UNITED STATES NAVY

QUARTERLY PROGRESS REPORT

PROJECT SQUID

A COOPERATIVE PROGRAM
OF FUNDAMENTAL RESEARCH IN JET PROPULSION
FOR THE
OFFICE OF NAVAL RESEARCH
OF THE
NAVY DEPARTMENT

CONTRACTS:

NYU— N6-ORI-11, TASK ORDER 2, NR 220-040
PIB— N6-ORI-98, TASK ORDER 2, NR 220-039
PRF— N6-ORI-104, TASK ORDER 1, NR 220-042
CAL— N6-ORI-119, TASK ORDER 1, NR 220-041
PRIN—N6-ORI-105, TASK ORDER 3, NR 220-038

1 OCTOBER 1948

NEW YORK UNIVERSITY

POLYTECHNIC INSTITUTE OF BROOKLYN

PURDUE UNIVERSITY

CORNELL AERONAUTICAL LABORATORY

PRINCETON UNIVERSITY

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1 OCTOBER 1948

TABLE OF CONTENTS

	Page
NEW YORK UNIVERSITY.	1
POLYTECHNIC INSTITUTE OF BROOKLYN	11
PURDUE UNIVERSITY	19
CORNELL AERONAUTICAL LABORATORY	31
PRINCETON UNIVERSITY	43

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CONTRACT N6ori-11, TASK ORDER II
DESIGNATION NO. NR 220-040

New York University
New York, New York
1 October 1948

INTRODUCTION

Since most of the members took their vacations during the last two months, work during this quarter has been slowed somewhat. However, among other things some of the conclusions concerning the mass flow ahead of the flame in Phase I have been confirmed, the wedge thermocouples completed, the microphonics eliminated from the Pressure Gauge and an adjustable schlieren system completed.

The departure of Dr. J. K. L. MacDonald for Inyokern has been a severe loss to Project SQUID as a whole and to the New York University group in particular. The impetus Dr. MacDonald has given the Project during the last two years will not be lost. The new Technical Director is Dr. G. E. Hudson.

PHASE

In connection with pulsating jet engines: to undertake theoretical and experimental investigations of (1) flame motions with controlled initial turbulence, (2) stationary flames with controlled turbulence, (3) suitable theoretical models based on the above observations and (4) statistical mechanics of non-uniform gases.

Summary

Further experiments have been made on the flame tube containing a grid which confirm the conclusions drawn in the 1 July Quarterly Progress Report concerning the nature of the high speed flame.

Experimental

Moving Flame Experiments. Experiments involving the use of local thermal gradients produced by hot wires, described in the Quarterly Progress Report of 1 July 1948, have been extended. These experiments have in all cases confirmed the tentative conclusions advanced in that report regarding the nature of the high speed grid flame.

Examples of the quantitative data obtained using the method are shown in Figure 1. This shows the time-position curves of both flame front and thermal gradient for four positions of the heated wire in the tube. In A, where the heated wire and hence the initial position of the gradient is 4½ inches from the grid, the flame is seen to overtake the gradient 9 1/2 inches from the grid. In B, C, and D, where the heated wire is 13 1/4, 18 3/8, and 30 inches, respectively, from the grid, the flame does not overtake the gradient within the tube. The gradient is pushed ahead of the flame at a velocity equal to that of the apparent flame velocity.

Conclusions regarding the nature of the flame may be summarized as follows:

The high apparent velocity of flame propagation is due to a high rate of burning which is the result of the burning of a large surface area per unit time. This large surface area of burning is created during the forcing of the burning surface through the grid (see Figure 1, 1 April 1948 Project SQUID Quarterly Progress Report). The burning and non-burning gases are intimately mixed throughout a region which has been found to extend to a distance of about ten inches from the grid. All gas beyond that point is pushed out of the tube by the expanding burning gases. Investigations are now under way to determine the details of combustion of the gas in the region of mixing.

A paper on this work, entitled *A Study of High Velocity Flames Developed by Grids in Tubes* was presented at the Third Symposium on Combustion and Flame and Explosion Phenomena, University of Wisconsin, and will be contained in the collection of papers presented at the Symposium.

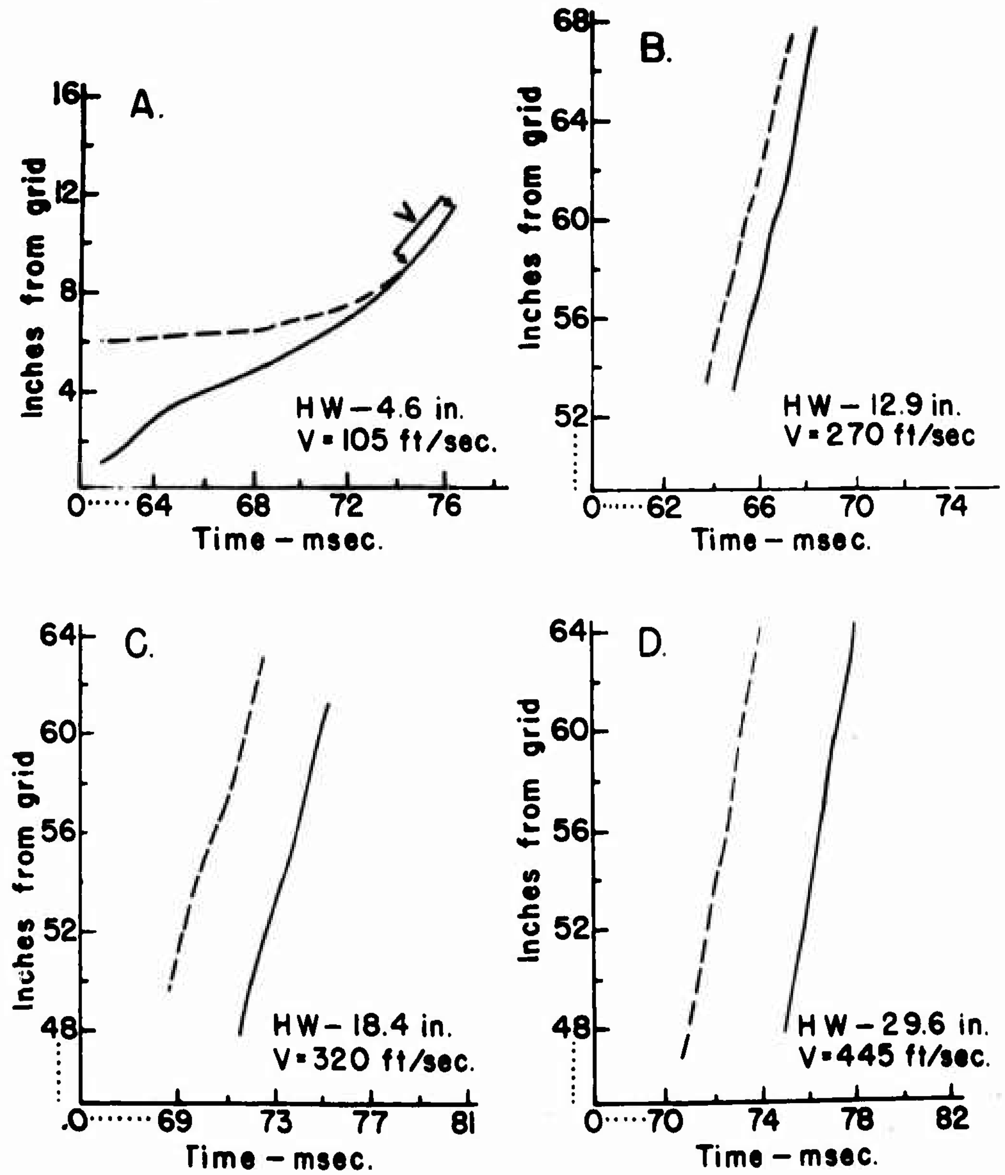

FIGURE 1

Distance versus time for flame fronts in a tube containing a grid and for thermal gradients initialed at various points in the tube ahead of the front. The time indicated is measured in each case from initial ignition of the flame. Inasmuch as the time for the flame to move from spark to grid is not reproducible, the time axes of the four graphs should not be compared with one another. Solid line--flame front; broken line- - gradient; HW - distance of heated wire from grid; V - velocity.

A spectral analysis of the visible radiation from the high speed flame showed that nearly all radiation is due to the NaD line. There is almost no contribution to the film exposure from the C-C and C-H bands prominent in the Bunsen flame. The source of the sodium is presumably extraneous dust in the system.

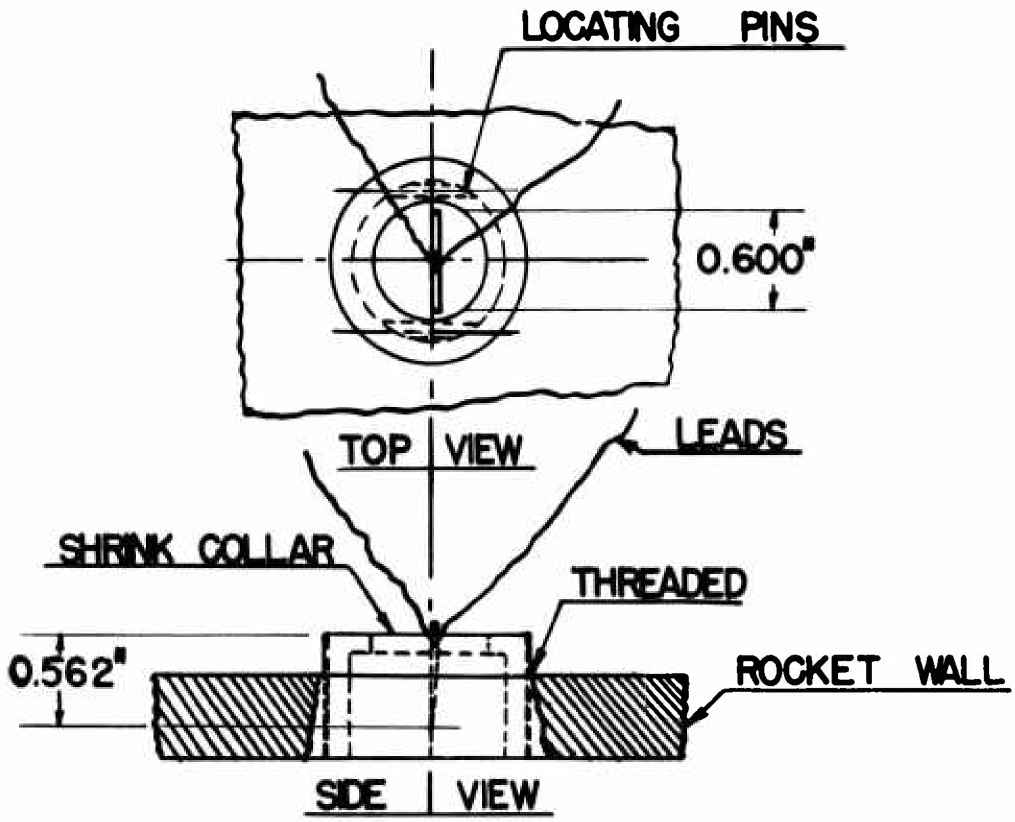

FIGURE 2

Proposed Open Type Wedge Thermocouple.

PHASE II

In connection with rockets and pulsating jet engines: to study (1) measurement of temperature dependence of conductivity and heat capacity of steels and other materials by means of adiabatic colorimetry and metallography, (2) characteristics of heat transfer between hot flowing gases and walls, using measurements of gas velocity and temperature by radiation and thermocouple devices, (3) calculations of temperature changes in jet and rocket walls.

Summary

The apparatus for measurement of specific heats of steel at high rates of change of temperature was rebuilt this quarter and records are now being taken. The work on wedge thermocouples has been completed and a memorandum on the subject has been published.

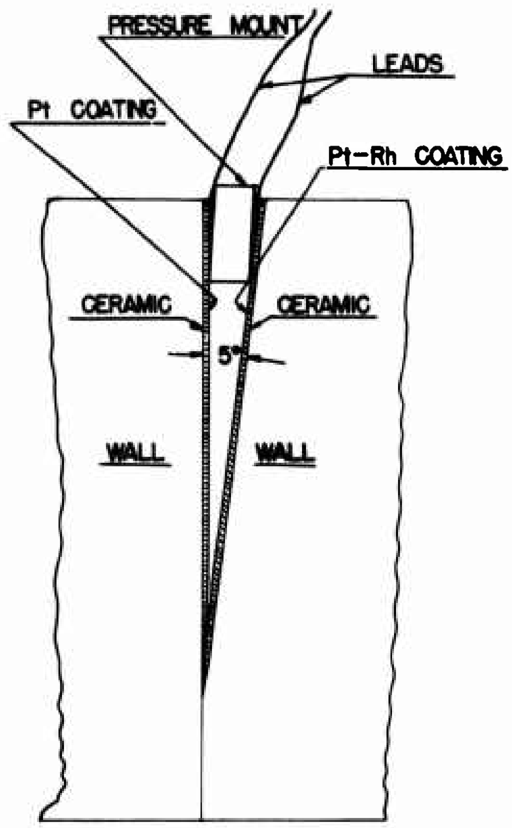

FIGURE 3

Enlarged View (4 times) of Wedge Opening of Proposed Thermocouple.

Experimental

Specific Heats of Steel at High Rates of Change of Temperature. The apparatus has been rebuilt to incorporate a modification of an inverter circuit suggested by the Allegany Ballistics Laboratory. The system shows some 60 cycle pickup but is far superior to any of the DC amplifiers that we have tried. A preliminary record has been successfully taken and a technical memorandum will be written as soon as the work is completed.

Wedge Thermocouple: Two wedges were completed in August and have been shipped out for test, one to Inyokern and another to Allegany Ballistics Laboratory. The resistance of the wedges was about 50 ohms which requires a high impedance circuit for high speed recording, so a circuit such as is being used in the specific heat apparatus mentioned above would be very useful. This type of wedge is limited in its usefulness by the fact that the knife edge must have a finite thickness, so in NYU Technical Memorandum No. 3 on this subject a new type is suggested. Figures 2 and 3 show sketches of this proposed thermocouple.

PHASE III

In connection with liquid rockets and pulsating jet engines: (1) to observe flame and particle motion, pressures, temperatures, densities, and effects of turbulence in pulsating and rocket jet devices; (2) to study water stream analogues for gas motion in pulsating jets and rockets in order to determine characteristics of simple theoretical models, and (3) to use the above for theoretical treatments of the internal ballistics of jet devices on the basis of justified simple models.

Summary

Some modifications of the PJ-31 set up at Rye have been made and some pressure and temperature gauge tests have been made, as reported in Phase IV. A schlieren optical system including some novel construction details has been set up, and a thrust stand for small pulse jets has been built. Work has been also carried on to develop a usable constant cross-section small pulse jet and preliminary studies of the external flow around a small pulse jet have been made.

Experimental

Large Scale Pulse Jet Observations. During this quarter relatively little work has been done on the PJ-31 set up at the Westchester County Airport, beyond making tests on the pressure and temperature measurement systems reported under Phase IV. However, the bomb has been mounted in the thrust stand, a thrust measuring device constructed and bench tested, and investigations made of reshaping and retempering used valve leaves.

A report is in preparation on the Field Test Program.

Small Scale Pulse Jet Observations. Since it was found that a great deal of time was consumed in setting up and adjusting the schlieren equipment used in observing combustion phenomena and flow in and around small pulse jets each time the experimental setup was changed, a semi-permanent schlieren system has been developed that has sufficient adaptability to be easily used with a number of different types of experimental equipment. This apparatus includes: (1) A light source and condenser assembly in which the position of the lamp and con-

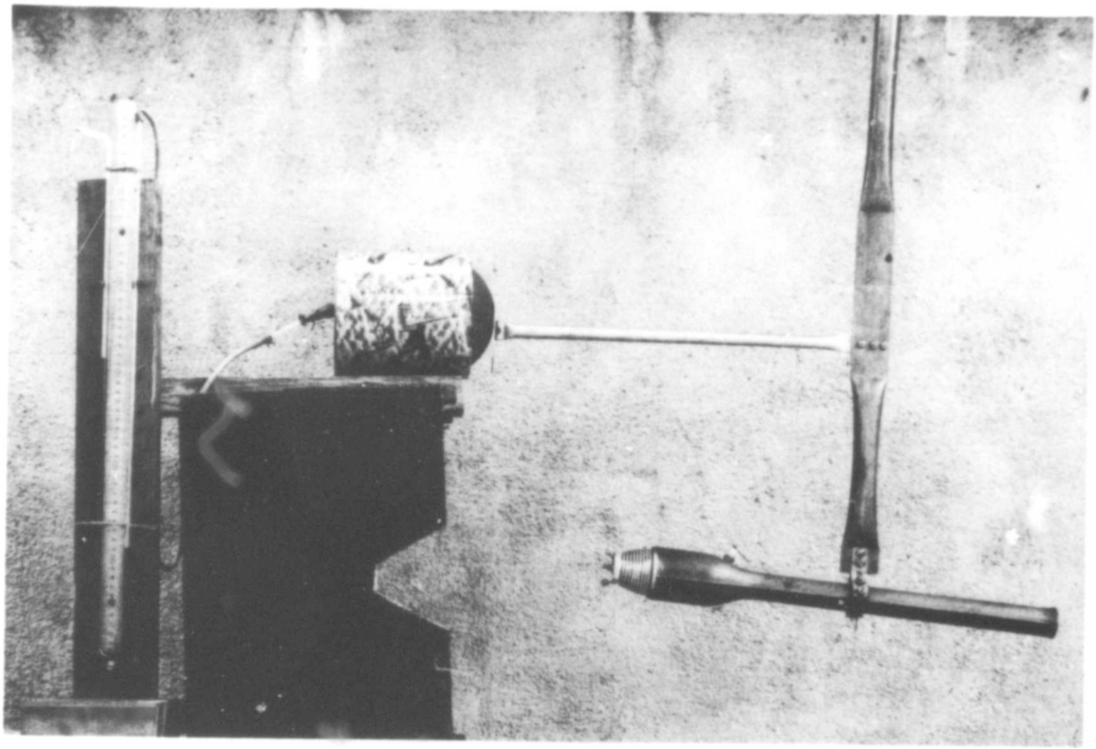

FIGURE 4

Thrust Stand for Small Pulse Jet Engines.

denser optics as well as the attitude of the complete unit can be easily yet accurately adjusted. (2) A knife edge assembly that can be adjusted to any desired position or attitude within a range of several inches. (3) A vibration-free yet easily adjustable mirror stand for the large parabolic mirrors. A technical memorandum on this equipment is now in preparation.

A thrust stand suitable for testing small pulse jet engines has been built that seems to have many advantages over most other types As shown in Figure 4 the thrust is transferred to a balloon connected to a water manometer. The advantages of this device whose calibration curve is shown in Figure 5 are its sensitivity, low friction loss, small travel, and easily observable reading. Several small pulse jets having a constant cross section throughout the entire distance from valves to exhaust have been constructed in the hope of simplifying the study of the theory of combustion. In the latest model though combustion is sustained after the spark is shut off, compressed air is still necessary.

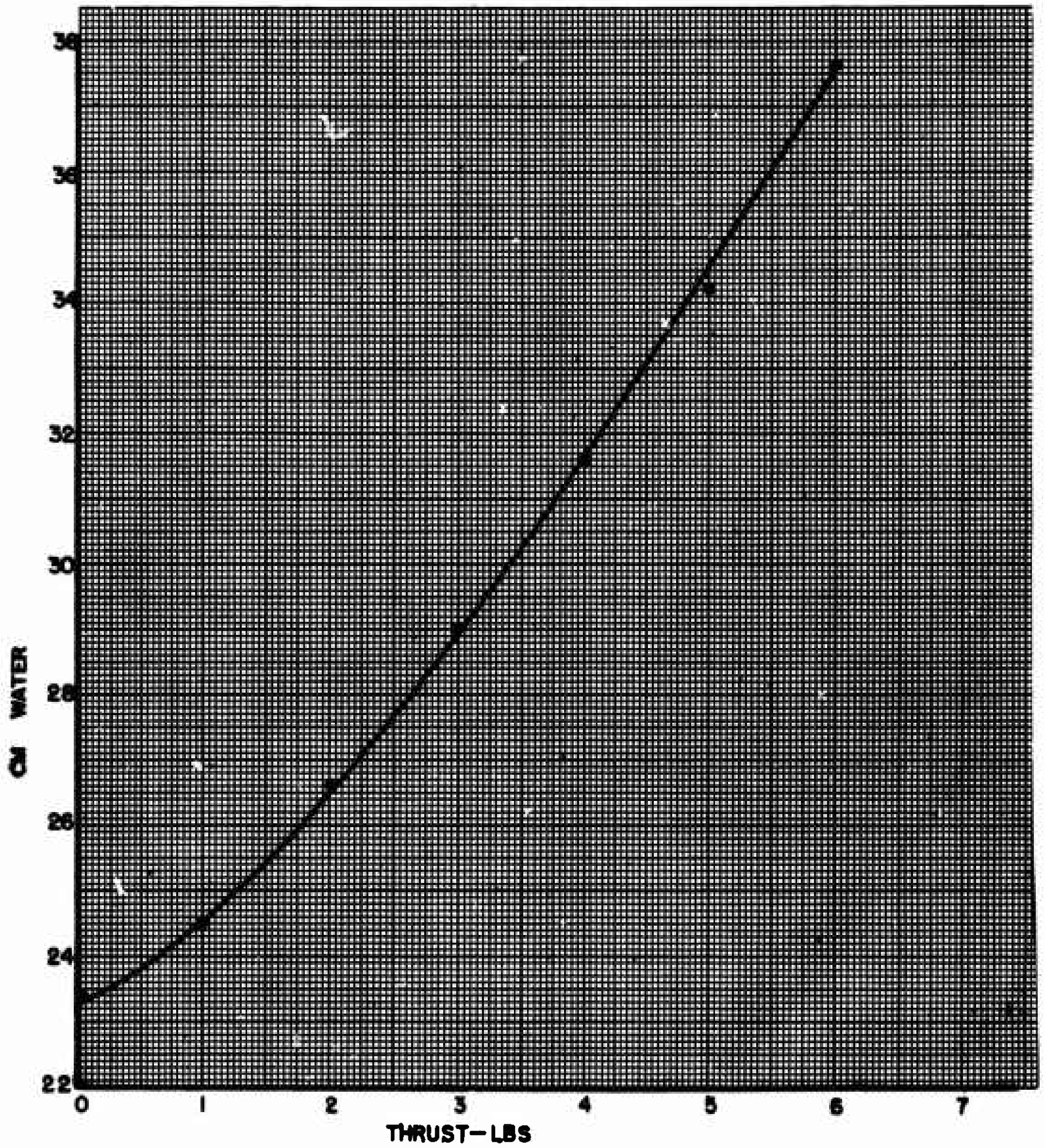

FIGURE 5

Calibration Curve for Small Thrust Stand.

A study is being made of the details of the external flow about a small pulse jet. High speed movies have been made of smoke flowing into the intake, around the engine and in the general field of flow beyond the exhaust. As shown in Figure 6, the smoke delivered from the smoke generator flows out of holes in a section of tubing making the airflow in the vertical plane visible.

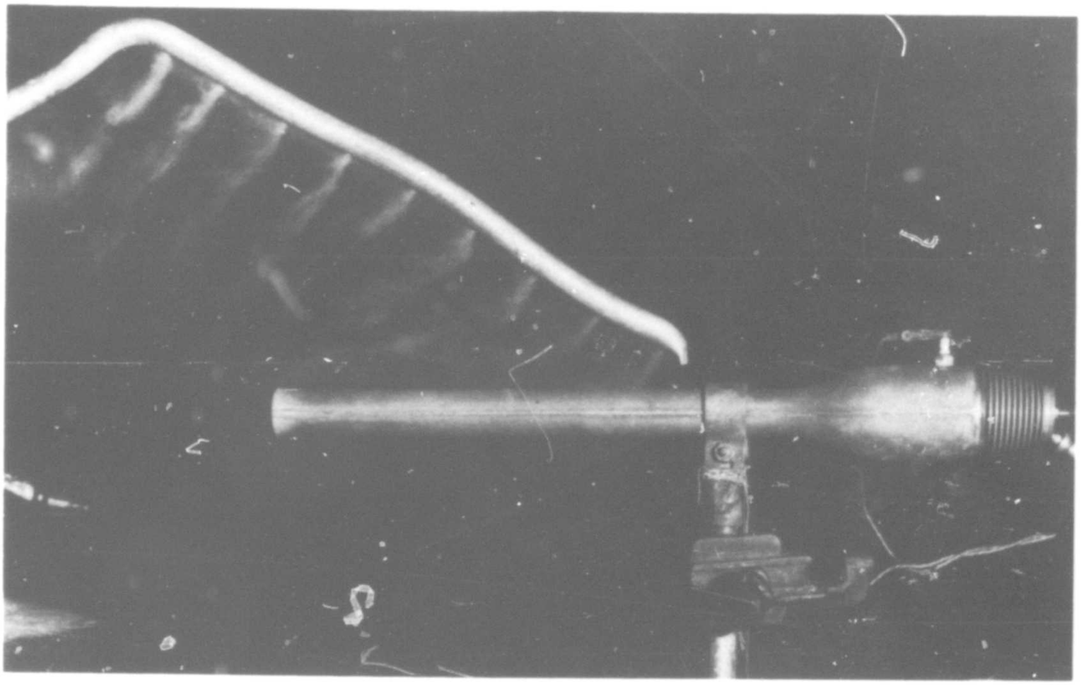

FIGURE 6

Example of Configuration Used In Studying External Flow Around Small Pulse Jet Engines.

PHASE IV

In connection with liquid rockets and pulsating jet engines, to develop instruments for recording (1) transient thrust, (2) pressure, temperatures, and densities of hot oscillating gases, and (3) gas velocities.

Summary

The modified gauge and receiver of the FM Pressure Gauge System have performed satisfactorily on the PJ-31. The temperature measurement system has been modified to use the radiation from the band 100 Å wide passed by the interference filter rather than the radiation from the sodium D-line, due to the extreme difficulty encountered in attempting to calibrate the system.

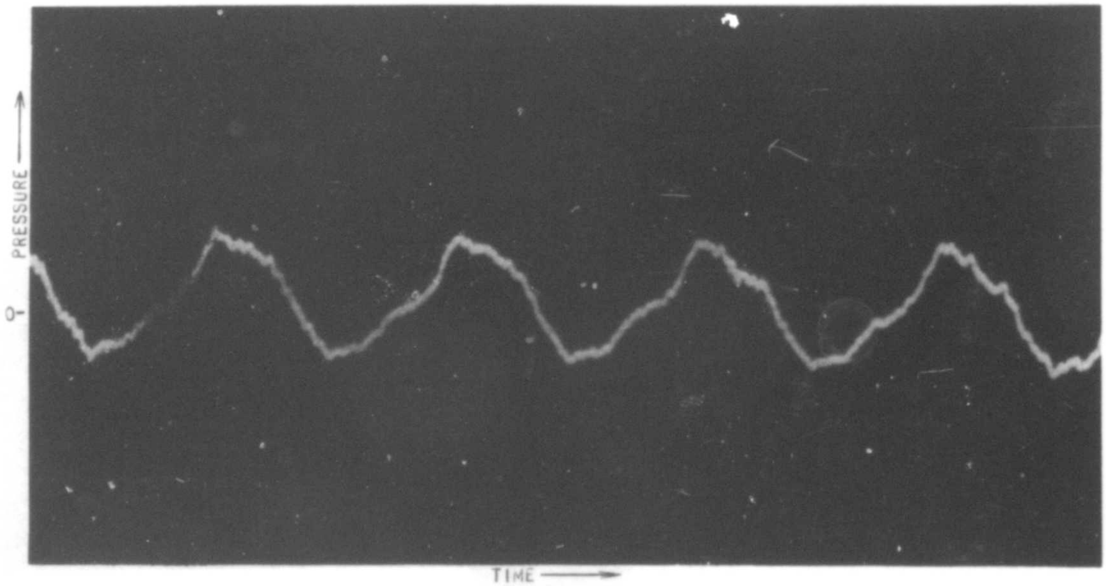

FIGURE 7

Pressure record taken with modified gauge and receiver of PJ-31 operating at low power; peak to peak pressures approximately 20 psig; cyclic rate approximately 40 cycles-sec.

Experimental

Pressure Gauge. Recent tests at Westchester County Airport and at the Polytechnic Institute of Brooklyn show that the pressure gauge is now free from microphonics when used on the PJ-31 and is rugged enough to withstand quite severe vibration. In addition the receiver has been modified to improve still further its low frequency response. A record of a calibrated run on the PJ-31 with this equipment is shown in Figure 7. The simultaneous pressure measurements at various points on the PJ-31 await the completion of the instrument trailer.

Temperature Measurement. Since extreme difficulty was encountered in attempting to calibrate the sodium D-line system along the lines described in the 1 July Quarterly Progress Report, this method has been abandoned at least temporarily.

Studies of the flame of the PJ-31 indicate that the radiation from the band 100 Å wide passed by the interference filter can be calibrated against a standardized strip lamp, and calibration runs and brightness tests show considerable promise.

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CONTRACT N6ori-98, TASK ORDER II
DESIGNATION NO. NR 220-039

Polytechnic Institute of Brooklyn
Brooklyn, New York
1 October 1948

PHASE NO. I

In connection with pulse jet engines: To study the intermittent air intake process and the overall aero-thermodynamical mechanism of the pulse jet at subsonic and supersonic speeds. The study will cover theoretical and experimental investigations of (1) reciprocating and rotating valve mechanisms, (2) internally coupled pulse jets and related devices, and (3) such processes as may be necessary for the formulation of a unified pulse jet thoery.

Summary

During this period two Technical Reports and four Technical Memoranda were completed, and others undertaken. The cold model of the PIBAL engine was tested in the PIBAL tunnel. Instrumentation for testing the model was finished and calibrated, and recording of the velocity distribution within the engine was partially completed. Comparison tests of the New York University capacitance type pressure pickup and the Statham strain-gage type pressure pickup were made. A new suspension for measurement of the instantaneous thrust of a pulse jet engine was designed, constructed, and tested with significant results. Further analytical work was undertaken in the

development of a unified pulse jet theory, results being included in a Technical Report. A Technical Report covering *Approximate Theory of Compressible Air Flow Through Reed Valves* is being prepared. X-ray equipment for measuring inner wall temperatures and gas densities has been procured, modifications have been made, and preliminary tests concluded. Initial results are reported in a Technical Memorandum.

Progress

ANALYTICAL WORK

Air Inflow Analysis. A Technical Report on *Compressible Flow Through Reed Valves for Pulse Jet Engines - II Clamped Reed Valves* by Paul Torda has been submitted for publication.

A second Technical Report on *Approximate Theory of Compressible Air Inflow Through Reed Valves for Pulse Jet Engines* by Paul Torda has been completed and is in the process of final editing.

Unified Pulse Jet Theory. This work was undertaken in an effort to satisfy the request of the Office of Naval Research to develop an approximate but still essentially reliable method of predicting the performance of pulse jets of different design.

Besides this purpose, it was expected that a basis might be provided for coordinating the numerous and often disconnected experimental data on flame propagation and the travel of discontinuity surfaces in the combustion chamber with an overall theory for pulse jet engines.

A special procedure was found for analysis of the effect of combustion and convection on the waves in the combustion chamber of a pulse jet using a semi-inverse method.

Different types of mass waves $\rho A=f(x,t)$ were chosen, partly according to experimental publications and partly giving the desired reciprocating mass flow process.

Until now, three such wave patterns have been assumed, namely:

(1) A wave merely outflowing such as to describe the first start of the pulse jet.
(2) A standing mass wave.
(3) A reciprocating mass wave as has been observed through the window of an operating pulse jet model.

The method of starting on the basis of a desired mass wave to derive velocity, temperature, pressure, heat input, and thrust function from it, has the great advantage of integrating exactly by quadratures without the necessity of linearization.

A Technical Report on case 1 was finished, but is not yet finally edited.

A Technical Report No. 11 on case 2 was submitted for publication.

A Technical Report on case 3 has been started, but its completion depends on a final decision of the Office of Naval Research. It might be added that the above procedure described in several progress reports and in Technical Report No. 11 does not in any way overlap the investigations undertaken concerning shockwaves and flame propagation at other places, but must rather be judged as a substratum in which the many scattered phenomena can be correlated.

EXPERIMENTAL WORK

Work at PIBAL. The wind tunnel model of the PIBAL rotating sleeve valve engine has been mounted in the wind tunnel and its drag measured with both stationary and rotating valves. Using hot wire equipment developed at PIBAL some velocity distribution measurements inside the engine have also been made.

The small scale test-stand for pulse jet thrust measurement has been completed. Test runs were made with the Dyna-jet, and the developed thrust was measured and recorded. These records show that it is now possible to measure the periodic fluctuation of the thrust. A small part of the record, including four working cycles, is shown in Figure 1, page 14.

Comparative calibration tests were made between the New York University capacitance type and the Statham strain-gage type pressure pickups. The results will be published as soon as evaluation of the data is completed.

The design and the construction of a simple though workable, X-ray spectrometer employing a Geiger Counter were begun. The purpose of this spectrometer is to supplant the photographic camera previously used for the detection of X-rays. The use of a Geiger tube greatly reduces the time required for obtaining an X-ray diagram since it is, for all pratical purposes, direct reading.

The equipment consists of a saddle supporting the furnace containing the sample metal, the X-ray slit system, and an arm mounting the Geiger tube and its slit system. This arm is mechanically moved by a worm-gear arrangement which permits a smooth coverage of all possible positions

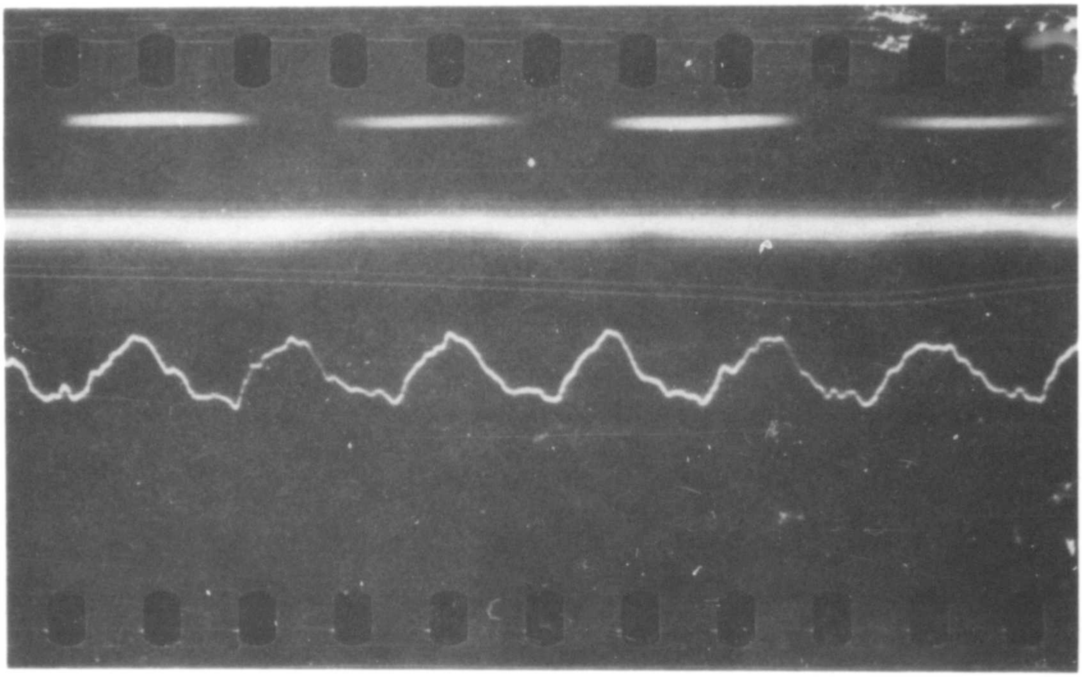

FIGURE 1

of the expected X-ray reflections. The Geiger tube and its slit system are adjustable over all parts of the arm. The slit system design comprises two adjustable slits placed at right angles to each other, providing all desirable passages for the reflected X-rays.

The detection set-up includes a Philips gamma ray Geiger tube, (type 62003) connected to a General Radio Company counter which, in turn, is wired to the Esterline-Angus recorder (model A.W.).

Preliminary tests with the sample metal at room temperature were made. Results were erratic, due partially to insufficient shielding and faulty wiring of the bread-board wired X-ray electrical system. These difficulties should be eliminated very soon as it is planned to use the spectrometer with a Philips X-ray diffraction unit recently acquired.

Work at the Williamsport Test Stand. Because of the decision of the Policy Committee to discontinue the hot test of the PIBAL rotating sleeve valve engine, no additional development work was done on the pulse jet test stand. Efforts have been concentrated on preparing for experimental verification of the Unified Theory for Pulse Jet Engines.

Plans

As work on Phase No. 1 will be discontinued on September 30th, the preparation of a closing Technical Memorandum and the finishing of such Technical Reports and Memoranda as have not yet been submitted will conclude this Phase of the work.

Effective September 30th, the X-ray experiments will be continued under Phase 3. In the very near future high temperature runs will be made. It is planned to measure temperatures above 1600°F with this system. (Any temperature measurements with the camera above 1600°F were precluded at which point the film emulsion became affected by the heat).

Work has begun to drive electrically the arm on the spectrometer. Circuitry is now being studied to permit the Geiger tube to be self-seeking through a servo mechanism. Plans for construction are also being formulated and when completed this unit will be assembled.

PHASE III

(1) To investigate the metallurgical, fabrication, and design problems involved in cooling rocket and intermittent jet motors by the diffusion of fluids through porous metal combustion chamber liners. (2) To study analytically and experimentally (a) the diffusion of fluids through porous media under high pressures and temperatures and (b) the effects (of this diffusion) on the internal aerodynamics. (3) To study problems in the field of physical chemistry pertinent to (1) and (2) with consideration given to the clogging of pores, the use of catalysts imbedded in the liner walls, and endothermic diffusion processes.

Summary

The paper entitled *Heat Transfer in Laminar Boundary Layer (Compressible Fluid) on a Porous Flat Plate with Fluid Injection* was revised and submitted for publication through the Paper Committee, 1948 Heat Transfer and Fluid Mechanics Institute. Investigation of heat transfer in the laminar boundary layer along a porous flat plate was continued with a more refined temperature profile assumed in the density and viscosity variation. A similar investigation covering a partially porous plate was made, and the problem of flow in a laminar boundary layer with pressure drop in the direction of flow has been calculated. A study of heat transfer in the turbulent layer was begun.

Hot wire anemometers and associated electrical gear have been completed and necessary alteration to the existing PIBAL turbulence channel has been finished. Experiments to determine optimum anemometer wire diameters and the amount of suction required for removal of initial boundary layer have been carried out.

Progress

Analytical Work. The main addition to the paper presented at the 1948 Heat Transfer and Fluid Mechanics Symposium was the solution of the case in which the viscosity was assumed to be proportional to the three-fourths power of the temperature. The parameter $\frac{V_0}{U}$ was changed to $\frac{Q}{W}$, the mass flow ratio, which was found to be more adequate. The final version of this paper was sent to the Paper Committee, 1948 Heat Transfer and Fluid Mechanics Institute, for publication.

The foregoing solution was extended to the case where the region of injection begins at a certain distance from the leading edge of the plate. The results found in this investigation will be given in a Technical Memorandum.

The problem of flow in a laminar boundary layer with pressure drop in the direction of flow has been investigated. The equation for the boundary layer thickness and length in direction of flow was obtained. The solution of boundary layer thickness as a function of length in the direction of flow is carried out for the case of linear pressure drop.

EXPERIMENTAL WORK

The modification of the PIBAL turbulence channel was carried out as follows: The porous plate was inscribed in the wall of the channel. At the same time a slot was cut into the wall to facilitate the removal of the initial boundary layer. Both the porous plate and the suction slot were provided with proper bells to build up the necessary pressure and suction, respectively. A supercharger was connected to the suction slot to remove the initial boundary layer and a nitrogen bottle was attached to the porous plate for injection. Fixtures for the hot wire equipment were installed on the tunnel walls.

Hot wire development was continued. Sensitivity for direction of flow was increased by increasing the ratio of the diameter to the spacing of the wires. The upper limit of the diameter of the wires determined by the current-carrying capacity of the soldered joints and the current sources was found to be 0.0008". A spacing of 0.0011" was attained. The error introduced by physical assymetry of the two legs of the hot wires was investigated, and error curves were plotted to permit the correction of final readings.

At the present time experiments are being run to find the ratio of channel velocity to suction velocities when the thickness of the boundary layer along the edge of the porous plate is zero.

Plans

Heat transfer in the laminar boundary layer on a porous flat plate with variable fluid injection will be investigated analytically. Investigation of heat transfer in the turbulent boundary layer will be begun.

When the ratio of channel velocity to suction velocity with zero boundary layer thickness is determined, it is proposed to locate experimentally the point of breakdown of laminar flow over the porous plate as a function of injection velocities. At a later date is is proposed to initiate similar experiments at elevated temperatures.

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CONTRACT N6ori-104, TASK ORDER I
DESIGNATION NO. NR 220-042

Purdue Research Foundation
and
Purdue University
Lafayette, Indiana
1 October 1948

PHASE II

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

Project Leader. H. J. Buttner, Professor of Automotive Engineering.

Summary

Activities during this period were divided into distinct divisions consisting of (a) a study of the effect of turbulence on continuous process combustion, (b) experimental determination of limits of several variables involved in flame holding, (c) development and application of a new procedure employing sodium line reversal technique for determining flame temperatures, (d) study of the possible application of the sodium line reversal method of temperature determination to an evaluation of mean temperature variation between turbulent and non-turbulent flames, (e) a brief check on the possibility of a change in the emission

spectrum of a bunsen-type flame when non-turbulent burning is changed to turbulent burning, and (f) completion of the Combustion Laboratory.

Progress

Studies of the normal flame propagation velocities in fluid streams having very low turbulence and flowing at mean velocities approaching sonic, indicate an apparent increase in the flame velocity with an increase in streams velocity even though the turbulent intensity, as measured by a hot wire anemometer, decreases in the unburned mixture stream. Thus at a mixture velocity of 1,000 feet per second, the flame velocity is 34 feet per second. This value was also reported by Dr. M. Evans[1] for combustion in a glass cylinder when the unburned gases moved ahead of the flame front at speeds approaching 1,000 feet per second. In our studies, the flame propagation velocity varies as the 0.43 power of the mixture velocity.

Turbulence creating devices were introduced into the main fluid stream of the contracting jet nozzle in such a manner that an evaluation of the effects of turbulence could be made while still incorporating the annulus-type of flame holder. For medium and high rates of flow the stability limits for burning become narrower when non-turbulent flow is developed into turbulent flow. Also a given increase in rate of flow of the main stream requires a greater increase in heat release from the annulus for turbulent conditions as compared to non-turbulent.

A Technical Memorandum was written on the effects of several variables on the flame holding function of the annulus type of flame holder developed at Purdue. This flame holder permits independent control of the mixture involved in the flame holding function. Of considerable interest is the relationship established between the amount of heat released in the flame holding mixture and the limits of stability of burning in the combined combustor.

The specific annulus heat release required for stable bu~ning--that is, the number of British Thermal Units of heat release required from the annulus per pound of mixture flowing in the main jet to maintain stable combustion--increases with an increase in annulus flow for constant rates of flow in the main stream. At low rates of flow in the annulus and for mixture strengths leaner than required for maximum heat release, the mixture strength must be increased with a decrease in annulus flow to maintain a constant heat release sufficient for ignition of the main stream. At higher rates of flow in the annulus an increase in mixture strength must be effected up to that required for maximum heat release to prevent blow-off of the annulus flame. It is possible to maintain stable combustion at very high rates of main jet flow with approximately 3 percent of the total mixture involved in the flame holding function. A still smaller percentage is undoubtedly possible if suitable provisions are made to prevent loss of the heat to the surrounding atmosphere in the unconfined burning existing in these experiments. Excepting for annulus flows approaching the minimum, a constant rate of heat release from the annulus is required regardless of the rate of flow in the main stream.

A series of experiments was conducted to determine the flame temperatures existing in non-turbulent burners. The photographic adaptation of Fery's[2] sodium line-reversal technique was used, and the temperature so obtained checked closely to calculated values. More exact values depend on the accurate control of conditions existing during the time required for film exposure and the precise location of the image in the optical system.

The brief attempts to correlate the apparent temperatures of a totally colored flame, using the Fery method under conditions of turbulent and non-turbulent burning, showed no apparent change with the change in turbulence. Difficulty in control of turbulence may have had a bearing on the results.

A study of the emission spectrum of a burner of the bunsen-type showed a decided reduction in the intensity of the continuum bands in the range of 2,000 to 5,000 Angstroms for the outer gas envelope when non-turbulent mixture flow to the burner was changed to turbulent flow. Densitometer surveys of the photographic plates, while not yet completed, indicate the same effects noted visually. No apparent change was detected in the flame front other than the shift of its position as recorded on the film.

The air supply system consisting of the low and high pressure headers and connecting ducts was installed, replacing the temperary system except for the sections which will incorporate after-coolers in the discharge system of each of the twelve superchargers.

An enclosure was erected around the burner to eliminate hazards and noise in the laboratory. Relocation of the burner control bench for better operation and flame observation was also completed.

PHASE NO. 3

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

Project Leader. H. J. Yearian, Professor of Physics.

Summary

X-ray diffraction studies of the oxides formed on 5, 11, 13, 17, and 26% chrome-iron and steels have been continued at 950° and 1000°C. and on chrome-nickel steels at 2000° and 2200°F.

Investigations of the effects of surface preparation on oxidation products and on the intensity of X-ray diffraction have been initiated.

A technique for stripping thin oxide films and examining the structure of their inner surface has been developed.

Progress

X-ray diffraction studies of the oxides formed on an 11% chrome-iron and on nominal 5, 13, 17, and 26% chrome-steels have been continued to temperatures of 950° and 1000° C, for oxidation times of 20 and 10 hours, respectively. Thick scales are formed on all specimens except the 17 and 26% alloys; these two have been further oxidized for 100 hours at 950°C.

Debye-Scherer photographs of total oxide samples (and in some cases where the oxide could be separated, of inner and outer layer samples) show both Fe_3O_4 and αFe_2O_3 type phases on all specimens. There is little deviation from compositions corresponding to 20 to 40% solid solution of $FeCr_2O_4$ in the Fe_3O_4 phase and 0 to 5% solid solution of Cr_2O_3 in the αFe_2O_3 phase, except for the 26% alloy, where the second phase is practically pure Cr_2O_3.

Comparison of photographs of the outside layers and inside layers of oxide shows that both structural types are present in the two layers in approximately the same proportions, except for the 11% chrome-iron, where the inner layer is predominantly Fe_3O_4. The amount of the Fe_2O_3 type tends to increase relative to the amount of the Fe_3O_4 type as the percentage of chromium in the alloy increases. Calculations of the intensities to be expected for known mole percentages of the two forms will permit a quantitative evaluation of the relative amounts of the two materials present.

Additional back reflection and/or Debye-Scherer photographs have been completed for a series of oxidations of these samples for 5, 20, and 100 hours at 900°C. In this series the oxygen was purified by being passed over Askarite rather than through KOH and a drier, and t the oxides show only a very small amount of the Cr_3C previously found on the surface. Debye-Scherer photographs have also been taken of the oxides formed on a series of nine samples of various composition Ni-Cr-steels when oxidized in air at 2000°F and at 2200°F. A considerable time will be required to finish the measurement and analysis of these films.

An X-ray diffraction investigation of the effect of polishing agent on the character of oxidation product has been started. Samples of a 13% Cr-steel rough polished on 3/0 paper, metallographically polished on a cloth lap with Cr_2O_3 and with Al_2O_3, have been investigated after oxidation at 905°C for 20 hours. The results with the first two surface preparations are similar, showing an Fe_3O_4 phase high in chromium and an αFe_2O_3 phase low in chromium, but with the Al_2O_3 polish there seems to be an additional Cr_2O_3 phase instead of Fe_3O_4. This work will be extended and paralleled by electron diffraction observations of the thinner oxides.

Systematic tests of the intensity anomaly observed in the X-ray absorption method (Annual Progress Report, Project SQUID, 31 December 1947) are in progress. It had been observed that a lightly oxidized steel surface gave a higher X-ray diffraction intensity than the original surface. Although an actual increase has not been observed in these tests, it has been demonstrated that the mechanical condition of the surface does influence the intensity observed-Surfaces rough polished on well used 3/0 paper give higher and broader peaks than do the same surfaces after two strokes on fresh 3/0 paper. The latter surfaces show very little change in intensity after twenty minutes of oxidation at 670°C and after chemical stripping of the very light oxide layer. The changes produced, which are due to the differing effects of absorption in the surface irregularities, are being correlated with the surface condition by means of electron micrographs. The correlation will be extended through several cycles of oxidation and oxide film removal. Increasing times of oxidation will be used in order to establish the effect of the variation in intensity on the absorption measurements.

The electron microscope studies of oxide formation on a 26% chromium steel have been continued to a total oxidation of 54 one - minute cycles at 650°C in air, and have been extended to 5, 13, and 17% alloys. The results are of the same nature as previously reported. A more or less uniform layer of oxide is formed over which crystallites grow, except on carbide precipitates and in their immediate neighborhood. On the lower chrome materials the growth of both film and crystallites is much more rapid than on the high chrome alloys, and the crystallites tend to have a characteristic vein-like tenuous appearance, rather than consisting of isolated particles.

The thin oxide films formed on the 11% alloy when heated in air for one minute and two minute periods (the maximum temperatures reached were 650°C and 900°C) have been stripped electrolytically. Transmission electron diffraction through the removed films shows αFe_2O_3 and Fe_3O_4 to be present; the former was found on the surface before stripping. Transmission electron micrographs of these films confirm the work by replica methods which show that the surface is covered with a quite uniform film on which crystallites grow as the time of oxidation increases. Methods are being worked out for mounting the removed film which will allow its inside surface to be examined by electron diffraction in reflection, in order that changes in this surface can be correlated with kind of alloy and exposure conditions.

While waiting for replacement of the copper target X-ray tube to be used with the low power electron microscope for investigation of the iron and chromium distribution in oxide layers, rather extensive measurements of the sensitivity of various plates have been made. With the low energy photoelectrons available (1000 to 4000 electron volts) the plate sensitivities are very low; a total charge of the order of 10^{-6} coulombs is necessary to produce unit optical density. Various theoretical calculations have been made to estimate the exposure time that would be needed to develop an image. With this low sensitivity the times seem unreasonably long. Investigation of special ultra-violet sensitive plates and of oiled plates shows, however, that a 50-fold increase in sensitivity is possible and may make the experiments feasible. The replacement tube was obtained recently but proved to be unsatisfactory, so that the equipment will have to be revised to accommodate one of our own continuously pumped tubes before the experiments proper can be resumed.

Plans

The X-ray diffraction identification of oxide structures will be continued on chrome-iron alloys using additional commercial types and on the Alloy Casting Institute chrome-nickel-iron alloys. An attempt will be made to evaluate the relative amounts of the two principal phases from the relative intensities of their patterns.

X-ray and electron diffraction and electron micrography will be used to investigate the effects of polish and other surface treatments on oxide formation, possibly including the effects of oxidation and natural scaling.

Attempts to correlate the oxide structure adjacent to the metal with alloy type and exposure conditions will be made by electron diffraction of stripped films.

Studies of the effect of changes in the metal surface on the reliability of the X-ray absorption analysis method will be continued.

PHASE NO. 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 both low and high temperatures

Project Leader. J. M. Smith, Associate Professor of Chemical Engineering.

Summary

Thermocouple failures required the dismantling and reconstruction of the apparatus. At the same time the electric heater for silica gel regeneration unit was installed. An investigation of the effect of wall temperature distribution was conducted. The investigation of air film coefficients in the temperature range 1750° - 2000° F is being continued.

Progress

Failure of several thermocouples required that new couples be calibrated and installed. While the apparatus was dismantled, the thermocouple shields were disassembled and polished to improve their reflecting power. At the same time the electric heater for the regeneration of silica gel, recently received, was connected into the system.

Several different types of temperature gradient along the test section tube wall were noted. Tests were run to ascertain the cause of variation and the effect of this variation on the heat transfer coefficient. As part of this investigation the effect of different methods of installation for surface couples was studied. Also investigated was the effect of varying thicknesses of insulation around the test section.

Having completed the aforementioned tests, the determination of heat transfer coefficients for air was continued in the range 1750° - 2000° F.

Plans

During the next quarter the investigation of heat transfer coefficients for air should be completed and a Technical Memorandum submitted reporting the results. The apparatus will then be modified so that a testing program using steam in place of air can be undertaken.

PHASE NO. 7

Statement of Problem. Investigation of rocket motors and liquid propellants at high chamber pressure.

Project Leader. M. J. Zucrow, Professor of Gas Turbines and Jet Propulsion.

Summary

The basic regeneratively cooled rocket motor design has been released to the machine shop for fabrication.

The subject matter outlining the procedure for the calculation of convective and radiant heat transfer from a rocket motor is being condensed before being issued as a manual.

The calculation of the values of theoretical specific impulse for heptane, octane, decane, and eicosane oxidized by white fuming nitric acid at chamber pressures from 300 psia to 2058 psia has been completed.

The difficulties in the apparatus for determining the ignition lag between oxidizer and fuel have been eliminated. Ignition lag tests of red fuming nitric acid and aniline at room temperatures showed a lag of about 0.09 second; whereas the lag for white fuming nitric acid was several times as much.

The rocket test pit has been completed and most of the equipment has been moved to the building for installation.

Progress

1. *Motor Design and Test Program.* The design of the basic regeneratively cooled motor has been completed, approved, and submitted to the machine shop. Material for the motor is on order, and fabrication will be started immediately upon receipt of the material. Further design of motors has not been carried out for the past two months because of more urgent design problems pertaining to the installation of testing equipment.

2. *Preliminary Analysis of Heat Transfer Problems.* Material for a manual outlining the procedure for the calculation of convective and radiant heat transfer from a rocket motor has been completed. Dr. Warner, assistant project leader, presented the method at a heat transfer meeting at the California Institute of Technology. This material is in the process of being condensed before being issued as a manual. This phase has been inactive during the past month because of more urgent problems.

3. *Propellant Thermochemistry.* The calculation of the values of theoretical specific impulse for heptane, octane, decane, and eicosane oxidized by white fuming nitric acid at chamber pressures from 300 psia to 2058 psia has been completed.

The equilibrium composition of the gases produced by the combustion of the fuel and oxidizer was calculated by the graphical method of Rudolph Kassner.

Increasing the chamber pressure from 300 psia to 2058 psia produces an average increase in specific impulse, of the four hydrocarbons studied, of 20.6% over the value at 300 psia. The correlation of the data obtained in these calculations indicates that the maximum theoretical specific impulse for a given propellant does not always occur at the conditions which give the maximum temperature of combustion but under conditions which produce gases with a lower mean molecular weight.

A thesis prepared for partial fulfillment of the requirements for the Master of Science degree is being edited for publication. The thesis discusses the significant results of this investigation.

4. *Ignition Lag Studies.* Shortly after the installation of the electronic timer in a temporary research laboratory, several difficulties were encountered. The original apparatus depended upon a single D.C. power supply to drive both the timing circuit and the phototube amplifier. Because of momentary overloads of this power supply's VR tube, and also to microphonic and thermal noise pickup, the ignition light signal was indiscernible from these extraneous effects. These difficulties were corrected by switching to a sepa-

rate battery power supply for the phototube amplifier, and by completely enclosing the amplifier and its external phototube assembly with grounded metal boxes.

Subsequent ignition lag tests revealed that while the ignition light signal was now easily recognized, another feature of the timing trace left something to be desired. Initially, the apparatus was designed so that the timing sweep was exponential in nature; that is, the sweep producing voltage change across a capacitor, with a fixed resistance in series, builds up exponentially (not linearly) with time, with current through the capacitor decreasing exponentially at the same time. This produced a compression effect upon the end of the dotted timing trace, resulting in loss of accuracy in that region where the time of the reaction's light signal was to be measured. To alleviate this undesirable feature, certain electronic modifications of the timer were made for the purpose of obtaining a linear sweep. The modifications included the insertion into the circuit of a constant current tube in series with the capacitor, which secured an essentially constant rate of capacitor charging and a resulting fairly linear rise in voltage. The sweep voltage thus produced was rather limited in magnitude. This necessitated the use of two amplifiers: the first to drive one oscilloscope vertical deflection plate in one direction; and the second, a paraphase amplifier, to drive the other plate at the same rate but in the opposite direction. In addition, the insertion of an attenuating neon bulb coupling network between the amplifier and its paraphase amplifier results in a constant average potential of the deflection plates, essentially the same value as the ground potential. That is, at any given instant during the timing trace, one plate is just as high above the ground as the other is below ground. This condition is essential for a well-defined timing trace. So far, the limited tests conducted with the modified timer tend to show that the apparatus will still give satisfactory timing sweeps over a range of about 100 micro seconds to about 5 seconds, with no appreciable time delays.

During the time that this apparatus was being modified and further developed, several ignition lag tests were run and recorded. In these tests, at ordinary room temperature the ignition lag for red fuming nitric acid with aniline ran about 0.09 second, while the lag for white fuming, though inconclusive, was several times this value.

At present, the complete laboratory setup is being moved from the temporary laboratory to the chemistry laboratory of the rocket test building at the airport. Upon installation of the apparatus in its new location, further ignition lag tests over wide temperature ranges will be continued until sufficient data for an M.S. thesis is obtained.

5. *Completion of Test Pits and Their Equipment*. The rocket test facility has been completed except for the installation of hardware on doors and some painting of woodwork.

The earth bunker has been completed and should give satisfactory service. The power plant equipment has been installed, and the 3KW gasoline generator is in operation. The 30 KW Diesel generator will be in operation as soon as an exhaust stack is available.

Various equipment, including tanks, instruments, and pipes, has been moved to the rocket test building for installation and service.

Plans

When the more urgent problems, such as the installation of equipment, are eliminated, detail designs are to be drawn up for other rocket motors of the series to be tested.

The investigation of catalysts to obtain a spontaneous ignition of hydrocarbon fuels using acid oxidizers is to be undertaken soon. Work is also planned to obtain accurate data on the ignition lag of various propellant combinations over a wide range of temperature.

Installation of equipment will be continued without interruption until completed.

REFERENCES

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[2] Fery, C., *Compt. rend.*, 137, 909-13 (1903).

QUARTERLY PROGRESS REPORT

PROJECT SQUID

A COOPERATIVE PROGRAM
OF FUNDAMENTAL RESEARCH IN JET PROPULSION
FOR THE
OFFICE OF NAVAL RESEARCH
OF THE
NAVY DEPARTMENT
CONTRACT N6ori-119, TASK ORDER I
DESIGNATION NO. NR 220-041

Cornell Aeronautical Laboratory, Inc.
Buffalo, New York
1 October 1948

PHASE I

In connection with jet propulsion engines: (1) to study the mechanism of non-steady flow in simple ducts with particular reference to acoustic jets, inflow and outflow phenomena in jet engines, and the stability of shock waves in diffusers, and (2) to study the operation of shrouded pulse jets.

Summary

A large number of experiments on the water table were carried out to study the effects of viscosity on the results obtained. These runs are being evaluated and compared with results obtained by the method of characteristics. Experiments with small valveless pulse jets have been continued using different configurations and fuels. Specific impulse values of over 2000 seconds have been obtained. A pressure gauge as developed by NYU was received. It showed considerable high and low frequency disturbances and the gauge head was very microphonic. The disturbances have been successfully eliminated but further work is required to eliminate microphonic effects. An attempt is being made to develop a theory for acoustic jets.

Progress

The experiments carried out so far have simulated the transient which occurs when a pipe which contains isentropically compressed air, is suddenly opened at one end. In order to study the influence of boundary layer and other viscosity effects the runs were carried out for various dimensions of the length and width of the test section and also with different water levels. Individual runs seemed to be well-reproducible.

Instrumentation for instantaneous recording of water depths has been completed. The depth probe now consists of three parallel platinum wires where the two outer wires form one electrode and the inner wire the other. A linear response could be obtained by suitable design of the bridge circuit instead of bending the wires. A simple oscillator was built to supply the required voltage for the probe. The oscillograph used for recording produces one-hundredth second time markings which is inconveniently short for the long recording times. Therefore, a small timer was built to indicate intervals of one-tenth of one second. It consists of a torsional pendulum which interrupts a light beam falling on a photoelectric cell. The cell output is fed to one of the galvanometers of the oscillograph which is also used to indicate the beginning of a transient to be recorded.

When the oscillograph records were compared with theoretical curves obtained from previously constructed wave diagrams, an inconsistency in the theoretical values was discovered. Continuous increase of the initial amplitude of the transient did not lead to a continuous increase of the following maxima. This was eventually traced to a peculiarity of the method of wave diagrams. These are now being replaced by characteristics diagrams which do not show this inconsistency. The necessity of redrawing these diagrams is delaying a complete evaluation of the experimental runs.

Jet Theory and Experiments. Experiments with small valveless pulse jets have been continued. The models were assembled from individual components in order to obtain a variety of configurations. The combustion chambers were all 4 inches long with diameters from 2.5 to 4 inches. Tailpipes were between 14 and 18 inches long and had a diameter of 1.5 inches. Both propane and methane were used as fuels. When the air-fuel ratio was varied, the operating frequency of the jet suddenly changed to a new value. Maximum specific impulses were obtained at frequencies which are lower than those at which the same model would operate with valves. The tailpipe length was found to be very critical. Under optimum conditions a change of one percent of the length of the model produced large variations of the specific impulse. The maximum values of specific impulse obtained were over 2000 seconds. It was also found that the ratio of combustion chamber and tail pipe diameter which gave maximum specific impulse depended on the fuel used.

A NYU pressure gauge was received but when tried, large high and low frequency interference was noted. These difficulties were eliminated by incorporating suitable filters. More serious was the microphonic sensitivity of the gauge head. Although more rigid mounting of components and stiffening of the frame improved the conditions to some extent, further work is still required before actual pulse jet cycles may be measured. The instrument was used, however, to determine the operating frequencies of the small pulse jets.

A two-dimensional glass-walled model of a valveless pulse jet was constructed and is ready for schlieren observations.

An attempt is being made to develop a theory of the acoustic jet but it is still in its developmental stage.

Plans

The water analogy experiments will be continued with the ultimate aim of studying the influence of shape on the performance of pulse jets.

Further experimentation is planned with small valveless pulse jets in an attempt to clarify the often puzzling results. Schlieren observation of the two-dimensional glass-walled jet-model will be carried out and it is hoped that these experiments will contribute further to the understanding of these jets. Further work on the pressure gauge is required to eliminate the microphonic effects. After this has been achieved, wide application will become possible which may lead together with other information to an experimental establishment of boundary conditions for large disturbances.

It is intended to construct an acoustic jet somewhat larger than the previous models and investigate further the influence of amplitude on the specific impulse. The attempt to develop a theory of such jets will be continued.

A Technical Memorandum describing the application of the method of characteristics to the propagation of flames in tubes will be completed (no work could be done on this during the present quarter).

PHASE II (a)

In connection with jet propulsion engines: to investigate ignition and flame propagation and stability as affected by physical parameters with particular reference to the interaction between flow disturbances and flame propagation.

Summary

Experiments with the combustion chamber were temporarily suspended; they will be resumed when a pair of schlieren mirrors can be obtained.

Preliminary tests of the flame tube have been performed. Operation of the electronic timing device for flame velocity measurement was entirely satisfactory. In several instances the results of the tests were not well reproducible; the causes are being investigated and an attempt will be made to eliminate them.

The study of the effects of disturbances on flame shape and flame stability has been continued; high-speed schlieren motion picture techniques proved to be very well-suited for this work.

A theoretical study of the hydrodynamical stability of flame fronts is under way.

Progress and Plans

Combustion chamber experiments. The modifications of the combustion chamber suggested by preliminary tests have been carried out, and operation without combustion has been tested. Further tests with combustion were not performed, because the schlieren mirrors used previously were on loan and are not available at present. The tests will be resumed when a pair of schlieren mirrors can be obtained.

Flame Tube Experiments. Tests of the electronic flame timer by means of auxiliary devices were satisfactory and preliminary experiments with the flame tube have been started.

In its present and final form, the timer generates a short voltage pulse whenever the flame passes one of the ionization gaps located along the tube. These pulses are recorded by a cathode-ray oscillograph. In order to increase the length of the oscillograph trace and thus the accuracy of time measurement, a triangular wave is applied to the vertical plates of the scope. Intensity modulation of the beam is used to record the pulses from the flame timer and weaker timing pulses from a calibrated oscillator.

The preliminary tests of the tube were performed with various propane-air mixture compositions, both with the ignition end closed and the other end open and vice-versa. With the ignition end closed, the flame was accelerated to high speeds relative to the tube by the expanding gas. Results were fairly well reproducible if the runs were performed on the same day. Discrepancies between runs on different days may have been caused by climatic influences. With the ignition end open, much lower flame speeds were observed, and the results were not well reproducible. In both cases, it was also found that the presence of the ionization gaps had a certain influence on flame speed, since the overall travel time of the flame increased slightly when the first gap was removed.

It will be recalled that the main object of this work is to investigate the influence of obstacles on flame travel. Before attempting to study such influences, it would appear desirable to eliminate the lack of reproducibility of undisturbed flame motion; experiments with the purpose of finding the causes of irreproducible results, and, if possible, their elimination, will therefore be performed.

Burner Experiments. The study of the influence of disturbances on flame shape and flame stability has been continued. High-speed motion picture techniques in combination with schlieren methods proved to be very well-suited for this work, particularly for the study of transient phenomena.

One group of phenomena which were studied in this way was the effect of sound on blow-off stability. It was found that sound of sufficient intensity at one of the resonant frequencies of the burner pipe caused the flame to lift from the burner. Within a certain range of flow velocities and compositions, the flame continued to burn in a lifted position as long as the sound disturbance was maintained, but blew off completely when the sound was removed. The motion picture confirmed the assumption that the vortex motion caused by the sound in the unburned gas jet stabilized the lifted flame. Figure 1 shows examples of motion pictures of seated and lifted flames under the influence of acoustical disturbances. Other phenomena studied include disturbances caused by a vibrating wire, blow-off after removing a stabilizing electrical field, and spontaneously vibrating inverted flames. A paper describing part of this work and the significance of these phenomena for the study of turbulent flames was presented at the Third Symposium on Flame, Combustion and Explosion Phenomena at Madison, Wisconsin.

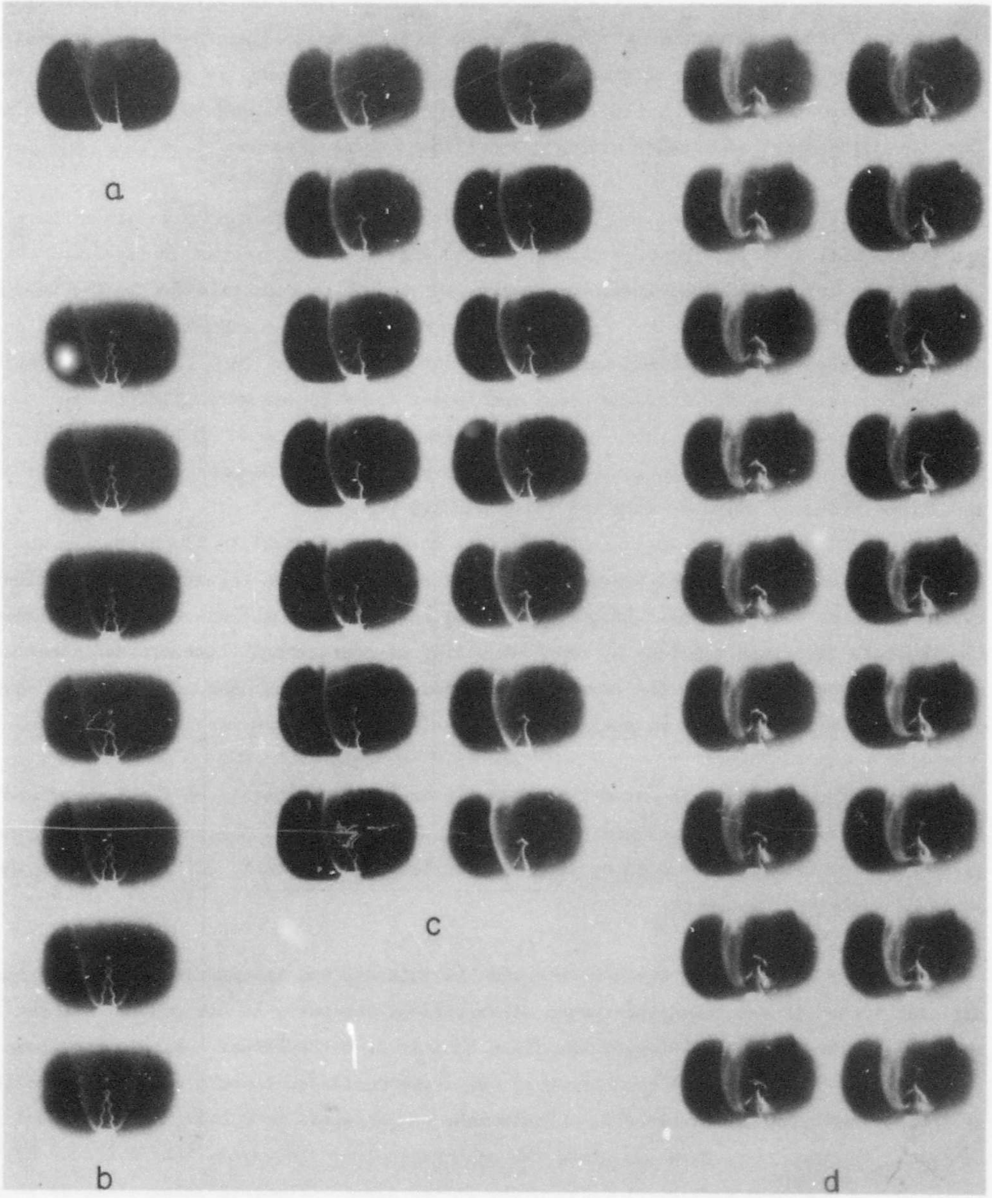

FIGURE 1

Schlieren motion pictures showing effects of acoustical disturbances on a Bunsen flame. Approximately 3300 frames/sec.

a. *without disturbance*	c. f = 250 cps *seated flame*
b. f = 500 cps *seated flame*	d. f = 250 cps *lifted flame*

The study of the effects of disturbances on burner flame is being continued. Attempts to observe the flow disturbances directly by means of particle injection will be resumed. A theoretical study of the hydrodynamical stability of flame fronts has been started.

PHASE II (b)

In connection with jet propulsion engines: to study the mechanism of combustion and attendant reactions through the application of spectrographic and other techniques.

Summary

In the application of spectrographic methods to the evaluation of combustion mechanisms, a series of experiments have been performed in an effort to ascertain the effect of pressure on the concentration of both the OH and CH radicals. The results, subject to further experimentation indicate: (1) that the OH concentration is proportional to A log p where p is the pressure at which the burning is taking place and A a constant; (2) that the CH concentration and the total intensity of the flame are interrelated indicating that the CH radical may be the primary source of emission.

Progress

In the study of the application of spectrographic methods to the evaluation of combustion mechanisms, a series of spectrophotometric exposures were made of the methane-oxygen flame in the region 2875 Å to 4871 Å. These exposures were taken at progressively lower pressures beginning at a maximum burner pressure of 47 mm and progressing down to a minimum burner pressure of 17mm with a constant O_2/F ratio of 2.2.

The exposures were made with the intention of investigating the effect, if any, of pressure on the concentration of both the OH and CH radicals. Microphotometer tracings of the densities of the OH bands in the region 3064 Å make it appear that the OH concentration is proportional to A log p where A is a constant (in this instant A was 1, however, the curve had not been corrected for the geometry of the experimental setup) and p the pressure at which the burning is taking place.

In making microphotometer tracings of the densities of the CH bands in the region 4315 Å, it was observed that maximum emission was obtained at a pressure of approximately 27mm. This observation together with a study of emission of the flame proper where it was noted that at a burner pressure of approximately 30mm, the intensity of the flame was at a maximum indicates that the CH radical may be the primary source of emission.

Plans

Further investigations of the parameters of combustion are in progress.

PHASE III

To study the properties and behavior of materials for high temperature application in connection with jet engines:

Summary

For the continuation of high temperature fatigue studies a literature search has been conducted to determine whether or not a commercial machine is available to carry on this work. No machine has been built to operate at the high frequencies, temperatures, and deflections that are desired.

The vacuum equipment for the high temperature metalloscope has been redesigned and the parts are on hand. Acceptable photomicrographs have been made with still cameras at room temperature.

A program is in progress for determining the high-temperature strain activation energies of several pure metals as a means of relating the high-temperature deformation mechanism with that of metallic diffusion. Tests have been completed for a 99.0% nickel sheet material.

The high-temperature tensile properties of six sheet materials in the temperature range of 80 to 1800°F were summarized and issued as CAL Technical Memorandum No. 21 of August 1, 1948.

Creep testing in conjunction with metallographic and X-ray diffraction studies are being made on Type 314 stainless steel with the objective of improving the high-temperature load-carrying-ability of such austentitic steels through proper use of the sigma phase constituent which is easily developed in these alloys.

Construction of two creep and rupture testing units has been completed to provide sufficient capacity for longer duration tests.

Apparatus and some preliminary tests have been completed for determining the effect of fluctuating tensile loads on the creep properties of high-temperature alloys. It would appear that frequency of stress fluctuation is a significant variable.

Progress

High Temperature Fatigue Test. The difficulties encountered in the evaluation of the data obtained on the pneumatic fatigue machine have led to the conclusion that it is unsuited to the production of the results that are desired. A literature search has been conducted to determine whether or not a suitable machine is available to carry on this work. No machines have been built to operate at the high frequencies, temperatures, and deflections that are desired.

High Temperature Metalloscope. It was found impossible to obtain a vacuum as low as 10^{-5}mm of mercury with the vacuum system as it was originally assembled. A vacuum technician was brought in from Distillation Products, Inc. to examine the system. He suggested several modifications which would increase both the speed and ultimate vacuum obtainable. The parts necessary to make these modifications are now on hand and the work is in progress.

Visual observations have been made of specimens being heated to temperatures as high as 1800°F. The formation of the oxide film was clearly visible. The first attempts to photograph specimens in the furnace were unsuccessful inasmuch as the unit could not be sufficiently reinforced or shock-mounted to eliminate the vibration present in the building. Due to the various tests being conducted, there is considerable vibration in the main building. The unit was therefore moved to the Fuels Laboratory which is isolated from the main Laboratory. Acceptable photomicrographs have been made with still cameras. It is still impossible to obtain clear pictures with the movie camera due to the vibration caused by the camera mechanism. Suspension mounting on a different type camera may be necessary to eliminate this difficulty.

Solution of the above difficulty and modification of the vacuum system appear to be the only factors delaying the use of the metalloscope for actual investigations of metals at high temperatures.

High Temperature Tensile Tests. During the course of investigating some fundamentals of high-temperature deformation using various available heat resistant alloys, conventional tensile data were accumulated as a by-product. These values of yield strength, tensile strength, proportional limit, modulus of elasticity, and percent elongation were obtained over the temperature range of 80 to 1800°F and a range of strain rates. CAL Technical Memorandum No. 21 of August 1, 1948 summarized this data for six sheet alloys and pointed out its utility from the design and materials evaluation standpoint.

A program is underway for determination of the high-temperature strain activation energies of several pure metals. As suggested by the results previously reported in CAL Technical Memorandum No. 17 of April 20, 1948, it is possible that one mode of high-temperature deformation may be related to a metallic diffusion mechanism. By comparing the diffusion activation energies with those of deformation when extrapolated to zero stress (and possibly zero strain) conditions, the plausibility of such a relationship may be judged. Sheet material of copper, iron, and aluminum of approximately 99.9% purity is in process of procurement for such high-temperature deformation tests. Other metals for which self-diffusion activation energy data is available will be studied if results from the first metals mentioned warrant further investigation.

High-temperature tensile tests were made on a 99.0% nickel sheet material. While this material is not of high purity, it was readily available in the laboratory and was examined while awaiting receipt of the 99.9% purity copper, iron, and aluminum sheet metals. Determination of the zero-stress activation energy value for this 99.0% nickel yielded a value of approximately 135,000 calories per mol. No values for the energy of self-diffusion for nickel are known from the literature.

High Temperature Creep Tests. Creep testing of the type 314 (25-20-2 Si) stainless steel has been continued in the temperature range of 1200 to 1800°F. While limiting creep stress data suitable for design purposes are accumulating from such tests, the main objective is to establish means of using the sigma constituent to advantage in austenitic iron-chromium-nickel alloys. To this end, heat treating, aging, metallographic, and X-ray diffraction studies have been in progress on the 310 and 314 stainless steels. On the basis of such observations, the more desirable types of microstructures are being selected for creep and rupture testing.

Construction of two creep and rupture testing units has been completed to provide additional capacity for longer duration tests up to 100 hours.

On the basis of a number of exploratory tests, a program has been planned for studying the effect of fluctuating load on the high-temperature creep rate. Originally it was planned to use fluctuating load frequencies of the order of 30 cycles per second or greater. However, it was found in the case of the 314 steel, that such frequencies have little effect on the creep rate except at temperatures in the 1800°F range. At lower temperatures, slower load fluctuations are required to influence the creep rate. Consequently a system has been constructed to permit dynamic tensile loading at frequencies ranging from 1½ to 1725 cycles per minute.

Plans

The problem of simulating the fatigue of metals at high temperatures with frequencies comparable to those encountered in pulse jets is to be studied further with regards to the mechanical means for the testing under controlled conditions.

The vacuum furnace of the metalloscope will be assembled with the optical system and it is planned to run off still and motion pictures of aluminum and steel at elevated temperatures this quarter.

It is planned to conduct high-temperature tensile tests on copper, aluminum, and iron of approximately 99.9% purity so as to permit comparison of the strain activation energies so determined with the known values for self-diffusion in these metals. Additional metals may be tested according to results obtained. Conventional high-temperature tensile properties for these pure metals will be compiled as a secondary objective.

An effort is being made to prepare creep test specimens of 314 stainless steel containing optimum quantities of sigma for improved high-temperature strength. Additional studies will be made of the mode of formation of sigma in this analysis in order that a systematic series of creep tests may be conducted toward this objective.

Fluctuating load creep tests are to be run in the temperature range of 1200 to 1800°F on Inconel X and 314 stainless steel. Other variables to be investigated include frequency of load variation, amplitude of load variation, and average stress level.

QUARTERLY PROGRESS REPORT

PROJECT SQUID

A COOPERATIVE PROGRAM
OF FUNDAMENTAL RESEARCH IN JET PROPULSION
FOR THE
OFFICE OF NAVAL RESEARCH
OF THE
NAVY DEPARTMENT
CONTRACT N6ori-105, TASK ORDER III
DESIGNATION NO. NR 220-038

Princeton University
Princeton, New Jersey
1 October 1948

PHASE II

Under Joint Sponsorship of:

Project BUMBLEBEE	and	*Project SQUID*
Bureau of Ordnance		*Office of Naval Research*
Navy Department		*Navy Department*
Applied Physics Laboratory		*Contract N6ori-105, Task Order III*
Contract NOrd-7920, Task PRN-3		*Designation No. NR 220-038*

Statement of Problem. To study (1) the characteristics of combustion in high-velocity fuel-oxidant streams, ignitibility. efficiency, after-burning, thrust, etc. (2) effects of sub-atmospheric pressures, (3) interactions between ionization and flame, (4) observation of optical and mass spectra, and (5) theory of adiabatic exothermic reaction.

Progress

Attention is being focussed on the kinetics and mechanism of gaseous oxidation reactions at reduced pressures, in order to provide a better understanding of the physico-chemical features of ignition and flame stabilization, and with a view to unearthing systems with practical application in the jet propulsion field. Combustibles now being studied include, butane, ammonia, diborane and aluminum borohydride.

With respect to butane-oxygen mixtures it has been found that hydrogen atoms from a discharge tube will cause quite rapid (though incomplete) reaction at room temperature and 0.3 mm. pressure. This indicates that the presence of a copious supply of free radicals (H-atoms) is sufficient for reaction even at room temperature. The rate of chain processes is thus less crucial than the initial formation of active particles even at these low pressures. It is also proposed to study very rich and very lean mixture of butane and oxygen in the ordinary slow reaction range, much as Avery et al. have recently reported. It is possible to distinguish a low- and a high-temperature reaction, which are affected differently by surface coatings of boric acid and of potassium chloride.

In the case of ammonia, extreme difficulty in the ignition of mixtures with oxygen goes hand in hand with a high temperature for even slow combustion. It further appears that reaction is much faster in very lean mixtures, as if ammonia were an inhibitor for its own oxidation.

Both diborane and aluminum borohydride appear to be rather unsusceptible to oxygen until temperatures are reached where decomposition begins to be appreciable. (about 250°C for diborane, and 150°C for the borohydride) At higher temperatures both compounds give up almost their full quota of hydrogen, leaving a metallic mirror on the walls of the glass container. Both compounds react with olefines, which may account for their efficacy in inducing combustion of the latter.

PHASE III

Statement of Problem. To study some of the problems associated with the development of propulsive devices of the ducted type. Specifically, these problems are: (a) Study of the mixing of two gas streams of different velocities. (b) Study of schemes to improve the mixing process. (c) Combustion chamber problems.

Personnel. This program is under the direction of Dr. J. V. Charyk of the Department of Aeronautical Engineering assisted by K. D. Miller, Jr. and H. L. Pool as Research Associates.

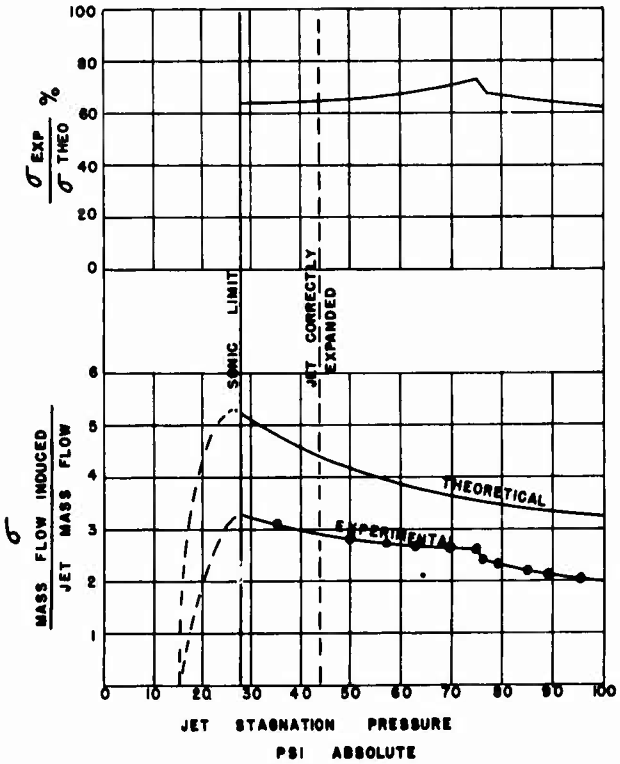

FIGURE 1

Two Dimensional Air Ejector
Results of Test 487-17

Summary

During the past quarter, test work with the two dimensional air ejector has been proceeding satisfactorily. Certain limited data has been obtained. On the hot jet system, work has been continued on the oxygen pumping system and some preliminary rocket tests have been made.

Progress

Two Dimensional Air Ejector. During the period covered by this report, the two dimensional air ejector described in previous reports has been in operation. A series of 24 tests comprising approximately eight runs each have been carried out on this apparatus.

All of these tests were made using a primary jet having a Mach number of 1.37. Tests have been made with different ejector area ratios under a wide variation of jet stagnation pressures The results of a typical test are presented in Figure 1. These tests are of a preliminary nature and as yet are largely exploratory in scope. To date, for example, only the overall ejector pumping ratio and induced air velocities have been measured. More extensive instrumentation is currently being installed in order to broaden the scope of the experiments.

Results of Tests. Results of a typical test in this first series are shown in Figure 1. This particular test was made with a straight ejector tube measuring 8 x 1½ inches and approximately 72 inches long. The jet has exit dimensions of 1½ inches by 0.27 inches. Information gained by visual observation indicated that mixing was largely complete about 36 inches downstream from the jet orifice. It is noted that the experimental curve experiences a break at about 75 psia. This break is a real phenomenon involving a sudden change in flow conditions. The exact nature of the phenomenon, however, is not completely understood. This point of discontinuity in slope is connected with a very noticeable change in noise of the ejector, both in level and in timbre. At the same point a marked visible change in the jet pattern is observed. Shadowgraph and schlieren studies are being initiated to investigate this phenomenon in some detail.

The upper curve connects points computed theoretically for the same conditions by the method contained in Reference 1. It will be noted that the shape of the two curves is similar up to the break point; the experimental curve maintains an almost constant ratio of 67 percent to the theoretical. This is fairly typical of the results of the first tests.

It has been found that the inlet geometry is quite critical; an ineptly shaped entrance drops the ratio to theoretical to 50 percent or less. Higher ratios than presented on Figure 1 have been obtained in a few cases up to 75 percent. It is expected that further study will yield some improvement in this ratio. Possible reasons for the lower experimental results are as follows.

1. For practical reasons it has not been possible to realize the theoretical conditions at the inlet. That is, the two streams cannot be made quite parallel. At the correctly expanded point, although the jet should be nearly axial, the induced air is of necessity inclined to allow for the structure of the primary nozzle. A new nozzle design is in process which will alter this situation. Also, at high stagnation pressures, the jet pattern is the familiar 'underexpanded' bell pattern so that in this case neither stream is axial.

2. In this long narrow ejector the boundary layer from the sides is very likely partially blocking the tube thus reducing the performance. Instrumentation to check this is currently in the process of installation.

3. The flow profiles may be far enough from the one-dimensional ideal as assumed theoretically to reduce the performance of the ejector.

Rocket Driven Ejector. During the period covered by this report, a 50 lb. thrust liquid oxygen-ethyl alcohol rocket motor has been designed and the first model fabricated. This motor was designed to be semi-expendable, using standard fittings and simple parts wherever possible.

The rocket was mounted in the rocket test chamber and installed using the pumping system described in a previous report. Certain developmental difficulties with the pumps were encountered which have not as yet been completely overcome. The first rocket motor suffered a 'hard start' but, as had been expected, only a few components of the system were damaged. A second motor has been assembled and is ready for test.

Further progress on this phase of the program will be presented in the next report.

Plans

Test work on the air ejector is to continue and present measurements will be augmented by the use of optical techniques. Theoretical calculations are being continued to compare the one-dimensional theory with the experimental results being obtained.

Testing and development of the propellant feed system for the hot jet setup is to continue at an accelerated rate.

PHASE IV

Statement of Problem. To investigate theoretically and experimentally a valveless intermittent jet engine.

Summary

Intermittent combustion pressure rise of 6 psi has been obtained with original type of fuel injection nozzle. A fuel injection nozzle which will inject the fuel from the interior of the tube, rather than from the walls is being procured, so as to obtain a more uniform mixture distribution.

PROGRESS

Tests. Transient pressure measurements during intermittent combustion with pilot flame ignition with the original 8 hole, 80 degree cone angle fuel injection nozzle mounted on the top wall indicated a peak pressure rise of about 3 psi. The fuel used was fuel oil number 2. The original nozzle and other nozzles with various numbers of spray holes and spray cone angles were modified by plugging and opening holes in an attempt to obtain a more uniform fuel-air mixture distribution. The combustion pressure rise was increased in this manner to about 5 psi, although the mixture distribution was still not thought satisfactory. The use of gasoline as fuel increased the combustion pressure rise to about 6 psi. The blower jet velocity for the above tests was 400 feet per second, the average velocity in the tube being about 200 feet per second.

Equipment. A fuel injection nozzle which will inject the fuel from the interior of the tube, rather than from the walls has been ordered. It is hoped that this type nozzle will provide a more uniform mixture distribution. A two cylinder fuel pump, which will increase the fuel flow quantity and the injection frequency has also been ordered.

Instrumentation. The schlieren system is rapidly nearing completion.

Plans

The main objective of immediate future studies is to determine the maximum combustion pressure rise obtainable in a constant area tube. These studies will include experimentation with fuel injection nozzles until a satisfactory fuel-air mixture distribution is obtained. The effect of position of the nozzle and the pilot flame ignition source on the pressure in the constant area tube will then be determined. Methods of increasing the combustion pressure rise, such as the effect of many ignition points, will be investigated. High speed schlieren motion pictures will be taken to determine the nature of the intermittent combustion process. Thrust measurements will be made. Theoretical studies of the pressure rise obtained in intermittent combustion in constant area tubes, will be made for various combustion times.

The next objective will be to determine both experimentally and theoretically the effect of various tube shapes on combustion pressure rise and thrust.

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ABSTRACT:

Progress achieved in "Project Squid" during the third quarter of 1948 is reported by five academic institutions, which present papers on the various research phases. Studies were continued in the thermodynamic field on flame motions in pulse and rocket engines; temperature dependence of conductivity; water stream analogues for gas motion; gas velocities; continuous-process combuttion; combustion in high velocity fuel-oxidant streams; mixing of gas streams; mechanism of non-steady flow; statical mechanics of non-uniform gases; and internal ballistics of jet engines. Moreover, diversified investigations were continued on: transient thrust; internally coupled pulsejets; valveless intermittent jet engines; cooling aspects; valve mechanisms; instrumentation; properties of materials; heat capacity of steels; and corrosion.

*Department

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