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FLOW IN A DISCRETE SLOTTED NOZZLE
WITH MASSIVE INJECTION

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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16. Abstract

An experimental investigation has been conducted to determine the effect of massive wall injection on the flow characteristics in a slotted nozzle. Some of the experiments were performed on a water table with a slotted-nozzle test section. This has 45° and 15° half angles of convergence and divergence, respectively, throat radius of 2.5 inches, and throat width of 3 inches. The hydraulic analogy was employed to qualitatively extend the results to a compressible gas flow through the nozzle. Experimental results from the water table include contours of constant Froude and Mach number with and without injection.

Photographic results are also presented for the injection through slots of CO_2 and Freon-12 into a main-stream air flow in a convergent-divergent nozzle in a wind tunnel. Schlieren photographs were used to visualize the flow, and qualitative agreement between the results from the gas tunnel and water table is good.

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FOREWARD

This report, one of a series of four, describes experimental results for flow in a slotted convergent-divergent nozzle with massive wall injection. The work was supported by the Nuclear Systems Division, NASA Lewis Research Center, under Grant NGR 03-002-213. Mr. Albert F. Kascak was the technical manager.

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SUMMARY

An experimental investigation has been conducted to determine the effect of massive wall injections on the flow characteristics in a slotted nozzle. Some of the experiments were performed on a water table with a slotted nozzle test section. This has 45° and 15° half angles of convergence, respectively, throat radius of 2.5 inches, and throat width of 3 inches. Three discrete slots were used for the water table study one at the entrance to the nozzle, one in the converging section, and one just upstream of the throat. The hydraulic analogy was employed to qualitatively extend the results to a compressible gas flow through the nozzle. Experimental results from the water table include contours of constant Froude and Mach number with and without injection.

Photographic results are also presented for the injection, through slots, of CO_2 and Freon-12 into a main-stream air flow in a convergent-divergent nozzle in a wind tunnel. Schlieren photographs were used to visualize the flow, and qualitative agreement between the results from the gas tunnel and the water table is good. The test section in the wind tunnel was geometrically similar to that used on the water table. A fourth slot was used in the wind tunnel work and was a rearward facing step in the supersonic region of the nozzle.

INTRODUCTION

Advanced rocket engines, in particular the gas core nuclear rocket, are expected to produce gas temperatures at the entrance to the nozzle in the neighborhood of 20,000°K [1]. A major portion of the nozzle heating is due to the thermal radiation from the high temperature gases in the nozzle and the nuclear reactor core. This contribution can be diminished by creating an optically thick protective fluid layer enveloping the hot core gases as they expand through the nozzle. This protective layer must exist adjacent to the nozzle wall and may be formed by injection of a suitable cooling fluid through the wall. In addition to providing a radiation shield, the injected fluid must also diminish the convective heat transfer through the mechanism of transpiration cooling.

There are two ways to protect the nozzle with an injected gas that has been seeded with submicron sized particles. Both have been investigated under this grant. They are cooling whereby the fluid is injected through a porous wall, often called transpiration cooling, and discrete slot injection where the fluid is injected through slots in the direction along the nozzle wall. Results for the porous nozzle have been presented in previous reports [2,3].

Those experiments were run on both a water table [4] and in an in-draft type wind tunnel [2]. The nozzles were made from porous material and injection was uniform over any one porous section but could be varied between sections since the nozzles were built with three independent porous sections forming the walls. Injection up to the order of 10 to 20 percent of the main stream mass flow rate was investigated.

In the present report an experimental approach is adopted for the study of nozzle flows with large injections through discrete slots. Based on the hydraulic analogy, a compressible gas flow is modeled with a water flow having a free surface. In its simplest form, the analogy applies between one-dimensional, open-channel liquid flow and isentropic, one-dimensional, internal gas flow. The flow variables in one-dimensional open-channel flow are local height and Froude number. They vary in the flow direction which is perpendicular to local gravitational acceleration. The local height and Froude number may be related to an equivalent local pressure and Mach number in an isentropic, one-dimensional nozzle gas flow. The analogy is exact for a perfect gas with a specific heat ratio γ of 2. If the channel width-ratio (local width to throat width) is set equal to the nozzle area ratio (local area to throat area), the Froude number is equal to the Mach number, and the square of the height-ratio (local to stagnation) is equal to pressure ratio (local to stagnation). Once the Mach number or pressure ratio is found in this manner, the other properties

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may be found directly from the isentropic tables. For gases with different γ, appropriate correction factors exist [5]. Previous reports in this series have described the analogy in more detail [3,4].

The hydraulic analogy does not apply directly to a flow with injection. Nevertheless, it is useful in a qualitative way to the analysis of this type of flow.

Photographic results are also presented for injection of different gases (CO_2, Freon-12) into the transonic region of a plane slotted nozzle operating with air as the main stream fluid. The qualitative agreement between the incompressible water table results and those obtained in the wind tunnel is good.

It has been shown that gases with low molecular weight provide the best thermal protection. In the gas core nuclear engine, hydrogen would be used to cqol the nozzle and this fluid meets the criteria. The hydrogen injected as a coolant would be significantly denser than the main stream hydrogen because of the temperature difference between the injectant and the main stream hydrogen. It is this condition that is modeled in the present gas tunnel experiments. Carbon dioxide and Freon-12 were used as the coolant fluid. Flow visualization was accomplished using a Schlieren system with a two microsecond spark source for photographic work.

It should be re-emphasized that the primary objective of this work is to determine general changes in the flow field characteristics caused by high rates of wall injection, and not the precise prediction of the flow field.

EXPERIMENTAL RESULTS - WATER TABLE

The hydraulic analogy was first discussed in detail in Preiswerk [6,7]. Loh [8] has reprinted much of this earlier work and has extended the analogy to the case of unsteady flows. In the analogy an assumption is made that accelerations in the vertical direction are negligible. To approximately meet this assumption, it is necessary to operate the water table with modest stagnation heights in the upstream region where the velocity approaches zero. For the slotted nozzle this is difficult since one must have sufficient height in the throat region for controlled blowing to be visualized. Thus with injection, it is necessary to operate with stagnation heights on the order of 2.5 to 3 inches instead of the more desirable 1 to 1.5 inches.

A detailed description of the water table facility is contained in reference [4]. Results from the water table studies for a porous nozzle are presented in [2] as is a more complete summary of the analogy. The effect of stagnation height is also documented in reference [2].

The water table flow visualization technique, described in detail in [3], produces color differences between fluid streams without the use of permanent dyes. This is accomplished through pH control of the main stream and the injected stream. A suitable acid-base indicator (here bromothymol-blue) is mixed into the solution. The injected fluid is made basic with the addition of sodium hydroxide and with the indicator appears as a blue fluid. The main stream is an aqueous solution of acetic acid and appears yellow.

This report emphasizes the wind tunnel, gas injection work. It should be noted here, however, that numerous still photographs were taken to visualize the fluid flow through the slotted nozzle on the water table. Figures 1 and 2 show the flow field with injection from the slots. Figure 1 has injection from slots 1, 2, and 3 on both sides of the nozzle. The mass injection rates as a percent of the non-injection main stream flow rate are: each slot 1, 3.6%; each slot 2, 6%; each slot 3, 3.5% for a total injection of 26.2% of the undisturbed main stream flow.

When injection occurs for a very favorable pressure gradient, as at slots 2 and 3, the injected fluid maintains its integrity for some distance along the wall. Figure 2 notes the thick injected layer at the throat when injection takes place from slot 2. Although not shown in a figure an injection equal to several percent of the main stream flow from slot 3 (just upstream of the throat) does not form such a thick layer.

The particular slot nozzle used in these experiments had 45° and 15° half angles of convergence and divergence, respectively, a throat radius of 2.5 inches, and a throat width of 3 inches. The slots were 0.060 inches wide and were located as follows: slot 1 just at the entrance to the nozzle, slot 2 about half way along the converging section, and slot 3 just upstream of the geometric nozzle throat.

Quantitative results were also obtained on the water table. Figure 3 shows a no-injection Froude number, and a Froude number with injection, as a function of position in the nozzle. The two-dimensionality of the flow field is evident. Froude number distributions are obtained by measuring the local water depth to obtain $\sqrt{gH}$. The water depth is determined by measuring with a pointed depth micrometer the distance to the water surface and the distance to the table surface. The difference is the local water height. The Froude number is then determined from

$$H_o = H(x) [1 + 0.5 \ F^2(x)]$$

This is a statement of the conservation of energy along the streamline.

Shown in Figure 4 is the corrected Froude number (corrected to a Mach number corresponding to $\gamma = 1.4$). The correction is particularly significant at high values of F.

Briefly the correction follows from equating the area ratio formula for the compressible-gas flow to the width-ratio result for water-table flow. These are:

$$\frac{A}{A_{th}} = \frac{1}{M}[(\frac{2}{\gamma+1})(1 + \frac{\gamma-1}{2} M)]^{(\gamma+1)/2(\gamma-1)}$$

and

$$\frac{B}{B_{th}} = \frac{1}{F}[(\frac{2}{3})(1 + \frac{F^2}{2})]^{3/2}$$

One can quickly see that in the analogy, F corresponds to M when $\gamma = 2$ for the analogous gas.

If one equates these two expressions, a single equation results which can be solved using specified values of γ and F. The value of M so obtained is called the "corrected Froude number" and it is this value which is shown in Figure 4. Details for obtaining the correction are given in [3].

On these figures the solid curves correspond to the case of no injection, and the dashed curves show the effect of injection through the slots. It is seen that the effect of slot injection is to move the critical "line" for $F = 1$ downstream. Exactly the same behavior was noted for the porous nozzle [2].

For these results the mass injection rates were an injection of $\dot{m}/\dot{m}_\infty = 0.055$ at each slot 2 and 0.045 at each slot 3. The total injection from both walls was thus 20 percent. It is also possible to determine an injection parameter. We have

$$\lambda = \rho_w v_w / \rho V$$

or here

$$\lambda = \frac{\dot{m}_{inj}}{\dot{m}_\infty} \left[\frac{A_\infty}{A_{slot}}\right]$$

For slot three the blowing parameter value would be $\lambda = 50$ for each percent of main stream flow injected through the slot. For a 4.5 percent injection therefore, $\lambda = 225$.

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EXPERIMENTAL RESULTS - GAS TUNNEL

The slotted nozzle utilized for most of the flow visualization is described here. The nozzle is an approximate 1:4 scale model of the nozzle installed on the water table and has a standard 15° expansion angle. Figure 5 shows a scale drawing of the nozzle which is also shown on Plate 1. Three slots are installed at or before the throat. A rearward facing step slot is in the divergent (supersonic) portion of the nozzle. Since the rearward step is in the supersonic portion, it has no effect on the performance of the first three slots.

The nozzle was originally designed to have a variable throat height by varying the shim height. For this report the nozzle throat was maintained a constant at 0.590 inch and the rearward facing step was placed so as to inject into an approximately Mach 2.5 flow.

The wind tunnel used in these experiments is a nominal 3 inch by 4.75 inch vacuum drive, in draft, supersonic tunnel. A run time of about 60 seconds can be achieved with the present throat width. The injectant fluid was delivered to the nozzle through a pipe which opened into a plenum placed between the pipe ends and the nozzle injection slots. The plenum included fine mesh screen to insure uniform injection across the width of the nozzle.

The mass flow rate for the free stream was calculated from one dimensional flow theory. The ambient temperature was assumed to be 540°R for all runs and the actual temperature was within three degrees of this. The ambient pressure was assumed to be constant at 13.58 psia. Actual pressures were within ± 0.2 psia of this value for all runs.

Using these data and the area of the throat section (0.590 inch by 2.875 inch) the mass flow rate without injection is calculated to be 30 lbm/min. This is the tunnel flow rate that was used for all injection calculations. For example, when a 10 percent gas injection rate was used, it was calculated on the basis of 10 percent of 30 lbm/min or 3 lbm/min.

The flow rate of the injected gas was measured with six rotameters in parallel. This allowed flow to be metered individually to any six slots. The temperature of the injected gas was measured with a thermocouple just prior to entering the rotameters. Because of the short run time for each set of data the only gas that showed any significant temperature variation was CO_2. The temperature of the CO_2 entering the rotameter varied from 500°R to 530°R. The rotameters were calibrated for

air flow at 14.7 psia and 70°F. The meter readings were converted to volume flow readings by a chart supplied by the manufacturer. These volume readings were converted to mass flow rates according to the formula

$$\dot{m} = (SCFM) \; \rho_o \left(\frac{P \; T_o \rho}{P_o T \rho_o}\right)^{1/2}$$

where

P = operating pressure (absolute) at the meter.

T = operating temperature at the meter.

ρ = density of injectant at 14.7 psia and 70°F.

P_o, T_o, ρ_o = air parameters at STP.

SCFM = read from chart furnished by the manufacturer.

For the injected gas to be effective as a coolant it is necessary that there be minimal mixing of the main stream and injected flow. To minimize mixing an attempt was made to match the velocity of the injectant gas to that of the local free stream in the subsonic portion of the nozzle. We have

$$V_{slot} = \dot{m}_{inj}/\rho A.$$

$\dot{m}_{inj}$ = mass flow rate of injected gas as determined from the rotameter.

ρ = density of injected gas at the slot.

A = area of the slot.

Table 1 presents the results for the three slots in the subsonic portion of the nozzle. To match velocities the free stream velocity was calculated at each slot location from one dimensional theory. At slot one we find

$$V_{slot, \; 1} = 78 \text{ ft/sec}$$

At slot two the free stream velocity is 134 ft/sec. and at slot three it is 557 ft/sec.

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Table 1. Slot Velocity as a Function of Injection.

SLOT NUMBER	PERCENT FLOW	INJECTION VELOCITY (ft/sec)
1	1 (CO_2)	75
	1 (Freon)	27
2	1 (CO_2)	70
	1 (Freon)	25
3	1 (CO_2)	151
	1 (Freon)	53

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From these calculations it appears that to match velocities for CO_2 would require an injectant flow approximately equal to 1 percent of the main flow at slot 1, 2 percent at slot 2, and about 4 percent at slot 3. Since there are slots on both the top and bottom of the nozzle this would imply that about 14 percent mass flow would be required to match velocities if all three subsonic slots were used at the same time. The experimental results indicated that matching at the first pairs of the slots was more important in maintaining a smooth flow field than matching at the third slot. At the third slot the pressure gradient is so favorable that even without matching the injected layer moves along the wall without much mixing.

The Schlieren apparatus was standard. The light source was a spark type light with a spark duration of approximately 2 microseconds.

Results

Gas was injected into the free stream through individual slots or combinations of slots. The injected flow as a percentage of the free stream, no-injection, flow rate varied at single slots from .1 to 18 percent. Table 2 presents a summary of the flow conditions used for the photographic plates.

Plate 1 is a view of the nozzle in place in the wind tunnel. Plates 2 and 3 show the effect on the flow pattern of low versus high injectant rates for injection in slot one only. Note that with a low injectant rate the injectant tends to become well mixed with the free stream and does not maintain a well defined boundary layer as well as with the high injectant rate. The high injectant mass flow rate also maintains a better defined injected layer through the throat area thus providing better thermal protection.

Plates 4 and 5 show low and high Freon-12 injectant rates through slot 2, the position of which is noted by the dark vertical line. It was possible to match the velocities of the free stream and injectant, but even with the velocities matched the thermal protection provided does not appear to be nearly as effective as when injecting through slot 1. Plates 6 and 7 show low and high injectant rates through slot 3. The injected layer is much thinner and tends to be "swept away" much quicker by the free stream.

Table 3 shows the percentage of the geometric throat area that is occupied by the injectant gas under different injection conditions. These data were obtained by direct measurement from photographs. Note that in general as the injectant mass rate increases the area available

Table 2. Flow Conditions for Plates 2-15.

PLATE	SLOT 1 $\dot{m}_1/\dot{m}^*_{inlet}$	SLOT 2 $\dot{m}_2/\dot{m}_{inlet}$	SLOT 3 $\dot{m}_3/\dot{m}_{inlet}$	SLOT 4 $\dot{m}_4/\dot{m}_{inlet}$
2	3%#	0	0	0
3	9	0	0	0
4	0	3	0	0
5	0	12	0	0
6	0	0	3	0
7	0	0	18	0
8	0	0	0	0.5
9	0	0	0	12
10	6	6	6	0
11	6	6	0	0
12	porous nozzle			
13	6	6	6	0
14	9	9	0	0
15	0	0	0	12

*Calculated fron one-dimensional flow theory.

#Injection from both sides so 3% is 6% total injection from both Slot 1's, etc.

Table 3. Percent Throat Area Required by Injectant.

INJECTANT	% $\dot{m}_{inlet}$	SLOTS	% THROAT AREA OCCUPIED BY INJECTED FLUID#
CO_2	3	1	7.7
CO_2	6	1	11.3
CO_2	9	1	18.3
CO_2	12	1	26.2
CO_2	3	2	5.08
CO_2	6	2	6.67
CO_2	12	2	12.5
CO_2	18	2	14.3
CO_2	12	1,2	25.8
F-12	3	1	14.3
F-12	3	2	16.9
F-12	9(3)*	1,2,(4)	17.2
F-12	12	2	30.0
F-12	12	1	28.6
F-12	36(12)	1,2,(4)	28.6

#Percent area figured on nozzle half-width and injection from one side.

*Numbers in parens are injection from Slot 4 which does not affect the throat flow.

to the free stream decreases but not in proportion to the injectant rate increase. This suggests that there is some optimum upper limit on the amount of gas injected.

The only difference that could be noted in the flow field for injection of CO_2 and Freon-12 was that the Freon-12 tended to enlarge the injected layer to a greater extent than the CO_2. This resulted in a larger portion of the throat area being occupied by the Freon-12.

Plates 8 and 9 show low and high injectant rates into the supersonic portion of the nozzle. The free stream Mach number at this position is approximately 2.5. Here again high mass flow rates tend to maintain a thicker injected layer for a longer distance along the nozzle. These photographs compare favorably with photographs taken in reference [9] where the injected gases were CO_2 and He at 500°R.

The injectant rates that would optimize the cooling of the nozzle would be some combination of injectant through several pairs of the slots. Plate 10 shows one possible combination that appears to offer a resonable choice of injectant rates. The flow through slot 1 establishes the thickness of the injected layer, while flow through the other slots provides additional thermal protection and maintains the cool layer at the wall. Plate 11 is for a similar condition but with injection from the first two slots only. Plate 14 indicates clearly the injected flow at slightly higher injection rates.

A considerable effort was directed at obtaining comparable flow visualization photographs with a porous nozzle. These results have been presented in [2]. In general the slotted nozzle performed better than the porous nozzle. The slotted nozzle provided thicker and better defined injected layers. With the porous nozzle it is impossible to match the injectant and free stream velocities even in the slow speed, upstream region of the nozzle. Plates 12 and 13 show flow with comparable injectant amounts for the slotted and porous nozzles.

Plate 15 is a close up with injection from the fourth slot only. Here we have a subsonic injection into a supersonic main stream flow.

For all of these cases it can be seen that injection does not disturb the mainstream flow pattern markedly from that found with no injection.

It is possible to calculate an approximate value for the blowing parameter, λ, from the data. The mass flow to each section was metered. Knowing the injection area the product $(\rho V)_{inj}$ can be calculated. The product $(\rho V)_\infty$ can be determined from one dimensional flow theory without injection. These have been obtained using the area ratios at the slot locations. The value of $(\rho V_{inj}/(\rho V)_\infty$ thus obtained is noted in Table 4.

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Table 4. Blowing Parameter λ as a Function of Injection.

| SLOT | $\lambda = (\rho V)_{INJ}/(\rho V)_{\infty}$ | | | |
| | $\dot{m}_{inj}/\dot{m}_{inlet}$ | | | |
	1%	3%	6%	10%
1	66	198	396	660
2	38	114	228	380
3	12	36	72	120
4	5	15	30	50

For slot 1, $(\rho V)_\infty$ is quite low so λ is very large. In turn this means that a thick injected layer can be expected. This is verified in the plates. This layer is carried smoothly through the throat, and with additional, but lesser, injection at the throat should provide good thermal protection for the wall. Not surprisingly, λ is smallest in the throat and supersonic regions and injection there provides only a thin layer.

The qualitative agreement between these figures for compressible flow and the previous figures for flow on the water table is good. On the water table, injection in the subsonic regions also produced a thick layer, but transonic injection results in only a thin layer.

In order to quantify the wind tunnel results, pressure transducer studies were made at positions along the nozzle centerline and near the injection slots. Tests were made to establish the pressure field without injection and then were redone with injection. The pressure distribution along the centerline was unaffected by injection. For pressure data taken at the slot in the injected fluid itself only very small changes were noted and then only at the largest injection rates. Thus the transducer data compliments the photographic results and also indicates that the effect of large injection is to not significantly alter the flow field.

DISCUSSION AND CONCLUSIONS

While no direct analogy could be established between compressible and incompressible flow, both with injection, analogous behavior was noted. For the case of no injection the hydraulic analogy indicates that Froude number results are equivalent to Mach number results for a gas with $\gamma = 2$. With injection such a simple relationship could not be established [2], but the results clearly indicate that water table results can be used to predict qualitatively what changes will take place in a gas nozzle with injection.

The incompressible experimental results for the slotted nozzle show that even with massive injection (where $\dot{m}_{inj}$ is of the order of 20 percent of the inlet mass flow) the main stream flow is not seriously disturbed. A one-dimensional analysis could probably be used to estimate the flow field if the area used in the calculation were the actual geometric area less the area required for the injected layer.

The compressible experimental results, obtained with the Schlieren system to visualize the flow field, also indicate that massive injection does not cause unusual phenomena to occur in the flow. The injected layer stays close to the wall and does not, for example, mix rapidly with the core flow. A potential problem noted and discussed in [2] was that it was difficult with the *porous* nozzle to obtain a thick blown layer at the throat. We find in this work that one can obtain a thick wall layer at the throat by injecting fluid through the slots upstream of the throat. It is the conclusion of this report that the slot nozzle represents a better potential design for cooling a gas core nuclear rocket nozzle than does the porous nozzle. The flow field is not adversely affected by large injection and using discrete slots one can control the placement of the coolant with a good degree of accuracy.

NOMENCLATURE

A = flow area

B = width of flow

F = Froude number, $V/\sqrt{gH}$

H = height of fluid

M = Mach number

$\dot{m}$ = mass flow

P = static pressure

R = gas constant

T = temperature

V = flow velocity

v_w = injection velocity

ρ = density

λ = blowing parameter

Subscripts

inj = injected

inlet = at inlet to nozzle (before injection)

o = stagnation conditions

slot = at a slot

th = nozzle throat

w = at the wall

∞ = at main stream conditions

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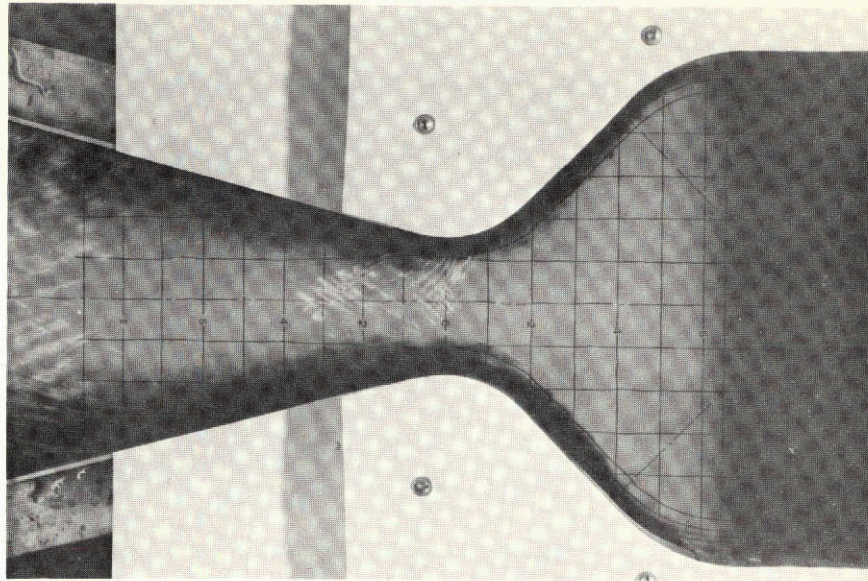
Figure 1   Water Table, Injection in top and bottom. Mass injection rates are, slot 1: 3.6%, slot 2: 6%, slot 3: 3.5%, total 26.6%
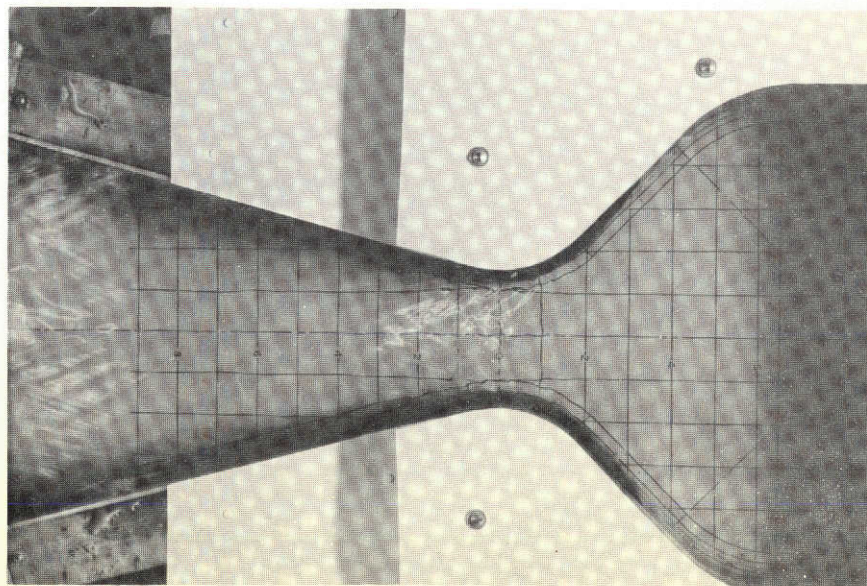
Figure 2   Water Table, Injection from slot 2 only . Mass injection rate is 3.6%.
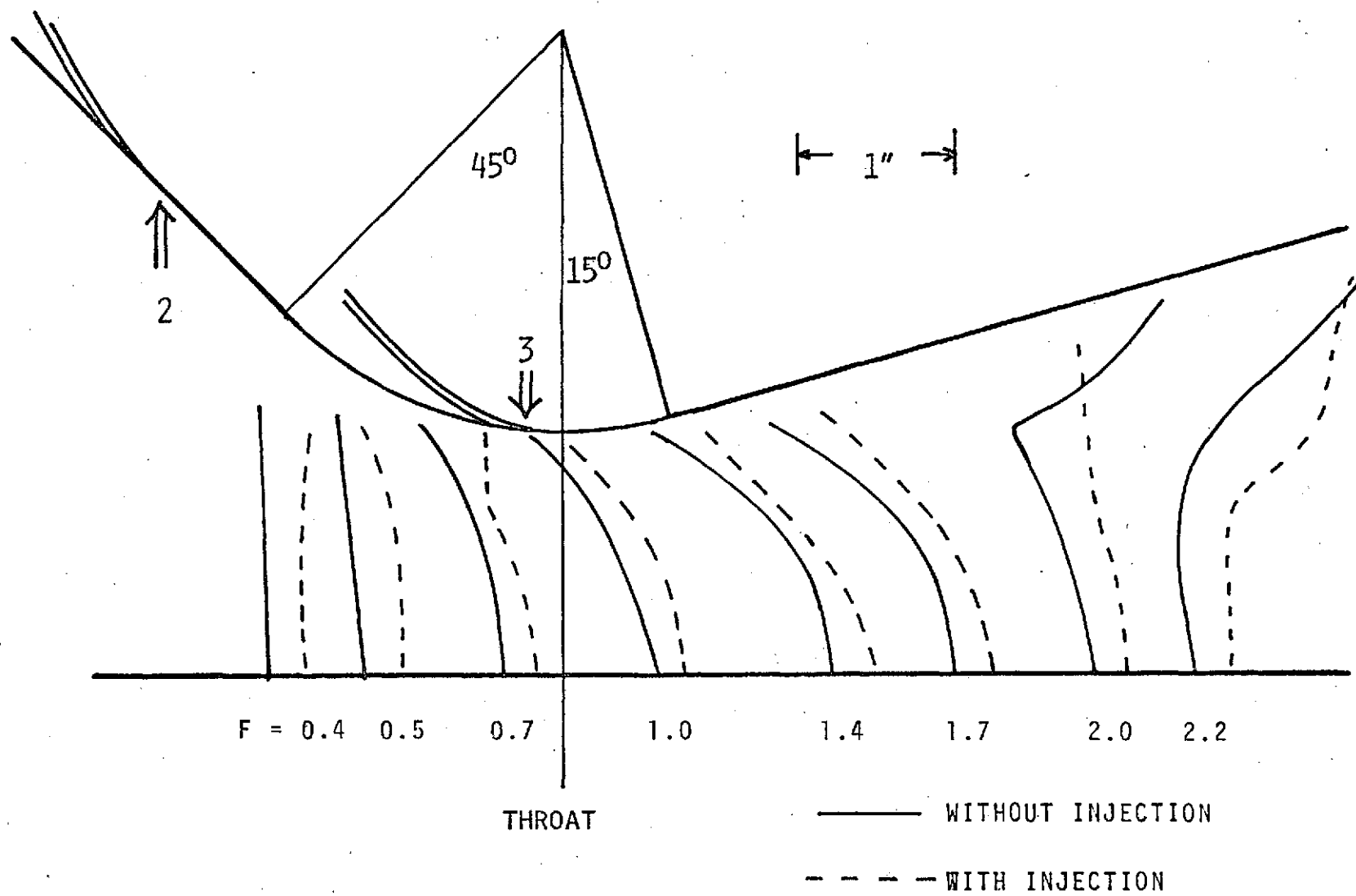
FIGURE 3   EFFECT OF INJECTION ON FROUDE NUMBER DISTRIBUTION
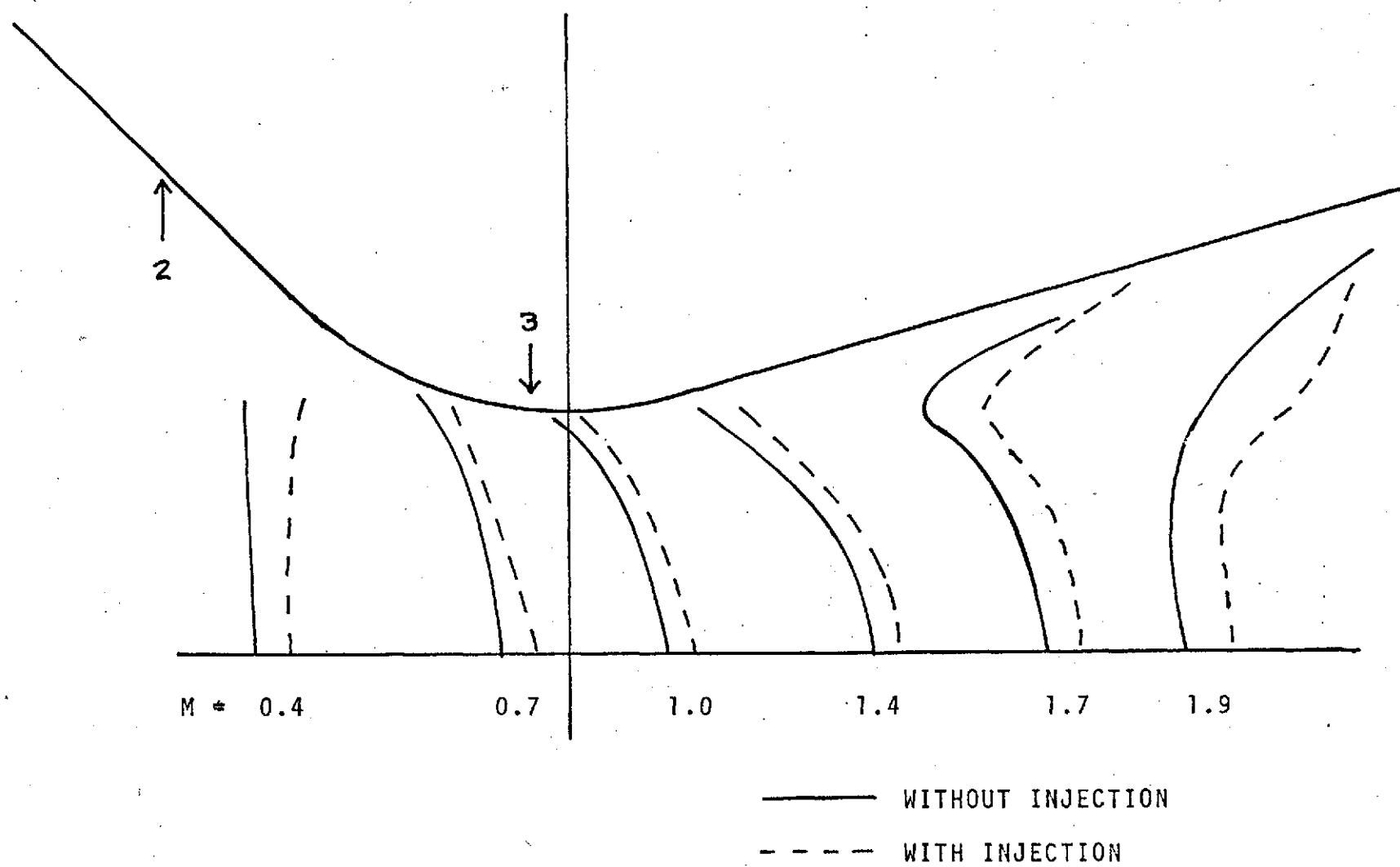
FIGURE 4   EFFECT OF INJECTION ON MACH NUMBER DISTRIBUTIONS

SLOT 1   SLOT 2   SLOT 3   SLOT 4
(0.031 in.) (0.035 in.)(0.030 in.)(0.0625 in.)

FLOW

SHIM   PLENUM AREAS   SHIM
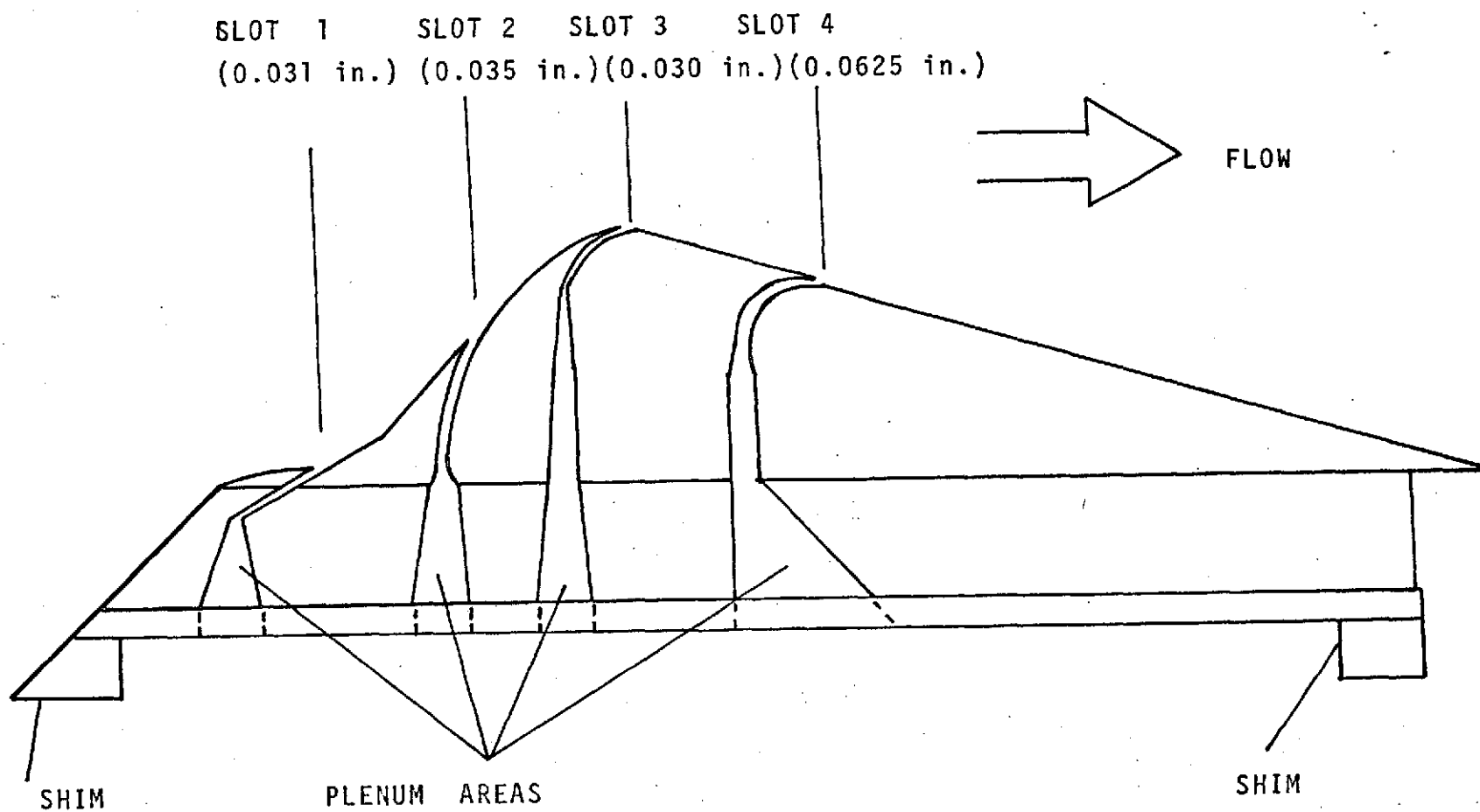
FIGURE 5   DIAGRAM OF NOZZLE SECTION
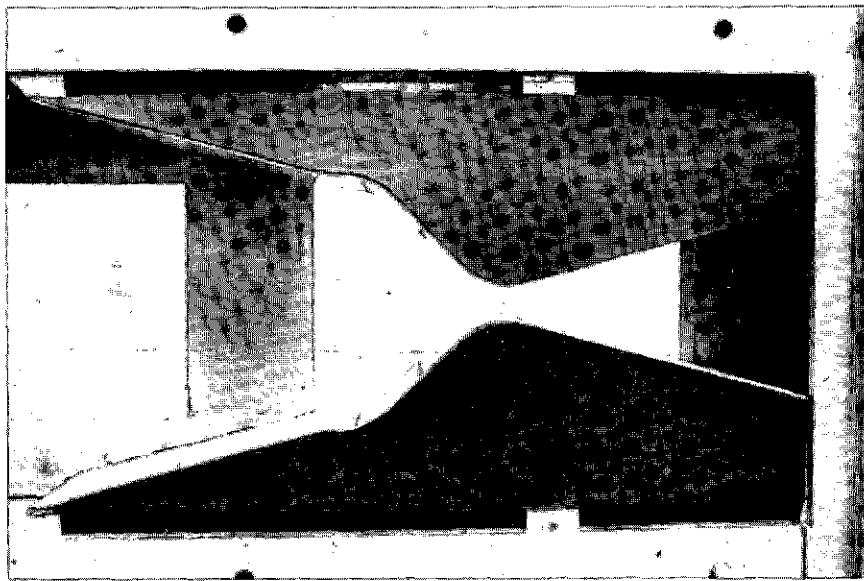
PLATE 1   SLOTTED NOZZLE IN POSITION
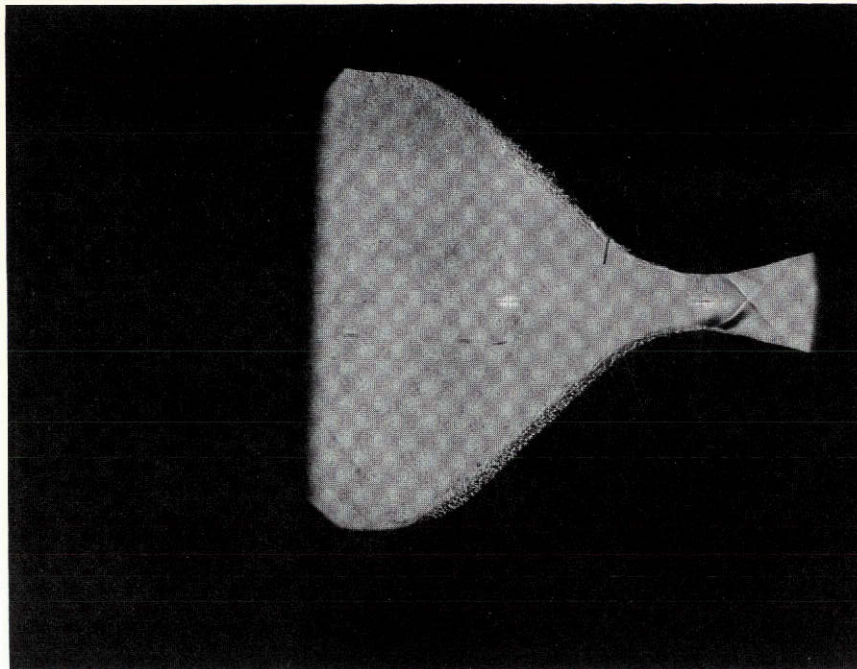
PLATE 2   INJECTION FROM SLOT 1
(CO_2 at 3 percent)
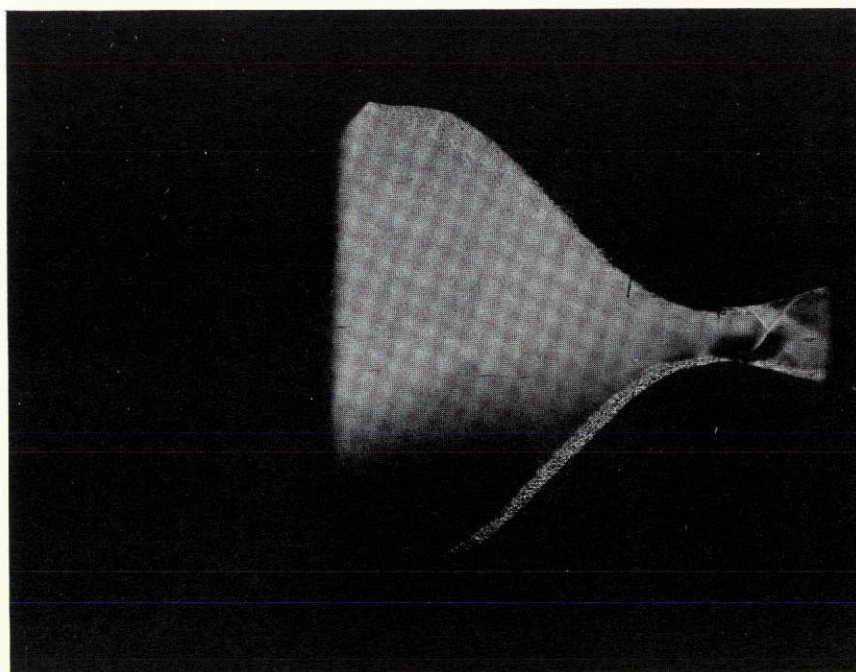
PLATE 3   INJECTION FROM SLOT 1
(CO_2 at 9 percent)
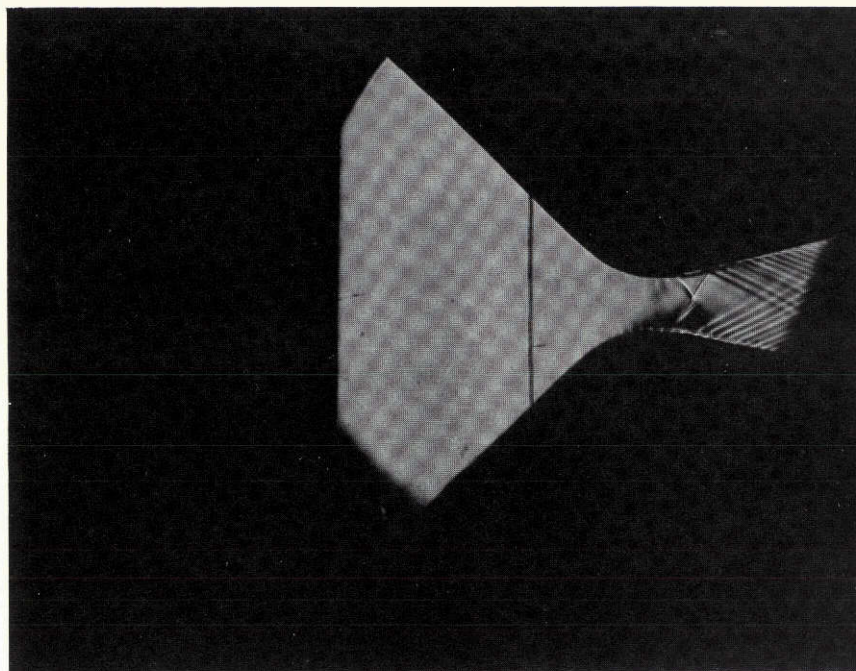
PLATE 4   INJECTION FROM SLOT 2
(FREON-12 at 3 percent)
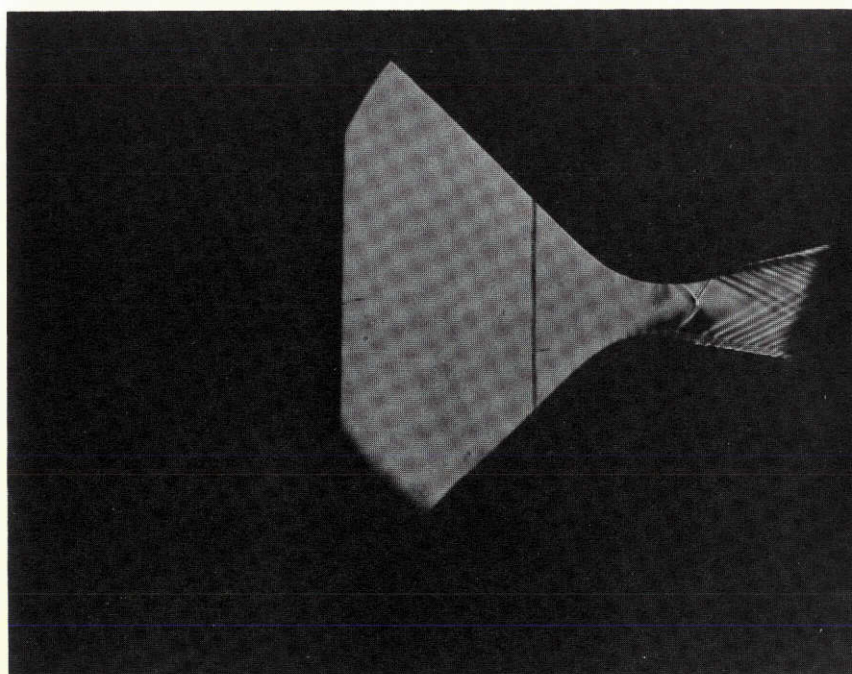
PLATE 5   INJECTION FROM SLOT 2
(FREON-12 at 12 percent)
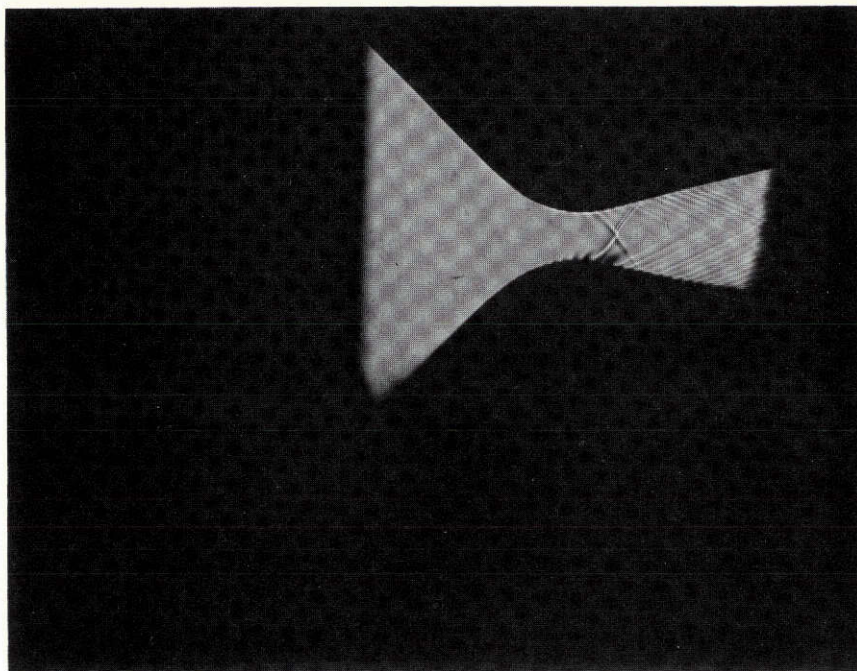
PLATE 6   INJECTION FROM SLOT 3
(CO$_2$ at 3 percent)
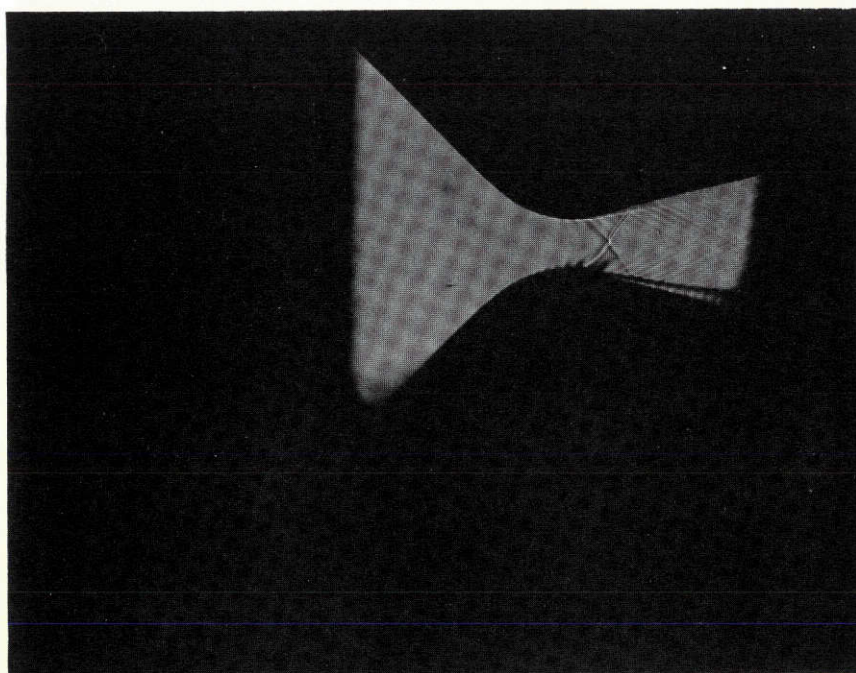
PLATE 7   INJECTION FROM SLOT 3
(CO$_2$ at 18 percent)
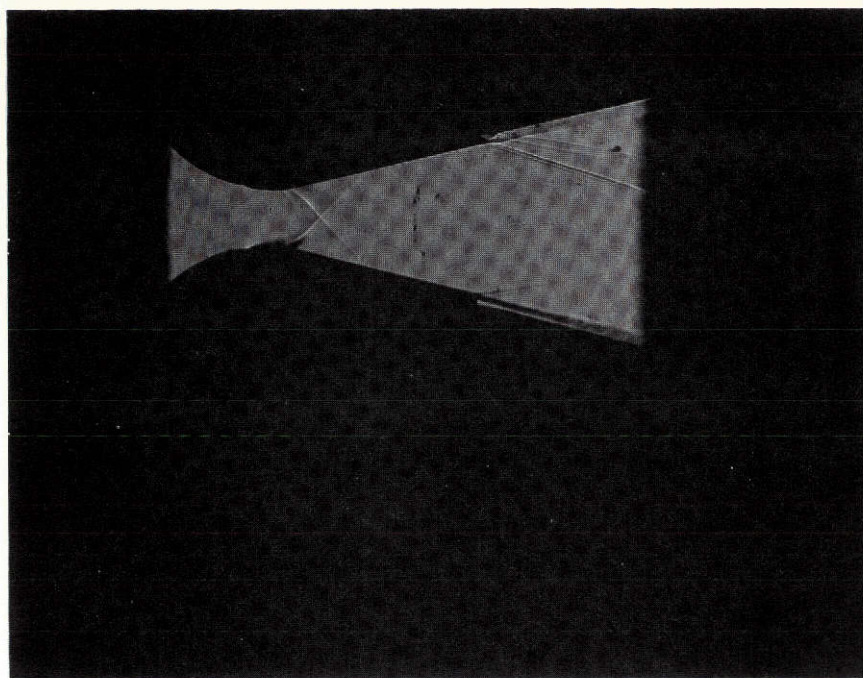
PLATE 8   INJECTION FROM SLOT   4
(CO$_2$ at 1 percent)
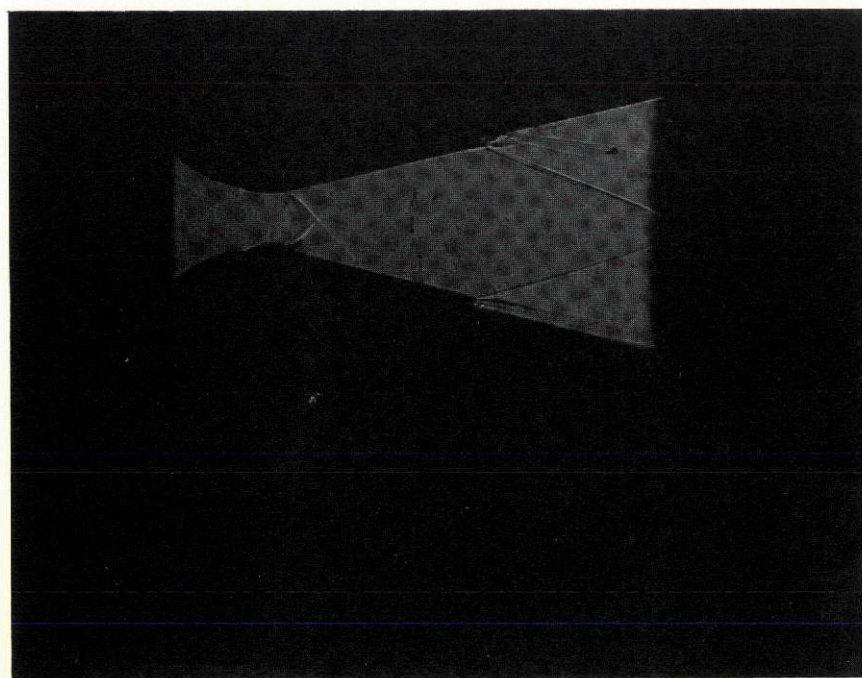
PLATE 9   INJECTION FROM SLOT   4
(CO$_2$ at 12 percent)
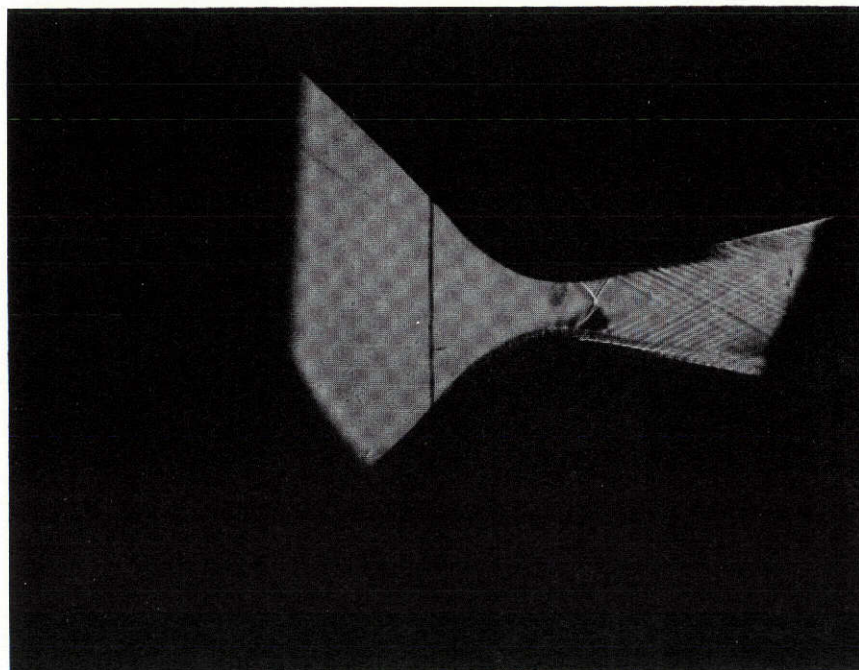
PLATE 10   INJECTION FROM SLOTS 1, 2, and 3
            (CO_2 at 6 percent from each slot)
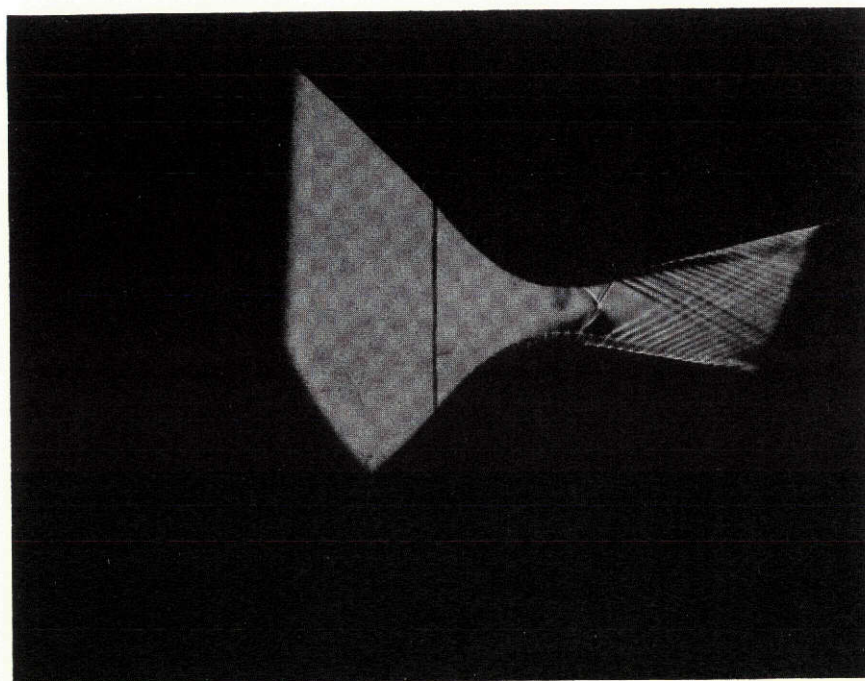
PLATE 11   INJECTION FROM SLOTS 1 and 2
(CO$_2$ at 6 percent from each slot)
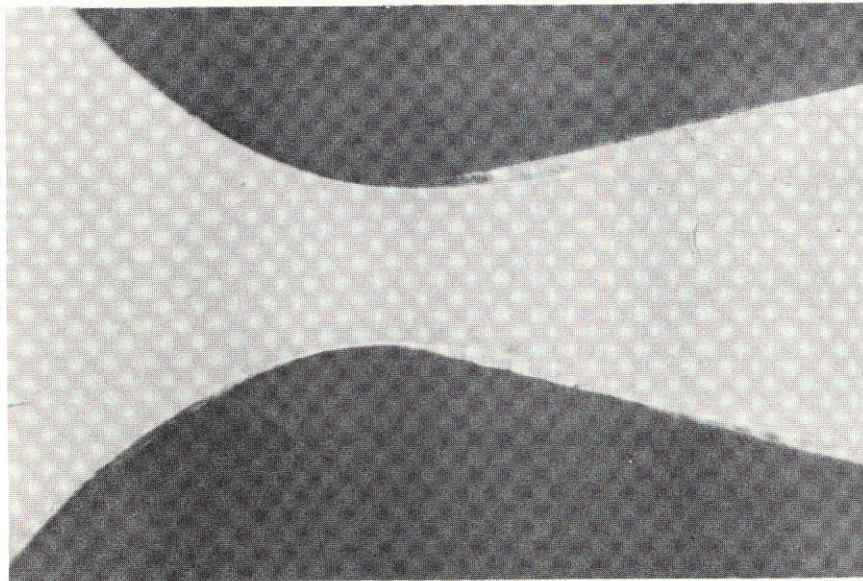
PLATE 12   INJECTION THROUGH A POROUS NOZZLE
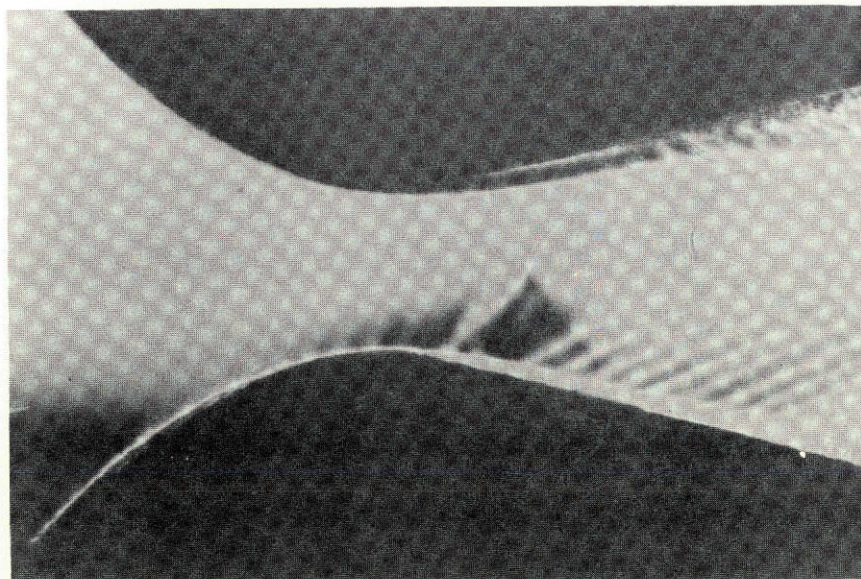(FREON-12 at 6 percent from each section)

PLATE 13   INJECTION FROM SLOTS 1, 2 and 3
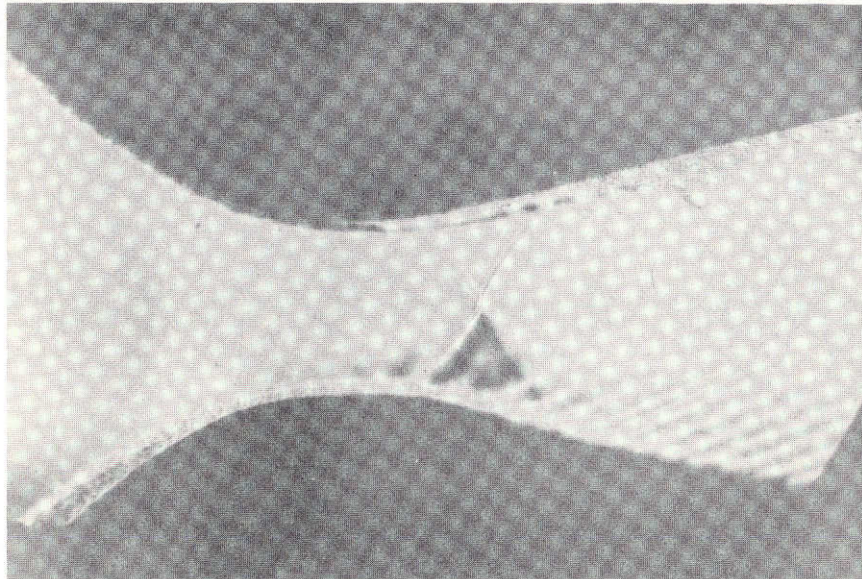(FREON-12 at 6 percent from each slot)

PLATE 14   INJECTION FROM SLOTS 1 and 2
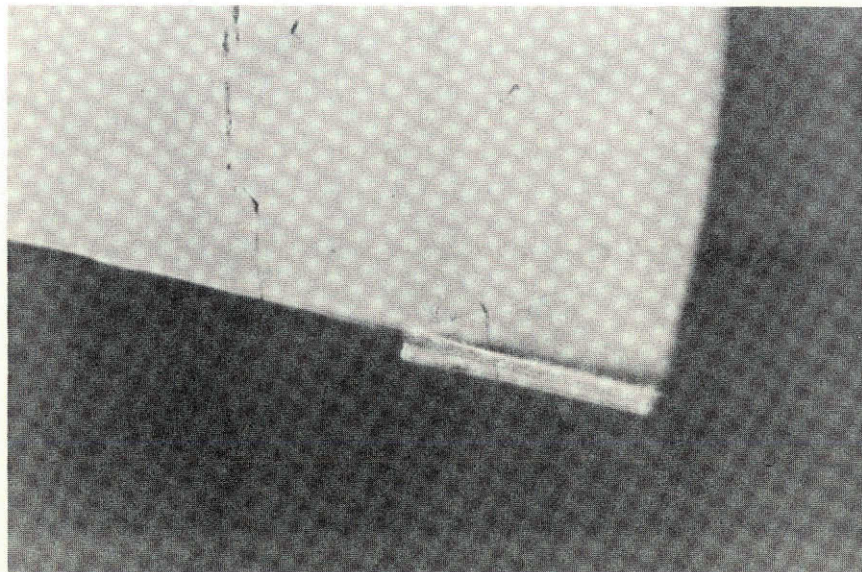(CO$_2$ at 9 percent from each slot)

PLATE 15   INJECTION FROM SLOT 4
(FREON-12 at 12 percent)