Aircraft Design I
Landing gear loads

The role of landing gear

The main goal of landing gear is to allow taxing on the ground and to absorb energy during landing. The knowledge of the loads, that is present during such maneuvers allows to size the landing gear structure.

All cases which could occur during normal exploitation and during emergency procedures are described in the regulations

Energy

- The energy, which must be absorbed by landing gear is the sum of kinetic energy due to vertical speed (descend) and potential energy:

$$E = \frac{mw^2}{2} + (mg - P_z)h$$

where:
E – energy of an aircraft due to vertical motion,
w – vertical component of aircraft's speed (descend),
h – the change of high of the CG from touchdown to max. deflection of shock absorbers

Energy

- The energy should be lesser (or equal at least) than work of absorbers, that could be written as follows:

$$L = Z(ih_a\eta_a + h_p\eta_p)$$

where
L – work of absorbers,
Z – max vertical force acting on the landing gear,
h_a – absorber travel,
i – absorbing ratio – CG travel / absorber travel,
η_a – damping coefficient of absorber(defined later),
h_p – tire travel,
η_p – damping coefficient of tire

Energy

- Assumption – absorbing work is performed by main gear, thus max. load acting on the main gear during landing is equal to:

$$Z = \frac{E}{ih_a\eta_a + h_p\eta_p} = \frac{\frac{mw^2}{2} + (mg - P_z)h}{ih_a\eta_a + h_p\eta_p}$$

To apply this formula we have to know max. acceptable descend value *w* and lift force P_z during touchdown.

Energy

Descend starts when:

Pz – mg < 0

(mg - Pz) is the force acting on the aircraft in vertical direction (downward). Due to too small lift force, vertical acceleration is present.

If we use two contradictory assumptions:

- lift force is equal to weight,
- lift force is equal to zero,

it is obvious, that real force is between these values – what regulations say about this?

CS-23.473 e

(e) Wing lift not exceeding two-thirds of the weight of the aeroplane may be assumed to exist throughout the landing impact and to act through the centre of gravity. The ground reaction load factor may be equal to the inertia load factor minus the ratio of the above assumed wing lift to the aeroplane weight.

(f) If energy absorption tests are made to determine the limit load factor corresponding to the required limit descent velocities, these tests must be made under CS 23.723 (a).

CS 23.723

CS 23.723 Shock absorption tests

(a) It must be shown that the limit load factors selected for design in accordance with CS 23.473 for take-off and landing weights, respectively, will not be exceeded. This must be shown by energy absorption tests except that analysis based on tests conducted on a landing gear system with identical energy absorption characteristics may be used for increases in previously approved take-off and landing weights.

(b) The landing gear may not fail, but may yield, in a test showing its reserve energy absorption capacity, simulating a descent velocity of 1·2 times the limit descent velocity, assuming wing lift equal to the weight of the aeroplane.

Load factor

The next step is to compute load factor increment during landing, which can be defined as follows:

$$\Delta n_L = \frac{Z}{m_L g}$$

if we consider, that before touchdown:

$$n_0 = \frac{P_Z}{m_L g}$$

we obtain load factor during landing:

$$n = \Delta n_L + n_0 = \frac{Z + P_Z}{m_L g}$$

Load factor

Horizontal force is defined as:

$$X = Z\mu$$

where μ - friction coefficient.

Load factor longwise ***x-x*** can be derived as follows:

$$n_x = \frac{X}{mg} = \frac{Z}{mg}\mu = \Delta n_L \mu$$

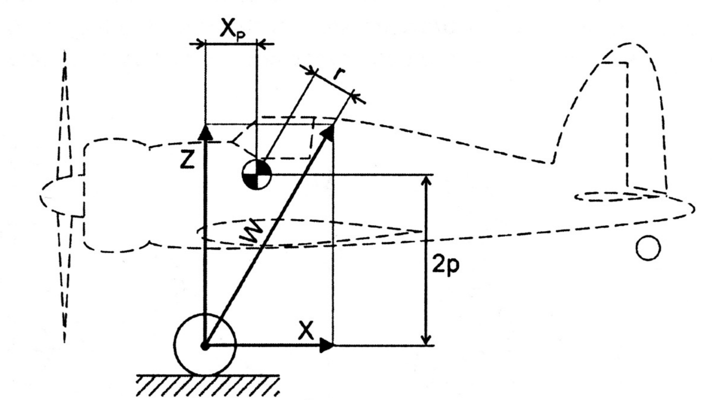
or:

$$n_x = \frac{Z}{mg}\mu = \frac{ma}{mg}\mu = \frac{\mu a}{g}$$

where a – vertical acceleration of an aircraft CG due to Z force.

Load factor

In computation we assume, that force X acts on wheel axis (excluding case, when brakes are active). The moment of force is equal to $X\frac{d}{2} = M_k = I_{kk}\varepsilon_k$ - thus needs to start wheel rotation before landing.



Load factor

Resultant force of Z and X usually gives moment, which can be defined as:

$$M = Wr = r\sqrt{Z^2 + X^2}$$

or more simply as:

$$M = Zx_p + Xz_p$$

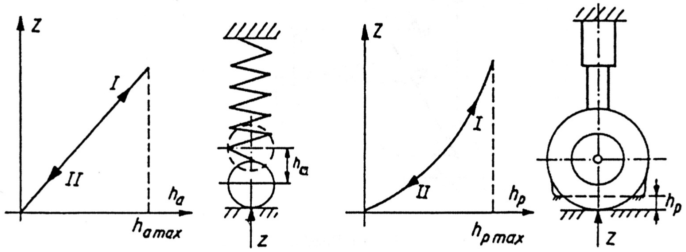
Moment causes angular acceleration:

$$\varepsilon = \frac{M}{I_{yy}}$$

when the value ε is known, load factor due this acceleration can be derived as function of distance x from CG

$$n_\varepsilon = \frac{\varepsilon x}{g}$$

Shock absorbers



The landing gear is loaded during on the ground taxing according to the dynamics rules. Landing gear has spring elements. Ideal spring is not able to absorb the energy. The hysteresis filed is almost equal to zero and after deflection spring brings back all absorbed energy. Such absorbers will cause, that not acceptable jumps will occur. The work of the spring is $L = Zh_a/2$ – it is the area below the spring characteristics.

Shock absorbers

We need high absorbing work, with as small deflections and vertical reactions Z as possible. We should increase the area below absorbing characteristic. The ideal absorber should give constant force, independent on it's deflection. This couldn't be acceptable during taxing on the not ideal runway.

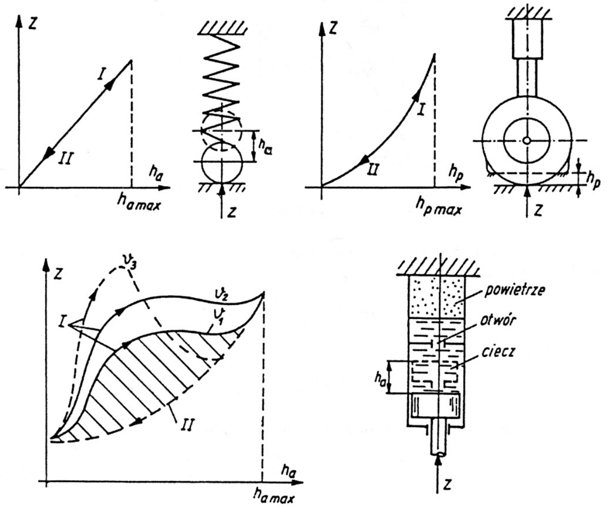
Then the work is equal to: $(Z \times h_a)$.

The ratio of the energy absorbed by real absorber to work of ideal absorber we call damping coefficient of absorber η_a.

It is the ratio of area below absorber characteristics to are af rectangle $Z \times h_a$. This coefficient is equal to $\eta_a = 0,5$ for spring; $\eta_a \cong 0,45$ for tire.

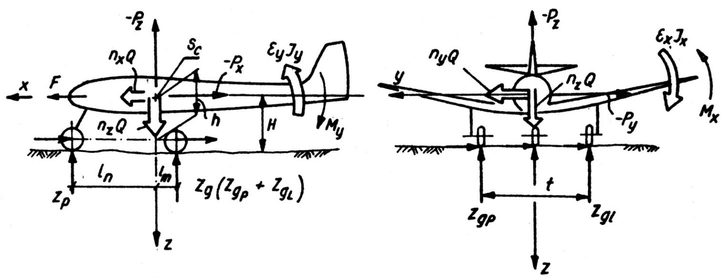
The hydro-pneumatic absorber has $\eta_a = 0,8$

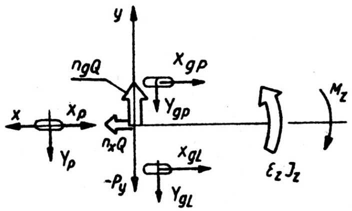
Shock absorbers



Absorbing characteristics: a – spring absorber, b - tire,
c – hydro-pneumatic absorber; I - load, II – load relief.
V1 < V2 < V3, V3 too fast motion of absorber (rapid increase of Z reaction, decrease of η_a). dashed area – really absorbed energy

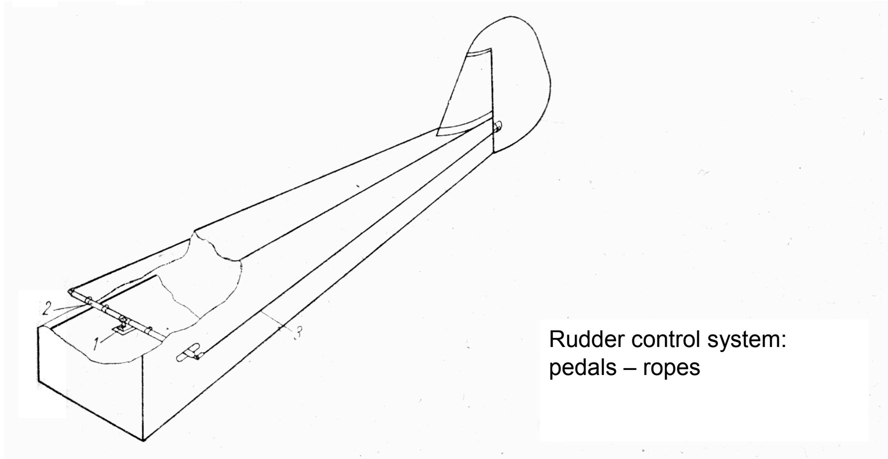
Typical forces system





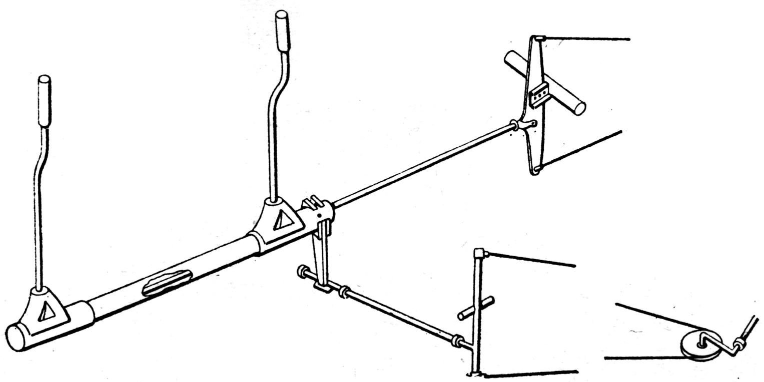
Control system loads

Control systems



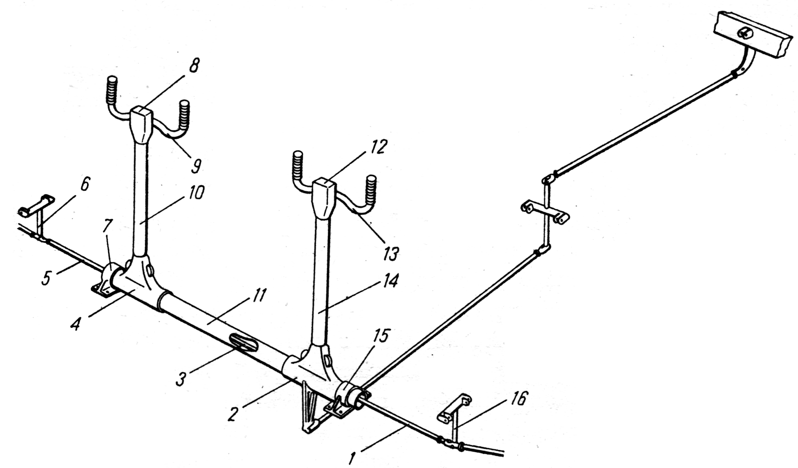
Rudder control system:
pedals – ropes

Control systems



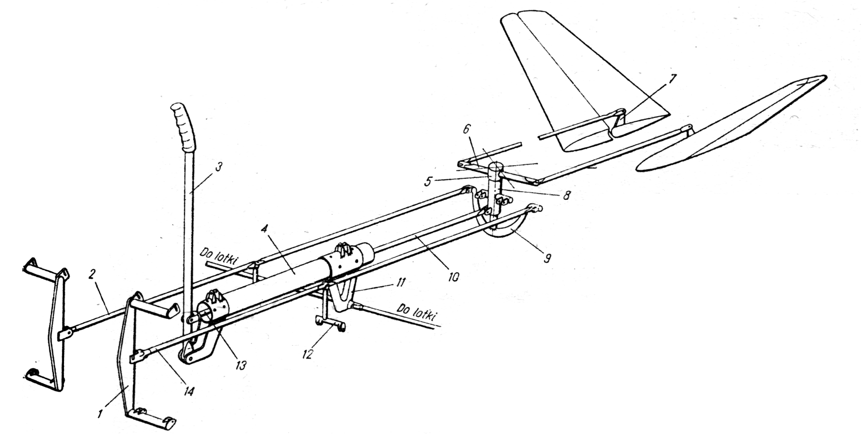
twin stick system

Control systems



twin wheel system

Control systems



v-tail control system

Main elements

- pulleys
- pushrods
  (struts and tensile rods)
- cables

The main sources of loads

- Pilot effort
- Autopilot
- hinge moments of control surfaces

CS 23.395 Control system loads

(a) Each flight control system and its supporting structure must be designed for loads corresponding to at least 125% of the computed hinge moments of the movable control surface in the conditions prescribed in CS 23.391 to 23.459. In addition, the following apply:

(1) The system limit loads need not exceed the higher of the loads that can be produced by the pilot and automatic devices operating the controls. However, autopilot forces need not be added to pilot forces. The system must be designed for the maximum effort of the pilot or autopilot, whichever is higher. In addition, if the pilot and the autopilot act in opposition, the part of the system between them may be designed for the maximum effort of the one that imposes the lesser load. Pilot forces used for design need not exceed the maximum forces prescribed in CS 23.397 (b).

(2) The design must, in any case, provide a rugged system for service use, considering jamming, ground gusts, taxying downwind, control inertia and friction. Compliance with this sub-paragraph may be shown by designing for loads resulting from application of the minimum forces prescribed in CS 23.397 (b).

(b) A 125% factor on computed hinge movements must be used to design elevator, aileron and rudder systems. However, a factor as low as 1·0 may be used if hinge moments are based on accurate flight test data, the exact reduction depending upon the accuracy and reliability of the data.

(c) Pilot forces used for design are assumed to act at the appropriate control grips or pads as they would in flight and to react at the attachments of the control system to the control surface horns.

CS 23.397 Limit control forces and torques

(a) In the control surface flight loading condition, the air loads on movable surfaces and the corresponding deflections need not exceed those that would result in flight from the application of any pilot force within the ranges specified in sub-paragraph (b) . In applying this criterion, the effects of control system boost and servo-mechanisms and the effects of tabs must be considered. The automatic pilot effort must be used for design if it alone can produce higher control surface loads than the human pilot.

(b) The limit pilot forces and torques are as follows:

Control	Maximum forces or torques for design weight, weight equal to or less than 2 268 kg (5 000 lb)[1]	Minimum forces or torques [2]
Aileron:		
Stick	298 N (67 lbf)	178 N (40 lbf)
Wheel [3]	222 DNm .... (50 D in lbf)[4]	178 DNm (40 D in lbf)[4]
Elevator:		
Stick	743 N (167 lbf)	445 N (100 lbf)
Wheel (symmetrical) .	890N (200 lbf)	445 N (100 lbf)
Wheel (unsym-metrical) [5]	....	445 N (100 lbf)
Rudder..........	890N (200 lbf)	667 N (150 lbf)

CS 23.399 Dual control system

(a) Each dual control system must be designed to withstand the force of the pilots operating in opposition, using individual pilot forces not less than the greater of –

(1) 0·75 times those obtained under CS 23.395; or

(2) The minimum forces specified in CS 23.397 (b).

(b) Each dual control system must be designed to withstand the forces of the pilots applied together in the same direction, using individual pilot forces not less than 0·75 times those obtained under CS 23.395.