News

LEWIS
RESEARCH
center

21000 BROOKPARK ROAD CLEVELAND, OHIO 44135
PUBLIC INFORMATION OFFICE
PHONE - (AREA CODE 216) 433-4000 EXT. 415

FOR RELEASE: IMMEDIATE

Release 66-54

Lynn Manley
(res: 243-3489)

CLEVELAND, Ohio, Sept. 16 -- About 2,000 top executives of government, business and industry will tour research facilities at the National Aeronautics and Space Administration's Lewis Research Center here Oct. 4-7, 1966.

Purpose of the 1966 NASA-Lewis Inspection is to brief aerospace leaders on research and development progress at the Cleveland Center. Identical programs will be held on each of the four days, followed by an Employee Open House on Sunday, October 9.

Emphasis during the all-day Inspection will be on Lewis' work in advanced research and technology. Formal presentations and exhibits will focus on work in: air-breathing engines, materials, basic research, space vehicles, advanced chemical rockets, space power generation and electric propulsion.

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In announcing the Inspection, Dr. Abe Silverstein, Lewis director, said the occasion has been planned so that visitors might examine some of Lewis' newest research facilities and learn the scope of the Center's work in support of NASA missions.

First-day visitors will be welcomed to Lewis by Dr. Silverstein and James E. Webb, NASA Administrator. Other NASA officials will serve as hosts during the ensuing three days.

Such inspections of NASA facilities are relatively new; however, they were held periodically from 1926 to 1958 under the National Advisory Committee for Aeronautics, NASA's predecessor. The first NACA inspection was held at the Langley Research Center in Virginia in 1926 and the last at the Ames Research Center in California in 1958. Lewis hosted its last inspection in 1957. They were discontinued during World War II. In 1959 and 1964 Langley held the only inspections since NASA was created in 1958.

Dr. Silverstein has named Willson H. Hunter as manager of the Lewis Inspection. Hunter, a veteran NACA/NASA engineer who has worked both at Lewis and at NASA Headquarters in Washington, also managed the 1957 Lewis inspection. He is being assisted this year by a team of Lewis staff members.

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FOR RELEASE: IMMEDIATE

Release 66-60

Lynn Manley
(res: 243-3489)

CLEVELAND, Ohio, Sept. 30 -- Advanced research and technology in support of NASA aerospace programs will highlight a tour and orientation here next week when the National Aeronautics and Space Administration's Lewis Research Center will host top executives from around the U.S.

Occasion is the 1966 NASA-Lewis Inspection, October 4 - 7. Some 1,800 leaders of Congress, government, universities, business and industry are expected to tour the Cleveland Center during the four-day program.

NASA Administrator James E. Webb and Dr. Abe Silverstein, Lewis director, will greet visitors on the first day of the Inspection, followed by a series of "stops" during which key work at Lewis will be explained and demonstrated. Identical programs are planned for each of the four days, with about 450 visitors expected each day.

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In addition to the tour of Lewis facilities, visitors will have an opportunity to view many exhibits representative of NASA work in space, including the Gemini VII spacecraft, a Centaur high-energy rocket vehicle, and models of many scientific spacecraft launched by Lewis-managed vehicles.

Gemini VII is the spacecraft in which Astronauts James Lovell and Frank Borman completed the longest manned mission to date--14 days--in December 1965. The Centaur vehicle, whose development has been directed by the Lewis Research Center, has successfully sent two Surveyor spacecraft on lunar trajectories. Surveyor I, launched last May 30 by an Atlas-Centaur vehicle, recorded the U. S.' first soft-landing on the Moon and subsequently returned to Earth thousands of high-quality, detailed photos of the lunar surface.

The 1966 NASA-Lewis Inspection has been planned to commemorate the Cleveland Center's 25th year as the nation's major laboratory for research in advanced aeronautical and space propulsion, as well as systems for generating electrical power in space. Visitors will hear detailed presentations and at the same time view facilities in which this work is actually being conducted. Major topics to be discussed include: advanced air-breathing engines, materials, basic research, space vehicles, advanced chemical rockets, space power generation and electric propulsion.

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This year's inspection will be the first held at Lewis since 1957 when the Center was a part of the National Advisory Committee for Aeronautics, NASA's predecessor agency. The Lewis staff has since grown to almost 5,000 employees, including 1,900 scientists and engineers, located at the main Cleveland facility and at the Plum Brook Station near Sandusy, Ohio.

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FOR RELEASE: Tuesday A.M.'s
October 4, 1966

Release 66-61

Lynn Manley
(res: 243-3489)

CLEVELAND, Ohio, Oct. 4 -- One of the nation's newest and most unique research facilities for studying weightlessness will be unveiled publicly for the first time today at the National Aeronautics and Space Administration's Lewis Research Center.

Some 450 visitors will witness a dramatic demonstration in Lewis' 500-foot deep Zero Gravity Research Facility during the first day of the 1966 NASA-Lewis Research Center Inspection. The demonstration, featuring an actual drop of a 1500-lb. test specimen in the vertical research facility, will be repeated during the four-day long Inspection with a different audience each day.

The 1966 Inspection is being hosted by NASA-Lewis to permit representatives of Congress, industry, business, universities and government to view firsthand the results of aerospace research and development taking place at the Cleveland Center. Visitors will tour Lewis facilities where they

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will see and hear demonstrations and presentations concerning advanced aerospace propulsion and systems for generating electrical power in space.

The Zero Gravity Facility, just recently completed, is expected to be a major attraction. The shaft, or drop tower, is the largest such facility in the U. S. for producing weightless conditions encountered in space. Actual free fall distance for specimens undergoing testing is 450 feet.

The basic structure of the facility is a shaft that extends 510 feet below grade. The shaft is lined with an 18-inch thick concrete casing 28 feet in diameter. Inside is a welded steel vacuum chamber 20 feet in diameter.

Five seconds of weightlessness can be produced by releasing the experiment from the top of the shaft. This time is doubled when the experiment is projected upwards from the bottom of the chamber by a Lewis-designed high-pressure accelerator. The experiment then falls free to a decelerator cart, thus traversing the 450-foot distance twice. The facility can handle experiments weighing up to 6000 pounds.

The decelerator cart is unique in itself. It stands 19 feet high, is 12 feet in diameter and weighs over 22 tons. It is retracted when the accelerator is used to propel objects upward, then can be deployed into its retrieval position in four seconds. Inside the device are millions of small spheres of expanded polystyrene, which permit deceleration of an experiment at a controlled rate. Experiments are decelerated at about 30 g's to prevent damage.

A 2500-pound experiment, traveling 176 feet per second, can be brought to a dead stop in about 15 feet of deceleration material. The energy absorbed in such an experiment is comparable to stopping a modern compact automobile traveling at 120 miles per hour in a distance of 15 feet without damage.

During actual testing, air pressure in the shaft is reduced by a vacuum system to that found at an altitude of 50 miles. This eliminates the need to surround experiments with drag shields as used in conventional drop towers.

A typical zero gravity experiment consists of a transparent tank containing test fluids. High-speed motion picture cameras record the fluid's behavior during zero-G operation. Other data such as pressures and temperatures are recorded onboard the experiment or transmitted via telemetry to receiving equipment. Operation of the Zero Gravity Facility is centered in a control room located in the service building where television monotors permit the test director to view all critical areas of the facility during a test.

Primary objective of the new facility is to provide space scientists with more detailed information on the behavior of fluids in a weightless environment. This is a particularly vital area concerning propellant positioning in rocket vehicles coasting in a zero-G condition.

During the past few years, studies of zero-G phenomena have been made in rocket ballistic flights, in aircraft flying brief zero-G parabolas, in other smaller drop towers, such as Lewis' 100-foot facility, and in some actual

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test flights by Centaur and Saturn upper stages. But for long-duration space exploration, when rocket vehicles will be required to coast for long periods under weightless conditions, present-day facilities and methods are insufficient.

The advantage of Lewis' new Zero Gravity Facility is that it is ground-based; experiments are controlled, results are readily available, modifications can be made, and the experiments can be repeated many times over.

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FOR RELEASE: TUESDAY A.M.'S
October 4, 1966
(Also released in Washington, D.C.)

Release 66-62

Joann T. Temple
(res: 777-0865)

CLEVELAND, Ohio, Oct. 4 -- An orbital flight experiment designed to advance the development of ion engines (electric thrusters) as propulsion units for future long-duration space missions is planned in late 1968 by the National Aeronautics and Space Administration.

The NASA Office of Advanced Research and Technology (OART) has authorized the agency's Lewis Research Center, Cleveland, to proceed with the second part of its SERT (Space Electric Rocket Test) Program. The first successful operation in space of an ion engine was conducted by Lewis during a 50-minute SERT I ballistic flight July 20, 1964.

This program extension calls for a satellite mission to evaluate the in-flight performance of electron-bombardment ion engines over a period

- more -

of six months or longer and to analyze the possible effects of such electric thrusters and their associated electric fields and voltages on other spacecraft components (such as solar cell arrays and radio transmitters and receivers).

Ion engines produce small amounts of thrust by ionizing and accelerating a propellant (in this case, mercury) to high velocities. They can be operated for prolonged periods or turned off and on at will for long duration missions.

Electric thruster applications range from existing single small units capable of controlling the attitude and orbits of satellites to potential multiple arrays capable of providing the primary post-launch propulsion for manned or unmanned interplanetary missions.

The SERT Program is managed by Lewis for OART with Raymond J. Rulis as Project Manager at Lewis.

In the SERT I flight, an ion engine built by the Lewis Center was operated twice for a total running time of 30 minutes. SERT I confirmed in-flight that positive ions racing out of the electron bombardment engine at speeds in excess of 100,000 mph could be effectively neutralized to achieve thrust.

Two ion engines designed and built by Lewis will be flown in this second flight of the SERT project. The characteristics of electron bombardment thrusters allow them to be scaled in power and size levels. Performance data from the 15 centimeter diameter (almost 6 inches) engines, for instance, will be applicable to engines more than three times as large.

Plans for the project call for launch by a Thorad. The two ion engines, each with a power input of one-kilowatt, will be attached to the Agena stage at the end opposite the Agena nozzle. Only one at a time will be fired.

The Agena will serve as the basic spacecraft and will be stabilized in a nozzle up position. It will be equipped with a 1 1/2 kilowatt solar cell array.

The Agena and its components, including solar cells for electric power, constitute flight equipment already operated in space. The only spacecraft portion not previously flight tested will be the new electric thrusters and their associated equipment.

The spacecraft will be integrated at the Lewis Center for launch into a 575-mile-high polar orbit from California's Western Test Range under the direction of the Lewis Agena Project Office.

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NASA-Lewis Research Center Inspection
October 4 - 7, 1966

AIR-BREATHING PROPULSION

The next generation of aircraft will include many advanced and specialized designs such as supersonic transports, giant subsonic carriers, vertical take-off and landing craft and advanced military planes. To make these 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 the 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.

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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 mid-chord 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 geometry 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 that the efficiency of these components becomes increasingly important.

The inlet and nozzle work will be conducted both in Lewis' 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 material 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 reducing the noise of turbojet engines. Recently, experiments have been initiated on this problem in fan jets and the prospects for reducing noise are very encouraging. In the turbojet, most of the objectionable noise is produced by the jet; however, most of the objectionable noise in a fan jet is produced by the fan.

In the jet engine, there is first an area of mechanical noise such as the compressor blades moving across the stationary stator blades which creates an interference noise. In the fan jet engine, this compressor whine, a siren-like effect, is frequently more annoying than the engine "roar."

To know where and how much to change the aerodynamic design of mechanical components requires extensive studies of rotating equipment in proper test facilities. A program to investigate the problem of jet engine noise from this viewpoint has been established at Lewis.

Meanwhile, a second approach to noise abatement has been undertaken in which sound absorbing devices and materials are being used to "doctor" up the existing machinery and make it less noisy. Noise reductions from 10 to 30 decibels should be possible through such an approach.

Lewis has used a combination of resonators for reducing noise and absorbing materials to dissipate the noise on the J-65 engine. The inlet cowling on the J-65 engine, used on Lewis' B-57 research aircraft, was modified and the inner surfaces were lined with porous metal supported over a one-inch cavity. A circumferential splitter ring and radial supports were similarly fabricated.

Slotted compressor blades, similar to those being investigated for the SST, show promise for further reducing noise in the fan jet engine.

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NASA-Lewis Research Center Inspection
October 4 - 7, 1966

SPACE POWER GENERATION

Stationary and Rotating Machinery Systems

Five years ago, fuel cells were exotic novelties in the power system family. Today they are flight-line items on the Gemini spacecraft.

Five years from now, which of the presently exotic ideas will become flight-line items? This is the guessing game which advanced technology engineers must play not only for five years into the future, but 10, 15 and even 20.

The choice of a power system for a specific mission is dictated by the power requirements and the nature of the mission. As future missions could range from large scientific spacecraft and manned orbiting space stations to lunar bases and manned interplanetary missions, future power needs will vary considerably. Advanced research and technology studies at Lewis, therefore, cover many aspects of the space power field--solar cells, batteries, fuel cells, isotope generators, thermionic diodes, large rotating machinery systems and nuclear thermionic systems.

Lewis work in batteries covers a broad spectrum ranging from fundamental electrochemical research to studies of batteries for use at extreme temperatures. Present off-the-shelf batteries have definite temperature limitations restricted to operation between -40° and 200° F. Beyond this range, they do not operate well, if at all. A low-temperature battery, being developed by Lewis for future space use, has been successfully tested at 130 degrees below zero.

In current spacecraft, batteries are usually secondary power sources backing up the solar cells which have always been the primary source of power aboard scientific satellites. A few years ago, arrays of these tiny solar "batteries" were small, putting out less than 100 watts. But, over the last decade, tremendous improvements have been made in their efficiency, weight and durability in the radiation environment of space. NASA recently launched the Orbiting Astronomical Observatory spacecraft with 114 square feet of solar cells putting out about 1000 watts.

Based on requirements for lighter, self-contained solar cells, Lewis scientists and contractors are making extensive studies of thin-film cells, which are made by heating a semiconductor material until it evaporates. The vapor is then condensed into an electricity-producing film only one thousandth of an inch thick.

The newer thin-film cells are less efficient than conventional silicon cells, but their desirable characteristics--flexibility, lighter weight, comparative economy--warrant additional research.

Permanent lunar bases and earth orbiting space stations may need power plants that can deliver up to 100 kilowatts of electric power continuously for as long as 10,000 hours. In addition to such life support needs, lightweight, high-output power systems will also be needed for propulsion in future interplanetary missions using electric engines.

Such high power needs will probably be best met with a nuclear space power generating system. Possible nuclear reactor powered systems now under study include an advanced vapor system, a mercury Rankine system (SNAP-8), a thermionic system, and Brayton systems.

SNAP-8 (System for Nuclear Auxiliary Power) is being developed under the joint direction of the Atomic Energy Commission and NASA. The AEC manages development of the reactor and NASA's Lewis Research Center directs development of the power conversion systems. Although SNAP-8 is not a propulsive power system, its technology could pave the way toward much higher power systems.

SNAP-8 is not being developed for a specific mission at this time. Instead, the program is aimed at developing components, subsystems, and system technology to the point where major system performance and development uncertainties are understood and resolved.

The conventional, earthbound, turbomachinery power-generation system is based on a Rankine thermodynamic cycle with water as the working fluid. Water is heated into steam in a boiler and this steam goes on to drive a turbine which provides the mechanical work necessary to produce electricity. The steam, having done its work, is condensed into water and re-cycled back into the boiler to begin the thermodynamic cycle again.

There is an inherent heat loss in any thermodynamic cycle. Removing this heat in space could be a problem since it must be radiated. To avoid unwieldy radiator sizes, the temperatures of the working fluid must be as high as practical. For this reason, mercury with a higher boiling temperature than water, was chosen for the SNAP-8 system designed for space.

The SNAP-8 power system is composed of four fluid loops. The primary loop passes through the reactor. A liquid sodium-potassium (NaK) eutectic mixture flows through this loop, picks up heat from the reactor, and carries it to a heat exchanger where it meets the mercury-Rankine loop. The NaK enters this heat exchanger at 1300° F.

The mercury -Rankine loop receives the heat from the NaK reactor coolant in the heat exchanger. Here liquid mercury is heated to about 1100° F., boiled, and the mercury vapor superheated to 1280° F. This superheated vapor is expanded through a turbine, condensed, and returned to the boiler via a pump.

In the heat rejection loop, the waste heat from the Rankine loop is transported by liquid NaK to a radiator that radiates the waste heat to space.

The fourth and final loop is a liquid organic fluid loop used to cool electrical equipment and to lubricate bearings.

A SNAP-8 research system being assembled at Lewis will incorporate flight components with the exception of the reactor and the radiator.

Even higher temperature liquid metals than mercury may be used in future nuclear systems. The heat transfer properties of the alkalai metals (sodium, potassium, rubidium) appear to be very useful. Lewis has been investigating the possible difficulties of working with these corrosive liquids. A large-scale potassium radiator operated for some 300 hours has provided much information on handling condensing potassium at temperatures ranging from 1400° F. at the radiator inlet to 600-800° F. at the outlet. Similarly, a sodium boiler has been built and tested. Due to the extreme reactivity of sodium and its 2000° F. boiling temperature, this research boiler had to

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be constructed of refractory columbium. Test runs were made in a large vacuum tank to prevent oxidation of the sensitive metal.

Of the possible nuclear systems, a Rankine cycle would offer the lowest weight for a given temperature level. Another advantage lies in its small radiator area; however, it does require a two-phase liquid metal system for which the technology is now only being formed.

The Brayton cycle uses a gas rather than a liquid as the working fluid, and its primary use will probably be in auxiliary power plants. It would avoid the problems associated with boiling and condensing a moving liquid in weightlessness and the possibility of erosion damaging moving parts. However, it would be heavier and have a larger radiator than a Rankine cycle system.

Much technology exists on the Brayton cycle where the basic cycle for space would be much the same as a jet engine. In a jet engine, a gas enters the compressor, emerges as ahigh pressure gas, then enters a combustor where fuel is added and the temperature increased. This high pressure, high temperature gas then passes through a turbine and is exhausted overboard.

In passing through the turbine it spins the turbine and produces work to run the compressor. In the case of a power generation system, it will develop power for the generator. In the case of a propulsion system such as the jet engine, the extra work goes to producing thrust.

Reasons for considering the Brayton cycle for use in space include its versatility, the fund of knowledge already available on the operation and application of the cycle, the wide power range and wide variety of possible heat sources applicable, and the high cycle efficiency possible. The latter is especially critical with isotopes or solar energy where heat input is at a premium.

An extensive technology program is now underway at Lewis aimed at better understanding the potential of the Brayton cycle and exploring specific problems that arise in its application. In component technology specifically, adequate performance--particularly in regard to small turbine machinery--is a major question as is mechanical reliability and integrity necessary for long term operation. Control and criticality of start-up are, of course, of interest also.

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A Brayton cycle turboalternator test facility at Lewis is being constructed to define the performance and operating problems of turboalternators. Aiming at systems studies of an 8-10 kilowatt solar Brayton system, Lewis has constructed a rigid metal mirror.

The mirror would be used to focus the Sun's rays on the heating tubes of the Brayton cycle. On a flight system these tubes would be placed in an insulated receiver mounted about 14 feet above the center of the mirror.

A 20-foot-wide prototype mirror has been developed by Lewis. It was made in 12 sections. Each section was machined from one inch magnesium plate and then formed in a unique process developed at Lewis. Each section was then coated with an epoxy and aluminized through a vacuum metalizing process. A flight system using a 30-foot mirror would provide from 8 to 10 kilowatts of electric power in space.

Because of the large radiator areas required and the potentially high cycle efficiency, primary application of the Brayton cycle in space would probably be at low and intermediate power levels.

Component work thus far indicates that acceptable performance can be achieved particularly with respect to the turbo-machinery. Stable gas bearings are also working with acceptable power losses.

The advanced nuclear vapor system is a Rankine cycle quite similar to power generating systems used for years in ground-based power plants. In the space system, a fluid, probably a liquid metal like lithium or a sodium-potassium eutectic mixture, will pass through a reactor. It acquires heat as it cools the reactor. Continuing on through the system, the hot reactor fluid meets the cooler thermodynamic working fluid and loses its heat in converting the working fluid into a hot vapor. The cooled reactor fluid is then cycled back through the reactor to continue the heat-exchanging process while the hot vapor moves on to drive a turbine and create electricity.

Design information and data on bearings, seals, pumps, electrical materials and emissive coatings for radiators is accumulating. The development of a single tube boiler has already been contracted and other components will follow over the next few years.

Lewis has done much work on thermionic diodes or converters. A thermionic converter consists of two metal electrodes separated by a small gap. Heat is supplied to one electrode, called the emitter. As the emitter temperature increases, electrons in the metal gain sufficient energy to overcome these binding forces and are, in effect, boiled out of the metal.

The electrons move into the gap and eventually reach the second electrode or collector. The collector must be cooled to be at a lower temperature than the emitter. Useful power can then be generated as the electrons return to the emitter through an external circuit. These converters produce some 60 watts of electric power per square inch of emitter surface area with an efficiency of about 15 per cent.

Lewis has been investigating means of improving the performance, stability and reliability of these converters. A solar, chemical or nuclear energy source could be used to supply heat to the emitter, however, nuclear reactors are of particular interest.

Thermionic ideas can also be applied to large reactor systems. Lewis nuclear programs in the thermionic area are proceeding on a broad front ranging from development of fuel fabrication techniques to irradiation of fuels and insulators in the Plum Brook reactor.

In theory, a nuclear thermionic system offers greater simplicity of operation than the turbine systems in a similar power range. Placed directly in a reactor, a thermionic diode will again operate because of a difference in temperature. The casing around the reactor's fuel elements would be tungsten which will "boil-off" electrons at about 3000° F. The electron stream then flows across a narrow gap through a semi-vacuum to a cooled anode. The flow of electrons thus sets up a power source quite similar to an ordinary battery.

Unlike an ordinary battery, the power available from such a nuclear thermionic system is expected to range from about 30 to 65 watts for every square inch of tungsten wrapping. Technology investigations of both this system and the nuclear heated vapor system are underway at Lewis.

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NASA-Lewis Research Center Inspection
October 4 - 7, 1966

ELECTRIC PROPULSION

and

CRYOMAGNETICS

All rockets work on the same basic principle: propellant mass is somehow exhausted from the rocket at a given velocity. The rate of this propellant mass flow times the exhaust velocity is equal to the thrust:

> 360,000 pounds in the Atlas which carried the first American into orbit;
>
> 430,000 pounds in Gemini's Titan II booster;
>
> 7.5 million pounds in the Saturn V being developed for the Apollo man-on-the-moon program; and
>
> six thousandths (0.00637) of a pound in the SERT-I electric rocket engine, the first ion engine to operate successfully in space.

Large chemical boosters attain their thrust by msssive propellant flow rates. Electric or ion engines attain their thrust by tremendous exhaust velocities, some 50,000 to 100,000 feet per second in present engines, but theoretically limited only by the speed of light. Since the ion engine's propellant flow rate is in the form of ions or charged molecules, the amount of propellant used is very small and the engines could operate continuously for months or even years.

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Total impulse is the rocket engineer's "mileage" figure. It is the product of the rocket's thrust times the time the rocket vehicle operates. Thus, a mission to Mars requires a certain total impulse, a mission to Venus, another total impulse. Any rocket that can meet the total impulse requirements--either through high thrust for matters of minutes or extremely low thrust at continuous operation--could be used.

Electric propulsion was originally considered for manned interplanetary missions and large scientific probes to the planets. Such missions would make use of huge arrays of electric engines and nuclear turboelectric generating devices.

These early mission studies assumed that the interplanetary mission would start in a low earth orbit, where the electric spacecraft had been placed by high-power chemical boosters capable of taking off from Earth's surface, which low-thrust electric engines are not.

Recent advances in solar cells and consequent increase in on-board electric power however have extended consideration of electric propulsion devices for much lower power levels as well. The first actual application of electric rocket engines was the attitude control or position keeping control of long-life satellites. This job will probably be the first widespread use of electric propulsion.

There are many possible variations of the thrustor for an electric propulsion system. Thrustors are the part of the system that provides the propulsive thrust. They are the backend of an entire propulsion system, including propellant, thrustor and electric power. Each thrustor requires different voltages and different sorts of electric currents --- AC, DC, radio frequency--although all have a similar propellant flow. Each needs some kind of power conversion system and control system to control the thrustor.

Basically, the thrustors can be separated into three principal categories--electrostatic, electrothermal and electromagnetic. Within each category there are variations.

The electrothermal systems are similar to chemical rockets except there is no combustion. A propellant gas is heated to a high temperature and expanded through a nozzle to produce thrust. These thrustors can achieve exhaust velocities twice that of chemical rockets but they are limited by the breakup and dissociation of the propellant gas molecules which absorbs energy without

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significantly raising the gas temperature much further.

Because of this upper limit on exhaust velocity, electrothermal thrustors will probably not be used on interplanetary missions but they could be used on short range trips to the Moon or for attitude control of large spacecraft. The arc-jet thrustor is in a fairly advanced state of development and, to date, operates around 40 per cent efficiency.

The propellant gas is heated by flowing through an electric arc.

The most promising electrothermal thrustor is the resistojet in which a resistance heating element, such as might be found in a toaster, is used to heat the propellant efficiently and reliably. Research on this thrustor has been completed by Lewis and it is the one electric thrustor that has been used in a practical application---the station-keeping of a satellite.

In the electrostatic engine, propellant atoms are ionized by removing an electron from each atom. The electrons are removed entirely from the ionization region at the same rate as the ions are accelerated rearward by the action of high voltage and magnetic fields. The electrons are re-added to the ion exhaust beam behind the engine via a neutralizer to make the final beam electrically neutral.

The most efficient means for producing ions in large electrostatic engines appears to be electron bombardment. It was such an engine that was designed and developed at Lewis for the first successful ion engine test in space aboard the SERT-I (Space Electric Rocket Test)suborbital spacecraft.

Another method for producing ions is contact ionization. Here the propellant atom loses an electron when it contacts a heated surface. Cesium propellant and a tungsten surface seem to be the best combination here. Contact ionization thrustors seem to be best suited for low-thrust applications.

Lewis work in the well developed electrostatic engines has included endurance tests, a scaling program to build and test large units, and clustering the smaller units to study possible interactions. In a recent endurance test, one engine ran in the simulated space of Lewis' 80-foot vacuum tank for more than six months---4870 hours---before failing due to a short in the accelerator system.

The largest ion thrustor built to date is a meter and a half (about five feet) in diameter and generates about a pound of thrust with 150 kilowatts in the jet.

Electromagnetic thrustor research is trying to use plasmas in a propulsion device. The change of state from gas to plasma involves an internal change in the molecular or atomic structure of the substance. Atoms are made up of negatively charged electrons, positively charged protons, and electrically neutral neutrons. In a netrual atom, such as those comprising ordinary matter, there are as many electrons around the nucleus of the atoms as there are protons in the nucleus,and the atom is electrically neutral. The atoms in a plasma are no longer atoms. They have lost one or more of their electrons and the resulting swirling mass of positive ions and negative electrons is a hot gas-like mass that conducts electricity.

Because it conducts electricity in much the same way that a copper wire does, a plasma could replace ordinary metallic conductors in an electric generator. Also because of their electrically charged character, both ions and plasmas are affected by electric and magnetic fields. Thus, they can be accelerated to very high velocities or, in the case of plasmas, they can be squeezed, heated, confined and otherwise manipulated by properly applied fields.

The most promising electromagnetic thrustor of this type is the magnetoplasmadynamic (MPD) device. A Lewis MPD thrustor has reached exhaust velocities of nearly 30 miles per second.

The growing maturity of ion and plasma technology requires work in the ability to generate and use very powerful beams of matter, to handle these beams in vacuum tanks, to interact them with solids in a predictable way, and ultimately, to perhaps even produce a controlled thermonuclear fusion reaction.

Although research and, in some cases, development hardware is being evolved through Lewis' electric propulsion program, there is much basic research also. Lewis scientists are investigating the basic physics of plasmas, simulating the solar wind around the Earth in vacuum tanks, and keeping pace in the rapidly expanding technology of magnetics and superconductivity.

Reducing a city's electric power sub-station to the size of a small office is just one of many possible extrapolations of NASA's current research on cryomagnetics and superconductivity.

Good conductors such as copper or aluminum show a decrease of 10,000 to 100,000 in resistance between room temperature and absolute zero. But, such common conductors are not usually very good superconductors if they have any superconducting properties at all. True superconductors show a very sharp drop in resistance at very low temperatures. Lead and tin are two such materials.

Superconductivity is explained physically by the drastic decrease in temperature reducing the internal activity in the atoms of the material. This reduced activity allows electrons to pass more easily through the lattice structure--thus, the material presents less resistance to electricity, the flow of electrons, and becomes superconducting.

Lewis research apparatus includes a 200,000 gauss liquid neon-cooled cryomagnet and several smaller superconducting magnets.

Although immediate applications of super-magnets may well be limited to the space program, many conventional devices, even such prosaic and well developed items as transformers, can be significantly improved by using superconducting materials. Electric power savings could be substantial and such systems would be greatly reduced in size, by factors of 10 to 100.

Since the highest temperature at which any known material is superconducting 427° F. below zero, all superconducting devices require liquid helium as a coolant. However, it is possible to use cryogenic but non-superconducting techniques to substantially reduce the total power consumption of many electrical systems.

A magnet to produce a magnetic field of 100,000 gauss (200,000 times stronger than the magnetic field of the Earth) would absorb 3000 kilowatts of electrical power if operated at room temperature. A cryo-magnet to do the same job would need only 120 kilowatts and a superconducting magnet would need none other than that to overcome heat leaks to the coolant.

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NASA-Lewis Research Center Inspection
October 4 - 7, 1966

ADVANCED CHEMICAL ROCKETS

As in all of man's exploration, advancement in space is paced by the ability to get there. Thus, continuing propulsion research and better rocket engines are a key part of our nation's future space program.

The advanced chemical rocket program at the National Aeronautics and Space Administration's Lewis Research Center has several goals: improved performance and reliability; reduced development time and cost; and increased size.

Rocket engines have been plagued with a problem of high-frequency combustion instability called "screech." Even during so-called "steady-state" operation, the combustion process is never entirely smooth. That is, pressures, temperatures and flow rates inside the engine continually fluctuate above and below some desired value.

If these fluctuations are random, the combustion process is stable. If, however, these fluctuations become organized at well defined frequencies, they can be maintained and even amplified by the combustion process itself. This amplification is called "screech." If severe enough, screech can damage or even destroy a rocket vehicle in flight.

Lewis experimenters are devoting considerable effort not only to developing ways of preventing screech but also, more fundamentally, to better understanding the nature and causes of combustion instability so that it can be

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avoided in initial design.

Research on combustion instability is moving along several lines, including acoustic liners, improved propellant injection techniques, more effective use of baffles, and dividing the combustion zone into a series of separate compartments.

In the past, the development of each new larger liquid rocket engine has required an extensive program either to eliminate screech or improve performance.

The 1 1/2-million-pound-thrust M-1 engine program being directed by Lewis had as one objective building an engine that would work right the first time. Theory, based on research, together with definitive small-scale experiments were used. The design for the M-1 injector and combustion chamber was based on research which has been 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.

From its very first test firing, this engine has demonstrated excellent performance, mechanical integrity, and screech-free operation. This experience with the M-1 liquid hydrogen/liquid oxygen engine indicates that such research methods can be successfully applied to the design of future rocket engines.

Lewis' program in solid rocket technology is similarly oriented toward developing large solid rocket motors. Although liquid rockets use more energetic propellants, solid rockets are simple, less expensive than liquid propellant rockets of comparable thrust, and have an excellent history of reliability. They can be preloaded and stored for long periods of time. Solids carry their own fuel and oxidizer in a single propellant mix.

The 260-inch diameter solid rocket program, one of Lewis' major development projects for NASA, is developing a rocket some 22 feet in diameter and 85 feet long. Two of these motors loaded with 1.6 million pounds of propellant have been static test fired. Each produced 3.25 million pounds of thrust for approximately two minutes. This is the highest thrust level ever attained by a single rocket motor.

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A third motor incorporating several advanced design concepts will be fired in June 1967. One important objective of this next step in the 260-program will be to further verify that the solid motor's thrust, using the same size case, can be tailored to meet a specific mission requirement. To prove this, the thrust-time program will be increased from 3.25 million pounds of thrust for two minutes to 5 million pounds of thrust for one and a half minutes.

Basic studies in solid motor technology, which also complement the 260 work, include study of the properties of high strength weldable steels and large rolled-ring forgings and motor case failure detection systems for proof testing and actual motor operation.

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MATERIALS

Being asked to build things from "unmachineable, unweldable, inflexible materials to impossible shapes, finishes and tolerances" is not far from the job aerospace fabrication engineers have been given. Similarly, materials scientists are frequently working on the frontiers of technology to meet the structural requirements of the space age.

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 and interpretation of materials testing procedures.

One aspect of materials research at Lewis has been the development of short term tests to determine the long term effects of operating environments on a material. For example, two relatively simple tensile tests on small samples can produce data necessary to predict the stress a large pressure tank can withstand without failing. Fatigue failure which may occur in a part, such as a spring, after millions of loading cycles can be predicted by a procedure using only one cycle of static loading.

Another major contribution is Lewis' method for determining long term creep of a material with short term tests. Most materials can hold a load

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less than that which causes them to fracture for an infinite length of time. However, at high temperatures even this light load will cause the material to elongate, or creep, with time until it finally fails. The ability to predict this failure and load limits is becoming increasingly important to designers. It is probably most important in the nuclear field where devices such as power generation facilities must operate for several decades in order to be economically competitive.

Pioneering research at Lewis and the Naval Research Laboratory over the last decade has resulted in the development of a new engineering science known as fracture mechanics with evaluation techniques such as crack toughness testing. This new discipline provides means of identifying and measuring the factors controlling the resistance of a metal to brittle fracture. This includes quantitative relationships between the results of laboratory crack toughness tests and actual service performance.

Physicists have known for many years that the actual strength of pure metals are often only 5 per cent of their theoretical strength. Now they know that materials in the form of small fibers have more nearly approached their theoretical strength. These whiskers, as they are called, generally have a diameter from about one millionth of an inch to a few thousandths of an inch.

A single fine wire of the metal or single crystal of it may reach 80 or 90 per cent 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.

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 monolithic 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. Lewis research has recently been directed toward

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the development of nickel base alloys with improved oxidation resistance.

Although the materials work at Lewis concentrates largely on metals, there has also 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. The plastics gain even greater strength at cryogenic temperatures.

While materials scientists search for new materials, fabrication engineers are finding new and better ways to work with existing metals and alloys.

Electron beam welding is an important part of the new fabrication picture. This type of welding is done in a vacuum to obtain the most efficient and concentrated beam. Electron beam welding gives the smallest weld and smallest heat effected area of any method. This means there is much less chance for distortion.

Despite the necessity for welding in a vacuum, the process can be used for large projects as well as small. Lewis assembled a 250-foot liquid metal heater from 20-foot lengths of columbium tubing. At NASA's Marshall Space Flight Center, a 33-foot diameter aluminum ring for the Saturn V booster is assembled by this method. Lewis has also applied for a patent on the first portable electron beam welding unit.

The laser shows much promise in this same general area although it is still in its infancy. It can be used to bore, by melting and evaporating, holes in any known material. With 27 million dollars now being spent annually on laser research, big things can be expected in the future.

High energy rate forming methods using explosives, spark discharge, vaporizing wire and electromagnetic means have advanced rapidly in recent years.

A method of magnetic forming eliminates the use of dies. Electrical discharge machining is a method of metal removal in which there is no contact between a piece being machined and the tool. As a result, it causes no distortion of the material. The work piece and tool are immersed in a dielectric fluid. An electric arc between the work piece and tool is used to melt minute quantities of the material which is then carried away by the dielectric fluid.

A similar method called electrochemical machining substitutes an electrolyte for the dielectric fluid, and operates by rapidly deplating an area of the workpiece.

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SPACE VEHICLES AND PROPELLANT HANDLING

The Lewis Research Center has development and management responsibility for Atlas-Centaur launch vehicles and launch vehicle management responsibility for all NASA unmanned scientific programs using Agena upper stages. This includes five different vehicles--Agena B and Agena D second stages and the Atlas, Thor and thrust-augmented Thor boosters. Various combinations of these are used in the Ranger, Mariner Mars, OGO (eccentric), OGO (polar), Nimbus, Echo, ISIS, OAO, Pageos, Lunar Orbiter, ATS and Mariner Venus programs. Atlas-Centaur, now an operational launch vehicle, is used in the Surveyor landing program.

Currently Lewis vehicle engineers are exploring the possibility of 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 long-tank TAT, called Thorad, will improve the vehicle's performance by means of additional fuel capacity.

In an effort to increase the cost effectiveness of the Agena vehicle and its boosters by reducing the modifications necessary for each mission, Lewis began a standardization program in 1965. To this end, standard shrouds, adapters and spacecraft interfaces were and are being established for the Agena to keep modifications that are unique to a mission to a minimum. In addition to reducing development costs for each mission, the reliability for the overall vehicle system will also be increased.

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The Lewis Agena project group has successfully managed the launches of such space successes as: Ranger 7, 8, and 9, which returned 17,259 close-up photographs of the moon; Mariner 4, which, some 7 1/2 months after launch, returned much scientific information from the near vicinity of Mars and also sent back the first close-up photographs of that planet; and ISIS-X, which put two satellites into near-perfect orbits with one launch vehicle. This project, incorporating a Canadian Alouette and a U.S. Explorer satellite, was the most intricate unmanned launch and one of the most accurate yet performed in the U.S. space sciences program.

Centaur, an upper-stage, hydrogen-fueled space vehicle, was developed for lunar and planetary missions. It is the first space vehicle developed by the U.S. employing high-energy liquid hydrogen as fuel.

Centaur completed its first successful launch from Cape Kennedy on Nov. 27, 1963. After initial boost by an Atlas launch vehicle, the Centaur second stage hydrogen engines were ignited and burned for full duration. This was the first known instance of hydrogen engines being ignited in space.

During a typical Centaur flight, with the objective of placing the Surveyor spacecraft on the moon, the Atlas booster's three main engines and two vernier engines are ignited on the pad.

After more than two minutes of powered flight, the two main engines are jettisoned. The sustainer engine continues to provide thrust with first stage power ending after four minutes of flight.

As Atlas power ends, a shaped charge cuts through the interstage adapter, separating the two stages. At the same time, retrorockets mounted on the aft end of the Atlas stage are fired to pull it away from the Centaur stage.

Within a very few seconds, the two hydrogen-fueled engines are ignited and the Centaur vehicle attains sufficient velocity to overcome the Earth's gravitational pull.

Centaur and its Surveyor payload are now on a direct trajectory toward the Moon. Once having overcome the Earth's gravity, Surveyor separates from Centaur and continues toward the Moon.

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This type of mission is called "direct ascent," i.e., the Centaur stage propulsion system is ignited one time to propel the payload on a trajectory to the Moon. A direct ascent mission provides fewer problems since the space launch vehicle is under power until it escapes the Earth's gravitational pull, thus eliminating prolonged periods of coasting under weightless conditions. This was the method used with the highly successful Surveyor I, the first U.S. attempt to soft-land on the Moon, June 2, 1966.

One disadvantage to this type of mission is what flight planners call the "launch window," the fixed time period during which a vehicle must be launched from a specific location on Earth to intercept the Moon.

Another method of reaching the Moon is via a so called "parking orbit." This method involves placing the Centaur/Surveyor combination into a low Earth orbit, about 100 miles high. This vehicle then coasts until it is in the proper position relative to the Moon. The Centaur engines are restarted and push Surveyor onto its flight to the Moon.

The hydrogen engines used on Centaur are designed to be stopped and restarted in space. During the later missions in the development program, Centaur will fly into Earth orbit, coast briefly, then restart its engines to accelerate the vehicle to escape velocity.

In both Agena and Centaur upper stages, the restart occurs in weightlessness or zero-g. Thus, handling and storage of the liquid propellants can be a substantial problem.

On Earth, liquids stay in the bottom of containers and gases stay on the top. This is not necessarily so in the weightlessness of coasting space flight. As liquid rocket fuels may be anywhere in the tank intermingled with gas, this could create serious problems both in pumping propellants to the engines and in relieving the tanks of excessive pressure by venting vapors from boiling hydrogen.

Extensive studies of fluid behavior and its relation to varied geometry of baffles and tanks have been done at Lewis. On the basis of these and similar studies, systems for controlling the position of propellants, were conceived for the Centaur coast phases. The results also apply to Saturn, also fueled with lightweight liquid hydrogen.

Each system involves maintaining position control over the propellants during the entire coast period by applying enough thrust to overcome residual drag. This procedure keeps the propellants in a predictable position which permits positive venting and restart, allows more accurate prediction of heat transfer and pressure rise, and avoids undesirable behavior during collection.

On Centaur, this thrust is produced by small rocket engines which burn for the 25-minute coast period. They use only a few pounds of propellant, and maintain the vehicle at only .0004g acceleration, which is enough to settle the liquids in the tanks.

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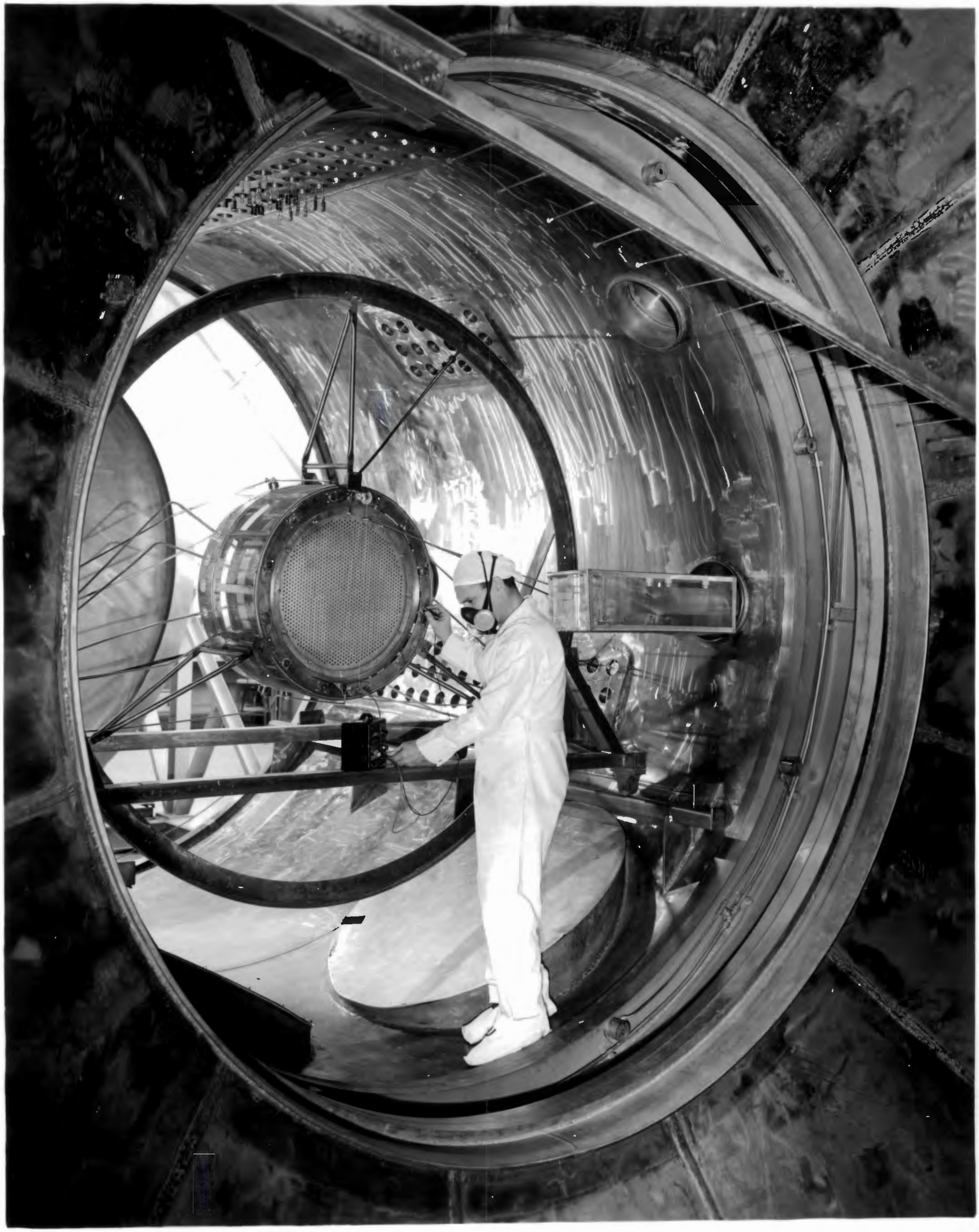
C-68264



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C-66-3763

Lewis engineers examine the inlet cowling on one of the J-65 engines used in the Center's B-57 research aircraft. The cowling has been modified by lining the inner surfaces with porous metal supported over a one-inch cavity. This modification has resulted in a substantial noise reduction when compared with the B-57's other conventional J-65 engine.

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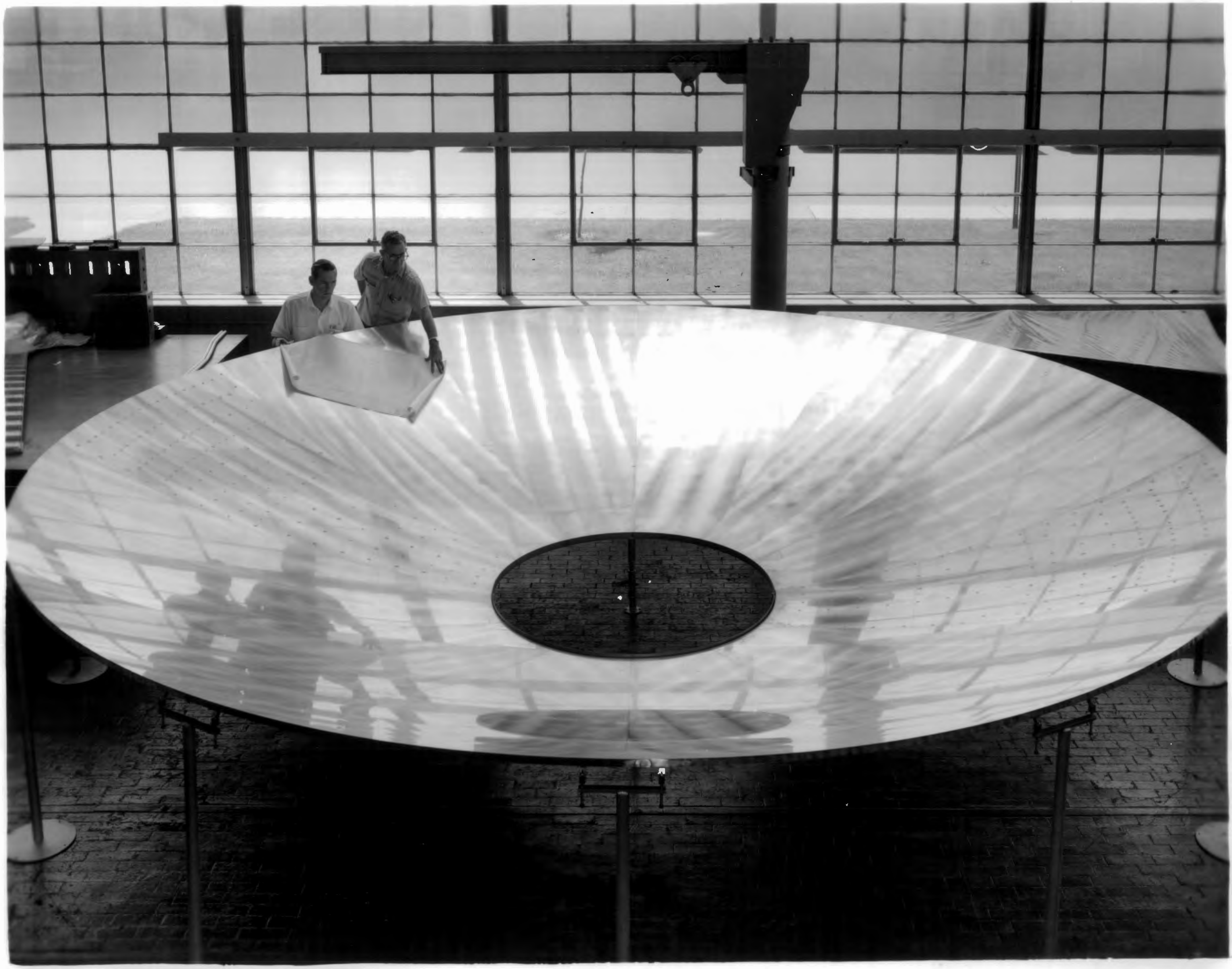
NASA
C-66-2471



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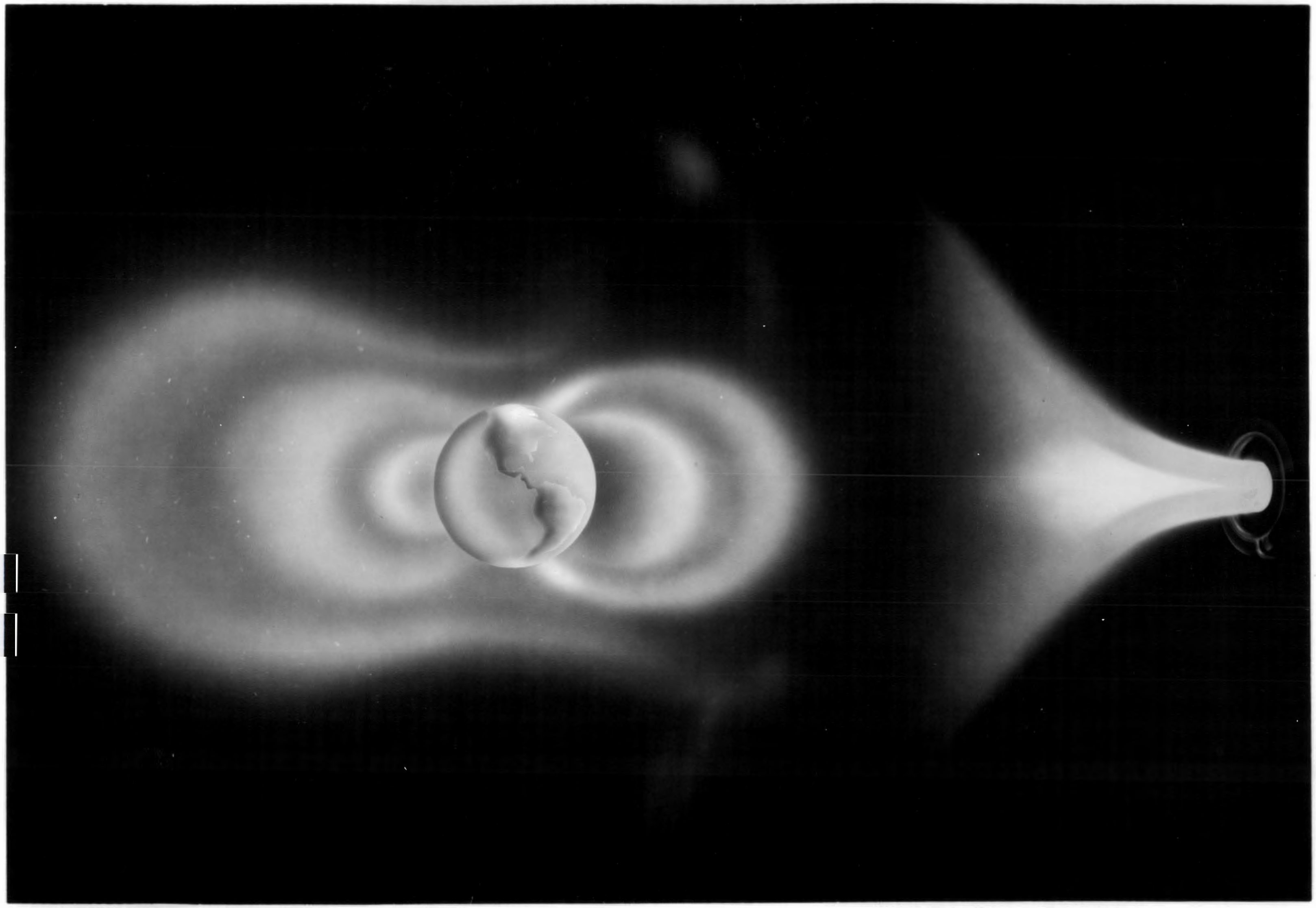
C-66-2471

Technicians check a 20-foot solar mirror built at the Lewis Research Center for work on space power generating devices. Formed of magnesium plates, the mirror was given an epoxy coating and then an evaporated aluminum finish. It will be used with a Brayton cycle electric generating system, similar in operation to a jet engine except that the energy produces electrical power rather than thrust. This Lewis concept is the first to use a rigid mirror. Other concepts using solar mirrors have involved folding or inflatable structures.

NASA
C-66-3764



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C-66-3764

This model of the Earth contains a coil which produces a magnetic field simulating that of the Earth. It is bombarded with a stream of ionized particles simulating the solar wind which actually impinges on the Earth's magnetic field. The bands or belts of luminous plasma which are formed are suggestive of the Van Allen belts actually found around the Earth. Scientists at Lewis are probing the plasma around the model and studying scaling laws in an attempt to find an explanation for the actual Van Allen belt formation.

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C-65-1246

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C-65-1246

Aerial view of the Lewis Research Center located on 350 acres adjacent to Cleveland Hopkins International Airport. The 6000-acre Plum Brook Station near Sandusky, Ohio, also is a Lewis-operated facility. The two locations employ 4800 persons, including 1900 engineers and scientists.

NASA
P64-1310

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P64-1310

B-1 and B-3 test stands at NASA Lewis Research Center's Plum Brook Station, Sandusky, Ohio. The B-1 Nuclear Rocket Engine Dynamics Stand (left) is being used for 15-second to 3-minute tests of the propellant system start-up characteristics of NERVA (nuclear engine for rocket vehicle applications). B-3 is the Nuclear Rocket Dynamics and Control Facility where non-nuclear tests of various components of large nuclear engines are being conducted.

NASA
C-66-3683

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C-66-3683

Technicians inspect a 1500-lb. experiment being prepared for testing in Lewis' 500-foot deep Zero Gravity Research Facility, just recently completed to augment research on fluids in a weightless environment. The chamber shaft extends 510 feet below grade and is lined with an 18-inch thick concrete casing 28 feet in diameter. Inside the shaft is a steel vacuum chamber 20 feet in diameter. The chamber can create a pressure similar to that found at 50 miles altitude. By dropping experiments from the top of the shaft, five seconds of weightlessness can be produced. This zero-G time is doubled when experiments are propelled upwards from the bottom by a high-pressure accelerator, permitted to fall free, then retrieved by a large decelerator cart. The Zero Gravity Research Facility can handle experiments weighing up to 6000 lbs.

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C-66-3684

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C-66-3684

Shown is the decelerator cart used to retrieve experiments in Lewis' Zero Gravity Research Facility. The cart is over 19 feet high, 12 feet in diameter and weighs 22 tons. It is filled with millions of small spheres of expanded polystyrene which permit deceleration of zero-G experiments at a controlled rate. Experimental vehicles are decelerated at about 30 G's to prevent damage. The Zero Gravity Facility can produce ten seconds of zero-G to study the reaction of fluids in a weightless condition.