On Menard Inserts in Supersonic Nozzles

J. L. Amick,* S. A. Harrington,** and H. P. Liepman***

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INTRODUCTION

Intentional changes of the design Mach Number in a nozzle with fixed contours by means of movable sidewall inserts were first reported by Menard. His work formed the starting point for studies in the Aerodynamics Laboratory of The University of Michigan into the potential usefulness of such inserts at low and high Mach Numbers. The study was motivated by the possibility of using Menard inserts as a simple and extremely economical technique of changing the Mach Number of a set of fixed nozzle blocks.

DISCUSSION

Consider a given two-dimensional symmetric nozzle with a uniform exit flow of Mach Number $M_0$; add to the plane walls of this nozzle properly shaped and located half bodies such that a new uniform flow of Mach Number $M_1 = M_0 + \Delta M$ results. The determination of the contours of these inserts and of their location relative to the basic nozzle cannot be carried out by any of the usual design procedures for two-dimensional or axisymmetric nozzles. Only the simple one-dimensional area ratio

$$\Gamma_3 = \omega_i (\cos \alpha_2 / \cos \alpha_1) (\int jh / dn) dh$$

which gives

$$\Gamma_3 = (dU_1 / dz) \left[ \int (L_1 / q_1) - \int (L_0 / q_0) \right] U_1$$

(4)

The circulation of this is a right-handed screw facing downstream.

The vorticity due to the shed circulation from the blades is also present downstream. The circulation associated with this is

$$\Gamma_3 = (dU_1 / dz) s \cos \alpha_3 (\tan \alpha_1 - \tan \alpha_2)$$

(5)

The direction of $\Gamma_3$ is the same as $\Gamma_1$.

The total streamwise circulation is therefore

$$\Gamma = \Gamma_1 - \Gamma_2 - \Gamma_3$$

(7)

The above method may be applied to an accelerating cascade when the following results are obtained. These results are the same as those obtained by Hawthorne with a different method.

$$\Gamma_1 = (dU_1 / dz) \left[ (\sin 2\alpha_1 - \sin 2\alpha_2) / 2 \cos \alpha_1 \right]$$

(6)

and

$$\Gamma_2 = (dU_1 / dz) \left[ \int (L_i / q_i) - \int (L_0 / q_0) \right] U_1$$

when $\alpha_1 = -\alpha_2$ as in an impulse cascade

$$\Gamma = 0$$

RESULTS

Low Mach Number Inserts

The technique described above was used to design a set of inserts for the 19 in. × 27.5 in. wind tunnel of the Ordnance Aerophysics Laboratory so that their Mach 1.5 nozzle would give Mach 1.6 flow of acceptable uniformity.

Inserts of the recommended design were manufactured and tested by the Ordnance Aerophysics Laboratory. The results were highly satisfactory and are reported in reference 2. Briefly, the desired Mach Number of 1.6 was achieved with the inserts in design position, and the flow uniformity was no worse than that of the basic Mach 1.5 nozzle. Off-design positions of the inserts, 6 in. upstream and downstream of the design, resulted in usable flows of Mach 1.57 and 1.63, respectively, with the most uniform flow being obtained in the latter position (Fig. 1). The cost of these inserts and their installation amounted to approximately 13 per cent of the expected cost of a new set of Mach 1.63 nozzle blocks.

High Mach Number Inserts

After this success at low Mach Numbers, the program of designing inserts for the OAL facility became quite ambitious. The first high Mach Number inserts were to boost the OAL Mach 2.23 nozzle to Mach 3.0. It was found that no inserts could be designed which would have a reasonable chance of giving acceptable flow at the Mach 3.0 level.

Next, a series of inserts (Fig. 2) were studied to bring the OAL Mach 2.75 nozzle to a Mach Number of 3.0. Exploratory tests with models of the proposed inserts were conducted in the Mach 2.84 nozzle of the 8 in. × 13 in. wind tunnel of the University. The first series of tests were made of so-called "short" inserts, shown in the upper portion of Fig. 2. The negative results of these tests are given in reference 4. The unsatisfactory flow of all three short inserts was primarily due to a strong lateral shock believed to originate in local regions of rapid expansion and cross flow just downstream of the effective throat of the nozzle-insert combination.

In order to alleviate the local expansion, a long cylindrical insert was tested as shown in the lower half of Fig. 2. The main result is given in Fig. 3 and shows that a flow of reasonable uniformity was obtained, and that the Mach 3.0 level of the basic nozzle was increased by an increment of 0.29. The lateral shocks

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REFERENCES


**Assistant in Research.

*** Associate Professor of Aeronautical Engineering.