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Pressure losses in three-leg pipe junctions: combining flows

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THE PREPARATION OF THIS DATA ITEM

The work of the permanent professional staff of the Engineering Sciences Data Unit on this particular Item was monitored and guided by the following Working Party.

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The Steering Group has benefited from the participation of members from several engineering disciplines. In particular, Mr B.H. Fisher has been appointed to represent the interests of structural engineering as the nominee of the Institution of Structural Engineers, Mr E.C. Firman has been appointed to represent the interests of mechanical engineering as the nominee of the Institution of Mechanical Engineers, and Dr J.M. Ilsley has been appointed to represent the interests of chemical engineering as the nominee of the Institution of Chemical Engineers.

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PRESSURE LOSSES IN THREE-LEG PIPE JUNCTIONS: COMBINING FLOWS

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PRESSURE LOSSES IN THREE-LEG PIPE JUNCTIONS: COMBINING FLOWS

1. NOTATION AND UNITS

		<i>SI</i>	<i>British</i>	
A	cross-sectional area of a junction leg	m^2	ft^2	ft^2
D	hydraulic diameter, $4A/\text{perimeter}$	m	ft	ft
f	Fanning friction factor	—	—	—
K	total-pressure loss coefficient (see Equations (3.1) and (3.2))	—	—	—
$\bar{K}$	mean value of K for junction with $Re_3 \geq 2 \times 10^5$	—	—	—
K'	total-pressure loss coefficient for sharp-cornered junction	—	—	—
ΔK	increment of loss coefficient for non-standard conditions	—	—	—
L	duct length from junction (see Sketch 3.1)	m	ft	ft
p_s	static pressure	N/m^2	pdl/ft^2	lbf/ft^2
p_t	total pressure (area averaged)	N/m^2	pdl/ft^2	lbf/ft^2
Q	volumetric flow rate of fluid	m^3/s	ft^3/s	ft^3/s
Re	Reynolds number, VD/ν	—	—	—
r	radius of corners (see Sketches 4.1 and 4.2)	m	ft	ft
V	mean flow velocity of fluid, Q/A	m/s	ft/s	ft/s
ν	local flow velocity	m/s	ft/s	ft/s
α	factor used in calculation of Reynolds number effect (see Section 5)	—	—	—
ϵ	mean effective surface roughness height	m	ft	ft
θ	leg angle (see Sketches 4.1 and 4.2)	degree	degree	degree
ν	fluid kinematic viscosity	m^2/s	ft^2/s	ft^2/s
ρ	fluid density	kg/m^3	lb/ft^3	slug/ft^3

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Suffixes

<i>1</i>	refers to leg 1 of junction (see Sketches 3.1 , 4.1 and 4.2)
<i>2</i>	refers to leg 2 of junction
<i>3</i>	refers to leg 3 of junction (note this leg always carries total flow of junction)
<i>13</i>	refers to conditions between leg 1 and leg 3
<i>23</i>	refers to conditions between leg 2 and leg 3
<i>E</i>	refers to effect of outer corner shape
<i>Re</i>	refers to effect of Reynolds number

2. INTRODUCTION

This Data Item presents pressure loss data for combining flows through planar three leg junctions, all running full. Data for Y-junctions and angled-junctions are given in non-dimensional form and apply to the steady flow of gases at Mach numbers not exceeding about 0.2, above which the effects of compressibility lead to increasing errors.

The information strictly applies to junctions where the inlet flow is fully developed and where there is a long downstream duct length, but in practice can be applied without significant error when there are 15 or more hydraulic diameters upstream and at least 4 diameters downstream of the junction. The effects of roughness are included in the losses associated with the upstream and downstream pipe lengths.

The correlations are based mainly on data for pipes of circular cross section but the data can be applied to rectangular ducts of height/width ratio between about 1/2 and 2.

The restrictions on the application and accuracy of the data are shown on the appropriate Figures and further information on the accuracy (and derivation) of the data is given in Section 6 and Table 9.1.

3. CALCULATION OF PRESSURE LOSS

3.1 Total-pressure Loss

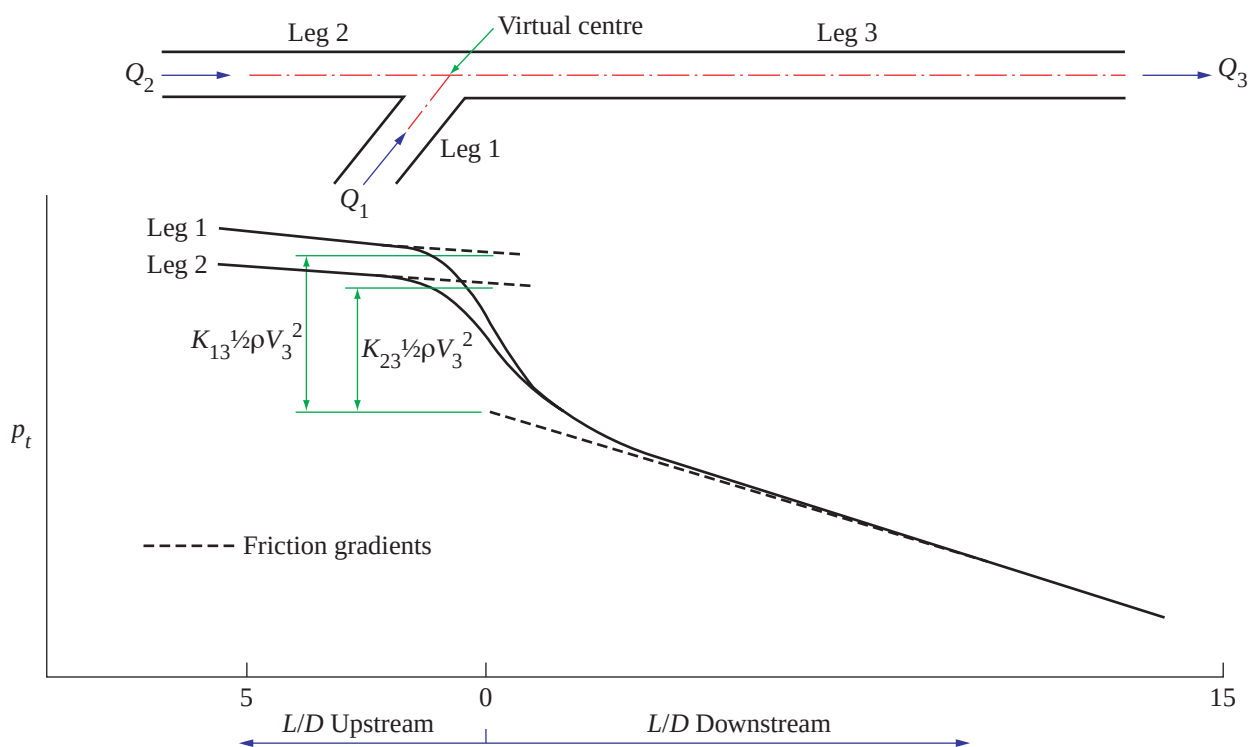
The total-pressure losses across pairs of inlet and outlet legs of a junction (in the absence of effects due to gravity) are calculated from

$$p_{t1} - p_{t3} = \underbrace{K_{13} \cdot \frac{1}{2}\rho V_3^2}_{\text{Junction loss}} + \underbrace{4f_1 \frac{L_1}{D_1} \cdot \frac{1}{2}\rho V_1^2}_{\text{Leg 1 pipe loss}} + \underbrace{4f_3 \frac{L_3}{D_3} \cdot \frac{1}{2}\rho V_3^2}_{\text{Leg 3 pipe loss}} \quad (3.1)$$

and

$$p_{t2} - p_{t3} = \underbrace{K_{23} \cdot \frac{1}{2}\rho V_3^2}_{\text{Junction loss}} + \underbrace{4f_2 \frac{L_2}{D_2} \cdot \frac{1}{2}\rho V_2^2}_{\text{Leg 2 pipe loss}} + \underbrace{4f_3 \frac{L_3}{D_3} \cdot \frac{1}{2}\rho V_3^2}_{\text{Leg 3 pipe loss}}, \quad (3.2)$$

where values of the total-pressure loss coefficients, K_{13} and K_{23} , are obtained from Sections 4 and 5 and Figures 1a to 4.



Sketch 3.1 Showing variation of total pressure in the vicinity of a junction

The last two terms on the right-hand side of Equations (3.1) and (3.2) are the straight pipe friction losses over lengths L_1 and L_3 , L_2 and L_3 respectively. Values of f_1 , f_2 and f_3 are found at appropriate values of ε/D and $Re = V_1 D_1/\nu$, $V_2 D_2/\nu$ and $V_3 D_3/\nu$ respectively from ESDU 66027.

3.2 Static-pressure Loss

The static-pressure loss across a pair of inlet and outlet legs can be estimated from

$$p_{s1} - p_{s3} = p_{t1} - p_{t3} - \frac{1}{2}\rho(V_1^2 - V_3^2), \quad (3.3)$$

for legs 1 and 3, and

$$p_{s2} - p_{s3} = p_{t2} - p_{t3} - \frac{1}{2}\rho(V_2^2 - V_3^2), \quad (3.4)$$

for legs 2 and 3.

Note that strictly

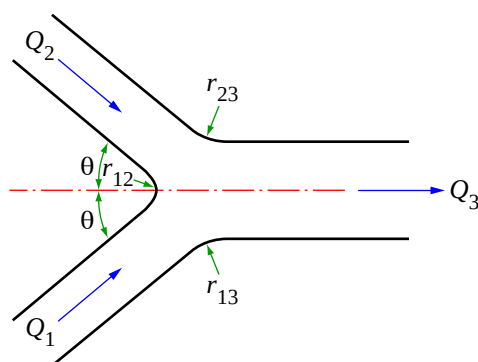
$$p_t = p_s + \frac{1}{2}\rho \int_0^A v^2 dA$$

where v is the local fluid velocity associated with flow area dA . In the case of fully-developed turbulent flow, the error involved is approximately 3 per cent of $\frac{1}{2}\rho V^2$ and has been ignored.

4. COMBINING FLOW DATA FOR $Re_3 \geq 2 \times 10^5$

The pressure loss coefficient between an inlet leg and the outlet leg (leg 3) for a combining flow junction is, in general, dependent on the flow ratio, Q/Q_3 , between each leg, the area ratio, A/A_3 , the leg angle, θ , the Reynolds number, $V_3 D_3/\nu$, and the corner radii between each leg. For many practical cases the effect of Re can be ignored but for $Re_3 < 2 \times 10^5$ this is not always so and reference should be made to Section 5 and Figure 4 for the appropriate correction.

4.1 Combining Y-junctions



Sketch 4.1

Data are presented for symmetrical Y-junctions as functions of flow ratio with $A_1 = A_2$. The total-pressure loss coefficient between legs 1 and 3 is given but the corresponding loss between legs 2 and 3 can be obtained by reversing the labels on legs 1 and 2 and repeating the calculations.

Data for combining Y-junctions with (nominally) sharp corners ($r_{13} = r_{23} = r_{12} = 0$) are presented in Figures 1a to 1e for $Re_3 \geq 2 \times 10^5$.

The effect of rounding the outer corners of a combining Y-junction is to reduce the loss coefficients from those given by Figure 1a to 1e for sharp edges. For rounded corners, *i.e.* $r_{13} > 0$, the loss coefficient is given by

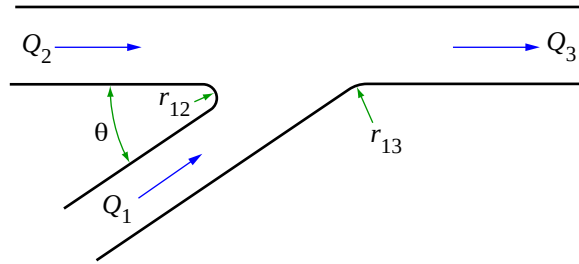
$$K_{13} = K'_{12} + \Delta K_E \quad (4.1)$$

where K'_{12} is given in Figures 1a to 1e. For $r_{13}/D_1 \leq 0.25$ and $(\cos\theta)/(A_1/A_3) \leq 1.0$,

$$\Delta K_E = \left(\frac{\cos\theta}{A_1/A_3} - 1 \right) \left(\frac{Q_1}{Q_3} \right)^2 \left(\frac{r_{13}}{D_1} \right)^{1/2}. \quad (4.2)$$

The fork radius, r_{12} , is not expected to have a significant effect on the loss coefficient.

4.2 Combining Angled-junctions



Sketch 4.2

Data are presented for sharp- and round-cornered angled-junctions with $A_3 = A_2$.

The total-pressure loss coefficient for $Re_3 \geq 2 \times 10^5$ between leg 1 and leg 3 is given in Figures 2a to 2e for sharp corners ($r_{13} = r_{12} = 0$) as a function of A_1/A_3 , Q_1/Q_3 and θ . With rounded outer corners the loss coefficient is smaller and is given by

$$K_{13} = K_{12}' + \Delta K_E \quad (4.3)$$

where K_{12}' is given in Figure 2a to 2e. For $r_{13}/D_1 \leq 0.25$ and $(\cos\theta)/(A_1/A_3) \leq 1.0$,

$$\Delta K_E = \left(\frac{\cos\theta}{A_1/A_3} - 1 \right) \left(\frac{Q_1}{Q_3} \right)^2 \left(\frac{r_{13}}{D_1} \right)^{1/2}. \quad (4.4)$$

The effect of a small fork radius, r_{12} , is not thought to be significant.

The total-pressure loss coefficient for $Re_3 \geq 2 \times 10^5$ between legs 2 and 3, K_{23}' , is given in Figures 3a to 3e for sharp corners. With a radius r_{13} , the loss coefficient is smaller and is given by:

$$K_{23} = K_{23}' + \Delta K_E \quad (4.5)$$

where ΔK_E is given by Equation (4.4) for $r_{13}/D_1 \leq 0.25$ and $(\cos\theta)/(A_1/A_3) \leq 1.0$.

5. EFFECT OF LOW REYNOLDS NUMBER ($Re_3 < 2 \times 10^5$)

The effect of Reynolds number on the pressure loss coefficient can be ignored for $Re_3 \geq 2 \times 10^5$. Below this value the pressure loss coefficient can increase very significantly but the effect is more pronounced on junctions with low loss coefficients than those with high loss coefficients. The limited number of data available indicates that for $Re_3 < 2 \times 10^5$, and for turbulent flow, the increments in K take the form

$$[\Delta K_{Re}]_{13} = |K_{13}| \times \frac{Q_1}{Q_3} \times (\alpha - 1) \quad (5.1)$$

and

$$[\Delta K_{Re}]_{23} = |K_{23}| \times \left(1 - \frac{Q_1}{Q_3}\right) \times (\alpha - 1) \quad (5.2)$$

where values of α are given by Figure 4 and K_{13} and K_{23} , given in Section 4, are uncorrected for low Re .

Data for the transition region (Re_3 less than about 10^4) are uncertain and no reliable information can be given.