UNITED STATES NAVY

PROJECT SQUID

No. 1
INTRODUCTORY REPORT

PRINCETON UNIVERSITY

REPORT NUMBER 1

INTRODUCTORY REPORT ON

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
31 DECEMBER 1946

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FOREWORD

Project SQUID is a cooperative fundamental research program in two important respects. It is a joint effort of the Bureau of Aeronautics and the Office of Naval Research. It is also a joint effort of the five associated academic institutions.

The Navy Department looks to Project SQUID for assistance in discovering new knowledge in the field of propulsive devices and in relating this information to the applied research and development program currently being sponsored by the Navy Department.

The program of Project SQUID is related to the entire fundamental scientific research program being sponsored by the Office of Naval Research. The integration of the basic information pertinent to propulsion will augment the current development program sponsored by the Bureau of Aeronautics in this field. The Navy Department hopes that both improvements in existing equipment, as well as novel design possibilities for future propulsive devices, will emerge from this program.

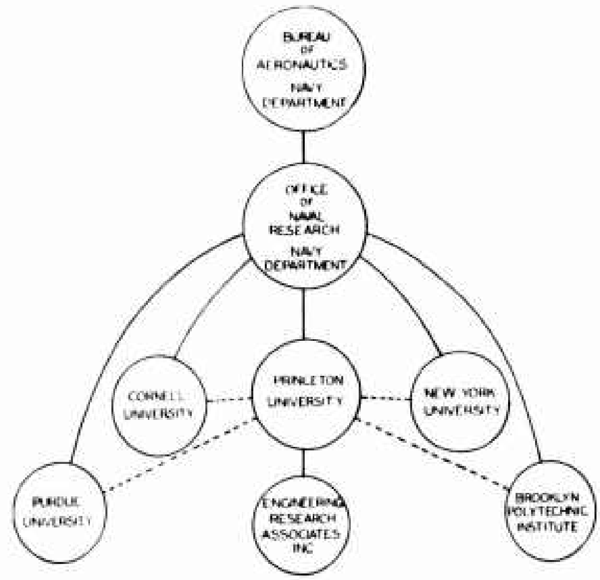
PAUL F. LEE, Rear Admiral
Chief of Naval Research

H. B. SALLADA, Rear Admiral
Chief, Bureau of Aeronautics

I. INTRODUCTION

Project SQUID is a program of fundamental scientific research sponsored by the Bureau of Aeronautics and the Office of Naval Research, Navy Department. This project was established in May 1946 at the request of the Bureau of Aeronautics for the purpose of sponsoring fundamental research to supplement the development, design, and production program of the Navy Department for liquid rocket and pulse jet propulsive devices. The research program is a joint enterprise of five academic institutions, each of which has a task-type contract with the Office of Naval Research. The universities contributing to this program are Cornell University, New York University, the Polytechnic Institute of Brooklyn, Princeton University, and Purdue University. Contracts with these universities for this program remain in effect until 30 June 1948.

The central administrative responsibility for this project has been assumed by Princeton University at the request of the Navy Department. Individual task assignments for the scientific research delineate only in a very general way the type and scope of work to be undertaken in connection with Project SQUID. Inasmuch as this program is supported by a transfer of funds from the Bureau of Aeronautics to the Office of Naval Research, the Bureau retains the responsibility for the technical direction, scope, and degree of sponsorship of Project SQUID. The Office of Naval Research, on the other hand, has accepted the responsibility for contractual, administrative, and fiscal matters.



PROJECT SQUID
CONTRACTUAL ORGANIZATION
Figure 1

II. OBJECTIVES

The principal concern of Project SQUID is with fundamental scientific research. Because of its basic character, the research carries no security classification. The importance of a return to fundamental studies in propulsion need not be emphasized further here. In common with almost every other scientific effort during the war, engineering development in this field has outgrown the fund of fundamental scientific information upon which a logical and comprehensive program must be maintained.

The effort in scientific research is being distributed among several objectives, broadly outlined below:

1. To continue the assimilation of basic scientific information and data needed to perfect equipments of current design.

2. To provide basic scientific information which is required to evaluate various proposed designs and to investigate these proposals to a degree which will enable prototype development.

3. To undertake fundamental scientific research out of which may arise the discovery of different and better designs of a type totally unforeseen at present.

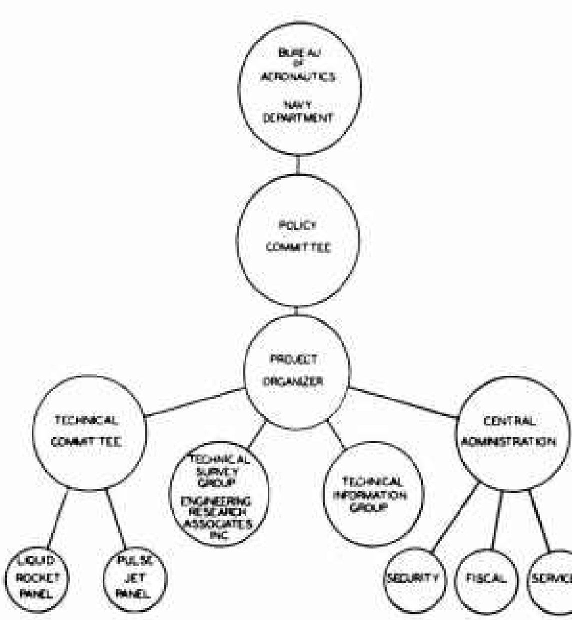
The current research program of Project SQUID bears directly on problems related to liquid rocket and pulse jet engines. No specific complete propulsive device is expected to result directly from this work, but the results arising from this fundamental scientific research will be capable of application to the development of prototype models.

A close working relationship has already been established with the Office of Naval Research and with the Bureau of Aeronautics. Through this relationship Project SQUID will act as an advisory agency to the Navy Department on the development of liquid rockets and pulse jet engines, and it will prepare technical reports in the form of monographs on selected parts of the field of propulsion. It is tentatively planned that these monographs and other significant contributions in the field may be incorporated into textbooks on the theoretical and experimental branches in the field of propulsion. At the request of the Bureau of Aeronautics, studies will also be made to evaluate programs of applied research and development undertaken by contractors or by government agencies for the Bureau of Aeronautics. Appropriate recommendations concerning the modification or the extension of work in these fields will be presented to the Bureau upon the conclusion of each study.

In order to maintain technical surveillance of the liquid rocket and pulse jet engine field, Project SQUID will maintain a close liaison with all branches of the Army and Navy concerned with research on and development of these devices. This relationship is imperative in providing and interpreting the results of fundamental research to scientists in development and in bringing the problems arising in development to the attention of scientists concerned only with fundamental research. An additional objective of this liaison function is to avoid unintentional duplication between Project SQUID and the large number of related research programs being conducted elsewhere under government sponsorship. In this sense it is important to state that it is not the purpose of Project SQUID to prevent duplication in scientific programs, since it is often advantageous to sponsor the efforts of several groups on a single problem.

III. MANAGEMENT ORGANIZATION

Princeton University has undertaken to accomplish the objectives set forth above by establishing a management organization to direct and supervise this program. The several departments of this organization include the Policy Committee as the central governing board, the Technical Committee concerned primarily with the program of research among the universities, and the Office of the Project Organizer as the central organization at Princeton. The functions of each of these departments are described below.



PROJECT SQUID
TECHNICAL ORGANIZATION

Figure 2

The Policy Committee

At an early meeting of the associated universities it was agreed that a central governing board should be established to provide direction for the entire program of Project SQUID. It was decided that the members of this committee should be outstanding scientists who have had wide experience both in conducting and in administering research. A committee of six scientists was recommended—three to be chosen from among the universities participating in Project SQUID and three from other research organizations.

The membership of the Policy Committee follows:

Dean Hugh S. Taylor, Chairman. Dean of the Graduate School and Chairman of the Department of Chemistry, Princeton University.

Dr. Arthur S. Adams. Provost, Cornell University.

Mr. Edward S. Roberts. Vice President in charge of Engineering, Chemical Construction Corporation.

Dr. Theodore C. von Karman. Director, Guggenheim Aeronautical Laboratory, California Institute of Technology, and Chairman of the Scientific Advisory Board to the Commanding General, Army Air Forces.

Dr. Richard C. Courant. Director of Research, Institute for Mathematics and Mechanics, and Head of the Department of Graduate Mathematics, New York University.

Dr. Augustus B. Kinzel. Vice President, Union Carbide & Carbon Research Laboratories, Inc., and Vice President, Electrometallurgical Co., Inc.

The Policy Committee is concerned with the broad planning of Project SQUID, including all policy matters of the program. The Committee is charged with the responsibility of determining the financial requirements for the entire project and the allocation of these funds to the several universities conducting research for Project SQUID. The Committee is also responsible for relating this project to other research being conducted in this field and for making the proper adjustments in the scope of Project SQUID to enhance its effectiveness.

The Technical Committee

The associated universities also agreed to establish a Technical Committee as a working scientific group to keep closely associated with the university research program. The membership of this committee includes three scientists from each of the universities associated with Project SQUID. The Technical Committee is responsible directly to the Policy Committee for the details and results of the research program. The Technical Committee reviews new proposals for research and proposals to alter phases of the research from the associated universities; the recommendations stemming from such reviews are then forwarded to the Policy Committee for discussion and for the advice and approval of the Navy Department.

Since Project SQUID is aimed toward research relating to liquid rockets and pulse jet engines, the Technical Committee has established as small working groups the Liquid Rocket Panel and the Pulse Jet Panel. Each Panel has a membership of five scientists, one appointed by each of the associated universities, and each is responsible for planning a comprehensive fundamental research program to be conducted by the associated universities in its specific field. Recommendations regarding new or additional assignments to individual university laboratories, together with periodic technical reports, are submitted to the Technical Committee for review and discussion.

The Office of the Project Organizer

The Project Organizer serves as ex officio member of the Policy Committee and, as the executive officer of the Policy Committee, is directly responsible to the Chairman. The Project Organizer also serves as Chairman of the Technical Committee.

As a representative of the Policy Committee, the Project Organizer must work closely with the participating university scientists to keep fully informed of the progress and planning of the scientific research and with representatives of the Navy Department in regard to fiscal, administrative, and scientific matters. The Project Organizer has established a central organization at Princeton to perform the required staff duties.

The Technical Sections provide scientific assistance to the Project Organizer in the rocket and pulse jet research fields.

The Office of the Project Organizer also maintains a Technical Information Section to collect, abstract, catalogue, and index technical reports relating to propulsion in order that an adequate central library may be accessible to the associated university scientists on a loan basis. This section also is responsible for the printing and distribution of Project SQUID reports.

The Administrative Section is concerned with clearance and security, maintaining fiscal records and performing other necessary services.

The Technical Survey Group

The Technical Survey Group has been established to conduct technical field surveys and to provide liaison between the scientists associated with Project SQUID and technical groups in the other laboratories working in the field of propulsion. This group is associated with the Office of the Project Organizer at Princeton.

The Engineering Research Associates, Inc., of Washington, D.C., is acting in this capacity under contract to Princeton University. The scientific personnel of Engineering Research Associates augment the staff of the Project Organizer. The current work of this group includes the preparation of a survey report on all research and development now being sponsored by the government in the field of liquid rockets and pulse jet engines.

IV. INITIAL RESEARCH PROGRAM

The current research program of Project SQUID was determined on the basis of an Initial Program Report submitted to the Navy Department by Princeton on 30 June 1946. This report contained research proposals from each of the associated universities. In every case the proposed research was governed entirely by the qualified scientific personnel and appropriate equipment available to each university. No new facilities were planned for the initial phase of the research program. The Policy Committee selected from these proposals certain phase assignments which, it was felt, constituted an effective initial effort for Project SQUID.

The phase assignments to be undertaken by each university are described briefly below, along with the methods by which these assignments are to be carried out.

Cornell University and the Cornell Aeronautical Laboratory

Cornell University is operating under Contract No. N6ori-119, Task Order No. I, Office of Naval Research, Navy Department. This research is divided among the Cornell Aeronautical Laboratory, Buffalo, and Cornell University, Ithaca, New York.

The facilities available at the Cornell Aeronautical Laboratory for aerodynamic experiments include a small subsonic and a small supersonic wind tunnel with working sections permitting a Mach number of 1.4 and 1.7 respectively. Also available is a complete apparatus for taking schlieren photographs.

A small cinder-block building has just been completed which is to be the new home of the burner group. The air-supply available at this time is about 3,000 cubic feet per minute at low pressure. Plans are under way for obtaining a much larger supply of air for the new laboratory. The new building also includes facilities (air, gas, water, bench lathe drill press, etc.) for complete bench testing of experimental units.

The Cornell Aeronautical Laboratory has a large, well-equipped model and instrument shop capable of constructing as many high precision models or instruments as may be required. This facility is available as needed.

The Materials Department offers well-equipped chemistry, fuels, and metallurgical laboratories. Among the many fine instruments with which the analytical division is equipped are a Beckman Model DU Quartz Spectrophotometer, complete gas analysis equipment, complete gasoline and oil testing equipment, a Perkin Elmer Infrared Spectrometer, and a Bausch and Lomb Littrow Spectrograph with a Dietert Multi-Source Unit and a Leeds and Northrup recording microphotometer. The following facilities are available for metallurgical work in connection with Project SQUID: the Hayes X-Ray Diffraction Unit; Westinghouse Mobile X-Ray Unit; Ajax Northrup converter and three melting furnaces; Standard Machinery Laboratory Rolling Mill; Brinell, Rockwell, superficial, Vickers, and Tukon hardness-testing machines; and an A.B.&L. Research Model metallographic unit with the necessary polishing equipment. The phase assignments being undertaken by Cornell are described below.

Phase No. 1. Theoretical and Wind Tunnel Investigations on Fluid Flow. Dr. J. V. Foa, Cornell Aeronautical Laboratory. This research is being conducted in connection with pulsating jet engines for the purpose of undertaking 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.

Plans have been made to test a number of two-dimensional diffuser models in the supersonic wind tunnel at Mach number of 1.7. Stagnation and static pressure measurements along the duct are to be made, as well as schlieren photographs of the shock pattern. It is planned also to employ a fluctuating back pressure to simulate the condition of intermittent combustion. A survey is to be made on the external surface of the ducted body in the unsteady condition of spill-over with pulsating back pressure.

Mathematical studies using the Fourier series of the MacDonald pressure cycle have been undertaken in order to determine the minimum requirements for the frequency response of a pickup. The study of available literature on the theory of the aeropulse is already under way, with a view to possible applications either of the water-channel analogy or of the electrical analogy in the investigation of pulsating flow phenomena.

Phase No. 2. Theory and Experimental Investigation of Pulse Jet Combustion. Dr. John L. Beal and Dr. J. V. Foa, Cornell Aeronautical Laboratory. In connection with pulse jet engines, this research includes a study of the theory of combustion and the effect of turbulence on flame propagation and cooling. It is intended to verify and augment existing theories by means of experimental investigation of ignition, combustion, flame holding, flame propagation, and cooling.

An attempt is under way to isolate the effects on flame propagation of flow velocity, composition of the mixture, pressure and temperature of the gas, turbulence, and mode of ignition. A special pyrex glass combustion chamber has been fabricated which permits movement of the source of ignition at a controlled speed across a chamber filled with a stationary mixture of known and uniform composition. The mixture can be maintained at carefully controlled pressures and temperatures. The flame pattern will be observed and recorded by means of high speed motion pictures, and attempts will be made to carry on other pertinent measurements across the flame front.

In the first experiments, control of the spark velocity will be achieved by external switching on a row of spark gaps inside the chamber. Preliminary experiments already carried out on the distributing switch give promising results when an air stream is directed toward the contacts. After using high speed motion pictures to study flame propagation under controlled conditions, it will be possible to investigate the influence of flow disturbances such as isotropic and non-isotropic turbulence of various intensities.

An experimental setup has been built for the study of the propagation of flames in tubes. It is intended to investigate how various types of constriction affect the formation of detonation waves and, especially, whether a high velocity, once reached, will be maintained under various conditions. To measure the velocity of flame propagation in these experiments a number of ionization gaps will be placed along the tube, and these gaps will record the passage of the flame front by means of an oscillograph. Except for the ionization gaps, this setup is now ready.

It is also planned to determine the speed of combustion by sampling the gas mixture at various points along the flame front. The gas samples, which are to be collected by means of a refrigerated sampling tube, will be analyzed.

Phase No. 3. Experimental Investigation of Temperature-Resistant and Fatigue-Resistant Materials. Loren W. Smith, Cornell Aeronautical Laboratory. This work is directed toward pulse jet engine applications and provides for experimental investigation of temperature-resistant and fatigue-resistant materials for intake valves and coatings, and it will include investigations of fabrication methods.

In connection with an experimental investigation of high-temperature and fatigue-resistant materials, the design and construction of a high-temperature metaloscope is a primary objective. The Tocco Company has recently completed an induction-heated soldering gun which may be suitable for the heating source in the metaloscope. Since there is at present no instrument which is suitable for these high temperature studies, the immediate plan calls for construction of such equipment so that basic studies of crystalline structure can be made.

New York University

New York University is operating under Contract No. N6ori-11, Task Order No. II, Office of Naval Research, Navy Department. The research at New York University includes the use of facilities at West Hall, University Heights, Bronx, and at Washington Square, Manhattan. The phase assignments at New York University are under the direction of Professor J. K. L. MacDonald.

Phase No. 1. Effect of Turbulence on Combustion. Professor J. K. L. MacDonald and Dr. Marjorie W. Evans, Department of Graduate Mathematical Physics. This research is being undertaken in connection with problems relating to pulse jet engine performance and provides for 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 of this phase is to determine the character of and parameters for flames in a combustible medium in which turbulent or eddy motion analagous to that in pulse jet engines is produced under controlled conditions. Analysis of high speed motion pictures of flames in the conventional buzz bomb motors indicates that effective flame speeds of the order of 200 feet per second relative to the gas do arise, for reasons which require study.

Phase No. 2. Thermal Conductivity and Heat Transfer. Professor G. E. Hudson, Department of Physics. This phase is applicable both to liquid rockets and to pulse jet engines and is intended to include: (1) the measurement of thermal conductivity and heat capacities of various steels and other materials used in jet engines, and to determine by use of adiabatic calorimetry and metallography how these parameters depend on the temperature and on the rate of heating; (2) the determination of characteristic parameters for heat transfer between hot turbulently flowing gases and walls by use of measurements of gas velocities, radiation intensities, and wall temperatures, (3) the use of results arising in (1) and (2) above to enable refined calculations of temperature changes in jet tubes.

The apparatus for measuring heat capacities of thin rods of steel at rates of heating up to 1,000° C. per second has been designed and nearly completely assembled. Heating will be produced by short circuiting storage batteries through the rod and temperature will be recorded either mechanically or oscillographically, using platinum platinum-rhodium thermocouples and a d-c amplifier.

Phase No. 3. Flame Motion and Analogy Studies. Professor J. K. L. MacDonald, Department of Graduate Mathematical Physics. This phase is applicable both to liquid rockets and pulse jet engines and provides for: (1) the observation of flame and particle motion, pressures, temperatures, densities, and effects of turbulence in pulsating and rocket jet devices; (2) the study of water stream analogs for gas motions in pulsating jets and rockets in order to determine characteristics of simple theoretical models; and (3) the use of the results in (1) and (2) for theoretical treatments of the internal ballistics of jet devices on the basis of justified simple models.

Two model pulse jet motors have been acquired for study and six transparent or adjustable jet motors with auxiliary equipment have been constructed for research purposes. Preliminary high speed motion pictures of a transparent motor were obtained and showed some details of the flame motion. A JB-2 buzz bomb motor has recently been received from the Army Air Forces, and a study of its reed valve characteristics under conditions of steady as well as artificially pulsed flow in a wind tunnel is planned.

Phase No. 4. Instrumentation. Dr. John W Hett, Research Associate. This phase provides for the development of instruments to record (1) transient thrust, (2) pressures, temperatures, and densities of hot oscillating gases, and (3) velocities.

Electronic and photographic equipment has been constructed for use in this phase. For thrusts and pressures the New York University group favors magnetostriction, condenser, and reluctance gages (in that order of preference). For oscillating gas temperatures, sodium radiation intensity or ratio of sodium to potassium radiation intensity, as determined by means of photo-electric multiplier tubes, is being considered. For particle velocity measurements either movie shadowgrams or schlieren pictures, using transparent walled jet tubes, is favored.

Phase No. 5. Drag Characteristics in Non-Steady or Supersonic Flow. Sam A. Schaaf, Lecturer in Graduate Mathematics. This phase is applicable to problems both in liquid rocket and pulse jet engine fields. It provides for a study of drag characteristics of pulse jet engines and other devices under conditions of non-steady or of supersonic flow, using firing range photography, wind tunnel measurements, and theoretical investigations.

Theoretical studies of non-steady skin drag on the front part of a paraboloid of revolution, simulating a streamlined head of a pulsating jet motor, are being undertaken. The external flow is being treated first as a non-steady potential flow, and the boundary layer is being treated first as incompressible but non-steady and subject to oscillating heat transfer from the surface of the paraboloid. Attempts to include compressibility and pulsating jet intake effects as well as other factors will eventually be made.

Polytechnic Institute of Brooklyn

The Polytechnic Institute of Brooklyn is operating under Contract No. N6ori-98, Task Order II, Office of Naval Research. The phase assignments are under the general supervision of Professor R. P. Harrington.

Phase No. 1. Valve Mechanisms at Subsonic and Supersonic Velocities. Professor H. J. Reissner, Department of Aeronautical Engineering and Applied Mechanics. The research in this phase is concerned primarily with 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.

Theoretical investigations of the two-dimensional compressible flow are being continued and extended for hinged and clamped-edge reed valves. As special cases, particular solutions of the differential flow equations have been investigated to give simple shapes of the reeds.

Phase No. 2. High Temperature Materials. Professor O. H. Henry, Department of Metallurgical Engineering. This research is directed toward (1) the investigation of causes of metal failure thus far encountered by evaluation of use tests on developed materials, and (2) the investigation and development of new alloys to resist pressure, temperature, and erosion conditions existing in propulsion units by modification of present alloys, development of new alloys, and use of powder metallurgy methods.

Work is continuing on the development of new techniques for studying high temperature alloys and materials including heat exchange, tensile tests, high speed fatigue tests at elevated temperatures, corrosion fatigue, and powder metallurgy techniques.

Princeton University

Princeton University is operating under Contract No. N6ori-105, Task Order III, Office of Naval Research. The principal effort in this project at the present time is centered in the Princeton Aeronautical Laboratory of the Aeronautical Engineering Department. Associated research under the sponsorship of another government agency is being sponsored in the Department of Chemistry and in the

Department of Physics. The phase assignments, directly and indirectly related to Project SQUID, are listed below:

Phase No. 1. Boundary Layer Investigations. Professor Lester Lees, Department of Aeronautical Engineering. This phase is a theoretical and experimental investigation of (1) the stability of the laminar boundary layer, (2) the interaction of the boundary layer with the external flow field at supersonic velocities as related to pressure distribution, bodies of revolution, and air foils, and (3) the interaction of shock waves in channels and diffusers.

Recent experimental investigations of the interaction between shock waves and the boundary layer in the transonic flow over air foils show that this interaction has important effects on the flow pattern and on the pressure distribution at the surface of the air foil. Interaction of the boundary layer and shock waves is of equal importance in supersonic flow over the rear of air foils and bodies of revolution. Experiments are being conducted to investigate the dependence of this phenomenon on the shape of the air foil on the strength of the trailing edge shock on the Mach number, and on the Reynolds number.

Phase No. 2. Combustion. Professor R. N. Pease, Department of Chemistry. This research is directed toward studying (1) combustion as related to high velocity fuel-oxidant, stream ignitability, efficiency, after-burning, and thrust; (2) the effects of subatmospheric pressure; (3) interactions between ionization and flame; (4) optical and mass spectra; and (5) the theory of adiabatic exothermic reaction.

This research is under sponsorship of another government agency, but Professor Pease, as a result of these investigations, provides valuable consultation to Project SQUID.

Phase No. 3. Measurements of Gas Flow at High Velocities. Professor Rudolf Ladenburg, Department of Physics. This research includes a study of jet performance and flow of gases at high velocities by optical means, interferometers, schlieren and x-ray analysis, and an explanation of the fundamental phenomena observed.

This work is not related directly to Project SQUID and is being sponsored by another government agency.

Purdue Research Foundation and Purdue University

Purdue University, through the Purdue Research Foundation, is operating under contract to the Office of Naval Research, Contract No. N6ori-104, Task Order I. The work at Purdue is divided among the School of Mechanical Engineering, the Physics Department, the Chemistry Department, and the Chemical Engineering Department. The phase assignments being undertaken by Purdue are described below.

Phase No. 1. Instrumentation. Professor George A. Hawkins, School of Mechanical Engineering. This research is a theoretical study of means for measuring rapidly fluctuating gas temperatures in order to develop instrumentation for obtaining and accurately controlling temperature in a calibrating chamber. It was decided that four of the many methods available for this work would be studied in detail. These include studies of the design of:

1. Special optical pyrometer using photocells and special related apparatus.

2. Shields and supports for an exposed thermocouple, including an exhaustive analysis of the time lag of the couple as influenced by such factors as wire, size, etc.

3. Shielded suction thermocouple, including a study of the lag of the couple as influenced by gas velocity, size of wire, etc. Air will be used to induce the gas flow through the suction thermocouple.

4. Hot-wire system including wire supports and necessary electrical elements. The study will cover the lag of the unit as influenced by such factors as velocity, gas temperature change, etc.

The necessary recording and testing equipments for this program are being designed. A complete review of the literature in this field is being performed.

Phase No. 2. Continuous Process Combustion. Professor H. J. Buttner, School of Mechanical Engineering. The purpose of this phase is to study (1) continuous combustion problems, (2) limits of scaled down combustion studies, (3) fuel introduction covering factors of spray pattern particle penetration and atomization, nozzle locations, injection and air stream velocities, (4) combustion in turbulent and non-turbulent air streams, (5) partial downstream air introduction, (6) burners in various air supplies, and (7) application of knowledge of conventional fuels to new fuels submitted by other investigators.

A major portion of all effort has been expended on the preparation of designs, layouts, and details of equipment and facilities for this phase. The design of a preliminary model of combustion chamber with the necessary piping and ducts has been released for fabrication. This equipment will be used in conjunction with the compressor equipment at the Automotive Laboratory. The combustion chamber will be 4 inches in inside diameter and 48 inches in length. Observation windows of several different materials have been ordered. These windows, which will be used for observations of turbulence and flames, will be required for two methods of temperature measurement contemplated at this time.

Several studies have been made on high temperature measurements. These studies have been directed toward the externally heated resistance wire method and the sodium lime reversal method.

Phase No. 3. Corrosion Products. Professor H. J. Yearian, Physics Department. This phase is to study and identify the structure layer formed by high-temperature, high-velocity, gaseous corrosion by means of electron diffraction, x-ray chemical, spectroscopic, and radioactive tracer methods.

The primary identification method to be used is by the comparison of x-ray and electron diffraction patterns obtained with patterns from known cc pounds.

Phase No. 4. Oxidation Reactions. Professor D. E. Holcomb, Department of Chemical Engineering. In this investigation studies will be made by means of bomb experiments on such parameters as temperature, pressure, concentration of reactants, and catalysts for various oxidation reactions.

An attempt is being made to measure directly and continuously the rate of combustion reactions. This would be superior to the indirect batch methods of measuring the rate of flame propagation and pressure rise in a closed bomb, previously reported in the literature. In general, the procedure under consideration is as follows:

1. Burn the fuel continuously in a reaction chamber, measuring the rates of consumption of fuel and oxidizing agent and the temperature and pressure obtained in the reaction chamber.

2. Measure the rate of egress of the reacting products through an opening in the side of the reaction chamber.

3. Quench the reaction at the time that the reacting products leave the chamber, using for this purpose a measured quantity of an inert gas or a liquid.

4. Analyze the resulting mixture of quench material, reacting products, fuel and oxidizing material, relating the quantities obtained to a known time interval.

Phase No. 5. Effect of Radiation on Heat Transfer. Professor J. M. Smith, Department of Chemical Engineering. This research is directed toward determining the radiation factor and its contribution to heat transfer coefficients inside of a pipe with gas flow at low and high temperatures.

The general procedure will be to pass pure radiating gases (water vapor and carbon dioxide) at temperatures up to 2,000° F. through a section of straight metal pipe and measure the total heat transferred from the gas to the pipe wall by the fall in temperature of the gas. This will give the combined heat transfer by radiation and convection. Three possible methods of isolating the radiation contribution have been considered, and it is proposed to investigate each in turn.

1. Evaluating the convection contribution from tests on non-radiating gases. It is proposed to pass nitrogen through the test section at the same conditions as above. The heat transfer rate in this case, when corrected for the differences between the physical properties of nitrogen and the radiating gases, should be a measure of the convection contribution.

2. Evaluating the convection contribution from low temperature data. By making measurements at low temperatures, where radiation is not significant, the convection contribution at these low temperatures can be determined. Then by estimating the effect of temperature on the convection coefficient from available data, the contribution at high temperatures could be estimated.

3. Radiation contribution determined from tests at several mass velocities. The convection coefficient of heat transfer in the test section would be expected to depend upon the mass velocity of gas flow, but the radiation coefficient should be independent of this quantity. By analyzing test data obtained at a series of mass velocities, the separate contributions of radiation and convection could be estimated. Effects of natural convection and conduction at low velocities may introduce difficulties in this method.

Phase No. 6 (F). Thermodynamics of Fuels and Oxidizers. Professor D. E. Holcomb, Department of Chemical Engineering. The purpose of this research is to determine experimentally the heats of formation and combustion, the specific heats, and other thermodynamic properties of various fuels and oxidizers used in pulse jet engines. A correlation of thermodynamic properties will be made so that calculations may be extended to include new fuels.

Phase No. 6 (G). Determination of Heats of Combustion. Professor H. Hunt, Department of Physical Chemistry. The subject of this research is the determination of heats of combustion of various chemical compounds. The method to be used is that previously followed by Miles and Hunt, Miller and Hunt, and Young and Hunt, modified as made necessary by the characteristics of the compounds to be studied. This apparatus was designed for high precision work and incorporates most of the requirements listed by White in his monograph on calorimetry.

APPENDIX A. ORGANIZATION OF PROJECT SQUID

1. Policy Committee
   - Dean Hugh S. Taylor, Chairman. Princeton University
   - Dr. Arthur S. Adams. Cornell University
   - Mr. Edward S. Roberts. Chemical Construction Corporation
   - Dr. Theodore von Karman. California Institute of Technology
   - Dr. Richard C. Courant. New York University
   - Dr. Augustus B. Kinzel. Union Carbide & Carbon Research Laboratories, Inc.
2. Technical Committee
   - Frank A. Parker, Chairman. Princeton University

   Cornell University

   - J. B. Rosser. Professor of Mathematics
   - J. V. Foa. Head, Propulsion Branch, Aerodynamics Department, Cornell Aeronautical Laboratory
   - J. L. Beal. Alternate; Head, Chemistry and Fuels Section, Cornell Aeronautical Laboratory

   New York University

   - A. F. Spilhaus. Director of Research, Professor and Head of Department of Meteorology
   - J. K. L. MacDonald. Professor of Graduate Mathematical Physics
   - G. E. Hudson. Alternate; Associate Professor of Physics

   Polytechnic Institute of Brooklyn

   - R. P. Harrington. Professor and Head of Department of Aeronautical Engineering and Applied Mechanics
   - H. J. Reissner. Professor of Aerodynamics and Aerostructures
   - P. A. Libby. Alternate; Research Associate

   Princeton University

   - R. N. Pease. Associate Professor of Chemistry
   - C. D. Perkins. Associate Professor of Aeronautical Engineering
   - J. V. Charyk. Alternate; Visiting Assistant Professor of Aeronautical Engineering

   Purdue University

   - H. B. Hass. Professor and Head of Department of Chemistry
   - H. J. Buttner. Professor of Automotive Engineering
   - M. J. Zucrow. Alternate; Professor of Jet Propulsion and Professor of Gas Turbines
3. Rocket Panel
   - J. B. Rosser, Chairman. Cornell University
   - J. V. Charyk. Princeton University
   - R. P. Harrington. Polytechnic Institute of Brooklyn
   - H. B. Hass. Purdue University
   - G. E. Hudson. New York University
4. Pulse Jet Panel
   - J. K. L. MacDonald, Chairman. New York University
   - H. J. Buttner. Purdue University
   - J. V. Foa. Cornell University
   - C. D. Perkins. Princeton University
   - H. J. Reissner. Polytechnic Institute of Brooklyn
5. Management Organization

   Office of the Project Organizer, Princeton University

   - F. A. Parker. Project Organizer
   - W. C. House. Chief Technical Aide
   - R. J. Woodrow. Contracting Representative
   - G. A. Bate. Administrative Officer

   Technical Survey Group, Engineering Research Associates, Inc.

   - J. H. Wakelin. Director
   - R. C. Bryant
   - J. W. Fitzgerald
   - B. H. T. Lindquist
   - A. W. Sloan

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Beal, John L. Head, Chemistry and Fuels Sections, Cornell Aeronautical Laboratory; Ph.D., University of Minnesota, 1934; Chemical Engineering; Combustion Analysis Studies, Project SQUID.

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Bryant, Royal C. Research Physicist, Engineering Research Associates, Inc.; M.A., Oxford University, England, 1935; Fluoride Reactions, Light Scattering; Member, Technical Survey Group, Project SQUID.

Buttner, Horace J. Professor of Automotive Engineering, Purdue University; B.S., Purdue University, 1931; Mechanical Engineering; Theory and Mechanisms of Internal Combustion Engines; Member, Technical Committee and Pulse Jet Panel, Project SQUID.

Charyk, Joseph V. Visiting Assistant Professor of Aeronautical Engineering, Princeton University; Ph.D., California Institute of Technology, 1946; Jet Propulsion, High Speed Aerodynamics; Member, Technical Committee and Rocket Panel, Project SQUID.

Courant, Richard C. Director of Research, Institute for Mathematics and Mechanics; Head, Department of Graduate Mathematics, New York University; Ph.D., Goettingen, 1910; Mathematical Analysis and Applied Mathematics; Member, Policy Committee, Project SQUID.

Engstrom, Howard T. Executive Vice President, Engineering Research Associates, Inc.; Ph.D., Yale, 1929; Theory of Algebraic Numbers and Abstract Algebras; Consultant to Technical Survey Group, Project SQUID.

Evans, Marjorie W. Laboratory Supervisor and Research Scientist, New York University; Ph.D., University of California, 1945; Thermodynamics and Tracer Chemistry; Research Associate, Project SQUID.

Fitzgerald, James W. Research Physicist, Engineering Research Associates, Inc.; B.S., Electrical Engineering, University of Wisconsin, 1939; Aco[illegible]s and Instrumentation; Member, Technical Survey Group, Project SQUID.

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Grey, James T., Jr. Senior Research Chemist, Cornell Aeronautical Laboratory; Ph.D., University of Buffalo, 1940; Plastics and Combustion; Studies on Pulse Jet Combustion, Project SQUID.

Harrington, Russell P. Professor and Head of Department of Aeronautical Engineering and Applied Mechanics, Polytechnic Institute of Brooklyn; Sc.D., University of Michigan, 1936; Aeronautical Engineering; Member, Technical Committee and Rocket Panel, Project SQUID.

Hass, Henry B. Professor of Chemistry and Head of Department of Chemistry, Purdue University; Ph.D., Ohio State University, 1925; Nitroparaffins and Chlorination of Hydrocarbons; Member, Technical Committee and Rocket Panel, Project SQUID.

Hawkins, George A. Professor of Thermodynamics and Westinghouse Professor in Heat Transfer, Purdue University; Ph.D., Purdue University, 1935; High Temperature Phenomena; Rocket Combustion Research, Project SQUID.

Henry, Otto H. Professor of Metallurgical Engineering and Head of Metallurgical Division, Polytechnic Institute of Brooklyn; M.M.E., Polytechnic Institute of Brooklyn, 1936; Physical Metallurgy and Heat Treatment; Metallurgical Research, Project SQUID.

Hett, John W. Research Associate, New York University; Ph.D., Columbia University; Instrumentation; Experimental Research and Consultation, Project SQUID.

Holcomb, D. E. Assistant Professor of Chemical Engineering, Purdue University; Ph.D., University of Michigan; Thermodynamics, Distillation and Unit Processes; Combustion Research, Project SQUID.

House, William C. Chief Technical Aide, Office of the Project Organizer, Project SQUID, Princeton University; B.S., California Institute of Technology, 1939; Aerodynamics and Jet Propulsion.

Hudson, George E. Associate Professor of Physics, New York University; Ph.D., Brown University, 1942; Physical Mechanics and Properties of Materials; Member, Rocket Panel, Project SQUID.

Hunt, Herschel. Professor of Chemistry, Purdue University; Ph.D., Indiana University, 1929; Physical Chemistry and Thermodynamics; Research on Heats of Combustion, Project SQUID.

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Lieber, Paul. Assistant Professor of Applied Mechanics, Department of Aeronautical Engineering and Applied Mechanics, Polytechnic Institute of Brooklyn; M.S., California Institute of Technology; Aerodynamics; Consultant to Project SQUID.

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MacDonald, James K. L. Professor of Graduate Mathematical Physics, New York University; Ph.D., Cambridge University, England, 1932; Gas Dynamics and Wave Analysis; Member, Technical Committee and Chairman, Pulse Jet Panel, Project SQUID.

Parker, Frank A. Project Organizer, Project SQUID Princeton University; A.B., Johns Hopkins University, 1939; Chemistry and Jet Propulsion; Member, Policy Committee and Chairman, Technical Committee, Project SQUID.

Pease, Robert N. Associate Professor of Chemistry, Princeton University; Ph.D., Princeton University, 1921; Kinetics of Oxidation and Catalytic Reactions; Member, Technical Committee, Project SQUID.

Perkins, Courtland D. Associate Professor of Aeronautical Engineering, Princeton University; M.S., Massachusetts Institute of Technology, 1941; Aeronautical Engineering; Boundary Layer Studies, Project SQUID.

Polanyi, Michael L. Aerodynamicist, Propulsion Branch, Cornell Aeronautical Laboratory; Doctor of Physics, Universita de Roma, Italy, 1941; Cosmic Rays, Combustion and Heat Transfer; Combustion and Gas Dynamics, Project SQUID.

Porter, Phillip K. Head of Materials Department, Cornell Aeronautical Laboratory; Ph.D., University of Illinois, 1923; Plastics and Metallurgy; Metallurgical Studies on Valve Mechanisms, Project SQUID.

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Rosser, J. Barkley. Professor of Mathematics, Cornell University; Ph.D., Princeton University, 1934; Mathematics; Member, Technical Committee and Chairman, Rocket Panel, Project SQUID.

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Schaaf, Sam A. Lecturer in Graduate Mathematics, New York University; Ph.D., University of California, 1944; Applied Mathematics; Research Associate, Project SQUID.

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Smith, Loren W. Head of Metallurgy Section, Cornell Aeronautical Laboratory; B.S., University of Buffalo, 1935; Chemical Engineering; High Temperature Materials and Instrumentation, Project SQUID.

Spilhaus, Athelstan F. Director of Research, Professor of Meteorology and Chairman of the Department of Meteorology, New York University; M.S., Massachusetts Institute of Technology, 1933; Meteorology and Oceanography; Member, Technical Committee, Project SQUID.

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von Karman, Theodore. Directory of the Guggenheim Aeronautical Laboratory, California Institute of Technology and Chairman of the Scientific Advisory Board to the Commanding General, Army Air Forces; Ph.D., Goettingen, 1908; Aerodynamics, Elasticity, Hydrodynamics and Thermodynamics; Member, Policy Committee, Project SQUID.

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Yearian, Hubert J. Professor of Physics, Purdue University; Ph.D., Purdue University, 1934; X-Ray and Electron Diffraction, Electron Microscopy; Corrosion Studies and Structure Analysis Project SQUID.

Zucrow, Maurice J. Professor of Jet Propulsion and Professor of Gas Turbines, Purdue University; Ph.D., Purdue University, 1928; Fluid Flow and Internal Combustion Engines; Member, Technical Committee, Project SQUID.

TITLE: Project Squid - No. 1 Introductory Report → 25 →

ATI- 13566

DIVISION (None)

ORIG. AGENCY NO. R-1

PUBLISHING NO. (Same)

AUTHOR(S) : (Not known)
ORIG. AGENCY : Princeton University, Princeton, N. J.
PUBLISHED BY : (Same)

DATE	U. S. CLASS.	COUNTRY	LANGUAGE	PAGES	ILLUSTRATIONS
Dec '46	Unclass.	U.S.	English	15	diagrs

ABSTRACT:

Project Squid is a program of fundamental scientific research to supplement development, design, and production program of Navy department for liquid rocket and pulse jet propulsive devices. No specific complete propulsive device is expected to result from this project, but results arising therefrom will be capable of application for development of prototype models. The research program of various universities affiliated with this project is described, along with methods by which these assignments are to be carried out.

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DIVISION: Power Plants, Rocket (4)
SECTION: Design and Description (12)

ATI SHEET NO.:

SUBJECT HEADINGS:
Engines, Rocket - Design (34108)
Jet Propulsion (54000)
Project Squid (75406)
Engines, Pulse jet (33975)

(UNPUBLISHED CARD) UNCLASSIFIED

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INTRODUCTORY REPORT ON PROJECT SQUID - AND APPENDIXES A AND B

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BUREAU OF AERONAUTICS, WASH., D.C. AND OFFICE OF NAVAL RESEARCH, WASH., D.C., USN PROJECT SQUID CONTR. NO. N5ORI-105

POWER PLANTS, JET AND TURBINE (5)
GENERAL (0)

JET PROPULSION - RESEARCH
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ENGINES, ROCKET
PROJECT SQUID

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