A&AE 421 Semester Project
Air Vehicle Mathematical Modeling, Dynamic Response and Control

General Objective

To write MATLAB computer programs for dynamic modeling and control system design of fixed wing aircraft. The software should be useful to future students who take the senior design courses AAE451 Aircraft Design or AAE450 Spacecraft Design.

Specific Objectives

1. Write a general purpose MATLAB computer program to take basic aircraft geometry, mass, and aerodynamic data, and, using empirical methods, produce a complete set of stability and control derivatives and inertia and geometry data in a format that can be used by dynamic response software developed for AAE421 (see for example the file Cessna182.m) located at the course web site http://roger.ecn.purdue.edu/~andrisan/Courses/AAE421_S2001/Docs_Out/DC_Software/index.html
2. Use the course stability and control software (FlatEarthAnal.m) to determine the following complete 12th order transfer functions, Q(s)/DeltaE(s), R(s)/deltaR(s), P(s)/DeltaA(s).
3. Use the course stability and control software (for example, CessnaLongSC.m and CessnaLatSC.m) to determine the following 4th order transfer functions, , Q(s)/DeltaE(s), R(s)/deltaR(s), P(s)/DeltaA(s).
4. Design three stability augmentation systems. One system uses pitch rate feedback to the elevator to increase the damping ratio of the short period mode. The second uses yaw rate feedback to the rudder to increase the damping ratio of the Dutch roll mode. And the third uses roll rate feedback to the aileron to decrease the time constant of the roll mode.

References

1. Jan Roskam, *Airplane Flight Mechanics and Automatic Flight Controls, PART 1*, Roskam Aviation and Engineering Corporation, 1994.
2. Jan Roskam, *Methods for Estimating Stability and Control Derivatives of Conventional Subsonic Airplanes*, published by the author, Roskam Aviation and Engineering Corporation, 1977.
3. Jan Roskam, AAA computer software. The on-line help information is most useful. We are trying to get this up in Grissom 380 but have not yet succeeded. Stay tuned.
4. Jan Roskam, *AIRPLANE DESIGN, Part VI: Preliminary Calculation of Aerodynamic, Thrust and Power Characteristics*, Roskam Aviation and Engineering Corporation, 1990.
5. Hoak, D. E., *USAF Stability and Control DATCOM*, Air Force Flight Dynamics Laboratory, published in nine volumes or sections, Volume 4 is the most useful. These volumes can be found I the Design Room, Grissom 100.

Teams

The class will be divided into four teams. The first three teams will model airplanes designed last semester in AAE451. Those aircraft are hanging from the ceiling of Grissom 380.

The fourth team will model some aspect of the flight of the Space Shuttle. Empirical methods are not effective for modeling the Space Shuttle. Students may determine a mathematical model of the Space Shuttle from the open literature. This will generally be a simpler process then what the three other teams will have to do to determine the mathematical models for their aircraft. However, the mathematical model of the Space Shuttle may well be more complex in nature and not of a form directly useable by the class software.

Exactly what the Space Shuttle team does in this project will be described to me in a formal written proposal due on Thursday, March 8, as part of Progress Report 1. I must approve your proposal but the choice of topic is left open at this time. Generally, the project needs to be "as hard" as the project done by the other teams.

Schedule

1. Students must self-organize themselves into the following teams. Team membership must be finalized by Thursday, March 1, 2001***. Each team must have no more then 6 members.***

    Team Orion (models the blue and gray biplane)
    Team Boiler Xpress 1 (models the yellow and black monoplane)
    Team Boiler Xpress 2 (also models the yellow and black monoplane)
    Team Space Shuttle (models the Space Shuttle)

2. Team Progress Report 1, Thursday, March 8. This presentation will summarize the plans your team has for completing the project and any initial progress you may have made. Team organization and your plan for equal workload distribution should be described. Team collaborations may also be discussed.

3. Team Progress Report 2, Thursday, March 29. Significant progress must be demonstrated and discussed regarding the computation of stability and control derivatives.

4. Team Progress Report 3, Thursday, April 12. Significant progress must be demonstrated and discussed regarding the design of feedback control laws.

5. Final Project Report, Thursday, April 26 (Dead Week).

Notes

1. This is a team-oriented project. All members of the team must contribute to the project. An evaluation of the performance of each team member will form part of your grade for the project. This project will be worth 1/4 of your grade for this course.

2. Progress reports and the final project report are 15- minute formal oral presentations with transparencies. Students must hand in an electronic version of the report in Powerpoint format for posting on the World Wide Web. Throughout the course of the semester all students must participate equally in the presentations.

3. CMARK can compute stability and control derivatives. However, it is very much a black box that provides little insight into how the stability and control derivative comes about and what are the important contributing factors to a particular derivative. Furthermore, the successful use of CMARK for stability and control derivatives is tricky and computationally intensive. Therefore, the use of CMARK for this project is not allowed.

4. Teams may collaborate and share approaches and code. Each team must submit one complete set of MATLAB code including all necessary functions and scripts. All individual pieces of code must indicate the primary and supporting authors.

5. Code must be extensively commented in MATLAB.

6. Each team must submit a separate user manual in electronic format. Word, Powerpoint or pdf formats are acceptable. The user manual should be written to be understandable to typical students in AAE451. It should include complete examples and sample results.

7. Root locus is an acceptable method for design of the three feedback control systems required for this project. Everyone on each team must learn about and be comfortable with the feedback control aspect of the project. The final exam in this course will cover feedback control design using the root locus method. Resource material on the control design process can be found at http://roger.ecn.purdue.edu/~andrisan/Courses/AAE451%20Fall2000/ControlLaws.html

8. Material about biplanes can be found at http://roger.ecn.purdue.edu/~andrisan/Courses/AAE451%20Fall2000/Biplane.html

9. Definitions of constants used in the course software must not be changed. A listing of course software follows.

A&AE 421 Semester Project
Air Vehicle Mathematical Modeling, Dynamic Response and Control
CONTROL SYSTEM DESIGN CRITERIA

Each team will assume that they have three rate gyros, one each to measure pitch rate, yaw rate and roll rate. Each rate gyro should be connected to the appropriate control surface to achieve the desired control action. Proper control action is

pitch rate (q) feedback to the elevator (δ_E) to change the short period damping ratio,

yaw rate (r) feedback to the rudder (δ_R) to change the damping ratio of the Dutch roll mode,

roll rate (p) feedback to the aileron (δ_A) to change the roll mode time constant.

The general control law is as follows.

control surface motion = - K*(angular rate) + pilot command to the control surface

(for example, $\delta_E = - K*q + \delta_{E\ \mathrm{command}}$)

The rate gyro system we will use has two gains. At any given time, which one of the two gains being used is selectable by the pilot. We will always set the first gain to zero so that we can shut off feedback whenever we have to. With feedback, instability or poor dynamic response of the aircraft is always possible.

There is also a gain sign switch on the gyro mixer box (on-board the aircraft). This switch sets the sign on the feedback gain in the equation above (i.e., -K or +K). It can only be changed while the aircraft in on the ground. The sign of the feedback will can be either stabilizing or de-stabilizing, depending on this switch setting. Each team will select the magnitude and sign of the feedback gain ($|K|<1.3$ deg/deg/sec) so that (if possible)

the damping ratio of the short period mode is 0.707 (short period pole is on a 45 degree line in the left half of the complex plane).

the damping ratio of the Dutch roll mode is 0.26 (Dutch roll pole is on a 75 degree line in the left half of the complex plane).

the roll mode time constant is 0.1 seconds (roll mode pole is at -10 radians/sec).

De-stabilizing feedback may be necessary to achieve one or more of these criteria.

Some guidance as to the magnitude of the feedback gains can be found at http://roger.ecn.purdue.edu/~andrisan/Courses/AAE451%20Fall2000/ControlLaws.html