AD-A952998

UNCLASSIFIED

COPY No. 110

UNITED STATES NAVY

PROJECT SQUID

FIELD SURVEY REPORT

ATI-12162

SUMMARY AND RECOMMENDATIONS

Volume III

30 June 1947

DOWNGRADED TO UNCLASSIFIED
Authority: ltr CNR; 429, signed by Ralph Roberts, Power Branch, undated
19 Dec 46

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

ENGINEERING RESEARCH ASSOCIATES, INC.

[redacted]

DTIC ELECTE NOV 16 1983 S E

DTIC FILE COPY

UNCLASSIFIED

83 11 15 239

SUMMARY AND RECOMMENDATIONS

UNCLASSIFIED

FIELD SURVEY REPORT

UNCLASSIFIED

PROJECT SQUID

SUMMARY AND RECOMMENDATIONS

Field Survey Report

Volume III

by

BERTIL H. T. LINDQUIST

Engineering Research Associates, Inc.

Washington, D. C.

30 June 1947

[redacted]

Princeton University, the central management organization of Project SQUID, arranged for the preparation of the *Field Survey Report* under Contract Number N6ori-105, Task Order III, with the Office of Naval Research, Navy Department.

This report was prepared by the Technical Survey Group of Project SQUID as a cooperative effort of Princeton University and Engineering Research Associates, Inc. Engineering Research Associates was given primary responsibility for the preparation of these reports in accordance with the provisions of Task Order II under Purchase Order Number 08451 with Princeton University.

TECHNICAL SURVEY GROUP

Engineering Research Associates, Inc.

J. H. Wakelin, Director

B. C. Bryant
R. B. Dillaway
J. W. Fitzgerald
B. H. T. Lindquist
A. W. Sloan
George Vaux

Princeton University

F. A. Parker
W. C. House

FOREWORD

The *Field Survey Report* on liquid propellant rockets and pulse jet engines was prepared at the suggestion of the Policy Committee, in order that the fundamental research in Project SQUID might be related to other projects and programs of research in this field, and to problems arising in the development of rocket and pulse jet engine equipment.

In order to fulfill this purpose, the *Field Survey Report* had to be more than a brief outline of the work of each contractor, but time did not permit it to be prepared as a monograph in each branch of the field of propulsion. The choice of presentation of the work in each volume of the report was governed in part by the amount of available information, and by its relation to the research now being sponsored by Project SQUID.

The Policy Committee will use the *Field Survey Report* as a basis for adjustments in the research program of Project SQUID, in order to ensure a more effective attack on the fundamental problems in the field of propulsion. The Policy Committee hopes that this report may also be useful to scientists conducting research and development in fields relating to propulsion, and to members of government organizations responsible for the planning and integration of research programs in propulsion.

HUGH S. TAYLOR, Chairman
Policy Committee, Project SQUID

PREFACE

The Field Survey Report was prepared by the Technical Survey Group, Project SQUID, under the direction of Engineering Research Associates, Inc.

The assembly of the material and the preparation of each part of the report was undertaken as a group effort, to which the staffs of both Princeton University and Engineering Research Associates, Inc., have contributed. Mr. F. A. Parker, Project Organizer, and Mr. W. C. House, Chief Technical Aide, of the central administrative staff of Project SQUID at Princeton served as members of the Technical Survey Group and prepared Volume II. In addition, Prof. J. V. Charyk of the Aeronautical Engineering Department at Princeton visited the California Institute of Technology and furnished basic information concerning the research program there. He also offered many helpful suggestions with regard to several parts of Volume I.

In the preparation of this report the members of the Technical Survey Group have received the assistance, counsel and cooperation of representatives of the War and Navy Departments and other Government agencies, and of representatives of academic and industrial laboratories who are under contract to the government for research and development in this field.

The authors are indebted to a number of scientists who have reviewed each part of the report and have offered much constructive criticism. The authors also wish to express their appreciation for the assistance which was so generously given by representatives of the Office of Naval Research and of the Bureau of Aeronautics.

THE TECHNICAL SURVEY GROUP

CONTENTS

CONTENTS — Continued

CONTENTS — Continued

I. INTRODUCTION

The information gathered for the Field Survey Report on liquid propellant rockets and pulse jet engines falls naturally into two divisions, research and development, which are treated in Volumes I and II respectively. Volume I contains a survey of the research in progress on liquid propellant rockets and pulse jet engines, and Volume II contains a survey of the development and state of the art in those fields.

It is evident that the work in Volume I will comprise the fundamental research conducted in several fields which must be considered as a unit to supply the knowledge necessary to the successful development of the complete rocket or pulse jet. These basic fields of research covered in Volume I consist of six parts:

1. Combustion,
2. Fuels,
3. Materials,
4. Fluid Mechanics,
5. Heat Transfer and Cooling,
6. Instrumentation.

Volume II, Development, is given in two parts:

1. Pulse Jet Engines,
2. Liquid Propellant Rockets.

These volumes are reviews of the present research and development activity and are not intended to be monographs on the subjects treated in the reports. Therefore, while they cannot be read as text books, they do contain the current information that will be found useful to research scientists and engineers working in the several fields. The intention is that they will also serve their original purpose as a source of information for the use of the Policy Committee of Project SQUID and the Armed Services in planning the research and development program to be sponsored by the government in the specific fields of liquid propellant rockets and pulse jet engines.

During the period of preparation of the various parts of the Field Survey Report, it became evident that a compendium or synopsis of the entire report would be of service to those whose duties include the planning of the general nation-wide program and to those who desired a general picture of the present status of liquid propellant rockets and pulse jet engines but did not require the detailed knowledge contained in the individual reports. It is hoped that Volume III will fulfill this need.

The Summary is a brief compendium of the contents of Volumes I and II. It will serve as a written symposium of the specified fields and will indicate the scope of the investigation.

The selection and assignment of the authors of the several Parts was based on their previous education and experience in scientific fields allied and associated with the various phases of the over-all jet propulsion research program. The associations developed between those authors and the research scientists and engineers engaged in performing the work under Project SQUID and similar programs provided an opportunity for a critical examination of the progress being made in research and development in jet propulsion. The opinions expressed by the people interviewed during the Field Survey and by the scientists who reviewed the final drafts of the reports were assembled for study and incorporation in the Recommendations Section of each report. The authors of the reports, in the course of the study of the material gathered during the interrogations and the assembly and reduction of that information in the comprehensive volumes, also discovered failures in the present program to meet specific needs. The Recommendations Section therefore consists of a composite of these conclusions. It is hoped that they will indicate program changes or additions which will produce data and information to meet future requirements and improve the present program.

From a consideration of the difficulties encountered and efforts expended by the Technical Survey Group in obtaining the basic information from which to conduct the Survey, it became evident that there existed no easily available procedure for obtaining the necessary information concerning the contracts in force between the Army or Navy and industrial or university contractors engaged in the research and development of the jet propulsion systems with which this survey is concerned. Since this information was assembled in the course of the preparation of the Field Survey Report, as an adjunct to the main task of conducting the survey, it was concluded, after consultation with responsible authorities in the Navy Department, that the inclusion of this information would be useful to those under whose direction this Survey was performed. The contractual information will be found following the Recommendations Section of this volume, and is tabulated both by contractor and by the agency under whose sponsorship the work is being conducted. The first tabulation lists under the name of each individual contractor, alphabetically, all the contracts for research and development in effect for the period ending June 1947, held by that contractor under the War and Navy Departments. The second tabulation is divided into groups by sponsoring agencies. Under each agency will be found the contracts listed alphabetically by contractor.

A great deal of precaution was taken to check the information contained in these tabulations, in an effort to insure the accuracy of the data submitted. However, it must be recognized that change orders and supplements are continuously being written and negotiated, altering the task assignments, delivery dates, costs, methods of payment, as well as other more obscure agreements contained in these contracts. The information, therefore, can be considered accurate up to the time the last investigation was accomplished, the end of the 1947 fiscal year.

One extremely useful and important device in any research or development concerned with jet propulsion is the wind tunnel. The wind tunnel or blower serves two distinct purposes. (1) that of providing a simulated flight condition in which the exterior and interior aerodynamics of the jet may be studied, and (2) that of providing a source of high velocity air, again simulating flight conditions, for the study of the combustion cycle of the jet and pre-flight adjustment of the burners.

A study was made of the facilities of each of the academic, industrial, or government laboratories at the time of the visits by members of the Technical Survey Group. The information thus obtained was screened for wind tunnel facilities in existence, under construction, or in design. These data were augmented through the assistance of the Aeronautical Board, the Office of Naval Research and the Bureau of Aeronautics. Any enhancement in the present program of Project SQUID or formulation of new programs must be governed in part by the available test facilities. The tabulation of wind tunnel facilities is therefore included as Appendix C in Volume III.

II. SUMMARY OF VOLUME I

PART 1, COMBUSTION.

The review of the research work on combustion includes that under government sponsorship, and in addition, a few projects under private sponsorship where the information has been made public. Brief discussions of the status of knowledge in fields of research important to combustion are given, to indicate the relation between the outstanding problems and the present research program.

The quantitative description of the combustion process in terms of the detailed mechanisms involved is possible at present only in principle. Before this can be achieved, formidable mathematical difficulties remain to be solved, and the separate phenomena which are part of the general combustion process must be investigated experimentally. The present research program on chemical kinetics, effect of turbulence on combustion, and chemical reactions in flowing streams is particularly important in this regard.

The research on ignition of combustible mixtures, normal flame velocity, conditions for maintaining stable flames in laminar and turbulent flow, and combustion in liquid sprays, is described. It appears likely that equations can be developed relating normal flame velocity to other observed flame phenomena, important from both the practical and theoretical points of view.

The acoustic vibrations caused by flames and the possibility of using acoustic fields in the study of flame phenomena are discussed.

Some of the combustion work in connection with the design of jet power plants is described to indicate the type and scope of the problems of combustion engineering.

PART 2, FUELS.

The review of fuels discusses the basis upon which fuels and oxidizers for jet propulsion engines can be selected, from a consideration of the chemical properties and atomic weights of the chemical elements which enter into their composition. The objective of any selection is to obtain propellants which not only release large amounts of thermal energy but also give low molecular weight gaseous reaction products. In this connection the significance of specific impulse as a basis for evaluating fuels is indicated. There are also included descriptions of the several classes of fuels and oxidizers, comparisons are made of the relative merits of fuels based upon their specific impulses, physical properties, hazardous properties, and availability. Some of the comparisons with respect to use in a jet motor are based on theoretical evaluations, but in the cases where operational data are available, such test results are considered. The upper limits of performance which can be expected from propellant systems are indicated.

The entire research and testing program for fuels and oxidizers has been classified by subject and the work in progress or contemplated on each subject is reviewed, with reference in each case to the Army or Navy contract under which the work is conducted. The intention has been to give sufficient detail to indicate the problems and the present status of the work.

A great many workers are collecting data on physical and thermodynamic properties of fuels, oxidants, and their reaction products not necessarily by laboratory experimentation but often by searching the literature. Many have also made or collected theoretical performance calculations on liquid propellants and some have made charts to shorten the calculations. Some thought has been given to the use of ultra high exhaust velocities by the use of atomic hydrogen or helium but little is being done at present experimentally on this subject. Hydrogen, helium, and steam, heated to high temperatures, have been used in theoretical calculations.

The possible oxidizing agents have been reviewed in the report on fuels with comparisons of their merits and disadvantages and a description is given of work that is being undertaken with respect to their preparation and the study of their properties and stability. Little is being done at present on fluorine or its derivatives.

In like manner the fuels have been treated, with respect to their production, their advantages and disadvantages, their hazards and stability. Under each fuel also, is given a review of the tests with all the oxidizing agents that are being considered. It may be noted that little is being done at present with liquid ammonia. Much work with hydrazine is contemplated when it becomes available. A great deal of work has been done with gasoline, alcohols, and mono-ethylaniline, and the monopropellants nitromethane and hydrogen peroxide.

The small amount of work on metals is discussed, as well as the very large program on the boranes and borohydrides which is projected for the time when the fuels themselves become available, and which is just now getting started.

There is also a review of the rather small effort concerned with new fuels, specifically the combinations of ammonia and amines with the boranes and borohydrides, and the addition of oxidizing agents to hydrogen peroxide.

PART 3, MATERIALS.

The review of materials of construction summarizes the government sponsored research work on metallic and ceramic materials suitable for use at elevated temperatures. In addition, brief discussions are given of the fields of research important in connection with the development of materials, of the present state of knowledge, and of outstanding problems.

No criterion exists by which the high temperature properties of a material can be predicted, and hence most of the work on the development of materials must be empirical. To furnish a logical basis for the guidance of a research program on materials, a better understanding of the solid state at elevated temperatures is important.

The most satisfactory high temperature alloys available at present are those developed for use in gas turbines. Further improvement of these alloys may be expected, but the requirements for rocket and pulse jet engines are so severe that work on the high melting point metals not commonly used for construction is to be emphasized.

The requirements for resistance to thermal shock and for strength at elevated temperature have opened new fields of research in ceramics about which little is known. High temperature techniques and testing methods need further study. The high melting compounds heretofore not used at all, or used only for special purposes, will be more thoroughly investigated.

PART 4, FLUID MECHANICS.

The review of fluid mechanics is a survey of research projects sponsored by the government in the field of compressible fluid flow, with particular reference to the bearing of these projects on aircraft propulsion devices.

The fundamental research on compressible fluid flow phenomena appears to be concentrated at the moment in the transonic and supersonic velocity regions, and is mainly concerned with the study of shock waves and their interaction with fluid and solid boundaries. Theoretical studies on transonic and supersonic flow phenomena are greatly retarded by the intractibility of the mathematical equations, when the effects of heat, viscosity, and compressibility are included in three dimensions. It is quite apparent that the physical facts relating to this domain will not be adequately explained, nor the mathematical equations easily solved, until mathematical computing mechanisms of very high speed and of highly advanced design are employed on these problems.

In the field of boundary layer investigations, the research in the subsonic domain is concerned with studies of boundary layer stability and the transition of a laminar to a turbulent boundary layer. The theory and mechanism of boundary layer stability appears to be well understood in the subsonic velocity region. In the transonic and supersonic region, the work on boundary layers concerns stability studies and the interaction of boundary layer and shock waves. Boundary layer theory for transonic and supersonic velocities is not well developed; this part of the fluid flow field is one of great importance to the control and maneuverability of air missiles.

The majority of the research on diffusers and nozzles is directed toward obtaining enough fundamental information for the improvement of diffuser and nozzle design, especially in the Mach number range from 1.5 to 3.5. The current development of missiles for this speed range demands fundamental information concerning compressible flow through ducts. The development and use of hydraulic analogy techniques has been concentrated on flow problems in relation to the improvement of diffuser or nozzle design. In only one project not connected with the design of channel shapes is the hydraulic technique used for investigating the fundamentals of wave interaction in compressible fluid flow.

The phenomenon of turbulence itself is very incompletely understood. As in the case of compressible fluid flow in the transonic or supersonic regions, a generalized theory of turbulence can be explained only through the solution of the equations of motion in three dimensions. In the case of turbulent flow, for example, the elimination of a dimension in the analysis eliminates the phenomena which the analysis is attempting to describe. It is only by chance that the one- and two-dimensional theories of turbulence can give as good an agreement with experiment as has been observed. With one or two exceptions, the effort in turbulence is concerned with its study in connection with phenomena whose mechanism is as little understood as turbulence itself. There is much interest in studying the combination of turbulence with combustion by correlating the velocity of a chemical reaction with changes in the controlled turbulence level of the fluid entering a combustion zone. It is unfortunate, however, that so much turbulent flow is created by the combustion process that the controlled turbulence introduced before combustion takes place has little apparent effect on the mechanism of the chemical reaction.

Closely associated with the macroscopic phenomena of turbulence is the mixing of fluid streams. This includes liquid-liquid mixing, liquid-gas mixing and gas-gas mixing of streams flowing at nearly the same or at greatly varying velocities. The cases of primary interest are, as one would suspect, the most complicated. These cases include the condition in which a phase change takes place, such as in the atomization of liquid fuels, or the condition in which there exists a shock front between two fluid streams with no evaporation or change in phase. Atomization processes are not well understood. Current work on their relation to combustion is being conducted on a purely empirical basis, in order to obtain enough experimental data to point the way toward a valid theory for the dependence of droplet size on viscosity, surface tension, droplet velocity and other parameters describing the fluid state.

The mechanics of non-uniform gases has just begun to receive widespread attention through the requirements of understanding flight conditions at high altitudes and under conditions where the mean free path is comparable with a linear dimension of the missile.

A relatively small effort is being exerted in the application of theory to the aerodynamic and to the combustion phenomena in a system subjected to periodic forces, such as the pulse jet.

The wind tunnel facilities now in operation or in design for transonic and supersonic research provide only for the undertaking of small scale studies of flow phenomena through or around airfoil sections. There are no facilities for full scale testing of body or wing sections of proposed guided missiles at supersonic speeds.

PART 5, HEAT TRANSFER AND COOLING.

In examining the present work on the heat transfer problem, it is found that a many-sided attack has been launched to develop means of control of the large amounts of heat which are evolved by jet propulsion devices. Nevertheless, before summarizing the work under way, it is desirable to consider in general what some of the pressing problems involve.

Basic heat transfer studies have been seriously neglected by investigators in the liquid rocket field. As rocket performance improves, these problems become more and more severe, so that future development work will be most adversely affected by the lack of knowledge of the fundamentals upon which heat transfer depends. For example, data for heat transfer by convection are not available for determining proper coefficients under conditions of high temperatures and Reynolds numbers, with variable flow rates. Some data by McAdams and his co-workers are available for temperatures of 1000°F and Reynolds numbers up to 500,000, but the flow conditions were constant so that the data do not apply specifically to this problem. Further, convergent and divergent nozzles give higher heat transfer rates than are produced in a straight-wall tube under equivalent conditions, and this must be considered. Emphasis on heat transfer is therefore extremely important at this time.

Another of the key theoretical problems, as yet unsolved, is that of heat transfer under conditions of high flux density, such as boiling heat transfer, or transfer from a wall to a liquid where the temperature of the wall is above the boiling point of the liquid. These are problems which must be attacked vigorously before a complete solution of porous and film cooling problems can be achieved.

Heretofore, radiation has not been of great importance as a heat transfer mechanism owing to the temperature ranges usually employed in most heat transfer applications. However, in a rocket motor combustion chamber, radiation can be responsible for 30% of the total heat transfer, although in the critical point of the throat this may amount to only 10% of the total. It is therefore evident that the radiation problem becomes most important at the high temperatures of high energy rockets.

At the present time there is considerable question as to how effective film cooling and sweat cooling will be in handling radiation heat transfer, and it is vital that much more work be conducted to study the effect of cooling on radiation. Further, the whole program of sweat cooling is still in its initial stages and only experimental motors exist which use sweat cooling. Regenerative and film cooling are proving inadequate at the high temperatures now encountered.

Work under approximately twenty-five contracts covers the field of heat transfer and cooling.

Investigations have been initiated to determine coefficients of heat transfer under conditions which are radically different from those encountered in the more classical engineering applications to internal combustion engines. Present data for coefficients are most unsatisfactory, therefore, and present work is designed to calculate coefficients under conditions of high temperatures, high velocities and fluctuating flow rates. Studies are also being made of transfer at high flux densities, and transfer to liquids at temperatures above their boiling points.

Some work is being done on the contribution of radiation to the total heat transfer. This phase has been considered only to a small degree previously and little is known about methods of control.

Cooling is receiving considerable attention, especially the use of porous cooling in the light of newly developed porous materials. This latter method appears more promising than film or regenerative cooling, but detailed study of the parameters involved will be necessary before full advantage can be taken of the possibilities.

PART 6, INSTRUMENTATION.

On the thesis that high temperatures and high gas velocities are, from the standpoint of instrumentation, the two most characteristic conditions of the liquid-rocket and pulse-jet fields, much emphasis is being placed on the measurement of parameters of systems involving combustion processes.

The actual survey material reviewed covers the principal experimental conditions under which measurements are made. Included are power plants, diffusion flames, stationary flames, moving flames, closed chambers, and soap bubbles. The instrumentation requirements for each condition are pointed out as well as some of the major difficulties. The three basic difficulties are (1) effects of the system on the instrument, (2) effects of the instrument on the system, and (3) fluctuations in the system.

The basic mechanisms of operation of some of the principal instruments and methods have been considered. These include techniques for measuring pressure, temperature, gas velocity, turbulence, flow patterns, flame propagation velocity, and others, together with their limitations and errors.

The most significant conclusion apparent from a review of work on instrumentation related to pulse jets and liquid rockets is that there is an insufficiency of dissemination of experimental methods and measurement techniques. This results in much duplication, wasted effort, and lost time. Often times the main aim in an investigation is neglected while effort is spent on developing an instrument in use elsewhere. There is a great need for a consolidation of methods already available and an integration of effort in methods being developed.

Another factor evident from this study has its origin in the diversity of schemes of measuring the same physical parameter. This results in difficulty in interpreting data from various sources. Standard methods, where possible, would be helpful and a reference laboratory is desirable.

Finally, the rather obvious conclusion is that in many cases no acceptable method exists for measurement of required parameters under relevant physical conditions and in other cases the methods are only moderately successful. The investigation of new techniques must be continued but under an integrated program.

III. SUMMARY OF VOLUME II

PART 1, PULSE JET ENGINES.

The major portion of the effort in pulse jet development in the United States has been directed toward the improvement of the German V-1 type motor. This effort has proceeded almost entirely along empirical lines and has led to the following improvements:

A. More than double the thrust per frontal cross-sectional area by effectively increasing the air valve intake area.

B. Increased valve life from 30 minutes to several hours by providing soft valve seats, sandwich type valves, positive valve seating, and reduction of seating velocity.

C. Reduction in specific fuel consumption from 4.0 to 2.6 lbs per lb of thrust, or lower.

The common hydrocarbon fuels used in Diesel and Otto cycle engines show negligible differences in performance; oxygen carrying fuels have not shown the favorable increase expected.

Further improvements are greatly retarded by the lack of a working theory for the pulse jet cycle. The existence of nonlinear oscillation problems, gas dynamics problems, turbulent combustion, and the formation of shock and detonation waves make the analysis of this cycle a difficult undertaking.

Pulse jet development is also dependent upon adequate test facilities. Internal and external aerodynamics are equally important and require simultaneous testing for accurate performance measurement. Flying test stands, such as the Naval Air Missiles

Test Center A-26 airplane, provide for two important variables, namely velocity and altitude. Obviously the ranges of these two variables are limited by the performance of the airplane. Unfortunately, ground facilities of the necessary size (and performance) have not been available to pulse jet development agencies. In some cases ramjet facilities could be used if they were to be made available. The operation of pulse jets at high subsonic and at supersonic speed ranges has not been investigated due to this facility problem. Cornell Aeronautical Laboratory has, however, investigated an intermittent supersonic diffuser for pulse jets.

The constant search for means to improve the efficiency and/or speed range of pulse jets has led to the proposal of several new types or configurations. These are listed below:

A. *The Ducted Pulse Jet* is a standard pulse jet immersed in a duct which has a supersonic diffuser on the front and a venturi type nozzle at the rear just behind the pulse jet nozzle. The principle is to slow the air to a subsonic speed in the duct at which speed the pulse jet will perform satisfactorily.

B. *The Pulse-Ramjet* is essentially the same as the ducted pulse jet except that additional fuel is injected into the duct at or near the pulse jet nozzle. The duct, therefore, acts also as a ramjet giving additional thrust.

C. *The Multiple Tube Pulse Jet* has been suggested as a means of reducing noise level when the various motors are operated out of phase; it has also been suggested as a means of providing nearly constant air flow into the diffuser of a duct which surrounds the motors.

D. *The Valveless Pulse Jet* has been proposed based on two different principles. In the first case a quarter wave tube (with respect to the main pulse jet cycle) is used as an entrance to the combustion chamber which may be of standard design. This quarter wave tube acting in resonance with the combustion chamber and tail pipe serves as an acoustical valve. The second type uses a supersonic diffuser in which an internal shock wave traveling back and forth acts as the valve. Tests by Cornell Aeronautical Laboratory with a supersonic diffuser and a fluctuating back pressure indicate that this is possible at high ram pressures.

E. *The Imposed Cycle Pulse Jet* is proposed to obtain higher peak combustion chamber pressures. In its simplest form the air inlet, fuel injection, and ingition can be controlled. The next step would control the exhaust portion of the cycle, by a suitable valve and timing mechanism.

F. *The Acoustical Radiation Jet* utilizes an oscillating piston in a tube. The piston cycle is the same as the natural resonant frequency of the tube and thrust is produced by the acoustic radiation pressure of the air column on the piston. Air is drawn in and exhausted at the open end of the tube. The Bodine Soundrive Company of Hollywood, California, is responsible for this development.

All of the above proposed pulse jets are being investigated from the theoretical and/or experimental standpoints.

PART 2, LIQUID PROPELLANT ROCKETS.

The two important advantages of the liquid propellant rocket are its ability to function in a vacuum and its independence of thrust with respect to velocity. It is useful and in many cases mandatory for propulsion of guided missiles, sounding rockets, interceptor aircraft, superperformance of aircraft, jet assisted take off, and torpedoes or other underwater missiles.

The principle of operation of liquid propellant rocket motors is simple. An injector provides a means of entrance of a combustible fluid to a combustion chamber where it is burned at a high chamber pressure and the nozzle then provides a means of converting the high pressure gases into a high velocity jet from which a thrust results. Thrust and mass flow rate are the basic measurements of performance taken on rocket test stands. From these the effective jet velocity may be calculated. (Thrust equals mass flow rate times effective jet velocity.) The characteristic jet velocity[1] c^* may be calculated from the thermochemical data or from the product of the chamber pressure and the nozzle area divided by the mass flow rate. The ratio of the effective exhaust velocity to the characteristic exhaust velocity is known as the thrust coefficient. It is dependent on the exhaust products ratio of specific heats, the chamber pressure and outside pressure, and the nozzle exit to throat area ratio. Specific impulse which is determined by dividing g, the gravitational constant, into the effective exhaust velocity, is a common performance parameter. The inverse figure of this is called the specific propellant consumption and is given in lbs per second per lb of thrust.

[1]May be regarded as a measure of merit of a given propellant combination.

It appears impossible to establish a performance parameter based on combustion chamber geometry. L*, known as the characteristic length, is the ratio of the combustion chamber volume to nozzle area. It is commonly used to define combustion chamber volume. It has no apparent effect on combustion efficiency above a certain value; its minimum value varies with the propellant combination.

There appears to be no upper limit to the size of motor which may be built from present design considerations. The lower limit appears to be of the order of 50 to 100 lbs. due to practical minimum size injector orifices, combustion chamber geometry and nozzle exits.

Regeneratively cooled motors are the most commonly used type today. The heavy, short duration, heat capacity type motors have been discarded. Film and transpiration, or sweat, cooled motors are presently receiving a great deal of attention since it is felt that regenerative motors may not be adequate for the high energy fuels.

The problems of injecting the propellants into the combustion chamber and properly mixing them are as manifold as are the possible propellant combinations. Taking into account all of the variables would be a tremendous task and it is important to note the present proximity of effective jet velocity to the theoretical value, indicating relatively high efficiencies for the common types now in use. Combustion stability (elimination of "chugging"), motor heat transfer, and safety from leakage inside and outside must be considered.

The use of spontaneously ignitable propellants has eliminated serious ignition problems in many cases. However many useful fuel combinations are not spontaneously ignitable and the problem has been handled without undue difficulty.

Once a rocket motor reaches a state of thermal equilibrium its duration is limited only by the amount of propellant available. Present day regeneratively cooled motors have demonstrated, without failure, an accumulated operation time of over twenty hours. The general adoption of the cylindrical form for motor construction indicates the influence of fabrication on motor design. Permanent assembly by welding, which virtually makes repair impossible, has generally been adopted because it provides a simple light weight leakproof joint. The possibilities of other methods of construction have not been thoroughly considered. Construction methods which would allow variable nozzle exit areas offer appreciable increases in efficiences where flight throughout a broad range of altitudes is encountered. This problem has not been seriously investigated to date.

Propellants are fed to rocket motors either by pumping or by pressurizing. The latter is simpler and usually lighter for operating periods up to 50 seconds. Pump fed systems are usually lighter for periods over 50 seconds and the major portion of the systems under development today are pump fed. Turbine driven high speed centrifugal pumps are, generally speaking, more efficient and satisfactory for the common propellants in use, since 65 to 85% of the total energy available may be realized. In most cases the turbine is driven by the exhaust gases of a separate combustion pot, however, several systems have been proposed or are under development where the exhaust gases of the rocket motor drive the turbine. Other pumping systems and drives have been considered but none is as fully developed or as successful as the above combinations.

The choice of liquid propellants for a given rocket system depends on several factors: (1) availability, (2) specific impulse, (3) density, (4) properties (chemical and physical), and (5) safety and handling characteristics. Propellant combinations which have a high combustion temperature and low average molecular weight of exhaust gases produce the highest specific impulse. In addition the density impulse (the product of specific impulse and density) has been found to be useful, since it gives an indication of the volume required to handle the propellants. This is particularly important in missile applications where drag is concerned, but it must be remembered that it has no fundamental significance with regard to motor performance. Basically, only four oxidizers have been developed to a usable point. These are red and white fuming nitric acid, mixed acid, liquid oxygen, and hydrogen peroxide. To this list fluorine, nitrogen dioxide and water have been added but have not at this time received extensive development. Liquid hydrogen, hydrazine, and ammonia have received considerable attention recently as very promising fuels. Considerable thought has also been given to light metal hydrides such as lithium and aluminum borohydride, and to diborane and pentaborane. They have not been produced in sufficient quantities to provide a good evaluation. Nitromethane and hydrogen peroxide are the only monopropellants that have received a good deal of attention. The low performance of hydrogen peroxide as a monopropellant has stopped its development and the hazardous characteristics of nitromethane have considerably slowed its progress.

Based on a good specific impulse, a reasonable chamber temperature, and a high density impulse the following propellant combinations show a great deal of promise.

Propellant Combination	Density Impulse
Hydrazine — Fluorine	357
Hydrazine — Hydrogen Peroxide	307
Hydrazine — Red Fuming Nitric Acid	288
Hydrazine — Liquid Oxygen	279
Aniline — Red Fuming Nitric Acid	307
Aniline — White Fuming Nitric Acid	294
Monoethylaniline — Mixed Acid	293
Nitromethane — Hydrogen Peroxide	276
Methyl Alcohol — Hydrogen Peroxide	278
Tonka — White Fuming Nitric Acid	306

Completed liquid rocket development in the United States has produced systems ranging in size from 100 lbs thrust to 20,000 lbs with operation from 20 seconds to continuous. The current development work in the United States may be conveniently divided into the following classes: (1) acid oxidizer systems, (2) gaseous and liquid oxidizer systems, (3) hydrogen peroxide systems, (4) nitromethane systems, (5) general propellant studies, including high energy fuels and systems, (6) rocket motor cooling, combustion chamber, and injector studies, and (7) component development and miscellaneous liquid rocket problems. The technical effort of eighteen agencies designing, building, or testing rocket equipment or components is discussed according to the above division. This includes research work applicable to the general problem as well as a brief description of complete rocket systems under development. These complete systems range in size from 220 lbs to 290,000 lbs thrust. The latter unit is in the design study stage by the M. W. Kellogg Company and is the largest known rocket power plant contemplated.

The abovementioned agencies employ approximately 567 engineers and scientists and 1367 technicians and mechanics. The facilities of each of the agencies are also briefly described.

IV. GENERAL RECOMMENDATIONS

The following recommendations do not apply specifically to any particular phase of Project SQUID or the general effort in propulsion. Instead, they represent a goal toward which effort should be directed for the universal enhancement of the jet propulsion program.

A. *SCIENTIFIC PERSONNEL.* There is a serious shortage of scientific personnel in both the research and development phases of the propulsion program. Little is being done to establish educational programs to provide for the training of scientists in this field. Those who have entered the jet propulsion field during and since the war have acquired background and experience in the field simply by working on specific problems. Only a few institutions provide the proper academic background necessary for technical personnel in this field. In order to arouse the interest of young and progressive scientists in jet propulsion it is recommended that an educational program be planned and initiated which will expose the problems in the field and present enough scientific and technological information to allow the novice a sufficient working knowledge to understand the scope and nature of the propulsion work.

B. *NEED FOR FUNDAMENTAL RESEACH.* The present requirements of the services for the development of propulsion devices cannot be fulfilled by making use of the fundamental scientific information now available. Problems arise in development, the solutions for which can only be found through the exploratory methods and techniques of research. As the future requirements in development will pose even more difficult problems for the research scientist, it is necessary that the program in jet propulsion be founded on a good working balance between fundamental research investigations and the development of devices of an improved or novel design. It is therefore recommended that the program for research in the field of jet propulsion be given adequate support to continue fundamental investigations and be given the proper assistance in making the results of these investigations useful to the development program.

C. *NEED FOR LONG RANGE PLANNING IN DEVELOPMENT.* There appears to be a tendency, with the reduced budgets for the general development programs, to return to the solution of problems by empirical methods. This procedure is not new; it was followed during the last peacetime period. Devices were improved bit by bit and model by model to the practical exclusion of long range development of radically new design. It characterizes particularly the development of the reciprocating engine and the military airplane. Had the government sponsored basic research in long range development the gas turbine and the highspeed airplane would have been realities long before the past war. It is recommended that the development program be shaped to support design studies and experimental work of an exploratory nature on devices of novel design. A program of this character will expose problems of a fundamental nature at an early stage and will permit planning the basic research so that it can contribute the required information to the development program at the proper time.

D. *NEED FOR COOPERATION BETWEEN RESEARCH SCIENTISTS AND DEVELOPMENT ENGINEERS.* The programs for fundamental research and development cannot proceed independently one of the other. The research scientist must know the types of problems facing the development engineer, and the development engineer must know what fundamental scientific information is available and how to use it. In examining both the research and the development contracts under government sponsorship it was found that work in the jet propulsion field of a rather specific nature was being conducted under broad contracts or phase assignments. Knowledge of all of the phase assignments or problems under each of the many broad contracts in this field would require an administrative structure much larger than any government unit of this character at present. The central problem is not that of making the government a clearing house between research and development for which this detailed knowledge would be necessary but is rather that of acquainting the personnel in each of the two fields with the information available in the other by personal contact of the respective members. It is therefore recommended that research scientists be used as consultants on development programs in fields in which they are specialists in order that they may become more closely associated with the technical details of the development work and that they may bring to bear the results of research on the development program.

E. *ADMINISTRATION OF RESEARCH AND DEVELOPMENT.* With the recent budget reductions throughout the federal government, there has been substantial curtailment in the funds for research and development. This is a necessary part of the adjustment to a peacetime economy. More serious, however, than the actual reduction of these funds to the Services is the severe cut which the administrative branches in government agencies have suffered. While still responsible for the administration of a research and development program amounting to many millions of dollars the government agencies, especially the Services, have been forced to reduce their staffs to a point where it is extremely difficult, if not impossible, for the remaining limited personnel to provide proper administration. Travel and communications cuts have prevented the responsible administrative personnel in the government from acquiring enough information about the technical program to know whether the public funds are being properly and wisely spent. If the present level of spending in this field is to continue it is strongly recommended that a larger portion of these funds be allocated to the government agencies administering research and development in order that the necessary trained personnel may be obtained and provision made for their travel to, and communication with, the research and development work for which they are responsible.

F. *SPECIFICATIONS.* The research and development projects visited during the Field Survey included work under both Army and Navy sponsorship as well as, in a very few cases, projects under joint sponsorship. Since the visits to the various contractors and military facilities were made in closely spaced intervals, the contrast and comparison of the governing specifications and regulations for Army and Navy project was conspicuous. It was noted in some instances that competitive designs for both Services were underway in close proximity and sometimes in the same facility. It became apparent that slight differences in general specifications as well as in design specifications caused some duplication of effort. It seemed that some slight compromise by either Army or Navy would result in the development of a missile or system capable of meeting the requirements of both. It is recognized that considerable effort has been expended and great progress made toward accomplishing this unification of specification in standard parts in the JAN Specifications. It is felt that further effort should be extended toward the achievement of these objectives in the specifications concerning the finished equipment.

G. *SYMPOSIA.* It is recognized that some duplication and isolation of effort is beneficial, since it serves as a check on similar work and may open new avenues of thought in the same field; but this isolation must not extend to the point where the solution of specific problems is retarded by the withholding of the essential knowledge of that solution by one investigator while others expend time and effort toward that same solution.

Each of the members of the Technical Survey Group, during the interrogations in which the information contained in the reports were gathered, requested a specific statement of policy from the contractor's technical representatives concerning the willingness of the contractor to attend and contribute to symposia. It is significant that enthusiasm and interest were universal.

It is recommended that effort of the sponsoring agencies be increased toward the establishment of meetings of the specialists concerned with the detailed fields of work being conducted in jet propulsion. It is emphasized that invitation to attend these symposia should extend beyond the administrative level to those scientists and engineers actually engaged in the performance of the detailed design, analysis, and production. The value of personal contact of personnel through these meetings cannot be overemphasized.

The costs incurred by the contractors in supplying personnel for these symposia should be a reimbursable item of expense. However, in some cases, no fund exists in the budget of the military facilities or testing laboratories for this contingency. It has been suggested that the establishment of a special fund to provide money for government agency employes to meet the additional expenses incurred in attending symposia would permit more extensive participation by government personnel.

V. RECOMMENDATIONS OF VOLUME I

PART 1, COMBUSTION.

It is believed that the program described in the report on combustion covers rather well the most significant and necessary projects in the field, though it is quite evident that more people should be working on such projects. It is also felt that some elaboration of the program should be made in the following specific instances:

A. Investigations of the mechanisms and the rates of reactions must be extended to include the propellant systems now being used in jet power plants and those proposed for future use. Metals, metal alkyls, metal hydrides, and hydrazine in their reactions with the usual oxidants need to be investigated. Similar information for the reactions of fluorine and its derivatives with fuels is pressingly required. Considerable work is being done on developing new techniques for studying the mechanism of combustion reactions but there is still a need for studying propellant systems, particularly liquid systems, using any techniques which may be available.

B. Chemical equilibria should be studied at high temperatures and pressures in static and flowing systems to determine the concentrations of the components at equilibrium, the time required for the establishment of equilibrium, and thermodynamic properties as a function of time. Studies of reactions in which some of the products are solid and the others gaseous are needed. This information, which is not available, is necessary for the accurate computation of rocket performance.

C. The thermodynamic properties of fuels and products of combustion should be determined at high temperatures over a range of pressures to give data for combustion calculations and for checking theory with experiment. Calculations and measurements are being made of some of these properties for some of the compounds, but the program needs to be extended.

D. Basic studies of combustion at high and at low pressures should be extended. Liquid propellant rockets operate presently at 300-400 pounds per square inch pressure, solid propellant rockets up to 2000 pounds per square inch. Investigations of the reactions of fuels with oxidizers at pressures at least up to 200 atmospheres (3000 pounds per square inch) are necessary. Determination of the mechanism of combustion may be more practicable at low pressures than at atmospheric pressure, and valuable information may be obtained, although the reactions may not be the same at low pressures as at atmospheric pressure.

E. Investigations of the effect of turbulence on combustion are of prime importance, and it appears that further development of the theory of turbulence and of techniques for measuring turbulence will be necessary in this connection. Turbulence is discussed in more detail in Part 4 of Volume I, "Fluid Mechanics."

F. The development of techniques for measuring the pressure, temperature, and velocity of moving gas streams should be emphasized here, although it will be mentioned again under Part 6 of Volume I, "Instrumentation." Instrumentation is one of the most difficult problems in combustion work.

G. More attention should be given to basic studies of ignition phenomena. Little is known about the energy requirements or about methods of reducing ignition delay.

H. Many combustion investigations have had too limited objectives. The studies have been carried out to learn what happens under specified experimental conditions with too little consideration of possible contributions to the understanding of the basic factors involved. Wherever possible, even in essentially development programs, experiments should be performed under simple, well-defined, and accurately measured conditions, so chosen that the results can be interpreted in terms of fundamental parameters. The immediate objective of combustion research is to develop quantitative relations between appropriate variables. The ultimate objective is to explain combustion in terms of the detailed mechanisms involved. These objectives can be attained only if suitable experimental data are available to check and guide theory.

I. A positive effort should be made to correlate the efforts of different groups working toward solutions of the same problems. Such coordination appears particularly desirable for studies described in this report under the headings. Chemical Kinetics, Turbulence, Flame Velocity and Stability, and Combustion in High Speed Gas Streams. These difficult and important problems, requiring the efforts of several groups, can be solved efficiently only by the free exchange of information on results, procedures, and experimental difficulties at the technical as well as the administrative level.

PART 2, FUELS.

Many of the problems faced at present with respect to fuels are of a practical nature, having to do with such matters as better methods for manufacturing them, methods of increasing their stability, lowering their freezing points, etc. These are not being neglected, though it is believed that in the specific case of hydrazine a laboratory investigation of methods of preparation would be worthwhile.

Very little work is being done with liquid ammonia as a jet fuel, though this stable substance gives excellent calculated values in propellant systems and needs more extensive investigation.

Further work is needed on determining why the boranes and borohydrides are unstable, and whether anything can be done to increase their stability. A more fundamental approach is needed than has heretofore been adopted. All of the decomposition reactions need to be identified and an effort made to determine which is the rate controlling reaction, and whether the energy relationships are such that there is a possibility of repressing a critical step in the process.

With respect to nitromethane and tetranitromethane, opinions differ as to their inherent stability although no one doubts that they will explode under certain circumstances. But no one has yet determined basically why they are unstable, or determined the sequence of reactions leading to their decomposition. Such an investigation would be very worthwhile and could assist in the selection of a stabilizing additive.

It is recognized that much thought has been given to the problem of making and stabilizing atomic hydrogen, and the conclusions are not encouraging. It is realized that atomic hydrogen has a very short life at ordinary temperatures, though not at 4000°C. It would seem desirable, under the circumstances, to undertake a limited program on the study of atomic hydrogen, and in addition, on metastable molecules involving hydrogen, helium, and argon.

Nothing is being done experimentally on the use of liquid fluorine, fluorine oxide, or the fluorine bromides and chlorides as oxidizing agents. Several institutions, however, have contemplated such work. An experimental program should be started, even though it cannot be pushed rapidly due to the difficult handling problems. The safe handling and proper storing of these toxic and corrosive materials is a large problem in itself which needs to be undertaken.

The thermodynamic properties of fuels, oxidizers, and products of combustion are being determined (or collected) by many investigators, but there is still needed much more information on them at very low and very high temperatures. The deviations from perfect gases of the combustion products at very high temperatures and pressures need more investigation. This includes the variations of the constant pressure and constant volume specific heats with temperature and pressure at the upper limits.

The dissociation equilibria of reaction products of fluorine at high temperatures need to be investigated. More information is needed, for example, on such products as HF, CF_4, NF_3, BF_3, LiF, and NaF. Programs have already been initiated to study the dissociation of the metallic oxides.

The problems of handling hydrogen peroxide are being well covered. There has been much good work done on its catalytic decomposition, and some work on its thermal decomposition but a reliable method of decomposing it thermally is needed. Such a study should be undertaken.

In evaluating fuel-oxidizer systems the large number of variables including physical properties, heats of combustion, ignition lag, specific impulse, density impulse, the constant pressure and constant volume ratio of specific heats of the reaction products, changes in volume on combustion, and combustion efficiency are at present treated in separate equations. It would be exceedingly useful if some way could be devised to combine these variables into a general equation which would express the over-all value of a fuel or a fuel-oxidant system.

There is a very great need, of course, for more information on the chemical kinetics of combustion reactions for all fuels whether they are carbonaceous, or a hydride of nitrogen or of a metal, and for the various oxidants, whether they are oxygen, hydrogen peroxide, nitric acid, a halogen, or specific combinations of these. This matter is referred to more specifically in Part 1 of Volume I, "Combustion."

PART 3, MATERIALS.

The research projects described in this report on materials make adequate provision for the development of metallic and ceramic materials for use in the near future by the improvement of the best of the materials now known. It is felt, however, that relatively more emphasis should be placed on the solution of the outstanding problems discussed in detail in

Section V of Part 3 of Volume I. The following recommendations are made based on a stu ly of the problems concerned with properties and development of materials, high temperature techniques, development of representative tests, and properties of materials for satisfactory performance:

A. Research on the physical and chemical factors which affect the properties of metals, alloys, and ceramics at high temperatures should be continued and extended.

B. Basic research to determine the properties which a material must have to give satisfactory performance should be extended. More information on the influence of thermal conductivity of metals and alloys is urgently required.

C. The development of high melting point metals, borides, carbides, nitrides, and oxides should be accelerated.

D. Special provision should be made for the development of high temperature techniques and apparatus to increase the temperature range over which quantitative data can be obtained.

E. A project should be set up to study testing procedures, particularly for ceramics, and eventually to recommend the adoption of the most suitable for general use.

F. More emphasis on investigations to establish the correlation between laboratory tests and service results is considered necessary for both metallic and ceramic materials.

PART 4, FLUID MECHANICS.

On the basis of the present survey of research projects sponsored by government agencies in the field of fluid mechanics, the following recommendations are made:

A. That a program be formulated to provide for a general study of compressible fluid flow problems on large scale computing machines. The solution of certain differential equations for three-dimensional flow is necessary to advance basic knowledge in fluid mechanics. In order to obtain solutions to certain problems in this field the work is so laborious as to preclude the possibility of manual computation. In the field of turbulence, for example, it would be helpful to undertake a three-dimensional analysis of one of the more successful two-dimensional theories. This should serve as a guide to the development of a general theory for large scale turbulence and ought to be undertaken in conjunction with Recommendation B below.

B. That additional sponsorship be provided for the formulation of a new theoretical approach to the theory of turbulence. There is only one such project planned, this will make use of modern advances in statistics aiming at a generalized theory for large scale turbulence. The effect of turbulent transport phenomena is of basic importance to the kinetics of combustion reactions.

C. That fundamental studies of atomization and mixing of liquid streams be continued. The influence of mixing and atomization on the combustion process is not clear. A program in this field must start with a study of the simple mixing of two fluid streams without combustion reactions; at a later stage these studies should be augmented by introducing a combustion reaction.

D. That the hydraulic analogy technique be investigated for more general use as a simple tool for qualitative compressible flow studies and as an educational aid to instruction in high velocity flow phenomena.

E. That the application of the theory of acoustic radiation be studied further with reference to the pulse jet engine and to the formulation of a valid theory of the pulse jet cycle.

F. That continued support be given to studies of boundary layer phenomena in the transonic and supersonic velocity range. A much better understanding of drag forces, surface heat problems, shock wave formation and interaction is essential to the advancement of the guided missiles program.

G. That the effect of high Reynolds numbers at high velocities, particularly in the supersonic range, be studied carefully before design specifications are formalized for a large supersonic wind tunnel.

H. That the design of a large supersonic wind tunnel with test section of the order of 20′ x 20′ for studies up to Mach number 3.0 be sponsored by the government, making use of the basic information in government sponsored and other research in this field for assistance in design. This design study should point out, if possible, what the capabilities of such a wind tunnel facility are and whether it appears feasible to test full scale missiles by this method as opposed to open range testing.

PART 5, HEAT TRANSFER AND COOLING.

From the survey on heat transfer and cooling, it is evident that all of the work being presently undertaken is of vital importance and should be carried on with dispatch. However, it is also apparent that much stronger emphasis should be placed on the objectives listed below.

A. The problems of high heat flux transfer and boiling heat transfer must be attacked with more vigor.

B. Fundamental heat transfer studies have been neglected, and a greater volume of work should be planned for investigations under conditions of high temperatures, variable flows, high Reynolds numbers, and convergent-divergent tube shape.

C. Further work should be initiated immediately on the study of the contribution of radiation, which becomes increasingly important at high temperatures. This should be correlated with cooling investigations to determine whether present cooling methods can cope with transfer by radiation.

D. Present cooling methods require further study to obtain maximum benefits. Porous cooling appears the most promising and must therefore be investigated much more widely, especially as it is least well understood.

E. No cooling method now envisaged will probably be adequate for motors heated by nuclear energy. It is therefore imperative that more emphasis be put on a search for new cooling methods that will promise satisfactory results.

Although work on all these points is now being carried on, it is felt that in no case is the volume of the effort proportional to the importance and urgency of the problems connected with each.

PART 6, INSTRUMENTATION.

The recommendations arising from a study of the survey of instrumentation includes five specific objectives.

A. *Instrumentation Committee.* — A central committee should be formed for the purpose of consolidating, disseminating and integrating measurement methods for jets, rockets, and associated basic research. This should be on a *nationwide* basis with cooperation from Universities, Armed Forces, Government Laboratories, Industrial Laboratories, and Scientific Societies.

B. *Instrumentation Symposia.* — Under the direction of the Committee, a series of symposia on measurement and calibration methods and instrumentation should be held.

C. *Instrumentation Bulletin.* — A regular bulletin relating to experimental techniques should be issued by the Committee. This would be based on contributions from the various cooperating laboratories.

D. *Instrumentation Handbook.*—A practical handbook on methods should be edited and published by the Committee. The handbook would include sections by various experts in the field.

E. *Reference Laboratory.* — A reference laboratory should be established under the direction of the Committee for the purpose of setting up standard methods and designs. Other laboratories throughout the country might be utilized for part of the program.

VI. RECOMMENDATIONS OF VOLUME II

PART 1, PULSE JET ENGINES.

Although the development of the pulse jet has been seriously retarded by the lack of a reliable theoretical evaluation of its operating cycle, its development has proceeded and advanced on an empirical basis. Modifications of the original V-1 engines have increased specific thrust and decreased specific weight and fuel consumption. The early engine burned for a half hour; new engines operate for many hours. Many other improvements have been accomplished during little more than two and one-half years of experimentation. Trial-and-error development has evolved some rather radical design changes, and in some cases has pointed the way to certain definite improvements.

The lack of a reliable theoretical method of evaluation makes the planning of future work entirely dependent upon scattered test results and intuitive planning without factual basis. Before suggesting a development program, many experts in the field were consulted. The following recommendations represent their considered opinion concerning a program for future work.

A. Since pulse jets are critically affected by their external aerodynamics, a large air supply is a primary requirement for testing. To insure any measure of success, tests must be made in free jets of large cross section and at Mach numbers extending from the subsonic to the supersonic range.

B. The over-all program should be directed toward increased operational velocity and efficiency with supersonic operation as the ultimate goal. Specific advancements have been made in this direction. An immediate program should proceed with the development of the supersonic ducted pulse jet.

C. Investigations should continue in an effort to establish an accurate theoretical prediction of pulse jet performance for all configurations and under all operating conditions. Combined theoretical and experimental attack must correlate the important factors affecting operation. Specifically, consideration should be given such parameters as internal and external aerodynamics, geometry factors affecting ignition, fuels and fuel injection, gas kinetics, and combustion.

D. In order to develop an expendable and efficient engine for subsonic operation, work should continue on the improvement of the conventional pulse jet. Future work, however, should be devoted to the application of specific scientific principles to engine design rather than improvement by trial-and-error methods.

E. Projects should be sponsored to evaluate test data on new types of pulse jet engines:

1. The valveless pulse jet operating on acoustical inlet principles.
2. The valveless supersonic pulse jet operating on the diffuser shock impedance effect.
3. The pulse ramjet.
4. The multiple tube pulse jet.
5. The acoustical radiation jet.

F. A limited amount of work should be devoted to the development of components:

1. Improvement in the operating life and air admission characteristics of the reed valve systems.
2. Development of more satisfactory fuel pumping, injection, and metering equipment.

PART 2, LIQUID PROPELLANT ROCKETS.

When reduced to its fundamentals, an organized over-all rocket development program must be directed towards the following three points:

1. Reduced specific propellant consumption.
2. Reduced weight of all structural parts.
3. Increased utility and reliability.

To proceed with the greatest efficiency towards these goals, the following program is recommended.

A. *General Program.*

1. A theoretical review by an unbiased agency of all of the known and proposed liquid propellants. This would include the establishment of a practical and consistent means of comparison of systems to the end that a selection of a small number (10 or less) of combinations upon which all national effort could be directed. The selection should be based on these four fields: aircraft assisted takeoff, aircraft superperformance, missile launching, and missile propulsion.

2. The establishment of a few well-equipped rocket test stations throughout the country rather than a large number of poor or modestly equipped stations.

3. The preparation of suitable textbooks in the field of jet propulsion on a national scale as a means of weeding out the tremendous mass of data now in existence. This has a secondary but no less important object in providing a better means of thoroughly and accurately educating newcomers to the field.

B. *Detailed Program should consist of the following:*

1. The study of the chemical kinetics of combustion and the rate of reaction of the various superior propellant combinations with the view in mind of increasing the speed of combustion, thus perhaps to make possible the reduction in chamber size with its consequent saving in weight. This should include the study of combustion catalysers of all conceivable types such such as fuel additives and catalytic walls of the chamber. This should also include the study of the effect of flow patterns on combustion with the view of establishing optimum combustion chamber shape.

2. The continued gathering of thermodynamic data on present, new or proposed propellants at high chamber pressures and temperatures.

3. The study, both theoretical and experimental, of the fundamental problems and parameters of liquid streams mixing in the high pressure and high temperature conditions of the rocket combustion chambers.

4. The theoretical and experimental study of the fundamental problems and parameters of heat transfer from the hot gases in the combustion chamber to the motor walls through the walls, and then into a gaseous or liquid coolant. This shall take into account the details in the respective boundary layers and should be extended to cover conditions encountered in sweat or porous wall cooling and in ceramic-lined walls.

5. The continued development of porous ceramic and metal wall liners for liquid rocket motors.

6. The study and development of mechanical construction methods to produce a large number of exactly controlled passages through rocket motor walls with the intent of producing optimum practical cooling conditions. This may be considered as a hybrid between multiple hole film cooling and porous wall sweat cooling.

7. The continued study of ceramic liners for rocket motors. Particular emphasis should be placed on those liners of the type such as are naturally formed in the operation of diborane motors.

8. The development of a rational and practical method of detailed stress analysis in rocket motors based on experimentally determined pressures and loads under running conditions. This shall include a study of rocket motor construction methods and possible improvements from the standpoint of ease of fabrication, light weight and optimum combustion chamber shape.

9. Expand present program in ducted rockets or rocket-ramjets in both the theoretical and experimental directions with the view toward improving the performance through the establishment of the parameters affecting the mixing of hot gas streams at high velocity with lower velocity cold streams.

10. Analyze the problems of pressure-fed rocket power plants to effect possible weight and volume reduction through heating of the pressurizing gas.

11. Analyze the problems of combustion chamber pressure in a pump-fed rocket engine in order to determine the optimum from the standpoint of the over-all specific impulse.

12. Study the problems of pumps and pump drives from mechanical, hydraulic, and thermodynamic standpoints for the purpose of showing favorable lines of attack in the design of light weight efficient propellant pumping plants for rocket engines.

13. Study the problems of rotating seals for high speed liquid oxygen and acid pumps.

14. Analyze the heat transfer conditions on turbine blades for the exhaust jet-driven turbopump. Provide specific answers to the following questions:

a. How long can a blade remain in the jet without damage? Upon what factors does this depend?

b. What is the effect of adding additional motors around the periphery of the turbine? What is the limiting number?

c. What is the mechanism of blade cooling?

d. What will be the effect of altitude on blade cooling?

e. Can the air cooling be replaced by propellant vapor? or should such coolant be applied to the blades?

15. Instrumentation should be developed for the rapid measurement of the flame temperature and jet velocities. Methods should be developed for hot gas sampling to aid in chemical kinetic and thermodynamic studies of combustion.

APPENDIX A

TABULATION OF CONTRACTS BY SPONSORING GOVERNMENT AGENCY

APPENDIX A

TABULATION OF CONTRACTS BY SPONSORING GOVERNMENT AGENCY

1. Navy Department

a. Bureau of Aeronautics

Contractor	Contract Number	Class.	Amount of Contract	Contract Duration	Specific Field
Aerojet Engineering Corp., Azusa, Calif.	NOa(s)-7968	R	$ 630,000	1 Jan 1946 to 30 Jun 1946	Rocket and pulse jet development.
	NOa(s)-8496	R	230,000	1 July 1946 to 1 July 1947	Rocket design.
	NOa(s)-8511	R	94,800	14 Apr 1947 to 14 Apr 1948	Rocket design.
	NOa(s)-8566	C	66,190	Renegotiating	Acid aniline rocket parameter study.
	NOa(s)-8620	R	73,012	14 Feb 1947 to 14 Aug 1948	Pulse jet instrumentation.
	PD	R	—	—	Pulse jet development.
Aeromarine Co., 5201 Old Springfield Pike, Dayton, Ohio	PD 21294-47	?	9,000	Under negotiation	Pulse jet development.
Aviation Corp. of America, Lycoming Div., Williamsport, Pa.	NOa(s)-4718	R	302,765.37	25 Jun 1944 to 30 Jun 1947	Combustion chamber development.
Bendix Aviation Corp., Bendix Products Div., South Bend, Indiana	NOa(s)-7978	C	2,099.20	18 Feb 1946 to 6 July 1946	Fuel metering unit design. Pressure regulators.
Eclipse-Pioneer Div., Teterboro, New Jersey	NOa(s)-7570	C	103,100	29 Sep 1945 to 30 Jan 1946	Turbopump system design and fabrication.
	NOa(s)-8060	C	133,400	27 Jun 1946 to 15 May 1947	Fuel feed turbopump design for rockets.
	NOa(s)-8396	C	20,375.60	28 Jun 1946 to 28 Dec 1946	Dual propellant turbopump assembly — design and build.
Bodine Soundrive Co., 3300 Cahuenga Pass, Los Angeles 28, Calif.	NOa(s)-8590	R	75,400	Under negotiation.	Pulse jet development.
California, University of, Los Angeles, Calif.	NOa(s)-7280	R	10,000	Jun 1946 to Jan 1947	Heat transfer research.
	NOa(s)-8649 (continuation of NOa(s)-7280)	R	49,900	May 1947 to Nov 1948	Gas turbine regenerator design.

Classification Code: C — Confidential.
R — Restricted.
S — Secret.
U — Unclassified.

APPENDIX A

TABULATION OF CONTRACTS BY SPONSORING GOVERNMENT AGENCY

1. Navy Department

a. Bureau of Aeronautics (Continued)

Contractor	Contract Number	Class.	Amount of Contract	Contract Duration	Specific Field
Consolidated Vultee Aircraft Corp., Downey, Calif.	NOa(s)-7222	C	3,508,296.22	7 Jul 1945 to 30 Jun 1948	Develop LARK missile.
	NOa(s)-8374	C	1,411,000.00	21 Jun 1946 to Indefinite	Develop LARK missile.
Continental Aviation & Engineering Corp., Muskegon, Michigan	NOa(s)-7900	U	315,113.30	28 Feb 1946 to 31 Dec 1946	Pulse jet production.
Curtiss Wright Corp., Airplane Div., Columbus, Ohio	NOa(s)-8275	C	401,843	14 Jun 1946 to 6 Apr 1947	Guided missile development.
Hughes Aircraft Co., Culver City, Calif.	NOa(s)-8285	C	770,914	19 Jun 1946 to 19 Dec 1947	Guided missile design.
Kaiser Cargo, Inc., Fleetwings Div., Bristol, Pa.	NOa(s)-7153	R	100,000	1 Jul 1945 to 1 Apr 1947	Ramjet development.
	NOa(s)-8274	C	313,500	14 Jun 1946 to 17 Apr 1947	Technical study and preliminary design of pilotless aircraft PA-I.
	NOa(s)-8504	R	30,000	22 Jul 1946 to November 1947	Pabst ramjet development.
McDonnell Aircraft Corp., St. Louis, Mo.	NOa(s)-7896	R	78,262	1 Apr 1946 to October 1946	Pulse jet production.
	NOa(s)-8646	R	100,000	Under negotiation	Pulse jet development.
	NOa(s)-8889	R	175,000	Under negotiation	Pulse jet production.
	NOa(s)-8891	R	53,000	Under negotiation	Pulse jet production.
Marquardt Aircraft Corp., 4221 Lincoln Blvd., Venice, Calif.	P.O.-37517 from U.S.C. to Marquardt under U.S.C. Contract NOa(s)-8257	R	12,254	16 weeks	Ramjet component study.
	Noa(s)-8271 (covers a P.O. from Grumman Aircraft B-18448)	C	32,860	4 Oct 1946 to 30 May 1947	Ramjet development.

APPENDIX A

TABULATION OF CONTRACTS BY SPONSORING GOVERNMENT AGENCY

1. Navy Department

a. Bureau of Aeronautics (Continued)

Contractor	Contract Number	Class.	Amount of Contract	Contract Duration	Specific Field
Marquardt Aircraft Corp. (continued)	NOa(s)-8520	R	115,640	29 Nov 1946 to 29 Jan 1948	Pulse jet studies.
Massachusetts Institute of Technology, Cambridge, Mass.	NOa(s)-8632 (47)	R	101,360	1 Sep 1946 to 30 Jun 1948	Combustion research.
Mines, Bureau of, U.S. Dept. of Interior, Pittsburgh, Pa.	NAer-00597	C	50,000	1 Mar 1946 to 30 Jun 1947	Solid fuel preparation.
Naval Air Missile Test Center, Point Mugu, Calif.	TED-PP-PAU-201-206	C & R	750,000	30 Jun 1946 to 30 Jun 1947	Pulse jet and rocket tests.
Naval Powder Factory, Indian Head, Maryland	P.O. 275-46	R	6,000	1 Jul 1946 to 3 June 1947	Fuels research.
Naval Research Laboratory, Bellevue, Washington, D. C.	TED NRL-3401 P.O. 249-46	C	382,500	30 Jun 1945 to 30 Jun 1947	Fuels, pulse jet development.
Radioplane Co., 7901 Woodly Ave., Metropolitan Airport, Van Nuys, Calif.	NOa(s)-8627	C	63,000	31 Dec 1946 to 31 Mar 1947	Ramjet test vehicle study.
Reaction Motors, Inc., Dover, N. J.	NOa(s)-7070	C	975,300	1 Jul 1945 to 31 Jul 1947	Rocket production.
	NOa(s)-7866	C	365,690	1 Jul 1945 to 30 Jun 1947	Rocket development.
	NOa(s)-8239	R	770,000	27 Jun 1946 to 31 Oct 1947	Rocket development.
	NOa(s)-8358	R	50,500	29 Jun 1946 to Indefinite	Servicing equipment design.
	NOa(s)-8368	C	895,000	Letter of intent	LARK rocket production.
	NOa(s)-8531	U	290,000	11 Sep 1946 to 16 Nov 1947	Rocket development.
	NOa(s)-8540	R	677,300	1 Jul 1946 to 31 Dec 1947	Rocket research and development.

APPENDIX A

TABULATION OF CONTRACTS BY SPONSORING GOVERNMENT AGENCY

1. Navy Department

a. Bureau of Aeronautics (Continued)

Contractor	Contract Number	Class.	Amount of Contract	Contract Duration	Specific Field
Ryan Aeronautical Corp. San Diego, Calif.	NOa(s)-8605	C	168,000	8 Nov 1946 to 8 Jul 1947	24-C Afterburner.
Southern California, Univ. of, Los Angeles, Calif.	NOa(s)-7598	C	321,000	August 1945 to August 1947	Ramjet development.
	NOa(s)-8164	C	137,000	June 1946 to August 1947	Ramjet design.
	NOa(s)-8257	C	396,000	July 1946 to March 1948	Combustion chamber and diffuser development.
Standards, National Bureau of, Conn. Ave. & Van Ness St., N.W., Washington, D. C.	NAer-00616	C	39,000	1 Feb 1946 to 30 Jun 1947	Solid fuels research.
	NAer-00617	R	76,000	30 Jun 1946 to 30 Jun 1947	Liquid and gaseous fuels. Combustion research.
	NAer-00626	U	13,333/ year	30 Jun 1946 to 30 Jun 1947	Hydrocarbon fuels research.

APPENDIX A

TABULATION OF CONTRACTS BY SPONSORING GOVERNMENT AGENCY

1. Navy Department

b. Bureau of Ordnance

Contractor	Contract Number	Class.	Amount of Contract	Contract Duration	Specific Field
Aerojet Engineering Corp., Azusa, Calif.	NOrd-9768	C	$ 443,370	19 Feb 1946 to 30 Jun 1947	Rocket component development.
	NOrd-9837	R	415,000	1 Apr 1946 to 31 Aug 1947	Rocket design.
Bell Aircraft Corp., Buffalo 5, N. Y.	NOrd-9876	R	1,300,000	1 Jun 1946 to 30 Jun 1948	Combustion, fuel, heat transfer, rocket studies. BUMBLEBEE Project.
Bendix Aviation Corp., Eclipse-Pioneer Div., Teterboro, N. J.	NOrd-9432	R (some tasks are Confidential)	2,672,187	1 Jul 1945 to 30 Nov 1947	Fuel metering system design for ramjets. Guidance and telemetering systems. BUMBLEBEE Project.
Buffalo Electro-Chemical Co., Buffalo, N. Y.	NOrd-9917	S		19 Jul 1946 to 15 Jul 1947	Hydrogen peroxide — catalytic studies.
California Institute of Technology, Pasadena, Calif.	NOrd-9612	U	800,000	1 Sep 1946 to 31 Aug 1947	Hydraulic research.
Consolidated Vultee Aircraft Corp., Downey, Calif.	NOrd-9028	R	3,870,320	1 Apr 1945 to 30 Sep 1947	Ramjet design, ramjet burners. Ignition studies. BUMBLEBEE Project.
Cornell Aeronautical Laboratory, P.O. Box 56, Buffalo 5, N. Y.	NOrd-10057	R & C	624,000	30 Jun 1947 to 31 Dec 1947	BUMBLEBEE Project.
Curtiss Wright Corp., Airplane Div., Columbus, Ohio	NOrd-8993	C	3,768,960	1 Apr 1945 to 30 Jun 1947	Research on combustion, fuels, aerodynamics. Now under supervision of Cornell Aero. Lab. BUMBLEBEE Project.
Delaware, University of, Newark, Delaware	NOrd-9845 (Subcontract from United Aircraft Corp.)	C	40,995/ year	1 Jun 1946 to 31 Dec 1947	Combustion research.
Experiment, Inc., P.O. Box 1-T, Richmond, Virginia	NOrd-9756	C	227,850	1 Jan 1946 to 30 Sep 1947	Ramjet combustion research. BUMBLEBEE Project.
Fairchild Engine & Airplane Corp., Ranger Engine Div., Farmingdale, Long Island, N. Y.	NOrd-9879	R	136,000	15 Jun 1946 to 30 Jun 1947	Alcohol and hydrogen peroxide internal combustion engines.

APPENDIX A

TABULATION OF CONTRACTS BY SPONSORING GOVERNMENT AGENCY

1. Navy Department

b. Bureau of Ordnance (Continued)

Contractor	Contract Number	Class.	Amount of Contract	Contract Duration	Specific Field
General Electric Co., Schenectady, N. Y.	NOrd-8606, TO-503	C	239,000	28 May 1945 to Indefinite	Gas turbine development for torpedoes.
Johns Hopkins University Baltimore, Md.	NOrd-8036	C	412,000	2 Feb 1945 to 31 Mar 1948	BUMBLEBEE research.
Applied Physics Laboratory, 8621 Georgia Ave., Silver Spring, Md.	NOrd-7386	R	11,602,000	1 Dec 1944 to 31 Mar 1948	BUMBLEBEE Project coordination.
Massachusetts Institute of Technology, Cambridge, Mass.	NOrd-9107, TO-C	C	200,000	9 Jul 1945 to 30 Jun 1947	Fuels research. Hydrogen peroxide.
	NOrd-9661	C	2,505,000	1 Nov 1945 to 30 Jun 1947	Aerodynamics, combustion, materials research toward a guided missile. METEOR Project.
Michigan, University of, Ann Arbor, Mich.	NOrd-7924	R	381,000	1 Jan 1945 to 31 Mar 1948	Aerodynamics research. Fuel spray study. BUMBLEBEE Project.
Naval Ordnance Test Station, Inyokern, California	Re6a order numbers	C & S	Indefinite time and amounts involved in this project.		Liquid and solid propellant rockets.
Pasadena, Calif.	Re6a order numbers	C	Indefinite time and amount involved in this project.		Hydropulse and hydroturbojet development.
Naval Torpedo Station, Newport, R. I.	Re6a-267	C	Approximately $ 250,000/year	Indefinite	Fuels research. Hydrogen peroxide.
New Mexico School of Mines, Station A, Albuquerque, N. M.	NOrd-7822	U	979,500	19 June 1946 to 30 Jun 1947	Missile aerodynamics study.
	NOrd-9817	R	1,183,500	29 Mar 1946 to 31 Mar 1948	"V-2" component design, and research on fluid flow and instrumentation. BUMBLEBEE Project.
North American Aviation, Inc., Inglewood, Calif.	NOrd-9784	C	166,488	15 Feb 1946 to 31 Dec 1947	Ramjet studies. BUMBLEBEE Project.
Standard Oil Development Laboratory, P.O. Box 243, Elizabeth B, N. J.	NOrd-(f)1414 and NOrd-9233	C	519,000	1 Apr 1946 to 30 Jun 1948	Ramjet: fuel system, and combustor development. BUMBLEBEE Project.

APPENDIX A

TABULATION OF CONTRACTS BY SPONSORING GOVERNMENT AGENCY

1. Navy Department

b. Bureau of Ordnance (Continued)

Contractor	Contract Number	Class.	Amount of Contract	Contract Duration	Specific Field
Texas, University of, 30 E 24th St., Austin, Texas	NOrd-9195	R	$23,000	1 Jun 1945 to 31 Mar 1948	Fuel and combustion research. BUMBLEBEE Project.
United Aircraft Corp., East Hartford, Conn.	NOrd-9845	C	750,000	11 Jun 1946 to 31 Aug 1947	Ramjet, aerodynamic and combustion studies. METEOR Project.
Virginia, University of, Charlottesville, Va.	NOrd-7873	C	300,000	1 Mar 1945 to 31 Mar 1948	Research on the physics of fluid flow; boundary layer and shock studies. BUMBLEBEE Project.
Wisconsin, University of, Madison, Wisconsin	NOrd-9938	R	125,000	23 Oct 1946 to 31 Jul 1948	Fuels and combustion research. BUMBLEBEE Project.

APPENDIX A

TABULATION OF CONTRACTS BY SPONSORING GOVERNMENT AGENCY

1. Navy Department

c. Bureau of Ships

Contractor	Contract Number	Class.	Amount of Contract	Contract Duration	Specific Field
Buffalo Electro-Chemical Co., Buffalo, N. Y.	NObs-31494	S	$ 250,000	1 Jul 1946 to 30 Jun 1948	Hydrogen peroxide study.
Engineering Experiment Station, Annapolis, Md.	EES TEST B 3254 (SRD-9)	U	35,000	1 Jul 1946 to 30 Jun 1948	Metals research.
Massachusetts Institute of Technology, Cambridge, Mass.	NObs-25391, TO-4	U	60,000	1 Jul 1947 to 31 Dec 1948	Metals research.
	NObs-25391, TO-6	U	80,000	1 Jul 1947 to 30 Jun 1949	Metals research.
Naval Research Laboratory, Bellevue, Washington 20, D. C.	M-83 SRD 502/46	U	15,000	1 Jul 1947 to 30 Jun 1948	Metals research.
Pennsylvania, University of, Philadelphia, Pa.	NObs-2477	R	270,000	1 Jul 1947 to 30 Jun 1948	Thermodynamic properties of gases; other research not of interest to this report.
Rensselaer Polytechnic Institute, Troy, N. Y.	NObs-31493	R	80,000	1 Jul 1946 to 30 Jun 1949	Metals research.
Standards, National Bureau of, Connecticut Ave. & Van Ness St., Washington 25, D. C.	Order No. S&A-25444 (NBS Project 3225)	U	36,000	30 Jun 1946 to 30 Jun 1947	Thermocouple pyrometers for gas turbines.
Stevens Institute of Technology, Hoboken, N. J.	NObs-45091	R	75,850	1 Nov 1946 to 30 Jun 1948	Metals research.

APPENDIX A

TABULATION OF CONTRACTS BY SPONSORING GOVERNMENT AGENCY

1. Navy Department

d. Office of Naval Research

Contractor	Contract Number	Class.	Amount of Contract	Contract Duration	Specific Field
Aerojet Engineering Corp., Azusa, Calif.	N6-ori-10, TO-1	C	$ 919,200	1 Jun 1946 to 30 Jun 1947	Hydrojet development.
Alfred University, Alfred, N. Y.	N6-ori-143	U	48,875	1 Jun 1946 to 1 Mar 1949	Ceramics research.
American Electro Metals Corp., Yonkers, N. Y.	N6-ori-256, TO-1	U	102,125	1 Nov 1946 to 31 Oct 1947	Metals research.
Battelle Memorial Institute, 505 King St., Columbus, Ohio	N5-ori-111, TO-1	U	330,666	14 Nov 1946 to 30 Sep 1947	Metals and ceramics development.
California Institute of Technology, Pasadena, Calif.	N6-ori-102, TO-4	U	108,000	21 Jun 1946 to 20 Jun 1948	Aerodynamics research.
	N6-ori-244, TO-2	U	80,000	1 Jan 1947 to 31 Dec 1947	Flow of fluids through rotating passages.
	FM-8 to NOrd-9612	U	45,000	1 Sep 1946 to 31 Aug 1947	Cavitation, dynamics of underwater bodies, hydraulic analogy for shock wave studies.
California, University of, Berkeley, Calif.	N6-ori-111, TO-4 and TO-5	U	22,450	15 Jun 1946 to Indefinite	Metals research.
	N7-onr-295, TO-3	U	258,500	10 Jan 1947 to 10 Jan 1949	Heat transfer and aerodynamics research at supersonic velocities and low pressures.
Carnegie Institute of Technology, Pittsburgh, Pa.	N6-ori-47, TO-7	U	38,880	1 Oct 1946 to 30 Sep 1947	Fuels research.
Catholic University of America, Wash., D. C.	N6-ori-255, TO-2	U	22,171	1 Nov 1946 to 1 Nov 1947	Metals research.
Chicago, University of Chicago, Illinois	N6-ori-20, TO-10	U	42,528	1 Jul 1946 to 30 Jun 1947	Fuels research. Hydrides.
Cornell Aeronautical Laboratory, P.O. Box 56, Buffalo, N. Y.	N6-ori-119, TO-1	U	310,160	Letter of intent to 30 Jun 1948	Propulsion research. Project SQUID.
	FM-18	U	1.00	Letter of intent	Supersonic aerodynamics.
Cornell University, Ithaca, N. Y.	N6-ori-91, TO-4	U	19,200	1 Jun 1946 to 31 May 1947	Molecular complexes of boron compounds.

APPENDIX A

TABULATION OF CONTRACTS BY SPONSORING GOVERNMENT AGENCY

1. Navy Department

d. Office of Naval Research (Continued)

Contractor	Contract Number	Class.	Amount of Contract	Contract Duration	Specific Field
Cornell University (continued)	N6-ori-213, TO-1	U	6,500	15 Oct 1946 to 14 Jun 1948	Structure of boro-hydrides.
	N6-ori-264, TO-2	U	13,600	1 Feb 1947 to 1 Feb 1948	Statistical mechanical transport theory.
	FM-19	U	62,439	Under negotiation	Propagation of compression waves.
Illinois Institute of Technology, Chicago, Illinois	N7-onr-329, TO-2	U	28,000	1 Apr 1947 to 31 Mar 1949	Metals research.
Illinois, University of, Urbana, Illinois	N6-ori-71, TO-4, 8 and 9	U	156,617	1 Jun 1946 to 30 Jun 1948	Aerodynamics, combustion, fuels, materials research.
	N6-ori-71, TO-11	U	28,345	1 Jun 1946 to 31 Aug 1947	Mixing of fluid streams.
Johns Hopkins University, Baltimore, Md.	N6-ori-243, TO-5	U	49,500	1 May 1947 to 30 Jun 1948	Supersonic wind tunnel design.
Massachusetts Institute of Technology, Cambridge, Mass.	N5-ori-78, TO-5	U	11,663	1 Mar 1946 to 31 Aug 1947	Heat transfer coefficients at supersonic speeds.
	N5-ori-78, TO-11	U	30,000	1 Jan 1947 to 1 Jan 1948	Heat transfer research.
Michigan, University of, Ann Arbor, Michigan	N6-ori-232, TO-4	U	26,000	1 Apr 1947 to 30 Mar 1948	Shock wave studies.
Mines, Bureau of. Dept. of the Interior, Pittsburgh, Pa.	NA-onr-27-47	U	110,000	1 Apr 1947 to 31 Mar 1949	Flame studies.
National Advisory Committee for Aeronautics, 1724 F St., N.W., Washington, D. C.	NA-onr-14-47	U	75,000	1 Dec 1946 to 30 Nov 1947	Supersonic wind tunnel design.
Naval Ordnance Laboratory, White Oak, Md.	P.O. 45-47	U	10,000	1 May 1947 to 30 Jun 1948	Aerodynamics of rarified gases — theoretical research.

APPENDIX A

TABULATION OF CONTRACTS BY SPONSORING GOVERNMENT AGENCY

1. Navy Department

d. Office of Naval Research (Continued)

Contractor	Contract Number	Class.	Amount of Contract	Contract Duration	Specific Field
Naval Ordnance Laboratory, White Oak, Md. (continued)	P.O. 46-47	U	15,000	1 Jun 1947 to 31 May 1948	Large scale turbulence — theoretical research.
	P.O. 49-47	U	30,000	1 May 1947 to 30 Jun 1948	Comparative flow analysis—experimental methods.
	P.O. 54-47	U	20,000	1 Jun 1947 to 31 May 1948	Development of high speed numerical techniques for solution of problems in fluid dynamics.
New York University, 45 Astor Place, New York, N. Y.	N6-ori-11, TO-2	U	382,000	1 May 1946 to 30 Jun 1948	Aerodynamics and combustion research. Project SQUID.
	N6-ori-201, TO-1	U	340,250	1 Sep 1946 to 31 Aug 1947	Mathematical analysis of aerodynamics and combustion.
Northwestern University, Evanston, Illinois	N6-ori-96, TO-4	U	30,000	1 Jan 1946 to 31 May 1947	Compressor study.
	N6-ori-158, TO-3	U	12,000	1 Jan 1947 to 31 Dec 1947	Aerodynamics and combustion research.
Ohio State University, Columbus, Ohio	N6-ori-17, TO-2	U	53,000	1 Jun 1946 to 31 Mar 1949	Corrosion research.
	N6-ori-17, TO-4	U	23,550	1 Oct 1946 to 30 Sep 1947	Thermodynamics research.
	N6-ori-225, TO-1, 3 and 4	U	61,450	1 Oct 1946 to 30 Sep 1947	Fuels and materials research.
	N6-ori-225, TO-9	U	32,500	1 Feb 1947 to 31 Jan 1948	Fuels research.
Pittsburgh, University of, Pittsburgh, Pa.	N6-ori-43, TO-1	U	75,776.25	1 Mar 1946 to 31 Mar 1949	Fuels research. Thermodynamic properties of boron compounds.
Polytechnic Institute of Brooklyn, Brooklyn, N. Y.	N6-ori-98, TO-2	U	290,000	1 May 1946 to 30 Jun 1948	Pulse jet valve, combustion and materials research. Project SQUID.
	N6-ori-206, TO-1	U	75,000	1 Oct 1946 to 30 Sept 1948	Boundary layer control.

APPENDIX A

TABULATION OF CONTRACTS BY SPONSORING GOVERNMENT AGENCY

1. Navy Department

d. Office of Naval Research (Continued)

Contractor	Contract Number	Class.	Amount of Contract	Contract Duration	Specific Field
Princeton University, Princeton, N. J.	N6-ori-105, TO-3	U	613,750	15 Apr 1946 to 30 Jun 1948	Boundary layer and shock wave interactions. Combustion, chemical kinetics, and fuels. Project SQUID.
	N6-ori-105, TO-2	U	153,650	1 Jun 1946 to 30 Sep 1948	Shock wave studies (transient fluid dynamics).
	FM-20	U	90,000	Under negotiation	Shock wave studies.
	FM-21 (continuation of BuOrd contract NOrd-9240, TO-1)	U	42,000	1 Sep 1947 to 31 Aug 1948	Investigation of gas flow by interferometry and shock waves.
Purdue University, Lafayette, Indiana	N6-ori-104, TO-1 and 2	U	430,712	1 May 1946 to 30 Jun 1948	Metals research, combustion, fuels and instrumentation research. Project SQUID.
Southern California, University of, Los Angeles, Calif.	N6-ori-238, TO-1	U	18,240	1 Oct 1946 to 15 Sep 1948	Boron compounds. Hydrides.
Standard Oil Development Laboratory, Box 243, Elizabeth B, N. J.	N6-ori-108, TO-1	U	103,448	7 Nov 1945 to 6 Nov 1947	Combustion research.
Standards, National Bureau of, Connecticut Ave. & Van Ness St., N.W., Washington 25, D. C.	NA-onr-7-47	U	24,000	1 Jan 1947 to 31 Dec 1948	Thermodynamic properties of inorganic substances.
	NA-onr-2-47	U	45,985	15 May 1946 to 30 Jun 1948	Ceramics research.
	NA-onr-8-47	U	24,000	1 Jan 1947 to 31 Dec 1948	Fuels research. Boron compounds.
Stanford University, Palo Alto, Calif.	N6-ori-154, TO-5	U	13,380	1 Nov 1946 to 31 Oct 1947	Corrosion research.
	N7-onr-251, TO-2	U	53,000	18 months	Heat transfer and flow-friction studies.
Washington, University of, Seattle, Wash.	N6-ori-217, TO-1	U	10,000	1 Oct 1946 to 1 Oct 1948	Boundary layer control for wide angle diffusers.

APPENDIX A

TABULATION OF CONTRACTS BY SPONSORING GOVERNMENT AGENCY

2. War Department

a. Army Air Forces

Contractor	Contract Number	Class.	Amount of Contract	Contract Duration	Specific Field
Aerojet Engineering Corp., Azusa, Calif.	W-33-038-ac-P.D. E. C. Phillips	C	$ 225,000.		Rocket fuels research.
	W-33-038-ac-11757 (14801) Maj. Bunze	U	334,661.33	31 May 1945 to 31 Dec 1946	Rocket development. Nitromethane turbo rocket unit.
	Subcontract under Consolidated Vultee Aircraft Corp. Prime Contract W-33-038-ac-14168 Col. H. J. Sands	S	200,000	Completed. Prime contract 29 Mar 1946 to 29 Feb 1948	Rocket performance calculations.
	W-33-038 ac-14549 (16100) Maj. Bunze	R	292,360.50	9 Dec 1946 to March 1947	Droppable rockets and rocket motors.
	W-33-038-ac-14835 P.O. (33-038) ac-47-1063-E	R	25,000	4 Nov 1946 to 1 Mar 1947	ME-163 rocket power plant test.
	W-33-038-ac-15309 (16610)	R	943,437.67	8 Apr 1947 to 30 June 1948	Turbo pump-fed rocket engine design.
Alfred University, Alfred, N. Y.	W-33-038-ac-14233 (15903) A. L. Berger	U	46,760	5 Jun 46 to 24 Jun 48	Ceramics research.
Armour Research Foundation, Illinois Institute of Technology, Chicago, Illinois	W-33-038-ac-16533	U	18,180.31	Mar 47 to Mar 49 (Contract approved 26 May 47)	Refractory coatings for metals.
Battelle Memorial Institute, 505 King St., Columbus, Ohio	W-33-038-ac-7202 (13489) J. B. Johnson	U	20,250	22 Jan 45 to 1 Mar 47	Metals research.
	Subcontract under Douglas Aircraft Contract W-33-038-ac-14105 Col. H. J. Sands	C (Prime contract Secret)	900,000	21 May 46 to 31 May 48	Fuels, combustion, materials, literature survey.
	W-33-038-ac-14202 (15872) G. L. Wander	C	233,000	6 Apr 46 to 2 May 48	Combustion research.
	W-33-038-ac-14320 (15990) A. L. Berger	U	60,000	15 May 46 to 15 May 48	Ceramics research.

APPENDIX A

TABULATION OF CONTRACTS BY SPONSORING GOVERNMENT AGENCY

2. War Department

a. Army Air Forces (Continued)

Contractor	Contract Number	Class.	Amount of Contract	Contract Duration	Specific Field
Bell Aircraft Corporation, Buffalo 5, N. Y.	W-33-038 ac-13450 (15357) J. B. Tuzson	R	103,847	26 Nov 45 to May 47	Ramjet flight test.
	W-33-038-ac-14169 (15831) Col. H. J. Sands	S	1,476,716.47	1 Apr 46 to 1 Jul 47	Design study "Rascal" ramjet power plant.
Bendix Aviation Corp., Special Products Western Div., Los Angeles, Calif.	W-33-038-ac-14219 Capt. F. T. Fazel	S	257,248.95	22 Apr 46 to 22 Jan 48 NOTE: Contract has not been signed by Bendix.	Supersonic air-to-air guided missile design.
Bendix Aviation Corp., Eclipse-Pioneer Div., Teterboro, N. J.	W-33-038-ac-14996 P.O. (33-038) 47-371-E R. E. Hoffman	U	14,952	9 Jul 46 to 15 Nov 46	Fuel system design. Intermittent jet engine fuel control.
Bendix Aviation Corp., Bendix Products Div., South Bend, Indiana	W-33-038-ac-15276 (16577) P.O. (33-038) 47-863-E	C	29,689	19 Apr 46 to 31 May 47	Ramjet control design study.
Boeing Aircraft Corp., Seattle 14, Wash.	W-33-038-ac-13875 (15447) Col. H. J. Sands	S	8,078,186.65	Letter contract 3 Jan 46 Definitive contract 24 Dec 46 Time of performance 18 Sept 45 to 1 Mar 48	Ramjet development. Supersonic ground-to-air pilotless aircraft.
Brown University, Providence, R. I.	W-33-038-ac-15004 (13651) Col. H. M. McCoy	U	224,925	5 Jun 46 to 4 Dec 47	Aerodynamics and combustion literature survey.
California Institute of Technology, Pasadena, Calif.	W-33-038-ac-4320 (12847) D. M. Ross	R	591,875	5 May 44 to 28 Feb 46	Ramjet research.
	W-33-038-ac-1717 (11592)	U	40,000 (Approx.)	1 Jul 46 to 30 Jun 47	Aerodynamics research.
	W-535-ac-20260 (5309) Maj. Bunze	U	Supp. #20 for $262,000 out of $676,000	7 Nov 45 to indefinite	Metals and ceramics research for rockets; liquid rocket fuels.
California, University of, Los Angeles, Calif.	W-33-038-ac-15229 Maj. J. Kelly	U	61,274	11 Jul 46 to 30 Jun 47	Heat transfer research.

APPENDIX A

TABULATION OF CONTRACTS BY SPONSORING GOVERNMENT AGENCY

2. War Department

a. Army Air Forces (Continued)

Contractor	Contract Number	Class.	Amount of Contract	Contract Duration	Specific Field
Chandler Evans Corp., Hartford, Conn.	W-33-038-ac-9287 P.O. 33-038-45-10460-E	U	24,500	7 May 45 to 15 Sept 45	Fuel metering for German pulse jets.
Colorado, University of, Boulder, Colo.	W-33-038-ac-16678	C	22,662	1 Mar 47 to 1 Mar 48	Spray formation and combustion of liquid fuels.
Commerce, U.S. Dept of, Bureau of Domestic Commerce, Wash., D. C.	W-33-038-ac-P.D. R. E. Hoffman	C	Still in discussion stage.		Fuels availability survey.
Consolidated Vultee Aircraft Corp., Downey, Calif.	W-33-038-ac-14168 Col. H. J. Sands	S	1,841,457.51	29 Mar 46 to 29 Feb 48	Guided missile development.
	W-33-038-ac-14547 (16098)	R	7,514,000.78	27 May 46 to indefinite	XP-92 development; ducted rocket development Project MX-813.
Continental Aviation & Engineering Corp., 12801 E. Jefferson Ave., Detroit 14, Mich.	W-33-038-ac-13371 (15277) NAer 40000-120	R	1,254,153.52	21 Dec 45 to 31 Dec 47	Pulse jet development.
Curtiss-Wright Corp., Airplane Division, Columbus, Ohio	W-33-038-ac-14161 (15831) Capt. W. M. Darling TSESA-7	S	1,998,054.45	29 Mar 46 to 1 Mar 48	Subsonic and supersonic guided missile design study.
Curtiss-Wright Corp., Propeller Division, Caldwell, N. J.	W-33-038-ac-14171 Maj. Bunze	R	345,958	28 Aug 46 to 23 Feb 47	Rocket development.
	W-33-038-ac-14827 (16276)	U	1,318,882	Jul 46 to 1 Jan 48	Development of complete 10,000 and 60,000 lb. thrust rocket propulsion system.
	W-33-038-ac-16269 (17230)	R	339,400	28 Jan 47 to 28 Jan 48	XS-2 airplane rocket power plant design and fabrication.
Douglas Aircraft Co., Santa Monica, Calif.	W-33-038-ac-10413 (14414) Col. G. F. Smith	U	1,040,000	30 May 45 to 30 Jun 48	Supersonic flight research airplane.
	W-33-038-ac-14105 Jack Leet, Maj.A.C. TSESA-7	S	10,000,000	Letter contract 2 Mar 46; deliv. date 30 Jun 48	To conduct study and research inter-continental warfare, other than surface.

APPENDIX A

TABULATION OF CONTRACTS BY SPONSORING GOVERNMENT AGENCY

2. War Department

a. Army Air Forces (Continued)

Contractor	Contract Number	Class.	Amount of Contract	Contract Duration	Specific Field
General Electric Co., Schenectady, N. Y.	W-33-038-ac-14499 L. C. Clousen, Maj. TSECON W. R. Ownes, TSECON	S	782,715.40	21 Apr 1946 to October 1947	Study and research on supersonic pilotless aircraft.
G. M. Giannini Corp., Pasadena, Calif.	W-33-038-ac-15322 J. B. Tuzson	U	99,305	October 1946 to July 1947	Pulse jet valve study.
	W-33-038-ac-14473 (16024)	R	261,723	23 May 1946 to 23 May 1947	Pulse jet development.
Goodyear Aircraft Corp., Akron, Ohio	W-33-038-ac-14153 Maj. John H. Evans TSEA-7	S	1,097,127.45	Letter contract 27 Mar 1946	Research and design study on pilotless aircaft.
Hughes Aircraft Corp., Culver City, Calif.	W-33-038-ac-14220 J. O. Miller	S	1,714,445.25	Letter contract 15 Apr 1946 to 18 Apr 1948	Rocket missile development.
Illinois, University of, Urbana, Illinois	W-33-038-ac-14520 (16071)	U	100,000	13 Jun 1946 to 31 May 1948	Ceramics research.
M. W. Kellogg Co.. Jersey City 3, N. J.	W-33-038-ac-13916 (15588) Maj. Bunzo AFP 412816	C	1,251,900.50	1 May 46 to 6 Jul 48	Research and development jet propulsion unit and reports.
	Subcontract under Republic Aviation Corp. No. W-33-038-ac-14208 Col. H. J. Sands	S	146,000	26 Sept 46 10 May 47	Rocket and ramjet development.
	W-33-038-ac-14221 (15891) Jack Leet	S	440,999.52	Letter contract 12 Apr 46 Completed before 30 Jun 47	Supersonic air-to-air pilotless aircraft.
	W-33-038-ac-15313 Maj. Bunzo	R	1,020,000	19 Jun 46 to 19 Sept 47	Turbo rocket engine.
Lockheed Aircraft Corp., Burbank, Calif.	W-33-038-ac-15916 (17032) D. C. Hamilton	U	167,650	1 Nov 46 to 1 Sept 47	Ramjet tests 20", 30", 48" Marquardt engines.

APPENDIX A

TABULATION OF CONTRACTS BY SPONSORING GOVERNMENT AGENCY

2. War Department

a. Army Air Forces (Continued)

Contractor	Contract Number	Class.	Amount of Contract	Contract Duration	Specific Field
Marquardt Aircraft Corp., 4221 Lincoln Blvd., Venice, Calif.	W-33-038-ac-15765 P.O. (33-038) 47-934-E D. M. Ross	R	97,000	8 Oct 46 to Jul 47	Three 48" M# 0.85 ramjets.
	W-33-038-ac-13449 (15356) D. M. Ross	U	65,530	23 Oct 45 to 5 Jul 47	Ramjet reaction turbine development.
	P.O. 46-170-CA under Douglas Contract W-33-038-ac-10413 Col. G. F. Smith	C	12,400	31 Oct 46 to 31 May 47	24-C Turbojet afterburner.
	W-33-038-ac-14123 (15793) D. M. Ross	U	48,360	14 May 46 to 15 Jul 47	Ramjet helicopter rotor development.
	W-33-038-ac-14152 (15822) W. E. Zins	C	52,100	4 Apr 46 to 1 Mar 47	Ramjet development; two 6-30-1.0 engines; three thrust mounts.
	P.O. GA 525080 M under Goodyear Contract W-33-038-ac-14153 (Col. D. W. Devine)	C	Undetermined.	27 Nov 46 to 27 Apr 47	Purchase of Marquardt 26" ramjet and C-20 metering unit.
	P.O. GA 525081M under Goodyear Contract W-33-038-ac-14153 Col. D. W. Devine	C	Undetermined; task assignment changed.	27 Nov 46 to 27 Apr 47	Ramjet development and tests.
	P.O. 102816 under McDonnell Contract W-33-038-ac-14242 Col. D. W. Devine	S	52,580	2 Aug 46 to 4 Apr 47	Ramjet development.
	W-33-038-ac-16366 J. E. Taylor TSEPP-5C	R	64,158	14 Mar 47 to 14 Apr 48	Ramjet control development.
	W-33-038-ac-16236 P.R. 14186 P.O. 47-2046 R. E. Hoffman	U	14,275	27 Jan 47 to 11 Jun 47	Fuel metering unit procurement.

APPENDIX A

TABULATION OF CONTRACTS BY SPONSORING GOVERNMENT AGENCY

2. War Department

a. Army Air Forces (Continued)

Contractor	Contract Number	Class.	Amount of Contract	Contract Duration	Specific Field
Marquardt Aircraft Corp. (cont'd)	W-33-038-ac-14042 (15711) AFP412839 Capt. R. C. Bogert, A.C. TSEPR-7 D. M. Ross	C	19,200	16 Jan 46 to 15 May 46	Construct six 20" ramjets.
Martin (Glenn L.) Co., Baltimore 3, Md.	W-33-038-ac-14158 (15828) Initiator: W. M. Darling. TSEA-7	S	1,827,620.79	27 Mar 46 to 23 Apr 47	Ground-to-ground guided missile development.
McDonnell Aircraft Corp., St. Louis, Mo.	W-33-038-ac-14856 (16305) Lt. H. R. Velkoff TSEPR-9	R	171,824.94	26 Mar 47 to 26 Feb 48	Ramjet helicopter rotor development and flyable test stand.
Menasco Manufacturing Co., 805 South San Fernando Blvd., Burbank Calif.	W-33-038-ac-14759 (16207) H. P. Barfield	R	465,700	17 May 1946 to 30 Jun 1947	Ramjet development.
	W-33-038-ac-15310 Col. R. J. Minty Chief, Power Plant Laboratory	R	1,900,808	18 Jun 1946 to 30 Jun 1948	XJ-37 Turbojet production.
	W-535-ac-40690 (10685)	R	2,783,009.98	17 Jun 1943 to 30 Jun 1947	Turbojet development.
Michigan, University of, Ann Arbor, Mich.	W-33-038-ac-13433 (15339) J. B. Tuzson	R	4,455	1 Nov 1945 to 28 Feb 1947	Pulse jet valve study.
	W-33-038-ac-14222 (15892) W. R. Owens L. C. Clousen, Maj. A. C., TSESA-7	S	1,799,500	3 Apr 1946 to 3 Jun 1949	Study and research on supersonic pilotless aircraft; wind tunnel tests.
Mines, Bureau of, U. S. Dept. of Interior, Pittsburgh, Pa.	P.O.-33-038-ac-46-3552-E E. C. Phillips	U	247,020	18 Apr 1946 to 1 Jun 1947	Fuels availability survey.
National Advisory Committee for Aeronautics, Flight Propulsion Research Laboratory, Cleveland, Ohio	No contract E. C. Phillips	C	No transfer of funds	Fiscal year	Fuel tests.

APPENDIX A

TABULATION OF CONTRACTS BY SPONSORING GOVERNMENT AGENCY

2. War Department

a. Army Air Forces (Continued)

Contractor	Contract Number	Class.	Amount of Contract	Contract Duration	Specific Field
North American Aviation Inc., Inglewood, Calif.	W-33-038-ac-14191 (15861) Col. H. J. Sands	S	6,306,583.85	22 Apr 1946 to 1 Nov 1947	Ground-to-ground guided missile design.
Northrop Aircraft, Inc., Hawthorne, Calif.	W-33-038-ac-14175 (15845)	S	2,199,971.51	28 Mar 1946 to 28 Mar 1947	Studies and reports on ground-to-ground supersonic and subsonic guided missiles.
Ohio State University, Columbus, Ohio	W-33-038-ac-11101 (14552) G. L. Wander	R	140,000	27 Jun 1945 to 1 Jul 1946	Fuels research.
	W-33-038-ac-14217 (15887) A. L. Berger	U	138,000	23 Apr 1946 to 23 Apr 1948	Ceramics research.
	W-33-038-ac-14794 (16243) G. L. Wander	R	209,902	27 Jun 1946 to 27 Jun 1947	Fuels research. Liquid H_2 as a/c fuel.
	W-33-038-ac-16368 (17278) Lt. Col. C. D. Bourcier, TSEAM-7	U	7,375	10 Feb 1947 to 10 Feb 1948	Metals research.
	W-33-038-ac-16308	U	8,025	1 Mar 1947 to 29 Feb 1948	Metals research.
Packard Motor Car Co., 1330 Laskee Road, Toledo, Ohio	W-33-038-ac-1850 (11728) R. H. Retz	R	4,500,000 (Approx.)	30 Jun 1945 to 30 Jun 1947	Turbojet design.
Pennsylvania State College, State College, Pa.	W-33-038-ac-13506 (15414) A. L. Berger	U	64,000	14 Nov 45 to 31 Oct. 48	Ceramics research.
Reaction Motors, Inc., Dover, N. J.	Subcontract under Consolidated Vultee Contract W-33-038-ac-14168 P.O. A-191-SA B-191-SA C-191-SA Col. H. J. Sands	C	Under re-negotiation		Rocket design.
Republic Aviation Corp., Farmingdale, L. I., N. Y.	W-33-038-ac-14208	S	2,010,663.37	5 Apr 46 to 10 May 47	Guided missile design MX773 studies

APPENDIX A

TABULATION OF CONTRACTS BY SPONSORING GOVERNMENT AGENCY

2. War Department

a. Army Air Forces (Continued)

Contractor	Contract Number	Class.	Amount of Contract	Contract Duration	Specific Field
Rutgers University New Brunswick, N. J.	W-33-038-ac-15800 A. L. Berger	U	44,712	22 Oct 46 to 30 Sept 48	Ceramics research.
Ryan Aeronautical Corp., San Diego, Calif.	W-33-038-ac-14265 (15935) J. Leet	S	140,962.50	8 Oct 46 to 8 Jun 47	Solid rocket design.
Standards, National Bureau of, Connecticut Ave. & Van Ness St., N.W., Wash. 25, D. C.	W-33-038-47-1468-E J. E. Taylor TSEPR-5C	U	95,500	26 Nov 46 to 26 Nov 47	Test instrument development.
Syracuse University, Syracuse, N. Y.	W-33-038-ac-15941 Initiator: Lt. Col. C. D. Bourcier, A. C. TSEAM-7	U	27,700.00	9 Dec 46 to 9 Dec 47	Metals research.
Union Oil Co. of Calif. Wilmington, Calif.	W-33-038-ac-13468 (15375) G. L. Wander	R	1.00	15 Jul 46 to 30 Jun 48	Hydrocarbon Fuels research.
Wright Aeronautical Corp., Woodridge, N. J.	W-33-038-ac-14145 (15815) L. B. Zambon TSEPP-7 AFP-421368	R	6,097,941.00	22 Nov 46 to Nov 47	Turbo-propeller and turbo-jet studies.
	Supplement only.		361,240.00		

APPENDIX A

TABULATION OF CONTRACTS BY SPONSORING GOVERNMENT AGENCY

2. War Department

b. Army Ordnance

Contractor	Contract Number	Class.	Amount of Contract	Contract Duration	Specific Field
Aerojet Engineering Corp., Azusa, Calif.	Sub-subcontract under Douglas Aircraft Co. subcontract with Bell Telephone Laboratories under prime contract W-30-069-ORD-3182	S		Through 1948	Rocket power plant design.
Bell Telephone Laboratories, Murray Hill, N. J.	W-30-069-ORD-3182	S	?	?	Coordination of development of complete guided missile
California Institute of Technology, Pasadena, Calif.	W-04-200-ORD-455	R	1,800,000	1 Jul 1947 to 1 Jul 1948	Guided missile research.
	W-04-200-ORD-1482	C	137,000	30 Jun 1946 to 30 Jun 1947	Rocket fuels research.
General Electric Co., Schenectady, N. Y.	W-30-115-ORD-1768	C	4,780,000	20 Nov 1944 to 30 Jun 1947	HERMES missile development. Bell XS-1 engine development.
National Research Corp., 100 Brookline Ave., Boston, Mass.	W-19-066-ORD-1046	U	30,000	1 Jun 1946 to 30 Jun 1947	Metals research.

APPENDIX B

TABULATION OF CONTRACTS BY CONTRACTOR

APPENDIX B. TABULATION OF CONTRACTS BY CONTRACTOR

Contractor	Sponsoring Agency	Contract Number	Class.	Specific Field
Aerojet Engineering Corp., Azusa, Calif.	Navy Bureau of Aeronautics	NOa(s)-7968	R	Rocket and pulse jet development.
		NOa(s)-8496	R	Rocket design.
		NOa(s)-8511	R	Rocket design.
		NOa(s)-8566	C	Acid-aniline rocket parameter study.
		NOa(s)-8620	R	Pulse jet instrumentation.
		PD	R	Pulse jet development.
	Navy Bureau of Ordnance	NOrd 9768	C	Rocket component development.
		NOrd-9837	R	Rocket design.
	Office of Naval Research	N6-ori-10, TO-1	C	Hydrojet development.
	Army Air Forces	W-33-038-ac-PD	C	Rocket fuels research.
		W-33-038-ac-11757 (14801)	U	Rocket development. Nitromethane turbo-rocket unit.
		W-33-038-ac-14168 (Subcontract from CVAC)	S	Rocket performance calculations.
		W-33-038-ac-14549 (16100)	R	Droppable rockets and rocket motors.
		W-33-038-ac-14835 P.O. (33-038) ac-4[illegible]-1063-E	R	German ME-163 rocket motor test.
		W-33-038-ac-15309 (16610)	R	Turbopump fed rocket engine design.
	Army Ordnance	Subcontract under Douglas Aircraft Co. subcontract with Bell Telephone Laboratories under prime contract W-30-069-ORD-3182	S	Rocket power plant design.
Aeromarine Co., 5201 Old Springfield Pike, Dayton, Ohio	Navy Bureau of Aeronautics	PD 21294-47	Under negotiation	Pulse jet development.

Classification Code:

C—Confidential
R—Restricted
S—Secret
U—Unclassified

APPENDIX B. TABULATION OF CONTRACTS BY CONTRACTOR (Continued)

Contractor	Sponsoring Agency	Contract Number	Class.	Specific Field
Alfred University Alfred, N. Y.	Office of Naval Research	N6-ori-143	U	Ceramics research.
	Army Air Forces	W-33-038-ac-14233 (15903)	U	Ceramics research.
American Electro Metals Corp., Yonkers, N. Y.	Office of Naval Research	N6 ori-256, TO-1	U	Metals research.
Armour Research Foundation, Illinois Institute of Technology, Chicago, Illinois	Army Air Forces	W-33-038-ac-16533	U	Refractory coatings for metals.
Aviation Corporation of America, Lycoming Division, Williamsport, Pa.	Navy Bureau of Aeronautics	NOa(s)-4718	R	Combustion chamber development.
Battelle Memorial Institute, 505 King St., Columbus, Ohio	Office of Naval Research	N5-ori-111, TO-1	U	Metals and ceramics development.
	National Advisory Committee for Aeronautics	NA-W-5385	?	Physical properties of magnesium alloys.
		NA-W-?	?	High temperature properties of aluminum base alloys.
	Army Air Forces	W-33-038 ac-7202 (13489)	U	Metals research.
		Subcontract from Douglas Aircraft under prime contract W-33-038-ac-14105	S (subcontract Conf.)	Fuels, combustion, materials literature survey.
		W-33-038-ac-14202 (15872)	C	Combustion research.
		W-33-038-ac-14320 (15990)	U	Ceramics research.
Bell Aircraft Corp., Buffalo 5, N. Y.	Navy Bureau of Ordnance	NOrd-9876	R	Combustion, fuel, heat transfer, rocket studies. Project METEOR.
	Army Air Forces	W-33-038-ac-13450 (15357)	R	Ramjet flight test.
		W-33-038-ac-14169 (15831)	S	Design study—"Rascal" ramjet powerplant.
Bell Telephone Laboratories, Murray Hill, N. J.	Army Ordnance	W-30 069-ORD-3182	S	Coordination of development of complete guided missile.
Bendix Aviation Corp., Bendix Products Div., South Bend, Indiana	Navy Bureau of Aeronautics	NOa(s)-7978	C	Fuel metering unit design. Pressure regulators.
	Army Air Forces	W-33-038-ac-15276 (16577) P.O.(33-038) 47-863-E	C	Design study for control of subsonic and supersonic ramjets.

APPENDIX B. TABULATION OF CONTRACTS BY CONTRACTOR (Continued)

Contractor	Sponsoring Agency	Contract Number	Class.	Specific Field
Bendix Aviation Corp. Eclipse-Pioneer Div., Teterboro, N. J.	Navy Bureau of Aeronautics	NOa(s)-7570	C	Turbopump system design and fabrication.
		NOa(s) 8060	C	Fuel feed turbopump design for rockets.
		NOa(s)-8396	C	Dual propellant turbopump assembly design and build.
	Navy Bureau of Ordnance	NOrd-9432	R (some tasks are Conf.)	Fuel metering system design for ramjets. Guidance and telemetering systems. BUMBLEBEE Project.
	Army Air Forces	W 33-038-ac-14996 P.O.(33-038) 47-371-E	U	Fuel flow control systems.
Special Products Western Div., Los Angeles, Calif.	Army Air Forces	W-33 038-ac-14219	S	Supersonic air-to-air guided missile design.
Bodine Soundrive Co., 3300 Cahuenga Pass, Los Angeles, Calif.	Navy Bureau of Aeronautics	NOa(s)-8596	R	Pulse jet development.
Boeing Aircraft Corp., Seattle 14, Wash.	Army Air Forces	W-33-038-ac-13875 (15447)	S	Ramjet development. Supersonic ground to air pilotless aircraft.
Brown University, Providence, R. I.	Army Air Forces	W-33-038-ac-15004 (13651)	R	Aerodynamics and combustion literature survey.
Buffalo Electro-Chemical Co., Buffalo 5, N. Y.	Navy Bureau of Ordnance	NOrd-9917	S	Hydrogen peroxide catalytic studies.
	Navy Bureau of Ships	NObs-31494	S	Hydrogen peroxide study.
California Institute of Technology, Pasadena, Calif.	Navy Bureau of Ordnance	NOrd-9612	U	Hydraulic research.
	Office of Naval Research	N6-ori-102, TO-4	U	Aerodynamics research
		N6-ori-244, TO-2	U	Flow of fluids through rotating passages.
		FM-8 to NOrd-9612	U	Cavitation, dynamics of underwater bodies, hydraulic analogy for shock wave studies.
	Army Air Forces	W-33-038-ac-1717 (11592)	U	Aerodynamics research.
		W-33-038-ac-4320 (12847)	R	Ramjet research.
		W-535-ac-20260 (5309)	U	Metals and ceramics research for rockets. Liquid rocket fuels.

APPENDIX B. TABULATION OF CONTRACTS BY CONTRACTOR (Continued)

Contractor	Sponsoring Agency	Contract Number	Class.	Specific Field
California Institute of Technology (continued)	Army Ordnance	W-04 200-ORD-455	R	Guided missile research.
		W 04-200-ORD-1482	C	Rocket fuels research.
California, University of, Los Angeles, Calif.	Navy Bureau of Aeronautics	NOa(s)-7280	R	Heat transfer research.
		NOa(s)-8649 (continuation of NOa(s)-7280)	R	Gas turbine regenerator design.
Berkeley, Calif.	Office of Naval Research	N6-ori 111, TO-4 and 5	U	Metals research.
		N7-onr-295, TO-3	U	Heat transfer and aerodynamics research at supersonic velocities and low pressures.
	Army Air Forces	W-33-038-ac-15229	U	Heat transfer research.
Carnegie Insitute of Technology, Pittsburgh, Pa.	Office of Naval Research	N6-ori-47, TO-7	U	Fuels research.
Catholic University of America, Wash., D. C.	Office of Naval Research	N6-ori-255, TO-2	U	Metals research.
Chandler Evans Corp., Hartford, Conn.	Army Air Forces	W-33-038-ac-9287 P.O. 33-038-45-10460-E	U	Fuel metering for German pulse jets.
Chicago, University of, Chicago, Illinois	Office of Naval Research	N6-ori-20, TO-10	U	Fuels research. Hydrides.
Colorado, University of, Boulder, Colorado	Army Air Forces	W-33-038-ac-16678	C	Spray formation and combustion of liquid fuels.
Commerce, Department of, Bureau of Domestic Commerce, Wash. 25, D.C.	Army Air Forces	W-33-038-ac-PD	C	Fuels availability survey.
Consolidated Vultee Aircraft Corp., Downey, Calif.	Navy Bureau of Aeronautics	NOa(s)-7222	C	Develop LARK missile.
		NOa(s)-8374	C	Develop LARK missile.
	Navy Bureau of Ordnance	NOrd-9028	R	Ramjet design. Ramjet burners. Ignition studies. BUMBLEBEE Project.
	Army Air Forces	W-33-038-ac-14168	S	Guided missile development. Project MX-774.
		W-33-038-ac-14547 (16098)	R	XP-92 development; ducted rocket development Project MX-813.

APPENDIX B. TABULATION OF CONTRACTS BY CONTRACTOR (Continued)

Contractor	Sponsoring Agency	Contract Number	Class.	Specific Field
Continental Aviation & Engineering Corp., Muskegon, Mich.	Navy Bureau of Aeronautics	NOa(s)-7900	U	Pulse jet production.
12801 E. Jefferson Ave., Detroit 14, Mich.	Army Air Forces and Navy Bureau of Aeronautics	W-33-038-ac-13371 (15277) NAer 40000-120	R	Pulse jet development.
Cornell Aeronautical Laboratory, P.O. Box 56, Buffalo, N. Y.	Navy Bureau of Ordnance	NOrd-10057	R&C	BUMBLEBEE Project.
	Office of Naval Research	N6-ori-119, TO-1	U	Propulsion research. Project SQUID.
		FM-18	U	Supersonic aerodynamics.
Cornell University, Ithaca, N. Y.	Office of Naval Research	N6-ori-91, TO-4	U	Molecular complexes of boron compounds.
		N6-ori-213, TO-1	U	Structure of boron hydrides.
		N6-ori-264, TO-2	U	Statistical mechanical transport theory.
		FM-19	U	Propagation of compression and expansion waves.
Curtiss Wright Corp., Airplane Division, Columbus, Ohio	Navy Bureau of Aeronautics	NOa(s)-8275	C	Guided missile development.
	Navy Bureau of Ordnance	NOrd-8993	C	Research on combustion, fuels, aerodynamics. Now under supervision of Cornell Aero. Lab. BUMBLEBEE Project.
	Army Air Forces	W-33-038-ac-14161 (15831)	S	Subsonic and supersonic guided missile design study.
Propeller Division, Caldwell, N. J.		W-33-038-ac-14171	R	Rocket development.
		W-33-038-ac-14827 (16276)	U	Rocket propulsion systems.
		W-33-038-ac 16269 (17230)	R	XS-2 airplane rocket powerplant design and fabrication.
Delaware, University of, Newark, Delaware	Navy Bureau of Ordnance	NOrd-9845 (Prime contract to United Aircraft Corp.)	C	Combustion research.

APPENDIX B. TABULATION OF CONTRACTS BY CONTRACTOR (Continued)

Contractor	Sponsoring Agency	Contract Number	Class.	Specific Field
Douglas Aircraft Co., Santa Monica, Calif.	Army Air Forces	W-33-038 ac-10413 (14414)	U	Supersonic flight research air plane.
		W-33-038-ac-14105	S	Inter-continental warfare study, other than surface.
Engineering Experiment Station, Annapolis, Md.	Navy Bureau of Ships	EES TEST B3254 (SRD-9)	U	Metals research.
Experiment, Inc., P.O. Box 1-T, Richmond, Va.	Navy Bureau of Ordnance	NOrd-9756	C	Ramjet combustion research. BUMBLEBEE Project.
Fairchild Engine & Air-plane Corp., Ranger Engine Div., Farmingdale, Long Island, N. Y.	Navy Bureau of Ordnance	NOrd-9879, TO-2	R	Alcohol and hydrogen peroxide internal combustion engine.
General Electric Co., Schenectady, N. Y.	Navy Bureau of Ordnance	NOrd-8606, Task 503	C	Gas turbine development for torpedoes.
	Army Air Forces	W-33-038-ac-14499	S	Research on supersonic pilotless aircraft.
	Army Ordnance	W-30-115-ORD-1768	C	Bell XS-1 engine development "Hermes" missile development.
G. M. Giannini Co., Inc., Pasadena, Calif.	Army Air Forces	W-33-038-ac-14473 (16024)	R	Pulse jet development.
		W-33-038-ac-15322	U	Pulse jet valve study.
Goodyear Aircraft Corp., Akron, Ohio	Army Air Forces	W-33-038-ac-14153	S	Research and design study on pilotless aircraft.
Hefco Laboratories, Inc., Detroit, Michigan	Independent work		C	Fuels research for compressorless gas turbine.
Hughes Aircraft Co., Culver City, Calif.	Navy Bureau of Aeronautics	NOa(s)-8285	C	Guided missile design.
	Army Air Forces	W-33-038-ac-14220	S	Rocket missile development.
Illinois Institute of Technology, Chicago, Illinois	Office of Naval Research	N7-onr-329, TO-2	U	Metals research.
Illinois, University of, Urbana, Illinois	Office of Naval Research	N6-ori-71, TO-4, 8 and 9	U	Aerodynamics, combustion, fuels, materials research.
		N6-ori-71, TO-11	U	Mixing of fluid streams.
	Army Air Forces	W-33-038-ac-14520 (16071)	U	Ceramics research.

APPENDIX B. TABULATION OF CONTRACTS BY CONTRACTOR (Continued)

Contractor	Sponsoring Agency	Contract Number	Class.	Specific Field
Johns Hopkins University, Baltimore, Md.	Navy Bureau of Ordnance	NOrd-8036	C	BUMBLEBEE research.
	Office of Naval Research	N6 ori-243, TO-5	U	Supersonic wind tunnel design.
Applied Physics Laboratory, 8621 Georgia Ave., Silver Spring, Md.	Navy Bureau of Ordnance	NOrd-7386	R	BUMBLEBEE Project coordination.
Kaiser Cargo, Inc., Fleetwings Division, Bristol, Pa.	Navy Bureau of Aeronautics	NOa(s)-7153	R	Ramjet development.
		NOa(s)-8274	C	Technical study and preliminary design of pilotless aircraft PA-I.
		NOa(s)-8504	R	Pabst ramjet development.
M. W. Kellogg Co., Jersey City 3, N. J.	Army Air Forces	W-33-038-ac-13916 (15588)	C	Research and development jet propulsion unit.
		Subcontract under Republic Aviation Corp. contract W-33-038 ac-14208	S	Rocket and ramjet development.
		W-33-038-ac-14221 (15891)	S	Supersonic air-to-air pilotless aircraft.
		W-33-038-ac-15313	R	Turbo-rocket engine.
Lockheed Aircraft Corp., Burbank, Calif.	Army Air Forces	W-33-038-ac-15916 (17032)	U	Ramjet tests 20", 30", 48" Marquardt engines.
McDonnell Aircraft Corp., St. Louis, Mo.	Navy Bureau of Aeronautics	NOa(s)-7896	R	Pulse jet production.
		NOa(s)-8646	R	Pulse jet development.
		NOa(s)-8889	R	Pulse jet production.
		NOa(s)-8891	R	Pulse jet production.
	Army Air Forces	W-33-038-ac-14856 (16305)	R	Ramjet helicopter rotor development and flyable test stand.
Marquardt Aircraft Co., 4221 Lincoln Blvd., Venice, Calif.	Independent work		Company Conf.	Ramjet helicopter development.
	Navy Bureau of Aeronautics	P.O. 37517 from U.S.C. to Marquardt under U.S.C. Contract NOa(s)-8257	R	Ramjet component study.
		NOa(s)-8271 covers a P.O. from Grumman Aircraft B-18448	C	Ramjet development.
		NOa(s)-8520	R	Pulse jet studies.

APPENDIX B. TABULATION OF CONTRACTS BY CONTRACTOR (Continued)

Contractor	Sponsoring Agency	Contract Number	Class.	Specific Field
Marquardt Aircraft Co. (continued)	Army Air Forces	P.O. 46-170-CA under Douglas Contract W-33-038-ac-10413	C	Afterburner development for 24 C engine.
		W-33 038-ac-13449 (15356)	U	Ramjet reaction turbine development.
		W-33-038-ac-14042 (15711) AFP 412839	C	Construct six 20″ diameter ramjets.
		W-33-038-ac-14123 (15793)	U	Ramjet helicopter rotor development.
		W-33-038-ac-14152 (15822)	C	Ramjet development.
		P.O. GA 525080M under Goodyear contract W-33-038-ac-14153	C	Purchase of Marquardt 26″ ramjet and C-20 metering unit.
		P.O. GA 525081M under Goodyear contract W-33-038-ac-14153	C	Ramjet development and tests.
		P.O. 102816 under McDonnell contract W-33-038-ac-14242	S	Ramjet development.
		W-33-038-ac-15765 P.O. (33-038) 47-934-E	R	Ramjet development. Construct three 48″ diameter M = 0.85 ramjets.
		W-33-038-ac-16236 PR14186 P.O. 47-2046	U	Fuel metering unit procurement.
		W-33-038-ac-16366	R	Ramjet control development.
Glenn L. Martin Co., Baltimore 3, Md.	Army Air Forces	W 33-038-ac-14158 (15828)	S	Ground-to-ground guided missile development.
Massachusetts Institute of Technology, Cambridge, Mass.	Navy Bureau of Aeronautics	NOa(s)-8632(47)	R	Combustion research.
	Navy Bureau of Ships	NObs-25391, TO-4 and 6	U	Metals research.
	Navy Bureau of Ordnance	NOrd-9107, TO-C	C	Fuels research. Hydrogen peroxide.
		NOrd-9661	C	Aerodynamics, combustion, materials research. Project METEOR.
	Office of Naval Research	N5-ori-78, TO-5	U	Heat transfer coefficients at supersonic speeds.
		N5-ori-78, TO-11	U	Heat transfer research.

APPENDIX B. TABULATION OF CONTRACTS BY CONTRACTOR (Continued)

Contractor	Sponsoring Agency	Contract Number	Class.	Specific Field
Menasco Manufacturing Co., 805 So. San Fernando Blvd., Burbank, Calif.	Army Air Forces	W-33-038-ac-14759 (16207)	R	Ramjet development.
		W-33-038-ac-15310	R	XJ-37 Turbojet production.
		W-535-ac-40690 (10685)	R	Turbojet development.
Michigan, University of, Ann Arbor, Mich.	Navy Bureau of Ordnance	NOrd-7924	R	Aerodynamics research. Fuel spray study. BUMBLEBEE Project.
	Office of Naval Research	N6 ori-232, TO-4	U	Shock wave studies.
	National Advisory Committee for Aeronautics	NA-W-5298	?	High temperature materials research; ceramic liners for turbojets.
	Army Air Forces	W-33-038-ac-13433 (15339)	R	Pulse jet valve study.
		W-33-038-ac-14222 (15892)	S	Wind tunnel tests on supersonic pilotless aircraft.
Mines, Bureau of, Dept. of the Interior, Pittsburgh, Pa.	Navy Bureau of Aeronautics	NAer-00597	C	Solid fuel preparation.
	Office of Naval Research	NA-onr-27-47	U	Flame studies.
	Army Air Forces	P.O. 33-038-ac-46-3552-E	U	Fuels availability survey.
National Advisory Committee for Aeronautics, Flight Propulsion Research Laboratory, Cleveland, Ohio	Army Air Forces	No contract	C	Fuels tests.
	National Advisory Committee for Aeronautics	No contract	C	Ramjet, rocket, and turbojet development.
National Advisory Committee for Aeronautics, 1724 F St., N.W., Washington 25, D. C.	Office of Naval Research	NA-onr-14-47	U	Supersonic wind tunnel design.
National Research Corp., 100 Brookline Ave., Boston 15, Mass.	Army Ordnance	W-19-066 ORD 1046	U	Metals research.
Naval Air Missile Test Center, Pt. Mugu, Calif.	Navy Bureau of Aeronautics	TED-PP-PAU-201-206	C & R	Pulse jet and rocket tests.
Naval Ordnance Laboratory, White Oak, Md.	Office of Naval Research	P.O. 45-47	U	Aerodynamics of rarified gases — theoretical research.
		P.O. 46-47	U	Large scale turbulence — theoretical research.
		P.O. 49-47	U	Comparative flow analysis — experimental methods.

APPENDIX B. TABULATION OF CONTRACTS BY CONTRACTOR (Continued)

Naval Ordnance Laboratory (continued)	Office of Naval Research (cont'd)	P.O. 54-47	U	Development of high speed numerical techniques for solution of problems in fluid dynamics.
Naval Ordnance Test Station, Inyokern, Calif.	Navy Bureau of Ordnance	Re6a-order numbers	C & S	Liquid and solid propellant rockets.
Naval Ordnance Test Station, Pasadena, Calif.	Navy Bureau of Ordnance	Re6a-order numbers	C	Hydropulse and hydro-turbojet development.
Naval Powder Factory, Indian Head, Md.	Navy Bureau of Aeronautics	P.O. 275-46	R	Fuels research.
Naval Research Laboratory, Bellevue, Washington 20, D. C.	Navy Bureau of Aeronautics	TED-NRL 3401 P.O. 249-46	C	Fuels, pulse jet development.
	Navy Bureau of Ships	M-83 SRD 502/46	U	Metals research.
Naval Torpedo Station, Newport, R. I.	Navy Bureau of Ordnance	Re6a-267	C	Fuels research. Hydrogen peroxide.
New Mexico School of Mines, Research and Development Div., Station A, Albuquerque, N. M.	Navy Bureau of Ordnance	NOrd-7822	U	Missile aerodynamics studies.
		NOrd-9817	R	V-2 component design and research on fluid flow and instrumentation. BUMBLEBEE Project.
New York University, 45 Astor Place, New York, N. Y.	Office of Naval Research	N6-ori-11, TO-2	U	Combustion and aerodynamics research. Project SQUID.
		N6-ori-201, TO-1	U	Mathematical analysis of aerodynamics and combustion.
		FM-22 to N6-ori-201, TO-1	U	Fluid mechanics, mathematics analysis, measuring instruments.
North American Aviation, Inc., Inglewood, Calif.	Navy Bureau of Ordnance	NOrd-9784	C	Ramjet studies. BUMBLEBEE Project.
	Army Air Forces	W-33-038-ac-14191 (15861)	S	Ground-to-ground guided missile design.
Northrop Aviation Corp., Hawthorne, Calif.	Army Air Forces	W 33-038-ac-14175 (15845)	S	Studies and reports on ground-to-ground supersonic and subsonic guided missiles.
Northwestern University, Evanston, Illinois	Office of Naval Research	N6-ori-96, TO-4	U	Compressor study.
		N6-ori-158, TO-3	U	Aerodynamics and combustion research.
Ohio State University, Columbus, Ohio	Office of Naval Research	N6-ori-17, TO-2 and 4	U	Corrosion and thermodynamics research.
		N7-onr-225, TO-1, 3, 4 and 9	U	Fuels and materials research.

APPENDIX B. TABULATION OF CONTRACTS BY CONTRACTOR (Continued)

Contractor	Sponsoring Agency	Contract Number	Class.	Specific Field
Ohio State University, Columbus, Ohio (continued)	Army Air Forces	W-33-038-ac-11101 (14552)	R	Fuels research.
		W-33-038-ac-14217 (15887)	U	Ceramics research.
		W-33-038-ac-14794 (16243)	R	Fuels research. Liquid hydrogen.
		W-33-038-ac-16308	U	Metals research.
		W-33-038-ac-16368 (17278)	U	Metals research.
Packard Motor Car Co., 1330 Lasky Road, Toledo, Ohio	Army Air Forces	W-33-038-ac-1850 (11728)	R	Turbojet design.
Pennsylvania, University of, Philadelphia, Pa.	Navy Bureau of Ships	NObs 2477	R	Thermodynamic properties of gases.
Pennsylvania State College, State College, Pa.	Army Air Forces	W-33-038-ac-13506 (15414)	U	Ceramics research.
Pittsburgh, University of, Pittsburgh, Pa.	Office of Naval Research	N6-ori-43, TO-1	U	Fuels research. Thermodynamic properties of boron compounds.
Polytechnic Institute of Brooklyn, Brooklyn, N. Y.	Office of Naval Research	N6-ori-98, TO-2	U	Pulse jet valve, combustion, and materials research. Project SQUID.
		N6-ori-206, TO-1	U	Boundary layer control.
Princeton University, Princeton, N. J.	Office of Naval Research	N6-ori-105, TO-3	U	Boundary layer and shock wave interactions. Combustion, chemical kinetics, and fuels. Project SQUID.
		N6-ori-105, TO-2	U	Shock wave studies (transient fluid dynamics).
		FM-20	U	Shock wave studies.
		FM-21 (continuation of BuOrd contract NOrd-9240, TO-1)	U	Investigation of gas flow by interferometry and shock waves.
Purdue University, Lafayette, Indiana	Office of Naval Research	N6-ori-104, TO-1, and 2	U	Metals research, combustion, fuels and instrumentation research. Project SQUID.
Radioplane Co., 7901 Woodly Ave., Metropolitan Airport, Van-Nuys, Calif.	Navy Bureau of Aeronautics	NOa(s)-8627	C	Ramjet test vehicle study.
Reaction Motors, Inc., Dover, N. J.	Navy Bureau of Aeronautics	NOa(s)-7070	C	Rocket production.
		NOa(s)-7866	C	Rocket development.
		NOa(s)-8239	R	Rocket development.
		NOa(s)-8358	R	Servicing equipment design.
		NOa(s)-8368	C	LARK rocket production.

APPENDIX B. TABULATION OF CONTRACTS BY CONTRACTOR (Continued)

Contractor	Sponsoring Agency	Contract Number	Class.	Specific Field
Reaction Motors, Inc. (continued)	Navy Bureau of Aeronautics (continued)	NOa(s)-8531	U	Rocket development.
		NOa(s)-8540	R	Rocket research and development.
	Army Air Forces	Subcontract under CVAC W-33-038-ac-14168 P.O.-A-191 SA; B-191-SA; C-191-SA	C	Rocket design.
Republic Aviation Corp., Farmingdale, Long Island, N. Y.	Army Air Forces	W-33 038-ac-14208	S	Guided missile design Project MX-773.
Rensselaer Polytechnic Institute, Troy, N. Y.	Navy Bureau of Ships	NObs-31493	R	Metals research.
Rutgers University, New Brunswick, N. J.	Army Air Forces	W-33 038-ac-15800	U	Ceramics research.
Ryan Aeronautical Corp., San Diego, Calif.	Navy Bureau of Aeronautics	NOa(s)-8605	C	24-C afterburner.
	Army Air Forces	W-33-038-ac-14265 (15935)	S	Solid rocket design.
	Independent work			Materials and instrumentation.
Southern California, University of, Los Angeles, Calif.	Navy Bureau of Aeronautics	NOa(s)-7598	C	Ramjet development.
		NOa(s)-8164	C	Ramjet design.
		NOa(s)-8257	C	Combustion chamber and diffuser development.
	Office of Naval Research	N6-ori-238, TO-1	U	Boron compounds. Hydrides.
Standard Oil Development Laboratory, P.O. Box 243, Elizabeth, N. J.	Navy Bureau of Ordnance	NOrd-(f)1414 and NOrd-9233	C	Ramjet: fuel system, and combustor development. BUMBLE BEE Project.
	Office of Naval Research	N6-ori-109, TO-1	U	Combustion research.
Standards, National Bureau of, Connecticut Ave. and Van Ness St., N.W., Washington, D. C.	Navy Bureau of Aeronautics	NAer-00616	C	Solid fuels research.
		NAer-00617	R	Liquid and gaseous fuels. Combustion research.
		NAer 00626	U	Hydrocarbon fuels research.
	Office of Naval Research	NA-ori-2-47	U	Ceramics research.
		NA-onr-7-47	U	Thermodynamic properties of inorganic substances.

APPENDIX B. TABULATION OF CONTRACTS BY CONTRACTOR (Continued)

Contractor	Sponsoring Agency	Contract Number	Class.	Specific Field
Standards, National Bureau of (continued)	Office of Naval Research	NA-onr-S-47	U	Fuels research. Boron compounds.
	National Advisory Committee for Aeronautics	S46-3, S47-1, S47-3	U	Aerodynamics research.
	Army Air Forces	W-33-038-47-1468-E	U	Test instrument development.
	Navy Bureau of Ships	S&A 25444 NBS Project 3225	U	Thermocouple pyrometers for gas turbines.
Stanford University, Palo Alto, Calif.	Office of Naval Research	N6-ori-154, TO-5	U	Corrosion research.
		N7-onr-251, TO-2	U	Heat transfer and flow-friction studies.
	National Advisory Committee for Aeronautics	NA-W-?	C	Thrust augmentation research.
Stevens Institute of Technology, Hoboken, N. J.	Navy Bureau of Ships	NObs-45091	R	Metals research.
Syracuse University, Syracuse, N. Y.	Army Air Forces	W-33-038-ac-15941	U	Metals research.
Texas, University of, Defense Research Laboratory, 50 E 24th St., Austin, Texas	Navy Bureau of Ordnance	NOrd-9195	R	Fuels, and combustion research. BUMBLEBEE Project.
Union Oil Co. of Calif., Wilmington, Calif.	Army Air Forces	W-33-038-ac-13468 (15375)	R	Hydrocarbon fuels research.
United Aircraft Corp., East Hartford, Conn.	Navy Bureau of Ordnance	NOrd 9845	C	Ramjet, aerodynamics, and combustion research. Project METEOR.
Virginia, University of, Charlottesville, Va.	Navy Bureau of Ordnance	NOrd-7873	C	Research on the physics of fluid flow. Boundary layer and shock wave studies. BUMBLEBEE Project.
	Independent work		U	Wind tunnel design study.
Washington, University of, Seattle, Wash.	Office of Naval Research	N6-ori-217, TO-1	U	Boundary layer control for wide angle diffusers.
Wisconsin, University of, Madison, Wisconsin	Navy Bureau of Ordnance	NOrd-9938	R	Fuels and combustion research. BUMBLEBEE Project.
Wright Aeronautical Corp., Woodridge, N. J.	Army Air Forces	W-33 038 ac-14145 (15815)	R	Turbo-propeller and turbojet studies.

APPENDIX C

WIND TUNNEL FACILITIES

APPENDIX C

1. WIND TUNNEL FACILITIES IN EXISTENCE

a. Subsonic

Organization — Location	Maximum Speed	Balance System	Size of Section	Throat; Type	Horse-power	Remarks
Akron, University of, Akron, Ohio	124 mph		6½ ft. dia.	Open; return		
Alabama, University of, Tuscaloosa, Alabama	120 mph		2 ft. 5 in. x 3 ft.	Open or closed; return		
Allied Aviation, Baltimore, Maryland	110 mph		7½ ft. dia.			
California Institute of Technology, Pasadena, California	200 mph		10 ft. dia.	Closed; return		¼ — 4 atmosphers variable pressure water cooled
California, University of, Berkeley, California	90 mph		3 x 3 ft.	Open; return		
	350 mph		7 in.	Non-return		Vacuum operated
Carnegie Institute of Technology, Pittsburgh, Pennsylvania	100 mph		4½ ft. dia.	Open		
Case School of Applied Science, Cleveland, Ohio	100 mph		3 x 3 ft.	Closed; return	75	Atmospheric
Catholic University, Washington, D. C.	40 mph	3 component balance	6 x 6 ft.		120	Model stationary air twist
	40 mph		8 x 8 ft.	Closed; non-return		At Cabin John, Maryland
	70 mph		3 x 3 ft.		80	
Consolidated Vultee Aircraft Corporation, Downey, California	100 mph		15 ft. dia.			
	275 mph		4 ft. dia.		300	Atmospheric
Consolidated Vultee Aircraft Corporation, San Diego, California	300 mph	6 component Baldwin Southwark	8 x 12 ft. Octagonal	Closed; return	2250	Atmospheric
Curtiss-Wright Corporation, Caldwell, New Jersey	90 mph	U.S. Army modified NPF		Open		
Detroit, University of, Detroit, Michigan	104 mph		7 x 10 ft.	Open or closed		Atmospheric
Douglas Aircraft, El Segundo, California	175 mph		30 x 45 in. 48 in. long		75	Atmospheric

APPENDIX C

1. WIND TUNNEL FACILITIES IN EXISTENCE

a. Subsonic (Continued)

Organization — Location	Maximum Speed	Balance System	Size of Section	Throat; Type	Horsepower	Remarks
Georgia Institute of Technology, Atlanta, Georgia	125 mph		9 ft. dia.	Closed; return		
G. M. Giannini, Pasadena, California	150 mph		1 x 1 ft.	Closed; return		
B. F. Goodrich Company, Akron, Ohio	80 mph	None	18 x 36 in. Elliptical 36 in. long	Open; return	20	Icing Tests — Elliptical Test Section
Guggenheim Airship Laboratory, Akron, Ohio	24 mph		15 x 16 ft.		35	Whirling arm
	34 mph		12 x 12 ft.		1000	Vertical gusts tunnel
	125 mph		6½ ft. dia.	Open	225	Lift, drag, yaw, moments and pressure distribution
Harvard University Cambridge, Massachusetts	175 mph		30 x 40 in.		80	Flight stability of incendiary bombs
Illinois, University of, Urbana, Illinois	130 mph		30 x 48 in.	Closed	50	
Kansas, University of, Lawrence, Kansas	90 mph		5 ft. dia.	Closed; return		
Lockheed Aircraft Corporation, Burbank, California	300 mph		8 x 12 ft.	Closed; return	1250	Atmospheric
	180 mph		12 in. circular	Closed; return	2000	
Louisiana State University, University, Louisiana	100 mph		4 ft. dia.	Closed		
Maryland, University of, College Park, Maryland	100 mph		3 ft. dia.	Open		
	350 mph	6 component balance	7¾ x 11 ft.	Closed; return		
Massachusetts Institute of Technology, Cambridge Massachusetts	80 mph		7½ ft. dia.	Closed; return	2800	Force measurements and powered model tests
	95 mph	NPL Balance	5 ft. dia.	Closed; return	95	
	120 mph	NPL Balance	5 x 7½ ft.	Closed	100	Atmospheric
	130 mph at 4 atmospheres 404 mph at ¼ atmospheres	6 component "Truncated pyramid" wire balance	7½ x 10 ft. 18 ft. long	Closed; Elliptical	2000	¼ to 4 atmospheres variable pressure Water cooled

APPENDIX C

1. WIND TUNNEL FACILITIES IN EXISTENCE

a. Subsonic (Continued)

Organization — Location	Maximum Speed	Balance System	Size of Section	Throat; Type	Horse-power	Remarks
Michigan, University of, Ann Arbor, Michigan	100 mph	3 component wire	8 ft. octagonal	Grocco Closed; double-return		Under modification
Minnesota, University of, Minneapolis, Minnesota	100 mph	3 component wire	4x x 4 ft.	Open; return		
	160 mph	Electric self-balancing 6 component beam balance	7 x 10 ft.	Closed; return	450	Atmospheric
National Advisory Committee for Aeronautics, Flight Propulsion Laboratory, Cleveland, Ohio	54 mph	Structural ring	5 ft. dia.	Closed; return		
	90 mph	Wire and modified NPL	5 ft. dia.	Closed; non-return		
	435 mph		6 x 9 ft.	Single; return	4160	Icing tunnel to —20°C
	500 mph		20 ft. dia.	Closed; return	18000	0.17 to 1 atmospheres variable pressure. (To 50,000 ft.) Air interchange up to 6000 pounds per minute
National Advisory Committee for Aeronautics, Langley Field, Virginia	60 mph		12 ft.—12-sided polygon	Open; return	280	Free flight tunnel. Freon 12 gas used
	62 mph		20 ft.—12-sided polygon	Closed; vertical, annular return	400	Free spinning tunnel
	100 mph (Model) Air gusts to 25 ft. per second	Catapult and arresting gear	8 x 14 ft.	Open; return	75	Model catapulted across vertical air jet of return flow tunnel
	118 mph		Full-scale	Open; double-return		
	120 mph		30 x 60 ft. elliptical 56 ft. jet length	Open	8000	Drag tests
	165 mph		3 x 7½ x 7 ft.	Closed; return	195	Low turbulence tunnel
	(220 mph) (220 mph) (360 mph)		(6 x 6 ft.) (6.3 ft. dia.) (6 x 2½ ft.) 22 ft. jet length	Closed; return	600	Adjustable working section size

APPENDIX C

1. WIND TUNNEL FACILITIES IN EXISTENCE

a. Subsonic (Continued)

Organization — Location	Maximum Speed	Balance System	Size of Section	Throat; Type	Horse-power	Remarks
National Advisory Committee for Aeronautics, Langley Field, Virginia	250 mph 2⅓ atmospheres		19 ft. dia. 28.5 ft. jet length	Closed	8000	1 to 2⅓ atmospheres variable pressure
	300 mph		7 x 10 ft. 15 ft. jet length	Closed; return	1600	Stability and control tunnel
	300 mph at 1 atmosphere		3 x 7½ ft.	Closed; return	2000	1 to 10 atmospheres variable pressure Air cooled
National Advisory Committee for Aeronautics, Moffett Field, California	255 mph	3 component balance	40 x 80 ft. oval	Closed; return		
	300 mph	6 component Taller and Cooper Half Yoke	7 x 10 ft. 14.72 ft. long	Closed; return	1600	Atmospheric
	300 mph	6 component Taller and Cooper Half Yoke	7 x 10 ft. 14.72 ft. long	Closed; return	1600	Atmospheric
National Bureau of Standards, Washington, D. C.	100 mph	NPL — wire balance	10 ft. dia. 40 ft. jet length	Closed; non-return	700	Boundary layer studies
	100 mph	NPL	4½ ft. dia. 19 ft. long	Closed; non-return	75	5 screen turbulence reducer. Air cooled
	205 mph		6 ft. dia. 12 ft. 8 in. long	Closed; non-return	750	5 screen turbulence reducer. Air cooled
Navy Department, #1 David W. Taylor Model Basin, Washington, D. C.	180 mph	6 component Toledo	8 x 10 ft. 14.25 ft. jet length	Closed	710	Coarse screen turbulence correctors water-cooled; atmospheric
Navy Department, #2 David W. Taylor Model Basin, Washington, D. C.	160 mph	6 component Toledo	8 x 10 ft. 14 ft. long	Closed	750 max.	Coarse screen turbulence correctors water-cooled
Navy Department, Navy Yard, Washington, D. C.	75 mph	Zahn 6 component	8 x 8 ft. 33 ft. long	Closed; return	500	Atmospheric
	107 mph	Cross-arm type	6.3 ft. dia. 6 ft. 7 in. jet length	NPL Open; return	200	Atmospheric
New York University, New York, New York	48 mph	Cross-arm Zahn	4 x 4 ft.	Closed		
	140 mph		9 ft. Octagonal	Closed; return		

APPENDIX C

1. WIND TUNNEL FACILITIES IN EXISTENCE

a. Subsonic (Continued)

Organization — Location	Maximum Speed	Balance System	Size of Section	Throat; Type	Horsepower	Remarks
North American Aviation Corporation, Inglewood, California	300 mph	6 component magnetic balance	7¾ x 11 ft.	Closed; return	2800	Atmospheric
Northrop Aircraft Corporation, Hawthorne, California	160 mph		10 ft. dia. 10 ft. long		1000	Tailless airplane tests — atmospheric
Northeastern University, Boston, Massachusetts	115 mph		3 ft. dia. hexagonal	Closed		
Notre Dame, University of, Notre Dame, Indiana	75 mph		38 x 38 in.			
Ohio State University, Columbus, Ohio	105 mph		3 ft. octagonal	Closed; return		
Oklahoma, University of, Norman, Oklahoma	300 mph		4 x 6 ft. elliptical	Closed; return		
Pennsylvania State College, State College, Pennsylvania	130 mph		3 x 4 ft.	Open or closed; return	125	Atmospheric
	280 mph		2 x 3 ft. 5 ft. long	Open or closed; return	250	Atmospheric
Pittsburgh, University of, Pittsburgh, Pennsylvania	90 mph		8 x 12 ft.	Open or closed; return		
	120 mph		4 ft. dia.	Open		
Polytechnic Institute of Brooklyn, Brooklyn, New York	100 mph		30 x 40 in.			Low turbulence (also small associated tunnels for instruction purposes)
	135 mph		3 ft. 5 in. x 3 ft. 5 in.	Open or closed		
Princeton University, Princeton, New Jersey	200 mph	Wire balance	4 x 5 ft.	Closed; return	250	Educational
Reaction Motors, Incorporated, Dover, New Jersey	150 mph		2 sq. ft.	Open; non-return		
Rensselaer Polytechnic Institute, Troy, New York	90 mph		8 x 12 ft.	Open or closed		
	130 mph		4 x 6 ft.	Closed; return	150	

APPENDIX C

1. WIND TUNNEL FACILITIES IN EXISTENCE

a. Subsonic (Continued)

Organization — Location	Maximum Speed	Balance System	Size of Section	Throat; Type	Horse-power	Remarks
Southern California, University of, at Fontana, California	105,000 cu ft/min at 35 psig		17 x 20 in.			
Southern California, University of, at Los Angeles, California	100 mph		3 x 5 ft.	Closed; return		
	400 mph		2 ft. dia.	Closed; return		
Stanford University, Palo Alto, California	100 mph	Hanging Wire	7.5 ft. dia.	Eiffel		
State College, Pullman, Washington	150 mph		3 ft. dia. hexagonal	Closed; return		
Texas A & M, College Station, Texas	150 mph		7 x 10 ft.	Closed; non-return	800	
Tri State College, Angola, Indiana	100 mph		51 x 30 in.	Open		
United Aircraft Corporation, Research Division, East Hartford, Connecticut	100 mph		4 x 6 ft. octagonal		75	Pilot tunnel
	170 mph		15 x 60 in.			Laminar flow channel
	550 mph		8 in. dia.	Closed		Model of 18 ft. wind tunnel
	(200 mph) (600 mph)		(18 ft. dia.) (8 ft. dia.)	Closed; return	5000	(1 tunnel with interchangeable working sections). Exchange cooling. Effective altitude 16,000 feet
United Aircraft Corporation, Sikorsky Division, Stratford, Connecticut	55 mph		5 ft. dia.		20	
Virginia, University of, Charlottesville, Virginia	120 mph		30 x 50 in.	Open or closed; return		
War Department, Army Air Forces, Wright Field, Dayton, Ohio	150 mph		12 ft. 16-sided polygon	Vertical; closed	1000	Spin tunnel, atmospheric
	300 mph		5 ft. dia. 18 ft. jet length	Closed; return	900	
	350 mph open 450 mph closed		20 ft. dia. 20 ft. jet length	Open or closed; return	30000	Up to 2 atmospheres variable pressure. Power supplied for supersonic running. Brine radiator cooling

APPENDIX C

1. WIND TUNNEL FACILITIES IN EXISTENCE

a. Subsonic (Continued)

Organization — Location	Maximum Speed	Balance System	Size of Section	Throat; Type	Horsepower	Remarks
Washington, University of, Seattle, Washington	55 mph	NPL Balance auxiliary	4 x 4 ft.	Closed		Boundary layer control apparatus, free flight
	90 mph		3 ft. hexagonal			
	250 mph		8 x 12 ft.	Closed; return	1000	Flutter model and general tests
Wichita, Municipal University of, Wichita, Kansas	112 mph		4 ft. dia.	Closed; return		

APPENDIX C

1. WIND TUNNEL FACILITIES IN EXISTENCE

b. Transonic

Organization — Location	Maximum Speed	Balance System	Size of Section	Throat; Type	Horse-power	Remarks
Boeing Aircraft Company, Seattle, Washington	Mach No. 0.95	Magnetic	8 x 12 ft. Octagonal 15 ft. jet length	Closed; return	15000	Slanting arch cover over working section Exchange and spray vane cooling
	Approx. Mach No. 1		Approx. 7 x 7 ft.	Closed		
California Institute of Technology, Pasadena, California	Mach No. 0.95	6 component balance with 1, 2, or 3 strut support	8½ x 12 ft.	Closed; return	12000	¼ — 4 atmospheres variable pressure water cooled (Cooperative wind tunnel)
Guggenheim Aeronautical Laboratory	Mach No. 0.8 to 1.1		2 x 20 in.			Two-dimensional tunnel
	Mach No. 0.8 to 0.9		1 x 10 in.	Induction type		Two-dimensional high speed subsonic tunnel
Cornell Aeronautical Laboratory, Buffalo, New York	Mach No. 0.4 at 4 atmos. Mach No. 0.6 at 1 atmos. Mach No. 0.9 at ¼ atmos.		8½ x 12 ft.	Closed	9000 normal, 15000 max.	Exchange cooling ¼ — 4 atmospheres variable pressure
	Mach No. 0.95		1.63 x 2.35 in.		300	Atmospheric
	Mach No. 0.95		3 x 16 in.	Closed circuit	600	Atmospheric
Lone Star Laboratory, Daingerfield, Texas (Bureau of Ordnance, Navy Department)	Low subsonic to near supersonic	3 component balance; inside sting	19 x 27½ in.	Closed; non-return	16000	⅔ to 3 Atmos
National Advisory Committee for Aeronautics, Langley Field, Virginia	Mach No. 0 to 1.0	Ring framed Toledo	8 ft. dia. 14.4 ft. jet length	Closed; return	16000	11 screen turbulence reducer. Air cooled
	Mach No. 0.4 to 1.0		12 ft. dia.	Closed	11000	
	Mach No. 1.0		7 x 10 ft. 15 ft. jet length	Closed; return	10000	Atmospheric tunnel
	Mach No. 1.0		24 in. dia. 16 in. jet length	Closed; non-return		
	Mach No. 0.2 to 1.4	3 component mechanical balance beams	4 x 18 in. 10 in. jet length	Closed; non-return		Atmospheric tunnel

APPENDIX C

1. WIND TUNNEL FACILITIES IN EXISTENCE

b. Transonic (Continued)

Organization — Location	Maximum Speed	Balance System	Size of Section	Throat; Type	Horse-power	Remarks
National Advisory Committee for Aeronautics, Langley Field, Virginia	Mach No. 0.812 to 1.0		4½ ft. dia. 9 ft. jet length	Induction type; Closed throat	1000	0 to 1.8 atmospheres Uses Freon 12 — for flutter research
National Advisory Committee for Aeronautics, Moffett Field, California	Mach No. 1.0		1 x 3½ ft.	Closed; return	2000	Low turbulence tunnel
	Mach No. 0.05 to 0.90		16 ft. dia.	Closed; return	27000	Air exchanger
	Mach No. 0.4 to 0.98		12 ft. dia.	Closed		¼ to 6 atmospheres variable pressure. Screen inlet. Water cooled
War Department, Army Air Forces, Wright Field, Dayton, Ohio	Mach No. 1.0		10 ft. dia. 16 ft. 7 in. long	Closed	40000	⅛ to 2 atmospheres variable pressure
War Department, Army Ordnance, Aberdeen Proving Ground, Aberdeen, Maryland	Mach No. 0.1 to 0.9	Tate-Emory hydraulic cells	15 x 20 in. 20 in. long	Closed	6000 normal 9000 max.	0.4 to 1.7 atmospheres (Also listed in supersonic group)
	Mach No. 0.1 to 0.9	Tate-Emory hydraulic cells	15 x 20 in. 36 in. long	Closed	13000	0.03 to 0.3 atmospheres (Also listed in supersonic group)

APPENDIX C

1. WIND TUNNEL FACILITIES IN EXISTENCE

c. Supersonic

Organization — Location	Maximum Speed	Balance System	Size of Section	Throat; Type	Horsepower	Remarks
California Institute of Technology, Pasadena, California, Guggenheim Aeronautical Laboratory	Mach No. 3.2		2½ x 2½ in.	Exhaust operated		Pilot to Aberdeen tunnel
	Mach No. 4		2½ x 2½ in.			Continuous operation
California, University of, Berkeley, California	Mach No. 3		⅜ x 1 in.	Closed; non-return		Vacuum operated steam ejector powered, at 1 in. of Hg.
Cornell Aeronautical Laboratory, Buffalo, New York	Mach No. 1.7		2¼ x 6⅞ in.	Closed; non-return	600	Vacuum operated — Atmospheric
Lockheed Aircaft Corporation, Burbank, California	Mach No. 1.4		3 x 16 in.	Open; non-return		
Lone Star Laboratory, Daingerfield, Texas (Bureau of Ordnance, Navy Department)	Mach No. 1.25 Mach No. 1.50 Mach No. 1.75 Mach No. 2.00 Mach No. 2.25 Mach No. 2.50	3 component balance; inside sting	19 x 27½ in.	Closed throat	16000	Speeds varied by changing nozzle sizes. ⅔ to 3 atmos. Arranged for combustion chamber tests
Michigan, University of, Ann Arbor, Michigan	Mach No. 4 to 4.5	3 component wire balance	8 x 13 in.	Closed; non-return		Vacuum operated
National Advisory Committee for Aeronautics, Flight Propulsion Research Laboratory, Cleveland, Ohio	Mach No. 2.2		18 x 18 in.	Closed; non-return		Exhaust from large tunnel
	Mach No. 1.85		20 in. dia.	Closed; non-return		Exhaust from large tunnel
	Mach No. 2.0		3½ x 3½ in.			
National Advisory Committee for Aeronautics, Langley Field, Virginia	Mach No. 1.35 to 2.0	3 component mechanical balance beams	7½ x 7½ in. to 7½ x 9 in. 11 in. jet length	Closed; non-return variable	1000	⅕ to ⅓ atmospheres
	Mach No. 2.2		4 x 4 in.	Closed; non-return		Sub atmospheric tunnel, flutter research

APPENDIX C

1. WIND TUNNEL FACILITIES IN EXISTENCE

c. Supersonic (Continued)

Organization — Location	Maximum Speed	Balance System	Size of Section	Throat; Type	Horse-power	Remarks
National Advisory Committee for Aeronautics, Moffett Field, California	Mach No. 2.3	Internal 3 component balance in sting	3 x 1 ft.	Closed; return		Pressure fed; variable density
	Mach No. 2.6	Internal 3 component balance in sting	8 x 8 in.	Closed; return		
	Mach No. 3.4	Internal 3 component balance in sting	3 x 1 ft.	Closed; return		Pressure fed; variable density
North American Aviation, Inc., Inglewood, California	Mach No. 1.25 to 3.25		1¾ to 4½ in.			Variable speed obtained by altering inlet diffuser
Northwestern University, Evanston, Illinois	Mach No. 1.6 at 25 psi gauge		2¼ in. dia.			
Southern California, University of, at Fontana, California	Mach No. 2.5		17 x 20 in.			A smaller throat is planned for Mach No. 3.0
Southern California, University of, at Los Angeles, California	Mach No. 2.0		4 x 4 in.	Non-return		
United Aircraft Corporation, East Hartford, Connecticut	Mach No. 1.4 Mach No. 1.5 Mach No. 1.6	6 component wire balance (under construction)	55 sq. in.	Closed; partial return		
War Department, Army Air Forces, Wright Field, Dayton, Ohio	Mach No. 2.5	6 component Eastman magnetic cells	2 x 2 ft.	Closed; return	5000	1/9 to 2 atmos. Pressure fed; brine radiator cooled
War Department, Army Ordnance, Aberdeen Proving Ground, Aberdeen, Maryland	Mach No. 1.3 to 1.7	Tate-Emory hydraulic cells	15 x 20 in. 20 in. long	Closed	6000 to 9000 max.	0.4 to 1.7 atmos. Pressure operated bomb tunnel. (Also listed in Transonic group)
	Mach No. 1.1 to 4.4	Tate-Emory hydraulic cells	15 x 20 in. 36 in. long	Closed; return	13000	0.03 to 3 atmos. Pressure operated ballistics tunnel. (Also listed in Transonic group)

APPENDIX C

2. WIND TUNNELS IN DESIGN OR UNDER CONSTRUCTION

Organization — Location	Maximum Speed	Balance System	Size of Section	Throat; Type	Horse-power	Remarks
Applied Physics Laboratory, Forest Grove Burner Laboratory, Forest Grove Station, Maryland	Mach No. to 7 with air Mach No. to 15 with helium		1 x 2.2 in.			Hypersonic tunnel intermittent flow
Bell Aircraft Corporation, Buffalo 5, New York	Mach No. 2.5 to 4		12 x 12 in. to 24 x 24 in.			Proposed supersonic channel for aerodynamic and combustion tests
California, University of, Berkeley, California	Mach No. 1.5 to 4.0		In design	Open		Continuous low pressure tunnel
California, Institute of Technology, Guggenheim Aeronautical Laboratory, Pasadena, California	Mach No. 10.0		5 x 5 in.			In design
California Institute of Technology, Jet Propulsion Laboratory, Pasadena, California	Mach No. 3.0 Mach No. 4.8		15 x 15 in. 15 x 20 in.	Proposed closed throat	9000	
Johns Hopkins University, Baltimore, Maryland	Mach No. 4.0		2 x 2 ft.			
Johns Hopkins University, Laurel, Maryland	Mach No. 10		1½ x 2.2 in.			
Marquardt Aircraft Company, Venice, California	Mach No. 0.5 to 0.9		5 x 7 ft.	48 in. 30 in.		Ramjet cold flow test tunnel for fuel distribution studies
Maryland, University of, College Park, Maryland	Mach No. 0.42		7¾ x 11 ft.		2800	
Massachusetts Institute of Technology, Cambridge, Massachusetts	Mach No. 1.5 Mach No. 2.0 Mach No. 2.5		18 x 24 in.	Closed throat	10000 to 12500 estimated	Speed varied by changing nozzle size. Due for operation latter part 1948
Michigan, University of, Ann Arbor, Michigan	Mach No. 5.0		9 x 13 in.			

UNCLASSIFIED

APPENDIX C

2. WIND TUNNELS IN DESIGN OR UNDER CONSTRUCTION (Continued)

Organization — Location	Maximum Speed	Balance System	Size of Section	Throat; Type	Horse-power	Remarks
Minnesota, University of, Gopher Ordnance Works, Rosemont, Minnesota	Mach No. 1.0		42.6 sq. in.	Closed; induction type		Designed specifications of removable test sections and throats for transonic tunnel. (Sec. A, Part 2)
	Mach No. 2.0		58.1 sq. in.			
	Mach No. 2.5		64.3 sq. in.			
	Mach No. 3.0		67.7 sq. in.			
	Transonic	3 component balance	16 x 16 in.	Closed; induction type		Under construction
	Mach No. 2.5		16 sq. ft.			In study stage
National Advisory Committee for Aeronautics, Flight Propulsion Research Laboratory, Cleveland, Ohio	Mach No. 2.0		6 x 8 ft.	Closed throat		Under construction
	Mach No. 4.5		2 x 2 ft.			
National Advisory Committee for Aeronautics, Langley Field, Virginia	Mach No. 0.3 to 1.4		4 x 16 in.			Experimental tunnel under construction for ONR
	Mach No. 1.4 to 4.0		4 x 4 in.			
	Mach No. 0.9		16 ft. dia. circular			(Modification of present tunnel)
National Advisory Committee for Aeronautics, Moffett Field, California	Mach No. 1.8		6 x 6 ft.			Continuous operation
	Mach No. 2.3			Closed throat		
	Mach No. 3.4		1 ft. x 3 ft. rectangular	Closed throat		Intermittent operation
Navy Department, Naval Ordnance Laboratory, White Oak, Maryland	Mach No. 1.22 to 5.18	3 component spring type magnetic pick-up remotely mounted (40 x 40 on tunnel only)	40 x 40 cm	Vacuum operated; non-return		Kochel tunnels "Blow down" type
	Mach No. 1.3 to 5.2		18 x 18 cm			
	Mach No. 2.5 to 5.2		80 x 80 cm			
			12 x 12 cm			
Navy Department, David W. Taylor Model Basin, Carderock, Maryland	Mach No. 0.90		9.84 ft. dia.	LFM	16000	Under construction
	Mach No. 3.2		8 x 8 in.	Sonthofen		German tunnel

UNCLASSIFIED

APPENDIX C

2. WIND TUNNELS IN DESIGN OR UNDER CONSTRUCTION (Continued)

Organization — Location	Maximum Speed	Balance System	Size of Section	Throat; Type	Horse-power	Remarks
North American Aviation, Inc., Inglewood, California	Mach No. 4.5	6 component wire "truncated pyramid" type (strain gauge)	15¾ x 15¾ in.			Intermittent flow 15-20 seconds duration
Princeton University, Princeton, New Jersey	Mach No. 1.5 to 5.0		4 x 5 in. to 4 x 8 in.	Closed; exhaust operated		Under construction
	Mach No. 1.5 to 5.0		3 x 1½ in. to 3 x 3 in.	Closed; exhaust operated		Under construction
War Department, Army Air Forces, Wright Field, Dayton, Ohio	Mach No. 2.5		1.31 x 1.31 ft.		4500	Ottobrun tunnel
Washington, University of, Seattle, Washington	Mach No. 4.0 to 8.0					Free flow tunnel (Design stage)

BUCK PRINTING COMPANY, *Boston, Mass.*