REPORT UMR - 35

PROGRESS REPORT NO. 7

AAF CONTRACT W33-038 ac 2100

PERIOD 7

1 July to 1 September, 1949

I. LIST OF FIGURES

II. Summary of Work Conducted During the Period

Blowoff Velocities of Flameholders

Pressure traverses were made of the flame area for the following cases:

1. Pressure pick up tube vertical - with burning
2. Pressure pick up tube vertical - no burning
3. Pressure pick up tube horizontal - with burning
4. Pressure pick up tube horizontal - no burning

These pressures were compared to the pressure obtained at the base of vertical cylindrical flameholder.

Traverses were made to obtain the variation in electrical conductivity throughout the flame area.

The system for obtaining blowoff data under vacuum was assembled but no experimental data was obtained.

Combustion Chamber Design

Experiments thus far have shown that for a simple combustion chamber using a gaseous fuel, the rough-burning problem can be reduced to control of the fuel-air ratio at the flameholder. Data on the ignition and combustion limits of a particular combustion chamber appear significant in the understanding of "rough-burning."

Pressure and Temperature Effects on Combustion

The installation of the new pressure-temperature system has been completed. A resonant acoustical vibration which affected the flame was eliminated. A heated flameholder was employed to stabilize a V-flame at pressures of approximately three-fourths psia. Dimensional analysis was used in an attempt to derive relations between important variables associated with combustion.

Flow Associated with the V-flame

An expression has been developed for the frequency of the tone emitted from a combustion chamber where the hot and cold gases are in resonance. The technique for taking shadowgraphs has been improved.

Detonation

Final assembly of the reservoir and valve section with the sliding valve and necessary sealing "O" rings has been completed. The electronic system to time and photograph the detonation wave has been partially constructed.

Blowdown Equipment

The air compressors have been prepared and are ready to deliver air to the high pressure accumulators. All components of the blowdown system have been ordered and/or fabricated and are being assembled as they arrive.

Experimental Techniques

The eight-inch interferometer for combustion and gas dynamic studies is now in the process of redesign and construction. A photoelectric triggering system for use in combustion was designed, constructed, and tested.

III. Progress

Blowoff Velocities of Flameholders

In the continuing effort for a better understanding of the mechanism of flameholding, this period was devoted to a study of the region behind the flameholder. Physical measurements of pressure and electrical conductivity were made in the flame region at various locations. For this purpose, an apparatus was constructed which permitted vertical and horizontal traverses to be made accurately.

The flameholder used in the experiments was constructed from a 1/4 inch copper tube, plugged at one end, and connected to a water manometer at the other end. A hole 0.040 inch in diameter was drilled through the brass plug. The flameholder was installed axially through the nozzle and thus a vertical, cylindrical flameholder was obtained which permitted measurement of the pressure at the base.

For the traverse measurements of pressure a piece of steel hypodermic tubing 0.042 inches in diameter, connected to a water manometer, was used. The tubing was oriented vertically (parallel to the direction of jet flow) in one set of experiments and horizontally (perpendicular to the direction of jet flow) in another set. Measurements were made with burning, and without burning, using a fuel-air ratio of 0.0942 and a jet velocity of 109 feet per second. A photograph of the flame at these conditions showing the hypodermic tubing oriented vertically is seen in Figure 1.

Horizontal traverses were made at different heights above the flameholder to obtain pressure measurements at 228 points in the flame region for each of the following cases: vertical tubing, with burning; vertical tubing, without burning; horizontal tubing, with burning; horizontal tubing, without burning.

The data obtained was plotted and each set of data seemed consistent within itself, i.e., smooth curves were obtained when plotting pressure against vertical or horizontal distance. The data was then plotted to obtain pressure contours and these plots are shown in Figures 2, 3, 4, and 5. The reading of the manometer connected to the flameholder was -0.2 cm. of water gage in the case of burning and -0.9 cm. of water gage in the case of no burning. These readings corresponded exactly to those obtained when the hypodermic tubing (oriented both vertically and horizontally) was placed directly over the hole in the flameholder.

A few experiments were performed with the tube placed vertically but pointed in the downstream direction. Although vacuums were generally obtained, a positive pressure was observed in the center of the flame at specific heights with a few fuel-air ratios.

It has been known for more than a century that gases from flames are conductors of electricity. Volta caused a discharge of electricity from the surface of a non-conductor by passing a flame over it.[1] An attempt was made with the present equipment to measure the conductivity of the flame at different locations. Two wires, 3/16 inch apart, were traversed through the flame area and the voltage drop between them, compared to a 10 megohm resistance, was measured.

[1] "Conduction of Electricity through Gases", Vol. 1, Thompson & Thomson, Cambridge, 1928.

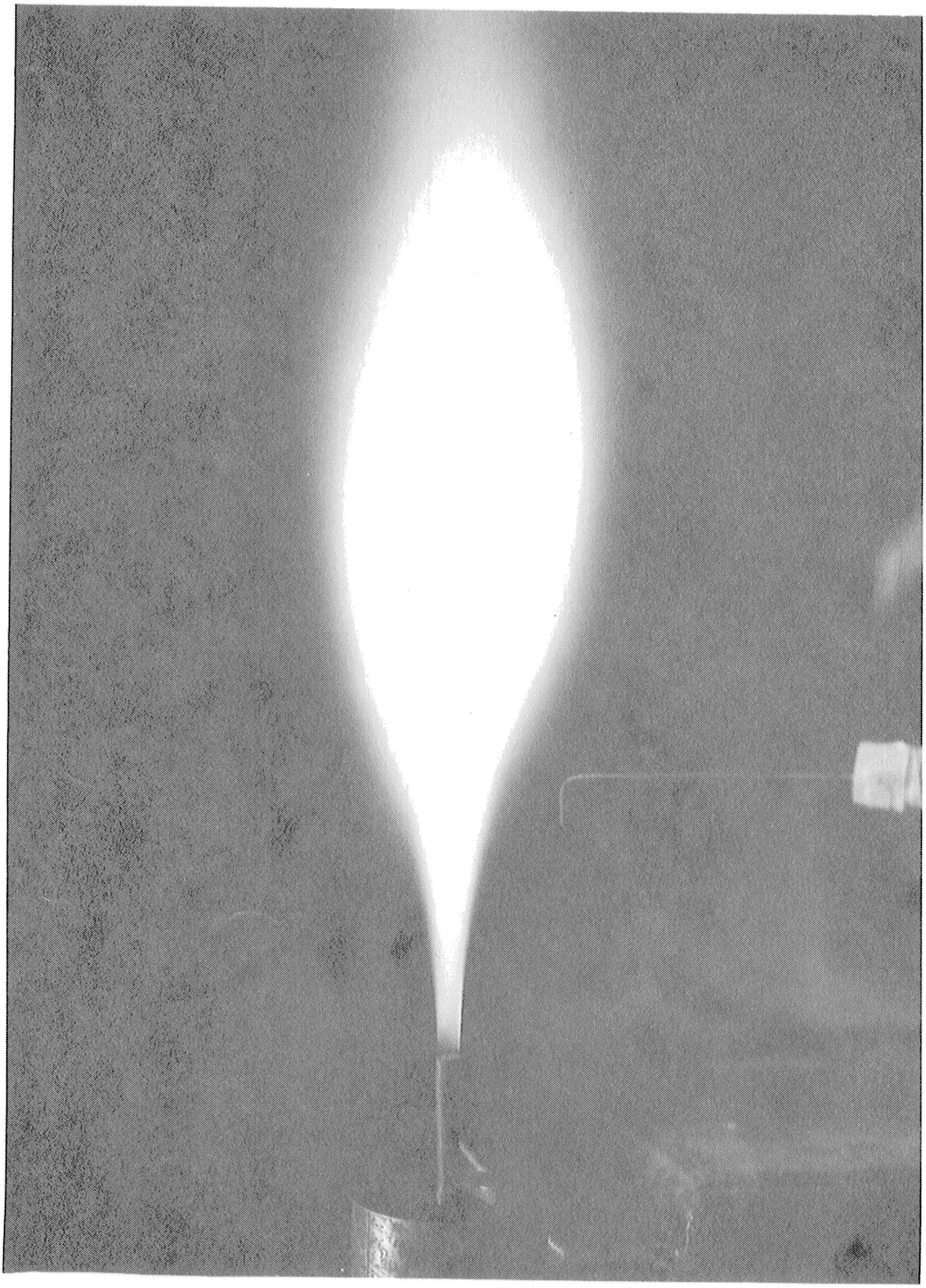


FIG. 1

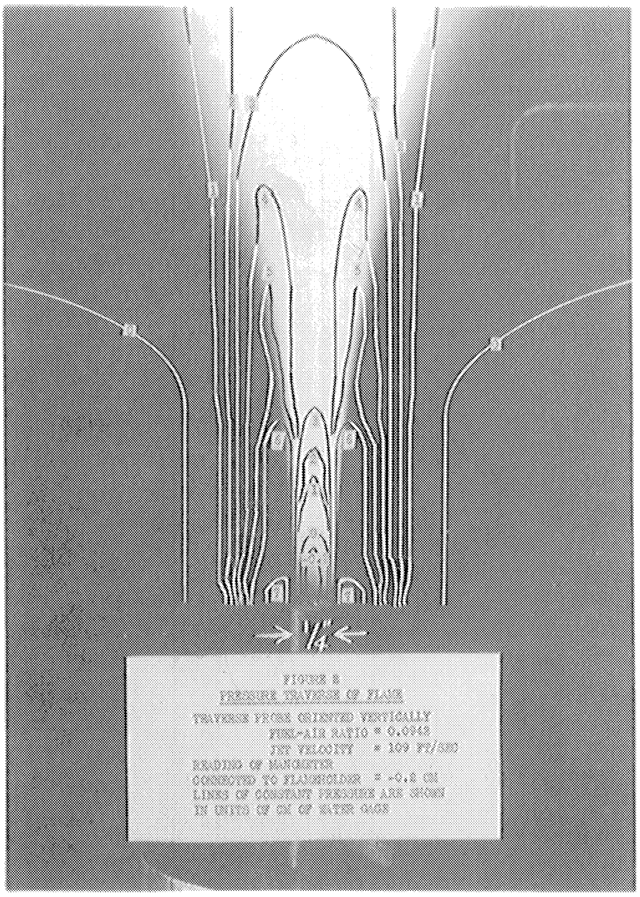


FIGURE 2
PRESSURE TRAVERSE OF FLAME

TRAVERSE TUBE ORIENTED VERTICALLY
FUEL-AIR RATIO = 0.0942
JET VELOCITY = 109 FT/SEC
READING OF MANOMETER
CONNECTED TO FLAMEHOLDER = -0.8 CM
LINES OF CONSTANT PRESSURE ARE SHOWN
IN UNITS OF CM OF WATER GAGE

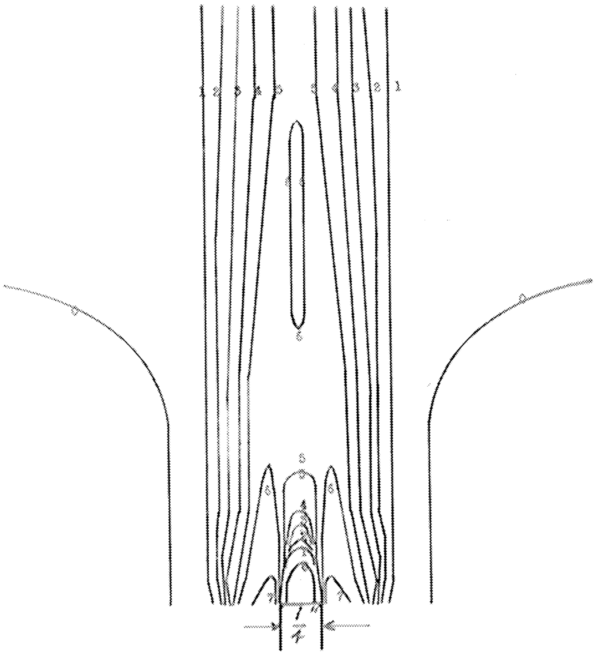


FIGURE 3
PRESSURE TRAVERSE - NO BURNING

TRAVERSE TUBE ORIENTED VERTICALLY
FUEL-AIR RATIO = 0.0942
JET VELOCITY = 109 FT/SEC
READING OF MANOMETER
CONNECTED TO FLAMEHOLDER = -0.9 CM
LINES OF CONSTANT PRESSURE ARE SHOWN
IN UNITS OF CM OF WATER GAGE

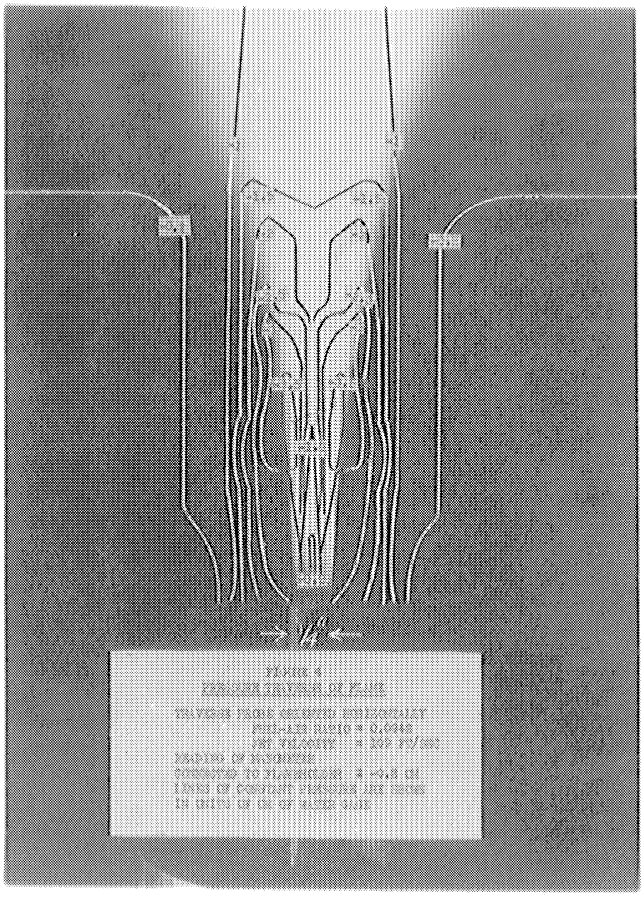


FIGURE 4
PRESSURE TRAVERSE OF FLAME

TRAVERSE TUBE ORIENTED HORIZONTALLY
FUEL-AIR RATIO = 0.0942
JET VELOCITY = 109 FT/SEC
READING OF MANOMETER
CONNECTED TO FLAMEHOLDER = -0.8 CM
LINES OF CONSTANT PRESSURE ARE SHOWN
IN UNITS OF CM OF WATER GAGE

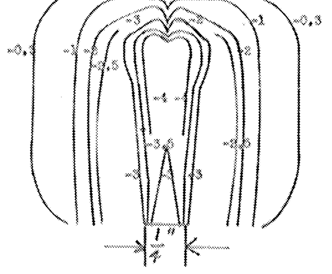


FIGURE 5
PRESSURE TRAVERSE - NO BURNING

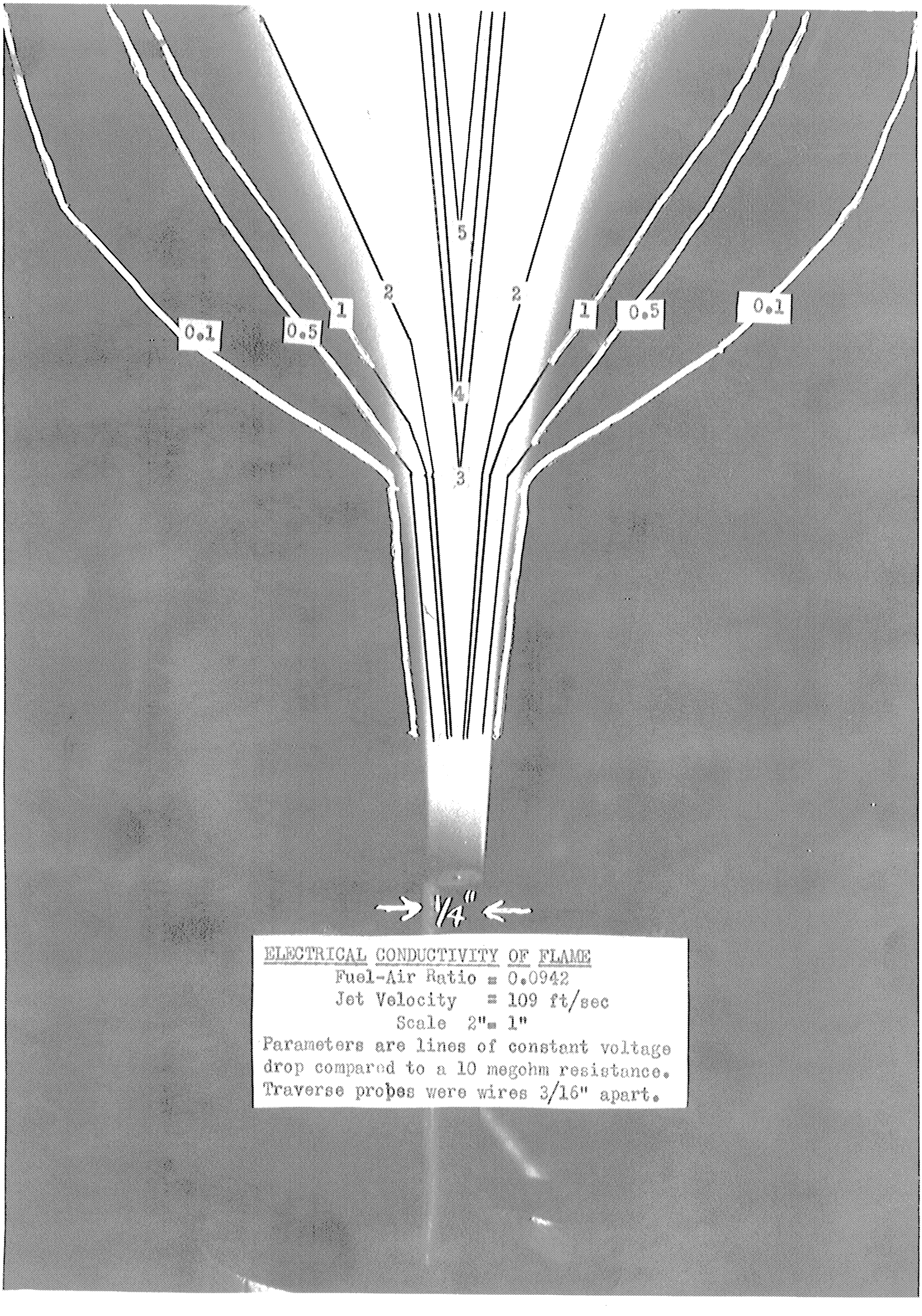
TRAVERSE TUBE ORIENTED HORIZONTALLY
FUEL-AIR RATIO = 0.0942
JET VELOCITY = 109 FT/SEC
READING OF MANOMETER
CONNECTED TO FLAMEHOLDER = -0.9 CM
LINES OF CONSTANT PRESSURE ARE SHOWN IN
UNITS OF CM OF WATER GAGE

A reading of 0 volts was obtained when no flame existed. The data obtained for a fuel-air ratio of 0.0942 and a jet velocity of 109 feet per second is shown in Figure 6. Fuel-air ratio seemingly caused greater variations in conductivity than did jet velocity.

The values shown in Figure 6, however, are integrated values and not point values since the conductivity of a larger volume of gas than the volume included between the wire tips is measured. In an attempt to decrease the magnitude of this effect, it was decided to measure the resistance between two parallel flat plates with an area large in comparison with the wire area. Accordingly, two plates, ca. 2 mm by 2 mm were affixed to the wires and traversed through the flame. However, the plates were so large that they acted as secondary flameholders and no data was obtained.

It should be noted that at locations above the pilot zone, the wires become incadescent, and therefore contribute an additional ionizing effect to the gases surrounding them. The combination of these two ionizing sources makes it virtually impossible to differentiate between them. It would be possible to obtain an empirical correlation between conductivity and fuel-air ratio or jet velocity for a given system, but at the present time it is believed that this would not add materially to a better understanding of the flameholding mechanism.

The system for obtaining blowoff velocities of flameholders under vacuum has been assembled but no experimental data have been obtained.



ELECTRICAL CONDUCTIVITY OF FLAME
Fuel-Air Ratio = 0.0942
Jet Velocity = 109 ft/sec
Scale 2" = 1"
Parameters are lines of constant voltage drop compared to a 10 megohm resistance. Traverse probes were wires 3/16" apart.

FIG. 5

Combustion Chamber Design

The work for this period contemplated at the writing of the last progress report was not carried out as outlined in order that a different approach to the "rough-burning" problem might be evaluated. From the experiments thus far conducted there is substantial evidence to support the belief that "rough-burning" is dependent on the characteristic combustion and ignition limits of the combustion chamber. It was found that "rough-burning" occurred in the range of fuel-air ratios where the mixture could be ignited but would not hold off the flameholder. This fuel-air ratio range has been obtained for one particular installation and appears to be predominantly rich. It is suspected that the "rough-burning" range is dependent on the ignition intensity and flameholder design as well as the particular fuel used. The ignition that causes the "rough-burning" may or may not be the intended ignition source--as a local hot spot would serve equally well.

At the beginning of this period tests indicated that the "mixing length" or distance between fuel injection and the flameholder had an effect on the "rough-burning." Further tests, however, showed that only the severity of the explosions depended to a certain extent on the mixing length, and that the fuel-air ratio at the flameholder was one of the important variables affecting the "rough-burning."

Pressure and Temperature Effects on Combustion Processes

Most of the present period was spent in the installation of the new pressure-temperature system. A schematic diagram of the equipment is shown in Figure 7. A photograph of the system is shown in Figure 8. It was observed in preliminary runs with the new burner tube, that a resonant condition was experienced between the V-flame burning above the convergent nozzle and the column of gas in the burner tube. This resulted in a vibrating flame, the oscillations of which were so severe that the flame would sometimes blow out even at low flow velocities. Shadowgraphs of the oscillating flame appear in Figure 9. Since acoustical effects on flames are being studied in another phase of the contract and the basic combustion phenomena being studied in this phase of the contract, i.e., flame speed and flame stability, could not be studied due to the oscillation of the flame front, it became necessary to eliminate the condition. A movement of the holder vertically in the jet seemed to change only the period of oscillation. The vibration was completely eliminated by the installation of a porous acoustical baffle located at the middle of the burner tube.

In preliminary tests of the new burner system it was observed that the V-flame seemed to have a wider stability range at reduced pressures than the Bunsen flame. V-flames were stabilized as low as 2 psia. Furthermore, the flame-angle was not deformed as in the case of the Bunsen flame at reduced pressures. It appears that a more accurate measurement of the flame speed at low pressures can be made with the use of the V-flame instead of the Bunsen flame. It was observed at low pressures that the gap between the flameholder and the apex of the V-flame increased slowly until blowoff occurred. This indicates that the fuel-air mixture was combustible but that the flameholder was unable to hold the flame. An electrically heated flameholder was used in an attempt to stabilize the flame at an even lower pressure. At 2 psia, the flame angle with this flameholder increased. This is consistent with the data obtained by Morrison and Dunlap[1]. Also, the gap between the apex of the V-flame and the flameholder, which is so pronounced at reduced pressures, was decreased considerably. By heating this flameholder to incadescence, it was possible to burn at pressures down to 0.75 psia, the limit of the present vacuum pump. At these low pressures the flame front appeared to have a definite thickness in contrast to a thin line at atmospheric pressures. Another interesting observation was a gradual change in color of the flame from blue near the apex of the flame to green near the upper portions. The flame front also appeared slightly concave upward. This might be due to a lower flame speed in the region where the flame was more green. If it were possible for the fuel-air mixture to be no longer homogeneous at low pressure but to be leaner near the flameholder and richer near the edges of the jet, both of the above effects, i.e., the concave appearance of the flame and the color change, would be observed. This will be investigated more thoroughly in later experiments.

1. UMM-21 - "Measurements of Flame Speeds with the V-flame"; R. B. Morrison and R. A. Dunlap, May, 1948.

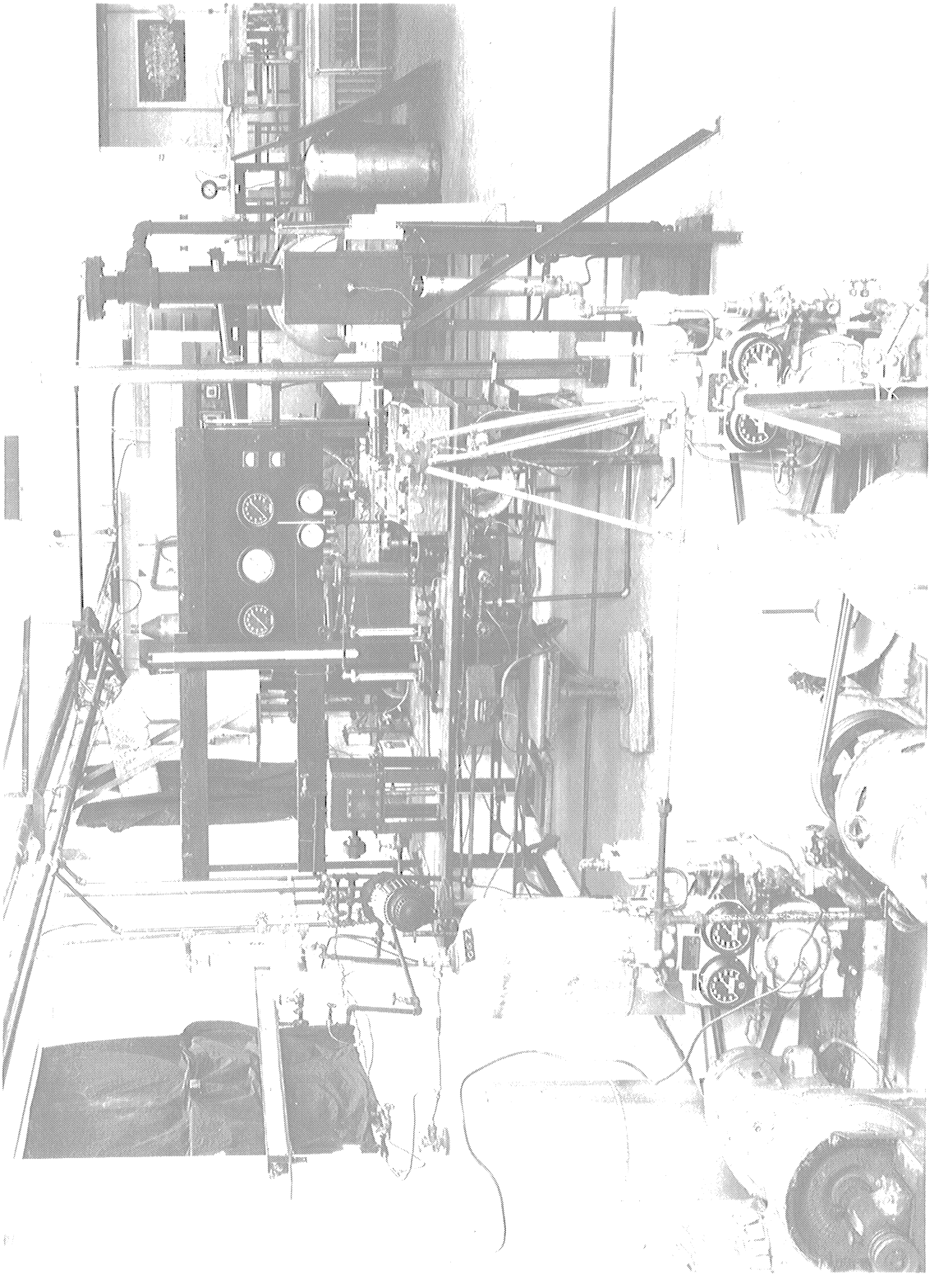
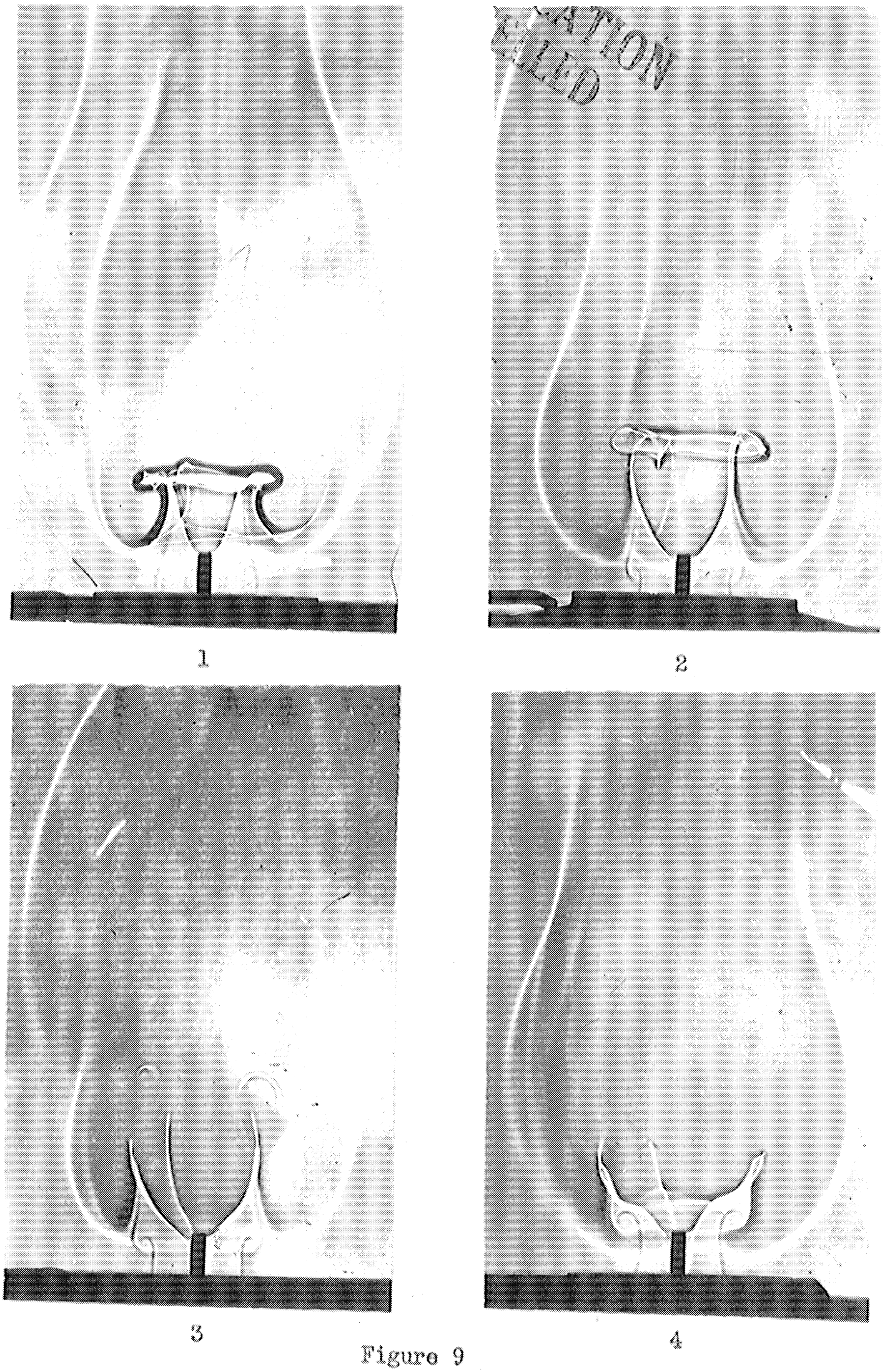


FIG. 8



1

2

3

4

Figure 9

SHADOWGRAPH OF VIBRATING FLAME AT ATMOSPHERIC PRESSURE

Shadowgraphs 1-4 indicate the oscillation cycle of the flame. The flame is burning from a rod flameholder mounted axially in a one-half inch jet. The vortices shed off the lip of the jet are in the unburned gas. Note that the vortices have a marked effect on the shape of the flame as they approach and enter the front. Fuel-air ratio = .067.

A series of runs were made at reduced pressure using rod flameholders mounted perpendicular to the jet and also mounted axially, producing respectively a two-dimensional and a three-dimensional V-flame. Runs will also be made using heated rod flameholders mounted perpendicular to the jet. A comparison of the data will be made in the future in an attempt to establish with more certainty the effect pressure has on flame speed.

Dimensional analysis was employed in an attempt to derive relations for flame speed, flame front thickness, and the distance between the visible flame and the flameholder in terms of such basic variables as pressure, temperature, density, etc. The analysis is being continued, but no important conclusions have been made to date.

Flow Associated with the V-flame

During experimentation with the confined V-flame it was observed that a definite tone or note is emitted from the combustion chamber. In order to further investigate this tone an expression was developed for the case where the unburned and burned gases are in resonance. The expression:

$$\frac{\Gamma_1}{\sqrt{\Gamma_1 R_1 T_1}} \tan \frac{2\pi n l_1}{\sqrt{\Gamma_1 R_1 T_1}} = \frac{-\Gamma_2}{\sqrt{\Gamma_2 R_2 T_2}} \tan \frac{2\pi n (L - l_1)}{\sqrt{\Gamma_2 R_2 T_2}}$$

results from the wave equations of motion.

(1) refers to unburned gas
(2) refers to burned gas
Γ = ratio of specific heats
T = Temperature of gas
R = Universal gas constant/mol. wt. of gas
n = Resonant frequency
L = Total length of combustion chamber
l = Length of column of unburned gas

This expression is similar to one developed by Lees[1] for a column of two gases where both ends of the column are antinodes. The experimental combustion chamber being used at the present is 1" x 1" x 12" with a .125" rod used as a flameholder. This flameholder was moved to various positions along the length of the combustion chamber and the resulting frequency of tone emitted checks closely with that calculated by the above expression.

An improvement has been made in the technique of taking shadowgraphs. With the equipment now set up it is possible to take a shadowgraph of the whole flame. Figure 10 is an example of such a shadowgraph.

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[1] C. L. Lees, Proceedings of Physical Society of London; Vol. 41, 1928-29

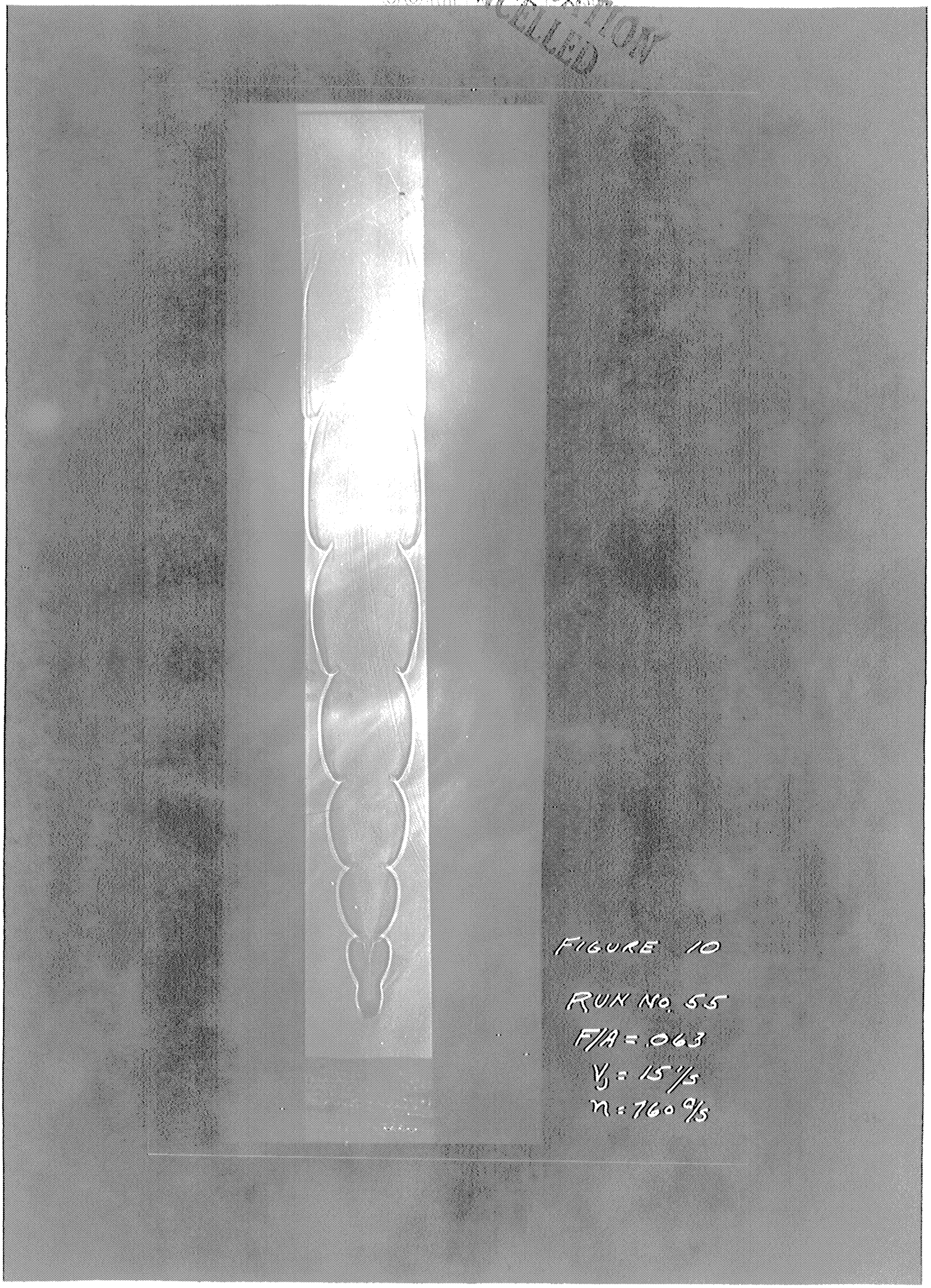


FIGURE 10

RUN NO. 55

$F/A = .063$

$V_j = 15\,'/s$

$n = 760\ c/s$

Detonation

Final assembly of the reservoir, valve section, and shock tube test section has been completed. This assembly included inserting the sealing bushing, the "O" rings for the valve mechanism, and the slide that will operate as a quick-opening gate valve. The valve stem has been dowelled to this slide and the whole assembly has been installed within the valve housing.

The spring activation mechanism has also been completed and mounted. When the spring is compressed, the port is closed. This separates the upstream high pressure reservoir gas from the one atmosphere fuel-air mixture in the shock tube test section. The necessary trip arrangement to allow for the die spring to operate has been fabricated and mounted. In connection with this a necessary stop has been fabricated and installed which will absorb the 600 pound force of the die spring with little or no recoil. This spring activation mechanism will be tested in the coming period with various reservoir gases at pressures up to 3,000 pounds.

The necessary electronic equipment for the spark source has been largely assembled. This will be used to take shadowgraph pictures of the shock wave as it moves down the tube. Two photoelectric cells have been partially set up and will be used as a direct reading type of measurement to time the passage of the shock down the tube. The cells will be installed so that either a gain in light intensity or a decrease in light intensity could be used to trigger the spark source.

The photoelectric cell was partially tested. The conventional operation of the shock tube is such that the high pressure reservoir gas moves downstream when the valve is opened. However, for these early tests the valve was closed, the tube was evacuated, and a cellophane membrane placed at the conventional downstream end. The cellophane was shattered, which allowed the one atmosphere of air outside of the shock tube to act as a reservoir gas, and a weak shock was sent down the tube in the direction opposite to which it would normally travel. Theoretically, the pressure in front of the shock was 2.16 pounds psia and the pressure behind the shock was 7.4 pounds psia.

It was felt that since the light is bent toward the normal when passing from a less dense to a more dense medium that directing a beam of light at an angle through the shock tube windows could be used to actuate the photoelectric cell. It was found that the beam of light so directed would trigger the photoelectric cell when the shock came down the tube. It did not operate repeatedly. It is believed, however, that when a shock wave of greater intensity, i.e., from a reservoir of 3,000 pounds, was sent down the tube in a conventional manner that the density ratio would be more than enough to deflect the beam of light and trigger the photoelectric cell. This will be investigated in the coming period.

It has been tentatively decided that two photoelectric cells could be used to obtain two pulses that will be directed into an oscilloscope with a known time base set in. A camera will be mounted and a picture taken of the two pulses caused by the passage of the shock. The position of the two pulses on the known time base would give the velocity of the shock wave. In conjunction with this the shock wave travelling down the tube will be compared with a sound wave caused by the passage of the shock down the tube. By comparing the known velocity of the sound wave to the velocity of the shock wave, a cross check on the photoelectric cell method will be obtained.

Blowdown Equipment

The two 3,000 psi air compressor units have been prepared for operation. All parts have been checked and have been operating satisfactorily up to 2,800 psi. The compressors are now ready to deliver air to the accumulators. Upper and lower flanges for the high pressure accumulators have been designed and machined and are now ready to be installed. All components of the system have also been ordered; the pressure reducing regulator, the plug type on-off valve, and the 3,000 psi fittings are still to arrive, however, The system is in the process of assembly and will be completed as soon as these units arrive.

With the exception of the sliding doors, the compressor building has been completed (see Figure 11). No separate heating units for the shed are to be installed for the protection of the compressors and engines; heat is to be provided from the laboratory proper by leaving the doors open to the shed.

The heat exchanger shell has been lined with circular segments of refractory firebrick, the lining having been made in short cylindrical rings which were cemented end to end and inserted in the exchanger shell. It is anticipated that the formation of shrinkage cracks is highly possible and that considerable trouble may be experienced with them. External water cooling of the heat exchanger shell may become necessary. The inner surface of the refractory liner has been treated with sodium silicate to prevent excessive spalling due to the high air velocities passing through the exchanger. No trouble with spalling is expected.

FIG. 11

Experimental Techniques and Instrumentation

The eight-inch interferometer for combustion and gas dynamic studies is now in the process of redesign and construction. Initially it was to be a duplicate of the one developed and built at the Power Plant Laboratory. However, several improvements are being incorporated in the instrument that will make it more adaptable to the anticipated applications, as well as considerably cheaper to manufacture. Some of the changes are:

1. the case enclosing the optical glass will be of a horseshoe shape; with both the free ends of identical design and joined with a 10 inch diameter commercial cast-iron pipe. This simplifies considerably the manufacture, and will be also much cheaper than the original.

2. a redesign of plate holders, to accommodate plates of equal thickness, according to the glass manufacturers specifications.

3. application of a double light source.

4. the provision for evacuation of the 10 inch pipe for compensation--to extend the compensation range for the anticipated vacuum experiments.

5. minor changes in adjustment mechanisms.

6. translational compensation on one of the mirrors, originally stationary.

7. camera and viewing boxes will be simplified.

8. a double wedge-type glass compensator.

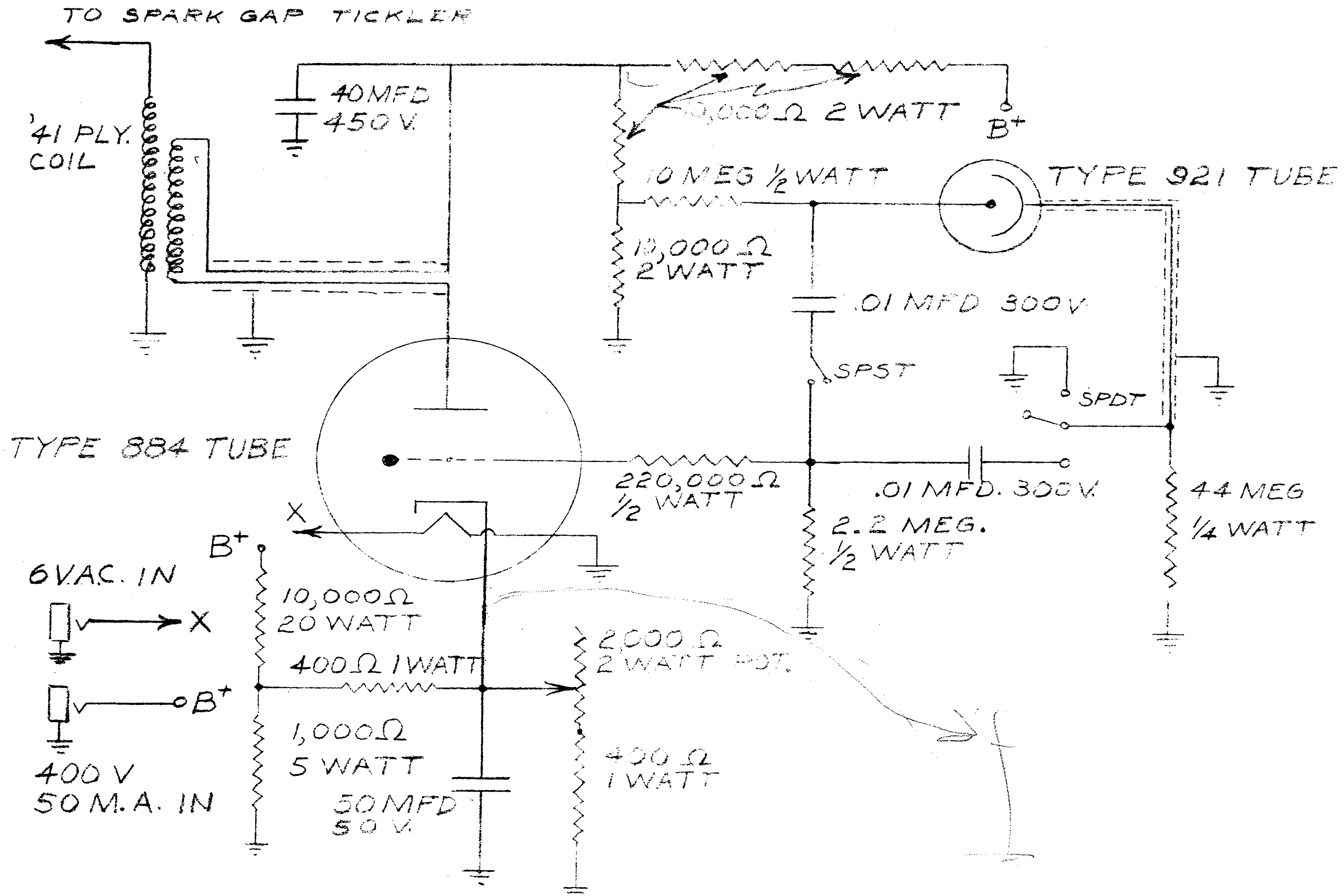
The interferometer will also incorporate a Schlieren system, which may be used with the same optical setup, simply by introducing retractable knife edges (not simultaneously).

The plates and mirrors in the optical system have already been ordered and should be delivered in the next progress period. The redesign of the plate holders has already been made.

The application of the interferometer in combustion experiments is being studied, in order to anticipate some of the problems and difficulties that may arise.

The Kerr cell studies have been temporarily postponed in order to concentrate the effort on the more pressing problems.

A photoelectric triggering system (Figure 12), which is to be used in the instrumentation of the flame studies, was designed, constructed, and tested. Some initial difficulties were encountered in the form of instability of the



SCHEMATIC OF TRIGGER CIRCUIT

FIGURE 12

circuit. These difficulties were eliminated by subsequent changes in circuit design and by use of shielded leads in critical portions of the circuit. It is felt that probably this system will not be adequate for application to the shock tube experiments. However, it should be adequate for flame studies.

The circuit consists basically of a photoelectric cell providing a triggering pulse to a thyratron type tube. It is so designed that it may be operated by a light increase or light decrease to the photoelectric cell. The type of operation may be selected by using the selector switches. The sensitivity is varied by the potentiometer in the cathode circuit of the thyratron tube.

Another thyratron triggering circuit is being designed which will incorporate a 2D21 and a 5C22 type thyratron. The 2D21, which has a smaller interelectrode capacitance and a shorter ionization time than the 884 tube, will provide a more positive triggering for the case of extremely short pulses as those generated in the case of the shock tube experiments.

VI. Program Planned for Period 8 (1 September to 1 November, 1949)

Blowoff Velocities of Flameholders

The vacuum system will be tested and the limits of the system will be determined. An effort will be made to obtain blowoff data under vacuum for spherical flameholders.

It is hoped that the main effect of lower pressure will be to increase the thickness of the boundary layer around the sphere. Since the geometry of the system is the same, the anticipated change in blowout limits might be attributed to a change in the boundary layer thickness, provided all other variables remain constant.

Combustion Chamber Design

Work will be continued to establish the relation between the ignition and combustion limits and "rough-burning" for various combustion chamber installations, and fuels. Efforts will be made to design an injection system whereby the fuel-air mixture can be more positively controlled at the flameholder independent of the air velocity past the holder.

Pressure and Temperature Effects on Combustion Processes

Before proceeding with the investigations of combustion phenomena throughout a wider range of pressures employing the V-flame and the new pressure-temperature installation, a completion of the runs begun earlier will be carried out. These runs were published in Progress Report No. 5 (UMR-31) and consisted of curves showing the variation of flame speed V_f and δ_q (the distance between the bottom of the flame cone and the lip of the Bunsen burner) with pressure. The range of pressure studied was from 4.7 psia to 42 psia; the fuel-air ratio employed was .067 pounds propane to pound air. A Bunsen type flame was used burning above a 1/4" diameter Bunsen tube with fully-developed Poiseuille flow. Similar runs will be made covering a wide range of combustible propane-air mixtures. This will complete the phase of pressure studies that can be accomplished on the small burner apparatus. These data will be presented in report form before further work will be done studying the effects of pressure and temperature on combustion phenomena with the large burner apparatus.

Flow Associated with the V-flame

Theoretical work on the wave type flame front observed in the confined combustion chamber will be continued.

Detonation

Initial tests of the timing circuit and spark source will be undertaken. The high pressure hydraulic pump to pressurize the reservoir gas from 3,000 up to 4,000 psia will be installed. Initial detonation tests with the shock tube will be undertaken as soon as the above circuits have been completed and calibrated.

Blowdown Equipment

The blowdown system is expected to be assembled and operating within the next two months. This includes the propane-air heating system which must be installed. It is expected that initial test runs will have been made and some data collected by that time.

Experimental Techniques and Instrumentation

The redesign and construction of the interferometer will be continued, as well as a study of its application to combustion problems. A thyratron triggering system for use in the shock tube experiments will be developed.

ACTIVITIES VISITED

Activities Visited	Subject Discussed
Cornell Aeronautical Laboratories Buffalo, New York	Instabilities in Flame Propagation
Cornell University, Ithaca, New York	Shock Tube Instrumentation
Wright-Patterson Air Base Dayton, Ohio	Progress Report Use of Interferometer on Flame Studies
Wright-Patterson Air Base Dayton, Ohio	Interferometer Alterations

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