FLIGHT DYNAMICS AE3202

NEW STYLE

EXAMINATION

August 24, 2011

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 points)

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 points)

A common definition of aerodynamic forces is that of the drag, side and lift force (D, S and L), expressed in the aerodynamic A-frame (positive in negative axis direction). When the forces are not acting in the centre of mass, a moment due to these forces is the result. To calculate this additional moment the aerodynamic force in the body B-frame is required. You are required to derive the following.

(a) **5 points** Derive the transformation matrix $\mathbf{T_{BA}}$ (from aerodynamic to body frame, see also Fig. 1). Before calculating the final transformation matrix $\mathbf{T_{BA}}$, specify the transformation matrices for each of the unit-axis rotations.

(b) **4 points** Derive the expressions of the 3 components of the aerodynamic force in the body frame, $\mathbf{F_{A,B}}$.

(c) **6 points** Calculate the resulting moment due to $\mathbf{F_{A,B}} = (X, Y, Z)^T$, see also Fig. 2. Give the individual expressions for the x, y and z components.

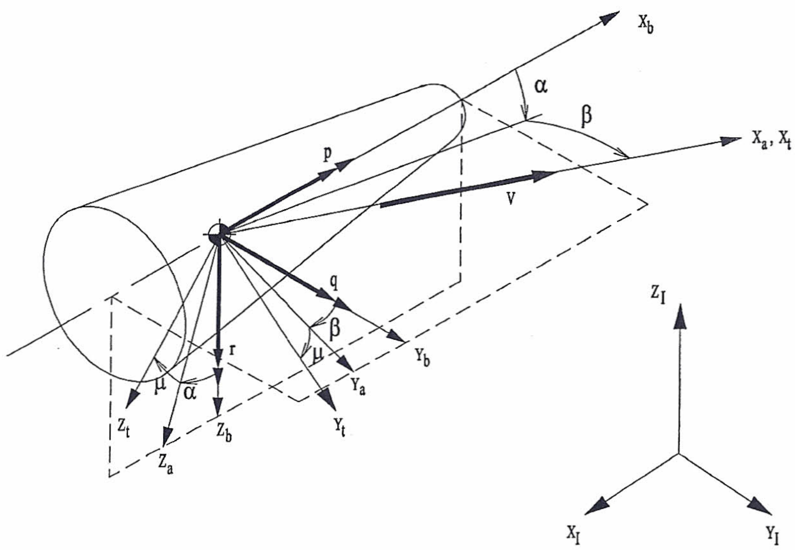

Figure 1: Aerodynamic-angle definition, including B- and A-frames

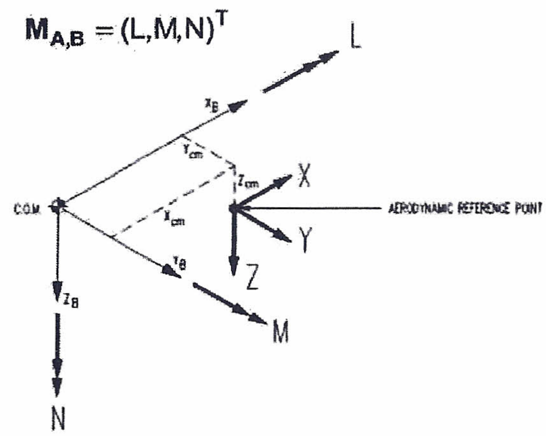

Figure 2: Aerodynamic moments due to forces acting in a point different than the c.o.m.

Question 3 (15 points)

Consider the aircraft in figure 3 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!

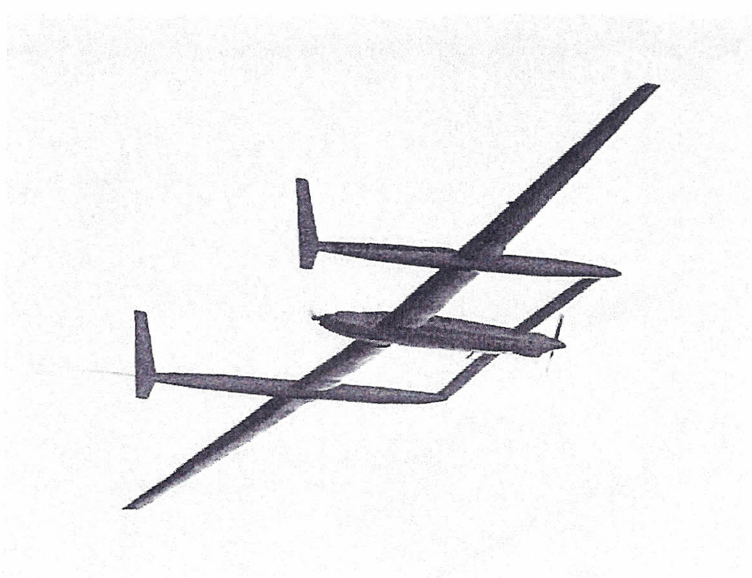

Figure 3: Rutan Voyager

Question 4 (20 points)

(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 points)

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 points)

For the linearization of the re-entry equations of motion, it is common to express the position and velocity in spherical components. The kinematic equations are in that case given by:

$$\dot{R} = V \sin\gamma \tag{1}$$

$$\dot{\tau} = \frac{V \cos\gamma \sin\chi}{R \cos\delta} \tag{2}$$

$$\dot{\delta} = \frac{V}{R} \cos\gamma \cos\chi \tag{3}$$

(a) **15 points** Linearize the above kinematic equations. Note: one can NOT assume that the nominal flight-path angle is small; only perturbations are considered to be small.

(b) **5 points** For a vehicle entering the atmosphere the following eigenvalue λ and eigenvector $\boldsymbol{\mu}$ are calculated: $\lambda = -0.7302 \cdot 10^{-7} \pm 0.7415 \cdot 10^{-2} j$ and $\boldsymbol{\mu} = (0.0129, 0, 1, 0, 0.1678 \cdot 10^{-3}, 0, 0.0226, 0, 0)^T$. The non-zero elements in $\boldsymbol{\mu}$ are related to $\Delta V, \Delta R, \Delta q$ and $\Delta\alpha$.
(i) Identify the eigenmode.
(ii) Calculate the natural frequency ω_n and halving time $T_{1/2}$ of this eigenmode.
(iii) Is this mode stable? Explain why.