SOME ASPECTS REGARDING IMPACT ABSORBERS APPLIED ON AIRCRAFT LANDING GEARS

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Abstract: *This paper is devoted to presentation of impact absorbers equations applied on aircraft landing gears.The landing gear shock absorber is an integral component of an aircraft's landing gear.*
The role of the shock absorber is to absorb and dissipate energy upon impact, such that the forces imposed on the aircraft's frame are tolerable. These accelerations must be acceptable not only to structural components, but also to everything contained within the aircraft (passengers, cargo, weapons, avionics etc).Designing a shock absorber is an iterative process, as each aircraft is individual and the shock absorber must be optimized to reduce size and weight, whilst maintaining the desired performance. The following set of equations offer a general starting point for this design process. Often the design must be altered from the initial conception to find an optimum balance between performance, weight and size.

Keywords: *impact absorption, damper equations, landing gear*

1. INTRODUCTION

Designing a shock absorber is an iterative process, as each aircraft is individual and the shock absorber must be optimized to reduce size and weight, whilst maintaining the desired performance. The following set of equations offer a general starting point for this design process. Often the design must be altered from the initial conception to find an optimum balance between performance, weight and size. These equations have been derived from a basic energy analysis of an aircraft during landing.The touchdown kinetic energy or the kinetic energy in the vertical direction at touchdown can be approximated from:

$$E_t = 0.5 \cdot (W_L) \cdot (\frac{v_Z^2}{g}) \qquad (1.1)$$

Where:

E_t – touchdown kinetic energy of the aircraft
W_L – weight of the aircraft at landing
V_Z – design vertical touch rate

This equation may be further extended to include potential energy term for completeness:

$$E_t = 0.5 \cdot (W_L) \cdot (\frac{v_Z^2}{g}) + (W_L - L)(S_S + S_t) \qquad (1.2)$$

Where:

L - the lift at landing
Ss - the shock absorber stroke
St - the tyre deflection

For conservative design it is assumed that all of the energy at touchdown is absorbed by the main landing gear. The energy that can be absorbed by the shock absorber and the tyres is as follows:

$$E_{absorbed} = W_L N_g (\eta_t S_t + \eta_S S_S) \qquad (1.3)$$

Where:

Ng - The landing gear load factor (the ratio of maximum load per leg to the maximum static load)

$\bullet_t$ - tyre efficiency

$\bullet_S$ - shock absorber efficiency

It is assumed that by definition: $W_L = n_S P_m$

As: n_S - number of main gear struts

P_m - the maximum static load per main gear

$$E_{absorbed} = n_S P_m N_g (\eta_t S_t + \eta_S S_S) \qquad (1.4)$$

Thus shock absorber energy can be equated to the touch down energy, Et:

$$\begin{aligned} &n_S P_m N_g (\eta_t S_t + \eta_S S_S) = \\ &0.5 \cdot (W_L) \cdot (\frac{v_Z^2}{g}) + (W_L - L)(S + S_t) \end{aligned} \qquad (1.5)$$

Design touchdown rates can be found in Section 1.2.1. Some rough values of efficiencies and landing gear load factors can be approximated from Sections 1.2.2 and 1.2.3. By using these values the required stroke length of the shock absorber can be determined. If we assume that the potential energy term is negligible, if the lift generated is approximately equal to the weight of the aircraft during landing, then the stroke length is determined by:

$$S_S = \left[\left\{ \frac{0.5 \cdot (W_L) \cdot (\frac{v_Z^2}{g})}{n_s P_m N_g} \right\} - \eta_t S_t \right] \Big/ \eta_S \qquad (1.6)$$

This above equation can further be simplified as $W_L = n_S P_m$ by definition:

$$S_S = \left[\left\{ \frac{v_Z^2}{2 g N_g} \right\} - \eta_t S_t \right] \Big/ \eta_S \qquad (1.7)$$

Note that the shock absorber stroke length does not depend on the aircraft's weight, but only on its vertical sink speed, load gear factor, the tyre parameters, and overall shock absorber efficiency [2]. For design length an inch is added to this length as an additional safety margin.

$$S_{S\_design} = S_S + 1/12\,ft \qquad (1.8)$$

The diameter of the shock absorber strut can be estimated from:

$$d_s = 0.041 + 0.0025\ P_m^{0.5} \qquad (1.9)$$

(in feet, where P_m is in pounds)

This analysis is only valid for telescopic strut or similar shock absorbers where the shock absorber stroke is equal to that of the wheel stroke.

For articulating and semi articulating configurations an independent analysis must be under taken to incorporate the relationship between stroke length and wheel travel [5].

1.2.1 Design touchdown rates

Table 1

	Design touchdown rates
FAR 23*	$4.4(W/S)_L^{0.25}$ fps
FAR 25	12 fps
USAF	10 fps
USN	10 fps for transports
	17 fps for other non-carrier based airplanes
	22 fps for carrier based airplanes

*no less than 7 fps and more than 10 fps

1.2.2 Gear load factors

Table 2

Aircraft type	N_{gear}
Large bomber	2.0-3.0
Commercial	2.7-3.0
General aviation	3.0
Air Force fighter	3.0-4.0
Navy fighter	5.0-6.0

1.2.3 Shock Absorber Efficiency

Table 3

Type	Efficiency, •
Steel leaf spring	0.50
Steel coil spring	0.62
Air spring	0.45
Rubber block	0.60
Rubber bungee	0.58
Oleo-pneumatic:	
-Fixed orifice	0.65-0.80
-Metered orifice	0.75-0.90
Tyre	0.47

1.2.4 Drop test Equations

To test a given landing gear a drop test is conducted. Each landing gear must pass this test in order to meet safety regulations, and demonstrate its reserve energy absorption capacity. The vertical kinetic energy can be calculated from the aircrafts sink speed and its weight and is given by equation 1.1.

The drop test on the landing gear is conducted with the same mass. At a given height the potential energy is given by:

$$E \quad = W_L H \qquad (1.10)$$

If we equate the potential energy of the drop test (Eq. 1.10) to the vertical kinetic energy of the aircraft (Eq. 1.1) then we get:

$$0.5 \cdot (W_L) \cdot (\frac{v_Z^2}{g}) = W_L H \qquad (1.11)$$

$$\therefore H = \frac{v_Z^2}{2g} \qquad (1.12)$$

For a given sink speed the drop test height can be calculated accordingly.For a sink speed: V_Z = 12 fps = 3.6m/s.Equivalent drop test height:

$$H = \frac{3.6^2}{2 \times 9.81} = 0.66m$$

2 CASE STUDIES

We made some case studies with an estimation of the stroke length for Cessna 177RG , Airbus A310 and MiG29 Fulcrum.

The calculus for each model was made using Eq. 1.7, shock absorber stroke:

$$S_S = \left[\left\{ {0.5\left(\frac{v_Z^2}{g}\right)} \Big/ {N_g} \right\} - \eta_t S_t \right] \Big/ \eta_S$$

The assumptions for each case are:

- All energy at landing is absorbed by shock absorber
- Lift at landing is equal to weight of aircraft
- Acceleration due to gravity, g = 9.81 m/s2
- Tyre deflection is negligible (data is unavailable)

2.1 Cessna 177RG

The Cessna 177RG is a general aviation aircraft that is primarily operated by private individuals and organizations.

The aircraft may carry 4 persons (including 1 crew), utilizes a high wing configuration, and is powered by a single engine. The maximum takeoff weight of the Cessna 177RG is 1100 kg.

Figure 1: *Cessna 177RG*

The main landing gear of the Cessna 177RG consists of a simple, solid spring landing gear (refer Fig. 1), in addition to a single wheel. Although such a system is cost effective and therefore appropriate for general aviation aircraft, it offers relatively poor shock performance. Apart from tyre scrubbing that results from lateral motion of the landing gear, the solid spring landing gear offers no shock absorption. The result is an aircraft that tends to bounce, similar to a car with poor shock absorbers.

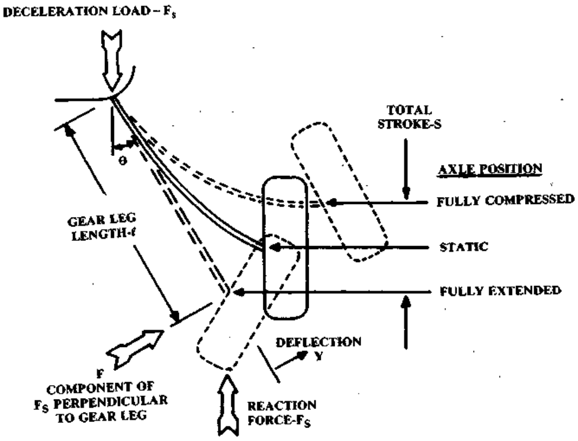

Figure 2: *Solid spring shock absorber with deflection*

Unlike the main landing gear system, the nose landing gear implements a telescopic, oleo-pneumatic shock absorber.

A more effective shock absorber is implemented, as it must support the Cessna 177RG engine.

In contrast to the main landing gear, this landing gear offers superior shock absorption. Note that in comparison to the oleo-pneumatic struts used on the Airbus A310, the nose landing gear shock absorber of the Cessna 177RG is much smaller. This is due to the relatively low mass and design touchdown rate of the aircraft.

2.1.1 Stroke Calculation

An estimation of the Cessna 177RG stroke length may be provided using Equation 1.7 and the assumptions mentioned:

Data

Design touchdown rate, V_Z = 10fps = 3.6576 m/s (FAR 23) (Section 1.2.1)
Gear load factor, Ng = 3.0 (Section 1.2.2)
Shock absorber efficiency, $\bullet_s$ = 0.50 (Section 1.2.3)

Results $S_S = 0.22021\text{m} = 8.66968 + 1\text{in} \approx 9.7\text{ in}$

2.2 Airbus A310

Figure 3: *Airbus 310*

The Airbus A310 is a medium range, transcontinental airliner. The maximum takeoff weight of a Airbus A310 is as much as 141,974 kg

The landing gear of the Airbus A310 is comprised of a retractable tricycle configuration.

The main landing gears (refer Figure 4), located underneath each wing, consist of dual tandem wheel layouts.

Multiple tyres not only disperse the load and therefore pressure within each tyre, but also increase shock absorption and protect the surface of the runway.

Each of the main landing gears consist of a side brace and drag brace for lateral and longitudinal loads (respectively), and a telescopic, oleo-pneumatic shock absorber for vertical loads.

This shock absorber has a relatively high stroke distance, due to the high aircraft weight, and the importance of energy dissipation for commercial aircraft.

The nose landing gear of the Airbus A310 consists of a twin wheel layout, at the end of a telescopic landing gear.

In comparison to the main landing gear, the nose landing gear contains fewer wheels and a smaller oleo-pneumatic shock absorber, due to the relatively small loads induced to the forward landing gear.

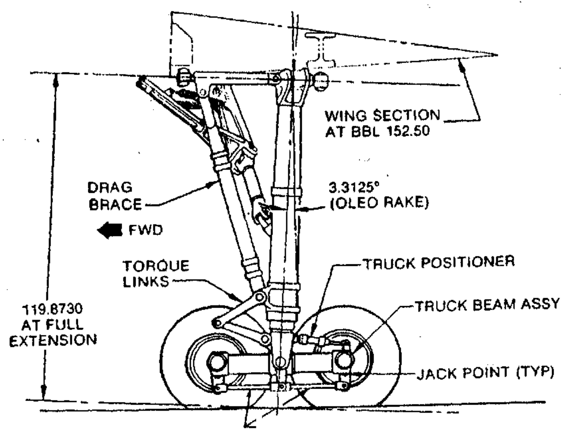

Figure 4: A310 main landing gear

2.2.1 Stroke Calculation

An estimation of the A 310 stroke length may be provided using Equation 1.7 and the assumptions mentioned:

Data

Design touchdown rate, V_Z = 12 fps = 3.6576 m/s (FAR 25) (Section 1.2.1)
Gear load factor, Ng = 2.85 (Section 1.2.2)
Shock absorber efficiency, $\bullet_s$ = 0.75 (Section 1.2.3)

Results $S_S = 10.189\,960\,63\,\text{in} + 1\,\text{in} \approx 11.2\,\text{in}$

2.3 MIG-29 Fulcrum

***Figure 5:** MiG 29 Fulcrum*

The MIG-29 FULCRUM is a supersonic, twin-engine, bomber and tactical reconnaissance aircraft. Its maximum takeoff weight is 16,750kg.

The MIG-29 Fulcrum landing gear is composed of a retractable tricycle configuration.

As illustrated in Figure 5 above, the relative size of the landing gear system is considerably larger in comparison with the Cessna 177RG.

This is a result of the large design vertical velocities of carrier based aircraft (refer Section 1.2.1).

Each main landing gear of the MIG-29 FULCRUM consists of a retractable, OLEO pneumatic shock absorber attached to a single wheel.

This system is implemented for its high efficiency, which is required for high vertical velocity landings.

Similarly to the main landing gear, the MIG-29 FULCRUM nose landing gear consists of a telescopic OLEO pneumatic shock absorber, however in a twin wheel arrangement.

***Figure 4:** MiG29 main landing gear*

2.3.1 Stroke Calculation

An estimation of the MiG 29 Fulcrum stroke length may be provided using Equation 1.7 and the assumptions mentioned:

Data

Design touchdown rate, V_Z = 22 fps = 6.7056 m/s (Section 1.2.1)
Gear load factor, Ng = 5.5 (Section 1.2.2)
Shock absorber efficiency, $\bullet_s$ = 0.75
(oleo pneumatic) (Section 1.2.3)

Results $S_S = 12.586141\text{in} + 1\text{in} \approx 13.6\,\text{in}$

3. DISCUTION

The outcome of the stroke length calculations for the Cessna 177RG, A 310, and MiG 29 Fulcrum are summarised in Table 4 below:

Table 4

Aircraft	Shock Absorber Stroke, S_S (inches)
Cessna 177RG	9.7
A 310	11.2
MiG 29	13.6

As expected, the shock absorber stroke length of the Cessna 177RG is the smallest stroke estimation of the three aircraft.

Although the main landing gear is relatively inefficient, the effect that the lower design speed has on decreasing the stroke length is of greater significance.

The stroke length of the Airbus 310 is in-between that of the Cessna 177RG and Mig 29 Fulcrum.

This result is due to the low design vertical speed in comparison to the Mig 29 Fulcrum, and the high speed relative to the Cessna.

The stroke length of the Mig 29 Fulcrum exceeds that of the Cessna 177RG and Airbus 310 by a significant margin.

This can be explained by the large design vertical velocity that such aircraft landing gears must tolerate upon landing.

Note that the above discussion does not indicate any relationship between the shock absorber stroke length and the weight of the aircraft.

Although this variable is critical in landing gear design, it simply 'cancels' in the energy analysis of aircraft at landing (refer Section 1.2).

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