Aircraft Design I
Fuselage loads

What are the sources of the loads acting on the fuselage

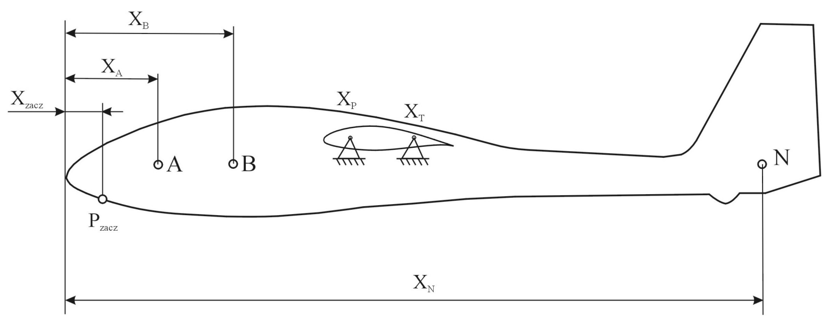
- the forces (reactions) from other elements joined with the fuselage – tail, landing gear, payload, equipment,
- aerodynamic loads – pressure distribution – important for high speed aircrafts (Ma>0.5) or for lifting fuselages,
- fuselage mass in acceleration field,
- difference of pressure between inner and outer space – only for fuselages with pressurization,
- propulsion units and other force installations, e.g. to tow sailplane behind the aircraft

Types of loads
(load models)

- “vertical” bending
- “horizontal” bending
- torque

What load model is assumed?

→ statically determinate beam, fixed in main wing-fuselage joints

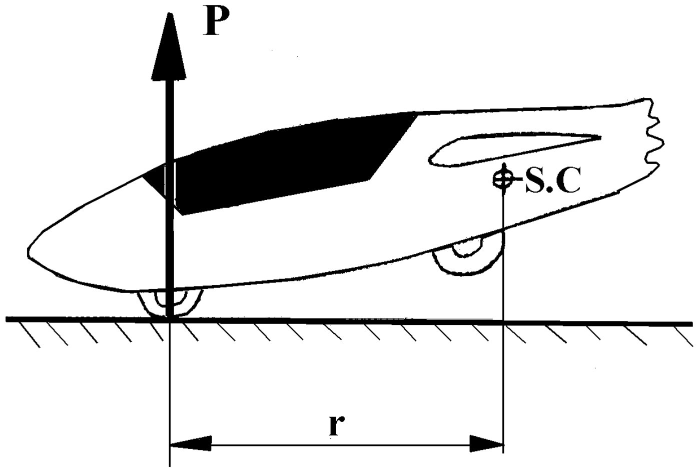


Vertical bending

"Vertical" bending

- Vertical "mass" forces due to mass elements presence A, B.......N depend on linear acceleration action on these masses
- Load factor n = 1 in steady level flight or n ≠ 1 in unsteady flight
- Load factor gives linear acceleration : $a_{ni} = n\,g$
- Linear acceleration is constant longwise the fuselage length

"Vertical" bending

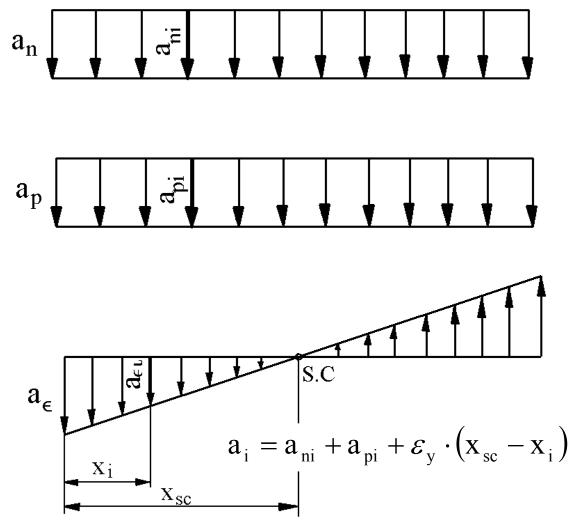


External force from nose wheel

"Vertical" bending

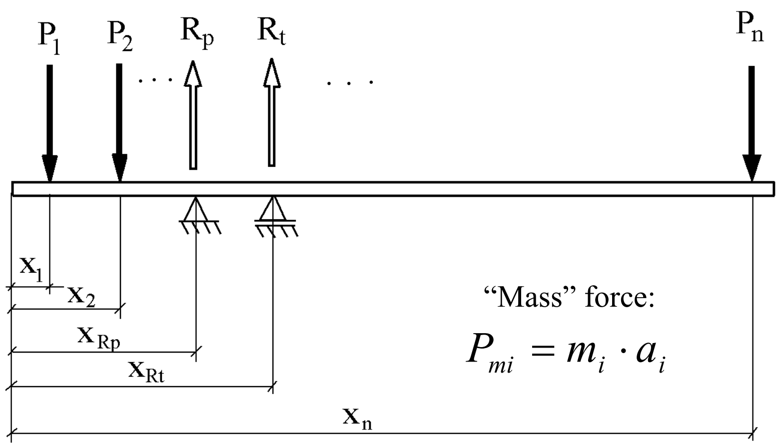
- external load acts with respect to gravity center and gives the linear and angular acceleration
- linear acceleration is constant longwise the fuselage and equal to: $a_{pi} = P/m$
- angular acceleration is equal to: $\varepsilon_y = M / J_y = P\,r / J_y$
- angular acceleration induces the linear acceleration, that varies in linear way versus distance to the gravity center: $a_{\varepsilon i} = \varepsilon_y\,(x_{SC}-x_i)$

"Vertical" bending



Accelerations versus fuselage length

The fuselage beam scheme



Load components

Reactions are derived from equilibrium condition:

equation of moments of forces:

$$\sum_{i=1}^{i=n} P_i \cdot x_i + R_p \cdot x_{Rp} + R_t \cdot x_{Rt} = 0$$

equation of forces:

$$\sum_{i=1}^{i=n} P_i + R_p + R_t$$

Load components

- shearing force

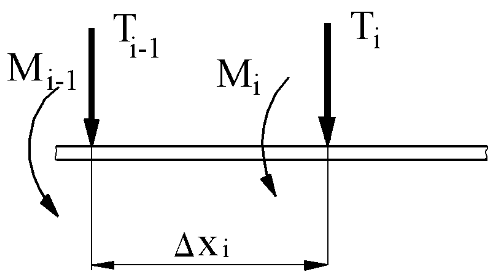
$$T_j = \sum_{i=1}^{i=j} P_i$$

- bending moment

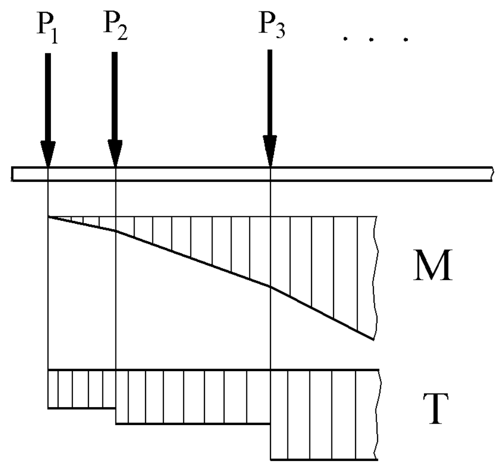
$$M_j = \sum_{i=1}^{i=j} \Delta M_i$$

- where:

$$\Delta M_i = T_{i-1} \cdot \Delta x_i$$

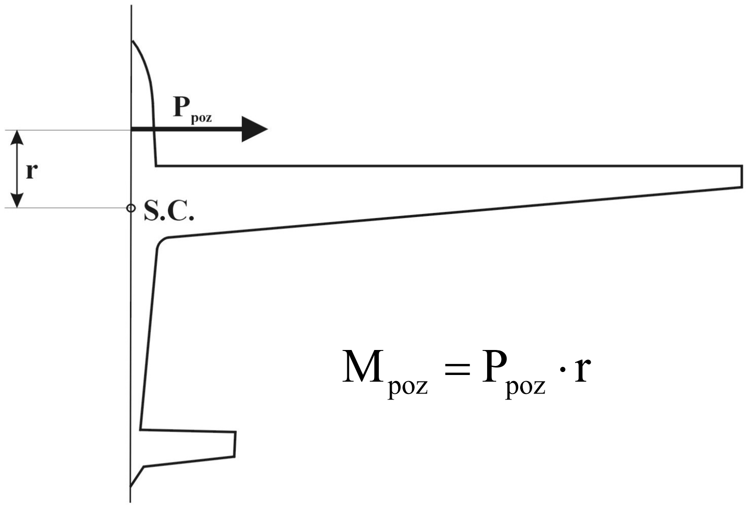


Load components



bending moment and shearing force versus fuselage length

Lateral loads



$$M_{poz} = P_{poz} \cdot r$$

"Horizontal" bending

„Horizontal" linear acceleration:

$$a_{bp} = \frac{P_{poz}}{m}$$

is constant versus fuselage length.

Moment „M_{poz}" is the source of angular acceleration:

$$\varepsilon_z = \frac{M_{poz}}{I_z}$$

where „I_z" is the inertia moment of the aircraft with respect to vertical axis „z"

"Horizontal" bending

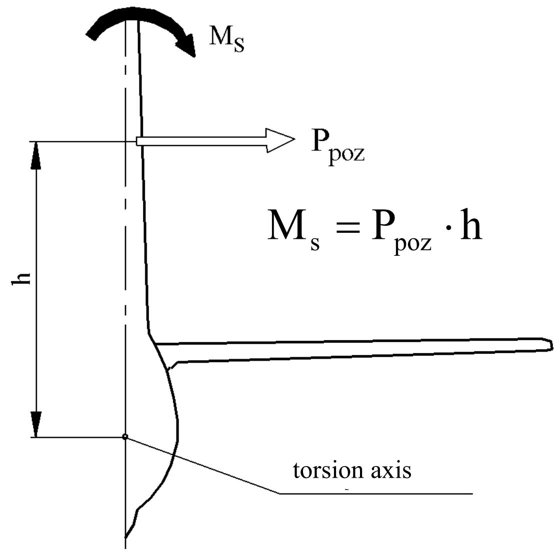
result linear acceleration acting on the mass „i"
(as in case of vertical bending) is equal to:

$$a_{bi} = a_{bp} + \varepsilon_z \cdot (x_{sc} - x_i)$$

Horizontal mass force is:

$$P_{mbi} = a_{bi} \cdot m_i$$

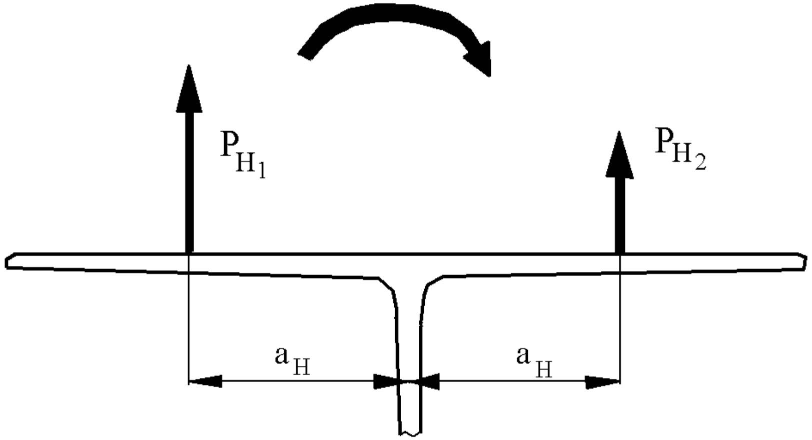
Fuselage torsion due to lateral force



$$M_s = P_{poz} \cdot h$$

Fuselage torsion due to unsymmetrical flow

$$M_s = \left(P_{H1} - P_{H2}\right)\cdot a_H$$



Computation

To size the fuselage structure we have to analyze all possible loads acting during flight and on the ground as well. The analysis of such big number of cases is very time consuming. To decrease the cost (time) of analysis we can create bending moments and shearing forces due to simply unit loads.

The loads versus *x* axis often don't give critical values for fuselage structure but allows to compute forces acting on the main wing-fuselage joints.

Loads versus *y* and *z* axes can be computed analyzing two simply cases.

Computing case

Assume, that in the plane (e.g. *x-z*) fuselage is loaded by "unit forces":

- from fuselage mass in constant acceleration field related to the load factor $n = 1$,
- from fuselage mass in acceleration field from angular acceleration ε_0 - thus the load factor is equal:

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

(generally it is easier to define the angular acceleration indirectly by the unit force acting on the horizontal tail P_{ZH0})

- aerodynamic force P_{ZH} acting on the horizontal tail

Computing case

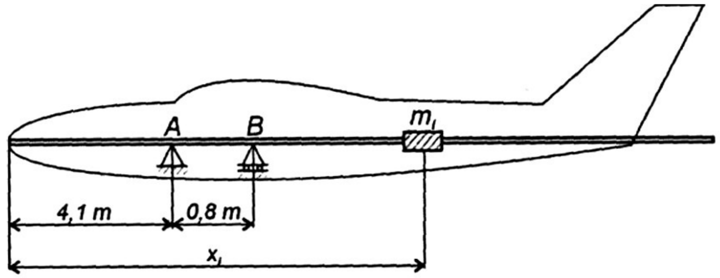
In each case the fuselage beam is in the equilibrium state (loads and reactions on the wing-fuselage joints). For cases defined before we have to create graphs of shearing forces and bending moments. Using these graphs we are able to compute current (A-A cut) shearing force and bending moment using the formulas:.

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

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

Computing case - example

For given mass breakdown and main wing-fuselage joints, create graphs of shearing force and bending moment, for the following unit loads: $n_j = 1$, $P_{Z\varepsilon j} = 1$ kN, $P_{ZHj} = 1$ kN. Assume, that: $J_y = 6223$ kg m^2



Computing case - example

Mass breakdown:

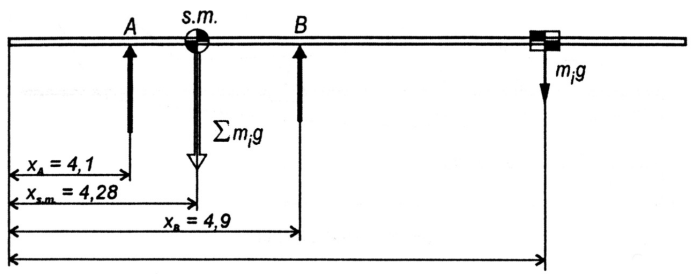
Lp.	Element	m_i [kg]	x_i [m]	$m_i x_i$	P_i[N]	$m_i x_i^2$	$m_i\ \varepsilon\ (x_i\text{-}x_{SC})$
1	Nose wheel	31	1.8	55.8	304	100.4	-66
2	steering wheel	20	2.3	46	196	105.8	-34
3	fuselage - 1st part	465	2.8	1302	4560	3645.6	-594
4	Crue seats	240	2.9	696	2354	2018.4	-286
5	engines	200	5.85	1170	1961	6844.5	271
6	fuselage 2nd part	232	6.1	1415.2	2275	8632.7	364
7	horizontal tail	25	9.5	237.5	245	2256.3	113
8	vertical tail	50	9.65	482.5	490	4656.1	232
		1263		5405	12386	28259.8	

gravity center is computed by use the formula:

$$X_{SC} = \frac{\sum_{i=1}^{n} m_i x_i}{\sum_{i=1}^{n} m_i} = 4.28 \text{ m}$$

Computing case - example

Reactions:



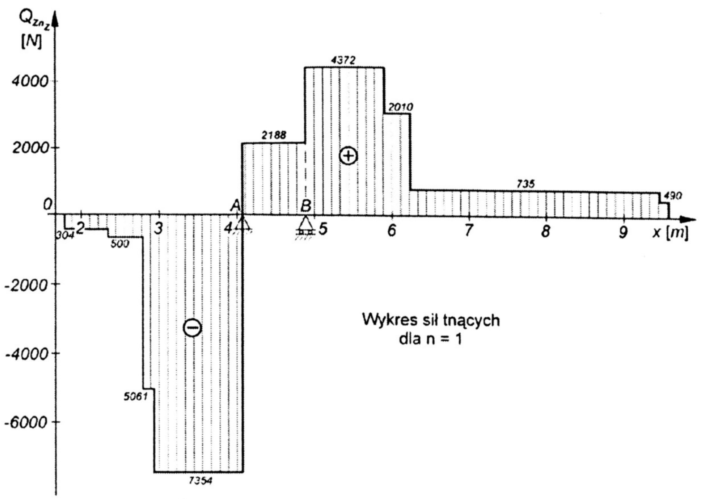
from formulas:

$$R_B = \frac{(x_{sm} - x_A)\sum m_i g}{x_A - x_B} = 2787 \text{ N}$$

$$R_A = \sum m_i g - R_B = 9603 \text{ N}$$

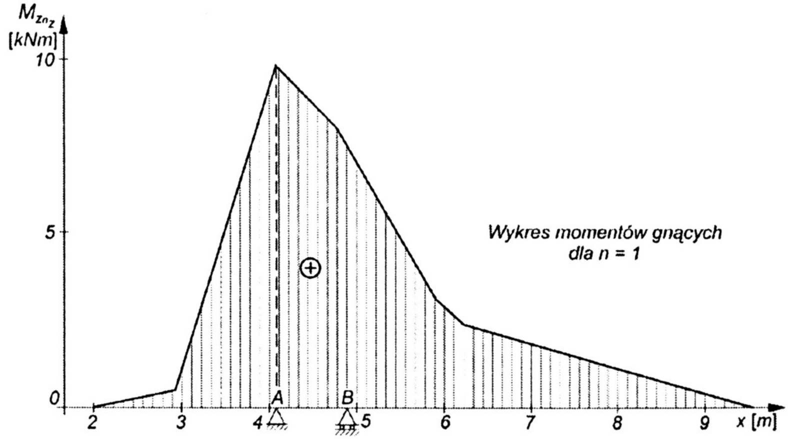
Computing case

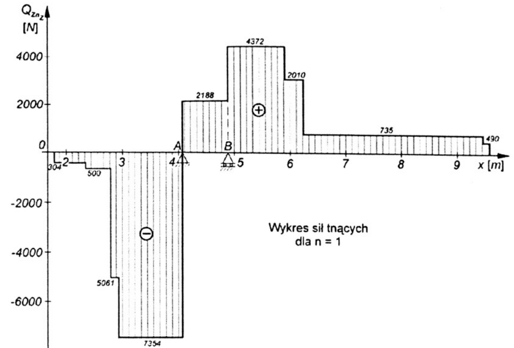
Shearing forces:

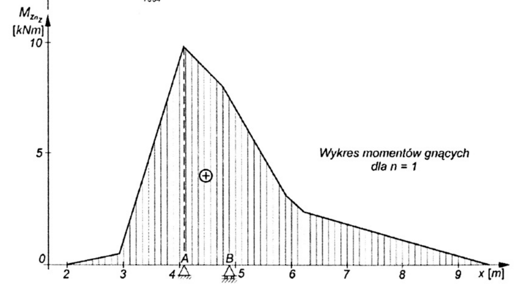


Computing case

Bending moment:



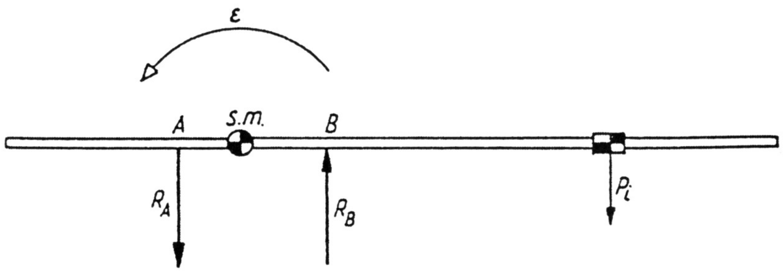




Computing case:
load factor n=1

Computing case - $P_{ZH\varepsilon} = 1\,\text{kN}$

Reactions



Loads: $$P_i = m_i \varepsilon (x_i - x_{SC})$$

Attention: Force $P_{ZH\varepsilon}$ is not load in fact – it only the source of angular acceleration

Computing case - $P_{ZH\varepsilon} = 1\,\text{kN}$

Reactions:

$$\varepsilon_j = \frac{P_{z_{H\varepsilon}} l_H}{I_{yy}} = \frac{1000 \cdot 5,37}{6223} = 0,863$$

where

$$l_H = (x_8 - x_{sc}) = 5,37\,\text{m}$$

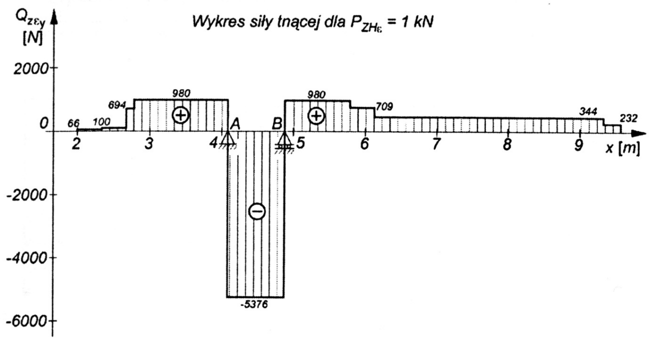
Reactions are equal to:

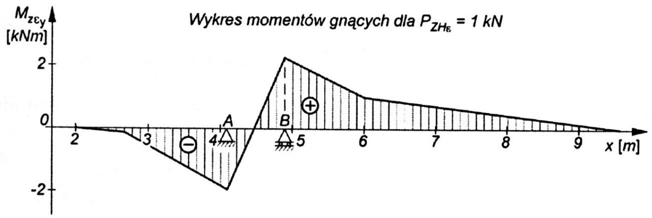
$$R_A = -R_B = \frac{\varepsilon_o I_{yykad}}{x_B - x_A} = \frac{0,863 \cdot 5892}{0,8} = 6356\,\text{N}$$

$$I_{yykad} = 1,15\left(\sum_1^8 m_i x_i^2 - x_{sm}^2 \sum_1^8 m_i\right) = 5892\ \text{kg} \cdot \text{m}^2$$

Computing case - $P_{ZH\varepsilon} = 1\,\text{kN}$

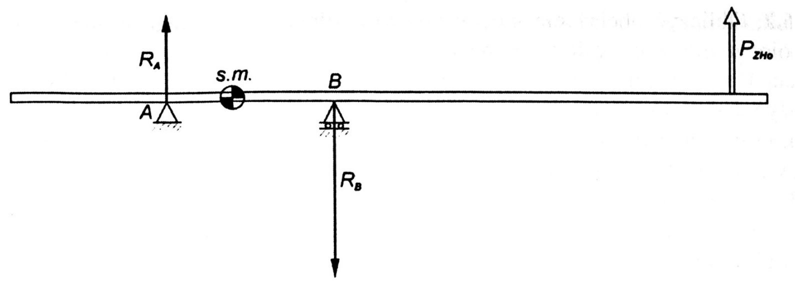
Loads components:





Computing case - $P_{ZH} = 1\,\text{kN}$

Reactions



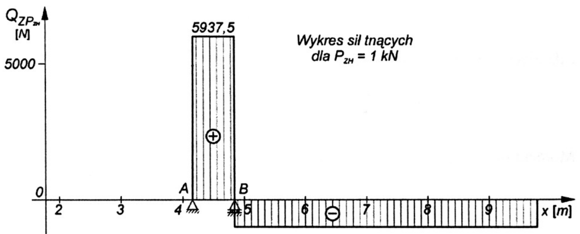
Reactions are equal to:

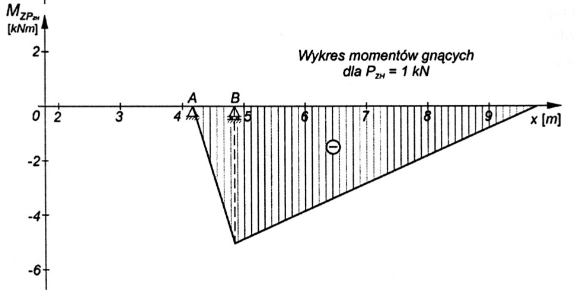
$$R_B = \frac{P_{z_{II}}(x_8 - x_A)}{x_B - x_A} = 6937{,}5\,\text{N}$$

$$R_A = 5937{,}5\,\text{N}$$

Computing case - $P_{ZH} = 1\,\text{kN}$

Load components:





Computing case

Total loads:

$$Q_{A-A} = Q_{Anj}\frac{n}{n_j} + Q_{A\varepsilon j}\frac{P_{z_{II\varepsilon}}}{P_{z_{II\varepsilon j}}} + Q_{AHj}\frac{P_{z_{II}}}{P_{z_{IIj}}}$$

$$M_{A-A} = M_{Anj}\frac{n}{n_j} + M_{A\varepsilon j}\frac{P_{z_{II\varepsilon}}}{P_{z_{II\varepsilon j}}} + M_{AHj}\frac{P_{z_{II}}}{P_{z_{IIj}}}$$

where:

- $Q_{A\text{-}A}$ i $M_{A\text{-}A}$ – total shearing force and bending moment in A-A cut,
- Q_{Anj}, $Q_{A\varepsilon j}$, Q_{AHj} – values of shearing force for unit loads, for cases defined before in A-A cut,
- M_{Anj}, $M_{A\varepsilon j}$, M_{AHj} - values of bending moment for unit loads, for cases defined before in A-A cut,
- n, $P_{ZH\varepsilon}$, P_{ZH} – real loads.

Fuselage loads – final remarks

- The loads computed longwise x axis could be used only to size the main joints. To size the fuselage structure we have to know the scheme of fuselage structure, also type of engine joints if it is mounted on the fuselage, type of landing gear joints, etc.
- Today aircrafts have often the pressurized cabins, what causes additional loads, which could be critical in fact; problem is complicated by discontinuity of the fuselage structure (windows, doors, etc.)