

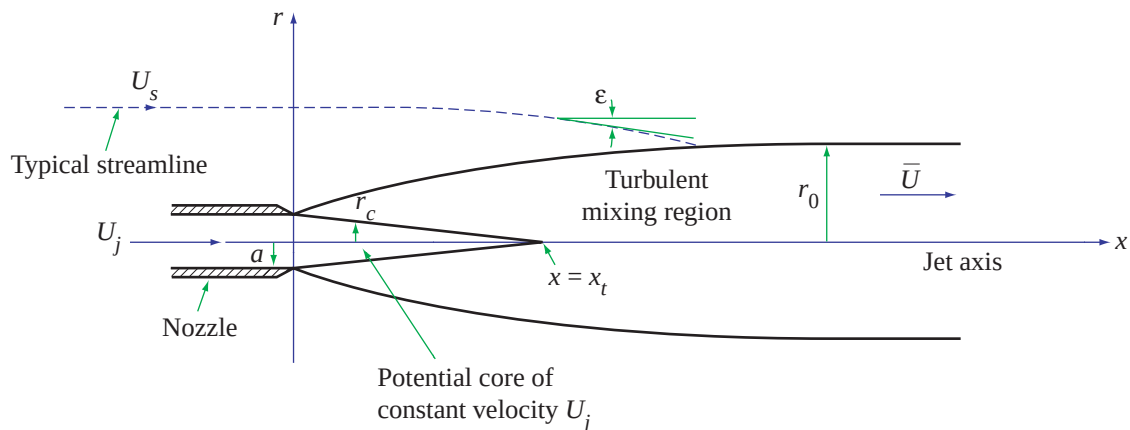
ESDU Aircraft 08.01.09

FLOW FIELD OF SUBSONIC AXISYMMETRIC JET IN A PARALLEL STREAM

1. NOTATION AND UNITS (see Sketch 1.1)

		<i>SI</i>	<i>British</i>
A	nozzle area	m^2	ft^2
a	nozzle radius	m	ft
F	net jet thrust, $\int_0^a 2\rho_j U_j (U_j - U_s) \pi r dr$	N	lbf
r	radial distance from jet axis	m	ft
r_c	value of r at boundary of potential core	m	ft
r_0	value of r at outer boundary of jet mixing region	m	ft
T_j	static temperature in jet exit	K	K
T_s	static temperature in external stream	K	K
U_j	jet exit velocity and velocity within potential core	m/s	ft/s
U_s	external stream velocity	m/s	ft/s
$\bar{U}$	time averaged velocity in axial direction in jet mixing region at x, r	m/s	ft/s
$\bar{U}_a$	value of $\bar{U}$ on jet axis at $x, 0$	m/s	ft/s
x	axial distance downstream from jet exit	m	ft
x_t	value of x at tip of core	m	ft
ϵ	deviation of external stream, positive towards jet axis	degree	degree
ρ_j	density at jet exit	kg/m^3	slug/ft^3
ρ_s	density of external stream	kg/m^3	slug/ft^3
μ	ratio of excess jet momentum flux to external stream momentum flux, per unit area, equals net jet thrust coefficient, $F/\rho_s U_s^2 A$		

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Sketch 1.1

2. NOTES

Derivations 2 to 4 indicate that the ratio of excess jet momentum flux to external stream momentum flux per unit area, μ , is a criterion of similarity for the flow configuration of heated subsonic jets. It is assumed that there are uniform distributions of velocity and temperature across and outside the exit plane of the jet nozzle. The parameter μ can then be written

$$\mu = \frac{F}{\rho_s U_s^2 A} = \frac{\rho_j U_j (U_j - U_s)}{\rho_s U_s^2} = \frac{\rho_j U_j}{\rho_s U_s} \left(\frac{U_j}{U_s} - 1 \right). \quad (2.1)$$

The data for external stream deviation are based on the theory of Derivation 2 for a cold incompressible jet, extended to the general case by the use of the criterion μ . For a given x/a and μ , the variation of ϵ with r/a is such that the quantity $(r/a)^n \epsilon$ is approximately constant, where the index n can be taken as 1.25 for $x < x_t$ and as unity for $x > x_t$. Figures 1 and 2 show the variation of $(r/a)^{1.25} \epsilon$ and of $(r/a) \epsilon$ with x/a and μ in the two respective regions.

The theory of Derivation 2 involves an empirically determined parameter c^2 , the ratio of the mixing length to the radius of the turbulent mixing region. It is suggested in Derivations 2 and 3 that in the developed jet its value is about 0.0067, and that in the core region it is nearer 0.005. Figures 1 and 2 are accordingly based on these two values in the respective regions, with a gradual transition between the two in the neighbourhood of $x = x_t$.

The results are not reliable close to the nozzle exit owing to internal and external boundary-layer effects (the curves in Figure 1 are shown dashed in this region). In practice, departure from the assumed uniform velocity and temperature distributions across the jet exit can be allowed for by taking a reduced effective nozzle radius, as in Derivation 5.

The velocity profile across the mixing region within the jet appears to be fairly well represented by a cosine distribution of the form

$$\frac{\bar{U} - U_s}{\bar{U}_a - U_s} = \frac{1}{2} \left\{ 1 + \cos \pi \frac{r - r_c}{r_0 - r_c} \right\}, \quad (2.2)$$

where, if $x < x_t$, $\bar{U}_a = U_j$, and if $x > x_t$, $r_c = 0$.

For the variation of $\bar{U}_a$ with distance downstream, Derivations 2, 6 and 7 suggest a hyperbolic decay in terms of the core length, x_t , i.e.

$$\frac{\bar{U}_a - U_s}{U_j - U_s} = \frac{x_t}{x}, \quad (2.3)$$

but there is little consistency in the data on the variation of the core length itself with the velocity and temperature ratios.

Figure 3 indicates the approximate positions of the boundaries of the turbulent mixing region and the core of a cold jet for values of U_s/U_j between 0 and 0.5 (based on data given in Derivations 1, 5 and 6). The variation of core length with μ for a cold jet is also shown in Figures 1 and 2 by the chain-dotted curves, $x = x_t$. The theory of Derivation 5 predicts a decrease of core length and a contraction of the jet boundaries as T_j is increased above T_s . For example, a change of $T_j = T_s$ to $T_j = 2T_s$ reduces x_t by about 10 per cent at $U_s/U_j = 0$ and 15 per cent at $U_s/U_j = 0.5$; the same change in T_j causes the boundaries to contract by 0.75a at all stations downstream of the core irrespective of the velocity ratio.

3. DERIVATION

The Derivation lists selected sources that have assisted in the preparation of this Item.

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|----|-------------------------------|--|
| 1. | ROLLS-ROYCE | Distribution of temperature and velocity in a jet in still air and in a moving stream. Rolls-Royce Experimental Department Report, 1943. |
| 2. | SQUIRE, H.B.
TROUPER, J. | Round jets in a general stream. ARC R&M 1974, 1944. |
| 3. | SQUIRE, H.B. | Jet flow and its effects on aircraft. RAE Rep. Aero. 2171, 1946. |
| 4. | RIBNER, H.S. | Field of flow about a jet and effect of jets on stability of jet propelled airplanes. NACA ACR L6C13 (TIL 2143), 1946. |
| 5. | SZABLEWSKI, W. | Die Ausbreitung eines Heissluftstrahles in bewegter Luft, 1 und 2 Teil, 1946. (2 Teil translated as NACA TM 1288, 1950.) |
| 6. | FORSTALL, W.
SHAPIRO, A.H. | Momentum and mass transfer in coaxial gas jets. <i>J. appl. Mech.</i> , Vol. 17, No. 4, 1950. |
| 7. | KÜCHEMANN, D.
WEBER, J. | <i>Aerodynamics of propulsion</i> . Ch. 10, McGraw-Hill, 1953. |