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UNITED STATES NAVY

PROJECT SQUID

SEMI-ANNUAL
PROGRESS REPORT

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SEMI-ANNUAL PROGRESS REPORT

PROJECT SQUID

A PROGRAM OF FUNDAMENTAL RESEARCH
ON LIQUID ROCKET AND PULSE JET PROPULSION

FOR THE
BUREAU OF AERONAUTICS AND THE OFFICE OF NAVAL RESEARCH
OF THE
NAVY DEPARTMENT

CONTRACT N60RI-105, TASK ORDER 1

PURDUE UNIVERSITY AND
PURDUE RESEARCH FOUNDATION
WEST LAFAYETTE, INDIANA
1 JANUARY 1947

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PHASE 1

Statement of Problem

The statement of the general problem as outlined briefly in a Navy document follows: "Development of a method of measuring instantaneous gas temperature fluctuating at frequencies from 50 to 100 cycles per second in a range from room temperature to 3,000° F. (pulse jet gases)."

The statement of the problem undertaken at Purdue University follows: A study of equipment and techniques for use in measuring or calculating the varying temperature of the gas in pulse jet engines. The temperature of the gas will be assumed to oscillate between 60° F. and 3,000° F. with a frequency of 50 to 200 cycles per second. The maximum gas velocity will be assumed to vary from zero to supersonic velocities.

Scope of the Project

The phase has been divided into the following sections:

A. A survey of the literature available to Purdue University will be made covering the following subjects: (1) methods and apparatus for measuring the temperature of gases flowing at subsonic velocities; (2) methods and apparatus for measuring rapidly changing gas temperatures; (3) methods and apparatus for measuring the temperature of gases flowing at supersonic velocities.

B. Following the survey of the literature, a theoretical analysis of the various methods will be made in an effort to select those methods which show promise for further study. Such factors as time lag of the measuring element and errors due to the various modes of heat transfer to and from the measuring element will be studied.

C. Apparatus will be constructed and tested on the basis of the conclusions reached as a result of the theoretical study.

Progress

A. The survey of the literature available at Purdue University is nearing completion. Approxi-

mately fifty documents dealing specifically with the problem have been reviewed. Many other references of a general nature have been studied to acquire background data. Forty-four different types of apparatus for measuring temperature were listed during the course of the review of the literature. Many of these methods could not be considered for this investigation due to serious operating limitations.

B. After many conferences, the staff selected three of the many methods for further study. It was decided that each method would be investigated independently of the others, and upon completion of the work covering each of the selected methods, all of the instruments would be tested under identical conditions. Based on these results, a final selection of the method to be used will be made. The temperature measuring methods selected for further study are:

1. A study of the design of a shielded bare thermocouple. The study will cover an analysis of the time lag of the measuring element as influenced by such factors as wire size, gas velocity, temperature change, and other variables.

2. A study of the design of a shielded suction thermocouple. The study will cover the time lag of the element as influenced by gas velocity and other variables.

3. A study of the design of a resistance thermometer including supports and necessary electrical apparatus. The time lag of the measuring element will be studied in an effort to determine the influence of such variables as wire size, gas velocity, and heat losses.

Owing to the short time intervals involved, the experimental measurements will be made by means of a cathode ray oscillograph and a rotating drum camera. After the characteristics of the individual temperature measuring elements have been analyzed, actual performance tests will be made. It is hoped that a pulse jet engine will be available for these tests.

PHASE 2

Statement of Problem

To study continuous process combustion with available fuels and oxidizers, determining effects of combustion chamber size and shape, fuel and oxidizer distribution, and turbulence.

Progress

The major portion of Phase 2 will deal with a study of continuous process combustion utilizing air as the oxidizing agent. Although combustion in the pulsating jet engine is not continuous, the most

direct approach to a study of the effects of numerous variables entering into the process appears to be possible through fixing one major variable, namely, intermittent air supply. After sufficient investigation has been made with the continuous process to permit evaluation of at least the major factors, such as effect of turbulence, combustion chamber configuration, fuel and air dispersion, fuel and air temperatures, flame holders, wall temperatures, etc. on combustion rate and efficiency, the intermittent or pulsating combustion should be explored. It is realized that any one of the factors could readily involve all contemplated facilities and personnel. Attempts will be made to concentrate activities on one or more factors which can best be handled. This will be determined after preliminary experimentation.

The results of this research should be directly applicable to both ram-jet or athodyd and turbo-jet combustion. These types are not directly under the scope of Project SQUID, as it now appears, but may readily become of great interest when consideration is directed toward composite designs such as ram and intermittent jets. This dual type is of importance when broadest operating speed ranges are imperative. Since most missiles and crafts will have to start from zero speed, propulsive devices such as the ram-jet must be given auxiliary assistance until high speed is reached. It is not improbable that a single combustion chamber could be utilized for both types of jet engines.

Since facilities are not yet available for supplying sufficient quantity of air at adequate pressures, efforts will be directed toward minimum scale operations for the purpose of developing techniques and instrumentation which should be directly applicable to the full sized operations.

With turbulence forming such a major part in rapidity of combustion, the initial work will involve simulation and measurement of turbulence, coupled with a determination of its effects on combustion. It is proposed to utilize schlieren apparatus to study minute disturbances in the incoming air stream, which will be made as non-turbulent as possible. Consideration has been given to means for supplying turbulent air without any appreciable reduction in mass movement of the main body of air. This naturally would require a greater pressure upstream. Also, the problem of maintaining identical mixture strength sections of high and low turbulence must be solved to eliminate erroneous analysis of effects of controlled local turbulence on combustion.

Consideration must be given to maintaining low turbulent conditions in the main body of the air stream. Since velocities will be high in this air stream, laminar flow will not exist. Consideration has been given to methods of retaining flow of low turbulence at high Reynolds number. Means for removing boundary air may aid in this, but it would be rather difficult to apply effectively to a combustion chamber. Jets of various contracting ratios will be used for the initial stages of experimentation.

Since it is desired to determine the flame velocity necessary to maintain a stable flame front, adequate provisions are being made to adjust the mass air flow rate to hold the flame in position so that the flame velocity may be computed.

Attempts will be made to ascertain the effects of fuel dispersion and droplet size. This work will not be started until a reasonable degree of information is obtained about mixtures of greatest homogeneity. Homogeneity could be attained if all fuel were vaporized prior to its introduction into the combustion chamber. Due to the hazardous character of this work and lack of facilities in an isolated area, studies with liquid fuels may not be possible. Propane or other fuels, gaseous in nature at normal temperatures, may be utilized and introduced into the entrance of the small scale combustion chamber located outside the Mechanical Engineering Laboratory. Introduction farther upstream would place an explosive mixture in the parts of the easily ruptured ducts which are within the building.

A determination of flame temperatures throughout the combustion chamber will be made to permit evaluation of the effects of turbulence and other factors affecting combustion. Initial measurement will be obtained with the flame discharging directly into the atmosphere. Provisions are being made to equip the chamber with glass windows of different materials to permit observation of a wide range of spectrum wave lengths. Designs are in progress incorporating complete sections of glass-walled chambers. Cooling of these sections remains a major problem. The use of full sections is desirable in that complete study can then be made of all sectors of a full cross section normal to the general mass movement of the gases. Two methods of flame temperature measurements are contemplated. These are the heated resistance wire and the sodium-line reversal methods. Either of these should permit localized temperature determinations. Since stable flames are anticipated, other methods of measurement will be possible, particularly in view of the fact that relative

values can be used if necessary. Thermocouples enclosed in sampling tubes also are of interest, since by use of this method it would be possible to analyze the gas on which a temperature measurement has already been obtained.

It is intended to determine the fundamental requirements for design of flame holders. These requirements must be integrated with the fuel spray mechanism. The flame holders also bear important relation to the configuration of the combustion chamber and to scaled-down effects which may be investigated.

Owing to the high heat release from combustion, adequate protection must be given to the chamber wall to maintain reasonable surface temperatures below the plastic point. Therefore, cooling will be required. Since reactions occur at surfaces in contact with combustible mixtures, it will be necessary to evaluate the effect of surface temperatures. In addition, surface materials should also be investigated. Chamber designs have included considerations of these problems.

Facilities and Equipment

Plans for facilities have been based on the need for housing the various instruments and combustion chambers and also for housing the tremendous source of power needed for driving the compressors. The minimum structure requirement is a 40' x 80' Quonset with suitable foundations and walls. Two-thirds of this structure is required for the engines and compressors. In view of the hazards and noise involved, location has been established at the Purdue Airport, remote from existing or contemplated buildings.

Provision was originally made to install ten Allison V-1710 aircraft engines, each driving its own auxiliary stage supercharger, to be used as a compressor. Owing to the absolute necessity for reducing costs to remain within the original estimates and to the greater simplicity subsequently discovered possible by a novel adaptation of compressors, the number of engine installations has been reduced to six, and the number of compressors from fifteen to twelve. With this arrangement a greater volume of air than was originally contemplated will be available, up to a discharge pressure of 17 psi. The new capacity will be 240,000 pounds of air per hour at

17 psi. The compressors can be two-staged for a discharge pressure of 45 psi and a flow of about 100,000 pounds of air per hour. Three headers will permit ample selectivity and matching of the compressors for various requirements up to the maximum values noted. The twelve compressors normally require about 4,200 horsepower, but since the engines can deliver under emergency over 12,000 horsepower, ample power is available.

A single compressor, identical to those previously mentioned, has been coupled to a dynamometer. Owing to the lower speed and power, it will be capable of supplying about one-third normal capacity at a lower pressure. By proper choice of combustion chamber dimensions and fuel rate, reasonably satisfactory preliminary data can be obtained.

Summary of Work Completed

Owing to limitations placed on personnel commitments, it has been necessary to confine activities mainly to the preparation of plans and equipment designs. Drawing and specifications for the building and services have been completed and placed in the hands of contractors for competitive bidding.

Critical items in many cases have been ordered and in some instances have already been received.

All necessary engines and compressors have been received, and preparations are under way for earliest possible operation.

All engine mounts and most of the compressor mounts, heat exchangers, controls for the engines and compressors, oil clarifiers, and oil system piping have been received, and mock-up operations have been started on the engines and related equipment.

Many of the necessary instruments, control panels, and operational devices are available and awaiting shipment.

Study has been made of applicable schlieren apparatus, and procurement has been initiated for components. Other devices, such as instantaneous pressure indicating instruments, have been procured or contracts made for procurement.

The small scale combustion chamber and related equipment has been installed, and certain modifications are being made in the light of initial air flow operations using the single compressor. Actual firing of the charge awaits completion of the high voltage ignition system and a suitably controlled fuel system.

PHASE 3

Statement of Problem

This phase undertakes the study of corrosion in connection with jet propulsion. The purpose of this research is to identify the corrosion products, to investigate the dependence of corrosion on the chemical and physical properties of the materials and on the conditions of exposure.

Progress

The first problem is to identify and study the corrosion products in various parts of jet motors.

The primary identification method to be used is a comparison of the X-ray and electron diffraction patterns obtained from the products with patterns obtained from known compounds. To facilitate the comparison, standardized charts showing the position and relative intensities of the diffraction lines of all known compounds likely to be found have been prepared from the A.I.M.E. structure cards and other sources. Since diffraction methods cannot answer all questions of identification (e.g. the differences between iron and chromium and between iron oxide and chromium oxide may be obscured if, due to stress or small particle size, the lines are broad), chemical and spectroscopic methods may also be necessary. Suitable spectroscopic equipment for this work is available.

Where representative samples of the corrosion may be removed by abrasion or stripping, conventional powder diffraction techniques can be used. For this work an additional X-ray diffraction unit has been completed for the usual Debye-Scherrer, back reflection methods, etc. A precision camera is under construction.

In many cases it will not be possible to obtain adequate representative specimens for investigation by the usual powder methods, and in other cases, such as in following the corrosion process with repeated exposures, it is not desirable to disturb the sample. Identification in this case requires some form of the reflection method. Electron diffraction is adequate for the outermost surface structure, but interpretations must take cognizance of possible change between exposure and examination. The back reflection X-ray technique is useful, but the exposures are long and identification difficult in most cases because of the complexity of the diffraction patterns at the large angles of observation and the

small range of angles available. To meet these needs, a Phillips X-ray focussing spectrometer was ordered. After many delays (including the loss of one large shipment in a local warehouse fire) installation is complete and preliminary work begun. This instrument uses a flat sample of powder or polycrystalline solid and Geiger counter registration. Intense patterns may be recorded directly on a strip-chart recorder. With weaker patterns, point by point counts are necessary.

In anticipation of slow delivery on this instrument, and because cases may arise in which the Fe K_{α} and Cu K_{α} radiations usable with it may not be adequate, modification of our Bragg ionization spectrometer to do similar work was undertaken. The instrument has been fitted with a new slit system and suitable specimen mounts. Materials for a filament stabilizing circuit for the X-ray tube have been received and assembly started.

The most critical part of the ionization spectrometer for powder sample work is the electrometer used to indicate ionization current. Various circuits have been tried with the special electrometer tubes developed during the war. The simplest of these, using grid modulation in a one-stage balanced circuit, was found satisfactory for single crystal work but not sufficiently sensitive for powder diffraction. During the past several weeks four types of additional amplification and indication circuits have been tried. The necessary sensitivity can easily be reached, but obtaining stability sufficient to make this sensitivity usable has been difficult. At present, with an input circuit of 20 second time constant, the indication sensitivity is 10^{-17} ampere with a fluctuation of 2 to 3×10^{-16} ampere. It is not yet known whether all of this fluctuation is due to tube and circuit noise or whether part of it is still due to fluctuations of the modulation oscillator and therefore might be reduced.

In some phases of the research, particularly the study of the corrosion process in its early stages, submicroscopic surface effects are important. To facilitate their study, the electron diffraction apparatus and electron microscope have been overhauled. A replica technique has been developed with the latter instrument for examination of the surfaces of solids.

In addition to the work of corrosion identification as outlined, it is proposed to attack the problem from a more fundamental but longer-range point of

view by a study of the corrosion process under controlled conditions. The contemplated steps are:

1. *Preparation of sample.*

a. Polish, etch, and wash. The object here is to prepare a surface as free of abrasion and cold working effects as possible. Special low temperature abrasion and electrolytic etch methods will be investigated.

b. Examination by electron diffraction and electron microscope to insure freedom from residue of part (a).

c. Heat treat in vacuum or neutral atmosphere at various temperatures and for times comparable to those to be used in the experiment.

d. Repeat (b). Also examine with the optical microscope and X-rays to obtain as much information as possible about the surface on which the corrosion experiment is to be made.

2. *Exposure to corroding atmospheres at various temperatures and pressures for increasing periods of time.*

3. *Examination of the corrosion layer.*

a. Optical and electron microscope photographs of the surface (by replica technique with the latter instrument, applicable only to the early stages of corrosion) and of sections. Preparation of sections is difficult but has been done with the optical microscope. Attempts will be made to extend the method to the electron instrument.

b. Determination of corrosion products as outlined above.

c. Determination of the thickness of the corrosion layer and, from this, the rate of attack. Change of pressure of reacting gas, gravimetric, temperature, chemical, and polarimetric methods have been

used. An additional X-ray method is under investigation. Two variations of the method are possible. The weakening of the base metal diffractive pattern by the absorption of the film may be used to determine the thickness of the film when its composition is known. Alternatively, the intensities of the diffraction patterns of base metal and film may be compared. From these data, at two angles of diffraction, one may determine both the absorption coefficient of the film and its thickness.

The methods and techniques outlined in these steps will be applied to iron and carbon steels and then extended to alloy steels, using oxygen as the corrosive agent. A quartz tube vacuum furnace for steps 1 and 2 is being assembled. Purification trains for oxygen and hydrogen will be incorporated. An additional furnace for air exposure is available. Steps 2 and 3 will be carried out separately. This involves treatment at one temperature and observation at another, with the attendant risk of changes in the corrosion layer. It is felt that every effort should be made to combine treatment and observation, or at least to make the structure identifications at the temperature of exposure. A certain amount of such work has been done previously by the electron diffraction method. Design of the necessary furnace for the electron diffraction camera is progressing. Such a furnace for the X-ray observations is more involved because of the wider aperture necessary for entrance and exit of the X-ray beam. If the X-ray method of thickness measurement is successful, design of an appropriate furnace will be attempted.

A survey of the extensive literature of corrosion has progressed almost to completion of a bibliography. The organization and assimilation of the material is continuing.

PHASE 4

Statement of Problem

The purpose of this research is to study, by means of bomb or continuous flow experiments, temperatures, pressures, and concentration of reactants for various oxidation reactions of materials which may be of value as fuel for rocket or jet engines.

Progress

The initial work on this project consisted of an extensive library search covering the field of oxidation or combustion reactions of fuels. This search indicated that a large part of the work which has

been done in connection with the combustion of fuels was carried out in constant volume bombs under batch conditions. The main objections to experiments of this type are: (1) samples of the material in the zone of combustion cannot be taken at desired time intervals as the combustion reaction proceeds; (2) the temperature in the combustion zone cannot be measured accurately because of the rapid rate of rise in temperature as the reaction proceeds; (3) the rate of increase in pressure as the combustion reaction proceeds must also be known; this can be measured with sufficient accuracy with present equipment and techniques; and (4) any samples

which could be obtained would probably have to be analyzed spectroscopically because of the small quantity of sample available.

Many of the objections to constant volume bomb experiments could be overcome by carrying out the combustion reaction under steady state continuous flow conditions at constant pressure. If steady state conditions are maintained in the combustion zone, the rate of change of any independent variable with time will be zero. The greatest difficulty to be expected in the operation of continuous flow equipment is the design and construction of a combustion chamber which will withstand temperatures in the range of 3,000°F to 5,000°F. If a continuous flow apparatus is used, samples from the combustion zone can be taken in any desired quantity.

The primary purpose in using a continuous flow apparatus is to attempt to quench the combustion reaction by rapidly cooling the reaction mixture to a

have been constructed for the preliminary investigation involving methane and air.

The first piece of equipment, shown in Figure 1, consists of a combustion chamber made from a ceramic sphere approximately one and one-half inches in diameter. The outlet of the combustion chamber is connected to the quenching tube through which the inert quenching gas flows. This equipment was not used to any great extent because of the difficulty in getting tight seals at the points where various connections were made in the combustion chamber. This piece of equipment would not withstand any appreciable pressure and had the added disadvantage of not permitting visual observation of the combustion zone.

The equipment sketched in Figures 2, 3, and 4 was constructed from Pyrex glass. In Figure 2 the combustion zone is approximately one-eighth inch long and one-eighth inch in diameter. The use of a

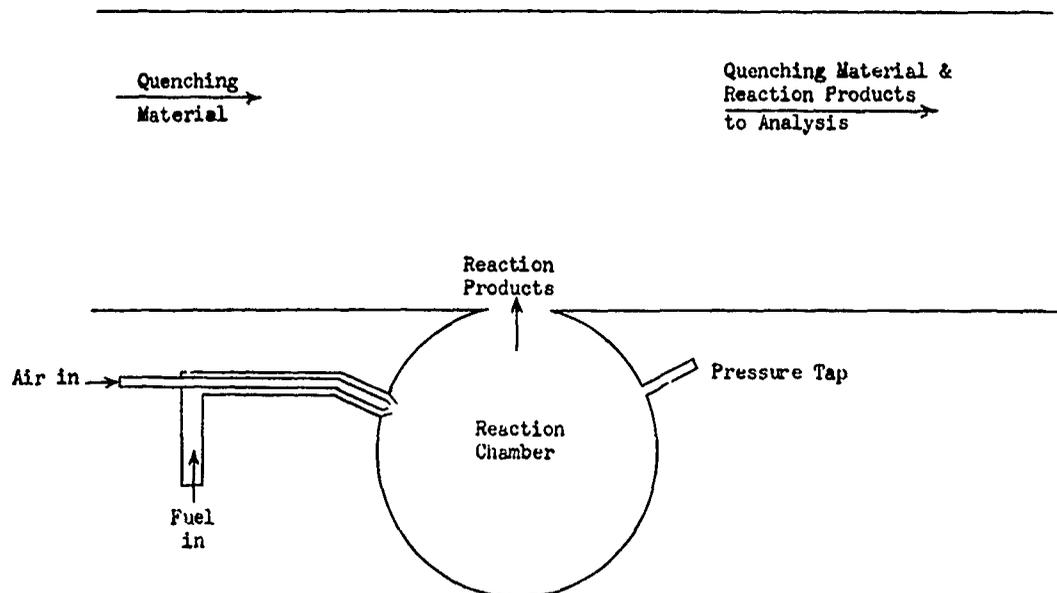


Figure 1. Spherical ceramic combustion chamber and quenching tube.

temperature at which the reaction rate is negligible. If such quenching can be accomplished, the effect of reaction time can be studied by varying the rate of input of oxygen and fuel for a combustion chamber of a given volume. The quenching medium used to cool the reaction products will be an inert gas.

Preliminary studies are to be made using mixtures of methane and air and methane and oxygen as the reacting mixture. Part of the preliminary work will be carried out in glass equipment so that visual observations can be made. Four pieces of equipment

combustion chamber of small volume will require relatively small quantities of oxygen and fuel for experiments involving short reaction times. The products of the combustion reaction will be quenched by the inert gas as they flow into the quenching tube as shown in Figure 2. In actual operation a constriction will be placed in the quenching tube opposite the combustion chamber outlet so that a high degree of turbulence will be obtained at the point of mixing of the combustion gases with the quenching gas. The gases leaving the exit of the quenching

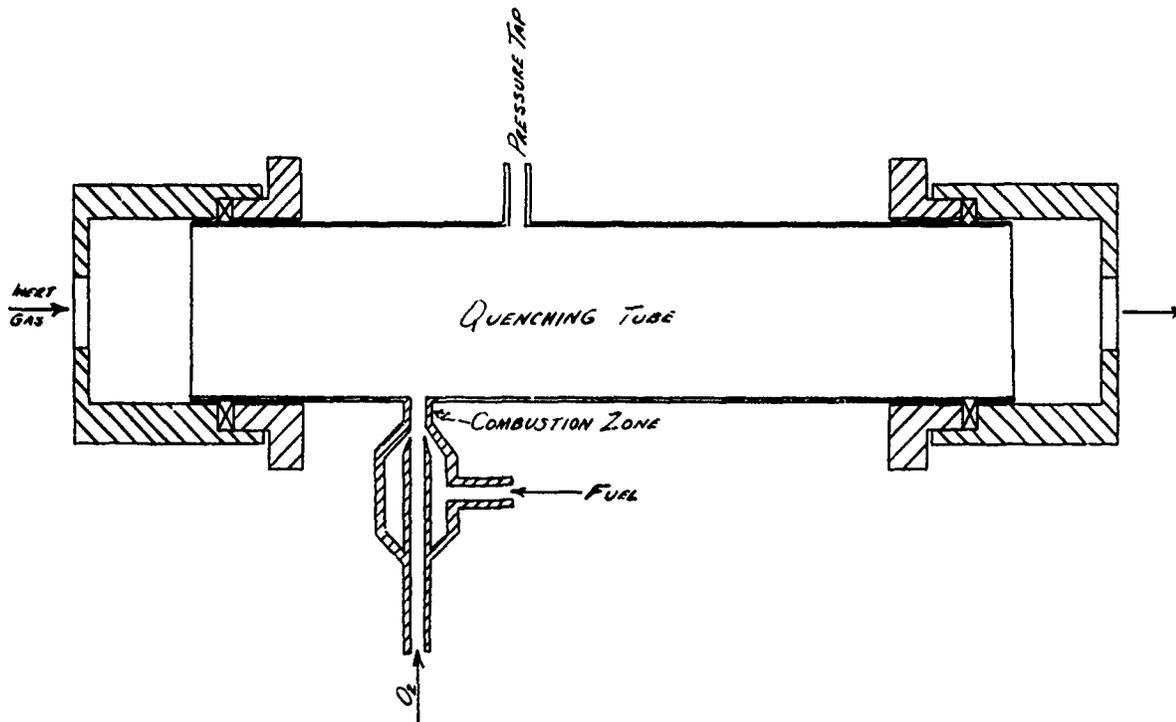


Figure 2. Extremely small combustion chamber with quenching tube.

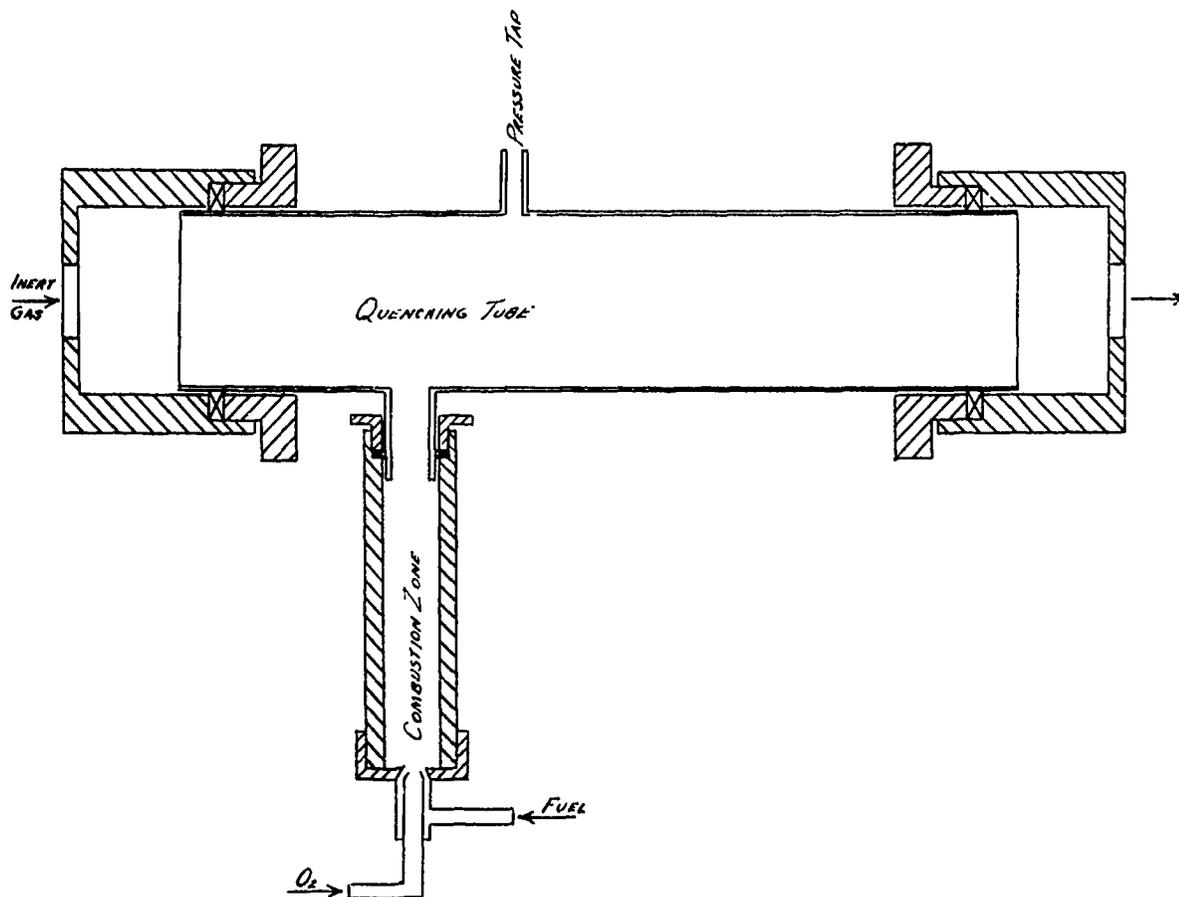


Figure 3. A burner within a quenching tube. The quenching gas flows parallel to the direction of the flame.

tube will pass into a scrubbing system. The mixture of fuel and air entering the combustion chamber will be ignited by means of a spark. The details of this arrangement are not shown in Figure 2.

The apparatus shown in Figure 3 consists of a burner placed inside the quenching tube with the quenching gas flowing parallel to the direction of the flame or of the flow of the products of combustion. This piece of apparatus can also be arranged so that the direction of flow of the quenching gas is counter-current to the direction of the flame or of the flow of the products of combustion. This type of

ity of quenching gas may be obtained at the point where the products of combustion from the combustion zone enter the quenching tube. The quenching tube as shown in Figures 2, 3, and 4 will be connected to other pieces of apparatus including the scrubbing system. The experimental data obtained from the glass equipment, together with the techniques based on visual observations, should make possible the design of equipment for use in the final studies on this project.

The preliminary experiments with methane and air are to be carried out in these pieces of equipment to determine if it is possible to stop the com-

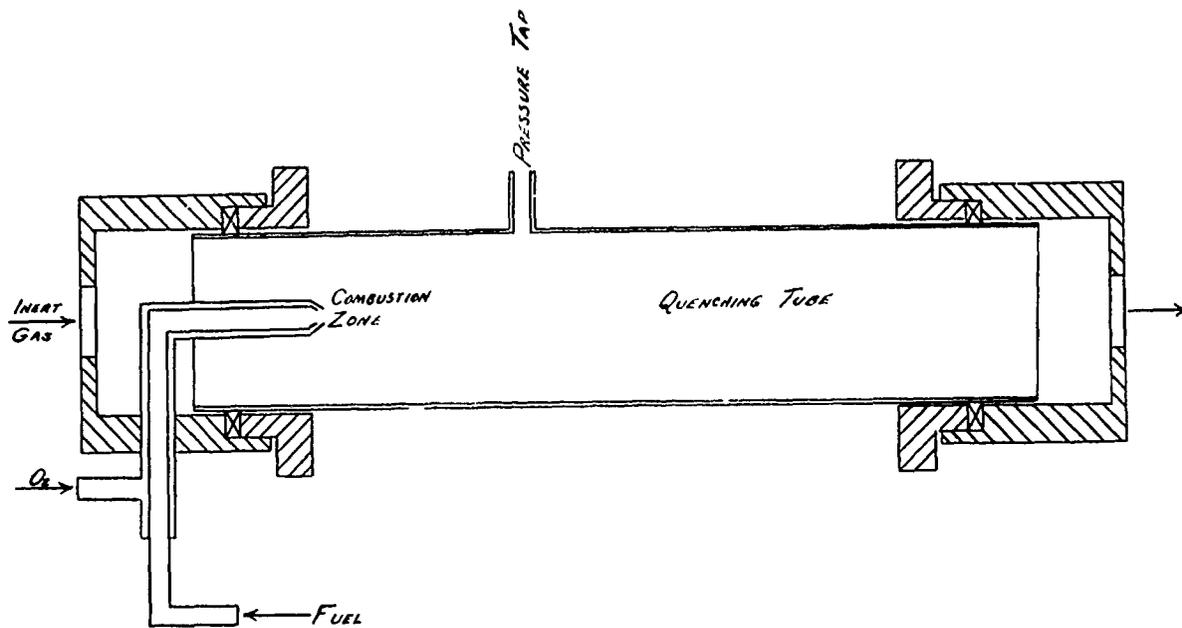


Figure 4. Small combustion chamber with quenching tube.

equipment will require some means of measuring the volume of the combustion zone at the end of the burner nozzle. The apparatus shown in Figure 4 is similar to that shown in Figure 2 except that the combustion chamber is larger in volume, and this will permit studies at longer reaction times if such studies are necessary. This piece of equipment will also require a restriction in the quenching tube opposite the combustion chamber so that a high veloc-

ity of quenching gas may be obtained at the point where the products of combustion from the combustion zone enter the quenching tube. If this step can be carried out successfully, the composition of the reacting mixture can be determined as a function of reaction time for constant values of the other independent variables. A qualitative determination of the components present in the combustion zone might be obtained from spectroscopic examination of the flame in the combustion chamber.

PHASE 5

Statement of Problem

The purpose of this research is to determine, for liquid fuel rockets and pulse jet engines, the radiation factor and its contribution to heat transfer coefficients inside a pipe with gas flow at low and high temperatures.

The problem as currently visualized will consist of passing various pure hot gases through a cooling section of pipe and determining the total heat transfer by accurately measuring the inlet and outlet temperatures and flow rates of the gases. By comparison of the values obtained for radiating gases

(water vapor and carbon dioxide) with those of a relatively non-radiating gas (nitrogen or purified air) a measure of the radiation factor will be obtained.

Progress

A. July 1 to December 1, 1946.

1. *Literature Survey.* The first step in the attack on this problem was a comprehensive survey of the available literature. Nearly thirty documents were reviewed, fourteen of which were found directly applicable to the problem. Of these, the works of Hottel, Eckert, and Fishenden were found to be the most useful. Both Hottel and Eckert measured the radiation from hot carbon dioxide and water vapor directly by the use of a thermopile, while Fishenden measured the radiation from flue gases in essentially the same manner proposed here. Their data have been used in the preliminary design of the equipment for the project.

2. *Proposed Method of Attack.* The proposed experimental procedure will consist of conducting pure radiating gases at a maximum temperature of 2,000° F through a cooling section of two-inch pipe and determining the total heat transfer from the gases by measuring the fall in temperature. Since

tions (temperature, velocity, etc.) as those for the radiating gas, and so determine the convection coefficient of heat transfer. Since radiation and conduction are parallel mechanisms of heat transfer, the radiation coefficient will be the difference between the total coefficient measured for the radiating gas and that measured for the non-radiating gas, corrected for differences in the physical properties of the two gases.

The second method will be to determine the coefficient of total heat transfer of the radiating gas over a range of low temperatures where radiation is so small that the convection coefficient can be accurately estimated from the total coefficient. Then it may be possible to extrapolate this convection coefficient to high temperatures and so obtain the net radiation contribution by difference.

3. *Preliminary Design of Equipment.* Figure 5 shows the general scheme of the experimental equipment. When air is used, it will be washed with a soda-lime solution to remove traces of carbon dioxide and then dried. When other gases are used, the soda-lime tank will be by-passed, the gases going directly to the pressure regulator and metering chamber. From the metering chamber, the stream will enter a gas-fired furnace, designed for an outlet

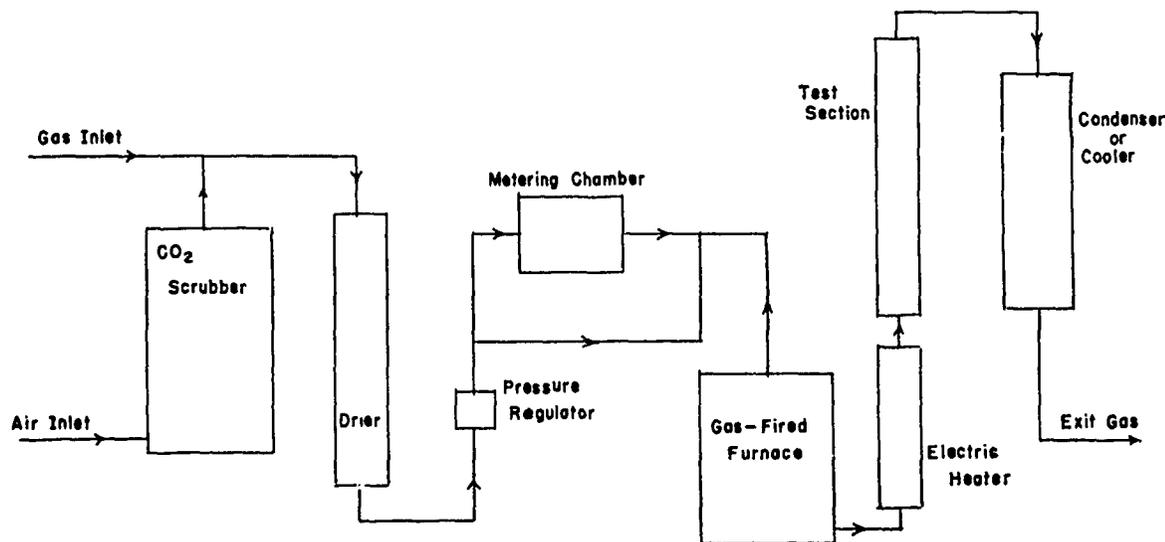


Figure 5. Flow diagram of proposed equipment for determining radiation factor and heat transfer coefficients.

this total heat transfer will be the result of both convection and radiation, a method for calculating the fraction of the transfer by radiation must be devised. Two methods are described.

The first method will be to pass a non-radiating gas through the test section under the same condi-

temperature of at least 1,500° F. Leaving the furnace, the gases will be heated to a maximum temperature of 2,000° F in the electrically heated section. The temperature of the gases entering the test section will be held constant by a controller regulating the amount of electrical input to the heater. Follow-

ing the test section is a condenser for water vapor when it is employed as the radiating gas, or for cooling other gases before they leave the system.

The design of the entire test section is not yet complete, but it will consist essentially of a two-inch alloy steel pipe approximately six feet long, partially insulated and provided with a heating element for control of the pipe wall temperature. The temperatures of the gas stream and pipe walls are to be measured with platinum-platinum-rhodium thermocouples suitably arranged and shielded (see section B) to minimize the radiation error inherent in this system for measuring the temperature of hot gases.

4. *Procurement of Equipment.* Much of the equipment has been requisitioned and many of the minor items secured, but difficulty has been encountered in the procurement of the alloy steels necessary for the high temperatures involved. This may cause considerable delay in the actual construction of the equipment. Every effort is being made to expedite these materials through available channels, and it is hoped that delay may be held to a minimum.

B. December 1 to December 31, 1946.

This period has been devoted to a study of various methods of measuring the temperature of the hot gases in the test section. Because of the large radiation errors entering into the measurement of the temperature of gases hotter than their surroundings, the problem of accurately measuring the true gas temperature is considered one of the chief obstacles in the experimental procedure. Several methods for solving this difficulty may be suitable and are indicated as follows:

1. The simultaneous use of thermocouples of decreasing diameter with or without the use of different numbers of shields. Plotting the readings of these thermocouples versus their diameter, yields a curve which, when extrapolated to zero diameter, indicates the true gas temperatures.

2. The simultaneous use of different numbers of shields on the same size thermocouples. By plotting the thermocouple readings versus the number of shields and extrapolating the curve to an infinite number of shields, the curve should approach the true gas temperature asymptotically. Theoretically this method is sound, but the difficulties involved may prove it impractical.

3. The use of multiple shields around a single thermocouple. This offers simplicity of operation,

but there would always be a certain amount of error involved in using only a small finite number of shields.

4. The use of a honeycomb construction of thin metal sheets surrounding the thermocouple placed in the center of the pipe and filling the pipe at the inlet and outlet of the test section. This would amount to a large number of shields surrounding the thermocouple and may decrease the radiation error below the accuracy of the thermocouple.

5. The use of a single adiabatic shield around the thermocouple. This requires an electrically heated shield surrounding the thermocouple. By heating this shield (while measuring its temperature with a second thermocouple) from a value below that of the thermocouple in the gas stream to a value above it, the true gas temperature will be indicated in the range where the two thermocouple readings are the same. It is hoped that this range will prove to be relatively narrow.

6. The use of an electrically heated "U" bend at the inlet and outlet of the test section with the thermocouple in the center of the bend. By maintaining the tube wall at the same temperature as the gas with the aid of a second thermocouple in the tube wall, the gas stream reading will be true gas temperature.

The last three of these methods appear the most promising from a theoretical standpoint, but few data are available to indicate their actual relative merits. The first phase of the experimental work, therefore, will be the evaluation of these various methods.¹

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PHASE 6 (F)

Statement of Problem

The purpose of this research is to determine experimentally the heats of formation and combustion, the specific heat, and other thermodynamic properties of various fuels and oxidizers used in pulsating jet engines. If possible a correlation of thermodynamic properties of these fuels may be made so that calculations may be extended to include new fuels.

Progress

The subject of major interest at the present time in this phase of the research project is the determination of heats of combustion by laboratory experiments. These heats of combustion can then be used to determine the heat of formation of the various fuels which are studied. The equipment for determining the heat of combustion will consist of an adiabatic calorimeter, a combustion tube for removing combustible gases in the oxygen supplied to the calorimeter bomb, and a gas scrubbing system for the products of combustion. The combustion tube will be made of Inconel, filled with copper oxide, and followed by a scrubbing chain to remove water and other products of combustion. The Inconel tube will be heated electrically to a temperature of about 600° C. Other investigators² have found that this

² Jessup and Greene, *Bur. Standards J. Research*, Vol. 13, p. 469, 1934.

Keffer, *J. Am. Chem. Soc.*, Vol. 56, p. 1,259, 1934; *J. Phys. Chem.*, Vol. 39, p. 277, 1935.

purification step is necessary if the oxygen used for combustion in the calorimeter contains any combustible material because the amount of this combustible material in the oxygen flowing to the calorimeter bomb varies with the pressure in the main oxygen cylinder. The inclusion of the purification apparatus will eliminate a number of calibration runs. Adiabatic conditions are to be maintained in the calorimeter by adding electrical energy to the jacket water. Automatic regulation of the jacket water temperature will be accomplished through differential thermels and a sensitive relay or amplification system. The initial and final temperature of the water in the calorimeter will be measured by a Beckman thermometer calibrated by the Bureau of Standards. This thermometer can be read to 0.01° C and approximated to about 0.005° C. The calorimeter is to be calibrated by use of standardized benzoic acid and this calibration will also be checked by use of electrical energy input into the calorimeter. The experimental work on this project has not been started as yet because of delays in the delivery of the main pieces of equipment. Most of the minor pieces of equipment are on hand. The calorimeter itself has not been delivered. Library work is being continued on the investigation of the various methods for determining the heat of combustion and the various types of calculation involved in each of these methods.

PHASE 6 (G)

Statement of Problem

The subject of the research on Phase 6(G) is the determination of heats of combustion of various chemical compounds suitable as high energy fuels and oxidizers.

Progress

The apparatus used by previous investigators³ was completely rebuilt, placed in serviceable condition, calibrated, and the heat capacity determined.

³ Miles and Hunt, *J. Phys. Chem.*, 45, 1946 (1941).

Miller and Hunt, *J. Phys. Chem.*, 49, 20 (1945).

J. A. Young, M.S. Thesis, Purdue University (1943).

White, *The Modern Calorimeter*, the Chemical Catalog Co. (1928).

Rossini, *Bur. Standards J. Research*, 6, 1 (1931).

Eckman and Rossini, *Bur. Standards J. Research*, 3, 597 (1929).

In calibrating the system, the heat evolved in the combustion of iron ignition wire as well as the heat given off by the electric current in heating the wire to its ignition temperature was evaluated. The heat capacity of the apparatus was determined by burning benzoic acid (standard sample No. 39f) obtained from the Bureau of Standards. The timing device, accurate to 0.1 second per hour was constantly checked with the short wave time signals from station WWV. A 9-junction copper-constantan thermocouple and a White double potentiometer of 10,000 microvolt range was used to measure the temperatures. The constant temperature air bath was maintained at 28° C, using alternating current. The apparatus has been so arranged that the electric power needed for the heater and ignition system is supplied at a constant rate.

Ten centimeters of iron ignition wire are used in each experiment. One milliliter of water is added to the bomb instead of 5 ml. as used by previous investigators in this laboratory. The weight of calorimeter water is determined by two weighings. The weighing bottle filled with water is balanced against a tare bottle of the same weight and volume and containing the same amount of water. After filling the calorimeter with water, the weighing bottle and the necessary brass weights are brought to the same balance point against the tare. The weight of water (equal to the brass weights used) is corrected to true mass values recorded to 0.01 g. As discussed previ-

ously, the calorimeter jacket never leaves the air thermostat, and the water with which it is filled comes from a constant temperature reservoir. "Check" readings, which correct for drift of the zero point of the galvanometer and for stray electromotive forces, were taken after every thermal reading. The actual value of the heat liberated will, of course, be evaluated when the calibration experiments are completed. Heats of combustion of the selected and desired compounds, among which are triethyl aluminum, trimethyl boron, and triethyl boron, will be determined as soon as the compounds are obtained.

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ABSTRACT

Liquid rocket and pulsejet research is presented. Method of measuring instantaneous gas temperature fluctuations is discussed and study of continuous combustion process with available fuels and oxidizers is described. Corrosion products in jet engine components were studied and radiation factor and its contribution to heat transfer coefficients for liquid fuel rockets and pulsejets were determined. Heats of combustion and various chemical compounds suited for high-energy fuels and oxidizers are determined by laboratory experiments.