Final project, due at 16:00 on March 12

The purpose of this set of problems is to analyze the stability and control of the Saab J35 Draken. You need not do all the different analyses mentioned, your grade will depend both on the amount of work you do and the quality of the work done. It is strongly recommended that you are very careful when performing the early parts as the following work will depend strongly on the quality of the early parts.

Present your results in the report that was developed in the previous assignments and improve the already existing parts based on the review sessions. The total length of the report should not be more than about 15 pages in single-column format and 10 point font.

The nonlinear simulation model

The aircraft model is provided as a set of template Matlab scripts that define some of the different functions needed to develop the simulation model.
The functions are:

File	Use
clongm02.m	Aerodynamic data
fplmod.m	Function defining the nonlinear equations of motion
initfpl35.m	Initialize the aerodynamic model
initrm6.m	Initialize the engine model
main.m	Main program example
rm6cal.m	Provides thrust and fuelburn
stdatm.m	The standard atmosphere

The scripts are not all complete and need some additional statements to produce a working model. Study the scripts carefully so that you understand how to use them before proceeding. The Matlab files are available on bf bilda.kth.se.

Constraints

The maximum allowed calibrated airspeed is 1350 km/h, and the thrust variable can only vary between 0 (no thrust) and 1 (full thrust). The fuel mass can be anywhere between 0 and 2323 kg, but remember that the airplane will not be airborne with more than 90% fuel and the airplane should never fly with less than 10% fuel. Load factor limits are -4 and +7. The nominal and most forward center of gravity position is xcg=10.0 meters. The elevator setting is limited to the range -25 to 10 degrees.

The particular model in the provided files is only valid for low speed flight (Mach < 0.7 roughly) but the model allows large angles of attack in the range -50 to +140 degrees. Only the longitudinal degrees of freedom are considered in this project.

Remember to only show results in figures that correspond to conditions that can actually be reached in flight even though you perform analysis over a wider range of flight conditions.

1. Equilibrium

Complete the model by adding the appropriate lines of Matlab code to the scripts and make sure that you can trim the aircraft for different flight conditions before proceeding.

Then, perform the following set of analyses at fuel mass 500 kg:

a) Find the level flight trim condition for all possible airspeeds up to Mach 0.7 at altitudes 0, 5000 and 10000 meters. Plot the angle of attack, elevator setting, thrust level as functions of the equilibrium airspeed. Plot the three curves, one for each altitude, in the same figures so that there is one figure for each state or control variable.

b) Investigate how the equilibrium elevator setting as a function of airspeed depends on the position of the center of gravity. In particular, investigate xcg=10.3 meters and compare to xcg=10.0 meters. What is the most rearward position of the center of gravity that should be allowed for this aircraft?

c) Find the elevator per g as defined in Etkin for Mach 0.5 at altitudes 0, 5000 and 10000 meters.

2. Linear stability

Linearize your nonlinear model and compute the stability eigenvalues for the longitudinal degrees of freedom. Show the eigenvalues as root locus plots with airspeed as parameter. Present graphs for the altitudes 0, 5000 and 10000 meters. Carefully investigate your results looking for possible instabilities.

For the altitudes above and the corresponding lowest and highest Mach number considered, compute the stability eigenvalues and identify the modes. Specify the time to half or double and frequency of oscillation for each mode.

3. Nonlinear simulation

Modify the scripts to perform nonlinear simulations for given settings of the elevator. Before each simulation, make sure to trim the aircraft so that equilibrium values of the state and control variables are used for initial values.

Your most important simulations should be clearly presented with a graph showing elevator input, altitude, angle of attitude, angle of attack and airspeed as a funtion of time.

Assume initial fuel 500 kg and flight at true airspeed 500 km/h at 11 km altitude. First assume that xcg is 10.2 meters. Run the simulation with the elevator fixed at the initial equilibrium value and analyze what goes on in comparison to what the linear stability analysis predicts. You will need to run the simulation for at least 300 seconds to understand what goes on.

3.1 Looping

Assume an initial condition represented by initial altitude 1 km, fuel level 500 kg, and true airspeed 700 km/h. Further, assume that the center of gravity is at 10.2 m. Trim the aircraft at the initial state and try to design a control input representing a looping. Remember to keep airspeed limited so that your simulation is valid with the subsonic aerodynamic data you have. Show the resulting trajectory in graphs showing your control input, altitude versus distance, airspeed, angle of attack and load factor.

3.2 The Cobra maneuver

Assume initial fuel 500 kg and flight at true airspeed 700 km/h and 10 km altitude. Make sure to fly at least 1 second at equilibrium elevator setting before changing the elevator. Abruptly apply stick aft (-25 degrees is maximum) and then return the stick to the equilibrium value. Modify your input until you achieve motion similar to what is presented in the video sequence referred to.

3.3 The superstall

Return to initial fuel 500 kg and flight at true airspeed 500 km/h at 11 km altitude. Make sure to fly at least 1 second at equilibrium elevator setting before changing the elevator. Abruptly apply stick aft (-25 degrees is maximum but about -10 should be enough) and then return the stick to the equilibrium value. Modify your input until you achieve a sustained superstall condition at high angle of attack. Carefully analyze the state of the aircraft in the superstall.

Revise your control input in order to execute a return to normal flight after the superstall. Make sure not to execute this command too early so that the superstall is fully developed before the exit command is applied. Carefully simulate the flight and make sure that the aircraft returns to a normal flight condition. Also, find an exit command that immediately brings the aircraft into a new but inverted superstall.

Investigate how a forward position of the center of gravity such as xcg = 10 meters changes the behaviour and also a more rearward close to the limit you obtained above.

4. Control system design

As an alternative to the work described in Section 3, you can design a control system for tracking a given flight path angle command. Assume that the desired flight path angle is given as a prescribed function of time, as done in the Draken performance analysis and optimization project. The task is to linearize the nonlinear model and design a controller, for example a PID controller, using the linear model and then implement the controller in the nonlinear model and perform simulations for different types flight path angle commands. Your controller should be robust and have reasonable performance for different subsonic Mach numbers and different altitudes.