XFLR5 Tutorial II - Dynamic Response Analysis

Mikolaj Kryger* and Paul Rumbach†

University of Notre Dame, Notre Dame, Indiana, 46556, USA

1 Introduction

XFLR5 is a computational tool for understanding the stability and performance of small, model-sized aircraft operating at low Reynolds numbers. This is the second part of the software tutorial, focused on the dynamic stability analysis.

This tutorial is a direct continuation of the first tutorial required for your previous assignment. This tutorial is split into 4 main sections: Loading the Previous Project, Plane Edition, Stability Simulations and Results Analysis. The first section of the document briefly outlines loading save files of the previous tutorial and checking their completeness. The second section involves making changes to the elevator's incidence angle to create a stable aircraft at a positive angle of attack. In the third section, the instructions on performing horizontal flight simulations and stability analysis simulations will be outlined. The conditions for the aircraft's horizontal flight will be determined using XFLR5's analysis tools. Using the stability analysis simulations the program will output the aircraft oscillatory modes' eigenvalues and frequencies. The Results Analysis will be shown in the fourth section. XFLR5 can visualize the oscillations in the 3D mode, as well as plot the eigenvalues or the dynamic response plot given a user-defined perturbation out of trim.

*Graduate Student, Department of Aerospace and Mechanical Engineering, University of Notre Dame, Notre Dame, IN 46556.

†Associate Teaching Professor, Department of Aerospace and Mechanical Engineering, University of Notre Dame, Notre Dame, IN 46556.

2 Loading the Previous Savefile

This tutorial uses the aircraft files from the previous assignment. Make sure you entered everything correctly. If you made any mistakes, you will need to correct them.

1. Open the XFLR5 program and load the previous project by clicking on the *File* → *Open* in the toolbar in the top-left corner of the screen.

2. You will use the 2D airfoil data created during the *Airfoil Batch Analysis* step of the previous tutorial. To check whether the simulation data was saved, click on *Module* → *XFoil Direct Analysis* in the top-left corner of the screen. If the simulation data was saved correctly, the calculated airfoil aerodynamic data should appear on the screen.

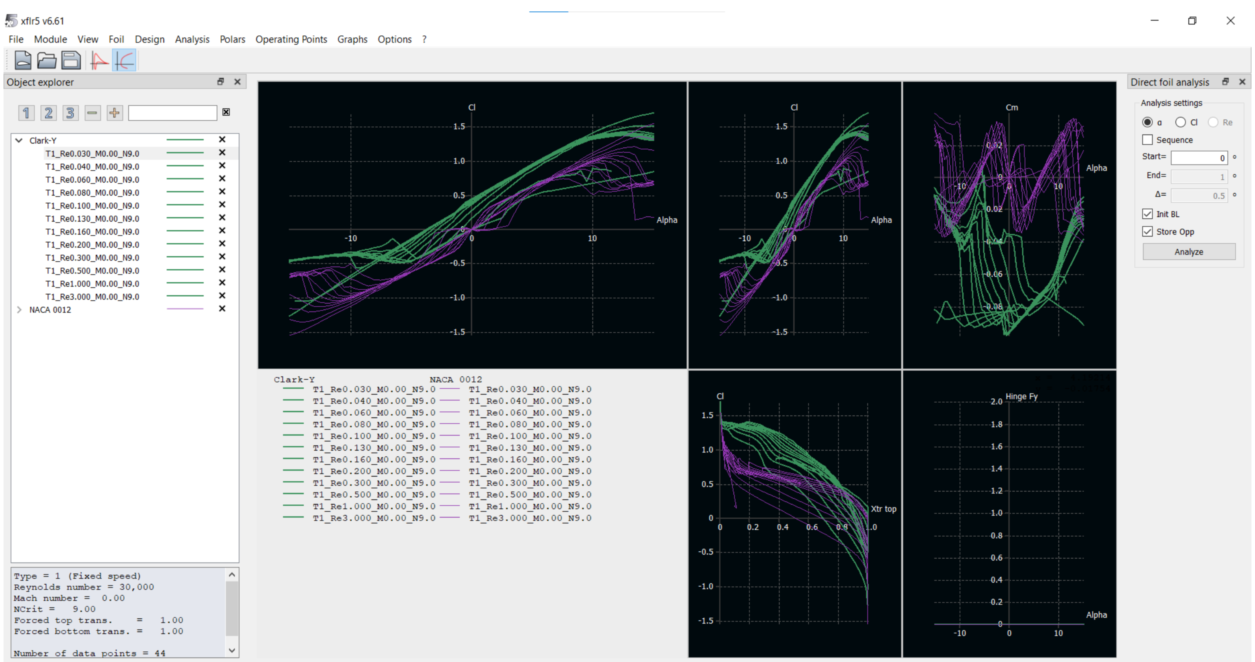

Figure 1: Clark-Y and NACA0012 aerodynamic data.

3. To check whether the aircraft design was saved click on *Module* → *Wing and Plane Design* in the top-left corner of the screen and open your project file from Tutorial 1. Alternatively, go to *file* → *Load Last Project.*

   on the drop-down menu *Plane* and choose *Current plane* → *Edit.* Ensure that the aircraft matches the one from the previous tutorial.

4. In case the simulation data and/or aircraft design are not present, please repeat the previous tutorial instructions. You can omit the steps shown in sections 4 and 5, as they are not required for the instructions shown in this tutorial.

3 Aircraft Modifications

The simulations and analysis in this tutorial will be performed on a more optimized version of the previous tutorial's aircraft. The objective is to ensure a positive trim angle of attack, as well as improve its glide ratio. To achieve that, change the elevator incidence angle.

1. Click on *Module* → *Wing and Plane Design* in the top-left corner of the screen.
2. In the same section of the screen find the drop-down menu *Plane* and choose *Current plane* → *Edit*.
3. Set the elevator tilt angle (horizontal tail incidence angle) to $i_t = -6.5°$.
4. Save the settings by clicking on the *Save* icon in the bottom-central part of the Plane Editor menu.

4 Simulations: Type 2 - Horizontal Flight Analysis & Type 7 - Stability Analysis

1. To begin the design analysis, find the *Analysis* drop-down menu in the top-left corner of the XFLR5 window. Choose *Define an Analysis* option. The analysis definition window should appear on the screen.

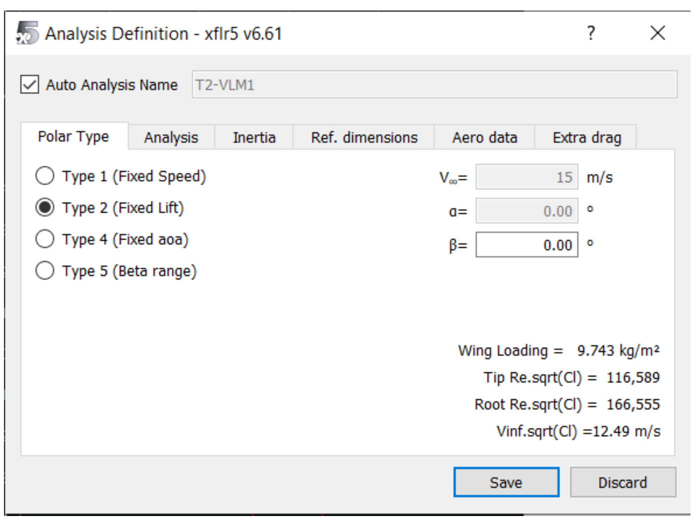

Figure 2: The plane analysis definition menu.

2. Select the Type 2 (Fixed Lift) analysis. This analysis type increments through a range of specified angles of attack, finding the conditions for horizontal flight $L = W$. The horizontal flight conditions do not imply that the airplane is in trim.
3. Go to the *Analysis* tab and select *Ring vortex (VLM2)* analysis type. Ensure that the *Viscous* checkbox is selected.

4. Click the *Save* button. The *Plane analysis* column should now be visible on the right side of the XFLR5 window.

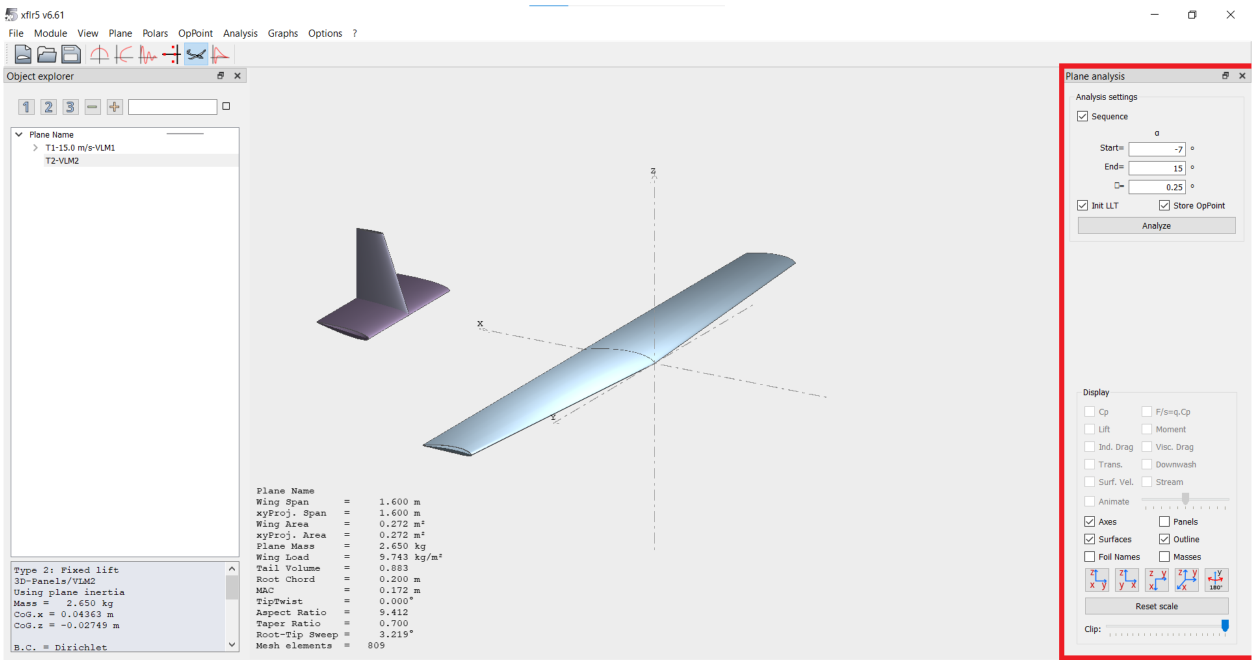

Figure 3: Plane analysis setup window.

5. Check the *Sequence* checkbox.
6. Set the start angle of attack to $-7°$ and end angle of attack to $15°$. Set the increment to $0.25°$. Select both checkboxes.
7. Click the *Analyze* button to begin the set of simulations.
8. A simulation log will appear on the screen with error warnings. Please close it.
9. We now have the all required aircraft data for horizontal flight and will proceed to the stability analysis. In the main XFLR5 window find the *Analysis* drop-down menu in the top-left corner. Click *Analysis* → *Define a Stability Analysis*. The *Stability Polar Menu* should now be visible on the screen.

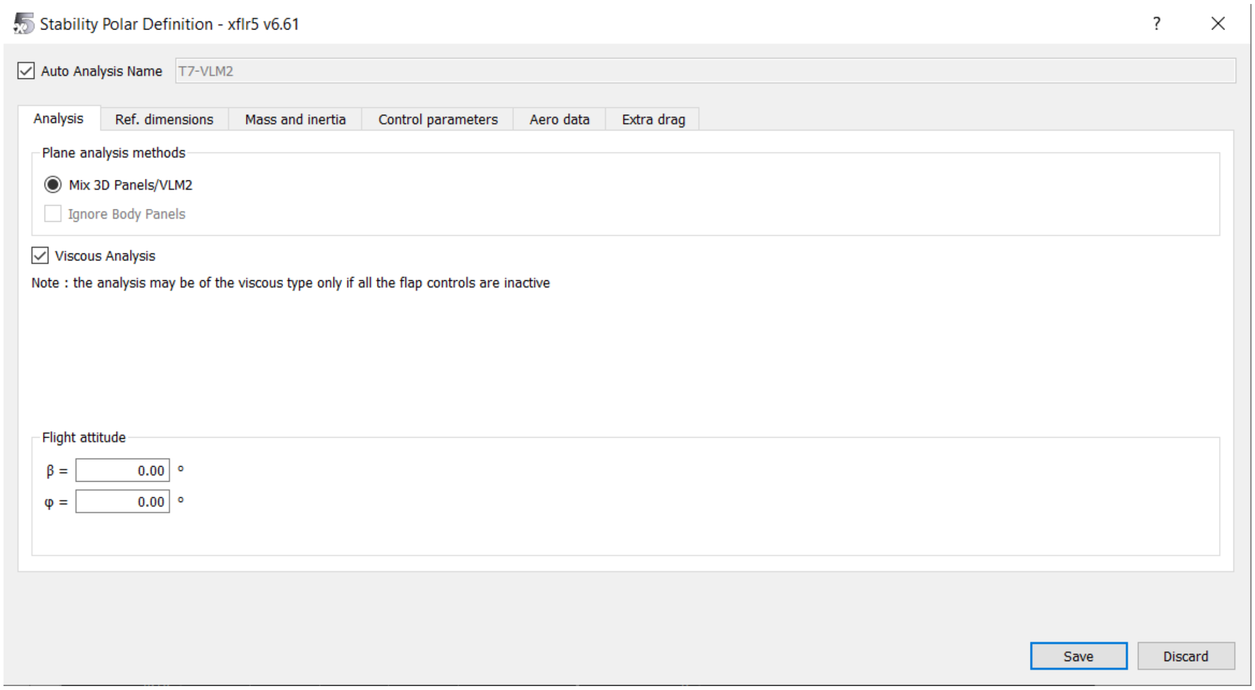

Figure 4: Stability polar (Type 7 analysis) menu illustration.

10. Make sure that the option *Mix 3D Panels/VLM2* is selected. Select the *Viscous Analysis* checkbox.

11. Click the *Save* button in the bottom-right corner of the menu. The plane analysis settings should appear on the right side of the screen.

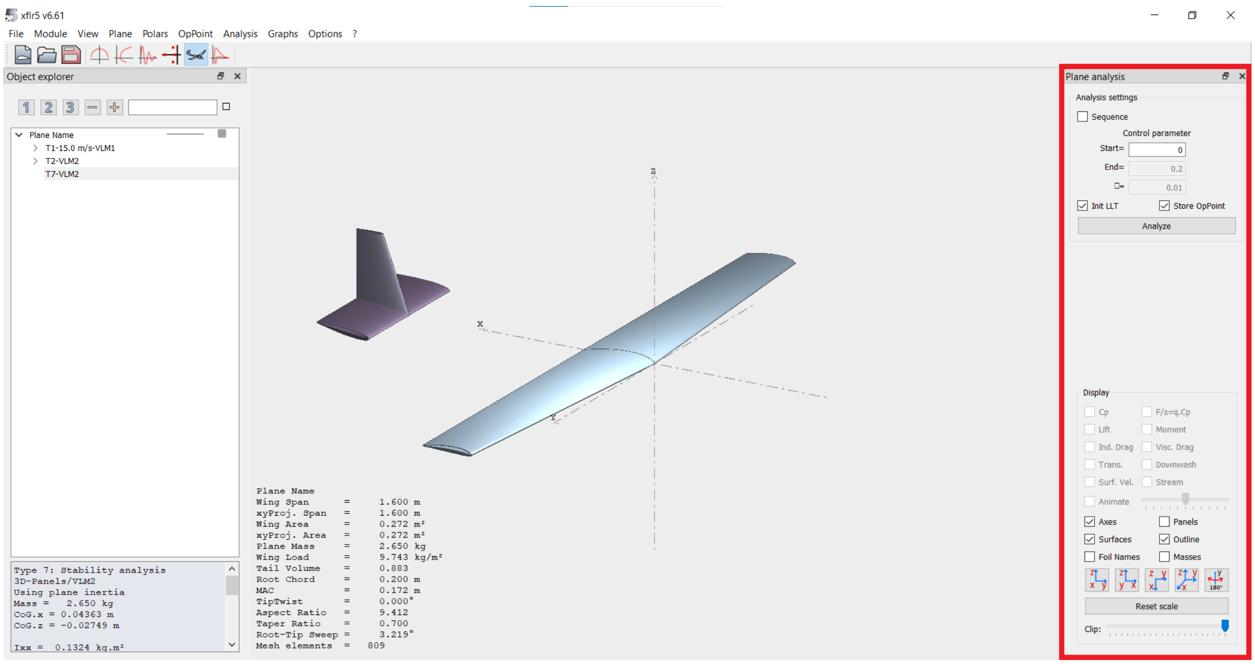

Figure 5: Stability analysis settings column.

12. De-select the *Sequence* checkbox. Ensure that checkboxes *Init LLM* and *Store OpPoint* are selected.

13. Begin the analysis by clicking the *Analyze* button, and *Poof!* the software will compute all of the stability derivative and coupling constants.

14. After the analysis is complete, press the "L" button on your keyboard. The simulation log should appear.

15. Examine the log, and carefully note the following parameters: center of gravity position, aircraft moments of inertia, trim angle of attack and velocity, stability derivatives, coupling constants, and eigenvalues of different oscillatory modes. Do the values seem reasonable?

16. After examining the outputs, close the simulation log.

5 Stability Simulation Result Analysis

5.1 3D Mode Visualization

To access the three-dimensional mode visualization option click on the plane icon at the top of the screen. The 3D visualization menu should appear on the screen.

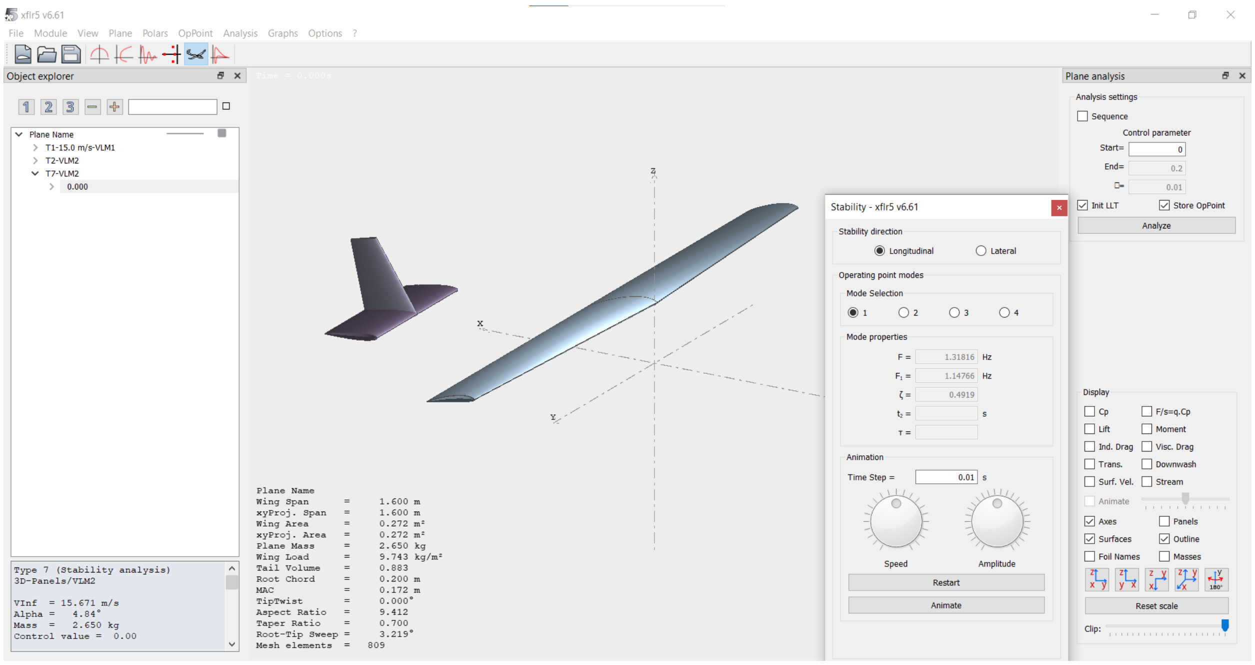

Figure 6: Illustration of the 3D visualization menu.

1. In the *Object explorer* window, select the 0.000 at the bottom of the list, beneath *T7-VLM2*.
2. Examine the *Stability* window. The *Stability direction* options allow for examining the longitudinal or lateral oscillations.
3. Mode selection window allows for selection of various modes of oscillation (oftentimes, some aircraft dynamic modes will be repeated).
4. Adjust the animation options and click the *Animate* button in the *Animation* window to see an animation of each of the various modes.

Deliverable 1: Based on your knowledge from the course, determine which mode number shown in the *Stability* window corresponds to which aircraft dynamic mode. Enter the following values into the Canvas quiz.

1. The short-period mode damped natural frequency (ringing frequency).
2. The short-period mode damping ratio.
3. The phugoid mode oscillation damped natural frequency (ringing frequency).

5.2 Root Locus Plot

XFLR5 allows you to examine the imaginary and real part of eigenvalues of various oscillatory modes. To see the root locus plot, click on the real-imaginary number line icon on the menu bar at the top of the screen.

Deliverable 2: Take a single screenshot of the root locus graph with the roots visibly shown on the graph. You may need to alter the plot thickness and color if needed. Upload the screenshot to the appropriate location in the Canvas assignment.

5.3 Plots of Dynamic Perturbation Response

Finally, the information on the aircraft stability can be used to obtain its response to perturbations from equilibrium (trim). Proceed to the Time Response View by clicking the damped sine wave icon on the menu bar at the top of the screen. The Time Response Menu should appear on the screen.

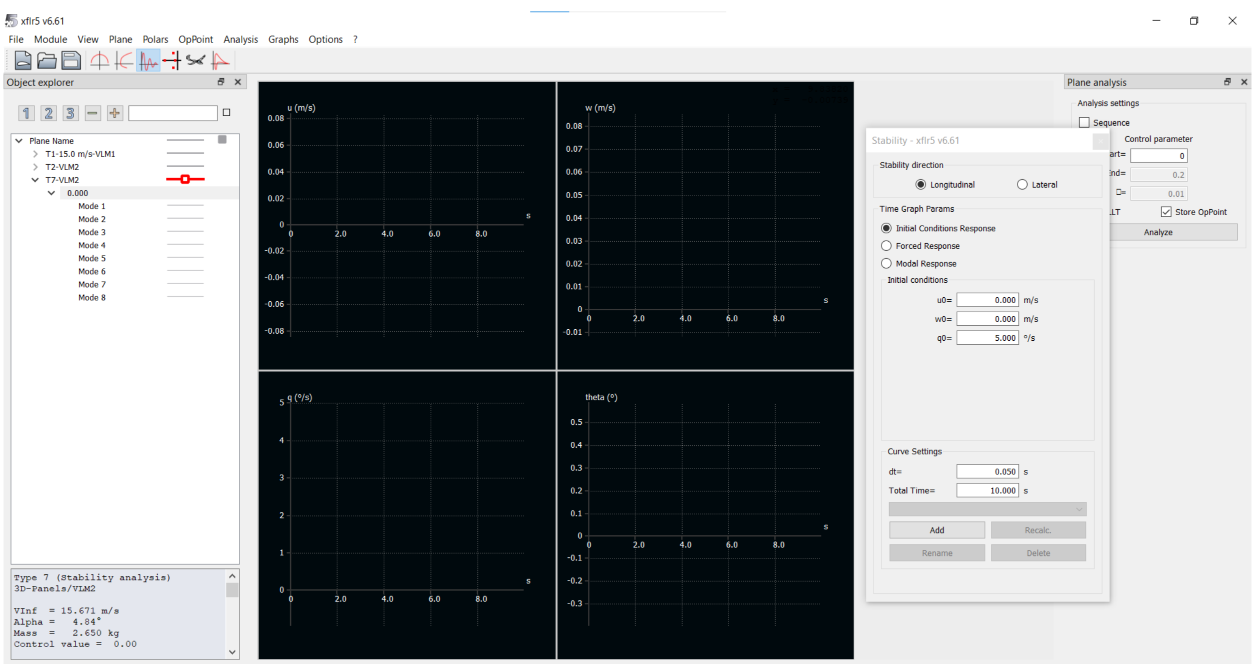

Figure 7: Illustration of the Time Response Menu.

1. Ensure that the 0.000 simulation point is selected in the Object explorer column on the left side of the window.

2. Select the Initial Condition Response in the Time Graph Params window.

3. Specify the amplitude of your initial perturbation.

4. To plot the time response click the *Add* icon in the Curve Settings window. Depending on the amplitude of the perturbation, damping and frequency of the activated oscillatory modes, adjust the total simulated time and the step size *dt*.

Deliverable 3: Perform an *Initial Conditions Response* stability analysis in the longitudinal direction. For all sub-points use the curve settings: *dt*= 0.050 s and *Total time*= 10.000 s. (This short amount of time will allow you to zoom in on the short period oscillations.) Use an initial perturbation of $u_0 = 10$ m/s, $w_0 = -2$ m/s and $q_0 = 0$ °/s. Take a screenshot of the aircraft response plots. Upload it to the appropriate location in the Canvas assignment.

Deliverable 4: Repeat the previous calculation using *Total time*= 300.000 s. (This long amount of time will allow you to zoom out and see the long period Phugoid oscillations.) Take a screenshot of the aircraft response plots. Upload it to the appropriate location in the Canvas assignment.

Deliverable 5: Now, check the results for the lateral modes. Enter the following values into the Canvas quiz.

1. The Dutch roll damped natural frequency (ringing frequency).
2. The Dutch roll damping ratio.
3. The time constant for roll response.