

INTRODUCTION TO THE MEASUREMENT OF THRUST IN FLIGHT. (AIR BREATHING DUCTED-FLOW ENGINES)

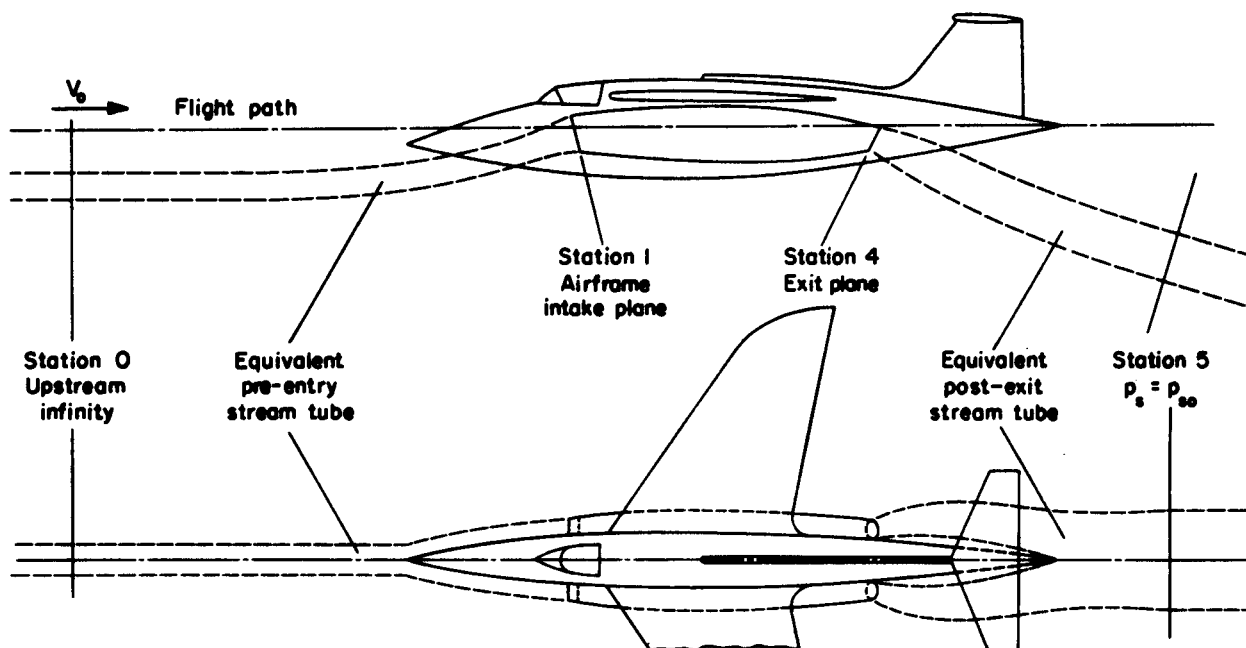
1. NOTATION AND UNITS*

		<i>SI</i>	<i>British</i>
A	cross-sectional area of equivalent internal flow stream tube (see Section 2)	m^2	ft^2
D_M	momentum drag (ram drag)	N	lbf
F_G	gross thrust	N	lbf
F_N	net thrust	N	lbf
m	mass flow	kg/s	slug/s
p_s	static pressure	N/m^2	lbf/ft^2
p_{s_0}	freestream static pressure	N/m^2	lbf/ft^2
V_0	aircraft true airspeed	m/s	ft/s
v	velocity	m/s	ft/s
ρ	density	kg/m^3	slug/ft^3
θ	engine flow direction angle relative to flight direction	rad	rad

Subscripts*

- 0, 1, 4 and 5 refer to stations indicated in Sketch 1.1
- int* and *std* refer to intrinsic and standard thrust (and drag) respectively
(see Sections 4 and 5).

* The system of subscripts, 0 to 5, denoting engine stations in this Item and in Item Nos 69007 and 69008 is not widely used elsewhere. A more widely-accepted system is defined in Reference 8 (see Sketch 1.1 in Item No. 76034) and has been applied to the subject of thrust measurement in Reference 9. While this does not affect the information given here, care should be taken to establish which convention is used in any particular application.



Sketch 1.1 DIAGRAMMATIC REPRESENTATION OF ENGINE INTERNAL FLOW

2. PRELIMINARY STATEMENT

The measurement of thrust in flight is required for two reasons:

- (i) so that, from the contributions of the engines to propulsion and to lift, the external forces on the airframe may be determined, and
- (ii) so that the actual performance of the installed engine may be compared with estimated performance.

Thrust is generally understood to be the force applied by the power plant(s) to the airframe and, in general, it has a component in both the drag and the lift directions. In the case of a conventional propeller, the greater part of the thrust is transmitted through the driving shaft but for ducted-flow engine installations (*e.g.* turbo-jet, turbo-fan and ducted propeller) it may be less obvious how the thrust is transmitted since part is applied through the mountings which attach the engine to the airframe and part by a distribution of pressure on the intake and outflow ducts and airframe.

All air breathing propulsive systems, however, operate on a common principle and the flow through them modifies the flow field surrounding – and hence the pressure distribution on – various parts of the airframe both in the immediate vicinity and well outside the immediate vicinity of the engines. The force distribution is dependent on the geometry of each particular aircraft, and conventions are necessary to define the components of the overall force. Such conventions must be applicable to any geometry. Furthermore, any conventions selected for defining the extent of the distribution of the other aerodynamic forces on the airframe must be consistent with those selected for thrust, since in steady level flight, for example, the component of thrust in the flight direction must be equal and opposite to the drag. The following discussion sets out the conventions chosen for use in this data sheet and in Item Nos. 69007 and 69008 and these conventions are in agreement with the recommendations of Aeronautical Research Council Panels (References 1 and 2).

For a ducted-flow engine the boundary between the internal and the external flows is considered to be all surfaces of the airframe and the engine and its associated ducts wetted by the internal flow, and also the surfaces enclosing the flow which will pass through or has passed through the engine. Due to turbulent mixing and entrainment such distinct surfaces cannot generally be identified in practice but it is convenient to consider these surfaces to be represented by equivalent stream tubes (see Sketch 1.1).

The first convention adopted is that thrust is defined as a force applied by the internal flow to the surfaces which bound it. All forces associated with the external flow then contribute to drag and lift. It is necessary to adopt a second convention defining the fore and aft extent of the equivalent internal flow stream tube by selecting two planes across it, one at or upstream of the duct inlet, the other at or downstream of the duct exit. Thrust quantities associated with particular positions of these planes are described in Sections 3, 4 and 5 and the relationships between them are illustrated in Table 2.1.

Having chosen the position of the planes, consideration of momentum changes through the closed surface thus obtained enables the thrust (*i.e.* the force acting on the total boundary surface, between the planes, of the internal flow) to be evaluated. There is (by definition) zero momentum flux across the surfaces which bound the internal flow and hence the thrust is obtained from two stream forces (see Aerodynamics Data Item No. 81004), one evaluated at the upstream transverse plane and associated with the inlet flow(s), the other evaluated at the downstream transverse plane and associated with the exit flow(s). The thrust force on the airframe is the vector resultant of these two stream forces.

TABLE 2.1 Diagrammatic Representation of Thrust Definitions

OVERALL GROSS THRUST			
STANDARD GROSS THRUST ($F_{G_{std}}$)			POST-EXIT THRUST
INTRINSIC MOMENTUM DRAG		INTRINSIC THRUST ($F_{N_{int}}$)	POST-EXIT THRUST
STANDARD MOMENTUM DRAG ($D_{M_{std}}$)	PRE-ENTRY THRUST	INTRINSIC THRUST ($F_{N_{int}}$)	POST-EXIT THRUST
STANDARD MOMENTUM DRAG ($D_{M_{std}}$)	STANDARD NET THRUST ($F_{N_{std}}$)		POST-EXIT THRUST
STANDARD MOMENTUM DRAG ($D_{M_{std}}$)	OVERALL NET THRUST		