# Intermittency in a Highly Accelerated Boundary Layer

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RESULTS of Ref. 1 revealed a new outer region associated with the turbulent boundary layer in a highly accelerated flow that differed appreciably from the intermittent outer region of a boundary layer in unaccelerated flow. The wake region normally associated with an unaccelerated boundary layer was found to disappear when the flow was accelerated. In addition, the accelerated boundary layer appeared to discharge ("detrain") mass rather than entrain freestream fluid. In this case the boundary layer appeared to develop within the wake of a much thicker upstream boundary layer. It was further demonstrated in Ref. 1 that the "detrained" layer of fluid was rotational and essentially inviscid.

A boundary-layer velocity profile which was measured in the accelerated flow of a conical nozzle Ref. 2 also contained a thick wake region of the type observed in Ref. 1. The conical nozzle of Ref. 2 was preceded by a pipe inlet which permitted the development of a relatively thick turbulent boundary layer ($\delta \approx 0.5$ in.) at the nozzle entrance. In view of the more recent results of Ref. 1, it would appear that the thick wake region of the boundary layer in the nozzle of Ref. 2 was the result of a "detrainment" of fluid from the thick boundary layer, which had developed in the pipe inlet. In order to gain insight concerning certain aspects of the turbulence structure of these "detraining" boundary layers, a hot wire probe was used in conjunction with the nozzle of Ref. 2 to measure the distribution of intermittency factor (fraction of time turbulence is present) in the accelerated boundary layer. The results of the intermittency measurements reported herein were obtained at a stagnation pressure which was sufficiently high to prevent laminarization of the turbulent boundary layer which developed in the pipe inlet. The effect of stagnation pressure on the intermittency and turbulence intensity measurements are presented in Ref. 3.

The experimental apparatus comprised a 6.5 in. inside diameter by 17.0 in. long pipe inlet coupled to a 30° half-angle of convergence by 15° half-angle of divergence conical nozzle (Ref. 2). The nozzle throat diameter was 1.5 in. Air at a stagnation temperature of 550°R and stagnation pressure of 300 psia was accelerated from Mach 0.03 in the pipe inlet to Mach 0.08 at the boundary-layer survey station in the nozzle.

A probe containing a 0.0002 in. diameter by 0.10 in. long tungsten hot wire was installed at the Mach 0.08 station in the nozzle. The probe was traversed point by point in a plane normal to the nozzle wall, starting in the freestream and proceeding until contact with the wall was achieved.

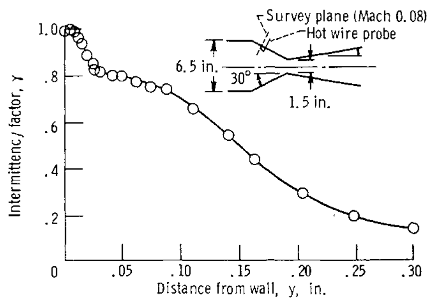


**Fig. 1 Distribution of intermittency factor in the nozzle; $T_0 = 550°$ *R*, $P_0 = 300$ psia.**

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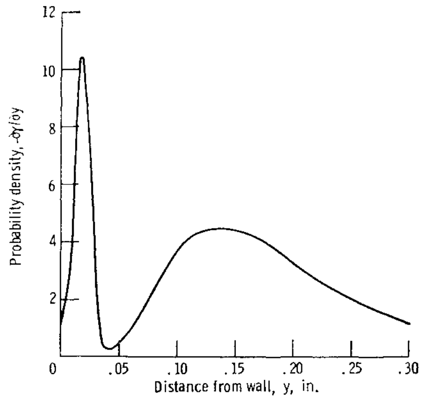


**Fig. 2 Probability density distribution of the instantaneous location of the turbulance front in the nozzle; $T_0 = 550°R$, $P_0 = 300$ psia.**

The signal from a constant temperature hot wire anemometer was filtered and fed through an intermittency circuit of the type described in Ref. 4. This circuit had provisions for a direct readout of the intermittency factor $\gamma$. The equipment was first used in a freejet in order to corroborate the results of Ref. 5 and thus provide a calibration of the instrumentation. The results of these freejet tests agreed within $\pm 3\%$ of the error function distribution of $\gamma$ given in Ref. 5.

The distribution of intermittency factor, $\gamma$ at the nozzle survey station is shown in Fig. 1. For flows with small pressure gradients, the intermittency factor varies according to the familiar Gaussian integral curve. The distribution in Fig. 1, however, deviates significantly from a Gaussian integral distribution especially in the near wall region ($y < 0.05$ in.). The general shape of the distribution suggests the existence of two distinct layers. The extent of the layers can best be determined by examination of the probability density of the instantaneous position of the front between turbulent and nonturbulent fluid. This probability density is proportional to the gradient of the intermittency as is shown in Fig. 2. The probability density distribution is composed of an approximate Gaussian distribution near the wall and a nonsymmetric distribution in the outer region. The junction of the distributions occurs at a position of $y = 0.035$ in. The outer portion of the distribution beyond $y = 0.035$ in. corresponds to the essentially inviscid thick wake region of the mean velocity profiles in Ref. 1. It therefore appears that the "detrained" layer of fluid is intermittent in nature and is about an order of magnitude thicker than the inner layer. These intermittency measurements complement the measurements of Ref. 1 and tend to substantiate the conclusion that the boundary layer is developed within the wake of the upstream boundary layer rather than in the free stream.

The composite distribution of the gradient of the intermittency factor of Fig. 2 obviously cannot be fitted to a single Gaussian form as has been conventional for lower pressure gradient flows. The shape of the distribution does suggest that it may be fitted, however, to a Gaussian distribution in the near wall region ($y < 0.035$ in.) and a log-normal distribution in the outer part ($y > 0.035$ in.). This then leads to an intermittency factor given by

$$\gamma = 0.405 \operatorname{erfc}[1.497(\ln y + 1.766)] + 0.085 \operatorname{erfc}[109.1(y - 0.0192)]$$

The first term of this relation describes the outer portion of the distribution and is described by a mean $\ln y$ of $-1.766$ and a deviation of 6.803. The second term describes the inner part of the distribution ($y < 0.035$ in.) and is described by a mean position of 0.0192 in. and a deviation of 0.00283. Although this relation closely fits the data presented herein, additional intermittency data should be obtained to verify the generality of the proposed function and the acceleration effects on the coefficients.


### References

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# Condensation in a Contoured-Nozzle Shock Tunnel


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## I. Introduction

ONE of the limiting conditions for a wind tunnel is established by the phenomenon of condensation. This occurs when the decreasing pressure and temperature of the expanding flow reach or exceed the air saturation "values." Therefore, for a given reservoir pressure there exists a minimum reservoir temperature necessary to prevent condensation and, hence, preserve the isentropic relationship required to obtain meaningful data. This required temperature has been shown to be somewhat below the theoretical prediction[1] for high Mach number because of an apparent supersaturation.[2–4]

Daum and Gyarmathy[3] have presented extensive data and empirical predictions for the degree of supersaturation possible in a blow-down type wind tunnel. They have shown that condensation at low pressures (<0.1 mm Hg) follows the predictions based on spontaneous nitrogen condensation, and that at higher pressures the seeding effects of small amounts of $H_2O$ and $CO_2$ condensing earlier influence the onset of condensation. On the basis of these results Daum and Gyarmathy have devised a conservative formula for predicting the occurrence of condensation in wind-tunnel nozzles. The difficulty with using the formula is that in the pressure range where seeding is dominant, the experimental data are quite scattered. Therefore, although the work of Daum and Gyarmathy may serve as a reliable guide, the condensation measurements must be made in order to accurately determine the extent to which one may supercool the flow in a particular nozzle that lies in the above pressure range.

In this study the condensation point in a contoured nozzle shock tunnel was sought. Static and Pitot pressure, which have been shown to be sensitive to the onset of condensation were measured at constant reservoir pressure, while the reservoir temperature was decreased to obtain freestream temperatures below the theoretical saturation curve of Ref. 4. This report describes these measurements and their interpretation, which indicate that only little supercooling can be obtained.

## II. Facility and Measurements

The Aerospace Corporation contoured nozzle shock tunnel with throat sized to produce Mach number 14.5 was used in these tests. Reservoir pressure and shock Mach number were measured with two model 601H piezoelectric pressure gages (Kistler Instrument Corporation, Clarence, New York) positioned near the end of the 24-ft driven section. The test section measurements were made with two Pitot probes positioned on each side of a static pressure probe (Fig. 1). The static pressure probe was instrumented with two Aerospace Corporation piezoelectric pressure gages‡ mounted in tandem 29 in. and 31.5 in. aft of the sharp nose. The Pitot probes were instrumented with model LC 60 piezoelectric pressure gages (Atlantic Research Corporation, Alexandria, Va.).

Two reservoir pressure ranges were studied—the lower obtained with 5000 psi in the driver and the higher with 10,000 psi in the driver.

The requirement that the shock tube remain tailored while the reservoir temperature was varied placed constraints on the driver gas sound velocity, which was, therefore, altered by adding argon to the helium driver gas. Thus as shock Mach number $M_s$ was reduced from 3.98 to 2.49, the diaphragm pressure ratio $p_4/p_1$ was reduced from 340 with pure helium to 57 with the helium diluted with 7.5% argon. Some "equi-

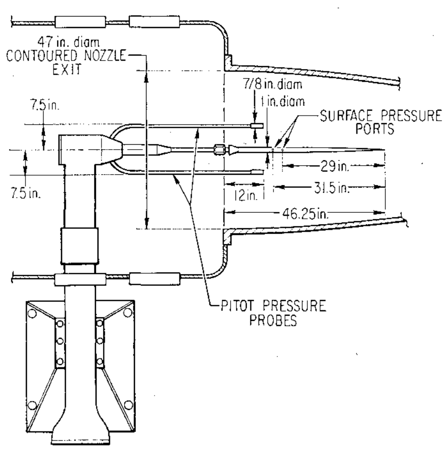


**Fig. 1 Instrument installation.**

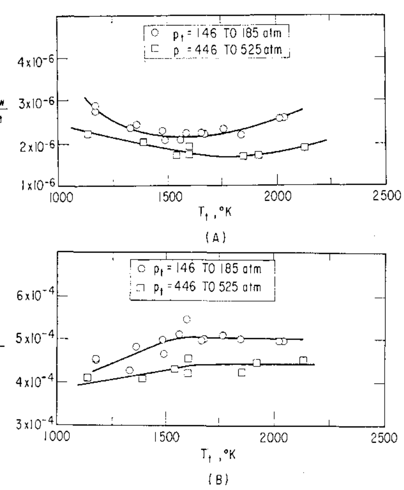


**Fig. 2 Effect of condensation on measured pressure; A) static pressure, B) Pitot pressure.**

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