row -0.313000641931E-03 -0.848584233733E-02
   4-Row  0.000000000000E+00  0.000000000000E+00
------------------------------------------------------------------------------------------------
Matrix C                    Size =  4 X  4
          1-Column              2-Column            3-Column            4-Column
   1-Row  0.100000000000E+01  0.000000000000E+00  0.000000000000E+00  0.000000000000E+00
   2-Row  0.000000000000E+00  0.100000000000E+01  0.000000000000E+00  0.000000000000E+00
   3-Row  0.000000000000E+00  0.000000000000E+00  0.100000000000E+01  0.000000000000E+00
   4-Row  0.000000000000E+00  0.000000000000E+00  0.000000000000E+00  0.100000000000E+01
------------------------------------------------------------------------------------------------
Matrix D                    Size =  4 X  2
          1-Column              2-Column
   1-Row  0.000000000000E+00  0.000000000000E+00
   2-Row  0.000000000000E+00  0.000000000000E+00
   3-Row  0.000000000000E+00  0.000000000000E+00
   4-Row  0.000000000000E+00  0.000000000000E+00
------------------------------------------------------------------------------------------------
Definition of System Variables
Inputs  =   2
   1   Aileron Deflection (rad)
   2   Rudder Deflection (rad)
Outputs =   4
   1   Roll Rate     (p-body)    (rad/sec)
   2   Yaw  Rate     (r-body)    (rad/sec)
   3   Angle of sideslip, beta,  (radian)
   4   p-Integral                (rad)
------------------------------------------------------------------------------------------------
```

6.2.1 Managing System Files

The systems file management utility is used for organizing system files and it is similar to the input data file management utility. Maintaining organized system files by introducing comments, labeling the system inputs, states, and output variables, keeping the systems and matrices in a sequential order, and deleting the unused older versions is a very attractive feature for documenting the analysis. The comments, notes and name-lists of the system variables are useful for remembering details, especially when you have to discontinue the analysis for a period of time and resume it later in the future. To get to the systems manager utility, the user must first select the project directory, and from the Flixan main menu select: "*File Management*", "*Managing System Files (Qdr)*", and "*Edit/ View/ Copy System Files*", as shown below.
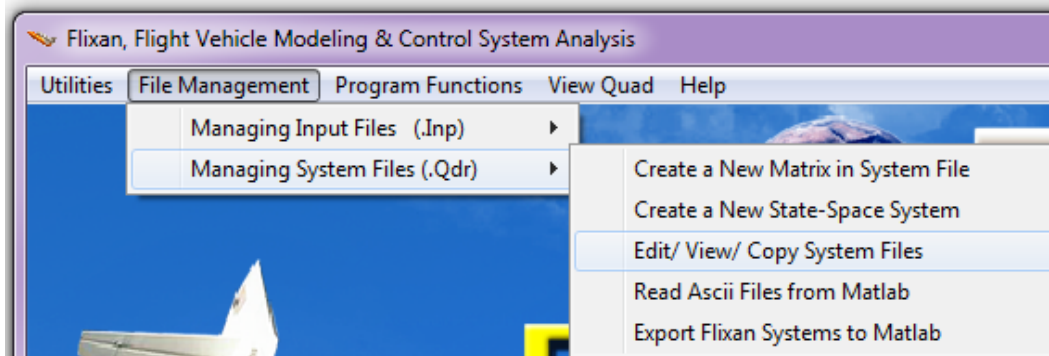
The systems file manager dialog is shown below. The menu on the left side shows the system files which are located in the project directory. The user selects a filename, for example, "*Shuttle_Stg1_T55.Qdr*", and clicks on "*Select Systems File*". The menu on the right will then display the titles of the systems or single matrices which are saved in the systems file, as shown below. The user is then able to perform several operations on this file using the dialog buttons. For example, delete some of the systems or matrices which are no longer used, move them to a different location within the file, and edit the systems file using a Flixan provided text editor. The repositioning of each item is defined relative to the top of the file. The "*View/ Modify Systems*" button is used to display the state-space system or matrix using color coded graphics, including tables of the system inputs, states, outputs, and display the user comments or notes that describe the system or the gain matrix. The state variable definitions and comments can be modified using the interactive dialogs.
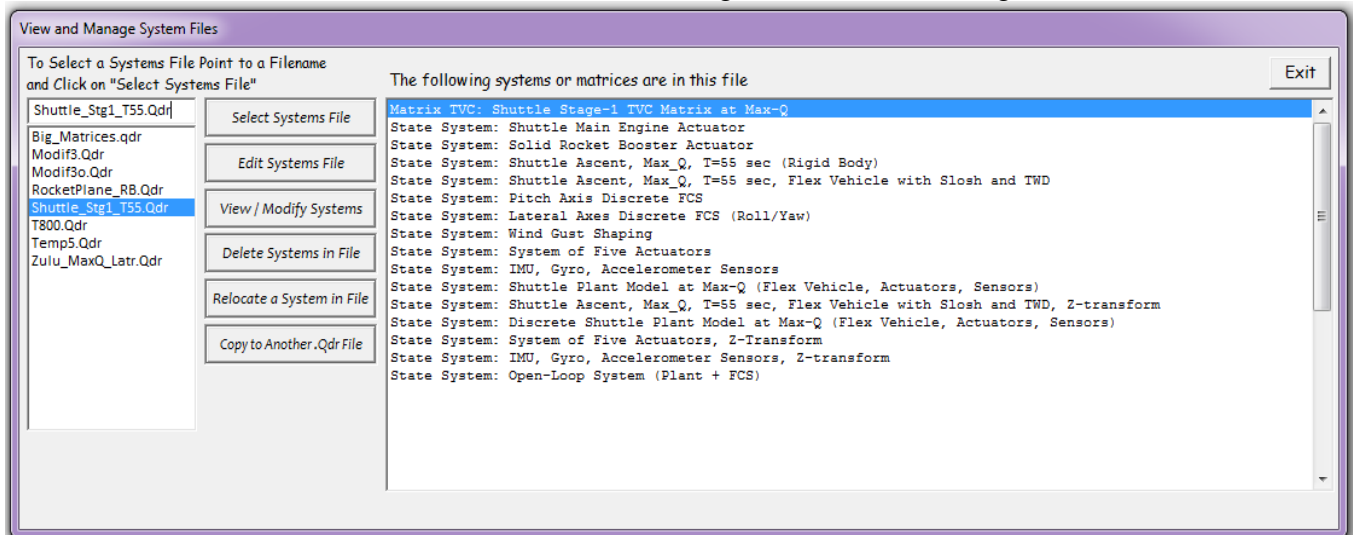
The "*Copy to Another .Qdr File*" button is used to copy a group of systems and single matrices to another systems file. You must first select from the right menu all the systems and matrices to copy from the original file and click on "*Copy to Another .Qdr File*" button. The lower part of the dialog opens up showing two additional menus and buttons. From the lower-left menu select the destination systems file. In this case we select the empty file "*NewFile.Qdr*" and click on "*Select Destination File*". The selected systems and matrices from the top-right menu will now appear in the lower-right display, but they are not copied yet. Click on "*Copy Selected Systems*" and the selected items will be copied to file "*NewFile.Qdr*". If the destination file is not empty but already includes some previous systems, these items will be preserved in this file after the transfer. The new items will be added at the bottom of the file and the lower-right display will show both old and new. Click on "*Close*" and the dialog will return to its original size showing only the top part.
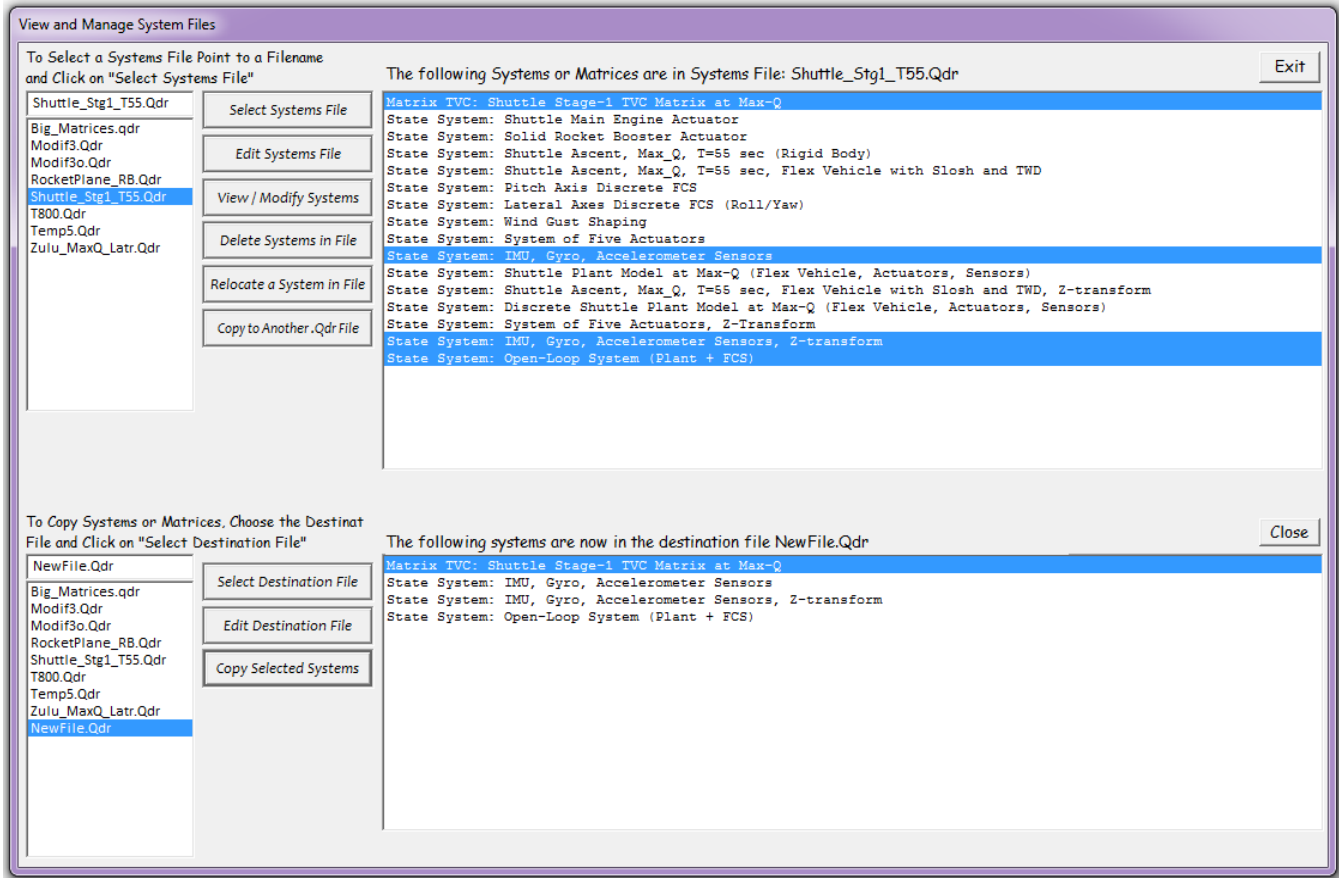
View or Modify Systems: The "*View/ Modify System*" button is used to graphically display a system or a single matrix using color coded graphics. Each matrix element appears as a small square of different colors. This is a convenient way for visualizing large matrices because the color coding provides an indication the magnitude of each element, which in general is a sufficient information, rather than reading the actual numbers. Numbers with high positive exponent gravitate toward the green, blue, and cyan regions of the color spectrum. Numbers with high negative exponent gravitate toward the orange, red, and brown regions. Zeros are black. Ones are bright white. Negative numbers have the minus (-) sign in front of the colored square. The actual value of each element can be read in the field located below the tabs by pointing the cursor on the matrix element and clicking the left mouse button. The matrix element values can also be changed by entering data using this field. The system display dialog also includes four tabs that provide additional information about the system. The comments tab displays comments or user notes about the system. There are also tabs that show the

system inputs, states, and output variables. There are similar tabs for single matrices. In addition to modifying the matrix elements, the variable definitions or comments can also be modified using this dialog. The new system, however, must be saved under a new title. The first system below is a lateral vehicle with four inputs and three outputs. The display shows the user comments. The second example shows a Shuttle main engine actuator. The display tab shows definitions of the state variables. The bottom display is pointing at matrix element B(1,1) that has a value of 40.22 .

The figure below shows a Shuttle TVC matrix which transforms the roll, pitch and yaw acceleration demands to pitch and yaw deflections for the 5 engines. The matrix name and title are shown on the top and they can be modified and saved to a different name and title. Every time you change something using this dialog, for example, a matrix element, the input-output definitions, the comments, the matrix name or title, you must remember to save the changes by clicking the "*Save Changes*" button. When the modifications are complete, click on the "*Exit*" button, and the new data will be saved as a separate system or matrix in the same systems file. You must remember to change the system or matrix title, otherwise, the modifications will not be accepted using the same title. You can later delete the old system or matrix and rename the new one, if you wish.
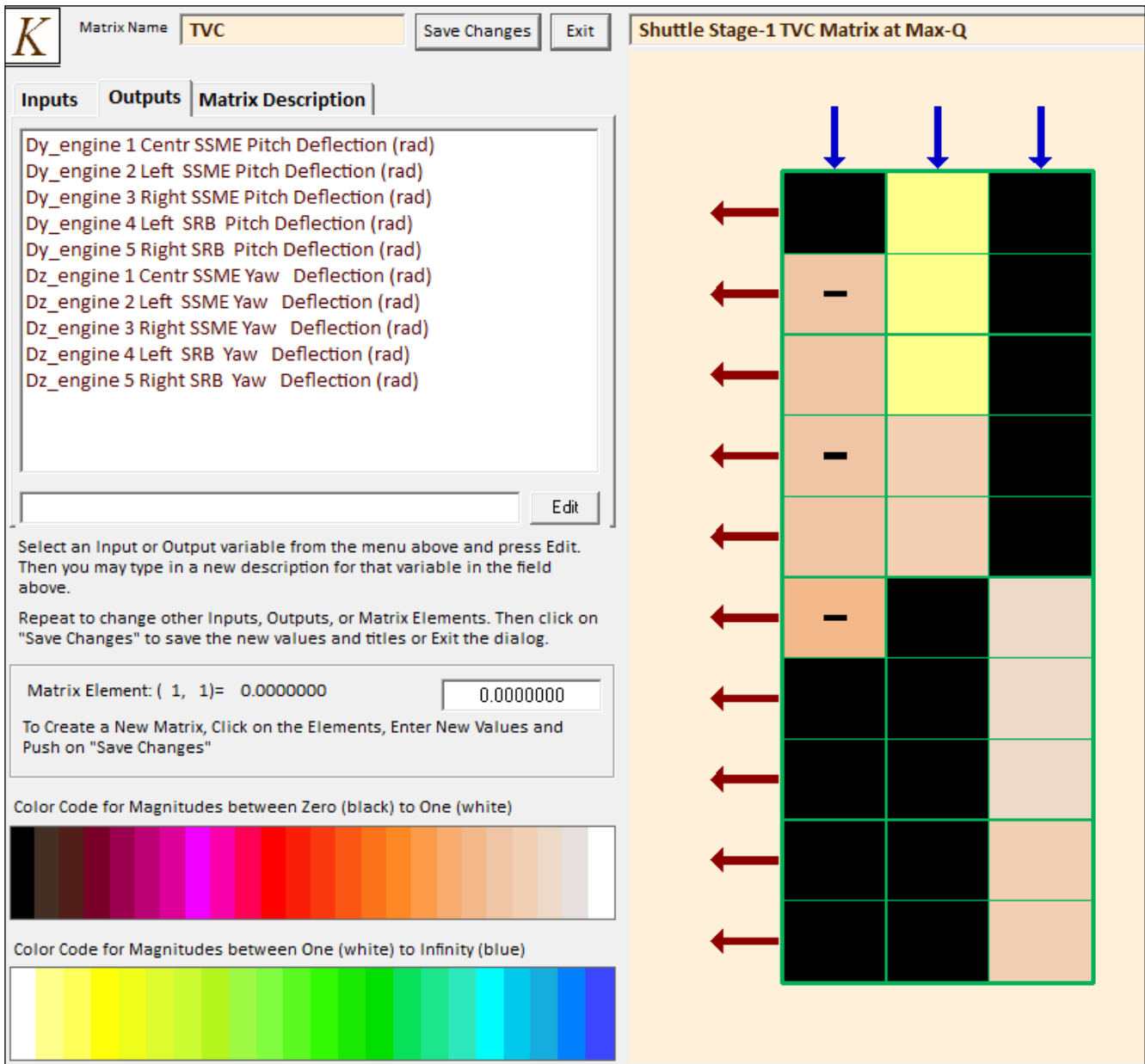
The following figures show two additional discrete systems sampled at 40 msec. A Shuttle lateral flight control system where the tab is showing its inputs, and a system of five actuators, three SSME and two SRB in block diagonal form. The second system's tab is showing the outputs.

130
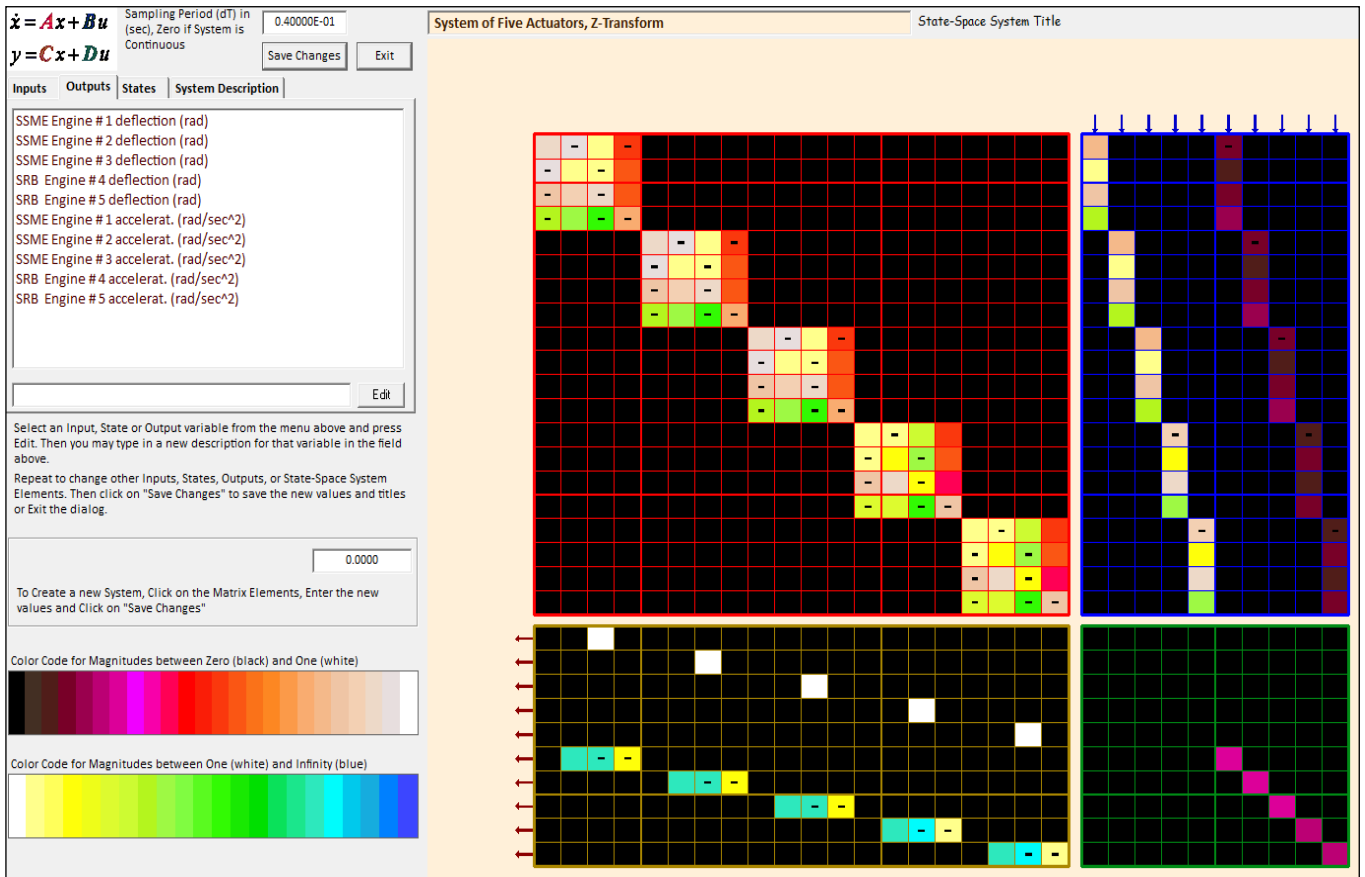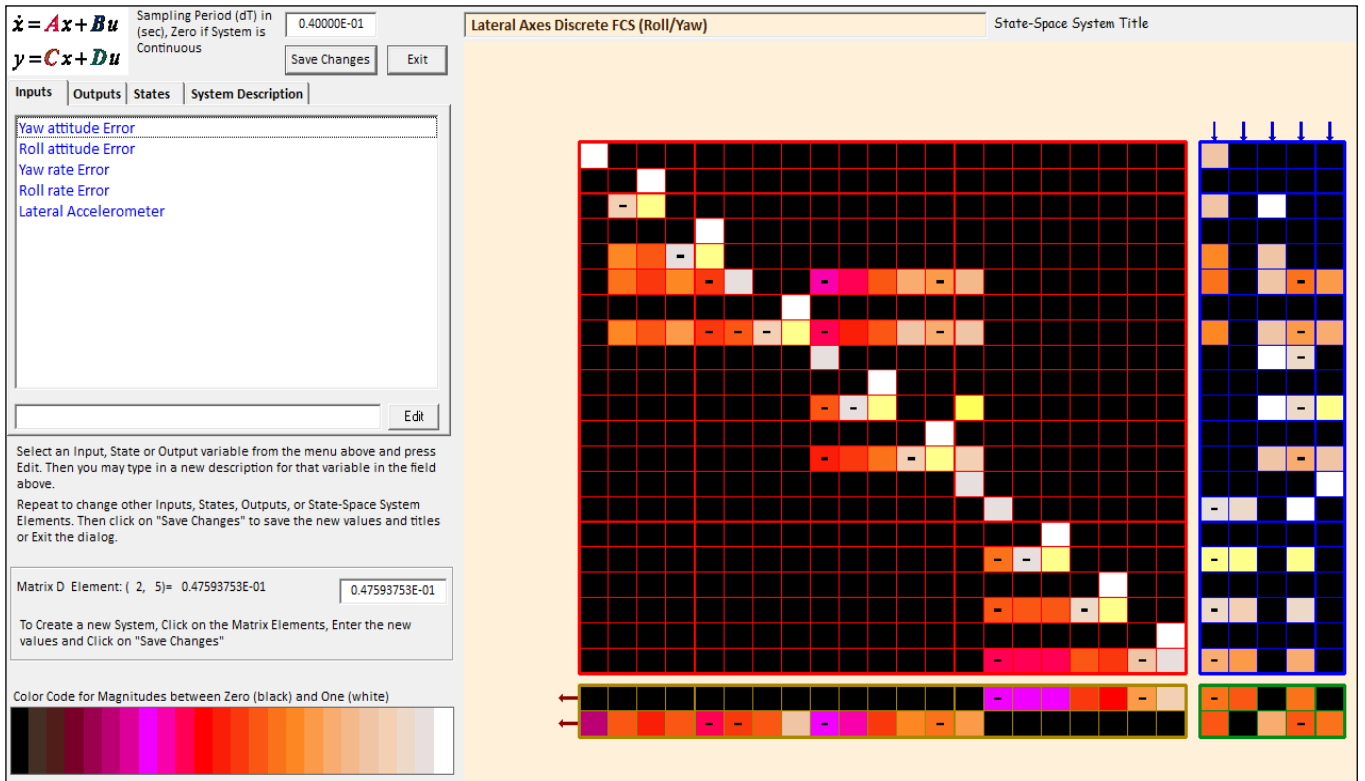
6.2.2 Creating a New System or a Matrix

The Flixan program also includes utilities for creating a new state-space system or a new matrix from scratch by entering the data using dialogs and then saving the system or matrix in a systems file (.Qdr). After selecting the project directory, from the Flixan main menu select "*File Management*", then "*Manage System Files*", and then "*Create a New State-Space System*" or "*Create a New Matrix*". For a new system the following dialog appears asking the user to define the number of the new system inputs, states, and outputs, and also the sampling period if the system is discrete described in terms of state-space difference equations. Otherwise, for a continuous system the sampling period is set to zero. In this case we arbitrarily define a system with 3 inputs, 2 outputs, and 5 states. The next menu shows the system files already existing in the current directory. A filename must be selected to save the new system or matrix. To create a new file the user must select "*NewFile.Qdr*". In this example, however, we select an existing systems file "*Temp5.Qdr*".
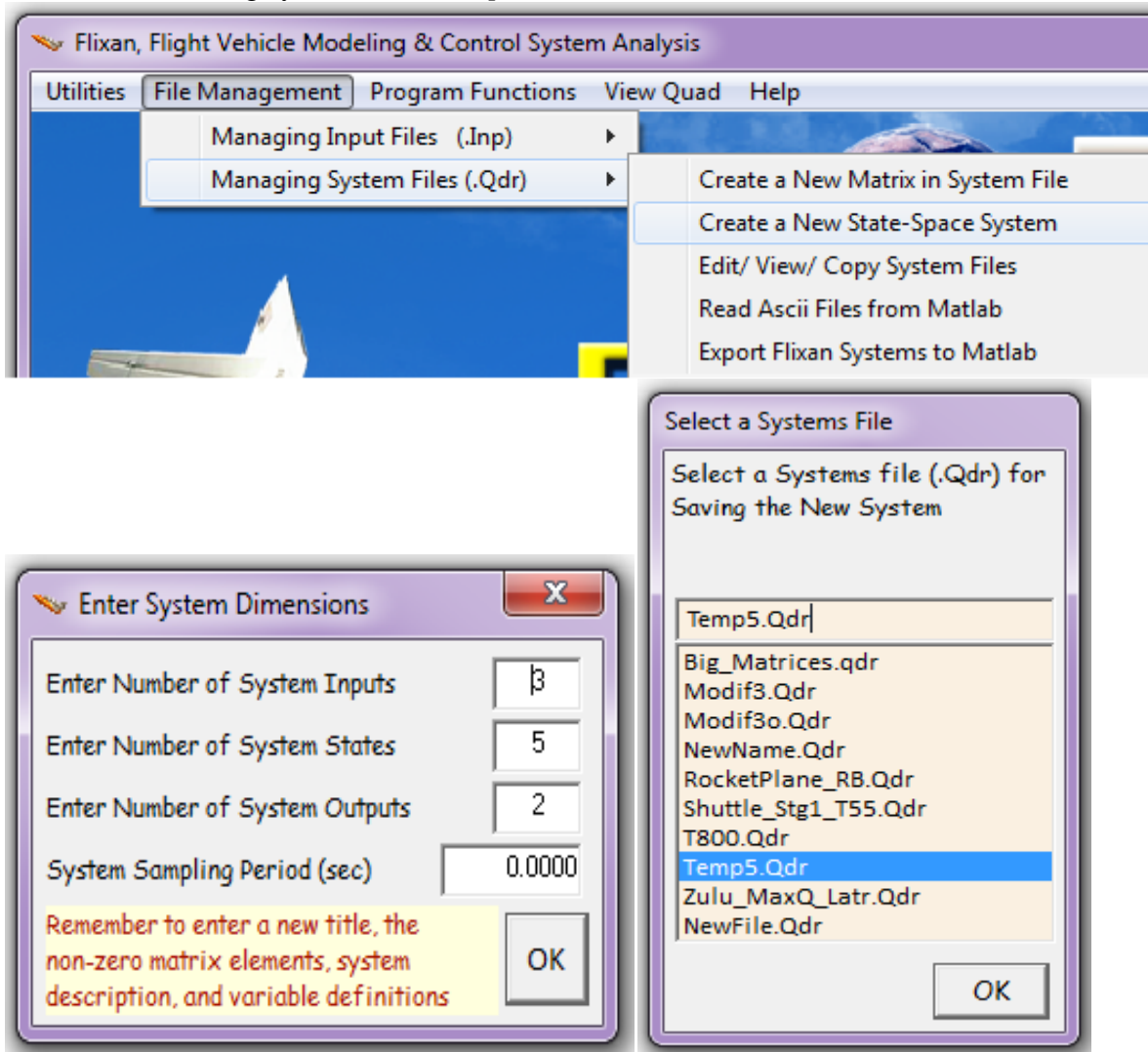
At this point a dialog appears that helps the user define the new system. Initially the four state-space matrices (A, B, C, D) are empty. The matrix element numbers are not yet entered and the element squares are black. In the upper hand left side of the dialog there a field with four tabs used for defining the new system's input, state, and output variables, and also for entering user comments about the system. The sizes of the four (A, B, C, D) matrices on the right are defined by the number of inputs,

states, and outputs. Their elements are initially set to zero (black) and they are ready to be painted by the user, one element at a time.

The user must point the cursor at a matrix element, click the mouse button to select the element, enter the value of the selected element in the field below the tabs, and click on the "Save Changes" button.

The matrix element then changes colors depending on the magnitude of the element. Small magnitude elements appear in brown, dark-red region, and large magnitude elements appear in the green and cyan regions. Ones appear in bright white, zeros are black, and there is a range of colors in between as a function of magnitude. Negative numbers appear with a minus sign in front of the matrix element.

The user must also enter the new system title in the title field on the top, a short description of the new system (less than 2000 characters long) in the system description tab, and also define the system input, state and output variables using the corresponding tabs. A default initial system title "*New System Title*" appears in the title field. This title must be changed to something different, "*User Created System*", is used in this example, and click on "*Save Changes*" button. When defining the system variables, initially the inputs, states, and outputs assume default titles, such as, "Input No: 1", etc, "State No: 1", etc, "Output No: 1", etc. These titles can be changed to something more descriptive. To rename the inputs, for example, the user must go to the Inputs tab in the dialog, select one of the inputs, and press "Edit". The original default label appears at the bottom of the inputs list, where it can be modified to something more descriptive, for example: "*Rudder Control Surface deflection in (deg)*". When the input relabeling is complete the user must click on "*Save Changes*" before selecting the state or output tab variables to rename. When all system definitions are complete the new system appears similar to the one shown in the second figure. The system is now ready to be saved in the systems file.

Click on "Exit" and the following dialog comes up asking about saving this new system in file. If the answer is "Yes" the new system will be saved in the bottom of file "*Temp5.Qdr*" in this example, and it will appear as shown in the next page.
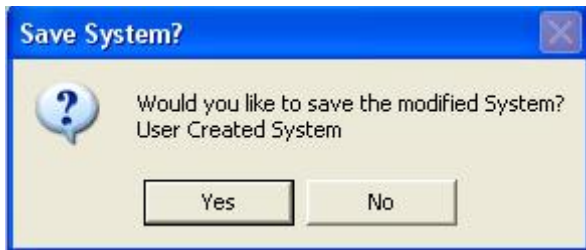
User Created System
! This is a user created system using the system creation dialog by typing the non-zero elements
! directly in the dialog. The user must first eneter the size of the new system, enter the new
! system title, define the state variables, and a short paragraph that describes the new system
! (not more than 2000 characters). To define a matrix element, point the mouse cursor to a matrix
! element, type the element value in the field below, and click "Save Changes". The element will
! change color according to the new value.
Number of Inputs, States, Outputs, Sample Time dT (for discrete)=   3   5   2   0.0000
Matrices: (A,B,C,D)

Matrix A   Size = 5 X 5

	1-Column	2-Column	3-Column	4-Column	5-Column
1-Row	-0.100000000000E+01	0.000000000000E+00	0.000000000000E+00	0.000000000000E+00	0.10000000
2-Row	0.000000000000E+00	-0.200000000000E+01	0.000000000000E+00	0.000000000000E+00	0.00000000
3-Row	0.000000000000E+00	0.000000000000E+00	0.500000000000E-02	0.100000000000E+01	0.00000000
4-Row	0.000000000000E+00	0.100000000000E-03	0.000000000000E+00	-0.600000000000E+01	0.00000000
5-Row	0.220000000000E+02	0.000000000000E+00	0.000000000000E+00	0.000000000000E+00	0.75000000

Matrix B   Size = 5 X 3

	1-Column	2-Column	3-Column
1-Row	0.110000000000E+02	0.000000000000E+00	0.000000000000E+00
2-Row	0.000000000000E+00	0.300000000000E+01	0.000000000000E+00
3-Row	0.000000000000E+00	0.000000000000E+00	0.333300000000E+04
4-Row	0.100000000000E+01	0.000000000000E+00	0.000000000000E+00
5-Row	0.000000000000E+00	0.000000000000E+00	0.000000000000E+00

Matrix C   Size = 2 X 5

	1-Column	2-Column	3-Column	4-Column	5-Column
1-Row	0.100000000000E+01	0.000000000000E+00	0.000000000000E+00	0.000000000000E+00	0.00000000
2-Row	0.000000000000E+00	0.200000000000E-01	0.000000000000E+00	0.150000000000E+01	0.00000000

Matrix D   Size = 2 X 3

	1-Column	2-Column	3-Column
1-Row	0.000000000000E+00	0.000000000000E+00	0.000000000000E+00
2-Row	0.000000000000E+00	0.000000000000E+00	0.600000000000E-06

Definition of System Variables

Inputs =   3
    1   Input No: 1
    2   Input No: 2
    3   Input No: 3

States =   5
    1   State No: 1
    2   State No: 2
    3   State No: 3
    4   State No: 4
    5   State No: 5

Outputs =   2
    1   Output No: 1
    2   Output No: 2