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Effect of Swirl on the Potential Core in Two-Dimensional Ejector Nozzles

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Introduction

IN the past, ejector nozzles were used to pump cooling air and to enhance engine thrust. A number of studies were made to investigate the pumping and performance characteristics of the axisymmetric ejector nozzles (see, for instance, Refs. 1-3). With the increasing emphasis on two-dimensional (2-D) nozzles, it now becomes appropriate to study the 2-D ejector nozzles. The two-dimensional version of the ejector nozzles enables the designer to reduce the mixing shroud length to save weight and still achieve sufficient primary plume entrainment and sufficient mixing between the primary and secondary streams. Since engine swirl enhances 2-D nozzle plume entrainment and mixing,[4] it is expected that swirl can further reduce the length of a 2-D ejector nozzle. Hence a semiempirical method for considering the swirl effect was derived to predict the potential core length of the 2-D primary nozzle. Preliminary water tunnel tests of a 2-D ejector nozzle model with and without swirl were also conducted to study the effects of swirl. The results are summarized in this Note to show that the combination of swirl and 2-D geometry can dramatically reduce the primary-nozzle potential core and hence the mixing shroud length. The information contained in this Note is useful for such applications as jet noise reduction.

The Model

A plexiglass model of a 2-D ejector nozzle is shown schematically in Fig. 1. The circular inlet duct transforms into a 2-D primary nozzle with an exit aspect ratio of 4. Plastic pinwheels with blade angles of 7.5, 15, and 22.5 deg are inserted in the circular duct as swirl vanes. A rectangular plexiglass duct is attached to the primary nozzle to form a mixing shroud.

Potential Core Length Prediction

Figure 2 is a sketch of a jet issuing from a 2-D primary nozzle with exit height d (the shorter side of the rectangular exit). The exit velocity is assumed to be uniform. The velocity V or V_c is the difference between the local jet velocity and the velocity at the edge of the jet (the secondary flow velocity).

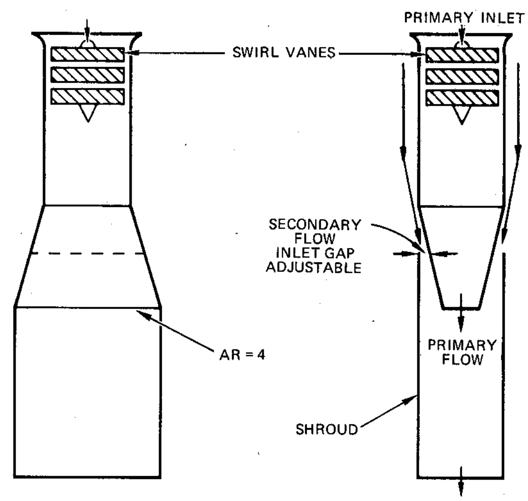

Fig. 1 Schematic of 2-D ejector nozzle model.

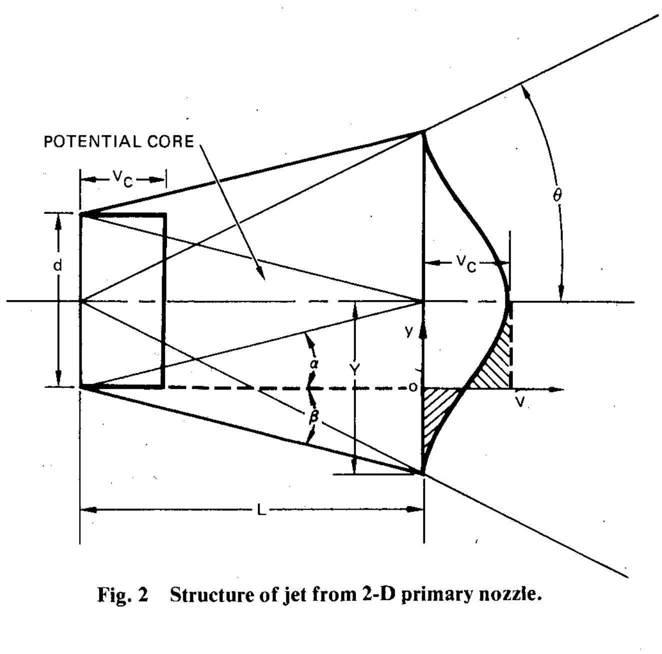

Fig. 2 Structure of jet from 2-D primary nozzle.

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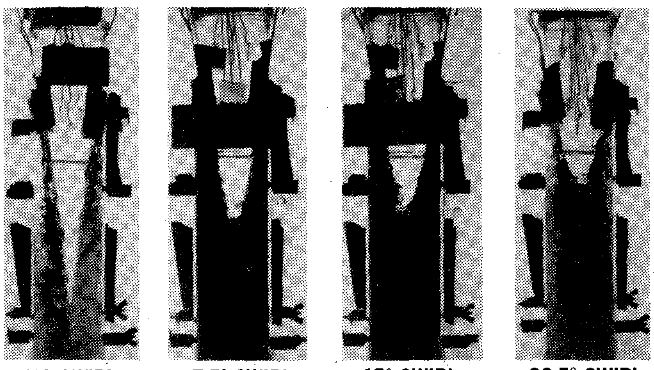

Fig. 3 Effect of swirl on potential core of 2-D primary nozzle.

Following Korst et al.,[5] we express the velocity ratio in a similar form as (see Fig. 2)

$$\frac{V}{V_c} = \frac{1 + \mathrm{erf}(4y/Y)}{2} \tag{1}$$

Since the error function is an odd function, the two shaded areas in Fig. 2 are the same, and the mixing angle α is equal to the mixing angle β. The former condition implies that the area under the velocity curve is conserved throughout the potential core. The latter condition leads to $Y = d$ (see Fig. 2). It follows that the potential core length L is given by

$$L = d/\tan\theta \tag{2}$$

The 10% velocity jet boundary angle without swirl was experimentally determined to be 9 deg (see Ref. 6), but Fig. 10-1 of Ref. 6 shows that the jet velocity practically vanishes at a boundary angle of approximately 12 deg without swirl. With swirl, however, the jet boundary angle θ must be specified. Following the modeling of Ref. 7, we assume that the jet boundary angle θ depends linearly on the swirl angle θ_s; specifically, the jet boundary angle is assumed to be

$$\theta = 12 \text{ deg} + \theta_s \tag{3}$$

Substitution of Eq. (3) into Eq. (2) finally gives

$$L = d/\tan(12 \text{ deg} + \theta_s) \tag{4}$$

Using Eq. (4), we obtain $L = 4.7$, 2.8, 2.0, and $1.5d$ for $\theta_s = 0$, 7.5, 15, and 22.5 deg, respectively.

Water Tunnel Tests

During the test, the model (see Fig. 1) was aligned with the flow in the center of the water tunnel. Dyes were released from tubes along the outer broad faces of the primary nozzle at the midpoints of both the long exit edges. The clear potential core of the primary flow was observed through the narrow side of the plexiglass shroud. Figure 3 shows the potential core without swirl, compared with the potential cores (in the plane of symmetry) obtained using swirl vanes with blade angles of 7.5, 15, and 22.5 deg; the dotted lines show the potential cores predicted by Eq. (4). The contrast between the core sizes with and without swirl is dramatic: a mere 7.5-deg swirl reduces the potential core to almost one-half of that without swirl. The reduction increases to about one-third for the maximum 22.5-deg swirl. Since the mixing shroud should be at least long enough to cover the potential core, the effect of swirl is to dramatically shorten the mixing shroud. A shorter shroud means a shorter ejector nozzle and saves weight. Sometimes, a longer shroud may be needed for sufficient pumping, regardless of how short the potential core with swirl can be. Even in this case, a shorter potential core due to swirl allows further mixing to take place in the shroud and thus results in a more uniform ejector nozzle exit velocity distribution (i.e., lower peak velocity) and hence a lower jet noise level.

Figure 3 also compares the predicted potential cores with those observed experimentally and shows good agreement. These photographs show the potential cores in the center of the shroud since the dyes were released along the midpoints of both the long exit edges of the primary nozzle. There is some core length variation away from the center towards the narrow side walls of the shroud. While the analysis slightly overpredicts the potential core in the center (Fig. 3), it slightly underpredicts the core away towards the walls. The prediction agrees fairly well with the observed average potential core length.

Conclusions

1) Swirl can considerably reduce the potential core of the 2-D primary nozzle and hence the length of a 2-D ejector nozzle.

2) The swirl produced by 7.5-deg blade angle guide vanes reduces the 2-D primary-nozzle potential core to almost one-half of that without swirl.

3) The derived semiempirical method predicts fairly well the potential core of the 2-D primary nozzle with or without swirl.

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