
FLIGHT DYNAMICS AE3302

EXAMINATION

October 27, 2010

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

This exam contains 6 questions.

You may use the formulas 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 human powered cable and pulley control system is a reversible control system.

(b) For the equations of motion of a fast aircraft, the Earth must be considered spherical and rotating.

(c) A flying wing aircraft always requires some form of feedback control to stabilize its short period motion.

(d) Maneuverability and unaugmented stability are mutually exclusive properties of an aircraft.

(e) It is difficult to vary the pitch rate q independently of the time rate of change of the angle of attack $\dot{\alpha}$.

(f) The forward half wing wing of a low wing aircraft experiences an increase in the angle of attack due to sideslip.

(g) If the stability derivative C_{n_p} is negative, then a positive rolling velocity causes a negative yawing moment.

(h) The stability derivative C_{l_r} of a conventional aircraft is always positive.

(i) If second order terms are included in the equations of motion of a conventional aircraft, then additional eigenmotions may be found.

(j) A conventional aircraft flying in a steady, straight sideslipping flight with positive β will have a negative roll angle ϕ.

Question 2 (10 %)

The orientation of one reference frame with respect to another can be described by Euler angles.

(a) What is the maximum number of Euler angles required to define the orientation of one reference frame with respect to another in three dimensional space?

(b) Give the transformation matrix $\mathbb{T}_{bE}$ for the 3-2-1 rotation sequence used to define the orientation of the body-fixed reference frame (F_b) with respect to the Earth-fixed reference frame (F_E). Before composing the final transformation matrix $\mathbb{T}_{bE}$, specify the transformation matrices for each of the rotations. You are allowed to write $\mathbb{T}_{bE}$ as a combination of the matrices you specified earlier.

Assume that the Earth is non-rotating and flat such that $F_E = F_O$.

Question 3 (15 %)

(a) Sketch the elevator deflection curve ($\delta_e - V$) if the following conditions hold:

- Statically unstable, stick fixed
- $C_{m_0} > 0$

Clearly indicate the negative and positive side of the axes and *explain* why the elevator trim curve has the shape you have drawn!

(b) Sketch the elevator control force curve ($F_e - V$) if the following conditions hold:

- Aircraft possesses control force stability.
- $\delta_{t_e} > \delta_{t_0}$

Clearly indicate the negative and positive side of the axes and *explain* why the elevator control force curve has the shape you have drawn!

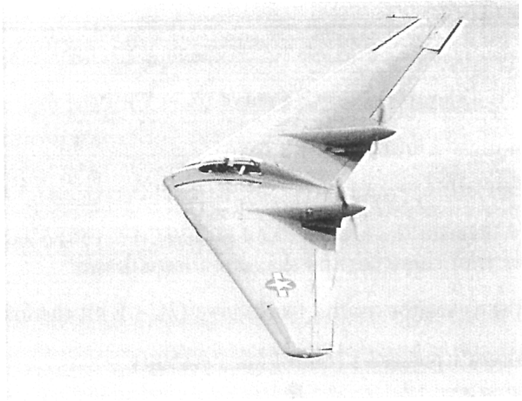

Figure 1: Northrop N9M flying wing

Question 4 (25 %)

A flying wing is an aircraft without a tailplane, see Figure 1. The characteristic modes of a flying wing differ significantly from those of a conventional aircraft. In this question the dynamics of the short period mode of a flying wing will be examined.

(a) From the full linearized longitudinal equations of motion, derive a simplified form describing the short period motion, such that the state vector becomes $[\alpha\ \frac{q\bar{c}}{V}]^T$. Additionally, the stability derivatives $C_{m_{\dot{\alpha}}}$, $C_{Z_{\dot{\alpha}}}$, C_{m_q} and C_{Z_q} are assumed to be zero.

(b) The characteristic equation of the simplified short period motion is given as $p(\lambda_c) = A\lambda_c^2 + B\lambda_c + C$. Derive symbolic values of A, B and C and then numerically calculate the corresponding eigenvalues. Does the flying wing have a stable short period motion? Use the numerical data from Table 1.

(c) In order to improve the flying qualities of the flying wing, an alpha feedback controller is integrated with the flight control system. This feedback controller has the following definition: $\delta_e = k_\alpha \alpha$. Derive the new characteristic equation of the form $p(\lambda_c) = A\lambda_c^2 + B\lambda_c + C$ for the simplified short period motion from part (b).

(d) For what range of the feedback gain k_α is the simplified short period stable? Use the numerical data from Table 1.

(e) For what range of the feedback gain k_α is the simplified short period both stable and periodic? Use the numerical data from Table 1.

$V = 80[ms^{-1}]$	$\mu_c = 50$	$K_Y^2 = 0.78$	$C_{X_0} = 0$	$C_{X_u} = -0.24$	$C_{X_\alpha} = 0.463$
$C_{Z_0} = -1.15$	$C_{Z_u} = -2.64$	$C_{Z_\alpha} = 0.51$	$C_{Z_q} = 0$	$C_{Z_{\dot{\alpha}}} = 0$	$C_{Z_{\delta_e}} = -0.41$
$C_{m_\alpha} = -0.78$	$C_{m_u} = 0$	$C_{m_{\dot{\alpha}}} = 0$	$C_{m_{\delta_e}} = -0.83$	$C_{m_q} = 0$	

Table 1: Aircraft data for question 4

Question 5 (25 %)

Consider a twin-engined jet aircraft with a conventional configuration, from which the aircraft data is summarized in Table 2.

m = 4800 kg	$C_L = 0.46$	V = 55 m s^{-1}
S = 31.80 m^2	b = 15.90 m	$\rho = 1.225$ kg m^{-3}
C_{Y_β} = -0.90	C_{ℓ_β} = -0.07	C_{n_β} = 0.13
$C_{Y_{\delta_a}}$ = 0	$C_{\ell_{\delta_a}}$ = -0.35	$C_{n_{\delta_a}}$ = -0.11
$C_{Y_{\delta_r}}$ = 0.21	$C_{\ell_{\delta_r}}$ = 0	$C_{n_{\delta_r}}$ = -0.05

Table 2: Aircraft data for question 5

During a cross-wind landing approach, in which the aircraft has to maintain a sideslip angle of $\beta = 6°$, the aircraft suffers a bird strike, which causes the right wing aileron to lock up at an angle of $\delta_{a_{fail}} = +20°$. The damage to the right wing aileron also causes an extra 'adverse yaw' effect. The left wing aileron still fully functional.
As a result of this, an unwanted rolling and yawing moment is acting on the aircraft. The total non-dimensional rolling moment coefficient, which includes the influence of both the damaged and the undamaged aileron, is given as follows:

$$C_{l_{\delta_a}}\delta_a \overset{failure}{\longrightarrow} \frac{1}{2}C_{l_{\delta_a}}\delta_a + \frac{1}{2}C_{l_{\delta_a}}\delta_{a_{fail}}$$

The total non-dimensional yawing moment coefficient, which includes the influence of both the damaged and the undamaged aileron due to aileron deflection, is given as follows:

$$C_{n_{\delta_a}}\delta_a \overset{failure}{\longrightarrow} \frac{1}{2}C_{n_{\delta_a}}\delta_a + \frac{1}{4}C_{n_{\delta_a}}\delta_{a_{fail}}$$

For a steady, straight, sideslipping flight, the equations of motion can be written in the form

$$\mathbf{A}\begin{bmatrix} \varphi \\ \beta \\ \delta_a \\ \delta_r \end{bmatrix} = \bar{c}$$

with $\mathbf{A}$ the system matrix, and $\bar{c}$ a vector containing the disturbance moments due to the aileron lockup.

(a) Write down the expressions for **A** and $\bar{c}$, using the equations of motion for steady, straight, sideslipping flight and the given expressions for the non-dimensional, total rolling and yawing coefficients due to aileron deflection.

(b) Calculate the required roll angle ϕ, the left wing aileron deflection δ_a and the rudder deflection δ_r in order to continue the cross-wind landing approach with $\beta = 6°$.

(c) It is given that the maximum aileron deflection is $\delta_{a_{max}} = \pm 25°$ and the maximum rudder deflection is $\delta_{r_{max}} = \pm 25°$. It is now clear that the pilot is unable to continue the cross-wind landing approach. Which control surface(s) is/are the limiting factor in this case?

(d) In order to reduce the deflections of the control surfaces, and to continue the cross-wind landing approach, 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 C_{n_e} give by

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

with $y_e = 1.5$ the lateral distance between the engines and the center of gravity of the aircraft.

Calculate the required differential thrust ΔT, the new roll angle ϕ and the new aileron deflection δ_a so that the control surface with the largest deflection under (b) has a deflection of 80% of its maximum deflection. The sideslip angle remains unchanged at $\beta = 6°$. The rolling effect due to differential thrust is neglected.

(e) It is clear that the aircraft considered in this question has some serious issues with regards to its flying characteristics. If you, as a professional Aerospace Engineer, were to advice the manufacturer of the aircraft to make a single structural modification, what modification would that be? Which single parameter from Table 2 is affected the most by your suggested modification? Clearly and briefly explain your reasoning!

Question 6 (15 %)

(a) How many eigenmotions does a conventional aircraft have if one considers only the linear equations of motion, and what are they called?

(b) What is the name of the lateral eigenmotion which is characterized by an oscillation? Draw the time response of the eigenmotion during **three** periods in a figure with p and r on the axes taking into account the following assumptions:

- The eigenmotion is stable.
- Only this eigenmotion is excited and that the initialization phase (i.e. the time interval when the eigenmotion is introduced) has passed.
- The time to half amplitude is equal to the period.
- The maximal values of p and r is 0.08 rad/s during the considering time interval.

Clearly indicate the direction of time by using arrows on the lines, i.e. —▷—▷—.