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REPORT UMR-23

PROGRESS REPORT NO. 2

AAF CONTRACT W33-038ac21100

Period 1 Sept. to 1 Nov. 1948

PROGRESS REPORT NO. II

AAF CONTRACT W 33 - 038 ac - 21100

PERIOD 2 1 September - 1 November 1948

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I SUMMARY

PAST WORK (Period I, 1 July - 1 September 1948)

A large portion of Period I was used in the design and setting up of small scale test equipment to be used in the initial investigation.

Blowoff Velocities

Some blowoff data on spherical flame holders were collected, reduced, and presented in Progress Report 1 (Ref. 1)

Large Scale Combustion Chamber

The limits of flow on the large scale combustion chamber were checked. The burner assembly was successfully operated several times with the aid of a hydrogen pilot flame.

Temperature and Pressure Effects on Combustion Processes

The small scale equipment to study the effects of pressure on combustion was designed and assembled.

Detonation

The initial calculations and design of a shock tube to study detonation were made.

PRESENT WORK (Period II, 1 September - 1 November 1948)

Blowoff Velocities

Blowoff equipment capable of 400 ft/sec in a 1 inch nozzle has been designed and largely assembled.

Large Scale Combustion Chamber

A method of combustion chamber evaluation based on momentum considerations has been worked out which does not necessitate any high temperature measurements.

Temperature and Pressure Effects on Combustion Processes

The equipment for these tests was tested and some minor changes were made.

Detonation

The calculations and design of the shock tube to be used to study detonation was furthered.

Flow associated with a V-Flame.

Conformal transformations have been attempted on the V-flame which indicate a solution is possible. This solution involves one arbitrary constant to be determined from existent experimental data.

Blowdown Equipment

The design study of the blow-down equipment was continued.

II PROGRESS

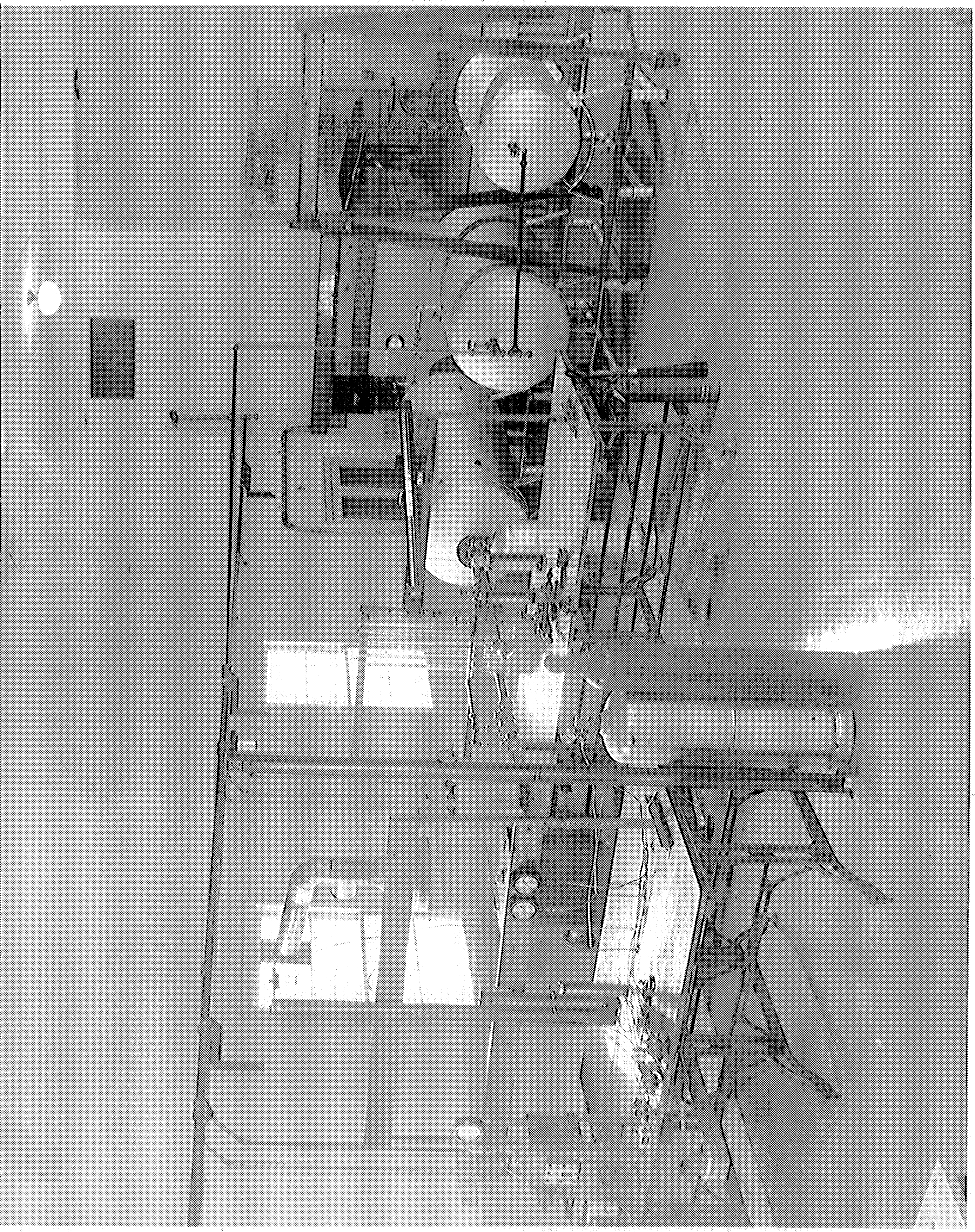
BLOW-OFF VELOCITIES OF FLAME HOLDERS

One hundred and fifty three experiments have been performed with the equipment described in the previous report. (Ref.1) The results obtained were plotted but are being recalculated for greater refinement by the mathematics group and are not available for this report.

These results indicated the desirability of having equipment capable of producing higher jet velocities as well as having a larger nozzle area to minimize the wall effect. Accordingly, equipment was designed to give a velocity of 400 ft./sec. in a 1 inch diameter nozzle. The equipment in its present state of assembly is shown in Figs.1 and 2.

Photograph

FIG. 1 Section of Propulsion Laboratory



Photograph

FIG. 2. Blow-off Velocity Equipment

LARGE SCALE COMBUSTION CHAMBER

Modification of the burner equipment has been approved and the necessary equipment ordered. This modification entails a combustion chamber arrangement whereby drag on the chamber can be measured in order that the heat release parameter can be evaluated without any high temperature measurements.

An arbitrary definition of combustion chamber efficiency has been agreed upon as a basis of comparing burner performance. Suffice it to say that a burner with 100% efficiency would have to add all of the heat of combustion that is theoretically available(equilibrium conditions and variable specific heats being accounted for) for a given fuel-air ratio in such a manner that the gases at the exit would have a uniform temperature and Mach number, i.e., one dimensional flow parameters will characterize the efficiency, as the best application of the heat of combustion is to increase the momentum of the air passing through the duct. The lack of one-dimensional flow at the exit of the burner would represent a poor distribution of the total energy and thus a lower net increase in the momentum; this in turn would result in a lower combustion change efficiency.

Some minor changes in the fuel lines will be made such that flow to the burner can be ascertained at all times. This work will be undertaken along with the modification of the burner.

TEMPERATURE AND PRESSURE EFFECTS ON COMBUSTION PROCESSES

The equipment as outlined in the previous Progress Report was assembled and a number of preliminary runs made. On the basis of these runs the following revisions were made in the equipment: The sensitivity and range of commercial rotameters were found inadequate. (Range of flows ranges from 0.1 to 3.0 cfm). A series of capillary flow tubes were designed and fabricated. Commercial "U" - tube manometers capable of withstanding 200 psia were installed for measurement of the fuel and air flow. These capillary flow tubes are now being calibrated for a pressure range from reduced pressures up to 200 psia. At high pressures ignition with a 10,000 volt coil is unsatisfactory. A higher capacity ignition system is being installed. A secondary air supply was introduced on the windows to clear them of the condensation formed by the combustion products. Small surge tanks are being installed in both the fuel and air lines to eliminate fluctuations of the manometers from rapid pressure variations in the combustion box. An additional safety feature of a "blow-out" flange and diaphragm was installed in the combustion box. To decrease the time required to make runs, a probable addition to the system will be a constant upstream pressure exhaust valve.

To date no test data has been obtained since the calibration of the capillary flow tubes is not complete. However, preliminary runs up to two atmospheres have been conducted which indicate that the present apparatus is satisfactory. The equipment is shown in Figs. 1 and 3.

FLOW ASSOCIATED WITH THE V-FLAME

The unconfined V-flame, a stationary flame burning in a free jet of combustible mixture, has a gas flow associated with it which can be briefly described as follows: (See figure 4) From the conservation of mass, momentum and energy through the flame front it can be shown that a fluid element will suffer a pressure drop on passing through the front. This pressure drop is the result of a momentum exchange normal to the front which will exert itself on the gases flowing up to the front. This force on the fluid element due to the momentum exchange is balanced by the centrifugal force on the element due to its traveling the curved path indicated by the streamline x-x. Figure 5 is a qualitative pressure and velocity plot along a streamline.

A theoretical analysis of this flow has been attempted by the utilization of the following basic relations, conservation of mass, momentum, energy and the equation of state. These four equations, however, reduce to only two, i.e., the conservation of mass and momentum as independent equations for the potential flow up to the front. These two equations do not provide sufficient information to describe the flow field quantitatively.

Since these equations do not yield results in a usable form, it seemed advisable to use a different approach. The problem was discussed with the Mathematics Group at the Research Center, and these men seem confident that an equation can be written for the flow up to the flame front by the use of certain conformal transformations. They are working on this approach at present.

Photograph

Fig. 3 Pressure and temperature equipment

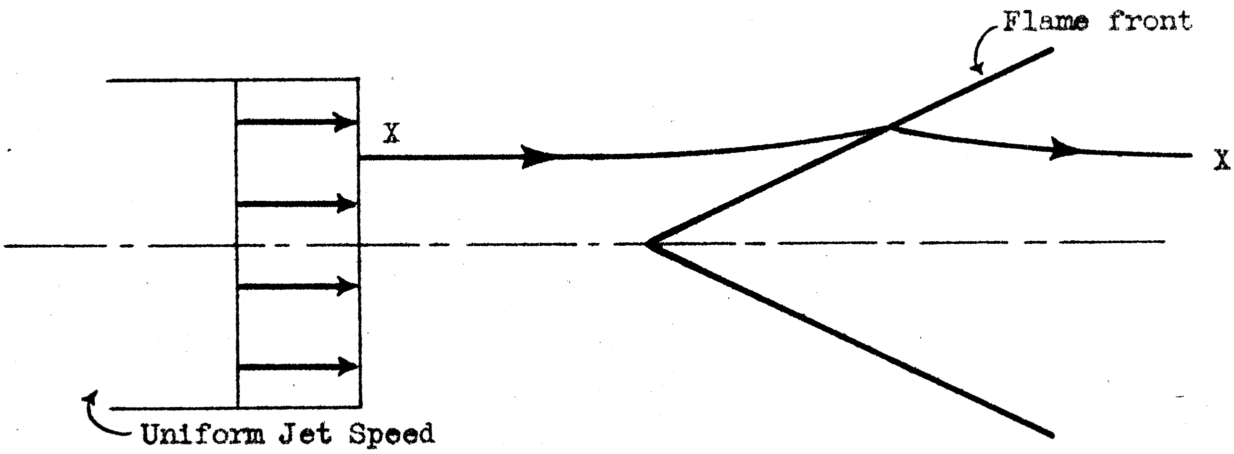


Fig. 4 -- STREAMLINE CONFIGURATION OF THE V-FLAME

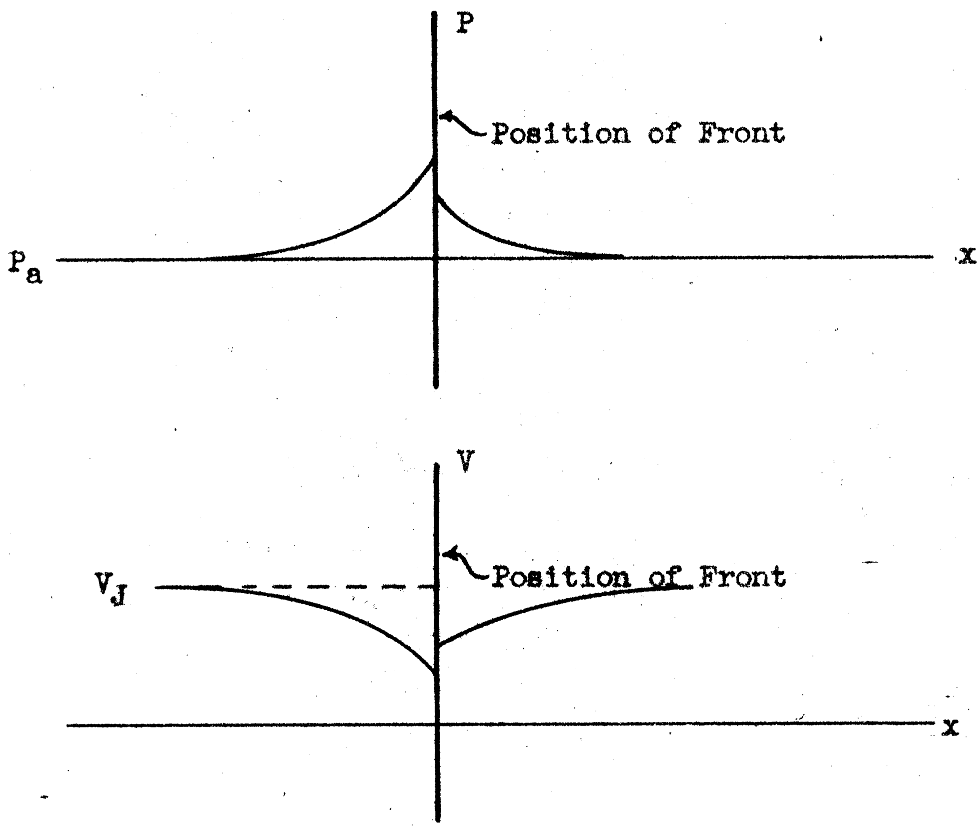


Fig. 5 -- PRESSURE AND VELOCITY VARIATIONS ACROSS A V-FLAME FRONT

DETONATION

The designed theoretical work for the construction of a shock tube to investigate detonation of gaseous fuel-air mixtures is continuing.

A shock wave will be sent down this tube into a combustible mixture (Fig.6). This shock is to be formed by quickly opening a port and allowing a high pressure wave to move down the tube. The speed at which the port is opened determines the time for the pressure wave to build into a shock wave. The faster the valve, the shorter the time required to form a normal shock.

Theoretical work to date indicated the practical limit for a shock velocity (as dictated by the pressure required to produce that velocity) is that of one traveling at about a Mach number of 5 with respect to undisturbed atmospheric conditions ahead of the moving shock wave.

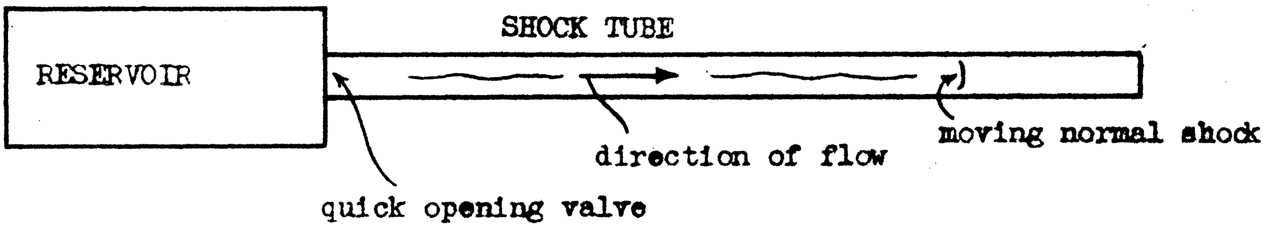


Fig. 6

SHOCK TUBE SCHEMATIC DIAGRAM

BLOW-DOWN EQUIPMENT

An analysis of a representative blow-down system has been made. Graphs of duration of run plotted vs. temperature, pressure, weight of air and weight flow rate of air for parameters of throat size at entrance to test section have been completed. Analyses have been made for both a simple blow-down system exhausting directly from storage into the atmosphere, and for a two-stage system using an intermediate constant-pressure tank exhausting through a test section, thence to the atmosphere. The effect of heat addition upon length of run is included. A rough layout of the blow-down system using the intermediate constant pressure tank has been made utilizing equipment on hand.

The constant pressure blow down system accounts for the effect of choking in any valve restrictions elsewhere in the system. It is designed so that the throat immediately upstream of the test section will at all times control the maximum mass flow through the system.

The constant pressure system incorporates a pressurized heat exchanger for maintaining constant temperature, constant pressure conditions in the test section as required by contract. The exact type of heat exchanger has not definitely been established, although considerable thought has been given to find a cheap, practical system of heating the intermediate pressure air. An analysis was made of a constant-volume hydrogen burning system which simultaneously increases the pressure and temperature in the storage tanks to 3000 psia and approximately 2000° R. This method has been found impractical for combustion research purposes because of the extremely large quantities of water formed. (20% by weight of the air in the tank).

Compression by a diaphragm separation system with burning hydrogen in one section and air in the other was discarded for lack of high temperature and pressure materials to do the job. It appears that hydrogen or any hydrocarbon burning in the system air source would be impractical because of the resulting contamination of the stream.

It appears that the most practical type of heat exchanger is a direct exchanger of heat from a high temperature, high heat capacity source to the moving air. Such an exchanger is in use at N.A.C.A, Langley Field, Virginia. At the present time a study is being made for cheap materials to be inserted in the heat exchanger body which would produce the desired end conditions.

Pumping requirements have been fairly well determined and the equipment is to be secured. Additional equipment such as valves, piping, etc. is expected to be determined shortly in the detailed layout of the system.

III ACTIVITIES VISITED

Activities Visited	Subjects Discussed
Battelle Memorial Institute Columbus, Ohio	Inverted V-flame Blow-off velocities Flame stability
Third Symposium on Combustion and Flame and Explosion Phenomena University of Wisconsin Madison, Wisconsin	Combustion, Flames, and Explosion phenomena
N.A.C.A. Laboratories Cleveland, Ohio	Combustion Chamber Measurements
JHUAPL Silver Springs, Md.	Blowdown Equipment
Langley Aeronautical Laboratory Langley Field, Va.	Blowdown Equipment

IV PROGRAM PLANNED FOR NEXT PERIOD

Blow-off Velocities of Flameholders

Additional assembly work, as well as calibration of orifices, needs to be accomplished before further test work can be done.

Large Scale Combustion Chamber

The calibration of the combustion chamber drag measuring equipment will follow its installation. Following the calibration runs, routine tests on the effect of high pressure fuel injection will be commenced.

Pressure and Temperature Effects on Combustion

Upon completion of the calibration of the flow measuring instruments an experimental study of the effect of pressure on combustion will be initiated, covering a range of pressures from reduced pressures to 200 psia.

Flow Associated with the V-Flame

The design and construction of a confined combustion chamber will be initiated. This chamber is to have a 1 inch x 1 inch square section with glass windows on two sides and will fit on existing equipment. A theoretical analysis of the flow thru the confined combustion chamber will also be started.

Detonation

The design and construction of the shock tube will be continued and the necessary photographic equipment will be developed.

REFERENCES

1) Progress Report No. 1 -- UMR-21 -- University of Michigan
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