

EFFECT OF INTAKE TOTAL PRESSURE LOSS ON NET THRUST AT TAKE-OFF: TURBO-JET AND TURBO-FAN ENGINES

1. NOTATION AND UNITS^{*†}

		SI	British
C_{intake}	thrust loss factor, see Equation (4.1)		
f_N	net thrust of one engine	N	lbf
Δf_N	change in net thrust, see Equation (4.1)	N	lbf
g	acceleration due to gravity	m/s ²	ft/s ²
M	Mach number [*]		
$\dot{m}$	mass airflow [*]	kg/s	slug/s
N_F	fan or low pressure compressor rotational speed	rev/min	rev/min
p_t	total pressure [*]	N/m ²	lbf/ft ²
T_{t_4}	turbine inlet temperature	K	K
$\dot{w}$	weight airflow [†]	N/s	lbf/s

Subscripts

<i>avg</i>	denotes average value
<i>s</i>	denotes static value
0	denotes value at sea level in International Standard Atmosphere (Item Nos 68046 and 72018 give numerical values)
2, 1 2	denote engine compressor or fan face, see Sketch 1.1 in Item No. 76034

^{*} No subscript is used when considering ambient, free stream or upstream-infinity conditions.

[†] Airflow is considered here in terms of weight flow in both British and SI systems of units since the engine specific thrust, *i.e.* thrust per unit airflow, is then expressed in the same units (seconds) in both systems. Although this procedure differs from the practice of considering flow in mass units in the SI system (see, for example, Item Nos 70020–22 and 73018–19), it has been used in Item No. 76034 and is continued here because of the close association of the two Items. In either system the corresponding mass flow can of course be obtained by making the substitution $\dot{m} = \dot{w}/g$.

2. INTRODUCTION

This Item gives a method for estimating the effect of intake total pressure loss on the net thrust of turbo-jet and turbo-fan engines at take-off conditions. The Item is intended for use in initial design calculations in conjunction with the engine thrust data given in Item No. 76034 although it is also applicable to uninstalled-engine thrusts obtained from other sources. Section 3 considers the total pressure loss characteristics of typical intakes while Section 4 presents data for use in estimating the consequent reduction in net thrust. A simple example of the use of the data is given in Section 5 and further illustrations of their use are to be found in the Examples of Sections 6.1 and 6.3 of Item No. 76034.

3. INTAKE TOTAL PRESSURE LOSS

The total pressure, p_{t_2} , (or $p_{t_{12}}$) at the front face of the compressor (or fan) of an installed engine usually differs from the free-stream value, p_t , due to the effects of the intake and, in some cases, of other parts of the airframe. The intake average total pressure loss* is usually expressed as

$$1 - \left(\frac{p_{t_2}}{p_t} \right)_{avg} \quad \text{or} \quad 1 - \left(\frac{p_{t_{12}}}{p_t} \right)_{avg}, \quad \text{where} \quad \left(\frac{p_{t_2}}{p_t} \right)_{avg} \quad \text{or} \quad \left(\frac{p_{t_{12}}}{p_t} \right)_{avg} \quad \text{is the intake total pressure recovery.}$$

In Figure the curves define bands of data giving typical variations of intake total pressure recovery with free-stream Mach number, M , for the following three classes of intake:

- (i) round-lip intakes designed to give high pressure recovery and followed by a straight duct to the engine,
- (ii) round-lip intakes with a long curved duct leading to the engine and designed for subsonic applications (this class includes intakes designed to give high pressure recovery at take-off conditions and intakes designed for low external drag at high subsonic speeds),
- (iii) sharp-lip intakes (with long and/or curved ducts) designed for transonic or supersonic applications but possibly including auxiliary intakes to improve flow at low forward speeds.

Note that at static conditions and at very low forward speeds a high intake pressure recovery is associated with a relatively large intake lip radius. In each of classes (i) to (iii) it is assumed that the total intake area in the take-off configuration is matched to the engine size so as to avoid excessive total pressure losses associated with high duct Mach numbers when the engine is operating at its take-off rating. For aeroplane designs where the take-off is not critical, lower values of pressure recovery may be acceptable, especially if a simpler or lighter design results. Lower values of pressure recovery may also result if the intake incorporates a large measure of noise suppression treatment or if the angle of incidence increases by a large amount.

* A full treatment of installation effects would also consider such effects as the steady-state distortion and the turbulence level at the compressor or fan face. However, these effects are not amenable to a generalised treatment and are usually ignored at the initial design stage.

4. EFFECT OF INTAKE TOTAL PRESSURE LOSS ON NET THRUST

Within the limitations given in Section 3, and for the levels of losses shown in Figure (see Section 4.2), the following expression gives the correction, Δf_N , to be applied to engine net thrust for the effect of intake average total pressure loss.

$$\Delta f_N = f_N \left[1 - \left(\frac{p_{t_2}}{p_t} \right)_{avg} \right] C_{intake} \quad (4.1)$$

Values of the thrust loss factor, C_{intake} , are given in Figure 2 for a range of values of engine specific thrust*, $(f_N/\dot{w})_{s,0}$. If required, guidance on values of $(f_N/\dot{w})_{s,0}$ can be obtained from Item No. 76034, Section 3.1.2 and Figure 9 (but see also Section 4.1 of this Item). The curves in Figure 2 give typical values of C_{intake} for engines operating at constant turbine inlet temperature, T_{t_4} , and for engines operating at constant fan or low pressure compressor rotational speed, N_F . These data have been computed for the family of engines described in Appendix A of Item No. 76034. The shaded area in Figure 2 represents the scatter of manufacturers' data for existing engines.

4.1 Reheated Engines

The data in Figure 2 are plotted for un-reheated engines. However, for engines equipped with reheat, the same value of C_{intake} may be assumed to apply in both reheat-on and reheat-off cases. Consequently, when Figure 2 is used to estimate a value of C_{intake} for an engine with reheat-on, the curves should be read at the value of $(f_N/\dot{w})_{s,0}$ for that engine with *reheat-off*. For cases where only the value of specific thrust with reheat-on is known, an estimate of the specific thrust with reheat-off can be obtained from Item No. 76034, Section 3.1.2 and Figure 9.

4.2 Range of Applicability of Figure 2

Figure 2 gives values of C_{intake} as a function of $(f_N/\dot{w})_{s,0}$. However, in practice C_{intake} increases with increase in the intake total pressure loss. This effect is taken into account in Figure 2 in so far as the values of C_{intake} were derived for the following, typical combinations of intake total pressure loss and engine type:

Engines of relatively high bypass ratio, i.e. $(f_N/\dot{w})_{s,0}$ less than about 50 s, were assumed to sustain a nominal intake total pressure loss of one per cent and the values of C_{intake} given for these engines can be applied reliably to intakes in classes (i) and (ii) of Section 3 and Figure . However, if an engine of this type is installed with an intake having a total pressure loss of about five per cent or more, the actual thrust loss will be greater than that estimated using the data of Figure 2.

Turbo-jet engines and relatively low bypass ratio turbo-fan engines, i.e. $(f_N/\dot{w})_{s,0}$ greater than about 50 s, were assumed to sustain a nominal total pressure loss of five per cent and the values of C_{intake} given for these engines can be applied reliably to intakes in class (iii) of Section 3 and Figure . However, if an engine of this type is installed with an intake having a total pressure loss of about one per cent, the actual thrust loss will be less than that estimated using the data of Figure 2.

* Engine net thrust per unit airflow, expressed in seconds, see footnote to Section 1.