AD-A094 626 STANFORD UNIV CA JOINT INST OF AERONAUTICS AND ACOUSTICS F/G 20/4
BASIC STUDIES OF MULTIPLE JETS AND WALL JETS.(U)
AUG 80 A KROTHAPALLI F49620-79-C-0189

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JOINT INSTITUTE OF AERONAUTICS AND ACOUSTICS
DEPARTMENT OF AERONAUTICS AND ACOUSTICS
STANFORD UNIVERSITY
STANFORD, CA 94305

STATUS REPORT

ON

BASIC STUDIES OF MULTIPLE JETS AND WALL JETS

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SUBMITTED TO THE

DIRECTORATE OF AEROSPACE SCIENCES
USAF OFFICE OF SCIENTIFIC RESEARCH
WASHINGTON, D.C.

FOR A PERIOD OF
JULY 1979 - AUGUST 1980

F49620-79-C-0189

BY

JOINT INSTITUTE OF AERONAUTICS AND ACOUSTICS
DEPARTMENT OF AERONAUTICS AND ACOUSTICS
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ABSTRACT

An experimental investigation of the flow field of an underexpanded rectangular jet issuing from a rectangular nozzle of aspect ratio 16.7 was undertaken. Tests were conducted for pressure ratios (settling chamber pressure/ambient pressure) ranging from 1.6 to 5.8. For pressure ratios greater than 1.9 the spectrum of the hot wire and microphone signals placed in the near field of the jet show discrete frequencies generally known as screech tones. At a pressure ratio of 3.7, Schlieren pictures show a distinct double wave pattern with their source being located at about 6 widths downstream. This results in an enhanced spreading of the jet as compared with other pressure ratios.

A series of experiments on unconfined multiple jets has been performed for pressure ratios ranging from 1.6 to 3.7. Schlieren pictures were obtained which shows that the individual jets do not attract each other and mixing with the ambient air (or secondary air) takes place quite independently. The importance of sound waves (generated in one of the jets) acting upon the neighboring jets is demonstrated. Using this technique, it is shown that the mixing can be enhanced.

STATUS OF THE EFFORT

In order to minimize errors in hot wire measurements, one of the steps taken is to maintain equal temperatures between the calibration gas and the test gas. The calibration gas is generally kept at room temperature (22°C). In the present set up, which is a blown down facility, the temperature in the settling chamber (see Fig. 1) varies considerably with changes in storage pressure, settling chamber pressure and ambient conditions, and generally below the room temperature. Thus, an attempt is made to bring the settling chamber temperature up to room temperature by installing a set of heaters in the air supply line as shown in Fig. 1. Figure 2 shows a typical calibration curve for settling chamber temperature (T_2) as a function of storage pressure (P_1) and number of heaters in use. As shown clearly, without the heaters the temperature of the gas for $P_1 < 2000$ psig is below the room temperature. With the use of heaters, this temperature is brought back to room temperature.

Flow Structure of a Single Rectangular Jet

Studies of the jet were made using Schlieren and shadowgraph techniques at pressure ratios varying from 1.6 to 5.8. Pictures taken looking at the narrow edge of the jet (in the plane containing the small dimension of the nozzle) are shown in Fig. 3. These pictures shown are for a range of pressure ratios varying from 1.6 to 5.8. Figure 3a represents a typical case of a subsonic jet at a pressure ratio of 1.6 or Mach number of 0.85. At pressure ratios greater than 1.9, shock cells are observed in regions close to the jet exit. Figure 3b shows the jet at a pressure ratio of 2.72. The picture shows sound waves eminating from the jet, and more spreading of the jet is noticed. As the pressure ratio increased to 3.7, an organized wave pattern appears in the near field of the jet as shown in Fig. 3c. The source of these waves on each side of the jet seem to be located at a distance of 6 widths downstream of the nozzle exit. Picture also shows a rapid spreading of the jet. At pressure ratios greater than 3.7, the organized wave pattern disappears and a decrease in spreading is observed as shown in Fig. 3d for a pressure ratio of 5.75.

The significant result obtained from these pictures is the spreading rate of the jet, which plays an important role in multiple jet mixing (see Reference 1). The flow considered here will spread linearly, i.e., $d\delta/dx = \delta' = \delta/x-x_0 = C$, where δ is some measure of the local scale of the flow, a thickness defined in some particular way. If an asympotic value of $\delta' = C$ can be determined from the picture, the x_0 is determined from the tangent, $\delta = C(x-x_0)$. Using this procedure, the spreading rate is obtained for various pressure ratios and is plotted in Fig. 4. It is noticed from this figure, at a pressure ratio of 3.7, the spreading rate is up by almost 50 percent when compared to the same at other pressure ratios. This gain in the spreading rate at a particular pressure ratio of 3.7 is yet to be understood. Some quantitative observations also can be made from these pictures, for example, the size of shock cell. The details of these results are presented in Reference 2.

The changes in mixing process can be related to the disturbances in the acoustic near-field of the jet. Thus, a more complete analysis of the frequency and amplitude of the sound waves in the near field as a function of pressure ratio was obtained. These results were obtained by analyzing the output of a microphone and hot wire located beside the jet as shown in Fig. 5. The results of this investigation are presented in Reference 2. One of the significant results from this investigation is the effect of the reflective surfaces near the nozzle exit. Using the reflective surfaces in order to enhance the visual character of the wave structure, previous investigators found the frequency of the normal radiation is twice that of the upstream and downstream radiation. While the present investigation shows the frequency of radiation is nearly equal in all directions, the frequency decreases continuously as the stagnation pressure increases. Experiments are conducted both with and without the reflecting surfaces near the exit. The results of this investigation is presented in Reference 2.

Some detailed measurements of the near flow have been obtained using the pitot-tube. The results are being analyzed at this time. The measurements of mean and turbulent velocity field using the hot-wire will be made during the next few months.

Flow Structure of Multiple Free Jet

To examine the mixing process in multiple free jet, short exposure (5 μs) Schlieren pictures were taken for the center three lobes at pressure ratios ranging from 1.6 to 5.8. Figure 6a represents a typical case of a subsonic jet at a pressure ratio of 1.6. As observed in an earlier investigation (Reference 1), the individual jets do not attract each other and mixing with ambient air takes place quite independently. Significant merging first seems to occur at a location of about 17 widths downstream of nozzle exit.

A picture of the jet for a pressure ratio of 2.42 is shown in Fig. 6b. As in the subsonic jet, mixing with ambient air takes place quite independently and merging first takes place around 12 widths. Figure 6c shows the picture for the jet at a pressure ratio of 3.7. It is observed that the mixing is quite enhanced, and the distinct wave pattern observed in a single jet is destroyed by the interaction of the individual jets.

For the configuration under investigation, it is found that the mixing is quite intense at a pressure ratio of 3.7. This is due to the fact that the spreading rate of a single free jet is quite large as shown in Fig. 4.

Detailed measurements of the mean and turbulent velocity field will be made during the next few months.

It has been shown that the nature of the flow from a nozzle can be greatly modified if sound waves are permitted to impinge upon the jet in the immediate neighborhood of the exit. This process generally produces a distinct vortex pattern and gives raise to oscillations of the jet column. A notable feature of such flow is the large angle of spread of the jet about 30°, in comparison with normal angle of about 18°. This is a result of engulfing the neighboring stream with the jet. This process is attractive in improving the mixing of multiple jets. Thus an attempt is made here to generate sound waves and impinge them on the neighboring jets. To generate the sound waves, the edge tone is used which is the sound resulting from the action of a jet emerging from a rectangular nozzle, and impinging on a wedge, systematically placed parallel to the long dimension of the nozzle. This arrangement is shown in Fig. 7. In this picture, jet is issuing at an exit Mach number of 0.85. Careful observation reveals the sound waves emanating from the jet column. These sound waves then propagate and impinge upon the neighboring jets (see Fig. 8). This action produces oscillations in the neighboring jets, and results in greater mixing between them. Figure 8 shows a picture of four jets with a wedge placed in one of them. Vortex pattern is clearly seen in the neighboring jets with enhanced mixing as compared to the jets without the wedge (see Fig. 6a).

This technique can be effectively used in improving the mixing in a multiple rectangular jet.

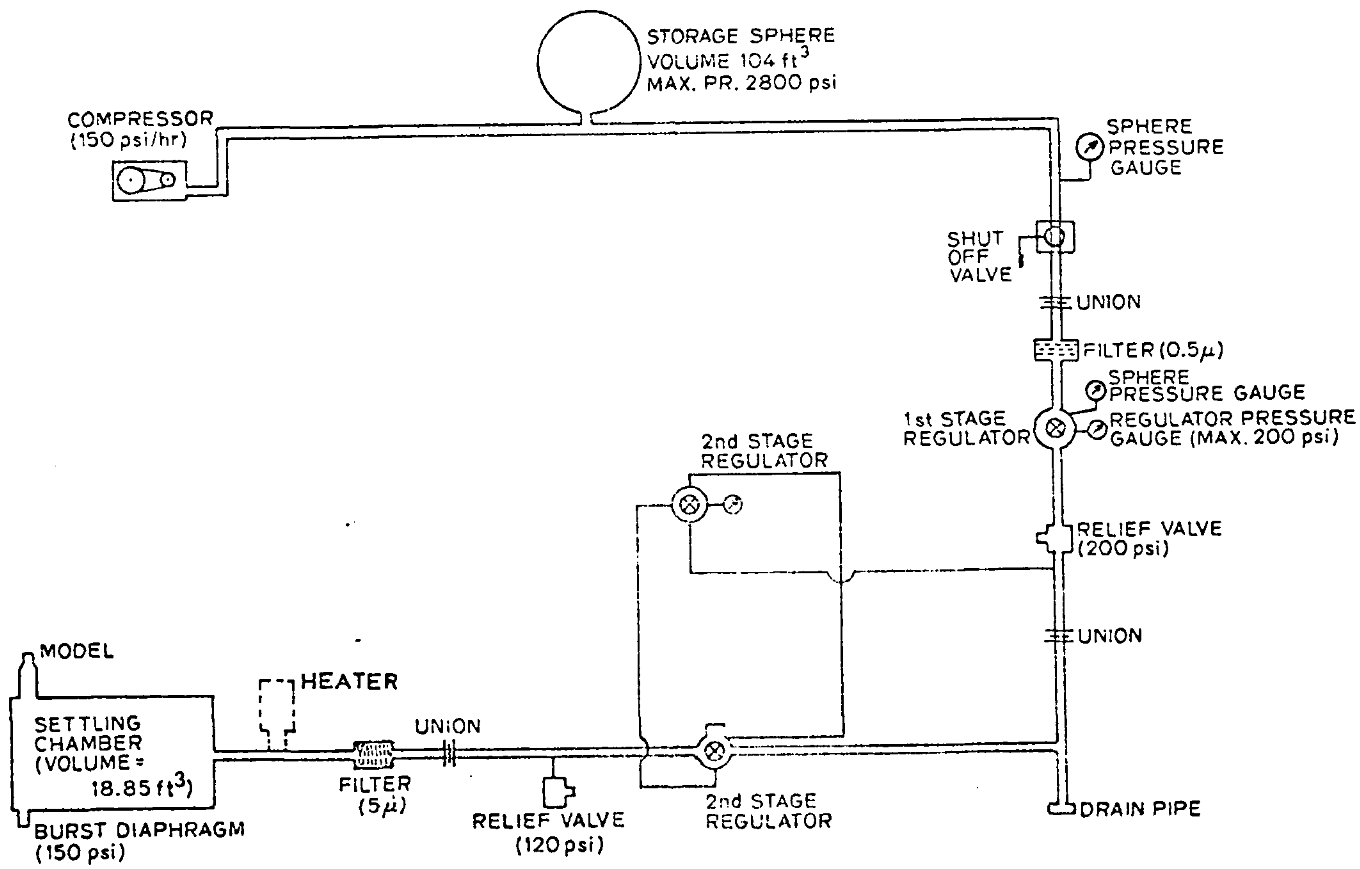


Fig. 1. Schematic of the Flow System.

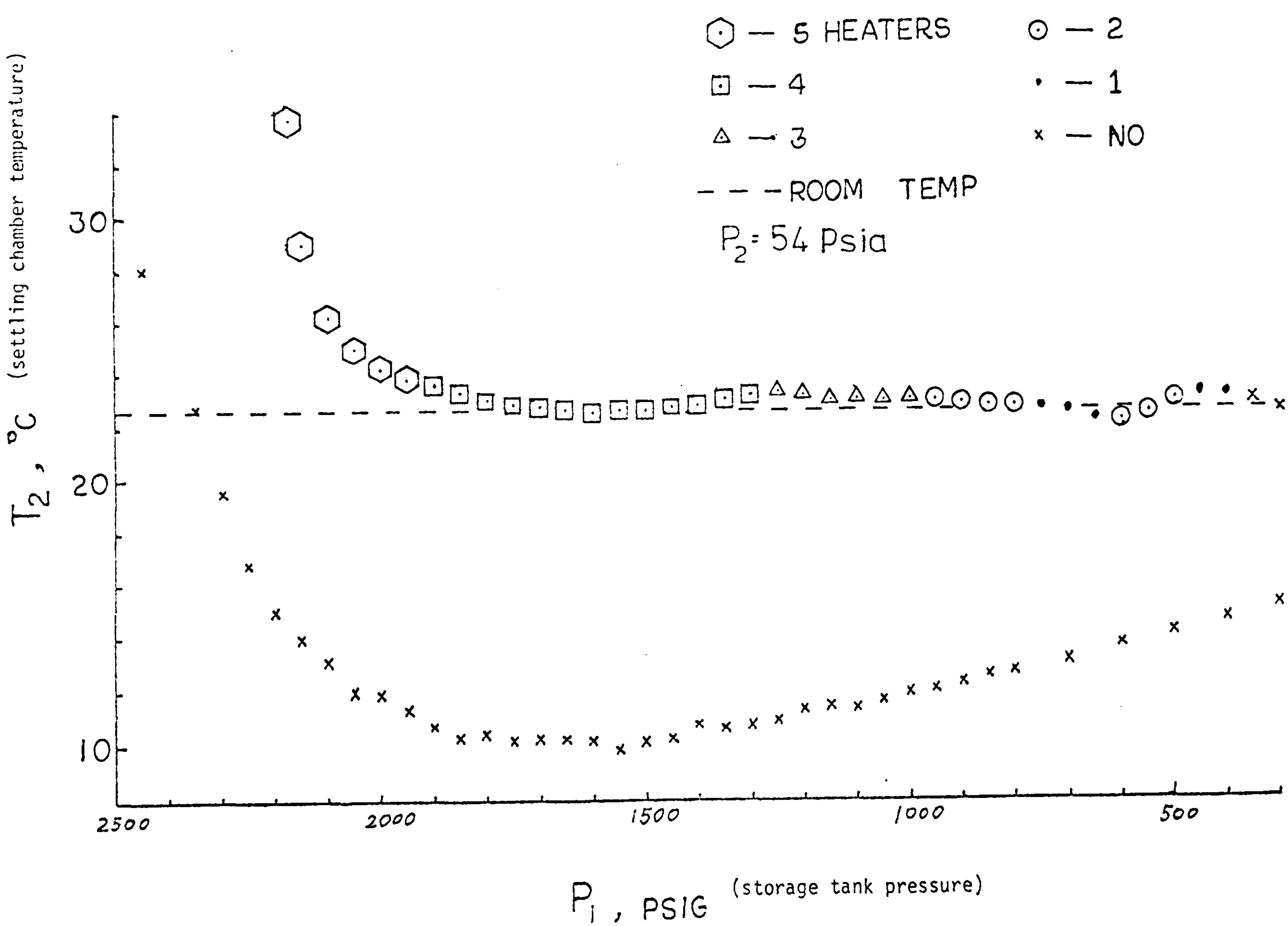
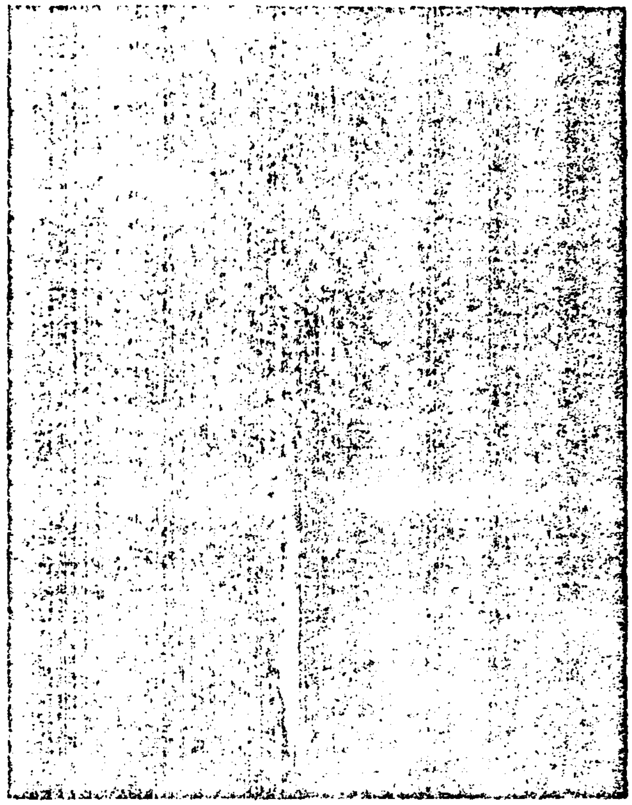
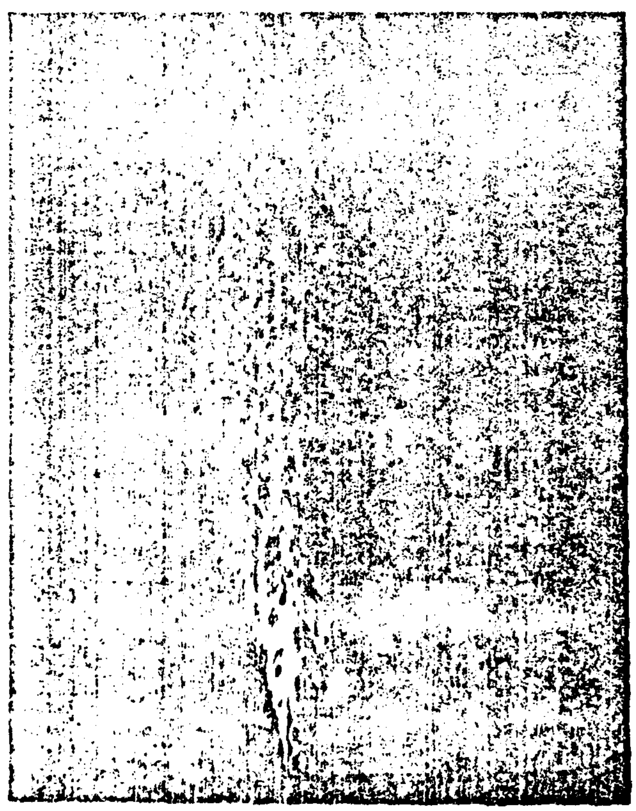


Fig. 2. Effect of Heaters on the Settling Chamber Temperature.

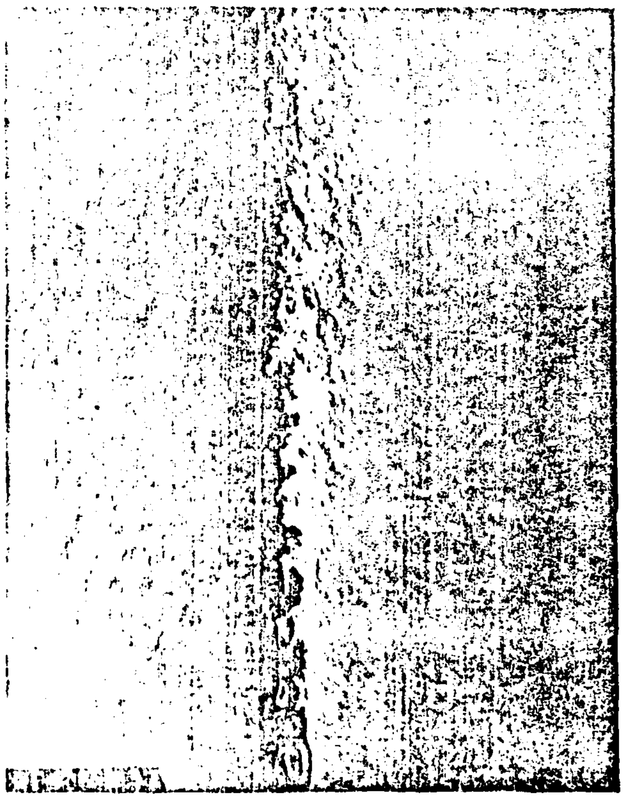


3a. $p_o/p_a = 1.6$



3b. $p_o/p_a = 2.7$

3c. $p_o/p_a = 3.7$



3d. $p_o/p_a = 5.75$

Fig. 3. Schlieren Pictures of the Jet at Different Pressure Ratios

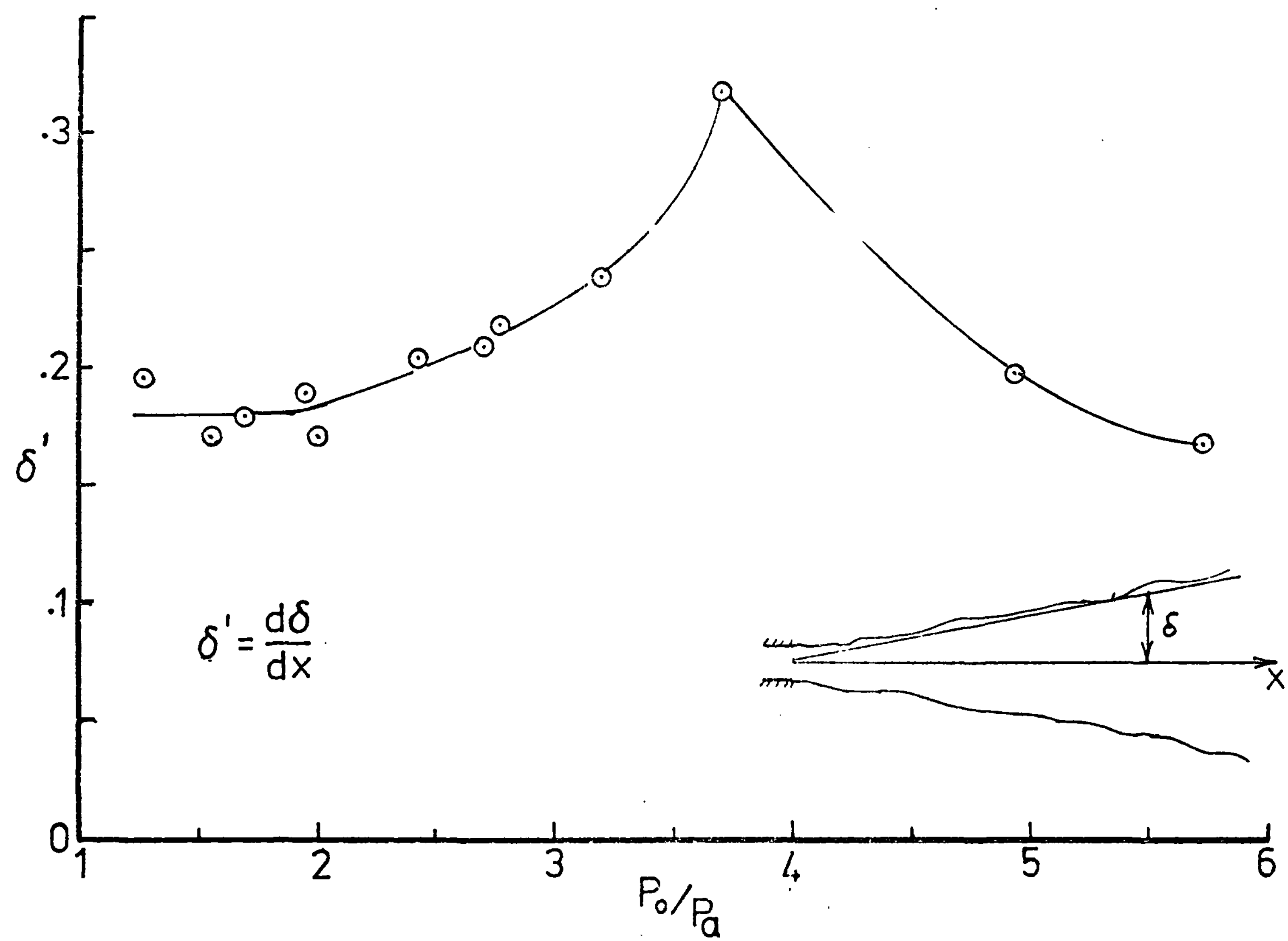


Fig. 4. Variation of the Spreading Rate with Pressure Ratio

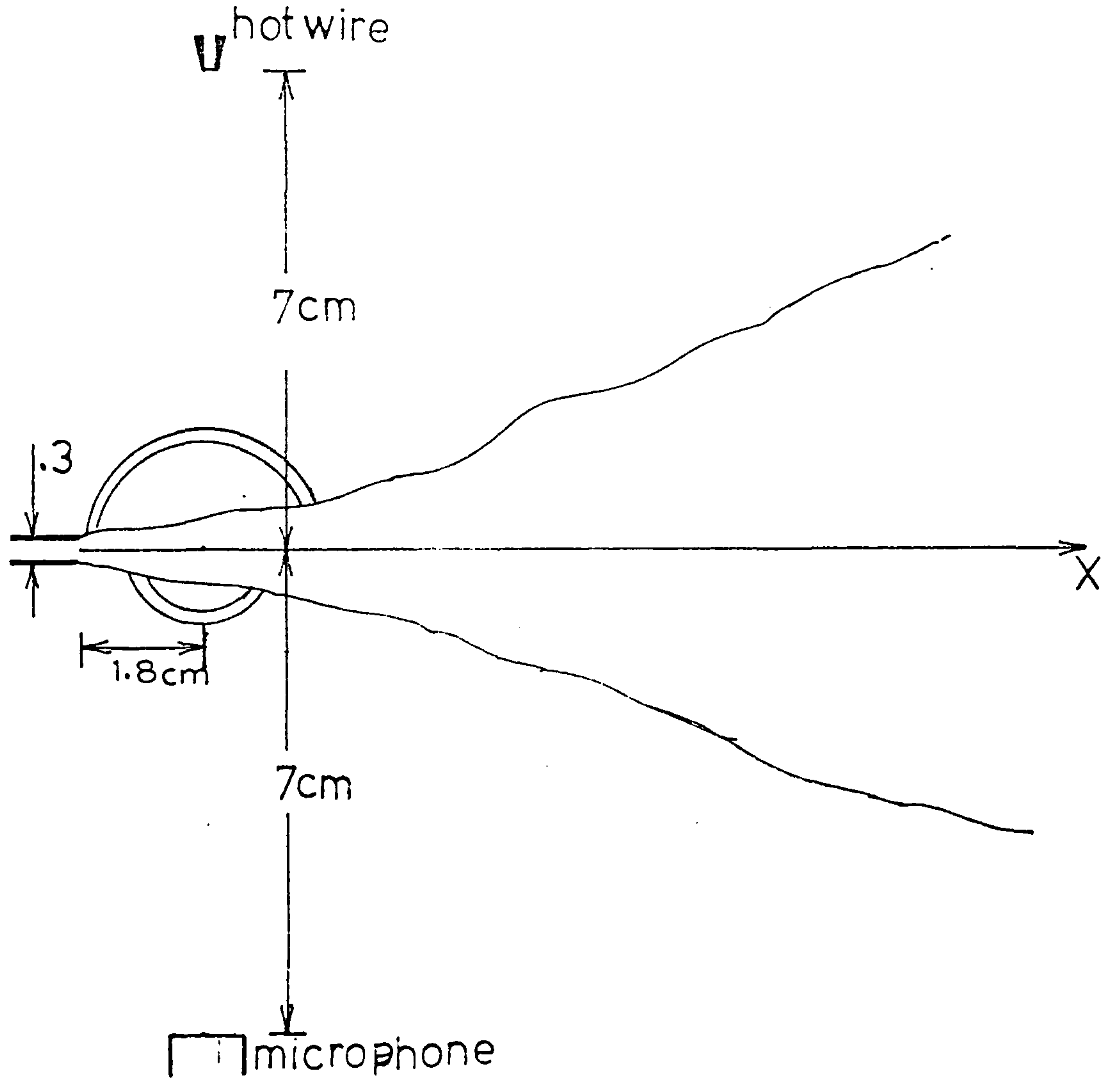
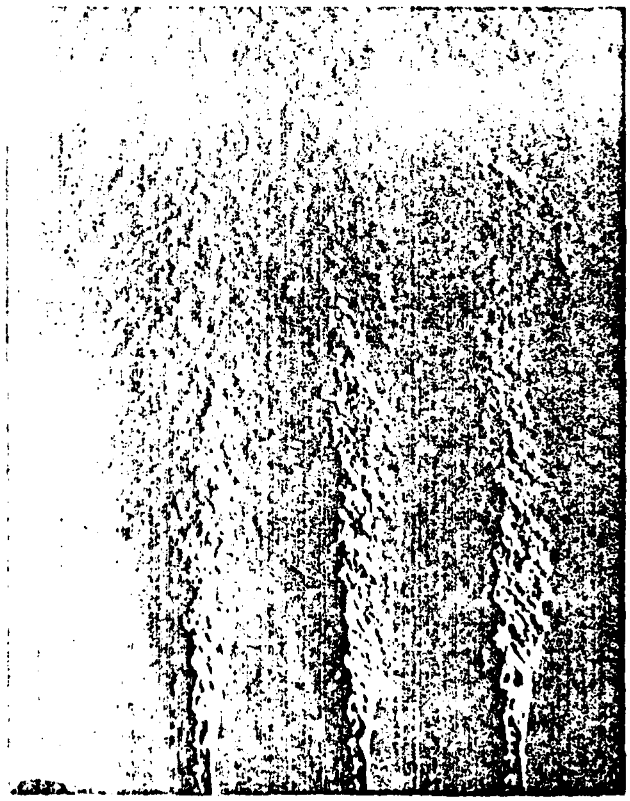
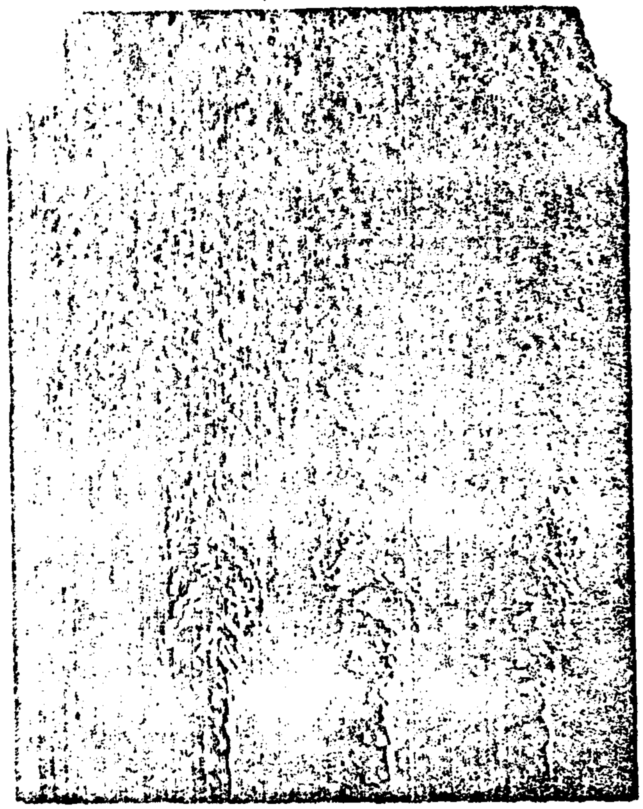


Fig. 5. Schematic Arrangement of the Hot Wire and Microphone for Near Field Measurements.

6a. $p_o/p_a = 1.6$



6b. $p_o/p_a = 2.42$



6c. $p_o/p_a = 3.7$

Fig. 6. Schlieren Pictures of Unconfined Multiple Jets at Different Pressure Ratios.

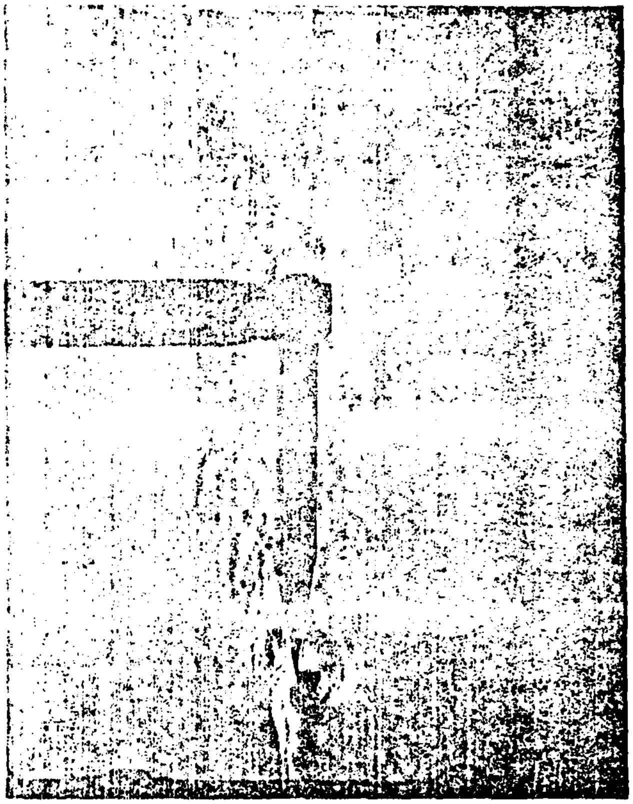


Fig. 7. Schlieren Picture of an Edge Tone at a Pressure Ratio of 1.6.

Fig. 8. Effect of an Edge Tone in a Multiple Jet Configuration.

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1. Krothapalli, A., Baganoff, D., and Karamcheti, K., "An Experimental Study of Multiple Jet Mixing," JIAA TR-23, June 1979.

2. Krothapalli, A., Baganoff, D., Hsia, Y., Karamcheti, K., "Some Features of Tones Generated by an Underexpanded Rectangular Jet," AIAA Paper No. 81-0060, to be presented at the 19th Aerospace Sciences Meeting, St. Louis, January 1981.

LIST OF PUBLICATIONS

1. "Some Features of Tones Generated by an Underexpanded Rectangular Jet" by A. Krothapalli, D. Baganoff, Y. Hsia, and K. Karamcheti. To be presented at the Aerospace Sciences Meeting in January 1981.

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: AFOSR-TR- 81-0033	2. GOVT ACCESSION NO.: AD-A094 626
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): BASIC STUDIES OF MULTIPLE JETS AND WALL JETS	5. TYPE OF REPORT & PERIOD COVERED: INTERIM
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): A KROTHAPALLI	8. CONTRACT OR GRANT NUMBER(s): F49620-79-C-0189
9. PERFORMING ORGANIZATION NAME AND ADDRESS: JOINT INSTITUTE FOR AERONAUTICS & ACOUSTICS, STANFORD UNIVERSITY, DEPT OF AERONAUTICS & ASTRONAUTICS/STANFORD CA	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 61102F, 2307/A1
11. CONTROLLING OFFICE NAME AND ADDRESS: AIR FORCE OFFICE OF SCIENTIFIC RESEARCH /NA, BOLLING AFB DC 20332	12. REPORT DATE: AUGUST 1980
	13. NUMBER OF PAGES: 21
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

TURBULENT JETS
MULTIPLE JETS
RECTANGULAR JETS
SPREADING RATE
SOUND GENERATION
FLOW STRUCTURE

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An experimental investigation of the flow field of an underexpanded rectangular jet issuing from a rectangular nozzle of aspect ratio 16.7 was undertaken. Tests were conducted for pressure ratios (settling chamber/ambient pressure) ranging from 1.6 to 5.8. For pressure ratios greater than 1.9 the spectrum of the hot wire and microphone signals placed in the near field of the jet show discrete frequencies generally known as screech tones. At a pressure ratio of 3.7, Schlieren pictures show a distinct double wave pattern with their source being located at

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