

EVOLVING DOCUMENT

ME 5070 Flight Dynamics



Homework

Date of this version: March 20, 2015

[Hyperlinks look like this.](#) Dates in headings below are the dates of the associated lecture.

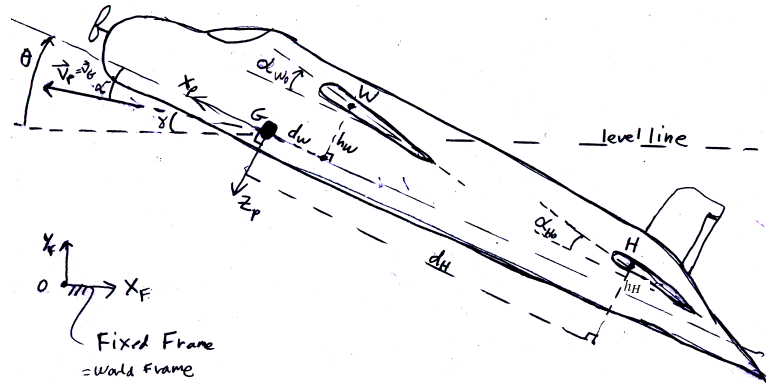
Due January 27, 2015

1. **Play with your balsa plane.** You need glue and/or tape.
 - (a) Put control surfaces onto your plane.
 - (b) Learn the names of them (flaps, ailerons, elevator, rudder).
 - (c) Go to a large open space. Outdoors is ok if it is dry and there is no wind.
 - (d) Trim the plane by adjusting (bending) the control surfaces and sliding the wing up and back, and learn to throw the plane, so you get a straight steady glide. Mark the wing position (if the wing slides around too much, jam something between it and the plane, like a piece of paper).
 - (e) One at a time, adjust the control surfaces and see the effect. Then adjust back for straight flight. Remember when adjusting ailerons that, now-a-days, since the Wright brothers, when one goes up the other goes down.
 - (f) Learn what each of the controls does to the flight.
 - (g) Balance the plane on your finger and find the center of mass.
 - (h) Add a weight at the center of mass (clay, paper clips, whatever) and, without re-adjusting the tabs or the wing position, throw for a steady glide. Does the glide angle change? The speed? Does this agree with theory? Be as precise as you can in your statements and which equations you are using from what sources.
 - (i) Look up 'coordinated flight'. See if you can achieve both a coordinated and both kinds of un-coordinated turns.
 - (j) Turn in informative descriptions of the things above, including a printout of a photo of your plane. Some of the questions above require quantitative reasoning which you should lay out as clearly as you can.
2. **Introduction to the X-Plane 9 flight simulator** with an eye towards learning the basics of flight control, and reviewing the fundamental principles of aerodynamics. Estimated time: 1.5-3 hours.

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- (a) Download X-Plane 9 from the X-Plane www site (downloads -; older versions).
 - (b) Do lessons 1-4 of the Flytlearn manual (linked on course www site). Do the tests to get an understanding of the aerodynamics and how X-Plane works. Don't be meticulous about filling in all of the charts and figures. Some tips:
 - i. There are tutorial videos (linked on our course www site).
 - ii. The menu is hidden. Move your mouse to the top of the screen to reveal it.
 - iii. To start the airplane, you probably need to change the control key that increase the throttle. The default key, F2, wont work on most computers. On the menu, go to Settings → Joystick, Keys, & Equipment → Keys. Find Engines/throttle up, and change the control to something convenient. Same with the Engines/throttle down key. Note: remember this menu if you ever want to use, find or change a keyboard shortcut.
 - iv. The pause button is p. Use it to look at the instruments, while cycling between different views of the plane, or while looking things up.
 - v. The Weather button is under Environment. The settings are a bit confusing, but if you follow the lesson plan you should be fine.
 - vi. To choose Final Approach in lesson 3, go to Settings → Quick Flight Setup.
 - vii. Deliverables: **a)** Some handed in results from the experiments above. **b)** comments on Piazza that either ask questions to other students, or answer them, or make interesting observations or tips.
3. **Read sections 3.1 and 3.2 of the text.** This will review aeronautics and prepare you for the coming material. Don't struggle with details now, just try to remember what you know and get a sense of the material in your head.

Due Tuesday February 2, 2015 (Extension to Thursday if you like.)

4. **2D glider simulation.** You are to simulate and animate the dynamics of a glider in free flight. You will solve the equations of linear and angular momentum balance using the following assumptions:



- Side view 2D
- Ambient air is still
- The only aerodynamic forces are on the wings and the horizontal stabilizer.
- There is no interaction between the wings (*i.e.*, ignore with wing downwash on the horizontal stabilizer).
- Assume, at least the first time you do the problem, that the rotation of the plane can be neglected when calculating the wind velocity at the wing and tail. That is, for aerodynamic purposes assume that $\vec{v}_H = \vec{v}_W = \vec{v}_G$.
- The centers of pressures=center of lift= aerodynamic centers = constants = W or H. (*i.e.*, do not take account that the lift and drag forces points of application change with angle of attack).
- State variables.
 - Position and velocity of plane in world/fixed frame:
 x_G, y_G and $v_{xG} = \dot{x}_G, v_{yG} = \dot{y}_G$.
 As vectors: $\vec{v}_P = v_{xG}\hat{i} + v_{yG}\hat{j}$ and $\vec{v}_P = \dot{x}_G\hat{i} + \dot{y}_G\hat{j}$
 - Attitude/pitch and pitch-rate of plane in world frame: θ and $\omega = \dot{\theta}$.
- Plane/problem parameters (see figure): ρ, S_W, S_H ; positions of W and H relative to G: d_W, h_W, d_H, h_H ; and angles of wing and tail relative to the plane: α_{W0}, α_{H0} .

The wings are symmetric and obey one of these two lift and drag laws,

- Use this first until your code is working well:

$$C_L = C_1 \sin(2\alpha_X), \quad C_D = C_{Dp} + C_1(1 - \cos(2\alpha_X)),$$

where X is either W or T.

- NACA 0015: <http://www.aerospaceweb.org/question/airfoils/q0150b.shtml>
- Plot both on the same graph, with constants chosen so they match as well as possible (C_{Dp} is small and $C_1 \approx 1$).

Your goal is to do as much as you can with this simulation given your time-budget for this course. To start with do a few common sense problems. For example if $d_W = h_W = h_H = \alpha_{W0} = \alpha_{H0}$ and $d_H > 0$ and the plane is dropped at any angle it should quickly straighten and then fly straight at that angle. If, additionally, you have set $C_{Dp} = 0$ the plane should accelerated with constant acceleration.

Due February 19, 2015

5. Expansions to your 2D longitudinal simulation.

- (a) Use root finding to find a trim condition for your plane (*e.g.*, mat labs FSOLVE).
- (b) Use perturbation experiments (*e.g.*, central difference calculation of derivatives) to find the matrix which linearizes the equations near the trim state (*e.g.*, write your own or do a google search for Matlab DERIVEST package.)
- (c) Solve the linear equations (using ODE23 is fine, or matrix exponential, or with eigenvalues and eigenvectors) and compare that solution with the solution to the full non-linear equations with the trim state subtracted out.

Due March 5, 2015

6. More simulation.

- (a) Add a motor. Make it a thrust force acting at a given α_{T0} relative to the plane line acting a distance d_T in front of the center of gravity and h_T above it. Motor thrust should be 1 if the thrust is mg . That is, the motor strength should be measured as “the thrust to weight ratio”. For a typical practical airplane this max’s out at about 1/2.
- (b) Redo your trim calculation and linearization with the added constraint that you have straight level flight.
- (c) Two Matlab things: 1) Replace ODE 23 with your own Euler (first order integrator), or any low order integrator that pleases you; 2) Get keyboard input to work so you can control elevator (horizontal stabilizer mounting/hinge angle) and thrust using mouse and/or keyboard.
- (d) Run your simulator with graphics in real time while you control thrust and elevator.
- (e) Have fun with your simulator.

Due March 26, 2015

7. Phugoid derivation. Assuming constant angle of attack and negligible rotary inertia, derive the non-linear and linear phugoid equations. What you hand in should be the most clear and complete and well explained document in the universe and it should be what you write without looking up *even one tiny thing*. That is, practice before you write your hand-in document. This derivation will be on the final exam.

8. Phugoid comparison.

- (a) For suitable initial conditions (plane oriented with correct angle of attack at the start, so that the short term pitch stabilization is not much excited), that are also notably far from trim (so that the linear equations are not accurate) find motions that show good agreement between the non-linear phugoid ODEs above (including drag) and the full fourth order non-linear ODEs. You will have to use numerical solution for both.

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- (b) Show a situation where the linearized phugoid equations agree well with the numerical solution of the full 4th order non-linear equations (choose special plane and drag parameters that make this agreement good).