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INFORMATION REPORT

SEMIANNUALLY. FORMER OFFICE OF AIR RESEARCH REPORT



U. S. AIR FORCE
AIR RESEARCH & DEVELOPMENT COMMAND
WRIGHT AIR DEVELOPMENT CENTER

WRIGHT-PATTERSON AIR FORCE BASE
OHIO

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FLIGHT RESEARCH LABORATORY



INFORMATION REPORT

ISSUE OF 30 JUNE 1952

FOREWORD

In order to bring to the attention of interested personnel the status of research projects being performed, supported, or sponsored by the Flight Research Laboratory, this semi-annual report (formerly a quarterly report) has been prepared. Preceding the technical progress of each group of projects, there appears a non-technical description of a significant accomplishment by that particular research branch. Many such accomplishments can be cited. Each semi-annual report will contain for each research branch, an accomplishment within a particular field of endeavor. Insofar as possible, this will be phrased in non-technical terms so as to be readily understood by all.

Although the Flight Research Laboratory is vested with the responsibility of undertaking applied research projects in support of the WADC development mission, it is not directed by the development laboratories. Projects may be suggested by these laboratories and the Flight Research Laboratory heartily encourages such suggestions; projects may be directed by higher authority, or they may be those thought to yield worthwhile results by the project scientist. In addition to having the responsibility for accomplishment of research in the physical sciences, any scientific personnel within the laboratory are always available for consulting services to laboratories or other Air Force agencies.

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FOREWORD (Cont)

It is hoped that through this report, engineers from the development laboratories will become sufficiently interested in projects being conducted by the Flight Research Laboratory, within their specialized fields, and will follow this research jointly with the project scientists of the Flight Research Laboratory.

Comments and inquiries regarding this publication should be addressed to:

Commanding General
Wright Air Development Center
Wright-Patterson Air Force Base, Ohio
ATTN: WORRP

APPROVED BY:

Leslie B. Williams
LESLIE B. WILLIAMS
Colonel, USAF
Chief, Flight Research Laboratory
Research Division

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467-1-12	Kinetics and Thermodynamics of Combustion Reactions
467-1-13	Bond Strengths and Decomposition of Single Molecules Kinetics
467-5	Project SQUID
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462-3-3	Ferrous Metal Detectors
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465-1-5	A Theoretical Study of Unsteady Interaction of Shock Wave and Boundary Layer in Transonic Flow
467-1-3	Flame and Ignition Phenomena

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MATHEMATICS RESEARCH BRANCH

The Mathematics Research Branch initiates and directs applied research in the field of mathematics, computation and simulation services for the USAF. The Applied Mathematics Research Section performs mathematical treatment of Air Force engineering and scientific problems. This treatment will generally fall in two categories: (1) the treatment of complex problems of known mathematical techniques, and (2) the development of new techniques for the treatment of such problems. The Simulation Research Section is responsible for all simulation activities. The Statistics Research Section is responsible for mathematical phases of research projects involving statistical methods, and assists WADC laboratories in solution of problems involving application of statistical procedures. A Computation Research Section performs consulting service in regard to automatic machine solution of all types of engineering problems, executes theoretical and experimental research in the field of machine computation and supplies computation services to USAF agencies and contractors through use of analogue, digital or IBM machines.

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PROGRESS OF SCIENCE THROUGH ELECTRONIC BRAINS

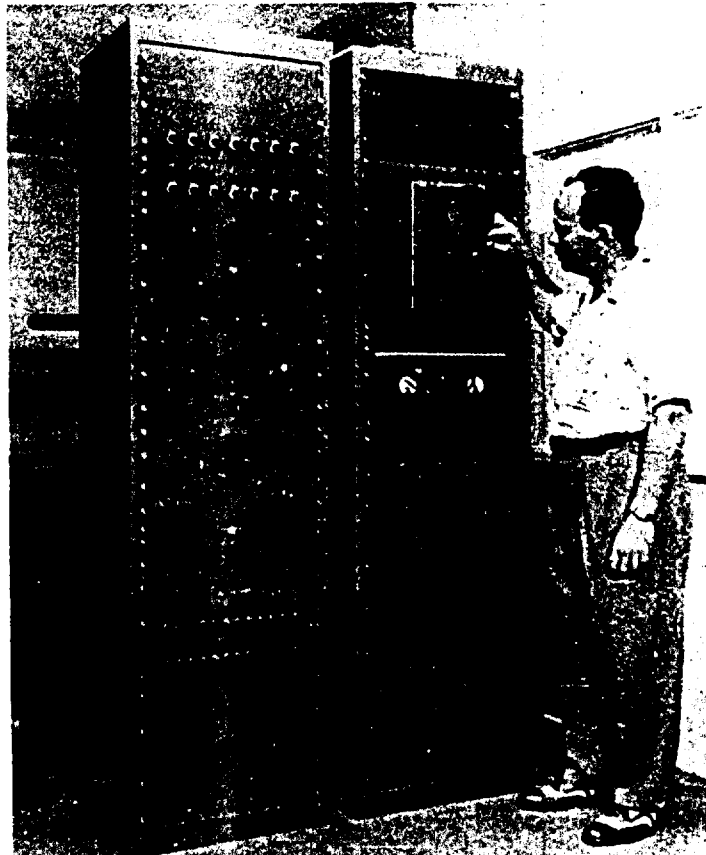
The Computation Research Section has provided, to date, automatic analogue and numerical computing services to twenty-five Air Force Contractors and thirty-five Air Force agencies for problems directly concerned with the development and production of advanced weapons to fulfill the Air Force mission. The knowledge and experience concentrated in a centralized computing service pays dividends in the more erudite approach to complex problems such as those that have been solved at the Computation Research Section.

One interesting problem concerned the design of a remotely controlled bomb which could follow definite trajectories. The mathematical studies performed on the computing devices at the Computation Research Section revealed that the problem was much more complex than originally expected and resulted in the requirement of further study by the manufacturer. Thus the computing service saved many man-hours and dollars which would otherwise have been expended in the construction and flight testing of a control system which could not be expected to work.

Another notable example of accomplishment was the computing of the aerodynamic characteristics of advanced aircraft and missile models at a cost of \$150.00 per hour which otherwise would have been determined in a wind tunnel at a cost of \$1000.00 per hour. The computing method is also 75 times faster than wind tunnel testing.

SOLVING 12TH ORDER POLYNOMIALS

The evaluation of polynomials has long been of prime importance to the engineer and the mathematician alike. When it is desired to evaluate a polynomial of degree higher than the fourth with real or complex values of the argument, so much mathematical manipulation is required that in several fields of investigation various approximate methods and diagnostic procedures have evolved to eliminate this drudgery. An example of this is the Nyquist diagram which is used to check system stability in feedback amplifier and servo-mechanism



Polynomial Plotter

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Solving 12th Order Polynomials (Cont)

design.

The Polynomial Evaluator was made by the Reeves Instrument Corporation from a prototype model developed by Mr. L. M. Warshawsky and Mr. W. Braun of the Analogue Unit. The machine will evaluate polynomials with real or complex coefficients of degree twelve or less for various values, real or complex, of the independent variable. The functional values may be read directly as discrete numbers or they may be plotted continuously on available recording equipment. In particular, roots of higher order equations are determined as values of the independent variable for which the polynomial will vanish. A special feature of this machine enables one to generate simultaneously two polynomials of degree six or less which may be of a Nyquist plot. Curve fitting may also be accomplished by using this machine. The fact that few, if any, preliminary calculations are required in using this device as well as the ease and speed with which an analysis of a polynomial can be made for a certain range of values indicates that this machine answers a major need of the research worker.

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TITLE: Investigate Analogue Machine Computation of Certain Classes of Partial Differential Equations

TASK NO.: 460-50-1 PRIORITY: 2 EST. COMPLETION: December 1952

SECURITY: Unclassified RESPONSIBLE SCIENTIST: Lt J.F. Riordan
EXT.: 23250

PRIME CONTRACTOR: None . Work being accomplished at WADC.

PURPOSE: The purpose of this task is to investigate the application of analogue computers to the solution of partial differential equations of the type occurring in compressible flow, flutter, structural vibrations, internal aerodynamics, etc.

TO DATE: Library work which was carried on to learn more about the current methods being used and to seek information which will suggest other methods has been completed. Present methods convert the partial differential equations either to a system of ordinary differential equations or to a system of algebraic equations by finite difference methods. A numerical example is being set up for which the exact solution is known in order to check the convergence of the approximate solution to the exact one. It is planned to employ the method of replacing the partial derivative with respect to one of the variables by an approximate differential relationship thereby reducing the problem to a system of ordinary differential equations.

* * * *

TITLE: Mathematical Coding of New Type Problems on Analogue Machines of the REAC Type

TASK NO.: 460-50-2 PRIORITY: EST. COMPLETION: September 1952

SECURITY: Unclassified RESPONSIBLE SCIENTIST: Lt J.F. Riordan
EXT.: 23250

PRIME CONTRACTOR: University of Notre Dame

PURPOSE: The purpose of this task is to improve the methods that have been devised for handling linear algebraic systems of equations on Reeves type analogue computers so that the number of machine components can be reduced and larger systems handled.

TO DATE: The project has failed to discover methods for reducing the machine components required to solve the general system of algebraic equations. It did confirm known practices from experience such as the benefits from dominance of diagonal terms in reducing the required components. An interesting by-product from this project is the paper entitled "A General Theory of the Iterative Methods of Solution of Linear Systems". The final report and one Technical Report have been received. Two further Technical Reports are expected. When they are

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"Project 460-50-2 (Cont)"

received, the project will be closed out.

Internal research carried out in connection with the work done by the contractor was directed toward solution of polynomial equations on the analogue computer. Following results of previous researchers, the solution of polynomial equations was attempted by reducing the solution to a condition or a system of linear secular equations. The end result of this attempt was to show that such a method of solution reduces in effect to direct computation of the values of the polynomial by the analogue computer. Based on this result, a routine has been devised by which the roots of the equation can be found quickly and accurately. Several polynomial equations have been solved by this method. The results show that the method is workable, and when used in combination with standard iterative procedures, leads to accurate results in a short time. A report describing the method has been written and will be submitted for publication.

* * * *

TITLE: Analogue Series Computers
TASK NO.: 460-50-3 PRIORITY: 2 EST. COMPLETION: June 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Max G. Scherberg
EXT.: 23250

PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this task is to develop an analogue computer to compute series expansions. In particular, power series and trigonometric series will be treated.

TO DATE: A breadboard model has been built as an auxiliary computer to the REAC and tested on third and sixth degree polynomials. A new principle of analogue computation is employed and methods will be sought to expand its use. More detailed mathematical investigations of the types of problems to which this device may be applied are being accomplished. Instrumentation is proceeding slowly, motivated by low priority assigned this project, and several ideas expressed by Flight Research Laboratory personnel are being considered for the instrumentation phase.

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TITLE: Investigation of a Nonlinear Differential Equation
TASK NO.: 460-50-7 PRIORITY: 2 EST. COMPLETION: June 1952
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Max G. Scherberg
EXT.: 23250

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"Project 460-50-7 (Cont)"

PRIME CONTRACTOR: University of Washington, Seattle

PURPOSE: The purpose of this task is to investigate the periodic solutions of the oscillator equation with quadratic damping, i.e., $\ddot{x} + b\dot{x}|\dot{x}| + w^2x = F(t + T)$, in which $F(t)$ is periodic and there are not the usual restrictions on the magnitudes of the positive constants b and w^2 .

TO DATE: The above equation is of interest in electrical circuits theory where velocity squared devices such as thermocouples and certain vacuum tubes are employed. The equation also has application in mechanics where the mechanism utilizes a so-called "hydraulic damper". Solutions to this equation may also be of interest for analyzing certain flight maneuvers where the damping is proportional to the square of the velocity. Solutions to this equation for certain values of the constants have been analytically computed. These solutions are being used as check cases for the evaluation of a special electronic computer; the results have been encouraging and the accuracy attained has been considered adequate for engineering applications. As a result, the investigation has been extended to include the more general case where $\ddot{x} + b\dot{x}|\dot{x}|^n + w^2x = F(t - T)$ with $n = 0.2, 0.4, 0.6, 0.8$ in the neighborhood of maximum amplitude. The contract has recently been extended an additional six months; the final report will be prepared during that time.

* * * *

TITLE: Dynamics of Opening Shock of a Parachute

TASK NO.: 460-50-11 PRIORITY: 2 EST. COMPLETION: July 1952

SECURITY: Unclassified RESPONSIBLE SCIENTIST: J.R. Foote EXT.: 23250

PRIME CONTRACTOR: None. Work being accomplished at WADC.

PURPOSE: The purpose of this project is to develop a theory for the opening shock phenomena of parachutes, particularly for high altitude opening.

TO DATE: A report has been prepared on the theoretical phase of the investigation. It reports on the development of the differential equations containing the several parameters defining the geometry and operating conditions of a parachute, the solution of which defines the opening motion of the parachute

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Project 460-50-11 (Cont)

and the variation of forces during the process. Experimental data is needed to evaluate some of the parameters so that the theory may be checked against experience. The experimental program set up for the evaluation of parameters is in process.

Data for specific samples of cloth such as used in man-carrying parachutes has been put into a suitable form and used in the theory. The mass-balance equation and the equation of motion have been solved together to provide the velocity and opening-rate histories of the opening. In developing the equation of motion of the system, a formula was used which corrects the steady state drag coefficient to account for higher dynamic pressure which occurs during opening. The formula is based on experimental data which indicates that parachute cloth is effectively less porous at the higher dynamic pressures.

The velocity history is predicted for four cloth samples at each of three low altitudes. For the "average" sample, the shock force and opening rate histories are calculated. A high altitude opening is calculated for the average sample. The forces are of the proper order of magnitude as shown from actual tests.

The work was presented at the Second Midwestern Conference on Fluid Mechanics, Ohio State University, 18 March 1952 and will be published in the Ohio State University Bulletin.

* * * *

TITLE: Mathematical Investigation of Downwash Behind Supersonic Wings
TASK NO.: 460-50-12 PRIORITY: 2 EST. COMPLETION: Continuing
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Max G. Scherberg
EXT.: 23250

PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this task is to develop information on the downwash, wash in, wash out and fore and aft wash behind wings in supersonic flight.

TO DATE: This project has been temporarily delayed due to higher priority work.

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TITLE: Radar Scatter Problems
TASK NO.: 460-50-16 PRIORITY: 2 EST. COMPLETION: July 1952
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Lt J.F. Riordan
EXT.: 23250
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this task is to obtain the integral for a number of values of various parameters involved.
TO DATE: This project has been completed and the final report is being prepared.

* * * *

TITLE: Computation of Compressible, Nonstationary Air Forces
TASK NO.: 460-50-15 PRIORITY: 2 EST. COMPLETION: March 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: H.E. Fettis EXT.: 23250
PRIME CONTRACTOR: University of Dayton
PURPOSE: The purpose of this task is to obtain a complete set of compressible flow wing and aileron lift and moment coefficients for use in flutter calculations.

TO DATE: The aerodynamic forces of an oscillating wing aileron combination are functions of the following three parameters: (1) the mach number (the ratio of speed "v" of the undisturbed air stream to the speed of sound under the same conditions of pressure and temperature). The conventional symbol for this quantity is M. (2) the reduced frequency. This is a dimensionless combination of the forward speed (measured in semi-chord lengths) to the frequency of the oscillation. The quantity is usually designated as "w". (3) the chord of the control surface as a ratio of the local semi-chord of the airfoil. The conventional symbol for this parameter is (1 - e), calculations have been completed for M = .7, w = .04(.04)52, e = .3, .5, .7. The ratio for e = .5 are contained in AFTR No. 6688. The remaining values will appear in supplements to that report. The contract has recently been extended. It is anticipated that values for e = .2 to e = .9 in increments of .1 will be obtained.

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TITLE: Computation of Non-Stationary Subsonic Air Forces
TASK NO.: 460-50-17 PRIORITY: 2 EST. COMPLETION: March 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: H.E. Fettis EXT.: 23250
PRIME CONTRACTOR: None. Work is being accomplished at WADC.

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"Project 460-50-17 (Cont)"

PURPOSE: The purpose of this task is to develop a practical method for the computation of non-stationary compressible aerodynamic lift and moment coefficients.

TO DATE: Presentation of a paper entitled "Reciprocal Relations in the Theory of Unsteady Flow over Thin Airfoil Sections" was made at the Second Mid-western Conference on Fluid Mechanics at Columbus, Ohio, March 17, 18 and 19, 1952.

Pertinent data recently received from the Amsterdam National Aeronautical Research Laboratory is being examined to determine its applicability to the computation program of 460-50-15. A computation program to be performed at Institute for Numerical Analysis is being drawn up, based on formulae recently developed by Eric Reissner. The results of these computations will serve as an independent check both on the results of the Dutch work and that being performed under 460-50-15. A consultation was held recently with Dr. Blanch of Institute for Numerical Analysis who will supervise the computation program. In this conference, numerous questions concerning details of the computation were discussed.

* * * *

TITLE: Nonlinear Partial Differential Equations
TASK NO.: 460-50-18 PRIORITY: 2 EST. COMPLETION: June 1952
SECURITY: Unclassified RESPONSIBLE SCIENTIST: H.E. Fettis EXT.: 23250
PRIME CONTRACTOR: None. Work being accomplished at WADC,
PURPOSE: The purpose of this project is to devise a method for solving a nonlinear partial differential equation on the REAC computer.

TO DATE: A possible method consisting of a suitable coordinate system has been set up for treating this problem. It has been formulated and is in the process of analysis to determine its suitability. Consideration is being given to the finite difference method in one variable so that the analogue computer may be used. The finite difference method was forwarded to Dr. Riess, formerly of Boston University and the originator of the problem, for evaluation. A similar approach by Dr. Eichelberger of Monsanto Laboratory was also sent to Dr. Riess for evaluation. Mr. Glazer of Boston University has recently taken over the duties of Dr. Riess.

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TITLE: Applied Mathematical Research in the Fields of Interest to the Military Establishment

TASK NO.: 460-50-21 PRIORITY: 2 EST. COMPLETION: July 1952

SECURITY: Unclassified RESPONSIBLE SCIENTIST: Max G. Scherberg
EXT.: 23250

PRIME CONTRACTOR: Carnegie Institute of Technology

PURPOSE: The purpose of this task is to provide basic qualitative and quantitative technical, non-technical, and engineering information on topics of interest to three supporting agencies and to help stimulate the development of technical and scientific personnel.

TO DATE: A progress report for the period 1 July 1951 to 9 February 1952 was received. Various fields of interest were reported; Elasticity and Plasticity, Fluid Dynamics, Mathematical Economics and Programming, Statistics, Relativity Theory and Quantum Mechanics, Vibrations and Supplemental Topics. A report entitled, "A Statistical Analogue for Natural Vibrations" and another report entitled, "A Note on the Convolution of Uniform Disturbances" were recently received.

* * * *

TITLE: Calculations of 1P Propeller Vibration Frequencies

TASK NO.: 460-50-22 PRIORITY: 2 EST. COMPLETION: July 1952

SECURITY: UNCLASSIFIED RESPONSIBLE SCIENTIST: H.E. Fettis EXT.: 23250

PRIME CONTRACTOR: None. Work being accomplished at WADC.

PURPOSE: The purpose of this task is to develop a practical method for the calculation of the natural vibration modes of a rotating, flexible propeller blade, taking into account the centrifugal field and the built-in twist of the blade.

TO DATE: Revised equations of motion resulting from the corrected curvature bending moment relation as verified by G.H. Handelman of Carnegie Institute of Technology, are being set up. Trial calculations to determine the effect of this change on the natural frequency are to be made. A proposal has been received from Purdue University to pursue work on this project; the proposal is being considered.

* * * *

TITLE: Derivation of Camera Formulae Useful in Study of Pilot Visibility

TASK NO.: 460-50-23 PRIORITY: 2 EST. COMPLETION: July 1953

SECURITY: Unclassified RESPONSIBLE SCIENTIST: H. Ferguson EXT.: 23250

PRIME CONTRACTOR: None. Work being accomplished at WADC.

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"Project 460-50-23 (Cont)"

PURPOSE: The purpose of this task is to derive formulae which will express the number of steradians of visibility of a pilot as a function of area on the film.

TO DATE: Formulas have been derived which give the number of steradians of visibility of a pilot as function of area on a film. The formulas have been turned over to interested personnel in the Aero Medical Laboratory. The project is being closed out.

* * * *

TITLE: Deceleration of Ballistic Type Missile on Re-entry Into Atmosphere
TASK NO.: 460-50-24 PRIORITY: 2 EST. COMPLETION: Continuing
SECURITY: SECRET RESPONSIBLE SCIENTIST: T. Rubin EXT.: 23250
PRIME CONTRACTOR: None. Work being performed at WADC.
PURPOSE: The purpose of this task is to determine whether suggested methods of inducing high decelerations in the upper portions of the atmosphere will reduce sufficiently the maximum decelerations obtained in flight to permit safe and continuing operation of the electronic equipment.

TO DATE: Calculations have indicated that tumbling of the configurations studied will not produce enough retardation to prevent serious aerodynamic heating. An alternate configuration consisting of the original conical form attached to a large cylindrical tank which is the fuel tank in the overall design was next tried. The results obtained with the larger configurations were more promising although still short of the required results even though obtained under the most optimistic conditions. At the present time, the use of high drag configurations in the higher altitudes to reduce speed and alleviate aerodynamic heating does not appear promising. One more effort will be made to determine whether successful decelerations may be accomplished by the above methods.

* * * *

TITLE: Investigation of Pilot Escape from High Speed Aircraft
TASK NO.: 460-50-25 PRIORITY: 2 EST. COMPLETION: November 1952
SECURITY: CONFIDENTIAL RESPONSIBLE SCIENTIST: H. Ferguson EXT.: 23250

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"Project 460-50-25 (Cont)"

PRIME CONTRACTOR: None. Work being accomplished at WADC.

PURPOSE: The purpose of this task is to make a mathematical investigation of methods for pilot escape from high speed aircraft under a variety of flight conditions related to the speed, altitude, attitude and structural design of the airplane.

TO DATE: Aero Medical Laboratory personnel are interested in acceleration of the various parts of the body of a pilot after ejection from an aircraft by an ejection seat which is tumbling. Results obtained will facilitate the designing of experiments. Formulae have been derived which give the acceleration in direction of head to foot, and chest to back, of the various parts of the body of the pilot for any time after the ejection. Graphs have been prepared which show the deceleration of the pilot and ejection seat at a variety of speeds. A report is being prepared summarizing the results obtained to date.

* * * *

TITLE: Wind Tunnel Circuit Resonance Investigation

TASK NO.: 460-50-26 PRIORITY: 2 EST. COMPLETION: October 1952

SECURITY: Restricted RESPONSIBLE SCIENTIST: F.R. Foote EXT.: 23250

PURPOSE: The purpose of this task is to determine the cavity and circuit resonance characteristics of the AEDC propulsion Wind Tunnel according to dimensions of preliminary design.

TO DATE: A survey of available reports on tunnel pulsations and resonance was made and summarized in written reports. Study was made of pulsations in incompressible non-viscous fluid for the purpose of determining whether total-head pickups or static pressure orifices are best for recording pressure variations at various frequencies. The Brown University report which, seemingly, started concern over the AEDC propulsion tunnel by predicting tunnel instability under certain conditions, was studied carefully. This theory is incomplete for Mach number one and various corrections and improvements were proposed and tried in order to make the theory applicable here. So far, none seems correct, and predictions of the theory are not borne out for the NACA large transonic tunnels, nor for the Wright Field 10-foot transonic tunnel. Other experimental test of the theory has not been made because of the short time available.

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Project 460-50-26 (Cont)

The hypothesis was made that tunnel length is the fundamental wave length for true circuit resonance and that the corresponding fundamental resonance frequency would be the time required for a pressure pulse to make one circuit. A theoretical analysis was made which predicts the time required. In cooperation with the Wind Tunnel Branch, an experimental apparatus was built by the FRL Technical Services Branch, consisting chiefly of a streamlined pressure tank which was closed at one end by several thicknesses of rubberized nylon. The diaphragms were burst by compressed air and measurements of the pressure results were taken at four points around the 10-foot tunnel, both at zero speed and at several running speeds. The photographic records are being studied and results are being checked against the theory.

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TITLE: Statistical Analysis of Breaking Strengths of Materials
TASK NO.: 460-51-4 PRIORITY: 2 EST. COMPLETION: Continuing
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Paul R. Rider EXT.: 23250
PURPOSE: The purpose of this task is to apply new methods of statistical analysis to data on fatigue of propeller flash welds, and in general, to improve the statistical methods for analyzing data on the breaking strength of materials. (It is expected that this experiment will result in the improvement of the strength of flash welds.)

TO DATE: Experiments in flash weld testing were performed and the data analyzed according to classical methods. Application of Dr. Gumbel's extreme value theory was applied. A Memorandum Report on the application of the extreme value theory to the problems of breaking strength of materials has been prepared by the Flight Research Laboratory personnel. Laboratory tests are being conducted to determine the optimum combination of current density, length of time of weld, and final upset pressure.

Dr. Irving Burr and Dr. Carl Kossack of Purdue University visited the Flight Research Laboratory on 2 June 1952 to discuss a proposal for research on this project. The representatives of Purdue University conferred with representatives of the Propeller and Materials Laboratory as well as representatives of the Flight Research Laboratory. An attempt is being made to integrate the engineering and statistical aspects of the problem.

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TITLE: Statistical Analysis of Food Preference and Acceptability of the IF-4 Combat Ration
TASK NO.: 460-51-6 PRIORITY: 2 EST. COMPLETION: March 1952
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Lt Mentzer EXT.: 23250
PRIME CONTRACTOR: None. Work is being accomplished at WADC.
PURPOSE: The purpose of this task is to analyze questionnaire data and provide information indicative of the preference and acceptability of the present IF-4 Combat Ration. (These results will furnish information for use in the preparation of future in-flight combat rations.)

TO DATE: Preliminary statistical assistance in the preparation of a food preference questionnaire used in this experimentation has been completed. Problems concerning sampling procedure and statistical validity of results have been solved. Questionnaires have been sent to seven Air Bases and scant returns have been received. A statistical analysis and interpretation of questionnaire results as to food preference are being performed.

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TITLE: Nutrients of Survival Rations
TASK NO.: 460-51-8 PRIORITY: 2 EST. COMPLETION: April 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Mary D. Lum EXT.: 23250
PRIME CONTRACTOR: None. Work is being done by WADC.
PURPOSE: The purpose of this task is to evaluate the combination of nutrients which will give optimum chances for survival under all climatic conditions. This study is to provide the necessary information for devising nutritional requirements for an all-climatic, global, all-purpose ration.

TO DATE: A satisfactory statistical "design" of an experimental plan has been formulated for testing the effects of four types of diets on Air Force personnel under different conditions of caloric intake, exercise, and water intake.

Data is presently being collected by the Aero-Medical Laboratory.
WADC.

* * * *

TITLE: Techniques of Visual Reconnaissance
TASK NO.: 460-51-13 PRIORITY: 2 EST. COMPLETION: July 1952
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Mary D. Lum EXT.: 23250
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this task is to evaluate NDRC Report, Vol. 2B and make suggestions as to appropriate research in reducing the statistical information on visual reconnaissance to practical methods of procedure.

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Project 460-51-13 (Cont)

TO DATE: The statistical content of NDRC Report, Vol. 2B, Chapters I-IV was evaluated. There appeared to be definite practical applications for the statistical information set forth on visual reconnaissance. Efforts are being made to conduct a full time, intensive research on the conversion of the general statistical information on visual reconnaissance into practical methods of procedures and actual operational directives.

A statistical investigation is being made of the optimum paths to be photographed for reconnaissance over a four mile by eight mile arch.

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TITLE: Estimation of Parameters in Stochastic Processes
TASK NO.: 460-51-17 PRIORITY: 2 EST. COMPLETION: February 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: P.R. Rider EXT.: 28206
PRIME CONTRACTOR: Dr. Henry B. Mann
PURPOSE: The purpose of this task is to advance the theory and the techniques of estimation of parameters of stochastic processes which will be valuable in analyzing tracking errors; analysis of certain nuclear phenomena, possibly in armor plate penetration; and various other applications.

TO DATE: Contract has been negotiated. Dr. Mann visited the Flight Research Laboratory on 28 May 1952 to further discuss the problem.

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TITLE: Statistical Analysis of Ranked Data
TASK NO.: 460-51-18 PRIORITY: 2 EST. COMPLETION: January 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: P.R. Rider EXT.: 28206
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this project is to provide a manual for use in handling statistical data arranged according to rank.

TO DATE: A draft of an appropriate Technical Report has been completed. The report is in the process of being published.

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TITLE: A Study of Poisson Samples with Some Data Missing
TASK NO.: 460-51-19 PRIORITY: 2 EST. COMPLETION: October 1952
SECURITY: Unclassified RESPONSIBLE SCIENTIST: P.R. Rider EXT.: 28206
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this project is to investigate truncated and fragmentary Poisson distributions.

TO DATE: The work of G. U. Yule on the subject is being investigated.

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TITLE: Computation Services, National Bureau of Standards
TASK NO.: 468-1-1 PRIORITY: 2 EST. COMPLETION: Continuing
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Maj Johnston EXT.: 28235
PRIME CONTRACTOR: National Bureau of Standards
PURPOSE: The purpose of this task is to make available the expert computing and consulting services of the Institute for Numerical Analysis, National Bureau of Standards for the Air Research and Development Command and USAF contractors, especially those on the west coast.

TO DATE: The large scale digital computer, SWAC, is now solving problems approximately twenty-five hours a week. The work on the Williams Tube memory is continuing and the results have been very satisfactory.

The solution of many Air Force problems is being accomplished with the IBM equipment as well as the SWAC.

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TITLE: Mark I and Mark IV Operations at Harvard
TASK NO.: 468-1-2 PRIORITY: 2 EST. COMPLETION: Continuing
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Maj Johnston EXT.: 28235
PRIME CONTRACTOR: Harvard Computation Laboratory, Harvard University
PURPOSE: The purpose of this task is to enable the ARDC and AF contractors to obtain numerical solutions to various research and engineering problems that would not be considered solvable by other means or prohibitively expensive.

TO DATE: Mark I is in operation 24 hours a day, five days a week, solving Air Force problems. Mark IV is assembled and in the final "de-bugging" stage and should be operating in the near future.

Additional funds have been applied to this contract to be used for the operation of Mark I and Mark IV and also to conduct research and development on computer components and techniques.

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TITLE: Computation Section Operation, Flight Research Laboratory
TASK NO.: 468-1-3 PRIORITY: 1C EST. COMPLETION: Continuing
SECURITY: Unclassified RESPONSIBLE SCIENTIST: E. P. Little EXT.: 28235

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Project No. 468-1-3 (Cont)

PRIME CONTRACTOR: None. Work is being accomplished at WADC.
PURPOSE: This task is concerned with the operation of the Analogue, IBM and OARAC Units of the Computation Research Section, Flight Research Laboratory in solving mathematical problems for the Air Force and its contractors.

TO DATE: The Computation Research Section has moved to Bay II, Building 57 where Analogue and IBM equipment is in operation. Three REAC's and three IBM CPC's are presently being used. The OARAC has not yet been delivered. A Tele-cordex is now available in the IBM Unit, but the Teleplotter was damaged in shipment and had to be returned. Typical problems on the Analogue equipment have included (1) Flutter Analysis for F51F - Aircraft Laboratory; (2) Line of Sight Control System for T-55 - Aircraft Laboratory; (3) Lateral Stability in Response Study MX155Y - Consolidated Aircraft and (4) Aircraft Response to Air Blast Loads - M.I.T. Problems on the IBM equipment have included (1) Transonic Flow Past a Wedge - Aircraft Laboratory; (2) Table for Project Daisy Mae - Photo Lab; (3) Bomb Trajectory for LABS - Armament Laboratory.

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TITLE: Computation Research
TASK NO.: 468-1-5 PRIORITY: 1C EST. COMPLETION: July 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Maj Johnston EXT: 28235
PRIME CONTRACTOR: Massachusetts Institute of Technology
PURPOSE: The purpose of this task is to extend the capabilities of existing computing equipment.

TO DATE: This contract has recently been negotiated. No progress reports have been received.

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TITLE: Computer Research, Ordnance Corporation
TASK NO.: 468-2-1 PRIORITY: 1C EST. COMPLETION: Continuing
SECURITY: Unclassified RESPONSIBLE SCIENTIST: E.P. Little EXT: 28235
PRIME CONTRACTOR: Institute for Advanced Study, Princeton University
PURPOSE: The purpose of this task is to design and develop an electronic digital computer for ease of mathematical coding and to discover improved mathematical techniques for use with such computers in order to solve more efficiently some of the scientific and engineering problems of interest to the USAF.

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Project No. 468-2-1 (Cont)

TO DATE: This is a joint Army, Navy, AEC, and USAF project. Progress reports have been received which outline the work being performed on the design and construction of a computer that has been built and will be retained in the Institute for Advanced Study, Princeton, New Jersey.

The computer is now in limited operation, but the error rate is still relatively high; furthermore, the input-output equipment is in a rudimentary stage. Additional funds were supplied for the continued support of this project by Air Research and Development Command.

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TITLE: Research and Construction, Polynomial Plotter
TASK NO.: 468-2-2 PRIORITY: 2 EST. COMPLETION: Continuing
SECURITY: Unclassified RESPONSIBLE SCIENTIST: L.M. Warshawsky EXT: 28235
PRIME CONTRACTOR: Reeves Instrument Corp.
PURPOSE: The purpose of this task is to develop a special purpose machine specially adapted for rapid solution of polynomial type problems frequently arising in engineering problems.

TO DATE: Tests of the device have shown definite inadequacies of design, especially in the demodulation circuit, isolation amplifiers and the reference signal generator. These conditions are being rectified by personnel of the Computation Research Section.

The contract costs were somewhat greater than the allowed figures, due to rising costs of material and personnel. An application for an over-run has been made.

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TITLE: Digital Computer, National Bureau of Standards
TASK NO.: 468-2-3 PRIORITY: 1C EST. COMPLETION: December 1952
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Maj Butsch EXT: 28235
PRIME CONTRACTOR: National Bureau of Standards
PURPOSE: The purpose of this task is to procure a suitable high speed electronic digital computer to be used in the Flight Research

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Project No. 468-2-3 (Cont)

Laboratory for the solution of engineering problems encountered by the ARDC and its contractors.

TO DATE: All parts of the machine have been received. The drum has been coated with magnetic oxide and all read-record heads have been installed. It was found that extra cooling was required to dissipate the heat created by the drive motor. Without the extra cooling, the thermal expansion of the drum assembly became excessive. The assembly has been operated with auxiliary cooling added and found to operate satisfactorily.

The main portion of the computer has been operating erratically during the last ninety days due to the excessive failures, (because of the hot humid weather) of the germanium crystal diodes. An air conditioning unit has been ordered by General Electric so that the computer may be operated within a tolerable range of the germanium diodes. During the winter months diode failure were practically negligible.

Difficulties have been experienced with the 12BH7 vacuum tubes used in the OARAC. As a result, a program has been initiated to replace these tubes if possible with a more suitable electronic tube.

A general detailed inspection of all of the component turrets has been initiated and is expected to last until mid August. The purpose of this inspection is to replace all doubtful diodes and examine all electronic components in the turrets.

It is expected that the input-output mechanisms will be in operation in August 1952. At that time problems may be prepared and coded on magnetic tapes for use when OARAC is in satisfactory operation.

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<u>TITLE:</u>	Investigate Barium Titanate Electrostatic Storage
<u>TASK NO.:</u>	468-2-4 <u>PRIORITY:</u> 2 <u>EST. COMPLETION:</u> July 1953
<u>SECURITY:</u>	Unclassified <u>RESPONSIBLE SCIENTIST:</u> Capt Mahler <u>EXT:</u> 28235
<u>PRIME CONTRACTOR:</u>	Catholic University, Washington, D.C.
<u>PURPOSE:</u>	The purpose of this task is to determine the usefulness of barium titanate material for memory devices in large scale digital computers.

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Project No. 468-2-4 (Cont)

TO DATE: Progress report number one was received from Catholic University of America, during June 1952. In order to study the details of developments and future plans, the contractor was visited. He has made a quartan counter using barium titanate capacitors as storage elements. He plans to pulse the counter with a transistor circuit. Transistors for which, will be supplied by the Computation Research Branch.

The contractor also plans to use thin slabs of barium titanate ceramic as large scale electrostatic storage mosaics. The active elements of such a mosaic are the crystals of pure barium titanate naturally imbedded in the ceramic. The contractor is now obtaining statistics on variance of charge density that can be stored over the surface of a slab. He is also attempting to manufacture barium titanate ceramic slabs that have the pure crystals in an orderly pattern with respect to location and orientation.

* * * *

TITLE: REAC Solution of Linear Algebraic Systems
TASK NO.: 468-2-5 PRIORITY: 2 EST. COMPLETION: July 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: W. Braun EXT.: 28235
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this task is to increase the utility of the Reeves Electronic Analogue Computer.

TO DATE: An auxiliary board of potentiometers has been built which will facilitate the application of the REAC to the solution of linear algebraic systems. This component is presently undergoing tests.

This computational device (to be used in conjunction with the REAC) has been subjected to preliminary tests. These tests have produced favorable results in obtaining the roots of linear algebraic systems up to and including a 10 x 10 system. The tests have also indicated the need of a better method of calibrating coefficients. A refinement of the original method has been devised and the necessary instrumentation is being completed. Final tests of this model are contemplated in the near future.

Due to the use of 1% input resistors in the summing amplifiers, setting potentiometers by the usual method was inaccurate. The inaccuracy of the input resistors was compensated for by measuring voltages at the outputs of the amplifiers. The rewiring necessary to permit the use of the potentiometers as extras on the REAC has been completed and checked.

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TITLE: Multiplex Multiplier
TASK NO.: 468-2-7 PRIORITY: 2 EST. COMPLETION: July 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Capt Haneman EXT: 28235
PRIME CONTRACTOR: Engineering Research Institute, University of Michigan
PURPOSE: The purpose of this task is to develop an improved multiplying device for electronic differential analyzers which will supplant the servos presently used.

TO DATE: Difficulties in pursuing the plan of development have led to the abandonment of this program. The presently accrued knowledge will be summarized in a final report and the useful components of the equipment will be turned over to the Flight Research Laboratory.

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TITLE: War Games Computer
TASK NO.: 468-2-8 PRIORITY: 2 EST. COMPLETION: Continuing
SECURITY: Confidential RESPONSIBLE SCIENTIST: Capt Mahler EXT: 28235
PRIME CONTRACTOR: Alabama Polytechnic Institute
PURPOSE: The purpose of this task is to make available a device for the quantitative and objective evaluation of different strategies for the conduct of a major air war in the defense of the United States.

TO DATE: Maj William D. Jones of USAFIT and the project monitor visited Alabama Institute to review the progress of this project. Completion of the initial version of the computer is expected by 15 September 1952 when a systematic series of games will be played. Recently, an interesting feature has been added; it is called a matrix used to simulate duels between attacking bombers and defending fighters. The matrix develops loss of both fighters and bombers as a result of these engagements.

* * * *

TITLE: Numerical Studies of Navier Stokes Equations
TASK NO.: 468-2-9 PRIORITY: 2 EST. COMPLETION: Continuing
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Maj Johnston EXT: 28235
PRIME CONTRACTOR: National Bureau of Standards
PURPOSE: The purpose of this task is to provide aerodynamicists with theoretically exact solutions to the basic equations of fluid dynamics for comparison with simplified analysis and with experiments.

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Project No. 468-2-9 (Cont)

TO DATE: The work on this project did not begin until November 1951, and therefore will continue until November 1952. This results from the fact that Dr. Henrici, the principal investigator, did not arrive in this country until November 1951. One progress report was received in March and was commented on favorably.

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TITLE: Numerical Studies of Compressible Flow Equations
TASK NO.: 468-2-10 PRIORITY: 2 EST. COMPLETION: October 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Maj Johnston EXT: 28235
PRIME CONTRACTOR: National Bureau of Standards
PURPOSE: The purpose of this supplement is to investigate the applicability of Bergman's method of orthogonal functions and Kernol functions for the determination of non-viscous adiabatic compressible subsonic flow in two dimensions by means of high speed automatic computing machines.

TO DATE: Additional funds will be applied to this contract. The latest progress report has not yet been received.

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TITLE: Automatic Reduction of Wind Tunnel Data
TASK NO.: 468-2-11 PRIORITY: 2 EST. COMPLETION: July 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Capt V. Haneman EXT: 28235
PRIME CONTRACTOR: University of Michigan
PURPOSE: The purpose of this project is to eliminate the present costly time consuming, process of manual reduction of wind tunnel by the fabrication of an automatic computer.

TO DATE: The formal contract expired on 30 June 1952 and the personnel at the University are in the process of writing a final report. The equipment has been constructed and is in the process of being "de-bugged" in the laboratory.

It is anticipated that the completed project will be evaluated on the two foot tunnel of the Wind Tunnel Laboratory. Plans for this operation are now being formulated. A technical paper is being prepared to present to the Automatic Data Reduction Symposium, Institute of Radio Engineers in late August. This paper will present the fundamental ideas of the unit and the laboratory measured accuracies of the system.

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TITLE: Williams Tube Research
TASK NO.: 468-2-12 PRIORITY: 2 EST. COMPLETION: Continuing
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Capt J. Smith EXT: 28235
PRIME CONTRACTOR: National Bureau of Standards
PURPOSE: The purpose of this supplement is to provide a satisfactory, reliable Williams storage tube to be utilized in many large scale calculators supported by the Air Force.

TO DATE: National Bureau of Standards has contracted for the modification of eighteen 3" experimental tubes. It is hoped that these modifications will result in surfaces with fewer blemishes. No quantitative data are available on these tubes at this time, hence comments on the foregoing must await more detailed study and experimentation.

The Vacuum Tube Products Company, California is conducting electron gun research sponsored by National Bureau of Standards.

National Bureau of Standards personnel are preparing an interim report on the project at this time, the regular progress report to be forwarded on 30 September 1952.

* * * *

TITLE: Photoelectric Analogue Computer
TASK NO.: 468-2-13 PRIORITY: 2 EST. COMPLETION: June 1954
SECURITY: Restr. RESPONSIBLE SCIENTIST: W. Braun EXT.: 33257
PRIME CONTRACTOR: Not available
PURPOSE: The purpose of this project is to develop a photoelectric analogue computer that shall be an aid in finding the most effective ground zero in attacking extensive target areas by a limited number of weapons and similar problems arising in the tactical evaluation of aerial photographs.

TO DATE: A simplified version of the computer has been designed and will be sent out for bids on its construction. The sum of \$90,000 will be transferred to Flight Research Laboratory to support the construction of this original model.

* * * *

TITLE: Barium Titanate High Speed Recorder
TASK NO.: 468-2-14 PRIORITY: 2 EST. COMPLETION: November 1952
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Capt J. Mahler EXT: 28235
PRIME CONTRACTOR: American Chronoscope Corporation
PURPOSE: The purpose of this project is to determine the feasibility of using piezo-electric barium titanate elements as recording styli in a high speed recorder.

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Project No. 468-2-14 (Cont)

TO DATE: A single 16 pencil record channel has been designed. It contains four basic components (1) an amplifier, (2) a switching device, (3) a pencil excitation drive, and (4) a paper drive. A diode selector is also being constructed.

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TITLE: Auto Correlation Computer
TASK NO.: 468-2-15 PRIORITY: 2 EST. COMPLETION: August 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Capt Haneman EXT.: 28235
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this project is to provide funds to investigate the field of computation involved in autocorrelation functions and to sponsor and encourage the study of such aspects of the field that seem profitable.

TO DATE: Purchase requests are being initiated to obtain equipment for the construction of an autocorrelation computer to be assembled, tested and used in the computer research section.

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TITLE: Angular Position Digitizer
TASK NO.: 468-2-16 PRIORITY: 2 EST. COMPLETION: January 1954
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Dr E.P. Little EXT.: 28235
PRIME CONTRACTOR: Broadview Research and Developmeht, Burlingame, California
PURPOSE: The purpose of this project is to design and develop an angular position digitizer of high accuracy, rapid response, and great reliability to provide binary signals for shaft rotation.

TO DATE: Contract is being negotiated.

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MECHANICS RESEARCH BRANCH

The Mechanics Research Branch is responsible for applied research in the field of mechanics, the major fields being research in automatic control of modern aircraft and guided missiles, structures research, research in vibration and stability, and research in magnetism and magnetic equipment.

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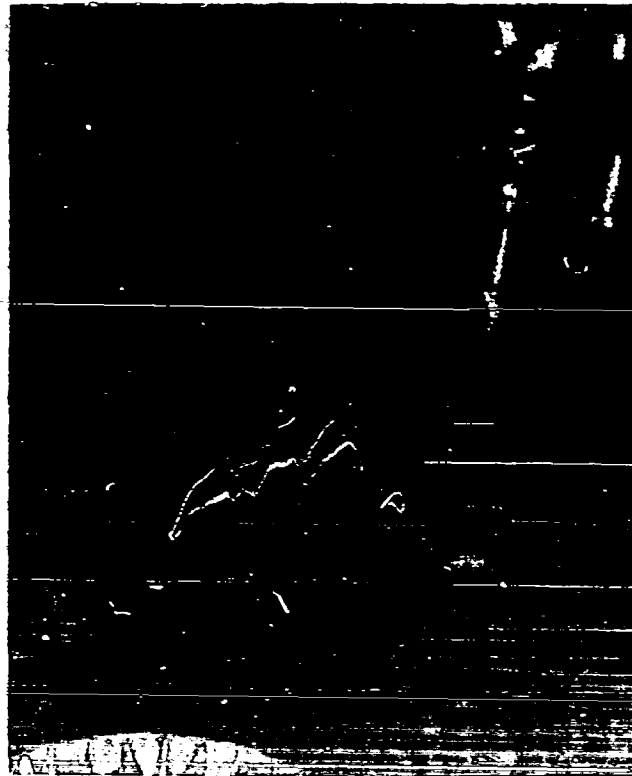
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WHY DOES A LANDING GEAR SHIMMY?

Landing gear shimmy (vibration) has been an ever present problem on aircraft for many years. Before the wide use of the tricycle landing gear, severe vibrations were excited by the tail wheel. In either case, the results were intolerable. At the outbreak of the Korean crisis, shimmy was present in several aircraft. In one instance, shimmy destroyed an experimental bomber. Because of the increasing frequency of shimmy, the Aircraft Laboratory brought the problem to the Flight Research Laboratory to enlist its help.

The problem was approached in a rational manner. First of all, the Mechanics Research Branch contracted Professor J. P. DenHartog to serve in a consulting capacity. Professor DenHartog, along with W. J. Moreland of the Flight Research Laboratory, canvassed the aircraft industry to discuss the existing cases of shimmy and the means used to correct them. All of industry was very familiar with this problem and has attempted to correct it by the application of trial and error methods. In the meantime, Aircraft Laboratory contracted Midwest Research to make a comprehensive search of the literature for past work done on the problem. The Germans had expended great effort from 1939 to 1944 in order to overcome it. In addition, the English, French, Russians, and NACA had done considerable work, but in no case was a satisfactory solution obtained. As a result, several analytical analyses were made of various systems utilizing parameters that had not previously been considered. The results were published in AFTR 6590, "Landing Gear Vibration", by William J. Moreland. Contained in the report are a series of design curves that predict either a stable or unstable aircraft.

This analysis by Professor Moreland has been praised throughout the aircraft industry. If an airplane can be provided for further tests, it is believed that the problem of "landing gear shimmy" will be well on the way to solution.



Shimmy Vibration Shake Test

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TITLE: Research in Artificial Stability and Control
TASK NO.: 461-1-2 **PRIORITY:** 1-B **EST. COMPLETION:** 28 February 1953
SECURITY: Restricted **RESPONSIBLE SCIENTIST:** Capt P.P. Cerussi **EXT.:** 20217
PRIME CONTRACTOR: Cornell Aeronautical Laboratory, Inc.
PURPOSE: The purpose of this task is to obtain actual flight test data on the optimum and minimum flyable longitudinal stability and control characteristics for fighter and bomber airplanes. This type of information has recently become significant in design with the advent of practical servomechanisms for the addition of artificial stability to airplanes; also, this information should be useful to those charged with the responsibility for establishing handling qualities specifications.

TO DATE: Two airplanes are to be used for the evaluation: one, a TB-26 light bomber; the second, an F-94 jet fighter. The elevators of these airplanes will be driven by irreversible hydraulic serves in response to control signals supplied by the pilot and signals provided by artificial stability sensors. The control stick will be driven by a second servo in response to pilot applied control force in a manner closely simulating the airplanes normal control forces. By adjusting the gains of the various channels of this equipment, the following parameters of longitudinal stability and control can be varied: phugoid period and damping, short period and damping, static elevator to trim vs. C_L and g , and static stick force vs. C_L and g . The extremes of stability and control that can be easily simulated and evaluated could not safely and economically be obtained in any other way.

Theoretical calculations for the two test airplanes have been completed. The design, construction and installation of the control equipment and instrumentation in the TB-26 aircraft is just about completed. Flight tests of the TB-26 aircraft should start within approximately one month. Design, construction and installation of the control equipment and instrumentation for the F-94 aircraft has recently been initiated. Several interesting aspects of this task which bear directly upon development projects are: (1) problems of longitudinal stability characteristics are becoming acute in the design of high performance jet aircraft; (2) determination of the feel characteristics that should be incorporated into powered boost controls are not presently available; (3) information on the design and operation of advanced type control systems utilized in interceptor aircraft are not available (for instance, should the control stick be mechanically connected to the elevator control surface?).

Answers to such questions as the above and others should be forthcoming from this research project.

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TITLE: Dynamics of Complex Aeronautical Systems
TASK NO.: 461-1-3 PRIORITY: 2 EST. COMPLETION: July 1952
SECURITY: Unclassified RESPONSIBLE SCIENTIST: O.P. Morgensen, Jr.
EXT.: 24159
PRIME CONTRACTOR: Consolidated Vultee Aircraft Corporation, Fort Worth, Texas
PURPOSE: The purpose of this task is to accomplish the following:

- (1) Determine adaptability of methods devised by M.I.T. in connection with Project MX-755 to the analysis of the dynamic characteristics of large bombardment aircraft.
- (2) Obtain general information on dynamics of complex systems in order to obtain a better understanding of the requirements for additional research on those systems.
- (3) Provide data that will serve as a basis for possible modification of future B-36 aircraft in order to improve those dynamic characteristics which affect their utility as bombardment aircraft.

TO DATE: Instrumentation procured for this program was used to correct E-6 auto-pilot difficulties such as Dutch roll with tail shake on B-36B aircraft. The program which was to have been accomplished on a B-36D aircraft was delayed due to the necessity of accomplishing an autopilot "fix" on the B-36B aircraft. Instrumentation for obtaining the dynamic response of the B-36D airplane was installed in one of these aircraft. Autopilot difficulties were encountered on the "D" model; those difficulties were corrected. A sinusoidal voltage generator was installed for supplying sinusoidal signals to the autopilot so that the response of the aircraft to sinusoidal inputs to the autopilot can be compared to the response obtained from Fourier analysis of transient inputs. Data reduction methods have been perfected and much data has been reduced.

Longitudinal and lateral dynamic response data has been received and is being reviewed at the Flight Research Laboratory.

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TITLE: Consultation Services on Dynamics of Complex Systems
TASK NO.: 461-1-4 PRIORITY: 2 EST. COMPLETION: February 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: O.P. Morgensen, Jr. EXT. 24159
PRIME CONTRACTOR: Cornell Aeronautical Laboratory
PURPOSE: The purpose of this task is to expedite the analysis and evaluation of data accumulated from various studies and tests in connection with USAF research, particularly in connection with the analysis of the dynamics of complex systems.

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Project 461-1-4 (Cont)

TO DATE: Cornell Aeronautical Laboratory specialists have assisted with the dynamic response program on the B-36D aircraft, have made several limited investigations on the phugoid motion of aircraft, and have done some preliminary work on the control of stalled aircraft. The contract for consulting services has been extended to February 1953. The contractor has also assisted the Applied Mechanics Branch with problems incidental to a non-linear yaw control for fighter aircraft.

TITLE: Oil Whip Study
TASK NO.: 461-1-6 PRIORITY: 2 EST. COMPLETION: February 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Paul E. Gies EXT.: 20217
PRIME CONTRACTOR: Rensselaer Polytechnic Institute
PURPOSE: The purpose of this task is to obtain information that will permit the safe design of high speed shafts supported by journal bearings.

TO DATE: Any shaft supported by full journal bearings that are film lubricated has an upper critical speed which cannot be exceeded. The phenomenon which limits the shaft speed is called oil whip. The oil whip usually starts at twice the critical speed of the shaft, although five times critical speed has been attained.

The contractor has fabricated the test apparatus and completed the test on the first shaft. Results to date have been good. In all cases, the eccentricity ratio was between 0.53 and 0.63 with impending oil whip.

A second rotor that will have a lower critical speed and higher bearing loads has just been mounted in the test rig for further testing.

TITLE: Investigation of Combined Open and Closed Loop Automatic Controls
TASK NO.: 461-1-7 PRIORITY: 2 EST. COMPLETION: March 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Maj Cohn L. Morrison
EXT.: 20217
PRIME CONTRACTOR: White-Rodgers Electric Company
PURPOSE: The purpose of this task is to conduct investigations of automatic control systems which involve a combination of open and closed loop control elements.

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Project 461-1-7 (Cont)

TO DATE: An electronic open and closed loop system has been built according to design criteria. This model and other experimental models will be constructed and studied experimentally and analyzed mathematically. The contractor is studying the possibilities of a more practical orientation to the project.

Several ideas have been conceived for practical and useful applications of the principle. Two of the applications are evolved from a study of a precision electronic power amplifier utilizing open-closed cycle principles. Papers have been published on these two applications.

Work on the power amplifier has progressed to the point where it has been demonstrated as practical to make a precision unit with the use of high efficiency Class "B" amplifier operating in conjunction with a low power feedback amplifier. The feedback amplifier provides destructive interference for distortion signals generated by the power amplifier as well as providing parameter changing signals. So far, there has been experimentation only with gain changing circuitry but there obviously is more which can be done - such as phase connection to minimize time delay errors when the input is periodic or quasi-periodic.

The same principle can be applied to a computing system A.C. power supply if a quantity of "pure" sine wave is required for the computer, gyros, etc. Such a device would be a regulating system, which may be considered as an automatic control with constant input.

Another application involving regulating action on an A.C. power source is a vernier feedback adjustment of frequency. Frequency adjustment may be achieved by use of a frequency changing transformer operated by frequency error signal. A technical report entitled, "Power System Frequency Regulator for use with Existing Aircraft" has been received from the contractor.

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<u>TITLE:</u>	Personal Service Contract of Professor J.P. DenHartog
<u>TASK NO.:</u>	461-1-11
<u>SECURITY:</u>	PRIORITY: 2 EST. COMPLETION: March 1953
<u>PRIME CONTRACTOR:</u>	Unclassified RESPONSIBLE SCIENTIST: W.J. Moreland EXT.: 20217
<u>PURPOSE:</u>	Professor J.B. DenHartog
	The purpose of this task is to obtain the consultant services of J.P. DenHartog to assist the Mechanics Research Group, Flight Research Laboratory, in the successful completion of its assignments.

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Project 461-1-11 (Cont)

TO DATE: Professor DenHartog was requested by Flight Research Laboratory to make an analysis of the problem of shock mounting of the 50 calibre machine gun to relieve the severe disturbances to the associated fire control equipment. The shock mounting design which resulted from this analysis has been constructed and found satisfactory. It has been discovered by Flight Research Laboratory personnel that the analysis of the 50 calibre gun is not generally applicable to other types of machine guns and further work is now underway to devise shock mounts for other armament.

TITLE: Survey of Research Material in the Field of "Noise"
TASK NO.: 461-1-12 PRIORITY: 2 EST. COMPLETION: July 1952
SECURITY: Unclassified RESPONSIBLE SCIENTIST: E. Millspaugh EXT.: 28136
PRIME CONTRACTOR: Dr. Jerome E. Levy
PURPOSE: The purpose of this task is to (1) compile an Air Force Report for engineering use that will explain the techniques of noise analysis, and (2) to standardize the terminology now used in the various noise analysis studies.

TO DATE: A final report on this task has been received and accepted as satisfactory. This project is being closed out.

TITLE: Manual "Systems Analysis of Aircraft"
TASK NO.: 461-1-14 PRIORITY: 2 EST. COMPLETION: August 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Capt P.P. Cerussi EXT.: 20217
PRIME CONTRACTOR: J. B. Rea Company
PURPOSE: The purpose of this task is to compile and publish a technical manual entitled, "Systems Analysis of Aircraft".

TO DATE: Dr. James B. Rea recently visited the Flight Research Laboratory to discuss proposed changes in the technical content of the book, as well as to suggest that the book be prepared in two (2) parts. Part 1, entitled, "Systems" would include the technical presentation of those engineering phases which are involved in the systems design. Part 2, entitled, "Fundamentals" would include those portions of the sciences which are required as a further expression or explanation to support Part 1.

Dr. Rea is also proposing to contract the preparation of the various chapters of this book to authorities in technical fields in lieu of his company preparing the complete manuscript. These proposed changes are being considered and formal request for them has not yet been received from the contractor.

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TITLE: Landing Gear Shimmy
TASK NO.: 461-1-15 PRIORITY: 2 EST. COMPLETION: Continuing
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Paul E. Gies EKT.: 20217
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this task is to study theoretically, in the laboratory and in the field, the problem of aircraft nose wheel shimmy and to determine design characteristics so as to minimize the destructive forces involved.

TO DATE: The landing gear shimmy project was initiated at the request of Aircraft Laboratory. At the time the project was initiated, it was pointed out that shimmy was being encountered in many operational and experimental models. One experimental aircraft was destroyed as a result of shimmy.

As a first step, the aircraft industry was visited and the problem discussed. In all cases, the means of eliminating the shimmy problem consisted of trial and error methods. No satisfactory analytical approach was available.

Since then, the report, "Landing Gear Shimmy " AFTR 6590 was completed and distributed. This report contains a method for determining the damping requirements in terms of dimensionless numbers which contain the parameters of the nose gear and airframe. Since the report was published, additional analytical investigations have been made and the design curves in the report have been expanded.

A laboratory model has been designed and is now being fabricated. The model investigation will be made to verify the assumptions in the report and to examine the effect of parameter changes on stability. In order to have a linear, controllable damper, the possibilities of an eddy current damper are being investigated.

At present, the field investigation is limited to a taxi test on a B-45. Plans have been completed and instruments calibrated for the installation. It is hoped that the test will present a full picture of modes and motion of the entire aircraft. Plans are being made for conducting tests on other operational aircraft that exhibit shimmy in order to analyze the aircraft with the theory contained in AFTR 6590.

* * * *

TITLE: Investigation of the Bending of Pre-Twisted Beams
TASK NO.: 461-1-16 PRIORITY: 2 EST. COMPLETION: February 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Capt. R.M. Rivello
EKT.: 20217
PRIME CONTRACTOR: Massachusetts Institute of Technology

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Project 461-1-16 (Cont)

PURPOSE: The purpose of this task is to develop a theory for computing the stresses and deflections of a pre-twisted beam subjected to bending.

TO DATE: A study is being made of the stresses and deflections of a pre-twisted beam of cruciform cross section subjected to pure bending. The cruciform section was selected so that the beam would have a constant moment of inertia about any centroidal axis. Preliminary tests had indicated that the resulting deflections exceed those computed by conventional beam theory and that the deviation is a function of the helix angle of the pre-twist. A Stress-Coat study has been made to determine the stress distribution in the beam. The beam has been instrumental with electrical resistance strain gages for more accurate stress determination. Stress data is currently being analysed.

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TITLE: Buckling of Flat Rectangular Panels Pre-Stressed by Initial Curvature

TASK NO.: 461-1-17 PRIORITY: 2 EST. COMPLETION: May 1953

SECURITY: Unclassified RESPONSIBLE SCIENTIST: Capt R.M. Rivello
EXT.: 20217

PRIME CONTRACTOR: New York University

PURPOSE: The purpose of this task is to conduct experimental and theoretical research to determine the feasibility of increasing the buckling stress of flat-sheet panels by pre-stressing, to be accomplished by elastically flattening the sheet which was initially curved by rolling.

TO DATE: Preliminary tests have shown that it is possible to double the buckling load of a clamped edge flat rectangular panel by first rolling the panel to an initial curvature and then elastically flattening it. The measured buckling loads exceeded computed loads, the reason being that the vertical members of the panel clamping frame were picking up part of the load and relieving the stresses in the panel. The clamping frame is being modified to correct this condition.

* * * *

TITLE: Vibration Isolation of Machine Guns

TASK NO.: 461-1-21 PRIORITY: 2 EST. COMPLETION: March 1953

SECURITY: Confidential RESPONSIBLE SCIENTIST: Lt T. Sanborn EXT.: 20217

PRIME CONTRACTOR: Internal

CONFIDENTIAL

Project 461-1-21 (Cont)

PURPOSE:

The purpose of this project is to develop a theory of machine gun vibration and to suggest methods whereby the shock loads transmitted by the gun to the aircraft structure may be reduced. It is imperative that this problem be solved because the large oscillatory loads which are at present transmitted to the aircraft cause malfunctioning of the electronic fire-control equipment.

TO DATE:

High-speed motion pictures have been made of the T-121 Gun in operation. These pictures reveal the behavior of the gun when mounted on the present spring system and indicate what must be done to insure proper operation of the gun when it is mounted on soft springs.

From the investigation, the following conclusions have been drawn:

- (1) A measurable amount of damping, either viscous or coulomb, is necessary to bring the gun into steady state operation.
- (2) Preload in the mounting springs contributes to the stability of the gun and reduces the overall recoil distance.
- (3) Soft mounting alters the firing rate. In general, the firing rate is reduced by the soft mount but on some occasions it has been increased.

A preliminary report has been written on revolver type guns which outlines the procedure for computing the optimum combination of values of spring rate, spring pre-load, and damping. Following the suggestions of this report, the Oldsmobile Division of General Motors was able to successfully soft mount a T-121 gun.

* * * *

TITLE:

Application of Nonlinear Control to an Aircraft in Yaw

TASK NO.:

461-2-1 PRIORITY: 1A EST. COMPLETION: January 1953

SECURITY:

Confidential RESPONSIBLE SCIENTIST Capt. P.P. Cerussi EXT: 26217

PRIME CONTRACTOR:

Cornell Aeronautical Laboratory

PURPOSE:

The purpose of this task is to investigate the application of nonlinear control to the improvement of the dynamic lateral stability characteristics of an airplane by artificial means.

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Project 461-2-1 (Cont)

TO DATE: Research investigations conducted under the original contract, 33(038)-12753 have been completed. AFTR 6712 entitled, "Dynamic Lateral Control Through Non-Linear Automatic Control" was prepared by Cornell Laboratory and covers this phase of the research.

Results of the flight tests conducted under this task indicated the possibility of improving the dynamic lateral stability of the aircraft, which in turn may possibly improve the aircraft's gun platform characteristics. In order to investigate this possibility further, a contract extension for additional research work covering the installation of a non-linear sideslip control in an F-86E aircraft was accomplished in January 1952.

The characteristics of the non-linear damper will be such that the percent critical damping in the neighborhood of zero sideslip will be very high and will reduce as the value of the sideslip angle is increased. The actuation of the rudder will be obtained by servo control of the aircraft's rudder trim tab, and means will be provided to eliminate undesirable increases of rudder pedal forces due to the action of the yaw damper during coordinated maneuvers of the aircraft.

Theoretical and analogical investigations of this control system for the F-86 have been completed for extended flight conditions. Installation of the control system is scheduled for completion 15 July 1952 and flight test will start 1 August 1952.

<u>TITLE:</u>	Nonlinear Smoothing and Predicting Filters
<u>TASK NO.:</u>	461-2-2 <u>PRIORITY:</u> 2 <u>EST. COMPLETION:</u> July 1952
<u>SECURITY:</u>	Unclassified <u>RESPONSIBLE SCIENTIST:</u> Lt D. Flechtner <u>EXT:</u> 20217
<u>PRIME CONTRACTOR:</u>	University of Notre Dame
<u>PURPOSE:</u>	The purpose of this task is to (1) obtain information for the improvement of fire control systems, (2) formulate design criteria for nonlinear components useful in guidance, instrumentation and control, (3) acquire basic information in nonlinear mechanics, and (4) stimulate mathematical research in nonlinear differential equations.

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Project 461-2-5 (Cont)

PRIME CONTRACTOR: Minneapolis Honeywell

PURPOSE: The purpose of this task is to conduct theoretical and experimental research on the application of nonlinear analysis and control techniques to problems associated with automatic control systems.

TO DATE: The University of Minnesota, a subcontractor to Minneapolis Honeywell, has studied the nonlinear differential equations which the contractor has supplied as applicable to the system. The type of nonlinearity studies was that of a saturated amplifier servo. Both analytical work and REAO studies were made of the acceleration limiting equations. Subharmonic response was examined in both REAO and analytical studies. The contractor is gathering information on noise from gusts and beams when airplanes are on instrument handling systems. It is expected that this data will aid in designing a prediction system which can be used to vary the parameters in the system for optimum performance.

A simulated saturating amplifier servo has been tested in an attempt to determine its adaptability for use as a noise filter. The following quantities which affect the operation were considered: servo damping ratio and natural frequency, signal frequency and amplitude, noise frequency and amplitude, and magnitude of saturation level. From the data obtained, it appears that in a filtering application the frequency and amplitude of the signal may be neglected except for the relation between signal frequency and servo natural frequency which determines the phase shift without noise. Servo damping ratio should apparently be one or less to provide sharp cutoff. The noise frequency is only of minor importance and then only for large noise amplitudes; of course, the frequency of noise must be above the band of signal frequencies to be filterable. It has been found that signal output increases with the increase of noise amplitude and that noise output remains practically constant for a fixed saturation level no matter how high the noise input is increased. This system thus appears to have a noise attenuation which increases with the increase of noise in the input. Considerable attenuation may be accomplished with only a slight increase in signal phase lag. It is believed that this phase lag and difficulties with large transient responses, etc., may be accommodated since the saturating amplifier servo senses noise in addition to filtering it. The error voltage is determined almost solely by the noise present and this error voltage may be used to control the saturation level. This system has been tried briefly and appears to have considerable merit.

The laborious computations associated with the general phase-space approach to the saturating amplifier servo are progressing toward completion. The work has been simplified by determining that some of the computations originally planned can be eliminated without seriously affecting the results. It has been shown that the trajectories which represent the solutions all enter a certain central region and never leave it. Computations may be limited to a determination of the iteration surfaces in this central region.

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Project 461-2-5 (Cont)

More beam noise data have been obtained. Several samples of recent data seem to indicate a relationship between heading and noise character. If true, this is a disturbing conclusion, since it increases the magnitude of the problem considerably. This point is being further investigated.

TITLE: Fundamental Data in Nonlinear Mechanics as Applied to Servomechanisms
TASK NO.: 461-2-6 **PRIORITY:** 2 **EST. COMPLETION:** October 1953
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** Lt D. Flechtner **EXT.:** 20217
PRIME CONTRACTOR: Cook Research Laboratory
PURPOSE: The purpose of this task is to provide fundamental data in nonlinear mechanics as applied to servomechanisms with a view of developing (a) engineering techniques which will assist engineering personnel in understanding practical non-linear mechanical systems, (b) an analytical approach to some of the problems of nonlinear mechanics, and (c) nonlinear devices which will improve the response of control systems.

TO DATE: Cook Research Laboratories has developed under contract with the Mechanics Research Branch of the Flight Research Laboratory, a new method of servo control. This system has been named "Dual-Mode" by Mr. Donald McDonald, chief engineer of Cook, since it exhibits two distinct methods or modes of control.

Cook Laboratories has shown that for specific classes of inputs a dual mode servo can be built which will have faster operation than a linearly designed servo; no overshoot, that is oscillation around "home plate" after a disturbance; and less input power to control the same output load. This control also exhibits a saving in weight over conventionally designed servos.

The project has produced the following significant results. It has been shown that the theoretical improvement in transient response predicted for dual mode servo operation over linear operation, can be obtained practically. A nonlinear servo can be constructed which need exhibit no overshoot in transient response for any value of input step disturbance. This nonlinear servo has the fast return characteristic of a lightly damped linear system (damping ratio 0.3) but does not have the associated overshoot which builds up an opposite error of 35% to 40% of the original error in the linear system.

It must be pointed out that to date, a formalized general mathematical solution proving that this control will work better under all conditions of input has not been accomplished. Intuitive, and experimental results have shown the dual-mode servo to have better response than a linear servo when subjected to

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Project 461-2-6 (Cont)

the types of inputs usually found in servo operation. It is hoped that a more general proof will be obtained as work continues. Mr. McDonalds firmly believes that the system is now of practical use and experimental servos of the electrical type constructed at Cook have given faster operation without overshoot thus experimentally proving the worth of the system.

Cook Research has submitted a technical report containing theory, physical construction, and wiring diagrams of the experimental dual mode servos which have been built. The report contains oscilloscope photos showing the improvement in response of the dual mode system. A typical response curve is shown in Figure #1. Figure #1 is a comparison of the response to a step function of the dual mode servo and an optimum linear servo. Figure #1 clearly shows the faster operation and elimination of overshoot due to dual mode operation. Table I (reprinted from the report) shows the weight and power savings which are associated with dual mode control. In Table I four standard methods of controlling 1/3 horsepower are compared with the dual mode method.

Table I - Comparison of Size, Weight and Power Requirements of Conventional and Dual Mode Servos of 1/3 Horsepower

CONVENTIONAL SYSTEMS

<u>Supply</u>	<u>Motor</u>	<u>Power Amplifier</u>	<u>Power Watts</u>	<u>Volume Cu. In.</u>	<u>Weight Lbs.</u>
24V D.C.	D.C.	Amplidyne & Control Field Amplifier	1300	500	40
115V 400 CPS	D.C.	Magnetic Amplifiers & Control Field Amplifier	1100	1100	35
115V 400 CPS	A.C.	Magnetic Amplifiers & Control Field Amplifier	800	600	30
24V D.C.	A.C.	Motor - Generator Set & Control Field Amplifier	800	1000	50

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Project 461-2-6 (Cont)

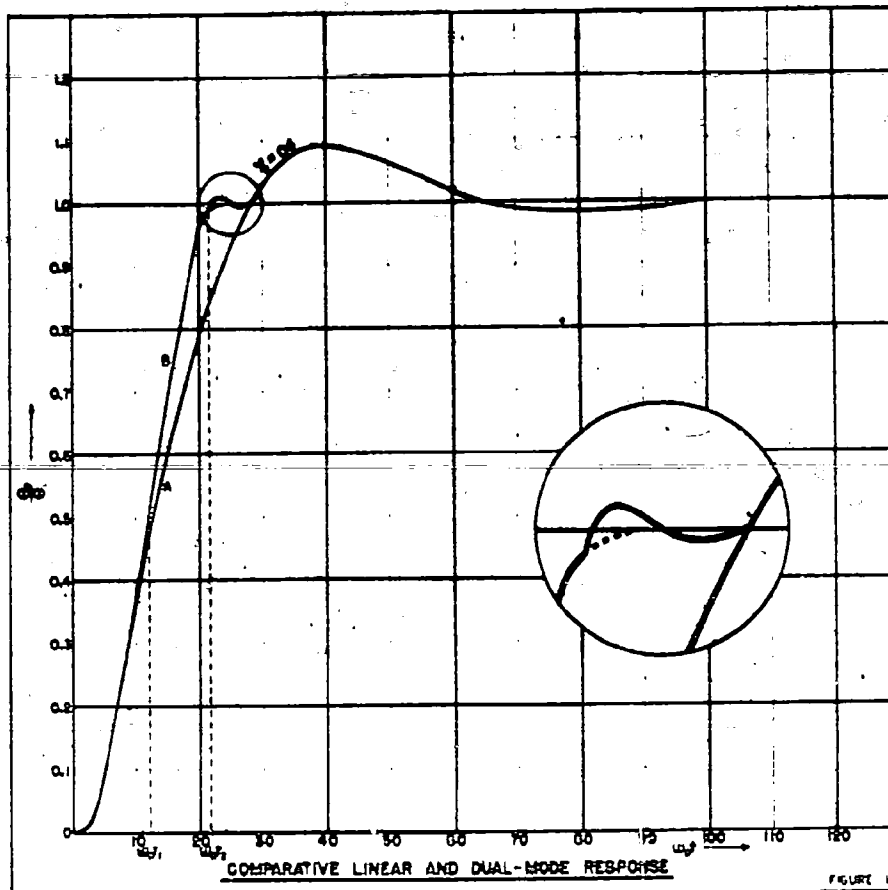
<u>Supply</u>	<u>Motor</u>	<u>Power Amplifier</u>	<u>Power Watts</u>	<u>Volume Cu. In.</u>	<u>Weight Lbs.</u>
<u>DUAL MODE SYSTEM</u>					
24V D.C.	D.C.		600	200	18

The comparison above shows that the Dual Mode Servo System provides;

- (1) Order of 2 to 1 saving in size and weight
- (2) A 40% or greater saving in power requirements for systems of the same H.P.

Also, the same ratios indicated above are to be expected upon extrapolation to higher horsepower levels.

It is thought that this system of control can be successfully adapted to hydraulic servos. It is planned to verify this by construction at Cook of a hydraulic servo which will work in the dual mode fashion.



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TITLE: Nonlinear Control Systems
TASK NO.: 461-2-9 **PRIORITY:** 2 **EST. COMPLETION:** July 1953
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** Maj G.L. Morrison
EXT.: 20217
PRIME CONTRACTOR: Princeton University
PURPOSE: The purpose of this task is to make theoretical and experimental investigations of certain problems of nonlinear mechanics, particularly those arising in connection with nonlinear controls.

TO DATE: A survey of the literature relative to this task has been completed. Initial work is being performed on general theoretical problems including stability and criteria for optimum performance. In addition, an experimental investigation is being made of the methods of measuring and characterizing the behavior of nonlinear systems, and of the transfer characteristics of two types of nonlinear systems. Two types of nonlinear elements, self-saturating magnetic amplifiers and two-phase induction motors as used in servomechanisms, are also being investigated.

A quarterly progress report was received from the contractor and contained data on the following topic headings which are being investigated.

- (1) The Stability of Nonlinear Systems
- (2) Nonlinear System Performance and the Design of Compensating Networks
- (3) Fundamental Consideration in the Design of the Primary Power Stage
- (4) Magnetic Amplifier Characteristics
- (5) Two-Phase Induction Motor Mechanics

TITLE: The Theory of the Linear Acceleration of Large Masses by Electrical Means
TASK NO.: 461-2-10 **PRIORITY:** 2 **EST. COMPLETION:** July 1952
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** K. Pohlhausen **EXT.:** 24155
K. Millsaps
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this task is to develop the theoretical basis for the performance of the linear acceleration of large masses by electrical means. (This information is necessary for determining the theoretical feasibility of electrically accelerating model missiles and aircraft, and the possibility of designing and constructing ultra velocity guns.)

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Project 461-2-10 (Cont)

TO DATE: Nonlinear differential equations describing the motion of such systems have been derived and the solutions obtained by desk calculation, electronic analogue computers and large scale digital computers. Two electrical sources (i.e., high energy batteries and large scale capacitors) have been considered. Individual and series accelerators have also been considered and the remaining case to be considered is the series capacitor accelerator which is scheduled for computation in the very near future. For the first time, a complete theoretical solution of an electrical circuit with a moving mechanical part which continuously changes the circuit characteristics have been obtained; a systematic study of solutions of a key problem on a variety of computers has been obtained.

Work on this project is completed and a final report will be prepared in approximately September of this year.

TITLE: A Nonlinear Research Study of the ATRAN Guidance System
TASK NO.: 461-2-12 PRIORITY: 2 EST. COMPLETION: May 1954
SECURITY: Confidential RESPONSIBLE SCIENTIST: Lt D. Flechtner EXT.: 20217
PRIME CONTRACTOR: Goodyear Aircraft Company
PURPOSE: The purpose of this task is to acquire fundamental data in the field of nonlinear mechanics. Specifically the servo loops of an automatic control system of the ATRAN guidance type will be studied mathematically and experimentally. The effects of nonlinearities, inherent in the system and purposely introduced, on system performance will be studied. Information gained in this manner will be used as a basis for formulating nonlinear design techniques. It is hoped to bring nonlinear design theory to the degree of utility of linear theory by providing analytical treatment and design criteria. The project may also deduce specifically information for the improvement of guidance systems.

TO DATE: A contract for the above research was negotiated on 1 May 1952.
The first progress report is due 1 August 1952.

TITLE: Nonlinear Study of Rate Gyroscopes
TASK NO.: 461-2-13 PRIORITY: 2 EST. COMPLETION: August 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Capt P.P. Cerussi
PRIME CONTRACTOR: Franklin Institute EXT.: 20217

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Project 461-2-13 (Cont)

PURPOSE:

The purpose of this task is to make an experimental and analytical investigation into the factors that contribute to the nonlinear outputs of gyroscopes when they are employed for detection and measurements of angular rates.

TO DATE:

Research work on this contract was initiated on 15 April 1952. A Quarterly Progress Report is now in preparation and should be forthcoming within the next month.

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TITLE:

Magnetics Materials Research

TASK NO.:

461-6-1 **PRIORITY:** 2 **EST. COMPLETION:** Continuing

SECURITY:

Unclassified **RESPONSIBLE SCIENTIST:** Maj R.I. Berge **EXT.:** 28292

PRIME CONTRACTOR:

Indiana Steel Products Company

PURPOSE:

The purpose of this project is to provide improved magnetic circuits in a variety of instrumentation and equipment which utilize such circuits. Improved instrumentation as well as a variety of equipment such as radar magnetrons, control circuit relays, several types of power transformers, magnetic amplifiers and pulse generators will result.

TO DATE:

The plans for establishing this important magnetics research project have been completed and a working contract is currently being negotiated.

* * * *

TITLE:

A Study of Order-Disorder in the Cobalt-Platinum System

TASK NO.:

461-6-2 (461-1-20) **PRIORITY:** 2 **EST. COMPLETION:** July 1953

SECURITY:

Unclassified **RESPONSIBLE SCIENTIST:** Capt E. Sellers, Jr.
EXT.: 28292

PRIME CONTRACTOR:

Carnegie Institute of Technology

PURPOSE:

The purpose of this task is to investigate further the potentials of the cobalt-platinum system which has already produced magnetic alloys with a coercivity twenty-five times better than the alnico type.

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Project 461-6-2 (461-1-20) (Cont)

TO DATE: Studies have been made on the copper-gold system to improve the research techniques and gain a better knowledge of this system while the samples and test arrangements are being prepared to study the cobalt-platinum systems. Such marked similarities exist between the two systems that this has been determined as the most expedient approach.

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PHYSICS RESEARCH BRANCH

The Physics Research Branch is responsible for applied physics research and basic physics research. The Basic Research Section conducts basic research in nuclear, atomic, molecular and classical physics of interest to WADC. The Applied Physics Research Section conducts applied research in physics of measurement and instrumentation, physics of electromagnetics, physics of systems and mechanical physics.

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CAN YOU DIVIDE A CIRCLE INTO 1,000,000 PARTS?

Theoretically, the smallest part of a circle can be divided and redivided, ad-infinity. There is no limit to the smallest number you can write, the same as there is no limit to the largest, but physically there is a lower limit because each measurement has some uncertainty. Our best dividing engines are capable of dividing a circle to within two seconds of arc, possibly to one second of arc; this is one part in a total of 1,296,000 parts. If it is desired to measure an angle to this accuracy, an astronomer can, by taking 20 or 30 separate measurements of an angle in a certain prescribed manner (to eliminate systematic errors), make measurements with an uncertainty of one second of arc. The Air Force has many measurements wherein a few seconds of arc are required. The number of these measurements to be made and the length of time available for each measurement preclude the use of the astronomers' methods. A high speed angle repeater was needed for our automatic guidance systems and for our missile test ranges.

The physics Research Branch of the Flight Research Laboratory, anticipating this need, has supplied the Air Force with a simple, small apparatus, which has been given the name - Micropositioner. It consists of two small glass discs on which have been placed an array of conductors. These discs are to be mounted on the shaft whose angle is to be measured; electromagnetic induction and a few vacuum tubes do the rest.

Now the Air Force can divide its circle into a million parts, measure the displacement at one point and reproduce it at another, at high speed.

This project was carried out with the Farrand Optical Company. Further work will prove its adaptability to our automatic guidance systems.

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TITLE: Ferroelectric Crystals
TASK NO.: 462-1-1 PRIORITY: 2 EST. COMPLETION: July 1954
SECURITY: Unclassified RESPONSIBLE SCIENTIST: W. Schofield EXT: 29123
PRIME CONTRACTOR: Pennsylvania State College
PURPOSE: The purpose of this task is to study the special characteristics of ferroelectrics as well as to predict the existence of ferroelectric properties in crystals on the basis of their structure.

TO DATE: A family of 900 crystals was examined and the interpreted data was used to improve the theory of ferroelectric and piezoelectric crystals. The improved theory predicted the new ferroelectric crystal, namely Lithium-Ammonium Tartrate. Examination of the properties of this crystal substantiated the new theory.

An older low temperature X-ray diffraction machine was built and operated successfully. It has shown the structure change in KH_2PO_4 at its low temperature ferroelectric Curie point. An improved version of such a machine is under construction.

Arrangements have been made with Brookhaven National Laboratory to carry out neutron diffraction of ferroelectric crystals to further improve the theory.

* * * *

TITLE: Skiagraphic Presentation and Interdiffusion Study
TASK NO.: 462-1-2 PRIORITY: 2 EST. COMPLETION: December 1952
SECURITY: Unclassified RESPONSIBLE SCIENTIST: B.B. Johnstone EXT: 29123
PRIME CONTRACTOR: University of Texas
PURPOSE: The purpose of this task is the study of the general problems connected with the presentation of low intensity and short duration X-ray shadows to a remote observer.

TO DATE: Dr. Antes of the University of Texas is studying the inter-diffusion of various metals by means of reflection of polarized light as a function of temperature. The techniques involved here are very difficult, the work being performed in a vacuum; the temperatures of the thin films are sometimes difficult to measure. Apparently the first choice of materials was unique for all of the parameters were easily measureable and the results were decisive. When the technique was applied to other metals, room temperature reaction rates were too slow, elevated temperature gave very steep slopes in the reaction rate and adequate control could not be obtained. The search for crystals which show marked change in optical properties when radiated with X-rays is continuing. The study of the X-ray conductive

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Project No. 462-1-2 (Cont)

properties of various fluorescent and special glasses has been completed. Investigation of electroluminescent phosphors is underway. Work on intermetallic diffusion has been concerned with the diffusion of copper through aluminum and the diffusion of oxygen in vacuum deposited titanium films.

The final report was received and a close-out will be initiated as soon as it is reviewed.

* * * *

TITLE: Piezoelectric Crystals
TASK NO.: 462-1-3 PRIORITY: 2 EST. COMPLETION: December 1952
SECURITY: Unclassified RESPONSIBLE SCIENTIST: W. Schofield & S. Cayzak
EXT.: 29123
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this task is the study of certain electrical and optical properties of piezoelectric crystals.

TO DATE: This project has been reactivated as of June 1952. Equipment for checking wave form of piezoelectric crystals used as oscillator governors has been ordered. Two theoretical approaches are being considered. (1) examination of the wave shape of a piezoelectric crystal oscillator to determine the mechanism of stress and strain. (2) examination of the stress and strain tensor and the dielectric strain tensor to determine if the tensor concept of piezoelectric effect is correct.

* * * *

TITLE: Ice Physics
TASK NO.: 462-1-6 PRIORITY: 2 EST. COMPLETION: July 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Lt Allen EXT.: 29123
PRIME CONTRACTOR: University of Michigan
PURPOSE: The purpose of this task is to gather information for the design of improved basic de-icing apparatus.

TO DATE: The contract has been awarded and work has begun. The contractor is setting up facilities and obtaining personnel.

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Project No. 462-1-6 (Cont)

The ground wind tunnel design is complete. Experimentation with the spray apparatus and work on the icing wind tunnel is continuing. Modification of a differential analyzer for water drop trajectory studies is in the planning stage. The determination of drop trajectories by means of an extension of Stoke's Law has been completed for several surfaces. The icing tunnel was adapted to be operated in the summer months by cooling the sample in the test section.

TITLE: Ice Nucleation
TASK NO.: 462-1-7 **PRIORITY:** 2 **EST. COMPLETION:** July 1953
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** Lt Allen **EXT.:** 29123
PRIME CONTRACTOR: Commonwealth Engineering Company, Dayton, Ohio
PURPOSE: The purpose of this task is to establish the background for the control of icing problems peculiar to Air Force operations.

TO DATE: The contract has been negotiated and Dr. Burger, the chief investigator, has initiated a literature search. Dr. Burger had a personal conference with Dr. Kraus, of the University of Cincinnati, to discuss some of the practical aspects of ice research. He also consulted with Dr. Varneget and Dr. Lowe of General Electric regarding techniques on ice nucleation. At present, the investigator is collecting equipment for the investigation.

TITLE: Domain Properties of Ferromagnetic Materials
TASK NO.: 462-1-8 **PRIORITY:** 2 **EST. COMPLETION:** July 1954
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** W. Schofield **EXT.:** 29123
PRIME CONTRACTOR: Brown University
PURPOSE: The purpose of this task is to study the behavior of magnetic domains in large crystals of ferromagnetic materials by means of pulsed ultrasonic techniques.

TO DATE: Large single crystals of nickel have been successfully grown and attenuation of ultra frequency energy (sonic waves) as a function of magnetic stress has been examined. The following has been found: (1) at magnetic saturation there is no frequency dependency on the attenuation; (2) At less than saturation values, the slope of the attenuation vs. frequency rises as the magnetic stress is lowered, (3) the magnitude of the change near 50 megacycles is about ten to one.

Arrangements have been made by Brown University to send samples to the Brookhaven pile for irradiation. The magnetic supersonic attenuation methods

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Project No. 462-1-8 (Cont)

will be used to test the amount of radiation damage to these pile irradiated samples.

TITLE: Physics of Penetration
TASK NO.: 462-2-1 **PRIORITY:** 2 **EST. COMPLETION:** July 1953
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** S.B. Johnstone **EXT.:** 29123
PRIME CONTRACTOR: None. Work is being done by WADD.
PURPOSE: The purpose of this task is to gain a better understanding of cutting, ramming and high-speed penetration of one body into another.

TO DATE: An analysis of the water displacement data is continuing. An investigation is being made of the deformation of plastic materials which offer principally coulomb type friction. Experimental apparatus has been assembled and data is being collected. The study of the penetration of plastic materials, sands and a combination of plastic and elastic substances has not yielded the similitude that was found in materials having only inertia resistance. Test results of homogeneous masses of materials have proven reproducible results to a high degree. The study of these results has revealed one principle fact - how very complex these results are.

A new quadripartite wedge has been made and eight tests have been made with this wedge at a dropping speed of 8 ft/sec. High speed pictures were taken and are being evaluated.

In a paper published in November 1951 by the Institute for Mathematics and Mechanics of New York University, there is presented an approximate theory for the vertical impact of a rigid circular cone on the plane surface of an ideal fluid. The impact force as a function of penetration depth is computed approximately for water and for cone angles between 140° and 170° . The force values were found not to be in agreement with measurements of Watanabe (Tokyo, 1930). From January 25 to February 25, 1952, this computation has been carried out for vertical impact on a fictitious ideal fluid with the mass density of iron. The impact forces versus penetration depth have been computed for several cone angles and for cone angles reasonably smaller than the head angles of the projectile ogives, and are found to be essentially in agreement with the impact forces measured by Kaupp (Essen, Germany, 1937) and Naval Research Laboratory (Washington D.C., 1938) in firing tests against steel armor plates.

Further theoretical work has been done with respect to the controversial question of whether high speed penetration of solids can be considered to be the same as equivalent high speed penetration of liquids. The reliability

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Project No. 462-2-1 (Cont)

of the approximations suggested by workers at New York University, and correlated with the experiments of Watanabe (Tokyo, 1930) have been explored. Instrumentation has been developed for measuring the pressure distribution over a wedge surface during penetration.

* * * *

TITLE: Fluid Dispersion
TASK NO.: 462-2-2 PRIORITY: 10 EST. COMPLETION: December 1952
SECURITY: Confidential RESPONSIBLE SCIENTIST: Maj Brown EXT.: 29123
PRIME CONTRACTOR: Olds and Barnes, Inc.
PURPOSE: The purpose of this task is to improve the hit probability of napalm against point targets.

TO DATE: The contractor has been organizing tests and negotiating sites for explosive testing.

Some preliminary static tests have been conducted, but full scale static tests are awaiting testing site at Edwards AFB. Necessary authorization for such a test site is still pending. The investigator has performed a number of very interesting experiments which point the way to the control of the dispersion, the rate of burning, and the adhesive quality of the burning mass.

* * * *

TITLE: An Instrument for the Instantaneous Analysis of Gas Mixture.
TASK NO.: 462-3-4 PRIORITY: 2 EST. COMPLETION: July 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: B.B. Johnston EXT.: 29123
PRIME CONTRACTOR: University of Arkansas
PURPOSE: The purpose of this task is to develop an instrument for the rapid analysis of gases.

TO DATE: The contract has only recently been negotiated. The contractor is now procuring special equipment, conducting a literature survey, tooling up for the fabrication of the radio frequency mass spectrometer tube, and designing circuits and equipment for use in the development of an instrument for gas analysis.

* * * *

TITLE: Cooling of Rotating Electrical Equipment
TASK NO.: 462-4-1 PRIORITY: 2 EST. COMPLETION: February 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: O.P. Morgenson, Jr. EXT.: 24159
PRIME CONTRACTOR: Ohio State University Research Foundation
PURPOSE: The purpose of this task is to accomplish the following:

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- (1) Investigate means to increase the range of environmental conditions under which a variety of rotating electrical equipment may be operated.
- (2) Study methods of reducing the power required to cool such equipment by convective processes.
- (3) Establish design criteria for selecting auxiliary cooling equipment when environmental conditions (speed and altitude preclude the possibility of cooling by convection.

TO DATE: Design of testing apparatus for blast cooled machines has been completed. Methods of loading alternating current generators are still being investigated. Methods of obtaining temperature measurements at various points on a rotating body have been studied in considerable detail; thermocouples with rotating contacts continually dipping in mercury were found to be applicable. A rather comprehensive survey of literature has been completed for reference pertinent to sources of heat within rotating electrical equipment, hot spots, causes of failure and cooling methods applicable to aircraft equipment. Two progress reports have been received, and preparation of a third progress report is in process.

* * * *

TITLE: Research in Optics
TASK NO.: 462-5-1 PRIORITY: 2 EST. COMPLETION: July 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: J.E. Clemens & B.B. Johnstone
EXT.: 29123

PRIME CONTRACTOR: National Bureau of Standards

PURPOSE: The purpose of this task is to provide methods of making large pieces of optical glass, making new types of glass, establishing new methods of machine computation, improving formulations of optical systems, and devising methods of grinding aspheric surfaces.

TO DATE: Work on theoretical optical instrumentation problems and on large optical blanks has continued. Several melts in the new platinum crucibles were made with encouraging results. The contractor is developing a continuous optical melt process, and experimentation is in process to develop a stirring system giving optimum mixing. A number of simple experiments were made with a synthetic substance closely resembling molten glass at a specific temperature with respect to viscosity and density, using a number of different type stirrers. Various shapes, forms, speeds, etc., were used. In most cases, simple type stirrers, viz. paddle, vane, propeller, showed regions in which very little mixing occurred. One shape, a two bladed affair, gave the best results. This shape was fabricated out of platinum and tested with molten glass with good results.

The latest progress covers research done on the following:

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Project No. 462-5-1 (Cont)

- (1) Fundamental Refractometry
 - a. Optical Design
 - b. Optical Techniques
 - c. Optical Performance
- (2) Optical Design
 - a. Optical Design Project
- (3) Optical Techniques
 - a. Figuring 10 inch Interferometer Plates
 - b. Rate of Polishing Glass
 - c. Large Optical Glass Blanks
 - d. Modified Twyman-Green Interferometer
- (4) Optical Performance
 - a. Microphotometric Analysis of Line Imagery
 - b. Visual Analysis of Line Imagery
 - c. Compensating Prism Effect by Camera Tipping
 - d. Distortion at Finite Ratios
 - e. Calibration of 24 inch K-17B Camera

TITLE: Optical Properties of Liquid Crystals
TASK NO.: 462-5-3 PRIORITY: 2 EST. COMPLETION: December 1952
SECURITY: Unclassified RESPONSIBLE SCIENTIST: B.B. Johnstone EXT.: 29123
PRIME CONTRACTOR: University of Cincinnati
PURPOSE: The purpose of this task is to study the optical properties of solution of liquid-crystalline materials under such conditions as may be required for operation as a light valve.

TO DATE: The contract has only recently been awarded.

* * * *

TITLE: Radio Wave Absorption
TASK NO.: 462-6-1 PRIORITY: 2 EST. COMPLETION: July 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: B.B. Johnstone EXT.: 29123
PRIME CONTRACTOR: University of Florida
PURPOSE: The purpose of this task is to reach a better understanding of radio wave propagation phenomena and its relation to atmospheric characteristics.

TO DATE: The university has constructed a tower for their microwave detection system adjacent to the Weather Bureau in order to coordinate more closely their work with that bureau. The tower, supporting equipment, standby power, tele-type, and radio communication has been provided. The station is now operating as a part of the network of which the Navy and Weather Bureau are a part.

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Project No. 462-6-1 (Cont)

Storm activity on one occasion during January was especially interesting. The radar photographic history of the storm gave a vivid picture of the precipitation pattern which accompanied the storm which agrees very well with the best analysis of synoptic weather reports.

Routine reporting and tracking of storm centers is continuing and the correlation between this new method of observation and the older methods of reporting are being made.

<u>TITLE:</u>	Optical Computation Machine
<u>TASK NO.:</u>	466-1-1 <u>PRIORITY:</u> 10 <u>EST. COMPLETION:</u> December 1952
<u>SECURITY:</u>	Confidential <u>RESPONSIBLE SCIENTIST:</u> E.B. Johnstone <u>EXT:</u> 29123
<u>PRIME CONTRACTOR:</u>	Perkin-Elmer Corporation
<u>PURPOSE:</u>	The purpose of this task is to investigate the possibilities of extending and improving optical computational methods by the utilization of machine computers similar to the Harvard Mark I.

TO DATE: Details are being worked out on the Harvard Mark I Computer and also the IBM electronic machine for setting up ray tracings for optical systems. Work has shown that both machines are suitable and, in certain cases, askew tracings can be accomplished on the IBM several times faster than on the Mark I.

The contractor proposed that permission be granted to work on two different optical formulae. One of them is based on the contractor's approach to obtain a completely color corrected optical system. A recent system worked out by Mr. McCarthy of the Perkin-Elmer Corporation resulted in an apochromatic system in which the color was reduced to a very small value; however, with the contractor's proposal, it is theoretically possible to reduce the color residual to zero. The other formula consists of a new method of obtaining a wide angle field theoretically up to 180° and practically up to 150° with a very simple optical system at unit magnification. Magnification can be introduced by conventional methods if desired. Both of these formulae could be of immediate value to the AF in military applications. A coating system has been established for skew ray tracing on both Mark I and the IBM type computer. Ray tracing and third order computation are in the nature of numerical analysis and can be accomplished on both machines. However, the Mark I is much too slow for this kind of cyclical work. Automatic machine lens design, however, involves the problem and poses the question of evaluating radii thickness and glass types that will satisfy the specific performance. It is intended to continue the automatic design as far as possible with both machines. Storage in the computer is a problem which will eventually have to be increased as more complex lens designs are to be studied.

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Project No. 466-1-1 (Cont)

A triple lens was coded up on the Harvard Mark I and was supplemented by additional calculations made on the electronic IBM machine and the various design parameters were run through, utilizing existing type glasses. The tabulation of the results gives every conceivable type of lens that can be made with three elements, including the goodness with respect to the seven different types of aberrations and deviations from the image quality. Many of these designs were found to have better quality than many of the now famous five-element camera lenses. Designs were available which covered the gamut from those suitable for telescopes, periscopes, binoculars, camera lenses and any other conceivable application.

In the near future, the computing machines will be set up for running out the four element series and then the five element series. Later, the problem will be reversed by setting an acceptable level of image quality and determining the minimum number of elements which will achieve this requirement. It can be predicted that inside of a year the government will own or will have available a complete coverage of all of the lens formulas involving theoretically the utmost in quality that can be achieved with the utilization of the now existing optical glass characteristics. This should make the United States preeminent in this aspect of the optical industry.

TITLE: Photogrammetric Reduction
TASK NO.: 466-1-2 PRIORITY: 2 EST. COMPLETION: July 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: C. Traenkle EXT.: 28292
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this task is to prove that an operational method of reduction, involving the projection of ray pencils, can be accomplished simply and with the same accuracy as the analytical method.

TO DATE: Photogrammetric reduction by modified multiplex equipment is being investigated. Comparisons have been made between the modified Traenkle and Anderson methods. The data indicates that the Traenkle method may reduce analysis time for photographs from two hours to ten minutes as compared to classical Anderson method. Fence Test range has been adopted for taking the master photograph; adjustment of special targets, and calibration of camera stand by a special collimator-telescope have been completed. Preliminary exposures were made and adjustment completed.

Dr. Traenkle of the Flight Research Laboratory has now completed a series of fence photographs in conjunction with the problem of developing a method of calibrating a camera and evaluating these photographic data. A series of reports covering this work is being written.

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Project No. 466-1-2 (Cont)

The results of four different independent experimental methods obtained in this laboratory for checking the accuracy of the Multiplex solution of resection in space have been reconsidered and analyzed. It can be shown that the errors resulting from all the different methods fit all the same theoretical formulae thus proving the correctness of its underlying error analysis. It can further be seen that the accuracy of the Multiplex method reaches closely to the theoretical limit of accuracy as given by the physical properties of the camera and lens itself. The results are now being compiled into a report.

A report is being prepared covering the theory and operational rules of the projective method as performed with the planigraph or multiplex equipment. Further progress regarding simplification and speeding up of restitution has been made at the following points:

(1) Control point array and adjustment rules, (2) Restitution geometry, and (3) Ground relief correction. The report mentioned above is intended as a Manual of Operation.

It has been established that the operational method is capable of an accuracy comparable to that of the analytical method. It now becomes necessary to determine whether this method can be applied practically and it is planned to train an individual of ordinary competence to perform the work. A comparison of his output will be made against similar talent operating with the conventional analytical methods.

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<u>TITLE:</u>	Photographic Nadir Point
<u>TASK NO.:</u>	466-1-3
<u>SECURITY:</u>	Unclassified
<u>PRIME CONTRACTOR:</u>	University of Michigan
<u>PURPOSE:</u>	The purpose of this task is to determine the performance of gyro-stabilized devices by photographic means.
<u>PRIORITY:</u>	2
<u>EST. COMPLETION:</u>	July 1953
<u>RESPONSIBLE SCIENTIST:</u>	B.B. Johnstone
<u>EXT.:</u>	29123

TO DATE: Work on stellar photographic calibration methods is progressing satisfactorily. Comparison tests between theodolite and photogrammetric methods are to be run.

A joint program has been inaugurated between Flight Research Laboratory and the Equipment and Armament Laboratories. Tests on compensated vertical gyro system (Sperry), Dynamic Study of K-1 System, and a high-speed Bomb Director are in process. In addition to the gyro testing, a new installation was started to test the K-4 Bombing System in a B-47 airplane. The installation in a B-29 aircraft has been completed.

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Project No. 466-1-3 (Cont)

Dr. Traenkle, of the Physics Branch, Flight Research Laboratory has prepared two papers on his operational method, and these have been distributed to contemporary researchers in this field for their comment. The application of the photogrammetric principle to nadir point definition in accelerating vehicles is being applied to test systems in a B-17, B-29 and a B-45 for analysis work at the request of other laboratories.

TITLE: Dynamics of Complex Systems
TASK NO.: 466-1-4 PRIORITY: 2 EST. COMPLETION: July 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Kerris & Waselt EXT: 29123
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this task is to study the dynamics of complex systems such as guidance, fire control, and other systems of interest to the Air Force.

TO DATE: Significant improvements in the theory of instrumentation of the SPIRE System have been made by the FRL staff. The transition from experimental to pre-production design for the NOEBS System is in process. A paper on the use of magnetically supported spinning balls has been completed. The tests of a new Lear version of the electro mechanical servo for use in the F-80 has been made in conjunction with the REAC.

At the request of the Guided Missiles Section and representatives of Holloman Air Force Base, a study was made on various methods of controlling maneuverable bombs. The report entitled "Line of Sight Control for Bombs" has been written and distributed to interested parties.

A recent report "Notes about the Motion of a Ferromagnetic Sphere Freely Rotating in a Magnetic Field" has been prepared. This report answers questions in connection with spinning balls at very high rpm's while supported by a magnetic field and having application as a free gyro. Actually, as is shown in the report, the precessive forces generated as by-products of the supporting field, even with the best known ferromagnetic materials, is of the same magnitude as erection torques applied to so-called vertical gyros. Qualitative tests on a laboratory model substantiated that fact.

Study has been made of navigational systems with inertial platform and Doppler radar. The combination of the two systems can be made in two separate ways; either to improve the damping of an inertial platform for using the information of a Doppler radar, or one can improve the short time indication of a Doppler radar by adding the information of accelerometers which are mounted on a horizontal platform. After the first part of the problem was finished last month, the second part could be attacked. The block diagram of a suitable arrangement of the components.

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was found, and the transfer function for this system could be deduced. The errors of the Doppler radar and the accelerometer information were incorporated. In addition to this treatment of actual systems, a general theoretical investigation of the possibilities of combining inertial and Doppler information was attempted.

The work on the dynamics of an inertial-doppler radar combination was presented to interested members of the MIT Instrumentation Laboratory. The development of the theory and the conclusions were agreed upon by all those present to be correct and sound. A report will be issued in a short time.

* * * *

TITLE: High Speed Bombing
TASK NO.: 466-1-5 **PRIORITY:** 2 **EST. COMPLETION:** January 1953
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** J. Schugt **EXT.:** 28292
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this task is to study high speed bombing problems and to design a director capable of vectoring a vehicle to the bomb release point in a minimum time.

TO DATE: Drawings for a high speed tactical bombing computer were produced. Further work on bombsight model is depending upon the completion of a shop facility. The endless belt on which various types of geometric patterns can be placed is in the process of fabrication and the electronic characteristics of the instrument are being examined.

* * * *

TITLE: Bombing Error Study
TASK NO.: 466-1-6 **PRIORITY:** 1B **EST. COMPLETION:** July 1953
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** J. Schugt **EXT.:** 28292
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this task is to determine the various sources and magnitudes of bombing errors.

TO DATE: The bombing error study technical analysis has been completed. The equipment for studying error sources in the B-50 airplane has been completed and is awaiting the arrival of the B-50. The Armament Laboratory has indicated that due to high priority assignment of B-50 aircraft, it would be possible to run only a portion of the program previously planned. A reduced flight test program is planned for determining the merit of vertical indicating instruments. The remainder of the program will be accomplished at a later date. The basic work and instruments developed in this study have been used by IEM for use in the testing of Perkin-Elmer bombsight, and the evaluation of their components and systems.

Theoretical studies have been performed on how the bombing

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Project No. 466-1-6 (Cont)

accuracy in diving could be improved by means of a complete wind solution. The continuation of the theoretical studies requires practical test data. Therefore, a test request with a test program has been forwarded to Air Force Armament Center, Eglin AFB, through WADC. The tests have been discussed with the Armament Laboratory and properly coordinated. They will be performed at AFAC with an F-84.

TITLE: Bomb Effectiveness Research
TASK NO.: 466-1-7 PRIORITY: 2 EST. COMPLETION: Continuing
SECURITY: Confidential RESPONSIBLE SCIENTIST: Maj Brown EXT.: 29123
PRIME CONTRACTOR: Purdue University Research Foundation
PURPOSE: The loss of production resulting from a bombing attack is a function of the characteristics of the attack and the characteristics of the target attacked. This project is to evaluate the above function, so that if the characteristics of the attack and the target are known, loss of production can be predicted with as much accuracy as possible.

TO DATE: The library is now well catalogued and fairly complete. The old Lehigh University Library has been supplemented by data collected on European trip. Phase I final report has been completed and work is continuing on refinement of statistical methods used thus far. The oil study program is well under way with the collection of data from the oil industry in the United States.

TITLE: Statics and Dynamics of Airborne Armament
TASK NO.: 466-1-8 PRIORITY: 2 EST. COMPLETION: June 1953
SECURITY: Confidential RESPONSIBLE SCIENTIST: Maj. H. Brown EXT.: 29123
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this task is to study the complete aircraft armament problem and to compile a comprehensive compendium of information concerning theories and practices in this field.

TO DATE: An extensive report covering the complete field of bombing, including the theory of the bombing problem, its instrumentation, the environment, the tactical situation, and the maintenance problem has been planned. The tentative chapter headings have been assigned and competent groups are being asked to participate in certain portions of this project. At present, five groups have agreed to participate.

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The following sources have been contacted during the past month to see if they may be able to make contributions toward this project: Dr. Diedrick, Ballistics Research Laboratory, Aberdeen Proving Ground, Mr. Robinow and Mr. Epstein of National Bureau of Standards. Dr. Diedrick supplied a short written treatise on Bomb Ballistics which may be suitable with little revision.

The editing of Volume I of the proposed text is taking on enormous proportions and it appears that it will be necessary to obtain contractual services in order to reduce the load on FRL personnel. Dr. Pike of Raytheon Corporation is being considered as a possible contractor.

* * * *

TITLE: Aerodynamic Study of Bomb Shapes
TASK NO.: 466-1-9 **PRIORITY:** 2 **EST. COMPLETION:** January 1953
SECURITY: Confidential **RESPONSIBLE SCIENTIST:** Otto Walchner **EXT.:** 24196
PRIME CONTRACTOR: None. Work being accomplished at WADC.
The purpose of this task is to provide data for improving bombing ballistics.

TO DATE: Some experimental tests have been conducted in the 5' wind tunnel, Wright-Patterson AFB, and a bomb shape has been developed which is stable without the conventional tail. The bomb configurations are shorter than conventional bombs and occupy less space in aircraft bomb bays. Two bombs of the 180 pound variety have been dropped at Eglin Field with B-29 and B-50 aircraft. Bomb dispersion was small which proved that good stability can be obtained without the conventional tail. Twenty more bombs are being constructed for shipment to Eglin Field for tests to demonstrate that the new bomb shape is less affected by bomb bay turbulence than conventional bomb shapes. A 500 pound design is also being undertaken. The above mentioned bombs are fitted with very small fins which do not extend radially beyond the base of the bomb. Wind tunnel tests are being conducted at Wright-Patterson AFB in order to eliminate fins altogether.

Wind tunnel tests were recently made on several bomb shapes which differ in certain aspects from previous ones. These shapes appear to be quite promising for they may be made to have low or high drag whichever is needed.

Photographic Reconnaissance Laboratory personnel have become very interested in utilizing new bomb shapes for flash bombs.

Drop tests on two bomb shapes will begin at Air Proving Ground, Eglin Field, as soon as a B-47 airplane is assigned.

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Project No. 466-1-9 (Cont)

Recent drops of three 100 models from 15,000 feet gave an indication of very small dispersions. Although at the present time it is too early to give any true quantity for this dispersion, it appears to be of the order of two or three mils.

TITLE: Coordinate Conversion Study
TASK NO.: 466-2-2 PRIORITY: 2 EST. COMPLETION: July 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: J. E. Williams
B.B. Johnstone EXT.: 29123
PURPOSE: The purpose of this task is to provide the theoretical and experimental background for the manufacture of a coordinate transformer having a reasonable size, weight, and manufacturing tolerances for use in aircraft fire control systems.

TO DATE: The contractor has engaged in preliminary design, theoretical investigations and logical computer layout. Information has been received from the contractor that a model of a coordinate conversion unit can be made in a box of 4 x 10 x 10 inches dimensions, having an accuracy of 5 mils with a possibility of an eventual accuracy of 2 mils.

The final report has been submitted by the contractor. It covers in a comprehensive and systematic manner, with the necessary supporting mathematical formulae, the various methods for accomplishing coordinate conversion. A closeout is being written on this project.

TITLE: Continuous Measurement of Fuel Quantity
TASK NO.: 466-2-4 PRIORITY: 2 EST. COMPLETION: July 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: F. Pensig EXT.: 29123
PRIME CONTRACTOR: Raytheon Manufacturing Company
PURPOSE: The purpose of this task is to investigate and develop fuel quantity measuring techniques.

TO DATE: Visits to various Strategic Air Command Bases, airframe companies and commercial airlines were made by the contractor personnel in order to discuss the

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Project No. 466-2-4 (Cont)

various problems associated with fuel measurement. Also, a very thorough and comprehensive patent research investigation has been made covering both the United States patent literature and a great deal of the German, French, English and Russian patent literature. Most of the information available on this problem has been obtained and has been summarized.

The manuscript on fuel quantity measuring techniques is nearing completion. The manuscript contains the contributions of more than 100 persons (all leaders in their fields) in instrumentation, electronics, air frame design, air tactics, nucleonics, chemistry, etc. The pertinent factors discussed include the tactical, structural, aerodynamic, psychological and chemical aspects.

A classification of fuel gaging principles is enumerated and, roughly, 140 new suggestions for fuel gage designs are considered. Nine of these were examined in some detail - gaging by radio frequency fields, by titration of dyes, by heat capacity of the fuel body, by float gages or buoyant probes, by capacitance type gages, by multiple fuel operated switches, by cyclical pumping of the fuel through a meter and by acoustical methods, and by the use of pressure gages. The conclusion drawn from this study is that improvement in fuel gaging will come primarily from better specifications of objectives and better detailed engineering, but the search for ingenious new gaging principles is decidedly not promising.

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<u>TITLE:</u>	Instrument Development
<u>TASK NO.:</u>	466-2-6 <u>PRIORITY:</u> 2 <u>EST. COMPLETION:</u> July 1953
<u>SECURITY:</u>	Unclassified <u>RESPONSIBLE SCIENTIST:</u> J.E. Clemens <u>EXT.:</u> 29123
<u>PRIME CONTRACTOR:</u>	None. Work being accomplished at WADC.
<u>PURPOSE:</u>	The purpose of this task is to develop better instrumentation in Flight Research Laboratory's field of research.

TO DATE: Theoretical and experimental investigations have been undertaken on the development of fuel flowmeters based on temperature gradient as a function of fuel flow, on an accelerometer utilizing quartz fibers, and on an instrument for measuring aircraft skid. A study is now in progress to determine the effect of wall temperature on the accuracy of the fuel flow meter. After this study is completed, a report on the flowmeters will be prepared. A report on the quartz fiber accelerometers has been prepared.

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Project No. 466-2-6 (Cont)

A report on Thomas flowmeters for fuels has been prepared. This report contains a theoretical investigation of flowmeters and results of experiments made with two types of flowmeters designed and constructed for these tests.

TITLE: Optical Instrumentation (Interferometry)
TASK NO.: 466-2-7 PRIORITY: 2 EST. COMPLETION: July 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: T. Zobel EXT.: 23223
PRIME CONTRACTOR: None. Work being accomplished at WADC
PURPOSE: The purpose of this task is to investigate the further utilization of optics as an instrumentation tool.

TO DATE: The laboratory setup consisting of the large interferometer and a specially built General Electric steam turbine has been completed. A stroboscopic light system was furnished by General Electric and has been installed. Several hundred photographs have been taken of airflow through the system at various turbine speeds and airspeeds at Mach Number of approximately 0.005. Many of these photographs have been evaluated and pressure distribution curves have been drawn. The remarkable fact proven by these photos is that even at extremely small Mach Numbers, differences in pressure distribution can be determined. This work verifies the fact that an interferometer is a useful and satisfactory tool for studying airflow through a turbine under dynamic conditions. However, many problems must be overcome before this tool may be applied to turbines operating at normal speeds. A stroboscopic light having a shorter duration and a sharper cutoff as well as increased power during the flash will be required.

Analysis work made on the dynamic turbine model indicated that the end effect of the six stator blade assembly was possibly masking the actual normal flow patterns. A series of pressure pickups in the turbine section have been installed and attached to the multiple manometer setup. Photographs of the manometers give a permanent record of the test conditions. The dams have also been installed at the end of the stator section to reduce the end loss. A short run has been made to compare with other tests. As yet, the manometer data has not been analyzed.

The second leg of the interferometer setup has been introduced into the system and satisfactory interference fringes have been obtained between the two legs. Holders for the 45° rotator plates have been obtained from the shop and the rotators and polarizers have been introduced into one of the legs. The work in connection with the study of the influence of the air dams in the turbine section is continuing and steps are being taken to instrument pressure pickup elements to measure the frequency gamut of the disturbances which may be of importance in connection with vibrational fatigue failure of the turbine blades. It has been found necessary to put non-reflective coatings on the elements of the small Michelson interferometer on which the study is being conducted.

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TITLE: High Speed Recorder
TASK NO.: 466-2-8 PRIORITY: 2 EST. COMPLETION: July 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Van Velsor EXT.: 29123
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this task is to develop high speed recorders for scientific investigations.

TO DATE: Investigations are underway to use light rays on photoconductive surfaces for depositing charges on sensitized paper, also a system for directly depositing charges on sensitized paper; also a system for directly depositing charges on paper by means of a specially constructed switch tube is being investigated.

The method of depositing a charge directly on paper has been set up on a vacuum system and is now undergoing test. The method of transferring the electrons from the beam of the gun to the paper with necessary fineness in granularity has been undergoing research.

Both systems have progressed to where suitable test methods must be devised. The basic phenomena has been established; the exploitation of this phenomena is proving more difficult than its establishment.

Installation of facilities necessary for ultimate fabrication of an experimental model is pending. Vacuum equipment, including the induction heater are not yet available. Multiple sealed samples have been prepared, but a slicing wheel is needed for parting the glass coated wire. An order for such a wheel has been submitted. Meanwhile, a stop gap procedure is being developed for slicing.

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TITLE: High Speed Optical Comparator
TASK NO.: 466-3-1 PRIORITY: 1C EST. COMPLETION: July 1953
SECURITY: Confidential RESPONSIBLE SCIENTIST: H. Kuesters EXT.: 29123
PRIME CONTRACTOR: None. Work being accomplished at WADC
PURPOSE: The purpose of this task is to develop an automatic comparator for improving the accuracy of gunsights and other airborne optical equipment.

TO DATE: Fundamental measurements have been made on airplane and sky contrast. A range finder has been built and satisfactory tests have been conducted at targets approximately 1000 ft. distance. Aircraft takeoffs were recorded with high signal to noise value. Sensitivity of the system and its application to various targets under a full gamut of sky, weather and time-of-day conditions is being tested; evaluation of the instrument for military use will be made upon completion of these tests.

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Project No. 466-3-1 (Cont)

Unstable installation of instrument electronic gear equipment caused misalignment that induced considerable noise. A complete realignment of the instrument was made on a concrete floor and decided improvement in waveform was observed. Final contrast threshold measurements are delayed until a helicopter may be secured when the weather conditions improve. An improved shielding to prevent stray pickup is being worked on.

During some tests of the range finder in the final preparations for making the measurements with the helicopter test target, some discrepancies were found in the shape and magnitude of the initiating telemetering pulse. In searching for the cause of this trouble, it was found that there was a small particle that had lodged in the slit, and that the cylindrical lens was not positioned properly and the multiplier was 1/16 of an inch out of position. These were corrected and the machine again tested completely over the slit length and was found to be satisfactory. The introduction of two additional transformers has resulted in a reduction of the voltage to the multiplier tubes. Thus, the compensated pulses were coming out a considerably different amplitude and were giving slight variations in the results. An attempt is being made to eliminate this trouble by setting up equal operating conditions for each multiplier tube.

Extensive tests have been made on the comparator against moving and fixed targets and the instrument has been found to yield results which lead us to believe that it is possible to make an automatic passive range finder using this principle.

<u>TITLE:</u>	Optical Amplifier
<u>TASK NO.:</u>	466-3-2
<u>SECURITY:</u>	PRIORITY: 1C
<u>PRIME CONTRACTOR:</u>	EST. COMPLETION: July 1953
<u>PURPOSE:</u>	Confidential
	RESPONSIBLE SCIENTIST: J.E. Clemens & B. Johnstone
	Freed Radio Corporation
	EXT.: 29123
	The purpose of this task is to develop methods of obtaining amplified optical signals from ground to aircraft.

TO DATE: Electron opacity experiments were conducted on single crystals and twinned crystals. These latter crystals have a high defect concentration. The experimental technique used in this investigation has been changed such that the whole crystal is illuminated instead of a fine spot so that an average value response can be obtained which will be independent of the local variations within the crystal. Investigations have been made of micro crystalline screens. Studies have been made to determine if the removal of secondary electrons have any effect on erasure time. Investigations of micro-crystalline screens, with metallic aluminum deposited by evaporation, gave a much higher contrast color under electron bombardment with the same conditions than did those screens with Al_K backing.

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Project No. 466-3-2 (Cont)

The investigation of the halogens and the resultant F center production as a result of the insertion of electrons into the lattice has been directed toward increasing the erasure speed. Current investigation concerns the changes brought about by the introduction of small quantities of sensitizing materials into the KCl forming the screens. F centers are thought to be generated by electrons captured by anion vacancies, that is, in the case of KCl, and F center results where an electron attached itself to a location in the lattice where a chlorine ion is missing. This theory would indicate that by inserting a bivalent potassium salt whereby the anion has a similar radius to that of the chlorine ion, additional suitable salt for these tests should be potassium sulphide. On the other hand, a favorable condition for erasure of F centers may be created by field distortion by bivalent cations of similar radius K. A suitable salt for this use would be calcium chloride. Tests made with a mixture of KCl and K₂S showed essentially complete erasure in 1/2 second at 94 degrees to 50 degrees Centigrade when irradiated with a defocused beam in contrast to 15% erasure in 8 minutes with the pure crystal.

The contractor is continuing his investigations, approaching the problem directly by the utilization of conventional apparatus and also continuing his investigations of other phenomena which appear attractive but are not yet perfected to such an extent as to make utilization proper. These latter investigations are concerned chiefly with the alkali halides and those crystals of the structure of dihydrogen phosphate. This concerns the detailed investigation in fundamental electron capacity procedures which are necessary to increase the contrast of the image by speedily removing the color center. These two objectives are somewhat contradictory to the normal behavior of crystals and to the present understanding of the electron capacity process. What is needed is more fundamental understanding of this phenomena, and in connection with the fundamental experimental investigations in this respect, Dr. R. W. Gurney, author of the "Bible" in this field, has been retained to investigate and consult on these problems.

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<u>TITLE:</u>	Micropositioner
<u>TASK NO.:</u>	466-3-3
<u>SECURITY:</u>	PRIORITY: 2 EST. COMPLETION: July 1953
<u>PRIME CONTRACTOR:</u>	Confidential RESPONSIBLE SCIENTIST: J.E. Clemens EXT.: 29123
<u>PURPOSE:</u>	The Farrand Optical Company
	The purpose of this task is to provide the theory for the design of high precision electromagnetic and electrostatic micro-positioning devices.

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Project No. 466-3-3 (Cont)

TO DATE: The successful test run of the laboratory model has been completed and specifications for the pre-production prototype have been prepared. The contractor recently assembled a complete servo system, which employed three inch inductosyns and the associated electronic equipment, and demonstrated an accuracy of plus or minus six seconds of arc over the whole range of 360 degrees. It is expected that this system will be redesigned for suitable Air Force application.

This task has been extended and further research has been directed to achieve five seconds of accuracy throughout 360 degrees plus, and also repackaging of the breadboard model into a size suitable for field test.

Farrand Optical Company has put together a complete servo system utilizing the three inch inductosyns and the associated electronic equipment previously developed which demonstrated an accuracy of plus or minus 6 seconds of arc over the whole range of 360 degrees plus. The reproducibility of this servo based upon tape recordings was well within plus or minus 3 seconds of arc.

A PR has been written extending the work for another 15 months. The main items called for on the PR are further research to achieve five seconds of accuracy throughout 360° plus, and a repackaging of the breadboard model into a size suitable for field test.

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TITLE: Electro-Capillary Transducers
TASK NO.: 466-3-4 PRIORITY: 2 EST. COMPLETION: July 1953
SECURITY: Restricted RESPONSIBLE SCIENTIST: B.B. Johnstone EXT: 29123
PRIME CONTRACTOR: A. N. Lucian
PURPOSE: The purpose of this task is to obtain fundamental data on electro-capillary phenomenon which will be ultimately used in the development and construction of practical transducers and sensing elements for measurement of displacement, force, pressure and acceleration.

TO DATE: Due to personnel difficulties, this project has been inactive for sometime.

* * * *

TITLE: Stellar Inertial Bombing
TASK NO.: 466-4-1 PRIORITY: 1B EST. COMPLETION: June 1953
SECURITY: Confidential RESPONSIBLE SCIENTIST: J.E. Clemens; B. Johnstone
PRIME CONTRACTOR: Massachusetts Institute of Technology EXT.: 29123

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Project No. 466-4-1 (Cont)

PURPOSE:

The purpose of this task is to develop and test an experimental model of equipment designed to locate a distant target, bomb it, and return to the takeoff position without the use of personnel during the mission.

TO DATE:

The stellar inertial guidance system known as the FRES System has been flown on test flights with satisfactory results. The development of an inertial system known as SPIRE is being pursued. Emphasis is being placed on the development of low drift gyros, outer gimbal servo systems, system dynamics, and the overall system configuration.

Satisfactory progress has been reported on Project SPIRE. Six test stands for gyro test work have been completed and are installed at Massachusetts Institute of Technology. These new test stands are expected to speed up considerably the gyro experimentation and the development of the SPIRE system.

First test runs on this equipment showed erratic operation, however, adjustments are correcting this defect.

Excellent progress has been made on the gimbal system of SPIRE. The fabrication and alignment have been completed and the system is partially wired. A test made on it tuned to 84.3 minutes as earth's radius pendulum functioned satisfactorily for a period of approximately eight hours.

The work and fabrication of the SPIRE system is continuing, and portions of the equipment are being installed in the B-29 test vehicle. A continuing program of the perfection and testing of low-drift gyros shows some degree of advancement.

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TITLE:

Tracking Control

TASK NO.:

466-4-2 PRIORITY: 2 EST. COMPLETION: July 1953

SECURITY:

Confidential RESPONSIBLE SCIENTIST: B.B. Johnstone EXT.: 29123

PRIME CONTRACTOR:

Massachusetts Institute of Technology

PURPOSE:

The purpose of this task is to improve the performance of airborne sighting equipment for fire control and interception.

TO DATE:

Three axis control of various types of interception has been worked out for the B-26 and applications of this technique are now being applied to the F-94.

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Project No. 466-4-2 (Cont)

Basic research stage (Phase I) of this task has been completed by the contractor. Negotiations are in progress between the contractor and the Armament Laboratory for the development stage (Phase II).

This project is inactive as far as Flight Research Laboratory is concerned and research in this task will be continued under E-466-4-3.

TITLE: Transonic Control
TASK NO.: 466-4-3 PRIORITY: 2 EST. COMPLETION: July 1955
SECURITY: Confidential RESPONSIBLE SCIENTIST: B. B. Johnstone EXT.: 29123
PRIME CONTRACTOR: Massachusetts Institute of Technology
PURPOSE: The purpose of this task is to study the design problems of aircraft control systems which will have optimum performance in the transonic range.

TO DATE: The contract has been negotiated with the contractor mentioned above. A research group is being organized and preliminary work has begun.

Dr. Guy Stever of MIT recently made a trip to England to examine the state of the art in transonics. The findings of Dr. Stever have been confirmed by William Milliken of Cornell Aeronautical Laboratory. The conclusions reached from this visit will be implemented into the study phase of this task.

A report entitled "Transonic Flow Past a Wedge at Zero Angle of Attack" has been submitted by a member of the Transonic group. The report will be issued as a WADC Technical Report and given suitable distribution.

The investigator has completed the design of the test vehicles and is now analyzing performance of these vehicles with respect to the aspects of automatic control. This investigation will yield certain undesirable structural and aerodynamic characteristics which will result in the redesign of the test vehicle and, in general, this process will be pursued until the process converges, so that continuing effort produces very little yield.

TITLE: Project RAND
TASK NO.: 466-6 PRIORITY: 2 EST. COMPLETION: Continuous
SECURITY: Unclassified thru Top Secret RESPONSIBLE SCIENTIST: Maj Q.A. Riepe
PRIME CONTRACTOR: The RAND Corporation, Santa Monica, California EXT.: 23213

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PURPOSE: Long range, scientific, military research, designed to air Air Force decisions.

TO DATE: Due to the nature of the project, RAND's studies are continuous and cover many fields of scientific research. Reports are submitted when any phase of a study has been completed or sufficient progress made to warrant a report.

* * * *

TITLE: Graduate Research Program.
TASK NO.: 466-7 PRIORITY: 2 EST. COMPLETION: Continuing
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Lt. Col. S. J. Cazyak EXT: 22154
PRIME CONTRACTOR: None.
PURPOSE: The purpose of the Graduate Research Program is to accomplish the following:

- (1) Explore the mutual interests of university students, faculty and the ARDC in the USAF Research and Development Program,
- (2) Invite the attention of all reputable scientific institutions to numerous scientific problems now confronting the USAF, and assist graduate students with the preparation of theses pertinent to the solution of those problems.
- (3) Provide an informal contact with reputable scientific institutions so that submission and proper handling of research proposals pertinent to the problems mentioned above will be expedited.

TO DATE: At the present time, action is being taken to formulate a new Suggested Theses List. The various laboratories within WADC which have been solicited for graduate thesis topics have responded with many worthy topics. Upon completion of this list, it will be distributed to carefully chosen scientific institutions of learning with an accompanying letter telling of the aims and functions of the program. It is planned to have some personal contact with universities which show particular interest in the program and in specific research projects.

* * * *

TITLE: An Investigation of the Properties of Single Synthetic Crystals
TASK NO.: 469-1-2 PRIORITY: 2 EST. COMPLETION: July 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Lt Col S.J. Cazyak EXT: 22154
PRIME CONTRACTOR: None. Research being performed by WADC.

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Project No. 469-1-2 (Cont)

PURPOSE: The purpose of this task is to investigate the physical properties of single synthetic crystals and devise a more comprehensive theory which would correlate the various crystal effects.

TO DATE: Of the six furnaces (4 combustion type, 2 bridgman type) under construction, two have been completed and instrumented sufficiently that crystals may be grown. At present, single crystals of ZnS and CdS are being grown by the sublimation method.

The preliminary equipment for photo conductivity measurements has been set up. (At the present only the order of magnitude of the current was determined.) The set up is being refined for quantitative measurements of photo conductivity.

The design and construction of the Hall-Effect apparatus is now underway and it is anticipated that this will be ready in approximately five (5) months.

TITLE: Investigation of Large Air Showers

TASK NO.: 469-2-2 **PRIORITY:** 2 **EST. COMPLETION:** September 1952

SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** Maj. R. Hart **EXT.:** 22154

PRIME CONTRACTOR: Tufts College

PURPOSE: The purpose of this task is to increase our knowledge of cosmic radiation and investigate the possible ionization effects of cosmic rays on AF personnel and equipment.

TO DATE: A coincidence array consisting of four large pulse type cylindrical ionization chambers has been in operation at Tufts College for some time and the data collected is now being analyzed. It is believed that the results will yield information on the high energy extreme of the cosmic ray spectrum. A similar apparatus consisting of large spherical pulse type ionization chambers is now in operation for making continuous measurements on the frequency of occurrence and size of air showers at sea level.

A fire in the laboratory at the first of this year caused considerable loss and damage to this equipment. The repairs and recalibration have caused unavoidable delay in completion of the research and submission of the final technical report. The project will be terminated as soon as this report is received.

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TITLE: Theory of Matter
TASK NO.: 469-2-6 PRIORITY: 2 EST. COMPLETION: 1 Yr from date of Contract
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Maj Hart EXT.: 22154
PRIME CONTRACTOR: University of Detroit
PURPOSE: The purpose of this task is to study the behavior of elementary particles so that a satisfactory theory of matter may be developed which will not break down when applied to the interaction of particles and structure of matter.

TO DATE: Contract has been awarded and the investigator has begun work on the project. The first phase consisting of a literature search is complete.

* * * *

TITLE: Interaction of Radio Frequency Radiation with Matter
TASK NO.: 469-3-3 PRIORITY: 2 EST. COMPLETION: 1954
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Capt H. Payne EXT.: 22154
PRIME CONTRACTOR: Ohio State University
PURPOSE: The purpose of this task is to obtain further information on molecular structures, atomic magnetic moments and their interactions with crystal lattices, nuclear spins and magnetic moments, nuclear spin-spin and spin-lattice interactions, nuclear quadrupole interactions and transitions, and other nuclear data with possible applications to solid state physics.

TO DATE: The contract AF 33(616)-29 was awarded in February to Ohio State. Two radio frequency spectrographs for studying nuclear magnetic resonance effects have been placed in operation. Also, a spectrograph for studying nuclear quadrupole transitions has been designed and placed in operation.

The development of electronic circuits and special equipment needed in contemplated work is underway.

* * * *

TITLE: Cross-Section Measurements
TASK NO.: 469-3-4 PRIORITY: 2 EST. COMPLETION: May 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Maj Hart EXT.: 22154
PRIME CONTRACTOR: None. Research being performed by WADC.
PURPOSE: The purpose of this project is to determine the neutron absorption and scattering (both elastic and inelastic) cross sections on various materials of interest to the AMP program.

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Project No. 469-3-4 (Cont)

TO DATE: Design plans of shielding and radiation monitoring methods have been approved by the Base Surgeon's Office. The shield for a radioactive neutron source is nearing completion and the neutron source and other equipment has been ordered.

TITLE: Radiometric and Isotopic Dilution Analytical Techniques
TASK NO.: 469-4-1 PRIORITY: 2 EST. COMPLETION: December 1952
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Maj Harv EXT: 22154
PRIME CONTRACTOR: Temple University Research Institute
PURPOSE: The purpose of this task is to conduct research in the evolution of simple, rapid, and low cost isotopic methods and techniques for the determination of the impurity content of certain metals.

TO DATE: Most of the equipment is now in operation and several batches of regular oxygen-zirconium and oxygen-titanium alloys have been prepared. Also some oxygen-18 enriched oxygen-Zirconium master alloys have been prepared. A literature survey of methods of preparing and analyzing samples of alloys containing O, N, S, and H is nearing completion.

Results obtained upon analyzing the various copper-oxygen samples proved the Isotopic method of Analysis capable of providing accurate, reproducible results. By refining the methods, very accurate data on impurity traces will be obtained. The contractor is now in the process of accomplishing this phase of the work.

Several samples of iron, titanium and chromium containing various concentrations of oxygen were analyzed by the mass spectrograph. Results have not as yet been returned from Consolidated Engineering Corporation in Pasadena, California.

TITLE: Neutron Spectrometry
TASK NO.: 469-5-2 PRIORITY: 2 EST. COMPLETION: December 1952
SECURITY: Unclassified RESPONSIBLE SCIENTIST: S.J. Cyszak EXT.: 22154
PRIME CONTRACTOR: University of Chicago
PURPOSE: The purpose of this task is to investigate the feasibility of various means for the energy measurement of high energy neutrons and to construct equipment to perform such measurements.

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Project No. 469-5-2 (Cont)

TO DATE: A contract for the research indicated above has recently been negotiated. The contractor has completed the construction of a high temperature furnace for crystal growing. Work has started on the growing of large single lithium tungstate crystals for the spectrometer. Construction of the electronic equipment for the spectrometer is now finished.

TITLE: Study of the Behavior of Gases at a Boundary Layer
TASK NO.: 469-5-3 PRIORITY: 2 EST. COMPLETION: October 1952
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Capt Payne EXT. 22154
PRIME CONTRACTOR: None. Research being accomplished at WADC.
PURPOSE: The purpose of this task is to provide a basis for deriving formulae relating such quantities as the heat transfer temperature and velocity gradient, etc., of a gas at a boundary surface in terms of known physical constants, and dynamic and thermodynamic variables.

TO DATE: A literature survey has been made. Calculations on the behavior of gases at boundary surfaces are being refined. The theory has been modified to consider time as a variable. The investigator tested the validity of the basic equations used. The tests have revealed certain erroneous assumptions, so that a new approach to this problem has been adopted.

Under this arrangement, the coefficients going with the series terms in the approximation expression of the molecular velocity distribution function at the wall, are so chosen as to give the most rapid approach in moving from the wall to the function assumed valid at a great distance from the wall. The validity of the assumption will be inferred from the results obtained.

TITLE: Study of Rupture Phenomena in Polymers
TASK NO.: 469-5-4 PRIORITY: 2 EST. COMPLETION: March 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Col Gysak EXT.: 22154
PRIME CONTRACTOR: University of Cincinnati
PURPOSE: The purpose of this supplement is to study the tensile strength distribution of polymers as a function of the non-dominant structure and this should make it possible to obtain valuable information concerning non-dominant structure by the detailed investigation of these distributions. Such a study should also allow

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Project No. 469-5-4 (Cont)

some deduction to be made regarding the relation between atomic or molecular forces and technical cohesion.

TO DATE:

Contract was negotiated in June 1952.

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METALLURGY RESEARCH BRANCH

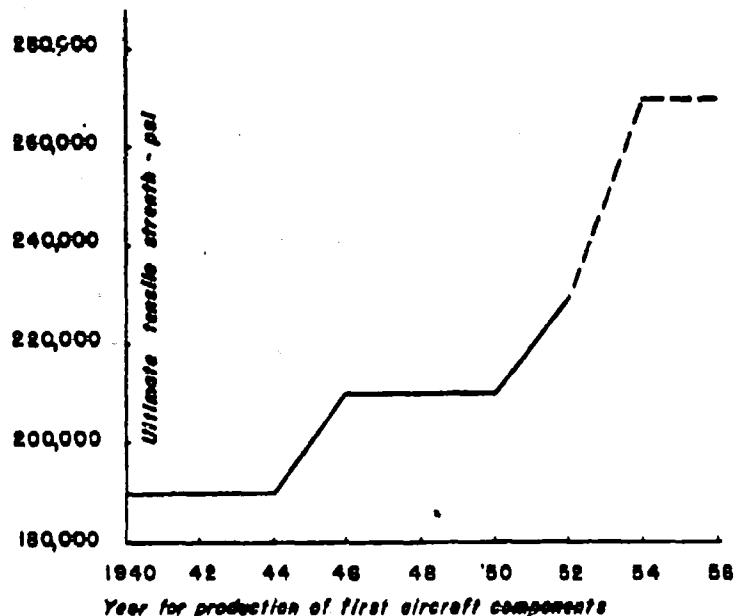
The Metallurgy Research Branch provides guidance, advice and assistance to the USAF on research problems in the field of metallurgy as applied to USAF application. The Physical Metallurgy Research Section is responsible for research in physical metallurgy including deformation of metals at normal and elevated temperatures, the structure of metals and alloys and certain aspects of solid state physics. The High Temperature Research Section is responsible for research on high temperature materials including cast and wrought alloys, metal-ceramic bodies and pure ceramics. Titanium and Light Metals Research Section is responsible for the development of alloys and evaluation of light metals for aircraft application, including research in titanium, magnesium, and aluminum fields. A Steel Research Section is responsible for research in the ferrous field, principally concerned with improvements in mechanical properties of low and medium alloy steels through changes in composition or heat treatment.

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STEEL STRENGTH LEVELS ARE GOING UP!

The alloy steel program in the Flight Research Laboratory is contributing valuable data concerning the use of steels at strength levels ranging from 220,000 to 250,000 psi. in components such as landing gear struts. The present useful strength level is from 200,000 to 220,000 psi. Data obtained on two new steels heat treated to high strength levels will be of great benefit in promoting their use as soon as possible. One of these, a vanadium-modified SAE 4330 (AMS 6427), has been rather thoroughly evaluated and will be quite useful at 220,000 to 240,000 psi. or higher strength. Another study, on the mechanical properties of a B-26 main strut made of "Hy-Tuf" steel, shows that this steel has superior load-carrying capacity to the presently used steels and that it would be useful in



IMPROVEMENT IN HIGH STRENGTH STEELS AS A RESULT OF RESEARCH
ON COMPOSITION, HEAT TREATMENT AND FORGING PRACTICE.

the range from 220,000 to 240,000 psi. Still another phase of the program has yielded a steel composition which has promise for use at 250,000 psi.

Redesign of new landing gears to make use of the high strength level of these steels will permit substantial savings of weight on large landing gears.

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"Steel Strength Levels are Going Up!" (Cont)

However, considerable additional evaluation and parts testing will be required before general use can be realized.

Further applied research by the FRL has been responsible for the production of a large heat of new boron steel developed as a substitute for the standard 4340 steel used in aircraft production. Use of this steel will conserve substantial amounts of the critical materials, nickel and molybdenum. This heat is being made available to a considerable number of aircraft manufacturers for evaluation.

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TITLE: Cermet Bodies Containing Silicon
TASK NO.: 463-4-1 PRIORITY: 2 EST. COMPLETION: July 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: M.A. Schwartz EXT: 26230
PRIME CONTRACTOR: None. Work Being accomplished at WADC.
PURPOSE: The purpose of this task is to study and develop new fabricating techniques and new materials of ceramic and cermet compositions for use in aircraft as power plant components and for other applications which are of interest to the Air Force.

TO DATE: SiC-metal systems are being investigated for use both as turbine bucket materials and as crucibles in which to melt titanium. In the crucible work, the following materials were investigated and found to be unsatisfactory: $TiO_{1.4}$ (11.8% oxygen), $TiC_{0.4}$ (9.1% carbon), and $SiC_{0.33}$ (7.7% carbon). Calcium oxide compounds and silicon-carbon-titanium mixtures have indicated some theoretical promise and are being investigated. Various crystalline modifications of SiO are being investigated as to stability and to possible application.

TITLE: Research on Refractory Materials
TASK NO.: 463-4-2 PRIORITY: 2 EST. COMPLETION: July 1953
SECURITY: Unclassified RESPONSIBLE CERAMIST: M.A. Schwartz EXT: 26230
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this task is to develop high temperature ceramic and cermet materials for potential aircraft application.

TO DATE: A study was completed on the influence of porosity ranging from 0 to 60% on the strength of pure sintered Al_2O_3 and sintered stabilized ZrO_2 . An almost exact relationship was indicated for the two materials. Tests will now be conducted to investigate orderly and precise arrangements of pores in the form of longitudinal holes.

Studies on the use of ZrO_2 as a cermet component have been confined to studies concerned with its stabilization. When sintered to 1860°F for one hour, 14% MgO (using MgF_2) was shown to stabilize completely the ZrO_2 . Thermal shock sensitivity of ZrO_2 containing metal additions will be investigated and protective coatings for ZrO_2 -metal bodies will be developed.

A small high temperature gas furnace has been completed and will be employed for firing specimens to temperatures ranging from 1800°C to 2300°C.

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TITLE: Research on the Deformation of Metals
TASK NO.: 463-5-1 PRIORITY: 2 EST. COMPLETION: May 1954
SECURITY: Unclassified RESPONSIBLE METALLURGIST: E.J. Hassell EXT.: 26230
PRIME CONTRACTOR: General Electric Research Laboratory
PURPOSE: The purpose of this task is to support basic research on the deformation of metals in order to establish relationships between changes of structure which will lead to improved metals and more accurate predictions of their creep properties at elevated temperatures.

TO DATE: A report, "Recovery and Creep in an Alloy Steel," by H. A. Lequear and J.D. Lubahn, dated February 1952, was received and given wide distribution. The mechanical properties of a chromemoly-vanadium steel were studied in some detail. By interrupting a creep test and observing that the creep rate is higher after the interruption than before and by further observing that the amount of creep increases with the duration of the interruption, it is possible to establish that recovery (reduction in the amount of strain hardening) has occurred. Recovery occurs in quenched and tempered Cr-Mo-V steel at 1000°F, but not at 800°F. When recovery occurs, the plastic creep rate becomes constant. The time required for the creep rate to become constant is proportional to the applied stress. In the absence of recovery, the plastic creep rate decreases continuously. Although recovery influences creep, it obviously does not cause the creep because there is pronounced creep at 800°F where recovery does not occur.

Analysis of the data obtained from creep tests of wires of pure silver at 600°, 400°, 200° and 25°C., after annealing at 900°, 800°, 700°C. to produce three different grain sizes, is underway.

Tests on copper at room temperature have been completed. The creep behavior in any range of strain can be calculated with sufficient accuracy for practical purposes, using the tensile curve and the rate change accompanying a small stress increment.

* * * *

TITLE: Mechanical Properties of Ferrite and Austenite Single Crystals at Low Temperatures
TASK NO.: 463-5-4 PRIORITY: 2 EST. COMPLETION: September 1953
SECURITY: Unclassified RESPONSIBLE METALLURGIST: Lt V.D. Smith EXT.: 26230
PRIME CONTRACTOR: University of Pennsylvania
PURPOSE: The purpose of this task is to perform fundamental research in metallurgy that may eventually lead to the improved performance of steels at low temperatures.

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Project No. 463-5-4 (Cont)

TO DATE: Additional tests on ingot iron single crystals have been performed in tension and compression. Three crystals were deformed in tension at 105°C. to obtain data at another low temperature approaching the projected liquid air tests. Critical resolved shear stresses in the vicinity 18,000 psi were obtained. Also, in two of the three specimens tested, twinning was observed by emanation of a "clicking" sound simultaneously with a slight drop in the autographic load-elongation curve and microscopic observation. A sharp drop in load was not observed at the initiation of yielding at this temperature. Compression tests were made on specimens of two orientations each at 180°C., 100°C., 20°C., and 200°C. No double yield was observed at any temperature. The critical resolved shear stress values fall on the same curve (C.R.S. vs. temp.) that contains the values obtained in tension. The plane of glide is roughly the same in compression as in tension, i.e., close to the plane of maximum shear.

Six single crystals of the pure titanium-killed ferrite (.26% added Ti) were deformed in tension at liquid air and room temperature. Data on the critical shear stress for the room temperature tests were obtained, and where possible, an analysis of asterism in lane photographs was carried out.

TITLE: Dynamic Microscopic Recording of Crystal Growth
TASK NO.: 463-5-5 PRIORITY: 2 EST. COMPLETION: May 1954
SECURITY: Unclassified RESPONSIBLE SCIENTIST: E.J. Hassell EXT.: 26230
PRIME CONTRACTOR: Johns Hopkins University
PURPOSE: The purpose of this task is to support fundamental research on microscopic recording of the deformation in metals as a result of stress or temperature with a view to introducing a new technique for metallurgical investigations.

TO DATE: Analyses of recent tests and the motion picture film record of the plastic deformation of high purity aluminum have been made. Propagation of slip bands at finite rates up to 7600 microns per second was observed at positions corresponding to the head of the slip direction. A similar propagation of slip bands at positions parallel to the slip direction has not been observed to date. Strain hardening retards the rate of propagation and is a factor controlling the location of a given slip band. It is concluded from the geometry of addition of slip bands that one band can extend its hardening effect to its neighbors. The unit process of slip is considered as a shear of a row of atoms in the slip direction. The growth of a slip band is considered as resulting from progressive participation in the shearing process by successive rows of atoms. Experimental

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Project No. 463-5-5 (Cont)

methods and analysis of results are presented in a technical report "Dynamic Formation of Slip Bands in Aluminum", dated 10 April 1952, by E. E. Chen and E. B. Pond.

Work is continuing on methods for producing single crystals containing fewer imperfections than normally present.

TITLE: Solid Solution Theory
TASK NO.: 463-5-6 **PRIORITY:** 2 **EST. COMPLETION:** February 1953
SECURITY: Unclassified **RESPONSIBLE METALLURGIST:** E.J. Hassell **EXT.:** 26239
PRIME CONTRACTOR: University of Pennsylvania
PURPOSE: The purpose of this task is to obtain fundamental information on the mechanism of solid solution alloying in metal systems in order to broaden the information available concerning the effect of foreign atoms on base alloys.

TO DATE: **X-ray Measurements:** After several attempts to grow single crystals of copper-gold alloy, one of the desired size has finally been obtained, containing 25 atomic percent copper. After mounting in the furnace, room temperature measurements have been made to determine the absorption correction for the nickel shielding and to provide one point on the temperature diffuse scattering curves needed for data correction at higher temperatures. X-ray measurements are now underway at elevated temperatures just below the critical ordering temperature (Approx. 390°C).

Volume Expansion Measurements: Single crystals of Cu-Au alloy containing 5, 10, 15 and 20 atomic percent gold were grown and annealed to definitely establish homogeneity. Final interferometric measurements are underway to determine the plot of true coefficient of expansion versus temperature.

Resistivity Measurements: These are being made over the range 450°C, and data for the critical ordering region (390°C) for Cu₃Au will soon be completed.

TITLE: Research on Diffusion and Related Phenomena
TASK NO.: 463-5-9 **PRIORITY:** 2 **EST. COMPLETION:** September 1953

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Project No. 463-5-9 (Cont)

SECURITY: Unclassified RESPONSIBLE METALLURGIST: E.J. Hassell EXT.: 26230
PRIME CONTRACTOR: Massachusetts Institute of Technology
PURPOSE: The purpose of this task is to provide the basis for an improved and more useful theory to describe the mechanism of the diffusion process in metals.

TO DATE: Diffusion: A paper, "The Measurement of Self-Diffusion Coefficients by Autoradiography" by H. C. Gatos and Ahmed Assam has been submitted to a technical journal for publication.

Molybdenum Welding: Significant improvements were made in the technique for producing pure molybdenum by decomposition of gaseous MoCl_3 . When bars and tubes of molybdenum produced by this method were rolled and swaged, considerable ductility was evidenced. The temperature of recrystallization was as low as any reported in the literature, indicating a high purity of the molybdenum so produced.

Deformation of Aluminum: Creep testing of coarse grained and single crystal specimens of high purity aluminum was carried out from 400°F to 1200°F. Slip bands were observed in all cases. Metallographic and X-ray methods revealed the presence of sub-grains. These are larger, the lower the applied stress. The average size of the sub-grains is smaller than the average slip band spacing. The results suggest that the slip process is the main mechanism of deformation at both high and low temperatures. Sub-grain formation is probably due to a polygonization process originated by local bending and simultaneous annealing. It appears that the well known difference in the over all high and low temperature behavior of polycrystalline material is related to the grain boundaries and not to the grains.

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TITLE: Metallurgical Translations
TASK NO.: 463-5-10 PRIORITY: 2 EST. COMPLETION: September 1952
SECURITY: Unclassified RESPONSIBLE METALLURGIST: E.J. Hassell EXT: 26230
PRIME CONTRACTOR: Henry M. Bratcher
PURPOSE: The purpose of this task is to translate Russian Metallurgical Journals of interest to the Metallurgical Research personnel.

TO DATE: Seventeen (17) translations from the German and Russian technical literature on various metallurgical subjects have been obtained from Mr. Bratcher during the past three months.

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TITLE: Application of X-ray Techniques to a Study of Plastic Deformation
TASK NO.: 463-5-11 PRIORITY: 2 EST. COMPLETION: April 1954
SECURITY: Unclassified RESPONSIBLE METALLURGIST: E.J. Hassell EXT: 26230
PRIME CONTRACTOR: National Bureau of Standards
PURPOSE: The purpose of this task is to provide information on the fundamentals of plastic deformation for aid in understanding many aspects of the mechanical behavior of metals.
TO DATE: Procurement negotiations were recently completed. No progress to report.

TITLE: Fundamental Study of Seizing and Galling Metals
TASK NO.: 463-5-13 PRIORITY: 2 EST. COMPLETION: January 1954
SECURITY: Unclassified RESPONSIBLE METALLURGIST: E.J. Hassell EXT: 26230
PRIME CONTRACTOR: Columbia University
PURPOSE: The purpose of this task is to investigate and establish the principles governing seizing and galling in metals. Emphasis is to be placed on titanium.

TO DATE: A friction measuring device has been constructed. This is a modification of the classic Bowden-Leben design. Provision has been made to obtain clean surfaces by use of a shaper and friction measurements will then be made in a controlled inert atmosphere.

TITLE: Technical Book, "Constitution Diagrams for Binary Alloys"
TASK NO.: 463-5-14 PRIORITY: 2 EST. COMPLETION: May 1954
SECURITY: Unclassified RESPONSIBLE METALLURGIST: E.J. Hassell EXT: 26230
PRIME CONTRACTOR: Armour Research Foundation
PURPOSE: The purpose of this task is to bring the only comprehensive metallurgical book on "constitution diagrams" up-to-date, and to publish it for the first time in English, thereby greatly increasing its utility.

TO DATE: Contract AF 33(616)-193 has recently been negotiated for the procurement of this book.

TITLE: Identification of Minor Phases in Alloys by Electronic Diffraction
TASK NO.: 463-5-15 PRIORITY: 2 EST. COMPLETION: January 1953

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Project No. 463-5-15 (Cont)

SECURITY: Unclassified RESPONSIBLE METALLURGIST: Lt V.D. Smith EXT: 26230
PRIME CONTRACTOR: University of Michigan
PURPOSE: The purpose of this task is to furnish reliable information on the presence and composition of minor phases in the alloys used in the high temperature components of modern aircraft engines and to aid in the development of the principles of the metallurgy of these alloys.

TO DATE: Present results include: (1) The identification of a NbC-CbN phase in N-155 and S816 alloys; (2) Strong indications of an M_{23}O_6 carbide and of a face centered cubic phase with a unit cell edge of 6.0 Å in N-155 alloy; and (3) The identification of an M_6O phase in 16-25-6 alloy.

Studies are being carried out to select suitable polishing, etching, and rinsing procedures for preparing specimens of 16-25-6, S816, Inconel-X and low-carbon N-155 alloys for electron diffraction studies as well as electron microscopy studies. Two good methods have been worked out for 16-25-6 and it appears that work on this alloy will be completed in the near future. Difficulties have been encountered in preparing samples of low-carbon N-155 alloy for electron diffraction studies.

Further studies, directed toward the correlation of the occurrence of the minor phases with the metallurgical treatments and microstructures of the alloy specimens are in progress.

* * * *

TITLE: Determination of Diffusion Rates in Titanium Base Alloys
TASK NO.: 463-5-16 PRIORITY: 2 EST. COMPLETION: May 1953
SECURITY: Unclassified RESPONSIBLE METALLURGIST: E.J. Hassell EXT.: 26230
PRIME CONTRACTOR: Battelle Memorial Institute
PURPOSE: The purpose of this task is to determine the diffusion rates in titanium of such elements as Cr, Mn, Mo, Fe, and Al which are generally used in making commercial titanium alloys and of other elements (O, N, C) which are often present during the commercial heat treating operations on these alloys.

TO DATE: This contract has been recently negotiated. The pure titanium necessary for the work has been ordered from the Foote Mineral Company. Using

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Project No. 463-5-16 (Cont)

material already on hand, the chemical etching characteristics as well as the technique of bonding titanium to titanium alloys is being studied to minimize experimental delays.

* * * *

TITLE: X-ray Diffraction Patterns
TASK NO.: 463-5-17 PRIORITY: 2 EST. COMPLETION: April 1953
SECURITY: Unclassified RESPONSIBLE CERAMIST: M.A. Schwartz EXT: 26230
PRIME CONTRACTOR: National Bureau of Standards
PURPOSE: The purpose of this task is to determine and record X-ray diffraction patterns for compounds of high purity to be used as standards. The patterns are used as a basis for comparing and evaluating duplicate ASTM file patterns, and as new information, to be added to the file.

TO DATE: Work on this contract commenced 1 April 1952. X-ray investigations of the following materials have now been reported: (1) Cadmium, (2) titanium, (3) antimony trichloride, senarmonite, (4) sodium bromide, (5) cesium dichloriodide, and (6) potassium dihydrogen phosphate.

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TITLE: Compressive Stress-Rupture Properties of High Temperature Materials
TASK NO.: 463-5-18 PRIORITY: 2A EST. COMPLETION: Unknown
SECURITY: Unclassified RESPONSIBLE SCIENTIST: E.J. Hassell EXT: 26230
PRIME CONTRACTOR: Unknown
PURPOSE: The purpose of this task is to study the stress-rupture behavior of materials in compression and compare these properties with stress-rupture data as obtained in the conventional manner by tensile loading for the ultimate purpose of shortening and simplifying test procedures.

TO DATE: Contract negotiations are almost complete.

* * * *

TITLE: Study of Transition Iron Carbides
TASK NO.: 463-5-19 PRIORITY: 2A EST. COMPLETION: January 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Lt V.D. Smith EXT: 26230
PRIME CONTRACTOR: U. S. Bureau of Mines

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Project No.: 463-5-19 (Cont)

PURPOSE: The purpose of this task is to study the intermediate forms of iron carbides to furnish additional data which may explain the temper embrittlement of steel.

TO DATE: This contract was negotiated in April 1952, but no progress reports have been obtained up to this time.

* * * *

TITLE: Effects of Ceramic Coatings on the Creep Rate of Metallic Single Crystals

TASK NO.: 463-5-20 PRIORITY: 2 EST. COMPLETION: June 1953

SECURITY: Unclassified RESPONSIBLE METALLURGIST: E.J. Hassell EXT: 26230

PRIME CONTRACTOR: National Bureau of Standards

PURPOSE: The purpose of this project is to study creep as a surface dependent phenomenon by determining the effect of ceramic coatings on the creep rate of coarsely grained metals and alloys.

TO DATE: Contract recently negotiated. Work on the project to commence in June 1952.

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TITLE: Fundamental Studies in Bainite and Low Carbon Martensite

TASK NO.: 463-6-1 PRIORITY: 2 EST. COMPLETION: November 1953

SECURITY: Unclassified RESPONSIBLE METALLURGIST: Lt V.D. Smith EXT: 26230

PRIME CONTRACTOR: Carnegie Institute of Technology

PURPOSE: The purpose of this task is to obtain basic information on the formation and effect of bainite on mechanical properties and on low carbon martensite in order to make more accurate predictions in the use of steel components and to produce better alloy steels.

TO DATE: The ninth quarterly report on this contract has been received. New tensile and impact data are presented on the steels already investigated and on some new compositions. Anisothermal bainite studies are being accented in order to relate commercial heat treating structures with isothermally formed bainitic structures. Ferrite morphology studies, which will subsequently aid in explaining the mechanism of the bainite reaction, are progressing in an effort to determine

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Project No. 463-6-1 (Cont)

the isothermal reaction morphology, kinetics, and mechanism of Widmanstatten side-plate formation. In connection with the study of low carbon martensites, the greatest emphasis was placed on tensile and impact tests of steels in the as-quenched condition or after low temperature tempering. The advisability of water quenching the suggested high strength steel analyses, reported in the previous quarter, is being discussed with strut fabricators.

This project has been concerned with a comprehensive testing program involving a limited number of steels. The final phase, which is just starting, will consist of a very large testing program involving a large number of available steels but with relatively fewer tests per steel.

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TITLE: Study of Directional Properties of Large Closed Die Forgings of Low Carbon, Low Alloy Steel

TASK NO.: 463-6-2 **PRIORITY:** 1A **EST. COMPLETION:** August 1952

SECURITY: Unclassified **RESPONSIBLE METALLURGIST:** Lt V.D. Smith **EXT:** 26230

PRIME CONTRACTOR: Ladish Company

PURPOSE: The purpose of this task is to study the directional properties developed in a large, closed-die forged landing gear strut heat treated to 220,000# psi minimum tensile strength.

TO DATE: The final report on this task described the forging, machining, heat treating, and mechanical testing of the critical section of the column. The quality of the Hy-Tuf forging is typical of steels of similar hardenability as indicated by macroetch and magnetic particle inspection tests. Forgeability is equal to that of SAE 4340 but the tendency of Hy-Tuf to form thermal ruptures is somewhat greater and would require slower cooling cycles after forging. With regard to mechanical tests, the uniformity of hardness is excellent. The yield strength to ultimate strength ratio for Hy-Tuf was .79 at the 220,000 to 230,000 psi tensile strength level. Notched bar impact tests are excellent at all temperatures investigated, i.e., 78, 32, -65 F. No test specimens exhibit coarse crystalline fracture.

The results of this study indicate that the load carrying capacity of a landing gear component made of Hy-Tuf steel would be greater than that provided by the present specifications. It should perform well in the tensile strength range from 220,000 to 240,000 psi. The report will be given wide distribution to landing gear manufacturers, steel makers, interested government agencies, research laboratories and aircraft companies.

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TITLE: Study of Temper Embrittlement in Alloy Steels
TASK NO.: 463-6-3 PRIORITY: 2 EST. COMPLETION: July 1953
SECURITY: Unclassified RESPONSIBLE METALLURGIST: Lt V.D. Smith EXT: 26230
PRIME CONTRACTOR: Case Institute of Technology
PURPOSE: The purpose of this task is to eliminate the embrittlement of quenched alloy steels tempered in the vicinity of 500°F.

TO DATE: The first annual summary report on this work has been received. Evaluation of a vanadium modified SAE 4330 steel and a SAE 4340 steel is nearly complete. The mechanical data presented indicate that there is no advantage in employing high strength bainitic structures instead of tempered martensite. Since the tempered martensitic structures showed little or no 500-600°F embrittlement, the bainitic structures were unable to minimize or eliminate this type of embrittlement. From the results of this study, it appears that the vanadium modified SAE 4330 is an excellent steel for use at high strength levels. In addition to the final studies already planned for this material, a limited notched stress-rupture study will be made.

Good progress was made in the X-ray diffraction studies of electrolytically isolated carbide products of the martensite decomposition. The non-embrittled state is associated with the formation of (Fe) iron carbide, while the embrittled state is associated with cementite in its initial stage of formation of (Fe) iron carbide, while cementite and ferrite are the products of the third stage. The second stage is the decomposition of retained austenite. It is generally recognized that the second stage bears no relation to the 500°F embrittlement. Future work will be directed toward clarification of the third stage.

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TITLE: Study of Creep in Titanium and Titanium Alloys
TASK NO.: 463-6-4 PRIORITY: 2 EST. COMPLETION: February 1953
SECURITY: Unclassified RESPONSIBLE METALLURGIST: E.J. Hassell EXT: 26230
PRIME CONTRACTOR: University of Michigan
PURPOSE: The purpose of this task is to study the phenomenon of creep in titanium and its alloys and to gain information leading to a plausible explanation of any unique or unexpected creep behavior at stresses significantly below the yield strength value. In addition, specific creep data on titanium, hitherto unavailable, will be obtained.

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TO DATE: Creep testing of fully annealed commercial titanium sheet (Ti-75) has now been completed at room temperature, 210°F, 400°F, and 600°F. In comparing results at the three higher temperatures, a maximum in the creep resistance was observed at 400°F. After cold working 40% and recovery for 100 hours at temperatures up to 750°F, creep behavior at room temperature was determined. Here again a maximum in the creep resistance was found for a recovery temperature of 400°F. Creep tests at both 210°F and 400°F on material cold worked 40%, with and without a recovery treatment for 100 hours at 550°F, indicate a higher creep resistance for the recovered material. These observations, coupled with results of tensile tests from 750°F to 1000°F, suggest a strain aging process is operative. The presence of this relatively complex phenomenon introduces more complexity in the data.

In studying the creep behavior of ferro-chrome alloyed titanium sheet (Ti-150), the effect of prior heat treatment is the main variable since this material is too difficult to cold work. The strengthening effect of water quenching from 1500°F is very marked. At 76°F, the practical upper stress limit is between 112,000 and 115,000 psi and the creep rate is only a tenth of that for a similar stress on air cooled material. As observed in the commercially pure titanium (Ti-75), the creep resistance of the alloyed material at 400°F is greater than at 210°F, indicating some sort of strain aging process.

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TITLE: Preferred Orientation in Titanium
TASK NO.: 463-6-7 PRIORITY: 2 EST. COMPLETION: March 1953
SECURITY: Unclassified RESPONSIBLE METALLURGIST: E.J. Hassell EXT: 26230
PRIME CONTRACTOR: University of Kentucky
PURPOSE: The purpose of this task is to provide important information on the mechanical working characteristics of titanium.

TO DATE: It has been found that iodide titanium sheet, cold rolled 97%, showed that the (1010) crystallographic direction was parallel to the rolling direction. Recrystallization at 1500°F after cold rolling, results in a 30° rotation of the crystal axis, bringing the (1120) direction parallel to the rolling direction. This rotation is similar to the behavior observed by others in zirconium.

In order to determine the effect of the preferred orientations on mechanical properties of sponge titanium, bend tests were made on sheet specimens after varying amounts of hot and cold work. Since the degree of preferredness is greater near the surface, successive layers were removed by etching and the test carried out after each removal. In every case, the capacity for bending was greater

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in the direction of rolling than across the rolling direction. Also, the capacity for bending increased as the more highly preferred oriented material was removed from the surface.

TITLE: Effect of Heat Treatment on the Structure of Commercial Titanium and its Alloys
TASK NO.: 463-6-6 PRIORITY: 2 EST. COMPLETION: November 1953
SECURITY: Unclassified RESPONSIBLE METALLURGIST: E.J. Hassell EXT.: 26230
PRIME CONTRACTOR: Armour Research Foundation
PURPOSE: The purpose of this task is to study the micro-structural characteristics of titanium and its alloys in order to obtain a full understanding of the structural changes occurring during various heat treatments.

TO DATE: The heat treatment and mechanical testing of tensile test pieces for a wide range of time and temperature combinations is completed for titanium alloys containing 3, 7, and 11% Molybdenum. Test pieces are in preparation for impact studies. The time - temperature - transformation relationships are being worked out for Ti-Mo alloys with intentional oxygen additions.

TITLE: Energy Studies of Solid Solutions of Magnesium Alloys
TASK NO.: 463-6-8 PRIORITY: 2 EST. COMPLETION: December 1953
SECURITY: Unclassified RESPONSIBLE METALLURGIST: Maj A. Marston EXT: 26230
PRIME CONTRACTOR: Dow Chemical Company
PURPOSE: The purpose of this task is to expedite the development of superior magnesium alloys by reducing the effort required to explore potentially good compositions.

TO DATE: Progress on the four (4) phases is as follows:

(1) Energy Studies - Effort on this phase has been cut in half because experimental difficulties are preventing rapid progress. Efforts are now concentrated on the use of a dropping calorimeter for determining the heat contents at elevated temperatures of magnesium-cadmium alloys so that recently published heat of formation data for this system can be used to construct a free energy-temperature-composition diagram for the system. When this is completed, consideration will be given to renewing the work on electro-potential measurements. While

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efforts to accurately measure free energy changes in magnesium alloys have not yet been successful, the great potential value of such measurements justifies continuing these attempts.

(2) Alloy Development Phase - The work contemplated in this phase has been completed. The 3% thorium, 1% zirconium alloy has been shown to have the best creep resistance in the maximum temperature range (to 600 F). However, other ~~magnesium-rare earth alloys~~ have been developed which have the optimum combination of properties when the maximum service temperature is lower. The Allison Division of General Motors Corporation has been furnished several diffuser castings of the thorium alloy for evaluation in the YT-40-A-6A Jet Engine in an application where the temperatures are high enough to cause warping of the presently used alloys.

(3) Theoretical Study of Effect of Rare Earth Additions - Creep testing at various temperatures has been completed on cell magnesium and is underway on a 1.2% cerium alloy. The dependence of creep rate on stress at varying temperatures has been studied. Results indicate that at high temperatures or low stress, deformation tends to occur by grain boundary flow, while at low temperatures or high stress, deformation tends to be by slip within the grains. Microstructural and microhardness studies will be included in future work.

(4) Protective Coatings and Films - After completing a thorough literature survey, the physical chemist has started experimental work. He has developed a very neat method of stripping corrosion films from magnesium alloys, using a Grignard reaction in diethyl ether to dissolve the metal away from the surface film. The following properties of these films will now be studied: 1. electrical resistance; 2. electrical capacitance; 3. rate of osmosis through the film; 4. rate of electro-osmosis through the film.

This contract has been extended for another year at the same rate of effort on phases three and four and at a reduced rate of effort on phase one.

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<u>TITLE:</u>	Electron Microscopy of Bainitic Structures
<u>TASK NO.:</u>	463-6-9 <u>PRIORITY:</u> 2 <u>EST. COMPLETION:</u> January 1953
<u>SECURITY:</u>	Unclassified <u>RESPONSIBLE METALLURGIST:</u> Lt V.D. Smith <u>EXT:</u> 26230
<u>PRIME CONTRACTOR:</u>	Stevens Institute of Technology
<u>PURPOSE:</u>	The purpose of this task is to produce Electron Micrographs showing detailed micro structures of bainitic steels which can be used in correlating these microstructures with the physical properties of the steels.

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TO DATE: Work to date has been largely directed toward the development of electron-microscopy techniques necessary for the examination of a series of heat-treated steels being studied in cooperation with Carnegie Institute of Technology. The polystyrene-silica or two-step positive replica technique has been found to give excellent replication of the surfaces of the steel specimens. The method has been standardized and the reproducibility is good. A problem was encountered in etching the specimens which necessitated a thorough study of the effect of etching time. Various combinations of electrolytic and acid etching cycles are also being investigated.

Interpretation of the electron microscope structures will not be complete until more work is done. Certain evidence from the present studies does, however, point to the fact that bainitic areas in steel structures can be examined by the electron microscope with far greater resolution than by the light microscope.

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TITLE: Determination of Residual Stresses
TASK NO.: 463-6-10 PRIORITY: 2 EST. COMPLETION: July 1953
SECURITY: Unclassified RESPONSIBLE METALLURGIST: Maj A. Marston EXT: 26230
PRIME CONTRACTOR: Lessells and Associates, Inc.
PURPOSE: The purpose of this task is to determine a residual stress pattern in a large landing gear strut, and to develop a more economical method, preferably non-destructive, for measuring of residual stresses in quenched and tempered steels.

TO DATE: A contract was negotiated in June 1952 for the work indicated above.

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TITLE: Mechanical Properties of a Titanium-based Alloy Containing 36% Aluminum
TASK NO.: 463-6-11 PRIORITY: 2 EST. COMPLETION: 1954
SECURITY: Unclassified RESPONSIBLE METALLURGIST: E.J. Hassell EXT: 26230
PRIME CONTRACTOR: Armour Research Foundation
PURPOSE: The purpose of this task is to investigate the mechanical properties and fabrication qualities of a titanium alloy containing approximately 36% aluminum, and to determine the best methods of alloy preparation and heat treatment for optimum forging characteristics.

TO DATE: A contract for this research project has been negotiated with Armour Research Foundation.

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TITLE: Martensite Type Reactions in Metals
TASK NO.: 463-6-12 PRIORITY: 2 EST. COMPLETION: December 1952
SECURITY: Unclassified RESPONSIBLE METALLURGIST: Lt V.D. Smith EXT: 26230
PRIME CONTRACTOR: Carnegie Institute of Technology
PURPOSE: The purpose of this task is to obtain fundamental information concerning phenomena of very short duration in metals.

TO DATE: The formation of both athermal and isothermal martensite in an Fe - Ni alloy with 30% Ni has been studied. The time of formation of both the athermal and isothermal martensite is of the order of 10^{-7} seconds. The temperature range investigated for the athermal transformation was -30° to -100° which is the Ms range of the alloy. The isothermal experiments were carried out at -60° , -95° , -105° , and at -195°C and they all gave the same result. This is in excellent agreement with the "Reaction-Path" theory of Cohen and Nashlin and appears to negate all nucleation and growth theories of the martensite transformation.

It appears that each unit signal corresponds to a unit transformation. However, a further check on this will be made by fitting a low temperature microscope stage into the system which will enable simultaneous recording of both the oscilloscope, and the sample placed in the microscope field. The strength and duration of the martensite signal varies directly with the size of the martensite plate formed.

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TITLE: Research on Flash Sintering
TASK NO.: 463-7-1 PRIORITY: 2 EST. COMPLETION: November 1952
SECURITY: Unclassified RESPONSIBLE CERAMIST: M.A. Schwartz EXT: 26230
PRIME CONTRACTOR: Metallurgical Research and Development Company
PURPOSE: The purpose of this task is to study the variables concerned with the flash sintering method of fabricating high strength structural materials for use at elevated temperatures.

TO DATE: Improved reproducibility of test results was accomplished by the application of higher pressures during the flash sintering operation. This was accomplished by first presintering compacts at higher temperatures than heretofore employed. Some tests were also conducted using 70% TiC-30% Ni mixture prepared by Kennametal, Inc. with improved strength properties resulting.

In regard to the die liner problem which is the critical factor at this time, a large number of ceramic manufacturers have been contacted, and test liners are being received from them and being evaluated.

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TITLE: Research on the Protection of Molybdenum
TASK NO.: 463-7-2 **PRIORITY:** 2 **EST. COMPLETION:** March 1953
SECURITY: Unclassified **RESPONSIBLE METALLURGIST:** Lt G.E. Johnson **EXT:** 26230
PRIME CONTRACTOR: Climax Molybdenum Company
PURPOSE: The purpose of this task is to develop a suitable protective coating for molybdenum in order to prevent or minimize its susceptibility to oxidation at elevated temperatures.

TO DATE: A summary report of the first year's progress has been received. Five different sprayed metal coatings were developed which successfully protected molybdenum from oxidation in air at 1700°F. for 500 hours. The coatings display good resistance to thermal shock and considerable ductility at 1700°F. Oxidation tests at 2400°F of as-sprayed specimens (no diffusion treatment) indicate this type of protection is adequate for extreme temperature, short life requirements.

Twenty-four (24) stress rupture specimens of sheet molybdenum, coated with the more promising compositions were obtained for evaluation at WADC. The coatings are in three layers, the first and third layers being an Al-12% Si alloy and the intermediate layer either a Cr-Mo-Si alloy or a Cr-Si alloy. Tests are now underway.

Future work will be in two phases. The first consists of an intensive testing and evaluation program for coatings developed by either the contractor or by other laboratories. The second phase involves continuation of research on new coatings and methods of application.

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TITLE: Research on Ternary Systems of Metal Ceramic Bodies
TASK NO.: 463-7-4 **PRIORITY:** 2 **EST. COMPLETION:** July 1952
SECURITY: Unclassified **RESPONSIBLE CERAMIST:** M.A. Schwartz **EXT:** 26230
PRIME CONTRACTOR: Rutgers University
PURPOSE: The purpose of this task is to obtain fundamental knowledge on titanium nitride metal bodies which will facilitate the development of improved materials for use at elevated temperatures.

TO DATE: Combinations of TiN with additions of Mo, Co, Cr, Ni-Cr, and Co-Cr were investigated as to strength and oxidation resistance. The Cr cermet exhibited good oxidation resistance having moderate strength and no loss of strength after firing and the weight gain on oxidation, but improved the strength after oxidation. Thermal shock resistance tests will be conducted in the near future.

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TITLE: Molybdenum Base Alloys Prepared by Powder Metallurgy Techniques
TASK NO.: 463-7-5 PRIORITY: 2 EST. COMPLETION: June 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Lt G.E. Johnson EXT: 26230
PRIME CONTRACTOR: Battelle Memorial Institute
PURPOSE: The purpose of this task is to prepare molybdenum base alloys by powder metallurgy techniques and evaluate the properties of the alloys.

TO DATE: Present work is concerned with the fabrication and evaluation of binary molybdenum alloys containing S, P, Sn, In, Ti, Zr, Nb, and Ta. Phosphorus in small quantities is an effective strengthener, 0.02% increasing the tensile strength of molybdenum 15,000 psi without reducing the elongation values. Sulfur is not harmful up to 0.1%. More binary alloys are being prepared for study of the effect of fabrication procedure on recrystallization. Metallographic examination of other specimens show partial recrystallization as a result of the 1250°-1100°C fabrication. Creep-rupture tests in vacuum on bare molybdenum alloys indicate that the nickel cladding technique, previously used for oxidation protection, contributed significantly to the strength values obtained.

Two papers are being prepared for publication: "Properties of Wrought Hydrogen-Sintered Molybdenum Alloys" and "Recrystallization of Wrought Hydrogen-Sintered Molybdenum Alloys".

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TITLE: Mechanical Properties of Oxide Single Crystals
TASK NO.: 463-7-6 PRIORITY: 2 EST. COMPLETION: November 1952
SECURITY: Unclassified RESPONSIBLE CERAMIST: M.A. Schwartz EXT: 26230
PRIME CONTRACTOR: National Bureau of Standards
PURPOSE: The purpose of this task is to determine the plastic deformation (stress-strain relations) and related mechanical and optical properties of ceramic oxide single crystals and the comparison of these properties with the properties of polycrystalline specimens for the purpose of changing the undesirable property of brittleness at high temperatures in ceramic bodies by increasing the grain size.

TO DATE: Sapphire rods, rutile boules, quartz crystals, and periclase crystals were procured for producing test specimens. An elevated temperature bending test furnace and rig were completed and placed in operation. However, test results indicated too large a spread of values and further refinements are being made. Tensile test grips for the creep furnace were completed and consist of stainless steel ball-and-socket joints and a split sleeve. Preliminary high temperature creep tests were conducted in which a sapphire rod was successfully held at a stress of 1.09×10^3 kg/cm² for one hour at 1200°C.

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TITLE: Diffusion Studies in Cermets Using Tracer Techniques
TASK NO.: 463-7-7 PRIORITY: 2 EST. COMPLETION: February 1953
SECURITY: Unclassified RESPONSIBLE CERAMIST: M.A. Schwartz EXT: 26230
PRIME CONTRACTOR: Alfred University
PURPOSE: The purpose of this task is two-fold; one, to determine the nature of and the rates of the diffusion of iron, cobalt and nickel into titanium carbide bodies; and, two, to study the reactions of metals and alloys with silicon carbide bodies in order to develop new cermets.

TO DATE: Phase A: Preliminary work was reported on a metallographic study of reactions between TiC and various metals. Samples of nickel and cobalt plated TiC, heated at 1000°C and 1150°C for varying times up to 9 days are being evaluated. Cobalt samples fired at 1150°C developed a pitted surface under the plating as compared to samples fired at 1000°C (24 hours) which had no indication of reaction.

Phase B: Thermodynamic data from the literature on SiC-metal systems has been compiled and evaluated. Wetting tests conducted by measuring the contact angles between molten Co, Ni, Cr, and Fe on dense SiC slabs have indicated the superior wetting characteristics of the Cr over the other three metals. A technique for hot pressing SiC crucibles by employing selective grain sizes has been successfully developed. Using these crucibles, Co, Cr, Ni, and Fe are melted and studies are being made of the bonding zones. X-ray analysis of the Ni-SiC system identified nickel silicides as reaction products.

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TITLE: Research on Ceramic Structures
TASK NO.: 463-7-8 PRIORITY: 2 EST. COMPLETION: December 1952
SECURITY: Unclassified RESPONSIBLE CERAMIST: M.A. Schwartz EXT: 26230
PRIME CONTRACTOR: University of California
PURPOSE: The purpose of this task is to explore the potential of using ceramic materials for structural components by prestressing them in compression using metal tension elements.

TO DATE: Work started 1 May 1952 on this contract and no progress has yet been reported.

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TITLE: Compressor Blade Alloy Research
TASK NO.: 463-7-9 PRIORITY: 2A EST. COMPLETION: February 1953
SECURITY: Unclassified RESPONSIBLE METALLURGIST: Lt G.E. Johnson EXT: 26230
PRIME CONTRACTOR: University of Minnesota

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Project No. 463-7-9 (Cont)

PURPOSE: The purpose of this task is to develop an improved compressor blade alloy of non-critical materials by powder metallurgy methods.

TO DATE: Over fifty ferrous matrix alloys have been made with additions of C, Mo, Ti, Ni, Cu, and Zn. Tensile strengths of over 100,000 psi in the as-sintered condition have been obtained. Alloy infiltration has increased the tensile strength of some of these alloys to over 150,000 psi.

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TITLE: Development of Chromium-Base Heat-Resistant High Temperature Materials

TASK NO.: 463-7-10 **PRIORITY:** 2 **EST. COMPLETION:** September 1953

SECURITY: Unclassified **RESPONSIBLE METALLURGIST:** Lt V.D. Smith **EXT:** 26230

PRIME CONTRACTOR: Battelle Memorial Institute

PURPOSE: The purpose of this task is to investigate the first phase of a program of research leading to the development of chromium base heat resistant alloys. The initial program is aimed at solving the problem of brittleness in chromium at room temperatures.

TO DATE: The contract was negotiated in March 1952 for the research indicated above.

Some of the equipment required for the very high purity chromium is already available, but additional equipment and modifications in existing equipment will be required to attain the desired degree of purity. It is anticipated that the preparation of the metal will be started the latter part of July.

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TITLE: Investigation of Rhenium

TASK NO.: 463-7-11 **PRIORITY:** 2 **EST. COMPLETION:** April 1954

SECURITY: Restricted **RESPONSIBLE METALLURGIST:** Maj A. Marston **EXT:** 26230

PRIME CONTRACTOR: Battelle Memorial Institute

PURPOSE: The purpose of this task is to determine in which of the several potential fields of application our limited resources of rhenium can most effectively be utilized.

TO DATE: A contract was negotiated in April 1952 for the research indicated above.

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TITLE: Evaluation of New High Temperature Materials
TASK NO.: 463-7-12 PRIORITY: 2 EST. COMPLETION: May 1953
SECURITY: Unclassified RESPONSIBLE CERAMIST: M.A. Schwartz EXT: 26230
PRIME CONTRACTOR: American Electro-Metal Corporation
PURPOSE: The purpose of this task is to survey and evaluate the lesser known intermetallic and metalloid materials for possible use in cermets for aircraft components requiring high temperature stability, oxidation resistance, thermal shock resistance and strength. This program will be of a broad enough nature so that it will be concluded in a series of recommendations based on laboratory results for intensive research on specific materials or classes of materials that might meet requirements for aircraft high temperature components.

TO DATE: A contract was negotiated in May 1952.

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TITLE: Vibratory Compacting of Metal and Ceramic Powders
TASK NO.: 463-7-13 PRIORITY: 2 EST. COMPLETION: May 1953
SECURITY: Unclassified RESPONSIBLE CERAMIST: M.A. Schwartz EXT: 26230
PRIME CONTRACTOR: North Carolina State College
PURPOSE: The purpose of this task is to investigate the variables concerned with vibratory compacting of metal and ceramic powders to form bodies of high density and close tolerances.

TO DATE: A contract was negotiated in April 1952, for this research. No progress has yet been reported.

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TITLE: Application of Fundamental Concepts of Bonding Metals and Ceramics
TASK NO.: 463-7-14 PRIORITY: 2 EST. COMPLETION: May 1953
SECURITY: Unclassified RESPONSIBLE CERAMIST: M.A. Schwartz EXT: 26230
PRIME CONTRACTOR: Armour Research Foundation
PURPOSE: The purpose of this task is to apply fundamental concepts of ionic and atomic structures to the development of cermet

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Project No. 463-7-14 (Cont)

materials which could be used to produce components for turbo-jet power plants.

TO DATE: A contract has been negotiated in April 1952 for this research. No progress has yet been reported.

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TITLE: An Investigation of Boron Steels
TASK NO.: 463-8-1 PRIORITY: 1A EST. COMPLETION: October 1952
SECURITY: Unclassified RESPONSIBLE METALLURGIST: Maj A. Marston EXT: 26230
PRIME CONTRACTOR: United States Steel Company
PURPOSE: The purpose of this task is to develop a boron steel which can be substituted for the standard 4340 aircraft steel.

TO DATE: A second heat of steel (65 tons) has been melted after the first heat proved unsatisfactory on etch tests. The second heat is clean and has very high hardenability, but is high (slightly above the specified content) in carbon and silicon. However, it can be used, and since two other projects have been waiting to evaluate this steel, the heat has been accepted. Some delay was caused by the Government inspectors requirement for a contract change before approving the actual composition of this experimental heat, but this has now been accomplished.

The amounts required for Projects R-463-8-2 and R-463-8-3 have been shipped and received, so that these evaluations are underway. Arrangements have also been made to furnish steel from this heat to a considerable number of other aircraft manufacturers and suppliers who wish to test this steel. The excess steel not required for this program will later be released for sale to other commercial users.

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TITLE: Metallurgical Evaluation of 43B40 (Boron-treated) Steel
TASK NO.: 463-8-2 PRIORITY: 1A EST. COMPLETION: October 1952
SECURITY: Unclassified RESPONSIBLE METALLURGIST: Maj A. Marston EXT: 26230
PRIME CONTRACTOR: Armour Research Foundation
PURPOSE: The purpose of this task is to make a thorough metallurgical evaluation of the boronized steel developed to replace 4340 so that the information may be provided for the potential users in the aircraft industry.

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Project No. 463-8-2 (Cont)

TO DATE: Six by six inch billets of both standard 4340 steel and the experimental 98B40 modified steel have finally been received and are undergoing heat treatment together. They will be compared at equivalent hardnesses to evaluate the new steel as a substitute material. The machining operations at the high hardness levels are expected to be very difficult, but the present interest in using steels at higher strength levels makes this information important.

TITLE: Evaluation of the Use of Boron Treated Steel in the J47 Engine
TASK NO.: 463-8-3 PRIORITY: 1A EST. COMPLETION: May 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Maj A. Marston EXT: 26230
PRIME CONTRACTOR: General Electric Company
PURPOSE: The purpose of this task is to evaluate the use of boronized alloy steel (developed to replace SAE 4340 steel) by actual application to aircraft engine parts now made of 4340 steel.

TO DATE: The steel for this project has now been received by the contractor and fabrication studies have started. Since the receipt of the steel involved much more delay than was anticipated when this contract was negotiated, a 'no cost' extension has been given to allow the contractor time to properly evaluate the material. This will involve not only fabricating turbine wheels and shafts, but also scheduling the wheels into current engine testing programs.

TITLE: Metallurgy of Boron in Iron and Steel
TASK NO.: 463-8-4 PRIORITY: 2 EST. COMPLETION: December 1952
SECURITY: Unclassified RESPONSIBLE METALLURGIST: Maj A. Marston EXT: 26230
PRIME CONTRACTOR: Ohio State University
PURPOSE: The purpose of this task is to determine the mechanism of the boron effect in steel and the factors which govern effective amounts of boron.

TO DATE: A thorough review of the literature on the chemistry and metallurgy of boron along with a critical analysis of the boron hardenability effect. A hypothesis for the mechanism of the boron hardenability effect was formulated. The results of this work have been written as a Technical Report, which should be received from the contractor shortly.

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Project No. 463-8-4 (Cont)

Experimental work has started on two phases of the research:
(a) the determination of the solubility and activity of boron in gamma iron, and
(b) the determination of the effect of boron on the interfacial tension between alpha and gamma iron in commercial steels.

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TITLE: Influence of Boron on the Hardenability of Steel
TASK NO.: 463-8-5 PRIORITY: 2 EST. COMPLETION: December 1953
SECURITY: Unclassified RESPONSIBLE METALLURGIST: Maj A. Marston EXT: 26230
PRIME CONTRACTOR: University of Chicago
PURPOSE: The purpose of this task is to provide the basic research necessary to understand the role of boron in steel.

TO DATE: The work is continuing on calculating interfacial energies from measurements of grain boundary angles in pure iron-carbon-boron alloys. Internal friction measurements are being used to determine whether boron is in interstitial or substitutional solid solution. Studies are continuing on measuring diffusion rates of boron in iron. The effects of both boron and nitrogen on the decomposition of austenite in pure iron-carbon-boron alloys is also being studied.

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TITLE: Study of the Mechanisms of the Boron Effect in Steel
TASK NO.: 463-8-6 PRIORITY: 2 EST. COMPLETION: February 1953
SECURITY: Unclassified RESPONSIBLE METALLURGIST: Maj A. Marston EXT: 26230
PRIME CONTRACTOR: Battelle Memorial Institute
PURPOSE: The purpose of this task is to evaluate the boron effect in steel, with particular emphasis to establish composition-hardenability relationships for boron. Such relationships are mandatory for the rapid, efficient development of boron-containing alloy steels.

TO DATE: A literature survey has been completed on the effect of boron on heat treatment of commercial types of steel. Experimental work has started in the effects of boron on rates of nucleation and growth of pearlite from austenite in commercial steels. Two, 200 pound, induction-melted heats of steel have been made, one with and one without .003% boron. End-quench hardenability curves have been prepared for the two ingots and the microstructures at various points on the Jominy bar has been studied to compare the different structures obtained. The necessary equipment has been assembled and wire has been drawn from both steels for use in isothermal transformation studies.

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TITLE: Effect of Boron and Titanium on the Mechanical Properties of High Temperature Austenitic Alloys
TASK NO.: 463-8-8 PRIORITY: 2 EST. COMPLETION DATE: December 1953
SECURITY: Unclassified RESPONSIBLE METALLURGIST: Maj A. Marston EXT: 26230
PRIME CONTRACTOR: University of Michigan
PURPOSE: The purpose of this project is to investigate the effect of boron and titanium additions in increasing the stress rupture properties of certain austenitic alloys used at high temperatures, and to evaluate a heat of this type of steel which will be produced on Project No. 463-8-9 by obtaining design data type creep curves on it.

TO DATE: A contract was negotiated in May 1952 on this project.

TITLE: Development and Experimental Production of an Improved Austenitic Alloy for High Temperature Service
TASK NO.: 463-8-9 PRIORITY: 2 EST. COMPLETION: July 1954
SECURITY: Unclassified RESPONSIBLE METALLURGIST: Maj A. Marston EXT: 26230
PRIME CONTRACTOR: Republic Steel Corporation and Allegheny Ludlum Steel Corp.
PURPOSE: The purpose of this project is to improve the properties of an iron base austenitic alloy containing approximately thirty percent alloy content to the point where it can be substituted for the presently used fifty percent alloy steels for use in turbine wheels and similar applications involving temperatures around 1250°F. This will conserve nickel, chromium, and molybdenum which are critical materials.

TO DATE: A contract has been negotiated with one major steel company and a contract is under negotiation with another. Both contractors will melt a considerable number of small laboratory heats of this alloy, varying the minor additions such as boron and titanium, then larger heats of the best compositions, and finally at least one of them will make a heat large enough to provide material for evaluation on a current jet engine.

TITLE: Evaluation of an Austenitic Alloy in Jet Engines
TASK NO.: 463-8-10 PRIORITY: 2 EST. COMPLETION: December 1953
SECURITY: Unclassified RESPONSIBLE METALLURGIST: Maj A. Marston EXT: 26230
PRIME CONTRACTOR: Not Available.
PURPOSE: The purpose of this project is to evaluate the improved austenitic alloy developed on Project 463-8-9 for use in jet engines.

TO DATE: Negotiation of a contract for this project has been delayed by difficulty in arriving at a contract satisfactory to both the potential contractor and the procurement authorities.

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CHEMISTRY RESEARCH BRANCH

The Chemistry Research Branch formulates and directs a program of applied research in the field of chemistry. A continuous survey of research requirements of WADC concludes that the following general areas of research should be emphasized:

- (1) Reactions and properties of matter at elevated temperatures
- (2) Lubricants and lubrication, particularly at extreme temperatures
- (3) Plastics and elastomers of unusual properties
- (4) Propellants and fuels
- (5) Mechanisms and prevention of deterioration or corrosion
- (6) Chemistry of photography, ranging from improvements in developers to basically new photographic processes
- (7) Inorganic micromolecules, especially for lubricant or plastic use
- (8) Explosives, including chemistry of explosions

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CHEMISTRY BRANCH, FLIGHT RESEARCH LABORATORY

The Flight Research Laboratory has, during the past several months, established a small, but first-rate laboratory for research in chemistry. While still only partially equipped, the chemistry laboratory has reached a stage where the supply and facilities problems are no longer the major time consumers.

The Chemistry Research Branch has been called on formally and informally, from time to time, by other WADC organizations for consultation and advice on chemical subjects. It is anticipated that this service will become increasingly valuable to other Air Force agencies as additional personnel in fields other than chemistry, have occasion to seek chemical information from this Branch.

Emphasis at present is being placed upon research in three general areas basic to Air Force technical progress:

1. Kinetics of flame reactions and mechanisms of energy transfer between molecules. Such information should lead to better understanding of processes taking place in Air Force Power Plants, through the use of improved fuels, homogeneous catalysts, and additives to fuels.
2. New substances of high thermal stability, including polymers, lubricants, heat exchange media, and other fluids. The approach is through the synthesis of entirely new systems of compounds from chemical constituent groups of known stability.
3. Mechanisms of deterioration of materials. A major cause of failure of Air Force material is deterioration, as in corrosion of metals, oxidation of fuels and lubricants, and degradation of cotton and other textiles. Investigations are in progress with the aim of (1) devising suitable analytical methods for evaluating causes of deterioration, (2) measuring rates of corrosion for mechanism studies, and (3) developing preventives of deterioration.

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TITLE: Polarographic Determination of the Diffusion Current Constants in Various Supporting Electrolytes at 25°C.
TASK NO.: 464-1-3 **PRIORITY:** 2A **EST. COMPLETION:** July 1953
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** Lt St. George **EXT:** 26230
PRIME CONTRACTOR: Armour Research Foundation
PURPOSE: The purpose of this task is to measure diffusion current constants which are characteristic of particular metal ions in order to permit easy and rapid analytical methods for analysis of metal alloys.

TO DATE: The final report on this project arrived in complete. Dr. Carrigan and Mr. Kre of Armour Research Foundation visited our office on 25 July and now fully understand the discrepancies, and will forward an addendum to the final report to include the information the contract calls for. The contract is to be closed out in the near future.

TITLE: Chemistry of Niobium (Columbium) and its Compounds
TASK NO.: 464-1-6 **PRIORITY:** 2 **EST. COMPLETION:** July 1953
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** None **EXT.:** 33227
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this task is to study chemical reactions undergone by niobium compounds especially with a view to improving the separation from tantalum to obtain the pure element.

TO DATE: This project has been temporarily delayed due to reassignment of original investigator.

TITLE: Interferometric Measurement of Incipient Corrosion on Thin Metal Films
TASK NO.: 464-1-7 **PRIORITY:** 2 **EST. COMPLETION:** July 1953
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** I. Lubing **EXT.:** 33227
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this task is to elucidate mechanisms of corrosion and passivity to chemical attack through measurement of rates of growth of corrosion films in the early stages.

TO DATE: Initial experiments have been conducted with the deposition of thin metal films by evaporation. The technique of preparing specimens to yield interference has not yet been satisfactorily mastered, but progress is being made.

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TITLE: Fundamentals of Adhesion
TASK NO.: 464-2-2 PRIORITY: 2 EST COMPLETION: July 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Lt Col Caylak KAT: 22154
PRIME CONTRACTOR: Case Institute of Technology
PURPOSE: The purpose of this task is to supply fundamental information regarding adhesion.

TO DATE: The contractor has made a literature search in adhesion. He has gathered material for a monograph on "The Fundamentals of Adhesion". The contractor held a symposium on adhesion in April. The papers of this symposium are being edited for publication. At present, the contractor is planning to investigate the fundamentals of adhesion by two (2) methods, i.e., loss factor and tensile test method. The investigators hope to determine from the dielectric loss factor the range of the forces involved in adhesion. It is hoped that from this data and the tensile test method data a correlation may be obtained which would give a better understanding of the factors involved in adhesion.

TITLE: Characterization of C₂₁-C₃₀ Hydrocarbons and Their Mixture
TASK NO.: 464-2-3 PRIORITY: 2 EST. COMPLETION: February 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Lt F. Hanks KAT: 33227
PRIME CONTRACTOR: Armour Research Foundation
PURPOSE: The purpose of this task is to study the members of the homologous series C₂₁-C₃₀ crystallographically, determine representative phase diagrams, and study the effect of pour point depressants on representative mixtures of the compounds.

TO DATE: Micro melting points of the ten pure compounds have been taken on the standard Kofler hot stage. An attempt has been made to determine the purity of each of the series of hydrocarbons so as to assure the accuracy of these melting points and subsequently determined phase diagrams. Preliminary eutectic temperatures have been determined on the Kofler hot stage for several binary and ternary systems. Because of the closeness of the refractive indices of the melt and solid components in these systems, a new hot stage incorporating phase microscope accessories has been built and is being tested. This contrast increasing device will also facilitate study of polymorphous forms which have been detected and transition temperature determined in the C₂₁ and C₃₀ hydrocarbons.

Crystallographic studies have been completed for heneicosane,

C₂₁H₄₄.

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TITLE: Thermal Conductivity of Hydrogen Fluoride Gas
TASK NO.: 464-2-4 **PRIORITY:** 2 **EST. COMPLETION:** July 1953
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** Lt F. Hawkes **EXT:** 33227
PRIME CONTRACTOR: Monsanto. Work being accomplished at WADC.
PURPOSE: The physico-chemical factors in the transfer of energy between gas molecules and solids are of interest in problems of heating and cooling in Air Force systems, especially at ultra high altitudes where the low gas density and high velocities give rise to special difficulties. This project is for the purpose of measuring the energy transfer parameters at high temperatures and low pressures for various gases, including hydrogen, nitrogen, oxygen, water vapor, and hydrogen fluoride.

TO DATE: The apparatus to make the desired measurements has been designed in terms of a pre-determined system of data collection. The glass vacuum rack for purification and delivery of desired pressures of gases to the hot wire apparatus has been completed. The measuring circuits for the hot wire apparatus wire temperature, gas pressure, and energy loss from wire - are partially completed and await the arrival of a Mueller type bridge and resistance thermometer which is to be the temperature standard for the experiment. The hot wire apparatus itself awaits the installation of thermocouples to be calibrated against the above temperature standard. A furnace for the calibration of the necessary thermocouples has been completed.

TITLE: Separation and Determination of Silicon, Tungsten, Titanium, Tantalum, and Columbium in Mixtures
TASK NO.: 464-3-1 **PRIORITY:** 2 **EST. COMPLETION:** October 1952
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** R.W. Mosher **EXT:** 33227
PRIME CONTRACTOR: Armour Research Foundation
PURPOSE: The purpose of this task is to facilitate the analysis of high temperature alloys which are used in connection with jet and rocket engines.

TO DATE: A literature survey was completed showing the status of the analytical chemistry of these materials. Two satisfactory methods have been worked out for the determination of silicon in varied synthetic mixtures of the oxides of silicon, titanium, tungsten, niobium and tantalum. Their relative merits were discussed. The ultimate proof of the method on Air Force material has not been tested.

Separation of the metals titanium, niobium and tantalum with use of ion exchange resins was tested. The preliminary data indicate that the method shows promise and that a systematic study will reveal the merits of the

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Project No. 464-3-1 (Cont)

method.

A study of organic precipitating agents has revealed one which shows good promise for the separation of titanium, niobium and tantalum one from one another. A detailed study should result in a useful analytical method.

TITLE: Investigation of Functions of Additives in Electroplating Baths and Development of a Theoretical Approach for Selection of Additives
TASK NO.: 464-3-2 PRIORITY: 2 EST. COMPLETION: July 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: I. Lubing EXT: 33227
PRIME CONTRACTOR: Kenyon College
PURPOSE: The purpose of this task is to improve the electroplating of aircraft components.

TO DATE: For accurate control of all the parameters of plating and the measurement of the quality of the plate, the design and construction of special equipment was necessary. Now completed are the following items: (1) Electrolytic cell assembly, (2) Special constant temperature water bath, (3) Nearly complete are the Water still, Photomicrograph and Brightness of deposit reflectance meter.

Certain plating solution chemical additives have been ordered, and the availability of other additives is being determined.

TITLE: Weathering Cellulosic Materials
TASK NO.: 464-3-4 PRIORITY: 2 EST. COMPLETION: November 1952
SECURITY: Unclassified RESPONSIBLE SCIENTIST: S. Baldwin EXT: 33227
PRIME CONTRACTOR: University of Texas
PURPOSE: The purpose of this task is to study the deterioration of cellulose induced by ultraviolet light and fungi.

TO DATE: The major difficulty in a study of the decomposition of cellulose by fungal attack is that of effecting a separation of the degraded cellulose from the attacking microorganisms. The rootlike filaments of the fungal

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growth (the mycelia) is certain to be trapped in the cellulose strands rendering a satisfactory direct mechanical separation impossible. However, a satisfactory separation of cellulose from mycelial fragments has now been effected by chemical fractionation. The procedure involves acetylating the cellulose sample to the triacetate, dispersing this acetate in organic solvent, and then regenerating it via careful saponification. The cellulose is believed to be unmodified chemically by this treatment. The separated mycelial fragments, which are largely protein in nature, contain no cellulosic material and, in turn, none of these fragments or their derivatives is carried over into the regenerated cellulose sample.

Quantitative determination of the reactive carbonyl groups in cellulose molecules is of major importance in connection with the study of the deterioration of cellulose both by microorganisms and by sun light (ultraviolet radiation). Their formation during fungal attack would indicate a hydrolytic type of deterioration and it is highly probable that they are also involved in photolysis. Attention has been given to the problem of ascertaining whether the Kiliani reaction (addition of hydrocyanic acid to a carbonyl group) is indeed applicable to cellulose for the quantitative determination of carbonyl groups. (Frampton, et. al., Anal. Chem., 23, 1244 (1951)). As the matter now stands, only the minimum number of carbonyl groups per unit weight of cellulose may be determined with certainty. The quantitative aspects of the Kiliani reaction as applied to cellulose might be established if the reaction were carried out in a homogeneous medium. The first step is that of establishing the conditions for the quantitative addition of hydrocyanic acid to the simple sugar derivatives in organic solvents. Accordingly, 2, 3, 4, 6-tetra-acetyl-glucose, and the corresponding acetyl derivatives of lactose and cellobiose have been prepared. Cellotriase and cellotetrase have been obtained from cellulose hydrolysates and these will be acetylated in the same manner. Studies involving the addition of hydrocyanic acid to these sugar derivatives are currently underway.

Many of the substances involved in this study are expensive in terms of time and effort spent in securing them. Methods of analysis used must involve a minimum expenditure of materials. In many instances, e.g., in identifying hydrolytic products from cellulose, etc., it is impossible to use melting point data. Consequently, it would be useful to have available a precise method for the determination of molecular weights where the material studied may be recovered. Accordingly, an apparatus and procedure have been developed for the determination of molecular weights. This data will be used in conjunction with elementary analysis of products involved in this study.

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TITLE: Formation of Ice in Hydrocarbons
TASK NO.: 464-3-5 PRIORITY: 2 EST. COMPLETION: July 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: B.K. Morse EXT.: 33227
PRIME CONTRACTOR: Oklahoma A & M
PURPOSE: The purpose of this task is to supply information which will eliminate the formation of ice in fuel systems components.

TO DATE: To study ice formation in hydrocarbons, hydrocarbons saturated with water are to be cooled, and the size and rate of growth of the water particles which separate are to be observed by light scattering techniques. To the date of the first quarterly report, 1 May 1952, effort was directed to the construction of the apparatus for the light scattering measurements. This piece of apparatus consists of a light source, a special absorption cell, a cooling system for the cell and an amplifier. Equipment and chemicals for the preparation and analysis of the water-saturated hydrocarbon samples was also assembled.

* * * *

TITLE: Arylated Organo-Silicon Compounds
TASK NO.: 464-3-6 PRIORITY: 2 EST. COMPLETION: January 1954
SECURITY: Unclassified RESPONSIBLE SCIENTIST: L. Spialter EXT.: 33227
PRIME CONTRACTOR: None. Work is being accomplished at WADC.
PURPOSE: The purpose of this task is to investigate the synthesis of highly arylated silane derivatives and the physical and chemical characteristics, particularly thermal stability, of such materials. The aim will be to correlate properties with structural features in the molecules.

TO DATE: Data are recorded in the chemical literature to the effect that tetraphenylsilane is a stable compound boiling without significant decomposition at a temperature within the range of 350° to 530°C; the exact boiling point depending on the investigator one accepts. In view of this extraordinary (for an organic compound) thermal stability, the present project was activated to investigate the synthesis and physical and chemical properties of molecules, large and small, containing only silicon-to-phenyl (or, more generally, -to- aromatic nuclei or aryl) bonds. Such compounds have never before been made and they could well have great utility for purposes where their unique thermal stability and physical properties form a desirable combination. For example, the lower molecular weight members of this general class of arylated organosilicon compounds may be useful heat exchange media whereas the higher polymers may give desirable plastics, resins, elastomers, coating materials, or lubricants, characterized by high heat resistance.

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Project No. 464-3-6 (Cont)

Tetraphenylsilane, the parent molecule of this family of compounds has been synthesized by the coupling of silicon tetrachloride with an alkali metal in an inert solvent. The relative reactivities of potassium versus sodium and the solvent behavior of diethyl ether versus toluene during the course of the reaction have been qualitatively evaluated. A redetermination of the boiling point of tetraphenylsilane, specially purified by a novel extraction procedure and melting at 234-235°C, gave a value of 430-432°C, agreeing with only one of a number of values given by other investigators. At this high temperature, in air, practically no decomposition was noted.

The problem of analyzing for the silicon content of the compounds to be synthesized and studied has been solved based on experiments with tetraphenylsilane. The procedure gives reproducible values within 2% relative error and is based on the chemical oxidative degradation of the silicon-containing compound by a boiling mixture of nitric and sulfuric acids.

Several preliminary attempts to prepare completely phenylated silicon-organic polymers by the indiscriminate coupling of silicon tetrachloride, chlorobenzene, and para-dichlorobenzene suggested that the efficient approach would be a stepwise synthesis of the pure simple low molecular-weight members of this series. In this direction, the necessary starting materials mono-, di-, and tri-phenylchlorosilanes and triphenylalkoxysilanes, have been prepared and, in several cases, new values for melting points were observed.

The synthesis of the second member of the completely para-phenylated organo-silicon series, 1,4-bis-(triphenylsilyl)-benzene is almost completed.

In the heterocyclic branch of this new family of compounds, tetra-2-pyridylsilane could not be prepared by the condensation of 2-bromopyridine and silicon tetrachloride with either magnesium, sodium, or potassium because of complex formation between the first two reagents. To overcome this difficulty, it is planned to use the non-complexing ethyl silicate instead of the silicon containing reactant.

A systematic nomenclature, simpler and easier to handle and to picture mentally than standard chemical terminology, has been developed for the classes of compounds to be prepared and studied in this project, to be called henceforth, the silarylenes. The new system will be written up for publication in the first paper of the series expected from this project.

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TITLE: Surface Reactions of Metals
TASK NO.: 464-4-2 **PRIORITY:** 2 **EST. COMPLETION:** June 1953
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** P.M. Williamson **EXT:** 33227
PRIME CONTRACTOR: University of Chicago, Institute for the Study of Metals
PURPOSE: To conduct fundamental studies on the chemical and physical properties of solid surfaces in order to understand and to control surface phenomena such as corrosion.

TO DATE: The early monitoring of this project, the oldest in the Chemistry Research Branch, permitted the Scientific Investigators great freedom in selecting research problems to serve the purpose of the project. These investigators, Dr. Robert Gomer, Dr. Herman H. Nachtrieb, and Dr. L.G. Schulz of the University of Chicago chose to do research respectively on the following: emission of electrons from metal surfaces in electric fields, self-diffusion in metals, and properties of metallic surfaces and adhering films.

Emission of Electrons from Metal Surfaces in Electric Fields:

A study of the emission of electrons in high voltage electric fields is a promising research tool to produce information concerning crystal structures of metal surfaces and bonds between metal substrates and adsorbed gases. Increased knowledge of the mechanism of adsorbed gases, such as carbon monoxide on nickel, should elucidate surface reactions of metals.

The apparatus for studying emission of electrons in electrical fields is the projection microscope by which the patterns of emitted electrons may be observed visually and recorded photographically. Although the basic principles of the projection microscope have been known for more than twenty years, its development as a tool for research is recent.

In beginning work with the projection microscope, it was pertinent to observe topographies of electron emitting surfaces. It was learned that the crystal habit of nickel changes with temperature, that there are hill and valley structures of the order of magnitude of 25-50 atom spacings, that surface migration of atoms occurs. All such information (the above are samples) will be described in the final report.

Basic scientific progress has been made in a study of the velocity distribution of electrons in field emission. This progress will be reported in a publication of title, "Velocity Distribution of Electrons in Field Emission". Resolution in the Projection Microscope". A copy of the manuscript with its abstract have been received. Two important findings are (1) that resolution of electrons from metallic surfaces is of the order of 30 angstroms, and (2) that resolution is practically independent of the applied voltage, i.e., field strength.

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Project No. 464-4-2 (Cont)

Additional progress is reported in a manuscript soon to be published. Its title is "Molecular Images with the Projection Microscope". The Ionization Potential of Zinc Phthalocyanine." The thing of most interest in this study is not the zinc phthalocyanine but the nature of image formation. The zinc phthalocyanine is simply a means to an end. Supporting evidence has been found that visual patterns of single molecules adsorbed on metal substrates can be explained as molecular images. The enlargement is about 10^7 fold, and the resolution of electrons emitted from adsorbed molecules is of the order of three to five angstroms. These small size tungsten surfaces exhibited irregularities of five to ten angstroms.

Self-Diffusion in Metals

A frequently important factor in the chemical reactivity of a metallic surface is the internal diffusion of atoms to or from the surface. In a study of surface reactions it is, therefore, pertinent to study diffusion and particularly self-diffusion because it is theoretically the simplest.

Because of the prime importance of understanding the mechanism of diffusion, work was initiated on this problem. The simplicity of the crystal structure of sodium made it a desirable metal to study. Progress has been made toward working out the mechanism of self-diffusion in sodium, though much remains to be done. The reports of this progress have been received in copies of two (2) manuscripts submitted for publication. They are "Self-Diffusion in Solid Sodium. I" and "Self-Diffusion in Solid Sodium. II. The Effect of Pressure".

Because diffusion constants may be fitted into Arrhenius type equations, which were formulated for reaction constants, the analogy between diffusion constants and reaction constants has been extended to include calculation of free energies, enthalpies, and volumes of activation for diffusion. Thus the entropy of activation has been found to favor the vacancy mechanism. (Diffusion constants are defined by Fick's Law.)

Evidence for the following relations also are reported in the above mentioned publications: (1) the free energy of activation of diffusion is a linear function of the melting point of the metal, (2) enthalpy of activation is proportional to the melting point, (3) the enthalpy of activation is 16.5 times the latent heat of fusion, (4) the effect of pressure on the diffusion constant is a function of the compressibility and the change in entropy of activation.

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Project No. 464-4-2 (Cont)

The above indicate that progress is being made toward elucidating the mechanism of diffusion. It is hoped that at the expiration date of this project there may be a basis for estimating the amount of additional research necessary to obtain a definitive clarification of diffusion through the use of Fick's Law, Arrhenius equations, and thermodynamic quantities.

Properties of Metallic Surfaces and Adhering Films:

Thin films of various substances adsorbed or chemisorbed to surfaces of metals and other solids markedly influence the properties of the substrates and are themselves importantly affected by the substrates. A study of the phenomena involved was undertaken as part of the larger study of the properties of solid surfaces. A better understanding of such properties should lead to development of better protected surfaces. One method is the deposition of thin metallic films. To make this successful the basic principles governing formations of films in general on substrates in general must be better known.

Early progress in this study was published under the title, "Growth of Alkali Halide Crystals from the Vapor Phase and from Solution onto Substrates of Mica". It was found that this substrate oriented the (111) face of deposited crystals in a direction normal to the substrate. It was also found that closely matched interatomic spacing of substrate and of deposited crystals favored initiation of growth through formation of a monolayer, and that mismatches exceeding 10% favored growth according to oriented nuclei.

Improvement in the technique of studying thin overgrowths was published under the title "Examination of Thin Overgrowths by Multiple Scattering of Electrons". The common reflection method of observing oriented overgrowths by electron diffraction was improved by using the reflected beam from the substrate as the incident beam on the deposit.

Since the physical and chemical properties of thin films are greatly affected by the thickness of the film, it is of prime importance to establish good methods for measuring thickness. Progress has been made in this direction by improving the method of using the Fabry-Perot interferometer for this purpose. This was published as, "An Interferometric Method for Accurate Thickness Measurements of Thin Evaporated Films", with the improved method the thickness of uniform thin films of silver was measured to an accuracy of ± 15 angstroms.

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Project No. 464-4-2 (Cont)

Optical methods for measuring film thickness necessarily involve reflection of light from surfaces. Surface reflection is attended by a number of phenomena, including change of phase. Investigations in this field have been published under two (2) titles, "Concerning the Values of Phase Changes Accompanying the Reflection of Light, and "An Experimental Study of the Change in Phase Accompanying Reflection of Light from Thin Evaporated Films". Of significance is the finding that for thin deposits exceeding several hundred angstroms in thickness the results are consistent with equations of electromagnetic theory but for thinner deposits they are explained by light scattering rather than by reflection.

An early estimation of the pertinence of continued research in optics to the study of surfaces and thin films is planned.

TITLE: The Chemistry of Boron Hydrides and Related Hydrides
TASK NO.: 464-4-3 **PRIORITY:** 2 **EST. COMPLETION:** January 1953
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** E.A. Reinhardt **EXT:** 33227
PRIME CONTRACTOR: University of Michigan
PURPOSE: The purpose of this task is to study the reaction of diborane and hydroxylamine yielding a complex, including stability studies and evaluation of polymerization possibilities. It is also intended to measure the exchangeability of hydrogen atoms bonded to boron and nitrogen atoms in diborane-ammonia complexes with a view to evaluation of bond character.

TO DATE: Experiments were carried out to elucidate the structures of diborate (B_2H_6) and the diammoniate of diborane ($B_2H_6 \cdot 2NH_3$). (1) The source of the hydrogen from the reaction of $B_2H_6 \cdot 2NH_3$ with sodium in liquid ammonia was studied by the use of deuterium as tracer. From $B_2D_6 \cdot 2NH_3$ all the hydrogen appeared as H_2 , but from $B_2H_6 \cdot 2ND_3$ about half was H_2 and half D_2 . These results show that hydrogen attached to boron is more negative than that attached to nitrogen, but that there is a considerable isotope effect in the reaction. (2) The quantity of hydrogen obtained from this reaction was found to be less than that predicted by the structure, $NH_4 (BH_3NH_2BH_3)-$ formulated in the literature, and the fact that the more active metal potassium releases more hydrogen than does sodium indicates also that this former model cannot be correct.

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Project No. 464-4-3 (Cont)

It has been found that there is no exchange between the hydrogen atoms in (liquid) ammonia and sodium borohydride. This is further evidence of the difference in the nature of hydrogen bonded to boron and to nitrogen.

The new compounds NH_4BH_4 and $(NH_4)_2BH_4$ have been prepared. These substances may be useful starting materials for the preparation of inorganic polymers.

TITLE: Flame Propagation Theory Tests
TASK NO.: 464-4-4 **PRIORITY:** 2 **EST. COMPLETION:** December 1952
SECURITY: Unclassified **RESPONSIBLE SCIENTISTS:** Lt M. St. George **EXT:** 33227
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this task is to measure rates of flame propagation in systems of geometrical and chemical simplicity with the aim of obtaining a variety of data by which existing theories can be treated.

TO DATE: Two approaches are being used to measure the so called fundamental flame velocity of combustible systems of present and potential Air Force interest. Apparatus has been developed for measurements at constant pressure in systems of (1) spherical symmetry, and (2) cylindrical symmetry, to permit evaluation of relative precisions of the two methods of measurements. A program of critical experiments has been laid out and coordination with other investigators, both in government laboratories and in other research institutions, has been accomplished. Several compounds have been synthesized, which are of special interest for experimental tests of the so-called active particle theory of flame propagation. Apparatus for the flame velocity measurements is under construction and in process of testing.

TITLE: Decomposition of Fuming Nitric Acid
TASK NO.: 464-4-5 **PRIORITY:** 2 **EST. COMPLETION:** July 1953
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** R.A. Reinhardt **EXT:** 33227
PRIME CONTRACTOR: None. Work is being accomplished at WADC.

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Project No. 464-4-5 (Cont)

PURPOSE:

The purpose of this task is to study the mechanism of the decomposition of red and white fuming nitric acid.

TO DATE:

Apparatus has been constructed for the preparation of pure nitric acid, and several small samples of the anhydrous acid have been made.

Apparatus is being built to study the course and the rate of the decomposition of fuming nitric acid.

In order to assist in studying this reaction, an analytical scheme has been devised to determine the concentration of both nitric acid and nitrogen dioxide in a single sample. Preliminary results indicate that the method is capable of a precision of at least 0.2% for both components, using ordinary volumetric equipment.

TITLE:

Synthesis, Reactions, and Properties of Spiroans and Related Compounds

TASK NO.:

464-4-6 **PRIORITY:** 2 **EST. COMPLETION:** July 1953

SECURITY:

Unclassified **RESPONSIBLE SCIENTIST:** Dr. S. Baldwin **EXT:** 33227

PRIME CONTRACTOR:

University of California

PURPOSE:

The purpose of this task is to extend the methods of synthesis of spiroans, to explore the reactions of particular spiroans that contain some unusual structural feature, and to study the physical properties of certain spiroans that exhibit unique symmetry properties or electronic configurations with a view toward possible utilization of these materials as lubricants and/or polymers at higher temperatures than presently available materials.

TO DATE:

A contract for the work indicated above has recently been negotiated. Work was started 1 July 1952.

TITLE:

Decomposition of Metal Carbonyls

TASK NO.:

464-4-7 **PRIORITY:** 2 **EST. COMPLETION:** April 1953

SECURITY:

Unclassified **RESPONSIBLE SCIENTIST:** L. Spialter **EXT:** 33227

PRIME CONTRACTOR:

None. Work is being accomplished at WADO.

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Project No. 464-4-7 (Cont)

PURPOSE:

The purpose of this project is to study the rates and mechanisms of decomposition of various metal carbonyls in solution and resulting powder particle size as a function of molecular structure, temperature, solvent, and pressure.

TO DATE:

This project is designed to study the thermal and photo-decomposition of metal carbonyls, such as those of nickel, cobalt, iron, tungsten, chromium, molybdenum, osmium, etc., in the liquid or solution phase to give suspensions of the corresponding metals. These suspensions are of interest in magnetics, ceramics and metallurgy.

Apparatus for synthesizing nickel carbonyl and similarly prepared molecules has been constructed. A vacuum train for handling and studying the metal carbonyls and their decomposition has also been built. Solvents for the decomposition studies have been purified.

Further work on this project has been postponed because of the transfer of the active experimenter from the Chemistry Research Branch. Work will be resumed when a suitably trained man becomes available.

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AERODYNAMICS RESEARCH BRANCH

The Aerodynamics Research Branch plans, initiates and monitors new research in the field of aerodynamics. This includes work in the fields of perfect fluids research, viscous fluids research, hypersonic and low density research, aircraft aerodynamics research, and missile aerodynamics research

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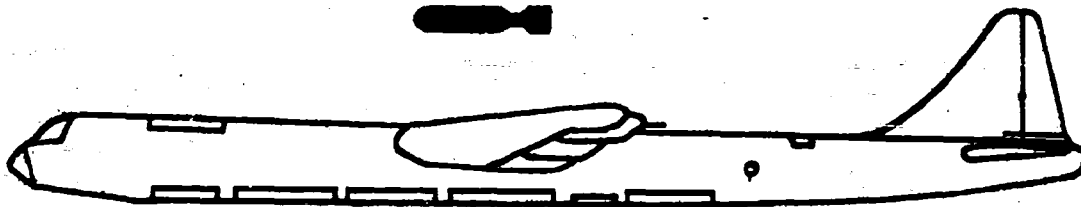
ACCOMPLISHMENT IN BOUNDARY LAYER CONTROL

The Flight Research Laboratory has supported the basic research work of Dr. W. Pfenniger in the field of drag reduction by control of the boundary layer through suction slots. On the basis of this basic work, Dr. Pfenniger, who was also under contract with the Aircraft Laboratory for development work in this field, was able to construct and test a wing model on which laminar flow over the entire airfoil was maintained at Reynolds numbers corresponding to high-speed full scale airplanes.

The FRL then requested Dr. Pfenniger to prepare a report showing the preliminary design of an airplane on which laminar flow could be maintained over the entire airplane. It was found from this study and discussion with Dr. Theorderson, and various European experts who have done basic work in the field, that a long range program to develop laminar flow aircraft was advisable. These studies revealed further that it was possible to build a 65,000 lb. airplane which was capable of carrying a 10,000 lb. load over a distance of 10,000 miles. In comparison, an airplane with similar load and range characteristics without boundary layer control would weigh in the vicinity of 230,000 lbs. In other words, an aircraft the size of a B-17 could be made to do the work of one the size of a B-36.

The Aircraft Laboratory now has the Northrop Company under contract to carry forward the development and further expansion of this boundary layer control program.

With Boundary
Layer Control



Without Boundary Layer Control

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TITLE: Unsteady Lifting Surface Theory
TASK NO.: 465-1-4 PRIORITY: 2 EST. COMPLETION: September 1952
SECURITY: Unclassified RESPONSIBLE SCIENTIST: L.S. Wasserman EXT: 24155
PRIME CONTRACTOR: Dr. Erick Reissner
PURPOSE: The purpose of this task is to modify the integral equation of the oscillating lifting surface so that the pressure distribution, force, and moment can be computed for flutter, gust load, and dynamic stability analysis.

TO DATE: A new form of the exact integral equation for the pressure distribution of the rectangular planform surface has been developed. This equation has been transformed into three simultaneous integral equations for spanwise variation of circulation, lift and mid-chord moment. Simplified methods for solving these equations will be established.

Further development of these three equations will be undertaken to generalize this equation in such a way that it will apply to lifting surfaces of arbitrary planform. The equations are not presently in a form suitable for engineering application. The contractor suggested that computations by automatic computers would be of value.

* * * *

TITLE: Wing Body Interference at Mach 1.9
TASK NO.: 465-2-9 PRIORITY: 2 EST. COMPLETION: March 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Fred L. Dunn EXT.: 24155
PRIME CONTRACTOR: University of Michigan
PURPOSE: The purpose of this task is to provide information on wing body interference at supersonic speeds.

TO DATE: A contract has recently been negotiated with the contractor mentioned above for the investigation of pressure distribution on a cylindrical fuselage in the presence of thin wings at two angles of attack and at a Mach No. of 1.9. The results of these tests will be compared with existing theory.

Analysis of data obtained from preliminary experiments on the simplest case of wing body interference, i.e., detached wing influencing body without body influencing wing, has been completed. The pressure distributions for relatively small wing angle of attack indicate the following: (a) relatively mild softening of pressure jumps where the wing shock impinges directly on the body; and (b) appreciable boundary layer cross flow on the body in the direction of the wing shock. For large wing incidence, such as wing angle of attack of eleven degrees, the boundary layer influences the pressure distributions on all parts of the body to such an extent that

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Project No. 465-2-9 (Cont)

results of nonviscous potential linearized theories are not likely to apply. Preliminary calculations using Ferrari linearized theory have been started. The contract for the construction of the model has been negotiated and the model is being constructed.

TITLE: Investigation of Lift Distribution on Low Aspect Ratio Wings at Subsonic Speeds
TASK NO.: 465-2-10 **PRIORITY:** 2 **EST. COMPLETION:** September 1952
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** I. S. Macosman **EXT:** 24155
PRIME CONTRACTOR: Cornell Aeronautical Laboratory, Inc.
PURPOSE: The purpose of this task is to provide a rational means for predicting lift distribution on low aspect ratio wings and on wing body combinations.

TO DATE: A contract has recently been negotiated with the contractor mentioned above for the development of a theory of lift distribution for low aspect ratio wings and wing body combinations at subsonic speeds. The results of this investigation will be compared with available experimental data. This data is needed for the design of delta wing airplanes.

Phase I of this project has been completed and the required report has been submitted. This report presents a solution to an integral equation for the lift distribution of a class of low aspect ratio wings, which has developed by H. R. Lawrence. Numerical results are charted in matrix form. With the aid of the matrices, the lift distribution for an arbitrary twist, camber, flap, etc., may be found, provided the wing is of the general class considered.

A report has been submitted showing the control surface effectiveness and hinge moment parameters for low aspect-ratio delta wings. Preliminary correlation with theory has been good. A number of missile and aircraft companies are doing additional correlation.

TITLE: Research on Stability of Flow in Boundary Layer Control, Air Induction Systems
TASK NO.: 465-2-12 **PRIORITY:** 2 **EST. COMPLETION:** September 1952
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** Hans Eckert **EXT:** 24155
PRIME CONTRACTOR: Cornell Aeronautical Laboratory, Inc.
PURPOSE: The purpose of this task is to explore experimentally the nature of static and dynamic instability of the flow in air induction systems with a view to providing data to facilitate the design of boundary layer control systems and solving other problems having to do with the instability of directed flows.

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Project 465-2-12 (Cont)

TO DATE: A survey of literature to determine the optimum size and shape of the slots to be employed in boundary layer control application has been completed. The model has been designed and is under construction.

A preliminary check was made in a 3" x 16" induction type tunnel with velocities of 200 to 300 ft/sec and Reynolds number of 1.8 to 2.6×10^6 . The turbulent boundary layer profile was measured for rates of suction from 0 to 11 ft³/sec. The highest suction corresponds to removal of the entire (0.35") boundary layer at tunnel velocity of 300 ft/sec.

Unstable flow is produced when only part of the boundary layer is removed, thus setting up an oscillation in the tunnel flow. An attempt to stabilize the system is being made by installing a screen in the suction plenum chamber and pressure capsules are being installed at strategic points to study this phenomena.

* * * *

TITLE: Vortex Generator for Boundary Layer Control Through Shock
TASK NO.: 465-2-16 PRIORITY: 2 EST. COMPLETION: September 1952
SECURITY: Restricted RESPONSIBLE SCIENTIST: L.S. Wasserman EXT.: 24155
PRIME CONTRACTOR: United Aircraft Corporation
PURPOSE: The purpose of this research is to learn to use vortex generators as boundary layer control devices in the presence of shock; it is also the purpose of this project to explore the potentialities of vortex generators in preventing or alleviating a breakdown and separation of the boundary layer flow.

TO DATE: The initial work on this project has been of an introductory nature with serious consideration being given to the analytical and experimental requirements which will provide adequate and reliable design criteria to meet the problem of boundary layer control devices in the presence of shock. Work has centered on the design and setup of a model test rig to be used in determining vortex generator parameters affecting boundary layer control through shock. The test rig has been run to a maximum Mach Number of 1.4. Satisfactory control of the shock strength and position, adverse gradient following the shock, and side wall boundary layer separation downstream of the shock have been realized.

Preliminary tests have been completed on a number of vortex generators showing specific improvement on boundary layer characteristics. A study has been initiated to obtain a better physical picture of the action of vortex generators. Larger scale tests have been eliminated, since it appears more advisable to do the testing on an actual airplane. Effort will be directed toward the application of vortex generators to swept wings.

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TITLE: Research in Transonic Aircraft Control Problems
TASK NO.: 465-2-17 PRIORITY: 2 EST. COMPLETION: July 1953
SECURITY: Confidential RESPONSIBLE SCIENTIST: L.S. Wasserman EXT.: 33155
PRIME CONTRACTOR: United Aircraft Corporation
PURPOSE: The purpose of this project is to provide pertinent knowledge and data on the problems of stability and control in transonic flight, and improved aerodynamic devices for control.
TO DATE: Contract was awarded in April on this project.

TITLE: Transonic Tunnel Experiments
TASK NO.: 465-3-3 PRIORITY: 2 EST. COMPLETION: January 1953
SECURITY: Confidential RESPONSIBLE SCIENTIST: L.S. Wasserman EXT.: 24155
PRIME CONTRACTOR: Cornell Aeronautical Laboratory
PURPOSE: The purpose of this task is to determine the extent to which transonic wind tunnel tests are indicative of the free-flight conditions and to establish methods of correction for such wind tunnel test results as will bring them into better agreement with free-flight data.

TO DATE: The contractor has investigated the shock formation over a wing throughout the transonic range by means of a small tunnel with perforated walls. He has also studied the effect of shocks of small auxiliary delta wings which form slots for the flow above the main wing. A pronounced effect of the shock configuration of the delta wings was observed and may prove helpful in the solution of certain problems of transonic flight.

It was originally planned that a 1 sq. ft. blow down type tunnel would be constructed for tests under this project; however, discovery of some surplus D.C. motors, which can be made available by the Bureau of Ships, has caused a revision of planning. A study has been made of the suitability of these motors for providing power for a continuous flow tunnel. Design studies indicate that it will be possible to generate a Reynolds number varying from ten million per foot at Mach number 1.0 to approximately two million per foot at Mach numbers from 2.0 to 2.5.

TITLE: Wind Tunnel Tests
TASK NO.: 465-4-3 PRIORITY: 2 EST. COMPLETION: March 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: L.S. Wasserman EXT.: 24155
PRIME CONTRACTOR: United Aircraft Corporation

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PURPOSE:

The purpose of this task is to conduct wind tunnel investigations to determine possible methods for reducing the undesirable forces and moments which occur on aerodynamic surfaces when the Mach Numbers are in the transonic range.

TO DATE:

The contract was awarded on 14 March 1951. The contractor has begun work on small models.

* * * *

TITLE:

Stability and Control in Stalled Flight

TASK NO.:

465-5-2 **PRIORITY:** 2 **EST. COMPLETION:** September 1952

SECURITY:

Unclassified **RESPONSIBLE SCIENTIST:** Fred L. Dorn **EXT.:** 24155

PRIME CONTRACTOR:

Cornell Aeronautical Laboratory, Inc.

PURPOSE:

The purpose of this task is to investigate the motions of an airplane during stalled flight with a view toward eventual automatic control of stalled aircraft.

TO DATE:

Flight tests have been flown with the greater part of the time being consumed by the adjustment of the auto-pilot in an attempt to find a stable combination of airplane and autopilot. On the more recent flights, the equipment was perfected to the point where some stalled transient responses could be obtained.

A number of automatic pilot controlled stalls have been made in which the airplane's attitude was controlled successfully throughout the stall. However, the autopilot combination has not yet been developed to a degree that will allow a detailed analysis to be made. Refinements are being made on the control system.

Calculations were made of the amplitude and phase of the yawing and sideslipping motion, referred to the roll rate, in the stalled lateral oscillation. This mode is analogous to the Dutch roll, mode in unstalled flight. These calculations will help in determining the suitability of yaw rate and sideslip sensing as an aid in controlling the stalled airplane.

The frequency response of the autopilot was calculated for several values of autopilot stiffness and amplifier "rate" setting. The results of these calculations should simplify adjusting the autopilot to minimize the objectionable 3 c.p.s. oscillation that has been present, without passing too much 10 c.p.s. buffeting signals to the control surfaces.

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TITLE: Research on Sky Train Principles
TASK NO.: 465-5-5 **PRIORITY:** 2 **EST. COMPLETION:** July 1953
SECURITY: Confidential **RESPONSIBLE SCIENTIST:** L.S. Wasserman **EXT.:** 24155
PRIME CONTRACTOR: Mr. Ray Holland, Jr., New Mexico Military Institute
PURPOSE: The purpose of this task is to determine the advantages and disadvantages of the sky train for long range AF missions.

TO DATE: A contract has recently been negotiated with the contractor mentioned above for evaluation of the sky train principle by the application of the latest scientific methods in aeronautics. Comparisons of the induced drag of rectangular wings to that of elliptical wings have been made using the Multhopp method of rectangular wing computation for varied conditions of load and lift distribution. These comparisons show that the advantage of elliptical wings over rectangular wings decreases to a point of relative insignificance at high aspect ratios. Connections of several types of flight units, tip to tip, to give large aspect ratios have been investigated. Theoretical considerations predict a large gain in efficiency for the sky train principle; however, whether a practical application of the method is feasible has not yet been proven.

Detailed calculations of the aerodynamics of the fleet, based on drag data for conventional aircraft, indicates that five units each about 1/5 of the weight of a B-36 would have, as a fleet, about the same range and payload as the B-36. Further improvements can be obtained by increasing the number of units in the fleet. Workable procedures and equipment have been developed on paper for hookup (in flight), for maintaining automatically the fleet alignment in elevation and roll, for piloting and maneuvering the fleet, and for maintaining fleet stability in gusts and rough air, as well as in smooth air.

The task has been completed but the final report has been delayed because of additional studies which were deemed desirable in order to determine the next step in the research. An additional year has been added to the contract. The contractor has submitted a report on methods of balancing out the roll moment on the tip airplane as part of the new contract.

* * * *

TITLE: Study of Bomb Bay Turbulence, Airplane Stability and Shock Wave Phenomena
TASK NO.: 465-5-8 **PRIORITY:** 1B **EST. COMPLETION:** December 1952
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** Fred L. Damm **EXT.:** 24155
PRIME CONTRACTOR: None. Work being accomplished at WADC.

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Project No. 465-5-8 (Cont)

PURPOSE:

The purpose of this task is to study the air flow conditions in the open bomb bay with the ultimate objective of alleviating bomb dropping difficulties.

TO DATE:

The instrumentation is 100% complete. The airplane will have a new pilot entrance door installed before the initial test flight is made. The airplane was removed to San Bernadino for almost eight months during 1951; it was returned to Wright Field in November 1951. All the pressure and electrical recording systems had to be replaced; instrumentation had to be recalibrated.

One instrumentation check flight and one test flight have been made. Slight modifications to bomb bay instrumentation are being made in preparation for the second flight. This modification is necessary due to the extreme turbulent flow which was observed on the initial flight. Various methods for visualizing the bomb bay flow will be tried in order to supplement the tuft data.

After several test flights, it was determined that the cameras in the bomb bay were running at too low a speed for photographing the fast moving tufts. Also, it was found that due to the unsteadiness of the direction indicating vanes in the bomb bay, the vane position indicators were unsatisfactory for their purpose. However, direct moving pictures of the vanes gave good qualitative results. Also, the vanes proved much more useful in indicating flow directions than did the tufts. As a result, high speed cameras running at 128 frames per second and one at 500 frames per second are being installed. Also, the number of vanes in the bomb bay are being greatly increased.

It has been found that movies of ping pong balls released in the top of the bomb bay while the bomb bay doors are open indicated well the flow patterns. However, the higher speed cameras are also needed here to allow a better tracing of the balls. The camera coverage of the bomb bay is also being improved with wide angle lenses and better camera angles.

The results show that a steady large vortex exists in about the front third of the bomb bay in the direction such that the flow in the top of the bomb bay is toward the nose of the airplane. The flow in the rear 2/3 of the bomb bay is relatively complicated and not very defined as yet. The velocity fluctuation instruments are being relocated in the rear of the bomb bay. In the past tests they have been in the front.

* * * *

TITLE:

Study of Shock Wave Boundary Layer Interaction and Boundary Layer Control Devices

TASK NO.:

465-5-9 PRIORITY: 2 EST. COMPLETION: September 1952

SECURITY:

Unclassified RESPONSIBLE SCIENTIST: W.C. Griffith EXT.: 24155

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Project No. 465-5-9 (Cont)

PRIME CONTRACTOR: None. Work being accomplished at WADC.

PURPOSE: The purpose of this task is to (1) learn the cause of loss of control and stability at high speeds and to try to establish the criteria necessary for predicting the occurrence of the various phenomena, (2) to develop methods for eliminating or delaying the difficulties to greater speeds, and (3) to develop instruments for making more accurate air flow measurements, such as boundary layer velocity profile and temperature distribution.

TO DATE: Instrumentation of the airplane to be used in the tests has been completed. Functional test flights are now in progress. Data from a flight on 15 January 1952 was plotted.

Six test flights have been flown since the last report. Several of the flights were unsuccessful due to mechanical difficulties encountered with the airplane. One of the flights was a pacer flight for the purpose of calibrating the airspeed system. Boundary layer data have been obtained on the wing in the clean condition and with straight rectangular vortex generators installed. These generators were set to give co-rotating vortices. A second set of generators consisting of 45° swept airfoils also adjusted to give co-rotating vortices have been installed.

A number of flight tests have been made with various configurations of vortex generators on the wing at the 30 percent chord location. The F-84 B airplane being used has shown no separation behind the normal shock standing on the clean wing, as indicated from tuft pictures. However, boundary layer shape parameter (H) values as high as 3.2 have been determined. (Usually the range of H from 1.8 to 2.6 indicates separation or imminent separation).

With the vortex generators installed at the 30% chord line, the boundary layer surveys indicated, in general, a sharp drop in velocity at about 0.8 inch above the wing surface. It appears that this may be due to the surveys being made in a vortex field. This point is under particular investigation now.

The airfoil wake surveys showed that for the range of conditions covered by the tests, the generators increased the drag. Analysis of the data shows that the vortices, for most of the configurations tested, are centered behind the generators at a height above the wing surface equal to about three times the local boundary layer thickness. A recommendation of the United Aircraft Corporation, which is studying vortex generators under an AF contract, is that the vortices should be located in height at the generating position about 1.2 times the local boundary layer thickness. Triangular planform generators are presently being installed in accordance with this recommendation.

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TITLE: Study of the Shock Wave Boundary Layer Interaction on the Wing of a B-45A Airplane
TASK NO.: 465-5-10 **PRIORITY:** 1B **EST. COMPLETION:** October 1952
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** Fred L. Daum **EXT.:** 2A155
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this project is to study the shock wave boundary layer interaction in order to gain a better understanding of the phenomena and to try to establish the criteria necessary for predicting some of the adverse effects related to the interaction.

TO DATE: The instrumentation of the airplane to be used in these tests is 100% completed.

The first test flight has been flown. The test data are presently being reduced. The maximum mach numbers are lower than had been anticipated, however it is expected that conditions may be reached, in which local supersonic flow will exist over the test station on the wing.

A number of test flights have been made, primarily for the purpose of the bomb bay turbulence investigation. Difficulties with the oscillating boundary layer probes have now been overcome. The boundary layer data obtained thus far is presently being reduced.

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TITLE: Investigation of the Propagation and Decay of Compression Shocks Emanating from an Airplane Flying above Mach Number 1
TASK NO.: 465-5-11 **PRIORITY:** 2 **EST. COMPLETION:** October 1952
SECURITY: Confidential **RESPONSIBLE SCIENTIST:** Fred L. Daum **EXT.:** 33155
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this task is to accomplish the following: (1) determine the pressure and propagation characteristics of the shock wave and establish the theory of the formation of the wave, (2) gain a better understanding of wave drag, and (3) determine the practicability of slight modification of the wing-fuselage juncture to lessen the total drag.

TO DATE: Seven test flights have been made to date, including one air speed calibration flight. Plans are being made now to supplement the airplane instrumentation with ground instrumentation. Sound pressure data obtained from the past flights are currently being evaluated.

Instrumentation on the ground beneath the diving F-86 airplane has been used for measuring the magnitudes of the pressure pulses reaching the ground.

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Project No. 465-5-11 (Cont)

The peak pressures were of the order of 1.5 pounds per square foot. The time history of the pressure measurements exhibited the characteristics of the N shaped pressure waves which have been measured on ballistic ranges. Several waves reached the ground from each dive with an inconsistent time spacing between the waves. So far, no direct correlation between the ground pressures and the pressures measured along the side of the fuselage have been possible. The noise level at the ground corresponding to the sound pressure of 1.5 p.s.f. amounts to 132 decibels.

Several tests were made where the instrumented F-80 airplane circled below the diving F-86. This technique proved rather fruitless in that the only successful sound pressure measurements made in this manner were at the low altitudes of 5000 feet. At higher altitudes, as the F-80 came nearer the diving F-86, the apparent difficulty was that the diving airplane could not be properly aimed during the dives so that the shock waves passed over the F-80. This technique has been abandoned in favor of one involving two diving F-86 airplanes where one of the airplanes, which is instrumented for recording the shock wave pressures, will pass the other airplane while at a mach number of about 1.05.

TITLE: Investigation of Transonic Aerodynamic Characteristics Using the Wing Flow Method
TASK NO.: 465-5-12 **PRIORITY:** 1B **EST. COMPLETION:** September 1953
SECURITY: Confidential **RESPONSIBLE SCIENTIST:** Fred L. Daum **EXT.:** 33155
PRIME CONTRACTOR: None. Work being accomplished at WADC
PURPOSE: The purpose of this task is to evaluate rapidly the most promising ideas for improving the various characteristics of aerodynamic performance such as stability, control, lift, and drag. The wing flow investigations will indicate which projects should be pursued further.

TO DATE: This task is in the process of being approved by the Projects Division.

TITLE: Investigation in Flight of Boundary Layer Control Effects on Aerodynamic Performance
TASK NO.: 465-5-13 **PRIORITY:** 2 **EST. COMPLETION:** October 1952
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** Fred L. Daum **EXT.:** 33155
PRIME CONTRACTOR: None. Work being accomplished at WADC

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Project No. 465-5-13 (Cont)

PURPOSE:

The purpose of this supplement is to determine what measures are necessary to delay in flight the transition of the boundary layer from laminar to turbulent flow until appreciable drag reduction and increased lift is obtained as has been done in the laboratory.

TO DATE:

Although this project has been set up, no efforts have been spent on the project because of the greater current interest in other internal projects. However, this still is important and it will be continued and eventually completed according to plans.

* * * *

TITLE:

Study of Compressibility Effects on Airfoil Pressure Distribution

TASK NO.:

465-5-14 PRIORITY: 2 EST. COMPLETION: December 1952

SECURITY:

Unclassified RESPONSIBLE SCIENTIST: W.C. Griffith EXT: 33155

PRIME CONTRACTOR:

None. Work being accomplished at WADC.

PURPOSE:

The purpose of this supplement is to analyze existing data and compressibility correction methods and try to develop a means for systematizing these data so that the full meaning and sense of the data may be realized.

TO DATE:

The task is in process of coordination.

* * * *

TITLE:

A Check and Extension of the Evaluation of the Sky Train Principle

TASK NO.:

465-5-15 PRIORITY: 2 EST. COMPLETION: December 1952

SECURITY:

Confidential RESPONSIBLE SCIENTIST: N. Smith EXT.: 33155

PRIME CONTRACTOR:

None. Work being accomplished at WADC.

PURPOSE:

The purpose of this supplement is to apply methods of calculating the induced drag of the wing made up of many interconnected wings by a more exact method than that presently know.

TO DATE:

This task is in process of coordination.

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AERO FACILITIES RESEARCH BRANCH

The Aero Facilities Research Branch formulates and directs a program of research on problems relating to the design of new facilities that will be required to support the WADC research and development program. The fields of research may include transonic, supersonic, and hypersonic flow; viscous effects in gases, special compressor cascades, air heating (high stagnation temperatures), and test instrumentation. Research efforts are generally concentrated on wind tunnel and engine test facility problems.

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ART OF WIND TUNNEL DESIGN ADVANCES THROUGH RESEARCH

The success of research on Aero Facilities cannot be directly measured in terms of air weapons improvement. Its value can only be reflected in the increased abilities of Research and Development facilities to simulate the high speed conditions of flight which our weapons are expected to attain. Facilities used by the USAF for development evaluations work have probably been responsible for saving more lives and valuable equipment than any other material development. Proving, evaluating and "de-bugging" constitute the major effort in that work called development. Without facilities of the most modern design, capable of simulating those conditions under which we hope our air weapons will operate, development progress would be exceedingly slow.

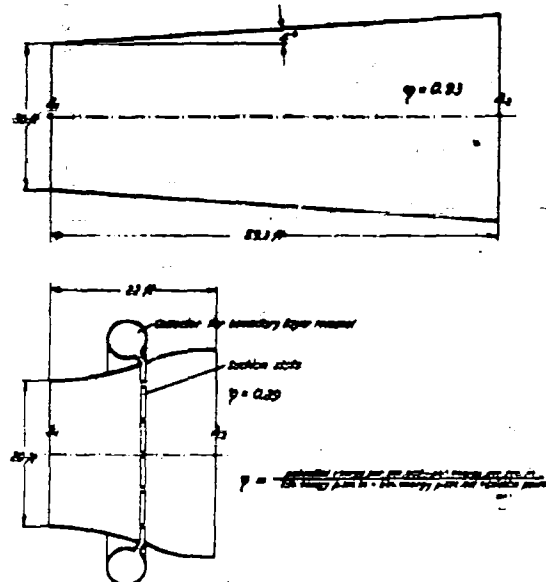
The Aero Facilities program at the present time covers some 22 projects dealing primarily with research on wind tunnels and engine testing facilities. Transonic, supersonic, and hypersonic flow problems are being studied. Most of the projects are in their first phases; some significant progress has been made, but the major accomplishments are yet to be realized. The type of research being conducted, utilizes complex test set-ups that require one to three years for their design and construction, after which the experimental research portion of the project will begin.

Of the present projects which have reached the testing stage, several have made contributions to the advancement of the art of wind tunnel design. One of the contributions of this program is "The Wide Angle Diffuser Study" by United Aircraft Corporation (R-465-6-13).

The increasing need for larger and larger multimillion dollar wind tunnels has made it imperative that designers strive for a maximum in performance of all components. Over all tunnel efficiency directly determines the amount of power which must be used to attain a given air speed.

While fairly efficient conical diffuser designs have been known for

Comparison between a conical diffuser and a wide angle diffuser with boundary layer removal. Loss ratio for both diffusers ≈ 0.8



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"Art of Wind Tunnel Design Advances Through Research" (Cont)

years, all have employed expansion angles of 6° to 8° . Such small angles lead to long structures for large area ratios of expansion. In a large diffuser (entrance diameter of the order of 20') large costs and appreciable amounts of critical materials are involved.

The amount of critical materials required for conventional diffusers can be reduced if the expansion angle were increased (A 6° diffuser required approximately three times as much material as a 20° diffuser). To attain this end, a research program was instituted with the United Aircraft Corporation under the direction of Mr. L. R. Manoni.

By employing suction and wall curvature to control the boundary layer, several wide angle diffusers were tested with very favorable results. It was possible to operate diffusers of approximately two to one area ratios and 20° equivalent cone angle at a net effectiveness of 89%, including suction power, for inlet Mach number as high as 0.80. (Effectiveness is a term comparable to "efficiency" used to describe the performance of diffusers). The internal portion of the diffuser flow, that is, all the flow except the portion removed by the suction slot, closely resembles a potential flow field such that the total head distribution at the exit of the diffuser is very nearly uniform.

In brief, application of the results of this research should produce substantial savings in construction costs of future wind tunnels. It is also quite possible that these results can be utilized in jet engine design, internal aircraft ducting, and other applications where weight and space may be at a premium.

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TITLE: Investigation of Viscous Effects on Flow of Gases in Hypersonic Wind Tunnels
TASK NO.: 465-6-1 **PRIORITY:** 2 **EST. COMPLETION:** April 1953
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** Capt Ross **EXT.:** 32377
PRIME CONTRACTOR: Princeton University
PURPOSE: To determine whether the condensation of air near the oxygen dew point is caused by impurities or by spontaneous nucleation. The studies will also determine the effects of viscosity on hypersonic pressure distributions. Extending the operating range of hypersonic wind tunnels to higher Mach number requires an understanding of air condensation phenomenon. Such an understanding will lead to savings in cost of flow generation and heating equipment by prevention of "over design"; Also by "under design" and consequent modifications.

TO DATE: Preliminary studies have been made on the utilization of gases other than air for hypersonic testing. A well under-expanded jet, operating with chamber pressures up to 200 psi has been used for these initial studies of high Mach number free jets. From these tests, it has been concluded that with the present equipment, Mach numbers to about 15 could be attained without condensation. The results would not include the effects of dissociation and ionization, but may be valuable in the study of some simple viscous effects.

Progress has been made in the theoretical analysis of steady hypersonic viscous flow over a semi-infinite flat plate in the region away from the leading edge. It has been shown that there is a wedge-like domain extending from the leading edge where the "higher order" viscous terms can be neglected. However, the pressure gradient normal to the plate is no longer negligible when the parameter M^2/R is not small compared with unity. It appears therefore in the "second approximation" to the flow. Solutions are obtained as asymptotic expansions in powers of $M^2/\sqrt{R}$. (M is free stream Mach number and R is the Reynolds number based on distance from the leading edge.)

The 4" x 4" hypersonic tunnel has been in operation for several weeks utilizing air as a test gas. From an analysis of the theoretical results obtained, it is clear that certain hypersonic effects do not become appreciable until $M=10$ or larger. Therefore, tests at lower Mach Numbers may not reveal some of the main features of hypersonic flow. For this reason, the plans are to utilize helium as a test gas, in that Mach Number of the order 17 may be possible without pre-heating.

TITLE: Performance of Open-Jet Type Wind Tunnels
TASK NO.: 465-6-2 **PRIORITY:** 2 **EST. COMPLETION:** December 1952

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Project No. 465-6-2 (Cont)

SECURITY:

Unclassified RESPONSIBLE SCIENTIST: Capt Ross EXT.: 32377

PRIME CONTRACTOR:

Ohio State University

PURPOSE:

The purpose of this task is to determine the optimum jet and diffuser characteristics for open-jet supersonic tunnels.

Supersonic tunnels constructed to date have utilized closed test sections almost exclusively. This has been done primarily for two reasons, i.e., extension of subsonic tunnel configurations to higher speeds, and more efficient utilization of power than could be attained in "open" type tunnels. Certain mechanical disadvantages are inherent in the closed system to offset these advantages. Model supports and instruments must be carefully designed to present a minimum of interference on model performance and tunnel choking; also change in test Mach Number requires expensive flexible walls or cumbersome removable nozzle blocks which must be exactly lined up with the test section walls. The open jet overcomes these difficulties to some extent but at the cost of increased power.

Testing of power plants full scale under actual operating conditions requires tremendous wind tunnel facilities. However, the open-jet principle is being extended to such test work under the term "free jet" testing. This research program will investigate the performance of the "free jet" as a function of jet dimensions. Considerable savings in costs for full scale testing will ensue if the free jet method can be perfected.

TO DATE:

The testing program using the 12 inch open-jet, high Mach number, blowdown type wind tunnel was continued. Scoops were added at the diffuser entrance to increase effectively the inlet area; the glass sidewalls of the diffuser were replaced with steel panels to permit use of higher starting pressures. With this combination, flow was readily "started" at a pressure ratio of 35.2 with the maximum physically attainable free-jet length (L/H 3.5). It was also possible to "start" the flow at smaller diffuser throat sizes with a resulting increase in diffuser efficiency. Occasionally "starts" were made at relatively lower pressures even though the tunnel geometry was not changed.

The addition of a porous plate and stilling screens within the stagnation chamber from three percent to approximately one percent.

Further work on this program will be delayed slightly to permit OSU to use the air supply for an urgent program on porous wall configurations for the AEDC transonic wind tunnel.

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TITLE: Pulse Starting of Supersonic Wind Tunnels
TASK NO.: 465-6-3 **PRIORITY:** 2 **EST. COMPLETION:** October 1952
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** Capt Ross **EXT.:** 32377
PRIME CONTRACTOR: University of Minnesota
PURPOSE:

The purpose of this task is to investigate a means of starting a supersonic wind tunnel with pressure ratios essentially equal to those required for running at a given Mach number. Recent theoretical work has indicated that a large part of the energy and compressor capacity needed to operate conventional supersonic wind tunnels with fixed geometry diffusers are required because of the starting process. Experimental verification of the starting process and the development of a starting technique may result in the saving of considerable power for future large scale supersonic wind tunnels.

TO DATE: Experiments were conducted on the $M=3.47$ test channel with a choking diffuser installed. It was found that regardless of the pressure ratio provided in the test channel it was impossible to establish stable supersonic flow even with a shock tube pressure pulse. It was observed that the pressure pulse did shift the shock pattern but the choking shock condition soon returned in the nozzle. Peak pressures as high as 5 atm. were recorded in the stagnation chamber due to starting shock tube pulse. A nozzle exit pressure of .1 atm. provided an overall pressure ratio of 50 which still did not establish satisfactory flow with the choking diffuser installed.

Future tests will include the application of a vane type diffuser to permit bleeding-off some of the air mass during the starting process so as to permit the normal shock to travel downstream.

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TITLE: Perforated Throat Type Transonic Wind Tunnel
TASK NO.: 465-6-4 **PRIORITY:** 2 **EST. COMPLETION:** July 1953
SECURITY: Confidential **RESPONSIBLE SCIENTIST:** E.G. Johnson **EXT.:** 32377
PRIME CONTRACTOR: Cornell Aeronautical Laboratory
PURPOSE:

The purpose of this task is to investigate the aerodynamic characteristics of a perforated plate type transonic wind tunnel test section.

The limitations on transonic wind tunnel testing have been very critical in high speed aircraft development. Large test sections and very small models have been the only acceptable solution to date, which leads to large expenditures for tunnel construction and questionable data from small models. A recent solution to this dilemma is the theory advanced on development of effective

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wave cancellation methods in the test section. One such method presently considered is the porous type test section which is proposed for this project.

TO DATE: The primary objective of current perforated throat research is to study the shock absorption characteristics of a perforated plate as influenced by the dimensions of the plate, the mass flow of air removed through the plate and the condition of the boundary layer over the plate.

Experiments have been made at a Mach number of 1.20, using both two and three dimensional bodies to generate compression shock waves to be impinged on a section of perforated plate on the floor of the tunnel. Pressure distribution on the floor and in the field between the floor and the model were measured. Data were obtained on boundary layer removal by the plenum section and increased diffuser efficiency due to discharging high energy air into the diffuser. As considerable pressure data were taken, the reduction and plotting of this data will be extremely beneficial in considerations pertaining to the design of a large scale facility.

TITLE: Research on Hypersonic Wind Tunnels
TASK NO.: 465-6-7 PRIORITY: 2 EST. COMPLETION: January 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Capt Ross EKT.: 32377
PRIME CONTRACTOR: California Institute of Technology
PURPOSE: The purpose of this task is to obtain data necessary for the proper design of large scale hypersonic wind tunnel facilities.

The condensation of air components is possible under certain operating conditions in hypersonic wind tunnels. The "how and when" of the phenomenon are not fully known; however, such knowledge is a prerequisite to the design of a satisfactory tunnel.

TO DATE: Memorandum No. 6 issued by C.I.T. under Contract DA-O1-495-ORD-19, jointly sponsored by Army Ordnance and USAF, fully covers this investigation.

As a part of this program on hypersonic tunnel research, an investigation was made of the supersaturation characteristics of air. A small stainless steel, two dimensional source flow nozzle supplied with bottled nitrogen was used for the condensation investigation. It was found that the nitrogen super-saturates at approximately 15°K or 1.2 Mach number when expanded from stagnation conditions of .70°F and pressures of 8.21 and 16.15 atm. A numerical method for solving the equations of motion with the aid of the experimental data allows the computation of the fluid temperature during the condensation process. The addition of small

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amounts of carbon dioxide reduced the degree of supersaturation obtainable with bottled nitrogen. This investigation has provided the first fundamental insight on the mechanisms of condensation.

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TITLE: Hypertballistic Research
TASK NO.: 465-6-8 PRIORITY: 2 EST. COMPLETION: June 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Capt Ross EXT.: 32377
PRIME CONTRACTOR: Naval Ordnance Laboratory
PURPOSE: The purpose of this task is to provide criteria for future hypersonic research facilities.

TO DATE: Experiments conducted in the NOL 12 x 12 cm. continuous hypertballistic wind tunnel have defined the limitations of present supersonic wind tunnels. Measurements of pressures in the nozzle show that air condensation occurs if flow pressure and temperature fall below the saturation line of air. This condensation can be eliminated by preheating the supply air of the wind tunnel. Tentative experimental criteria of minimum supply temperatures to minimize air condensation effects on the flow in the test section are presented. It is found that only static pressure and shock angle measurements are sensitive to air liquefaction effects. Results of the thermodynamic treatment of the condensation process and some measurements on boundary layers and possible flow separation at high Mach numbers have been evaluated.

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TITLE: Air Foil Cascades
TASK NO.: 465-6-9 PRIORITY: 2 EST. COMPLETION: March 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: M. Lawson EXT.: 32377
PRIME CONTRACTOR: Purdue University
PURPOSE: The purpose of this task is to investigate various cascade of airfoils having specific applications to wind tunnel compressors.

The trend toward large single unit axial flow compressors for powering supersonic wind tunnels makes it necessary that such equipment be designed to result in maximum performance at minimum cost. This problem is complex and needs to be attacked from many angles; one attack is to develop blade sections having characteristics peculiar to wind tunnel needs.

The basic requirements for such a blade section are a high critical Mach number and insensitivity to moderate changes in

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incidence angles. Present blade sections have a critical Mach number, approximately 0.9. However, changes in incidence angles drastically lowers this limiting Mach number and forces the designer to select his design point at somewhat lower values. This research program will investigate through the use of stationary blade cascades and blade shapes, which better satisfy the above requirements than presently available sections.

TO DATE: Tests were conducted on a cascade model incorporating blade sections as proposed by the Westinghouse Electric and Manufacturing Company for use in the Propulsion Wind Tunnel Compressor slated for installation at AEDC. Runs at 0°, plus 3° incidence angles have been completed; analysis of these data is now underway. Additional tests at plus 6° and minus 6° incidence angles are planned for the very near future. On completion of these runs further investigation of the effect of nose shape on choking sensitivity as a function of incidence angles will be studied experimentally.

Two technical reports on experimental phases of the research contract were completed and distributed during the month of February. Copies of these reports have been received by Flight Research Laboratory and are listed below:

"Supplemental Tests on Effect of Blade Height and Upstream Turbulence", R. C. Binder

"Summary Report on Tests with Different Nose Shapes", R.C. Binder

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TITLE: Supersonic Nozzles and Diffusers
TASK NO.: 465-6-10 PRIORITY: 2 EST. COMPLETION: March 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: E. Walk EXT.: 32377
PRIME CONTRACTOR: University of Texas
PURPOSE: The purpose of this task is to provide added information on the design of supersonic test channels with emphasis on nozzles and diffusers. Reduction of tunnel losses and thereby increasing overall tunnel efficiency is of prime importance in the design of experimental aerodynamic testing facilities. The largest part of these losses occur in the diffusers and nozzle section. This proposal concerns itself with the analysis of the losses and recommendations for minimizing them.

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TO DATE: A report, "Aerodynamic Characteristics of Nozzles and Diffusers for Supersonic Tunnels", received from the contractor is summarized in this part as follows:

In the experimental results covered in Part I, the performance of subsonic conical diffusers with fully turbulent flow at the diffuser inlet are reviewed. Experiments were conducted at 4° and 6° total expansion angle and investigations were made at area ratios of 3, 6, and 9. The total pressure recovery was determined as a function of available energy at the diffuser entrance. Results are included from experiments on three-dimensional supersonic nozzles for a Mach number of 5. The nozzle studies were an axi symmetric nozzle of circular cross section and an asymmetric nozzle of square cross section.

In Part II, a method is presented for calculation of the boundary layer growth in the case of steady, two dimensional, incompressible flow with an adverse pressure gradient. The ultimate aim is to derive a method for making calculations of this sort for the case of compressible flow, and the significant feature of the present method is that it may be extended to take account of compressibility. Comparison of theoretical calculations and experimental results show a fair correlation. It is believed that further refinement of the theory will lead to satisfactory correlation.

<u>TITLE:</u>	Adjustable Supersonic Nozzle
<u>TASK NO.:</u>	465-6-11
<u>SECURITY:</u>	Unclassified
<u>PRIME CONTRACTOR:</u>	University of Michigan
<u>PURPOSE:</u>	The purpose of this task is to provide criteria for adjustable nozzle design for supersonic wind tunnels. Experience to date has necessitated the fabrication of nozzle blocks for various Mach numbers in test channels. The NACA has produced variable corner nozzles but the flow has not been too acceptable to date. It is proposed to design a satisfactory variable Mach number nozzle and evaluate the performance characteristics.
	<u>PRIORITY:</u> 2 <u>EST. COMPLETION:</u> December 1952
	<u>RESPONSIBLE SCIENTIST:</u> E. Walk <u>EXT:</u> 32377

TO DATE: Experiments on the modified subsonic and transonic regions of the corner nozzle were completed. The results indicate that the modification of the original contour has eliminated the separation from the leading edge of the lower block in the $M=1.40$ position. Therefore, the flow up to and including the sonic line may be considered satisfactory for the Mach number range 1.4 and 4.0 on the basis of the investigation conducted at the limits of the range. Satisfactory agreement between theory and experiment has been achieved for these regions of the nozzle flow.

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Fabrication and assembly of ducting to the air reservoir is nearing completion. The nozzle design is progressing with details now being completed. Most of the preliminary instrumentation design has been accomplished. An investigation into the accuracy of interferometer in supersonic flow has been written up as Wind Tunnel Memorandum 226.

TITLE: Research on Scavenging Systems
TASK NO.: 465-6-12 PRIORITY: 2 EST. COMPLETION: February 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: E. Walk EXT.: 32377
PRIME CONTRACTOR: Cornell Aeronautical Laboratory
PURPOSE: The purpose of this task is to obtain data which can be used in designing suitable scavenging systems for supersonic wind tunnels. Proper simulation of altitude operating conditions of power plants in a wind tunnel, requires adequate removal of the products of combustion. Contamination of the main air stream with even a small percentage of exhaust gases would in a short time invalidate test results. Removal of exhaust gases discharged into a supersonic air stream has introduced a whole battery of aerodynamic design problems which must be evaluated to assure the development of a satisfactory scavenging system.

TO DATE: Progress has been slowed down due to the use of the 8' x 10' wind tunnel on higher priority projects. Re-examination of previously obtained data is underway in an effort to obtain better correlation with the work of other investigations in this field.

TITLE: Wide Angle Diffuser Study
TASK NO.: 465-6-13 PRIORITY: 2 EST. COMPLETION: December 1952
SECURITY: Unclassified RESPONSIBLE SCIENTIST: R.H. Mills EXT.: 32377
PRIME CONTRACTOR: United Aircraft Corporation
PURPOSE: The purpose of this task is to investigate a means of improving the efficiency of wide angle diffusers for wind tunnels. The problem of increasing tunnel efficiency is essential in test facility design. The major subsonic losses occur in the diffuser section; thus, concentration of effort to increase overall

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efficiency is concerned with this diffuser section. A proposed wide angle diffuser appears to provide a possible improvement on previous designs. A thorough analysis of this problem is very well justified in view of considerable future aero facility development.

TO DATE: By employing suction and wall curvature to control the boundary layer, an idea conceived by Dr. A.A. Griffith, several wide angle diffusers were designed and tested with very favorable results. It was possible to operate diffusers of approximately 2 to 1 area ratio and 20° equivalent cone angle at a net effectivenesses, including suction power, of 94% for inlet Mach numbers as high as 0.80. The internal portion of the diffuser flow, that is, all the flow except the portion removed at the suction slot, closely resembles a potential flow field such that the total head distribution at the exit of the diffuser is very nearly uniform.

There appears to be a practical limit to the magnitude of angles at which these diffusers are feasible. For example, it was not practical to operate a 4.25 to 1 area ratio diffuser with an equivalent conical angle of 40° because of its extreme sensitivity to slight disturbances. In order to eliminate this sensitivity it was necessary to remove an excessively large portion of the inlet flow. However, it has been shown that within its limits this type diffuser can out perform an equivalent conical diffuser of much greater length and thus may have many applications.

<u>TITLE:</u>	Flow Visualization Research
<u>TASK NO.:</u>	465-6-14
<u>SECURITY:</u>	Unclassified
<u>PRIME CONTRACTOR:</u>	University of California
<u>PURPOSE:</u>	The purpose of this task is to conduct a fundamental investigation of flow visualization at very low pressure, where existing Schlieren and interferometer techniques no longer have sufficient sensitivity to permit observation of the flow.
	<u>PRIORITY:</u> 2 <u>EST. COMPLETION:</u> Continuing
	<u>RESPONSIBLE SCIENTIST:</u> Capt Ross <u>EXT.:</u> 32377

TO DATE: Tests in the transparent pipe equipment, using dry air and an R.F. Discharge have been completed. Several runs were made in the No. 3 wind tunnel using a cross stream electrode system with 60 cycle A.C. power. Both hollow cathode and hemispherical electrode geometries were tested. A long life moderate intensity afterglow was produced with air, allowing photographic studies to be made. The persistence of this afterglow hampered the tests by increasing the background density of the photographs. Methods of quenching this persistence after the stream has passed through the test chamber are now being investigated.

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The addition of NO to the air stream as a means of increasing the glow was investigated with RF excitation. For low power inputs (1/4 to 1/2 KW input to RF oscillator) the addition of approximately one-tenth of one percent NO to the main stream, no visual increase could be noticed, leading to an assumption that a saturation intensity level had been reached.

Spectrographic observations of the separate types of nitrogen glow confirms the belief that both a long life Loree-Raligh afterglow and a second ~~shortlife more intense afterglow~~ can be excited. Ion probe measurements of the two afterglows produced in the transparent pipe equipment indicates that no abnormally high ion level exists in the short life intense afterglow. Final spectra and absorption data have been collected for two reports to be issued describing the 1470A oxygen, absorption flow visualization of a strong source of 1450A and a second report will deal with the performance tests of the vacuum spectrograph monochromator used for the absorption investigation.

TITLE: Research on Mixing Process of Jet Impinging Into a Stream of Large Mass
TASK NO.: 465-6-17 PRIORITY: 2 EST. COMPLETION: March 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: E. Walk EXT: 32377
PRIME CONTRACTOR: University of Illinois
PURPOSE: The purpose of this task is to investigate analytically the turbulent mixing process of two merging air streams flowing at different velocities.

The mixing of two fluid streams occurs many times in modern aircraft machinery, e.g., jet propulsion devices, scavenging in propulsion wind tunnels, jet pumps, etc. There are cases where the secondary flow is induced by the primary jet only, but often the secondary stream has a velocity before mixing occurs. For proper evaluation and design of the component parts, such as flame holders, augmentation devices, tail cones and for proper design of scavenging systems of propulsion tunnels, the knowledge of the mixing mechanism is necessary. However, no complete understanding of this mechanism exists, in spite of the numerous investigations which have attempted to clarify the mechanism involved in the mixing of two streams.

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TO DATE: This program is concerned with the theoretical analysis of three different flow cases and progress on each is indicated as follows: (1) Laminar, incompressible, non-symmetric case: two similar approximate analysis using different boundary conditions have been made. The numerical work on both has been started. (2) Laminar, compressible, symmetric case: the analysis has been completed and is ready for numerical work. (3) Turbulent, incompressible, non-symmetric case: the basic analysis of the mixing of two turbulent incompressible streams with different velocities has been completed.

The numerical work for the approximate solution in the laminar, incompressible, non-symmetric case has been completed. The exact solution of this is being analyzed. A technical report using the Von Karman similarity concept for the turbulent, incompressible, symmetric case has been written and will be published soon.

TITLE: Heat Transfer to Flat Surfaces in Supersonic Flow
TASK NO.: 465-6-19 PRIORITY: 2 EST. COMPLETION: April 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: E. Walk EXT.: 32377
PRIME CONTRACTOR: Massachusetts Institute of Technology
PURPOSE:

The purpose of this task is to provide data that can be used to predict heat transfer rates and wall temperatures in supersonic wind tunnel test section. The problem of transfer of heat from a supersonic stream to a surface is of great importance in the design of large supersonic wind tunnels where every effort is being made to simulate free flight stagnation temperature. At the higher Mach numbers these temperatures become quite high, and information on how much heat is transferred to the tunnel walls is essential to the design of test section, windows and support systems. In the case of large supersonic wind tunnels, where the operating cost is high, the question is - how long will it take after a run for the tunnel to cool down enough to permit an operator to enter and make adjustments or modifications. If the time is too long, the increased initial cost of cooling this portion of the tunnel will have to be accepted.

TO DATE: Technical reports are now being prepared on the literature survey, plate and instrumentation design, mounting device design, and several theoretical studies on temperature distributions in the wind tunnel stilling chamber.

Tests are underway in the supersonic laboratory wind tunnel to determine recovery factors on a flat plate. Several preliminary tests indicated the need of minor modifications which are included in the revised design. The experi-

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ments now going on will investigate the following parameters: (1) Recovery factors for laminar and turbulent layers. (2) Laminar and turbulent velocity and temperature profiles. (3) Boundary layer growth. (4) Effect of surface roughness on 1 and 3 above.

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TITLE: Measurement of Free-Stream Static Pressure at Supersonic Speeds
TASK NO.: 465-6-23 **PRIORITY:** 2 **EST. COMPLETION:** March 1953
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** R.H. Mills **EXT:** 32377
PRIME CONTRACTOR: University of Michigan
PURPOSE: The purpose of this task is to develop a device for measuring accurately, free-stream static pressure at supersonic velocities. Well designed and constructed wind tunnels are of no avail unless adequate instrumentation is available to measure satisfactorily the test conditions. In addition to research and development on tunnels, it is also essential that advancements in instrumentation techniques be made. The accurate measurement of free stream static pressure is a very desirable accomplishment. The proposed program advances an idea for a means of evaluating this parameter.

TO DATE: The following referenced report has been submitted by the contractor which completes the study on this task. The reproducible copy has been forwarded to the Document Service Center for future demand distribution and can be referenced as follows:

Bailey, H.E. & Phinney, R.E., "An Experimental Evaluation of a Wedge Type Free-Stream Static-Pressure Probe", University of Michigan, Engineering Research Institute WRM-227, Final Report, Contract AF33(038)-20799, May 1952.

The statistical study made at Mach number 1.90 indicates that the probable error for a measurement of the static pressure is 0.5 percent. The measurements indicate no tip effect at Mach number 1.90 and 2.85. However, at Mach number 1.45 there is a definite tip effect which makes itself felt both directly and through its interaction with the effects due to angle of attack, surface

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roughness and leading edge bluntness. Except for the instances in which the tip effect interacts with some other effect, the wedge probe reacts to variations in such parameters as angle of attack, surface roughness, leading edge bluntness, roll and yaw, in the manner predicted by theory.

Since the wedge probe responds to variations in angle of attack in a linear manner, its use as a device to simultaneously measure static pressure and flow inclination makes it a good instrument for the calibration of supersonic wind tunnels. Also, the use of the wedge probe for the determination of static pressure in free flight possesses certain advantages over the use of a needle pressure probe.

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TITLE: Supersonic Wind Tunnel Skewed Diffuser Investigation
TASK NO.: 465-6-24 PRIORITY: 2 EST. COMPLETION: August 1952
SECURITY: Unclassified RESPONSIBLE SCIENTIST: R.H. Mills EXT.: 32377
PRIME CONTRACTOR: None. Work being accomplished at WADC
PURPOSE: The purpose of this task is to obtain data from model tests and thus evaluate the actual performance of a skewed diffuser.

TO DATE: This project has been completed and will be closed out as soon as the final report is reviewed by Flight Research Laboratory.

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TITLE: Experimental Investigation of High Mass Flow Wind Tunnel Compressors
TASK NO.: 465-6-25 PRIORITY: 2 EST. COMPLETION: December 1952
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Dr. Hans Von Ohain EXT.: 32377
PRIME CONTRACTOR: Propulsion Research Corporation
PURPOSE: The purpose of this task is to investigate a method of increasing the mass flow through wind tunnel compressors. With recent Aero Facilities Expansion, the need for higher mass flow compressors is essential. A new method of design and evaluation of a "High Mass Flow" axial-flow compressor is proposed. This work is a continuation of previous work carried on at Northrop Aircraft Co.

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TO DATE: Installation of the test compressor and instrumentation has been completed. Shakedown testing is now in progress; first data taking runs should start about 15 July. Since the last reporting date, the following analytical studies have been undertaken: (1) Performance of high mass flow compressors with blade angle shift. (2) Specific calculations to show the "full radius ratio" test compressor operation with variable stationary blading stagger angles. (3) Operation of compressor into the higher transonic Mach number region by removal of the guide vanes. (4) The use of stationary inducers to give more freedom of choice of both tangential and axial velocity distribution.

TITLE: Research on Porous Wall Transonic Wind Tunnel Configurations
TASK NO.: 465-6-26 PRIORITY: 2 EST. COMPLETION: November 1952
SECURITY: Confidential RESPONSIBLE SCIENTIST: E.G. Johnson EXT: 32377
PRIME CONTRACTOR: United Aircraft Corporation
PURPOSE: The purpose of this task is to obtain data on the performance and basic design parameters of porous wall transonic wind tunnel test sections. The problem of cancelling or minimizing the effect of shock wave reflection from a jet boundary striking the model under test, is a fundamental problem which must be solved before successful testing at transonic speeds can be realized. For the past two years, United Aircraft Corporation has been investigating the field of transonic flow with most of its efforts concentrated on: (a) the problem of using porous surfaces to absorb shock waves and (b) use of supersonic test stream surrounded by a subsonic stream to reduce interference and choking effects.

TO DATE: A report containing the results and conclusions derived from small scale studies conducted at the research department of the United Aircraft Corporation covering a speed range from a Mach number of .8 to 1.6 has been received from the contractor.

Specifically, the results presented therein were obtained from studies of a 6" by 6 1/4" porous wall transonic test section in combination with fixed two dimensional solid nozzles designed to generate flows of 1.0, 1.3, and 1.6 Mach number. The studies were directed toward obtaining information relative to flow uniformity, boundary layer removal techniques, and power requirements. Auxiliary suction was utilized to control the plenum tank pressure surrounding the test section. The porous boundaries were made up of perforated plates having a hole

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diameter of 0.020 inches, a wall thickness of 0.017 inches, and a porosity (open area/total area) of 20%. Most of the data presented were obtained with only two walls porous to determine the effect on flow uniformity.

TITLE: Aerodynamic Heater
TASK NO.: 465-6-27 PRIORITY: 2 EST. COMPLETION: Continuing
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Capt Ross EXT.: 32377
PRIME CONTRACTOR: Polytechnic Institute of Brooklyn
PURPOSE:

The purpose of this task is to develop a heating system which will allow high Mach number flight stagnation temperature simulation in a hypersonic wind tunnel. The problem of simulating flight stagnation temperatures at high Mach numbers is very severe. For instance, at a Mach number of 15 stagnation temperatures of the order of 17,000° may occur. There have been two experimental approaches to this problem suggested. One, the use of an impulse type of compression-heater system; this system will permit temperatures of the above order to be obtained but the practical run duration is very limited, around one tenth of a second. This system will be considered in a separate RDO.

TO DATE: The portion of a technical report presenting the analysis of the idealized compression heater has been completed; the presentation of the results of various heat transfer calculations which indicate how the idealized performance of the compression is affected by heat transfer, is underway. The analysis substantiates earlier conclusions as to the feasibility of constructing such a heater. It also points out that the "critical design factor" at the moment is the radiative heat transfer rate between the hot compressed gases and the walls of cylinder in which they are contained. Further work is planned to quantitatively define this phenomenon prior to going ahead with the fabrication of a model heater.

TITLE: Rotating Diffusers
TASK NO.: 465-6-28 PRIORITY: 2 EST. COMPLETION: Continuing
SECURITY: Unclassified RESPONSIBLE SCIENTIST: Dr. H. Von Chain EXT.: 32377
PRIME CONTRACTOR: Propulsion Research Corporation
PURPOSE: The purpose of this task is to investigate a device (the rotating diffuser) for decelerating a supersonic airstream to a subsonic velocity. It is anticipated that such a device will be an

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improvement over present diffusion methods for large supersonic Wind Tunnels. Reduction of the power requirements of supersonic wind tunnels is a problem which assumes greater proportions with the increase of test section size. The energy losses associated with conventional types of diffusers are high; reduction of these losses by even a small margin is the constant aim of wind tunnel designers. Improvements in diffuser efficiency would, in a particular design, result in smaller drive power requirements, reduced physical size of compressor plants, and substantial savings in construction and operating costs.

Present design practices in small tunnels are to utilize flexible walls in diffusers in an attempt to control the inevitable "shock". Such control aims at causing the shock to occur in a minimum area section (called a second throat) where the Mach number approaches unity. This aim, while desirable, is difficult to attain for a test Mach number above 2. This method is difficult to employ in a large tunnel because of the mechanical problems encountered in the manufacture of large, accurate, flexible plates.

TO DATE:

Contract has been negotiated. No technical progress to report.

TITLE:

Research on Structures Test Facilities

TASK NO.:

465-6-29 PRIORITY: 2 EST. COMPLETION: March 1953

SECURITY:

Unclassified RESPONSIBLE SCIENTIST: E.G. Johnson EXT: 32377

PRIME CONTRACTOR:

Polytechnic Institute of Brooklyn

PURPOSE:

The purpose of this task is to investigate facilities suitable for the testing of structural elements under conditions simulating the effects of aerodynamic heating. In the past decade considerable advancement has been made in the fields of aerodynamics and propulsion. The advances made during the same period in structural design and analysis are, in comparison, insignificant. Without adequate airframes, it will be impossible to utilize presently developed power plants. This critical structural state has been partly due to the lack of test facilities which can properly simulate free flight conditions and applicable structural theory.

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One of the current major structural problems is the thermal effects in aircraft structures. This condition is encountered at supersonic velocities due to aerodynamic heating. The program, "Use of High Frequency Induction Heating Equipment", is proposed to investigate a promising approach to one of the problems of facilities for simulating the effect of aerodynamic heating on aircraft structures.

TO DATE:

Contract has been negotiated. No technical progress to report.

TITLE:
TASK NO.:
SECURITY:
PRIME CONTRACTOR:
PURPOSE:

Research on a Facility for Simulating Atmospheric Gusts
465-6-30 PRIORITY: 2 EST. COMPLETION: August 1953
Unclassified RESPONSIBLE SCIENTIST: E.G. Johnson EXT: 32377
Not Available

The purpose of this task is to develop a test facility from which experimental data on gust loads as a function of planform aspect ratio and gust shape, can be obtained, which could be utilized as design criteria for future high speed aircraft.

The present trend in high speed aircraft designs have led to the production of aircraft with very thin wings and high landings and takeoff speed. This trend has amplified the critical need for more data on the gust load as a function of planform, aspect ratio, and gust shape. Theoretical studies have been made on gust effects but experimental data for their support are very limited. If a method is found for the production of gusts of a predictable intensity at low speeds, it is quite possible that this method could be used at higher velocities. The data obtained could then cover landing, takeoff and higher speed conditions.

TO DATE:

The contract is being negotiated.

TITLE:
TASK NO.:
SECURITY:

Gas Turbine Drives for Wind Tunnels
465-6-31 PRIORITY: 2 EST. COMPLETION: Continuing
Unclassified RESPONSIBLE SCIENTIST: Dr. H. VonOhain EXT: 32377

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Project No. 465-6-31 (Cont)

PRIME CONTRACTOR: None. Work being accomplished at WADC.

PURPOSE: The purpose of this task is: (1) To determine the feasibility of, and problems associated with, building a gas turbine drive system in the 750,000 - 1,000,000 horsepower range for use on large supersonic wind tunnels; (2) Prepare a design study on a gas turbine drive for varying a wind tunnel with test section area of 300 - 400 square feet.

TO DATE: A brief study has been made of the use of a number of standard aircraft de-icing axial flow blowers for studying the possible instability of a number of compressors discharging into a common duct. Units currently in use on the B-47, F-80, and C-119 appear satisfactory for use in such an experiment. Arrangements will be made to acquire approximately 10 units to set up a model test rig for the investigation of stability and control problems.

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PROPULSION RESEARCH BRANCH

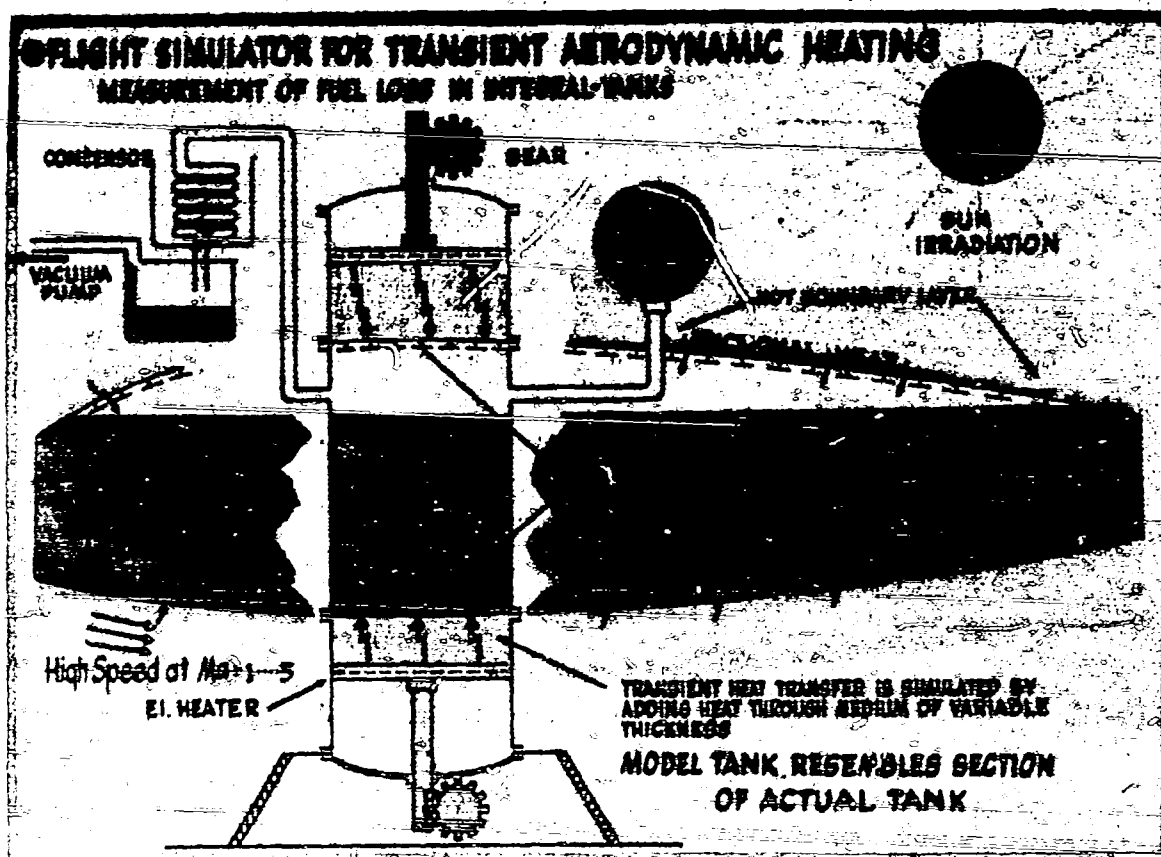
The Propulsion Research Branch plans, monitors, and performs applied research in areas of science which relate to the propulsion of aircraft. Further, it conducts applied research to the extent of assessing the practicability of new or unused scientific principles and indicating the methods whereby such principles may be used in the development of improved equipment. An Energy Release Processes Research Section is responsible for research in energy release processes, such as the release of energy from chemical and nuclear fuels in a form suitable for utilization in propulsion devices. The Mass and Energy Dynamics Research Section performs work such as research in fluid dynamics and aero-elasticity of propulsion equipment together with all research in mass and energy transfer processes. An Energy Systems Analysis Research Section is responsible for energy systems analysis research such as the theoretical and experimental analysis of aircraft propulsive systems, investigations of the dynamics of such systems, and comparative performance evaluations of these systems.

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FLIGHT SIMULATOR FOR TRANSIENT AERODYNAMIC HEATING

Upon request of a leading aircraft manufacturer, the Propulsion Research Branch of the Flight Research Laboratory recently established a project (R-467-2-16) for the investigation of fuel losses due to aerodynamic heating from integral wing tanks of a long-range, high-speed aircraft. After an analysis of the problem, it was deemed feasible to attack the transient heat transfer problem related to fuel evaporation by aerodynamic heating to a greater degree of accuracy by experimentation rather than by analytical means. The proposed method calls for a relatively simple laboratory bench rig consisting of three major components: a heat source (as substitute for the hot boundary layer), a test surface (as substitute for the skin of the airplane) and a heat sink (as substitute for internal heat consumption of the airplane). Such an experimental attack appears promising since



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"Flight Simulator for Transient Aerodynamic Heating" (Cont)

it is found possible to simulate the transient external and internal heat transfer conditions in the laboratory by relatively simple means.

At the present time, a simulator of kind shown is under construction for use in solving fuel loss problems in connection with MX-1626. It is expected that this simulator will materially decrease the cost and time required to accomplish this development, supplanting elaborate flight-test and wind-tunnel experimentation that would otherwise be necessary. It is hardly possible to estimate the monetary savings to the Air Force which may accrue as a result of the introduction of this simulator. However, some concept of the possible impact of this device may be gained from consideration of the fact that the NACA projects a new \$4,000,000 wind-tunnel facility for investigation of the effect of aerodynamic heating on structural strength; this simulator, if successful, would obviate the necessity for tunnel test of complete structures and reduce the problem to one of high-temperature materials testing.

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TITLE: Combustion of Liquid and Gaseous Fuels
TASK NO.: 467-1-4 **PRIORITY:** 2 **EXT. COMPLETION:** 15 October 1953
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** L. E. Dunn **EXT.:** 27153
PRIME CONTRACTOR: Battelle Memorial Institute
PURPOSE: The purpose of this task is to make a comprehensive study of the physical and chemical phenomena associated with the combustion of liquid and gaseous fuels with the objective of building a firm basis of scientific knowledge upon which the design of combustion equipment and the control of combustion processes can be based.

TO DATE: In Phase 1, "Reactions During the Combustion of a Gas", the experimental program on the detection of free radicals by the indirect method using the mass spectrometer has been halted temporarily to permit the use of the instrument on Phase 5. Investigations of the use of the chemical reagent DPH for the study of intermediates in combustion reactions are continuing.

Major progress has been made, in Phase 2, "Burning Characteristics of Fuel Mists", in the experimental determination of drop-size distribution for liquid fuel mists, using the six-stage cascade impactor.

As part of Phase 5, "Effect of Imposed Physical Influences on the Combustion Process", a new concept of the mechanism by which atmospheric oxygen affects Bunsen flames has been presented and experimental data verifying the concept have been obtained. Investigations under Phase 5 have also led to a new concept of flame stability for laminar Bunsen flames and experimental data obtained are in agreement. The mass spectrometer, transferred from Phase 1, is finding a useful application in the study of stability.

In Phase 6, "The Combination of Mixed Fuels", a new apparatus has been built for studying the stability of flames of premixed air and fuel in both laminar and turbulent flow.

A comprehensive review of research on spark ignition in gases was recently released under Phase 7, "Ignition Processes". The best known of the early work and all recent work on spark ignition are described and evaluated in this report to provide a ready reference as to the contents and relative merits of the often quoted references on this subject.

Work is now underway on Phase 8, "Similarities in Combustion", after a somewhat slow beginning. As a first step in the correlation and application of data from combustion experiments, Hirschfelder's equations for the transport properties of gases are being examined in the light of the theory of corresponding states.

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TITLE: Detonative Combustion
TASK NO.: 467-1-5 **PRIORITY:** 2 **EST. COMPLETION:** February 1953
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** Lt E. Dunn **EXT.:** 27153
PRIME CONTRACTOR: University of Michigan
PURPOSE: The purpose of this task is to investigate the fluid mechanics and physical chemistry of detonation.

TO DATE: A report covering all research work carried out under the contract to date has been completed and will be released in the near future. Work to date includes the development of the necessary equipment for the timing and photographing of detonation waves and shock waves in the shock tube and the measurement of experimental detonation velocities for various gaseous mixtures. Analyses of detonation processes were made which connect the thermodynamic properties of a detonation explicitly to the dynamic properties. From these theoretical analyses, a normalizing parameter which could be used to correlate experimental detonation velocities was obtained. The solution of the one-dimensional unsteady flow problem associated with shock tubes and as applied to detonative combustion was carried out. All experimental detonation velocities obtained were correlated by means of two dimensionless relations; one a heating parameter, and the other the Mach number of the detonation.

A paper entitled, "A Study of Detonative Phenomena in Gaseous Mixtures by the Use of Shock Tube Techniques" was presented by University of Michigan personnel during June 1952 at the meeting of the American Society of Mechanical Engineers in Cincinnati. This paper contained essentially a summary of the information given in the above-mentioned report.

The research work is now being extended to other phases of investigation of detonation in non-flowing gas mixtures. Experimental studies, including photographs, are being made of a moving detonation wave in ducts of non-uniform cross section, in order to supplement and/or test existing theories of propagation, particularly with reference to change of cross-section, obstructions and possible boundary layer effects.

TITLE: Kinetics of Hydrocarbon Oxidation and Collisions in Gases
TASK NO.: 476-1-6 **PRIORITY:** 2 **EST. COMPLETION:** October 1952
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** Capt J. Bierlein **EXT.:** 27153
PRIME CONTRACTOR: Bureau of Mines
PURPOSE: The purpose of this task is to investigate the mechanism of the initial attack of hydrocarbons by oxygen and the application of modern kinetic theory of gases to the prediction of the number of binary and ternary collisions per unit of time under specified conditions of temperature and pressure.

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Project No. 467-1-6 (Cont)

TO DATE: Work has centered about the oxidation of carbon monoxide, formaldehyde, and acetaldehyde - all of which are believed to be important intermediates in the combustion of hydrocarbon fuels. The Bureau of Mines has succeeded in adding considerable quantitative detail to existing knowledge of the kinetic of these substances, and techniques have been developed which have made it possible to identify the various peroxy compounds which are formed in the combustion process. However, it does not appear that much practical use can be made of this information until it is integrated with the various hydrodynamic and molecular processes which also govern the overall combustion process. As a step in this direction, another phase of this project is aimed at improving the present understanding of collision processes between molecules, especially with respect to energy exchange and the formation of activated complexes. A theoretical study has been in progress which has led to the formulation of a modified kinetic theory of gases, in which account is taken of the effect of intermolecular forces; previous treatments of real-gas kinetics have not emphasized the effect of chemical reaction. This study, although by no means complete, has reached a stage of development warranting the publication of an interim report of findings; this report is now in preparation.

An additional sub-task has recently been incorporated into this project to exploit an effect discovered independently by the contractor - the arrest of flame propagation by high shear rates in gases. It is believed that this phenomenon (which can be interpreted solely on the grounds of hydrodynamics and heat transfer) may explain many of the observed characteristics of turbulent flames, especially those stabilized on flame holders. Progress to date has consisted of the design and construction of suitable apparatus for testing the provisional theory. It is expected that the results of the experiments to be performed may have immediate and fruitful application to the design of operational equipment.

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<u>TITLE:</u>	Kinetics of Rocket Exhaust Gases
<u>TASK NO.:</u>	467-1-7 <u>PRIORITY:</u> 2 <u>EST. COMPLETION:</u> June 1953
<u>SECURITY:</u>	Unclassified <u>RESPONSIBLE SCIENTIST:</u> Capt J. Bierlein <u>EXT:</u> 27153
<u>PRIME CONTRACTOR:</u>	Aerojet Engineering Corporation
<u>PURPOSE:</u>	The purpose of this task is to improve present methods of predicting performance (thrust, combustion efficiency, etc.) by the spectrographic measurement of the temperature and composition of rocket exhaust gases.

TO DATE: This project was established to develop the techniques of emission spectroscopy for the measurement of local values of composition and temperature in rocket exhaust gases. Contingent on the success of the technique, it was

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Project No. 467-1-7 (Cont)

hoped that the method might be adapted to the observation of combustion and expansion processes in transparent rocket engines. This would make possible the station by station comparison of the real and ideal behavior of the working fluid and afford valuable clues for improving the design of the engine.

The contractor has now completed a one year program of experimentation in which a large number of spectrograms has been made in both the visible and the infra-red ranges of wave length. The results are summarized in WADC Technical Report 52-108. The results have been primarily negative; it appears that most of the important chemical species in exhaust gases do not emit with sufficient intensity to make this a practical method of gas analysis. There is a possibility that temperature measurements can be made by using either a strong line or band naturally present in the gas or by introducing a small quantity of a strong emitter. However, it is questionable whether any method that might be developed would possess significant advantages over those already available.

It is clear that the application of spectroscopic observation to rocket gases is not so straightforward and immediately useful as had been hoped. The use of absorption, rather than emission, methods might lead to more encouraging results, although it is by no means certain that successful results will be obtained.

TITLE: Thermodynamic Properties of Combustion Products of Kerosene-Air Mixtures
TASK NO.: 467-1-9 **PRIORITY:** 2 **EST. COMPLETION:** September 1952
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** Capt J. Bierlein **EXT:** 27153
PRIME CONTRACTOR: Bureau of Mines
PURPOSE: The purpose of this task is the preparation of tables and charts of the thermodynamic properties and equilibrium composition of the combustion products of kerosene-air mixtures over an extended range of temperature and pressure.

TO DATE: This is a computing project established with the Bureau of Mines for the purpose of producing a standard self-consistent tabulation of thermodynamic data for use in performance estimates on air breathing engines. Using a simple hydrocarbon (decene) to typify present-day jet fuels, the properties of the combustion products (temperature, enthalpy, entropy) have been computed for a range of pressures, initial air temperatures, and mixture strengths which is adequate to cover engine operating conditions. The tabular data are now complete and are being reduced to convenient graphical form at WADC under RDX 467-4-2. The present project will be closed out.

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TITLE: Research on Minimum Chamber Volume for Combustion of Gases
TASK NO.: 467-1-10 **PRIORITY:** 2 **EST. COMPLETION:** September 1952
SECURITY: Restricted **RESPONSIBLE SCIENTIST:** Lt. R.H. Murray **EXT:** 27153
PRIME CONTRACTOR: Reaction Motors, Incorporated
PURPOSE: The purpose of this task is to obtain and analyze fundamental data on the minimum chamber volume required for the combustion of ethane, ethanol, ethylamine, nitroethane and acetaldehyde.

TO DATE: This study is directed toward a correlation between minimum chamber volume for optimum performance and characteristic oxidation rates of a series of related compounds.

The investigations to be made in accomplishing the object are divided into three (3) phases: (1) The experimental determination of the relative oxidation rates of a series of organic compounds differing in only one (1) functional group. (2) The experimental determination of the minimum combustion chamber volume compatible with optimum performance, employing characteristic velocity as the performance parameter. (3) The correlation of data obtained in phases one and two to obtain a workable relationship.

The series selected for evaluation includes, ethanol, ethylamine, nitroethane and acetaldehyde.

A preliminary attempt to correlate the data obtained under this contract has yielded some relationships which if substantiated and expanded will be of importance.

A correlation is indicated between the slow oxidation data, flame speed data, and motor test data obtained during this investigation. The reciprocal of the slope of the slow oxidation curve, $(\%O_2)/(\log \text{ time})$, is exponentially related to the chamber length for optimum combustion efficiency divided by the flow rate cubed. The reciprocal of the slope is also directly related to the apparent flame speed and exponentially related to the free energy of formation of the fuel.

There is a statistical limit imposed upon these results due to the fact that the information was obtained for only four fuels, acetaldehyde, ethanol, ethane and ethylamine. It is hoped that future work will remove this insufficiency.

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TITLE: Kinetics of Carbon Disulfide Oxidation
TASK NO.: 467-1-11 **PRIORITY:** 2 **EST. COMPLETION:** March 1953
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** Lt R. Murray **EXT.:** 27153
PRIME CONTRACTOR: Franklin Institute of the State of Pennsylvania

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Project No. 467-1-11 (Cont)

PURPOSE:

The purpose of this task is to provide basic information on the kinetics of oxidation of carbon disulfide and to clarify the details of carbon oxidation as an aid in understanding the general problem of combustion of carbonaceous fuels.

TO DATE:

In the course of its studies, the Franklin Institute has investigated the ignition boundaries of the $\text{CS}_2\text{-O}_2$ system. No difficulties were encountered in obtaining the low pressure boundary and values for the high pressure (and) limit have also been determined. The reproducibility has been found sufficient to obtain smooth curves for the variation of induction time with pressure as well as temperature.

An efficient system has been developed for accurately determining induction times by utilizing a completely automatic electronic apparatus.

The data exhibits the lower and upper boundaries characteristic of a branched chain reaction. Small deviations are attributed to changes in the size of the flask caused by the purging of the reaction vessel. It is hoped that these variations can be eliminated by the use of quartz vessels.

The accuracy of the data as already presented will permit the significant testing of mechanistic deductions when sufficient data, both ignition and spectroscopic, have been accumulated.

It should be possible to obtain an activation energy from sufficiently accurate data showing induction time variation with temperature.

While exact solution has not been attempted at this time, an approximate solution was attempted yielding interesting information. An activation energy of 20 Kcal/mol was obtained. In the case of the consecutive reactions which probably occur during chain initiation and branching, this low activation energy represents the overall difference between the potential energy level of the reactants and that of the activated complex of highest energy. Thus it is at least possible to say, at present, that during the induction period there is no activated complex formed at a potential energy level higher than 20 Kcal above the reactants, and that probably no one reaction of the consecutive series of reactions possesses an energy of activation very much greater than 20 Kcal.

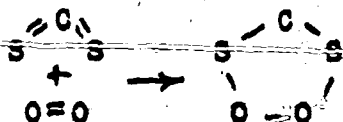
Some speculation has been made as to the source of chain initiation. The CS_2 molecule is thermally stable and at 800°C its dissociation into CS and S is

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Project No. 467-1-11 (Cont)

slight. According to the literature, the stability of the CS radical to oxidation by O_2 is sufficient to make improbable its role as an initiating active center. Also, it is dubious whether S atoms at less than $800^\circ C$ and in small concentrations would provide sufficient reactivity to initiate the usual course of events.

Hence a reaction of low activation energy was postulated resulting in an active unstable product such as a cyclic peroxide



which would decompose into a variety of products including COS and SO, the latter acting to provide O atoms by the reaction $SO + O_2 \rightarrow SO_2 + O$

No further speculation regarding the chain branching reaction itself has been made up to this time.

The spectroscopic phase of this project has been retarded by several important factors, which have been effectively dealt with now and should permit reasonable experimental progress.

<u>TITLE:</u>	Investigation of Combustion Phenomena at High Pressures
<u>TASK NO.:</u>	467-1-16 <u>PRIORITY:</u> 2 <u>EST. COMPLETION:</u> 10 February 1953
<u>SECURITY:</u>	Unclassified <u>RESPONSIBLE SCIENTIST:</u> Lt R.H. Murray <u>EXT:</u> 27153
<u>PRIME CONTRACTOR:</u>	Ohio State University Research Foundation
<u>PURPOSE:</u>	The purpose of this task is to investigate the mechanism and reaction kinetics of combustion processes at high pressures in order to place the design of combustors and the selection of propellants for aircraft use upon a more rational basis than exists at present.

TO DATE: This contract with the Ohio State University Research Foundation was entered into on 15 April 1952. During the brief period it has been in force,

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Project No. 467-1-16 (Cont)

the following work has been performed: Construction of the combustion chamber, development of the high pressure system and design of the burner tips to provide for maintaining a constant tip temperature.

It is hoped that some significant contributions will be provided by the work in the future.

TITLE: Flame Properties in Homogeneous Gas Mixtures
TASK NO.: 467-1-17 **PRIORITY:** 2 **EST. COMPLETION:** January 1953
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** Capt J. Bierlein **EXT:** 27153
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this task is to develop an idealized theoretical treatment to describe the initiation and development of deflagration waves and to test the validity of the theory by appropriate experiments.

TO DATE: Progress on this project is reviewed under three (3) phases:
(1) Ignition of flowing gas mixtures. An apparatus has been designed for passing a laminar stream of combustible gas over a heated surface at a known rate. For a series of surface temperatures, the maximum flow rate at which ignition just occurs will be determined. An attempt will be made to characterize the ignition threshold by means of the temperature profile (normal to the surface) which exists just at the ignition point. It is hoped that it may be possible to identify the threshold profile with the concepts of minimum ignition energy and quenching distance, as determined in quiescent systems. If this can be done, a criterion will be available for the design of ignition equipment in engines. (2) Mathematical investigation of the microstructure and propagation velocity of plane deflagration waves. A rigorous mathematical formulation of the problem has been accomplished. The result is $n - 1$ simultaneous equations, where n is the number of chemical species present in the wave. Of the total number of equations, $n - 1 - r$ are non linear ordinary differential equations (r being the number of different kinds of atoms in the system); the remaining r equations are algebraic. A numerical solution will be attempted for a kinetically simple system (hydrogen-bromine). Necessary tables of thermodynamic and kinetic data are being assembled for this purpose. If successful, the solution of this problem will be an important step in bridging the gap between the classical theory of reaction rates and the prediction of the behavior of flames. (3) Experimental determination of the thermal microstructure

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Project No. 467-1-17 (Cont)

of deflagration waves. An apparatus is being perfected to apply a refractometric method to the determination of the temperature profile across a wave. It consists of a low-pressure chamber in which a two-dimensional flame is established on a slot burner. The image of a finely-graduated uniform scale is projected through the edge of the flame and focussed on a photographic plate; due to the variation in refractive index across the wave front, the image of the scale will be non-uniform in its graduations. From the displacement of the individual markings on the scale, it is possible to infer the way in which the temperature rises across the wave.

TITLE: Investigation of Detonative Combustion
TASK NO.: 467-1-18 **PRIORITY:** 2 **EST. COMPLETION:** 1955
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** Lt R. Dunn **EXT.:** 27153
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this task is to investigate the existing theories of detonative combustion in gaseous mixtures in order to evaluate the possible advantages of this type of combustion in propulsion devices.

TO DATE: A rough detonation tube, made from standard pipe and designed for preliminary detonation tests on non-flowing gas mixtures, was fabricated and installed. Preliminary detonation tests were made with several gas mixtures and under various conditions. A hot-wire igniter and specially designed ionization probes were fabricated and checked out satisfactorily on the rough detonation tube, along with an electronic counter of the type to be used for wave velocity measurements in this project.

Calculations of detonation temperature pressure and velocity for $H_2 - Br_2$ mixtures were made on the basis of classical theory. These calculations will be useful in connection with later experimental work.

A precision detonation tube (to be used for wave velocity measurements, both steady and transient) was fabricated and installed. Six improved ionization probes and a hot wire igniter for the precision detonation tube were fabricated and installed and preliminary tests conducted. The complete electronic timing equipment for wave velocity measurements, including five 100 KC electronic counters, was checked out in a series of detonation tests. Complete redesign of the ionization probes was found to be necessary and the new probes are now being fabricated.

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Project No. 467-1-18 (Cont)

A supersonic flow nozzle, a "cold model" has been fabricated for use in preliminary tests with air alone (no combustion) at a Mach number of approximately 3, with provisions being made for visual observation of the shock wave under various conditions. The air compressor and compressed air tanks have been installed outside the test room. The mount for the nozzle, and other necessary auxiliary equipment are being fabricated and assembled.

Preliminary design of a subsonic flow channel, to be used for investigation of boundary layer and other low velocity effects on detonation waves in gaseous mixtures, has been completed. A work order has been initiated for final design work and shop work, and the final design work is presently underway.

TITLE: Investigation of Surface Combustion in Burners
TASK NO.: 467-1-19 PRIORITY: 2 EST. COMPLETION: March 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: K. Schaller EXT.: 27153
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this task is to investigate surface combustion in burners and to ascertain its effect on the combustion process.

TO DATE: It is presumed that surface combustion occurs on the walls of burners which do not have flame holders. Stated tests have disclosed that ceramic lined combustion chambers maintain their combustion efficiency over a wider range of air-fuel ratios and retain their flames at higher mass flow rates than conventional burners with flame holders. Data available on this is not conclusive and it is hoped that additional study will clarify the effects of heated surfaces on combustion efficiency and combustor capacity.

The principal efforts of the project to date have been concentrated on the problem of obtaining the necessary laboratory facilities for this task. Designs have been completed and final layout drawings have been prepared for a burner test room and an air facility capable of providing a maximum flow of 1 lb. of air per second at a pressure of 100 psia. Plans for an annex to Building 190T to house these test facilities have been presented to and approved by the Planning Board of Air Installations Division. Funds for the construction were allocated in the FY 1953 Budget. Further progress in securing the facilities have been halted temporarily by the decision to establish laboratories for the Propulsion Group in Building 173T.

This project is now in a state of suspension due to the transfer of the responsible scientist to other tasks.

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TITLE: Fundamentals of Turbulent Combustion
TASK NO.: 467-1-20 PRIORITY: 2 EST. COMPLETION: June 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: D.G. Samaras EXT: 27153
PRIME CONTRACTOR: None. Work being accomplished at WADC
PURPOSE: The purpose of this task is to provide a better understanding of the dynamics of combustion.

TO DATE: Several ideas developed in the past from experimental information and theoretical developments were consolidated into a new theory of turbulent combustion. This new theory is more or less an extension of modern isothermal turbulent theories. An analysis of the generalized momentum, energy and continuity equations was made; the turbulent diffusion coefficients (tensor components) of the different species of combustion have been defined and correlated. An experimental rig is in the process of construction in order to evaluate the above diffusion coefficients and test the validity of the new theory.

TITLE: Critique of Combustion Kinetics
TASK NO.: 467-1-21 PRIORITY: 2 EST. COMPLETION: August 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: K. Scheller EXT: 27153
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this project is to evaluate and correlate existing information on combustion kinetics with the objective of indicating new methods of approach to this problem and designing critical experiments to lay the foundation for a rational theory of the combustion process.

TO DATE: No work has been accomplished on this task to date. It is intended to initiate the literature survey in October 1952.

TITLE: Survey of Catalytic Combustion
TASK NO.: 467-1-22 PRIORITY: 2 EST. COMPLETION: May 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: K. Scheller EXT.: 27153
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this project is to evaluate and correlate existing information on catalytic combustion with the objective of recommending new methods of approach to the problem, and to design critical experiments in order to resolve theoretical controversies.

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Project No. 467-1-22 (Cont)

TO DATE: Bibliographies on catalytic combustion and combustion in general have been obtained from CADO and have been reviewed. Only a very few pertinent references to literature were found in this manner. A literature survey is now in progress and has disclosed some reports of interest. A review is being made of current theories of chemical and physical catalysis. A book in Russian, published in the USSR in 1946, entitled "Surface Combustion" by M.B. Ravich has been located in the files of the Air Technical Intelligence Center. It is intended to have this document translated if its contents warrant it.

TITLE: Study of Turbulent Combustion
TASK NO.: 467-1-23 PRIORITY: 1A EST. COMPLETION: August 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: K. Scheller EXT.: 27153
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this project is to evaluate and correlate existing information on turbulent combustion with the objective of attacking the problem from a new viewpoint and establishing a more satisfactory theory of turbulent combustion.

TO DATE: Work on this task has not yet been initiated. After reviewing and digesting the literature, a report will be written.

TITLE: Heat Transfer from a Supersonic Stream at High Temperature and Fluxes
TASK NO.: 467-2-1 PRIORITY: 2 EST. COMPLETION: December 1952
SECURITY: Unclassified RESPONSIBLE SCIENTIST: E. Soehngen EXT.: 27153
PRIME CONTRACTOR: Battelle Memorial Institute
PURPOSE: The purpose of this task is threefold; (1) the measurement of rates of heat transfer from a stream of hot gases in a tube at supersonic mach numbers, (2) the study of the test results thus obtained in the light of fundamental theories, and (3) a transfer under the test conditions.

TO DATE: Tests were run at mach 3 and temperatures up to 6000°R. Unsatisfactory results could be traced to improper combustion operation. After a redesigned injector system and new, improved instrumentation were employed, some

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Project No. 467-2-1 (Cont)

heat transfer coefficients were measured as average values over the length of the test section. Attempts to measure the distribution of the local values also failed.

The data obtained so far check with theoretical data calculated for flat plates by van Driest within 30%. They are about 50% lower than test data obtained by Michler and Tate for subsonic flow in pipes.

Considerable scattering of the test data was observed. The following conclusions may be drawn: (1) The data obtained do not represent with sufficient reliability, a solution of the subject problem. The agreement with theory is only fair. Effects of incomplete combustion, gas dissociation, gas radiation and incomplete knowledge of property data are important parameters, the influence of which could only be very roughly estimated. They certainly determine the reliability of the data obtained to a great extent. (2) At the present state of the art, it does not seem possible to investigate simultaneously the two-fold effect of high velocity and high temperatures on supersonic flow in a pipe. Both effects must be solved separately before a fruitful approach to the compound problem will be reached. Consequently extension of the project has not been recommended and it will be closed out after a detailed evaluation of the results has been made.

TITLE: Radiation Characteristics of Gases Heated Under Controlled Conditions.
TASK NO.: 467-2-2 **PRIORITY:** 2 **EST. COMPLETION:** February 1953
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** Erich Soetngen **EXT:** 27153
PRIME CONTRACTOR: Industrial Scientific Company
PURPOSE: The purpose of this investigation is to study infrared emission and absorption spectra of carbon dioxide heated by external sources under controlled conditions. (This program may serve to indicate whether infrared radiation pyrometer for use as a turbojet control sensing element.)

TO DATE: The larger part of this contract period was spent in designing, constructing and calibrating the experimental equipment required for quick and reliable series testing of gases under various controlled conditions. This phase has been described by one technical and two progress reports.

Upon completion of the experimental set-up, some preliminary investigative tests were conducted on gas mixtures of 5 to 100% carbon dioxide in

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Project No. 467-2-2 (Cont)

nitrogen at three temperature levels ranging up to 1500°F. These tests indicated that the experimental set-up will cover the range under consideration with sufficient accuracy.

Some tests with CO₂ were conducted a short time prior to expiration of the contract. The test findings were presented in a final report which covers six measurements of gas absorptivity represented by 300 data, evaluated in terms of gas emissivity, as well as three measurements of gas emissivity. Temperature levels up to 1800°F were covered. Some of the more significant results are as follows: (1) The indirect method of determining the gas emissivity by measuring the absorptivity proved to be much simpler and more accurate than the direct method of measuring the emissivity. (2) The spectral emissivity of carbon dioxide becomes less dependent on temperature as the temperature increases. (3) At low partial and absolute pressures, a considerable deviation from Beer's law has been found.

In conclusion, the project has resulted in the development of a tool which allows the reliable routine series testing of gas emissivity up to 2000°F and up to two atmospheres in pressure. The few data taken, cover only a small part of the entire first range anticipated. Nevertheless, it is not recommended to extend the project for another period since a similar project, covering a considerably wider range has been started recently at the National Bureau of Standards under the sponsorship of the Power Plant Laboratory of WADC. The project is therefore being closed out.

<u>TITLE:</u>	Critique of Existing Heat Transfer Theory
<u>TASK NO.:</u>	467-2-3 <u>PRIORITY:</u> 2 <u>EST. COMPLETION:</u> Continuing
<u>SECURITY:</u>	Unclassified <u>RESPONSIBLE SCIENTIST:</u> D.G. Samaras <u>EXT.:</u> 27153
<u>PRIME CONTRACTOR:</u>	None. Work being accomplished at WADC.
<u>PURPOSE:</u>	The purpose of this task is to make a critical review of the present status of heat transfer theory to determine its failings and indicate directions for necessary research.

TO DATE: Work on the first paper has been completed. FRL Technical Report, #8 "Heat Propagation, Past and Future," has been published and initial distribution has been made.

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TITLE: Steady State Radiative Heat Transfer in Non-Thermodynamic Equilibrium
TASK NO.: 467-2-4 **PRIORITY:** 2 **EST. COMPLETION:** April 1953
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** J. Loch **EXT.:** 27153
PRIME CONTRACTOR: University of Utah
PURPOSE: The purpose of this task is a study of observations of outer solar atmospheres with the objective of obtaining information on radiative heat transfer through the investigation of the radiation field and radiative transport of energy in solar gases.

TO DATE: This task was originated with the objective of determining whether solar atmosphere research data might be of use in the solution of aerodynamic heating problems associated with hypersonic flight speeds. A number of technical reports have been submitted under this contract; of these, two, "The General Theory of Compressional Waves in a Fluid and its Application to Specific Problems", and "The Theory of Turbulent Velocity Fields in the Presence of Force Fields and Application to the Solar Ionization Zone and Meteorological Phenomena" by Dr. E. Parker come closest to bearing on the problem in mind. However, by and large, the work accomplished, while of an excellent scientific grade, has shown that this approach to the problems of high speed aerodynamic heating is not very likely to succeed in the foreseeable future. There is a possibility that this approach may some day aid in the solution of problems of combustion kinetics. However, a great deal of work in reducing present solar theories and data to a tractable form must be accomplished before this can take place.

List of Technical Reports submitted to date:

1. A Study of the Physical State of and Energy Transport Processes in Non-Thermodynamic Equilibrium Gaseous Atmospheres
2. Departures from Thermodynamic Equilibrium in the Chromospheric Hydrodynamic Field
3. The General Theory of Compressional Waves in a Fluid and Its Application to Specific Problems
4. The Theory of Turbulent Velocity Fields in the Presence of Force Fields and Application to the Solar Ionization Zone and Meteorological Phenomena

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TITLE: The Energetics of Nonisothermal and Irreversible Processes
TASK NO.: 467-2-5 PRIORITY: 2. EST. COMPLETION: April 1954
SECURITY: Unclassified RESPONSIBLE SCIENTIST: J. Loch EXT.: 27153
PRIME CONTRACTOR: Columbia University
PURPOSE: The purpose of this task is to provide a better general knowledge of thermodynamics which may eventually be used in designing better jet propulsion systems.

TO DATE: A great deal of time has been lost to date in efforts to bring the principal investigator, Mr. Hans Holten, Jr., from Norway to conduct this work. There is some hope now that Mr. Holten will be immigrated to this country before the end of 1953. However, in the meantime, since negotiations with Columbia University were first opened by this Laboratory, the mission and functions of the Flight Research Laboratory have been reoriented, it is now believed that this contract falls into the domain of the Office of Scientific Research at Headquarters, ARDC. It is therefore being recommended that all records and data pertaining to this task be transferred to that organization as soon as possible.

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TITLE: Instrumentation for Heat Transfer and Fluid Flow Investigations
TASK NO.: 467-2-6 PRIORITY: 2 EST. COMPLETION: Continuing
SECURITY: Unclassified RESPONSIBLE SCIENTIST: L.E. Bollinger EXT.: 27153
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this task is to obtain heat transfer data on liquid cooled turbine blades which are subjected to high centrifugal forces.

TO DATE: A fairly complete file of catalogues and literature describing commercially available electronic and optical instrumentation equipment has been established. A file index system was set up to facilitate the location of particular catalogues which describe specific types of instruments.

A study was made on general instrumentation required for a laboratory and appropriate procurement action has been taken. To date, a considerable majority of the equipment has been received but no facilities have been provided for their use.

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TITLE: Pressure and Temperature Effects on Laminar Boundary Layers
TASK NO.: 467-2-7 PRIORITY: 2 EST. COMPLETION: Continuing
SECURITY: Unclassified RESPONSIBLE SCIENTIST: H.U. Eckert EXT.: 27153

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Project No. 467-2-7 (Cont)

PRIME CONTRACTOR: Ohio State University

PURPOSE:

The purpose of this task is to obtain basic information on pressure gradient, friction, heat transfer, temperature recovery, and stability of the laminar boundary layer.

TO DATE:

Equations applicable to the temperature recovery in laminar boundary layers on insulated wedges have been solved on the analogue computer. The solution indicated that the pressure gradient had no effect on the temperature recovery factor. Integration of the equations applicable to the thermal boundary layer of isothermal (constant surface temperature) wedges revealed definite pressure gradient effects. Pressure gradient has a more pronounced effect on the heat transfer coefficients of fluids with high Prandtl Numbers than on gases. It has also been found that at high Prandtl Numbers, the temperature recovery obeys the one third power law rather than the square root law, and at extremely low Prandtl Numbers the temperature recovery is zero. A solution for the thermal boundary layer of a surface along which the temperature is represented by analytic function and the local free stream velocity distribution such as to yield similar boundary layer profiles has been found using Bessel functions. The results have been tabulated on a computer for practical applications. An exact solution of the thermal boundary layer equation has been obtained for the region near a blunt forward stagnation point. Discovery of an exact solution for the case of laminar viscous incompressible flow toward a rotating disc has been reported. Text of a note concerning this subject has been submitted to the Flight Research Laboratory with request for permission of publication in the "Readers Forum" of the "Journal of Aeronautical Sciences". Discussions concerning extending present work to hypersonic flow have been in process.

TITLE:

Heat Transfer to Boundary Layers with Variable Free Stream Pressures

TASK NO.:

467-2-8 PRIORITY: 2 EST. COMPLETION: Continuing

SECURITY:

Unclassified RESPONSIBLE SCIENTIST: H.U. Eckert EXT.: 27153

PRIME CONTRACTOR:

University of California

PURPOSE:

The purpose of this task is to obtain information (theoretical and experimental) on heat transfer to, or from, a moving air-stream for eventual application to aircraft heating and cooling problems.

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Project No. 467-2-8 (Cont)

TO DATE: In continuation of the program to develop techniques for the calculation of heat transfer to, and from, air streams, theoretical as well as experimental work has been accomplished. On the theoretical side: (1) a review has been made of existing methods of laminar boundary layer calculation, (2) the case of heat transfer to laminar wedge flows with variable wall temperature has been solved, (3) a new method has been developed for calculation of heat transfer to turbulent boundary layers with variable free stream velocity and, (4) the case of heat transfer to laminar wedge flows with large temperature differences has been solved.

On the experimental side, the determination of local heat transfer coefficients for elliptical cylinders has been extended to various types of free stream velocity variation by changing the orientation of the cylinder. Standard methods of predicting the local heat transfer coefficients appear to be sufficiently accurate for design purposes. Aerodynamic heating effects which are present at the test air velocities can be satisfactorily accounted for, which demonstrates the adequacy of the usual recovery factor specification.

Experimental work related to the effect of large temperature differences was only partly successful since the model which had a goldplating to minimize radiation losses failed at surface temperatures above 500° Fahrenheit.

TITLE: Heat Exchange Between Bodies and Gases in Supersonic Flow
TASK NO.: 467-2-11 PRIORITY: 2 EST. COMPLETION: January 1956
SECURITY: Unclassified RESPONSIBLE SCIENTIST: H.U. Eckert EXT.: 27153
PRIME CONTRACTOR: Naval Ordnance Laboratory
PURPOSE: The purpose of this task is to direct (1) investigations of aerodynamic heating effects occurring on skin surfaces, (2) establishment of proper scaling laws relating to heating effects, (3) and theoretical investigations of the aerothermodynamic effects attendant to the flight of aircraft and missiles in the supersonic flow region.

TO DATE: Measurements of recovery factors and heat transfer coefficients in the 40 by 40 centimeter intermittent tunnel and the 18 by 18 centimeter continuous tunnel of the Naval Ordnance Laboratory which cover Mach number ranges

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Project No. 467-2-11 (Cont)

from 1.5 to 5 have been extended from cone-cylinder combinations to hemisphere-cylinder bodies, spheres and cylinders in cross flow. Special investigations were made of the effect of boundary layer history on recovery temperatures, the effect of time-varying air supply temperature on heat transfer, and the effect of heat conduction on thermocouple temperature measurements. Efforts have been made to set up a measure for the turbulence level in supersonic flow. Since evaluation of hot wire data is extremely difficult at supersonic speeds, an arbitrary measure for comparison of turbulence levels in several wind tunnels is obtained from determination of the transition Reynolds number on a 5 degree cone.

Temperature surveys have been made in the wake of a cylinder. In contrast to the low speed results of Ryan in Switzerland, no particularly low temperatures have been found. The difference is believed to be due to the fact that the high speed flow does not permit the formation of large vortices in the wake.

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TITLE: Heat Transfer in Two-Dimensional Steady, Laminar Incompressible Flow Between Non-parallel Plane Walls
TASK NO.: 467-2-12 PRIORITY: 2 EST. COMPLETION: December 1952
SECURITY: Unclassified RESPONSIBLE SCIENTIST: K. Folhausen EXT.: 23250
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this task is to (1) obtain an exact mathematical solution of the problem of heat transfer in two dimensional steady, laminar, incompressible flow between non-parallel plane walls, (2) to obtain answers to this problem for a number of cases of practical interest, (3) to obtain an experimental verification of these predicated results.

TO DATE: This project has only recently been inaugurated, hence no progress reports are available at this date.

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TITLE: Convective Heat Transfer to Extremely Viscous Fluids
TASK NO.: 467-2-13 PRIORITY: 2 EST. COMPLETION: January 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: H.U.Eckert EXT.: 27153

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Project No. 467-2-13 (Cont)

PRIME CONTRACTOR: None. Work being accomplished by WADC.

PURPOSE: The purpose of this task is to obtain fundamental data on free and forced convection heat transfer phenomena involving extremely viscous fluids. Such data will provide a rational basis for the design of heat exchangers of such fluids, as well as to shed light on some unsolved problems of convective heat transfer at very high Prandtl numbers and very low Grashof and Reynolds Numbers.

TO DATE: The study phase including a literature survey and the layout and design of the experimental set up, has been completed. The basic test rig has been built, for measurements of free convection of heat transfer, consisting of a test chamber equipped with moving thermocouples for the measurements of temperature fields around the test models. Several test fluids - hydrocarbon-polymers with high temperature coefficients and silicon polymers with low temperatures coefficients have been obtained. Test models are on order and instrumentation plans have been completed.

The literature survey yielded little information of value. So far no data have been found which may assist in solving the problem of heat transfer to extremely viscous fluids. Consideration is being given to the extension of the experiments on forced convection flows. Progress has been slow due to a lack of man/power and laboratory installations.

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TITLE: Interferometric Study of Free Convection Heat Transfer Phenomena in Gases

TASK NO.: 467-2-14 PRIORITY: 2 EST. COMPLETION: July 1953

SECURITY: Unclassified RESPONSIBLE SCIENTIST: E. Stehngen EXT.: 27153

PRIME CONTRACTOR: None. Work being accomplished at WADC.

PURPOSE: The purpose of this task is to obtain data on the distribution of local heat transfer coefficients for free convection from various surface configurations under different environmental conditions.

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Project No. 467-2-14 (Cont)

TO DATE: When the project was initiated, the interferometer had been disassembled because of a move to another laboratory. At the same time, the optical parts had been shipped to the manufacturer for a complete overhaul. Additional new windows and compensator plates have been ordered so that the equipment might be adjusted to the highest standard. A motion picture camera is being converted to special use with the interferometer.

Further work will be done to construct a multilamp illumination system ~~including a camera-controlled flash-power supply to use with a high speed camera.~~

Work will be curtailed due to the changing of location of the Propulsion Branch when reinstallation takes place, a modification of the adjustment system will be made.

Cooperation and coordination with the USAF and other agencies have been established.

TITLE: Unsteady-State Heat Transfer in Regenerative Heat Exchangers
TASK NO.: 467-2-15 PRIORITY: 2 EST. COMPLETION: July 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: E. Soehngen EXT.: 27153
PRIME CONTRACTOR: Illinois Institute of Technology
PURPOSE: The purpose of this task is to obtain basic data essential to the design of regenerator cores, and to develop a well-grounded theory of the regenerator adequate for aircraft applications.

TO DATE: This project is an extension of a similar one initiated by the Power Plant Laboratory of WADC in 1949 (and later transferred to the Flight Research Laboratory). In contrast to the former project, the new one emphasizes the basic phenomena of regenerative heat transfer. The equipment already designed and partially constructed under the earlier contract is being rebuilt and modified to meet the new requirements as specified under the current contract.

TITLE: Flight Simulator for Transient Aerodynamic Heating
TASK NO.: 467-2-16 PRIORITY: 1A EST. COMPLETION: December 1952
SECURITY: Restricted RESPONSIBLE SCIENTIST: E. Soehngen EXT.: 27153
PRIME CONTRACTOR: None. Work being accomplished at WADC.

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Project No. 467-2-16 (Cont)

PURPOSE:

The purpose of this project is to obtain basic numerical data necessary for the solution of the following problems: (1) loss of fuel in integral and semi-integral wing tanks by evaporation due to the combined effects of transient changes of altitude and aerodynamic heating, together with the influence of different design parameters, (2) fundamentals of steady state heat transfer by free convection from horizontal surfaces to resting, agitated, or foaming fluids of homogeneous or heterogeneous composition under boiling and non-boiling conditions, (3) time temperature distributions within structural elements in thermal contact with surfaces exposed to transient high speed airflow.

This data will make possible the prediction of maximum time for a given high speed aircraft for any possible flight plan. It will also serve as basic information for design work, as well as for the assessment of various schemes for minimizing fuel evaporation losses.

TO DATE:

The first phase of the project, which has been started at the request of an aircraft contractor, has been completed.

A laboratory test set up for measuring fuel losses due to aerodynamic heating from tanks in high speed aircraft subjected to transient flight conditions. The construction of the first rig is almost completed; it will be tested and modified where necessary prior to the construction of a second rig.

A report has been written covering the fundamental ideas and operational characteristics of the simulated system as applied to fuel tanks. However, it has been found desirable to include the latent theoretical findings required for proper simulation as well as to cover other problems of high speed flight systems which may be solved by applying the simulator principal. Therefore, the report will be rewritten and generalized.

* * * *

TITLE:

Peripheral Pump Investigation

TASK NO.:

467-3-1 PRIORITY: 1B EST. COMPLETION: December 1952

SECURITY:

Unclassified RESPONSIBLE SCIENTIST: K. Cramer EXT.: 27153

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Project No. 467-3-1 (Cont)

PRIME CONTRACTOR: None. Work being accomplished by WADC.

PURPOSE: The purpose of this task is the investigation of the flow processes taking place in peripheral pumps, with particular reference to the pumping of rocket propellants.

TO DATE: In April of 1950 this project was initiated as a task under a more general contract with the Ohio State University. The contract was terminated with the contractor in July 1950 due to the loss of their qualified personnel and it was then decided to continue it as an internal project in the Propulsion Branch of the Flight Research Laboratory.

As an internal project, Dr. F. Weinig of the Propulsion Branch developed a theory based upon traction to describe the characteristics of this type pump. Three peripheral pumps of different capacities were purchased at that time for one phase of the test program. Two test rigs were proposed and the necessary equipment purchased. The rig for the study of the flow patterns was designed and, after considerable difficulties in the obtaining of equipment and laboratory facilities were surmounted, the rig was constructed. When the operating limits of the rig were established, a series of high speed motion pictures were taken of the flow patterns to determine the proper photographic and flow visualization techniques required for the study of the internal flow patterns of the peripheral pump. At present, these films are being evaluated to determine the best method of tracing the complex flow patterns in this pump.

* * * *

TITLE: Pump Cavitation Literature Survey

TASK NO.: 467-3-2 PRIORITY: 2 EST. COMPLETION: February 1954

SECURITY: Restricted RESPONSIBLE SCIENTIST: J. Loch EXT.: 27153

PRIME CONTRACTOR: None. Work being accomplished at WADC.

PURPOSE: The purpose of this task is to investigate cavitation; (1) fundamental understanding, (2) development of methods for predicting, avoiding and delaying the onset of cavitation, and (3) fundamentals of hydraulic machining operation in the cavitation region.

TO DATE: The first phase of this task, dealing with a review of the basic literature on cavitation, has been virtually completed, with special attention being paid to the problem of cavitation in centrifugal pumps. Recent

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data obtained during the development testing of high output turbine-pump sets for rocket engines has revealed that phenomena which were formerly thought of as being little or no influence on the cavitation characteristics of pumps give rise to appreciable deviations from predicted characteristics. An example of this is the clearance of the wearing ring of a pump. Certain suggestions for experimental work in the investigation of cavitation in centrifugal pumps have been made and are now being evaluated. A method has also been proposed for calculating the pressure distribution in a centrifugal pump impeller, based on experimental data of Uchimaru in Japan. A paper on this has been prepared and is now being edited for publication.

* * * *

TITLE: Two Dimensional Supersonic Compressor Cascade Testing Technique
TASK NO.: 467-3-3 **PRIORITY:** 2 **EST. COMPLETION:** Continuing
SECURITY: Confidential **RESPONSIBLE SCIENTIST:** H. Bokert **EXT.:** 27153
PRIME CONTRACTOR: Research Foundation of the University of Toledo
PURPOSE: The purpose of this task is to determine a reliable experimental technique for the testing of two-dimensional supersonic compressor cascades.

TO DATE: The final report has been received and appraised. A report closing out this task will be written in the near future. Regarding the testing techniques, it was found that for the range of pressure ratios covered by the tests, no special consideration is necessary as regards the boundary conditions at the cascade ends. It was further found that good correlation existed between the static pressures measured by wall statics and probe surveys and the information obtained from Schlieren pictures.

Concerning the character of the supersonic cascade flow, it was found to be essentially two dimensional and corresponded closely to the design flow pattern in the entrance region of the cascade. In the divergent section, large deviations from the expected pattern developed, with the flow separating from the passage walls even at low pressure ratios. From photographs obtained in the course of the investigation, it appears this separation is caused by the incident shock originating at the profile trailing edges. The separation occurs a considerable distance upstream of the point of incidence of the shock, and its extent increases rapidly with increasing pressure ratio. At a pressure ratio of 2.59 the separation reached the cascade throat, thereby transforming the region downstream of the throat effectively into a passage of constant cross-sectional

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Project No. 467-3-3 (Cont)

area. It seems that as a direct consequence, the shock does not find a stable location within the cascade and it is forced to move upstream to the leading edges of the profiles. The maximum static pressure ratio that could be achieved through the cascade was thereby limited to 4.46 in comparison with 7.73 as predicted by theory.

Further investigation of these difficulties will be made under Task No. B-467-3-9, Effect of Boundary Layers on the Performance of a Two-Dimensional Supersonic Compressor Cascade.

* * * *

TITLE: Evaluation of Supersonic and High-Speed Subsonic Compressors
TASK NO.: 467-3-4 **PRIORITY:** 2 **EST. COMPLETION:** June 1953
SECURITY: Confidential **RESPONSIBLE SCIENTIST:** J. Loeh **EXT.:** 27153
PRIME CONTRACTOR: Prof Seymour Bogdonoff, Princeton University
PURPOSE: The purpose of this task is to consolidate the existing knowledge and further develop the theoretical work on supersonic compressors.

TO DATE: This task is aimed at a consideration of the problems involved in the development of the supersonic compressor from a fundamental fluid mechanics standpoint, as well as from a more utilitarian point of view. Basically, the work falls into three parts. The first of these is concerned with the supersonic compressor as such, with particular attention being paid to the problems of starting, separation, and the three-dimensional shock wave structure in a supersonic compressor passage. Radial equilibrium conditions for the supersonic compressor have been carefully studied and a preliminary report submitted. There seems to be no real difficulty in designing supersonic compressors including radial equilibrium in either the rotor or the stator. Of considerable interest is a conclusion reached from the shock wave boundary layer analysis work that high performance may be attainable in a very small supersonic compressor if very thin laminar boundary layers can be obtained. This is based upon recent work that such layers can support high pressure gradients.

The analysis of boundary layers in adverse pressure gradients in supersonic flow has continued as more experimental data has become available. The possibility of obtaining high pressure ratios without separation seems quite good and results obtained so far show that pressure ratios of the order of 3 can be obtained in a channel with a turbulent boundary layer with efficiencies of over 90%. Work along these lines is continuing, but it depends primarily on obtaining specific experimental data.

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Project No. 467-3-4 (Cont)

The work on high speed subsonic compressors has included the gathering of data to establish limits of loading and Mach number for supersonic axial flow compressor blades. Data is already available which shows that stage pressure ratios of 1.4 to 1.5 are possible with good efficiency, but no limits have been established. Based on the new series of two dimensional cascade tests made by Eridin and his co-workers at NACA Langley, an analysis has been made to determine optimum solidity, stagger and turning angles for maximum pressure rise and power absorbed. Results obtained for the two dimensional analysis have been submitted in a preliminary report.

Calculations have been made of multi-stage compressor performance as affected by single stage characteristics, with emphasis on operation with part of the compressor operating stalled or as a turbine. This is the condition for starting or low speed operation. A recent NACA report, TN 2589, gives an excellent analysis which supplements the present work very well. Specific limitations inherent in such calculations make it very difficult to obtain general results. There may be considerable shifts in permissible loading limits and critical Mach numbers in the near future. Calculations are being carried out in an attempt to approximate the maximum limits to be expected.

High pressure single stage tests have been analyzed to provide data for the compatibility studies which are concerned with the possibility of using supersonic and subsonic stages in series in a multi-stage machine. Such a combination of supersonic or transonic first stage with a highly efficient multi-stage unit has the potentiality of providing a very compact machine of high mass flow and high efficiency. The first part of this analysis has been the recalculation of existing supersonic and transonic data on the basis of exit volume flows to determine whether it is possible to design a subsonic following unit.

Two interesting points have arisen. First, the range of the combined unit will be limited by the subsonic part if of fixed geometry. However, variable stators - perhaps only on the first subsonic stage - would be of great importance. Second, the surge or stall line reverses its slope for complete supersonic performance. This makes it difficult to match a subsonic unit to the portion of the supersonic unit operating curve where the output is at a maximum. This analysis is being continued and will include all available experimental data.

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TITLE: Fluid Oscillation Excitors
TASK NO.: 467-3-5 **PRIORITY:** 2 **EST. COMPLETION:** Completed
SECURITY: Restricted **RESPONSIBLE SCIENTIST:** J. Losh **EXT.:** 27153
PRIME CONTRACTOR: General Electric Company, Thermal Power Systems Division
PURPOSE: The purpose of this task is the determination of optimum means of producing controlled pressure and velocity oscillations in a gas stream, supersonic and subsonic, which are used for research on the fluid oscillation phenomena occurring in modern aircraft power plants.

TO DATE: This task, which had as its aim the investigation of certain methods of exciting controlled oscillations in a flowing gas stream, has not been completed. The results of the investigation are embodied in seven volumes as follows:

- Part 1 - A Generalized Study of Methods and Mechanisms for Introducing Fluid Oscillations into a Gas Stream
- Part 2 - A Survey of Methods of Pressure Measurement
- Part 3 - A Survey of Methods of Temperature Measurement
- Part 4 - A Survey of Methods of Flow Velocity Measurement
- Part 5 - A Survey of Methods of Flow Visualization
- Part 6 - A Survey of Methods of Measuring Torques in Rotating Machinery
- Part 7 - A Survey of Methods of Measuring Angular Velocities of Rotating Machinery

Evaluation of the report is not yet completed. The types of fluid oscillation excitors which were considered in this investigation included the following: mechanical transducers, electrical or electromagnetic oscillators, magnetostrictive transducers, piezoelectric transducers, flow choppers or sirens, horn type acoustic transformers, as well as the theory of acoustic radiation from a piston source. It was found that finite amplitude effects must definitely be considered in any work involving high intensity waves in flow through tubes. The problem which remained unsolved was the experimental use of probes for the measurement of dynamic pressures in an oscillating flow fluid. Since many of the experimental difficulties which will be encountered in our own study of oscillating flows will be concerned with instrumentation, a survey of instrumentation means of possible use in our investigations was included as part of this contract. In general, the six volumes of the final report dealing with instrumentation may be considered as forming an excellent reference work and instruction manual for experimental engineers.

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TITLE: Monograph on Injection of Liquids Into a Gas Stream
TASK NO.: 467-3-6 **PRIORITY:** 2 **EST. COMPLETION:** December 1952
SECURITY: Restricted **RESPONSIBLE SCIENTIST:** J. Lech **EXT.:** 27153
PRIME CONTRACTOR: Battelle Memorial Institute
PURPOSE: The purpose of this task is the compilation, critical correlation and appraisal of present information on the continuous injection of liquids into a gas stream. The study will include atomization, evaporation and diffusion processes both with and without heat release (combustion).

~~AS ORDER~~ In the two years which have elapsed since the inauguration of this task, the bulk of the monograph has been written and is now being reviewed for technical accuracy prior to loan distribution to other research investigators and industrial firms for their comments and contributions. Approximately 22 chapters are presently planned for the monograph, of which the following have been received to date:

- | | |
|------------|--|
| Chapter 1 | The Mechanism of Atomization |
| Chapter 2 | The Methods of Atomization |
| Chapter 3 | Nozzle Design |
| Chapter 4 | Spray Analysis |
| Chapter 5 | Ballistics of Single Droplets |
| Chapter 7 | The Thermodynamics and Kinetics of Evaporation |
| Chapter 8 | Single Droplet Evaporation |
| Chapter 11 | The Equations of Fluid Dynamics |
| Chapter 12 | Turbulence |
| Chapter 13 | Theories of Flame Parameter |
| Chapter 14 | Combustion Kinetics |
| Chapter 15 | Flame Speed Studies |
| Chapter 16 | Analysis of Flame-Propagation Studies |
| Chapter 17 | Turbulent Combustion |
| Chapter 18 | Diffusion Flames |

It is planned that as each chapter is approved by this Laboratory, sufficient copies will be reproduced to permit distribution to all qualified research investigators and industrial concerns having an interest in the subject. The chapters will be distributed on a loan basis for a period which may vary from 3 to 6 months, during which time the recipient of the given chapter will make his comments on the contents thereof, together with any suggestions or contributions

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Project No. 467-3-6 (Cont)

which he or they may be able to make toward the end of producing a top quality reference work in this field. It is planned that the final version of this monograph will be published in book form by one of the leading technical publishers of the country.

TITLE: Two and Three Dimensional High Mach Number Supersonic Ramjet Diffusers
TASK NO.: 467-3-7 **PRIORITY:** 2 **EST. COMPLETION:** December 1952
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** H.U. Eckert **EXT.:** 27153
PRIME CONTRACTOR: General Electric Company
PURPOSE: The purpose of this task is the generalized design of a diffusing mechanism for use in admitting, decelerating and transporting ambient air to the combustion chamber or chambers of a supersonic (Mach 4 - 5) ramjet engine.

TO DATE: Work accomplished in the first quarter of 1952 consisted of analytical studies of a two dimensional asymmetrical ramjet design for a flight Mach Number of five. The contour of the spike was so chosen that initial shock and compression lines for this Mach Number intersected at the tip of the inlet lip. Three types of inlets were investigated: divergent, convergent-divergent, and the perforated lip. Their effect upon pressure recovery was calculated for various values of the Mach Number at the flame holder and presented in charts. In the second quarter, the effort has been concentrated upon planning of an experimental test program and design and manufacturing of test models. Since boundary layer growth and stability are assumed to play an important part in the diffuser performance, two different tests were designed to provide detailed boundary layer information along the spike and the inlet lip.

The first set of tests consisted of the firing of about 20 projectiles with isentropic nose spikes at Mach numbers between two and four in the pressurized ballistic range of the Naval Ordnance Laboratory. Missile diameter was 20 millimeters and ambient pressure raised from one to one-tenth of an atmosphere. Evaluation of shadow pictures from the flying projectiles will give information about the location of the transition zone and possible separation of the boundary layer.

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Project No. 467-3-7 (Cont)

The second experiment consisted in the wind tunnel testing of a two dimensional diffuser spike model at the Jet Propulsion Laboratory. The model is equipped with pressure taps for determination of the pressure rise along the spike and boundary layer rakes at the inlet position. The height of scoops for dividing the boundary layer from the main flow will be chosen, according to the thickness of the boundary layer measured at this place.

TITLE: Computation of Blade Flutter in Supersonic Axial Flow Compressors
TASK NO.: 467-3-8 **PRIORITY:** 2 **EST. COMPLETION:** December 1942
SECURITY: Confidential **RESPONSIBLE SCIENTIST:** J. Loch **EXT.:** 27153
PRIME CONTRACTOR: New York University
PURPOSE: The purpose of this task is to compute the flutter characteristics of supersonic axial flow compressor blades, using available aerodynamic data on supersonic compressor cascades.

TO DATE: As a first step toward the analytical determination of the flutter speed of supersonic axial flow compressor blades, the following problems have been studied: (1) a critical review of existing methods for the calculation of the flutter speed, (2) a review of existing methods for the calculation of the torsional constant for an arbitrary section, (3) a survey of existing aerodynamic data on supersonic compressor blades.

Various methods for calculating the critical speed and frequency as well as the uncoupled modes for oscillating cantilever beams were reviewed. For the most part, the literature is concerned with the flutter of wings wherein centrifugal force plays no part or with the flutter of uniform beams in a centrifugal force field. In any event, the addition of a centrifugal force field and the consideration of cases where the beams are no longer uniform adds considerable complexity to the problem. It was found that some methods which were valid for the calculation of wing flutter became extremely doubtful or broke down completely upon the addition of centrifugal force effects. The methods which seem to be applicable to the problem at hand provided that suitable air force data can be obtained are as follows:

1. Methods for Calculating Uncoupled Modes and Frequencies:
 - a. Rayleigh's Method

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Project No. 467-3-8 (Cont)

- b. Stodola's Method
- c. Holzer-Myklestad Method
- d. Timoshenko's Method (Correction for Centrifugal Force)

2. Methods of Calculating the Flutter Frequency and Speed for Cantilever Beams:

a. Mindlin's Methods:

- (1) Semirigidity hypothesis
- (2) Exact equations

- b. Grossman's Method
- c. Goland-Luke Method, with extension by Runyan and Watkins

Coming to the problem of calculating the torsional constant for bars with arbitrary section shape, there appear to be, in addition to numerical and variational methods, two distinct schemes for the practical solution of the Saint Venant torsion problem. Both are subject to restrictions on the form of the section boundary and the nature of these restrictions should serve to determine which scheme to utilize in any particular example. The first method expresses the solution (the stress function) in powers of a thickness parameter and hence is restricted to contours with high length-to-thickness ratio. The second scheme employs complex mapping and requires first, that the function which maps the section contour into a circle (or near circle) be known; and second that continuity be arranged for in the gradient of the complex stress function at singular points in the transformation. The mapping method is subject to a further complication when the singly connected domain of the physical problem is mapped from a doubly connected domain in the image or transformed plane. This involves the collapse of the inner boundary, under the transformation, to a zero area contour or slit in the physical plane and hence imposes additional conditions on the complex stress function in order to insure continuity across the slit in the physical plane. These schemes are essentially embodied in the methods of three investigators, as follows: (1) Duncan's Method; (2) Morris's Method; (3) Abramyan's Method. The limitations of these various methods will be investigated for the case of classical flutter of plants fixed at the root. At a later date, this analysis will be extended to the important practical problem of stall flutter in compressors.

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TITLE: Effect of Boundary Layers on Performance of Two Dimensional Supersonic Compressor Cascades
TASK NO.: 467-3-9 **PRIORITY:** 2 **EST. COMPLETION:** July 1953
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** H.U. Eckert **EKT.:** 27153
PRIME CONTRACTOR: Research Foundation of the University of Toledo
PURPOSE: The purpose of this task is to determine the effect of boundary layers on the performance of (1) a single two dimensional supersonic vane passage, and (2) a two dimensional supersonic compressor cascade.

TO DATE: Previous wind tunnel studies of a supersonic cascade at Mach 2.3 with diamond shaped profiles had shown that in the entrance part of the passages the flow followed theoretical predictions, while in the rear part the behavior was quite different and almost no compression was obtained. Schlieren photographs indicated that this was due to separation of the boundary layer from the surfaces of the profile. In order to conduct a closer study of this effect, an enlarged model consisting of a single vane passage has been built and is being tested. The tests are accompanied by a study of the available literature on boundary layer shock wave interaction phenomena.

TITLE: Survey of Information on Two Dimensional Cascades
TASK NO.: 467-3-10 **PRIORITY:** 2 **EST. COMPLETION:** November 1952
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** J. Loeh **EKT.:** 27153
PRIME CONTRACTOR: Brown University
PURPOSE: The purpose of this task is to provide a complete systematic survey of all available data, both theoretical and experimental, on two-dimensional cascades for use in guiding future Air Force work in this field and for aiding the designers of turbomachinery.

TO DATE: A complete bibliography of two dimensional cascade theory and pertinent cascade experiments is being compiled. This bibliography includes both theoretical and experimental work which has been or is being done. Theoretical papers involved concern the radial flow, as well as the straight cascade.

A detailed comparison has been made of several theoretical methods and the results which have been obtained by their use for the ratio of the lift of

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the airfoil in the straight cascade to the lift of the isolated airfoil. Excellent agreement has been found among several of the methods investigated as to the effect of angle of attack. Other methods are now under investigation. One of these methods gives results which are not in agreement with those previously mentioned. The reason for this departure can be explained by the fact that the conformal transformation does not give the desired contour.

The effect of the finite thickness of the profiles used in a straight cascade can be considered as a displacement effect. Those corrections, which are necessary in order to proceed from infinitely thin airfoils to airfoils of finite thickness, are in satisfactory agreement when calculated by the different methods involved.

Experiments on cascades with accelerated flow confirm the cascade theory. Experiments on cascades with decelerated flow depart somewhat from the theoretical predictions. This departure is believed to be due largely to the more rapid growth of the boundary layer in a flow with an increasing static pressure.

Some of the experimental results which have been studied are considered to be unreliable - primarily because two dimensional flow within the test set up itself is not positively confirmed.

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<u>TITLE:</u>	Axial Flow Compressor Blading Systems of High Deflection Angle
<u>TASK NO.:</u>	467-3-11 <u>PRIORITY:</u> 2 <u>EST. COMPLETION:</u> January 1955
<u>SECURITY:</u>	Confidential <u>RESPONSIBLE SCIENTIST:</u> J. Loch <u>EXT.:</u> 27153
<u>PRIME CONTRACTOR:</u>	Johns Hopkins University
<u>PURPOSE:</u>	The purpose of this task is to study the advancement of knowledge of flow phenomena in strongly deflecting vane systems or passages, and to study the subsequent determination of means for increasing the mass flow and stage pressure ratio of axial-flow compressors for given overall dimensions and rotational speeds.

TO DATE: The contract recently went into effect and analytical work was begun. However, no results are available at this date.

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TITLE: Viscosity Effects on Two-dimensional Flows Through Subsonic Axial Flow Compressors and Turbines
TASK NO.: 467-3-12 **PRIORITY:** 2 **EST. COMPLETION:** March 1953
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** J. Loch **EXT.:** 27153
PRIME CONTRACTOR: University of Illinois
PURPOSE: The purpose of this task is the analysis of viscous effects on two-dimensional incompressible and two-dimensional subsonic compressible flows through axial-flow compressors and turbines.

TO DATE: The contract recently went into effect and analytical work was begun. However, no results are available at this date.

TITLE: Mixing of Predominantly Gaseous Phase Fluid Streams
TASK NO.: 467-3-13 **PRIORITY:** 2 **EST. COMPLETION:** December 1952
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** J. Loch **EXT.:** 27153
PRIME CONTRACTOR: University of Illinois
PURPOSE: The purpose of this task is to (1) form an improved theory as to the mechanism of the fluid stream mixing process, and (2) determine the relationships among the pertinent parameters used to describe the mixing process to permit the prediction of the performance of any system having a coplanar, coaxial, intersecting, ducted or free stream configuration.

TO DATE: There has been a delay in receipt of reports on this task from the University of Illinois and it is therefore impossible at this time to make a report of progress to date under the Air Force sponsored portion of the program.

TITLE: Incompressible and Compressible Subsonic Flow Through Three-Dimensional Cascades
TASK NO.: 467-3-14 **PRIORITY:** 2 **EST. COMPLETION:** March 1954
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** J. Loch **EXT.:** 27153
PRIME CONTRACTOR: Armour Research Foundation
PURPOSE: The purpose of this task is to experimentally and theoretically investigate three-dimensional cascades as used in turbomachinery with particular emphasis on conditions existing in the runners of such machines.

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TO DATE: Principal personnel working on this task at the Armour Research Foundation visited this Laboratory during the month of July for the purpose of holding a technical discussion with Propulsion Branch personnel. In general, the procedure to be followed will be to extend the theory for an infinite number of blades using the concept of bound vortices to be the case of a finite number of blades by experimental and analytical procedures. This will be followed by the subsequent experimental verification of the resultant theory. To this end, a three dimensional cascade test stand has been designed, together with a 14" mixed flow centrifugal impeller having provision for varying the number of blades. The rotor has been designed on the basis of the theory for an infinite number of blades. The deviation of the experimental data from that predicted by theory for each different number of blades will be used to form a realistic basis for the modification of the infinite number of blades theory to a finite number of blades. Provision is being made in the instrumentation for circumferential and axial pressure and velocity traverses, as well as for the measurement of power input, mechanical losses, flow velocity, and mass flow rate and pressure distribution along the blades.

The principal investigator, Dr. Spennhake, left for Europe on indefinite leave for several months on 28 July 1952. Provisions have been made for him to continue his work under this contract during his absence from this country. It is anticipated that his visit abroad will be beneficial for the Flight Research Laboratory turbo-machinery research program in that Dr. Spennhake will make contact with the leading turbo-machinery researchers abroad during his stay there and will bring back this knowledge with him on his return to this country.

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TITLE: Approximation Methods for Turbulent Boundary Layers in Compressible Flow with Pressure Gradients
TASK NO.: 467-3-15 PRIORITY: 2 EST. COMPLETION: January 1954
SECURITY: Unclassified RESPONSIBLE SCIENTIST: H.U. Bokert EXT.: 27153
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this task is to develop a method of calculating two-dimensional turbulent boundary layers along smooth insulated surfaces in compressible flow with longitudinal pressure gradients.

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TO DATE: Since no experimental data are available which permit evaluation of the energy theorem for compressible turbulent boundary layers in a similar way to that which has been suggested for incompressible flow in some recent papers, an attempt has been made to account for the variation of the velocity profile with variation of the free stream velocity by a simple superposition method. This method is based upon the assumption that the whole fluid within the boundary layer follows variations of the free stream velocity disregarding the friction losses near the surface. By considering the value of the velocity profile parameter at a suitable wall distance as characteristic for the profile, a simple relation between profile parameter and relative velocity change is obtained. Comparison with a few available experimental data shows qualitative agreement for accelerated and moderately decelerated flows, while the quantitative effect is underestimated.

TITLE: Aircraft Propulsion Pumping Systems
TASK NO.: 467-4-1 PRIORITY: 2 EST. COMPLETION: January 1953
SECURITY: Confidential RESPONSIBLE SCIENTIST: J. Loch EXT.: 27153
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this task is to study the various systems which can be employed to pump the fluids used in the operation of aircraft power plants.

TO DATE: A survey has been made of the various pumping applications in aircraft propulsion systems, and a list of the important variables concerned in the evaluation of pumps has been compiled. Various systems of pump classification have been investigated and a new one devised which, it is believed, may lead to a unification and simplification of some lines of pump work. According to this system, a pump is classified as either rotating or non-rotating and cross classified as either positive displacement or flow, referring to the immediate means by which the fluid pressure is increased.

A British report dealing with the same problem, but only for rocket power plants, was received. While the classification of the pumping machinery used is not the same as that tentatively adapted for our own investigation, some valuable information in qualitative form is contained in the report. Unfortunately, virtually no quantitative data is given, and hence the essential work of this task is still to be accomplished.

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TITLE: Comparative Performance of Aircraft Propulsion Systems
TASK NO.: 467-4-2 **PRIORITY:** 2 **EST. COMPLETION:** Continuing
SECURITY: Confidential **RESPONSIBLE SCIENTIST:** J. Loch **EXT.:** 27153
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this task is to study the comparative performance of aircraft propulsion systems which may consist of one or more power plants of various types of outputs.
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TO DATE: The first part of this investigation was the standardization of fuel thermodynamic characteristics for airbreathing propulsion systems.

A program was then initiated to obtain the required thermodynamic data which would not contain the shortcomings of previous presentations. As one part of the program, a contract was let to the Bureau of Mines which covered the calculation of thermodynamic properties of the combustion properties of a standard fuel-air mixture (AF Contract No. 33-038-51-4123).

A WADC Technical Note is now in the process of being prepared; it is based essentially on the thermodynamic properties of gases given by the National Bureau of Standards tables and the data compiled by the Bureau of Mines. Values will be given for inlet temperatures of 300° to 2000°K and flame temperatures from 1000° to 4000° over the pressure range of 0.1 to 100 atmos. and for fuel-air ratios of 0 to 0.20, making due allowances for dissociation. Data will be presented in graphical forms for true and mean specific heat of dry air and combustion products, specific heat ratio, gas constant and combustion temperature rise for the compression, combustion and expansion cycles. It is expected that this paper will be ready for publication in the near future.

TITLE: Preturbine Injection and Reheating
TASK NO.: 467-4-3 **PRIORITY:** 2 **EST. COMPLETION:** Continuing
SECURITY: Confidential **RESPONSIBLE SCIENTIST:** D.G. Semaras **EXT.:** 27153
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this task is to investigate the potentialities of preturbine injection afterburning or reheat equipped aircraft gas turbines.

TO DATE: The afterburning turbojet was introduced more than a decade ago, however, its utilization was not so wide as that of the simple turbojet. Considerable work was done during World War II and after, which established its ranges of utilization. Among other uses of the afterburning turbojet, the following are

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the most important: (1) Transonic fighter, (2) Supersonic bomber, (3) Supersonic guided missile.

The military requirements of the above three installations are different. Two are the present day available modes of afterburning, namely, liquid fuel injection and vaporized fuel injection. The following are the main types of injection: (1) Preburner injection, (2) Afterburner upstream injection with flame holder, (3) Afterburner upstream flame stabilized in turbine wakes, (4) Afterburner downstream injection with flame holders, (5) Turbine downstream injectors.

The following table shows a comparison of the main characteristics

Type	Combustion efficiency	Pressure Losses	Temperature Distribution	Screeching
1	good	low	bad	free
2	good	low	good	badly
3	good	low	good	free
4	not so good	high	maybe good	very badly
5	poor	not so high	maybe good	maybe free

The same types of injection may be used for fuel vaporization, however, another method was found to be extremely advantageous at high-flight Mach speeds (above 2.0). This type vaporizes the fuel in the turbine blading and injects the fuel vapor in the gas stream. The cooling of the turbine blading permits higher combustion temperatures in the main combustor and requires a considerably shorter afterburner. The thermodynamic efficiency of this system is higher than that of the aircooled system. The improvements in range as compared to the aircooled afterburning turbojet is 10% to 35% higher.

Utilization of less strategic material shows considerably larger improvements.

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A Technical Note is in the process of publication giving complete account of the project.

The work is continuing into other phases of the afterburning problem.

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TITLE: Direct Measurement of Rocket Exhaust Velocities
TASK NO.: 467-4-4 PRIORITY: 2 EST. COMPLETION: July 1953
SECURITY: Restricted RESPONSIBLE SCIENTIST: L.E. Bollinger EXT.: 27153
PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The purpose of this task is to determine by direct methods the velocity of gases exhausted by a gaseous and/or liquid propellant rocket thrust chamber.

TO DATE: It has been decided that premixed gaseous hydrogen and gaseous oxygen will be used for the rocket motor propellant combination.

The motor with associated equipment is now being set up. It is expected that the motor will be fired before 1 September 1952. However, some delay will be experienced before actual velocity measurements can be made because of the necessary development work on the 10mc. electronic gates. Until the gates are available, preliminary tests will be made with the rocket motor. This is necessary because no premixed gaseous hydrogen-gaseous oxygen rocket has been successfully operated to date.

With information obtained by an investigator on a contract sponsored by the Propulsion Branch it is expected that no serious difficulties will be encountered insofar as the motor operations are concerned.

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TITLE: Flow Visualization Methods Study
TASK NO.: 467-4-5 PRIORITY: 2 EST. COMPLETION: Continuing
SECURITY: Unclassified RESPONSIBLE SCIENTIST: K. Kissell EXT.: 27153
PRIME CONTRACTOR: None. Work being accomplished at WADC
PURPOSE: The purpose of this task is to develop systematized techniques for the visualization of fluid flow in various physical situations of immediate and future application in propulsion research.

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TO DATE: A program for the study of flow visualization in rotating machinery utilizing a transparent peripheral pump has been initiated. The flow patterns will first be traced by use of suspended particles, air bubbles, powdered aluminum, or suitable motion picture camera from two perpendicular directions. The first test runs have shown that, as expected, the lighting of the particles will be the principal problem in obtaining the data. The reduction of the data will not begin until better records are obtained. Improved lighting is at present prevented by lack of power in the test facilities - all available circuits having been saturated with the lamps and camera.

A survey of the literature for flow visualization techniques is being conducted. Many references have been obtained in addition to those given in a report prepared by the General Electric Company at Flight Research Laboratory's request. These are being digested for release as an interim technical report and for selection of techniques for specific evaluation for USAF use.

TITLE: Boundary Layer Radioactive Tracer Technique
TASK NO.: 467-4-6 **PRIORITY:** 2 **EST. COMPLETION:** 1 January 1953
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** L.E. Bollinger **EXT.:** 27153
PRIME CONTRACTOR: Department of Engineering Research, North Carolina State College
PURPOSE: The purpose of this task is to develop a technique for using radioactive tracers in a study of the relative motions of various portions of a fluid flowing through a pipe or other ducts. In particular, it is desired to apply this technique to the boundary layers of the fluid immediately adjacent to the duct walls.

TO DATE: Counters have been designed and constructed to receive the output of the sodium iodide crystal-photomultiplier tube radiation detector. The 30 foot column and support tower have been completed. A 5 foot section of precision bore glass tubing will be used for the test section.

Preliminary tests, using dyes in a scale model of the column, have been made to study the problem of achieving planar interfaces between the radioactive and non-radioactive solutions. It is believed that a method has been perfected. Tests on the actual column will be conducted with dyes to confirm the validity of the method successfully used on the scale model.

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TITLE: Rocket Temperature Measurements
TASK NO.: 467-4-7 **PRIORITY:** 2 **EST. COMPLETION:** July 1953
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** L.E. Bollinger **EXT.:** 27153
PRIME CONTRACTOR: None. Work being accomplished at WADD.
PURPOSE: The purpose of this task is to determine suitable instrumentation to measure the temperature of hot gases and solids at various regions in a rocket chamber and in the jet stream.

TO DATE: Procurement action has been initiated to obtain special 16 stage infrared photomultiplier tubes. These will be used as detectors in a high temperature system.

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TITLE: Performance Analysis of Ramjet and Reheat Turbojet Engines
TASK NO.: 467-4-8 **PRIORITY:** 1B **EST. COMPLETION:** December 1952
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** D.G. Samaras **EXT.:** 27153
PRIME CONTRACTOR: None. Work being accomplished at WADD.
PURPOSE: This study is necessary for the selection of the optimum type of power plant for supersonic aircraft and missiles.

TO DATE: Performance calculations are proceeding satisfactorily. Meanwhile, statistical data on performance coefficients have been gathered.

Work on the thermodynamic data of a standard fuel of Project 467-4-2 is near completion and will be used in the performance calculations of this project.

The older method of performance analysis has been considerably improved.

The work of incorporating recent experimental data on blade cooling into the older ones has been started.

The same as above in the case of supersonic inlets.

From a few spot calculations, it is obvious that the turbojet with afterburning suitability reaches Mach speed of the order of 3.0 to 3.5. Above these Mach speeds, the ramjet shows better suitability.

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TITLE: Unsteady Flow Instrumentation
TASK NO.: 467-4-9 **PRIORITY:** 2 **EST. COMPLETION:** July 1953
SECURITY: Unclassified **RESPONSIBLE SCIENTIST:** L.E. Bollinger **EXT.:** 27153

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Project No. 467-4-9 (Cont)

PRIME CONTRACTOR: None. Work being accomplished at WADC.
PURPOSE: The determination of suitable instrumentation to measure various temperatures, pressures, flows, oscillations, etc., which occur during unsteady flow conditions in rocket motor and wind tunnel.
TO DATE: A special evaporator to vacuum coat quartz fibers with metals has been designed. The fibers will be used as part of a high frequency temperature transducer.

TITLE: Non-thermal Propulsion Survey
TASK NO.: 467-4-10 PRIORITY: 3 EST. COMPLETION: June 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: K. Kissell EXT.: 27153
PRIME CONTRACTOR: None. Work being performed at WADC.
PURPOSE: The purpose of this task is to consider generalized propulsion systems not primarily utilizing thermal energy release for propulsive effect.

TO DATE: This project was initiated to insure a constant awareness of the possibilities of utilizing propulsion systems not depending primarily on thermal energy release for their propulsive forces. This includes continuous survey of the literature and the analysis of systems to determine their technological feasibility.

Lack of manpower and low priority have not permitted much work on this project. A library search is in progress but is moving slowly. Correspondence has been initiated with specialists in field theory, including Dr. Einstein, to obtain their opinions on the present possibilities of non-thermal propulsion.

TITLE: In-flight Heat Transfer and Cooling
TASK NO.: 467-4-11 PRIORITY: 2 EST. COMPLETION: July 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: E.D. Stephens EXT.: 27153

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Project No. 467-4-11 (Cont)

PRIME CONTRACTOR: None. Work being performed at WADO.

PURPOSE: The purpose of this task is to provide information which will be required in the determination of cooling requirements for engines, aircraft cabins, compartments, components, etc.

TO DATE: The first phase of this project was concerned with a review of the upper atmosphere. The available data presents a picture of qualitative order at lower altitudes; however, the order of agreement becomes progressively less with increase in altitude. An understanding is required of the heat exchange mechanism in the upper regions of the atmosphere.

It is concluded that the tentative standard data (NACA TN 1200) should be used pending the availability of more consistent information that might warrant modification of the tentative data. A report has been written on this phase of the project.

The effects of aerodynamic heating based upon the tentative standard atmosphere were then investigated. The following charts have been prepared from calculated data: (1) Adiabatic wall temperature (steady state) for different free stream Mach numbers (1-10) and altitudes (0-300,000 ft.), (2) Total heat flow (or total cooling load in Btu/ft²hr.) from a wedge-shaped wing during steady state flight at predetermined surface temperatures depending upon the strength requirement of the structural material (cooling load vs Mach number at 0-300,000 ft.), (3) Surface temperature vs Mach number where no cooling is required to maintain limited surface temperatures, and (4) Endurance flight time vs free stream Mach numbers for a double wedge in steady state flight with extreme cooling of upper and lower front surfaces of the wedge.

The surface temperature and endurance flight time of a wing made of other materials (titanium and steel) will also be shown.

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TITLE: Application of Detonative Combustion to Pulse Jet Engines
TASK NO.: 467-4-12 PRIORITY: 2 EST. COMPLETION: January 1953

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Project No. 467-4-12 (Cont)

SECURITY: Unclassified RESPONSIBLE SCIENTIST: B.T. Wolfson EXT.: 27153
PRIME CONTRACTOR: Aero-Physics Development Corporation
PURPOSE: The purpose of this task is to do research and development on an application of detonative combustion phenomena peculiar to pulse-jet propulsion systems.

TO DATE: The purpose of this investigation is to determine the feasibility of the application of detonative combustion to a pulse jet engine. This is to be accomplished by the utilization of all available information on the component parts of the pulse compression detonative combustion jet system in making a theoretical performance evaluation of this system as compared to the conventional pulse jet and turbojet systems.

To date, the contractor has presented an evaluation between his system and the conventional pulse jet and turbojet engines. However, these comparisons were misleading insofar as they were based on the assumption of 100% efficiency of operation of all the cycles being compared. These discrepancies will be corrected by the contractor, insofar as a realistic performance evaluation will be made based on actual efficiencies of the component parts of each system compared.

Insofar as experimental installation and work is concerned, the ADC nearly completed fabrication and installation of a simple detonation tube -2" dia., 40 ft. long, divided into two chambers by a diaphragm. One of the first things planned for investigation in this tube is the initiation of a detonation wave - possibly using ethylene as a fuel.

Also, the ADC has constructed a breadboard model of their system incorporated in a model of a propulsion unit. A discussion of this model and of the modifications in their basic system is to be presented by the contractor in a forthcoming report.

Future Plans

During the remainder of the contract, the ADC is to continue their investigation of the theoretical performance evaluation of their systems as compared to the conventional pulse and turbo jet systems.

Also, they will conduct minor experimental work necessary to substantiate fundamental information utilized in the theoretical performance evaluation.

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TYPE: Glow Discharge for Turbulence Measurements
TASK NO.: 467-4-13 PRIORITY: 2 EST. COMPLETION: January 1953
SECURITY: Unclassified RESPONSIBLE SCIENTIST: L.E. Bollinger EXT.: 37150
PRIME CONTRACTOR: University of Minnesota
PURPOSE: The purpose of this task is to investigate means other than the hot-wire for measuring turbulence and to attempt to measure pressure fluctuation in an airflow.

TO DATE: Considerable delays have been experienced on this project. The contractor discovered, after the first year's operation, that the corona discharge instrument's response was primarily a function of density rather than pressure as originally assumed. The contract was renewed for a year to develop this instrument into a useful research tool. Because of the delays in getting the project renewed, most of the personnel were transferred to other work since no funds were left over from the original contract. The first quarter's work on the extension has produced nothing new. Apparently most of the time was consumed in obtaining personnel and re-establishing operation of the test equipment.

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