PITOT AND STATIC TUBES IN SUPERSONIC FLOW

1. NOTATION AND UNITS

		SI	*British*
H_1	free-stream total pressure	N/m^2	lbf/ft^2
H_2	total pressure behind a normal shock wave with Mach number M_1 upstream	N/m^2	lbf/ft^2
M_1	free-stream Mach number		
p_1	free-stream static pressure	N/m^2	lbf/ft^2
γ	ratio of specific heat capacity at constant pressure to specific heat capacity at constant volume, taken as 1.4 for air		

2. NOTES

The pressure registered by a pitot tube at zero yaw in a subsonic stream is equal to the total pressure of the stream. Exceptions arise if the Reynolds number based on the diameter of the tube is very low (less than about 250), or if the turbulence of the stream is very high; these matters are discussed in Derivations 1, 7, 8 and 9. The mouth of the tube must be free of burrs and perpendicular to the axis; the shape of the nose does not otherwise affect the reading at zero yaw although it may have a considerable effect on the change of reading when the tube is yawed (see, for example, Derivation 5).

In supersonic flow a shock wave, through which there is a loss of total pressure, is formed in front of the pitot tube, and there is a region of subsonic flow between the shock and the mouth of the tube. It is usually sufficiently accurate to assume that the shock wave is normal to the flow over the stream tube leading to the mouth of the tube, and that no losses of total pressure occur between the shock and the tube. The tube is thus assumed to register the total pressure H_2 downstream of a normal shock, the conditions upstream being those of the undisturbed stream. Using the equations for a normal shock wave, the ratios H_2/H_1 and p_1/H_2 have been calculated (Derivation 6) and are plotted against M_1 in Figure 1. A curve for p_1/H_1 calculated for isentropic flow is also included, and is used at subsonic speeds where the pitot pressure is equal to H_1. These curves enable M_1 to be found from the pitot pressure H_2 provided that H_1 or p_1 is known. Alternatively they give the value of the free-stream total pressure H_1 if the free-stream Mach number and the pitot pressure are known. The accuracy of the determination of Mach number from pressure measurements is discussed in Derivation 4.

The free-stream static pressure p_1 is usually measured by a suitably designed static tube. At subsonic speeds the static holes are frequently positioned so that the pressure fall round the nose is balanced at the position of the holes by the pressure rise ahead of the stem used to support the tube. This is not possible at supersonic speeds because the up-stream effect of the stem is absent, and it is therefore necessary to place the holes well behind the nose to ensure that the effect of the nose on the measured pressure is small. It appears (Derivation 3) that it is necessary to position the holes at least ten external tube diameters behind the nose, and that if this is done the shape of the nose has little effect on the measured pressure. It is usual, however, to make the nose conical or ogival to keep the disturbance that it causes small. If a region of strong adverse pressure gradient, such as a shock wave, strikes the tube the reading should be treated with caution because

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the boundary layer may separate from the tube wall ahead of the shock, and thus affect the measured pressure (see Derivations 2 and 3). The upstream effect of such a shock wave is much larger if the boundary layer on the tube is laminar than if it is turbulent; for this reason transition to turbulent flow is sometimes fixed near the nose of the tube by means of a spoiler.

Information on the effects of yaw on the readings of pitot and static tubes at supersonic speeds is contained in Derivations 3 and 9; the data in Derivation 3 suggest that the effects are of the same order as at low speeds, *e.g*. the normal type pitot tube is insensitive to yaw up to about 12°, and a one per cent change in the reading of a static tube is produced by about 3° yaw. It is however possible to design pitot tubes which are insensitive to yaw up to much greater angles (see Derivation 9).

3. DERIVATION

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