FLIGHT DYNAMICS AE3302

EXAMINATION

August 25, 2010

Delft University of Technology
Faculty of Aerospace Engineering
Control and Simulation Division

This exam contains 6 questions.

You may use the formulae on the given formula sheets.

Hand in your derivations

PLEASE NOTE

Always write down the correct units for each computed parameter value. Be mindful for any required conversion before making any computations. **Always** write down the derivations of your answers.

Question 1 (10 %)

Decide for every statement whether it is True or False. No explanation is required!

(a) A Fly-by-wire control system is a reversible control system.

(b) For the equations of motion of a fast aircraft, the Earth can be considered flat and non-rotating.

(c) For a wing, the neutral point is the point where the line of action of the resultant aerodynamic force C_R crosses the mean aerodynamic chord.

(d) The main wing of a conventional aircraft reduces the local dynamic pressure at the horizontal tailplane.

(e) The contribution of the wing to C_{l_β} is caused by the difference in geometric angle of attack of the left and right hand halves of the wing in sideslipping flight.

(f) The contribution of the fuselage to C_{n_β} is destabilizing.

(g) The wing of a conventional aircraft has a negative contribution to C_{l_p}.

(h) In the phugoid motion, the pitch rate and airspeed vary in particular.

(i) A more negative C_{l_β} leads to a more damped Dutch roll motion.

(j) In general, an unstable spiral mode is preferable over an unstable Dutch roll mode.

Question 2 (15 %)

Derive the transformation matrix between the inertial reference frame and the aerodynamic reference frame. Assume that the Earth is flat and non-rotating, i.e. $F^I \equiv F^E \equiv F^O$. To make derivations easier, one commonly uses intermediate coordinates frames. It this case one would derive the complete transformation matrix by first computing the transformation matrix between F^I and F^b and then computing the transformation matrix between F^b and F^a. Use the 3-2-1 rotation sequence which is commonly used in the aerospace industry to construct the transformation matrix between F^I and F^b, and next construct the transformation matrix between F^b and F^a.

Write the complete transformation matrix as a product of the transformation matrices per rotation. You do not have to convert the product into a single matrix but the multiplication sequence should be correctly defined!

Hint: A total of 5 rotations are required!

Question 3 (15 %)

Consider the aircraft in figure 1 which is the Rutan Voyager. The Rutan Voyager was the first aircraft to fly around the world non-stop. In order to maximize its range, the Voyager had 17 fuel tanks; 8 in each wing and nacelle and 1 in the fuselage. In total, the fuel tanks contained over 3000kg of fuel, while its empty weight was around 1000kg.

(a) Explain where the center of gravity is located: aft of the main wing, between the main wing and the canard or in front of the canard.

(b) This aircraft is longitudinally stable (i.e. $C_{m_\alpha} < 0$). Explain, using only words, why it is longitudinally stable.

(c) In the case of (3b), what is the advantage of having a canard instead of a horizontal stabilizer?

(d) The pilots of the Voyager had to constantly trim the aircraft. Why was this the case, and how do you suggest they should perform this task? Clearly explain your answer in terms of the static longitudinal stability!

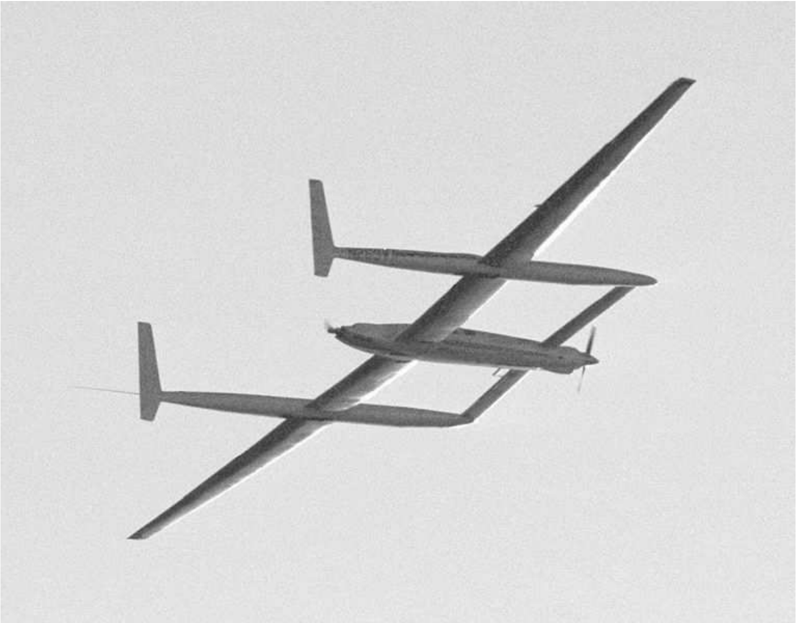

Figure 1: Rutan Voyager

Question 4 (20 %)

(a) Draw the lateral stability diagram for a conventional aircraft. Clearly indicate which parameters are on the axes. Also indicate the regions where the Dutch roll and spiral motion are stable and where they are unstable.

(b) Imagine an aircraft that has a convergent spiral motion while the Dutch roll is unstable. If you could change the geometric properties of just one part of the aircraft (wings, tail, fuselage, vertical stabilizer or horizontal stabilizer) what alteration is required to make the Dutch roll stable while keeping a convergent spiral motion? Present two possible alterations.

(c) Clearly indicate in the figure of question (4a) in which region the aircraft of question (4b) falls before the alteration (mark the location with a circle). Indicate by means of an arrow which path is followed through the lateral stability diagram when performing each alteration presented in question (4b). Indicate which arrow belongs to which alteration.

(d) What is the sign of the aerodynamic coefficient C_{n_p} for a conventional aircraft which has a positive wing sweep? Explain what the contribution of the wing is for this aerodynamic coefficient. Clearly mention how the aerodynamic forces which define this contribution are generated.

Question 5 (20 %)

Consider a twin-engined jet aircraft, from which the aircraft data is summarized in Table 1.

m = 65000 kg	C_L = 0.46	V = 100 m s^{-1}	S = 125 m^2	b = 35 m
ρ = 1.225 kg m^{-3}	C_{Y_β} = -0.90	C_{ℓ_β} = -0.25	C_{n_β} = 0.1	$C_{Y_{\delta_a}}$ = 0
$C_{\ell_{\delta_a}}$ = -0.08	$C_{n_{\delta_a}}$ = -0.01	$C_{Y_{\delta_r}}$ = 0.55	$C_{\ell_{\delta_r}}$ = -0.04	$C_{n_{\delta_r}}$ = -0.25

Table 1: Aircraft data for question 5

During a landing approach, the aircraft is hit by lighting, which leads to an electrical failure in the rudder actuator system causing the rudder to lock up at an angle of $\delta_{r_{fail}} = +7.0°$. As a result of this, an unwanted yawing and rolling moment is acting on the aircraft.

(a) From the full set of lateral equations of motion, derive the set of equations for steady, straight, sideslipping flight. Clearly indicate which simplifications are made!

(b) Calculate the required sideslip angle β, the roll angle ϕ, and the aileron deflection δ_a in order to continue the landing approach.

(c) It is given that the maximum aileron deflection is $\delta_{a_{max}} = \pm 25°$. It is now clear that the pilot is unable to continue the landing approach. In order to reduce aileron deflections, the pilot sets the engines to generate a differential thrust. The non-dimensional moment produced by the differential thrust is $C_{n_e} \cdot \Delta T$ with the coefficient C_{n_e} given by:

$$C_{n_e} = \frac{y_e}{\frac{1}{2}\rho V^2 S b}$$

with $y_e = 6.5$ the lateral distance between the engines and the center of gravity of the aircraft.

Rewrite the equations of motion for steady, straight, sideslipping flight from part (5a) such that they also include the differential thrust ΔT.

(d) Calculate the required differential thrust ΔT, the new sideslip angle β and the new roll angle ϕ such that the ailerons have a deflection of 80% of their maximum deflection.

Question 6 (20 %)

Consider an aircraft for which the non-dimensional symmetrical homogeneous equations of motion are,

$$\begin{bmatrix} -1-500D_c & 1 & -2 & 0 \\ -4 & -5-125D_c & 0 & 165 \\ 0 & 0 & -D_c & 1 \\ 0 & -2-8D_c & 0 & -10-365D_c \end{bmatrix} \begin{bmatrix} \hat{u} \\ \alpha \\ \theta \\ \frac{q\bar{c}}{V} \end{bmatrix} = \underline{0}$$

(a) Starting with the equations of motion printed above, derive a simplified expression for the phugoid, assuming that the contributions of both $\dot{q}$ and $\dot{\alpha}$ are negligible.

(b) Determine the characteristic equation of the simplified expression for the phugoid from part (6a).

(c) Determine also the non-dimensional eigenvalues λ_c, and the corresponding *dimensional* period P, the time to damp to half amplitude $T\frac{1}{2}$ the undamped natural frequency ω_0 and the damping ratio ζ.

(d) What happens to the magnitude of $P, T\frac{1}{2}, \omega_0, \zeta$ if:

- (i) The center of gravity is shifted forward (assuming this only affects C_{m_α}).
- (ii) The weight is increased.
- (iii) The airspeed is increased (assuming the stability derivatives do not change).

Case	P	$T_{\frac{1}{2}}$	ω_0	ζ
i.	$+/-/0$	$+/-/0$	$+/-/0$	$+/-/0$