Exercise 2 - Solutions

Fixed-wing Control and Simulation

1 Simulation of Sky-Sailor in Open-Loop

a) Open the subsystems and observe how the simulation model was created. The subsystem **Initial conditions** allows you to set the initial position, velocity (groundspeed), angles and angular rates of the airplane.

Notice that the ***initial conditions*** *are found* ***inside the block Sky-sailor/6 DoF Dynamics/Initial conditions*** *and* ***not as the inputs of the controller****: those are the feedback controller set-points… Also notice that you might have to actually turn off (double-click) the Control on/off switch depending on what you want to simulate…*

b) Observe the open-loop dynamic stability: set the initial pitch angle to 12°, the speed to 8 m/s and run the simulation with motor off.

This lets us observe the static and dynamic longitudinal stability. Clearly, the Sky-Sailor is stable: with all controls set to zero, the speed converges to approximately 8.5 m/s.

Notice that the initial conditions are found ***inside the block Sky-sailor/6 DoF Dynamics/Initial conditions*** *and not as the inputs of the controller. Also notice that you might have to actually turn off (double-click) the Control on/off switch.*

c) Analyze the forces and moments in **figure1**. Can you explain them?

The lift and drag components are shown (absolute, not coefficients) in green per surface element. The moments are drawn in red: the total moments reduced to the CoG are shown. Therefore, the moments in x-direction are of different sign for the left and right wing.

d) What's the period of the characteristic oscillation (phugoid)? How about the amplitude half-value period? Hint: insert scopes from the library browser in order to monitor the interesting state variables or run **show_uav_final** in the Matlab console after the simulation finished.

The phugoid period amounts to about 6.5 s. The amplitude is halved within around 16 s.

e) Now find the v-tail control surface deflections (symmetric!) that correspond to 14 m/s total speed. Hint: also adjust the initial conditions closer to what you think will be the equilibrium values. Reset controls and initial conditions.

Iteratively, a value of 0.86° is found.

f) Investigate the influence of the CoG location: open **param.m** and change to the value 3 cm forward. What's happening? How about, if you move it 3 cm backwards? Can you explain the effects? Reset to the correct CoG.

For the CoG moved to the front, the equilibrium speed is increased significantly to 15 m/s. The reason for this is that the lever arm of the lift force at the main wing has increased, thus the pitch moment coefficient curve has its equilibrium at a smaller angle of attack. Also, the CoG is further in front of the Aerodynamic Center, therefore the static stability is higher. In the case of the CoG further behind, the trajectory diverges: the CoG was *moved behind the Aerodynamic Center, therefore neither static nor dynamic longitudinal stability is given anymore.*

g) Switch on some wind: this will also generate turbulences. Also adjust the initial speeds accordingly, since they represent groundspeed and not airspeed. What is your verdict concerning dynamic stability of all modes?

   The longitudinal modes are clearly stable, this could be observed also in the previous tasks. The Dutch roll mode is also stable, since the corresponding roll-yaw motion is bounded. Also the spiral mode seems to be stable: at least within the simulated time, the airplane does not enter spiraling.

2 Simulation of the Sky-Sailor in Closed-Loop

a) Explore the control structure.

b) Set small roll and pitch angles, leave the speed at 9 m/s and run the simulation. Does the result correspond to your expectations?

c) Try the feedback controlled airplane with the CoG position at the back. Can you see a difference? Move the CoG back to the correct position.

   The feedback controlled airplane can easily cope with the (quite slow) unstable longitudinal pole: consequently, hardly any difference in behavior can be observed.

d) Now try a bit more violent angles, find the limitations of the controller, the airplane respectively.

   With steeper angles, the airspeed also needs to be adjusted. At some point, however, the propulsion system is not capable anymore of delivering enough power. You can only go to smaller (i.e. more negative) pitch angles – meaning that the airplane will fly downward. Notice that this is not a limitation of the controller, but of the system. The controller with the default parameters can only be destabilized if angles (particularly roll) are requested that require control moments or thrust beyond saturation, or that would require lift beyond stall. A more serious controller would have to control the angle of attack watch and adapt the requested set-points.

e) Increase the rate control proportional gains gradually. How can you explain the reaction? Do you think the reference tracking is good? How about aerodynamic efficiency? Reset to the original values.

   The control action is increased: first this results in a better reference tracking at the price of more aerodynamic drag (and more power consumed at the servos). If the gains are increased further, the airplane starts to jitter. Now it is only the servo rate limiters that keep the airplane from being unstable.

f) Now increase the gains of the attitude controller. Can you explain the resulting behavior? Reset the gains.

   Increasing those gains results in worse tracking behavior at some point, or even instability. The reason is that the bandwidths of the succeeding control loops are not well separated anymore.

g) Tune the gains such that a better controller will result (in your opinion). If you are convinced to have found the perfect controller, call the assistant.

h) Switch on some wind again. Is your controller robust enough?