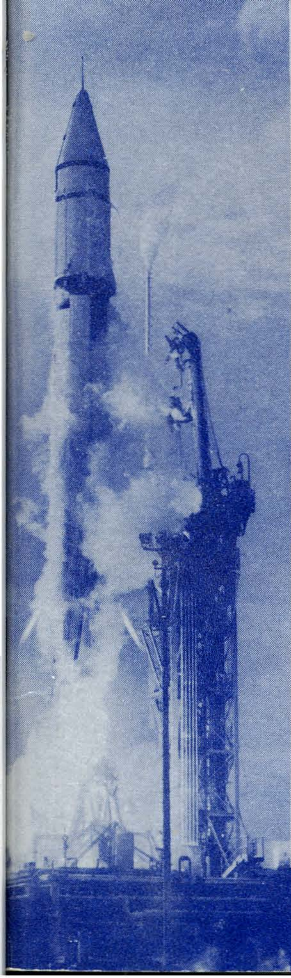
1966 INSPECTION OF LEWIS RESEARCH CENTER

CLEVELAND, OHIO

OCTOBER 4 TO 7



RESEARCH AND TECHNOLOGY ON PROPULSION, SPACE POWER, AND SPACE VEHICLES

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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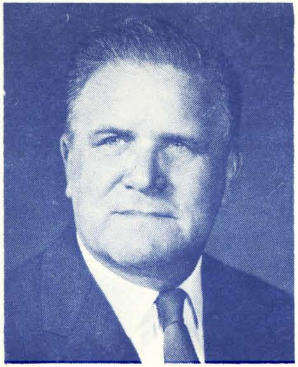


James E. Webb

The tradition of Inspections at Field Centers predates the National Aeronautics and Space Administration. The National Advisory Committee for Aeronautics (NACA), a predecessor NASA agency, held inspections for many years and these events were looked forward to eagerly by technicians, scientists and engineers. They served as valuable devices for keeping those interested in aeronautics well informed and stimulated.

NASA has carried on this valuable and useful tradition. The 1966 Inspection of NASA's Lewis Research Center again opens our doors to many segments of our technological and university community and is a welcomed opportunity to present another progress report to the nation.

Lewis occupies a unique position in that it is both a basic research laboratory and a development organization. Its role in NASA is to provide the knowledge necessary to build better propulsion systems and the electrical power plants needed both in space and for the exploration of the surface of the moon and perhaps the planets.

Perhaps equally as important as its NASA role, is the fact that the new knowledge it uncovers about the basic nature of our world and the advances it makes in technology are as applicable to our everyday lives as they are to a trip to another planet.

The stimulus and leadership which NASA, through centers like Lewis, is providing to the rapid expansion of science and technology, is a force which is affecting people all over the world as well as the generations to come. It is essential that leaders in every facet of life recognize this growth and take full advantage of it.

James E. Webb

Administrator, NASA

Dr. Abe Silverstein

NASA's spectacular manned and unmanned space flights, that have done so much to initiate the exploration of space and introduce the utilization of space for the benefit of man, are well known to all of you.

These accomplishments, magnificent as they are, are a part of the iceberg that is above the surface. The basic research and long range developments that undergird them are not as apparent even though they occupy the efforts of more than half of the NASA staff.

Our 1966 Inspection and those of the past enable you to inspect the facilities that we use in our basic and applied research and hear about some of the progress that is being accomplished. The character of our work in the future depends on what we learn today.

It is particularly appropriate for the Lewis Research Center to hold an Inspection in 1966. This marks the 25th year since ground was broken in Cleveland to build what has become this country's major center for advanced research in aeronautical and space propulsion and in the generation of electrical power for the exploration of space.

Inspections at Lewis began after World War II and were continued through 1957. We became part of the newly-created National Aeronautics and Space Administration on October 1, 1958. Since then we have nearly doubled our staff and increased the scope of our investigations many fold.

Work at Lewis ranges from studying the imperfections of a single crystal of metal on an atomic level to managing the development, construction and launch of rocket vehicles carrying many of America's most important scientific spacecraft. Mariner, Nimbus, the Orbiting Geophysical Observatories, Ranger, Surveyor and Lunar Orbiter all were boosted onto their journeys in space with rocket vehicles managed by Lewis.

In the air-breathing engine field, projects in many areas, from materials to turbines, are moving forward to help support the future transportation needs of the nation.

During your visit here you will be seeing some of the facilities and people who are helping to share our future in space. It is a bright future and one we can all be proud to participate in.

Abe Silverstein

Director, Lewis Research Center

LEWIS RESEARCH CENTER

Twenty-five years ago, NASA's Lewis Research Center was born as the Aircraft Engine Research Laboratory of the former National Advisory Committee for Aeronautics (NACA). As Dr. George Lewis and other dignitaries turned the first shovelfulls of earth, it is doubtful that anyone foresaw the magnitude of the advancement of the science of flight which would take place during the coming years, nor the important part which the new center would play.

Secrecy surrounded the initial work because of World War II, but in May, 1944 NACA was able to announce that Cleveland's Aircraft Engine Research Laboratory had developed means for greatly increasing the amount of high octane aircraft gasoline available to the war effort, had developed water injection systems to increase the power of aircraft engines and had played an important role in the development of turbosuperchargers.

Later, it was revealed the laboratory had solved the serious B-29 engine overheating problem and added five and a half tons to the B-29 payload through improvements of exhaust turbines and solving high altitude fuel vaporization problems. These accomplishments were a major help in our war against Japan.

On February 16, 1944, the lab's Altitude Wind Tunnel was put into operation. When the Korean war came along it was afterburners developed in the AWT that helped U. S. F-86's sprint into action.

Through the years, Lewis has left an indelible mark on every commercial and military jet engine made in this country.

Today it is helping solve the problems involved in building the Supersonic Transports of the 1970's which will jet passengers from coast to coast in less than two hours.

There is no sharp dividing line between the aircraft engine work and the rocket propulsion and power generation work which occupies many of the lab's 4900 employees today. Early rocket work began as early as 1945 and by the early 1950's Lewis engineers were firing high-energy liquid-hydrogen liquid-oxygen engines.

On October 1, 1958, Lewis became a part of the National Aeronautics and Space Administration as the agency's primary center for research in the fields of propulsion and power generation.

In November 1961, Dr. Abe Silverstein, who had been serving as Director of Space Flight Programs in NASA Headquarters, returned to Lewis to direct a major expansion of the basic research laboratory into a research and development organization of much greater scope.

Today Lewis is responsible for all of NASA's intermediate launch vehicles for unmanned scientific missions. It has been responsible for developing the Atlas-Centaur rocket, our nation's first high energy launch vehicle, which is being used for Surveyor flights to the moon. Centaur has also been selected to launch Mariner spacecraft to Mars in 1969.

Lewis also has management responsibility for Atlas, Atlas-Agena, Thor-Agena and Thrust Augmented Thor-Agena launch vehicles for unmanned scientific missions. These vehicles were used for sending Mariner to Mars. the Ranger and Lunar Orbiter spacecraft to the moon and such satellites as Nimbus, PAGEOS and the Orbiting Geophysical Observatories into an earth orbit.

Other major development projects at Lewis include SNAP-8, a 35,000 watt nuclear electric power generation device and the 260-inch solid motor technology program.

Lewis pioneered in liquid hydrogen technology and continues in the high energy field with research and development of liquid hydrogen-liquid fluorine systems as well as the M-1 technology program which is drawing to a close. The first electric rocket engine to operate in space was invented and built at Lewis. The lab is also busy with work in support of the NERVA program and several advanced nuclear rocket engine concepts.

In addition to nuclear power generation, Lewis has made many contributions in solar cells, fuel cells, thermionics and has initiated work on a solar-Brayton cycle system.

In early 1966, Dr. Silverstein again reorganized a large segment of the lab to provide the necessary research and development support in propulsion and materials fields for the national supersonic transport program.

The Space Nuclear Propulsion Office, (SNPO), a joint organization of NASA and the Atomic Energy Commission, also maintains an office at Lewis. SNPO-C is responsible for technical and administrative direction of the NERVA program, and maintaining liaison with Lewis, which as part of its nuclear rocket activities, lends support in non-nuclear areas to the NERVA program.

As Lewis stands on the threshold of its second 25 years, it is just as true today as it was in 1941 that probably no one can foretell the tremendous advancements which will be made in science and technology. One thing is clear, however, the Lewis Research Center is ready and determined to continue to play an important part.

PLUM BROOK

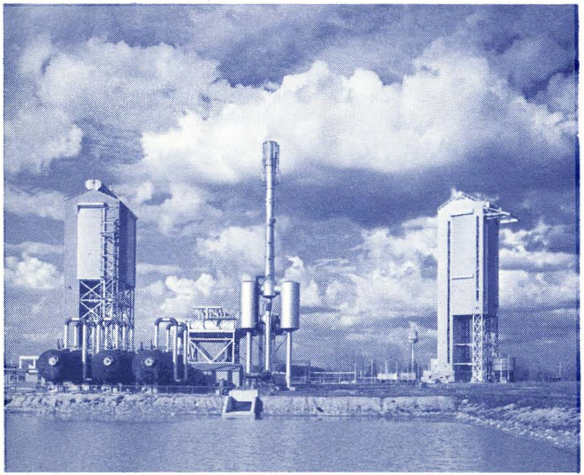
A decision by the NACA in the mid-1950's to construct a nuclear research reactor and the growing magnitude of work with rocket engines made it evident that a testing station more remote from the Cleveland metropolitan area was needed. In 1956, Plum Brook Station was established on 6500 acres near Sandusky owned by the Army and formerly the site of an ordnance explosives plant.

Ground was broken for the 60,000 kilowatt reactor in October 1956. Rocket test facilities were built as additional parcels of the site were leased to NASA by the Army. NASA assumed full control and title to the Plum Brook area in March 1963 as the reactor was being readied for its first full power operation.

Today work at Plum Brook falls into two general areas: (1) studies using the reactor in basic research associated with the nation's efforts to develop a nuclear rocket and development of components and systems for space nuclear power devices; and (2) test programs of rocket engine systems, components and high-energy fuels.

One of the interesting investigations going on in the reactor facility is determination of the effect of the combination of radiation and liquid hydrogen temperatures (-420 degrees F) on materials to be used in nuclear rocket engines. The test specimens are placed in a cryostat which maintains the low temperature and contains equipment to pull on the specimen and record any elongation while it is being irradiated in the reactor.

Large test stands are also being used at Plum Brook to gain better understanding of nuclear rocketry. B-1 and B-3 test stands are used to flow liquid hydrogen through components and complete unfueled nuclear rocket engines. A steam ejector system is used to produce altitude test conditions.

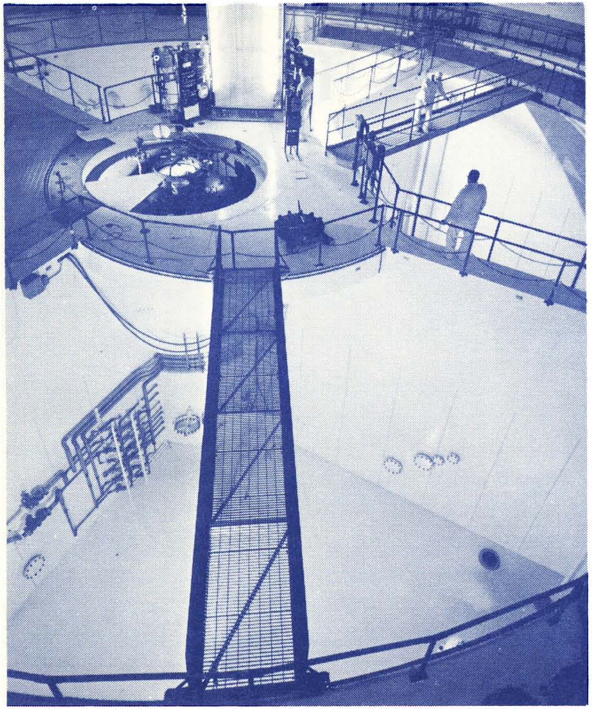


B-1 and B-3 nuclear rocket stands

It was a series of tests in these Plum Brook facilities that first verified the bootstrap startup capability of a NERVA type nuclear rocket engine. Bootstrap is the term used to describe the startup of an engine flow system when no external power is supplied to the system.

Test areas for rocket engines, turbopumps and cryogenic propellant tanks are constantly active.

The large Dynamic Research Test Stand at Plum Brook has been used to determine the structural strength of the Atlas-Centaur launch vehicle. It is equipped with electromagnetic shakers to simulate aerodynamic forces encountered on lift-off and bending devices for simulating wind loads during flight through the atmosphere. These tests showed that the buckling that takes place during flight actually increases the strength of the Atlas-Centaur combination. Because of the wind conditions prevailing at Cape Kennedy



Inside reactor containment vessel

on May 30, 1966, the Surveyor spacecraft would not have been launched to the moon if this strength increase had not been discovered earlier at Plum Brook.

Today a number of important new facilities are under construction. The largest is the 26 million dollar Space Propulsion Facility. The heart of the facility is a huge 100 by 120 foot vacuum chamber in which pressure and temperature conditions existing at altitudes up to 100 miles can be produced for long periods of time. Six foot thick reinforced concrete shielding and other safeguards will allow the testing of full size nuclear space power generation systems such as SNAP-8.

A hot hydrogen facility is also being built to test nuclear rocket nozzles. Later it will be converted into a hypersonic aerodynamic research facility.

MATERIALS RESEARCH

An advance in the materials field means advances in the technology of many other fields. Very often the strength of a material, its ductility, or its ability to withstand extreme environments, is the pacing element in the development of more advanced aircraft engines and space hardware.

At Lewis, materials research goes on in many areas; polymers, liquid metals, refractory metals, superalloys, fiber composites, dispersion strengthening and the development of materials testing procedures.

The ability to determine the long term behavior of a metal through short term tests is an extremely important tool. This ability is particularly important in the design of systems which may have to run several years without maintenance. The Lewis Materials and Structures Division has made outstanding contributions in this area.

Pioneering research at Lewis and the Naval Research Laboratory over more than a decade has resulted in the development of a new engineering science known as fracture mechanics and evaluation of techniques such as crack toughness testing. The purpose of this new discipline is to provide means of identifying and measuring the factors that control the resistance of a metal to brittle fracture and to relate in a quantitative way the results of laboratory crack toughness tests to service performance.

Crack toughness tests put a sharply notched specimen of the candidate metal through conditions similar to those expected to be encountered in actual use. The notch simulates the presence of a flaw in the material such as may be produced during welding or fabrication.

An extensive screening test was recently initiated at Lewis to select sheet alloys for the skins of supersonic transports. On the basis of these tests a field of 67 candidate alloys was reduced to eight, which were then given more extensive testing by the aircraft industry.

Materials research at Lewis is concerned with finding and improving the qualities of materials useful at both ends of the temperature scale. Because of their high temperature strength and good fabricability the refractory metal alloys of columbium and tantalum will be needed for space electric power systems.

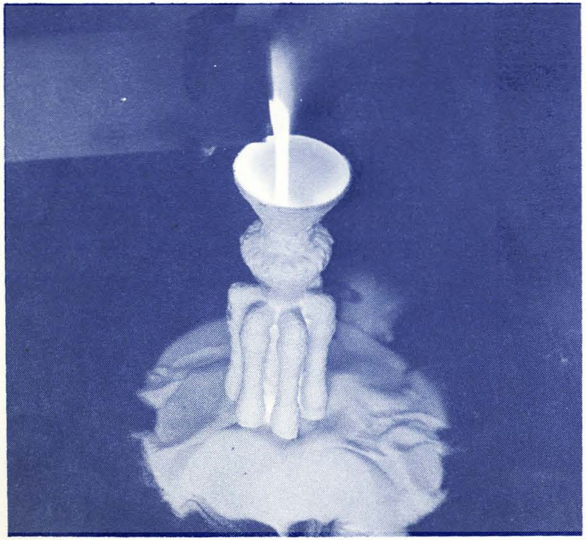
One of the most promising types of systems uses a boiling fluid such as potassium at temperatures of 2000 degrees F. Heat would be provided by a nuclear reactor.

The refractory materials used to contain the boiling potassium must be resistant to the corrosive attack of the potassium if a successful system is to be developed.

It was known that very small amounts of oxygen dissolved in the refractory metals promote corrosion. One simple solution to preventing the oxygen from entering into the corrosion process apparently is the addition of a small amount of a "getter" metal to the refractory metal. Getter metals such as zirconium and hafnium readily react with oxygen to form stable oxides and reduce the availability of free oxygen.

Tests conducted with alloys containing a "getter element" showed good corrosion resistance in the presence of boiling potassium while non-gettered alloys were seriously attacked. From the evidence it appears that gettered refractory metal alloys are suitable for use in space systems which would operate for more than a year.

At much higher temperatures, above those at which columbium and tantalum would be useful, tungsten alloys are of interest. Tungsten is our most refractory metal, with a melting point of 6170 degrees F, more than twice that of steel. Future space applications might include rocket nozzles, space power systems and re-entry vehicles.



New super alloy takes shape

Tungsten, however, has several drawbacks. Its primary fault is lack of ductility at room temperatures. Several years ago, it was demonstrated elsewhere that ductility could be substantially improved by alloying tungsten with 26 percent rhenium, another rare and expensive refractory element.

Lewis has since discovered that the ductility of tungsten can be improved by adding just 2 to 9 percent rhenium if the alloys are prepared by a very high purity method such as electron beam melting. This process boils off impurities during melting in a high vacuum.

Research is now aimed at understanding the mechanism by which small amounts of rhenium improve the ductility of tungsten.

Much of this work centers about study of changes in the crystal lattice of alloyed and unalloyed tungsten.

Lewis materials engineers have also been concerned with improving the high temperature strength of tungsten. A tungsten-hafnium alloy developed here has the highest hot strength of any known metallic alloy. At 3500 degrees F, its tensile strength is six times greater than pure tungsten.

Another approach to achieving greater strength in metals is fiber reinforcement. The strength of a piece of bulk metal is often only 5 percent of the theoretical strength of that material. A single fine wire of the metal or single crystal of it may reach 80 or 90 percent of the material's theoretical strength. Examples of the excellent tensile strength achieved in fiber form are: 600, 000 psi for drawn steel wire, 1 million psi for silica fibers, and over 3 million psi for aluminum-oxide whiskers.

To make use of this strength in a structure, the fibers are imbedded in a matrix of another metal. Some of the problems involved in making fiber composites concern possible reactions between the matrix and fiber materials during fabrication or operation.

In addition to strength, composites offer a number of other advantages over more conventional monolithic materials. The metal matrix can serve to protect the fibers from oxidation. A crack formed by the failure of one fiber doesn't necessarily lead to failure of the entire specimen as often happens with homogeneous materials.

The improvement of the oxidation resistance of superalloys is essential for use at the high temperatures that will be encountered in engines for the supersonic transport. Research at Lewis has recently been directed toward the development of nickel base alloys with improved oxidation resistance.

Comparing one new Lewis alloy with two alloys in use in engines today, the Lewis alloy has twice the oxidation resistance at 1900 degrees F of the nickel base cast alloy MAR-M-200 and ten times that of the nickel base sheet alloy René 41.

Significant improvements in the ductility of another superalloy, L-605, has also been achieved through study at Lewis. This alloy is commonly used for transition ducting between the combustion chamber and stator vane inlet in commercial and military jet engines and in the afterburner liners of military jet engines.

Dispersion strengthening is also being used in the effort to produce better superalloys for the advanced jet engines. Advances in processing these types of metals as well as producing greater strengths are being made.

Although the materials work at Lewis concentrates largely on metals, there has been good progress in the use of polymers, especially for cryogenic propellant tanks. Pound for pound, certain plastics are many times stronger than commonly used metallic materials at room temperature, and the plastics gain even greater strength at cryogenic temperatures.

Fiberglass filaments can be wound into extremely high strength, light weight tanks. The problem with applying fiberglass to the production of cryogenic tankage, though, is the inherently porous nature of the material. Polymeric films liners for fiberglass filament wound tanks offer an attractive solution. Lewis instituted basic studies and now have produced a superior polyethylene terephthalate film for cryogenic applications. This in itself does not solve the liner problem but it does point the way.

AIR BREATHING PROPULSION

The next generation of aircraft will include many advanced and specialized designs such as Supersonic Transports, giant subsonic carriers, Verticle Take-Off and Landing craft and advanced military planes. To make such aircraft technically feasible and economically sound requires a major effort in advancing the technology of structural materials and air breathing propulsion.

Lewis has expanded its efforts in the air breathing propulsion field to meet needs for all these aircraft.

The problems presented by the SST are associated with its speed of more than three times that of present commercial transports. To achieve this, the engines for the SST will have to produce about 60,000 pounds of thrust, four times that of present engines.

One of the major problems with supersonic flight is that the entire engine is immersed in an air stream 600 degrees hotter than conventional turbojet engines. As a result the combustion system and turbine are forced to operate at temperatures at the softening point of present materials. Turbine inlet temperatures will go well above 2000 degrees F.

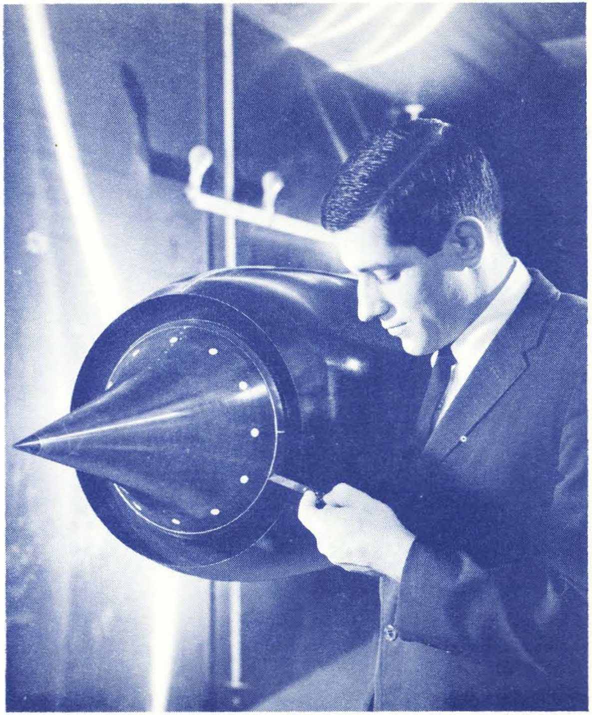
A major materials effort is underway at Lewis to develop materials capable of operating at these higher temperatures and still have the same durability of present day engines.

Durability is a key factor in engine operating costs and is measured by the time between overhauls. Current subsonic jets operate from 3000 to 7000 hours between major overhauls and the new supersonic engines must strive for similar reliability.

One of the methods of achieving the necessary reliability of materials is through better cooling methods. In the turbine area, new methods for flowing cooling air through the turbine blades are being studied.

Experiments using impingement cooling of the leading edge of the blade are underway. This internal cooling system uses jets of air to cool the leading edge which has the greatest amount of heat input. Ordinary convection cooling is being used in the midchord section along with fins to augment the surface area. Film cooling is being studied for the trailing edge of the blade where it is difficult to locate internal cooling passages.

Inlet and nozzle portions of the supersonic engine present problems also. Lewis work in this area is concerned with providing methods and controls for varying the geo-



Supersonic engine inlet

Proposed engine placement on F-106

metry of these two parts with a minimum of complexity.

Both the nozzle and inlet to the engine for an SST must go through a number of configurations during flight. As flight speed increases a greater percentage of the total thrust is contributed by the nozzle and engine inlet, so the efficiency of these components becomes increasingly important.

The inlet and nozzle work will be conducted both in the 10 by 10 foot Supersonic Wind Tunnel and in flight with a F-106 aircraft. The F-106 was chosen by Lewis because its large swept wing permits the installation of the research engine nacelles in a manner representative of the way they will be mounted on the SST.

Experiments with slotted compressor blades may lead to greater efficiency in compressors. By raising the amount of compression that can be produced by each stage it may be possible to reduce the number of stages needed. This would result in a weight saving which is always an important consideration in aircraft.

The purpose of the slotted blades is to prevent the air flow over the surface of the blade from separating and creating dead air zones. If the air flow can be controlled in this manner, it is possible to increase the angle of the blades in relation to the air stream and so achieve greater compression.

The work with slots in compressor blades is analogous to the use of slots in the wings of aircraft to prevent stalling. Stalling occurs when the angle of attack of the wing to the direction of air flow reaches a point where the flow separates rather than follows the wings surface. This produces a dead air zone and reduces lift.

A side benefit to the use of slots on compressor blades is noise reduction. Much of the compressor noise in a jet engine can come from the formation of the dead air zones. If the dead air zones are decreased, noise will be also.

The air breathing engine work at Lewis includes turbine aerodynamics, bearings and seals, combustion, special fuels and lubricants and materials as well as additional work in turbine blade cooling, compressor design and inlet and nozzle configurations.

The Lewis work is not aimed exclusively at any particular engine but will be applicable to a wide variety of advanced engines. It is a broad base effort to advance our country's technology in the air breathing engine field.

JET ENGINE NOISE

In the past Lewis has made significant contributions to the reduction of the noise produced by turbo-jet engines. Recently experiments on fan jets have been instituted and the prospects for reducing their noise looks very encouraging.

Several approaches are being studied. Lewis has modified the inlet cowling for the J-65 engine on its B-57 research aircraft. The inner surfaces of the cowling were lined with porous metal supported over a 1-inch cavity. The porous metal and cavities are designed to be effective sound absorbers in the 3000 cycle per second range. A circumferential splitter ring and radial supports were also fabricated in the same way.

Measured noise levels with the modified and unmodified cowling show a reduction of about 12 decibels in the level of whine.

The Lewis laboratory has instituted a program to find methods for reducing the noise generated by compressors and fans. The program includes experiments with full-scale fans.

Lewis, other government agencies and the aircraft industry are giving high priority to research on means of reducing jet engine noise.

Measuring jet engine noise

SPACE VEHICLES

The one thing you will not see as you tour the Lewis Research Center is the tall skeleton-like skyscrapers of launch pads and gantries. Yet 74.2 percent of the Lewis research and development budget is spent for the design, manufacture and launch of these huge work horses of the space age.

Lewis is responsible for managing NASA's intermediate weight rockets for unmanned space flights: the Atlas, Atlas-Agena, Thor-Agena, Thrust Augmented Thor-Agena and Atlas-Centaur.

These rocket vehicles have launched all three types of moon probes . . . Ranger, Surveyor and Lunar Orbiter. They support earth orbital missions such as the Nimbus weather satellite program, the Orbiting Geophysical Observatories, the Orbiting Astronomical Observatories and the PAGEOS Geodetic satellites. Lewis was also responsible for the Atlas-Agena that launched the Mariner spacecraft to Mars.

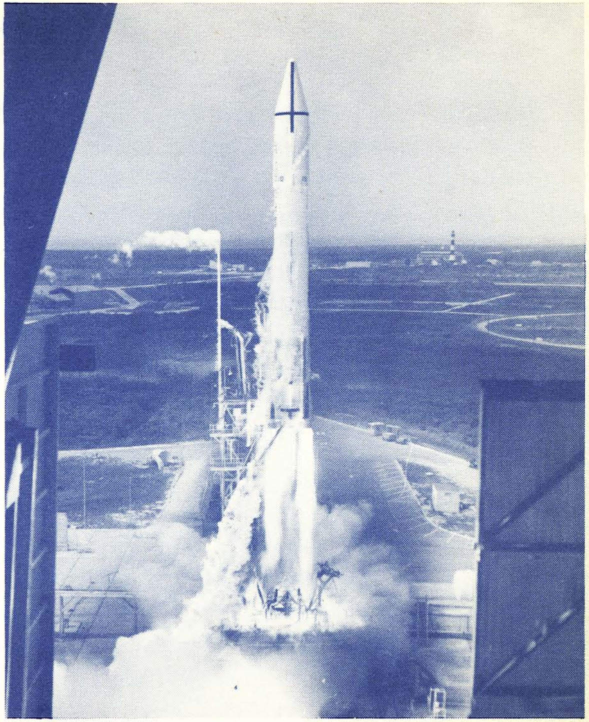
The Atlas-Centaur combination has been selected to launch the Mariner Mars '69 spacecraft also.

Currently Lewis' vehicle engineers are working with contractors toward improving both the Atlas and Thor boosters. An uprated Atlas, called the 3-A, will have longer tanks and thus more payload capacity. Similarly, a Thrust Augmented Thor is also being revised with a lengthened tank to improve payload launch performance through increased propellant capacity.

In an effort to increase the cost effectiveness of the Agena second stage vehicle and its boosters, Lewis began a standardization program in 1965. Standard shrouds, adapters and spacecraft interfaces have been developed to keep to a minimum the modifications necessary for each mission. In addition to reducing costs for each mission, the overall reliability of the standardized vehicle system is increased.

Centaur, the first U.S. high energy upper stage, was developed under the management of Lewis and is now operational. The development of the liquid hydrogen-liquid oxygen fueled Centaur is a good illustration of the way in which Lewis provides a research back-up and development testing capability to complement the work of private industry.

The shaped charge separation system which separates the Centaur from its Atlas booster and liquid helium pre-launch engine chill down system were developed at Lewis. Solutions to problems with the jettison system for the nose fairing and with hydrogen vent valves were also found at Lewis.



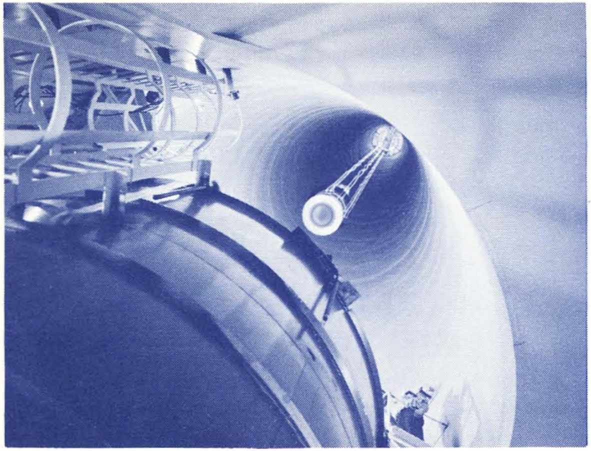
Surveyor I launched with Centaur

Space vehicles like Centaur and Saturn S-IVB stage are designed to coast in space for varying periods of time and then to restart their engines. During the coast period the propellants in the vehicles are in a state of weightlessness.

On earth, liquids stay positioned nicely in the bottom of the container while gases go to the top. If we want to empty the container, we simply open a valve and pump the fluid out the bottom. In weightlessness the problem is not that simple. The liquid is free to move about in the tank. If it is a wetting fluid such as liquid hydrogen, it will spread out over the walls of the tank and enclose the vapor. Starting a propellant pump is a rocket where there is insufficient propellant or a combination of propellant and vapor over the pump inlet can destroy the pump and, of course, will prevent a second burn of the rocket engines. Another problem is propellant loss when liquids are not kept away from vent valves.

Research on the behavior of fluids in a weightless condition have been conducted through the use of a 100 foot drop tower, research aircraft, and Aerobee and WASP rocket vehicles. The WASP rocket was developed especially by Lewis for weightlessness tests using a Centaur tank configuration. The results of the WASP flight early in 1966 showed for the first time that the problem of managing liquid hydrogen in a weightless condition had been licked. Very small amounts of thrust, even for large systems, are enough to keep the liquid hydrogen settled.

An important new tool in the study of weightless conditions is the new Zero Gravity Facility at Lewis unveiled for the first time at the 1966 Inspection. Evacuation of its 500 foot vertical shaft permits five seconds of free-fall, or weightlessness, without the need for drag shields on the experiment. Shooting the experiment up from the bottom, with free fall afterwards, can double this duration to 10 seconds. The 20 foot diam-



Zero gravity facility

eter of this shaft makes it possible to experiment in an earth based laboratory with far larger models and systems than has ever been possible before.

Two basic approaches to controlling propellants under zero-G conditions have been studied at Lewis. One is the use of small thrustors to provide low level acceleration to keep the propellant settled in the bottom of the tanks during the entire coast phase. This approach is taken on both Centaur and the Saturn S-IVB stage.

During the coast phase it is important to use just the right amount of thrust to keep the propellants bottomed. Too little thrust will permit small disturbances such as astronaut movements in a manned vehicle to disturb the liquid, while too much thrust may set it in violent motion.

The second method of propellant management is the use of baffles within the propellant tank. Screens, spheres and standpipes mounted over the pump inlet are a few of the configurations studied. Such baffles take advantage of the surface energy of the fluids. On earth this energy is insignificant compared with gravity. In zero-G, however, surface energy is one of the strongest forces left, and thus is an effective means of control.

ADVANCED CHEMICAL PROPULSION

Advancement in the exploration of space depends on the advancement of propulsion technology. The chemical rocket program at Lewis is aimed at improving the performance, reliability, increasing the size and reducing the development time and cost of tomorrow's rocket engines.

In order to accomplish the goal of better engines, Lewis conducts research and engineering studies in many areas. One of these areas concerns the problems of combustion instability, a problem that has plagued many rocket engines and added cost and time to their development programs.

Combustion instability has been the object of serious study at Lewis for many years and a great deal has been learned about how to prevent or eliminate it.

One of the more obstreperous types of instability is known as screech. Its name is descriptive of the noise it makes in a rocket engine.

Screech is a form of high frequency combustion instability in a rocket engine. It has been identified as a high amplitude pressure wave in the combustion chamber gases. This wave is driven by the combustion process at frequencies set by the dimensions of the combustion chamber.

The reason screech is so serious is that it scrubs away the protective boundary layers of gas along the walls of the combustion chamber and allows the walls to be heated to much higher temperatures. Since most rocket engines operate with gas temperatures well above the melting point of the material from which they are made, the engine can be badly damaged by any decay of the cooling process . . . in fact, engine screech may be followed within seconds by the engine dissolving in flames!

One of the more promising ways to suppress screech is to absorb or cancel the acoustic waves in the rocket chamber before they can interact with the combustion process. This is called acoustic damping.

Baffles that divide the combustion zone into a series of separate compartments have successfully prevented screech.

Lewis scientists and engineers are also studying ways to smooth out the combustion process by improved propellant injection techniques and by the effective use of acoustic liners. In theory the acoustic liners used in combustion chambers are much like the acoustic tile used on the ceilings of homes and offices.

Most of the combustion instability research at Lewis has involved relatively small rocket engines, but the proof that it can be applied successfully to large engines was demonstrated vividly with the combustion chamber for the M-1 rocket engine.

The M-1 program, under the management of Lewis, was originally designed to provide a 1.5 million pound thrust liquid hydrogen-liquid oxygen rocket engine for use on upper stages of post-Apollo type launch vehicles. Lack of a specific mission and budgetary considerations led to cancelling the project, however, to insure that the greatest possible benefit would be derived from the money already invested, the work was carried on through full power tests of the uncooled thrust chamber.

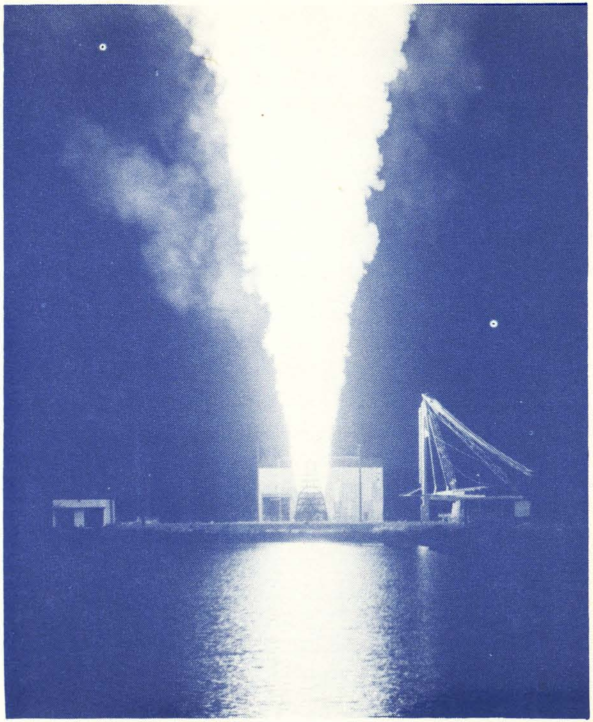
The design for the M-1 injector and combustion chamber was based on research conducted on high energy rocket engines at Lewis since the early 1950's as well as features proven in the RL-10, J-2 and F-1 engines.

The customary cut-and-try process was avoided. Instead, theory and definitive small scale experiments were used to produce a design that would work the first time.

Right from the beginning, the M-1 has demonstrated excellent performance, mechanical integrity and good stability. This is the first time an injector for a large rocket engine has given such good results on the first try.

Success of the M-1 design shows the validity of previous theory and the ability to scale up, or extrapolate, small scale results to a very large chamber such as the M-1.

Lewis is also exploring many areas of solid rocket technology and manages the 260-inch Large Solid Rocket Technology Project.



260-Inch solid rocket test

The solid rocket is basically simple. It is less expensive than a comparable liquid propellant rocket and has an excellent history of reliability. These advantages make it attractive for use as booster stages, strap-on thrust augmentation devices for increasing the lifting capability of present launch vehicles, retrothrust systems and many accessory thrusters on board space vehicles.

The first two 260-inch solid motors produced nearly 3.5 million pounds of thrust for a two minute period, the highest thrust level ever achieved by a single rocket motor. A third motor, incorporating several more advanced design concepts, will be fired in June 1967.

One important objective of the third firing (SL-3) will be to verify that the thrust of large solid motors can be tailored to meet a specific mission requirement. The thrust level will be raised to about 5 million pounds of thrust for a period of one and a half minutes by using a faster burning propellant and larger nozzle throat.

A different type of nozzle, called a submerged nozzle, will be used for the SL-3. In addition to reducing overall length of the motor, the new nozzle will be adaptable later to tests of various types of steering systems. A method of controlling propellant burnout is also incorporated in the new motor.

Basic studies are also being conducted in solid motor technology at Lewis which complement the 260-inch project. In the materials area, evaluations are being made of the properties of high strength weldable steels and of large rolled-ring forgings. Motor case failure detection systems for proof testing and actual motor operation are also being developed.

SPACE POWER

INTRODUCTION

One of the absolute necessities for completion of useful missions by satellites, space probes and manned spacecraft is an adequate supply of electrical power. Electricity is needed to operate instruments, perform experiments, radio or televise information back to earth, receive data and commands and maintain the proper environment in the spacecraft, particularly in the case of manned flights.

Out of the hundreds of satellites and space probes launched so far, only PAGEOS (Passive Geophysical Earth Orbiting Satellite) has not required an electric power supply.

Power needs have ranged from just a few watts in small scientific satellites like the Explorers, to a few hundred watts in large orbiting observatories, and up to 1.5 to 3 kilowatts in the Gemini and Apollo manned spacecraft.

Projected needs include tens to hundreds of kilowatts for such possible applications as advanced communications satellites, manned space stations and lunar exploration. Interplanetary flights with electric rocket engines may require more than 1000 kilowatts.

Electrical power is needed in a variety of forms, also. Current density, voltages, duration of need, and whether it is A.C. or D.C. change as the missions change.

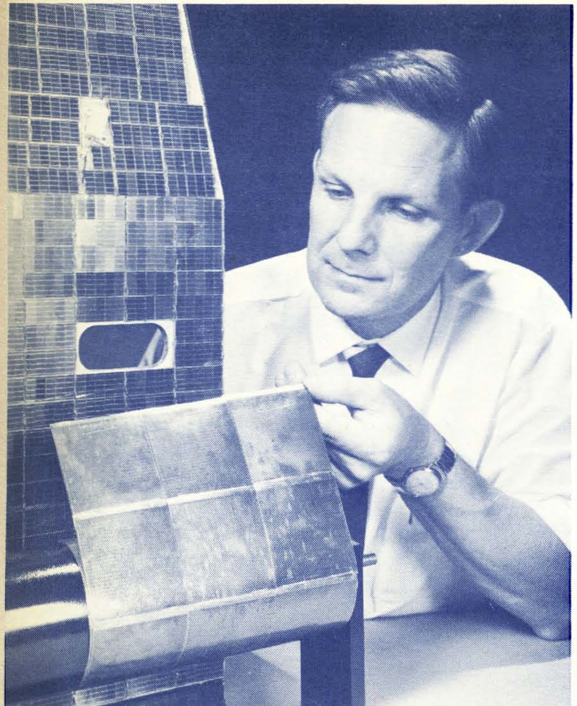
The technical problem is to provide for a particular, specialized power requirement with the most appropriate combination of energy source . . . chemical, solar or nuclear . . . and conversion system. For instance, the modest power needs and long duration operation of most unmanned satellites have been met by solar cells in combination with storage batteries. The batteries permit occasional large power consumption as well as operation when the spacecraft is in the earth's shadow. During daylight periods the batteries are continuously charged by the solar cells. Short duration manned space flights have relied on batteries, but for more extended missions of Gemini and Apollo, the fuel cell system that is used is lighter weight than batteries and circumvents operational problems of maneuvering a spacecraft fitted with very large solar cell arrays that must be aimed at the sun.

Lewis' research and development tasks on power for space flight are directed both at improving the performance and reliability of present systems and at developing technology so that suitable new systems will be available to match future requirements.

STATIONARY POWER SYSTEMS

A major part of NASA's anticipated space power needs of the future are covered by direct energy conversion techniques. Direct energy conversion means the direct conversion of chemical, nuclear, or solar energy to electricity without first using this energy to drive rotating machinery of some sort.

In general, batteries are useful for short times and relatively low power levels. As operating time and power requirements increase, fuel cells are more attractive. For long times at low powers, solar cells are useful. Sun-powered dynamic or rotating systems, for which a parabolic mirror is needed, appear desirable for moderate power requirements over long periods.



Thin film solar cells

Nuclear systems will be used for high power and long durations. Since no one system meets all potential needs, research and development work must be performed on all of them.

Lewis has a number of programs currently underway to improve battery performance. Among the rechargeable batteries, basic research into the fundamental chemistry of nickel-oxide and cadmium components is being conducted to try to extend life and energy output.

The silver-oxide-zinc rechargeable battery can provide three times the energy of the nickel-cadmium cell. Previously, silver-oxide-zinc batteries have been plagued with many problems which limit their useful life, in particular, the number of charge-discharge cycles that they can endure is limited. Under Lewis support, a new type of silver-oxide-zinc rechargeable battery is being developed that has operated fifteen times the life-span of previous types and is serviceable over an even broader temperature range . . . from 32° to 250° F.

Two new batteries are also under development for extreme temperature conditions. One will operate at the 800° to 1000° F range such as is found closer to the sun and on the surface of Venus. The other works down to -140° F which corresponds to conditions on Mars.

Improvement of reliability and power density of small batteries is an example of the way in which space age requirements benefit the entire consumer market.

Programs at Lewis on fuel cells have emphasized increasing life and efficiency. A fuel cell is in essence a continuous battery, with the reacting materials stored outside of the cell and fed to it as electrical power is required.

One promising development at Lewis is the development of a new flexible electrode which has shown stable operation for several months at high efficiency.

Fuel cells operating on hydrogen and oxygen have powered five of the two-man Gemini spacecraft. Others have been qualified for Apollo and will be used on NASA's Biosatellites.

The hydrogen-oxygen cell will probably continue to be the major space fuel cell for the foreseeable future. However Lewis is working on a number of advanced ideas. One concept under development will decompose storable rocket propellants to obtain hydrogen and oxygen for use in a conventional fuel cell.

Because the overall efficiency of a fuel cell can be about twice that of an efficient steam power-generating station, and several times more efficient than an automobile engine in use, their potential value in the future economy of the nation is enormous.

Methods for achieving good reliability and maintaining performance for long periods of time have been largely developed for thermionic converters. This has been an objective of Lewis work in this area for a number of years.

A thermionic converter consists of two metal electrodes separated by a small gap. Heat is supplied to one electrode, called an emitter. As the emitter temperature increases, electrons are boiled out of the metal. The electrons move across the gap to a second electrode which is maintained at a lower temperature. An easily ionized gas like metallic cesium in the gap between electrodes improves performance. Useful power is generated as the electrons return to the emitter through an external circuit.

A thermionic converter produces some 60 watts of electrical power per square inch of emitter surface area, with an energy conversion efficiency of about 15 percent, based on an emitter temperature of about 3000° F. In this case the collector temperature would be maintained at about 1500° F. Tungsten is usually used for the emitter and niobium for the collector.

A solar, chemical, or nuclear heat source can be used to supply heat for a thermionic converter. Nuclear reactors are particularly attractive. In a reactor, the emitter can serve as a container for the nuclear fuel. The collector would be positioned around the emitter. In one concept, the reactor fuel tubes are converter cells arranged end to end and electrically connected in series, very much like batteries in a flashlight case.

The thermionic reactor system would consist of a reactor, converters, liquid metal coolant loop to cool the collectors and a space radiator. A one megawatt (1,000,000 watt) system would require about 500 converters with the reactor about 28 inches long and 18 inches in diameter.

The Lewis nuclear thermionic programs are proceeding on a broad front extending from development of fuel fabrication techniques to irradiation of fuels and insulators in the Plum Brook Reactor. One program has established the compatibility of tungsten with all nuclear fuels of interest. Techniques for making cylindrical fuel forms and vapor deposition of tungsten emitters have been developed also.

Many contributions have been made by Lewis scientists in the solar cell field. And recently a new, super blue, silicon solar cell has been announced by Lewis which has a lifetime in space three times longer than cells currently available.

The silicon solar cell is the most common source of electrical power for spacecraft. They are made from thin slices of silicon crystals and so are quite brittle. Producing the power needed for large spacecraft like Nimbus, OGO, Mariner, and Lunar Orbiter requires large arrays of cells which are complex and costly.

To reduce the cost, weight, and complexity of these solar cell arrays, Lewis has been pursuing a program to develop thin film solar cells which would be larger and very flexible. The thin film cells are made by depositing a layer of cadmium sulfide on the flexible plastic backing.

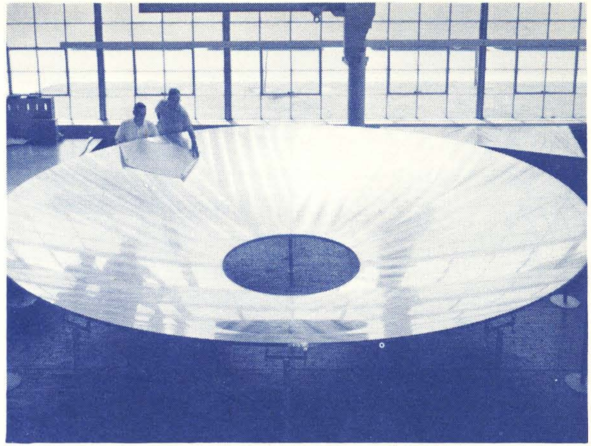
Silicon solar cells must be carried on rigid panels that are folded for launch. Thin film cells might conceivably be rolled up like a flag or window blind and then simply unfurled in space. They are also lighter than the silicon cells.

Present thin film work at Lewis is concerned primarily with raising the efficiency of the cells which is still somewhat lower than the silicon type, although recent advancements have made considerable improvements.

One of the recent Lewis programs in the field of power generation involves the use of a parabolic solar mirror to concentrate the sun's rays for use by a Brayton cycle power generation system.

Techniques for fabricating rigid solar mirrors that are light weight have been developed. A 20 foot solar mirror weighing just 300 pounds was first demonstrated at the 1966 Inspection.

The unit consists of twelve sectors bolted together. The sectors were made from one inch thick magnesium plate. To save weight, essential in any piece of space hardware, most of the magnesium plate



20-Foot solar mirror

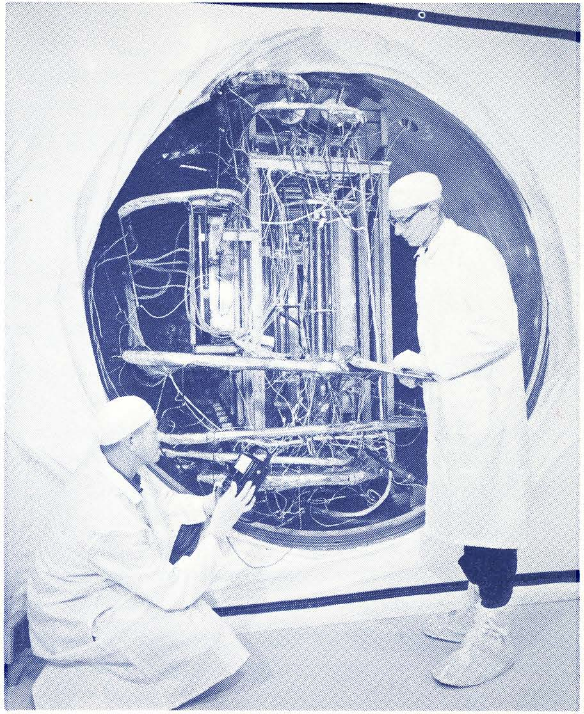
was machined away leaving a honeycomb grid on the rear side. The thickness of the magnesium between the grid sides is between 50 and 60 thousandths of an inch.

After being hot formed by a unique vacuum forming process developed at Lewis, the surface of the mirror is treated with a glossy epoxy resin. Aluminum is then evaporated onto the surface in a vacuum retort. Since the aluminized surface is very thin and easily scratched, a top coating of lacquer is applied.

A Brayton system using a solar mirror 20 to 30 feet in diameter would produce from 5 to 10 kilowatts over long periods of time.

ROTATING POWER SYSTEMS

The sophisticated space missions of the future may require hundreds and even thousands of kilowatts of electrical power. At the present time there are no fully developed power systems to serve multi-channel TV satellites, lunar bases, or large electric propulsion systems for manned exploration of other planets.



Liquid sodium boiler facility

However, the Lewis Research Center is working on the technology that will be required to satisfy these needs. Appropriate systems for large power generation are turbine machines driven either by hot, high pressure gas (Brayton cycle), or by high temperature vapor (Rankine cycle). Either method, to be successful in space applications, requires large advances in the technology of pumps, turbines, bearings, heat exchangers, and radiators.

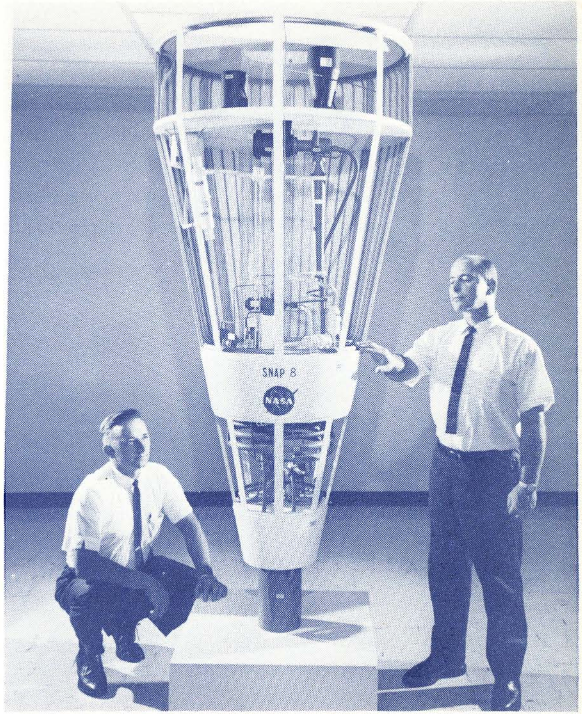
Brayton cycle systems are attractive for applications using both solar and nuclear heat sources. With a solar mirror, the sun's rays would be focused on a heat absorber which would transfer the heat to the operating gas, such as argon. The hot gas passes through two turbines. The first turbine drives a compressor that pumps the gas through the system, and the second drives an alternator to produce the electrical power. Part of the residual heat is put back into the system with a heat exchanger. The remaining heat is then transferred to a liquid loop which rejects the waste heat to space through a radiator.

Most solar powered applications would probably be earth orbiting satellites or space stations. To obtain the heat to operate while in the earth's shadow, heat storage capacity is designed into the heat absorber. Heat storage is accomplished by melting a heat storage material such as lithium fluoride.

The Rankine system is the same basic power generation system used on earth in steam powerplants. In space, liquid metals would be used for the working fluid instead of water. The advantage of using liquid metals is that they allow higher operating temperatures for reasonable operating pressures. This higher temperature results in higher cycle efficiency, and, most important, a smaller radiator for waste heat rejection; most of the weight and size of these systems is in the radiator.

A specific effort in this field has been the SNAP-8, 35 kilowatt nuclear system. SNAP-8 is being developed under the joint direction of the Atomic Energy Commission and NASA. AEC manages the reactor development, while NASA's Lewis Research Center directs development of the power conversion system. Lewis is also engaged in experimental and analytical programs, in house, which are an integral part of the SNAP-8 development effort.

To date, all power conversion components have met performance requirements with the exception of the turbine. The turbine which runs on mercury vapor, has experienced severe materials problems; primarily, reduced ductility of the metals. A new turbine mechanical and aerodynamic design is being worked out now by Lewis and its contractor, Aerojet-General. The next turbine scheduled for early 1967 is expected to approach the desired 10,000 hour design life level.



Model of SNAP-8 power system

BASIC RESEARCH

Lewis is conducting basic investigations in fields of plasma physics, nuclear physics, solid state physics, chemical kinetics, electrochemistry, high temperature chemistry, polymer chemistry and physics, friction and lubrication, gas dynamics, heat transfer and fluid physics, cryophysics and a number of others.

Studies of defects in the structure of crystalline solids on an atomic level provide a good illustration of the broad implications a basic research project can have.

Crystals are made up of regular arrays of atoms whose geometric arrangement depends on the forces of attraction and repulsion. Strength, ductility, electrical conductivity, and response to damage by light and nuclear radiation, are strongly dependent on imperfections in the regularity of arrangement of the atoms.

One of the ways in which the arrangement of atoms in a crystal is studied at Lewis is with a Field Ion Microscope which provides a magnification of about seven million times. This magnification permits a scientist actually to see the individual atoms and to study their arrangements, dislocations, and defects such as vacancies, impurity atoms, and interstitial atoms.

Another method of studying crystal lattice defects used at Lewis is absorption spectroscopy. The general utility of this method can be illustrated in studying the effects of radiation on ruby laser crystals. Lasers are attractive for a number of space uses.

Basic laser research

Ruby is aluminum oxide containing a small amount of chromium impurity. However, the chromium atoms which give the ruby crystal its laser properties must exist in only one of several possible states. Conversion of the chromium atoms to another state can occur if they are exposed to radiation of the sort that exists in the Van Allen belts or are given off by on-board nuclear devices.

The absorption spectrophotometer records the amount of light absorbed by the atoms in a crystal lattice. In the case of the ruby crystal it is possible to determine the effects of varying exposure to radiation by its absorption characteristics.

A third method for studying lattice defects is to study processes such as diffusion in which they play a role. Diffusion is the process by which atoms move in a solid. The motion occurs either by the interchange of an atom with a vacant lattice site or by the jumping of an atom from one interstitial position to another.

Diffusion rates can be measured in several ways and the diffusion curves established yield basic information about the details of the atom jump processes, the energy required to form a vacancy, and lattice distortion around a vacant site.

At Lewis, attention is focused primarily on diffusion in high temperature structural materials. A better understanding is needed because their failure during high temperature use is primarily by diffusion processes.

So in the case of basic research into the defect structures of crystal lattices, it is apparent that the information may find application in areas as diverse as lasers and jet engine turbine blades.

Another basic research area at Lewis is chemical kinetics. Chemical kinetics is concerned with the detailed mechanisms and rates of reactions. Studies of the rates of reaction among atoms, radicals and simple molecules at high temperature have given valuable support to both chemical rocket and air-breathing engine development work.

Maximum performance in chemical rockets and ramjets, for instance, depends on conversion of the fuels to the normal products of complete combustion. The difference in the performance of engines having complete combustion and incomplete combustion is very significant.

Techniques for study of reaction rates include the use of shock tubes, molecular beams, mass spectrometers, and the use of radiofrequency generated atoms and radicals.

Although the results of this basic research are applied to propulsion system studies at

Lewis, the same data have much wider usefulness, such as for certain industrial chemistry processes. Also, atomic reactions are important to understanding the chemistry of the upper atmosphere and may be an important factor in the formation of smog.

Another area of investigation is the Hall effect. The Hall effect gives a measure of the numbers and mobility of electrons and other charged carriers in a semiconductor. This is particularly applicable to the development work with solar cells but is equally applicable to other facets of the electronics industry.

At Lewis a highly automated method of measuring the Hall effect is used. An apparatus is used which passes current through a small sample of semiconductor material, applies a magnetic field that causes the charged carriers to drift from one side of the material to the other and then measures the current induced by this drift.

Another tool of basic research used at Lewis is the gas laser interferometer which is being used to determine the particle density in a thermionic diode. Thermionic diodes are being considered for use in nuclear reactors to produce electrical power for spacecraft in the future.

Plasma particle density is determined by measuring the difference between the frequencies of two laser beams, one of which is passing through the diode plasma.

Basic research is methodic, exacting and its pursuit even in a minute segment of a field of scientific interest may stretch over a lifetime. But each new bit of knowledge that is uncovered adds to our understanding of that field and may lead to undreamed of benefits in the future.

ELECTRIC PROPULSION

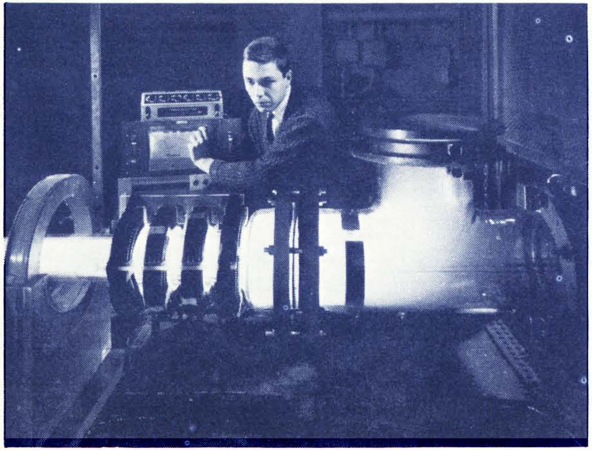
As man reaches farther out into space, to the other planets in our solar system or beyond, new, more efficient propulsion systems are needed.

Electric propulsion offers great promise in this area and is one of the advanced propulsion concepts that has been under study at Lewis for a number of years.

The advantage of electric propulsion stems from the high propellant exhaust velocities possible. These high velocities mean that much less propellant need be carried, making room for additional payload. Chemical rockets, such as the Atlas and Saturn, have exhaust velocities of two to three miles a second. Electric thrustor exhaust can reach almost any velocity up to the speed of light. Practical considerations, such as the amount of electrical power needed, limit this to about 20 to 50 miles per second at present.

Electric propulsion was originally considered for manned interplanetary missions and large interplanetary probes using huge arrays of electric engines powered by nuclear turboelectric generating devices.

In addition to manned missions, the recent developments in solar cells are leading to consideration of electric propulsion for much lower power levels such as attitude control, maintaining the position of synchronous satellites and thrust augmentation of interplanetary probes. Early studies assumed that interplanetary missions would start in a low earth orbit and then, using their electric engines, spiral slowly out. With thrust augmentation, the vehicle would be boosted to escape velocity by a chemical rocket. The electric engines would then be used only during the interplanetary portion of the flight. Although thrust augmentation requires larger chemical rocket boosters than the earlier approach, it does make it possible to obtain some of the advantages of electric propulsion with a much lower-powered system.



Plasma engine research

There are three general types of electric thrustor. The electrothermal type uses electric power to heat a propellant, similar to the way combustion heats the propellant in a chemical rocket.

The most promising electrothermal thrustor is the resistojet in which a resistance heating element (such as you might find in a toaster) is used to heat the propellent. The resistojet is simple, efficient and reliable. Research on this thrustor has been completed at Lewis and it is the one electric thrustor that has been used in a practical application - the station keeping of a satellite.

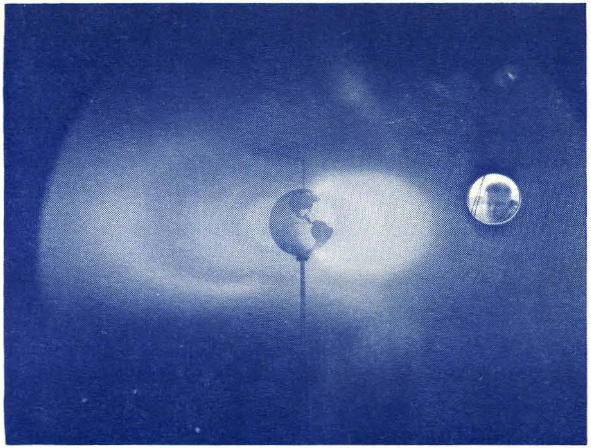
Although an electrothermal thrustor can produce higher exhaust velocities than a chemical rocket, temperature limitations of materials still keep it far below the optimum for electric propulsion.

The second general type of electric thrustor is the electromagnetic type. The electromagnetic thrustor uses the interaction of a current and a magnetic field, similar to that used in many electric motors. The moving conductors of the current in an electric motor are copper wires, but in an electromagnetic thrustor, the conductor is a plasma or ionized gas. An ion is simply an atom with an electron removed. It then becomes positively charged and is called an ion. A plasma is a gas composed of ions and electrons and can conduct an electrical current similar to the way a wire does.

The most promising thrustor of this type is the magnetoplasmadynamic (MPD) thrustor.

A Lewis MPD thrustor has produced exhaust velocities of nearly 30 miles per second.

One of the major advantages of an MPD thrustor is the simplicity of associated electrical circuitry. Unlike the electrostatic engine, to be discussed next, it re-



Artificial Van Allen belts

quires little more than the engine and a power source. Considerable testing remains, however, before a MPD thrustor will be ready for use in space.

The third and most highly developed type of electric thrustor is the electrostatic engine.

The electrostatic engine uses an ionized propellant. However, instead of a plasma consisting of both ions and electrons, only the positively charged ions are used. Because the propellant has a positive charge it can be accelerated electrically and ejected from the nozzle at a high exhaust velocity. Once the propellant leaves the nozzle the electrons that were stripped from the atoms earlier, to form the ions, are replaced to avoid having the ions attracted back to the engine which would stop the beam.

It was a Lewis engineer who designed and built the first electrostatic thrustor to operate successfully in space. The engine was an electron bombardment type, which means that the ions were produced by bombarding atoms of mercury vapor with energetic electrons.

Electron bombardment appears to be the most efficient method of producing ions for large engines.

Contact ionization is another way of producing ions. Here an atom loses an electron when it contacts a hot surface. Only certain combinations of atoms and surfaces produce contact ionization. Cesium atoms striking a tungsten surface at about 2000° F seems to be the best combination.

Contact ionization thrustors appear to be best suited for low-thrust applications.

The first electrostatic engine was tested on the SERT-I (Space Electric Rocket Test) flight. The SERT thrustor's propellant beam measured just 5 inches in diameter. Since that time Lewis has built and tested engines with beams up to 5 feet in diameter.

The first interplanetary probes to use electric rocket engines will probably use engines just slightly larger than SERT-I engines. Later applications will require the larger units.

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