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THIS MONTH'S COVER PICTURE

This month's cover picture, taken by Dick Schenz, shows the takeoff of one of the Society's Mail Rockets, fired at Searles Lake on March 27, 1948. Eight rockets were fired, carrying a total of 4200 specially stamped and cacheted covers from Inyo County across the lake to San Bernardino County. The complete story of the mail flight will be told in the next issue of ASTRO-JET. ###

A COMPARISON BETWEEN THE BALLISTITE UNRESTRICTED SOLID PROPELLANT ROCKET AND THE MICROGRAIN SOLID PROPELLANT ROCKET

— George James —

The purpose of this paper is to present a comparison between ballistite unrestricted solid propellant rockets, used extensively by the armed forces and developed during the war, and the micrograin type of rocket developed by the Reaction Research Society.

Since reaction propulsion is a comparatively recent science, the following short resume of some of the basic terms is presented.

BASIC TERMS

REACTION PROPULSION — The science that directly applies Newton's Third Law of Motion to the propulsion of devices.

ROCKET PROPULSION—The division of reaction propulsion in which the devices carry all the material necessary for their propulsion.

SOLID PROPELLANT ROCKET PROPULSION SYSTEM—A rocket propulsion system that contains its propellant in one solid or semi-solid material; which in the case of the solid propellant system is called the propellant.

MICROGRAIN SOLID PROPELLANT SYSTEM—A solid propellant system in which the propellant is in the form of very small grains or, more commonly, dust.

UNRESTRICTED SOLID PROPELLANT SYSTEM (BALLISTITE) — A solid propellant system in which the propellant is in the form of a large grain or

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This paper by George James, president and research director of the RRS, was presented at the technical meeting of December 9, 1947.

grains (compared to micrograin) and is free to burn on all sides.

SEMI-RESTRICTED SOLID PROPELLANT SYSTEM—A solid propellant system in which the propellant is in the form of a large grain or grains and inhibited so as to burn on more than one but not all surfaces.

"The principal parts of a solid propellant rocket engine are: THE PROPELLANT CHARGE—to generate high pressure gases rapidly; the CHARGE contained in the propellant TUBE which must withstand the gas pressure; one or more nozzles at the rear end to control the pressure, direct the gas discharge in smooth rearward flow and improve thrust efficiency; and a POWDER TRAP or GRID to support and retain the charge during burning.[1]"

"The gases generated by the propellant in a rocket engine exert equal pressure in all directions. Since they can escape only toward the rear, there is an unbalanced force forward which provides about 70 percent of the thrust. In passing through a properly designed nozzle the gasses expand to a lower pressure, with increasing velocity, and by pushing against the outward flaring portion of the nozzle, they provide the remainder of the total thrust.[2]"

For maximum accuracy the propellant charge should burn very rapidly. If the rocket fires for a long time the change of the center of weight will throw it off its course. Due to the small size of the micrograin particles (and resulting great burning area) it shows much better rapid burning characteristics than ballistite. A ballistite rod, prepared so that it will burn on only one surface (restricted) has a linear burning rate of 1.1 inches per second as compared to a linear burning rate of 60.1 inches per second[3] for present micrograin propellants.

In order to better understand these two types of rockets, a history of their development will be presented, before we compare more of their characteristics.

A HISTORY OF THE BALLISTITE UNRESTRICTED ROCKET

On the behalf of the Army and Navy, the N.D.R.C.[4] began rocket research in 1940, five years after the Germans had started.

The first project was to develop a practical rocket to be used to accelerate a fourteen inch armor-piercing bomb in order to achieve greater penetration

Since the group was starting from scratch, it was not until 1942 that a production version of the rocket bomb was developed.

Although the armed forces no longer had any need for a weapon of this type, its development had supplied invaluable training to the N.D.R.C. rocketeers.

One of the main things learned was that the most powerful propellant for this type of rocket was ballistite, consisting of 60% nirtocellulose and 40% nitroglycerine.

The biggest difficulty in producing the ballistite war rockets was the slow production of propellant. By the end of the war $150,000,000 worth was being produced monthly but this was still not enough.[5]

Almost all the rockets used during the war were developments of the N.D.R.C. One of the most famous of these is the Bazooka. The largest rockets developed were the aircraft rockets, Holy Moses and Tiny Tim.

The first of these if 5 inches in diameter, 6 feet long, uses 24 pounds of propellant and has a total weight of 140 pounds, including a 50 pound warhead.

Tiny Tim is the first of the large solid propellant rockets. It is 10 feet 3 inches long and 11-3/4 inches in dianeter, carries a 590 pound warhead and 146 pounds of propellant. This rocket was first put into use a short time befor V-J day, against the Japanese on Okinawa.

A HISTORY OF THE MICROGRAIN ROCKET

Due to the handicap of not having unlimited finances, the development of the micrograin rocket is far less spectacular than that of the unrestricted ballistite rocket.

It is believed that the Reaction Research Society is alone in conducting research on micrograin rockets.

The first micrograin propellant was developed quite accidentally by two of the Society's members early in 1943. A certain semi-restricted rocket propellant consisted of potassium nitrate, sugar, zinc dust and sulphur. It was found that potassium nitrate and sugar would burn independently. Two members decided to find what would happen when zinc and sulphur were ignited. This mixture burned far more rapidly and vigorously than any previous Society-developed propellant. Consequently, it was used in many of the early Society rocket units.[6]

The early micrograin models were very small because no use had been developed for this type of rocket.

There was even a time when many of the members did not consider the micrograin rocket as a true rocket, because it did not carry its own oxygen; not realizing that sulfur also has the powers of an oxidizing agent.

The first micrograin rockets were made of soldered tin plate tubes; later cast aluminum tubes were used. For some curious reason the use of either steel or aluminum tubing did not occur to anyone until much later. Tests[7] have conclusively proven that the only practical type of tubing is that made of materials of higher melting points than that of aluminum.

In the early part of 1946, after deciding that large semi-restricted rockets would be too difficult to construct for landing device testing, the micrograin rocket was turned to in hopes that it would be suitable for the purpose. That year, 1946, saw the micrograin rocket change from a mere curiosity to a practical research tool. Calculations show that, where size is not a determining factor, the micrograin rocket can be used advantageously as a booster for larger rockets.

One of the largest micrograin rockets is the MILER. This rocket is $2\frac{1}{2}$ inches in diameter, 15 feet long, contains 26 pounds of propellant, and weighs a total of 54 pounds including a 10 pound payload. On March 23, 1947, the MILER I carried a dummy load of 350 letters a distance of 3500 feet. This rocket was used for the RRS Mail Rocket Flight I.

THE MANUFACTURE OF BALLISTITE

The making of rocket ballistite is one of the most dangerous jobs in the explosives industry.

"Thousands of manufacturing plants go for years without a fire - and their first fire is often their last. But in Sunflower, Kansas, there is a factory that averages 150 outbreaks a day in one division, with a recent high mark of 259 fires in a single 24 hour period. This factory is one of the largest powder plants in the world... Yet it has the lowest accident rate in American industry.

"Sunflower Ordnance Works...covering an area of 40 square miles, dotted with nearly 5000 buildings is one of the five plants that manufacture rocket ballistite.

"It is on the ballistite lines at Sunflower where 60 percent of the operators are girls, that the 150 daily fires occur. Yet so efficient is the protection provided that there have been no fatalities and only 17 "lost time" injuries. These workers, handling the most treacherous powder ever made, are actually four times safer on the job than they would be at home.

"Ballistite manufacture begins by treating cotton with nitric acid to produce nitrocellulose or guncotton. This is mixed with nitroglycerine and other ingredients and agitated into a goo, or slurry, in huge tanks equipped with rubber bladed beaters. When you peer into a tank your spine tingles as you realize that it is whipping up nitroglycerine and guncotton ... the calm confidence of the experiences powder men soon dissipates your fears.

"...the Americans saw ways to speed up British methods. Nearly every time-saving change, however, introduced greater risk and called for more elaborate safety precautions. For example, after the British mixed the powder they dry it for 24 hours before rolling it; our men reasoned that by heating the rollers the stuff could be dried and rolled in one operation. Since ballistite is nearly 50 percent nitroglycerine... this proposal was appaling; but so were the production figures... Accordingly, safety men were called in to take out the risk.

"By the time the slurry leaves the mixing houses it is dried to a slightly moist paste and transferred to the roll houses. About six pounds of this paste is dumped onto a pair of bulky steel rollers heated to 210 degrees. Working somewhat like a wringer, these rolls compress the paste into a sheet resembling a black rubber blanket...The rolls are now started on their run which, in four or five minutes, will cook and compress the powder into its blanket form. At the prescribed time she (the operator)... flips a lever and a blade slices the powder blanket off the rollers, dropping it into a tray beneath...during this operation most of the fires occur.

"Although there are only six pounds of powder in most of the machines the stuff burns like a huge blowtorch. Long tongues of flame roar out, followed by clouds of yellowish, choking smoke; often chunks of flaming powder are flung in all directions... Yet the machines are in operation again within 20 minutes. The fire never gets beyond its point of origin... The explanation...lies in the ingenious protection system ... They (the engineers) succeeded in developing a system which puts a torrent of water on a fire in a half second, and has frequently done it in one fifth of a second.

"The deluge system is installed as an integral part of each machine. Hyper-sensitive detectors are set just a few inches above, below, and behind the machine. The machine is flanked by open fog nozzles, and other nozzles cover the remainder of the room and the operator. When the temperature of the powder rises suddenly, as it does just before a fire, the detectors trip the valve mechanism, sending water out of each nozzle at the rate of about 35 gallons per minute ...Most of the fires are put out in five seconds, with much of the powder still unburned."[8]

After the propellant is made, there is quite a bit still to be done before it can be used in rockets. It must be molded into the proper size grains.

At the present there are two ways of molding ballistite into grains. The first of these is to mix the powder with a solvent and squeeze it through dies at moderate pressure. Only small thin-walled grains can be made in this manner for if the walls are too thick, the solvent will not evaporate, resulting in ruined powder. The second, or British method, consists of taking the dry propellant, heating it (carefully!) and squeezing it through dies at a very high pressure. Since there is no solvent to evaporate in this process, thick walled grains can be made for large rockets.

Sometimes, after the grains are made, inhibitor strips are glued to various parts to regulate burning.

The cost of finished ballistite rocket propellant is estimated to be from $5.00 to $10.00 per pound, depending on the size of the grains.

MANUFACTURE OF MICROGRAIN PROPELLANTS

The manufacture of micrograin propellants is far simpler and much less hazardous than that of ballistite.

The ingredients are first weighed out and then mixed together in a mixing vessel. These two steps complete the actual manufacture of the propellant.

The cost of finished micrograin propellant is at the present time about $.20 a pound. This low cost is due to the fact that Society members do not charge for their labor. If the RRS paid for labor, the cost would rise to about $.50 a pound.

THE CONSTRUCTION OF BALLISTITE AND MICROGRAIN ROCKETS

Because of the high pressures required for the proper combustion of ballistite, the weight of the propellant chamber is very great.

The smallest ballistite rocket on which figures are available is called the 5 inch HVAR (Holy Moses). This rocket (described earlier) has a weight of 90 pounds without the warhead and 66 pounds without its 24 pounds of propellant.

Because of the much lower chamber pressure required for the combustion of present micrograin propellants, it is possible to construct lighter weight propellant chambers than possible with unrestricted ballistite rockets.

A good example of the construction of a micrograin rocket is the MILER. This rocket used a stainless steel propellant chamber 10 feet long, 2-3/8 inches inside diameter and 2-1/2 inches outside diameter. The weight of the complete chamber including nozzle and head was 16 pounds. The chamber held 26 pounds of propellant.

THE PERFORMANCE CHARACTERISTICS OF BALLISTIVE AND MICROGRAIN PROPELLANTS

Ballistite has a specific impulse of about 200 seconds. This is, if one pound is burned in one second, 200 pounds of thrust will result.

However, it has several disadvantages. The first of these is that ballistite is very sensitive to temperature, making its performance at extremes of temperature not dependable. At temperatures of about zero it burns so slowly that the rockets do not operate properly and at temperatures of over one hundred, it burns so rapidly that the rockets may explode. Because ballistite grains, as used in unrestricted rockets, burn on all surfaces it is not possible to use long slender grains, for they will break when the rocket fires. This means that the rockets usually cannot be longer than twelve times their diameter.

At the present it appears that it will be possible to raise the specific impulse of micrograin propellants to about 50 seconds. Not much data has been collected on their temperature sensitivity. It is believed that one of the rockets on Mail Flight I exploded because of the excessive temperature at Yuma (120°F). Micrograin rockets appear to have a linear burning rate in excess of 5 feet per second and can be built with very high length versus diameter ratios without negatively affecting the burning characteristics. This means that long, slender, streamlined rockets can be built.

The 5 inch HVAR rocket contains 24 pounds of propellant and makes 4800 pounds thrust for one second. The weight of the empty chamber is 66 pounds.

The MILER contains 26 pounds of propellant and with improvement could make a total thrust of 1300 pounds. However, since it fires for two seconds it would only make 650 pounds thrust per second. The empty chamber weighs 16 pounds.

Since the amount of powder used is not a very good comparison of performance, let us design a micrograin rocket that has the same thrust as the 5 inch HVAR. To get 4800 pounds thrust we would have to burn 96 pounds of micrograin propellant in one second. This calls for a chamber a little over 5 inches in diameter and five feet long (almost the same as the HVAR). Because we do not need as high a chamber pressure, it would probably be possible to make the propellant chamber weigh 44 pounds. This gives our rocket a total weight of 140 pounds—50 pounds more weight than the HVAR. Because of this extra weight our micrograin rocket would go only a little over half as far as the ballistite rocket.

However this is not the complete story, for the HVAR would cost from $120 to $240 to fire, whereas the micrograin rocket would cost only $48 to fire. Consequently, the micrograin rocket would go over half as far for less than half the cost.

USES OF BALLISTITE AND MICROGRAIN ROCKETS

The ballistite rocket with its high performance and overall light weight is ideally suited for military use since the armed forces want light weight, high performance equipment, apparently regardless of cost.

Micrograin rockets would seem to be more suited for peace-time uses, such as taking off small planes, accelerating race cars, testing landing devices for larger rockets, and acting as emergency brakes, because of the low cost of their moderate performance.

FUTURE IMPROVEMENTS

Due to war time necessity, the ballistite rocket was developed nearly to perfection at a cost of many millions of dollars.

Not more than $100 has been spent on micrograin research, due to the small research fund of the RRS. Consequently, they are far from perfected. Possibly, with more research, it will be possible to greatly improve the performance of the micrograin rocket and even lower the cost.

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TURBOJET ENGINE PERFORMANCE CHARACTERISTICS WITH REFERENCE TO METHODS OF AUGMENTATION

—Edward Woll —

The thrust required for present day military aircraft to fulfill cruising speed specifications is being amply furnished by the jet engines now in use. But in numerous instances it is found that these jet propelled airplanes, powered by jet engines that meet the guaranteed takeoff thrust, require takeoff runs that are longer than a normal run with a propellor driven airplane. There are times when the jet assist rocket is used to keep the takeoff run within practical bounds. Instances like this occur when military necessity calls for an extra heavy pay load. The takeoff problem is further aggravated by operating out of small emergency loading fields or airports located at high altitudes or in equatorial regions.

The poor takeoff and the poor low speed climb and acceleration of the jet propelled air-

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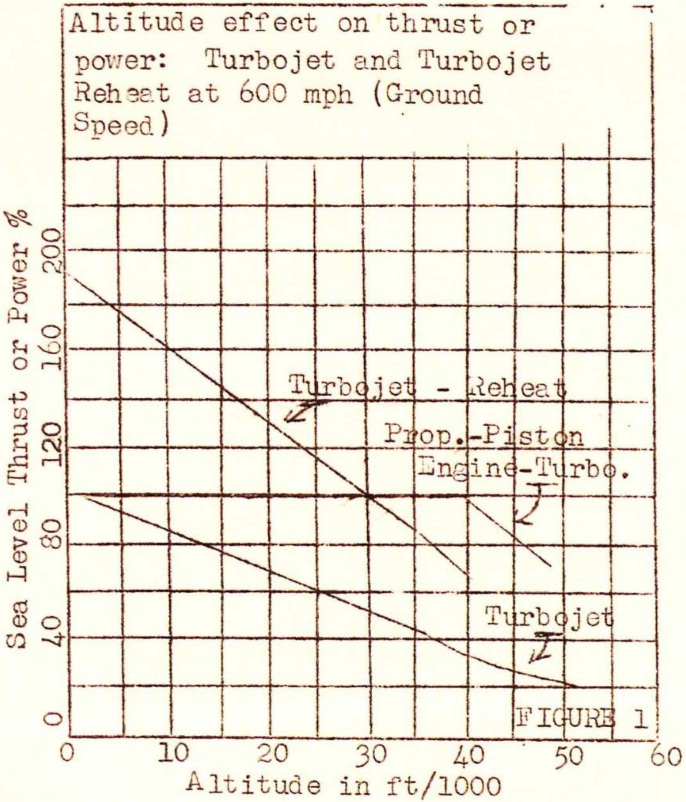
Mr. Edward Woll is associated with the Aircraft Gas Turbine Engineering Division of the General Electric Company. This paper was presented at a meeting of the Southern California Section of the Society of Automotive Engineers on February 5, 1949, and is reprinted with permission. At this meeting George James, president and research director of the Reaction Research Society, spoke on the Society and its aims, and presented motion pictures of the Society's work. Motion pictures of the WAC Corporal rocket and captured German V-2 films were shown.

craft is a result pf a fundamental characteristic of the simple turbo-jet engine. The design of the engine is a compromise between a favorable thrust-weight ratio, and the best thermodynamic and propulsive efficiencies in order to fulfill cruising requirements and other operating conditions satisfactorily. The result is a relatively light and compact unit handling a small amount of air as compared to a propellor and discharging this air at a high velocity. For jet engines now in use the thrust-horsepower ratio is approximately 0.6 as compared to propellor units where the thrust-horsepower ratio is approximately 3. This low ratio of thrust to horsepower for the turbojet accounts for the poor takeoff characteristics of the jet propelled airplane.

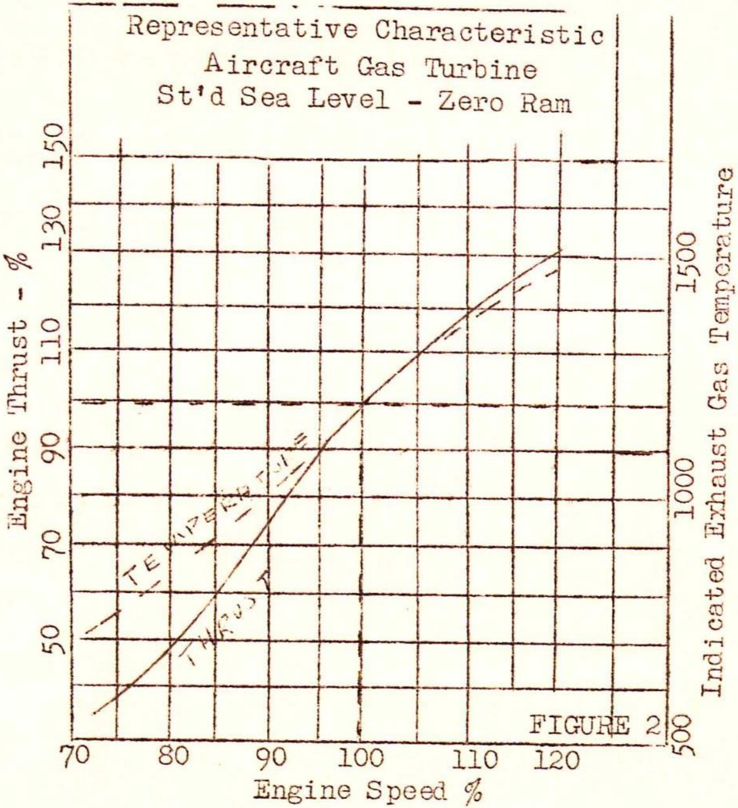
Another characteristic of the turbojet that merits consideration is shown in Figure 1. The rate at which the thrust falls off with altitude is clearly indicated for the turbojet engine. Poor climbing rates and the lack of a high degree of maneuverability at extremely high altitude is the result of this type of characteristic. The decreasing thrust is due simply to the less dense air that is available to the engine at altitude. The effect would be still greater were it not for the increase in jet velocity. The power output of the piston engine was similarly affected until the introduction of the turbosupercharger.

Characteristics of the foregoing types make it difficult for the jet propelled airplane to meet certain military applications: for example, where a short takeoff run is essential as in carrier operation; and where adequate thrust is required at high altitude to maintain good maneuverability. It is therefore mandatory that the useful range of the turbojet be expanded so that it more than just fulfills military appli-



Altitude effect on thrust or power: Turbojet and Turbojet Reheat at 600 mph (Ground Speed)

FIGURE 1



Representative Characteristic Aircraft Gas Turbine St'd Sea Level - Zero Ram

FIGURE 2

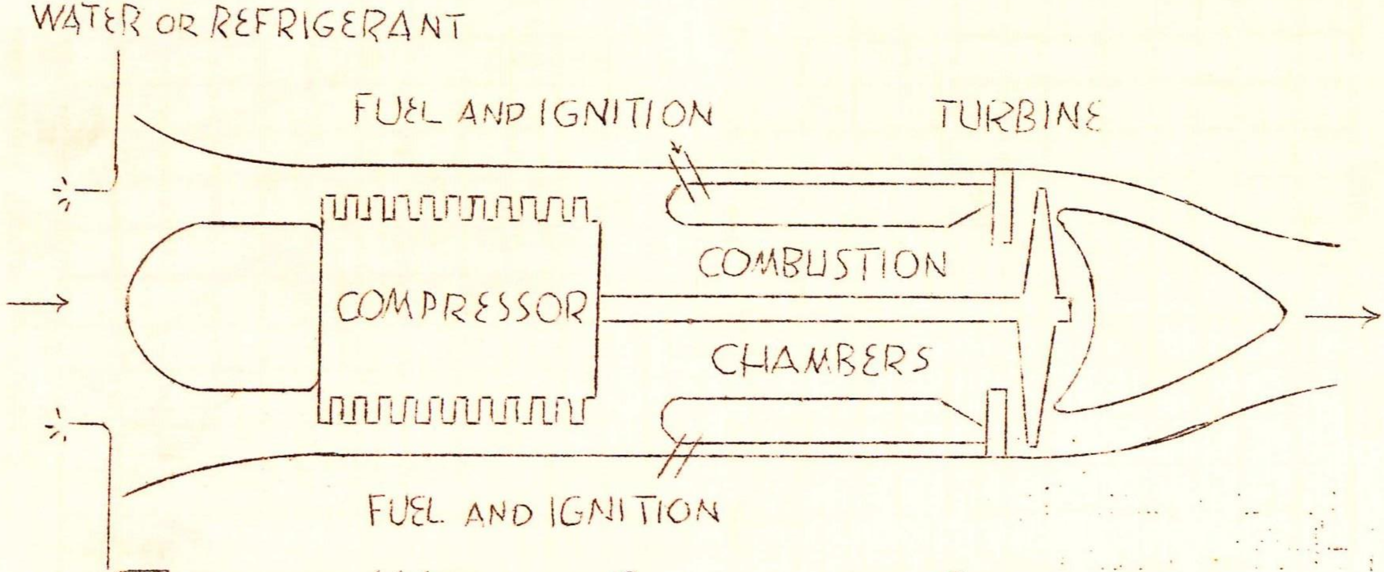


Figure 3: Water or Refrigerant Injection

cations where high speed is essential. This can be done by augmenting the thrust in a number of ways. Augmentation is no solution for the low-propulsive efficiency but does make up for it in offering a means to increase the thrust of power plants now in use. It is a means to gain more thrust for very little additional weight and complication without resorting to extra large engines or additional engines for most airplane applications.

Many schemes to augment the thrust have been proposed and developed. These are:

1. Engine overspeed.
2. Water injection at the compressor inlet or into the combustion chambers.
3. Injection of a refrigeant such as ammonia, carbon dioxide, etc. at the compressor inlet.
4. "Bleed-Burn" cycle.
5. Reheat cycle or tailpipe burning.
6. Or combinations of the above schemes.

Overspeed is not an augmentation method in the strict sense as used herein, but it is a simple means to increase the thrust for short periods. Figure 2 shows the rise in thrust with increasing engine speed. It also shows the abnormally high exhaust gas temperatures under overspeed conditions. Four or five per cent overspeed has been used with successful results in high flight speed tests and also in ground proof tests to establish a war emergency rating. Augmenting in this manner is not a recommended procedure except in emergency since overspeeding with overheating is a direct cause of shorter engine life.

Another simple augmentation method is obtained with water injection. In this scheme water is sprayed into the air either at the compressor inlet or upstream of the compressor as shown in Figure 3 or injected directly into the

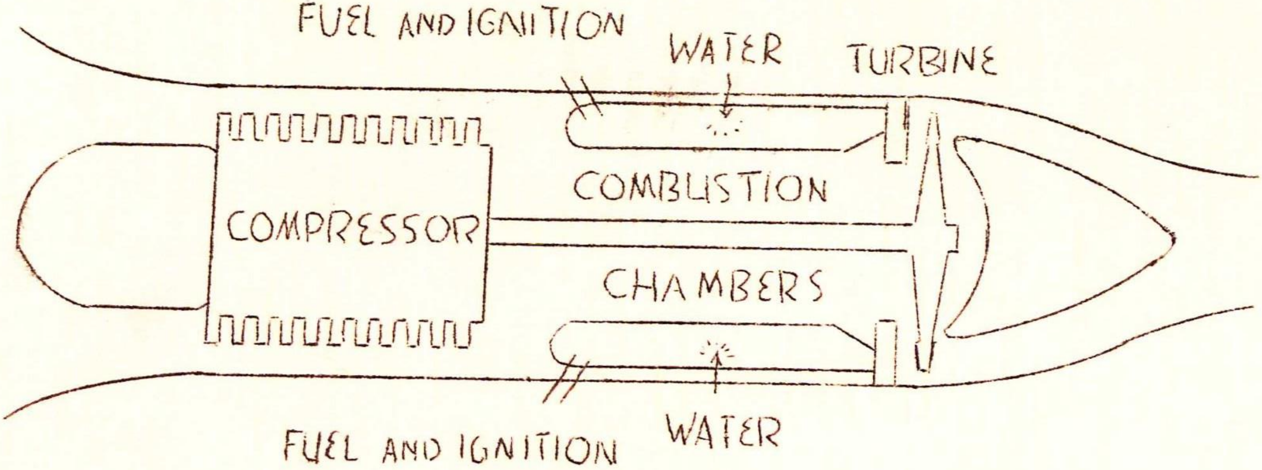
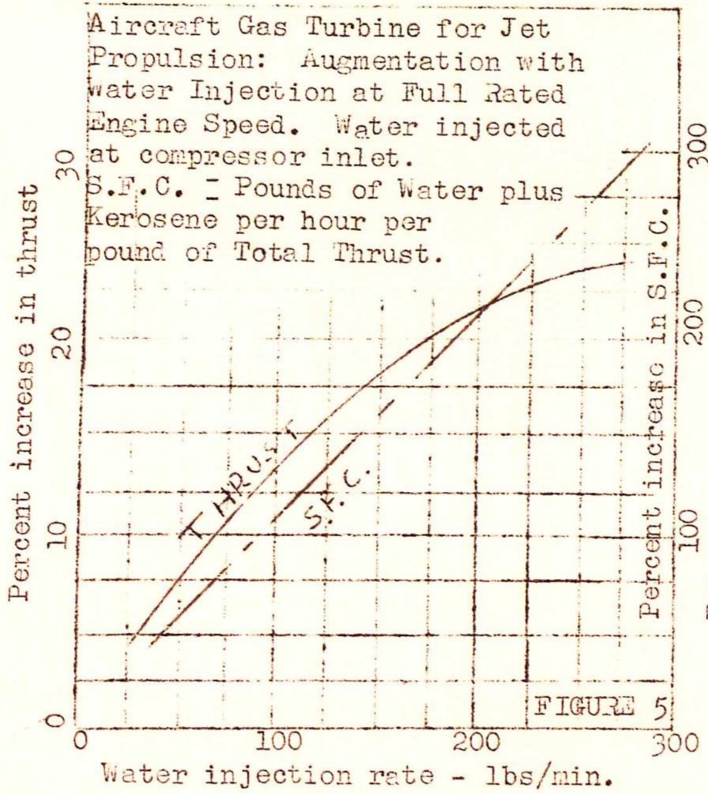


Figure 4: Water Injection

combustion chambers as shown in Figure 4. Injecting the water at the compressor inlet results in the following:

1. The incoming air is cooled (if the air is not saturated.)
2. The air is cooled as it is being compressed.
3. The pressure across the jet nozzle increases.
4. The mass of fluid handled by the mechine is increased.

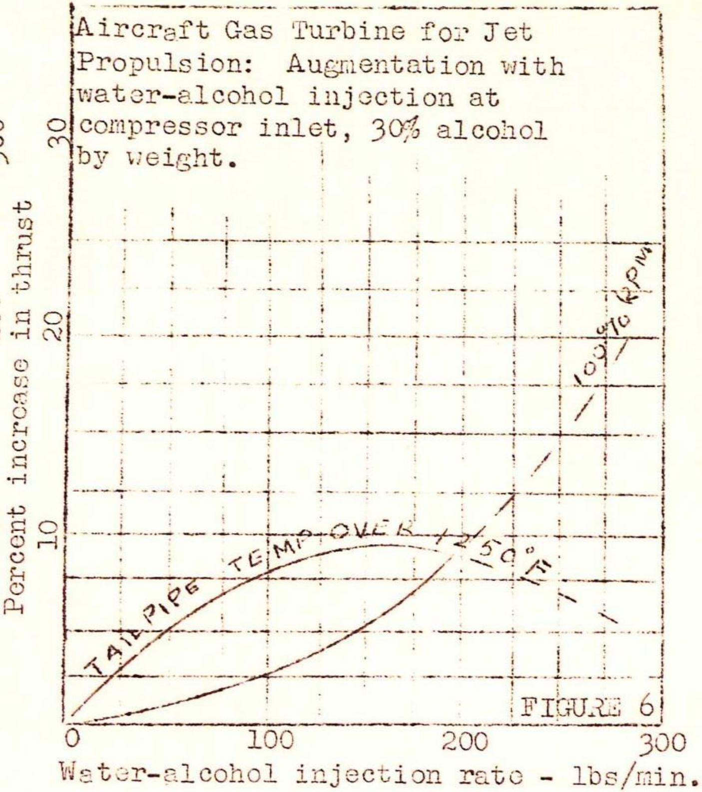
Figure 5 shows that a 24% increase in thrust can be realized with water injection in a centrifugal machine. It also shows that the increase in thrust is obtained at a very high specific liquid consumption. Water-alcohol injection tests on an axial flow compressor turbojet showed an increase in thrust of 12% to 16%. The slightly higher thrust was obtained with water injection at the compressor inlet while the lower value occurred when water and alcohol were injected into the combustion chambers. Figure 6 shows some early test results on water-alcohol injection at the inlet of the engine. It is to be noted that up to an injection rate of 200 pounds per minute the tailpipe temperature drops below the maximum allowable temperature of 1250°F when the engine speed is held constant; beyond 200 pounds per minute, the exhaust temperature exceeds 1250°F. Introducing water-alcohol mixtures at the compressor inlet was discontinued when it was found that the fluid would not mix thoroughly with the air and was forced outward to the stator casing, cooling it, and causing it to shrink and interfere with the rotor. Figure 7 shows the performance when a 30% alcohol and 70% water mixture is introduced into the combustion chambers. The alcohol is used here simply as a source of heat for converting the water into steam. With compressor



Aircraft Gas Turbine for Jet Propulsion: Augmentation with water Injection at Full Rated Engine Speed. Water injected at compressor inlet.

S.F.C. = Pounds of Water plus Kerosene per hour per pound of Total Thrust.

FIGURE 5



Aircraft Gas Turbine for Jet Propulsion: Augmentation with water-alcohol injection at compressor inlet, 30% alcohol by weight.

FIGURE 6

inlet injection, the alcohol also furnishes a fair amount of antifreeze protection. With the 30% - 70% mixture the main engine fuel system does not supply any more fuel than is normally required. It has been found in these tests that approximately half of the increased thrust is due to the increased mass passing through the jet nozzle and the remainder is due to the increased velocity.

A very interesting cycle is that investigated by the N.A.C.A. and commonly referred to as the "bleed-burn" cycle. Figure 8 shows a sketch of an axial flow machine which has been modified to make use of this cycle. Here a small per cent of the total air flow is bled from the high pressure part of the system. In order to maintain full engine speed and also the same engine thrust, water is injected into the combustion chambers to replace the air that has been extracted. The extracted air is led out through a separate duct to an auxiliary combustion chamber thus by-passing the turbine. Here the air is heated to a temperature higher than is permissible had it remained within the main engine. This hot gas is then discharged in a similar manner as the main stream that is passing through the engine, but at a much higher velocity, thus increasing the thrust of the overall machine. Again it is found that the high liquid rate makes this scheme usable only for takeoff. A combination of water injection at the compressor inlet and "bleed-burn" has also been tried.

The reheat cycle, commonly referred to as "tailpipe burning," appears to be the most practical augmentation scheme. The ideal cycle is shown in the enthalpy-entropy diagram in Figure 9. In the normal cycle, the velocity of the gas leaving the exhaust nozzle is proportional to the square root of the enthalpy charge as repre-

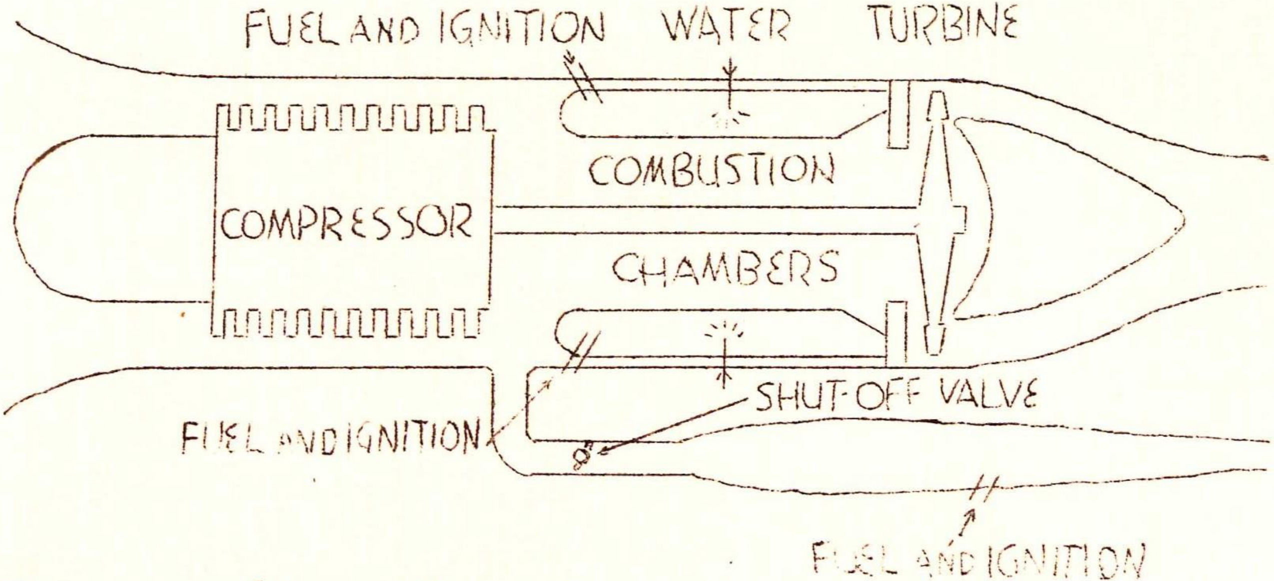
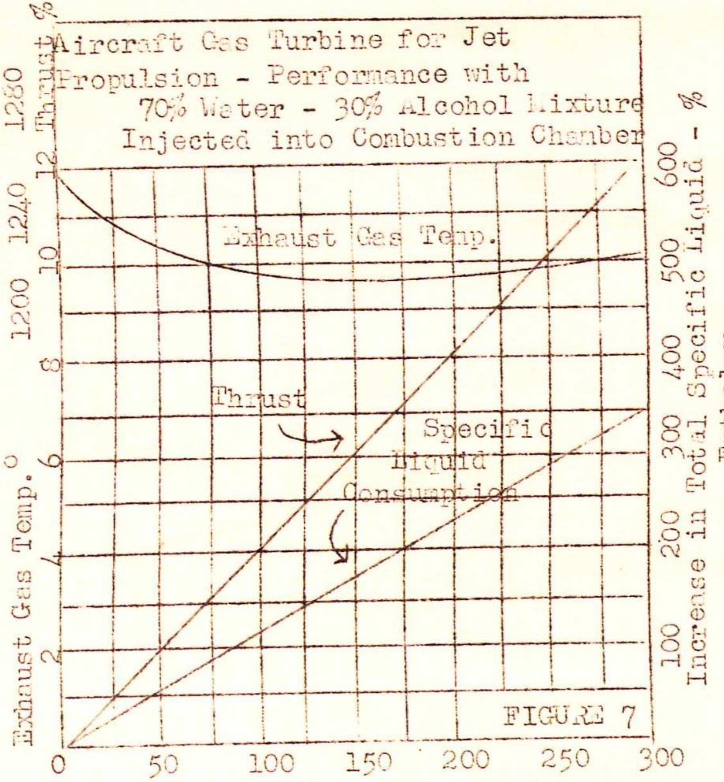
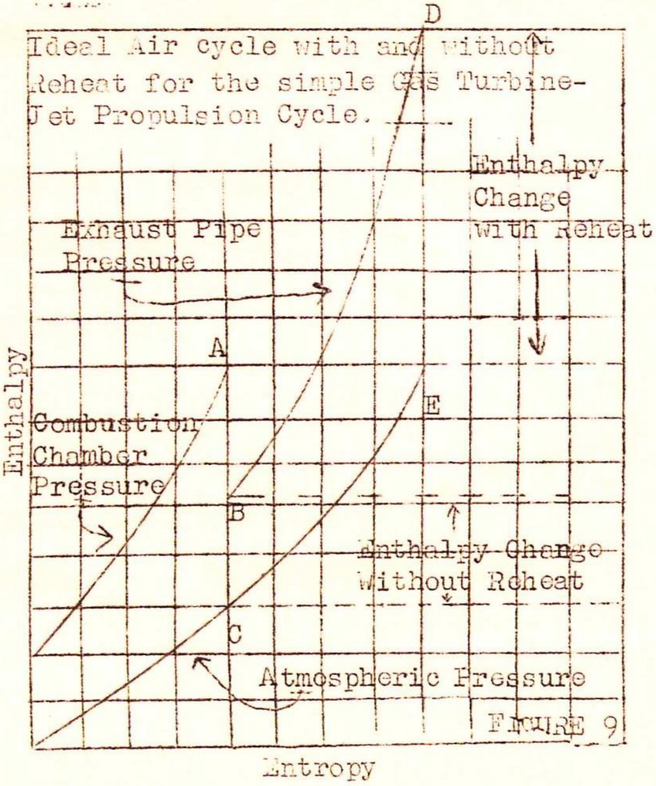


Figure 8 - Bleed-Burn Cycle



Aircraft Gas Turbine for Jet Propulsion - Performance with 70% Water - 30% Alcohol Mixture Injected into Combustion Chamber

FIGURE 7



Ideal Air cycle with and without Reheat for the simple Gas Turbine-Jet Propulsion Cycle.

FIGURE 9

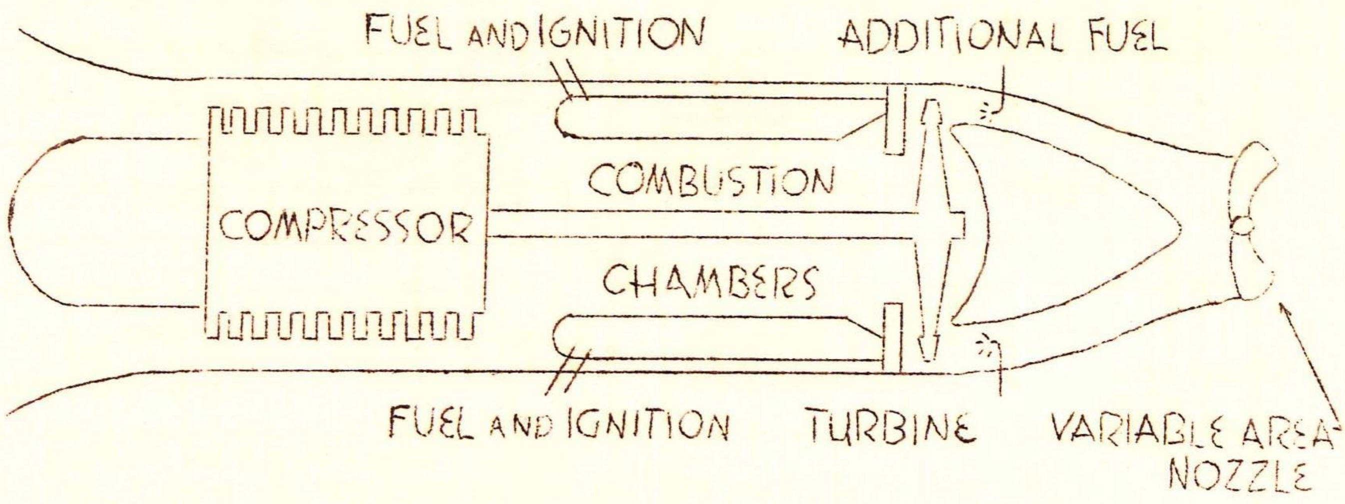
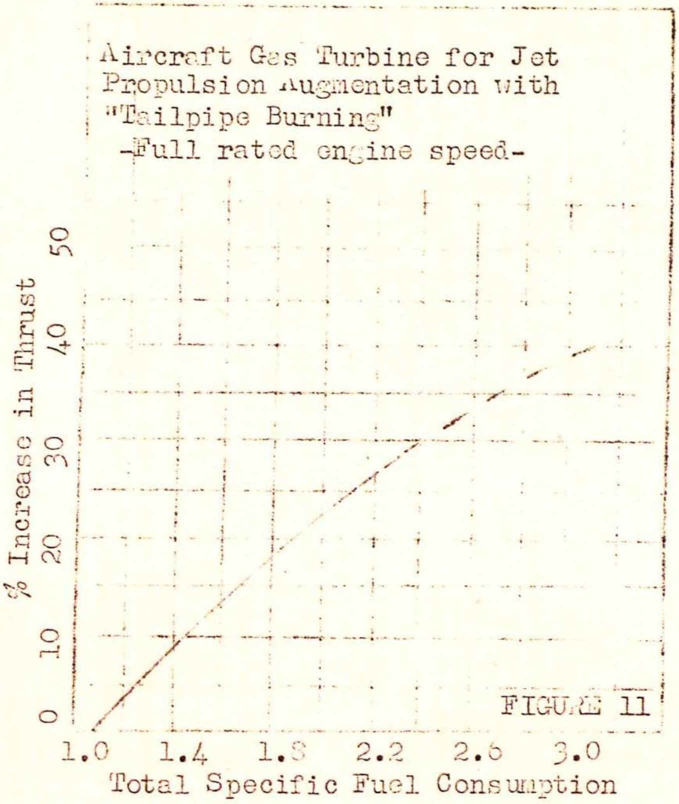


Figure 10 - Reheat Cycle

sented by the line BC. In the reheat cycle, after the expansion through the turbine as represented by AB, heat is added at a point downstream of the turbine wheel at nearly constant pressure along BD yielding a temperature much higher than could be withstood by the stressed turbine blades. Expansion then takes place along DE. In this manner, it is possible to eject the gas at a high velocity, much higher than without reheat, and increase the thrust accordingly. The sketch in Figure 10 shows a simple diagram of the reheat cycle.

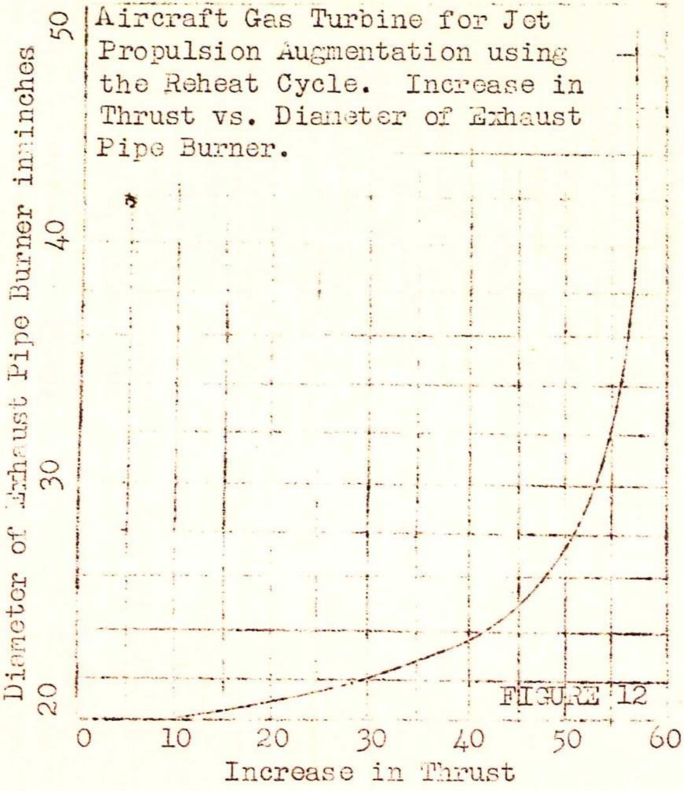
Figure 11 shows the degree of augmentation at zero ram plotted against total specific fuel consumption (engine fuel and reheat burner fuel). With this method there is the lowest specific fuel consumption commensurate with high thrusts. The cycle can be used at takeoff, and as long as there is fuel in the airplane to keep the ship airborne, it is also possible to obtain augmented thrust with tailpipe burning in flight. In addition the net thrust is further augmented at higher airplane speeds; at 600 miles per hour the net thrust with tailpipe burning is nearly equal to the output of two turbojet engines operating in the normal manner. The reheat burner also makes it possible to maintain dry sea level thrust up to higher altitudes. This is shown in Figure 1. At 600 miles per hour, sea level thrust can be maintained up to approximately 30,000 feet. At lower speeds, sea level thrust will be maintained to lower altitudes but not less than 20,000 feet.

Full advantage of the reheat cycle cannot be realized unless adequate space is provided for the tailpipe burner. Figure 12 shows what is potentially available in thrust for different tailpipe burner diameters for a 5000 pound dry thrust engine at sea level and zero ram. A burner of adequate size is also essential to ob-



Aircraft Gas Turbine for Jet Propulsion Augmentation with "Tailpipe Burning"
-Full rated engine speed-

FIGURE 11



Aircraft Gas Turbine for Jet Propulsion Augmentation using the Reheat Cycle. Increase in Thrust vs. Diameter of Exhaust Pipe Burner.

FIGURE 12

tain stable and efficient combustion over a wide range of fuel flows at all altitudes.

The reheat burner is an integral part of the whole propulsion unit along with a variable area jet nozzle and an automatic control. The variable area jet nozzle is essential so that the jet nozzle area can be properly set when the tailpipe burner is not used and increased when there is reheating to that the engine can be kept at full rated speed without exceeding the maximum allowable exhaust temperature in the vicinity of the turbine wheel. The control system must be fully automatic so that the nozzle area and reheat burner fuel flow are properly coordinated at all speeds and altitudes. This is absolutely essential in order to insure the safety of the pilot and the airplane.

The augmentation methods mentioned above might be regarded as "tricks," but they are simple and direct ways to obtain increased thrust without resorting to the development of new engines. In all the methods, the additional thrust is obtained at the expense of high specific liquid consumptions, but with only a slight increase in the weight of the whole propulsion unit. However, until more progress is made in the field of high temperature metallurgy and more effective means are found to protect parts that are exposed to high temperatures, thrust augmentation will be used.

Acknowledgement is given hereby to the National Advisory Committee for Aeronautics who have been extremely active in developing various methods to augment the thrust of the turbojet engine. The Committee's work in this field has given the services and industry, excellent guidance and in so doing has accelerated the application of various augmentation schemes to airplanes either in service now or in the near future.

SOLID LIQUID RUN NO. 16--July 10, 1948

—George James—

Recently the Society released both 8mm and 16mm films on Solid-Liquid Run No. 16. Despite the fact that the run itself was unsuccessful, the films are of interest for their documentation of RRS liquid propellant procedure.

Solid-Liquid Engine No. 2, using as propellants red fuming nitric acid and a wood solid charge was mounted on liquid propellant test stand No. 3 for this experiment. Ignition was to be started with a solid propellant ignitor.

Due to the hazardous nature of red fuming nitric acid, great care was taken to protect personell. The propellant tank loader wore protective goggles, apron and gloves. The stand operators were located in a dugout and observed the run through a periscope. Three movie cameras were used to record data.

After the propellant tank was loaded and the wood rod inserted into the combustion chamber, the area was cleared and the operators placed 400 pounds of nitrogen pressure in the regulating tank. Upon a signal from the crew chief, the solid-propellant ignitor was fired and then the red fuming nitric acid was injected into the combustion chamber. Unfortunately, ignition did not occur and the only result was a great brown cloud composed of nitric acid and nitrogen tetroxide. After the acid tank had been blown dry, the system was closed down, making it safe for the crew to approach. Examination revealed that although the ignitor had raised chamber pressure for a moment to 500 pounds, its duration was so short that the wood was hardly charred.

REACTION RESEARCH SOCIETY

PURPOSE

The REACTION RESEARCH SOCIETY, founded in 1943, is a non-profit organization whose purpose is the development of reaction propulsion and its applications, the promotion of interest is this science, and its allied educational and technical activities.

MEMBERSHIP

At the present time there are two main classes of membership in the Reaction Research Society, Active and Associate. Active membership is for the interested and qualified persons who by their membership indicate their willingness to engage in the activities of the society. Active members hold full scientific or research membership in the society and have the privilege of attending meetings and testings of the society. Active members receive all society publications published during their membership and are eligible to conduct society sponsored research and to hold office in local society groups. This class of membership is $5.00 per year. Associate membership is for those interested and qualified persons who find it inconvenient to devote sufficient time on work of the society to warrant an active membership. They have all the privileges of active members except holding office in local society groups, serving as a project or testing chief or in any other manner being in charge of a society technical or scientific research activity. This class of membership is $3.00 per year. If you are interested in joining the society, please write to:

SECRETARY, REACTION RESEARCH SOCIETY
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