ASEN 3128 Aircraft Dynamics
Fall 2021

Lab 6: Fixed-Wing Aircraft Linear Equations

Assigned Tuesday, November 2, 2021
Due Tuesday, November 16, 2021, before lab section starts

For all assignments, students will work in groups of three to four students. Groups are determined by the instructors. A single assignment should be submitted for the group.

OBJECTIVES

1. Determine the linear matrices for the Tempest UAS.
2. Investigate the mode shapes and behaviors of the Tempest UAS.
3. Compare results using linear and full nonlinear simulations.

BACKGROUND

Students are given a set of MATLAB functions that simulate the full nonlinear dynamics of a fixed wing aircraft. Additional functions are incomplete and will need to be finished by the students before the simulation works.

For this assignment students are simulating aircraft behavior and comparing results using both the linear models (calculated from new functions written for this assignment) and the full nonlinear equations of motion.

The key step in making valid comparisons is initializing both simulations correctly, with physically reasonable values. For example, the linear longitudinal matrices enable simulation of the perturbation variables Δu, Δw, Δq, $\Delta \theta$, Δx_E, and Δz_E. These can be compared to the full nonlinear simulation by recalling the definition of the perturbation terms, e.g. $u = u_0 + \Delta u$, $w = w_0 + \Delta w$, etc. Thus, after simulating the perturbation equations, the corresponding full state variables can be calculated for comparison with the full nonlinear simulation results.

The same relationships need to be used to correctly initialize the full nonlinear simulation. For example, when trying to simulate the phugoid mode we initialize the linear simulation with the real component of the phugoid eigenvector. This defines the initial perturbation values. When comparing to the full nonlinear simulation, the initial perturbations must be added to the trim state to define the initial aircraft state.

Linear system solutions always scale to the size of the input, thus the relative behavior of the variables in the linear simulation can be seen regardless of size. However, the full nonlinear simulation includes nonlinearities like geometric functions that do not scale linearly. Most obviously, the nonlinear equations recognize the $0 = 2\pi = 4\pi$ radians, whereas the linear equations do not.

PROBLEMS

1. Investigate the eigenvalues (poles) of the modes of the Tempest UAS. For this problem, there is no background wind. Determine the trim variables and linear matrices such that the Tempest unmanned aircraft is in trim at height h = 2438.5 and airspeed V = 22 m/s.

   a) Write the function:

   ```
   [Alon, Blon, Alat, Blat] = AircraftLinearModel(trim_definition,
   trim_variables, aircraft_parameters)
   ```

   where the output `Alon` is the 6 x 6 longitudinal matrix augmented to account for the x- and z-position perturbations and `Alat` is the 6 x 6 lateral matrix augmented with yaw and y-position perturbations. The `Blon` and `Blat` matrices will be 6 x 2 zero matrices for this assignment.

   b) Using the function created in Part (a), determine the poles (eigenvalues) for the short period, phugoid, roll, spiral, and dutch roll modes of the Tempest UAS. Identify which eigenvalue corresponds to which mode, and determine the natural frequency and damping ratio for the oscillatory modes, and the time-to-half or time-to-double for the exponential modes.

   c) Create phasor plots for the oscillatory modes of the Tempest. For longitudinal modes plot the non-dimensional forward speed $\hat{u}$, non-dimensional z-component speed $\hat{w}$ (angle of attack), pitch rate Δq, and pitch angle $\Delta\theta$ perturbation terms. Scale the plots so the pitch angle term is 1. For the lateral modes plot the non-dimensional y-component speed $\hat{v}$ (sideslip), roll rate Δp, yaw rate Δr, roll angle $\Delta\phi$, and yaw angle $\Delta\psi$. Scale the plots so the roll angle term is 1.

2. Investigate the longitudinal dynamics of the Tempest UAS. For this problem, there is no background wind. Determine the trim variables such that the Tempest unmanned aircraft starts at height h = 2438.5 and airspeed V = 22 m/s.

   a) Simulate the phugoid response of the aircraft using both the `initial.m` function to determine perturbation variables and using the full nonlinear (ODE45) simulation. Be sure to initialize the nonlinear model to be consistent with the mode shape. To determine the initial conditions, identify the phugoid mode eigenvector, scale the eigenvector as specified, and then take the real components of the scaled eigenvector as the initial perturbations. Use all six variables from the eigenvector and scale the eigenvector such that the pitch angle perturbation is 2 degrees. Run both simulations for 250 sec. Use your `PlotAircraftSim` function to plot the results of both simulations on the same figures. Describe the modal motion.

   b) Simulate the short period response of the aircraft using both the `initial.m` function to determine perturbation variables and using the full nonlinear simulation. Be sure to initialize the simulation to be consistent with the mode shape. Use all six variables from the linear matrix eigenvector and scale the initial condition such that the pitch angle perturbation is 2 degrees. Run both simulations for 2 sec. Use your `PlotAircraftSim` function to plot the results of both simulations on the same figures. Describe the modal motion.

c) Repeat Part (b), but running the simulation for 25 sec. Comment on the behavior of the two simulation models.

d) Repeat Part (a) for different scalings (i.e. so the initial pitch is 5 degrees, 10 degrees, etc.). At what point are the perturbations no longer "small", i.e. at what point do the simulations differ significantly?

3. Investigate the lateral dynamics of the Tempest UAS. For this problem, there is no background wind. Determine the trim variables such that the Tempest unmanned aircraft starts at height h = 2438.5 and airspeed V = 22 m/s.

   a) Simulate the dutch roll response of the aircraft using both the `initial.m` function to determine perturbation variables and using the full nonlinear simulation. Be sure to initialize the model to be consistent with the mode shape. Use all six variables from the linear matrix eigenvector and scale the initial condition such that the roll angle perturbation is 2 degrees. Run both simulations for 10 sec. Use your `PlotAircraftSim` function to plot the results of both simulations on the same figures. Describe the modal motion.

   b) Simulate the spiral response of the aircraft using both the `initial.m` function to determine perturbation variables and using the full nonlinear simulation. Be sure to initialize the model to be consistent with the mode shape. Use all six variables from the linear matrix eigenvector and scale the initial condition such that the roll angle perturbation is 2 degrees. Run both simulations for 25 sec. Use your `PlotAircraftSim` function to plot the results of both simulations on the same figures. Describe the modal motion.

   c) Repeat Part (b), but run the simulation for 100 sec. Why are the behaviors, especially the paths, of the two simulations so different? Consider physical as well as numerical reasons.

   d) Simulate the roll mode response of the aircraft using both the `initial.m` function to determine perturbation variables and using the full nonlinear simulation. Be sure to initialize the model to be consistent with the mode shape. Use all six variables from the linear matrix eigenvector and scale the initial condition such that the roll angle perturbation is 2 degrees. Run both simulations for 1 sec. Use your `PlotAircraftSim` function to plot the results of both simulations on the same figures. Describe the modal motion.

   e) Repeat Part (d), but running the simulation for 150 sec. Comment on the behavior of the aircraft.

ASSIGNMENT/SUBMISSION INSTRUCTIONS

This assignment does not require a full lab report. Instead, submit a **single PDF file** that includes answers to all questions with plots generated for the problems and the text of any code specifically requested for a problem. All code used for the assignment should be included as an appendix. Only a single example of the code is expected, even if students made multiple versions (eg. each student wrote their own).

Be sure to add titles to all figures that include both the problem number and a description of the plot (eg. "2.c Output x versus Time"). The assignment will be evaluated based on: 1) correct answers; 2) proper commenting and documenting of code; and 3) the quality of the figures submitted (eg. labeling, axis, etc.).

All lab assignments should include the Team Participation table and should be completed and acknowledged by all team members. Description of the Team Participation table is provided in a separate document.