UNITED STATES NAVY

PROJECT SQUID

QUARTERLY PROGRESS REPORT

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

1 APRIL 1947

NEW YORK UNIVERSITY
POLYTECHNIC INSTITUTE OF BROOKLYN
PURDUE UNIVERSITY
CORNELL AERONAUTICAL LABORATORY
PRINCETON UNIVERSITY

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CONTRACT N6ORI-119, TASK ORDER I

CORNELL AERONAUTICAL LABORATORY
BUFFALO, NEW YORK

1 APRIL 1947

PHASE NO. 1

In connection with pulsating-jet engines: to undertake theoretical and wind-tunnel investigations on flows and losses in diffuser inlets, diffusers, intake valves, exhaust nozzles, and thrust-augmenting ducts for subsonic and supersonic pulsating jets.

SUMMARY

Two-dimensional diffuser models were tested at a Mach number of 1.7 in the Cornell Aeronautical Laboratory Supersonic Wind Tunnel. Striae photographs were made of the shock patterns in these diffusers. A diffuser is now being studied which uses fluctuating back pressure to simulate intermittent combustion.

The effect of spillover on the pressure distribution on the external surfaces of ducted bodies was simulated in wind-tunnel tests of both blunt and sharp wedges.

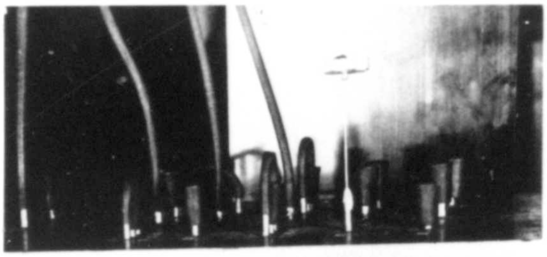
A study of gas flow in half-open pipes was started and the possibility of representing the conditions by means of electrical or hydrodynamical model experiments is being investigated.

PROGRESS

A two-dimensional Kantrowitz diffuser designed for M = 1.7 was tested at this Mach number. A butterfly valve, which can be set to any desired angle with respect to the diffuser axis, or which can be rotated by means of an electric motor drive, was installed at the diffuser outlet. The test setup is shown in Figures 1 and 2. To detect the motion of the normal shock in the diffuser as the valve was turned, a series of striae photographs was made at a speed of 4 microseconds. This motion of the normal shock is shown in Figures 3, 4 and 5.

A two-dimensional model was used to investigate the effect of spillover on external wave drag. This model consists of a single wedge with one blunt and one sharp edge. Either the sharp or blunt edge can be used forward, and the thickness of the blunt edge can be increased. The blunt edge simulates the external shape of a ducted body with steady spillover from the duct entrance. There are static pressure holes in the upper surfaces of the wedge.

Measurements of these static pressures were made at a free-stream Mach number of approximately 1.7. The results of these tests indicate that the effect of steady spillover is to increase the wave drag over most of the external surface, but to decrease it in a narrow region near the lip. Striae observations show that there is a region of intense expansion following the detached shock.



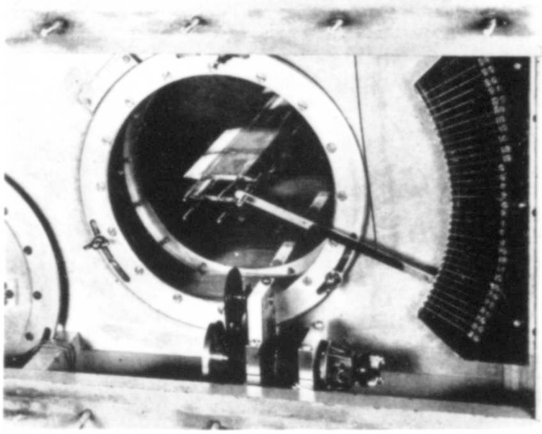


Figure 1. Model Setup for Operating Valve by Hand.

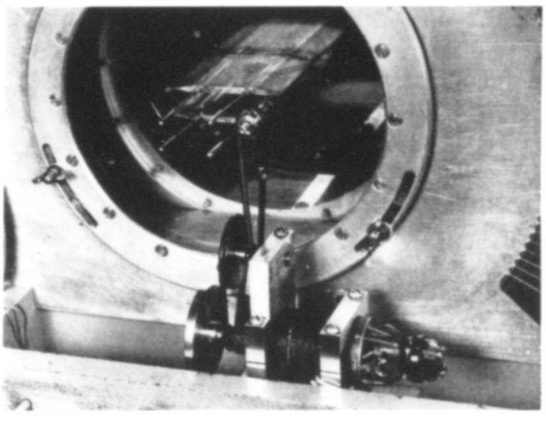


Figure 2. Model Setup for Operating Valve by Motor.

This expansion culminates in a second shock aft of the lip.

The problems of gas flow in a pipe suddenly opened at one end were studied. It was found that the air, which initially is under pressure, expands, and that oscillations are set up in the system. Relations are being derived which show the effect of the shape of the pipe, of the amplitude of oscillations, and of the nature of the gas on the resonance frequency. There is a perfect similarity between the pressure waves in a gas

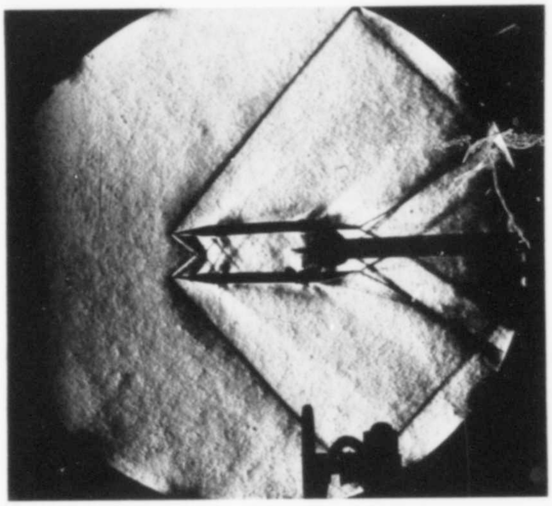


Figure 3. Valve At 0°.

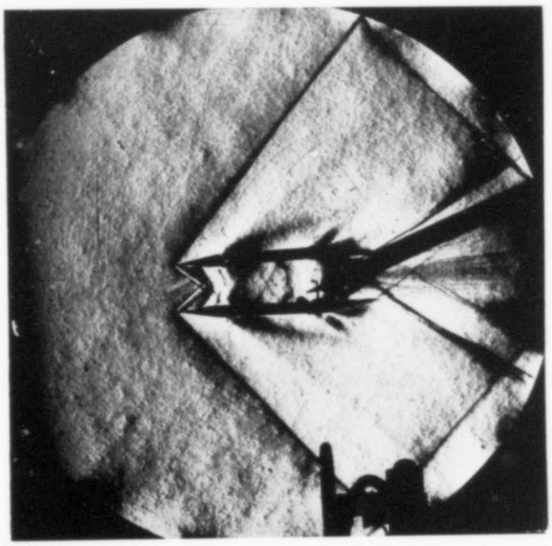


Figure 4. Valve At 21°

and electric waves along a transmission line for acoustical oscillations, but for large amplitudes the underlying differential equations become nonlinear in a different way. All attempts to develop a satisfactory electrical equivalent circuit have

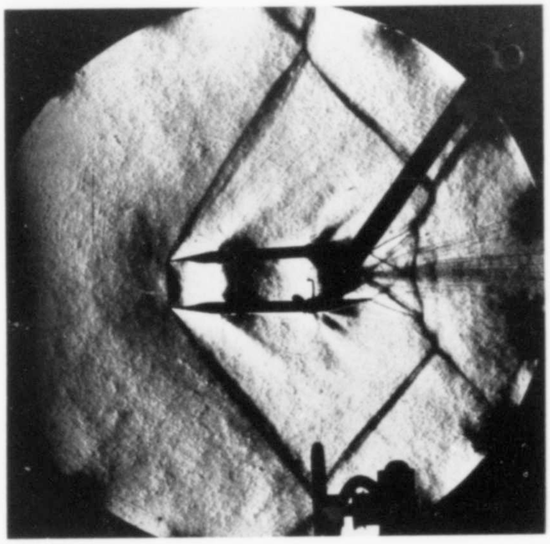


Figure 5. Valve At 60°.

failed for this reason. An attempt is now being made (following a suggestion by Dr. V. Paschkis of Columbia University) to see whether, instead of a continuous solution, a good approximation in steps might not be possible after all.

Paralleling this study, the possibility is being investigated of using the property of surface gravity waves in open water channels to simulate conditions of a gas in a pulse jet after burning is completed. It appears that this approach should give valuable information on the operation of a pulse jet.

PLANS

Tests of the diffuser with the rotating valve will be continued. An attempt will be made to determine whether a relationship can be established between the amplitude of the pressure fluctuations and the frequency of the pulsations so that the normal shock will not be forced out of the diffuser. The variation of pressure and shock position inside the diffuser will be determined with varying positions of the valve (simulating varying amounts of back pressure). High-speed motion pictures will also be made to ascertain the exact fluctuation of conditions in the diffuser.

Conclusions reached on the hydrodynamical analogy will be tested by comparing experiments of equivalent setups both for pressure waves in gas and surface waves in water. If satisfactory agreement can be obtained, a variety of problems can be investigated by the comparatively simple water analogy. These problems include optimum shape of ducts to obtain maximum thrust, optimum valve operation and the comparative value of different types of valves. If a way can be found, a similar program will be followed on the electrical analogy.

PHASE NO. 2

In connection with pulsating-jet engines: to study the theory of combustion, effect of turbulence on flame propagation and cooling, and to verify and augment existing theories by means of experimental investigation of ignition, combustion, flame holding, flame propagation and cooling.

SUMMARY

The preliminary experiments have been completed to move a spark through a combustion chamber by means of a magnetic field across the electrodes, and a full-scale setup is being designed. The apparatus for studying flame propagation in a steel tube has also been completed and experiments have been started to find the optimum configuration for the ionization gaps. These gaps are used to measure flame velocities. Experiments are being carried out to take high-speed movie films of striae patterns. Successful films up to 1000 frames per second have been taken. General problems on instrumentation are being continuously studied.

Tentative plans have been made for studying the possible catalytic influence of combustion-chamber-wall materials. A description of these plans has been sent to the chairmen of the Pulse Jet and Rocket Panels.

Proving tests have been run to establish the efficiency of a refrigerated probe for sampling combustion gases. While results are encouraging, difficulties have been encountered in obtaining a satisfactory equilibrium mixture for sampling purposes.

PROGRESS

The preliminary experiments with the pyrex-glass combustion chamber indicate that high-speed movies of the flame can be successfully taken up to the maximum speed of the camera (4000 frames per second). With the small magnet used for the first experiments, a spark was moved at a speed of about 10 feet per second. A much stronger permanent magnet has now been ordered and improvements are being made to the combustion-chamber design on the basis of preliminary experiments.

Experimentation with the steel combustion tube has started. The first step is to find the optimum arrangement of the ionization gaps. Their orientation relative to the flame front, in addition to the geometry of the ionization gap itself, are being investigated.

Since the mercury ac arc, normally used for striae observations, is not suitable for taking high-speed movie films because of the resulting periodic variation of light intensity on the film, a dc carbon arc was tried. A film taken at 1000 frames per second was well-exposed. Now, by a simple modification of the optical system, attempts are being made to focus the striae pattern directly on the film (16 mm) of the high-speed movie camera, instead of photographing the screen. It remains to be seen whether elimination of the screen is not more than offset by the reduction of quality of the optical system.

A study was begun on the possible catalytic influence of combustion-chamber-wall materials. It is generally known that combustion takes place very readily on certain solid surfaces. This fact is utilized in surface combustion furnaces in which combustion occurs on the porous surface of refractories. Welsbach mantles in lanterns produce intense brilliance on the surface of the metal oxides used in the mantle. A recent study by Curtiss-Wright developed a catalytic flame holder and igniter in which a platinum surface is used to promote combustion.

The use of such materials in combustion-chamber walls seems of particular interest in propulsion devices where space, weight, and time are at a premium.

The specific objective of this work is to study the catalytic effect of wall materials on the capacity of a combustion chamber and on the completeness of combustion.

It has been previously reported that a water-cooled triple-walled sampling tube of 0.020-inch internal diameter gave indications of justifying the theoretical calculations of its ability to freeze the CO_2 and H_2O dissociation equilibrium. The experiments which have been conducted from January through March have been complicated by the difficulty of obtaining an equilibrium gas mixture for sampling purposes. Numerous experimental setups have been developed and tested to overcome this difficulty.

The experimental trials can be divided roughly into two classes. The first includes those experiments in which a flowing CO_2 system was used; the second includes those in which flames were used as a source of equilibrium products. Using a Zircofrax tube and an Alundum tube sealed with sodium silicate, CO_2 was heated to the order of 3000°F by heating the refractory tubes with an oxy-gas flame. The temperatures were determined with an optical pyrometer. The sample was collected by inserting the sampling tube into the exit end of the refractory tube to the point of closest proximity to the region of maximum temperature.

With the Zircofrax tube, no decomposition of the CO_2 was observed. This could be due to recombination either in the cool portion of the heated tube or in the refrigerated sampling tube itself, since the gas approached and entered at a relatively slow velocity. In order to eliminate the latter possibility, tubes of very small diameter were constructed of Alundum. A higher rate of flow was used and samples were again collected. The amounts of oxygen and carbon monoxide found were in the order of magnitude predicted for the dissociation calculated at the observed temperature. However, small discrepancies indicated that leakage might have occurred through the Alundum walls.

To eliminate this possibility, a platinum tube of 0.020-inch internal diameter was fabricated. It was heated by a 60-cycle alternating current to temperatures just below its softening point (approximately 3100°F). A series of tests were conducted in which the temperature was gradually stepped up. No decomposition of the CO_2 was observed. This may have been due either to the malfunctioning of the sampling tube, or the reassociation of the gases in that portion of the platinum tube which was cooled by the proximity of the sampling tube (approximately 0.25 inch).

Previous investigators like Sand, Nernst and von Wartenberg have used a refinement of this method to determine dissociation constants of water vapor and carbon dioxide. They have pointed out certain design considerations which limit the usefulness of this method.

Through a long tube, heated over an length *ab* to a temperature *t*, the vapors are passed, and, in passing from *a* to *b*, proceed toward dissociation equilibrium. Then over a distance *bc*, which is small compared to *ab*, the gases are cooled to a temperature so low that the equilibrium is frozen. Further, the cross-sectional area of *bc* must be such that the gases are cooled in a minimum of time so that the equilibrium obtained at temperature *t* is not appreciably disturbed. This is usually accomplished by use of a narrow capillary tube. Thus *ab* must be long enough so that equilibrium is attained, and the time of cooling in *bc* must be so short that it is not disturbed. At low temperatures, equilibrium would only be obtained for a very great length. At high temperatures, the disturbance due to the finite time of cooling becomes appreciable.

Thus the authors point out that for any physical setup the geometry of that setup governs and delimits a region corresponding to a temperature range in which the observed dissociation agrees with that theoretically calculated for dissociation. Below this temperature range, equilibrium is not established in the length *ab*, and above this range the disturbance of the equilibrium because of the finite time of cooling is appreciable.

These men have not used temperatures in excess of 1478°K. The fact that they have not worked at high temperatures may indicate that satisfactory sampling tubes can not be made to operate in gas mixtures at such temperatures.

Another approach to the problem was tried. A series of tests was run in which samples of gas were withdrawn from flames produced by various types of burners. Both methane of 99.2 per cent purity and a mixture of natural gas and producer gas of known average composition were used as fuels.

The combination of a natural gas and a producer gas was burned in an oxy-gas torch with oxygen. Samples were withdrawn from the outer cone of the flame. The analysis of the gas withdrawn shows amounts of CO, H_2 and O_2 which correspond to equilibrium at a high temperature, but not, in results so far obtained, at a temperature as high as the calculated flame temperature. In a typical analysis the following results were obtained.

CO_2	39.5%	on dry basis
O_2	3.9	
CO	24.4	
H_2	12.9	
CH_4	2.0%	on dry basis
C_2H_6	0.4	
Inert	16.9	
H_2O	114.2	

From the partial pressures of CO_2 and O_2, it was computed that the amount of decomposition of CO_2 corresponds to the equilibrium amounts at 4160°F. From the partial pressures of H_2O, H_2 and O_2, it was computed that the amount of decomposition of H_2O also corresponds to the equilibrium amounts at 4160°F. The excellent agreement between these temperatures shows that the refrigerated sampling tube affects the two reactions in the same manner. The calculated flame temperature, based on the analysis of the fuel gas and the above analysis of the gas from the flame, is considerably higher than 4160°F. This calculated flame temperature, however, should be corrected for the heat amounts absorbed in decomposition reactions not shown in the analysis, such as decomposition of O_2 and H_2, and formation of CH_2 and OH—. This correction will bring the calculated flame temperature in better agreement with that calculated from the equilibrium amounts of CO, H_2 and O_2. If this agreement can be obtained, either by corrected calculation of flame temperature or by direct measurement of the gas temperature, it will be shown that the refrigerated sampling tube cools the gas rapidly enough to obtain samples containing representative amounts of decomposed CO_2 and H_2O.

In order to simplify the reaction, pure methane was used as a fuel. A metered mixture of methane and air was supplied under pressure to a Meker-type burner. The refrigerated sampling tube was inserted in the flame about 0.25 inch above the inner cones and a sample was withdrawn. It was then possible to calculate the flame temperature from the analytical data, the air-fuel ratio and the hydrogen-carbon balance. The flame temperature could also be calculated from the extent of dissociation based on the analysis. These values could then be compared with the known values determined from the input.

The results of a series of runs are shown in Table 1.

It will be noted that the results in Run 1 are extremely good. However, in this case the analysis for CO was made by absorption in acid cuprous chloride. When similar runs were attempted (3 and 4) using a suspension of cuprous sulfate and beta-napthol, the results were not so well in line. Much higher quantities of carbon monoxide were detected. Although the flame temperature calculated from the analysis agrees very well with the theoretical value calculated from the air-fuel ratio, the value calculated from the apparent dissociation of the CO_2 is much too high. This indicates that the combustion of the methane was incomplete. To check this point, increased air-fuel ratios were used, but incomplete combustions were still obtained (runs 5 and 6).

These tests are, therefore, inconclusive. Since equilibrium was not established in the flame, no accurate check of the efficiency of the sampling tube was obtained. Although there are indications that the tube can stop the re-association of carbon monoxide and oxygen to carbon dioxide, the proof is not rigorous. In Run 1 it is possible that equilibrium actually was established in the flame, but the discrepancy in the carbon dioxide analyses leaves even this in question.

PLANS

A new glass combustion chamber will be built when the new magnet has been tested. This chamber will have flat side walls so that striae patterns, in addition to high-speed movies, can be obtained. When the apparatus has been installed, a study will begin on the effects of various disturbances on flame propagation under controlled conditions of temperature, pressure, and mixture composition. The steel combustion tube will be used to study the effect of various constrictions on flame propagation, and to determine to what extent the high velocities reached are being maintained in the remaining section of the tube.

Experimental work will be started shortly to study the catalytic effect of combustion-chamber-wall materials.

In an attempt to provide a rigorous proof of the efficiency of the tube, gas mixtures will be sampled which have been allowed sufficient time to attain equilibrium. The exact experimental techniques are being detailed. The procedure will probably be to heat carbon dioxide in a static system, rather than in a flowing system as has been previously reported, or to repeat the platinum-tube experiment since that tube has a larger bore than the present sampling tube.

TABLE 1

Run	1	2	3	4	5	6
Fuel	CH_4	CH_4	CH_4	CH_4	CH_4	CH_4
A/F (input)	17.3	14.9	17.0	17.0	21.6	18.2*
A/F (calculated from analysis)	17.3	10.4	14.15	14.12		
Analysis						
CO_2	11.4 vol%	9.15 vol%	5.53 vol%	4.03 vol%	5.8 vol%	7.26 vol%
O_2	9.22 "	7.70 "	10.44 "	12.97 "	9.7 "	9.35 "
CO‡	0.45 "	10.98 "	6.79 "	8.88 "	6.7 "	2.61 "
H_2	0.0 "	0.22 "	0.0 "	1.45 "		
CH_4	0.65 "	0.0 "	1.38 "	0.45 "		
N_2	78.28 "	71.95 "	75.86 "	72.22 "		
Hydrogen/Carbon Balance						
(input)	0.333	0.333	0.333	0.333		
(found)	0.292	0.268	0.294	0.302		
Flame Temperature (Theoretical for (A/F)	3600°F	3600°F approx.	3600°F	3600°F		
Flame Temperature (Calculated from analysis)	3500°F	greater than 4000°F	3600°F	3500°F		
Flame Temperature (calculated for dissociation of CO_2	3600°F	greater than 4000°F	greater than 4000°F	greater than 4000°F		
Comment	Sampling tube operated efficiently	Incomplete combustion inconclusive	Incomplete combustion inconclusive	Incomplete combustion inconclusive	Incomplete combustion inconclusive	Incomplete combustion inconclusive

* Gas velocity 1.6 times slower than in 5.

‡ Cuprous chloride was used to absorb CO in the first run and a suspension of cuprous sulfate and beta-napthol was used in the remainder.

PHASE NO. 3

In connection with pulsating-jet engines: To undertake experimental investigation of temperature-and fatigue-resistant materials for intake valves and coatings, and of fabrication methods and techniques to cover said materials.

SUMMARY

The vibration machine has been constructed and preliminary tests are being run.

Two types of microscope stage furnaces, one heated by induction and the other by a resistance

winding, are being constructed. The Tocco Heat Gun has been selected as a source of induction heat. A revised design of the optical system for the metaloscope permits photographing and visual observation simultaneously.

PROGRESS

The pneumatic-resonant vibration machine has been designed and built. A furnace, shown in Fig. 6, is placed around the specimen.

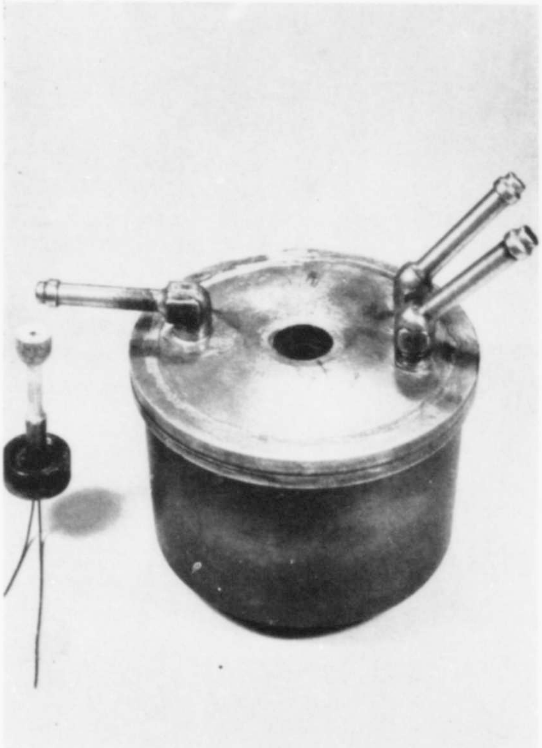


Figure 6. Resistance Furnace for Metaloscope

Preliminary tests are being conducted to determine operating characteristics of the machine at elevated temperatures. Some difficulty has been encountered in determining specimen size and stress during tests. Maximum testing temperature will be about 2000°F. The furnace is so designed that the specimen will be heated at the area of maximum stress.

Attempts were made to use the Ajax 20kw converter as a source of heat for the microscope furnace. A cylindrical piece of steel of 0.5-inch diameter was heated to approximately 1300°F with 15kw for about two minutes. A simple coupler arrangement was used in which a coil was placed inside one of the existing furnaces and coupled to the heating coil. However, the water-cooled copper leads and the necessity for a close coupling to the furnace coil made the arrangement impractical for use on a metaloscope stage.

The Tocco Heat Gun, a small portable inductor unit about the size of an electric hand drill, has been selected as the source of induction heat. Power is furnished by a 15kw Tocco Jr. and supplied to the gun through 10-foot flexible leads.

An experimental vacuum furnace was constructed by sealing a water-cooled brass plate to a glass petri dish. Glass was selected so that the specimen could heat up inside the vacuum chamber and still not heat the container. However, when vacuum was pulled on this setup, the thin petri dish collapsed. The new design has a ⅛-inch-thick glass plate sealed into the bottom of a brass container. Both top and bottom of this furnace will be water-cooled.

A furnace which has a resistance element as a heat source is also being constructed. This furnace is similar in design to those used by previous investigators in this field. It will be used to check the work that has been done and will be available should induction heating prove impractical. This work has been awaiting the arrival of refractories.

The design of the optical system has been revised so that visual observation and photographing of the specimen can be accomplished simultaneously. This permits controlling the camera while the reactions are being photographed.

Orders have been placed for the following equipment: Tocco Heat Gun, vacuum gauge, potentiometer for measuring temperatures, vacuum pump for evacuating the furnace, resistance windings for the resistance furnace, refractories and cements for construction of furnaces. A formal quotation on the revised optical system has not been received but is expected within a few weeks. Temperature-controlling equipment will not be ordered until further experiments are conducted to determine the type needed.

PLANS

Instrumentation of the vibration machine will be made to permit recording the vibration rate, temperature and specimen amplitude. Sufficient data will be collected to work out the fatigue curve on a temperature basis.

After both a resistance furnace and a furnace for use with the Tocco Heat Gun have been constructed, they will be tested for their ability to hold a vacuum. The resistance furnace will also be tested for heating ability. When this stage is reached, auxiliary equipment will be arranged and tested as it arrives.

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CONTRACT N6ORI-11, TASK ORDER II

NEW YORK UNIVERSITY
NEW YORK CITY
1 APRIL 1947

INTRODUCTION

During the first quarter of 1947, the staff of Project Squid at New York University was increased, with a corresponding increase in the number of parts of Phases which are being actively worked on. At the same time new plants and equipment facilities, which had been expected for a long time, materialized, so that the physical background of much of the future work is now determined. Not among the least of these acquisitions are the test spaces and facilities to be at Reaction Motors, Inc., near Lake Denmark, N. J., which are projected for use in connection with the main experimental work on pulsejets and liquid fuel rockets. Thus, physically, Project Squid at New York University was characterized by a period of expansion.

Technically, progress continued apace, mainly in Phase I, having to do with flame propagation and combustion studies, and in Phase IV, dealing with instrumentation. Work on the other phases, chiefly because of the aforementioned expansion, is rapidly gaining momentum.

Specifically, in connection with the plant and equipment growth, the following items should be noted. The thermomechanics laboratory associated with the West Hall offices and laboratories at University Heights has been in use for a month as a small jet testing laboratory. In this laboratory will also be located the supersonic blowdown tunnel, which utilizes a series of air bottles pressurized to 3000 psi by an Ingersoll-Rand four-stage compressor which has been received from the Navy. Two trailers have been acquired; one is being fitted out for use as a portable mount for the Merlin engine-supercharger blower for stationary flame studies at Lake Denmark, and the other is a Mobile Electronics Laboratory kindly loaned to us by Dr. Paul Fye, Director of the Underwater Explosion Research Laboratory at Woods Hole, Massachusetts, and with the cooperation of the Bureau of Ordnance, Navy Department.

The enthusiastic cooperation of Reaction Motors, Inc., officials has enabled plans to be executed for immediate tests of the JB-2 pulsejet engine, work on which began on 31 March. At first, the installations and work will be temporary and preliminary. More permanent facilities, shops, laboratories, and test stands are being planned in detail, specifically for stationary flame studies (Phase I) and pulsejet studies (Phases III and IV).

PHASE NO. 1

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. (The main objective in this phase is to determine the character of, and parameters for, flames in a combustible medium in which turbulent or eddy motion analogous to that in pulsating jet motors is produced under controlled conditions. Analysis of high speed movies of flame motions in Buzz-bomb motors indicates that effective flame speeds of the order of 200 feet sec relative to the gas do arise, for reasons which require study).

SUMMARY

The experimental work on combustion and flame propagation studies proceeded rapidly with the indirect verification of the fact that the high flame speeds in a moving-flame tube, due to the presence of a turbulence making grid, were not due solely to gross mass motion of the burning gases. These moving flame studies were then oriented toward obtaining information which would lead to the values of certain fundamental parameters needed in the development of the pulsejet theory and the theory of flame propagation in turbulent media. Stationary burner flame experiments were also carried out in the investigation of the effect of turbulence on flame propagation, with the introduction of one or two interesting techniques. The setting up of a stationary flame tube at the Lake Denmark site is expected to aid these investigations greatly.

The main theoretical work on this phase was concerned with the development of a physical description of the propagation of a flame moving down a tube. This theory makes use of certain empirically observed relations, such as the velocity-time curve to evaluate some fundamental parameters which occur. The longer range theoretical work on non-uniform gases proceeded mainly in the direction of more explicit formulation of the mathematical statement of the problem.

EXPERIMENTAL

Moving Flame Experiments.—The moving flame studies have been carried out in two pyrex flame tubes, one of which was four feet long, the other, which was introduced more recently, is eight feet long. In the four-foot flame tube, more observations were made on the flame motion through a two-foot sleeve of wet tissue paper which was added at the open end. The velocities in this sleeve remained very high, corroborating the preliminary observation reported in the semi-annual report that, despite the great reduction in flow speed of the gas which must occur in the shattered sleeve, the flame velocity relative to the tube drops only gradually.

A series of experiments have been carried out in the four-foot tube and the eight-foot tube to obtain reproducible flame velocity-time curves with and without grids near the igniters to produce turbulence or swirling. In the four-foot tube, there was no significant difference observed between two different types of igniter. At first, in the eight-foot tube, anomalies in the velocity occurred, so that in some experiments the flame actually appeared to reverse its motion. This reversal appears to have been traced to reflection of a compression wave from the floor at the open end of the vertical tube. When the tube end was elevated 33 inches above the floor, this phenomena disappeared and has not been observed since.

Shadowgrams have been attempted using a Mercury arc (operated on AC) as a light source and more satisfactorily with a Zirconium light. In both cases, the pattern of the pyrex tube obscured any flame shadows.

Stationary Flame.—An intensified program of investigation of turbulent diffusion coefficients in burner flames and their effect on flame propagation is under way. A Meker burner has been remodelled so that air and fuel flow into the burner can be measured. Calibration of flow meters for this use have been made. Apparatus for studying the controlled flame is being set up so that temperature measurements and sodium diffusion measurements may be conveniently made at various points in the flame. The local average velocity of the gas near the point at which the turbulence angle is being measured is simply obtained by suddenly withdrawing a sodium bead on a wire from the flame and taking motion pictures of the boundary of the incandescent vapor as it flows upward with the gas.

A Merlin engine now at New York University is being rebuilt so that it drives its own supercharger as a blower. This unit will be mounted on a trailer and taken to Lake Denmark and used to supply air for a stationary flame tube.

Shock Ignition Experiments.—The attempts to obtain ignition with the shock tube were unsuccessful due to the necessity for higher temperatures throughout the entire tube. This meant that the whole set-up has had to be redesigned and a much more elaborate apparatus constructed. The apparatus is nearing completion. It is hoped that this study will lead to an understanding of the phenomena of reignition in pulsejets.

THEORETICAL

Combustion in Flame Tubes.—Using one-dimensionalized thermo-aerodynamical equations, calculations have been made of pressures, temperatures, and flame front positions versus time in moving-flame tubes, in terms of the parameters: average *rate of release of energy* per unit mass in the burning gas, average *velocity*, and *acceleration*, of the flame front with respect to the gas. Values of these parameters will be chosen to fit data on the four-foot and eight-foot pyrex flame tubes.

This theoretical formulation has been extended to include a definite zone of burning (about 2 or 3 feet wide in the 8-foot tube). This characteristic may be included in the theory by assuming that each layer of gas burns for a finite time, less than the time taken by the flame front to travel the length of the tube.

NON-UNIFORM GASES

Effort on the theory of non-uniform gases in systems with chemical reactions has been concentrated on describing the *behavior* of systems in an appropriate phase-space, and in non-Maxwellian equilibrium. Some equations have been derived but, due to their complexity, analytic solutions seem feasible only under very special conditions.

FUTURE PLANS

More work is to be done on obtaining reproducible velocity time curves in the moving-flame tube; experiments on turbulence in the stationary burner flame and on the new shock tube will continue. Theoretical work on non-uniform gases is to proceed along the lines indicated, and calculations on the flame tube will be made.

PHASE NO. 2

In connection with liquid rockets and pulsating jet engines: to study (1) measurement of temperature dependence of conductivity and heat capacity of steels and other materials, (2) *adiabatic* calorimetry and metallography, (3) characteristics of heat transfer between hot flowing gases and walls, using measurements of gas velocity and temperature by radiation and thermocouple devices, (4) calculation of temperature changes in jet and rocket walls.

SUMMARY

The experimental study of the specific heat of steel at high rates of change of temperature is proceeding slowly; no quantitative results have yet been obtained. Theoretical work on non-linear heat conduction has been mainly an extension of previous results reported in the semi-annual report. Future work will continue along these lines.

EXPERIMENTAL

The apparatus for measurement of specific heats of metals undergoing rapid changes in temperature has been completed. A tiny thermocouple has been welded to a steel bar which is surrounded by a nitrogenous atmosphere, and which is heated rapidly by a current supplied by storage batteries. The change in temperature versus time, as well as the power input versus time is recorded on an associated oscilloscope. So far, only preliminary photographs have been taken of the temperature-time curves. It is expected to be able to infer from these measurements whether the anomalous changes in specific heats, which occur at particular temperatures under static conditions, also occur under rapidly changing circumstances, as in a rocket wall.

THEORETICAL

A general analytical method for solving problems in heat flow, in particular in wedges and tetrahedra, has been developed and is expected to be of use in connection with wall temperature measurements in jet engines. An investigation has begun of the types of boundary conditions which can be treated with the previously developed particular solutions of the non-linear heat conduction equation. Sample numerical calculations have also been made for heat flow in a standard steel plate.

FUTURE PLANS

Quantitative results concerning the variation of specific heat with temperature rate will be obtained. Also more controlled experiments are planned in which the temperature will be held to a small range around a high average temperature, while the effect of rapid rates of change of temperature are studied. Theoretical work on the non-linear heat flow equation will continue.

PHASE NO. 3

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 motions 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

Observations of flame motions in the combustion chamber and tail pipe of small transparent-walled pulsejets were made; the back flow corresponding to the initiation of each cycle was easily discernible. Tests were run of the Mark I pulsejet, which has a combustion chamber and tail pipe adjustable in length; this jet has resonated for short periods and will be of use in indi-

cating the effect of varying several fundamental parameters, as well as in preliminary pressure instrumentation tests. In the immediate future, similar observations and studies are to be made of the JB-2 pulsejet engine at Lake Denmark.

EXPERIMENTAL

Transparent-walled Pulsejets.—Several streak photographic observations of the flame motion in transparent-walled pulsejets, which utilize a Minijet valve bank and fuel injection system, were made. These photographs appear as a sequence of traces, each made by a knot of flame travelling through the combustion chamber and down the tailpipe during each cycle. Each trace has ordinarily a "kink" in it (sometimes two if proper resonance has not been achieved). These kinks indicate that the motion of the flame is momentarily reversed as the gas reverses its flow and recompresses the fresh mixture in the combustion chamber. Some burning appears to be present in the combustion chamber at all times, which flares up as the fresh mixture is compressed by the back flow, and a new knot of flame shoots down the tube. The frequency of occurrence of these knots of flame agrees with the frequency (250 cps) usually quoted for the Minijet. The fact that there is continuous burning in the combustion chamber, instead of intermittent burning is possibly due to the short period of the Minijet cycle as compared to the time needed for combustion.

Adjustable Pulsejet.—Preliminary tests have been made of a pulsejet, designated as Mark I in previous reports. The lengths of the combustion chamber and tailpipe of this jet can be varied over a combined range from 4 to 6 feet. The preliminary trials were to establish the range of conditions under which the jet could be made to resonate; thus far, runs of only a few seconds duration have been made, but it has been observed that it is possible to obtain resonance at several settings of the tailpipe and combustion chamber lengths. When operating satisfactorily, average thrust, internal pressure, and fuel flow measurements will also be taken. In addition, this jet will be used to perfect pressure gage instrumentation for use with the JB-2 engine.

JB-2 Engine.—The JB-2 buzz bomb and engine have been transported to a test site at Reaction Motors, Inc. Pressure, temperature, flame and gas velocity and density measurements, will be made on the engine and on modifications of it, with and without ram air. For the present, tests are being made to determine starting and stopping characteristics and techniques. When this work has gained momentum, it will constitute a major phase of the Squid program at New York University, since results will be used to check and advance an existing theory of the Pulsejet.

Test Stands.—A thrust stand has been constructed to measure average thrusts exerted by the Mark I jet. A rotating arm miniature jet testing stand is in process of construction.

THEORETICAL

A report on a pre-compressing pulsejet has been kindly received by Mr. L. B. Edelman who had been concerned previously with relevant experimental work. His suggestions are being incorporated in a final review of the report which will be submitted to the Administrative Group of Squid for publication.

FUTURE PLANS

Studies of the Mark I jet are to continue, and observations and studies are to be made of the JB-2 engine at Lake Denmark.

PHASE NO. 4

In connection with liquid rockets and pulsating jet engines: to develop instruments for recording transient thrust and pressures, temperatures and densities of hot oscillating gases, and gas velocities.

SUMMARY

Progress in instrumentation during the first quarter was marked by the completion and initial testing of a variety of gauges and techniques. A great deal of necessary allied electronic equipment was acquired or constructed during this time.

Pressure Pickups, Amplifiers and Calibration.—Several different types of pressure pickups have been investigated as to their suitability for use in measuring transient pressures in pulsejets and flame tubes. Some types have already been eliminated.

A Cox crystal gauge was used to obtain preliminary estimates of pressures near the igniter in a moving-flame tube. Poor frequency response made the results doubtful.

Two tourmaline piezo-electric crystal pressure pickups were kindly furnished us by the Cambridge-Thermionic Corp. through the courtesy of Dr. A. Arons of Stevens Institute. An amplifier was built for use with these pickups which would have a good low-frequency linear response. This set-up was calibrated at several sensitivities; pressure measurements made with the gauge in the moving-flame tube indicated more adequate thermal insulation than the existing wax coating was needed in order to make more reliable long-time pressure records. Thus the tourmaline gauge in its present form is not practicable for pulsejet use, but it will be used on the moving flame tubes for short time records.

A water-cooled adapter has been built for use with both condenser type and magnetostriction type pickups. This will be mounted in the wall of the Mark I jet and the pressure gauges screwed into it—pressure being transmitted through a set of holes in the adapter to the sensitive face.

Several condenser gauge pickups have been built and tested. An FM circuit for use with these gauges was constructed and showed a good sensitivity. It is being modified to see if a greater output can be obtained for a given noise and microphonic level. The idea is to modulate a high frequency (50MC) oscillator having a small tuning capacity of which the gauge is a fairly large proportion. This will make the frequency shift greater for a given pressure. Then the signal is mixed with another oscillator and lowered to 10MC, the frequency required by the discriminator. The frequency *shift* is now a larger percentage of the carrier frequency. This unit, oscillator and cathode follower, to overcome line impedance problems, will be mounted on a cylindrical housing which screws onto the back of the condenser gauge. All parts will be buried in wax to avoid vibration.

A magnetostriction gauge has been constructed and operates successfully after the removal of an iron thermocouple from the nickel core where it was installed to check the water-cooling system. Since this type of gauge is sensitive to time rates of change of pressure, an integrating amplifier was built for use with the gauge. This unit integrates accurately down to 5 cycles per second. Experiments are being conducted to determine if the output of the integrating unit can be used with the tourmaline gauge amplifier and cathode ray tube.

It is necessary to calibrate the pressure gauges accurately under conditions which simulate those to be encountered in practice. For this purpose, a pressure gauge calibrator, consisting of a pressure chamber in which pressures varying periodically with the time can be produced, has been designed and is now out for bid.

Temperature Measurement Devices and Allied Equipment.—A photocell circuit for measuring the temperature of a tungsten ribbon lamp, has been completed. Calibration with an optical pyrometer will follow. The tungsten ribbon lamp itself is to furnish the background spectrum in the sodium "D" line reversal method of measurement of the temperature of the stationary burner flame and turbulence experiments.

A new high resolution spectroscope has been designed and is under construction. This, after delivery in April, will be employed in the sodium "D" line reversal method, and in the "two line" method of temperature measurement which employs potassium emission line, as well.

An electronic photometer, employing a photomultiplier tube, is to be used to measure the transient temperatures of the flaming regions in the pulsejets. This instrument is being calibrated at present against a thick sodium flame the temperature of which in turn will be determined by the sodium "D" reversal method. A satisfactory burner for the sodium flame has been developed from an ordinary welding and cutting torch. This enables the flow of gas and oxygen to be conveniently controlled with a consequent control on the flame temperature from 1800° C. to 2200° C.

Work is proceeding on the design and construction of a new highly-filtered, electron stabilized, power supply for the photomultiplier tube. An electronic DC to AC inverter of the type described in the OSRD Report 5868 has been constructed and is now being tested. This will eliminate the difficulties attendant upon the use of DC amplifiers for the photomultiplier output voltage.

Flame-coloring techniques.—In order to observe the flame temperatures in a pulsejet, or flame tube, it is hoped to be able to color the flames with some sodium or potassium compound and then employ the electronic photometer. Several unsuccessful attempts have been made to color a blow torch flame with sodium naphthanate—unsuccessful mainly because of high carbonation. Future work will include actual tests in glass-walled jets. It is hoped to receive a potassium naphthanate solution from Nuodex Co. as promised by Mr. Minich, Vice President. This may make it possible to use the "two line" system for determination of the temperatures.

Fluid Velocity Measurements.—It is hoped that it will be possible to measure the mass flow of gases in a pulsejet by means of radioactive tracer technique in which a pulse of radioactive material is injected into the engine and its progress observed thereafter. The use of Iodine 131, half life 8 days, is contemplated. However, inquiries at Oak Ridge as to its availabilty have not yet been answered.

The same method of measurement of gas velocity in the pulsejet tests or in the moving flame experiments is contemplated with the use of a pulse of sodium vapor instead of a radioactive element.

A study of hot-wire anemometry for measuring average fuel rates has begun.

FUTURE PLANS

The oscillographic equipment in the Woods Hole Mobile Laboratory is being studied and repaired. New oscillographic recording units are being built. It is hoped to test the pressure instrumentation on the Mark I jet, and try the transient temperature photometer with the transparent walled jet.

PHASE NO. 5

In connection with liquid rockets and pulsating jet engines: to study drag characteristics of pulsating jet and other devices under conditions of non-steady or of supersonic flow, using firing range photography, wind tunnel measurements and theoretical investigations.

SUMMARY

A theoretical analysis of non-steady flow, including aspirator effects, around a pulsejet tube has begun. This problem is being attacked by a step-by-step procedure, working from an extremely idealized case and gradually adding the complicating features of the real situation. Experimental work on artificially pulsed flow in pulsejet tubes and on flow through reed valves will begin as soon as sufficient personnel is acquired to handle this task.

THEORETICAL

The preliminary mode of attack on the non-steady flow problem consists in attempting to combine a set of sources, sinks, dipoles, and other elements, in the proper configuration to build up a three dimensional potential flow pattern in which the outline of the pulsejet tube would be one of the streamlines. Studies are for the moment limited to non-compressible non-viscous fluids; they will be extended to compressible real fluids involving pulsating elements with the ultimate aim of bringing out the flow and drag characteristics of pulsejet devices.

FUTURE PLANS

Theoretical work on the non-steady flow is to continue, with calculations being made on potential flow around a pulsejet. Experimental work on flow through reed valves is to begin.

QUARTERLY 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 N6ORI-98, TASK ORDER II

POLYTECHNIC INSTITUTE OF BROOKLYN
BROOKLYN, NEW YORK
1 APRIL 1947

In connection with the present report it should be pointed out that Phases 1 and 2, which deal with the flow through valve systems of pulse-jet propulsion units and with the solution of metallurgical problems concerned with both pulsejets and liquid-fueled rockets, were commenced in the late summer of 1946. Phases 3 and 4, dealing with the problems of the cooling of combustion chamber walls by the use of porous liners and a study of the structure of shock waves, were begun in early February, 1947. In the case of the latter two phases, therefore, this report covers the work done in approximately the past two months.

The index of the research articles contained on the thirty-two microfilm reels, submitted by the Project SQUID Library, has been completed during the past quarter. Mimeographed copies of all the titles have been sent to all members of Project SQUID. The index covered 731 periodicals and in certain cases gave a short description of the material where it was deemed pertinent to Project SQUID.

Joint arrangements are underway with New York University for the procurement of facilities and in some instances technicians to carry out experimental work at the testing facilities of Reaction Motors, Inc., at Lake Denmark, New Jersey. Such arrangements will probably become final in the near future. Certain experimental problems in connection with both pulsejets and liquid-fueled rockets will be investigated.

Dr. Shao-Wen Yuan has returned to the Polytechnic Institute and has taken over the analytical direction of the work under Phase 3. Several other members have been added to the research staff during the past three months. These have been mainly research assistants and fellows.

Professors Lieber and Harrington visited certain research institutions in California during the week of March 9th to discuss problems on theoretical aspects and experimental techniques concerned with certain phases of Project SQUID. The institutions visited included the Guggenheim Aeronautical Laboratory of the California Institute of Technology, JPL CIT, Naval Air Missile Test Center at Point Mugu, Aerojet Engineering Corporation, Marquardt Aircraft Company, and Giannini Corporation. Methods for the manufacture of porous and permeable powdered metal liners and methods of testing were discussed with Dr. Duvez at JPL CIT. Desired physical characteristics of such metals and the method of test procedure were discussed with Messrs. Warfel and Young of Aerojet Engineering Corporation. Considerable time was spent with Mr. Pelton of Aerojet Engineering Corporation, discussing the experimental installation and testing procedures for pulse-jets. Of particular interest was the Allison-driven ducted propeller system for creating large volume, medium velocity air flows for pulse-jet testing. Considerable time was spent in discussions with Mr. R. E. Marquardt of Marquardt Aircraft Company with emphasis on the design and construction of their proposed supersonic wind tunnel. The information obtained was considered to be extremely valuable.

PHASE NO. 1

To study performance of reciprocating and rotating valve mechanisms at subsonic and supersonic velocities; namely, (1) the aerodynamic forces exerted in periodic compressible flow on periodically moving valve surfaces and (2) the dynamics of the valve mechanism itself under the action of the aerodynamic forces obtained from the first part.

SUMMARY

The analytical investigations of the reed valve inflow process have been continued. It has been found that the hinged valve reeds move without bending. Further progress has been made on the design of the rotating sleeve valves and the thermodynamical calculations for the unit incorporating this type of valve.

PROGRESS

The study of the two problems of reed valves and rotating valves has been continued.

1. Further analytical investigations have been carried out for both hinged and fixed reed valves. The analysis of the hinged valves has been simplified and nearly completed. The analysis of the valves with fixed ends has been formulated and the computation is progressing.

As stated in previous reports, the analysis starts out from a simple basic flow, satisfying the continuity equation, but requiring small corrections (pertubations) in the Euler dynamic equations of flow. The whole set of these equations is based on a supposition of non-steady, compressible, two-dimensional flow with isentropic change of state. An isentropic change of state during the inflow process is assumed for the present and will be modified to a polytropic one if temperature measurements on actual units point to the non-validity of the assumption. The elastic and inertia properties of the reeds are adapted to the time rate of change of the stream line pattern.

The analysis of the process, representing inflow between hinged reed valves, yields a linear equation for the temporary stream lines. This means that if the reeds shall follow the shape of the bounding stream line, they must be made rigid enough to move without excessive bending. This points to a possible advantage with regard to the life endurance of this type of valve. The arbitrary constants in the equations will be calculated after the mechanism of the temperature and pressure changes in the combustion chamber is established. Preliminary investigations are being conducted to determine the optimum geometrical configuration of the combustion chamber and tail pipe for the combustion phenomena of the intermittent jet engine.

2. The analysis of the flow in the combustion chamber and the tail pipe is also essential for the final design of the rotating sleeve valves and for the axial and transverse dimensions of the duct.

As described in former reports two alternatives are being investigated for the application of rotating sleeve valves: (a) rotating valves at the intake with conventional tail pipe fitted to the combustion chamber and (b) rotating valves at both the intake and the exhaust with a stub diffusor fitted at the rear end.

The general designs on these lines has been progressing, keeping in view simplifications and heat endurance, particularly with regard to the rotating parts.

PLANS

It is intended to continue the analytical investigations of the reed valves and of the combustion chamber phenomena.

The detail drawings for the first model incorporating rotating sleeve valves at the intake only and having a conventional tail pipe will be finished and possibly the manufacture of the model started.

PHASE NO. 2

(1) To investigate causes of metal failure thus far encountered by evaluation of use tests on developed materials and (2) To investigate and develop new alloys to resist pressure, temperature and erosion conditions existing in propulsion units by (a) modification of present alloys, (b) development of new alloys, and (c) use of powder metallurgy methods.

SUMMARY

Various metallurgical problems, dealing with rocket and jet motor design, are being investigated. The following is a brief discussion of each problem.

PROGRESS

The report of progress on this phase may be presented best under several sub-headings as follows:

High Temperature Fatigue.—The Henry high speed fatigue machine is being modified for use at high temperatures. This machine is of the resonance type, using rotational motion of permanent magnets past the cantilever specimen to induce vibrations of the specimen.

Before proceeding with the building of a furnace setup for this machine, it was felt more important to correlate present results and check concordance with other methods. This has led into a more careful analysis of the actual vibration, stressing and failure of the specimen.

The formulation has been improved for calculating maximum stress, but due to this, it was felt that a more careful study of the stress distribution due to vibration was necessary. This study is now being pursued. It was also deemed wise that amplitude be determined more accurately. This was done by the arrangement of having the specimen scratch its amplitude on waxed kymograph paper. This method proved to be more accurate than the former micrometer setup which affected the vibrational amplitude of the specimen. It is felt, however, that this method (waxed paper) is not too practical for routine testing.

Therefore, methods of measuring amplitude are being studied with the view of developing a continuously indicating method. An optical method is presently favored. It is also planned to alter the vise for holding specimen, as it has been found that pressure can affect the natural period by changing the amount of energy dissipated to the vise.

Tensile Type Tests.—Work is progressing on both tests, i.e., having constant stress with variable temperature, and constant strain with variable temperature. A modified creep apparatus has been designed for carrying out these tests.

Two of the modified creep machines are under construction, one for each test. These two machines differ from each other in that one is a creep test setup equipped for varying temperature and the other will be set up to apply strain at a constant rate while the load is indicated on a weighing system.

In connection with this work two additional problems have been injected. One is the selection and building of a suitable extensometer to be used in conjunction with these tests. The second is the construction of a dilatometer which will be used in these tests. The data from the second is needed especially for the process while proceeding through the critical temperatures. These two problems are now in the library phase.

Thermal Conduction and Temperature Gradients.—The proposed method of studying temperature or temperature distribution, by observing the metallographic changes occurring in martensite, involves considerable preparatory work.

First, standard temperature treated samples have to be made up and the sensitivity to time at a given temperature determined. Secondly, sample parts must be made in which we are interested in studying temperature distribution. These parts must be heat-treated to the martensitic condition. After these parts have been subjected to actual service temperatures, they must be metallographically studied and compared with the structures of the temperature standard specimens.

It is planned to start on the standard temperature samples and the selection of the most suitable steel for these studies in the next quarter.

Study of the Be-Cr System.—This system was selected for study primarily as a means of developing techniques, for it is known to be a difficult combination. There is evidence that if these alloys could be produced they might have desirable properties for the solution of the present problem.

Techniques of powder metallurgy have been initially applied but it is now felt from the work that Be does not lend itself to alloying in the powdered form due to the heavy film of oxide on each particle. It appears that the melting of massive materials will be more easily accomplished than sintering of Be and Cr powders.

A small induction furnace has been obtained to be used with our present induction power units for this melting. Massive Be and Cr have been obtained and excessive difficulties are not expected with the argon atmosphere melting that is planned.

For the determinations of the cooling and melting points, it may be necessary to use a small precious metal resistance wound furnace.

Powder Metallurgy.—Carbides and nitrides are being studied with the view to applying their properties to the field of rocket and jet propulsion materials through the technique of powder metallurgy. Library work is continuing.

The first procedure being undertaken is the study of the wetting characteristics of various carbides and refractory metals to find those carbides that can be advantageously used with given metals such as platinum, chromium, tungsten, etc.

It is felt that carbon arc methods should be satisfactory for heating or fusion, and therefore construction of a small setup for holding the arc and materials to be fused is underway.

Hot impact compacting work has now proceeded to the experimental stage, and a die block is now being machined for use with the present impact machine.

It is planned that, when the die and furnace are set up, a study will first be made of the compacting of copper metal powder under these conditions and used as a basis for comparison with other methods.

PLANS

Due to the breakdown of subject matter under "Progress", it appeared to be expedient to include plans for future work under each sub-heading.

PHASE NO. 3

(a) 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. (b) To study analytically and experimentally (1) the diffusion of fluids through porous media under high pressures and temperatures and (2) the effects (of this diffusion) on the internal aerodynamics. (c) To study problems in the field of physical-chemistry pertinent to (a) and (b) with consideration given to the clogging of pores, the use of catalysts imbedded in the liner walls, and endothermic diffusion processes.

SUMMARY

Inasmuch as this investigation has been underway for a period of less than two months, a summary is not practical at this time.

PROGRESS

The collection of experimental data on previous porous metal liner investigations of other research groups is continuing. As soon as sufficient information is available, systematic experimental and theoretical investigations on the flow problems will begin.

As far as part (b) above is concerned the internal aero-thermodynamic problems were started by the investigation of the flow of hot gas over a flat plate under the condition of uniform gas injection from the bottom of the plate.

The momentum equation and the corresponding energy equation for the boundary layer have been set up for a perfect gas. The velocity of injection was assumed to be uniformly distributed along the plate.

The solutions for the laminar boundary layer are underway. The methods used are similar to those given in Pohlhausen's solution of the laminar boundary layer equation, i.e., the use of a polynomial as an approximation to the velocity and temperature profiles. The solutions of these simultaneous equations will give a laminar boundary layer expression and a temperature profile across this layer with the injection velocity as a parameter for any given boundary temperatures. The injection velocity can then be determined, which in turn will determine the porosity of the liner.

PLANS

As soon as any conclusion can be drawn between the above results and the experimental data, it is expected that the turbulent boundary layer with a temperature drop across this layer can be calculated with a properly assumed mixture length.

The relation between pressure and velocity of fluids passing through porous cells will be investigated both analytically and experimentally.

Specific research on parts (a) and (c) is just getting underway and will be reported in the next quarter.

PHASE NO. 4

To extend the present knowledge of problems arising in supersonic flow in and around propulsion devices. It is particularly proposed to continue research on the mechanics, thermodynamics, and molecular kinetics of the quasi-discontinuity or shock wave of gases in laminar and turbulent flow.

SUMMARY

The general three dimensional dynamic equations of compressible, steady flow, the continuity equation, the equation of state, and the equation of heat balance have been set up for a perfect gas, including viscosity, conduction, and convection.

One dimensional flow was the first case to be investigated. A solution was obtained, satisfying the four equations for one dimensional flow, which gave a continuous transition through the shock wave. The change of the steepness of the slope of the flow variables through the shock wave was found to depend upon the mass flow.

PROGRESS

The complete set of equations for the problem of the structure of a shock wave was established. This set contains the Eulerian dynamic equations of compressible steady flow, the continuity equation, the equation of state of the fluid, and the heat balance of flow. These equations have been set up for one-, two-, and three-dimensional flows in cartesian coordinates, and for the two and three dimensional cases in cylindrical coordinates. The number of these equations and of the variables are equal to each other in one-, two-, and three-dimensional flows.

The heat balance equation for steady flow, expressing that no heat is accumulating at any point, takes into account viscous or turbulent energy dissipation, heat conduction and heat convection. This equation requires special consideration in regard to the case of turbulent dissipation and in regard to the value of the specific heat in the convection term.

The first problem treated in detail was the one-dimensional uniform flow with heat dissipation due to dilatation of a volume element, heat conduction and convection. It was reduced to a non-linear differential equation of third order containing only the flow velocity.

For this case in which extraneous body or boundary forces are absent the equation indicates one solution of constant velocity so that the appearance of a shock wave represents what is similar to a branching point at which the flow departs from a constant velocity. The second solution for the velocity distribution arises when a certain Mach number is exceeded.

One first solution has been found and is being developed in regard to velocity, pressure, temperature, density, Mach number, and entropy distribution. This solution gives a continuous transition of the flow variables through a standing wave with the steepness of the slope of these variables through this transition region changing with the mass flow.

Work has also been started on two-dimensional flow between plane as well as circular boundaries with laminar shear friction. It was found that such a flow requires transverse or radial velocities to make the set of equations consistent. The first case treated assumes that the squares of these transverse velocities are negligible.

PLANS

It is intended to continue the development of the one dimensional solution so as to obtain complete mathematical formulae for all the flow variables, and to ascertain the effects caused by the influence of viscous dissipation, heat conduction and heat convection upon the relative magnitudes of these flow variables. When these are known it is planned to compute numerical results.

In the next step the case of two dimensional flow with slight transverse change in velocity will be treated in detail.

Considerable thought is being given to the future experimental program.

QUARTERLY 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 N6ORI-105, TASK ORDER III

PRINCETON UNIVERSITY
PRINCETON, NEW JERSEY
1 APRIL 1947

The Office of the Project Organizer, in co-operation with Engineering Research Associates, Incorporated, has been actively engaged in the preparation of the Field Survey Report on Liquid Rockets and Pulse Jets. Approximately eighty agencies were visited during January, February and March, and this virtually completes that part of the program.

Initial rough drafts of each of the following sections of the Survey have been written and are now in the process of final revision.

- Aerodynamics
- Combustion
- Heat Transfer and Cooling
- Tabular Data on Contracts, Contractors and Research Personnel

The following sections are being prepared:

- Liquid Rocket Engines
- Pulse Jet Engines
- Instrumentation
- Materials
- Fuels

Statement of Phase Assignment

PHASE NO. 1

SPECIFIC PROBLEM

In connection with liquid rockets and pulsating jet engines: to investigate theoretically and experimentally

(1) the stability of laminar boundary layer,

(2) the interaction of boundary layer with external flow field at supersonic velocities, as it affects pressure distribution around bodies of revolution, airfoils, etc.,

(3) interaction of shock waves in channels and diffusers.

PROGRESS

Equipment.—In March, contractors were selected for the major items of equipment for the "blow-down" supersonic tunnel. ONR approval of the contracts and purchase requests is expected shortly.

John H. Carl and Sons, Rockville Centre, New York, will install the motors, compressors, air bottles, and the main regulating valve and control system; furnish and install piping, air filters, coolers, etc., and all quick opening and safety valves, and carry out a hydraulic test of the entire system to 5000 psi, for a fixed price of $30,500. The completion date is six weeks after receipt of all materials.

The Dravo Corporation, Philadelphia, Pa., will furnish the main reducing-regulator valve and the hydraulically-operated control system for this valve for a fixed price of $7,120. Substitution of the single 8″ Belfield valve and Askania control system for the bank of 14 Foster 2½″ regulator valves originally proposed makes possible a considerable simplification in the fabrication and also in the operation of the air supply system. Delivery of the Askania equipment is 12-14 weeks, but Belfield estimates that approximately six months will be required for the fabrication of the 8″ valve. Every effort will be made to reduce this time interval substantially by furnishing material from Navy stores, and by utilizing Navy foundry facilities whenever possible.

With the arrival (1st April) of eighteen 15 cu. ft. air accumulator bottles and one 25 cu. ft. bottle, the supply of storage tanks is complete for the present.

Building Alterations, etc.—ONR approval has been received for the alterations to the old Concrete Testing Laboratory and also for the installation of the concrete foundation blocks for the two Worthington compressors. Matthews Construction Company will begin operations when CPA approval is received.

Optical Apparatus.—A Project Order for approximately $10,000 has been requested from ONR for the fabrication of the 4″ interferometer plates and six 4″ and four 9″ wind tunnel "windows" and frames at the Naval Gun Factory. The additional 4″ "windows" were ordered because the long delivery time of ten months for the 9″ windows will necessitate using 4″ windows in both the large and small supersonic jets for a time. All the necessary drawings have been forwarded to the Naval Gun Factory and work will commence shortly after the Project Order is obtained.

Rough blanks for the 9″ interferometer plates were ordered so that optical glass, which is in short supply, might be available should it become desirable to build the 9″ interferometer next year.

Orders have also been placed for the light source and miscellaneous lenses and optical flats for the pilot tunnel and other apparatus.

Pilot Tunnel.—Design of the pilot supersonic tunnel (test section 2½″ x 1″) is proceeding. The tunnel will be housed initially in the vertical firing range. A 2″ interferometer for studies with this tunnel and other apparatus is under construction.

THEORETICAL STUDIES

(1) *Boundary Layer-Shock Wave Interaction.*—A technical report is in preparation on the theoretical aspects of the interaction between shock waves and boundary layer in transonic and supersonic flow. The reflection of a shock wave from the laminar boundary layer in transonic flow as an angular or Prandtl-Meyer expansion region is analyzed in terms of the character of the flow in the laminar boundary layer when the static pressure is increasing in the main flow direction, i.e., when the flow is decelerating.

An attempt is made to clarify the interaction between an oblique shock wave and a laminar boundary layer in the case of the plane supersonic flow in a corner. The pressure rise "spreads" upstream in the boundary layer and affects the external flow. A start is made toward relating this "spread" to the behavior of the thin "sub-layer" of the laminar boundary layer adjacent to the surface, in which inertia forces are negligible and viscous forces dominate.

(2) *Wake Behind Two Dimensional Airfoil in Supersonic Flow.*—It is often assumed that the flow around a cylindrical airfoil moving with supersonic velocity at an angle of attack becomes a uniform parallel stream again on passing through the trailing-edge shock and expansion regions. At low supersonic Mach numbers the departures from this simple picture are insignificant. However, the air passing over the upper surface of an inclined flat-plate airfoil (for example) is accelerated at the leading edge, and therefore the trailing edge shock originating from the upper surface occurs at a higher Mach number than the leading-edge shock on the lower surface. At high supersonic Mach numbers the difference in strengths of these two shocks for the *same* flow deflection means that the actual flow deflection at the trailing edge must be different than at the leading edge, in order that the pressure shall be continuous and the upper and lower surface streamlines parallel at the rear of airfoil. Calculations are in progress to determine the magnitude of the "downwash" at and immediately behind the airfoil. Previous work by Lighthill (British Reports and Memoranda No. 1933) appears to be in error, since it neglects the difference between the isentropic pressure-density relation and the Rankine-Hugoniot relation in an oblique shock.

QUARTERLY 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 N6ORI-104, TASK ORDER I

PURDUE RESEARCH FOUNDATION
and
PURDUE UNIVERSITY
LAFAYETTE, INDIANA

1 APRIL 1947

PHASE NO. 1

STATEMENT OF PROBLEM

Development of a method of measuring instantaneous gas temperatures fluctuating at frequencies from 50 to 100 cycles per second in a range of temperatures from room temperature to 3,000° F. (pulse-jet gases).

SUMMARY

The major part of a survey of the literature available at Purdue University has been completed. Theoretical and experimental studies dealing with factors affecting lag are in progress as well as the design and construction of special thermocouples.

PROGRESS

Because of the following circumstances, it was decided to limit the study to the measurement of gas temperatures by means of thermocouples:

(a) Impossibility of expanding the staff as rapidly as had been expected, because of the difficulties of hiring engineers. At present 1 full-time engineer, one three-quarter time engineer, and several part-time senior engineering students are employed on the project.

(b) Early limitation placed upon the budgeted funds for the purchase of special equipment.

(c) Suggestions received from outstanding authorities, concerning the use of thermocouples as a means of temperature determination.

(d) Important facts acquired during the literature survey.

It is recognized, without question, by the investigators at Purdue University that the problems involved in the use of thermocouples for measuring the temperatures of gases under transient conditions are many and may be unsolvable. However, from the point of view of engineering use, the many advantages of a system based on the thermocouple are obvious. It may be possible to devise a satisfactory system employing thermoelements which may not measure the actual temperature but, by use of suitable correction terms, may be used to determine the temperature within ten percent plus or minus. This type of apparatus would find wide use from the standpoint of engineering design. The investigators have, therefore, elected to proceed along this avenue of development work. The scope of the program and the progress made are presented in the following discussions:

(1) Survey of the literature available to the research staff at Purdue University.

The major part of the survey of the literature has been completed. Methods and apparatus used for measuring the temperatures of gases flowing at subsonic and supersonic velocities have been studied. It is hoped that restricted information dealing with the subject will at an early date, be released by the Navy to the engineering staff working on the project.

(2) Experimental and theoretical studies of bare, shielded, and suction types of thermocouples.

Theoretical studies covering the various factors that influence the time lag of the measuring element are in progress.

(3) Design of suitable apparatus for detecting, amplifying, observing, and recording the electrical impulses from thermocouples.

Apparatus has been constructed and is being tested and calibrated. The time lag of the instruments has been reduced to values far below the minimum time lag of the measuring element.

PLANS

In the course of the next several months, experimental as well as theoretical studies will be made of actual thermocouple installations.

PHASE NO. 2

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.

SUMMARY

Reasonably satisfactory combustion was obtained with propane and air mixtures. Quantitative values of flame speed were not obtained. Combustion of fuel-oil and air was unsatisfactory

and thus indicated the necessity of improving fuel dispersion and vaporization.

PROGRESS

Preliminary operation of the small-scale combustion set-up disclosed numerous faults which created fire hazards due to leakage of liquid fuel and discharge of flame in the vicinity of buildings. Modifications, which included a heavier combustion chamber with leak-proof connections and a heat-resistant Vycor cylinder for observation of flames, were incorporated. With these modifications it was possible to discharge flames and gases vertically. A flame-quenching water spray is quickly available for emergency use. Provisions were made to prevent fuel from running back through the inclined air-supply duct within the building, a condition that might have created a hazard in case of flash-back.

Modifications of the fuel system were made to include a liquid-fuel supply with a controllable pressure range up to 1000 p.s.i. and sufficient power for more than 2000 pounds of fuel per hour, a supply which is ample for combustion with the 20,000-pounds air capacity per hour available from one supercharger. Also, a multi-unit propane fuel system with provisions for measuring flow was set up. Several designs of fuel-discharge nozzles and tubes were prepared to obtain maximum dispersion with a minimum of restriction to flow and also to permit selective use of propane and liquid fuels in any ratio.

A high-voltage ignition system with various types and locations of sparkgaps was constructed to obtain the satisfactory spark necessitated by use of low volatility fuel and low air-supply temperature.

To permit the attaining and controlling of higher air temperatures and to eliminate supercharger surging, a by-pass has been incorporated around the centrifugal supercharger. Thus it will be possible to evaluate the effects of air temperature on combustion efficiency, flame speed, etc.

Several runs were made to determine the degree of flame stability with fuel oil and propane gas as fuels and with variation of mass-mixture flow through the perforated burner plate covering the discharge end of the contracting-air nozzle to be used for later experiments. Reasonable stability of flame appeared with maximum calculated mixture velocities of sixty feet per second and with propane used as a fuel. Sufficient vaporization and dispersion of the fuel oil was not obtained, a fact resulting in greatly delayed burning so that the liquid fuel coated the surfaces of the duct system downstream from the initial point of burning. However, combustion was obtained and flame held at certain areas of the burner plate mass when mixture-velocities approached one hundred and eighty feet per second.

Explosion of gases resulted in failure of the Vycor glass cylinder, which prevented continuation of these studies until suitable replacements are obtained. The procurement of pyrex as well as Vycor cylinders and the fabrication of a steel cylinder with suitable window inserts had been initiated before the failure, so that a minimum of delay will occur before the resumption of experimentation.

The mock-up of the various systems required for the operation of the engine and superchargers to be used as a source of air supply for combustion has proceeded to the point where the fabrication of identical equipment for all six engines and twelve superchargers can be started.

Numerous contacts were made with various offices of the U. S. Navy to obtain approval of the structure to house the project. The final approval has not yet been obtained. The hazards and noise associated with the research prevents desired experimentation on the campus with the small-scale facilities constructed for temporary use.

PLANS

It is anticipated that both quantitative and qualitative study of continuous process combustion can be initiated in the next quarterly period with the use of more volatile fuels, such as propane. A study of the effect of possibly one variable, such as mixture temperature, on combustion rate is projected.

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, to investigate the process of corrosion as affected by the chemical and physical properties of the materials, and the conditions of exposure.

SUMMARY

The oxide layers formed on high chrome-steel alloys at high temperatures have been investigated by x-ray and electron diffraction methods. Under certain conditions a rough scale is formed which is found to contain FeO, Fe_3O_4 or $FeO \cdot Cr_2O_3$, small amounts of the mixed ferric-chromic oxides, and larger amounts of the pure (ic) oxides.

Under other conditions a protective layer is formed which is too thin for x-ray diffraction analysis. By an x-ray absorption analysis the chromium content is found to decrease from 26% to 21% after increasing the oxidation from ten to twenty hours. The thickness corresponds to approximately 0.4 and 0.7 milligram of oxide cm².

PROGRESS

The protective oxides formed on chromium-steel samples when heated to 775-800° C. in air or oxygen are being investigated by x-ray, electron diffraction, and electron-microscope methods in order to understand the mechanism of self-protection of heat-resistant alloys.

The identification of the various oxides present, from their x-ray or electron diffraction patterns, is complicated by the many crystalline forms that may occur and the very close similarity of many of the patterns.

In regard to 18 Cr-Fe steel which, when oxidized in air at 800° C., gave a rough but adherent blue-grey scale, the following conclusions may be drawn:

1. FeO constitutes less than 10% of the scale.
2. There is strong evidence that $FeO \cdot Fe_2O_3$ and or $FeO \cdot Cr_2O_3$ are present only in small amounts.
3. One or more of the oxides, $3Fe_2O_3 \cdot Cr_2O_3$, $Fe_2O_3 \cdot Cr_2O_3$, and $3Cr_2O_3 \cdot Fe_2O_3$ are present in greater proportions than those mentioned in item two.
4. Fe_2O_3, and either Cr_2O_3 or $3Cr_2O_3 \cdot Fe_2O_3$, are the most prevalent oxides.

It has been impossible to determine the physical arrangement of the various oxides in the scale because of the small amount of oxide present.

Electron-diffraction patterns taken by "reflection" from a surface yield the crystalline structure of a very thin layer near the surface, because of the limited penetration by even high-energy electrons. For the sample 18 Cr-Fe steel, Cr_2O_3 is found on the surface. This is in agreement with the experience of Gulbranson, Phelps and Hickman, who have compared the structure found by electron diffraction from the surface with that obtained by transmission after stripping the oxide film from the base. In contrast with this, the earlier work of Pfeil and others with relatively heavy scales indicates that the iron oxides tend to be on the surface and the chromium oxides near the metal. In view of the fundamental importance of this question, apparatus for electrolytically stripping the scale has been set up, so that transmission experiments can be made. After preliminary experiments, this apparatus is being revised to simplify the retrieving of the film after removal.

When other specimens of the sample discussed above are exposed under similar conditions, a very thin, yellow-brown, adherent film is formed. The cause of this different behavior has not been completely determined, but it seems to be associated with the degree and quality of polish of the specimen. The protection offered by the smooth coating is much greater than by the rough scale. After twenty hours of oxidation at 775° C. the diffraction patterns of the oxide are still too weak for satisfactory analysis.

A second x-ray method of investigation has been used. The intensity of a crystal-diffraction line from the base metal may be compared with the weakened intensity found for it when the base metal is covered with the oxide scale. Since the absorption coefficient is not known, because the composition of the oxide layer is uncertain, the thickness of the layer cannot be calculated from this weakening. It has been found, however, that if the weakening is observed with two different radiations of suitable wave length, the approximate percentage of chromium in the layer may be computed. By using Fe $K\alpha$ radiation, the absorption in chromium is found to be larger than in iron, but with Cu $K\alpha$ radiation the reverse is true. Because of this differential effect, the percentage of chromium may be found even when the exact state of oxidation is not known.

The rough type of scale formed in two hours at 800° C. is found to be approximately 10% chromium with 1.2 milligrams of oxide cm². The smooth type of layer after 10 hours at 775° C. is approximately 26% chromium, and 0.4 milligram of oxide cm²; after 20 hours, it is approximately 21% chromium and 0.7 milligram of oxide cm².

Attempts are being made to develop techniques for the preparation of polished and etched cross-sections through the oxide layer which are suitable for optical and electron-microscope examination. It is difficult to obtain a sufficiently flat and clean surface across the boundary between the hard specimen and the softer mounting material, but some progress has been made.

PLANS

Binary alloys of various compositions of Cr-Fe, Ni-Fe, and Ni-Cr have been ordered. When these materials are available, systematic investigations of them will be made by the methods described. Development of the film stripping technique and cross-section preparation will continue. It is hoped that the latter may be extended to permit the making of sections thin enough for x-ray microradiography. If this can be done, it should be possible to establish the segregation of the metal components in the oxide layer.

PHASE NO. 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 that may be of value as fuel for a rocket or jet engine.

SUMMARY

Several qualitative experiments were made in a continuous-flow system with mixtures of methane and air burning in a glass combustion chamber. An attempt has been made to find some method for analyzing the gases present in a flame. However, it is doubtful if even a qualitative spectroscopic analysis which would determine all of the constituents present could be made of the flame.

PROGRESS

The original plan for this investigation was to investigate reaction rates by continuous combustion of a fuel in a reaction tube by quenching the reaction during its progress by means of an inert gas. Initial experiments of a qualitative nature were made on the problem of propagating a stationary flame inside a tube. A mixture of methane and air was used as the reacting mixture.

The flame consisted essentially of three zones, the first of which was a very thin reaction zone where rapid combustion occurred, a zone of after burning within the tube extending from the flame front to the end of the tube, and a third zone extending from the end of the tube and resembling a weak Bunsen flame. The thin reaction zone was highly luminescent and the heat given off in this zone was so intense that it caused the glass wall adjacent to it to soften in a very short time. This indicates that most of the reaction between the methane and the air occurred in this zone. The thinness of the reacting zone, indicating a fast reaction, suggested difficulties in sampling the reaction products at various time intervals after initial ignition of reactants. Since it is the region of fast reaction that is the subject of this research, some thought was given to the method of analyzing the combustion products during the process of the combustion.

The maximum linear velocity of reactants flowing through the reaction chamber is limited by the burning speed of the reactant mixture. The data of Lewis and Von Elbe (J. Chem. Phys. **2**, 283, 1934), on the decomposition of ozone to form oxygen indicate that the majority of the reaction occurred in the time of the order of 0.0000004 second. These results are not exact; however, the order of their magnitude is significant. These results show that it would be impossible to create a gas velocity which required in the reaction tube to elongate the flame front sufficiently for purposes of analysis.

Spectroscopy was considered as a means of studying the progress of the combustion reaction. Qualitative spectroscopy has already been employed to establish the existence of certain compounds in the flames of hydrocarbon. Quantitative spectroscopy might offer a possible solution to the analysis of combustion products during the combustion, but quantitative spectroscopy has not been completely developed for analyses of this sort.

Another method that may be of value in this study is the use of a constant-volume bomb. Results from this type of equipment may be obtained in the form of pressure rise during reaction, time for the flame front to traverse the gaseous region, and possibly the maximum temperature reached during combustion. Bomb experiments have, in the past, provided the major portion of the present knowledge of the combustion reaction, but can give no indication of actual reaction rates, since the amount of material burned inside a bomb in a given time is more dependent upon the flame speed than upon the reaction rate.

PLANS

In view of the difficulties which would arise in attempting to measure combustion rates, as distinguished from flame velocities, it appears that some modification of the original problem should be made. The present plans should perhaps be directed toward a study of flame velocities for one or more fuels, and toward determination of whether such data would be useful in studies concerned with jet propelled engines.

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 low and also at high temperatures.

SUMMARY

The apparatus required for the successful conclusion of this project is beginning to arrive. Most of the time during the quarter has been spent in building and assembling the various parts of the experimental equipment. The remainder of the period has been utilized to outline the test program and to define and foresee the chief difficulties that may be encountered.

PROGRESS

During the past three months orders have been placed for all the remaining important pieces of equipment. Some of this material has arrived and most of the time has been spent in constructing and assembling apparatus. In particular, the gas-fired furnace for preheating the gas stream has been installed and a Nichrome coil fabricated for insertion in the furnace.

Some thought has been given to establishing the sequence to be followed in the experimental work. To separate the radiation heat-transfer rate from the measured total rate, which is the real objective of the project, will require an accurate knowledge of the convection heat-transfer rate. It is proposed to obtain this information from experimental measurements in the same apparatus on a non-radiating gas such as nitrogen. Therefore, the first experimental work to be undertaken when the equipment is in operation, will be to evaluate the convection heat-transfer rate at high temperatures. These results, while not fulfilling the ultimate objective of the project, should be worth while, because there are so few data on convection coefficients at temperatures of 2000° F. and above.

PLANS

In the next quarter the main objective will be to complete the construction and calibration of the experimental apparatus and to begin the experimental studies as outlined.

PHASE NO. 6F

STATEMENT OF PROBLEM

The purpose of this research is to determine experimentally the heat of formation and combustion, the specific heats, 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.

SUMMARY

Delays in the delivery of equipment have held up actual experimental work on this project. We have received notification from the manufacturers that the main pieces of equipment will arrive within one or two weeks.

PROGRESS

At the present time this research is being directed toward the determination of heats of formation of compounds which might be useful as fuels in pulsating jet engines. The heats of formation will be determined from standard heats of combustion obtained by use of an adiabatic calorimeter. The experimental work in this research program has not been started as yet because of delays in delivery of equipment. All the minor pieces of equipment have been obtained and assembled, and the only piece of equipment which is lacking is the adiabatic calorimeter. The manufacturers indicated that this calorimeter was to be shipped on 15 March 1947. After all the equipment has been assembled, the calorimeter will be calibrated by use of a standard material such as benzoic acid obtained from the Bureau of Standards, before making any determination on a new fuel.

The planning division of the Office of Naval Research of the Navy Department has suggested a number of compounds whose heats of formation are desired. A number of these compounds can be obtained from commercial sources; a number of them, however, will be prepared in the laboratories of Purdue University. A library survey has indicated that the available data for one of the types of compounds suggested by the Office of Naval Research are very meager. For this reason, the present research at the outset will be directed toward determining the heats of formation for this type of compounds.

PLANS

The experimental work in the immediate future is to be directed toward the determination of the heats of formation of one of the types of compounds suggested by the Office of Naval Research. Heats of formation of all derivatives of this type of compound will be determined, provided samples of the various derivatives can be obtained, and with this information it may be possible to determine the effect of group contribution in estimating the heats of formation of similar compounds.

PHASE NO. 6G

STATEMENT OF PROBLEM

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

SUMMARY

The apparatus for the determination of heats of combustion has been calibrated. The metal organic compounds to be furnished by Aerojet Engineering Corporation have not arrived; meanwhile the heats of combustion of rocket fuels as developed at Purdue are being determined. The first compound to be studied is the methyl ester of nitroacetic acid.

PROGRESS

During the early months of this project, and preceding the period covered by this report, the apparatus to be used in determining the heats of combustion of the compounds selected for investigation was cleaned and repaired and placed in operating condition. The potentiometer, the analytical balances, the weights, and the volumetric glassware were calibrated, and a routine of operation for the combustion experiments was established. Thus, at the beginning of this quarter only the calibration of the calorimeter required completion before beginning the combustion experiments on those compounds whose heats of combustion are desired.

During this period from 1 January to 31 March, the preliminary calibration experiments were completed and the value of the heat capacity of the calorimeter in calories per microvolt was determined. Also, certain improvements were incorporated in the apparatus which would permit more accurate temperature control, greater precision of time measurement, and greater ease of manipulation of the apparatus.

Arrangements were made with the Aerojet Engineering Corporation for obtaining samples of the metal-organic compounds whose heats of combustion are to be determined. The samples have not as yet been delivered. Several oxidizers of the type used in rocket fuels devised at Purdue have been considered, and work has been started on the determination of the heat of combustion of one of these fuels, the methyl ester of nitroacetic acid.

PLANS

Future work will consist of measuring the heats of combustion of the compounds selected as soon as the compounds are available. In addition, it is intended to conduct further calibration experiments so that any change in the heat capacity of the calorimeter or any variation in the oxygen used may be detected as soon as it occurs and corrective steps taken.

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ABSTRACT:

Theoretical and expertmentat tnvestigations are being conducted by research institutions on rocket and pulse jet engines operating at supersonic speeds. Ftow tests were made in wind tunnel, and problem of shock waves occurring at supersonic speeds is discussed. Description is given of method of spark propagation in combustion chamber. Information obtained from flame studies.was used in determintng fundamental parameters for propagation theory.

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