Chapter 5 Shock Absorber Design

5.1. Introduction

The basic function of the shock absorber is to absorb and dissipate the impact kinetic energy to the extent that accelerations imposed upon the airframe are reduced to a tolerable level [2 and 20]. Existing shock absorbers can be divided into two classes based on the type of the spring being used: those using a solid spring made of steel or rubber and those using a fluid spring with gas or oil, or a mixture of the two that is generally referred to as oleo-pneumatic. The high gear and weight efficiencies associated with the oleo-pneumatic shock absorber make it the preferred design for commercial transports [2].

Based on the analysis procedure as outlined in this chapter, algorithms were developed to determine the required stroke and piston length to meet the given design conditions, as well as the energy absorption capacity of the shock absorber.

5.2. Oleo-Pneumatic Shock Strut Design

The basic weight support function of the oleo-pneumatic shock struts, which have a high efficiency under dynamic conditions both in terms of energy absorption and dissipation, is provided by a compressed cylinder of air and oil. A single-acting shock absorber, which is the most commonly used design for commercial transports, is shown in Fig. 5.1. This type of shock strut absorbs energy by first forcing a chamber of oil against a chamber of dry air or nitrogen and then compressing the gas and oil. During the compression process, the oil and gas either remain separated or are mixed depending on the type of design. After the initial impact, energy is dissipated as the air pressure forces the oil back into its chamber through recoil orifices.

Although the compression orifice could be merely a hole in the orifice plate, most designs have a metering pin extending through it, and by varying the pin diameter the orifice area is varied. This variation is adjusted so that the strut load is fairly constant under dynamic loading. If this can be made constant, the gear efficiency would be 100 percent. In practice, this is never obtained and efficiencies of 80 to 90 percent are more usual [4]. Since only the efficiency factor is of interest in the conceptual design phase, no additional discussion on the design of the metering pin will be provided.

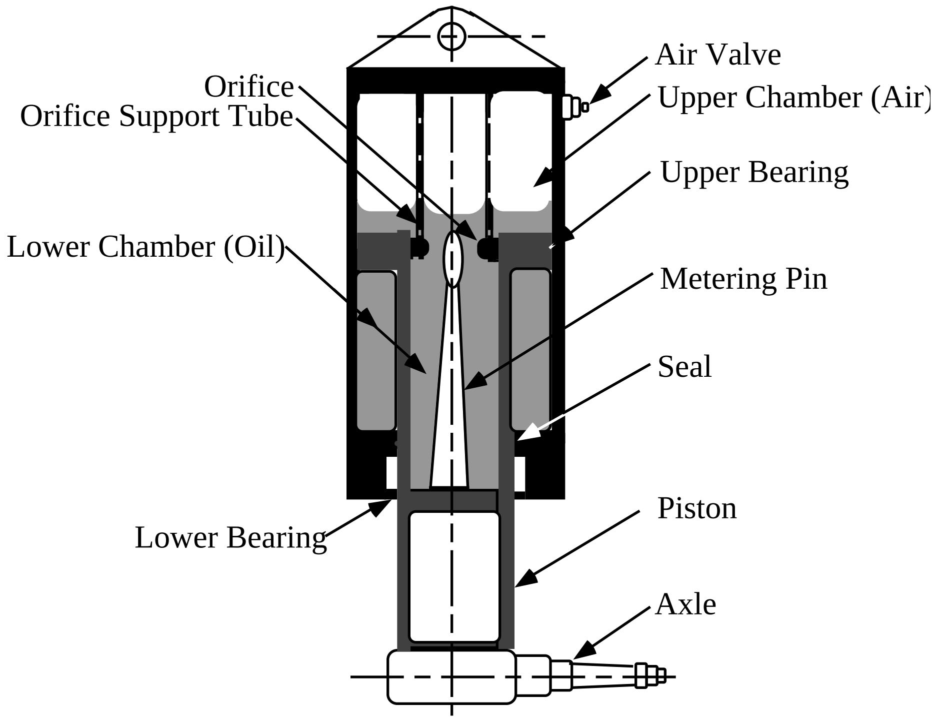

Figure 5.1 Single-acting shock absorber, after [4], with no attribution

5.2.1. Stroke Calculation

The first step in calculating the stroke (S) is to select the design reaction factor (N), sometimes called the landing load factor. This factor should not be confused with the aircraft load factor, which results from maneuvers or atmospheric disturbances. For a transport-type aircraft the landing load factor varies from 0.7 to 1.5, with 1.2 being the most widely used value [2].

Sink speed (V_s) is usually legislated by the procuring authority and/or the regulations pertaining to a particular category of aircraft. The FAA requires that a transport-type aircraft be able to withstand the shock of landing at 10 ft/s at the design landing weight and 6 ft/s at maximum gross weight [19]. In practice, sink speeds of this magnitude rarely occur due to ground effects and flare-out of the aircraft prior to touchdown.

The total energy (E) of the aircraft at the instant of touchdown, which consists of kinetic and potential energy, is approximated using the expression [2, p. 35]

$$E = \frac{WV^2}{2g} + (W - L)(S + S_t) \tag{5.1}$$

where W is the aircraft weight, V is the sink speed, g is the gravitational acceleration, L is the wing lift, and S_t is the tire deflection. S is shock absorber stroke, which is the value we are trying to find. Given that the kinetic energy capacity of the shock absorber and tire must be equal to the total energy, Eq. (5.1) becomes [2, p. 35]

$$\eta_s SNW + \eta_t S_t NW = \frac{WV^2}{2g} + (W - L)(S + S_t) \tag{5.2}$$

where η_s and η_t are the shock absorber and tire absorber efficiency factors, respectively. The former is generally assumed to be 0.47 and the latter 0.8 for an oleo-pneumatic strut [2]. To maintain an adequate safety margin, an extra one inch of stroke is usually added to the calculated stroke.

5.2.2. Compression Ratios

Compression ratios are the ratios of the pressure under one condition divided by the pressure under another condition, *e.g.*, fully compressed to static. Two compression ratios are normally considered: static to fully extended and fully compressed to static. For transport-type aircraft, where floor height variation is important, a ratio of 4:1 for the static to extended case and 3:1 for the compressed to static case would be satisfactory [2]. Assuming a static pressure (P_2) of 1,500 psi, which enables standard compressors to be used for servicing and provides enough margin to allow for aircraft growth, pressures at the extended (P_1) and compressed (P_3) positions are calculated using the compression ratios given above. Note that the piston area (A), and subsequently the displacement volume (d), are both a function of the static pressure, that is

$$A = \frac{F}{P_2} \tag{5.3}$$

and

$$d = SA \tag{5.4}$$

where F is the maximum static load per strut.

5.2.3. The Load-stroke Curve

The energy absorbed by the strut during its stroke is obtained by integrating the area beneath the load-stroke curve, which relates the magnitude of the applied ground loads to the stroke traversed. Standard notation for shock strut sizing uses the subscript *1* to denote the fully extended position, *2* to denote the static position, and *3* to denote the compressed position. To accommodate excess energy produced in a heavy or semi-crash landing, shock absorbers are designed such that the piston is not fully bottomed even at the compressed position, *i.e.*, $V_3 \neq 0$. The reserve air volume, which is assumed to be 10 percent of the displacement [2], allows the shock strut at a predetermined load to move through extra travel, absorbing the excess energy by the work done. Hence, the air volume at the fully-extended position is approximated as [2, p. 100]

$$V_1 = V_3 + d \tag{5.5}$$

Pressures between the extended and static positions are defined by the isothermal compression curve, which is representative of normal ground handling activity [2, p. 100]

$$P_1 V_1 = P_x V_x = const \tag{5.6}$$

Given the relationships of Eqs (5.4) and (5.5), the pressure at stroke *X* is obtained using the expression [2, p. 100]

$$P_x = \frac{P_1 V_1}{V_x} = \frac{P_1 (V_3 + d)}{V_1 - XA} \qquad S_{extend} < X < S_{static} \tag{5.7}$$

Pressures obtained using Eq. (5.7) are then multiplied by the piston area to arrive at the design loads as shown on the load-stroke curve.

A polytropic, *i.e.*, real-gas, compression curve should be considered for pressures between the static and compressed positions. It is representative of dynamic compression cases such as landing impact and bump traversal and is based upon PV^n being constant [2], hence

$$P_x = P_2 \left(\frac{V_2}{V_1 - XA} \right)^n \qquad S_{static} < X < S_{compress} \tag{5.8}$$

The constant n can either be 1.35 or 1.1; the former is used when the gas and oil are separated and the latter when they are mixed during compression. The distance from the static to the fully compressed position is largely a matter of choice. Statistical data indicate that transport-type aircraft typically have further compression beyond the static position of about 16 percent [2] of the total stroke, a figure which tends to give a hard ride while taxiing. However, with the static position being so far up the load-stroke curve, where a large amount of energy is absorbed with a relatively small stroke travel, aircraft weight variations do not result in substantial gear deflections. That is, the built-in margin minimizes the need of redesigning the baseline shock strut for uses on future growth versions of the aircraft. Again, the pressures obtained using Eq. (5.9) are multiplied by the piston area to arrive at the design loads. At this point the values of P_1 and P_3 should be checked to ensure that the former is greater than 60 psi to avoid sticking due to friction between the piston and the cylinder wall, while the latter is less than 6,000 psi to prevent seal leakage [2].

5.2.4. Internal Cylinder Length

As specified by MIL-L-8552, the distance between the outer ends of the bearings shall be not less than 2.75 times the internal cylinder/piston outside diameter (*D*). Thus the minimum piston length is given by [2, p. 111]

$$L_{pist} = S + 2.75D \tag{5.9}$$

where

$$D = \sqrt{\frac{4A}{\pi}} \tag{5.10}$$

5.2.5. Sample Calculation

The load-stroke curve of a notional single-acting shock absorber is generated for illustrative purposes. Based on the design requirements as stated in Table 5.1, Eq. (5.3) gives a piston cross-sectional area of 33.3 in^2, while Eq. (5.4) places the total displacement at 666.7 in^3. Using the 16 percent extension figure, the static position at which the gas law switches from isothermal to polytropic gas law is estimated to be 3.2 inches from the fully compressed position, *i.e.*, X at 16.8 inches. Loads corresponding to isothermal and polytropic compression were determined using Eqs (5.7) and (5.8), respectively, and presented in Table 5.2. The corresponding load-stroke curves are shown in Fig. 5.2.

Table 5.1 Shock absorber sizing parameters

Parameter	**Design value**
Total stroke	20.0 in
Static position	16 percent of total stroke
Static load	50,000 lb
Static pressure	1,500 lb
Compression ratio	4:1 static to extended
	3:1 compressed to static

Table 5.2 Calculations of isothermal and polytropic compression

***X*, in.**	***V*, in^3**	**P_{iso}, psi**	**P_{poly}, psi**	**P_{comb}, psi**	**F_{comb}, lb**
0.0	727.3	375.0	375.0	375.0	12500.0
2.0	660.6	412.8	427.0	412.8	13760.0
4.0	593.9	459.2	493.0	459.2	15306.7
6.0	527.3	517.2	578.9	517.2	17240.0
8.0	460.6	592.1	694.8	592.1	19736.7
10.0	393.9	692.4	858.2	692.4	23080.0
12.0	327.3	833.3	1102.0	833.3	27776.7
14.0	260.6	1046.5	1498.9	1046.5	34883.3
16.0	193.9	1406.5	2234.2	1406.5	46883.3
16.8	167.3	1630.2	2726.6	1630.2	54340.0
18.0	127.3	2142.5	3943.0	2214.6	73820.0
20.0	60.6	4500.6	10740.1	5645.3	188176.7

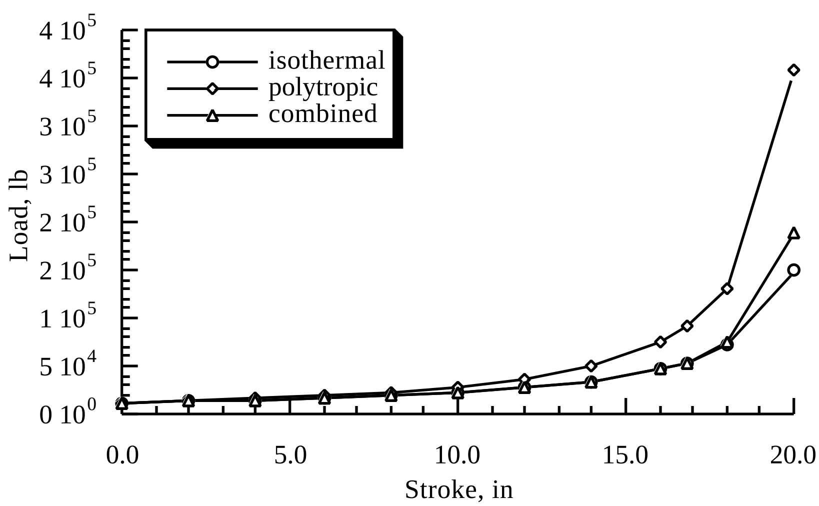

Figure 5.2 The load-stroke curve