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Liquid Propellant Rocket Development*

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The subject of liquid propellant rocket development is one which has become greatly broadened in the past three years. In order to cover each phase of liquid rocket development in detail it would be necessary to spend considerably more time than is presently available, therefore we might consider the broad aspects of this subject and possibly at a later meeting more detailed explanations can be given to specific phases.

In considering liquid propellant rocket development it is necessary to discuss briefly a number of terms which are widely used.

THRUST — Thrust is a measurement of power derived from the rocket engine or any type of power plant whereby the power is obtained directly from the jet velocity of the gases of combustion. A rough approximation or comparison between thrust in pounds and horsepower is obtained if you consider that at approximately at 375 miles per hour one pound of thrust is equivalent to one horsepower. Since the conversion from horsepower to thrust in pounds takes into account the speed at which the aircraft is traveling the following formula will enable you to calculate it for any speed:

$$\text{H.P.} = \frac{\textbf{Thrust}\text{ in pounds x Air Speed Ft./Sec.}}{550}$$

SPECIFIC IMPULSE—Specific Impulse is measured in seconds, or pound of thrust, per pound of propellant per second. It is the reciprocal of specific propellant consumption. The higher the specific impulse is, the lower the specific propellant consumption results. Thus, in the development of rocket engines we are constantly striving to increase the specific impulse.

JET VELOCITY — Jet Velocity is expressed in feet per second and for the average rocket engine ranges from 6,000 ft. per second upwards to approximately 8,000 ft. per second.

MIXTURE RATIO — Mixture Ratio is a term applied to the ratio by weight of fuel to exidizer.

REGENERATIVE — Regenerative is a term applied to a rocket engine which has one or the other of the propellants passing through the jacket around the combustion chamber to keep the temperature of the combustion chamber within safe working limits of the material.

In considering the rocket engine, the main difference between a "Liquid Propellant Rocket Engine" and any other means of propulsion which derives the power directly from the fuel is that the rocket engine operates on a propellant or propellants which combines or consist of both the fuel, as well as the oxidizer. In all other means of propulsion which derive their power directly from the gas, the oxygen in the air provides the oxidizer which burns with the fuel. This is one of the prime factors which establishes the field of application of the "Liquid Propellant Rocket Engine."

The considerations involved can be broken down into the several components which are combined in a liquid propellant rocket engine. The first consideration is the injection of propellants. In order to understand the injection problem we must first consider the overall characteristics of the rocket engine. The engine consists fundamentally of a combustion chamber wherein the propellants which are injected, mix and

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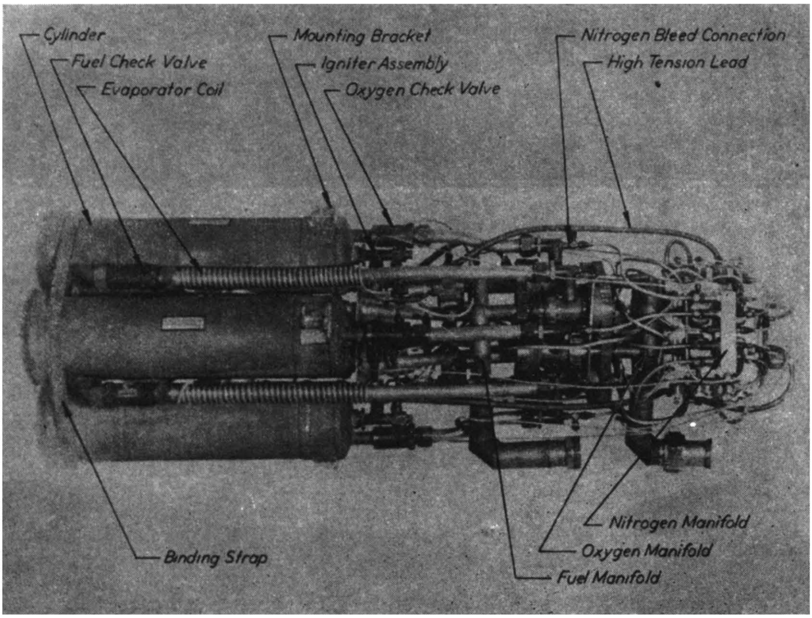
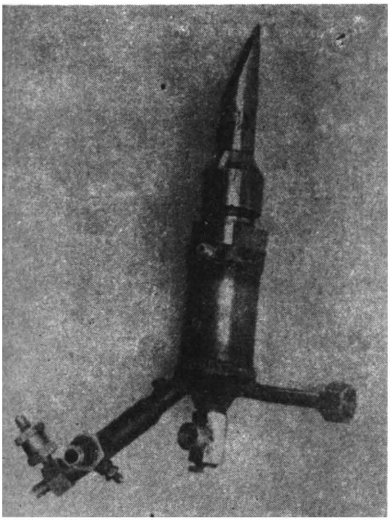
*October Meeting, American Rocket Society.



SIDE VIEW OF 1500N4C ROCKET ENGINE.

burn in a very small fraction of a second. The pressure in this combustion chamber depending on the propellants used, may range from 150 lbs. up to approximately 700 p.s.i. Recent indications are that this chamber pressure may be increased up to well over 1000 p.s.i. in the near future for certain applications.

Good practice indicates that it is most practical to use pressurized type of injection for "Liquid Propellant Rocket Engines" for thrus' ratings less than 1000 pounds and for durations of thirty seconds or less. For durations in excess of thirty seconds, for applications where a very high injection pressure is required or where a large rocket engine is involved, the pump unit is the ideal means of injection. Since it is necessary to handle large flows of propellants at pressures in the range which have been indicated, it is necessary to operate the centrifugal pump at speeds ranging from 7,000 r.p.m. up to 50,000 r.p.m. The horsepower required to drive these pumps is reasonably large for engines having a thrust range above 5,000 lbs. Depending on the efficiency of the pump the brake horsepower for a rocket engine having a thrust rating of approximately 10,000 lbs. would be between 125 h.p. and 150 h.p. On this same basis a rocket engine having a thrust rating of 100,000 lbs. would require approximately 1250 to 1500 h.p. In view of the high speed at which the pumps operate a turbine drive provides a very compact power plant. The fluid medium in driving the turbine is high pressure gas from a gas generator. This gas generator may use either the same propellants that are used in the rocket engine or may employ a separate propellant. In either case the gas generator for a turbine having a rating between 125 h.p. and 150 h.p. is approximately 5" in diameter and possibly 10" in length and would have a weight of approximately 15 lbs. not including connecting piping.

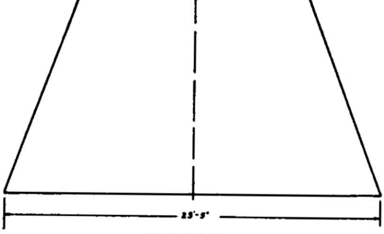


GAS GENERATOR TO PRODUCE HIGH PRESSURE GAS FOR 75 H.P. TURBO PUMP.

Now that we are familiar with the means of injection, we might consider for a moment propellants. Liquid propellants may be divided into two classes, or possibly for clarification purposes, three classes: Namely, monopropellants, bi-propellants, and multi-propellants. As the name implies, monopropellants are those where only one propellant is required for operation of the rocket engine. This propellant, in order to provide reasonably efficient combustion must represent as close as possible to a stoichiometric mixture of fuel to oxidizer. Monopropellants as we know them today, have been found to be quite sensitive, particularly heat sensitivity. Also, those with which we are familiar, have not proved to give a very attractive specific impulse.

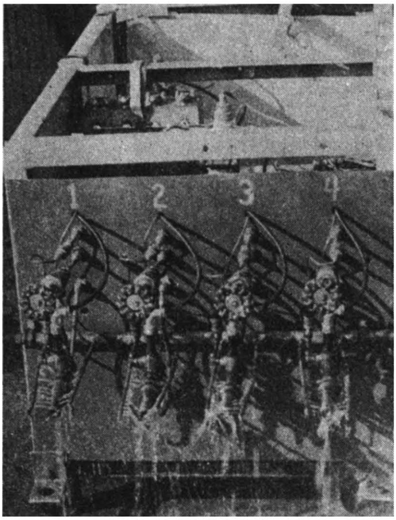
A bi-propellant consists of two propellants; one which is commonly known as the oxidizer and the other as the fuel. The most commonly used propellants which can be mentioned are liquid oxygen and ethyl alcohol. The liquid oxygen being the oxidizer and the ethyl alcohol the fuel. All of you are familiar with ethyl alcohol and know that it is no more dangerous to handle than several hydrocarbons in common use today. Tremendous quantities of liquid oxygen are used daily in the field of welding and cutting, as well as in steel mill processes. There are several other bi-propellants which are equally as safe from the stand-point of handling and use. In duscussing bi-propellants it is well to mention that there are two sub-classes; one which ignites spontaneously when combined in the combustion chamber, and the other which requires a hot spark before ignition takes place. Of those most commonly known, which ignite spontaneously, are nitric acid, and mono-ethylaniline. We are all familiar with precautions which must be taken with nitric acid and in so far as mono-ethylaniline is concerned, it is toxic, if the gases are inhaled by personnel or taken internally. With reasonable precautions however, this is quite a satisfactory bi-propellant.

In the multi-propellant group, we could again consider liquid oxygen and alcohol and combine water as a third propellant which was used in the past to reduce the flame temperature. Liquid oxygen, gasoline, and water is another



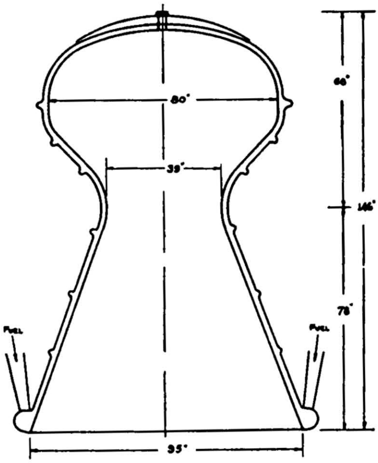
5,000,000 Pound
Liquid Propellant Rocket Engine

example of a multi-propellant. Multi-propellants have been used to a very small extent since it is necessary to provide a separate pump and separate tankage for each propellant, and as can be seen, this can become very much of a problem from the standpoint of aircraft design.



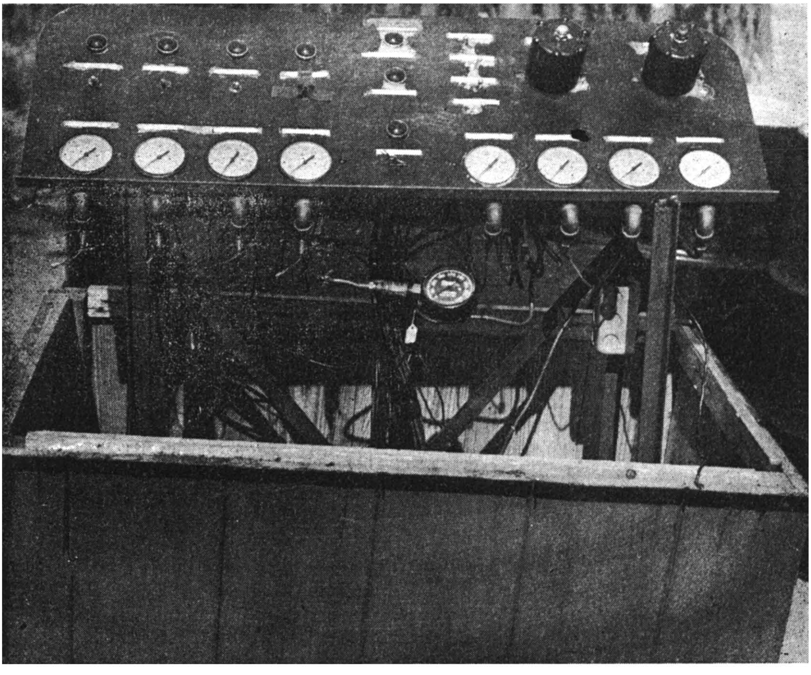
IGNITERS FOR 1500N4C ROCKET ENGINE RECEIVING INITIAL OPERATIONAL TEST.

In discussing bi-propellants, brief mention was made of the ignition of propellants. Considering briefly the monopropellants, the major problem is initiation of ignition. This usually involves the use of a catalyst to start and premote the chemical reaction. In addition, since the monopropellants which are known today, in some instances are not a stoichiometric mixture, it is necessary to provide an excess usually of oxidizer, in the form of oxygen or an oxygen carrying chemical. In the case of bi-propellants, as we have mentioned, some of these are spontaneous when the two propellants come in contact with each other. For these propellants no catalyst, additional oxidizer, or spark is required. It is essential however, that both propellants are injected into the combustion chamber at the same time. If there is an accumulation of one or the other, prior to injection of the second, difficulties can occur. In the case of an engine operating on liquid oxygen and alcohol, since these two propellants are not spontaneously ignitible on contact with each other, it is necessary to provide an igniter. The most common type of igniter, is one which provides the proper mixture of oxygen and alcohol, so designed that it may be ignited by a standard spark plug, providing a high tension spark.



500,000 Pound
Liquid Propellant Rocket Engine

In the development of rocket engines the trend is definitely towards very large rocket engines which may extend up to several hundred thousands pounds thrust. In the development of these engines, having a larger thrust rating, the physical dimensions do not increase directly with the increase in thrust. As an example, the combustion chamber remains theoretically the same length for the 1,000 pound engine as for the 100,000 pound engine. The reason for this is, that assuming it is possible to develop an injection and mixing system for the propellants, which does not require any longer period of time for mixing in the 1,000 pound engine than in the 100,000 pound engine and since the burning time for a combustion mixture of propellants at a fixed pressure remains constant, theoretically the length of the combustion chamber should likewise remain fixed regardless of the size of the rocket engine. Experience has indicated however, that since a longer period of time is required for the proper injection and mixing of larger quantities of propellants, the combustion chamber must be lengthened by a small percentage for increase thrust rating. The nozzle size is a function of the mass of gases flowing through the nozzle throat, assuming that the jet velocity remains constant during the scaling-up procedure. Therefore, the area of the throat will increase in direct proportion to the increase in thrust. The length of the nozzle must maintain the proper contour to join up with the combustion chamber and also to provide expansion of the gases from the pressure occurring at the throat to thte exit pressure at the nozzle. The most difficult problem as we scale-up the rocket engine from the smaller sizes to the several hundred thousand pound thrust units, is to provide adequate and proper injection of the propellants. As a matter of interest, it is understood that the German A-4 or V-2 rocket engine injection system was first designed for possibly a rocket engine having a thrust rating of between 1,000 and 2,000 pounds. After this injector head was developed, the procedure was to install a large number of these injector heads into the combustion chamber of the V-2 engine. This accounts for the series of cups or individual injectors which you may have observed in this engine. It is known that in later developments the German scientists agree that this was an expedient to their problem, however, as development of rocket engine injectors continued it was found



CONTROL PANEL FOR OPERATION OF THE 1500N4C ROCKET ENGINE.

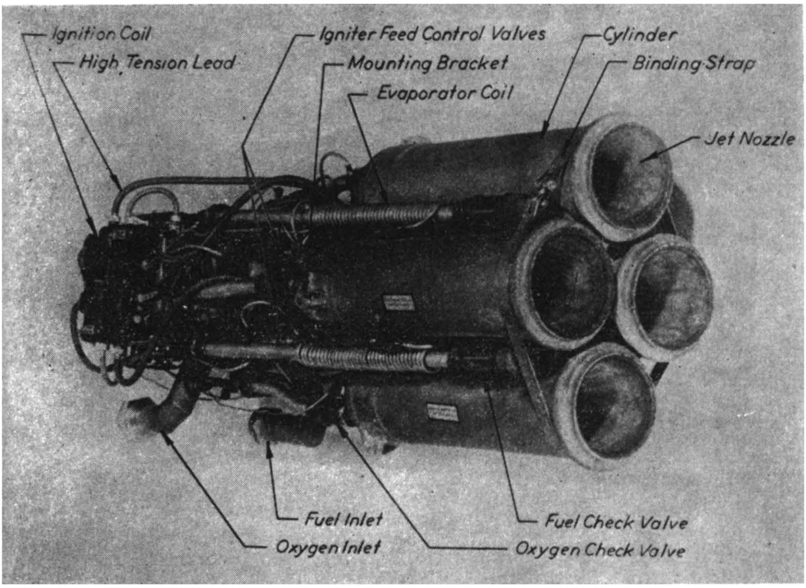
desirable to design the injector head for the specific engine, which was to be developed. This latter procedure has been carried out as a basis for injector design for the most part in this country. Leaving the rocket engine as such, for a moment, consideration should be given to the pumps, gas generator, turbine, propellant valves, control valves, igniters. All of these sub-assemblies require an individual development program, since practically none of these items are commercially available. In the case of pumps speeds are far in excess of anything which the hydraulic pump industry has developed to date. In the case of propellant valves, delay action is necessary as well as seats which will withstand the propellants handled. None of these are available on the market today and must be developed during the development of the rocket engine. Therefore, as the regenerative rocket engine, which has sometimes been called, "A Tin Can", becomes an accepted source of power for aircraft, the unit more and more becomes a scientifically engineered device involving the most advanced contributions of science and engineering.

Now that we have discussed the various problems involved in scaling up the size of a liquid propellant rocket engine into the range which is in the planning and development stage today we might consider what the physical characteristics of some of these engines are as shown by the comparison which we have here.

Proceeding from the development stage to the test stage of the rocket engine, in order to verify or correct analytical calculations, it is necessary to measure the thrust which is produced, the pressures which are occurring in the combustion chamber, as well as in the propellant manifolds, the control pressure for the propellant valves, and the propellant tank pressures. Of great importance also is instrumentation to record instantaneous flows of both the oxidizer and the fuel in order to insure that the mixture ratio is correct. Of equally great importance is the determination of temperatures of the propellant flowing between the outer jacket and the combustion chamber of the rocket engine, as well as the temperature of the gases in the combustion chamber. Presently available instrumentation does not make it possible to accurately record the gas temperature in the combustion chamber during combustion.

There are several means of measuring the thrust produced by a rocket engine. A hydraulic cylinder or hydraulic diaphragm are the most common methods. Recently strain gauges have been employed as a satisfactory and convenient means. Recently, however, a pneumatic type of thrust balance has been developed which is very sensitive. This device involves the use of standard pressure recorders, to record thrust. In the determination of pressures occurring in the propellant manifolds, combustion chamber and propellant valve control pressures standard precision type recorders have proven very satisfactory.

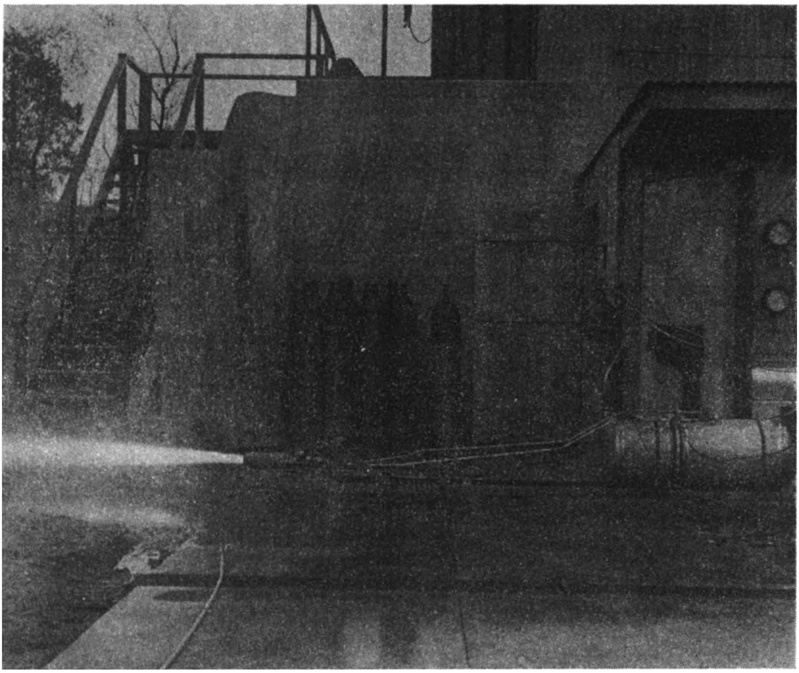
One of the most difficult determination is that of propellant flow. Until recently the procedure was to use tanks with sight gauges, which would show the initial amount of propellant and the propellant remaining in the tanks, at the completion of the run. This did not give an indication of possible variation in flows during the run. Another means is to suspend the tanks and to weight them by standard means or by special electrical gap methods. Early use of this means of weighing tanks was very cumbersome and did not prove too satisfactory. The most satisfactory means for registering and recording flows is by means of a rotameter, or by a calibrated flow meter. Either of these devices require careful calibration and in most cases special designs must be developed to operate



NOZZLE END VIEW OF 1500N4C ROCKET ENGINE.

satisfactory with rocket engines. In addition to adequate instrumentation, before rocket engine testing can be undertaken it is necessary to consider the safety of personnel. In view of the newness of the field, it is usually considered advisable to conduct all initial experiments on rocket engines in a barricaded cell. This cell should not be completely enclosed since a rapid build-up of the gases of combustion during malfunctioning of the unit could very well be disastrous if confined. Therefore, the test cell must be designed to provide adequate protection but also allow rapid release of gas pressure in the region of the engine itself. In the case of propellant tankage, tanks must be adequately protected to provide immediate shut-off of propellants in the event of malfunctioning of the engine, as well as provision to prevent the tank from becoming pierced in the event detonation should take place within the engine. Most important is that the tanks be provided with suitable valving so that they may be isolated, thereby, confining the fire or detonation resulting from malfunctioning of the rocket engine from spreading to the main propellant tanks. If this precaution is taken, little damage will usually result from the propellants contained in the propellant lines or the engine at the time of malfunctioning.

Since the proper operation of the rocket engine is largely dependent upon the injection pressure, as well as the mixture ratio, experience has shown that for every aircraft installation it is desirable to test the rocket engine with an exact prototype of the tankage, valving, and connecting plumbing as installed in the final aircraft. By this means it is possible to accurately determine the pressure drop through the gas pressure feed system, gas pressure control valves, and the propellant lines. Once this information is determined, it is possible to calibrate the rocket engine to meet these conditions and operate satisfactorily. It is most essential



ROCKET ENGINE MOCKED UP WITH PROPELLANT TANKAGE.

in progressing from the prototype aircraft to the production aircraft that no change be made in the valving, plumbing, or tankage. Another condition which directly affects the injection pressure of the propellants, and likewise the mixture ratio is the affect of acceleration. Most rocket powered aircraft are subject to reasonably high positive accelleration during the take-off and may be subject to either positive, negative, or zero accelleration during flight. All of these considerations must be taken into account in the design of the rocket engine and turbo pump injection systems. In order to simulate as many of these conditions as possible, it is necessary to test the rocket engines in various attitudes, which will be experienced in flight with the pumps, tankage, valving, and plumbing mounted as an assembly and placed in various attitudes as an assembly to as closely as possible approximate the conditions during flight. In the case of small rocket engines mounting of the entire assembly on such a frame is not of great consequence, however, as the size of the rocket engine increases the propellant tankage becomes larger, propellant lines become larger, and in general, the problem becomes much more complex.

With a large rocket engine, the problem of dissipating the intense heat from the exhaust jet is a major problem during static tests. Present means of accomplishing the dissipation of heat is a steel jacketed water cooled lining for the floor and walls of the test pit flume. Methods initially employed were to design the flume much the same as a standard water tube boiler, however, new and improved methods of accomplishing this are now in the development stage.

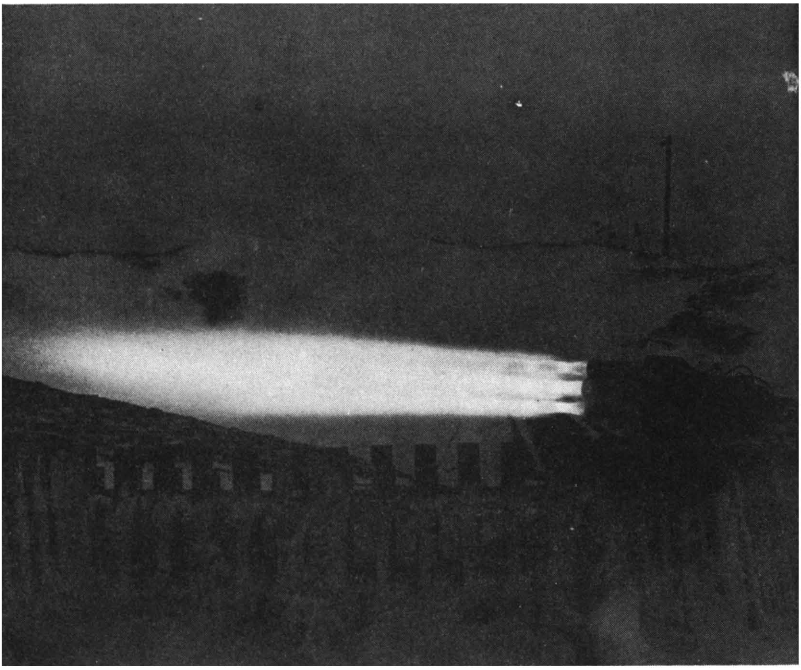
1500 N4C ROCKET ENGINE OPERATING AT 30° INCLINED POSITION.

Last, but not least, a major consideration in the testing of rocket engines is public annoyance. The exhaust from a rocket engine when operating properly is high-pitched and generates a high-frequency shock wave. In order to avoid public annoyance, it is necessary to locate a rocket engine test cell several miles from any inhabited area, in order that the noise may be partially dissipated.

With reference to the application of the rocket engine the most important consideration is the fact that this means of propulsion is adaptable to aircraft flying at any speed up to several times the speed of sound or Mach number of between five and ten if desired. Since the rocket engine carries with it both oxidizer as well as fuel, it can operate at any altitude from sea-level to infinity. Due to the greater expansion ratio at the higher altitudes the efficiency of the rocket engine, if properly designed, may increase between 15 and 20 percent from sea-level to 100,000 ft. altitude. It is true that the propellant consumption of the rocket engine is excessive as compared to the air-free type of power plants such as the conventional reciprocating engine or the turbojet, which obtains the oxygen from the air. However, while the rocket engine improves in efficiency at altitudes, the overall efficiency of the reciprocating engine or turbojet decreases at altitude.

The following curve which shows altitude versus specific impulse shows graphically the effect of altitudes on the rocket engine as compared with an air free type of engine such as the turbojet or ramjet.

A second consideration is that as the aircraft ascends to higher altitudes the air becomes, so called "thinner" with a reduction in drag on the aircraft. This drag continues to be reduced with increased altitudes until at between one hundred and one hundred and twenty five thousand feet altitude, at which no air-free engine has yet been operated including the "Ramjet", the drag on the aircraft is only a fraction of the drag at sea-level. Therefore, for higher altitude long range flights the rocket engine can show definite promise, even from the standpoint of propellant consumption.



FOUR CYLINDERS FIRING ON 1500 N4C ROCKET ENGINE IN HORIZONTAL POSITION.

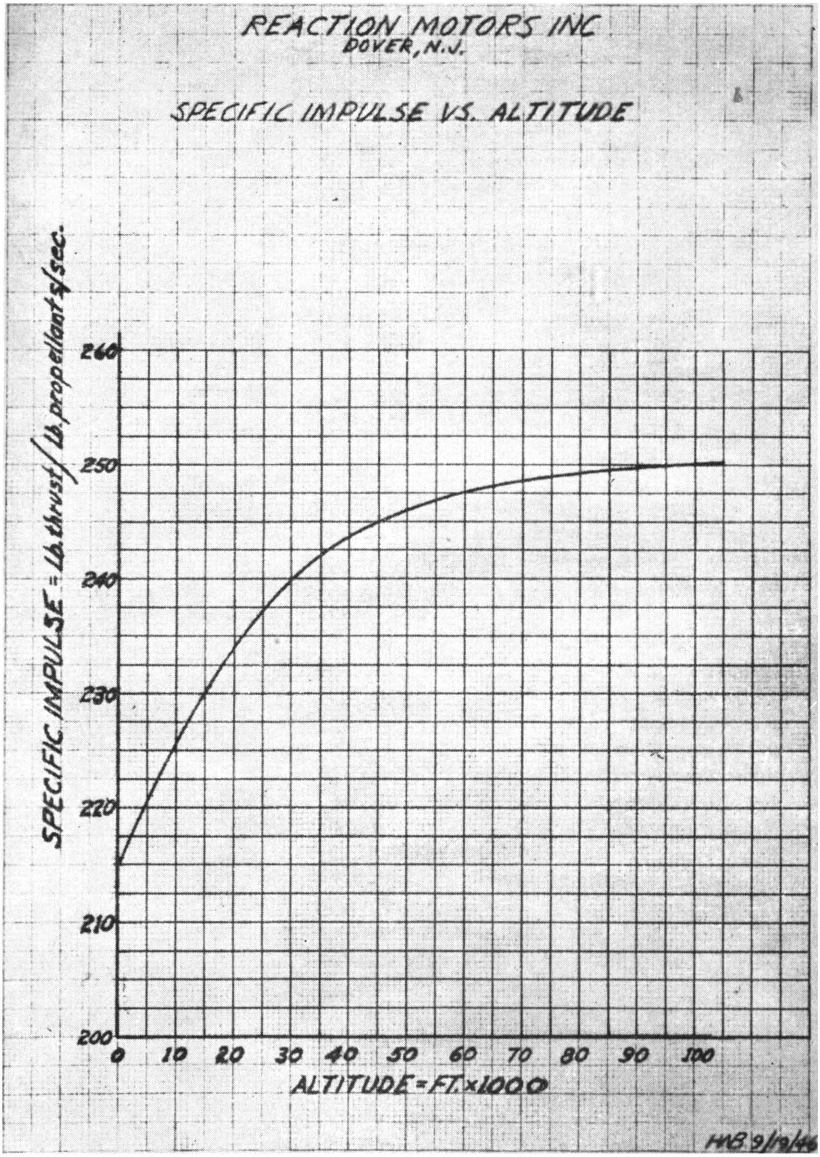
COMPARISON OF LIQUID PROPELLANT ROCKET ENGINE DIMENSIONS AND WEIGHTS

THRUST RATING in Pounds	Length in Inches	DIAMETER IN INCHES Nozzle Throat	DIAMETER IN INCHES Nozzle Exit	Diameter Propellant Lines in In.	Weight of Engine in Pounds	*Pressure Tank in Weight 60 Secs.	Pump System Weight 60 Secs.
220	9	.75	1.6	½	5	32	48
2,000	22	2.5	5.5	1	25	320	160
8,000	30	5.0	11.0	2	110	1,280	420
20,000	48	8.0	17.6	3¼	300	3,200	950
60,000	70	13.7	30.2	5½		9,600	2,800
100,000		17.7	38.9	10		16,000	4,450
500,000	150	39.0	95.0	22½			
5,000,000	312	124.0	305.0	71			

Above tabulated values are based on a constant propellant feed pressure and specific impulse.

*Does not include weight of propellants. Tankage on the basis of 60 seconds operational duration.

Lastly, the rocket engine has the inherent characteristic that it is mounted in the tail of the aircraft which allows for clean aerodynamic design and does not necessitate an inflow of air in the forward section of the aircraft, with a consequent decrease in drag.



Some Possibilities For Rocket Propellants

Part I of Four Parts

By ARTHUR S. LEONARD*

SYMBOLS

(For subscripts, see bottom of this list.)

C_P = specific heat at constant pressure, cal. per gram mole per °C.

C_v = specific heat at constant volume, cal. per gram mole per °C.

ΔE = change in internal energy due to change in state, such as fusion or vaporization, cal. per gram mole.

h° = enthalpy, based on 0° K, cal. per gram.

h°_e = effective enthalpy, based on 0° K, cal. per gram.

Δh°_{0e} = effective enthalpy of formation at 0° K, cal. per gram.

H° = total heat content, based on 0° K, cal. per gram mole.

H°_e = effective total heat content, based on 0° K, cal. per gram mole.

ΔH = change in total heat content due to chemical reaction or change in state, such as fusion or vaporization, cal. per gram mole.

ΔH°_0 = heat of formation at 0° K, from elements at 0° K, cal. per gram mole.

ΔH°_{0e} = effecticve heat of formation at 0° K, from elements at 0° K, cal. per gram mole.

ΔH^T_T = heat of formation at T° K, from elements at T° K, cal. per gram mole.

J = mechanical equivalent of heat = 4.186 x 10^7 dyne cm. per cal.

M_P = mass of initial charge of propellant, grams.

M_R = final mass of rocket, grams.

dm = increment of mass of propellant or reaction products, grams.

M = molecular weight, grams per gram mole.

N = number of moles, gram moles.

P = static, or external pressure, dynes per sq. cm.

R = gas constant = 8.31 v 10^7 dyne cm. per °C per gram mole.

R_P = pressure ratio = P_c/P_m, dimensionless.

t = temperature, °C.

T = absolute temperature, °K = t + 273.

u_j = jet velocity, cm. per sec.

u_r = velocity of increment of mass of reaction products relative to starting

u_R = point, in direction opposite to motion of rocket, cm. per sec.

instantaneous velocity of rocket, cm. per sec.

U_r = mean velocity of reaction products relative to starting point, in direction opposite to motion of rocket, cm. per sec.

U_R = final velocity of rocket, cm. per sec.

V = specific volume, cu. cm. per gram mole.

ΔV = change in volume due to change in state such as fusion or vaporization, cu. cm. per gram mole.

V_P = total volume of propellant containers, or initial charge of propellant, cu. cm.

dV_P = increment of volume of propellant containers or propellant, cu. cm.

V = ratio specific heat at constant pressure to specific heat at constant volume, dimensionless.

N_n = nozzle efficiency, dimensionless.

P_P = propellant density, grams per cu. cm.

Σ = denotes the summation of the quantities following it.

Subscripts

($)_c$ denotes properties in the combustion chamber.

($)_f$ denotes properties of the fuel.

($)_F$ denotes fusion.

($)_m$ denotes properties at mouth of nozzle.

($)_o$ denotes properties of the oxidizer.

($)_r$ denotes properties of the reaction products.

($)_T$ denotes properties at T° K.

($)_v$ denotes vaporization.

SUMMARY

The puropse of this investigation is to determine the relative suitability of various chemical substances for use as rocket propellants. The primary objective is to select the propellants which will give the rocket the highest possible final velocity. New equations are derived by which the various elements and compounds may be rated. This method of rating has opened up, for experimental investigation, a whole new class of materials which, by the previous criteria, appeared to hold very little promise of being useful as propellants. Included in this group, are elements and compounds of high density.

Theoretical Analysis

By solving the differential equation for the motion of the rocket, we obtain the following expression:

$$U_R = U_J \log_e \left(1 + \frac{m_P}{m_R}\right)$$

(1)

In this and the equations which follow, it is assumed that the rocket is moving in a vacuum and free from the force of gravity. From this equation, it is obvious that, in order to make the final velocity of the rocket (U_R) as high as possible, we should strive to make the jet velocity (U_J) and weight ratio ($1 + m_P/m_R$) as high as possible. Beyond this, however, it suggests very little else that might be done to improve the performance of the rocket.

By making a different approach to the problem, we may bring out other important facts. Instead of concentrating on the motion of the rocket, let us consider the motion of the propellant, or products of reaction. Starting with the Law of Conservation of Momentum, we may write:

$$m_R U_R = m_P U_r$$

(2)

This equation states that the final momentum of the products of reaction is equal and opposite to that of the rocket. In this equation, the two masses and the final velocity of the rocket may be represented by definite quantities. The mean velocity of the reaction products relative to the starting point on the other hand, must be expressed in the form of an integral as follows:

$$u_r = \frac{\int_0^{m_P} U_r \, dm}{\int_0^{m_P} dm}$$

(3)

The denominator of this fraction may be integrated immediately to give Eqs.

(4) and (4a) as follows:

$$U_r = \frac{1}{m_p}\int_0^{m_p} U_r\,dm \qquad 4$$

$$U_r\,m_p = \int_0^{m_p} U_r\,dm \qquad 4a$$

Combining Eqs. (2) and (4a)

$$U_R\,m_R = \int_0^{m_p} U_r\,dm \qquad 5$$

$$U_R = \frac{1}{m_R}\int_0^{m_p} U_r\,dm \qquad 5a$$

At the start of firing, u_r is equal to the jet velocity (u_j). As the rocket gains speed in the direction opposite to u_j, u_r is diminished accordingly. Eq. (6) expresses this relationship:

$$u_r = u_j - u_R$$

(6)

In order to determine how the density of the propellant will affect the performance of the rocket, we may write the following equation:

$$dm = P_P dV_P$$

(7)

From Eqs. (5a), (6) and (7)

$$U_R = \frac{1}{m_R}\int_0^{V_p} (U_j - U_R)\,\rho_p\,dV_p$$

(8)

Now, let us consider each term of Eq. (8) to determine what may be done to make U_R as large as possible. Starting with the mass of the empty rocket (M_R), we see that the final velocity (U_R) may be increased by reducing the final mass. This may be accomplished through the use of improved alloys and more efficient design. A further reduction in M_R may be obtained by designing the rocket so that empty propellant containers and booster motors can be jettisoned as soon as they are no longer needed. This is the principle of the step-rocket. However, these devices are outside of the scope of this investigation and will be left to the metallurgists and design engineers.

After M_R has been reduced to its smallest possible value, the only other thing that can be done to make U_R a maximum is to make

$$\int_0^{V_p} (U_j - U_R)\,\rho_p\,dV_p$$

(9)

as large as possible. In a general way, this may be accomplished by making V_P, u_j, and P_P as large as possible. Exploring the possibilities along these lines, we find that not much can be done about increasing V_P. This is based on the assumption that, in reducing the mass of the empty rocket to a minimum, the propellant containers have been designed as light as possible for their volume, and any increase in their capacity must necessarily be accomplished by a corresponding increase in their mass. Therefore, in order to not have to increase M_R we must not increase V_P. This leaves us with only u_j and P_P to work on.

Propellant Density

In order to determine the effects of propellant density on the final velocity of the rocket, let us go back again to Eq. (8). This equation indicates that, other things being equal, the final velocity of the rocket will be directly proportional to the propellant density. This immediately suggests that we should use the densest possible propellant. Unfortunately, the "other things" are not equal, so this suggestion must be modified.

When we consider the effect of an increase in propellant density on the mass of the empty rocket, we find that some of the structural parts may have to be made stronger and, therefore, heavier. The denser propellant will require a motor of greater thrust. If the thermal efficiency is to be maintained, this will require a larger and heavier motor. Different chemical and physical properties associated with the denser propellant may make necessary or allow changes in the construction of the propellant tanks, pumps, and piping which may either increase or decrease the weight of the empty rocket. However, the net increase or decrease in the mass of the empty rocket made necessary or permitted by even a relatively great change in propellant density, should not be large. Therefore, in making a preliminary comparison of proposed propellants, we will assume that the weight of the empty rocket is unaffected by changes in the propellant density. This assumption, however, should be reviewed, and perhaps modified, in making a final choice of oxidizer and fuel.

When we compare estimated jet velocities which might be obtained with different propellant combinations, we find lower velocities associated with the denser propellants. The densest propellant, therefore, will not necessarily give to the rocket the highest final velocity.

Offhand, it would appear that the value of

$$\int_0^{V_P} (u_J - u_R)\, \rho_P \, dV_P$$

and, therefore, the final velocity of the rocket, would be made a maximum if, into each increment of volume of the propellant tanks, we put the propellant possessing the highest value for the product, $(u_J - u_R)P_P$. Unfortunately, an exact solution of this problem is not that easy. For this reason, it will not be presented at this point, but left to be dealt with later. However, a qualitative solution should not be out of place, and will be given at this point.

At the start of firing, u_R is equal to zero, and the expression, $(u_J - u_R)P_P$, reduces to $u_J P_P$. Therefore, the best propellant, for this part of the flight, is the one which gives the greatest value for this product. Since the jet velocity is roughly proportional to the square root of the enthalpy of reaction, a two percent change in the value for this latter property will produce only a one percent change in the jet velocity. Under these conditions, a second propellant, having a reaction energy two percent lower than that of the first, will be just as effective if its density is only one percent higher. Therefore, in the selection of a propellant for the start of the flight, density will exert more influence than will reaction energy. As a result of this, the most effective propellant for the first part of the firing period will turn out to be a combination possessing a rather high density, but, perhaps, only a moderate enthalpy of reaction. In fact, at the start of firing, high density is so important that, with high-energy-low-density propellants, such as liquid oxygen-gasoline mixtures, a considerable increase in the final velocity of the rocket may be obtained through the use of the correct amount of a very dense but inert diluent, such as mercury or molten lead.

Incidentally, this method of raising the final velocity of the rocket may turn out to be much more practical than it appears at first thought. Even without taking into account the reduction in the amount of energy lost through dissociation, calculations indicate that a very substantial increase in the final velocity may be realized. Actually, the reduction in reaction temperature resulting from the injection of an inert substance into the combustion chamber will reduce greatly the amount of dissociation of the principle products of reaction. This will have the effect of increasing the combustion efficiency of the active ingredients of the propellant. Also, the addition of a monatomic gas, such as mercury vapor, to the polyatomic reaction products will raise the value of V for the mixture as a whole. This will raise the nozzle efficiency. The net result will be a considerably smaller reduction in jet velocity than would be expected from a consideration of just the heat capacities and relative amounts of diluent and active ingredients.

Another thing which may be done to raise the final velocity is to use two or more different propellants at the same time. We may find the product, u_jP_P, for certain blends of different propellants to be higher than that for any single propellant. Under such circumstances, the best propellant for the start of the firing period will consist of a blend of two or more different propellant mixtures. If a common oxidizer or a common fuel is employed in these mixtures, two or more fuels and a single oxidizer, or two or more oxidizers and a single fuel is all that will be required.

One of the difficulties with which we may be confronted, when trying to make use of these principles, is the unequal dissociation of the different reaction products. We might run into this difficulty if we were to use both lithium and mercury in the fuel and fluorine as the oxidizer. It might be found that the reaction between the lithium and fluorine would raise the whole mixture of reaction products to a temperature at which the mercury fluoride was almost completely dissociated. Under such circumstances, it would be better not to provide any fluorine to react with the mercury, but to employ the latter substance merely as an inert diluent.

As the rocket gains speed and u_R becomes appreciably compared with u_j, the most effective propellant will turn out to be a different combination, or at least a different blend of propellants, having a slightly lower density but a higher effective enthalpy of reaction. Finally, as the end of firing is approached, the most effective propellant will be one giving the highest, or nearly the highest possible jet velocity, but having, perhaps, a relatively low density.

From the above description of the physical significance of the solution of Eq. (8), we can see that, in order to make the best possible use of the available volume of the propellant containers, we should use a propellant of continually changing density and reaction energy. The firing period should start with a high-density mixture and end with a high-energy combination. This will require the use of two or more fuels, two or more oxidizers, or both. A similar result may be obtained by employing a single high-energy propellant, and injecting into the rocket motor, in continually decreasing amounts, a very dense but inert substance, such as mercury.

END OF PART I.

PART II WILL APPEAR IN THE NEXT ISSUE OF THE JOURNAL.

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Elementary Formulae of Rocket & Jet Propulsion

By M. Z. KRZYWOBLOCKI

Assume the simplest possible type of a thermal jet engine, i.e. a nozzle of a suitable shape with a fuel injection device. Let the coefficient of the internal efficiency be equal to unity. The air enters in the front with the velocity v equal to the velocity of the propelled body with respect to the earth and leaves with the velocity c by virtue of the combustion of the fuel. The first part of the total kinetic energy in the combustion chamber is equal:

$$L_1 = (a\,m_f\,c^2/2) + m_f\,(v^2 + c^2)/2 \tag{1}$$

where $c\,m_f$ = mass of the air in one second, a=air fuel ration by weight, m_f =mass of the fuel in one second, c= velocity of the outflowing gases with respect to the walls of the nozzle.

The energy of the outflowing gases:

$$L_2 = (a + 1)\,m_f\,(c - v)^2/2 \tag{2}$$

The energy of the entering air:

$$L_3 = a\,m_f\,v^2/2 \tag{3}$$

The increase in the energy of the body:

$$L = L_1 - L_2 - L_3 = [\,(a+1)\,m_f\,c - a\,m_f\,v\,]\,v \tag{4}$$

The reactional force of the outflowing gases:

$$F = L/v = a\,m_f\,(c-v) + m_f\,c \tag{5}$$

$$n = \frac{L}{L_1} = \frac{2\,[\,(a + 1)\,c - a\,v\,]\,v}{[\,(a + 1)\,c^2 + v^2\,]} \tag{6}$$

where n = the instantaneous coefficient of the external efficiency.

For c = constant and a = constant from dn/dv = 0 one obtains:

$$n_{max.} = (a+1)/\,[\,a+(a^2+a+1)^{1/2}\,] \tag{7}$$

for

$$c = [\,a\,v + v\,(a^2 + a + 1)^{1/2}\,]/(a+1) \tag{8}$$

Of course, the useful power is equal to L.

These formulae may be transformed for two extreme cases:

(a) pure rocket, i.e. without taking the air from outside:

$$a=o,\ m_f=m,\quad F=mc,\ n=2vc/(c^2+v^2),$$

$$n_{max} = 1 \text{ for } c = v$$

(b) neglect the mass of the fuel in comparison with the mass of the air:

$$m_f=0,\ (a+1)\,m_f=a\,m_f=m,\ (a+1) \cong a, \tag{9}$$

$$F=m\,(c-v),\ n=2\,(c-v)\,v/c^2, \tag{10}$$

Using (10) one obtains from dn/du=0:

$$n_{max} = 1/2 \text{ for } c = 2v \tag{11}$$

In the case of an intermittent-firing duct engine, when the air is forced into the combustor by ram effect the above derived formulate may be applied as approximate under the simplifying assumption that all the losses are neglected and that the actual process is substituted by an equivalent continuous-firing process similar to that one which takes place in an athodyd. One also may take all the losses into account by means of a suitably chosen coefficient of the internal efficiency.

In all the consideration above the coefficient of the internal efficiency

$$n_i = \frac{(\text{real velocity})^2}{(\text{theoretical velocity})^2} \quad (12)$$

was assumed to be equal to 1. In practical calculations its value is less than 1. Also the pressure of the exhaust gases at the mouth of the nozzle was assumed to be equal to the pressure of the outside air.

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Under-Water Rocket Power Weapon

Rocket power, most recently harnessed force for propelling planes and projectiles through the air, has now been adapted for use under the sea.

The weapon, a new aerial torpedo—called the Hydro-Bomb—uses the thrust of burning, expanding gases to propel itself through water instead of air. It was developed and built for the Army Air Forces by the Westinghouse Electric Corporation and was nearly ready for combat use as the Japanese capitulated.

The simplest and the least expensive to manufacture of all aerial torpedoes, the Hydro-Bomb was to be the answer to the Army Air Forces' appeal for a fast missile that could stand the shock of being dropped 600 feet or more from a plane going 300 mph and permit the torpedo-carrying plane to keep out of the range in which anti-aircraft fire becomes almost suicidal.

Made in Transformer Plant

Development of the unique weapon took many months of labor by Westinghouse Research Laboratory scientists and by engineers of the Sharon division of the Company, working in cooperation with the Air Materiel Command. The Transformer Division plant of the Company here already was experienced in producing wakeless electrical torpedoes for the Navy.

"The Army first approached us asking development of an aerial torpedo propelled by unconventional methods," said F. L. Snyder, Westinghouse Transformer Division engineering manager. "At our Research Laboratories, Dr. Stewart Way and Dr. Earl A. Gulbransen, who had been working on rockets and jet propulsion, conceived the idea of propelling the torpedoes with a true rocket motor, pushing the 2300 pound projectile through the water much the same as a Fourth of July skyrocket is projected through the air."

From this idea was developed the Hydro-Bomb, the engine of which is nothing more than a large pipe packed with solid fuel which, when burning, creates expanding gases that are expelled through a nozzle. Escape of the expanding gases through the nozzle sets up a reaction against the Hydro-Bomb like the kick of a discharged shotgun, thus pushing it through the water. At one place the nozzle is only five-eighths of an inch wide to compress the gases, then it expands like the barrel of an ancient blunderbus, being two and three-fourths inches in diameter at the end.

Rocket Ignited as Torpedo Hits Water

The Hydro-Bomb has much the appearance of a submarine torpedo. It is slightly shorter and has a diameter approximately two inches greater than most torpedoes. Its warhead can carry approximately 600 pounds of high explosive and the rocket motor can push it through water at 40 knots — a speed comparable with that of the fastest compressed air or electric torpedoes.

The Hydro-Bomb is dropped from a plane speeding at 300 or more miles per hour. The impact on striking the water throws a switch that ignites the rocket motor's solid fuel. The motor can develop a thrust of 1,000 pounds. Electrical controls with a gyroscope keep the bomb on the path in which it was aimed and special controls regulate the under water depth of its operation, Mr. Snyder said.

Many Problems Overcome

The initial major problem of designing a rocket motor that could give a sustained thrust for the required period was followed by many other problems that were eventually worked out, he continued.

"Virtually every part of the Hydro-Bomb had to be shock treated to withstand the terrific impact occasioned when it was dropped from heights well above those for the normal aerial torpedo," he pointed out. "The gyro and depth controls all were shock-treated as was the rocket motor. To keep the impact from damaging the rudders and elevators, a ring of steel was placed around them in such a manner as to absorb the shock and still allow them free operation.

"A water trip switch had to be devised that would work every time, yet not be affected by the tremendous speed with which the torpedo passed through the air," he continued. "Safety measures to assure that the rocket motor would not start while attached to the plane were necessary, resulting in development of a fuse which kept electrical contacts shorted until the Hydro-Bomb left the plane. Special gaskets that expanded equally with the metal parts under heat of the rocket motor also were developed."

Tested at Lake Pymatuning

Tests of the Hydro-Bomb were conducted at Lake Pymatuning, 20 miles north of Sharon, where the Department of Forests and Waters of the State of Pennsylvania allowed Westinghouse to set up testing facilities for it and for the electrical torpedoes made by the Company. Here, running qualities of the aerial torpedoes were checked and they later were shipped to Newport, R. I., for impact tests. Although Army requirements demanded that the Hydro-Bombs stand a 600 foot drop from a speeding plane into water without damage, one of the bombs, not set for detonation, was dropped from a plane flying 2,000 feet over the ocean. Upon recovery it was found to be undamaged.

A true rocket motor such as used in the Hydro-Bomb can operate under water because it supplies its own oxygen for combustion from ingredients of the solid fuel propellant rather than obtaining it from the air, Mr. Snyder pointed out.

From An Army Ordnance Association Bulletin:

Guided Missiles:

The earth is becoming too small a place for the Ordnance guided-missile program. Development of rocket weapons already has progressed to the point where Ordnance is seeking ocean bases from which to launch super-long-range missiles. A joint Army-Navy commission of which the Ordnance Department is a member is searching the United States, the Caribbean, and Pacific areas for a range where it will be possible to test contemplated rockets over a distance of 2,000 miles.

On July 30th a new world's altitude record of 104 miles was achieved by Ordnance technicians at the White Sands Proving Ground, New Mexico, with a German V-2 rocket. The rocket descended 69 miles north of the launching platform, gouging a deep crater in the desert. Instruments carried in the nose came down intact and are expected to provide more information than ever before was available concerning cosmic rays, temperatures, and pressures at very high altitudes. Major General Everett S. Hughes, Chief of Ordnance, believes that rockets of the future will be capable of traveling thousands of miles.

One practical result of the current altitude tests is the possibility of using special war heads on anti-aircraft weapons which will neutralize the threat of high-altitude bomber formations. It is anticipated that some of the bombers of the future will fly at altitudes far above effective anti-aircraft gun ranges. It is difficult now for pursuit craft to attack enemy bombers flying in formation because of the protection they give to each other. To solve this problem, Ordnance scientists are planning the development of a guided missile which would carry a charge intended to be exploded in the midst of an enemy bomber formation where it would be highly destructive.

Ordnance experts are of the opinion that tests of the Nazi V-2 rocket are only a prelude to an era of long-range guided missiles capable of spanning oceans, and possibly of circling the globe. Ordnance scientists are preparing for the advent of these supersonic rockets. Plans are under way for a hypervelocity wind tunnel and a companion hypervelocity free flight range which will permit speeds of eight or ten times the velocity of sound. By firing missiles in free flight in the new hypervelocity range, which will contain refrigerated gases, tremendous velocities can be obtained and measurements of the aerodynamic characteristics of missiles can be taken by spark photography, Schlieren photography, and interferometer techniques.

Improved fuels have already resulted in altitudes roughly double those achieved by the Germans with their V-2 rockets. Further improvements in fuels and combustion are expected to send the V-2 to an altitude of at least 200 miles in the near future. That altitude would be mathematically equivalent to a horizontal range of 3,000 miles or more. However, actual tests of horizontal range cannot be made until a base is established somewhere from which rockets may be launched safely on flatter trajectories than those now employed. Recent news reports from Scandinavian countries seem to indicate that Russian rocket experiments already are being made on the basis of range rather than altitude. These reports have told of mysterious missiles passing at great speed over those countries "from an undetermined source." It would appear that the Soviet iron curtain can now be shifted at will with the aid of guided missiles.

Army ground forces has established an Antiaircraft Artillery and Guided Missile Center at Fort Bliss, Tex. This move is in line with the AGF policy of keeping abreast of every new Ordnance development in military science. Plans call for extensive demonstrations of new Ordnance atomic weapons and the development of tactics, techniques, and organizations of guided-missile units for use in the Army Ground Forces. Thus there will be no duplication of effort. Ordnance will design and develop guided missiles while Army Ground Forces will prescribe their desired characteristics and study their use by combat teams.

Effect of Sun's Heat on Space Rockets

By G. C. ELLERTON, Jr.
Commander, U. S. Navy.

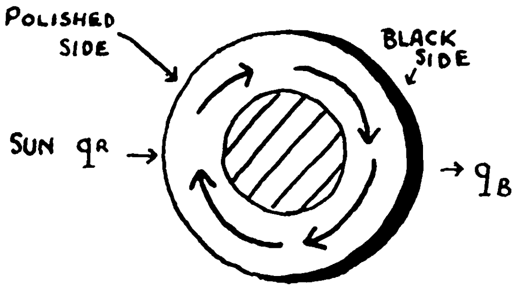
(Editor's Note: Commander Ellerton's letter came to us from the Pacific, where he is serving on the staff of Commander Minecraft).

I have read "The Journal" with much interest since I began to receive it last year. Since that time I have had the opportunity of reading a few other works concerning the design and use of rockets of various types. My interest has not been concentrated around any one particular in this field. However, I have given some thought to the several schemes and devices proposed for interplanetary travel. As I have said, my reading has been very much limited and perhaps I have missed the point which brings this question to my mind. Has anyone considered the possibility that any passenger-carrying interplanetary vehicle may become unbearably hot for human beings due to the absorption of the radiant energy from the sun?

Once the rocket is out of the protecting envelope of the earth's atmosphere and out of the earth's shadow it will be subjected to the direct undiffused rays of the sun. Even though the outer skin of the rocket be of a highly reflecting surface there will still be some absorption of the radiant heat. The temperature of the rocket will slowly rise until the temperature of the skin is such that the rate of absorption of radiant heat is equal to the rate of heat radiated from the rocket. Since there will be no surrounding medium in interplanetary space there can be no loss of heat by convection or conduction.

Assuming that such a condition exists, I would propose this means of reducing the temperature of the rocket in space. The method involves the readiating of the heat energy from the sun at a rate which will be equal to or greater than the rate at which radiant heat energy is absorbed by the rocket.

The control of rocket body temperature by reradiating of heat energy received from the sun might be accomplished by some such scheme as I have attempted to show in the sketch.



The large sleeve completely surrounds the rocket body and is free to rotate relative to the rocket body. One half of the sleeve is highly polished and the other half made to have the characteristics of a black body. A circulating fluid may or may not be necessary in the space between the rocket body and the sleeve.

The operation of this heat control sleeve would be as follows. Once the rocket is out of the atmosphere and on its course the sleeve would be rotated by some interior control mechanism until the polished surface was facing the sun. Whatever radiant energy is absorbed by the reflecting surface would be carried by the circulating fluid to the black side from which it would be radiated at a rate nearly proportional to the fourth power of the absolute temperature of the black surface.

I do not think it would be difficult to approximate the quantities of heat energy envolved. The following are suggested relations to use in the approach.

Qr — Heat energy radiated per unit area per unit time from the surface of the sun.

q_r — Heat energy per unit of projected area per unit time striking the rocket body from the sun.

R — Distance of rocket from center of the sun.

r — Radius of the sun.

Therefore $$q_r = \frac{Qr\ r^2}{R^2} K$$

C — Coefficient of absorption of the polished side of the rocket sleeve.

A_p — Projected area of the polished side of the sleeve in the direction of the sun.

q_a — Heat energy absorbed by the polished side of the sleeve.
Therefore $q_a = q_r\ C\ A_p$

e — Coefficient of emissivity of the black side of the sleeve.

T — Absolute temperature of the black side of the sleeve.

A_b — Radiating area of the black side of the sleeve.

q_b — Heat energy radiated from the black side of the sleeve.
Therefore $q_b = K\ e\ T^4\ A_b$

In order to prevent heating of the rocket body

$$q_a = q_b$$

Therefore

$$K\ e\ T^4\ A_b = k\ \frac{Q_r\ r^2}{R^2}\ C\ A_p$$

By proper substitution and evaluation of constants the value of T can be obtained. If there were no spacing between the heat control sleeve and the rocket body this value of T would represent the temperature to which the interior of the rocket would be subjected. It would be interesting to follow through with the calculation to determine whether or not the rocket would be too hot or too cold for human comfort. I would like to try my hand at this myself but I do not have access here in Japan to the necessary data.

If T turns out to be a temperature too high for human existance, then a space between rocket body and sleeve will be necessary. It will also be necessary that the rocket body have a high reflectivity to prevent the heat trans ferring fluid from giving up energy to the interior. If T is discovered to be a temperature too low for human existance then it is obvious that a space need not be provided between the sleeve and the rocket body. In this case the sleeve would have to be adjusted relative to the rocket body in order that as much as necessary of the black surface is exposed to the sun to maintain comfortable rocket body temperature.

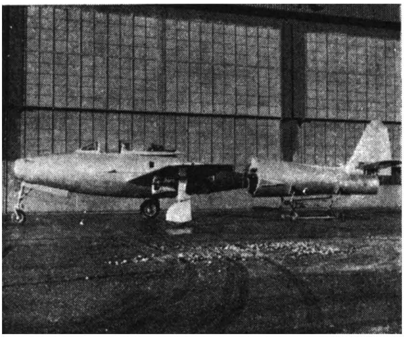
I may be pretty far off the beam on this subject but I would appreciate a comment from any of the members of the society who might have better information.

Jet Planes and Gapa in the Army Air Forces

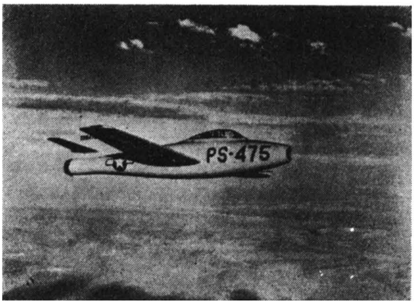
By ESTELLE R. SCHOENHOLTZ

Ten-miles-a-minute fighter speeds now, 1,000 miles per hour in the future—is the Army Air Force prediction for its rocket jet research. Just five years have passed since engineer Colonel Donald Keirn went to England to "determine the desirability of adopting package power plants and to investigate late developments of sleeve valves." The "sleeve valve" blueprint he sent back to Wright Field turned out to be the RAF's jet plane; the "package power plant" was its successfully flight-tested gas turbine engine. Together, the gas turbine plus AAF planes, especially designed to offer little resistance to air flow, have since flown at speeds above 600 miles per hour, challenging the barrier of the "sonic wall."

The jet engine is amazingly simple. Air flows through intake ducts to the engine where it is compressed by high-speed fans. Under pressure it is forced into a combustion chamber, mixed with fuel, and burned. Directing the powerful, burning gases through a turbine wheel spins the turbine thousands of times per minute to drive the compressors. Then the jet is nozzled down for greater force, and blasted out through an exhaust at the rear, creating a forward thrust.



Bisected view of the new Republic P-84 Thunderjet, showing that the rear section of the fuselage is quickly removable to permit complete replacement of the G.E. TG axial flow jet engine in 50 minutes.



Flight view of the P-84 Thunderjet, product of Republic Aviation Corporation and the Air Materiel Command.

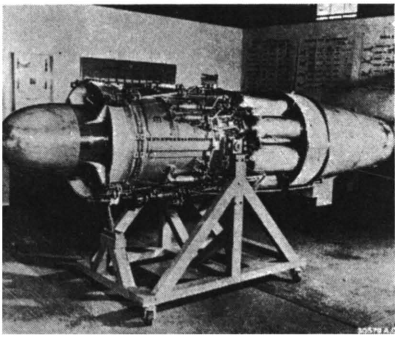
AAF jet designs have been under constant refinement since the first twin-engined XP-59 broke into speeds of 400 miles per hour. Working in cooperation with Air Materiel Command engineers, General Electric developed a direct-flow engine capable of developing 4,200

The XP-83, Bell Aircraft's Twin jet fighter in flight.

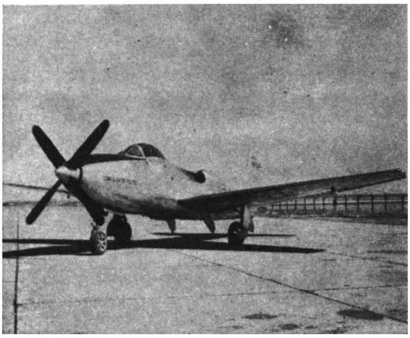
pounds of thrust. The compressor and turbine of this new J-33 engine were connected by a shaft and moved as a unit, the only moving part in the whole engine. Lubrication, therefore, was simple, and the 1,800-pound engine could be removed from a plane and replaced in approximately 20 minutes. Engine performance was so smooth, a vibrator had to be installed to insure proper functioning of the instrument panel needles. This Super G-E Jet was built to power the P-80 Shooting Star, the record-breaking jet plane that shattered all marks in a non-stop flight from California to New York—time 4:13:26. Pilot Colonel William Councill was awarded the Distinguished Flying Cross for the historic flight.

A compromise between propellered planes and jets to include features of each was a next research step, producing the long-range XP-81, a fighter tested in January 1946. Based on the principle that a propeller loses its thrust efficiency at high speed while a pure jet engine becomes more efficient, this new weapon can operate on either engine or both. A gas turbine converts jet power into rotational power to drive the four-bladed nose propeller, and also provides additional thrust from an exhaust jet. In addition, the XP-81 contains a centrifugal-flow jet engine in the rear, similar to the Shooting Star. When both propeller and jet engines are operated together, the ship travels faster than any conventional propellered fighter and farther than any pure jet fighter yet designed.

Swifter than the Shooting Star is the Thunderjet, the latest AAF single-jet fighter. Its speed tops 610 miles an hour at a service ceiling above 40,000 feet. General Electric's largest jet engine makes a giant tube of the plane; air enters at the nose and sweeps straight through the turbine, nozzling out back of the tail. The P-84 is aerodynamically clean, flush riveted and specially treated for skin smoothness, concealing internally all radio antennae and guns. Anticipating higher altitudes and greater speed, the plane's pilot has been equipped not only with a fully pressurized cockpit, but also with automatic air conditioning. In addition, an ejector seat will discharge him from the plane at any speed should his engine mishandle. This latest jet fighter is the AAF's bid for new world speed records.



General Electric J-35 axial flow turbo-jet engine.



Consolidated-Vultee XP-81 combination gas turbine driven prop and jet engine job.

The basic problem in developing jet engines has been the turbine. As speeds mount, turbine and compressor wheels literally have been torn apart by sheer centrifugal force. New alloys must be achieved that can withstand terrific temperatures and still rotate at very high velocities. In addition, jet planes of the future will require thinner, high-speed wings to reduce drag and vibration, thus escaping the compressibility shock waves that have set up a "sonic wall."

But Army Air Force research extends beyond piloted craft; pilotless, guided missiles are essential to the defense of America's sky boundaries. At isolated Wendover Field, Utah, tests are being conducted on a heretofore secret guided missile—GAPA, the Ground-to-Air Pilotless Aircraft. The pencil-slim, 10-foot-long missile is rocket-propelled, and can accelerate to a very high speed within a few seconds after launching, by means of a booster unit attached to the tail. When perfected, GAPA will be able to seek out and destroy any possible enemy planes or missiles before they reach their targets. First test models of the new missile involve principles that may have far-reaching effects on designs for future passenger or cargo-carrying aircraft. Army Air Force research is double-channeled—for potential American defense, and for limitless peacetime aeronautic progress.

UNITED STATES PATENTS

The following patents were compiled from issues of the Official Gazette of the U.S. Patent Office. Copies of patents may be obtained from the Commissioner of Patents, Washington, D.C., at 25 cents each.

No. 2,390,161, "Airplane Power Plant"; Pierre Ernest Mercier, Westport, Conn.

No. 2,396,568, "Apparatus for Steering Aircraft"; Robert H. Goddard, Roswell, N. Mex., assignor of one-half to The Daniel and Florence Guggenheim Foundation, New York, N. Y.

No. 2,401,941, "Exhaust Thrust Augmenter"; John G. Lee, Farmington, Conn., assignor to United Aircraft Corporation, East Hartford, Conn.

No. 2,402,363, "Turbine Apparatus"; Donald Bradbury, Prospect Park, Pa., assignor to Westinghouse Electric Corporation, East Pittsburgh, Pa.

No. 2,402,809, "Projectile"; Warren H. Farr, Grosse Pointe Farms, Mich., assignor, by mesne assignments, to the United States of America.

No. 2,402,826, "Control Means for Jet Propulsion Apparatus"; Isaac Lubbock, Great St. Helens, London, England, assignor to The Asiatic Petroleum Company Limited, London, England.

No. 2,404,334, "Aircraft Propulsion System and Power Unit"; Frank Whittle, Rugby, England, assignor to Power Jets Limited, London, England.

No. 2,404,335, "Liquid Fuel Burner, Vaporizer, and Combustion Engine"; Frank Whittle, Rugby, England, assignor to Power Jets Limited, London, Eng.

No. 2,404,767, "Jet Propulsion Plant"; Fritz Albert Max Heppner, Leamington Spa, England, assignor to Armstrong Siddeley Motors Limited, Coventry, Eng.

No. 2,404,954, "Aircraft Power Plant"; Frank W. Godsey, Jr., Wilkinsburg, Pa., assignor to Westinghouse Electric Corporation, East Pittsburgh, Pa.

No. 2,405,415, "Rocket Projectile"; Carolus L. Eksergian, Detroit, Mich., assignor, by mesne assignments, to United States of America.

No. 2,405,465, "Jet Propulsion Motor"; Martin Summerfield, Pasadena, Calif., assignor to Aerojet Engineering Corporation, Azusa, Calif.

No. 2,405,723, "Propulsion Apparatus"; Stewart Way, Pittsburgh, Pa., assignor to Westinghouse Electric Corporation, East Pittsburgh, Pa.

No. 2,405,919, "Fluid Flow Energy Transformer"; Frank Whittle, Rugby, England, assignor to Power Jets Limited, London, England.

No. 2,406,560, "Rocket Motor"; Winslow B. Pope, Detroit, Mich., assignor, by mesne assignment, to United States of America.

No. 2,406,926, "System of Jet Propulsion"; Martin Summerfield, Pasadena, Calif., assignor to Aerojet Engineering Corporation, Azusa, Calif.

No. 2,407,852, "Reaction Motor"; Apollo M.O. Smith, Bell, Calif., assignor to Aerojet Engineering Corporation, Azusa, Calif.

No. 2,408,099, "Variable-Area Nozzle for Jet-Propelled Aircraft"; Albert Sherman, Hampton, Va.

No. 2,408,111, "Two-Stage Rocket System"; Robert C. Truax, Ray C. Stiff, Jr., William Schubert, and James R. Patton, Jr., United States Navy, and Robertson Youngquist, Annapolis, Md.

No. 2,408,112, "Rocket Motor Cooling System"; Robert C. Truax, Ray C. Stiff, Jr., William Schubert, and James R. Patton, Jr., United States Navy, and Robertson Youngquist, Annapolis, Md.

No. 2,408,743, "Jet-Propulsion Apparatus for Aircraft"; Albert George Elliott, Derby, England.

No. 2,409,036, "Feeding Device for Combustion Chambers"; Robert H. Goddard, Roswell, N. Mex., assignor of one-half to The Daniel and Florence Guggenheim Foundation, New York, N. Y.

No. 2,409,176, "Gas Turbine System"; Robert C. Allen, Wauwatosa, Wis., assignor to Allis-Chalmers Manufacturing Company, Milwaukee, Wis.

No. 2,409,177, "Jet Propulsion Apparatus"; Robert C. Allen and John T. Rettaliata, Waufatosa, Wis., assignors to Allis-Chalmers Manufacturing Company, Milwaukee, Wis.

—C.G.

BOOK REVIEW

"Atomic Energy in Cosmic and Human Life" by G. GAMOW.

161 pp, illustrated, MacMillan Company. Reviewed by ROY HEALY.

Since Hiroshima there has been a flood of books on atomic energy, the majority of these hastily prepared to catch the ready market. For those who found the Smythe report fairly heavy going, this recently issued book by Dr. George Gamow of George Washington University, noted throughout the scientific world for his contribution to the theory of atomic nuclei, will be very welcome. It answers in clear and technically accurate fashion many of the questions which have arisen in engineering minds regarding this most promising field. Mr. Gardner's speculations on atomic rocket propulsion in the last issue of the Journal illustrates the current interest among rocket technicians in applying the tremendous energy released in fission to generating a jet of extreme velocity.

Dr. Gamow suggests that the present destructive use of fission should be curtailed and that instead this new power should be developed for special flight. We could quibble with the author, and also with Prof. H. N. Russell of Princeton, for both state that chemical fuels lack the necessary power to free man from the earth. (Rocket investigators have frequently proven that, given a large enough mass ratio, it is perfectly possible to attain the escape velocity with "conventional" propellants.) But we can hardly dispute the statement that atomic engines would tremendously simplify the problem and possibly even make such voyages economically feasible.

Most discussion of atomic rocket power presumes that the released thermal energy will be used to energize water, hydrogen or other material stored aboard. Such a method involves the release of tremendous heat and pressure within the rocket motor, far above those which can be handled today with current metallurgical technique. Dr. Gamo rent metallurgical technique. Dr. Gamow suggests that, "Instead of turning the kinetic energy of high-speed particles originating in nuclear reactions into heat and then converting this heat again into kinetic energy of gas flow, one could use directly the mechanical recoil of reacting nuclei. Thus, for example, if we have a thin layer of alpha-decaying radioactive substance spread on a supporting metal plate, alpha-particles ejected from decaying atomic nuclei will give to the plate a recoil-push in the opposite direction and make it move with steadily increasing velocity. The layer must be rather thin (a fraction of a millimeter) to prevent the alpha-particles formed in its interior from being stuck in it before reaching the surface. The necessary thinness of the layer, and a rather large amount of radioactive material necessary to drive the rocket-ship, would require a very large area emitting alpha-particles, so that the whole thing would look like a giant sail with the area of probably many hundred square feet. A thin metal-sheet sail, covered on one side with a deposit of radioactive material — might be folded as an umbrella while the rocket-ship is crossing the thick layers of terrestrial atmosphere, being driven in the interior stages of its journey by an ordinary chemical jet propulsion motor. When it gets out into empty interstellar space it opens its tail and sails proud as a peacock toward the stars".

In addition to such fascinating speculation the book provides, in its first section, a fine historical background to present research, leading up to the final splitting of the atom. The second part is devoted to atomic power as the cosmic motivating force; it includes a novel theory on the formation of the universe. Part III describes wartime research in nuclear physics which led to separation of the uranium isotope 235 and the discovery of plutonium. The construction of "atomic piles" and problems connected with their utilization are covered and their possible peacetime applications described.

"GAS TURBINES AND JET PROPULSION FOR AIRCRAFT"

As Britain and the United States continue their race to be first to fly a jet-propelled plane faster than the speed of sound—Aircraft Books Inc., 370 Lexington Avenue, N. Y. C., announces publication of the new, enlarged fourth edition of **"Gas Turbines And Jet Propulsion For Aircraft,"** by G. Geoffrey Smith, M.B.E., on, or about Dec. 10. (Cloth Cover $5.)

Mr. Smith, the editorial director of **"Flight"** and **"Aircraft Production,"** London, is an internationally known authority on jet-propulsion. A 4000 volume British edition was reported sold out in two weeks.

The new edition has been enlarged from 80 to 246 pages. Photographs, drawings and graphs have been increased to 200 and the volume has been extended from 10 to 21 chapters.

It contains an exhaustive study of gas turbines as applied to aircraft, including application of the new power unit to ships, railroads, and automobiles. The book deals extensively with the fundamental principles, construction, operating, testing and maintenance of the engines.

A complete analysis is made of all known jet-propelled planes and engines today in operation or projected in the United States and Britain. German jet fighters and bombers are also described in detail. All are illustrated by photographs and drawings.

The British authority gives detailed specifications, performance, characteristics and other data where available. He shows how speed, operating height, rate of climb, carrying capacity and range have improved beyond recognition in recent years.

Other aspects of the new aviation development, included for the first time in the new volume include: Metallurgy . . . problems associated with turbine disc and blades, Testing and Maintenance, (The control room of the De-Havilland test house is described and illustrated.) Combustion Systems . . . fuel equipment and control, Gas Turbine Components . . . radial and axial compressors, and Thrust and Performance.

* * *

Elevators And Levitators

Electronic And Mechanical Gravity Counteractives

By CEDRIC GILES

Of more or less general interest to the exponent of the combustion type of jet propulsion are the varied ideas expounded in the raising of objects against gravity. Excluding magical and spiritual levitation manifestations, a survey of the proposed sources of power for space travel may be of real value to future investigators. Little will be said of the theory and possibilities of present rocket propulsion engines, which exhaust a jet of molecular gas, which the readers are no doubt familiar with. Naturally, at the same time any vehicle dependent upon the atmosphere for lifting itself cannot be considered.

Five Proposals

Early in the 20th century a magazine article by Ernest G. Dodge[1] advanced five conceivable methods by which man had deemed it possible to reach the earth's satellite and described the feasibility of each.

The Tower plan, which undertakes the building of a structure to the sky; the Projectile or Jules Verne idea of reaching the moon by space gun; the Recoil plan, where the motivating power is the reaction developed; the Levitation theory, employing a form of anti-gravity screens; and the Repulsion principle, dealing with repulsive magnetic and electrical forces. The author considered the last method the most probable way that a motivating energy for locomotion through space would be obtained, and that the problem of sky travel would be investigated before many generations.

Mechanical Levitators

The momentarily acceleration of solid bodies for counteracting gravity and producing a source of propulsive power has been suggested numerous times. The general procedure is to derive a reaction from centrifugal forces, by revolving weights or lopsided discs, unbalanced arms, wheelwork, or accelerating metal balls through tubing by gas pressure as shown in Fig. 1. A reaction is produced by the sudden downward acceleration of the metal balls.

The majority of such systems are very similar to the mechanisms of "perpetual motion machines." In all these schemes the main difficulty lies in returning the weights to the starting point for reuse without undue reaction loss. As the contrivances when efficient operate generally by the power of gravity, efficiency would reduce with altitude as gravity lessened.

Impulses Versus Impact

Twelve years ago, a member of the Society, Harry W. Bull[2], experimented with a new type of reaction motor consisting of two reciprocating weighted disks mounted on a shaft in a cylinder similar to Fig. 2. When the disks were suddenly thrown apart, by explosive or other means, the one striking a flat steel plate would give a weak force, derived from the impact, while the other disk thrown against a spring actuated a strong impulsive force. The difference in the efficacy of the two forces was about three times more force by impulse than by impact, which caused the cylinder to move forcibly in the direction of the spring.

Although the original device operated by electromagnets, a globular aircraft was visualized at the time propelled by opposite impulse-impact pistons driven by explosive mixtures in upright cylinders.

Magnetic Repulsion

The nullification of gravity for space journeys dates back to the historical writings of Astor[3] and Wells[4]. In the first case the space flyer was repelled from the earth by a mysterious force called "apergy," and in the second a shield of the gravity-nullifying "cavorite" was placed between space vessel and vacated planet.

Illustrated in Fig. 3 is the Gernsback "Space Flyer"[5] idea, a metal sphere 75 ft. in diameter equipped with an annulling gravitation system. A two pole system of electric wires radiate around the sphere for supplying a special gravity nullifying wave action. By switching the current on in any section gravity would cease to exist and the flyer would travel in the opposite direction. A steel circumferential belt was to be used for landing purposes.

In one instance Cyrano de Bergerac, in his 17th century novels on voyages to the moon and sun, had his hero stand in the flying chariot and by throwing a lodestone ahead of him draw the aerial car forward. This is very similar to the schoolboy fanciful version of the astronaut sitting in an iron chair lifted by an overhead magnet attached by a long arm to the chair.

Electromagnetic Levitation

The electrification of certain objects has been found in some cases to set up repulsive fields and in others to lessen their weight. From the laboratory experiment in which a highly and permanently magnetized bar of cobalt steel, guided by uprights, floats freely over a similar magnet, being held suspended by the magnetic repulsion of like poles, is but a step to the modern demonstration of "electromagnetic levitation."

In one arrangement, Fig. 4, an aluminum or special alloy disk or shallow plate is placed over a unit containing a number of separate poles and coils fed by ordinary 60 cycle alternating current. When the current is turned on the laminated soft-iron cores are energized by the magnetic coils and a magnetic field is built up inducing electric currents in the plate. By the laws of induction the interaction between the two fields causes a mechanical force to push the disk aloft until it reaches a point where the magnetic forces just balance.

Recently a member of the Society, Henry Hassey, suggested the possibility of offsetting the force of gravity on an aircraft by locating stationary electrostatic generator-transmitters on the ground and a smaller model in the aircraft. Through magnetic repulsive action the aircraft was to be repelled from the ground.

Another member of the Society, Robert J. McLaughlin, has for a number of years experimented with gravity nullifying self-centered power devices. At last reports some devices showed positive results but due to their fragility were in need of reconstruction.

Electric Gun

Somewhat of a similar nature to the Jules Verne gun-fired projectile is the idea of initial projectile populsion by electromagnetic waves. Described by John Munro[6] in writings* shortly before the turn of the century the "electric gun" for supplying a uniform acceleration to a projectile has been discussed in great detail in later years.

High frequency current generators sends magnetic waves from windings through the electric gun. The metallic projectile upon being released in the energized coil-wound gun, will attempt to overtake the fast moving magnetic field. Proper regulation can control the speed of the projectile within the gun and the muzzle velocity.

Also contemplated is mail and passenger trains which travel while suspended in a magnetic field in a vacuum tube propelled by electromagnets. For interested persons a technical supplement in the semi-fictional book "Zero To Eighty" by Dr. E. F. Northrup[7] considers in detail the mathematical data of a large solenoid gun and other electrically propelled devices.

Electric Whirl

In 1742, Andreas Gordon, a Scotch Benedictine monk, generated static electricity to run an electric whirl as exemplified in Fig. 5. Electric charges upon being discharged from the points of the horizontally mounted pinwheel causes it to rotate backwards by reaction, in the manner of the rotary water sprinkler. In public demonstrations of high voltage experiments electricity stepped up by transformers is applied to separate pinwheel electrodes. Chemical mixtures are generally placed on the electrodes and the escaping voltage from the electrode points causes flashovers of various colors.

Levitators

An interesting experiment was described in 1935, by W. D. Verschoyle, before a member of the staff of Flight Publication. The apparatus consisted of small paper cylinders containing simple electrical apparatus connected by a fine wire with a high potential electric source, an additional wire being grounded or connected to a high capacity condenser. The "levitors" when suspended and connected to the electric source of 5 amps. at 220 V, were actively repelled from the earth and floated in the air, and tended to lift the wire.

Mention was made that alternating current, aluminum or copper discs, or any coil of the usual electromagnetic type was not used, and the electrical energy was transformed into some new form which interferes with the weight of

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*The principle of the step rocket through a system of multiple discharges is also mentioned.

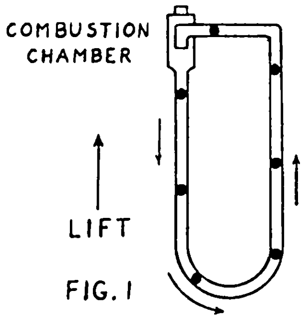

FIG. 1

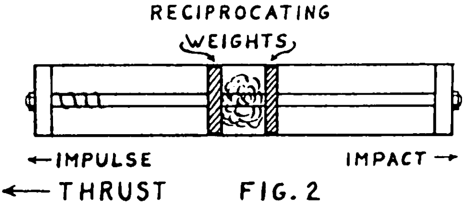

FIG. 2

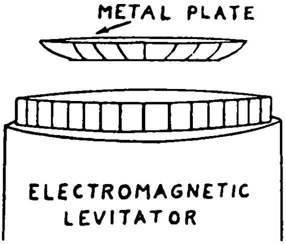

FIG. 4

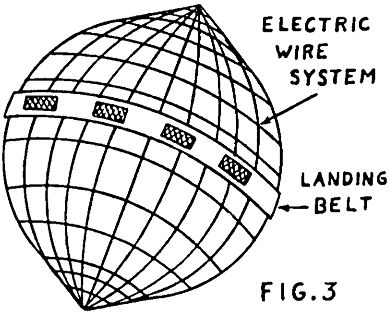

FIG. 3

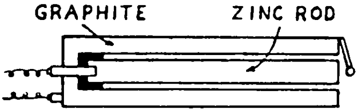

FIG. 6

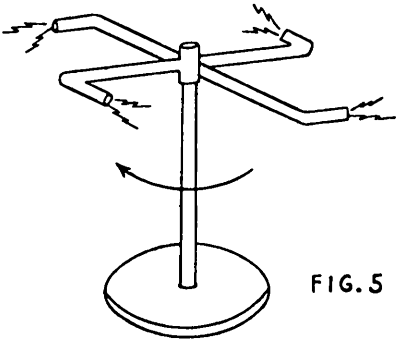

FIG. 5

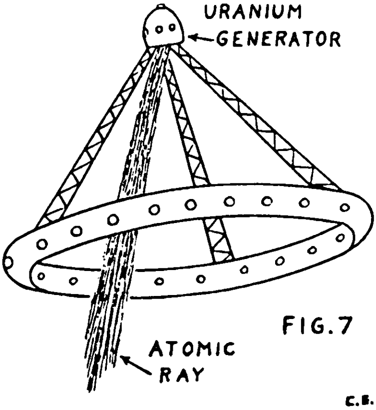

FIG. 7

C.E.

matter and actually reverses gravity influences.

Electric Rocket Motor

Some years back, Bernard Smith, of the California Rocket Society, conducted a series of experiments with an electric rocket motor comprised of a cylindrical steel casing having a heavy inner graphite lining as shown in Fig. 6. Fuel consisted of a coated zinc rod placed within the motor and securely fastened to the graphite at the closed end of the motor by asbestos insulation packing and extending rearwards. An electric welding motor-generator set supplied current to electrodes attached to the rod and steel casing.

A bar of metal was used to touch the zinc rod and graphite liner at the open end to close the electric circuit. The zinc rod immediately vaporized exhausting a stream of zinc oxide and zinc particles from the motor to provide a reaction. It was found that in approximately a second a 35 volt 300 amp. current would volatize an 8 by 3/16 in. fuel rod.

A second arrangement consisted of two separate fuel rods as conductors with A.C. current flowing through each in turn. With a plurality of fuel rods the motor, being out of the circuit, may be constructed of lighter material. A possible method of coiled fuel wire feeding was also suggested. The main disadvantage of these applications appears to be the difficulty encountered in continuously feeding fuel to enable a reasonable firing time.

Electronic Devices

One proposal based on cathode ray experiments suggests the separation of hydrogen gas into electrons and protons and emitting each stream of atom component through individual tubes. The streams of electronic particles would be actuated by electrostatic fields at very high speeds and deflected in concentrated beams by electromagnetic plates or fields charged by oscillating circuits. The partial manufactured vacuum required in the atmosphere for this device would be on tap in airless space.

Another source ventures that in lieu of gaseous hydrogen a metal such as zinc be vaporized and be changed to metallic ions by bombarding with Roentgen or other external rays. The metallic ions would then be ejected from a long tube while under acceleration by electrical or magnetic fields.

Solar Radiations

Harnessing the radiations of the sun by solar heat devices has been fairly successful, though in the final analysis the captured energy to be of use must be converted into a propulsive thrust. In one form of thermoelectric battery sunlight is permitted to fall on a series of junctions of copper and iron wires. The metals on being heated become positively and negatively charged and an electric current flows. Two dissimilar materials for constituting the thermoelectric circuit may be designed in a wide variety of arrangements.

In the well-known sun motor, banks of photo voltaic cells generally composed of copper coated with copper oxide or a compound of selenium and silver convert light energy into electric power. Solar focusing mirrors and lenses for delivering power to a utilizing plant have been proposed various times. In all these ideas the apparent main problems are the setting of the sun at night, the minute amount of power produced, and the uneconomical operation due to the large area required for equipment.

Of futuristic magnitude is the giant space mirror conceived by Oberth[7] for concentrating heat rays of the sun earthwards. With the absence of air evident, a reflector consisting of metallic sodium discs was ascertained the most practical design.

Several other less explicit manifestations may hold promise, as, light exerts a minute force upon the surface it strikes, the sunlight drives comet tails away, sun heat has a tendency to repel dark bodies in a vacuum, and the energy present in cosmic rays and other space radiations may be put to work.

Atomic Power

In a book published in 1917, Arthur Train[8] described his "Flying Ring," an imaginative space flying machine operated by atomic power as depicted in Fig. 7. The spaceship was composed of a large hollow ring suspended from a uranium power generator which projected a powerful atomic ray. The ray upon striking the earth, atmosphere, or the ether of space would propel the ring by reaction. Steering was accomplished by tilting the ray.

Many of the possibilities of utilizing the locked up energy in the atom for propulsive purposes have been considered the last few years in the JOURNAL[9]. Generally the application to rockets deals with the disintergration of atomic material for direct propulsion or the employment of the heat released to heat a working fluid for providing the ultimate thrust. In all cases the need of a gaseous or electronic jet is essential to supply the rocket drive.

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The Variable Nozzle As A Means of Maintaining Rocket Engine Efficiency When Throttling

By *HARRY W. BURDETT

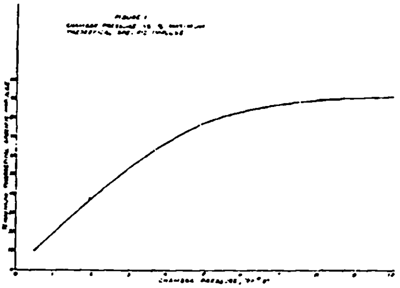
It is the purpose of this paper to stimulate discussion of means of improving rocket engine efficiency during throttling through the medium of a variable exhaust nozzle whose characteristics may be adjusted to suit varied operating conditions. No attempt will be made to devise mechanisms for these purposes, instead, considerations will be limited to a perusal of conditions present which would dictate their requirements.

The two (2) major variables which must be controlled are:

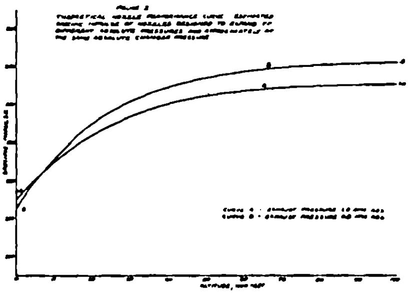
1. The thrust over a predetermined range.

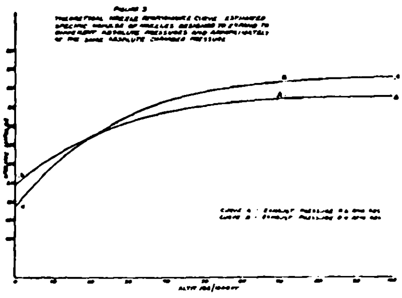
2. The exit nozzle expansion ratio over a range from sea-level back pressure up to zero back pressure (or whatever the atmospheric pressure is at the peak design altitude).

The efficiency of any rocket engine improves with increased combustion chamber pressure (See figure 1). We must, therefore, assume that the engine under consideration has a design chamber pressure which may not be exceeded because of practical limitations of the particular installation for which it is intended. The problem then resolves itself into one of maintaining the optimum fixed chamber pressure over the predetermined range of thrust and altitude changes.



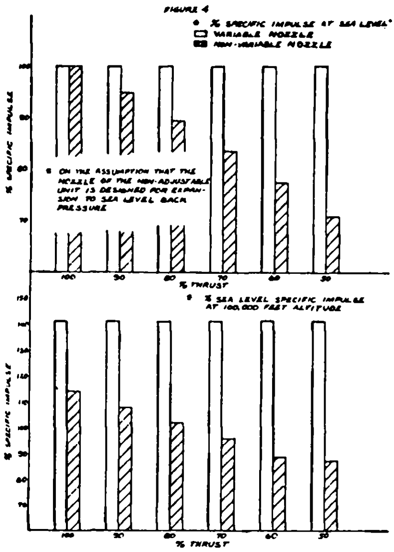
The accompanying curves (Figures 2 and 3) indicate the relationship between specific impulse and altitude (therefore back pressure) for a typical set of exhaust nozzles designed for expansion to different percentages of atmospheric pressure. It is to be understood that the particular curves shown are for a specific chamber pressure. It would be the purpose of the variable nozzle design to adjust the exit cone expansion ratio to the particular altitude to which the engine would be operating. This would, therefore, permit the engine to operate at greatest efficiency at all altitudes.

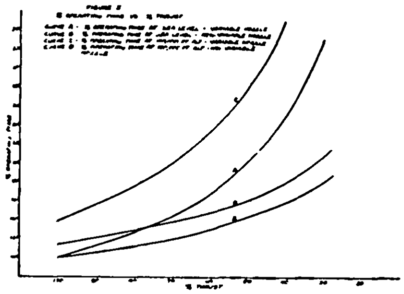




Since, at any given altitude, and therefore expansion ratio setting, we have a particular optimum specific impulse value at which we can operate, variation of the thrust would require a corresponding throttling of total propellant flow but, of course, no variation in the propellant mixture ratio. In allowing for this, a factor which would have to be compensated for is the increase of specific impulse with altitude, and, therefore, decrease of total propellant flow for a given thrust rating.

The advantages of throttling by the method indicated in this article stand out remarkably when compared with the performance of engines which are throttled simply by reducing the total propellant flow. The accompanying charts (Figures 4 and 5) give a numerical comparison between two (2) rocket engines having the same medium thrust and specific impulse rating and limited to the same weight of propellants for operation.





In conclusion, we might summarize the problems to be encountered in designing a throttling mechanism which will be capable of properly handling the many variables discussed above:

1. Cooling over wide flow ranges.
2. Weight.
3. Simplicity.
4. Injection characteristics.
5. Automatic coordination of all variables.
6. Size.

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*Senior Project Engineer
Reaction Motors, Inc.

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Recorder: S: T. Robinson, Vice-President, Taylor Turbine Corporation.

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Captain A. G. Bardwell, Jr., Wright Field, Dayton, Ohio.

"Liquid Propellant Rocket Motors"
J. H. Wyld, Reaction Motors, Inc., Dover, N. J.

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All sessions in cooperation with the Gas Engine Power and Aviation Sections of the American Society of Mechanical Engineers.

JOINT DINNER — A.R.S. — A.S.M.E.

6:00 P.M. — Hotel Pennsylvania

Speaker: Dr. C. N. Hickman, Bell Telephone Laboratories, Wartime Chief of Section H., Division 3, N.D.R.C.

"Rocket Projectile Development", with films and slides.

Introduction by Alfred Africano, Rocket Section, Curtiss-Wright Corporation, Caldwell, New Jersey.

See Following Page for Remainder of Program.

FRIDAY, DECEMBER 6th

2nd Technical Session, 9:00 A.M.:

Chairman: Lovell Lawrence, Jr., Reaction Motors, Inc., Dover, New Jersey.

Recorder: L. P. Heath, Assistant to President, Reaction Motors, Inc., Dover, N. J.

"Long Range Rocket Bombs"
Major H. L. Karsch, Ordnance Department, Chief Proof Officer, White Sands Proving Grounds.

"Rocket Power Plants for Aircraft", with films and slides
Harry N. Burdette, Reaction Motors, Inc., Dover, New Jersey.

"Testing Naval Pilotless Aircraft", with films
Commander Grayson Merrill, U.S.N.; Technical Director, Naval Pilotless Aircraft Unit, Mojave, Cal.

"Rocket Engineering Has Its Feet on the Ground",
Aerojet Engineering Corporation, Azusa, California.

JOINT A.R.S. — A.S.M.E. LUNCHEON

12:15 P.M. — Hotel Pennsylvania

Speaker: Air Commodore Frank Whittle, R.A.F.

"Development of Turbojet Engines"
Introduction by R. G. Standerwick, Aircraft Gas Turbine Engineering Division, General Electric Co., Lynn, Mass.

Toastmaster: Eugene O'Brien, president-elect, A.S.M.E.

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3rd Technical Session, 2:30 P.M.:

Chairman: R. F. Gagg, Wright Aeronautical Corporation, Woodridge, N. J.

Recorder: C. Constantino, Asst. Project Engineer, Wright Aeronautical Corporation, Woodridge, New Jersey.

"Problems of Supersonic Aircraft Flight", with films
Lt. Col. Carl E. Reichert, Aircraft Laboratory, Air Material Command, A.A.F.

"Critical Analysis of Dr. R. H. Goddard's Rocket Research", with films and slides.
Alfred Africano, Rocket Section, Curtiss-Wright Corporation, Caldwell, N. J.