Engineering Notes

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Noise and Thrust Characteristics of Shrouded Multi-Nozzles of Circular Cross Section

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Introduction

ENGINE exhaust nozzles equipped with shrouds and sound-attenuating liners have been recently made the object of theoretical calculations on the expected noise attenuation and static thrust increases in comparison to unshrouded nozzles; also initial experiments have been conducted in the UTSI Aeroacoustic Laboratory[1] on shrouded configurations. For both calculations and experiments, it was assumed that an engine would provide a given primary air flow at a definite pressure ratio with respect to the ambient air pressure; this mass flow and pressure ratio is not to change by the addition of the shroud. With the shroud attached, the static pressure at the exit of the primary nozzle will be somewhat reduced because of the ejector effect under the shroud; hence, the exit area of the primary nozzle was adjusted so that the total mass flow through the nozzle with shroud at its larger pressure ratio is the same as that without the shroud.

At the downstream end of the shroud channel, a diffuser or a nozzle is usually added. It is noted that, at the exit of the diffuser or nozzle, the static pressure is equal to the ambient pressure, and also equal to the total pressure of the secondary air as long as the airplane is not moving. The basic configuration for a primary nozzle with a shroud is presented in Fig. 1.

The primary nozzle exhausts into a shrouded channel and by mixing with the surrounding secondary air produces an ejector effect. The net result of such mixing within the shrouded channel is that, at the exit, a larger air flow emerges with lower velocity in comparison to the primary nozzle. Because the flow velocity at the channel exit affects the exhaust jet noise by a high power (for instance, by the eighth power), the exhaust noise is greatly reduced. This is in spite of the fact that the total mass flow is increased in comparison to that of the primary nozzle since the mass flow of a jet affects the noise generation only approximately with the first power. It can also be shown[2] that shrouded nozzle assemblies are capable of generating a thrust increase if the flow losses within the system are sufficiently low.

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Index categories: Aircraft Noise, Powerplant; Aircraft Powerplant Design and Installation.

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There are some critical design conditions, however, which need to be satisfied when the shrouded nozzle configuration is to both reduce the noise and increase the thrust. Shrouds with very large internal surfaces are capable of noise reduction; however, large shroud friction would be detrimental to thrust. To achieve both noise attenuation and thrust increase, the mixing of the primary air with the secondary air within the shroud must be accelerated as much as possible so that the channel length can be short. Accelerated mixing for the same amount of primary air leads to slot or multiple primary nozzle configurations. In the initial experiments two primary nozzles were utilized. The channel walls were equipped with liners to attenuate the strong noise of the initial mixing zones and trap noise within the shroud before the jet emerges into the ambient air.

Theoretical Analysis

In analyzing a typical shroud configuration, as d in Fig. 1, it was assumed initially that frictionless flow exists throughout the entire shroud channel; only the mixing losses between the entrance and the exit of the channel were incorporated. Furthermore it is assumed that complete mixing has been achieved with a constant-velocity profile at the end of the channel, the mixing losses can be determined readily through the momentum equation of fluid dynamics. In reality, the condition of uniform flow cannot be fully reached, but only approached.

The calculated noise reduction for frictionless flow varies from approximatyely 9 db reduction for the shroud with an area ratio of 2, to 14 db reduction for the shroud with an area ratio of 4, and to 17 db for the shroud with an area ratio of 6. These large reductions of sound-power are attributed mainly to the reduction of shroud exit velocity. For the shroud with an area ratio of 4, for instance, an exit Mach number of about $M=0.5$ is established instead of $M=0.9$ for the unshrouded primary nozzle. It is noted that these ideal reductions are obtained with the assumption that the noise in the mixing area within the shroud is attenuated fully by the noise-absorbing liner. Results for the noise reduction and thrust increase by secondary mass flow and shroud additions are shown in the composite plot of Fig. 2. This figure clearly indicates that large noise reductions with significant thrust increases can be achieved by relatively large secondary air flows.

After the initial frictionless flow calculations were completed, a brief estimate of the influence of friction was per-

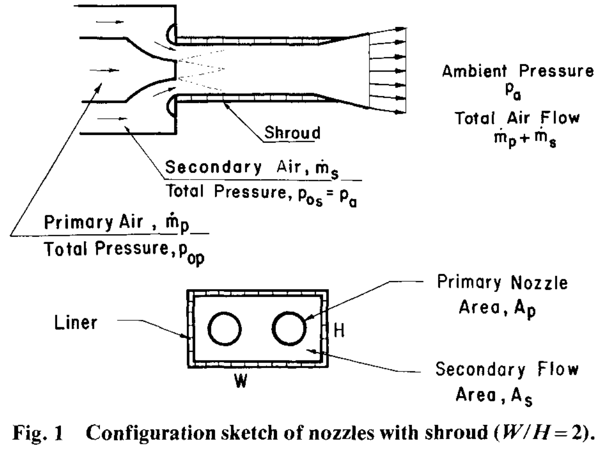

Fig. 1 Configuration sketch of nozzles with shroud ($W/H=2$).

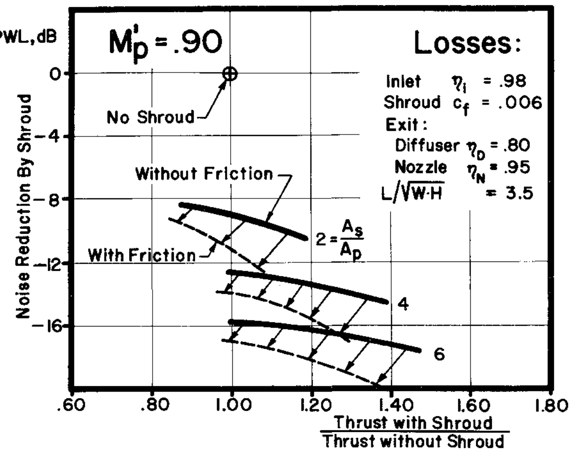

Fig. 2 Noise reduction and static thrust increase by shroud addition (theory).

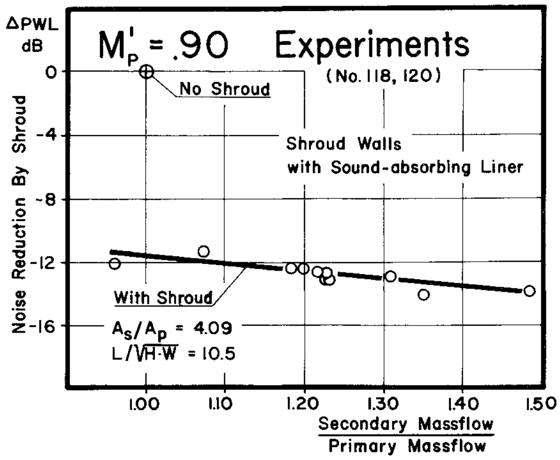

Fig. 3 Shroud experiments: noise reduction as function of secondary mass flow ratio.

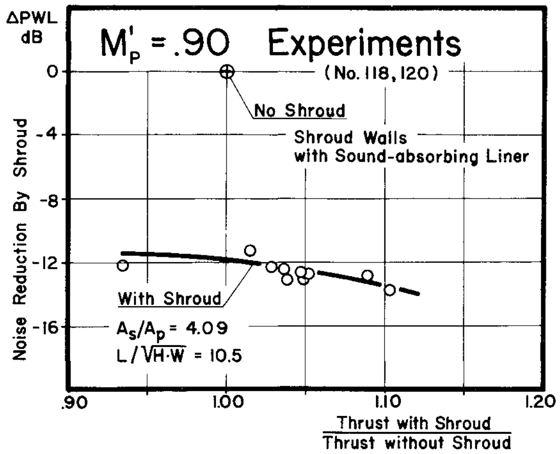

Fig. 4 Shroud experiments: noise reduction as function of static thrust ratio.

formed by assuming loss coefficients and treating the entire shroud flow as a one-dimensional flow (Fig. 2). The losses were introduced as total pressure losses of the flow through the channel, and their effect on the exit velocity at one-dimensional flow conditions was determined. The length of the shroud channel was selected as 3.5 times the mean channel height, that is:

$$L = 3.5\,(WH)^{1/2}$$

(Fig. 2). As expected, the resulting reduction of exit velocity due to internal friction causes a further reduction of jet noise, but is also accompanied by a sizable reduction of thrust. Nevertheless, considering for example the case of a shroud with an area ratio of 4, the noise would be reduced by approximately 16 db while at the same time the thrust would be increased by 25%. These values apply to a ratio of secondary to primary mass flow of about 1.5.

Experiments

A shroud was built to accommodate a secondary to primary area ratio of 4 (Fig. 1). All four walls of the shroud channel were equipped with sound-attenuating liners consisting of honeycomb elements covered with wire cloth. The length of the channel was made 10.5 times the mean height of the channel, that is $L = 10.5\,(HW)^{1/2}$. The objective of future tests will be to determine the influence of the length of the channel as well as of the type of noise attenuating liners on noise and thrust.

In the experiments, the total sound-power of the shroud configurations was measured without an exit diffuser or nozzle attached to the shroud channel. To represent properly actual static thrust conditions, the total pressure of the secondary flow must be equal to the ambient pressure. In the experiments with a ratio of secondary to primary mass flow of about one, the above pressure conditions were approximately fulfilled. For all other test points, this pressure condition was not fulfilled. Thus, the observed experimental data were corrected by adding analytically a diffuser or nozzle as required, calculating the exit velocities, and assuming the Lighthill parameter to be applicable for determining the noise correction. Since no reliable information is available at this time to differentiate in the experiments between the internal mixing noise and the exhaust jet noise, the correction, described previously, was arbitrarily reduced to two-thirds of the calculated value.

In Fig. 3, the results of two experimental runs are plotted with respect to noise reduction by the shroud as a function of the secondary to primary air flow ratio. The data show a noise power reduction between 12 and 14 db. It is noted again that no correction of the noise data due to addition of an exit diffuser or nozzle was necessary at a mass flow ratio of approximately one; the other data points were corrected as described above.

For the same experiments, the static thrust ratio for the configurations without and with shroud was calculated from the shroud exit conditions, and plotted as a function of sound-power reduction in Fig. 4. The experimental results indicate that a sizable sound-power reduction of more than 12 db can be accomplished without loss of thrust; to the contrary, a thrust increase can be achieved by means of proper proportioning the secondary mass flow ratio to the dimensions of the shroud.

Conclusions

One-dimensional calculations and initial experiments for shrouded nozzles tend to confirm that such configurations exhibit a significant potential for exhaust noise reduction without a penalty of static thrust. If properly designed, shrouded nozzles can simultaneously increase the thrust and reduce noise by substantial amounts.

References

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[2]Nagaraja, K. S., Hammond, D. L., and Graetch, J. E., "One-Dimensional Compressible Ejector Flows," AIAA Paper 73-1184, Las Vegas, Nev., 1973.