Some Measurements on the Effect of Tripping the Two-Dimensional Shear Layer

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Introduction

IN comparing the half jet data of Liepmann and Laufer[1] (undisturbed turbulent mixing region) with that of Wygnanski and Fiedler[2] (tripped turbulent mixing region), differences in intensity levels and entrainment characteristics are in evidence. As suggested by the latter authors, these disagreements were possibly caused by their use of a splitter plate trip wire, an arrangement not utilized by Liepmann and Laufer. Bradshaw's studies[3] on the effect of initial conditions on development of a free shear layer similarly confirm this conjecture.

Important experimental results on the shear layer mixing process have also been published by such authors as Davies,[4] Sunyach and Mathieu,[5] Brown and Roshko,[6] Spencer and Jones,[7] and Champagne et al.[8] This evidence of continuing interest in the turbulent shear layer has prompted the current Note which documents comparative velocity measurements, undertaken some time ago[9] in an attempt to clarify the observed differences between the Liepmann and Laufer Wygnanski and Fiedler results. The present data therefore represent additional results on the effect of shear layer tripping and thus may prove of interest to those investigators currently studying the development and structure of the two-dimensional mixing region.

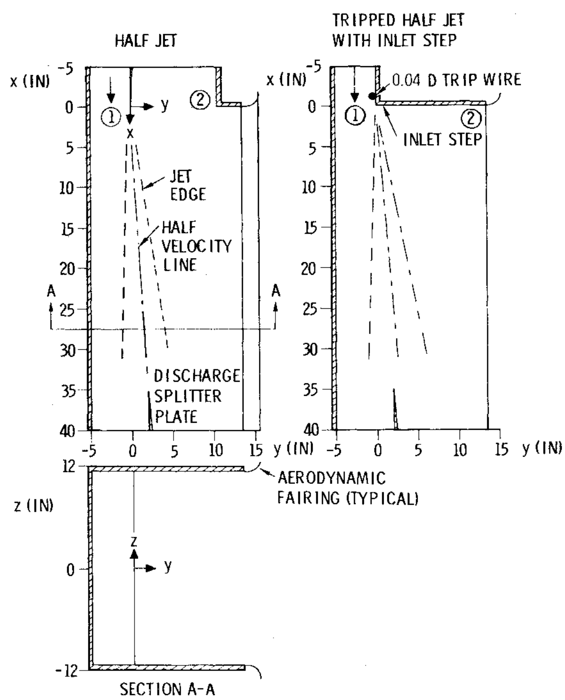

Fig. 1 Shear layer configurations.

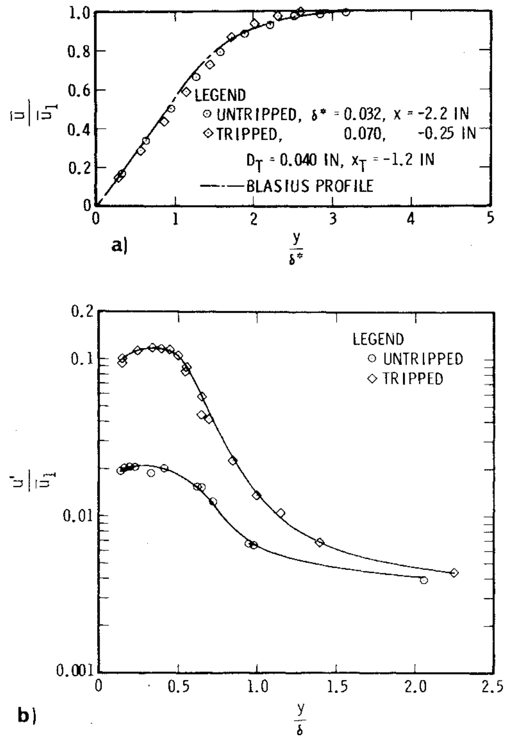

Fig. 2 Boundary layer profiles for inlet splitter plate. a) Mean velocity. b) Velocity intensity.

Experimental Technique

In order to study the effect of initial conditions on the development of the half jet flowfield, three jet configurations were investigated with hot wire anemometry. These included the undisturbed jet design,[1] the tripped half jet with inlet step, and the untripped jet with inlet step. The latter configuration, which is similar to the Wygnanski and Fiedler design but without the wire trip was found to give nearly identical results to the Liepmann and Laufer configuration and thus only limited data on this design will be presented herein.

The mixing region flowfields investigated (Fig. 1) were established within the test section of a low-speed wind tunnel. For this recirculating facility core, flow velocities at the test section inlet (5 in. × 24 in.) were maintained at 50 fps, for all present results. The corresponding Reynolds number for the furthest downstream station investigated was approximately 7×10^5. Tunnel design characteristics were sufficiently optimized so as to reduce turbulent intensities in the core flow of the half jet to an acceptable 0.4%. All mean and fluctuating velocity data presented herein were obtained in the conventional manner

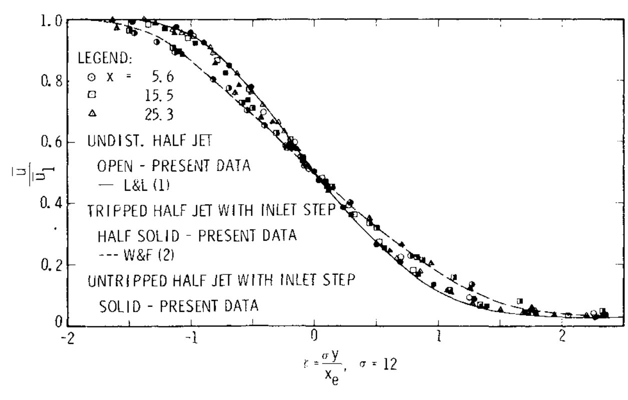

Fig. 3 Mean velocity profile summary.

Received July 17, 1974. This research was supported in part by Advanced Research Projects Agency under Contract F04701-70-C-0152. The author gratefully acknowledges the technical assistance of T. Kubota, California Institute of Technology and J. Laufer, University of Southern California.

Index categories: Jets, Wakes and Viscid-Inviscid Flow Interactions; Viscous Nonboundary-Layer Flows.

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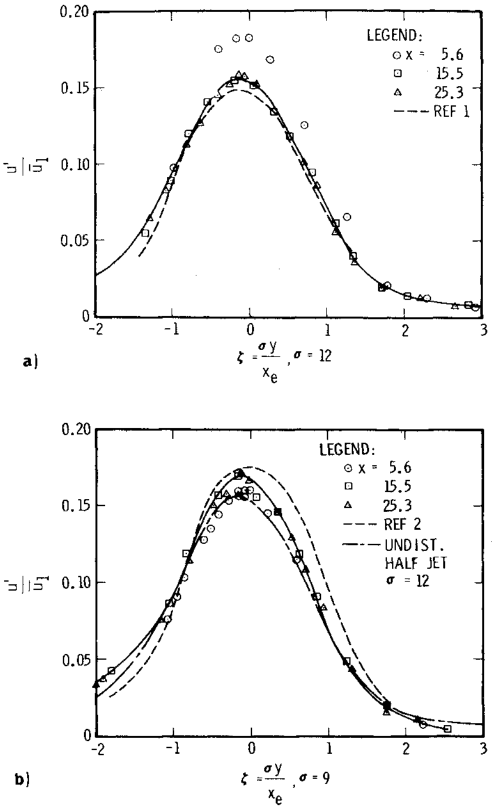

Fig. 4 **Velocity intensity profiles. a) Undisturbed half jet. b) Tripped half jet with inlet step.**

through use of a constant temperature anemometer and a single tungsten wire probe (0.00015 in. diam). A Thermo-Systems, Inc., linearizer provided analog output signals proportional to velocity.

Results

Splitter plate boundary-layer profiles are presented in Fig. 2 for configurations one and two. Both mean velocity profiles are seen to follow the laminar Blasius distribution while the rms velocity fluctuations for the tripped case are considerably higher than those for the untripped configuration. Clearly the wire trip was unsuccessful in "triggering" transition. This is not surprising since the freestream Reynolds number was only 1000 based on the undisturbed boundary-layer displacement thickness. Its main effects are the generation of large amplitude velocity fluctuations and the thickening of the boundary layer.

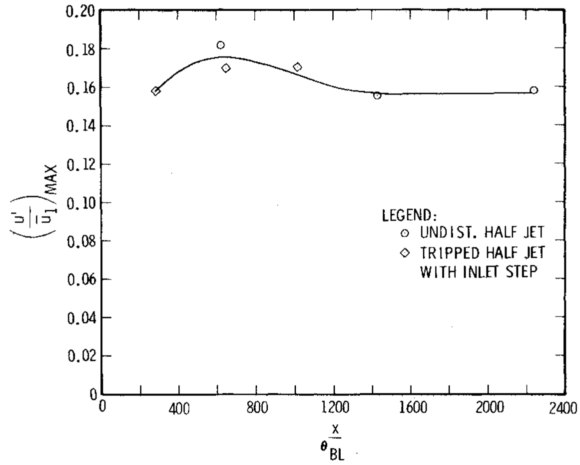

Fig. 5 Dependence of velocity intensity on normalized axial distance.

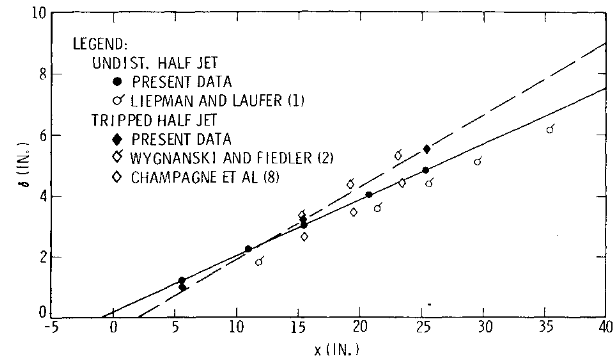

Fig. 6 Tangent slope thickness summary.

The consequences of these effects are considerable as shown in Figs. 3 and 4. Data for both the undisturbed mixing region and the tripped half jet with inlet step are presented on these figures. In general, the present data for the tripped and untripped cases reproduce in a favorable manner corresponding results of previous investigators. The difference in spreading rate between the cases in evidence on Fig. 3 requires, in order to bring the tripped data into agreement with the results for the untripped configuration ($\sigma = 12$), a diffusion parameter of roughly $\sigma = 9$ as noted also be Wygnanski and Fiedler. Also the lower values of fluctuating intensity at the downstream stations observed for the undisturbed half jet appear to be a real phenomena and primarily a function of the lower disturbance level for the inlet boundary layer and *not* the result of equipment sensitivity as suspected in Ref. 2. Another interesting finding from the intensity results of Fig. 4 is the variation of peak intensity with axial distance. In the undisturbed case the peak intensities decay initially whereas for the tripped case a growth behavior is exhibited. These trends as well as the differences in the downstream turbulence levels emphasize the importance of initial conditions to the development of the two-dimensional mixing region and are similar to the findings of Bradshaw[3] for his free shear layer studies. The mixing region results of Sato[10] also show a comparable dependence of transition onset on initial boundary layer properties. As suggested by Bradshaw, one approximate method for estimating the turbulent state of a shear layer is to examine the variation of maximum intensity with axial distance normalized by the initial boundary-layer momentum thickness. Figure 5 presents results of such a composite plot and the tentative conclusion is drawn that an axial distance greater than roughly 1500 momentum thicknesses may be required in order to achieve self-preserving flow for the turbulent mixing region. This compares with the value of $x/\theta_{BL} = 1000$ cited by Bradshaw from his studies. Again referring to Figs. 3 and 4 the commonly observed result for turbulent flows where mean properties achieve similarity "sooner" than turbulence quantities is clearly evident.

Further evidence of the sensitivity of the jet properties to initial conditions is given in Fig. 6 which shows the variation of the jet's tangent slope thickness with axial distance. These velocity results illustrate that good agreement exists between the spread rates (slope) as measured herein and by previous investigators for comparable configurations. The larger mass entrainment experienced by the tripped half jet is illustrated by the relatively faster rate of growth of thickness with axial distance for this configuration in comparison to the undisturbed mixing region. Additional discussion and further comparison of the present results with growth data measured by other investigators are given by Champagne et al.[8]

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Experimental Investigation of the Characteristics of a Hollow Cathode MPD Arc Thruster

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SEVERAL investigations have been made related to the physical processes involved near the cathode of an MPD arc thruster,[1,2] and some recent experimental results show that the thruster with hollow cathode is superior to that with conventional one in several respects as follows: thrust characteristics, thermal efficiencies, stability of operation, etc.[3,4] In the present experiments, operating characteristics under applied magnetic fields, such as the total reaction force (thrust), the reaction force which acts on electrode assembly or on magnetic coil, and the pressure at cathode tip, were evaluated for MPD arc thrusters with hollow and conventional cathode. And using these results, we investigated the difference between the physical processes involved in such thrusters.

Apparatus and Experimental Procedure

Figure 1 shows the MPD arc thruster used. The nozzle-shaped anode (copper) has a throat diam of 10 mm. Two types of cathode are used, which are a hollow cathode (tungsten tube of 6 mm o.d. and 3 mm i.d.) and a conventional cathode (6 mm diam tungsten rod with conical tip). In the case of conventional cathode, propellant is supplied through the port at the wall of arc chamber and in the case of hollow cathode, through the port at the cathode tip.

The electrode assembly was mounted on a parallelogram-pendulum thrust stand, and the electrical power for the arc was brought onto the stand through mercury pots. Deflection of the stand was sensed by a linear differential transformer. The total reaction force (thrust), T_t, was measured, mounting the magnetic coil on the electrode assembly. The reaction force which acts on the electrode assembly, T_{ea}, was measured, attaching the magnetic coil to the coil holder connected rigidly with a vacuum tank. In this case, the interaction force between current passing through the electrode assembly and applied magnetic field was excluded, evaluating it by reversing the direction of magnetic field. To check this technique, the interaction force was also measured at some operating points, using an electrode assembly in which the cathode is shorted to the anode. Using T_t and T_{ea}, the reaction force which acts on the magnetic coil, T_{mc}, can be obtained from $T_{mc} = T_t - T_{ea}$.

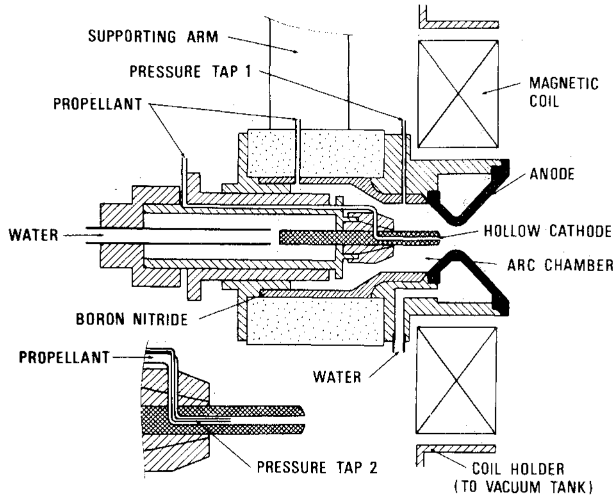

Fig. 1 MPD arc thruster used (hollow cathode is installed).

Two taps are provided for the measurement of pressure in the thruster. Tap 1, drilled through the insulator, senses the arc chamber pressure. In the case of conventional cathode, Tap 2 (2 mm i.d.) is located at the cathode tip, sensing a pressure which is approximately equal to the pressure at the center of cathode spot. In the case of hollow cathode, Tap 2, which is made of porcelain tube of 0.8 mm o.d. and 0.5 mm i.d., is located at 15 mm upstream from the tip in the passage of hollow cathode, because of experimental difficulty (see the magnified figure in Fig. 1). In the present experimental conditions, at the position of Tap 2, the dynamic pressure of flowing gas is less than one-tenth of the static pressure, and so it can be assumed that the pressure sensed by Tap 2 is approximately equal to the pressure of flowing gas.

All experiments used argon as the propellant and were conducted in a 0.5-m-diam by 1.2-m-long vacuum chamber. In these experiments the background pressure was maintained at about 5×10^{-2} torr. The experimental results shown in Ref. 5 suggest that the background pressure in the present experiments is not sufficiently low to obtain accurate data of performance; however, the results of the present experiments will be useful for the understanding of the physical processes involved. In the present experiments, arc current (I) was varied from 150 to 700 amp and propellant mass flow rate ($\dot{m}$), from 15 to 60 mg/sec, at applied magnetic field (B), measured at cathode tip, up to about 2000 gauss.

Results and Discussion

Figure 2 shows a typical example of the behavior of the total reaction force (T_t) and the reaction force on the electrode assembly (T_{ea}) vs the applied magnetic field, for the case of hollow and conventional cathode. In this experiment ($\dot{m}$: 30 mg/sec), the arc current was fixed at 700 amp, while the arc voltage increased, with increasing magnetic field, from 20 to 25 v

Received July 25, 1974.
Index categories: Electric and Advanced Space Propulsion; Plasma Dynamics and MHD.

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