Assignment #4: Stability — ME 415

due 10/6/2021 before midnight via Learning Suite — 50 possible points

For this assignment your group will divide and conquer. Form subgroups and choose one of the following three tasks. You (individually) only need to work and report on one task, but your team collectively needs to complete all of them. Subgroup 1 is probably just a one-person task, but that is up to you. The tasks have some parts that can be done independently, but because this is a design problem the three parts are interconnected and so team-wide coordination will be needed. For subtasks where two people work together, you can share the same report between the two of you (this homework only).

All groups will use at least some functionality within XFLR5. The referenced tutorial videos for XFLR5 are available here. You may want to share one XFLR5 file team-wide to make sure you stay consistent. For each task I note the *minimum* set of tutorial videos that will help you complete the task at hand, but you may find some of the other videos helpful.

Even though you are only responsible for writing up one area, it would be beneficial to learn from the other subgroups so that you have a reasonable understanding of all the tasks (even just watching the other XFLR5 videos for the other tasks would help accomplish this). Provide clear detail on your design analysis. That will help the rest of your team understand and will make it easier at the end of the semester when you work on your final reports.

Subgroup 1: Layout and Sizing

4.1 Perform initial sizing of your tail surfaces using statistical approaches. Report the following (just a sketch is fine for this initial rough sizing):

- The dimensions of the tails.
- Placement on the aircraft.
- Design rationale used.

4.2 Layout all components of your aircraft in order to estimate mass properties that will be input into XFLR5. You can do the layout entirely within XFLR5 (the relevant tutorial video is #7). Alternatively, you could use any CAD program. XFLR5 is probably easier, but the advantages of CAD are that you can predict more accurate mass properties, visualize placement, and create a nice rendered image.

Work with subgroup 3 to input mass properties. There are multiple ways to do this but if you get mass properties from CAD one easy way is to "Define a Stability Analysis", go to the mass/inertia tab, unselect the box for "use plane inertia", then directly input the mass properties. Similarly, the aerodynamic analysis of subgroup 2 need to input the center of mass in a similar way (moments of inertia are not needed for aerodynamics). Provide views of the aircraft model either in CAD or in XFLR5 with the lumped masses and discuss design rationale.

4.3 Work with subgroup 3 to iterate on the placement of components in order to achieve the desired stability behavior. After a satisfactory stable layout is determined report the total mass (m), the center of mass relative to the leading edge of the main wing (x_{cg} and z_{cg}), and the nonzero moments of inertia ($I_{xx}, I_{yy}, I_{zz}, I_{xz}$). The other two moments of inertia will be zero for a symmetric aircraft.

Subgroup 2: More Detailed Aerodynamics

4.1 Perform a more detailed drag analysis of the full aircraft using XFLR5. The most relevant tutorial videos for this task are: 1, 2, 6, 7 (you can ignore the mass properties part for your task), and 8. A few points to keep in mind:

- For the airfoil analyses, be sure to sweep across the *full* range of Reynolds numbers and lift coefficients for your aircraft, otherwise you'll get an error "Point is out of the flight envelope" (see video 11 if running into this problem).

- XFLR5 doesn't always perform well with bodies of revolution (i.e., fuselage), depending on the type of analysis you use, so you may need to stick with hand calculations for those components and add those drag contributions manually in the "Extra Drag" section of "Define an Analysis".
- Make sure you use consistent reference values when comparing with your hw2 results.
- Pay attention to the transition locations on your airfoil (transition from laminar to turbulent flow). When you define an analysis for an airfoil there is an option called "Forced transition" and two values "TripLocation" for the top and bottom. If you leave it at 1.0 it will calculate a transition location based on Reynolds number, which will be too optimistic given the surface finish of your aircraft and the atmospheric conditions close to ground. Leaving the bottom at 1.0 is probably, ok but I'd force transition at the top at like 10% chord (TripLocation (top) = 0.1)
- Set the altitude dependent parameters if you want to look at absolute data—if you only look at normalized coefficients then it doesn't matter.
- XFLR5 defines the taper ratio backwards from the typical convention.

Contrast the following results as compared to those from homework 2:

- plot of lift-to-drag ratio (L/D) as a function of flight speed
- the C_L that maximizes L/D
- the corresponding flight speed

4.2 XFLR5 makes it easy to evaluate the impact of various airfoils and wing configurations (see for example video 10). Perform at least one design study (e.g., change the airfoils, wing sizing). Provide evidence and discuss rationale for any changes that were made (or justify why you stuck with the current design). Show dimensioned drawings and discuss rationale of any design changes.

4.3 Determine the incidence (angle) of your tail so that it is roughly trimmed in pitch ($C_m = 0$) at the design angle of attack. You can always adjust your elevator to provide pitch trim, but it generally helps to get the tail set so that the nominal position requires zero elevator. Report the incidence of the tail and show the pitching moment curve (C_m vs α or C_m vs C_L). Note that this angle depends on the center of mass location, so coordinate with the other groups.

Subgroup 3: Stability

Use XFLR5 to analyze the static and dynamic stability of your aircraft and perform better sizing of your tail and c.g. placement. The relevant tutorial videos are: 12, 13, 14, 15, 16.

4.1 Determine your aircraft's neutral point. For a desired static margin determine the requisite c.g. and work with the other groups so that this is consistent. Report the neutral point location and your static margin.

4.2 Analyze the dynamic stability.

- Plot the open loop eigenvalues and label each mode.
- Report the following stability derivatives:

$$C_{L,\alpha}, C_{m,\alpha}, C_{n,\beta}, C_{roll,\beta}$$

Discuss the significance of your values. Are they reasonable? Are there improvements that need to be made?

4.3 Redesign the aircraft as needed to improve stability (see video 16 in particular). You are only required to do one study for the purposes of this homework, but you may want to consider more than one for your design. Some design changes you may wish to consider that will have a strong affect on stability include: wing dihedral angle, winglet sizing and angle, vertical tail sizing, horizontal tail sizing and/or its incidence angle, c.g. location and weights. Note that improvements in one area will likely have negative consequences elsewhere (e.g., decreased stability in another mode, increased weight, decreased L/D) .

- Show your design study and explain the results.
- Discuss the design change(s) you made with dimensioned drawings and rationale.
- Show relevant plots and quantify the impact of changes on key metrics (both positive and negative).