Project 9 – Fuselage loads

Usually fuselage is considered as a beam supported by main wing-fuselage joints. The main sources of fuselage loads are as follows:

- Reaction of other components of an aeroplane which are mounted to the fuselage, especially: horizontal and vertical tail, landing gear, reaction of point mass, payload, devices, etc.
- Aerodynamic loads
- Load due to pressurization of cabin (if present).
- Engines and other power units assembled with the fuselage

This project does not include full analysis of fuselage loads but incorporated body forces and loads of horizontal and vertical tail, and engine as well.

Power unit

Evaluation of load from the power unit requires to analyze all cases to find the most critical one, that means case, which gives the greatest load. These loads influence engine mount, pylon, construction, etc. The loads include:

a) Engine thrust
b) Torque
c) Gyroscopic moment
d) Body forces

Ad. a)

For jet engines - maximum value of the engine thrust can be obtained from an engine's characteristic.

For turboprop and piston engines - maximum value of the engine thrust can be obtained from equation (9.1)

$$F = \frac{\eta N}{V} \tag{9.1}$$

where:

η – efficiency of propeller
N – power of engine [W]
V– air speed [m/s]
F – thrust of engine-propeller unit [N]

Note that, maximum thrust of the engine-propeller unit is not the maximum power of the engine point.

Ad. b) Maximum torque of a piston engine or a turboprop can be bigger than average torque which can be calculated basing on known value of power and rpm. This excess of torque can be caused by rough running of the engine. For piston engines it depends on cylinders number. For turbojet engines torque is determined by maximum angular acceleration of rotating masses of engine. For calculations ***k*** coefficient is applied, ***k*** is equal to rate of maximum torque M_{max} to average torque $M_{average}$ appropriated for assumed engine.

$$k = \frac{M_{max}}{M_{average}} \tag{9.2}$$

The ***k*** coefficient should be obtained from engine's characteristic, if the characteristic is unavailable then the coefficient should be assumed based on current regulations of aircraft design.

$$M_{max} = k\frac{N}{\omega_S} \tag{9.3}$$

where:
ω_s – angular velocity of propeller [1/s]

For turbojet engines:

$$M_{max} = J_{OS}\varepsilon_S k \tag{9.4}$$

where:
- J_{os} – moment of inertia of rotating mass of the engine
- ε_s – maximum angular acceleration of rotating mass of the engine (from engine data)
- k – coefficient (k>1) to allow possible increase of ε_s

Ad. c) Gyroscopic moment depends on: polar moment of inertia J_o of rotating mass of engine, angular velocity of this mass and perpendicular angular velocity of airplane ω_y or ω_z during angular motion around y or z axis. Regulation (CS 23.371) includes the angular velocity values, that should be taken to analysis. The angular velocity ω_y can be calculated based on analysis of circular motion.

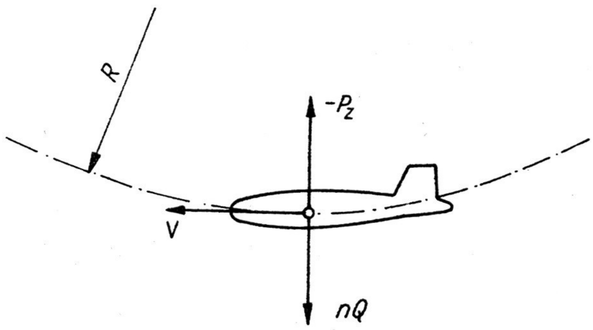

Fig. 9.1 – Symmetrical curvilinear motion of airplane
(W. Błażewicz – Budowa samolotów, Warszawa 1979)

From circular motion shown on the Fig.9.1:

$$nQ = mg + m\omega_y^2 R \tag{9.5}$$

hence:

$$n - 1 = \frac{\omega_y^2 R}{g} \tag{9.6}$$

$$V = \omega_y R \tag{9.7}$$

$$\omega_y = \frac{g(n-1)}{V} \tag{9.8}$$

Gyroscopic moment is calculated from:

$$M_{GYR} = J_O \Omega \omega_y \tag{9.9}$$

where:
Ω – angular velocity of rotating elements (propeller, turbine, etc.)
J_o – moment of inertia of rotating elements (if data is unavailable than mass of a propeller or rotating elements of turbine engine should be estimated, according to flowing cases:

- propeller should be assumed as a solid beam
- disk of turbine as a solid cylinder

Repeat the same scheme for angular velocity ω_z.

ATTENTION: Correct calculation of angular velocity is very important, that means the angular velocity should be calculated for the mostly loaded point of the load envelope (V-n diagram).

Ad. d) body forces require to calculate the appropriate load factor longwise each axis. The n_z can be taken directly from load envelop. The n_x and n_y are defined in airworthiness regulation or can be calculated by analysis of critical cases**.**
Body (mass) forces are calculated from following formulas:

$$F_X = n_X Q_S, \quad F_Y = n_Y Q_S, \quad F_Z = n_Z Q_S \tag{9.10}$$

where:
Q_s – weight of power unit

The final result should be presents in a table (see for example)

Agriculture aircraft – load of power unit –example

Load	Max. value	Critical case
Fx	20000[N]	Take off thrust
Fy	10000[N]	Body force – turn for Va
Fz	15000[N]	Body force – point D of load envelop
Mx	55000 [Nm]	Max torque
My	2500 [Nm]	Gyroscopic moment point A
Mz	2500 [Nm]	Gyroscopic moment point D

General (external) load of fuselage

Fig. 9.2 presents the scheme of beam supported by main wing-fuselage joints, which is used to the analysis of the fuselage loads.

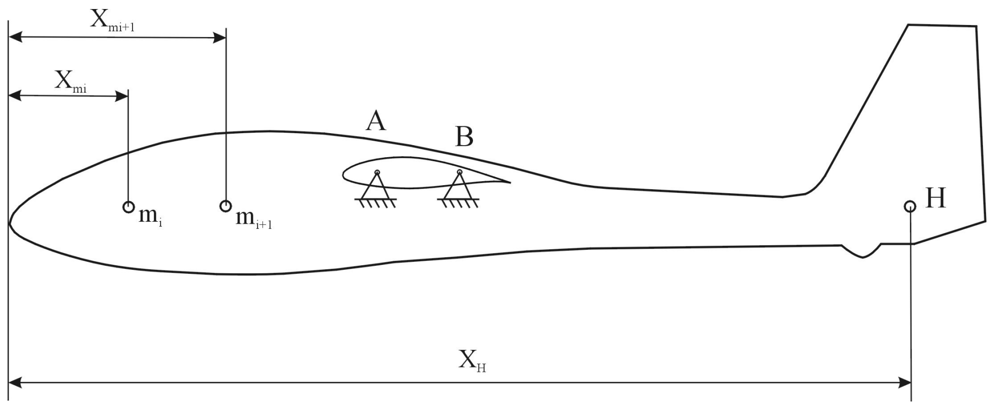

Fig.9.2 – Scheme use to analysis of fuselage load

Three cases of "unit" loads are considered (force 1N, moment 1Nm, load factor n=1):

- Generated by mass of the fuselage due to acceleration, that corresponds to load factor equal 1 (n=1)
- Generated by mass of fuselage due to acceleration, that corresponds to assumed angular acceleration ε_0 around centre of mass; it means, that the load factor is equal:

$$n_\varepsilon = \frac{\varepsilon_0 x_i}{g}$$

(usually it is easier to define angular acceleration by P_{ZH0} that is the force acting on the horizontal tail and causes angular acceleration)

- Horizontal tail aerodynamic force P_{ZH}

In each case the fuselage is loaded by forces and reaction of main fuselage-wing joints but the beam is in equilibrium state. For all cases diagram of bending moment and shearing force should be made. Value of the bending moment and the shearing forces for any section (A-A) can by calculated using equations 9.11 and 9.12.

$$Q_{A-A} = Q_{Anj}\frac{n}{n_j} + Q_{A\varepsilon j}\frac{P_{zH\varepsilon}}{P_{zH\varepsilon j}} + Q_{AHj}\frac{P_{zH}}{P_{zHj}} \tag{9.11}$$

$$M_{A-A} = M_{Anj}\frac{n}{n_j} + M_{A\varepsilon j}\frac{P_{zH\varepsilon}}{P_{zH\varepsilon j}} + M_{AHj}\frac{P_{zH}}{P_{zHj}} \tag{9.12}$$

gdzie:

- Q_{A-A} & M_{A-A} - bending moment and shearing force for assumed load, for section A-A,
- Q_{Anj}, $Q_{A\varepsilon j}$, Q_{AHj} – value of shearing force for corresponding load case (1kN or 1kNm), for section A-A,
- M_{Anj}, $M_{A\varepsilon j}$, M_{AHj} - value of bending moment for corresponding load case (1kN or 1kNm), for section A-A,
- n, $P_{ZH\varepsilon}$, P_{ZH} – real values for considered cases,
- n_j, $P_{ZH\varepsilon j}$, P_{ZHj} – unit values for considered cases.

Schemat obliczeń dla obciążeń jednostkowych:

a) the first step is to prepare (in table form) a list of mass which have influence on fuselage load (this list should be prepared basing on Project no. 3). If mass analysis of fuselage was made rough a more particularly calculations are necessary. Next step is to calculate a centre of gravity for fuselage (x_{sc_k}) and a moment of inertia for the fuselage (J_{yy_k}), to this calculations use equations 9.13

$$x_{SC\_k} = \frac{\sum_{i=1}^{n} m_i x_i}{\sum_{i=1}^{n} m_i} \quad , \quad J_{yy\_k} = (\sum_{i=1}^{n} m_i x_i^2 - x_{SC\_k}^2 \sum_{i=1}^{n} m_i) \tag{9.13}$$

b) for n=1 calculate reaction in A and B supports, that equilibrium conditions:

$$\sum_{i=1}^{n} P_i + R_A + R_B = 0 \tag{9.14}$$

$$\sum_{i=1}^{n} P_i x_{mi} + R_A x_A + R_B x_B = 0 \tag{9.15}$$

where:

$$P_i = m_i g \tag{9.16}$$

ATTENTION: equation 9.13-14 are correct for assumption that the force P_i and reaction R_A and R_B have the same signs (positive signs), that means the sign of gravity force is negative.

c) make a diagram of bending moment and shearing force for above mentioned **case** (n=1),

d) assuming unit force acting on the horizontal tail P_{ZH}=1kN, calculate angular acceleration using formula:

$$\varepsilon = \frac{-P_{ZH} l_H}{J_{yy}} \tag{9.17}$$

where:

l_H – distance between the airplane centre of gravity to ¼ of horizontal tial MAC $(x_H - x_{SC})$, where x_{SC} is an airplane centre of gravity,

J_{yy} – moment of inertia with respect to lateral axis (perpendicular to symmetry plane of airplane which crossed centre of gravity of airplane).

e) calculate body forces using formula:

$$P_{i\varepsilon} = m_i \varepsilon (x_i - x_{SC\_k}) \tag{9.18}$$

f) calculate reactions in supports A & B, it can be done using eq. 9.14-9.15) or directly from formula:

$$R_A = -R_B = \frac{\varepsilon J_{yy\_k}}{x_B - x_A} \tag{9.19}$$

g) make a diagram of bending moment and shearing force for cases mentioned above (for angular acceleration case, use equation 9.17)

h) calculate reactions in supports A & B, for unit force acting on the horizontal tail P_{ZH}=1kN, using formulas:

$$R_B = \frac{P_{ZH}(x_A - x_H)}{x_B - x_A} \quad , \quad R_A = -P_{ZH} - R_B \qquad (9.20)$$

i) make a diagram of bending moment and shearing force for (P_{ZH}=1kN).

Final calculations of the fuselage loads require estimation of critical values of load factor (n), angular acceleration value and forces acting on the horizontal tail as well. Maximum load factor value should correspond with airworthiness regulation. The total load should be calculated using equations 9.11-9.12. The final result should include diagrams of the total bending moment and shearing force and values of reaction in supports as well.

References

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5. R. Cymerkiewicz „Budowa samolotów", WKiŁ, Warszawa 1982