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Swirl Generator for Independent Variation of Swirl and Velocity Profile

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Introduction

A SWIRL generator that allows both the swirl parameter and the shape of the axial velocity profile at the swirler exit to be varied independently, was devised for some recent studies of the effects of inlet conditions on the occurrence of central backflow in swirling flow. Figure 1 shows the essential features of the design. Swirl is produced by admitting air through four tangential entries, whose length L may be varied by means of a sliding sleeve, thus controlling the angular momentum imparted to the flow. To achieve a uniform inlet velocity, each tangential duct is provided with a movable partition attached to the sleeve and a bell-mounted entry. A second, nonswirling stream enters through a central tube, reducing the swirl intensity of the resulting flow. By regulating the proportions of air introduced tangentially and axially as well as the inlet length L, both the swirl intensity and the shape of the axial velocity profile at the swirler exit can be varied. The principle of combining axial and tangential streams is well known as a means of controlling swirl,[1-4] but has not previously been employed for the expressed purpose of velocity profile variation as well.

Measurement of Performance

The velocity profiles produced were measured with a five-hole Pitot probe at the port shown in Fig. 1. During these tests the swirl generator discharged into a cylindrical tube of 305 mm diam, while the Reynolds number lay between 0.8×10^6 and 2.5×10^6. The tip of the axial inlet tube was kept 10 mm forward of the end of the tangential inlet for all L settings (Fig. 1). Operating conditions are specified by the inlet length L and the ratio ξ

$$\xi = \dot{m}_t/(\dot{m}_t + \dot{m}_a) \tag{1}$$

where $\dot{m}_t$ and $\dot{m}_a$ are the tangential and axial mass flows, respectively. The outlet flow is characterized by the dimensionless angular momentum flux Ω,

$$\Omega = \frac{2\pi}{RI}\int_0^R \rho u w r^2 \mathrm{d}r \tag{2}$$

where u and w are the measured local axial and tangential velocities, respectively, r the radius, ρ the density, and I a momentum flux based on the mean axial velocity $\bar{u}$:

$$I = \pi R^2 \rho \bar{u}^2 \tag{3}$$

where

$$\bar{u} = (\dot{m}_t + \dot{m}_a)/\rho\pi R^2 \tag{4}$$

Evaluation of $\bar{u}$ by integration of the velocity data eliminated most measurement error from Ω.

Figure 2 plots the measured Ω as a function of L and ξ, while Fig. 3 indicates the degree to which velocity profile shapes can be varied at approximately constant Ω. The unsteady flow region marked in Fig. 2, discovered by flow visualization with smoke, is probably caused by vortex shedding in the wake of the central tube, which behaves as a bluff body as $\dot{m}_a$ approaches 0. The position of the axial inlet tube was found to have some effect on angular momentum flux, a position further forward than that shown in Fig. 1 giving a slightly higher Ω, especially at high ξ and small L.

Correlation of Angular Momentum Flux

The usual means of calculating the angular momentum flux produced by a tangential entry assumes a uniform velocity u_t in the n entry ducts,[4,5] giving

$$\Omega = \frac{\dot{m}_t u_t e}{IR} = \frac{\dot{m}_t^2 e}{\rho n b L I R} \tag{5}$$

where

$$e = R - b/2 \tag{6}$$

The swirler was found to produce a higher Ω than predicted by Eq. (5), suggesting that the jet leaving each entry undergoes contraction and acceleration as it combines with flow from preceding entries. To describe this, a contraction coefficient C_c is introduced, so that

$$u_t = \frac{\dot{m}_t}{\rho n b L C_c} \tag{7}$$

Frictional losses of angular momentum are equal to the torque T exerted by the tube wall,

$$T = 2\pi\tau_\phi R^2 X \tag{8}$$

with the shear stress expressed as

$$\tau_\phi = f_\phi \rho u_t^2/8 \tag{9}$$

where f_ϕ is a friction factor, analogous to that in simple pipe flow, and u_t is assumed to be typical of tangential velocities near the wall. Combining Eqs. (4), (5), and (7) and subtract-

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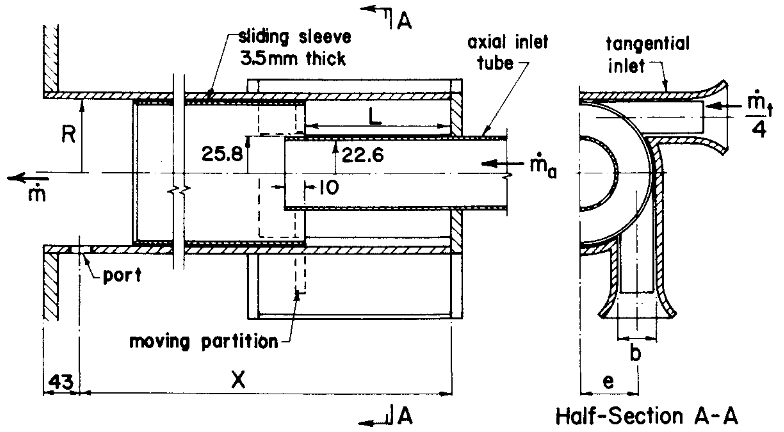

Fig. 1 The axial-tangential swirl generator. Dimensions: $b = 25.6$ mm, $e = 38.0$ mm, $L =$ variable, $R = 50.8$ mm, $X = 529$ mm (other dimensions in mm).

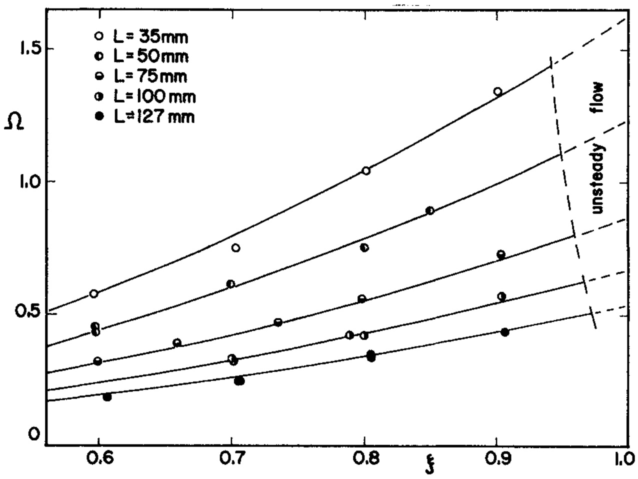

Fig. 2 Dimensionless angular momentum flux Ω as function of L and ξ.

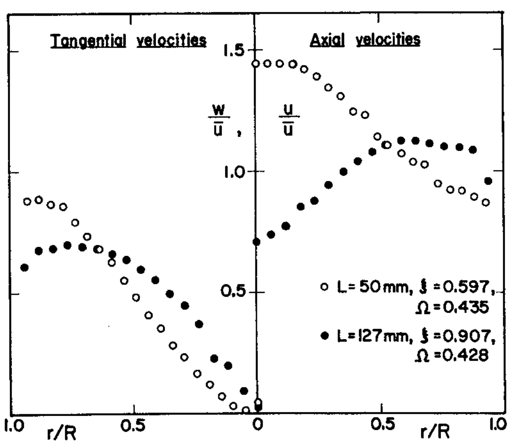

Fig. 3 Profiles of axial and tangential velocities at approximately constant Ω and various inlet lengths L.

ing (T/IR) gives the outlet Ω as

$$\Omega = \pi \xi^2 R \left[\frac{e}{nbLC_c} - \frac{\pi f_\phi R^2 X}{4n^2 b^2 L^2 C_c^2} \right] \tag{10}$$

Least squares fitting gave $C_c = 0.82$ and $f_\phi = 0.022$, the latter being about twice that for simple smooth pipe flow at the same Re. This equation is plotted in Fig. 2, and fits all experimental points within 7%.

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Vibration of a Large Space Beam Under Gravity Effect

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Introduction

MOST spacecraft launched to date have undergone structural ground tests to verify the mathematical models of the structures.[1-2] The effect of gravity on these traditional space structures was considered only from a static point of view, or completely disregarded. This is because of their stiffness and compactness, and also because they were

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