JOURNAL

OF THE

AMERICAN ROCKET SOCIETY

NUMBER 69 MARCH, 1947

CONTENTS

Published by the

AMERICAN ROCKET SOCIETY INC.

NACA Scientists Reveal Torrid Zone in Upper Atmosphere

The existence of perpetually torrid layers of air in the otherwise cold upper atmosphere was revealed here today by the National Advisory Committee for Aeronautics, government aeronautical research agency. Publication of the results of a new study by a special NACA subcommittee reveals the existence of a 170° hot zone extending from an altitude of about 30 miles to an altitude of more than 40 miles.

Higher than this the air grows colder and drops to below zero temperature at about 50 miles. From this point the air begins to grow hot again and reaches the boiling point at an altitude of 400,000 ft., the present limit of the investigation. It had previously been assumed that the air remained at a constant temperature of —67° F. upwards from an altitude of about 35,000 ft.

This new information on the outer reaches of the earth's air envelope is the result of research in many branches of science compiled by a special group established by the NACA in April 1946 to extend the known standards to the heights considered for future operation. The committee, headed by Dr. Harry Wexler of the U. S. Weather Bureau, included representatives from the Army, Navy, universities and other government agencies.

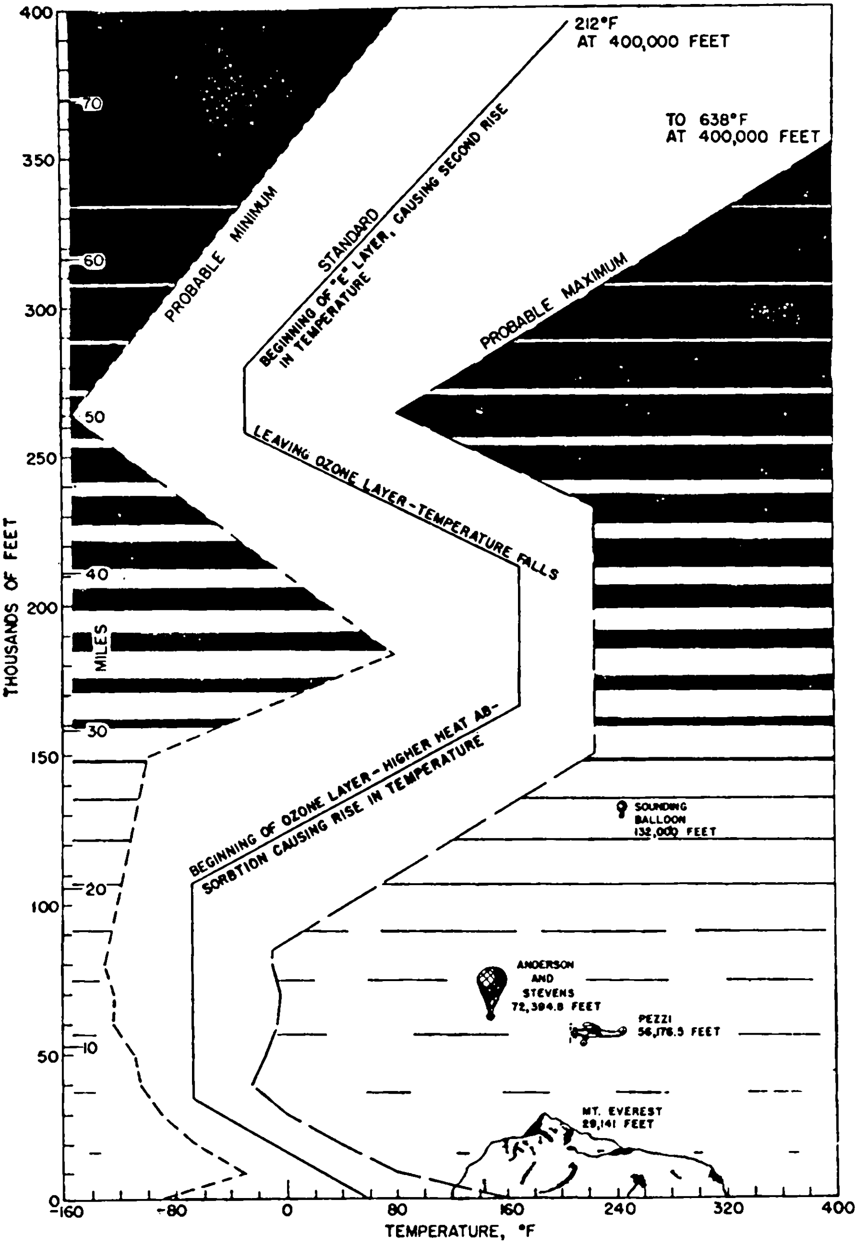
Establishment of a "standard" atmosphere is a necessary prerequisite to the development of new aircraft and guided missiles designed for upper atmosphere travel. These new findings will make necessary new design and construction techniques to permit aircraft operation in these torrid zones.

The previous NACA standard atmosphere data was officially adopted in 1925 and included the range from sea level to 65,000 ft. The present tentative tables are intended to establish the same standards extending the range from 65,000 to 400,000 ft. They have been evolved as a combined result of direct observation by radiosonde ballons, calculations based on known temperature changes, astronomical observations, and other indirect means. The predictions and calculations made over a period of time have been closely confirmed by recent V-2 observations and remarkably close agreement has been shown. The tentative tables compiled by the Committee show temperature, density, pressure, speed of sound and many other properties.

The accompanying chart shows graphically the changes of temperature with increasing altitude. The centerline marked "Standard" represents the probable average temperature and serves as a base line for design and performance criteria. The outer lines labeled "Minimum" and "Maximum" represent extremes to be expected due to variation in solar heat during day and night, seasonal variation, and the cyclic variation in the sun's energy output. These extremes serve as standards for estimating limits of performance.

The reasons for the fluctuations of temperature lie in the changing compostion of the air itself. The first increase in temperature begins at about 104,000 feet in the "ozone layer", which has the property of absorbing and holding more heat from the sun than the air below it. This causes an increase in temperature up to the upper limits of the ozone layer, where the temperature begins to fall off.

The ozone layer, composed of heavy oxygen or O_3, acts as a protective screen against too great an intensity of ultraviolet rays from the sun. The formation of ozone in the air is favored by the presence of large cold air masses,



NACA TENTATIVE STANDARD ATMOSPHERE

which is one reason for seasonal variation in temperature. The greater quantity of ozone produced in winter adds to the effect of the tilt of the earth away from the sun in preventing solar radiation from heating part of the earth.

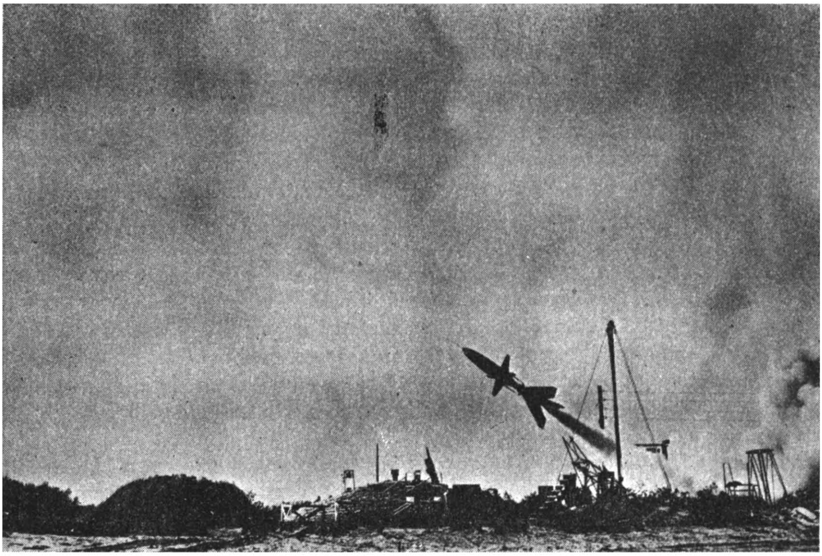
The second rise in temperature is caused by the presence of another layer which varies in height from 250,000 to 275,000 feet. It is composed partly of cosmic dust particles, which also hold more heat than the atmosphere below. This layer is also a region of "ionization", or exchange of free electrons. This process in itself generates a certain amount of heat. The layer is known as the Kennelly-Heaviside layer, in connection with reflection of radio waves. It is more briefly designated the "E" layer.

The V-2 research program has made possible the first direct measurements of temperature, upon which nearly all calculations of other properties are based at hitherto unreached altitudes. The close check between the most recent findings from these firings and the physical calculations has confirmed their validity, furnishing a reasonable basis for a "standard upper atmosphere" for design and performance criteria.

Research is being continued by all available means to improve accuracy and extend the range of the present data.

* * *

Secret Guided Missile



Launching of MX-570, Model B, Wallops Island Test Station.

The "Tiamat", a guided research missile, which has been developed in great secrecy over a period of two years by the National Advisory Committee for Aeronautics, government aeronautical research agency, was revealed here today. The missile is not a war weapon, it was pointed out, but has been developed and tested as a model for future missiles containing explosive warheads and target-seeking equipment.

NACA scientists describe the "Tiamat" as "the first guided missile to be flown successfully through a predetermined program of maneuvers." The missile is 14 ft. 4 in. long and weighs about 600 lbs. It has a flying speed of approximately 600 miles per hour, although its design can be adapted to supersonic missiles powered by various types of jet engines.

The "Tiamat", one of the first successful "step" rockets, is launched from a zero-length rocket launcher by the power of a "rocket booster" assembly mounted on its tail. This assembly produces 7200 lbs. of thrust for 3½ seconds, which is sufficient time to get the missile up to its normal flying speed. After exhaustion of the rocket booster, the entire assembly drops away in flight and an internal rocket engine, which develops 200 lbs. of thrust continuously for 45 seconds, continues the flight.

Because the "Tiamat" is a research missile, not a war weapon, it carries a large quantity of instrumentation on its flights to provide a record of such basic information as speed, control movements, degrees and speed of roll and data on its vertical and lateral acceleration. This information is transmitted to the ground by telemetering equipment located within the missile. In addition, both radar and optical equipment is used near the launching site to track the movements of the missile during its flight.

Design of the "Tiamat" was first suggested by Mr. Robert T. Jones, NACA aerodynamicist, at a joint NACA-AAF-Industry conference on guided missiles held in great secrecy at the NACA Langley Memorial Aeronautical Laboratory, December 7, 1944. Following approval of the design, which had already been subjected to preliminary wind tunnel tests durinig November, 1944, the AAF authorized an experimental research program designed to produce the basic configuration of a guided missile.

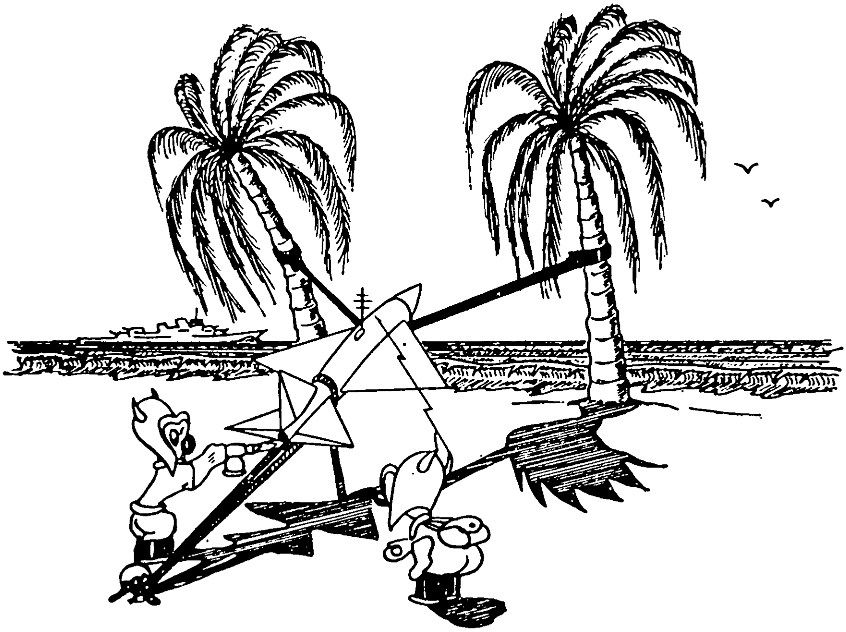
The odd name of the missile stems from Tiamat, an Assyrian-Babylonian goddess, who plotted the overthrow of Marduk, king of the gods.

The "Tiamat" is a research missile designed and tested to provide basic data applicable to all guided missiles and is, therefore, not a specific weapon design. Such questions as the number and type of control surfaces and their location, center-of-gravity travel limits, stability and control criteria, servo mechanism type and design, application of various forms of propulsion, warheads, target-seeking equipment, etc. are investigated with the "Tiamat".

Fundamental research of this type, conducted by the National Advisory Committee for Aeronautics, is a necessity before a comprehensive program of guided missile production and development can be activated. Although numerous experimental guided missiles are now in the preliminary test stage, considerable additional basic data is required. The "Tiamat", therefore, was designed specifically as a "guinea pig" for numerous tests, results of which wilil prove vitally usefu to the Army Air Forces, Nava Aviation and the aircraft manufacturing industry in the nation's guided missile development program.

Testing Naval Pilotless Aircraft

By GRAYSON MERRILL, Commander, USN



I. INTRODUCTION

The day in 1943 that Allied ships were first sunk by German jet propelled pilotless aircraft marks a turning point in history. The impact of this event and and the subsequent impacts of V-1, V-2, and the atomic bomb have led to a national conviction that guided missiles loaded with atomic armament constitute the most promising weapons of future warfare.

The engineers and executives of the American Rocket Society and the American Association of Mechanical Engineers are certain to be in the forefront of national efforts in this field. It is from their viewpoint that this paper has been written. Its objective is to present a semi-technical description of what is involved in the testing of guided missiles, with emphasis on the pilotless aircraft class, and to outline the plans of various government agencies to provide the necessary facilities.

II. NATURE OF PILOTLESS AIRCRAFT

A guided missile may be defined as a space traversing weapon which carries within itself the means to control its flight path. Great variation exists in the means of control, which includes remote radio control, confinement to a radar beam locked on the target, and target seeking devices utilizing radar, heat, light, sound, or magnetic emanations. Still more variation is available in the airframe which may be anything from a steerable bomb or rocket to a true aircraft. The pilotless aircraft is simply a guided missile whose aerodynamic surfaces are sufficiently large to furnish its chief sustentation in flight. In fact, very little can be said about the testing of pilotless aircraft which is not equally applicable to guided missiles.

One of the most striking things about guided missiles is the wide variety of uses to which they can be put. They are capable of replacing or complementing all guns, except perhaps infantry-borne arms! Thus, we may live to see the sixteen-inch rifles of battleships as well as their anti-aircraft guns replaced by guided missiles Cities may be protected from future air attacks by guided missile batteries. Instead of guns and rockets, future aircraft may carry various offensive and defensive guided missiles. Likewise, bombs and torpedoes are likely to go by the board.

A concept as broad as this is difficult to justify until it is realized that modern guns have just about reached their limit of range and that shell projectiles, having an appreciable time of flight and no means of adjusting their trajectories to catch dodging targets, cannot compete with guided missiles on this score. Of course, the competition between conventional weapons and guided missiles cannot be decided dogmatically in the latter's favor. Generally speaking, the guided missile should have a longer effective range, be usable under more adverse tactical circumstances, and give a higher ratio of kills to shots fired. On the other hand, the gun is simple, cheap, reliable, and lends itself to the shot-gun principle of a high volume of fire. The niche for guided missiles in tomorrow's Army and Navy can only be determined on the basis of complete tests of the missiles themselves. Probably, like all weapons of the past, they will become simply one of several tools by which men wage war. It is safe only to say at this time that never before has a weapon of such broad potentiality been visualized for development.

Guided missiles are customarily broken down into basic types according to where they came from and where they are going. For example, the "ground-to-air" type is launched from the ground against an airborne target. Here is a feasible table of the basic types.

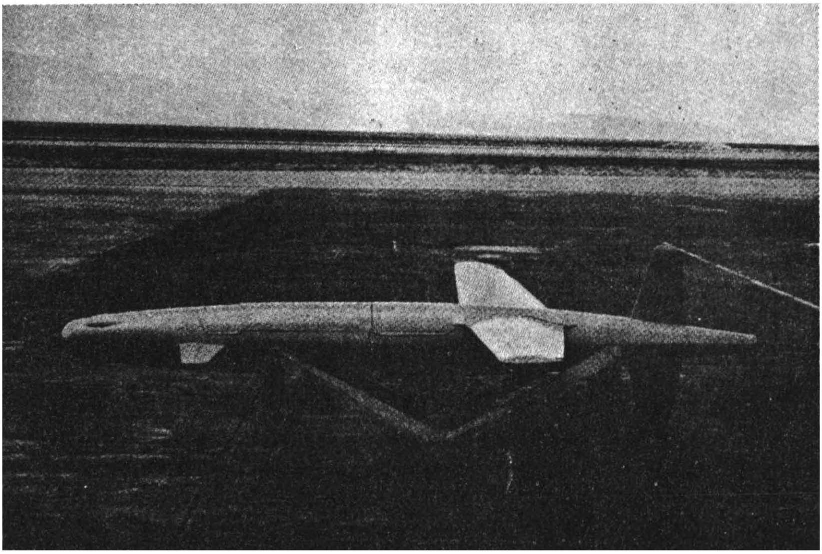
Army	**Navy**
Ground-to-Air	Ship-to-Air
Ground-to-Ship	Ship-to-Ship
Ground-to-Ground	Ship-to-Ground
Air-to-Air	Air-to-Air
Air-to-Ground	Air-to-Ground
Air-to-Ship	Air-to-Ship

In many cases one missile may serve in two or more types of categories. For example, an air-to-ground missile is often very effective as an air-to-ship missile.

A cursory glance at the above table might lead one to conclude that the same type of missile should serve both the Army and Navy. This is generally not true, chiefly because of the different tactics involved and the different launching conditions. For example, a missile launched from a large bomber is generally impossible to launch from a small carrier plane. Likewise a ground-to-air missile against a large bomber formation is likely to be useless as a ship-to-air weapon against a suicide plane attack.

It is well now to disect these guided missiles, so to speak, in order to learn what tools a designer has to work with and what the test director must later test.

The first thing a designer needs is a statement of what his guided missile must do. This is always given in general terms and not in terms of what speed must be attained, how much it must weigh, etc. An example for a ship-to-air guided missile might be to develop a guided missile which, operating in conjunction with existing ship search



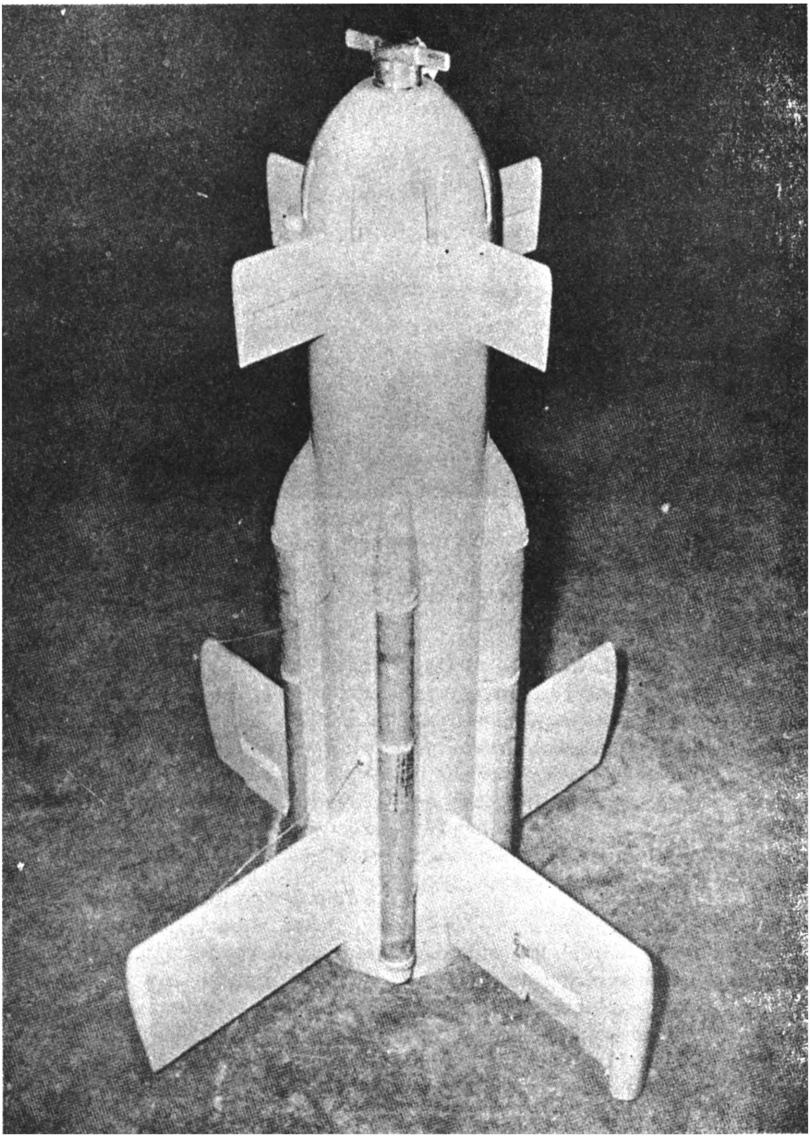
KU2N-1 GORGON IIA. **This is a winged, rocket propelled, air-to-air missile which is directed to its target by a radio control link with the mother plane using tracking information obtained by a television set carried in the missile.**

radars, can be launched at and destroy an enemy bomber flying no more than 600 miles per hour and no higher than 40,000 feet. The bomber may detect the launching and take evasive action. If the detected bomber elects to attack, he must be destroyed before reaching ten miles horizontal range of the firing ship in order to prevent his launching a guided missile attack of his own.

With this statement of the problem, the designer can launch into a study leading to the evolution of specific weight, performance, and the like. It can be categorically stated here that the problem of designing a guided missile of this type far outweighs in difficulty that of designing a new fighter or bomber airplane. It is in fact a problem of utilizing a number of separate sciences some of which are themselves in the embryonic stage. To mention a few applicable to the problem: supersonic aerodynamics, advanced mathematics, physics, jet propulsion, electronics, and external and terminal ballistics. Unfortunately, there are few organizations in our nation which employ experts in all of these fields. This is one of our most serious national problems.

As a design takes shape on the drawing board, we are able to recognize certain basic components which are always present in any guided missile. These are the airframe, the propulsion system, the guidance system, and the armament system. Closely associated with the guided missile is the launching system.

Viewed from the standpoint of testing, guided missiles have certain peculiarities, the effects of which must be recognized at the outset. Generally it is impossible for a human pilot to ride in these missiles. Consequently we are



KAN-1, LITTLE JOE, a short-range anti-aircraft missile designed to be launched from a ship-board catapault with the aid of standard rockets. It is radio-controlled, flare-sighted and powered by a JATO solid fuel rocket.

obliged to use very extensive instrumentation and special control equipment in order to get the most out of a given flight. This is especially true since each flight is a one shot affair. To date, no practicable scheme has been devised for the recovery, by parachute or otherwise, of really high speed missiles.

The dependence of guided missiles upon complicated control mechanisms makes their operation rather hazardous to nearby life and property. It is characteristic of the initial flights to be quite erratic and any device for the reliable self-destruction of a maverick missile is as yet not in sight. For this reason and because of the inherently long flight ranges it is necessary to provide flight test ranges more extensive and devoid of human activity than those heretofore available. They are so extensive and expensive to operate that only the government can afford to establish such ranges.

III. EXISTING AND PROPOSED FLIGHT TEST RANGES

The most extensive flight test ranges are being operated by the armed services. Complementing these ranges, less extensive facilities are being operated by other government agencies and in some cases, by private enterprise.

The main Army Air Forces test range is at Wendover, Utah. Here, use is made of the enormous salt flats associated with the Great Salt Lake. About 100 miles of range is available. The Air Materiel Command controls the work at this station.

The Army Ordnance Department of the Ground Forces operates a range of about 100 miles extent at White Sands, New Mexico. This is the site of the present V-2 testing. The Navy is constructing facilities to support its own expected overland work on the same range. Thus joint use has been achieved of a very expensive facility with resulting saving to the taxpayers.

The Navy's Bureau of Ordnance controls a range of about 25 miles extent at Inyokern, California. Thanks to its wartime work in rocket trajectories, Inyokern is equipped with one of the best of existing instrumentation systems.

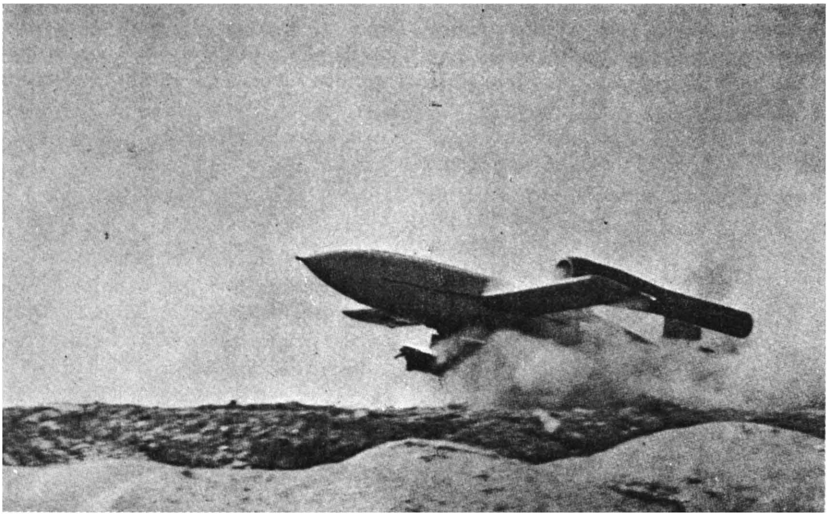
The only Naval overwater test range is proposed by the Navy at Point Mugu, California. Here the recently organized Naval Air Missile Test Center is located. The heart of this range is a potential string of observation posts to be located on the Santa Barbara Channel Islands. Trajectories of 100 odd miles can be closely observed, and plotted from these vantage points.

V. PREFLIGHT TESTING

The previously mentioned expensive nature of guided missile flight testing makes it imperative to gain a maximum of prior knowledge through laboratory type preflight testing. This comprises a series of tests on each of its components and on the assembled whole.

The propulsion system, if it is one of the air consuming types such as ramjet, pulsejet or turbojet, is tested in an open circuit air blast facility. Such measurements as specific fuel consumption, gross and net thrusts, operating temperatures, and dynamic vibration forcing functions are determined. Rocket motors, which do not require air, are similarly tested in well-barricaded static test pits. Very often the propulsion component will be mounted in a piloted aircraft and flight tested prior to any flights in the ultimate guided missile.

The guidance system is tested in breadboard configuration on a flight simulator table. The time constants of the system are checked and a multitude of quantitative data taken. The performance under very high altitude and low temperature conditions is ascertained. It is then mounted in a piloted aircraft and made to operate under flight conditions closely simulating its final use.



KUW-1 LOON, a copy of the German V-1 missile. This is a pilotless aircraft propelled by a pulsejet engine and having at present a range of 150 miles. Launching can be effected from several types of ground systems, and probably from ships.

The airframe is subjected to a vibration analysis, chiefly from the point of view of adverse effects on other components such as guidance. Presumably, its strength to withstand launching and flight accelerations has been proven by contractor-directed static tests. Thus it remains for the Navy to provide for its proper installation on a Naval aircraft if it is an airborne weapon or on a Naval vessel if it is shipborne.

The armament component must be proven from the point of view of its destructive effect and the reliability of its fusing system. The former is generally carried out at ordnance proving grounds, specially fitted out for the work.

The launching device usually takes the form of an aircraft bomb rack or variation thereof, a catapult, or a launching rail system utilizing rockets. All of these must be tested with "dead-loads" prior to entrusting the final missile to their caprices. Where it is significant, a time history of the launching accelerations is taken.

Once the components have completed their tests the missile is subjected to certain preflight tests in the assembled condition. Perhaps the most important is the imposition of accelerations which simulate, as closely as possible, those to be expected in actual operation. Instrumentation must be employed to study the component's behavior during this process. This test is closely coupled to a vibration test whereunder the adverse effects, if any, of propulsion induced vibration are determined. The entire missile is also subjected to the equivalent of very high altitude and low temperature. Finally, the interaction of electronic circuits is tested from an electrical noise interference viewpoint.

VI. FLIGHT TESTING

The business of flight testing guided missiles is surprisingly analogous to crime detection. The developing engineer may be sure that the missile will perform criminally at the outset and that a sharp analytical mind will be required if the fault is to be discovered.

First of all the flight test plan must be good. As a rule only one unknown may be inserted into the program at a time. At the same time the number of test articles is limited so that a certain number of calculated risks must be assumed if expenses are not to skyrocket.

A typical flight test program will approach the following problems in order: launchings, aerodynamic stability, flight characteristics, performance under guidance, and performance against the target. Successful solution of these problems constitutes completion of the development phase whereupon the armed services take over on the test and tactical evaluation phases.

VII. FACILITIES REQUIRED FOR FLIGHT TESTING

Any crime is soluble in proportion to the amount of evidence available. Consequently all flight tests are conducted so as to give the maximum of engineering or tactical data after the inevitable crash. The greatest tool for gathering this evidence is instrumentation. The instrumentation for guided missiles is conveniently divisible into the two classes "external" and "internal."

External instrumentation comprises the devices and techniques used to record flight data developed externally to the missile. Its purpose is to give a time history of the missile's trajectory in terms of position, velocity, and acceleration. Sometimes it is feasible to obtain attitude and control surface data by use of telephoto cameras.

Heretofore, the techniques of external instrumentation have been almost exclusively employed by the nation's ordnance proving grounds in connection with ordinary projectile trajectories. Today the aircraft industry is becoming familiar with these techniques through the testing of pilotless aircraft.

A modern external instrumentation system will include visual tracking photo-theodolites, high speed cameras for the study of launching and initial flight, telephoto cameras to record very critical portions of the flight such as target interceptions, chain radars for non-visual long range tracking, and Doppler radio systems for non-visual tracking and precise velocity measurements. All of these must be related by an accurate time synchronization system and coordinated by a command communication system.

Internal instrumentation comprises the devices and techniques used to record flight data developed internally to the missile. Its purpose is to give a time history of the missile's attitude about the three axes of roll, yaw, and pitch; its altitude airspeed, angle of attack, and position with respect to a target; the axial and rotational accelerations being encountered; and the performance of its components.

The techniques for internal instrumentation have been well developed by the aircraft industry and it is to this industry that the ordnance fraternity is now turning for help on the testing of guided missiles.

At first thought it might appear that instruments for the measurement of the foregoing items already exist. In general, this is true except that these must now be redesigned to meet additional requirements, such as ability to withstand the launching accelerations and to operate under the violent flight conditions which exist when something goes wrong and we are depending upon the instruments to tell us the story.

Another major problem is to record the output of these instruments in such a way that they may be studied subsequent to the test. The most popular methods for doing this are radio telemetering and photographic recording with recovery of the film either from an armored camera or from a flight ejected and parachute-recovered capsule.

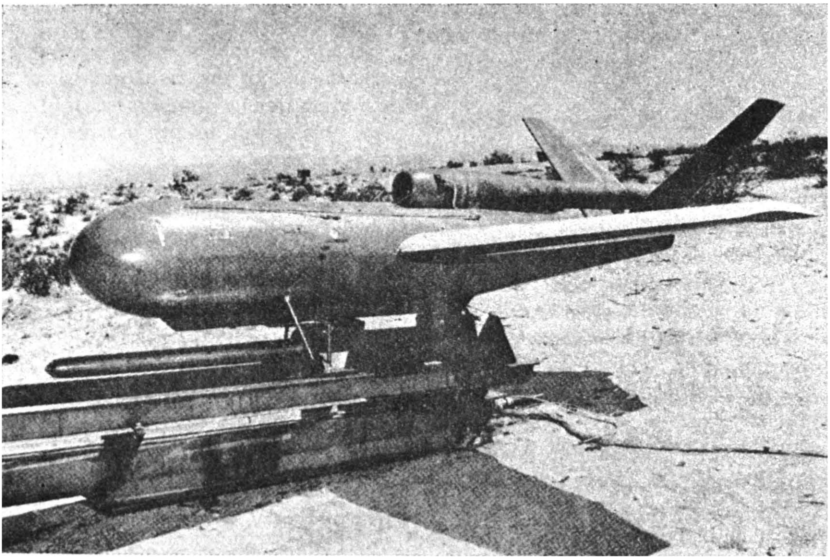
It is of utmost importance to provide for the rapid reduction of flight test data. Normally the contractor's engineers are desirous of analyzing the flight before the next test is undertaken, particularly when a failure was involved. Thus waiting for the reduction of test data represents expensive idling time for the contractor which must be reduced to a minimum. Such a minimum can be achieved by the employment of time saving computing machines and plenty of analyzing personnel.

Providing realistic targets for flight tests is another important function of the test range. The Navy provides radio controlled boats and looks forward to radio controlled ships in the future. Heat seeking devices can be accommodated with radio controlled trucks into whose bodies the equivalent of a ship's boiler has been built. Begg Rock, which juts 15 feet out of the sea off Point Mugu, makes an ideal non-sinkable ship target for radar homing and other guided missiles. Radio controlled Grumman Hellcat fighters are used as targets for antiaircraft missiles.

Flight testing guided missiles is inherently a dangerous business. Consequently certain fundamental precautions are usually taken. Until the stages of erratic flight have been passed, launchings should be made from a point well removed from human activity. San Nicholas Island has been chosen by the Navy for this purpose. High speed chase planes with live ammunition should, if possible, tail each flight with orders to shoot down a wildly erratic missile. Lastly, protection must be afforded the test personnel at launching site, observation posts, and impact point.

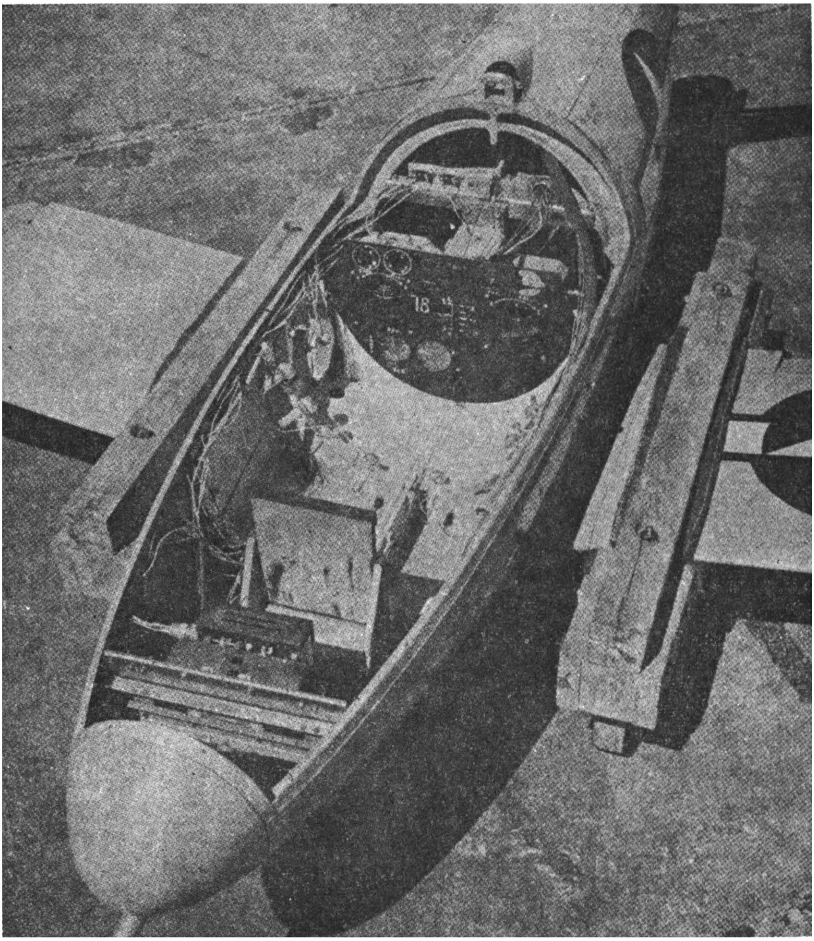
VIII. NAVAL TACTICAL EVALUATION

Up to now we have been treating the testing of guided missiles primarily from an engineering standpoint. Once the missile has passed its engineering tests and is a reliable flying machine it is then necessary to prove its worth as a military weapon through tactical

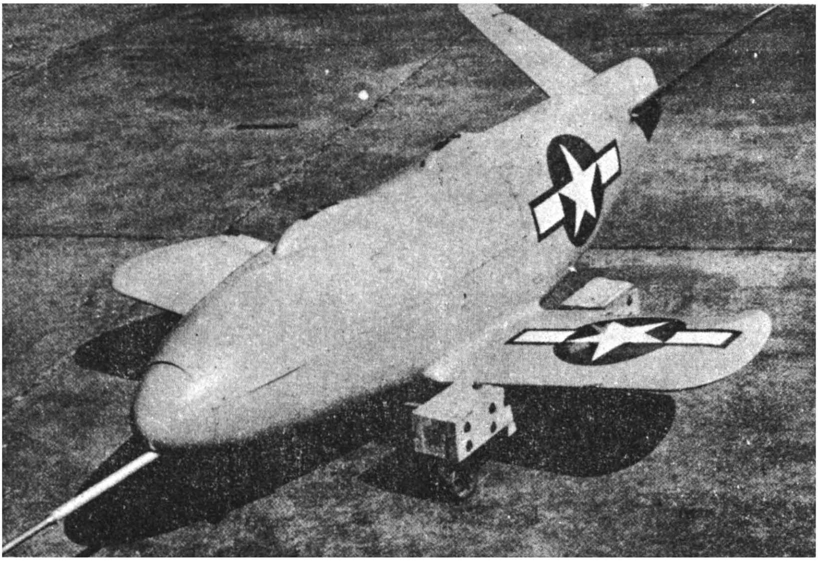


KDD-1 Target Drone, a remote radio-controlled pilotless aerial target, powered by one McDonnell pulsejet engine, and designed primarily for use as an antiaircraft gunnery training target.

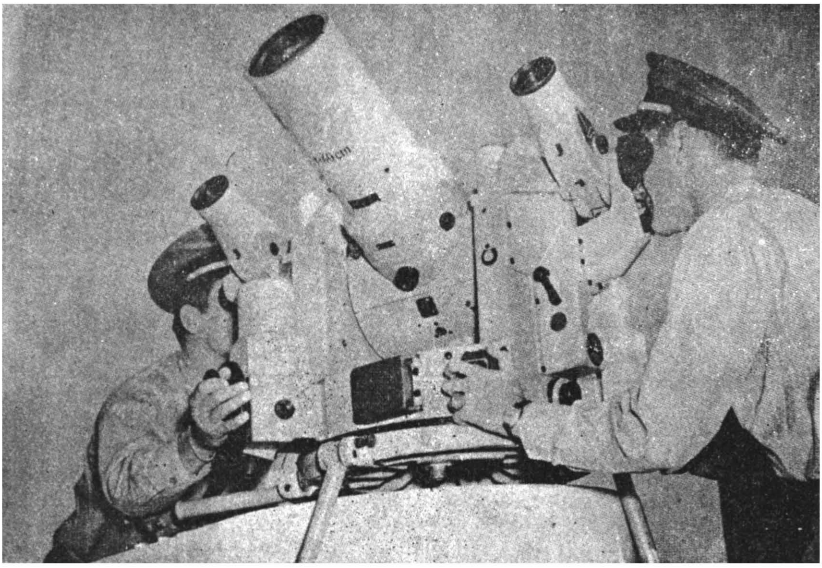
evaluation. Tactical evaluation is really a wringing out process where performance under actual conditions is ascertained. The missile is no longer babied. Run of the mine enlisted men replace trained technicians for operations and maintenance. Launchings are made with cold salt spray coming over a pitching ship's bow. Flights are made in fog, rain, and thunderstorms. Finally, target ships are sunk, aircraft are shot down, or shore installations destroyed. In the process of all this, the best means of tactical employment is evolved. Then, and only then, the final score is totaled and a new weapon takes its place in the Fleet or sinks into oblivion, as the case may be.



KUD-1 GARGOYLE, Showing Installation of Instrument Panel



KUD-1 GARGOYLE, an air-to-surface radio controlled powered glide bomb carrying a standard 1,000 pound general purpose or armor-piercing pay load. The missile is launched from a carrier aircraft and is designed for use against maneuvering targets such as ships.



CAPTURED GERMAN ASKANIA CINE-THEODOLITE
for Determining Trajectories of Guided Missiles

Dr. Robert H. Goddard (deceased) — Pioneer in American Rocket Development

Aircraft Turbo-Jet and Prop-Jet Starter Systems

Bq CAPTAIN A. G. BARDWELL, Jr.

Electrical Branch, Equipment Laboratory Engineering Division,

Air Materiel Command, Dayton, Ohio.

Contributed by the American Rocket Society and Oil & Gas Power — Aviation Divisions for presentation at the Annual Meeting, New York, N. Y., December 2 - 6, 1946, of The American Society of Mechanical Engineers.

INTRODUCTION

Starter systems for aircraft engines are not longer in the category which will permit providing only a slightly larger starter and battery for an increase in the size of the engine. At the present time it appears that an internal combustion engine starter and a solid propellant turbine starter may provide starter systems which will be satisfactory for existing turbo-jet and gas turbine engines. However, the starting requirements of future engines may be of such magnitude as to render a completely self-contained airborne starter system undesirable or impractical as a result of not only the complexity of the system but also the excessive weights encountered. The problem of providing a light weight, compact, and reliable starter system has become one which requires a completely new and vigorous approach and which must not be hindered by requirements imposed as a result of the fond memories of the barnstorming era.

Starting systems for combustion type engines are generally considered to include (1) the initial ignition system, (2) the initial fuel supply system, (3) the initial lubrication system as well as (4) the device or system which imparts motion to the rotative parts and maintains the motion until the engine is capable of self-sustained operation. Although all four of the aforementioned are of prime importance, this presentation will deal only with the latter, hereinafter referred to as the starter system, as it relates to aircraft turbo-jet and gas turbine engines.

A turbo-jet engine is defined as a turbine type engine which is designed to deliver only enough rotative power necessary to drive the compressor and various accessories such as fuel pumps, oil pumps, generators, etc. The remainder of the power is delivered in the form of pure thrust power.

STARTER SYSTEM REQUIREMENTS AND EXISTING SYSTEMS

The gas turbine engine presents the greatest power requirement in starting because of that power necessary to rotate the propeller at high speed, as illustrated in Figure 1. It is possible that this would be lessened with a satisfactory declutching arrangement between the engine and propeller. However, inasmuch as no system has been developed to date which will economically, with regard to weight and power, and satisfactorily accomplish this, the possible use of such a system will not be considered in this presentation.

The starter system thus must provide sufficient power (1) to overcome the inherent mechanical friction losses of the engine, (2) accelerate the rotating members of the engine in a short period of time to the desired speeds and (3) to operate the compressor at a speed and over an adequate period of time which will provide adequate air-flow conditions necessary to obtain satisfactory ignition, burning, and turbine temperature.

MAKE-UP SHEET FOR MECHANICAL ENGINEERING

Top of Running Head

Top of Reading Matter

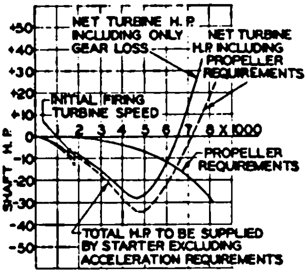


Fig. 1

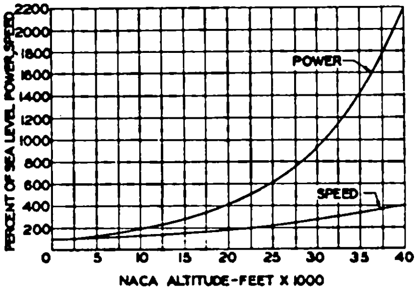


Fig. 2

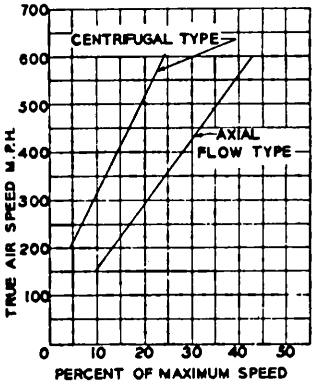


Fig. 3

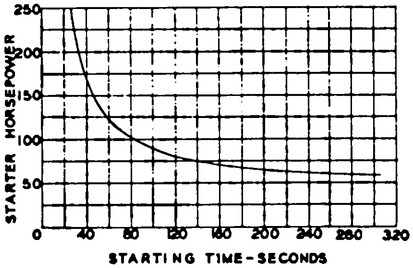


Fig. 4

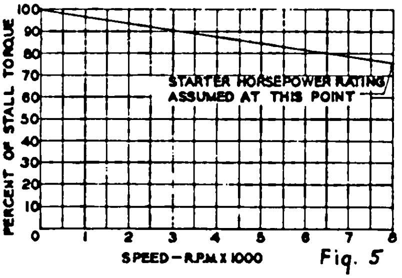


Fig. 5

FIGURE I — Typical Gas Turbine Starting Power Requirements.

FIGURE II — Power and speed characteristics of an ideal compressor to provide a given air flow neglecting air ram effect.

FIGURE III — Windmilling characteristics of turbo-jet engines having axial flow and centrifugal type compressors.

FIGURE IV — Influence of starting time upon starter power assuming typical starting requirements, Figure I, and starter torque-speed characteristics, Figure V.

FIGURE V — Assumed torque-speed characteristics of starter.

Other than that necessary for initial breakway, the inherent mechanical friction losses account for a relatively small portion of the starter power necessary.

The power necessary to accelerate the rotating members to the desired speed in a predetermined period of time accounts for a large portion of the starter power necessary. Although a maximum starting time has not been specified, certain tactical operations and applications make a 30 second start very desirable and a 60 second start the maximum permissible. The practical limitations on the starting time will be subsequently discussed.

The power necessary to operate the compressor at a speed which will provide adequate air-flow conditions necessary to obtain satisfactory ignition, burning and turbine temperature accounts for the largest portion of the starter power necessary. This portion, however, is dependent on the starting time inasmuch as the power necessary to accelerate a mass is inversely proportional to the time required for the acceleration assuming a constant acceleration.

$$P = K . \frac{1}{t} . I . a$$

where P = power necessary to accelerate a mass

t = the time necessary to accelerate a mass

I = Moment of Inertia of the mass to be accelerated

a = the acceleration

K = a constant

Conventional reciprocating type of aircraft engines generally employ the 28 volt D-C direct cranking starters designed to operate at a starter terminal voltage of 15 to 18 volts D-C. (The voltage of 15 to 18 volts has been found to be the starter terminal voltage generally obtained from standard 24 volt aircraft batteries during heavy load conditions imposed by the starter system). Other starters, such as the inertia starters, the combination inertia-direct cranking starters, the cartridge starters, the air starters and many others, have been used but are generally being replaced by the direct cranking starters. The largest such starter now being used is rated at approximately five horsepower and weighs approximately 28 pounds.

Direct cranking electric starters and combination starter-generators are being used on turbo-jet engines at the present time. The General Electric Type I-40 and TG-180 and the Westinghouse Type 24 turbo-jet engines require approximately a ten horsepower unit. These starters and combination starter-generators are designed to operate on a terminal voltage of from 12 to 17 volts D.C. which is obtained from a 24 volt D.C. high rate discharge battery under load.

This type of starter system, in order to be entirely self-contained in the aircraft, weighs approximately 140 pounds. Ten pounds of this weight is assumed to be chargeable to the necessary cable. Approximately 30 pounds of this weight is chargeable to the starter, however, in the case of the combination starter-generator which is used on the General Electric TG-180 turbo-jet engine, this may be reduced by as much as 15 pounds as a result of the weight saving accomplished by combining the starter and generator into a single unit. Approximately 100 pounds of the battery weight is assumed to be chargeable to the starter system. Although the total weight of the battery in the aircraft electrical system is 150 pounds, it is assumed that a battery weighing 50 pounds will be necessary for electrical system stability.

Equivalent German turbo-jet engines were found to be equipped with the Riedel reciprocating type internal combustion starter engine weighing approximately 50 pounds. However, this type of system provides starting power only at sea level conditions and lengthens the starting time by approximately four times including warm-up time necessary for the starter. Development of a larger and more automatic unit has been initiated by the Army Air Forces in order to study in greater detail the advantages and disadvantages of this type of starter system. It is anticipated that a starter system weighing approximately 85 pounds may be obtained which will produce sea level starts comparable to the present 28 volt D.C. electrical system using high-rate discharge batteries.

At the present time, starter systems are required to be capable of starting turbo-jet and gas turbine engines under any condition including re-starts at altitude. This requirement is of no consequence when considering gas turbine engines inasmuch as the windmilling effect of the propeller will supply sufficient power to obtain a start. However, this requirement may potentially be of utmost importance and magnitude for turbo-jet engines as is indicated in Figure II which is obtained by making the obviously false assumption that no effect will be derived from the ram effect of the forward motion of the airplane. Other assumptions that were made in order to simplify the calculations are (1) that a given weight of air flow through the compressor is necessary for starting (2) that the power demand necessary to obtain this given weight of air flow represents the maximum requirements (3) that no work will be realized from the expansion of the air through the turbine prior to reaching the compressor speed where the required weight of air flow occurs (4) that the power required to drive a compressor varies directly with the cube of the speed of the compressor, inversely with the absolute temperature of the intake air, and directly with the density of the intake air.

$$P = K \cdot N^3 \cdot \frac{1}{T} \cdot p$$

where P = Power required to drive the Compressor

N = Speed of the compressor

T = Absolute temperature of the air at the inlet

p = Density of the air at the inlet

K = a constant

The ram effect of the forward motion of the aircraft upon the starting characteristics of the turbo-jet engine is at the present time only partially known. However, this ram effect upon the windmilling speed of the engine is shown in Figure III based on NACA Test Data and has been found to be independent of the atmospheric pressure altitude.

The necessity of providing a given weight of airflow through the compressor is by no means the only major influencing factor. Among other major factors are the ignition characteristics and the burner or combustion chamber characteristics. Investigations are being conducted at the present time to determine the mutual effect of these three factors on the altitude starting characteristics. If these investigations reveal that the starter assistance in flight conditions is unnecessary, a weight saving of approximately 55 pounds may be realized immediately by the use of the reciprocating type internal combustion starter engine.

As the size of the turbo-jet engines and, particularly, gas turbine engines increases, the required starter power increases at a much greater rate than that for conventional reciprocating type aircraft engines. For example, a starter system for the General Electric Type TG-100 gas turbine engine may be required to deliver approximately 70 horsepower maximum in order to obtain a start in 60 seconds, whereas a starter for an engine rated at approximately twice the output may require a starter to deliver up to 250 horsepower. In comparison, increasing a reciprocating type aircraft engine displacement by a factor of two increases the starting power required by a factor of approximately one and one-half. Thus, the largest starter for a reciprocating type aircraft engine is not anticipated to be larger than ten horsepower whereas it is anticipated that a starter capable of delivering up to 1000 horsepower may be necessary for gas turbine engines.

Heretofore, the time necessary to start aircraft engines has not been of major importance inasmuch as a short starting time does not materially add to the flexibility of aircraft equipped with conventional reciprocating engines because an engine warm-up period is required. However, aircraft equipped with turbo-jet and gas turbine engines may take off at such time as the desired engine speed has been attained. Furthermore, the taxiing of such aircraft is undesirable because of the excessive fuel consumption encountered. This feature makes it very desirable to tow such aircraft to the take-off point prior to starting which in turn makes rapid starting desirable if not imperative. However, practical limits to the time necessary to start turbo-jet and gas turbine engines must be determined. Figure IV presents an indication of the rate at which the starter power increases with a decrease in starting time. The data for this curve was derived from the Typical Gas Turbine Starting Requirements, Figure I, and assumed starter torque-speed characteristic shown in Figure V rating the starter at maximum speed. The moment of inertia of all the rotating parts with respect to the turbine shaft was assumed to be 150 pound-feet squared.

FUTURE STARTER SYSTEMS — SELF CONTAINED

To meet the requirement of larger starter systems, a small turbine starter mounted directly on the engine and powered by a solid propellant contained in a cartridge is being developed. It is anticipated that the unit will weigh approximately 115 pounds including the propellant necessary to start a gas turbine engine in 30 seconds. The weight of the propellant is approximately 30 pounds which results in an engine mounted, airborne weight, of approximately 85 pounds. Although this system offers many advantages, particularly in a large weight saving, it is not anticipated that the most desirable starter system will result from applications of this type. Many inherent disadvantages, such as safety in handling, storing, and using, operational reliability, special supply problems, et cetera, may prove of such consequence as to render such a system entirely impractical at the present time. However, if investigation relative to the starting power required at altitude reveals that a large amount of power my be required, it may become necessary to accept these disadvantages for the present time and attempt to overcome them in the future.

There is under development at the present time a starter system which will employ the power available from an airborne auxiliary power plant. Such a unit will have as its prime function the supply of electrical power necessary for operation of the aircraft. Therefore, during the starting period, the entire capacity of the auxiliary power plant is available. At the present time, the hydraulically transmitted system being developed appears to yield an economical result. It is anticipated that such a system may be installed at a weight cost of less than 50 pounds per aircraft engine based on a 25 to 30 horsepower starting demand.

Considerable thought has been given to the possibility of using the excess power available at sea level from turbo-alternator units currently under development. Such a unit, which is designed to be capable of delivering approximately 100 horsepower at 40,000 feet altitude, will potentially be capable of delivering in excess of 400 horsepower at sea level, all of which may be considered to be available for starting. At the present time, it appears that a small gas starter turbine mounted on the aircraft engine will provide the most satisfactory system The power available from the turbo-alternator unit may be transmitted to the starter turbine by (1) the further expansion of the exhaust gases through the starter turbine, (2) bleeding the excess air available from the compressor and utilizing the exhaust from the turbo-alternator unit, regeneratively. It is anticipated that such a system rated at 400 to 500 horsepower will impose a starter system weight of less than 50 pounds per engine on the aircraft weight.

As the size of the gas turbine engines increases and as the starter power requirements correspondingly increase, it is anticipated that it may not be practical to provide aircraft with self-contained starter-systems. The requirement of providing self-contained starter systems appears to be motivated by the memory of forced landings in pastures, highways, and emergency landing strips. It should be realized, however, that future aircraft which will be powered by large gas turbine engines having high starting requirements will not be capable of successfully landing or taking off under the aforementioned conditions. For this reason, external or ground powered starter systems are being investigated.

FUTURE STARTER SYSTEMS — GROUND POWERED

Under consideration as a ground powered starter system is a mechanically transmitted system. This system may result in mounting a reciprocating type aircraft engine on a portable device permitting the unit to be taken to a convenient point near the engine nacelle where a mechanical connection may be made to the aircraft gas turbine engine to accomplish the start. The hazards to personnel as well as equipment that are inherent with high speed, high torque flexible drives are the chief objectionable features of the system. However, this system would potentially have wide application with respect to the different sizes of gas turbine starters, i.e. the same ground unit may be used to start a wide range of gas turbine engine sizes. The possibility of using an electric motor, A.C. or D.C. in lieu of the reciprocating type aircraft engine is also being considered. Such a system would potentially result in a lighter portable unit and in greater reliability. However, initial installation may be considerably more involved inasmuch as permanent features such as a large centrally located power station, fixed outlets, et cetera must necessarily be installed.

A hydraulically transmitted system is also under consideration as a ground powered starter system. This system would provide a hydraulic starter motor on each engine. The hydraulic connection may be made at each nacelle or at a central point on the airframe and controlled by a selector valve arrangement actuated by the aircraft engine operator. The source of hydraulic power may be from a pump mounted on a portable device which would permit adequate flexibility on a flight line. If the characteristics of a hydraulic system are found to be most desirable, the features of the central electrical power plant as mentioned in connection with the mechanically transmitted system may be utilized by providing an electric motor to actuate the portable pump-accumulator unit. The use of a central hydraulic power station with convenient outlets on the flight line may potentially be practical if the advantages over the portable pump-accumulator unit would justify such an elaborate installation at well established bases.

A system utilizing compressed air as a ground powered starter system is also under consideration. This system would provide a small starter turbine mounted on the gas turbine engine with appropriate connections to a convenient point on the engine nacelle or airframe. It is anticipated that a liquid fuel would be mixed with the air and burned at a station prior to its expansion through the starter turbine thus obtaining a much larger amount of energy from the air being supplied. In order to limit the volume of the air container and certain related equipment to as small as possible, air pressures of 1000 pounds per square inch may be employed. The method by which the compressed air is obtained may be by any number of different methods such as a reciprocating type engine or electric motor, pump and accumulator mounted on a portable device or a central power station supplying compressed air to fixed outlets located conveniently on the flight line.

A ground powered starter system utilizing an electric starter motor mounted on the engine is not being considered inasmuch as the weight of the electric motor will be excessive. It is anticipated that the mechanical, hydraulic, and compressed air transmission type of ground powered starter systems will all result in approximately the same airborne starter weight per aircraft engine, i.e. less than 50 pounds for a starter system rated at from 400 to 1000 horsepower.

Investigations are being conducted with regard to the possibility of utilizing special combustion chambers and nozzles acting directly on the main turbine wheel. However, data available at this time indicates that this system is impractical due to the non-uniform thermal stresses that are necessarily imposed on the turbine blades. The use of compressed air without any addition of heat will necessitate large quantities far in excess of the realm of feasibility.

The use of a self-contained electrical starter system operating from a 24 volt battery has been very satisfactcry in connection with reciprocating type aircraft engines. However, it is apparent that such a system may be entirely undesirable and unsatisfactory for present and particularly future turbo-jet and gas turbine engines. The internal combustion, reciprocating starter engine and the solid propellant turbine starters are potentially a temporary solution and should by no means be considered as an ultimate or final solution. Ground powered starter systems as outlined also represent an interim solution. Thus, the problem of starting aircraft engines has ceased to become one of merely increasing the size of the motor and the capacity of the batteries to meet with an increase in the size of the motor and the capacity of the batteries to meet with an increase in the size of the engine. It requires a completely new and vigorous approach not to be hindered by fond memories and requirements so imposed.

BIBLIOGRAPHY

"Investigations of Jet Propulsion Engines in the NACA Altitude Wind Tunnel", A. Silverstein, NACA ACR No. E5H23, August 1945.

SUMMARY

In summing up, the following table presents a weight-power comparison of the several systems under development.

Type of Starter System	Airborne Weight Per Engine	Approximate Rating
28 Volt D.C. Electrical	140 pounds	10 Horsepower
Reciprocating Internal Combustion	85 pounds (estimated)	30 Horsepower
Aux. Power Unit with Hydraulic Drive	50 pounds (estimated)	30 Horsepower
Solid Propellant Turbine	115 pounds (estimated)	250 Horsepower
Turbo-Alternator Bleed Off	50 pounds (estimated)	400 Horsepower
Ground Powered Starter Systems	50 pounds (estimated)	400 to 1000 Horsepower

Discussion of Paper

Aircraft Turbo-Jet and Prop-Jet Starter Systems

By NOAH S. DAVIS, Jr.
Special Projects Dept., Buffalo Electro-Chemical Company, Buffalo 7, N. Y.

There appears to be an omission on possible types of starters for the gas turbine and turbo-jet engines; namely, starters systems using liquid propellants.

These liquid systems can be divided into two classes — mono-propellants and di-propellants. In the former, are such liquids as Nitro-methane and High Strength Hydrogen Peroxide; while in the latter, are combinations such as Nitric Acid and Aniline or Hydrogen Peroxide and Hydrazine Hydrate.

This discussion will be limited to the use of High Strength Hydrogen Peroxide as a mono-propellant or as a di-propellant, as I do not feel qualified to discuss the other liquid propellants but do have some familiarity with developments involving the use of high concentration of Hydrogen Peroxide. References also will be made only to declassified information.

The Germans used Hydrogen Peroxide to launch V-1 bombs, to drive fuel pumps in the V-2 and to drive torpedoes, ME163 and 262 airplanes, and submarines. In the V-1 and V-2, the high temperature steam, resulting from the instantaneous dissociation of 80-82% Hydrogen Peroxide, was used as the motive power. While in the other applications, not only this steam was used but also the oxygen from the decomposition was employed to burn a second fuel, such as Hydrazine Hydrate and Alcohol or Diesel Oil.

The same principle of using the "bottled energy" of the High Strength Hydrogen Peroxide could be used to drive a starter for the gas turbine or turbo-jet engine. This system would be compact and would have a low weight. As an example of the size of unit required, a reference can be made to the boiler on the V-2 rocket, which drove the 500 HP steam turbine at 4000 R.P.M. This boiler was about four inches in diameter and fourteen inches long.

There is now available in this country a 90% Hydrogen Peroxide which can be decomposed instantly by either a liquid or a solid catalyst to high temperature and high pressure steam and oxygen. The steam can be used directly in a turbine as a mono-propellant, or it can be combined with a fuel and used as a di-propellant in starters for the gas turbine and turbo jet engine.

The direct decomposition of 90% Hydrogen Peroxide results in combustion products of 71% steam vapor (superheated steam) and 29% oxygen by volume (57.6% steam and 42.4% oxygen by weight) at temperatures approximately 1350°F, corresponding to a heat release of 1120 B.T.U. per lb. of peroxide solution.

Supersonic and Transonic Aircraft Problems

By LT. COL. CARL E. REICHERT,

Aircraft Laboratory, Air Material Command, A.A.F.

Presented at the Annual Convention of the American Rocket Society, New York, N. Y., December 6, 1946

A great honor has been conferred on me, especially the invitation which said that I was particularly qualified to discuss supersonic and transonic aircraft problems. Throughout my disertation the emphasis is going to be placed entirely on that word problem. As so ably put by General Craigie quite recently in that "with respect to many of the major problems confronting us today we stand about where the Wright Brothers stood when they were contemplating their first flights some forty odd years ago".

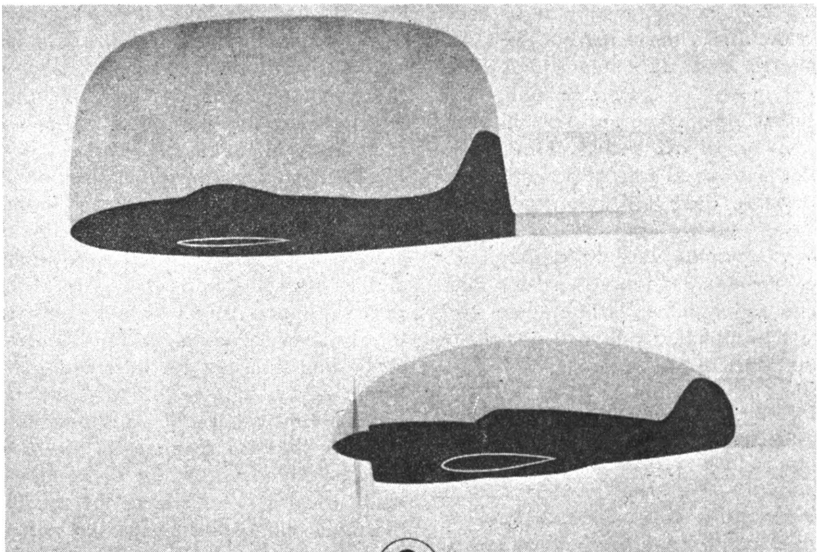
Before going into the problems of transonic and supersonic flight I would like to just mention that we have not, nor do we expect to, drop our studies of subsonic flight. Among the subsonic aircraft a great deal of effort is being placed on the development of transport aircraft because of the obvious certainty of global warfare in event of another crisis. In addition to aerodynamics in transport, such items as cold weather operation under adverse flying conditions are receiving much attention.

I feel that many of our problems in the design of transonic and supersonic aircraft are fairy ghosts. Ghosts because we have not been able to physically feel the sort of thing our slide rules and small scale test data tell us. Remember in high school algebra that if some one had set up the equation for Anne's age, her brothers' temperature and the length of the rope the solution for how fast the train was traveling was simple. That is precisely where we are today. We are trying to set up the equation. We are convinced that we will find a solution and that it will be just a matter of time until that solution is found. In fact, reading Sunday Supplements and Comic Magazines indicates that their authors have the solutions.

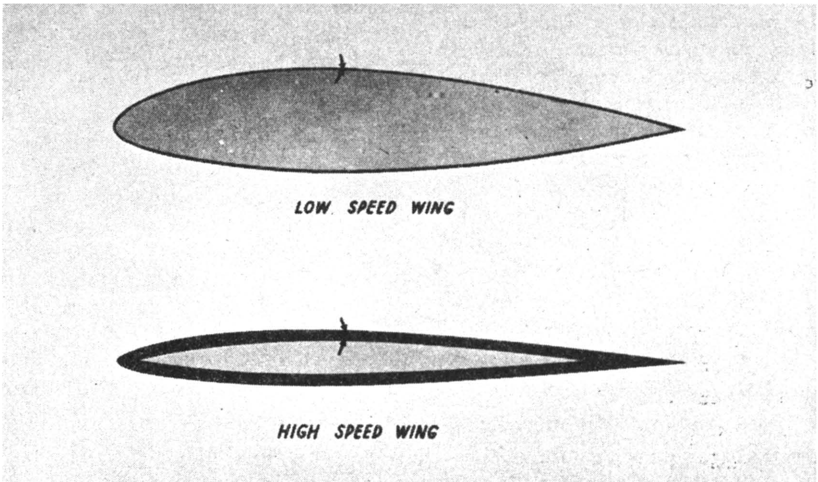
(Figure 1) Some of the terms that we are sure will fit into the eventual equation for transonic and supersonic flight are: Structures, aerodynamic shapes, control, propulsion installations, materials, armament, and escape provisions. (Figure 2) One of the biggest problems in structural considerations is the increase in loadings with a sizeable decrease in space to absorb these loadings. (Figure 3) As an example the P-80, which travels about fifty percent faster than the old P-40, must absorb approximately 300 percent as much load in approximately the same dimensional space. (Figure 4). In another example, the wing skin thickness in the aircraft of the last World War seldom exceeded 1/16 inch, whereas the skin thicknesses of half inch seem necessary at the present. Wings, which to date have seldom been less than 15 percent thick, must not exceed six percent thick if supersonic speeds are to be realized.

(Figure 5) The aerodynamic shape of transonic and supersonic aircraft will probably bear only a vague resemblance to contemporary aircraft. (Figure 6) To cite a few instances, wings and control surfaces will have exceedingly sharp leading edges, in fact it has been suggested that aircraft manufacturers contact makers of razors for their latest on creating sharp edges. (Figure 7) In addition to the sharp leading edges it appears that the **transonic** airplane will have wings and tail surfaces swept back very much like the paper darts that Junior makes with your favorite sports page. (Figure 8) The wings of

Figures 1, 2, 5, 9, 11, 15, 17, 18, 20, 21, are not shown as they were not particularly important and space was lacking.



③

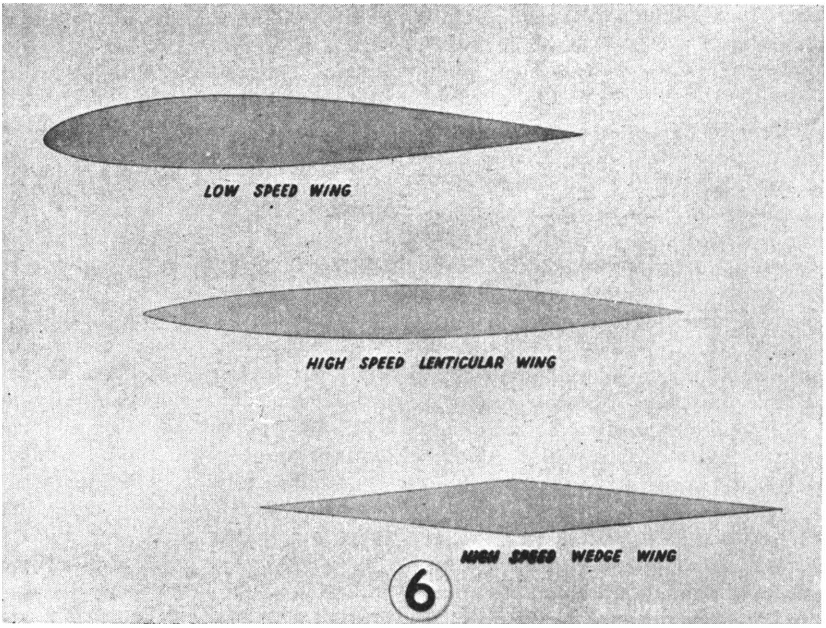


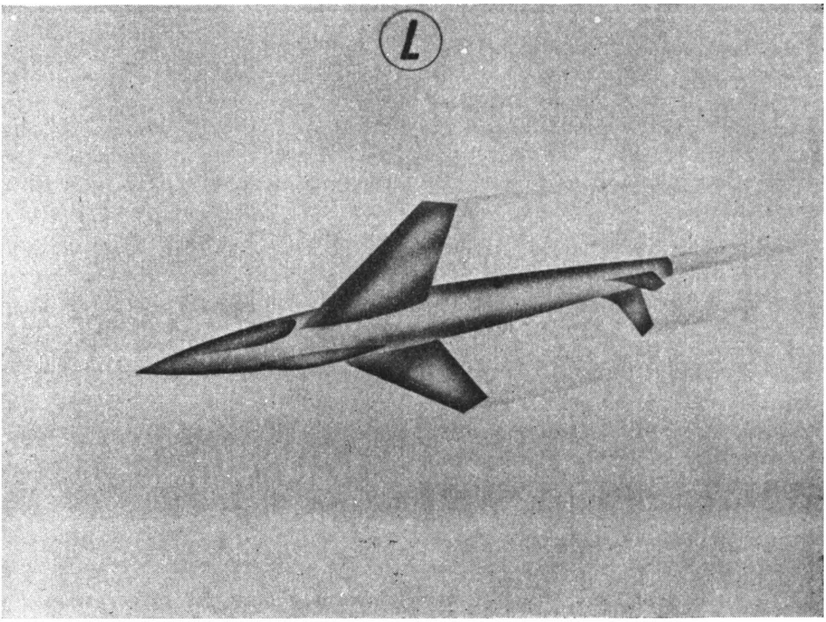
④

the **supersonic** airplane, what there is of it, will probably be of very low aspect ratio, that is, the span to chord ratio will be in the order of 2 to 3. The fuselages and nacelles will be extremely long for their maximum cross sectional dimensions and will probably be bodies of revolution. Further the bodies will be as free of protuberances as possible. Such things as windshields, radomes, turrets and antennaes will have to coincide with the aerodynamic lines. Present indications are that horizontal tail surfaces, where used, will be set exceptionally high if not on top of the vertical tail surfaces.

(Figure 9) From the standpoint of controls we are not too sure we even recognize the problems, just worries. (Figure 10) Our wind tunnels warn us of some rather severe control force reversals, i.e., the pilot will have to pull on the stick to get the nose down and push to get it up. Another decided worry of high speed flight has been what we call snaking, i.e., the airplane oscillates violently directionally. We began to experience this with our P-51 and were able to cure it. The P-80 then showed the same tendencies and we have been able to cure it. Ailerons have been another source of control problem where they vibrate at extremely high frequency and fairly high amplitude. We have been able to name it as buzz in spite of the fact we are not yet too certain as to its cause. Most of these and similar control problems can be handled by the use of irreversible control systems. A disadvantage however of irreversible and/or power controls is that the pilot is robbed of feel of his airplane. We are working very seriously now to work out a method of feed back force so that our pilots will not be able to change their course of flight so rapidly that catastrophic accelerations are applied to the aircraft structure.

(Figure 11) The problems involved in the installation of propulsion units are one of the most challenging in high speed flight. (Figure 12) As mentioned previously under aerodynamic shapes the airplane size is shrinking violently. At the same time the power demand is increasing. When placed above or below the wing the power plant installation involves us in intersections that cause tremendous drag rises with increase in speed. We have tried design studies with the propulsive units at the wing tips, and they look quite promising on unswept wings but from German data they can not be tolerated on a swept wing. (Figure 13) Where the number and/or size of units permits it appears that the fuselage is the ideal spot aerodynamically for the engines, since it does not increase the number of intersections and raises the volumetric efficiency of the fuselage. Some of the disadvantages of the propulsive units in the fuselage are first, the installation of satisfactory inlets without compromising vision and other functional requirements in the forward portion of the airplane and second, the long length of exhaust pipes which in addition to being a fire hazard, reduces the effective thrust. (Figure 14) Under propulsive systems installation, fuel also is introducing some problems. Again it is space limitations that cause the greatest difficulties. It seems odd to hear an airplane designer who has always been most weight conscious say, "I don't care what the fuel weighs, just so it doesn't occupy any space". Of course as the speeds of airplanes increases the fuel burnt per unit of time or distance also increases. As a result of the increase in fuel requirement the size of our aircraft is mounting in leaps and bounds to maintain range. Fighters that have been weighing 10,000 to 15,000 pounds, are now approximately 20,000 to 30,000 pounds and bombers of approximately 100,000 pounds are near 200,000 pounds. Some idea of fuel con-


LOW SPEED WING
HIGH SPEED LENTICULAR WING
HIGH SPEED WEDGE WING
6

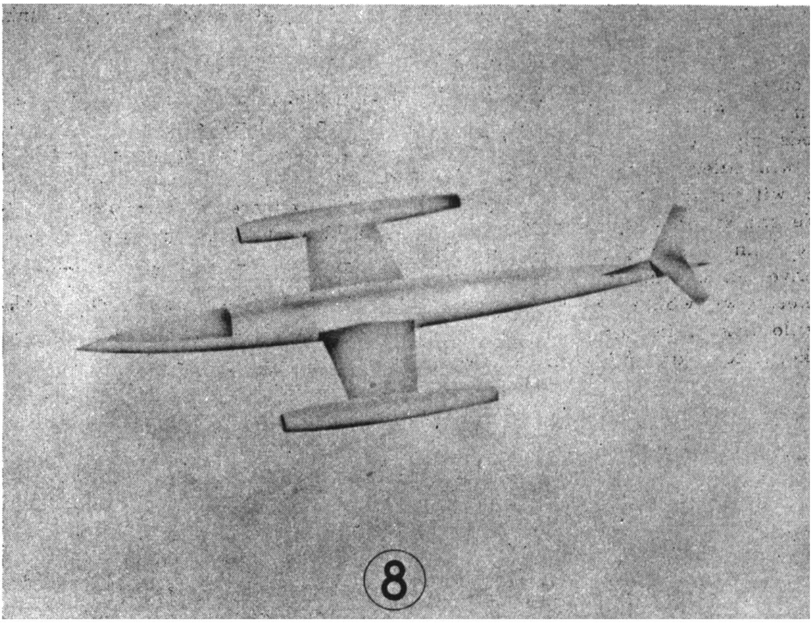

L

sumption in missiles can be obtained from the German V-2 which burnt nine tons of fuel in a little over one minute, to deliver a one ton bomb approximately 200 miles.

(Figure 15) I believe that the problems of materials can be lumped into the conventional strength-weight relation except that the thought of temperature must also be included. (Figure 16) Turbo superchargers, turbines, compressor blades, combustion chambers and rocket jet materials are of extreme importance. Much work has been done and is being continued on both ceramic coatings and internal cooling to assist in withstanding stress at elevated temperature. Regardless of how successful theso problems yield to an answer there will still need to be research on basic materials that will permit still higher temperatures if we are to realize an increase in thermal efficiency. Materials of construction are also being given a thorough study from a temperature standpoint. At speeds in the order of 2 or 3 times the velocity of sound outer skin temperatures of 300°F to 600°F are anticipated. Of course in addition to the structural materials insulation for temperature and sound, transparent material of high heat and impact resistance and textiles of both high strength and heat resistance are also being studied.

(Figure 17) Armament, another very important item in our formula, will also cause some sleepless nights and bald heads before a satisfactory answer in higher speeds is obtained. The air loads on any exposed barrels and launching tubes will be too large to be tolerated. (Figure 18) The exposed barrel of a present .50 caliber machine gun will deflect 3 mils when pointed crossways to the flight path at a speed of 400 miles per hour. In contemporary aircraft even streamlined turrets have caused considerable airplane control and buffeting problems at speeds of only 400 miles per hour. (Figure 19) At firing rates as high as 1,000 rounds per minute two rounds of ammunition per weapon are the most hits that can be made on a body 50 feet long if the target is traveling at 500 miles per hour with respect to the weapons. As mentioned under materials, when high speed aircraft are built of high strength thick gauge material the lethal load required to dispose of an airplane will be much greater than any contemporary machine gun. The problem of armament seems to boil down to the following: Just as the world needs a good 5-cent cigar, the high speed tactical airplane must have a power operated device capable of automatically dispatching a high lethal charge to several miles range in a carrier that sniffs its way within a few inches of the vulnerable spot of a target. I forgot to mention that at no time during its operation must it extend itself beyond the normal lines of the airplane, and it must occupy a minimum of space within the airplane.

(Figure 20) And now the last of the factors that I mentioned to go into our formula and that is escape from our high speed aircraft. Perhaps I should go into the entire picture of crew accommodation but the problem of escape is one of our biggest headaches at the moment. I won't even argue the point here as to why, when considering push button atomic war, we even consider man carrying or man operated craft at transonic and supersonic speeds. (Figure 21) You have probably read and are familiar with our demonstration of seat ejection where the pilot or other member of a crew can be thrown from an airplane. This system appears to be an answer for speeds of 400 to 500 miles per hour. At higher speeds we are reasonably certain that the human

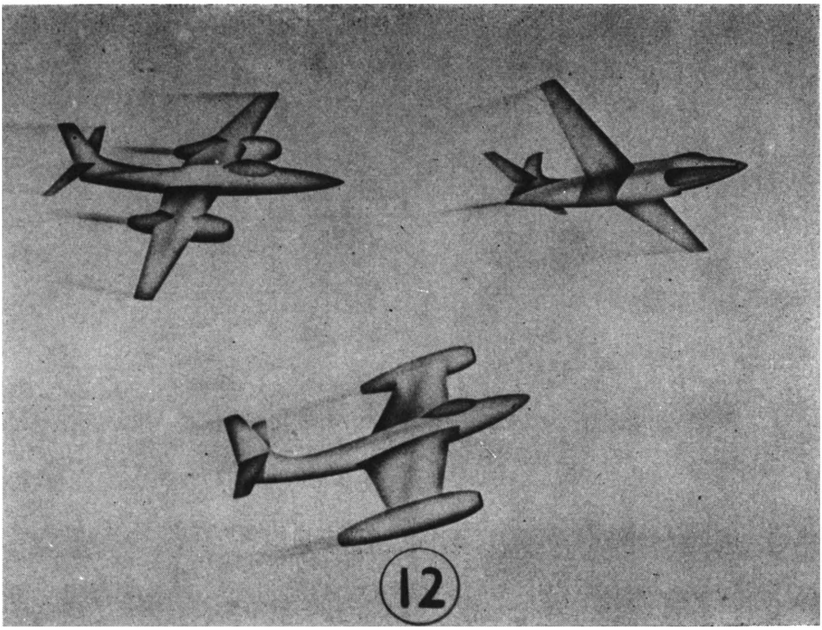


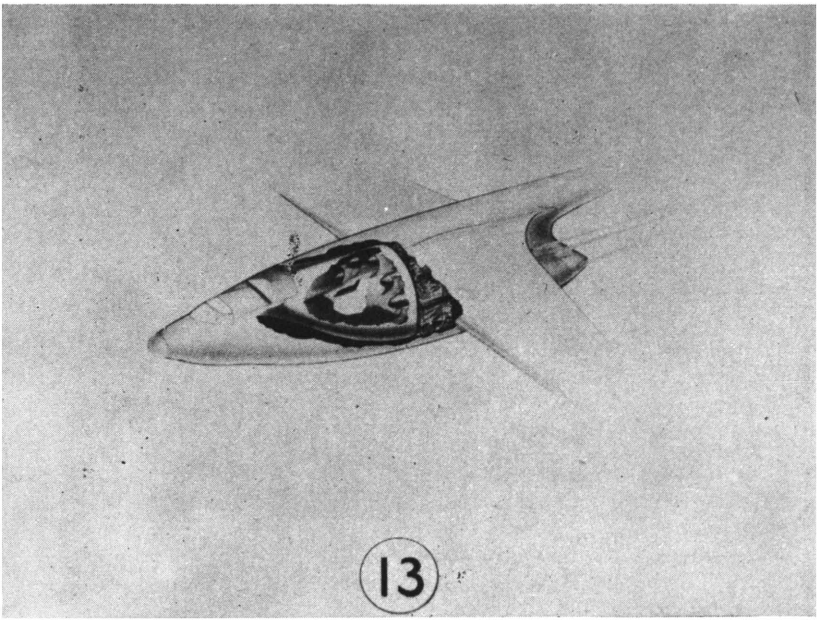
8

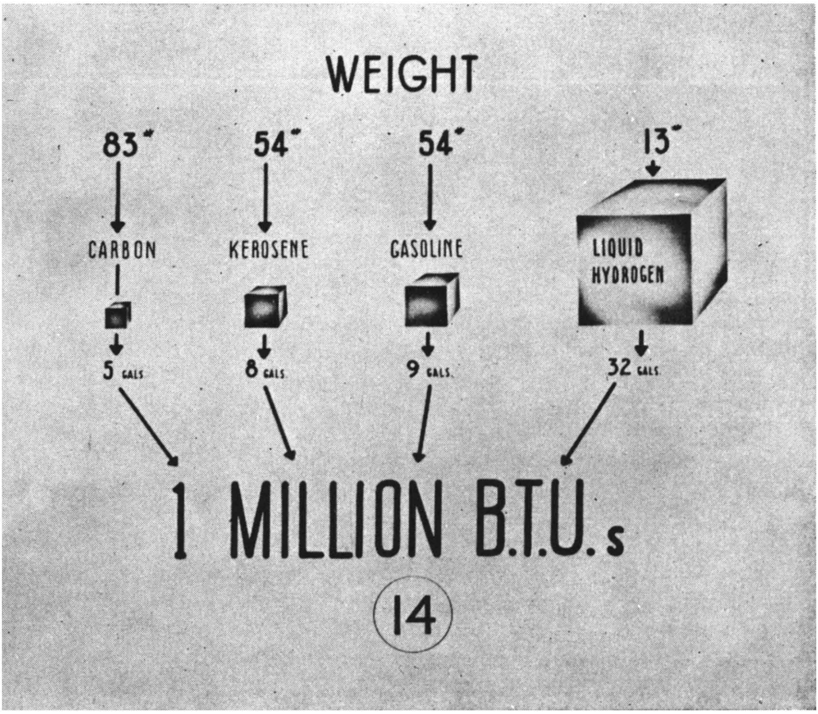
10

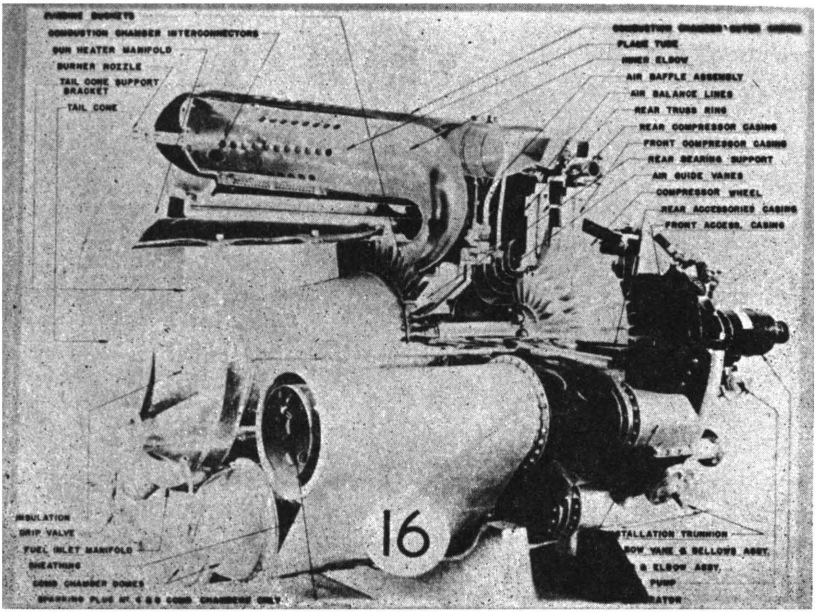
body cannot withstand the dynamics pressure or accelerations. (Figure 22) Our problem then is to have a capsule or portion of the airplane that can be separated from the airplane at all speeds, altitudes and attitudes of flight, that will safely carry the crew members, without any tumbling, to an altitude and speed where the crew member can finish his trip to the ground in a conventional manner. (Figure 23) As a finesse we would like to have our capsule deliver its cargo all the way to the surface and be equipped with life raft, radio, stoves, rations, bunks, etc.

This pretty much concludes my dissertation on some of the more obvious problems that face us in our quest of transonic and supersonic speeds. I don't believe they are insurmountable problems, but at the moment they do pose a challenging front to engineers and scientists not only in aeronautics but also in chemistry, mechanics, medicine, textiles, astrology, meteorology, etc.

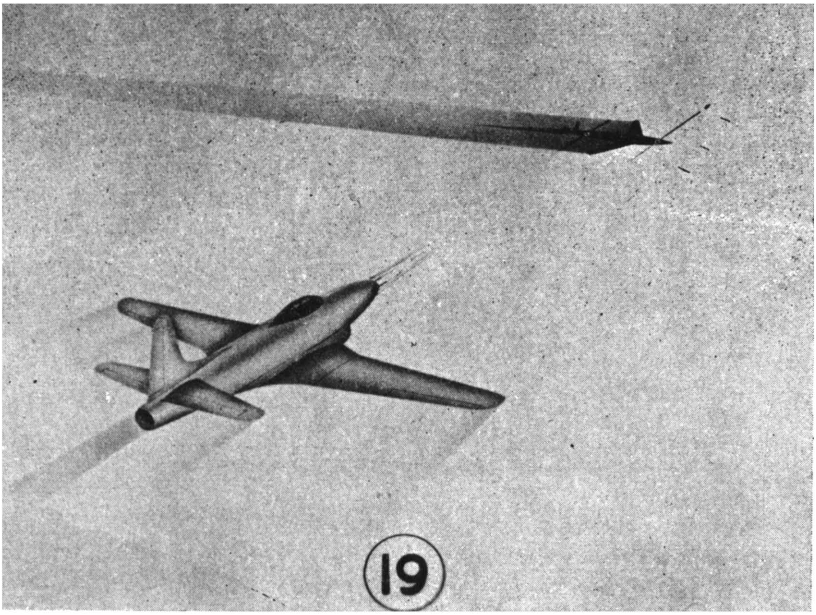



13

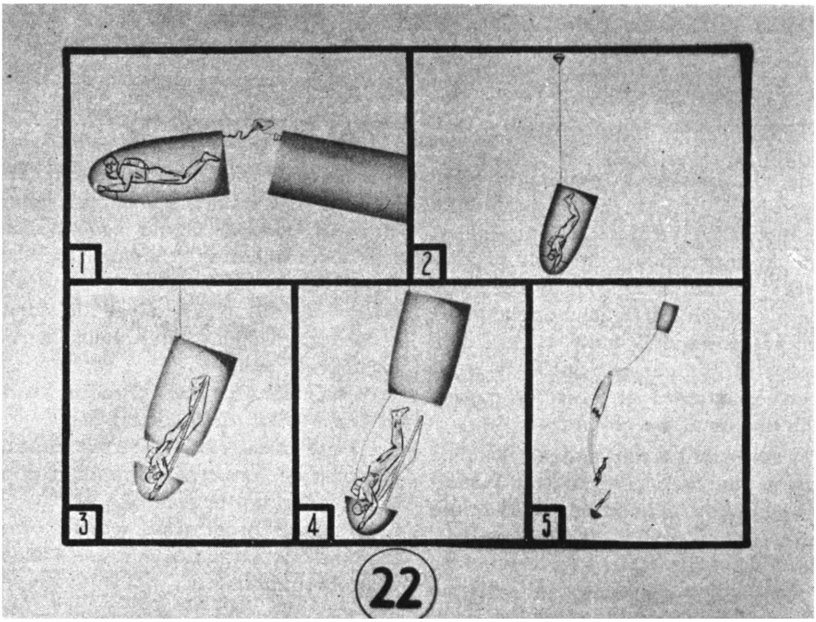

WEIGHT
83#
54#
54#
13#
CARBON
KEROSENE
GASOLINE
LIQUID HYDROGEN
5 GALS.
8 GALS.
9 GALS.
32 GALS.
1 MILLION B.T.U.s
14

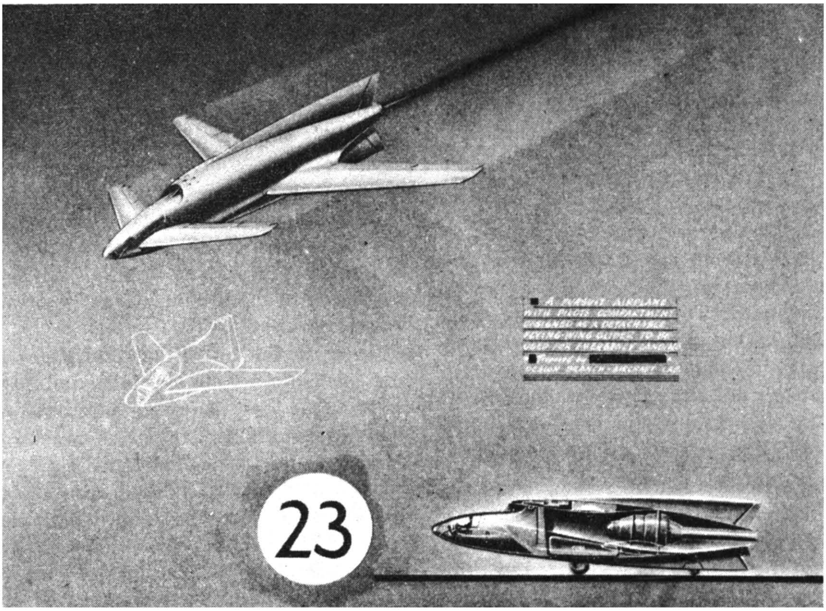

TURBINE BUCKETS
COMBUSTION CHAMBER INTERCONNECTORS
GUN HEATER MANIFOLD
BURNER NOZZLE
TAIL CONE SUPPORT BRACKET
TAIL CONE
COMBUSTION CHAMBER OUTER CASING
FLAME TUBE
INNER ELBOW
AIR BAFFLE ASSEMBLY
AIR BALANCE LINES
REAR TRUSS RING
REAR COMPRESSOR CASING
FRONT COMPRESSOR CASING
REAR BEARING SUPPORT
AIR GUIDE VANES
COMPRESSOR WHEEL
REAR ACCESSORIES CASING
FRONT ACCESSR. CASING
INSULATION
DRIP VALVE
FUEL INLET MANIFOLD
SHEATHING
COMB. CHAMBER DOMES
SPARKING PLUG AT 4 & 8 COMB. CHAMBERS ONLY
STALLATION TRUNNION
BOW VANE & BELLOWS ASSY.
& ELBOW ASSY.
PUMP
ATOR

16



19


1
2
3
4
5
22


A PURSUIT AIRPLANE WITH PILOTS COMPARTMENT DESIGNED AS A DETACHABLE FLYING-WING GLIDER TO BE USED FOR EMERGENCY LANDING
Proposed by [redacted]
DESIGN BRANCH - AIRCRAFT LAB
23

Commercial Applications of Rocket Power

By MR. DAN A. KIMBALL, Vice President
Aerojet Engineering Corporation, Azusa, California

Presented at the Annual Convention of the American Rocket Society, New York, N. Y. December 6, 1946

The jet assisted take-off unit, nicknamed JATO, is now complementing its war record by taking a position of increasing importance in the field of commercial air transport. This is only one example of the peacetime applications of rocket power. We hear a great deal about trips to the moon, but there is also an abundance of work for rockets much nearer to the ground.

On the recent record-making distance flight of the Navy's "Truculent Turtle", four standard 12-second, 1000-pound thrust JATO's made take-off possible, with the heaviest load ever carried by a twin-engine airplane. Jet assisted take-off for transport aircraft has been approved by the Civil Aeronautics Administration (Certificate R-1). The first installations are now being made on cargo planes. Under appropriate conditions, dropping of exhausted rocket motors will be permitted.

Wider use of the JATO units will enable air transport firms to operate profitably from short airfields and from high altitude airfields. Faster schedules will be possible because of fewer refueling stops. In brief, gross weight limits no longer need be determined by the take-off power available in the airplane engines. Each thousand pounds of supplemental thrust corresponds to about 350 additional engine horsepower, at 100 mph. One 12-second, 1000-pound rocket motor reduces the take-off distance of a fully-loaded DC-3 airplane by about one-third.

Since the rocket is a constant thrust device, its horsepower equivalent is directly proportional to the speed at which the system is propelled. The solid propellant motors now in production are rated at 160 to 180 pound-seconds of impulse per pound of propellant, and at 60 to 100 pound-seconds per pound of motor, loaded. Liquid combinations offer considerably higher impulse-weight ratios, as well as the feature of thrust control. Applications of liquid propellant systems have been almost exclusively military.

Further possible uses of rocket power in commercial air transport are:

(1) jet decelerator units for quicker stopping on runways, on landing or after decision not to take off;

(2) stand-by jet assist motors for instantaneous extra thrust to meet emergency requirements.

For example, an airplane about to land may suddenly be required to climb because of the appearance of some obstacle. At higher altitudes, internal-combustion engines and propellers suffer severe losses in efficiency while rocket thrust **increases** slightly with altitude (due to higher jet expansion ratio).

The "junior" JATO's now in development will supply 250 or 500 pounds thrust for 12 seconds. These units will be useful as take-off assistance for light airplanes, particularly amphibians. They will also furnish emergency power in case of engine failure, adding materially to the gliding range of small aircraft.

Rocket power offers an ideal launching system for gliders. Investigations in progress are designed to eliminate the undesirable smoke which now accompanies most rocket jets. Application of jet units to racing cars or to speedboats will permit super performance on short runs. Other cases of infrequent, short-duration high-thrust demand where rocket power can replace expensive machinery are:

(a) opening or closing flood gates, drawbridges, fire barriers;

(b) emergency stopping of high-inertia mechanisms such as power presses;

(c) operating solenoid controlled devices in the event of power failure.

A second class of applications is suggested by a basic property of all jet propulsion—the property of requiring nothing to "push against" except the mass of the jet itself. This characteristic is, of course, possessed by thermal jet (turbojet, pulsejet, ramjet) power plants, as well as by rockets. The thermal jet devices are dependent upon atmospheric oxygen for combustion of fuel, and in fact operate more efficiently with large amounts of excess air. It is thus evident that the rocket alone is capable of propulsion in the absence of an atmosphere containing oxidizing material. However, the turbojet and pulsejet share with the rocket the ability to propel or decelerate surface vehicles without dependence upon **traction.**

Many centuries ago, Archimedes offered to move the earth, given a "place to stand". Today we make direct application of Newton's third law of motion, and eliminate the need of a "place to stand". We can move the earth in a given direction by pushing a mass away from the earth in the opposite direction; the earth is then propelled by a force equal and opposite to that we have exerted upon the ejected mass. In other words, we can "lift ourselves by our bootstraps" simply by cutting them off and throwing them away at high velocity.

The simple and ancient principle of impulse and reaction now enables us to move trucks which are stuck in mud, or to stop and start trains independently of tractive force transmitted to the rails. In these cases the conventional power plants are limited by inadequate **traction** rather than by inadequate power.

The third class of rocket applications is characterized, as were the others, by high power demand for short duration or infrequent use. The rocket motor will now be considered as a gas generator for driving a small gas turbine. This system is the best now available for converting jet energy to drive rotating machines. In special cases such as the heliocopter, jet units may be mounted on rotors, for direct circular propulsion. However, the gas generator—gas turbine combination (with reducing gear) appears to have a great future as a compact source of high torque for short intervals of time.

In addition to compactness and high power output this power plant is quite inexpensive, and it develops full power in a fraction of a second. The conventional air-consuming gas turbine requires a bulky, expensive compressor, and the turbine wheel itself must develop two to three times the net power output because of the large demand of the compressor. Studies indicate the practicability of the rocket-gas turbine-reducing gear combination for starting or stopping heavy machinery.

One proposed "power-pack" unit is expected to deliver 240 horsepower at 2500 rpm for about 20 seconds with a solid propellant cartridge. The total weight of this 240-horsepower unit, including reducing gear, is about 150 pounds (100 pounds of which is the loaded propellant cartridge). Recently a logging concern directed an inquiry to our organization regarding a portable turbine-driven saw for use in rugged forest country. A solid propellant system with readily attached cartridges would have an important weight advantage over a gasoline engine, but propellant cost and the difficulty of on-off control prevent an immediate application in this case. Some study has been given to the possible use of rocket-turbine units as supplementary power for trucks climbing hills.

A word might be appropriate here regarding the kind of men and the kind of organization it takes to put rocket power to work. To date, very little manpower has been devoted to making celestial flight plans. But men are being trained to do such jobs, as evidenced by the recent announcement of a course on Astronautics by the University of California at Los Angeles.

The down-to-earth rocket problems start with chemistry. Liquid and solid propellant combinations are "discovered" in a fairly straight-forward fashion: by combing the chart of chemical elements and seeking out suitable fuels and oxidizers. The long job here, and the one requiring inspiration, is the development of the combinations which theoretically are good, and the elimination of their serious disadvantages.

Hand-in-hand with chemical research and development go metallurgical, structural, and heat transfer investigations. Our very best energy-producing chemicals are often thwarted in doing their job by the lack of materials which can "take it". Efficiency suffers by the addition of diluents for temperature control.

Fluid mechanics, including the behavior of liquid propellants and that of supersonic gas jets, ranks high in the necessary studies. Efficient nozzles must be designed. Liquids must be pumped or pressurized, and flow regulators are a necessity.

Control systems for starting and stopping rocket motors must be worked out in great detail. This phase, and the instrumentation requirements, demand the services of capable electrical and mechanical engineers.

Add to this list the need for production and testing specialists, and the picture of a "den of jet-men" takes form. We "jet-men" have learned a great deal in our part of the world struggle recently ended, and we see an expanding field of service in the peace-time world.

* * *

BOOK REVIEW

"Aircraft Engines of the World 1946," by Paul H. Wilkinson. Published by Paul H. Wilkinson, New York City. $9.00. 357 pages. Illus.

The fourth edition of this aircraft engine annual now numbers 320 pages and contains a 52 page jet engine section. The latest engine of the United States and Great Britain are included as well as new designs from such countries as Australia, Brazil, Spain, Switzerland, Sweden, France and the U.S.S.R.

Its information is well laid out, and together with several pages of engine tabulations and a comprehensive index, is an asset to the library of aeronautical and engine designers.

"Diesel Operation and Maintenance," by Orville L. Adams. Prentice-Hall, Inc., New York City. $5.00. 366 pages. Illus.

This volume has a wealth of practical information on Diesel engines; it not only covers the experience of the author in teaching on the subject of Diesels, but the opening chapters are a text in themselves on Diesel applications, metallurgical problems, and fundamentals. Despite the advent of jet propulsion powerplants and the general acceptance of gasoline-powered reciprocating engines, there is a huge field where the diesel only holds sway.

A valuable book for the man who works with Diesels and an equally informative and permanent reference work for the engineer who wants to know more about them.

(Continued on page 48)

Analysis of the First Two American V-2 Flights

By R. W. PORTER

Aeronautic & Marine Engineering Divisions, General Electric Company, Schenectady, N. Y.

The biggest and most powerful rocket ever made was demonstrated by the Army Ordnance on 10 May of 1946 to top experts of the Army, Navy, and Air Forces who met at the White Sands Proving Ground near Las Cruces, New Mexico, to see a test flight of the German V2. This missile is more accurately called the A4 since that name was used by its designers and by the German army; however, the name V2 was applied by American and British newsmen long before even the exact nature of this weapon was known and it is still the most commonly used designation. Many of the visitors to the Proving Ground had been on the receiving end of V2 operations against London or Antwerp during the war, but for most of them it was the first opportunity to study the complicated control system, to watch preparations for launching, and to see the huge rocket, looking for all the world like a Buck Rogers space ship, rise slowly and majestically, accelebrate to higher and higher velocities, and finally disappear into a clear blue sky.

The launching on 10 May was the second trial of the V2 in this country. A preliminary launching was made on 16 April to determine whether or not the methods of assembly and testing used at the Proving Ground were adequate. In this first test the propulsion equipment operated satisfactorily and the launching was successful. Immediately after the rocket left the ground, however, a failure occurred in the control system which caused it to rotate about its longitudinal axis and eventually spin violently. There was a moderate wind from the east at the time of launching, which caused the missile to turn in that direction because of its inherent aerodynamic stability. After a power flight of about nineteen seconds it was judged to be far enough from the launching site to be ditched with safety, so the jet was cut off by means of the radio emergency transmitter. It landed 5.3 miles from the point of launching and reached a maximum altitude of about 3.5 miles. In this case the propellant tanks were about two-thirds full at the time of impact; the resulting explosion raised a plume of dust hundreds of feet into the air and produced a loud report at the launching area. Nevertheless many of the sturdier parts of the rocket were found reasonably intact in or near the crater and instruments packed in the warhead for test were found with records in useable condition.

About fifteen seconds after the launching of this first missile, tail surface IV was torn loose from the body and came down separately. The appearance of this piece indicated that it had been repeatedly overstressed, probably by the violent spin, and had finally torn away ripping the spot-welded skin and breaking the stressed members. This surface carried both the AN/APN 55 S. band beacon receiving antenna and the **ARW-17** (40 mc) emergency receiver antenna and although both were torn away with the tail surface the emergency receiver operated properly and the beacon signal was strong and steady throughout the entire flight. Such a phenomena can only be explained by the assumption that the coaxial cables used to connect the receivers with the antennas were severed in such a way as to leave appreciable lengths of the center conductors uncovered and ungrounded outside the body of the rocket and that these acted as receiving antennas with sufficient gain to operate the receivers at the relatively short range.

Although the cause of the difficulty in the 16 April firing is not positively known, Mitchel camera records of that test show that the rocket began to rotate about its longitudinal axis almost immediately after leaving the launching stand, accelerating at a rate approximately equal to that which would be caused by the torque of one fully-deflated jet vane. The most likely explanation is that a small piece of jet vane I or III was broken loose during ignition, either because of a defect in the graphite vane itself, or because of impact from a piece of the igniter being blown out of the venturi. The effect of breaking a piece of graphite away from the heel or trailing edge of the vane would be to unbalance the torques produced by the jet and cause the vane to deflect fully one way or the other. It is also possible that the trouble might have been caused by failure of one of the electric-hydraulic servomoters which operate the vanes, or of one of the electrical connections to a servomoter. This explanation seems unlikely however, in view of the fact that the entire control system had been tested as a matter of routine just before launching and found to be operating normally.

In order to guard against the possibility of vane trouble in subsequent tests, the following procedure has been established: (a) All vanes are X-rayed from both sides; vanes showing any indication of cracks, large voids or inclusions are rejected. (A number of rejects have been found.) (b) All vanes are tested mechanically at a load only a little less than that which has been found to make a good sample fail. (c) Shortly before launching, the vanes to be used are dried by baking in an oven at approximately 160°C. for three hours. As an added precaution, a heavy cardboard jacket is fitted over each vane before launching to minimize the possibility of damage from flying igniter parts. These jackets are burned or torn off as soon as the full thrust of the jet is developed.

The flight on May' 10 was generally satisfactory although the range was short and the altitude higher than expected. Ignition was normal, the rocket built up thrust and raised itself off the launching stand smoothly, and appeared to travel straight upwards at constantly increasing speed with no discernable oscillation. The sound made by the jet was loud, of course, but there was no indication of roughness and the flame appearance was normal with sharp diamonds clearly evident. At an estimated height of about 30,000 feet a dense white vapour trail began to form which continued until the jet was shut off by the integrating accelerometer. This vapour trail remained for many minutes, gradually taking on a crooked appearance and finally being dissipated by the winds of the upper atmosphere and turbulence set up by the rocket.

To an untrained eye it appeared that the rocket was heading straight up or perhaps bending a little in the opposite direction to the intended line of flight although to those who had planned the flight, the tilting program looked normal. Examination of the test results now indicates that, for reasons as yet unknown, the final angle of tilt was about 4 degrees too small. During the ten minutes after the launching there was a hush as many pairs of ears and eyes tried to hear the sound or see the cloud of dust raised by the impact, but no indication was seen or heard. A gusty wind of twelve to fifteen miles per hour made a high background noise, and raised enough dust to obscure vision near the horizon.

Shortly after the impact occurred preliminary information as to its location was telephoned in from the radar station whereupon the ground crew, consisting of three jeeps and a radio truck, set out to find the wreckage. Several liaison aircraft which took off immediately after the launching made contact wtih the ground party a little later, describing the location of the impact and giving directions by flying the correct course and by circling over the point.

The appearance of the crater indicated a very high velocity impact with no chemical explosion or fire following. It was estimated to be at least thirty feet in diameter at the top and thirty feet deep. The Earth at this point consisted of a mixture of wet sand and gypsum, dry on top, overlaying hard gypsum rock. Many large boulders had been blasted out of the rock, a few being tossed as far as fifty or sixty feet from the crater, others falling back into the crater and sliding to the bottom. Some loose masses of wet sand and gypsum were thrown to great distances, perhaps as much as five hundred feet.

No parts of the rocket were to be found in the crater, although it is possible that some were buried under the boulders at the bottom. Most of the parts were found at distances up to a thousand feet, the distribution being most dense at one to three hundred feet and to the lee side of the hole. None of the vegetation in this area, even the pieces blasted out of the crater, were burned except in one small spot at a distance from the impact where a fire had obviously been started by a piece of hot metal. The parts of the missile which were picked up however show the affect of intense heat as well as violent mechanical shock. Identifiable scraps of the war head, instrument compartment, skin, tanks, venturi, thrust ring, pumps, graphite vanes, and other widely distributed parts were picked up. Most of these, although not all, were heavily coated with scale. Pieces of sheet metal were usually crumpled into balls; some of the pieces of skin had been almost completely converted into oxide cinders.

Noticeably absent were parts of the electrical control. No parts of any of the control instruments or radio gear were identified, and of the wiring only two small bits were found; a two inch length of coaxial cable with the outer conductor gone and a small piece of fourteen-conductor cable wrapped in a section of the skin with all of the insulation burned away. Although a two hour search netted only about fifty pounds of scrap parts, and it is doubtful if a more careful search would result in recovery of more than two or three times that amount, unless sizeable masses of metal are found to be buried in the crater itself. There is no reason to believe that any part of the rocket came off in the air and landed at a different point since bits and pieces of various parts of the rocket all the way from the nose to the tail were found in the crater, and since the rocket must have been good aerodynamically to have maintained such an enormous speed at impact.

Since none of the "wreckage-test" instruments or records were recovered, and it seems likely that none will be recovered in useful condition, it can be concluded that in any future test where this type of data recovery is desired it will be necessary to insure breakup of the rocket in the air by means of a small explosive charge.

Following are some of the more important bits of numerical data relating to the test on May 10, 1946:

		Measure	Predicted
1.	North coordinate of impact from launching point.	24.5 miles*	41.5 miles
2.	West coordinate of impact from launching point.	2.0 miles*	2.0 miles
3.	Altitude	70.8 miles*	68.7 miles
4.	Time of burning	59.2 seconds	59.4 sec.
5.	Weight of missile at instant of launching	27800.0 pounds	27900.0 pounds
6.	Center of gravity, full (measured from base of venturi)	250.0 inches	237.5 inches

* Radar Measurement. Checked by survey.

The following abbreviated time schedule of the operations involved in preparing the rocket for firing indicates the complexity of the job and the degree of teamwork required:

0900 9 May—Rocket leaves hangar on Meillerwagon.
0930 —Rocket raised into position at launching area.
1030 —Electrical and pneumatic test connections made.
1100 —Level rocket and adjust gyro mounting plate.
1300 —Air test of turbo pump system, testing of gyro and servo system, testing of normal and emergency cut-off equipment.
1400 —Resetting of controls, closing service panels, sealing the rocket, anchoring to ground.
0840 10 May—Check electrical resistance, retest controls.
0920 —Start filling alcohol tanks. Mount jet vanes and shields, paper cups change missile batteries.
1100 —Installation of pyrotechnic igniter.
1230 —Start filling oxygen tanks and compressed air tanks.
1300 —Final leveling of missile.
1315 —Start filling peroxide and permanganate tanks.
1330 —Adjust beacon, turn on emergency receiver and close all service panels. Remove anchor wires.
1340 —Turn on inverter 3 (integrator).
1345 —Turn on inverters 1 and 2, remove Meillerwagon and other cars.
1350 —Turn on servo-motors and adjust vanes by means of vane potentiometers. Sprinkle area with water. Close ignition circuit.
1357 —Clear area. Give warning signal.
1400 —Launch missile.

The entire project has required the close coordination of the efforts of all of the participating Services, and of Industry. The Proving Ground with all its facilities is provided and operated by the Army Ordnance Department. Component testing, assembly, and launching operations are performed for the most part by a special team of German civilians, supervised and assisted by Ordnance officers and enlisted men and by General Electric engineers. Missing components, large scale repairs, and the necessary propellants are supplied by industrial concerns such as the General Electric Company, Linde Air Products Company, Buffalo Electrochemical

Company, and many others. Radio equipment such as emergency cut-off transmitter and receivers is supplied and operated by the Naval Research Laboratory, and the beacons which are installed in the missile as well as the SCR-584 ground equipment is supplied and operated by the Signal Corps. All of these organizations are to be especially commended for their excellent performance and cooperation.

Now that it has been shown the job can be done, testing of a more scientific nature will begin in earnest. This testing program falls into two classifications, tests to study the characteristics and behavior of the missile itself, and tests of a general scientific nature which can only be made at the great altitude to which this missile can climb. A complete list of all of the tests planned is beyond the scope of this article, but as an example of the first class it is expected that values will be determined for lift and drag coefficients, control forces, skin temperatures, accelerations, vibration, radio field strength and for the various pressures, temperatures and other quantities of interest to the rocket motor designer. The second class will include measurements of cosmic rays and of other forms of radiation, physical, chemical and electrical measurements of the atmosphere itself at great heights, and other related tests. Data resulting from these tests will be telemetered to the ground during the test or will be recovered by ejecting a parachute container out of the rocket at the top of its trajectory or by causing the rocket to break up in the air so it will land more slowly.

By extensive repairing of damaged parts and by manufacturing in this country many parts which are missing or which cannot be repaired, it will be possible to launch about fifty A-4's at the White Sands Proving Ground. The program of test launching will probably continue for one or two years, and will constitute a major scientific effort on the part of the participating Services.

Rocket Powerplants For Aircraft

By H. W. BURDETT

Sr. Project Engineer, Reaction Motors, Inc.

I. BRIEF REVIEW OF CURRENT APPLICATION.

In general, the applications of rocket power at this time have been limited principally to controlled missiles, military piloted aircraft, and research aircraft. Typical controlled missile applications are:

(1) The German V-2, or as it is sometimes known the A-4.

(2) Some American missiles which cannot be discussed at this time.

(3) Several German anti-aircraft controlled rockets.

(4) The most outstanding military aircraft which employed solely rocket power propulsion, the German Messerschmitt ME-163B. American applications have been strictly limited to jet assisted take-off type rocket powerplants, until very recently.

Application of rocket power to research aircraft may be divided into two categories. The first is that of the high altitude sounding rocket type, such as the WAC Corporal. The second is to supersonic aircraft, such as the Bell XS-1. The writer had hoped at this time to be able to give some details of the performance of the Bell XS-1 and some of the operational problems connected with rocket engines and related equipment. However, it has not been possible to obtain clearance for the reference data.

It may be generally stated, that with the exception of jet assisted take-off application, rocket power is actually supersonic power and that rockets will come into their own as aircraft speeds exceed 1000 miles per hour. On this basis, the ME163B is of interest only from the standpoint that it is the first of a long family of rocket powered aircraft. Actually the ME163B is a subsonic aircraft and the application of rocket power in this case was intended to give phenomenal rate of climb characteristics.

The V-2, perhaps, is the most efficient application of rocket power. As we all know, this missile attains speeds very greatly in excess of 1000 miles per hour and at the end of the powered period of flight reaches a velocity of sufficient magnitude so that the overall efficiency of the powerplant at that point was in the neighborhood of 20%. This value compares very favorably with current turbo-jet performance.

II. DESCRIPTION OF REACTION MOTORS, INC. MODEL 1500N4C POWERPLANT.

(A) General performance data and Characteristics:

The first American attempt to produce the supersonic piloted aircraft is, of course, credited to the Bell Aircraft Corporation. The Bell XS-1 airplanes employs a Reaction Motors, Inc. Model 6000C4 powerplant. The writer cannot disclose the details of this powerplant at present, but a similar unit developed for the U. S. Navy can be described. This is the 1500N4C.

The Reaction Motors Model 1500N4C is a 6000 lb. thrust rocket engine operating on liquid-oxygen and a mixture of ethyl alcohol and water. Rated specific propellant consumption is .0054 lbs. of propellants per sec. per lb. of thrust. The unit consists of four (4) main combustion cylinders, each developing 1500 lbs. minimum rated thrust. The engine weighs 210 lbs., is approximately 4½ ft. long, and will fit through an elliptical hole 13½" by 18" on the minor and major axes.

The engine weighs less than 210 lbs. giving a thrust/weight rate ratio of 28.6. The weight/thrust ratio conversely is .035.

With some minor exceptions, such as piping and control box, the entire unit is constructed of stainless steel. The major components of the engine are almost entirely of welded construction. The major components of the engine are; the combustion cylinders, the propellant valves (of which there are two (2) types—fuel and oxygen), the propellant manifolds (fuel and oxygen), the control box, the igniters, and the main support beam. It is the function of the fuel manifold to distribute the alcohol-water fuel from the main feed line to the four (4) cylinder feed lines. The oxygen manifold has a similar function, in taking the oxygen from the main feed line and supplying it to the four (4) cylinder feed lines. It is the purpose of the propellant valves to control the flow of fuel and oxygen from the manifolds to the cylinders. The main beam assembly, to full thrust instantaneously as its name implies, is provided to support all the other components of the engine as a single unit. It is the purpose of the igniters to start the firing of the individual combustion cylinders. Once the cylinders are in operation the igniters cease firing. The combustion cylinders, of course, are the heart of the rocket engine and are the actual components which generate the powerful thrust. The control box regulates all phases of the operation of the complete powerplant, and is actuated from a suitably instrumented and equipped control panel, usually located in the cockpit of the airplane. ....

Basically, the successful development of this engine may be attributed to three (3) major engineering achievements:

(1) combustion cylinder capable of sustained operation

(2) dependable and safe igniter and ignition system, and

(3) an adequate control system

The first and, of course, most important of these achievements is the development of a combustion chamber capable of withstanding temperatures in the neighborhood of 5000°F, but which will cool properly and not have its physical characteristics changed due to the high thermal stress conditions which are extant. When one of the combustion chambers is firing, it is possible to rest one's hand on the outside of the chamber because of their excellent cooling characteristics. It has been customary, until very recently, to measure the life a rocket engine in terms of minutes of operation rather than hours of operation. It can be safely stated that the life of the 1500N4C engine (that is time required between major overhauls) may be considered to be of the same order of magnitude as that of the current turbo-jet engines. The actual firing time of the V-2 engine which also used alcohol and liquid oxygen as the propellants, was about 68 seconds, or slightly over a minute. The only engine of comparable durability to the 1500N4C is the Walther hydrogen-peroxide engine used in the ME163B. This engine, however, developed a little more than one-half (½) the thrust of the 1500N4C and yet weighed more than one-half (½) again as much.

The second feature attributing to the success of the 1500N4C and subsequent engines is the development of a dependable igniter and ignition system. Since the available jet horsepower of one of the 1500 lb. thrust combustion cylinders is in the neighborhood of 1800 horsepower, it is obvious that it is not desirable to have the unit to come up to full thrust instantaneously. It is the purpose of the igniter to permit full thrust to be attained over a reasonable time interval, say two (2) to five (5) seconds. The igniter might be considered to be a small rocket engine, thereby giving a two (2) stage build up to full operating thrust.

The third item, which is of great importance, is the control system. This may be considered to be the brain of the engine and is essential to the safe operation of the unit. Complete details of its operation and construction are still on a "restricted" basis, but it may be stated that it functions principally through sensing the various pressure and flow conditions during the operating period and controls the variables affecting engine performance.

III. INSTALLATION FEATURES OF THE 1500N4C ROCKET POWERPLANT.

Installation of the 1500N4C powerplant in an aircraft takes but a matter of a few minutes. The only connections that need be made consist of attaching the engine to the airframe at four (4) mounting points, attaching the main fuel and oxygen feed lines from the tanks or pumps to the manifold inlets on the engine, and connecting the electric lead wires into a standard socket upon the control box at the front end of the engine. If the aircraft is properly instrumented and equipped all that is required to operate the engines is to load the propellant tanks and pressurize them, close the master switch and then flip the firing switches for any one of the cylinders.

IV. PRACTICAL APPLICATION OF THE ROCKET ENGINE TO VARIOUS TYPES OF AIRCRAFT IN THE NEAR FUTURE.

Because of its high rate of propellant consumption, the practical application of the rocket engine to aircraft in the near future is dependent mainly upon improved operating efficiency and therefore, reduced propellant consumption. This improved efficiency in general, can be achieved in four (4) ways:

(a) New types of propellants having higher energy content.

(b) Operating the combustion chamber at higher chamber pressures since this improves specific impulse.

(c) Improvement of engine design (for example, improved injection characteristics for better mixing and therefore better combustion efficiency).

(d) Throttling with a variable nozzle.

In relation to improving rocket engine efficiency the possibility of new types of propellants is probably the major source of improvement at this time. The discussion thus far has been limited principally to the 1500N4C engine which employs liquid oxygen and ethyl alcohol as the propellants. Gasoline and several other hydro-carbons, of course, have a much higher energy content than ethyl alcohol, but their characteristics as coolants are relatively poor.

Operation of the combustion chamber at higher pressures than those at the present time, should bring specific impulse values from the region of 200 seconds to about 300 seconds, thereby giving a 50% increase in running time for the same weight of propellants and equal thrust. Although there might be no weight saving in the engine itself, there would be a corresponding reduction in size of the engine. Obviously, for the same running time there would be a 33% reduction in the weight of propellants carried and the weight of the propellant pumps and tanks would decrease appreciably as well.

The third means of increasing efficiency (i.e. improvement of engine design) is basically a function of the ingenuity and facilities which the engine manufacturer can bring to bear on the many problems of engine design.

The fourth method of obtaining optimum efficiency is through throttling with a variable nozzle. This is covered in greater detail in a recent paper by the writer, which appeared in December, 1946 number of the Journal of the American Rocket Society. Briefly, this method permits variation of thrust at constant chamber pressure and with a variable expansion ratio to adapt the nozzle to the particular back pressure to which it is expanding. This permits optimum specific impulse to be obtained at all times, regardless of altitude or thrust setting.

Assuming that efficiencies can be brought to a reasonable figure, the question then arises as to whether the rocket is better adaptable to short range interceptor type aircraft and controlled missiles or to long range transport and military aircraft.

Let us consider first the interceptor type aircraft. The operating requirements would be dictated by the nature of the enemy aircraft and the practical limitations of the servicing facilities of the defending air base with their related logistic problems. The latter considerations limiting, in large measure, the nature of the rocket propellants from the standpoint of storage and handling. Enemy aircraft would probably be either high speed, high altitude bombers or controlled missiles of the V-2 type. In either case, a phenomenal rate of climb and the ability to cruise at near sonic velocity with flash speeds at supersonic velocities would be required. A combination of turbo-jet and rocket power could be used whereby the turbo-jet would be operated at all times and the rocket engine would be available for boost during take-off and climb and for short high speed periods. If kerosene were the turbo-jet fuel, it could also be used in the rocket engine with an auxiliary supply of an oxidizer, say liquid oxygen, for use with the rocket engine. This would simplify the supply problem by eliminating the need for another supply system for special rocket fuel, to say nothing of reducing the airframe manufacturer's problems with regard to tankage, plumbing, and controls. Use of a "standard" fuel like kerosene might, on the other hand, cause the efficiency (and hence operating time) to be reduced an excessive amount in comparison with that obtainable with a fuel of higher energy content. In turn, however, this gain in operating time of the rocket engine with a special fuel might justify an all rocket powered interceptor. In the following table, a comparison of two (2) theoretical interceptors, gives an approximate relationship between these two (2) proposals:

	Turbo-jet and Rocket	**Rocket Only**
Fuel	Kerosene	Special
Oxidizer	Liquid Oxygen	Liquid Oxygen
Specific Impulse (Rocket Only)	225 seconds	400
Firing time of Rockets (same weight of rocket fuels)	10 minutes	17.8 minutes
Thrust of Rocket Engine	10000 lbs.	10000 lbs.
Thrust of Turbo-jet	5000 lbs.	
Turbo-jet Fuel Spec. Consumption	.90	——
Turbo-jet Fuel for one hour	4500 lbs.	——
Additional Firing Time of Rocket with 4500 lbs. of Propellants	——	—— 3 minutes
Total Time on Rocket Power Only	10 minutes	20.8 minutes
Probable Cruising Speed	600 m.p.h.	700 - 900 m.p.h.

The last item is, of course, one of pure conjecture, but it may safely be assumed that the structural characteristics of the pure rocket interceptor and its rapid decrease in weight (1500 lb./min. to be exact) would permit an appreciable increase in cruising speed. Also, the cruising thrust would be 10000 lbs. as compared with 5000 lbs. on the turbo-jet.

The foregoing table illustrates the basic problem. The choice in the case of a long range bomber or transport type aircraft would undoubtedly rest with the combined turbo-jet rocket powerplant system, since only take-off boost and high speed flight in the target area would be required. In the distant future, long range aircraft with rocket powerplants exclusively will probably travel as free projectiles "coasting" for the bulk of the flight time through the outer fringes of the atmosphere.

V. CONCLUSION.

We feel that there can be no doubt that we are on the threshold of an era of aircraft development, which completely staggers the imagination with its potentialities. Rocket power will come into its own when aircraft speeds approaching the jet velocities of the powerplant are attained. At this point the overall efficiency of the rocket engine will be purely a function of its thermal efficiency, which in the next few years will exceed 60%. The aircraft speeds will be of the order of 10000 to 15000 miles per hour.

In conclusion, we may summarize the prospects of rocket power for aircraft as follows:

1. Application of rocket power to aircraft at present comes under four (4) categories:
    (a) Interceptor type aircraft
    (b) Jet assisted take-off for all types of aircraft
    (c) Research aircraft and,
    (d) Controlled missiles
2. Degree of application depends up-

on reducing fuel (i.e. propellant) consumption by improving efficiency.

3. In the more distant future, supersonic flight with optimum efficiency can be made only with rocket type powerplants.

...NEW ACTIVE MEMBERS...

Edward F. Chandler
New York, N. Y.

Delwyn L. Olson
Dover, N. J.

Reeves Morrisson
Gladstonbury, Conn.

Warren A. Sherrer
Pequannok, N. J.

William P. Munger
Morris Plains, N. J.

Nathan Carver
Hillside, N. J.

Dan A. Kimball
Los Angeles, Calif.

Johns C. Somers
Jackson Heights, N. Y.

J. M. Van Vleet
Milwaukee, Wisconsin

N. J. Limber
Rockville Center, N. Y.

Henry A. Jatczak
W. Orange, N. J.

Morton Gerla
Forest Hills, L. I., N. Y.

Joseph W. Mollek, Jr.
Montclair, N. J.

James N. Nutt, Jr.
Dover, N. J.

Neil Walter O'Rourke
Dover, N. J.

Peter H. Palen
Paterson, N. J.

Mirabeau C. Towns, Jr.
Denville, N. J.

S. A. Broughton
Forest Hills, N. Y.

Noah S. Davis, Jr.
Buffalo 14, N. Y.

J. C. DeHaven
Columbus, Ohio

Alfred K. Huse
Dover, N. J.

James W. Fitzgerald
Packanack Lake, N. J.

Frank Alanson Coss
Dover, N. J.

Alfred Voedisch, Jr.
Springfield, Ohio

Richard F. Gompertz
Dayton 1, Ohio

Charles H. Martens
Dayton, Ohio

Alfred W. Hardy
Staten Island, N. Y.

Oliver H. Jacobson
Venice, Calif.

James R. Randolph
Orange, N. J.

Herbert J. Grosch
Ingelwood, Calif.

Alexander A. Maselawitch
Osborn, Ohio

Henry Fever
W. Lafayette, Ind.

Frederick James Lewis
Takoma Park, Md.

Frances Silver, 5th
Martinsburg, W. Va.

Laurence P. Heath
Rockaway Valley, N. J.

R. M. Garrison
Owing, Ill.

Dr. W. E. Kuhn
Scarsdale, N. Y.

Charles H. Smith, Jr.
Shaker Hts., Ohio

Four Aircraft Gas Turbines Power New XB-46 Bomber

Four aircraft gas turbines, designed and developed by the General Electric Company, make up the powerplant for the Army Air Forces' first four-engine jet-propelled XB-46 bomber, which was made public recently at the Consolidated Vultee Aircraft plant at San Diego, Calif.

Classified by the AAF as a medium bomber, the XB-46 has two of the powerful General Electric turbo jet engines mounted on either side of the 113-ft wing span of the new aircraft. The plans is slightly more than 105 ft. in length.

Any details of the new bomber, such as the specific type of gas turbines used as the powerplant, are restricted until the XB-46 makes its initial flight "in the next 90 days or so," according to the AAF.

Currently, the XB-46 is undergoing ground tests at the Consolidated Vultee factory in San Diego.

THE ROCKET SOCIETIES

(Additional to list appearing in the Journal of the American Rocket Society (Astronautics), No. 60, Dec. 1944).

Association des Aero-Clubs Universitaires et Scolaires de France Section Astronautique. 5 Rue des Ursulines, Paris-V, France. Founded 1945, by A. Ananoff. Director, A. Ananoff.

L'Astronef. No. 1 (July 1946).

Australia Astronauts Society (formerly Australia Rocket Society), 219 High St., Prahan, Melbourne, Australia. Reorganized 1945. First President, J. A. Georges; Present President, same.

British Interplanetary Society, Ltd., Albemarle House, Piccadilly, London W.1, England. Founded 1945, by the British Interplanetary Society and the Combined British Astronautical Societies. First Chairman of Council, E. Burgess.

Journal. Vol. 6, Nos. 1-3 (June-Dec. 1946).

Bulletin. Vol. 1, Nos. 1-9 (Jan.-Nov. 1946).

Combined British Astronautical Societies Groups.

Eccles. Eccles, Manchester. Founded 1944, by J. D. Page, H. N. Mitchell and T. Gainsborough. First Chairman, J. D. Page.

Farnborough. Farnborough. Founded 1944, by J. Humphries. First Chairman, J. Humphries.

Hereford. Herefordshire. Founded 1945. First Chairman, E. Burgess.

London. London. Founded 1945, by L. Gilbert, G. Brosan and C. Fleisher. First Chairman, G. Brosan.

Manchester. Manchester. Founded 1944, by E. Burgess. First Chairman, E. Burgess.

Midlands. Birmingham. Founded 1944, by G. Richardson. First Chairman, G. Richardson.

Chicago Rocket Society. 455 West 60th St., Chicago 21, Ill. Founded 1946, by G. A. Whittington and H. G. Edler. First President, G. A. Whittington; Present President, W. Proell.

Rocket News Letter. Vol. 1, Nos. 1-2 (Nov.-Dec. 1946).

Decatur Rocket Society. 718 West Packard, Decatur, Ill. Founded 1945, by P. Andrews and D. W. Terry, Jr. First President, D. W. Terry, Jr.; Present President, same.

Georgia School of Technology Rocket Society. Box 2397, Atlanta, Ga. Founded 1945, by H. J. Mason. First President, H. J. Mason.

Hastings Interplanetary Society. Hastings, England. Founded 1937, by J. A. Clarke. First President, J. A. Clarke.

Leeds Rocket Society. Leeds, England. Founded 1937, by H. Gottliffe. First President, H. Gottliffe.

Melbourne University Interplanetary Society. Ormond College, Carlton N.3, Melbourne, Australia. Founded 1945. First President, Dr. H. C. Corben.

Midlands Interplanetary Society. Birmingham, England. Founded 1942, by G. Richardson. First President, G. Richardson.

Pacific Rocket Society. (formerly South Pasadena Rocket Society), 1130 Fair Oaks Ave., South Pasadena, Calif. Founded 1945, by E. V., Sawyer. First President, E. V. Sawyer; Present President, same.

Pacific Rockets. Nos. 1-3 (June-Dec. 1946).

Reaction Research Society (formerly Glendale Rocket Society), 3262 Castera Ave., Glendale 8, Calif. Reorganized 1946. Present President, G. James.

Astro-Jet. Nos. 9-15 (Sept. 1944-Nov. 1946).

R.R.S. Notes. Nos. 7-15 (Apr.-Dec. 1946).

Rocket Society of Cincinnati. University of Cincinnati, Cincinnati 21, Ohio. Founded 1944, by W. Friedlander. First President, W. Friedlander; Present President, same.

Society for Rocket Experimentation. 1512 Woodward Ave., Springfield, Ohio. Founded 1939, by K. L. Braun, Jr. First President, K. L. Braun, Jr.; Present President, same.

— C.G.

(Continued from Page 36)

"Applied Atomic Power," by R. Tom Sawyer, Edward S. C. Smith, A. H. Fox and H. R. Austin. Prentice-Hall, Inc. New York City. $4.00. 427 pages. Illus.

Tom Sawyer, well known among jet and rocket engineers for his work, "The Modern Gas Turbine," now does it again. With three collaborators, he has produced the first practical work to merit the attention of serious engineers. After perusing the popular material that has been published after the atomic bomb, professional men were still at a loss for practical information on possible atomic processes and industrial applications. This work covers the field as far as it is possible to do so today.

"Development of the British Gas Turbine Jet Unit." AMERICAN EDITION published by the American Society of Mechanical Engineers with the permission of the Institution of Mechanical Engineers. Price $3.00.

This volume comprises the lectures sponsored by the Institution of Mechanical Engineers on researches conducted in Great Britain to find general solutions to the basic problems of the gas turbine engine which will be applicable to most forms of power plant. Contents: (1) Early researches on the axial type of gas turbine engine; (2) design and development of centrifugel compressors for aircraft gas turbines; (3) fluid dynamics; (4) design of axial compressors; (5) combustion in gas turbines; (6) apparatus and techniques for testing gas turbine engines; (7) vibration problems in gas turbine ingines; (8) turbine for the simple jet propulsion engine; (9) recent developments in materials for gas turbines.

Published in January, 1947, the A.S.-M.E. has done a real service to the aircraft industry and propulsion field in bringing out this excellent volume.

With its 8 x 11 inch format, numerous illustrations, diagrams and charts, it is a must for every aircraft and engine designer.

EDITOR'S NOTES

1. It was not possible to include Part II of "Some Possibilities for Rocket Propellants", by Arthur S. Leonard, in this issue of the Journal. Mr. Leonard recently had made some revisions to his article which increased the length considerably. However, it will now appear as a three part article, the second part to appear in the next issue of the Journal.

2. Active members of the American Rocket Society are now receiving the Journal of the British Rocket Society in addition to the A.R.S. Journal. Arrangements have been made with the British organization to exchange journals on a limited scale. The English journal is on a high level and contains many interesting features. This is just one more valuable service extended to active members only. It is suggested that associate members write in to the secretary of the society and request active membership forms, so that their qualifications can be considered. Single copies may be obtained at $1.00 each.

3. As will be noted, this issue contains several papers presented at the Annual Convention of the A.R.S. held in December, 1946, in conjunction with the A.S.M.E. annual meeting. Watch for additional interesting material in the next issue.