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
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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.

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ABSTRACT

Progress has been made on investigations of reed valve inflow process and on design of rotating sleeve valve. Henry high-speed fatigue testing machine is being changed for use at high temperatures. In connection with supersonic flow, general three-dimensional dynamic equations were set up for perfect gas flow, including viscosity, conduction, and convection. Carbides and nitrides are being investigated for the purpose of applying them to engine materials through powder metallurgy.

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