ASEN 3801 Aerospace Vehicle Dynamics and Control Lab
Fall 2025

Lab 5: Fixed-Wing Aircraft Simulation and Control

Assigned Tuesday, November 11, 2025
Due Tuesday, December 2, 2025, at 11:59pm

OBJECTIVES

1. Calculate aerodynamic forces and moments from the aircraft state, control surfaces, and aerodynamic coefficients
2. Use MATLAB to simulate the flight of a fixed-wing aircraft
3. Determine modal characteristics from aircraft performance data

BACKGROUND

A state vector formulation will be used throughout this course to describe the full nonlinear aircraft dynamics. Aircraft dynamics are described by a set of 12 differential equations we derived in lecture. For these equations, we have the state vector:

$$\mathbf{x} = [x_E \quad y_E \quad z_E \quad \phi \quad \theta \quad \psi \quad u^E \quad v^E \quad w^E \quad p \quad q \quad r]^{\mathrm{T}} \tag{1}$$

where $[x_E \quad y_E \quad z_E]^{\mathrm{T}}$ describes the aircraft's inertial position, $[\phi \quad \theta \quad \psi]^{\mathrm{T}}$ are the Euler angles that describe the aircraft orientation, $[u^E \quad v^E \quad w^E]^{\mathrm{T}}$ describes the aircraft velocity, and $[p \quad q \quad r]^{\mathrm{T}}$ describes the aircraft angular velocity. The control surfaces are combined into the input vector:

$$\mathbf{u} = [\delta_e \quad \delta_a \quad \delta_r \quad \delta_t]^{\mathrm{T}} \tag{2}$$

<u>Nondimensional Aerodynamic Forces and Moments</u>

In order to simulate the aircraft dynamics, we need to be able to relate the aerodynamic forces $[X \quad Y \quad Z]^{\mathrm{T}}$ and moments $[L \quad M \quad N]^{\mathrm{T}}$ to the states and control inputs. However, aerodynamic data is typically given in terms of lift and drag coefficient derivatives. Therefore, we first determine the lift, drag, and thrust coefficients and then convert the results into the body coordinate coefficients. The expressions given below have been discussed in your Aircraft Dynamics course. The non-dimensional aerodynamic coefficients are:

$$
\begin{aligned}
C_L &= C_{L_0} + C_{L_\alpha}\alpha + C_{L_q}\hat{q} + C_{L_{\delta_e}}\delta_e \\
C_D &= C_{D_0} + K{C_L}^2 \\
C_T &= 2\frac{S_{prop}}{S}C_{prop}\frac{\delta_t}{V^2}[V + \delta_t(k_m - V)][k_m - V] \\
C_Y &= C_{Y_\beta}\beta + C_{Y_p}\hat{p} + C_{Y_r}\hat{r} + C_{Y_{\delta_a}}\delta_a + C_{Y_{\delta_r}}\delta_r \\
C_l &= C_{l_\beta}\beta + C_{l_p}\hat{p} + C_{l_r}\hat{r} + C_{l_{\delta_a}}\delta_a + C_{l_{\delta_r}}\delta_r \\
C_m &= C_{m_0} + C_{m_\alpha}\alpha + C_{m_q}\hat{q} + C_{m_{\delta_e}}\delta_e \\
C_n &= C_{n_\beta}\beta + C_{n_p}\hat{p} + C_{n_r}\hat{r} + C_{n_{\delta_a}}\delta_a + C_{n_{\delta_r}}\delta_r
\end{aligned} \tag{3}
$$

where $\hat{p}$, $\hat{q}$, and $\hat{r}$ are nondimensional versions of the angular velocity components, $K = 1/(\pi e AR)$ is determined from the aspect ratio AR and Oswald's efficiency factor e, S_{prop} is the cross-section area the engine's propeller sweeps out, C_{prop} is the engine coefficient, and k_m is a motor constant. In the case of the data provided for this lab, the body coordinate of the aircraft is aligned with the thrust line of the engine. As a result, the lift coefficient may not be zero when the angle of attack is zero. The terms C_{L_0} and C_{m_0} are the coefficient values for zero angle of attack, not the trim values. All non-dimensional coefficients are linear in the aircraft state except the drag coefficient C_D and the thrust coefficient C_T. The thrust coefficient is a function of the airspeed V. Values for the coefficients are provided in the parameter file `ttwistor.m`.

Equation (3) provides the aerodynamic coefficients for lift, drag, and thrust, which must be converted into the body X- and Z- coefficients (the remaining apply directly to the body coordinates. These coefficients are:

$$
\begin{aligned}
C_X &= C_T - C_D\cos\alpha + C_L\sin\alpha \\
C_Z &= -C_D\sin\alpha - C_L\cos\alpha
\end{aligned} \tag{4}
$$

Dimensional Aerodynamic Forces and Moments

Table 4.1 in *Dynamics of Flight* provides expressions for relating the nondimensional rates and coefficients to their dimensional counterparts, which are summarized here:

$$\hat{p} = (pb)/(2V)$$
$$\hat{q} = (q\bar{c})/(2V) \tag{5}$$
$$\hat{r} = (rb)/(2V)$$

$$\begin{aligned} X &= SQC_X & \qquad L &= bSQC_l \\ Y &= SQC_Y & \qquad M &= \bar{c}SQC_m \\ Z &= SQC_Z & \qquad N &= bSQC_n \end{aligned} \tag{6}$$

where $Q = \frac{1}{2}\rho V^2$ is the dynamic pressure, and L is the roll moment (not lift).

For this assignment, students are given the function `AeroForcesAndMoments.m`, which returns the dimensional aerodynamic force vector and the dimensional aerodynamic moment vector.

MATLAB Structures

One of the challenges in creating a simulation capability that can be generalized to different aircraft models is passing the aircraft parameters to the functions that need them. In this class, we will use a MATLAB structure to create a single data type that includes all aircraft parameters. In particular, you will be given the M-file `ttwistor.m` that defines the structure `aircraft_parameters` that includes all constant parameters for that aircraft at that trim condition. Unlike variables or arrays that index entries by a number within parentheses (for example, “`x(1)`”), a structure defines each component by a unique label separated from the main variable name by a period (for example, “`aircraft_parameters.S`”.

Density and Altitude

The air density ρ plays an important role in the creation of aerodynamic forces and moments. The density varies as a function of altitude (height). There are a variety of models that describe this relationship. We will use the `stdatmo.m` function provided by MATLAB in all our simulations,
eg. `density = stdatmo(height).`

PROBLEMS

This lab assignment will study the dynamics of the RECUV Ttwistor uncrewed aircraft.

Problem 1

Update the following function:

```
PlotAircraftSim(time, aircraft_state_array, control_input_array, fig, col)
```

Update your plot simulation function from Lab 4 so the subplots for the control input variables show elevator, aileron, and rudder in degrees and throttle as a fraction from 0 to 1. Be sure to update the labels of the subplots.

Problem 2

Write the function:

```
xdot = AircraftEOM(time, aircraft_state, aircraft_surfaces, wind_inertial,
aircraft_parameters)
```

This function calculates the equations of motion for the fixed-wing aircraft with constant control surfaces. The inputs are time, the 12 x 1 aircraft state vector, the 4 x 1 control surface vector, the 3 x 1 inertial wind velocity in inertial coordinates, and the aircraft parameter structure. The output is the derivative of the state vector. Note: students are expected to use the provided function `AeroForcesAndMoments.m` in this function.

Use `ode45` in MATLAB to simulate the aircraft equations of motion in the following conditions. Plot and describe the results. When describing the results, use quantitative terms as much as possible, eg. "the pitch angle oscillated with a period of 5 seconds and decayed with a settling time of 1.2 sec". In all cases, let the simulations run long enough to see the behavior reach steady state.

1. The aircraft initial state and control inputs all set to zero except the inertial velocity component in the body x-direction is set to the airspeed V = 21 m/s and the height is set to h = 1609.34 m (1 mile = Boulder, CO!). The main purpose of this simulation is to verify that your simulation works, since the aircraft should stay near the trim flight condition. Why should we not expect this to be a trim condition?

2. The aircraft initial state and control inputs are at the following trim values:

$$\mathbf{x}_0 = [\begin{array}{cccc} 0\text{ m}, & 0\text{ m}, & -1800\text{ m}, & \cdots \\ 0°, & 0.02780\text{ rad}, & 0°, & \cdots \\ 20.99\text{ m/s}, & 0\text{ m/s}, & 0.5837\text{ m/s}, & \cdots \\ 0\text{ deg/s}, & 0\text{ deg/s}, & 0\text{ deg/s} &]^{\mathrm{T}} \end{array}$$

$$\mathbf{u}_0 = [0.1079\text{ rad} \quad 0 \quad 0 \quad 0.3182]^{\mathrm{T}}$$

3. For initial aircraft state and control surface inputs:

$$\mathbf{x}_0 = [\begin{array}{cccc} 0\text{ m}, & 0\text{ m}, & -1800\text{ m}, & \cdots \\ 15°, & -12°, & 270°, & \cdots \\ 19\text{ m/s}, & 3\text{ m/s}, & -2\text{ m/s}, & \cdots \\ 0.08\text{ deg/s}, & -0.2\text{ deg/s}, & 0\text{ deg/s} &]^{\mathrm{T}} \end{array}$$

$$\mathbf{u}_0 = [5°, \quad 2°, \quad -13°, \quad 0.3]^{\mathrm{T}}$$

Problem 3

Write a new function for the equations of motion that includes the application of a doublet to the elevator input in order to excite the longitudinal dynamics of the aircraft:

```
xdot = AircraftEOMDoublet(time, aircraft_state, aircraft_surfaces, doublet_size,
doublet_time, wind_inertial, aircraft_parameters)
```

A doublet is a small positive pulse followed by a small negative pulse added to the trim control value. In this case, the equation for the elevator input $\delta_e(t)$ is:

$$\delta_e(t) = \begin{cases} \delta_{e,trim} + \text{doublet\_size} & 0 < t \leq \text{doublet\_time} \\ \delta_{e,trim} - \text{doublet\_size} & \text{doublet\_time} < t \leq 2 \cdot \text{doublet\_time} \\ \delta_{e,trim} & t > 2 \cdot \text{doublet\_time} \end{cases} \tag{7}$$

where $\delta_{e,trim}$ is the trim value that comes from the `aircraft_surfaces` input.

1. Use `ode45` in MATLAB to simulate the aircraft equations of motion. Simulate the aircraft equations of motion for 3 seconds. The aircraft initial state and control inputs are the trim values from Problem 2.2. Apply a doublet of size 15° and duration `doublet_time` = 0.25 sec. Plot the results. The response immediately after the doublet, ie. from 0.5 sec to approximately 1.5 sec, is the short period modal response of the aircraft. From this simulation, estimate the natural frequency and damping ratio of the short period mode of the aircraft.

2. Repeat the simulation above but let it run for 100 seconds. The slow oscillation, eg. in the variable u_E, is the phugoid modal response of the aircraft. From this simulation, estimate the natural frequency and damping ratio of the phugoid mode of the aircraft.

SUBMISSION REQUIREMENTS & FORMAT

Submit a single PDF document detailing the results of the assignment. The document should include enough discussion and detail to explain what you did and justify any conclusion you make. Be sure to address all questions.

In an appendix to your submission, include all functions written to perform the simulations. Further, include in the appendix versions of all M-files and models used to run the simulations. Do not include every variation of the M-file (eg. for every different initial condition), but for each major type of comparison or simulation.

Be sure to select the correct pages that are associated with each problem in Gradescope and double-check that your submission is readable.

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.