PRELIMINARY DESIGN OF AIRCRAFT SHOCK ABSORBER

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Abstract—Landing gear is the structural element which takes all the loads when the aircraft manoeuvre on ground and take-off and landing. 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 as heat upon impact, such that the forces imposed on the aircraft's frame are tolerable. The shock absorber may be an independent element or integrated with the landing gear strut. The aircraft may tend to land in a smooth manner or even in a rough manner; the landing gear components must be able to withstand the entire force.

IndexTerms – Shock Absorber, Landing Gear, Design, Aircraft etc.

I. INTRODUCTION

Landing gear is the structural element which takes all the loads when the aircraft manoeuvre on ground and take-off and landing. The main functions of the landing gear are energy absorption at landing, braking, steering and withstand taxing, manoeuvring load. Without the landing gear, this energy would not be dissipated and would impact the airframe, damaging it with time. The purpose of the landing gear is to provide the suspension during taxiing, take-off and landing. It is designed to absorb and dissipate the kinetic energy of the landing impact, therefore reducing the impact loads transmitted to the airframes and the structures of the aircraft. The landing gear also facilitates braking system using a wheel braking and also provides directional control. Steering of the aircraft on the ground is by using the nose wheel steering system. The landing gear are often retracted to minimize the aerodynamic drag on the aircraft during flight. The landing gear system includes:

- Shock absorber
- Extension or retraction mechanism
- Brakes
- Wheel
- Tires
- Links and braces

II. METHODOLOGY

Methodology deals with the systematic representation of the methods used in the design or an analysis. The paper deals with encompasses the theoretical calculation for the preliminary design. It also includes a consideration of concepts and theories which underlie these methods**.**

2.1 PRELIMINARY DESIGN

As the name implies, in the preliminary design phase, the parameters that are determined are not final and will be altered later. In addition, in this phase, parameters are essential and will directly influence the entire detail design phase. Therefore the ultimate care must be taken to insure the accuracy of the results of the preliminary design phase. The preliminary design phase is performed to Estimate aircraft maximum take-off weight

2.2 MAXIMUM TAKE-OFF WEIGHT ESTIMATION

The general technique to estimate the maximum take-off weight is as follows: the aircraft weight is broken into several parts. Some parts are determined based on statistics, but some are calculated from performance equations.

Maximum take-off weight (W_{TO}) is broken into four elements [1]

- Payload weight (W_{PL})
- Crew weight (W_C)
- Fuel weight (W_F)
- Empty weight (W_E)

$$W_{TO} = W_{PL} + W_C + W_F + W_E \qquad (1)$$

The payload weight and crew weight are almost known and determined from the given data and are not depending on the aircraft take-off weight. On the other hand, the empty weight and fuel weight are both functions of the maximum take-off weight. Hence, to simplify the calculation, both the fuel weight and empty weight are expressed as fractions of the maximum take-off weight. Hence: $W_{TO} = W_{PL} + W_C + \left(\frac{W_F}{W_{TO}}\right) W_{TO} + \left(\frac{W_E}{W_{TO}}\right) W_{TO}$

Thus:

$$W_{TO} = \frac{W_{PL} + W_C}{1 - \left(\frac{W_F}{W_{TO}}\right) - \left(\frac{W_E}{W_{TO}}\right)} \qquad (2)$$

Problem statement:

To design a conventional civil transport aircraft that can carry 120 passengers plus their luggage. The aircraft must be able to fly with a cruise speed of Mach number 0.8, and have a range of 6500 km. The aircraft is equipped with two high bypass ratio turbofan engines and is cruising at 35,000 ft altitude.

Solution:-

Stage 1: *The aircraft is stated to be civil transport and to carry 120 passengers. Hence, the aircraft must follow FAR Part 25. Therefore, all selections must be based on Federal Aviation Regulations. The regular mission profile for this aircraft consists of taxi and take-off, climb, cruise, descent, and landing.*

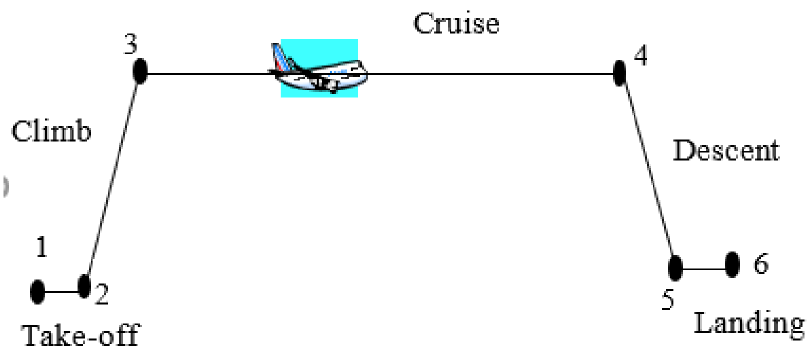

Fig. 2.1. Mission profile for the transport aircraft [1]

Stage 2: *Weight of flight crew and attendants*

The number of flight attendants is regulated by FAR Part 125, Section 125.269: For airplanes having more than 100 passengers, two flight attendants plus one additional flight attendant for each unit of 50 passengers above 100 passengers.

Since there are 120 passengers, number of flight attendants must be 3.

Flight crew members are assumed to have a weight of 200 lbs. On the other hand, flight attendant's weight is 140 lb be allocated for a flight attendant whose sex in unknown. Thus, the total weight of flight crew members and flight attendants is:

$200 + 200 + (3 \times 140) => W_C = 820\, lb$

Stage 3: *The weight of payloads*

The payload for a passenger aircraft primarily includes passengers and their luggage and baggage. Passengers could be a combination of adult males, adult females, children, and infants. FAA has regulated that passenger weight should be considered in maximum case that is 180lb

$(120 \times 180) + (120 \times 100) => W_{PL} = 33{,}600\, lb$

Stage 4: *Fuel weight ratios for the segments of taxi, take-off, climb, descent, approach and landing*

Using Table 3.2 and the numbering system shown in Fig. 3.1, we will have the following fuel weight ratios:

Taxi, take-off: $\frac{W_2}{W_1} = 0.98$

Climb: $\frac{W_3}{W_1} = 0.97$

Descent: $\frac{W_5}{W_4} = 0.99$

Approach and landing: $\frac{W_6}{W_5} = 0.997$

Stage 5: *Fuel weight ratio for the segment of range*

The aircraft has jet (turbofan) engine, so equation 3.7 must be employed. In this flight mission, cruise is the third phase of flight.

$$\frac{W_4}{W_3} = e^{\frac{-RC}{0.866V(L/D)max}}$$

Where range (R) is 9500 km, C is 0.4 lb/hr/lb or 0.4/3600 1/sec, and (L/D)max is. The aircraft speed (V) would be the Mach number times the speed of sound [1].

$$V = M \times a = 0.8 \times 296.6 = 237.3 \frac{m}{sec} \Longrightarrow 778.5 \frac{ft}{sec}$$

Where the speed of sound at 35,000ft altitude is 296.6 m/sec. Thus,

$$\frac{W_4}{W_3} = e^{\frac{-65{,}00{,}000 \times 3.28 \times \frac{0.4}{3600}}{0.866 \times 778.5 \times 17}} \Longrightarrow e^{-0.207}$$

$$\therefore \frac{W_4}{W_3} = 0.813$$

Stage 6: *Overall fuel weight ratio*

By using equation

$$\frac{W_6}{W_1} = \frac{W_2}{W_1} \times \frac{W_3}{W_2} \times \frac{W_4}{W_3} \times \frac{W_5}{W_4} \times \frac{W_6}{W_5} = 0.98 \times 0.97 \times 0.813 \times 0.99 \times 0.997 = 0.763$$

Substituting the value in equation 3.6

$$\frac{W_F}{W_{TO}} = 1.05\left(1 - \frac{W_6}{W_1}\right) = 1.05(1 - 0.763) = 0.249$$

Stage 7: *Substitution*

Substituting the values in equation 3.3

$$W_{TO} = \frac{W_{PL} + W_C}{1 - \left(\frac{W_F}{W_{TO}}\right) - \left(\frac{W_E}{W_{TO}}\right)} = \frac{33{,}600 + 820}{1 - 0.249 - \left(\frac{W_E}{W_{TO}}\right)} = \frac{34{,}420}{0.751 - \left(\frac{W_E}{W_{TO}}\right)}$$

Stage 8: *empty weight ratio*

The empty weight ratio is established by using equation 3.8,

$$a = -7.754 \times 10^{-8}\,, b = 0.576$$

Thus:

$$\frac{W_E}{W_{TO}} = aW_{TO} + b \Longrightarrow \frac{W_E}{W_{TO}} = -7.754 \times 10^{-8} W_{TO} + 0.576$$

Step 9: *Solve the equation analytically*

Table 1 Trial and error technique to determine maximum take-off weight of the aircraft

Iteration	Step 1	Step 2	Step 3
	Guess W_{TO} (lb)	Substitute W_{TO} of Step 1 into the equation $\frac{W_E}{W_{TO}} = -7.754 \times 10^{-8} W_{TO} + 0.576$	Substitute W_E/W_{TO} of Step 2 into the second equation: $W_{TO} = \frac{34{,}420}{0.751 - \left(\frac{W_E}{W_{TO}}\right)}$
1	1,00,000	0.5682	1,88,340 lb
2	1,88,340	0.5759	1,96,685 lb
3	1,96,685	0.5607	1,80,918 lb
4	1,80,918	0.5619	1,82,088 lb
5	1,82,088	0.5618	1,82,001 lb
6	1,82,001	0.5618	1,82,008 lb

Thus, the aircraft maximum take-off weight is:

$$\boldsymbol{W_{TO} = 1{,}82{,}008\ lb = 82{,}557\ kgs}$$

III. RESULTS AND DISCUSSION

The calculations were made to estimate the maximum take-off weight of an aircraft depending upon the number of pilots and crew, fuel, and payloads (passengers, loads, luggage, and cargo). According to the methodology specified in the previous chapter, the following results can be obtained to design the shock strut.

3.1 WHEEL LOADING

The first step in calculating the load on the wheel is to calculate the design aircraft landing weight. For a transport-type aircraft the landing load factor varies from 0.7 to 1.5 of the calculated aircraft weight.

Aircraft weight = 1,82,008 lb

∴ Design aircraft weight = 1.5 × 1,82,008 = 2,73,012 lb

Weight on nose landing gear is taken as 12% of W_{TO}

NLG = 32761 lb

Weight on main landing gear is taken as 88% of W_{TO}

MLG= 2,40,250 lb

Since there are two main landing gears, load on each is 2,40,250/2

Therefore, load on each main landing gear strut = 1,20,125 lb

According to the configuration selected, each MLG will have two tires. Therefore, load on each tire is 60,062.5 lb.

Therefore, tire selected is the Michelin Air Bias type VII + Type III 50 x 20.0 – 20 (data taken from Michelin Tire Data Hand Book) [2].

where,

50 = Maximum diameter when fully inflated, i.e., 50 inches

20.0 = Width of the tire when fully loaded i.e., 20 inches

20 = Rim diameter i.e., 20 inches

3.2 STRUT PISTON DIAMETER:-

Strut is pressurised with nitrogen at 1500 psi, hence the piston area is given by

Area $= \frac{Load\ on\ the\ strut}{pressure} = \frac{1{,}20{,}125}{1500} = 80.08\ inch$

Diameter of the piston is given by,

Area of piston $= \frac{\pi d^2}{4}$

Then, diameter d = $\sqrt{\frac{A \times 4}{\pi}} = \sqrt{\frac{80.08 \times 4}{\pi}} = 10.1\ inch \cong 26\ cm$

3.3 PISTON STROKE:-

The touchdown kinetic energy or the kinetic energy in the vertical direction at touchdown can be approximated from the equation,

$$E_{total} = \frac{WV^2}{2g} + (W - L)(S_S + S_t)$$

where W is the aircraft weight, V is the sink speed, g is the gravitational acceleration, L is the wing lift, and St is the tire deflection, SS is shock absorber stroke. The kinetic energy capacity of the shock absorber and tire must be equal to the total energy [3].

Thus, $E_{total} = \eta_S S_S NW + \eta_t S_t NW$

where η_S and η_t are the shock absorber and tire absorber efficiency factors, respectively. It is generally assumed to be 0.8 and the latter 0.47 for an oleo-pneumatic strut [19]. N is the landing gear load factor.

$$\therefore \eta_S S_S NW + \eta_t S_t NW = \frac{WV^2}{2g} + (W - L)(S_S + S_t)$$

if we assume that the potential energy term is negligible and if the lift generated is approximately equal to the weight of the aircraft during landing, then the stroke length is determined by[3],

$$S_S = \left[\frac{V^2}{2gN} - \eta_t S_t\right] / \eta_S$$

Static load radius SLR $= \frac{D_m}{2} - deflection\% \times \left(\frac{D_m - D_F}{2}\right)$

$$= \frac{49.5}{2} - 31\% \times \left(\frac{49.5 - 20}{2}\right) = 24.75 - 0.31 \times \left(\frac{29.5}{2}\right) = 20.17\ inch$$

Then, $S_t = 25 - 20.17 = 4.83\ inch$

$\therefore S_S = \left[\frac{100}{2 \times 32 \times 3} - 0.47 \times \frac{4.83}{12}\right] / 0.8 = 0.418\ ft = 5.016\ inch$

To maintain an adequate safety margin, an extra one inch of stroke is usually added to the calculated stroke.

Therefore, $S = S_S + 1 = 6.016\ inch$

The displacement volume of the shock absorber strut is given by,

$D = S \times A$= $481.76\ inch^3$

3.4 STROKE VOLUME:-

The volume of the gas and oil in the shock strut is considered as the stroke volume. Standard notation for shock strut volume is used where V_1 to denotes the fully extended position, V_2 to denotes the static position, and V_3 to denotes the compressed position. Generally, the fully extended position is when there is on load acting on the strut, static position is during taxiing and the compressed position is when the aircraft touches down during the landing. To maintain an tolerable safety margin during heavy or semi-crash landing, shock absorbers are designed such that the piston is not fully bottomed even at the compressed position. The safety margin of 10% of the displacement is maintained. The static position is about 16 percent of the total stroke [4].

First, the strut-compressed case is considered.

The piston is not fully bottomed at the compressed position, i.e., $V_3 \neq 0$. The reserve air volume of 10% of the displacement is maintained.

$V_3 = 10\% \times 481.76 = 48.176\ inch^3$

Thus, the volume when the strut is fully extended is given by,

$$V_1 = V_3 + d \quad (3)$$

$\therefore V_1 = 48.176 + 481.76 = 529.96\ inch^3$

Static position is the16% of the total stroke volume V_1

$V_2 = 16\%\ of\ V_1$= $84.79\ inch^3$

3.5 PRESSURE:-

The pressure inside the shock absorber cylinder during extended and static positions are defined by the isothermal compression equation,

$$P_1V_1 = P_xV_x = constant \quad (4)$$

From the stroke (S) the pressure during isothermal compression is calculated,

$$i.e., P_x = \frac{P_1V_1}{V_x} = \frac{P_1V_1}{V_1 - xA}$$

The pressure at stroke (S) calculated using the above equation, where P_1=375 psi, x is the stroke V_1 is the fully extended volume and A is area of the piston.

$$P_s = \frac{375 \times 529.96}{529.96 - (5.016 \times 80.08)} = 1549.25\ psi$$

Therefore, the isothermal pressure of the gas is approximately 1500 psi during extended and static positions.

The pressure inside the shock absorber cylinder during compressed position is expressed by the polytropic equation,

$$P_2{V_2}^n = P_x{V_x}^n = constant \quad (5)$$

$$\therefore P_x = P_2\left[\frac{V_2}{V_x}\right]^n = P_2\left[\frac{V_2}{V_2 - xA}\right]^n$$

where n is constant and is given as 1.35 or 1.1 [3], this is used when the gas and oil are separated and they are mixed during compression. The pressure inside the cylinder should be maintained less than 6,000 psi to prevent seal leakage during the compression.

$$P_x = 1500 \times \left[\frac{84.79}{84.79 - (x \times 80.08)}\right]^{1.35}$$

When,

$x = 0.6'' \Rightarrow P_x = 4638\, psi$

$\boldsymbol{x = 0.68'' \Rightarrow P_x = 6007\, psi}$

Therefore, the piston can be displaced upto a maximum of 0.68 inch from the static position.

3.6 STRUT WALL THICKNESS:-

The assumed material of the strut is Maraging steel with an yield strength of 1800 MPa for a maximum pressure to be handled of 6000 psi.
The thickness of the strut is given by,

$$Thickness = \frac{max.pressure \times diameter\ of\ piston}{2 \times yield\ strength} = 3.94\, mm$$

IV. CONCLUSION

In this work the preliminary design of a 120-seater passenger aircraft. All the parameters like weight, fuselage length, wing area, fuel, etc, are calculated. These calculations are based on preliminary design of aircraft and they need to be iterated again and again as the data of the aircraft gets frozen.

When shocks occur caused by hard landings and by taxiing over rough surfaces they are absorbed efficiently by oleo-pneumatic shock absorbers and tyres. Thus, the most effective type of shock absorber system is oleo-pneumatic shock strut.

The future holds many new developments in landing gear shock absorbers, as we strive towards an endless pursuit of performance. There are many innovative energy absorption principles capable of shock absorption in aircraft landing gear.

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