

EFFECT OF CABIN PRESSURE ON CLIMB AND DESCENT RATES

1. NOTATION AND UNITS*

		<i>SI</i>	<i>British</i>
g	acceleration due to gravity	m/s ²	ft/s ²
g_0	standard sea level value of g	m/s ²	ft/s ²
H	geopotential height*	m	ft
p	atmospheric pressure	N/m ²	lbf/in ²
p_c	pressure in cabin	N/m ²	lbf/in ²
t	time	min	min
Δp_c	maximum cabin pressure differential, $(p_c - p)$	N/m ²	lbf/in ²
ρ	air density	kg/m ³	slug/ft ³

2. INTRODUCTION

Climb and descent profiles are dependent on a number of factors. For military aircraft these are the aerodynamic and structural limitations of the design together with a requirement for optimisation of some parameter, such as time-to-height or range (see References 4 to 6). With civil aircraft (and some military aircraft) selection of climb and descent profiles has, in addition, to give consideration to such aspects of passenger comfort as cabin inclination and rate of change of cabin air pressure.

This Data Item discusses the ways in which cabin pressure affects the climb and descent.

3. DISCUSSION

3.1 Cabin Pressure

The maximum cabin pressure differential (*i.e.* the difference between the air pressure within the cabin and the atmospheric pressure) is governed by the capability of the air conditioning and pressurisation system, the strength of the fuselage structure, and the maximum operating altitude[†] of the aircraft.

3.1.1 Civil aircraft

Cabin altitudes corresponding to various levels of pressure differential are shown in Figure 1, together with the cabin altitude resulting from maximum pressure differential at maximum operating altitude for a number of civil aircraft (mostly turboprop and turbofan powered business aircraft and airliners). It will be seen that maximum cabin altitude is normally between 6000 ft and 12000 ft; for most civil transport aircraft it is no

* This Data Item is written in terms of the International Standard Atmosphere in which geopotential height and pressure height are identical. Data Item No. 77022 (Reference 2) gives the relationship between geopotential height and pressure height for off-standard atmospheres.

† The term "altitude" is used to mean "pressure height".

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greater than 8000 ft.

A typical airliner might have a structure and system designed for a maximum pressure differential of 8.3 lbf/in² (57.2 kN/m²). This would provide a cabin altitude of 8000 ft when the aircraft is flying at 41 000 ft. It would also allow sea level conditions to be maintained up to an altitude of 21 000 ft.

3.1.2 Military aircraft

Military aircraft may be specified* as having either a low or high differential pressure system.

A military aircraft with a *low differential pressure system* will have a structure and system designed for a maximum pressure differential not less than 4 lbf/in² (28 kN/m²). A maximum cabin altitude not exceeding 22000 ft will be maintained at some specified maximum operational altitude. Pressurisation will start at 4900 ft and maximum differential pressure will be reached at a cabin altitude of 16400 ft. Between these two altitudes the cabin pressure will vary linearly with atmospheric pressure.

For aircraft with *high differential pressure systems*, the maximum cabin differential pressure is required to be as high as possible consistent with weight and other considerations. As a minimum, it should permit a cabin altitude

no greater than 6060 ft at the maximum cruising altitude, and

no greater than 8200 ft at the service ceiling.

3.2 Rate of Change of Cabin Pressure

Excessive rate of change of cabin pressure can lead to a build up of differential pressure across the eardrums. At little more than 0.5 lbf/in² (equivalent to about 1000 ft near sea level) this differential pressure would cause pain and vertigo (see Reference 1). The ability to relieve the pressure difference by ventilating the middle ear (with such actions as yawning and swallowing) varies between individuals – extremes are represented by combat aircrew and unfit, untrained, sleeping civilians.

3.2.1 Civil aircraft

Commercial air transport caters for a wide range of individuals, including many who find difficulty in ventilating the middle ear. Limitation of the rate of change of cabin pressure is therefore a major factor in defining descent profiles for rapid descent of civil aircraft (the effect is present in the climb, to a lesser degree). It is generally accepted that passengers can, with only slight discomfort, accept rates of up to 0.16 (lbf/in²)/min[†] (1.1 (kN/m²)/min) in the descent (*i.e.* when cabin pressure is increasing) and 0.213 (lbf/in²)/min[‡] (1.47 (kN/m²)/min) in the climb (*i.e.* when cabin pressure is decreasing).

3.2.2 Military aircraft

Healthy adults (*e.g.* military aircrew), well trained in techniques of relieving the pressure difference, are capable of withstanding 50 (lbf/in²)/min (6 (kN/m²)/min) without discomfort – see Reference 1. The acceptability of rates of this order enables climbs and descents of combat aircraft with low differential pressure systems to be performed without any consideration of cabin pressure changes.

Rates of change of cabin pressure of military aircraft with high differential pressure systems are more

* Figures and definitions used for military aircraft are based on Reference 3. They may differ in some respects from other design standards.

† Equivalent to a rate of descent of 300 ft/min at sea level.

‡ Equivalent to a rate of climb of 400 ft/min at sea level. (Reference 1 quotes 500 ft/min, *i.e.* 0.267 (lbf/in²)/min (1.84 (kN/m²)/min)).

restricted (Reference 3), with a requirement that they should not exceed

- (a) 0.29 (lbf/in²)/min (2 (kN/m²)/min) for transport aircraft, and
- (b) 1.02 (lbf/in²)/min (7 (kN/m²)/min) for all other types of aircraft.

3.3 Effect on Climb and Descent Schedules

Climb and descent profiles of civil aircraft and of those military aircraft which have high differential pressure systems have to be selected so that the cabin pressure and its rate of change with time are always within the restrictions discussed in Sections 3.1 and 3.2 (and also within the capability of the air conditioning and pressurisation system).

Figure 2 shows the various factors that determine the range of pressures that are possible in the cabin at any height during the flight. Curve ABCD shows atmospheric pressure and line CG indicates pressure at the maximum cabin altitude^{*}; the pressure in the cabin will not be less than the value represented by BCG. Curve EFGH represents atmospheric pressure plus the maximum cabin differential and line BF indicates atmospheric pressure at 1500 ft[†]; the pressure in the cabin will not be greater than the value represented by BFG. The point G, at which the maximum pressure differential plus atmospheric pressure corresponds to the maximum cabin altitude, determines the maximum operating altitude for the aircraft.

In a climb starting from point B, the cabin pressure could

- (a) maintain circuit level cabin altitude as long as possible, *i.e.* follow BF to J (where the pressure differential equals that at the desired cruise altitude), then JKL (constant pressure differential) to the cruise point L,
- (b) be allowed to decrease with atmospheric pressure until maximum cabin altitude is reached, *i.e.* follow BCL, or
- (c) follow any pattern between these two extremes.

Similar options are available in the descent.

In practice, possible rates of climb are such that there is normally no problem in conforming with the limitations on maximum rate of change of cabin pressure in the climb. The essential aspect is that the climb takes long enough for the cabin pressure to decrease from the circuit level to the cabin altitude at the acceptable maximum rate.

On the other hand, possible rates of descent are such that a high speed descent has to be constrained in order to satisfy the limitations on rate of change of cabin pressure. Again, the essential aspect is that the descent takes long enough for the cabin pressure to increase from the cabin altitude to the circuit level at the acceptable maximum rate. This is shown at the top of Figure 2. If the cabin altitude is 8000 ft then the pressure difference is such that the descent time to the circuit height[‡] of 1500 ft must be at least 18.75 minutes. One simply-defined method of ensuring that the limitations are met splits the descent into two phases, as follows.

^{*} Taken as 8000 ft in this example.

[†] Circuit height; *i.e.* aircraft height above the airfield, is the starting point for climbs and the finishing point for descents. In this example the airfield is assumed to be located at sea level.