UMR - 41

PROGRESS REPORT NO. 11

AAF CONTRACT W33-038 ac 21100

Period 11

1 March, 1950, to 1 May, 1950

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Combustion Chamber Design

Ceramic-lined Combustion Chamber - Testing of the ceramic-lined combustion chamber has been delayed so as to construct an adequate test stand for this burner.

Pressure and Temperature Effects on Combustion

Existing equipment was modified in order to determine the effect of elevated temperatures and varying pressures on flame speeds. Preliminary data has been obtained but is not presented.

Flow Associated with the V-Flame

The frequency of the tone emitted from a 1" x 1" x 24" combustion chamber was recorded and compared with the theoretical prediction. Good agreement was found. The effect of the resonant condition on blowoff velocity was noted.

Detonation

Fuel-air mixtures of acetylene-oxygen were successfully detonated with a shock wave. A wedge was installed to calibrate an electronic timing circuit that has been partially completed.

Blowdown Equipment

The effect of increasing mixture temperature upon the blowoff velocity of a spherical flame holder was determined. It appears that the blowoff velocity for a given sphere is a direct function of the temperature of the entering mixture.

Experimental Techniques

A device for accurately measuring small time intervals has been completed. Preliminary tests have been made.

Design and fabrication of the interferometer is being continued.

III. PROGRESS

Blowoff Velocities of Flame Holders

The study of the effects of system geometry upon blowoff velocities was concluded during this period. The blowoff velocities obtained under vacuum which were previously reported[1], were obtained with a 3/8 inch diameter nozzle in a rectangular test chamber 10" x 12" x 19". The effect of this chamber on blowoff velocities of the unconfined jet was determined for various heights of the flame holder above the nozzle by using a 1/16 inch diameter spherical flame holder and a constant propane-air ratio of 0.080.

Figure 1 shows the effect of confinement of the flame upon blowoff velocities at various flame holder heights above the jet. The data in Figure 1 is for a 5/8 inch diameter nozzle. Figure 2 shows the same comparison as Figure 1 except that data is for a 3/8 inch diameter nozzle. As may be seen from a comparison of Figures 1 and 2, the addition of the test chamber has a more deleterious effect upon blowoff velocity for a 5/8 inch diameter nozzle than for a 3/8 inch diameter nozzle. Both of these series of tests were conducted with glass wool and 100 mesh screens upstream of the nozzle.

In Figure 3 the height of the flame holder above the nozzle is plotted versus the mass velocity at blowoff for the 3/8 and 5/8 inch diameter nozzle, both unconfined and containing glass wool and 100 mesh screens upstream of the nozzle. From this figure it may be seen that higher blowoff velocities are obtained with the 3/8 inch nozzle than with the 5/8 inch nozzle at flame holder heights up to about 7/32 of an inch above the nozzle. At flame holder heights greater than 7/32 inch, the 5/8 inch diameter nozzle is superior.

Figure 4 is a comparison of the blowoff velocities of the 3/8 inch diameter and 5/8 inch diameter nozzles when the glass wool and 100 mesh screens are removed from the chamber upstream of the nozzle. This figure shows that blowoff velocities for the 3/8 inch diameter nozzle without the glass wool, not appreciably affected by the superposition of the test chamber. (These were the conditions used to obtain the data under vacuum previously reported.) The difference between the effects of the two nozzles for these conditions is about the same as for the conditions of Figure 3, i.e., at low flame holder heights, the 3/8 inch diameter nozzle yields highest blowoff velocities. It should be noted that it was impossible to ignite the mixture while using the 5/8 inch diameter nozzle without glass wool upstream of the nozzle with the burner outside the test chamber when the flame holder was at 0 height. It was impossible to ignite the mixture at any height of the flame holder above the nozzle when the 5/8 inch nozzle, without glass wool, was placed in the test chamber.

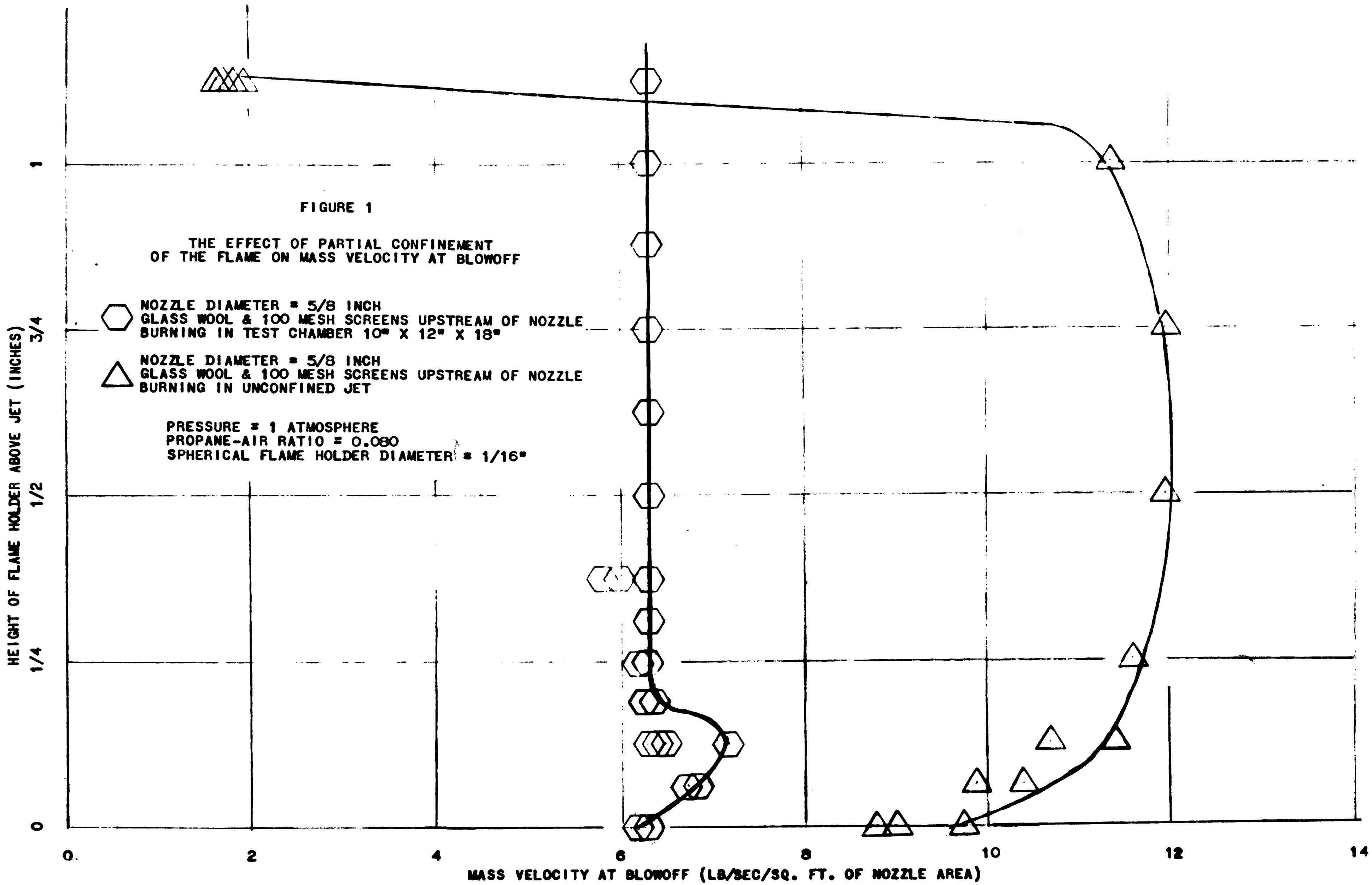
FIGURE 1
THE EFFECT OF PARTIAL CONFINEMENT
OF THE FLAME ON MASS VELOCITY AT BLOWOFF
NOZZLE DIAMETER = 5/8 INCH
GLASS WOOL & 100 MESH SCREENS UPSTREAM OF NOZZLE
BURNING IN TEST CHAMBER 10" X 12" X 18"
NOZZLE DIAMETER = 5/8 INCH
GLASS WOOL & 100 MESH SCREENS UPSTREAM OF NOZZLE
BURNING IN UNCONFINED JET
PRESSURE = 1 ATMOSPHERE
PROPANE-AIR RATIO = 0.080
SPHERICAL FLAME HOLDER DIAMETER = 1/16"
HEIGHT OF FLAME HOLDER ABOVE JET (INCHES)
0
1/4
1/2
3/4
1
0.
2
4
6
8
10
12
14
MASS VELOCITY AT BLOWOFF (LB/SEC/SQ. FT. OF NOZZLE AREA)

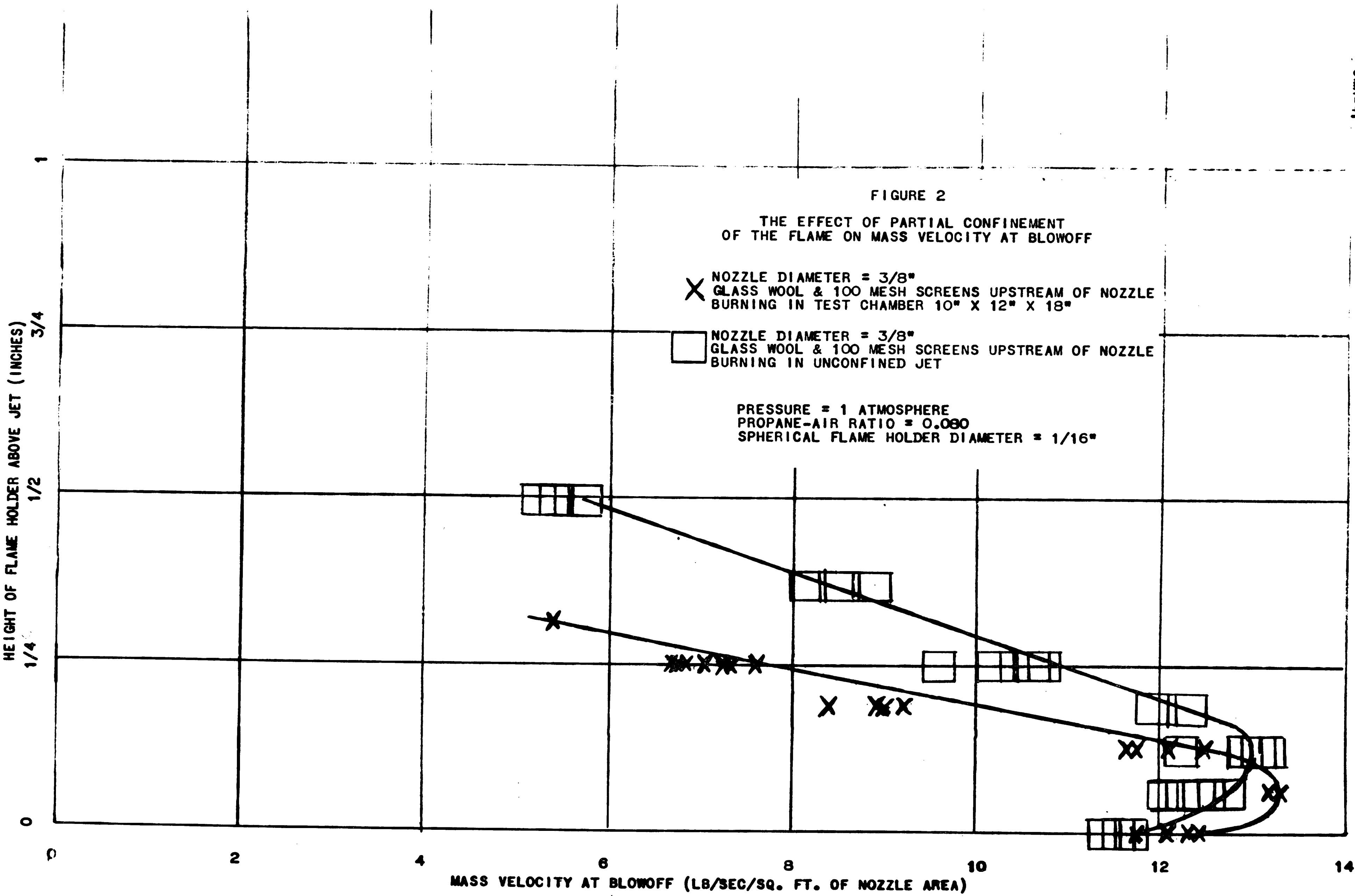

FIGURE 2

THE EFFECT OF PARTIAL CONFINEMENT OF THE FLAME ON MASS VELOCITY AT BLOWOFF

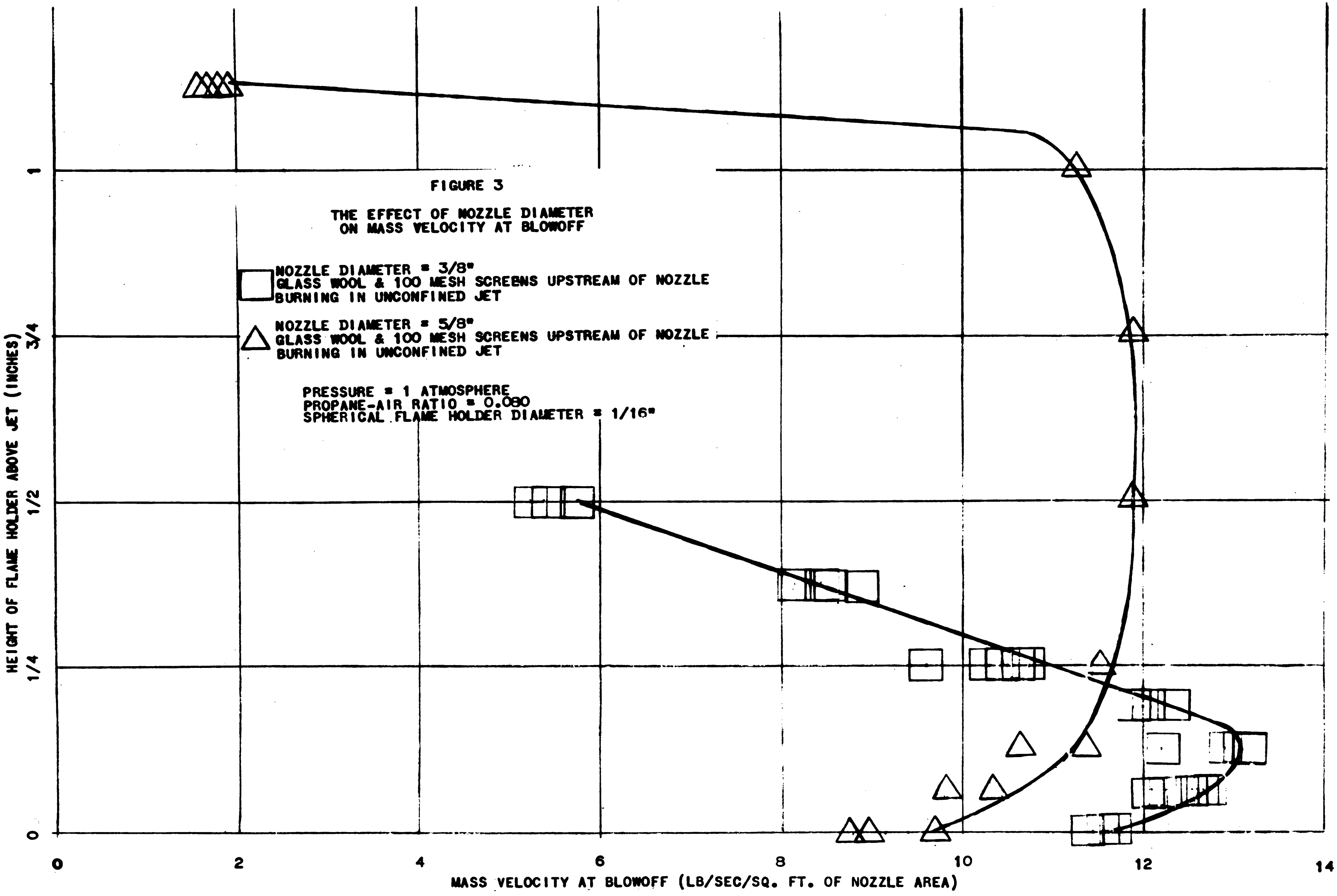

FIGURE 3

THE EFFECT OF NOZZLE DIAMETER
ON MASS VELOCITY AT BLOWOFF

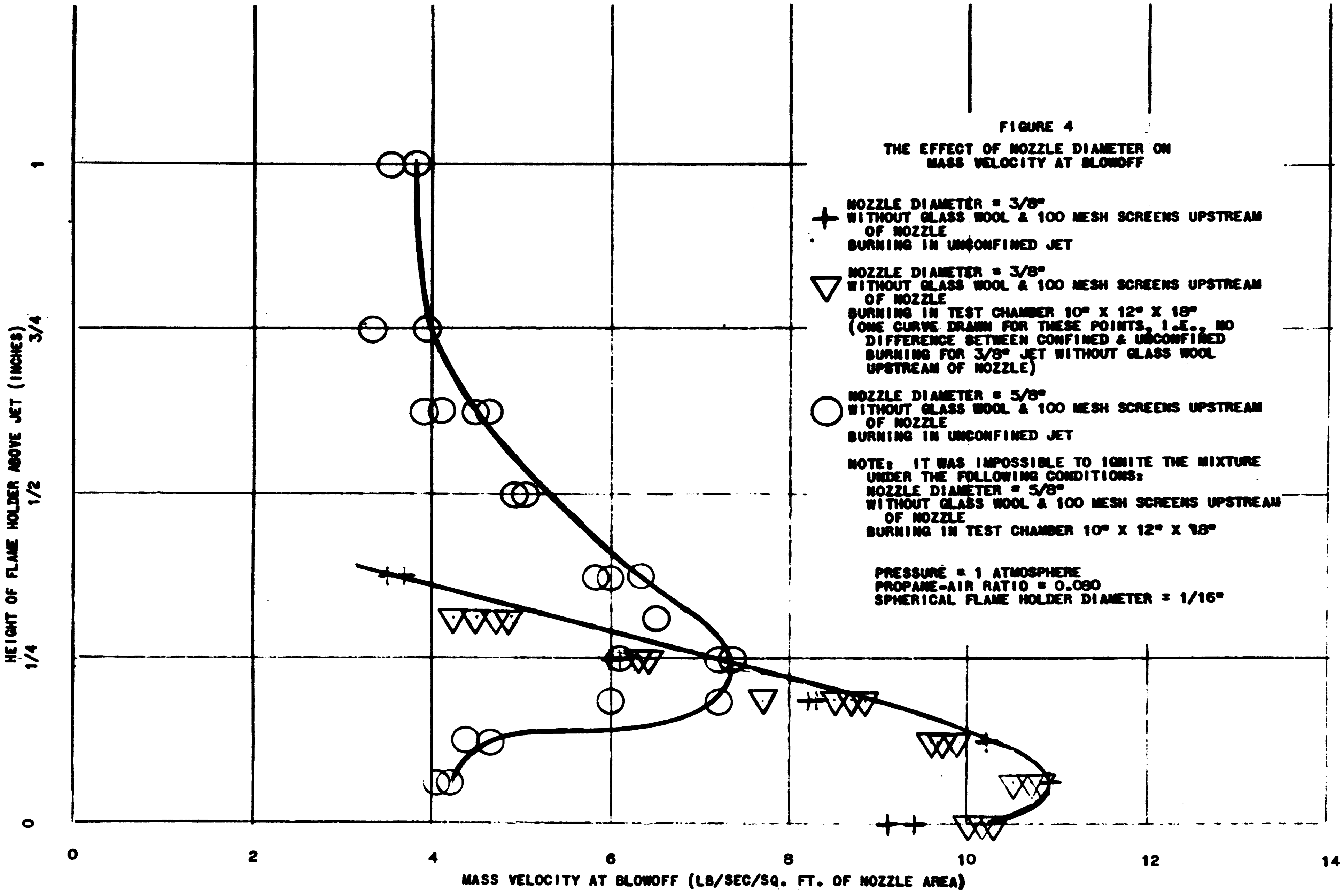

FIGURE 4

THE EFFECT OF NOZZLE DIAMETER ON MASS VELOCITY AT BLOWOFF

Figure 5 compares the 3/8 inch diameter and 5/8 inch diameter nozzles, into which glass wool and 100 mesh screens were inserted upstream, when they were used inside the test chamber. Again, the use of the 3/8 inch diameter nozzle resulted in a higher mass velocity at blowoff for low flame holder heights, but the 5/8 inch diameter nozzle had a much wider range of operation.

Figure 6 shows the increase in mass velocity at blowoff obtained in a 5/8 inch diameter nozzle, obtained by adding glass wool and 100 mesh screens upstream of the nozzle.

Figures 7, 8, and 9 are shadowgraphs of flames burning from a spherical flame holder, showing the effect on combustion of adding glass wool upstream of the 5/8 inch diameter nozzle, at different heights of the flame holder above the nozzle. Figures 7 and 8 may be compared, since they are of burning at essentially the same mass velocity.

This work concludes the testing program of blowoff velocities in System 2.[2] The blowoff data obtained with this system included testing four spherical flame holders, with nine fuel-air ratios at pressures from 0.4 to 1 atm. with a 3/8 inch nozzle. In addition, tests were performed which showed the great effect of system geometry upon blowoff velocity, i.e., eight nozzle sizes, different heights of the flame holder above the nozzle, as well as the effects of insertion of glass wool upstream of the nozzle and super position of test chambers upon the free jet. All the above data will be further analyzed. In general, it was found that a ratio of test chamber area to nozzle area of 1300 to 1 did not differ appreciably from an unconfined jet, but that a ratio of 400 to 1 did have a disadvantageous effect on combustion.

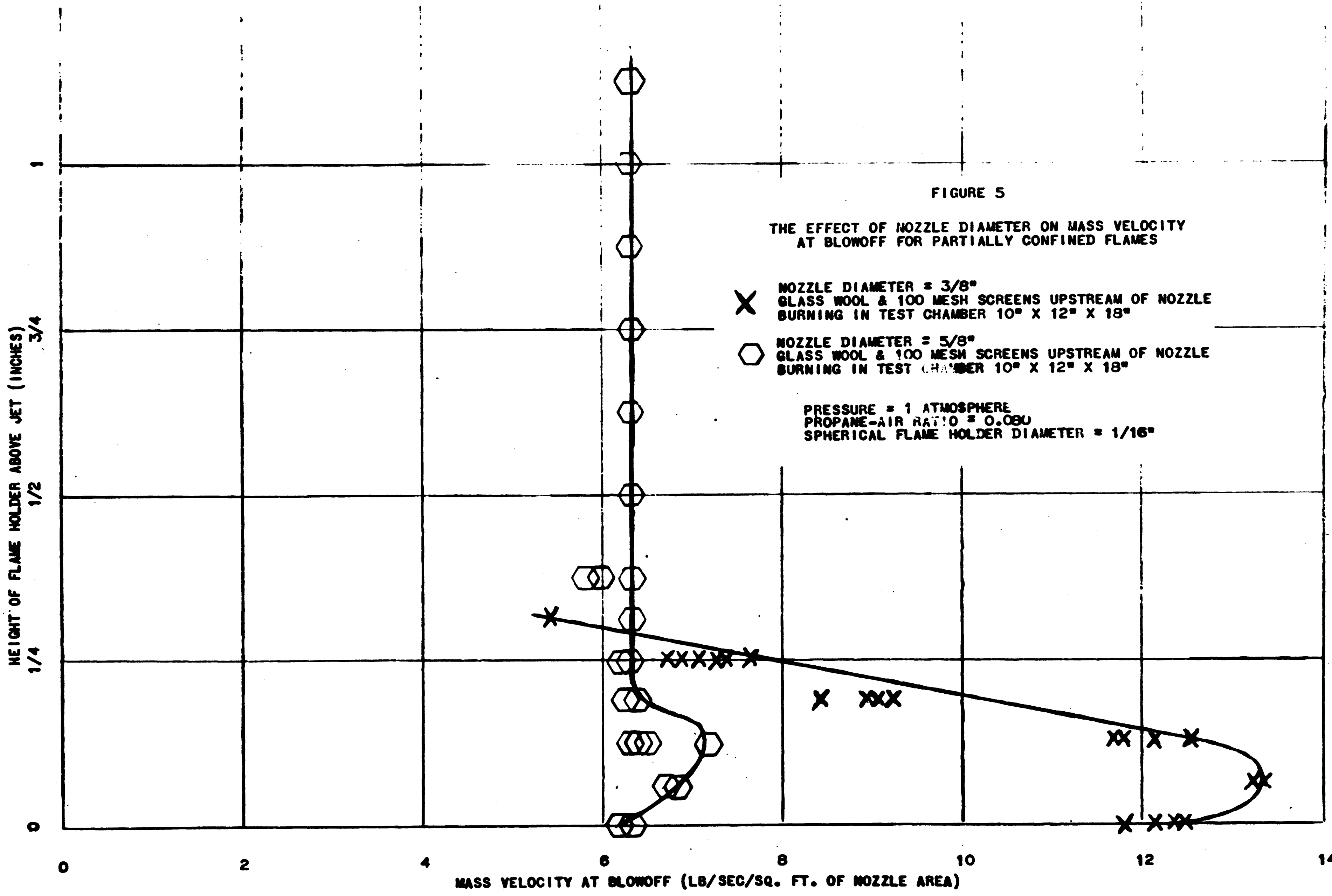

FIGURE 5

THE EFFECT OF NOZZLE DIAMETER ON MASS VELOCITY AT BLOWOFF FOR PARTIALLY CONFINED FLAMES

X NOZZLE DIAMETER = 3/8"
GLASS WOOL & 100 MESH SCREENS UPSTREAM OF NOZZLE
BURNING IN TEST CHAMBER 10" X 12" X 18"

⬡ NOZZLE DIAMETER = 5/8"
GLASS WOOL & 100 MESH SCREENS UPSTREAM OF NOZZLE
BURNING IN TEST CHAMBER 10" X 12" X 18"

PRESSURE = 1 ATMOSPHERE
PROPANE-AIR RATIO = 0.080
SPHERICAL FLAME HOLDER DIAMETER = 1/16"

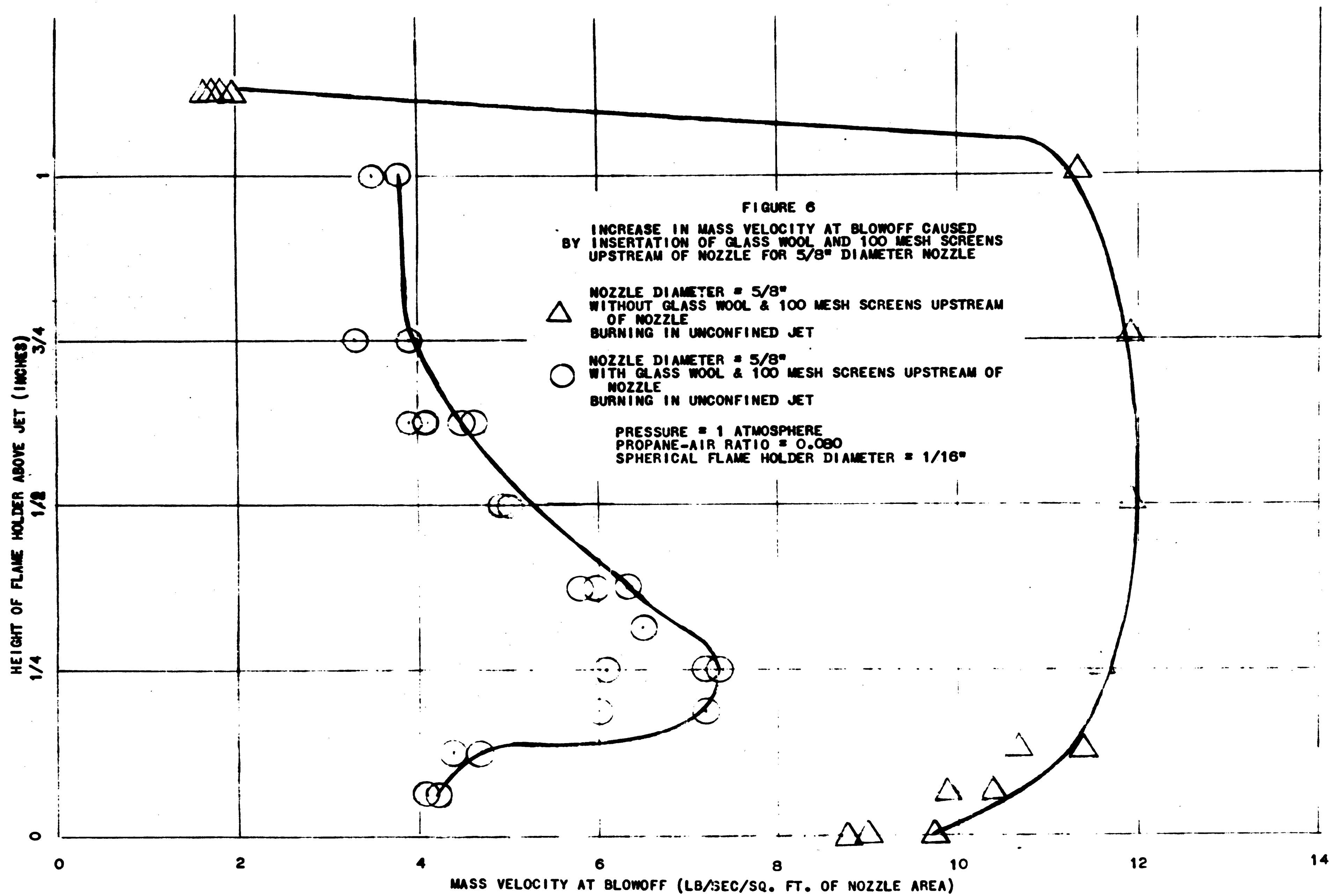
FIGURE 6
INCREASE IN MASS VELOCITY AT BLOWOFF CAUSED BY INSERTATION OF GLASS WOOL AND 100 MESH SCREENS UPSTREAM OF NOZZLE FOR 5/8" DIAMETER NOZZLE
NOZZLE DIAMETER = 5/8" WITHOUT GLASS WOOL & 100 MESH SCREENS UPSTREAM OF NOZZLE BURNING IN UNCONFINED JET
NOZZLE DIAMETER = 5/8" WITH GLASS WOOL & 100 MESH SCREENS UPSTREAM OF NOZZLE BURNING IN UNCONFINED JET
PRESSURE = 1 ATMOSPHERE
PROPANE-AIR RATIO = 0.080
SPHERICAL FLAME HOLDER DIAMETER = 1/16"
HEIGHT OF FLAME HOLDER ABOVE JET (INCHES)
0
1/4
1/2
3/4
1
0
2
4
6
8
10
12
14
MASS VELOCITY AT BLOWOFF (LB/SEC/SQ. FT. OF NOZZLE AREA)

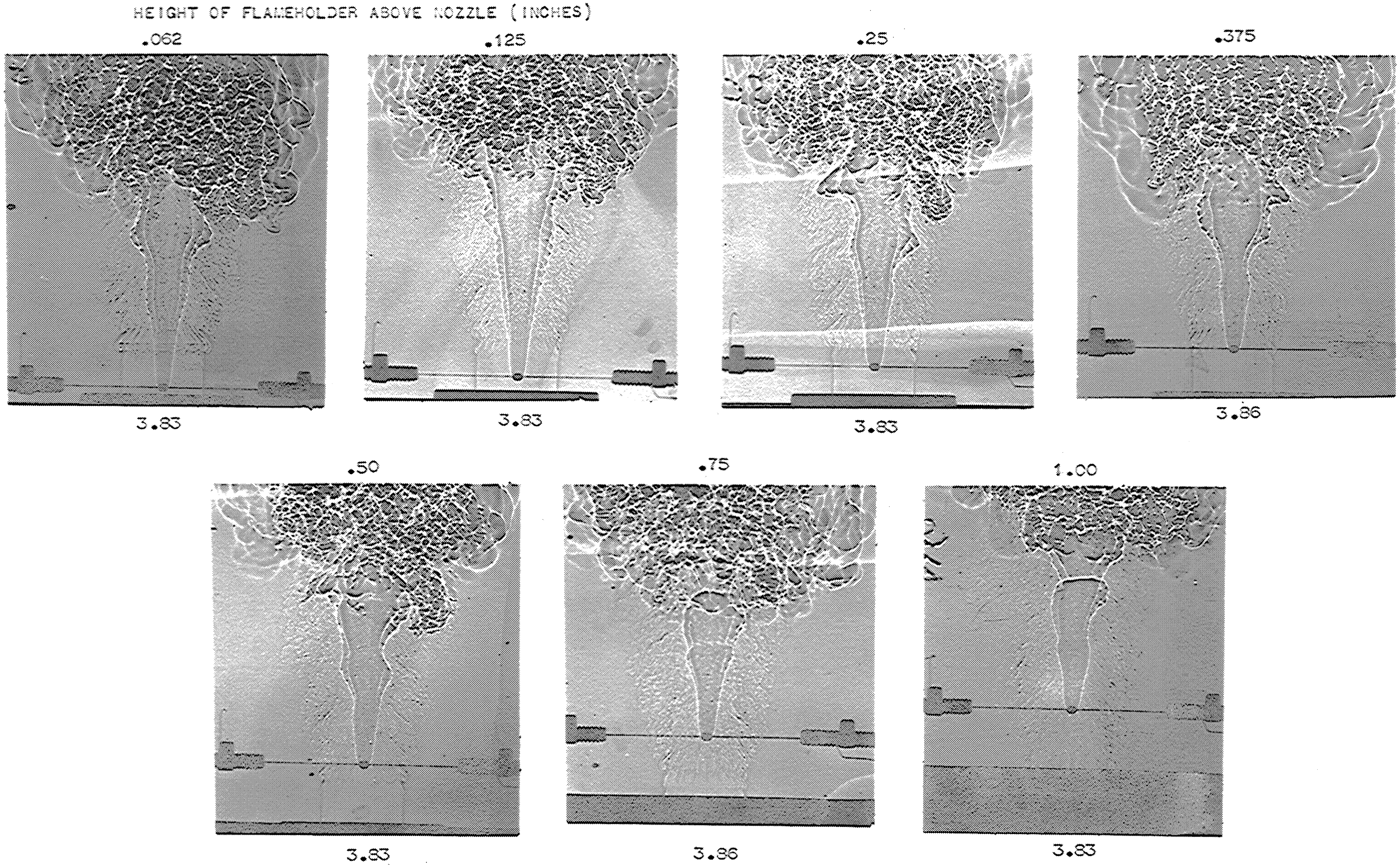

FIG. 7 SHADOWGRAPHS SHOWING EFFECT OF HEIGHT OF FLAME HOLDER ABOVE NOZZLE ON COMBUSTION IN AN UNCONFINED JET FOR A MASS VELOCITY RANGE OF 3.83 TO 3.86 LB/SEC/SQ/FT. OF NOZZLE AREA WITH GLASS WOOL AND 100 MESH SCREENS UPSTREAM OF NOZZLE

SPHERICAL FLAMEHOLDER DIA. 1/16 IN   PROPANE-AIR MIXTURE .080 (BY WT)

NOZZLE DIAMETER 5/8 IN.   PRESSURE 1 ATMOSPHERE

HEIGHT OF FLAMEHOLDER ABOVE NOZZLE (INCHES)

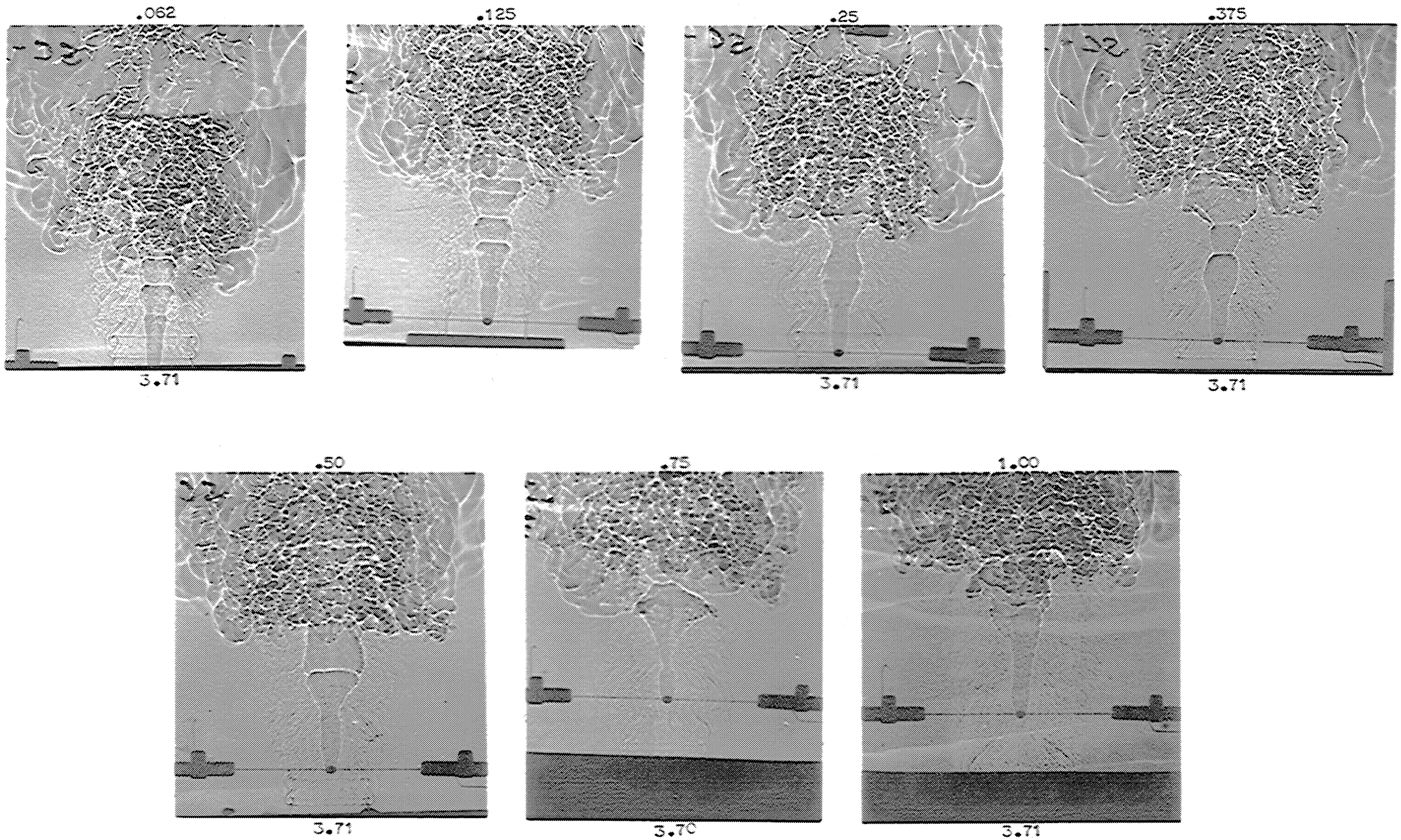

FIG. 8 SHADOWGRAPHS SHOWING EFFECT OF HEIGHT OF FLAMEHOLDER ABOVE NOZZLE ON COMBUSTION IN AN UNCONFINED JET FOR A MASS VELOCITY RANGE OF 3.70 TO 3.71 LB/SEC/SQ/FT. OF NOZZLE AREA WITHOUT GLASS WOOL OR 100 MESH SCREENS UPSTREAM OF NOZZLE

SPHERICAL FLAMEHOLDER DIA. 1/16 IN PROPANE-AIR MIXTURE .080 (BY WT)

NOZZLE DIAMETER 5/8 IN. PRESSURE 1 ATMOSPHERE

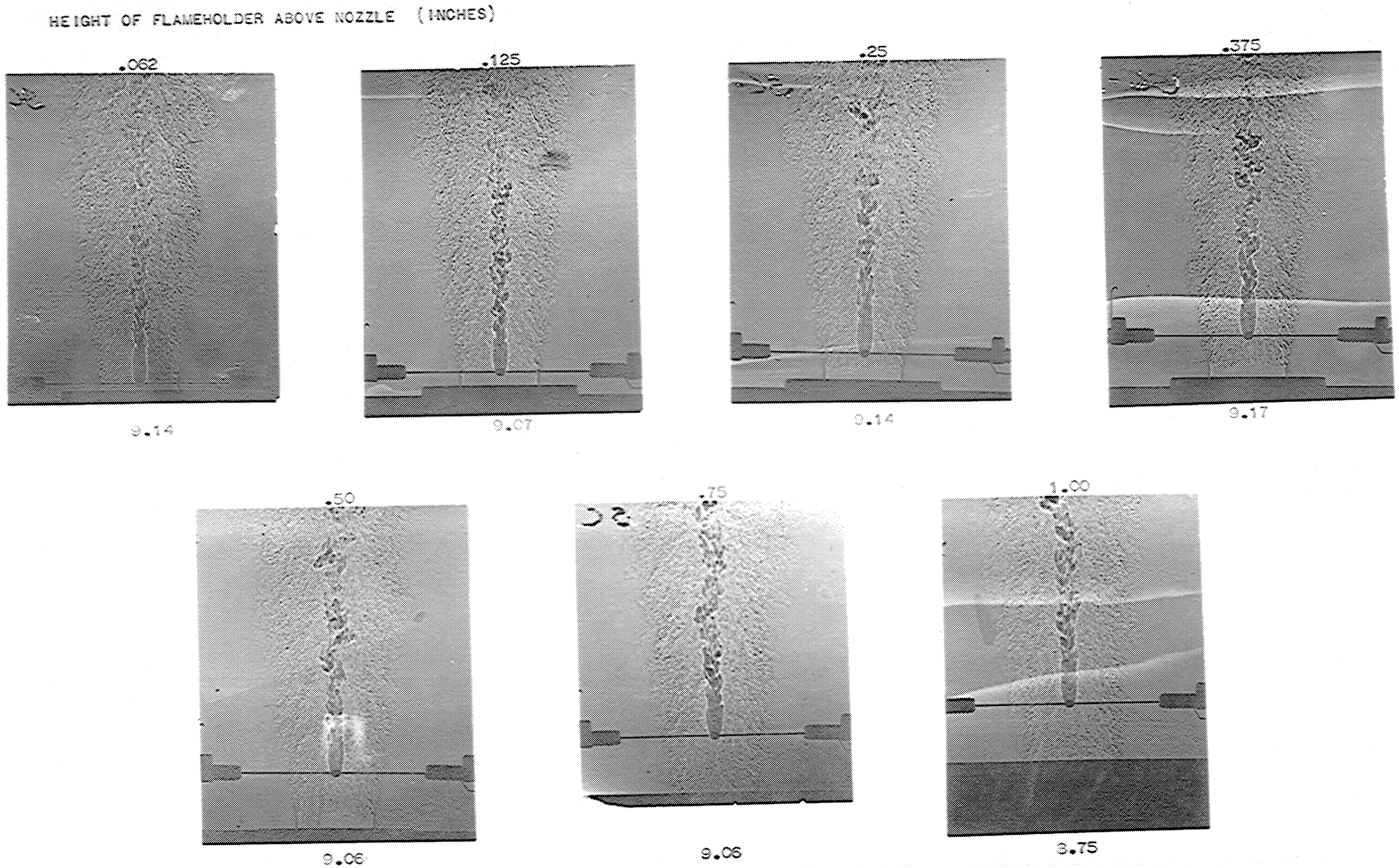

FIG. 9 SHADOWGRAPHS SHOWING EFFECT OF HEIGHT OF FLAMEHOLDER ABOVE NOZZLE ON COMBUSTION IN AN UNCONFINED JET FOR A MASS VELOCITY RANGE OF 8.75 TO 9.17 LB/SEC/SQ/FT. OF NOZZLE AREA WITH GLASS WOOL AND 100 MESH SCREENS UPSTREAM OF NOZZLE

SPHERICAL FLAMEHOLDER DIA. 1/16 IN PROPANE-AIR MIXTURE .080 (BY WT)

NOZZLE DIAMETER 5/8 IN. PRESSURE 1 ATMOSPHERE

Pressure and Temperature Effects on Combustion Processes

The apparatus used to study Bunsen flames at elevated temperatures and at various pressures was modified. Experiments were initiated in order to gain information on the effect of pressure and temperature on flame speed for propane-air mixtures. The pressures were varied between 4" Hg. and 6 atmospheres. The flame cone appears steady with inlet gas temperatures as high as 400°F. It is contemplated that ethylene and air mixtures will also be tested. It will be attempted to study flames at temperatures up to the auto-ignition point of the inlet gas mixture.

Combustion Chamber Design

Ceramic-lined Combustion Chamber - Testing of the ceramic-lined combustion chamber was delayed during the last period. This time was devoted to the construction of a test stand for the burner, since preliminary experiments indicated that it was hazardous to test the burner on existing facilities. A few details of construction need to be completed.

The test stand has been designed to provide an air flow rate of twelve pounds per second with the necessary fuel flow for burning in this air. Instrumentation to provide for measurement of all essential quantities has been provided.

The procurement of materials for the burner has been continued, and a variety of materials are now on hand on which tests will be conducted.

Flow Associated with the V-Flame

The frequency of the tone emitted from the 24" x 1" x 1" combustion chamber previously described was recorded by means of a cathode-ray oscilloscope and a high-speed camera. This frequency was recorded for a baffle type flame holder located at various positions along the length of the chamber. All data was taken at one jet velocity V_j and at two fuel-air ratios. The results of these data are plotted in Figure 11, showing frequency (ν) as a function of flame holder position (ℓ). As evidenced by a sample oscilloscope record, (Figure 10) the pulsations emitted from the chamber are made up of several component frequencies. Inasmuch as the large amplitude pulsation is the one of most interest, the frequency of that motion is the one plotted in Figure 11.

In Figure 11 is also shown the variation of frequency of tone with flame holder position obtained from the equation[5]

$$-C_1 \gamma_1 \tan \frac{2\pi \nu (L-X)}{C_2} = C_2 \gamma_2 \tan \frac{2\pi \nu X}{C_1} \quad \text{(Equation 1)}$$

where C = velocity of sound
L = combustion chamber length
ν = resonance frequency
X = distance of flame holder from combustion chamber entrance
γ = ratio of specific heats

subscripts 1 and 2 refer to unburned and burned gases respectively.

The temperature ratio used in the calculations was the maximum obtained experimentally,[3] hence the curve plotted is for one F/A ratio only. As an approximation γ_1 was assumed equal to γ_2.

The comparison between the experimental and theoretical values as shown in Figure 11 is good. This agreement, and the agreement of

Figure 10

Sample oscillograph record of sound emitted from combustion chamber for a particular flame holder position. Run #87c. 120 CPS pulse was used as a timing mark.

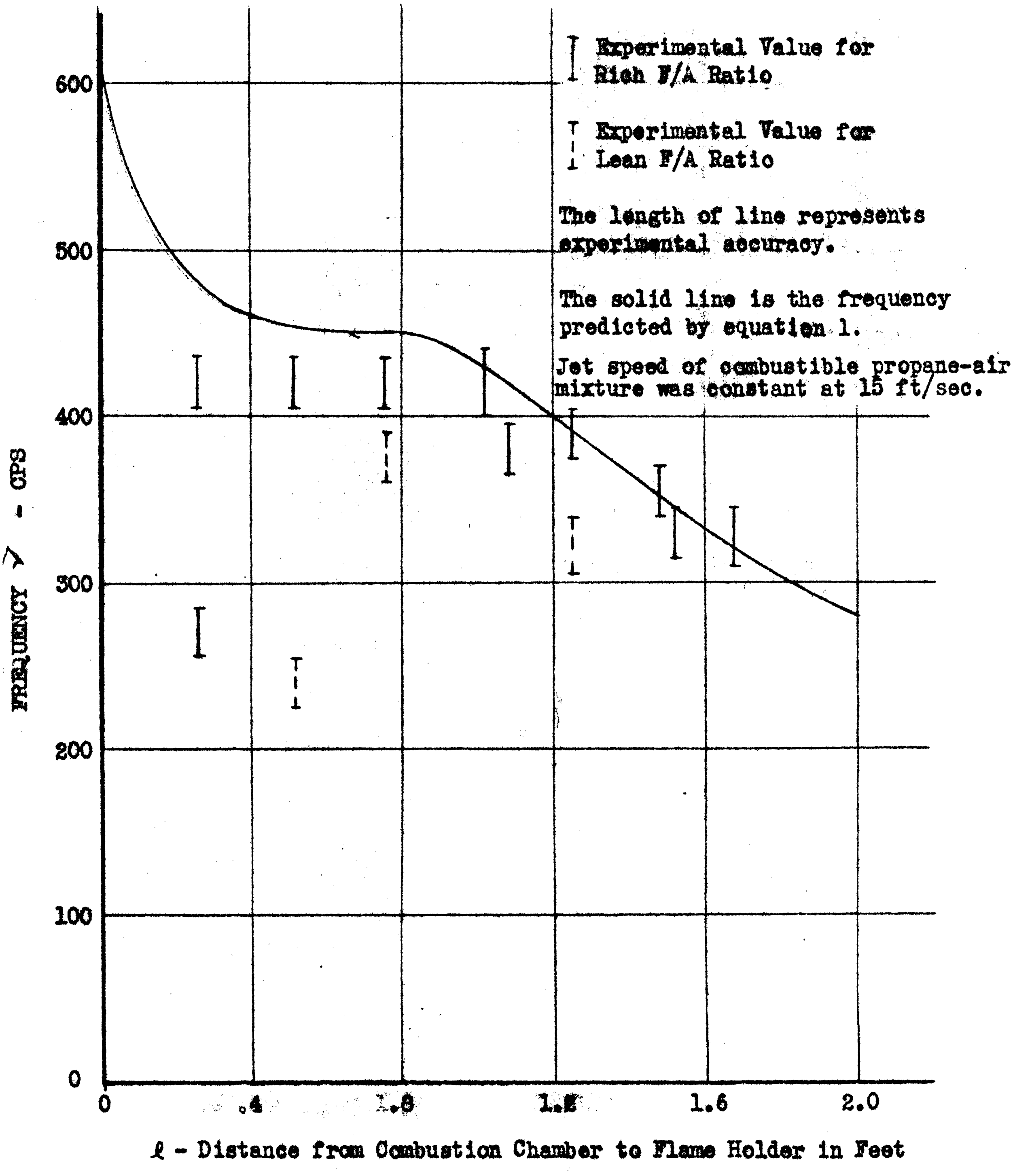

Figure 11

FREQUENCY OF TONE EMITTED FROM A 1" x 1" x 24" COMBUSTION CHAMBER AS A FUNCTION OF FLAME HOLDER POSITION

Detonation

The diaphragm holder for the shock tube has been re-machined; rupture of the diaphragm is sufficiently rapid to ignite acetylene-oxygen mixtures, but propane-air mixtures have not yet been detonated. A wedge has been inserted in the tube for measurement of speed of gas flow.

An electronic circuit has been successfully constructed to measure the speed of a detonation front as it passes between two ionization probes in the tube. Preliminary measurements have been made in a pipe of circular cross-section; probes have been inserted in the shock tube.

Information has been obtained on two methods of making fast shadowgraphs for the purpose of viewing the detonation front.

Blowdown System

The effect of inlet mixture temperature on the flame-holding ability of a spherical flame holder has been tested and graphed (see Figure 13). Equipment and test set-up used has been essentially described[6] with a few minor changes. Good mixture distribution and closer temperature and air flow control was provided in the modified set-up. Total pressure drop from the point of measurement to the nozzle jet was measured, as well as the temperature at the jet. The spherical flame holder used in the tests was 0.125 inches in diameter; the diameter of the jet was 0.625 inches. The flame holder was located within one-eighth of an inch from the lip of the nozzle to minimize turbulence effects. Fuel-air ratios used in the tests were those which would provide maximum blowoff velocities, at a given inlet temperature. The effect of small changes in fuel-air ratio upon blowoff velocity at points extremely near the maximum blowoff velocity, is not very critical. Hency, the variation in blowoff velocity from a slightly righ mixture to a slightly lean mixture is so small as to be nearly negligible.[7] Thus it was felt that the blowoff velocities obtained were maximum.

From Figure 13 it can be seen that the blowoff velocity is a direct function of the inlet mixture temperature. It is expected that as the mixture temperature is increased to the point at which spontaneous ignition takes place, the amount of heat necessary to be supplied to this mixture by the pilot zone aft of the flame holder, would be decreased. Therefore, for a given amount of heat supplied to the incoming mixture by the pilot zone, the mass flow which can be heated to ignition by the pilot zone increases as the mixture temperature increases. Since the mass flow per unit time is the product of density, area, and velocity, then for a given density and area, the blowoff velocity of the mixture is also increased.

It was noted that as the temperature of the mixture was increased, the downstream side of the flame holder glowed brighter and brighter, the color increasing from a dull red to a brilliant yellow. At the maximum inlet temperatures tested, spontaneous ignition of the mixture in the nozzle appeared imminent.

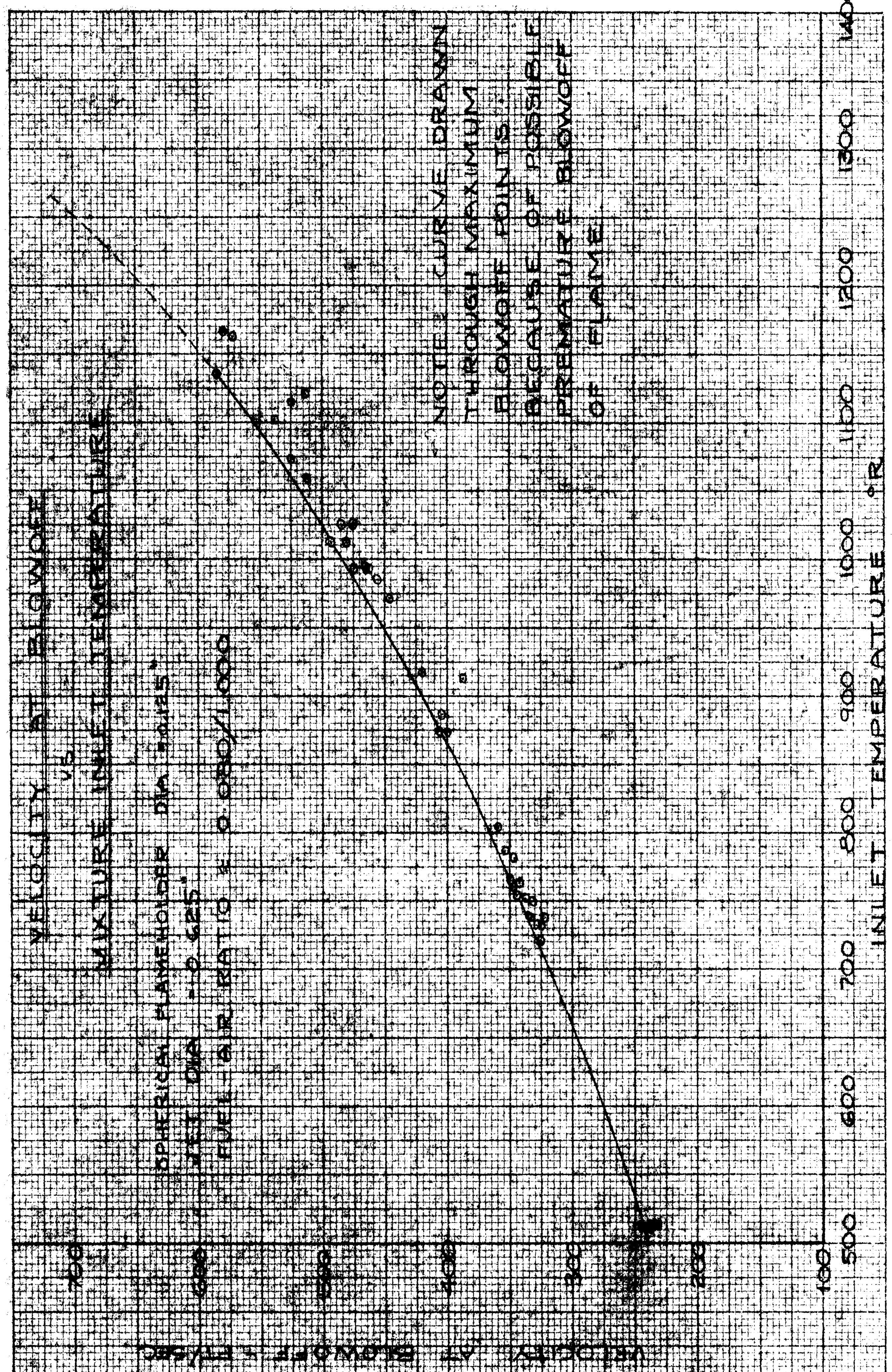
VELOCITY AT BLOWOFF
VS
MIXTURE INLET TEMPERATURE
SPHERICAL FLAMEHOLDER DIA = 0.125"
JET DIA = 0.625"
FUEL-AIR RATIO = 0.080/1.000
NOTE: CURVE DRAWN
THROUGH MAXIMUM
BLOWOFF POINTS
BECAUSE OF POSSIBLE
PREMATURE BLOWOFF
OF FLAME
VELOCITY AT BLOWOFF - FT/SEC
100
200
300
400
500
600
700
500
600
700
800
900
1000
1100
1200
1300
1400
INLET TEMPERATURE °R

Figure 13

Experimental Techniques

A device for conveniently and accurately measuring small time intervals has been completed. The device uses thyratron bleed on a resistance-capacitance network to measure time. Two thyratrons are controlled by the circuit to be measured--one initiates the bleed and the other stops it. The voltage at a proper point in the R-C network indicates the amount of bleed and hence the duration of bleed.

Interferometer - Cost estimates for the Schlieren assembly and miscellaneous parts have been received. Fabrication is pending final checking. Detail design of the projection box assembly is being continued. Preliminary design of the control system has been started.

An electronic flashing unit has been designed and assembled for flashing a B-H6 mercury lamp. The air supply for cooling the B-H6 lamp in continuous operation has been assembled. Work on the two-inch interferometer is being continued.

BIBLIOGRAPHY

1) Progress Report No. 8 -- UMR-36 -- University of Michigan AAF Contract W33-038 ac-21100 -- Figures 4-13, pages 11-20

2 Progress Report No. 9 -- UMR-37 -- University of Michigan AAF Contract W33-038 ac-21100 -- Figures 1-12, pages 8-19

2) Progress Report No. 8 -- UMR-36 -- University of Michigan AAF Contract W33-038 ac-21100 -- Figure 2, page 8

3) Morrison, R. B., and R. A. Dunlap, "Measurement of Flame Speeds with the V-Flame", UMM-21, University of Michigan, page 27

4) Progress Report No. 8 -- UMR-36 -- University of Michigan AAF Contract W33-038 ac-21100.

5) Dunlap, R. A., "Resonance in a Parallel-walled Combustion Chamber", UMM-43, University of Michigan, Appendix I

6) Progress Report No. 9 -- UMR-37 -- University of Michigan AAF Contract W33-038 ac-21100

7) ibid., Figure 5, page 12