TECHNOLOGY IN THE SERVICE OF MAN

NASA

LEWIS RESEARCH CENTER

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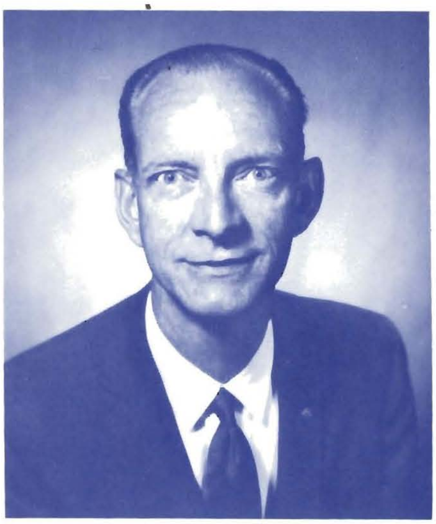
1973

THE DIRECTOR'S MESSAGE



Welcome to the Lewis Research Center. For more than three decades this Center has served the nation, first as the aircraft propulsion research laboratory of the National Advisory Committee for Aeronautics, and, since 1958, as the National Aeronautics and Space Administration's center for propulsion and power for aeronautical and space application. We are proud to have played a part in the development of our nation's truly great aeronautical posture and in the creation of the capabilities for our exciting and rewarding venture into space.

Now, on the eve of NASA's 15th Anniversary, we see the technical capabilities born of aeronautics and space programs being applied ever more broadly to the many needs of people here on Earth. All of us of Lewis are pleased that we are able to show you our Center and to share with you a few selected examples of "Technology in the Service of Man".

Bruce T. Lundin

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TECHNOLOGY IN THE SERVICE OF MAN

NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER

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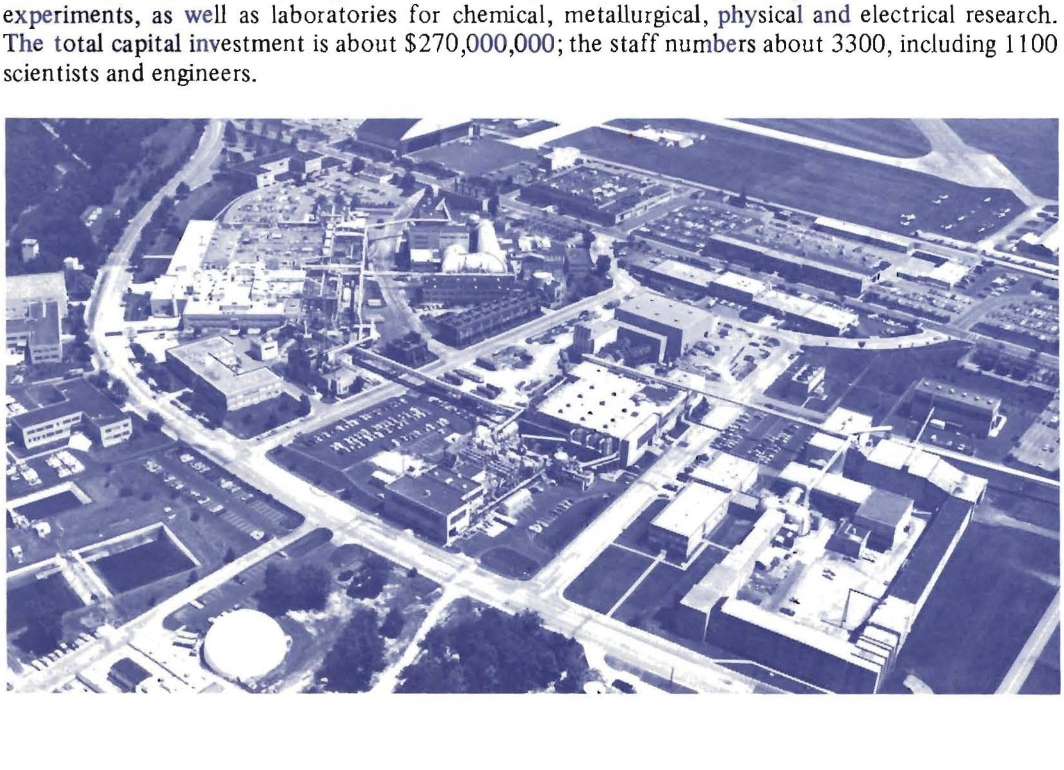
As the propulsion research center of NACA until 1958, the Center's task was to advance the technology of our nation's aircraft engines. From this effort, in partnership with other research laboratories and the American industry, came many benefits to our nation. The air arm of our military forces was strengthened, a new level of mobility was provided to our people and their goods, and American aircraft came to dominate the commercial fleets of the free world.

In October of 1958, just 15 years ago, Lewis became part of the National Aeronautics and Space Administration with a broadened responsibility in the fields of both propulsion and power for both aeronautical and space applications. Here our technologies have helped explore the planets, place men on the Moon, measure the stars, and view the resources and environment of our Earth from a vantage point in space. The ultimate benefits of this new knowledge and these new technical capabilities are truly immeasurable.

"Technology in the Service of Man" presents a few examples of the impact of these aerospace accomplishments on all of us. Furthermore, it is a report by the Lewis Center on its stewardship of resources, and it is an overview of the ongoing work here.

The Lewis Research Center occupies 350 acres adjacent to Cleveland Hopkins International Airport and 8000 acres at the Plum Brook Station near Sandusky, about 50 miles west of Cleveland. The physical plant comprises a number of unique major facilities such as altitude chambers, wind tunnels, huge vacuum tanks, and a 500 foot deep chamber for free-fall experiments, as well as laboratories for chemical, metallurgical, physical and electrical research. The total capital investment is about $270,000,000; the staff numbers about 3300, including 1100 scientists and engineers.



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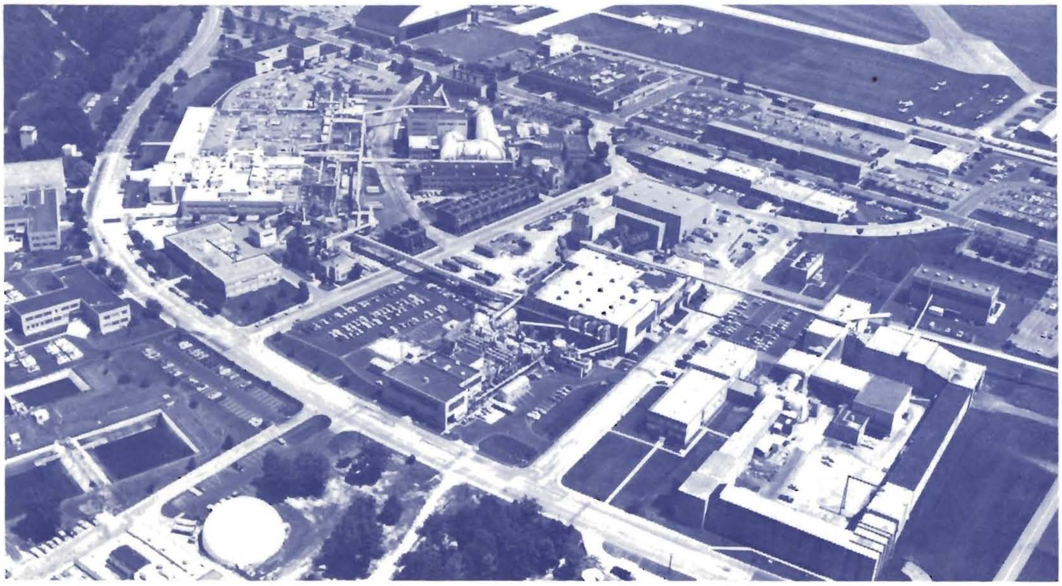


QUIETING THE FLEET

Civil aviation has had a major impact on the way of life in the United States, and the demand for this mode of transportation is increasing. But the simple fact that the noise from commercial jet aircraft irritates people has meant that the use and growth of existing airports and the creation of new ones have been severely limited. So flying becomes less economical, useful, convenient, and pleasant than it ought to be.

As NASA's principal field center for research in aircraft propulsion, Lewis has worked for a number of years on ways to reduce aircraft noise. Research focuses on the two main sources of noise in aircraft engines: jet noise, produced as the hot jet exhaust mixes violently with the atmosphere, and machinery noise, generated primarily by the fan but also by other turbomachinery.

Advances made in the 1960's on high bypass ratio turbofan engines have helped to reduce jet noise already. Today's wide-bodied DC-10 and 747 jets are powered by these quieter engines.

Since jet noise is created by the violent mixing of the exhaust stream from the engine with the surrounding air, a small decrease in jet velocity makes a significant reduction in jet noise.

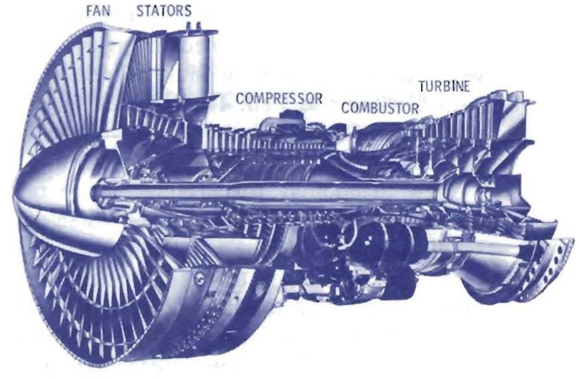
The high bypass ratio engine is quieter because it has a lower jet velocity. But since engine thrust is the product of airflow and jet velocity, the high bypass turbofan engine produces the same thrust as a "pure" turbojet engine by having several times as much airflow.

The use of the high bypass ratio engine is not the answer to aircraft noise, however. In modern engines where the jet noise has been reduced by the high bypass ratio, the fan noise then dominates the noise picture, especially during a landing approach.

In a typical modern fan stage the air enters the inlet and is compressed by the rotor. The rotor also imparts to the flow a swirl, which is eliminated by straightening vanes called stators.

Fans have two characteristic types of sound superimposed on a wide spectrum of noise: (1) a high-pitched, whine sound at discrete frequencies and related to blade passage frequency and (2) a lower pitched buzz saw sound. This buzz saw sound is formed as a result of the shock waves formed at the fan blade tips when the fans operate at supersonic speeds. The wide spectrum of noise is caused by random pressure fluctuations in the fan.

Research on fan noise generation has identified several methods for fan noise reduction. One way to reduce fan noise is to increase the spacing between the rotor and stator. The reason this increased spacing reduces noise is explained as follows: Each rotor blade has a wake behind it similar to the wake in the water behind a moving boat. Rotor rotation produces a periodic impingement of these wakes on the stator vanes which directly or indirectly generates the sound associated with blade-passage frequency mentioned above. By increasing the separation, the wakes dissipate more before they hit the stator vanes, and the noise is reduced.



Typical high bypass ratio engine

Another way of reducing fan noise is to select the optimum number of rotor blades and stator vanes in order to eliminate wake interaction events that lead to discrete frequency sounds. The least noise is obtained when there are about two stator vanes for each rotor blade. This noise reduction principle was developed at Pratt & Whitney Aircraft.

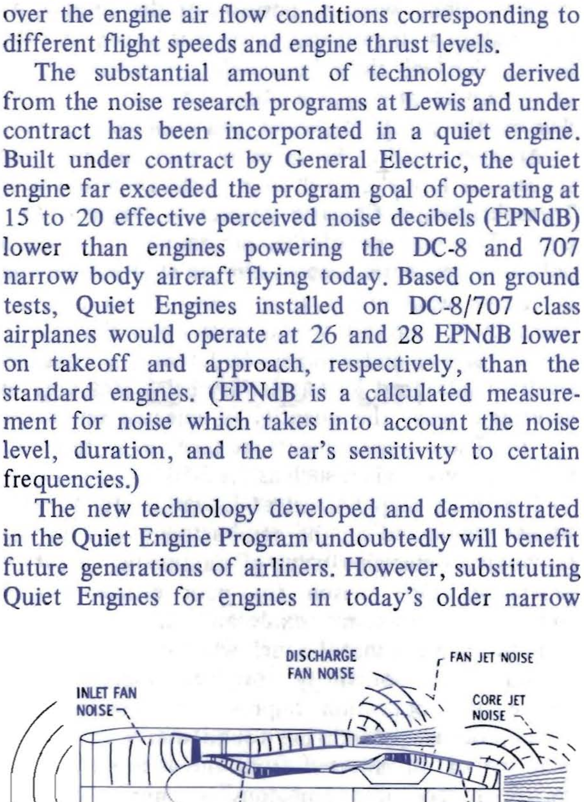
Another technique that shows promise for fan noise reduction involves leaning the stator vanes. These vanes are usually radial, but it has been found that leaning them circumferentially reduces fan noise. A 2-3-decibel reduction in back-end fan noise was obtained with stators leaned 30 degrees from radial. Stator lean also reduces the blade passage frequency noise.

Incorporating the best noise reduction techniques into new fan designs significantly lowers their noise levels; however, further improvement can come from suppressors that absorb or eliminate noise energy. Engine suppressor material is similar to that found in phone booths or in ceiling tile. The surface that faces the noise source contains small holes. Behind this surface are enclosed cavities. Noise energy, in the form of small pressure waves, enters the cavities through these holes and then bounces out again. This entering and exiting action reduces the noise energy by the friction or viscous losses encountered in this process. Suppression material is usually placed on the inlet flow passage walls. The fan discharge duct is similarly treated. Occasionally, the material is placed on the compressor inlet duct walls and behind the turbine. If more acoustic treatment is needed, additional surfaces can be placed in the flow passages.

Lewis engineers are experimenting with a novel method of suppressing the fan front-end noise without acoustic treatment. This technique relies on the physical principle that sound waves cannot travel upstream through air flowing at the speed of sound. This concept is called the sonic inlet. Unlike a conventional inlet, the sonic inlet has a throat area small enough to raise the air velocity in it to the velocity of sound. When the sound waves from the fan reach the sonic point, their forward speed is the same as the incoming flow. Thus, they cannot propagate out the inlet. This concept requires a variable area inlet to maintain sonic inlet conditions over the engine air flow conditions corresponding to different flight speeds and engine thrust levels.

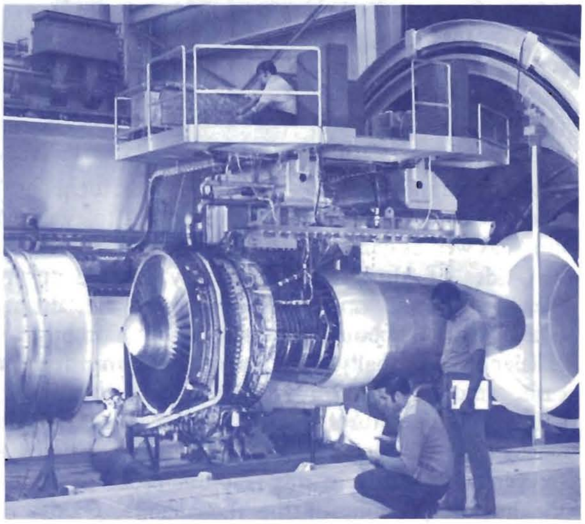
The substantial amount of technology derived from the noise research programs at Lewis and under contract has been incorporated in a quiet engine. Built under contract by General Electric, the quiet engine far exceeded the program goal of operating at 15 to 20 effective perceived noise decibels (EPNdB) lower than engines powering the DC-8 and 707 narrow body aircraft flying today. Based on ground tests, Quiet Engines installed on DC-8/707 class airplanes would operate at 26 and 28 EPNdB lower on takeoff and approach, respectively, than the standard engines. (EPNdB is a calculated measurement for noise which takes into account the noise level, duration, and the ear's sensitivity to certain frequencies.)

The new technology developed and demonstrated in the Quiet Engine Program undoubtedly will benefit future generations of airliners. However, substituting Quiet Engines for engines in today's older narrow body commercial airplanes is prohibitively expensive; consequently, NASA, in cooperation with the Federal Aviation Administration, is exploring how present engines can be made quieter through less expensive modifications.



Turbofan noise sources

One approach being pursued by NASA is called the Refan Program. This approach is to replace the present two-stage fan with a larger and quieter single-stage fan and add acoustic treatment to the nacelle. To maintain the proper airflow conditions to the engine core, two booster stages must be added to the engine compressor.


Testing the NASA Quiet Engine

The Refan Program focuses on reducing the noise of DC-9 and 727 transports which make up a large segment of the U.S. narrow-body fleet of commercial jets today. While expensive, modifying these planes is expected to reduce noise-affected areas near airports by 75 percent or more.

Ground tests with a refanned 727 are to begin in 1974 and flight tests with a refanned DC-9 in 1975. If these demonstrations are successful and noise regulations on narrow-bodied airliners are imposed, companies may begin retrofitting aircraft as early as 1976 - a quiet tribute to the nation's bicentennial anniversary.

Advanced technology and techniques to solve the aircraft noise problem are being studied at other NASA centers as well. Research on engines and aircraft, experiments with new flight procedures, and studies of community response to noise are leading the way to quieter skies tomorrow.

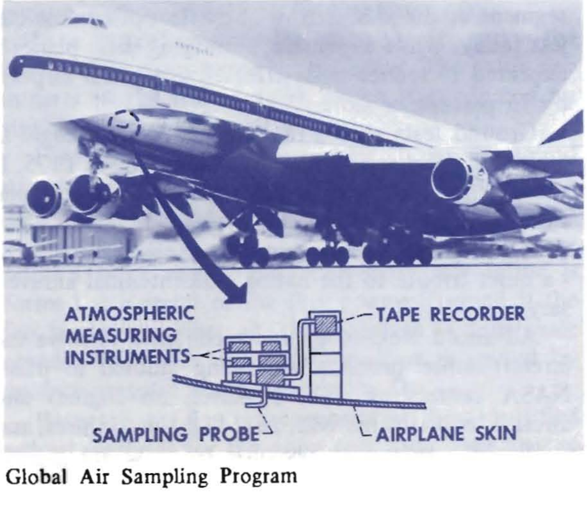
CLEANER SKIES

The present concern over air pollution both near the ground and in the stratosphere has led to a number of programs at Lewis aimed at ways in which pollution from aircraft engines can be minimized.

The major emissions from gas turbine engines are carbon monoxide, unburned or partially oxidized hydrocarbons and oxides of nitrogen, and smoke. Each of these pollutants tends to be emitted from the gas turbine engine at rather specific operating conditions. The gas turbine engine operates at very nearly 100 percent combustion efficiency at all operating conditions except idle. At idle, carbon monoxide and unburned or partially burned hydrocarbons are emitted. These two constituents are typically characteristic of poor combustion efficiency.

Once these incompletely burned constituents are in the atmosphere, other reactions can take place. Hydrocarbons mix with air and other pollutants and when exposed to sunlight they slowly react to form new compounds, generically named "photochemical smog." Photochemical smog is an irritant to eyes and lungs, as well as damaging to plant life.

Oxides of nitrogen are primarily emitted during the high power operation of the engine, during takeoff and climbout. Here the engine combustion efficiency is virtually 100 percent and emissions of carbon monoxide and hydrocarbons are virtually nil. The high temperatures and pressures generated within the engine during takeoff favor the reaction of oxygen with nitrogen; this reaction proceeds within the hottest portions of the flame zone. Oxides of nitrogen are very reactive compounds and in the atmosphere can react with other pollutants such as hydrocarbons. They are a major contributor to the formation of photochemical smog. Smoke has been reduced to acceptable levels in recent generations of engines.



Global Air Sampling Program

The first questions to be answered when studying pollution is "how much of these pollutants are we producing and what are their concentrations in the atmosphere?"

An important first step in understanding the air pollution problem is to know the composition of the air. Consequently, Lewis is involved in measuring the concentration of pollutants in all levels of the atmosphere from typical urban air all the way into the upper layers of the stratosphere.

In one such program at Lewis, the Global Air Sampling Program, the constituents of the atmosphere are measured at the 20 to 40 thousand foot altitudes where most present-day jet transports cruise. Air sampling probes and instrument packages on 747 aircraft flying regular global routes will continuously record the levels of the minor atmospheric constituents along with the position of the aircraft. As the quality of these data grows, it is hoped that the information will show how pollutant concentrations in the upper atmosphere change due to air, traffic density, the change in seasons, and local weather.

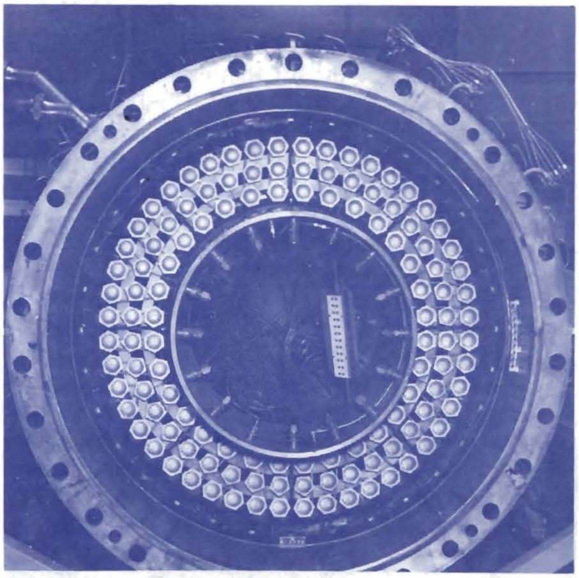
Another effort to measure atmospheric constituents is Lewis' contribution to the Department of Transportation's Climatic Impact Assessment Program. The purpose of this program is to measure pollutant concentrations within the stratosphere and determine what effect, if any, an increase in those levels by jet aircraft would have upon the atmospheric balance and climate. At Lewis, the emission levels of advanced jet engines are being measured to determine what the quantity of injected pollutants will be. These measurements are taken in altitude test facilities using engines such as the J-58.

The other major effort at Lewis has to do with studies conducted on the combustors of gas turbine engines to determine ways of minimizing pollutant generation. One reason for poor efficiency and emission of carbon monoxide and unburned hydrocarbons at idle is that the fuel, when sprayed into the combustor, is not finely atomized. Increasing the degree of atomization improves combustion efficiency. Lewis research has found that a very small quantity of air injected from the fuel nozzle can greatly reduce idle emissions by improving fuel atomization.

Controlling the emission of oxides of nitrogen is a far more difficult problem. It requires decreasing the residence time of gases in the hottest portions of the flame and minimizing temperature nonuniformities, particularly the hot zones in the combustor. Accomplishing these goals requires a new combustor concept. One such concept developed at Lewis is the modular swirl-can combustor. The swirl-can combustor spreads the flame zone uniformly across the entire combustor to minimize hot zones. Additionally, this combustor mixes the hot gases with the remaining combustor air very rapidly. This rapid mixing reduces the flame temperature to levels where oxides of nitrogen are not formed or before the reactions forming them have been completed.

This combustor concept is just one of many new combustor concepts being investigated in Lewis' Experimental Clean Combustor Program. The Clean Combustor Program is a contracted as well as an in-house effort to investigate new combustor designs that have the potential of significantly reduced emission levels. This program will require all of Lewis' skill and knowledge plus that of the major commercial engine manufacturers if the reduced emission goals are to be achieved by the 1979 date specified by the Environmental Protection Agency. The emission levels for carbon monoxide, hydrocarbons, and oxides of nitrogen must be reduced by approximately two-thirds of their present value to meet program goals and standards.

At the present time, Lewis is in the first phase of the Clean Combustor Program. Contracts have been awarded to two of the major commercial jet engine manufacturers to explore a variety of new combustor designs. The next phase of this program will consist of further refinement of the best ideas, and the third phase will be the actual measurement of emissions from these combustors installed in an engine. The third phase of this program should be completed during 1975.



Swirl can combustor test hardware

POWERED LIFT

Air traffic congestion, already bad at some of the nation's large metropolitan airports, can only become worse unless something is done. There is expected to be at least a five fold increase in demand for air travel by 1990.

More than half of that increase will involve trips of 500 miles or less. At these shorter ranges airplanes that use short runways should be practical and economical.

The use of shorter runways, perhaps 2000 to 2500 feet long, combined with improvements in traffic control systems, will mean that the capacity of an existing large airport can just about be tripled. Short-haul planes used for transportation between, or even within, cities could also operate out of small airports.

Lewis is working on the propulsion systems technology needed to make practical, efficient short-haul aircraft that use short runways.

The shorter runway lengths mean slower approach and takeoff speeds. It's not difficult to design aircraft for low landing speeds and takeoff. A Piper Cub or any similar light plane is an example; it has a large wing compared to the airplane weight. But these airplanes have a very low cruise speed. Also, they are sensitive to wind gusts and hence give a bumpy ride. What is difficult is to design an airplane with a high cruise speed and a comfortable ride with low takeoff and landing speeds. An airplane with the same cruise speed, about 600 mph, and the same ride comfort as the current jets is desirable. This speed requires using the same size wing relative to airplane weight as the

Specifically, the Lewis Center has been responsible for managing the operation of the Thor/Agena, Atlas/Agena, and the Atlas/Centaur launch vehicles and the development of the Atlas/Centaur vehicle. There are 20 additional Atlas/Centaur launches planned which will support communications satellite programs for commercial organizations such as COMSAT and AT&T, which pay for the total cost of the launch and for the Department of Defense; high energy astronomical observations of the HEAO program; and planetary investigation of Mercury using the planet Venus for gravity assist.

The continuing program includes the integration of the Centaur vehicle with the Titan III booster. Titan III/Centaur will triple the orbital payload weight possible with Atlas/Centaur and quintuple the payload weight to Mars or Venus. Scheduled for its initial flight early next year, Titan III/Centaur will support many missions, including the Viking Mars lander, the Helios Solar Probe mission, which is a cooperative program with the government of West Germany, and a data-gathering flyby of Saturn with Jupiter used for a gravity assist on the way.

Atlas/Centaur launch of Pioneer 10 to Jupiter

These four Lewis managed launch vehicles are part of a larger family of NASA launch vehicles which have successfully launched over 250 operational payloads since NASA was created in 1958. These vehicles range in size from the Scout vehicle, which has a maximum diameter of 3.3 feet, stands about 74 feet high, and weighs about 48,000 pounds at lift-off, to the Saturn V vehicle, which has a maximum diameter of 33 feet, stands about 380 feet high, and weighs 6.3 million pounds at lift-off.

Much of the technology advanced or created to turn these vehicles into successful working tools to serve mankind is itself useful in a wide variety of applications. This new technology offers potential solutions to some of the world's most pressing problems. To understand this observation, first consider the anatomy of the Centaur vehicle.

A little over a decade ago, Centaur represented an evolutionary step from conventional rocketry to the high-energy fueled vehicles that use liquid hydrogen and liquid oxygen. Many of the development problems in Centaur demanded solutions that were then beyond the current state-of-the-art. For instance the use of liquid hydrogen as a fuel, which has a temperature of -423 degrees fahrenheit, required a special tank construction and materials that would not freeze, become brittle, or fail under the stresses of space flight. Even the behavior of the liquid propellants, hydrogen and oxygen, under weightless conditions was unknown.

The Centaur vehicle evolved as a structure 10 feet in diameter, 30 feet in length, and weighing about 35,000 pounds fully tanked. The propellant tank structure is thin-walled stainless steel and is pressure stabilized to provide structural integrity. The Centaur is powered by two RL-10 engines, which are restartable in flight, for a total thrust of 30,000 pounds.

The hydrogen tank sidewall and forward bulkhead are insulated with multiple layers of aluminized mylar to prevent propellant boiloff from aerodynamic heating during ascent through the atmosphere and from solar radiation during long coast periods in flight.

The Centaur guidance and flight control system integrates autopilot, attitude control, steering, and sequencing functions into the airborne computer software. This system also provides steering and sequencing functions for the Atlas and for the Titan booster portions of flight.

Now consider the impact of these technical developments on other fields.

The electronic requirements of launch vehicles became one of the "technology drivers" that helped create an entire new industry that is still expanding today - the semiconductor industry. The names of semiconductors, such as diodes, transistors, and integrated circuits, were unknown less than 25 years ago, but can be found today in mail order catalogs. The number of products based on the advances in the semiconductor field ranges from power for human hearts to pocket computers.

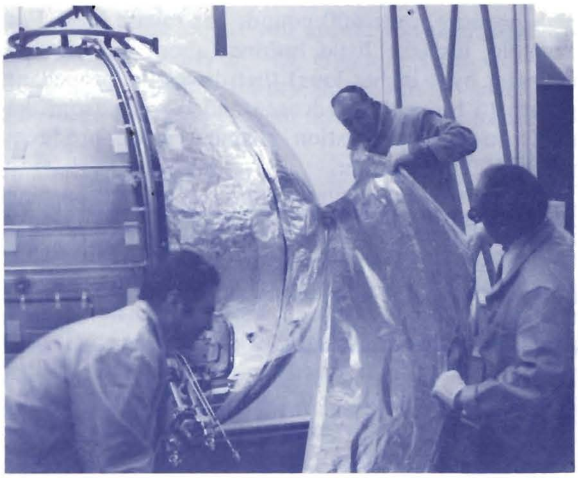
To minimize the volume of the propellants in the Centaur vehicle, the normally gaseous hydrogen and oxygen are liquefied; the temperature of liquid hydrogen is below -420 degrees fahrenheit, and the temperature of liquid oxygen is about -300 degrees fahrenheit.

These very cold temperatures lead to a number of problems, one of which is the embrittlement of metals. New metal alloys had to be developed to provide storage containers for these liquids.

In order to prevent these liquids from evaporating too rapidly, new high performance insulations had to be developed. These insulations, which must operate in a vacuum, consist of highly reflective, metallized plastic films separated by low conductivity spacers. A thousand times more effective than conventional insulation, only a ½-inch thickness of this new insulation can keep an ice cube from melting for more than 3 years.

Not only can this insulation be used to keep cold things cold, but it can also be used to afford protection to humans from becoming too cold. For example, metallized plastic sheets are commercially available as very compact emergency blankets for hikers, campers, and mountain climbers as protection from extreme cold. They are also routinely carried by some rescue squads of policemen and firemen in order to protect accident victims from loss of body heat. The principle of reflective insulation can also be used to protect humans from becoming too hot; for example, the reflective coated firefighter's suit.

Because the space program required large quantities of cryogenic propellants, strong impetus was given to an industry that was in its infancy in the early fifties. The space program did not develop all of the uses to which liquefied gases, or cryogenics, are being put today, but the impetus that the space program has given to the routine manufacturing, storage, and shipping of certain cryogens has provided benefits to everyone years sooner than would have otherwise occurred. Liquefaction plants are routinely manufacturing liquid hydrogen, liquid nitrogen, and liquid oxygen. Large storage tanks contain the fluids either at the manufacturing plant while awaiting shipment or at the user's plant. For transportation, railroad tank cars were developed, and, with these tank cars available shipments are routinely made to steel processing plants where high grade steel is made by the oxygen reduction process. This process could not reach maturity in this country until large quantities of liquid oxygen became available. For shipments to users not served by rail, safe over-the-road trucks were developed. Until the techniques of production and handling of cryogens were developed, hospitals had to depend on bulky tanks of gaseous oxygen placed in individual rooms. Now hospitals can have each room serviced safely by oxygen stored compactly in liquefied form in a centralized area.


Insulating a liquid hydrogen tank

Other uses to which cryogens are being put are to chill scrap metal so that it can be easily broken up, processed, and packaged. Rapid freezing of food maintains quality and prolongs storage life. Refrigerator trucks and railroad cars now use liquid nitrogen to pre-cool the storage space or to maintain the food at very, very low temperatures.

Among the burgeoning research and development activities with liquid hydrogen and liquid helium is an effort in the electric power industry to achieve a superconducting power conductor by using alloys that lose all electric resistance at liquid helium temperature. Such a conductor would be many times smaller for the same electric load as conventional conductors.

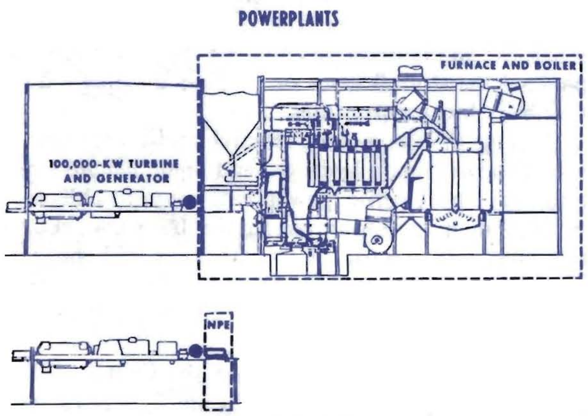
Engines such as the RL-10's in the Centaur stage produce tremendous power in a small package because of the high energy available from the combustion of hydrogen fuel and because they operate at high pressure, over 400 pounds per square inch. For example, just the little turbine (about 7 inches in diameter by 4 inches long) that drives the propellant pumps to bring the hydrogen and oxygen from the tanks to the combustion chamber alone produces nearly 600 horsepower.

Hydrogen and oxygen are very clean burning propellants; the exhaust from this rocket engine is entirely steam plus excess hydrogen. As a steam generator, the RL-10 could actually furnish enough energy to provide electricity for 70,000 homes if it were hooked up to a steam turbine driving an electric generator like those used by most electric utility companies today.

In such a power system, water would be added to the combustor to reduce the temperature from about 6000 degrees fahrenheit to 1500 degrees fahrenheit for the turbine. And just the right amounts of hydrogen and oxygen would be burned so only steam would come out of the combustor.

The hydrogen-oxygen power system is not a far-out idea and has many advantages over today's conventional electric power generating plants. It would be much smaller because it uses rocket-type high pressure combustion, rather than low pressure air-fed boilers that are as big as a seven-story building. It would not consume any of our dwindling fossil fuels such as coal, oil, and natural gas and, of course, would produce no pollution.

A powerplant is being installed by the Commonwealth Edison Company in Joliet, Illinois, to provide additional power during peak demand periods. Designed to serve 10,000 homes, it will use light hydrocarbon fuel and oxygen until a cheaper and more plentiful supply of hydrogen is available.



Size comparison of coal fired steam plant for electric power generation with one using rocket type combustor

Space insulation for fire fighting

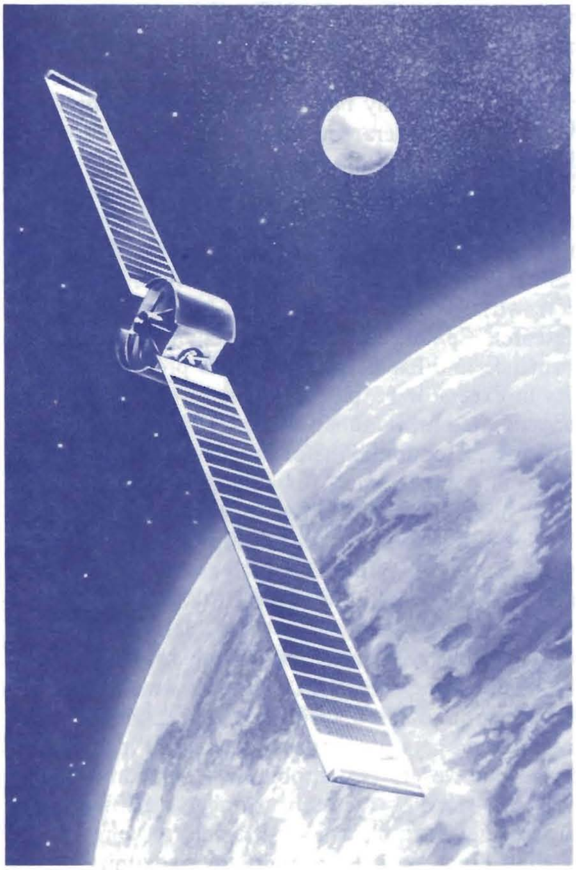
Today a growing number of scientists and engineers believe that the vision of a hydrogen economy is approaching reality. One concept that has been proposed envisions a series of large nuclear power plants built on floating platforms some miles offshore. The electrical power produced by the nuclear plants would be used on the spot to electrolyze sea water causing it to decompose into its main gaseous elements, hydrogen and oxygen. Both gases would flow to shore continuously through pipes. Unlike electricity which cannot be easily stored in large quantities but must be used as it is generated, some of the hydrogen could be stored as a gas in underground cavities or as a liquefied gas in large insulated tanks to meet fluctuating power demands. Hydrogen could also be used directly in aircraft, motor vehicles and furnaces.

At underground distribution points, the streams of hydrogen and oxygen from the sea would be piped to electric power generating plants as well as to a wide variety of industrial processes and transportation systems.

Twenty years ago, the Lewis Research Center began pioneering research on hydrogen-oxygen rocket engines. Much of the experience Lewis and others have gained since then and the technology developed for spacecraft propulsion are directly applicable to terrestrial uses of hydrogen.

The technology and engineering development represented in our launch vehicles has opened the door to space, and thereby, a whole new dimension to the future of man. Here on Earth the technology and engineering development embodied in every component of these launch vehicles and in astrionics, cryogenics, fabrication techniques, insulation, and propulsion is being applied in many ways throughout our economy to create new goods and services, new methods of management and manufacture, new business and industries, and thus, new jobs and wealth.

SPACE ELECTRONICS TECHNOLOGY



Communication Technology Satellite (CTS)

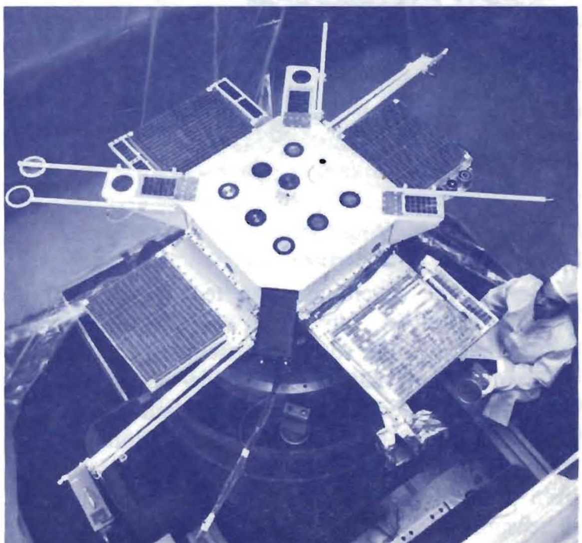
Communication by satellite was among the early space experiments of NASA. During each of its 15 years NASA has increased its contributions to the efficiency and utility of communication spacecraft.

NASA's first experiments were with both reflector and repeater spacecraft in low Earth orbit. The ECHO-I spacecraft of 1960 and later the ECHO-II were, respectively, 100- and 135-foot diameter spheres of thin plastic coated with aluminum that simply reflected radio waves around the curvature of the Earth. The system required powerful transmitters, large antennas, and very sensitive receivers. Repeater spacecraft receive the radio frequency signal, amplify it, and retransmit it. Experiments with satellites such as the Army's Score and Courier, the Bell System's Telstar, and NASA's Relay and Syncom established the technology that is the basis for the present commercial communications satellite: repeater satellites in geostationary orbit. This geostationary orbit is at about 22,300 statute miles where orbital time is 24 hours and a spacecraft will appear to remain stationary over a point on the equator. Thus, for our 8000-mile-diameter Earth, three orbital locations, 120 degrees apart, provide line-of-sight global coverage.

Under the ownership and management of COMSAT Corporation, communications satellites have moved from the first generation 240-channel Intelsat in 1965 to the present fourth generation Intelsat with more than 6000 channels for voice, TV, or data and with greatly increased life expectancy. With several Intelsat IV's maintained over the Atlantic, Pacific, and Indian oceans, the nations of the world are linked in the transactions of commerce, culture, and personal relations as never before.

Meanwhile, advances in technology pertinent to communications satellites have continued. One objective is to move toward a more optimum system by placing more broadcasting power aboard the spacecraft to reduce the power, size, and cost of the ground transmitters, antennas, and receivers. The chart shows the relationship between spacecraft power and system cost.

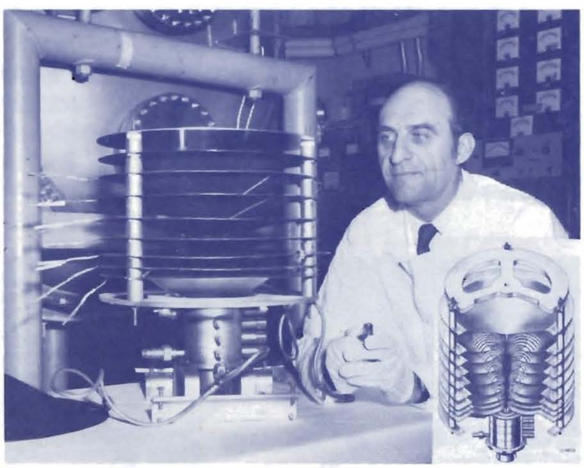
Present spacecraft such as Intelsat IV still require ground facilities costing tens-of-thousands of dollars, probably too much for small medical clinics, schools, most city police stations, businesses, etc. One goal is to reduce the cost to only a few thousand dollars.



SPHINX spacecraft prepared for dynamic testing

There are two spacecraft scheduled to be launched in the near future as part of an effort to establish this capability. An Applications Technology Satellite (ATS-F) spacecraft, one of a series of multi-purpose satellites, will use a 20-watt repeater system, but it will have a very large spacecraft antenna to provide a high signal strength. However, very high gain antennas have very narrow beam widths; that is, they can provide this high signal strength only over a small area. The ATS-F spacecraft will be able to provide a sufficiently strong signal to make low cost transmitters and receivers possible, but only over an area the size of a state.

The Communications Technology Satellite (CTS) being developed by Canada in a cooperative program with NASA uses a lower gain antenna capable of covering a region as large as one-third of the United States with a broadcasting tube having ten times the power used in the ATS-F spacecraft. This 200-watt tube is being supplied by the Lewis Research Center.



Depressed collector broadcast tube

Besides the development of technology for high power broadcasting tubes for spacecraft, Lewis activities that contribute to the efficiency and utility of communication spacecraft include work on contoured beam antennas, high voltage phenomena, solar array technology, and thrusters for station keeping.

Work with the spacecraft broadcasting tube has been primarily concerned with raising efficiency and increasing life. At a conventional tube efficiency of 20 percent, the electrical power generated by the solar array must be five times the broadcast power, and four-fifths of the solar generated electrical power must be rejected as heat. Thus, low tube efficiency is reflected in increased size, weight, cost, and complexity of the spacecraft. Furthermore, as the transmitted power is increased to, say 200 watts, the efficiency obviously becomes much more important. And future spacecraft might even incorporate several such tubes for multiple channel coverage.

One way of increasing the efficiency is through the application of so-called "depressed" collectors. A novel version of a very efficient depressed collector has been invented and perfected at Lewis. In conjunction with a beam "refocusing" device, the Lewis Research Center collector has achieved record performance and has helped the tubes produce efficiencies in excess of 55 percent. This invention has been incorporated in the tube for the CTS satellite.

Another requirement for spaceborne electronics is a long life expectancy, for example, 5 to 10 years. Lewis has conducted, for a number of years, an active and productive program to improve the life and performance of cathodes, which are the determining factor for the overall life of tubes.

To obtain needed new data pertinent to developing devices such as radio frequency amplifiers, solar cell arrays, etc., NASA would normally perform tests in ground-based facilities that can simulate the anticipated operational environment. For high voltage devices, however, two problems are encountered in even the largest vacuum chambers: difficulty in duplicating space plasma and change to the resistance of the plasma path because of the proximity of the chamber walls. Thus, it is necessary to perform certain engineering experiments in space. The SPHINX spacecraft is a special purpose satellite for particular engineering experiments.

SPHINX is an acronym for Space Plasma High Voltage Inter-action Experiment. It is designed to obtain engineering data that are necessary for designing high voltage systems such as the radio frequency amplifiers and high-voltage solar arrays that will be exposed directly to the space plasma. It will also obtain flight data that will serve as a bench mark for future vacuum chamber testing of high voltage systems.

To provide direct broadcasting by synchronous satellites to home or community television sets in specific geographical areas, antennas having shaped beam patterns become increasingly important. By highly shaping the antenna beam pattern to fit the grographical boundary of a given area or country, one can achieve maximum utilization of the available radiated power as well as minimize the interference, or spillover, to adjacent areas. Also, by contouring the beam, one can distribute the radiated power more evenly over the entire coverage area.

For Alaska, for instance, a satellite using a conventional parabolic antenna delivers only one-fourth the total radiated energy to the land area of the state. A contoured beam antenna would deliver one-half or more of the radiated energy which could provide highly contoured beams, high antenna gain, low losses, and low sidelobe levels or spillover to adjacent areas. One of the most promising spacecraft antenna systems is the waveguide lens antenna. An "egg crate" lens structure is used to focus each of the beams from the "horns" that feed radiation to the antenna. Here the feed assembly could be of most any configuration (such as the shape of Alaska) and would not cause any blockage of the radiated beam.

Further work at the Lewis Research Center on contoured beam antennas comprises analytical studies of the lens antenna system, leading to contractor and in-house hardware development of feed assemblies and antenna components for the high-frequency high-power communication spacecraft systems.

Lewis is also developing technology to reduce the cost of solar cells and arrays. Studies include how to make cells with more output and ways to reduce the cost of assembling them into arrays. The solar cell program has as its goal an increase in efficiency to 18 percent from the present level of 11 percent. With the higher output from each cell, the number of cells, the size of the arrays, and the cost of the arrays can be reduced by at least one-third.

A method for reducing the cost of assembling arrays is being developed in which a large sheet of clear plastic is used to encapsulate many cells as a module, or array subassembly. The plastic cover sheet, the cells, and a plastic substrate sheet are bonded together in a single process much like that used to make plastic-covered identification cards. The top plastic sheet replaces the cover glasses that are now cemented individually to each cell to protect them from radiation in space. The new process saves at least $500 per square foot in material and labor costs.

With further improvement in this array fabrication process and development of the high efficiency solar cell, Lewis hopes to reduce the cost of solar arrays to less than one-half the present cost. The new module is flexible, so this process is very well suited to making the lightweight, unfolding arrays that will be used on many future spacecraft.

CLEAN ENERGY

The United States, with only 6 percent of the world's population, uses about one-third of the world's energy. This huge appetite is satisfied mainly by burning the fossil fuels: gas, oil, and coal. A small but important part of U.S. electricity produced today comes from hydroelectric generators and an even smaller part from nuclear power stations. Dependence on burning fossil fuels presents two sizable problems: first, burning these fuels dirties the environment with waste chemicals and heat, usually in just the locations where most people live; and second, even if the problem of chemical and thermal pollution is solved, the relatively easy-to-obtain supplies of gas and oil will probably run out during the next generation or two.

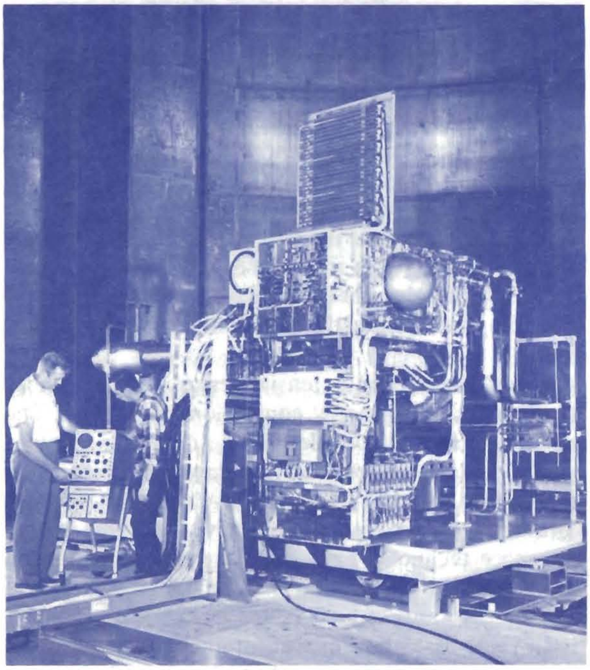
At the present use rate it will soon be necessary to manufacture gas or liquid petroleum from coal or from low grade shale oil. Methods will have to be worked out so that those reserves can be tapped without destroying vast surface areas of the country with processes such as strip mining. Nuclear reactors could be used to make hydrogen fuel from water, but first large nuclear power stations must be acceptable as part of the environment. If society chooses to minimize the future use of nuclear energy, the only long range alternative is a vast expansion of the direct use of solar radiation from the Sun. Whichever course is chosen to solve the energy problems, the various technologies of energy conversion will play a critical role.

Lewis has had an extensive research and development program in energy conversion since 1961. The work has ranged from developing radiation resistant solar cells to large rotating machinery generators run by boiling liquids (Rankine cycle) or hot gases (Brayton cycle). Not surprisingly, one area where aerospace technology can make a major contribution is in gas turbine systems, a major research and development area at Lewis since 1945.

In years past, the study of internal air flow was the subject of extensive research at Lewis and at many other laboratories around the world. Gas turbine designers were often forced to compromise their designs simply because many of the design calculations they needed to do were beyond the capacity of their computer systems.

Computer programs developed by Lewis and the aerospace industry during the past 10 years have gone a long way toward upgrading gas turbine design calculations to a point which permits the designers to make final design decisions with all the required information in front of them.

A natural law says that in order to extract work efficiently from a hot gas, as is produced in the combustors of a gas turbine, the gas should be allowed to start its work at the highest possible temperature. But, to build a turbine wheel that can stand higher combustor temperatures like 2000 degrees fahrenheit or more requires cooling the critical turbine parts. Lewis has been experimenting for some years with new materials, fabrication techniques, and cooling techniques using hollow blades. A new turbine facility at Lewis is being designed to operate cooled turbines in gases at up to 4000 degrees fahrenheit at pressures of 560 pounds per square inch. This will be the highest temperature and pressure capability of any such facility in this country.



Brayton cycle generator being tested in Space Power Facility

Concept for producing electric power from solar thermal energy

A part of this Lewis turbine technology is being put to use right now in a cooperative effort with the Environmental Protection Agency. Lewis has begun a program to develop an experimental gas turbine engine for automobiles. It is anticipated that such an engine will provide good performance and meet the 1976 emission standards.

Technology from machines like the Lewis low cost aircraft engine and from cooled turbine blades can perhaps help the electric utility industry to meet the mushrooming demand for power. Aircraft type turbine engines are already being built for emergency power supplies, and this area could be developed further.

More advanced concepts look even more promising. High temperature, gas-cooled nuclear reactors, for example, combined with a closed-cycle gas turbine would make more efficient use of the heat available than the present low temperature nuclear steam power plants. The large volumes of cooling gas from the high temperature reactor would be used to generate electric power by expanding them through high efficiency gas turbines. Lewis experience in such closed Brayton systems for space power may be valuable in developing the ground based equipment.

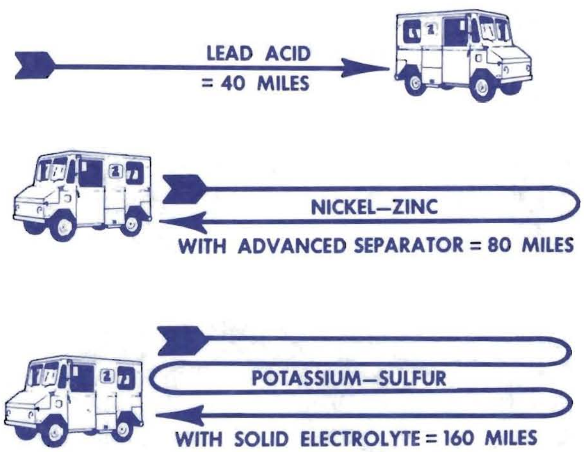
Although turbine machines will continue to dominate our conversion of fossil fuels into useful energy form, advanced research at Lewis in superconducting magnets and in an area called magnetohydrodynamics (MHD) may have an influence on the future of efficient energy conversion. MHD is the study of very hot, moving gases conducting electrical current in a magnetic field. These hot treated gases, called plasmas, can conduct electricity just as a wire does. When they flow rapidly through a magnetic field, electricity is produced just as in a wire wound generator. Lewis has been experimenting with MHD generators for many years and plans to start construction soon on an advanced concept using cryogenically cooled electromagnets. The new generator will produce four times the power densities as previous generators.

The gases for the MHD generator come from a rocket-type combustor. These gases are much hotter than even a cooled turbine could stand. However, after they pass through the MHD section they are just about right to continue on through a turbine. This two-fold use of the same fuel looks very promising as a means of increasing the efficiency with which energy is squeezed out of remaining resources.

Another type of turbine that is getting a new look is the windmill. Lewis helped the National Science Foundation organize a conference in June 1973 which brought together experts on wind energy from all over the world for the first time. During the conference, a 5 year joint NSF/Lewis program was revealed which would study wind energy conversion systems. The program includes research, development, and testing of prototype systems. Associated studies such as determining the total wind energy available in the nation will be carried out as well. One immediate project for Lewis is a conceptual design for a large windmill capable of producing 100 kilowatts of electric power. The government of Puerto Rico requested the design.

Conversion of the Sun's energy by solar cells is technically feasible but far too costly for large scale use. Some use of solar cells is presently being made. Lewis, for instance, built and maintains a small solar powered weather station on the Cleveland lakefront which radios the readings back to Lewis on a continuous basis as a feasibility demonstration. Lewis has now provided the complete solar cell/battery system to the National Weather Service for a demonstration in Alaska and Virginia. Looking ahead just a few years it appears solar cells will be used for barrier flashers, warning lights, and telephone communication in remote areas. Before they can be put to large scale use the cost must be reduced by a factor of several hundred.

Batteries and fuel cells are other important areas of work. Fuel cells, in contrast to batteries, can operate continuously as long as they are supplied with fuel and oxidizer such as hydrogen and oxygen. Lewis has the responsibility of increasing the performance and life of fuel cell systems for space missions. Right now Lewis engineers are developing new catalysts and materials for fuel cells that are lighter, longer lasting, and cheaper than today's aerospace fuel cells. Long life and low cost are very important to Earth-bound applications that hope to take advantage of fuel cell's ability to use fuels more efficiently and with much fewer emissions than other types of engines. For space applications, Lewis has been working for more than a decade to develop long life batteries with more energy per pound of battery weight. During that time it has also developed many batteries for specialized uses such as high and low temperature environments. The two most significant developments to come out of this work by Lewis and its contractors, however, are a greatly improved zinc anode and an inorganic separator element. Together they have helped lead to a three to fourfold increase in the life of silver zinc batteries for space use. Sufficient silver is not available for widespread use in batteries for terrestrial applications. However, preliminary investigations indicate the same separator technology might be applicable to nickel-zinc batteries that would be able to store more than twice the amount of energy per pound as the present lead acid batteries.



Increasing the range of electric vehicles
(1000 lbs of batteries)

Lewis engineers are also investigating experimental solid electrolyte materials that would allow the manufacture of batteries of still higher energy density, such as potassium-sulfur batteries. Such batteries would allow an electric vehicle to go twice as far per charge as nickel zinc cells.

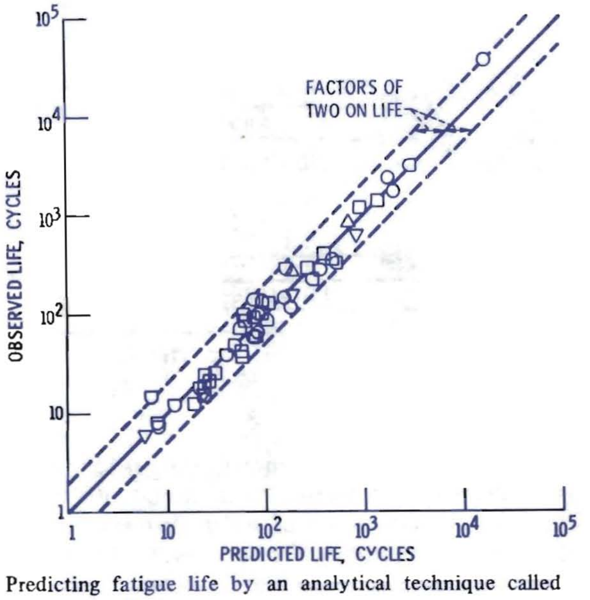
MATERIALS FOR MAN

Although the principal objectives of the work at Lewis in materials and structures are aerospace oriented, the progress being made has a major bearing on the way we all live.

Lewis has long been involved in the development of materials to meet the ever increasing demand for higher and higher temperature devices. Refractory metals, superalloys, composite materials, powder metallurgy, fracture mechanics, metal fatigue and the development of techniques to predict long term material properties from short term test data are all fields in which Lewis has established a world-wide reputation.

Some recent topics of contemporary relevance include applying knowledge of fatigue to improving the reliability of structures; contributing to the development of lower cost manufacturing processes for high temperature superalloys; advancing the technology of ceramic materials to replace heavier metallic materials; developing higher temperature turbine machinery components and low cost automobile antipollution devices; contributing to the development of advanced fire retardant polymers; and advancing the field of composite materials technology.

One major phenomenon that affects the reliability of structural components is metal fatigue. The term "fatigue" defines the gradual "tiring" process that materials exhibit. We know a great deal about the design of structures subjected to static loads. We know less about designing efficiently for dynamic loading conditions.



Predicting fatigue life by an analytical technique called Strainrange Partitioning

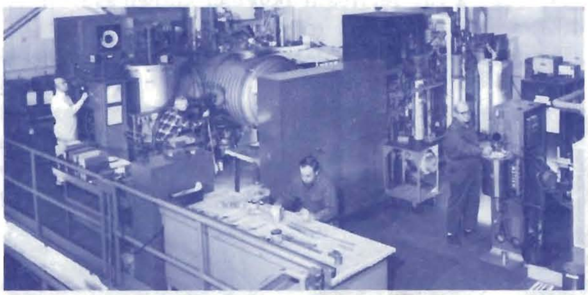
A further complication in fatigue is that consistently repeatable fatigue lives are not the norm. The fatigue process is particularly sensitive to slight inhomogeneities in materials such as notches, inclusions, and differences in surface finish not always detectable by conventional inspection techniques. Lewis is investigating the mechanisms governing the fatigue process and formulating methods that will allow us to predict the lives of structures when they are subjected to complex dynamic loadings while at high temperature.

During the past 2 years, Lewis engineers have developed an entirely new and what promises to be an extremely accurate method of predicting fatigue life in advance of service. It is called the Strainrange Partitioning method and can be applied to all types of complex cyclic loading spectra. It takes into account the effects of temperature as well as mechanically applied loads and it is equally applicable to all metals, ferrous and non-ferrous alike.

The illustration is a representation of some of the results engineers have obtained to date in predicting fatigue life by this method. Each point on the figure is a laboratory test point. The actual specimen life is plotted against the predicted life. If all the predictions were perfect, all the data points would fall on the 45 degree line. Although perfect agreement was not attained, the agreement shown is exceptionally good. It falls within a factor of 2. In fatigue experiments one encounters at least this much variation.

Various industrial organizations presently are evaluating this method in their laboratories. It is expected that the Strainrange Partioning method will permit designers of complex structures, whether they be automobiles, airplanes, or some type of complex industrial machinery, to achieve far more reliable products.

Manufacturing costs represent a major portion of the cost of most products. This observation is particularly true of high temperature nickel and cobalt alloys, the so-called superalloys used in the hot components of turbomachinery such as the turbine disks and blades. To achieve maximum turbojet engine performance, these components operate at temperatures exceeding the capabilities of the best steels and at the same time must sustain very high loads caused by the high rotational speeds involved. Because these alloys must be so strong, it is presently a difficult and costly procedure to shape or form them. A major aspect of Lewis' materials effort is intended to make superalloys stronger for their intended use in engines, yet make them more readily formable. Formability is aided by superplastic deformation of superalloys made by a new process called the prealloyed powder process. The powders are made by atomizing a multi-component molten metal with a gas stream and letting the atomized droplets solidify into powders almost instantaneously. These powders can then be compacted to any desired structural shape. The result is a significantly different metallurgical structure compared with that of the same alloy conventionally cast as a slab and then forged to a desired shape.



Furnaces for working with refractory metals

The tensile properties of the NASA TRW VI-A, in the prealloyed powder product form and in the cast form, were compared over a temperature range from room temperature to 2000 degrees fahrenheit. The powder product showed a marked strength advantage up to 1400 degrees fahrenheit. Above 1500 degrees fahrenheit there is a rapid drop in its strength. Accompanying the drop in strength, however, is a dramatic increase in ductility for the powder product. At 2000 degrees fahrenheit, its elongation is over 300 percent (more than an order of magnitude greater than that of the conventional cast version of the alloy). The very high ductility is referred to as superplasticity, and it is this property that makes it possible to eliminate many of the steps in a conventional "forging" operation. In other words, the material can be formed to any desired shape by applying low loads at 2000 degrees fahrenheit temperature and the finished part can then be used in the temperature range up to 1400 degrees fahrenheit where the prealloyed powder product shows such a marked strength advantage. Currently, research is being directed toward devising methods of altering the metallurgical structure of superplastically formed parts so that their strength can be increased at temperatures above 1400 degrees fahrenheit as well, and the usable temperature range extended still further.

The prealloyed powder concept is already beginning to find applicability in the aircraft industry. Far wider use throughout the entire industrial community can confidently be expected.

Reduced weight and the ability to withstand ever higher temperatures are major goals of materials research for jet engines. Ceramics offer great promise for substantial improvements in these properties. Lewis research has shown certain ceramics, namely silicon carbide and silicon nitride, to be most promising for particular turbomachinery applications.

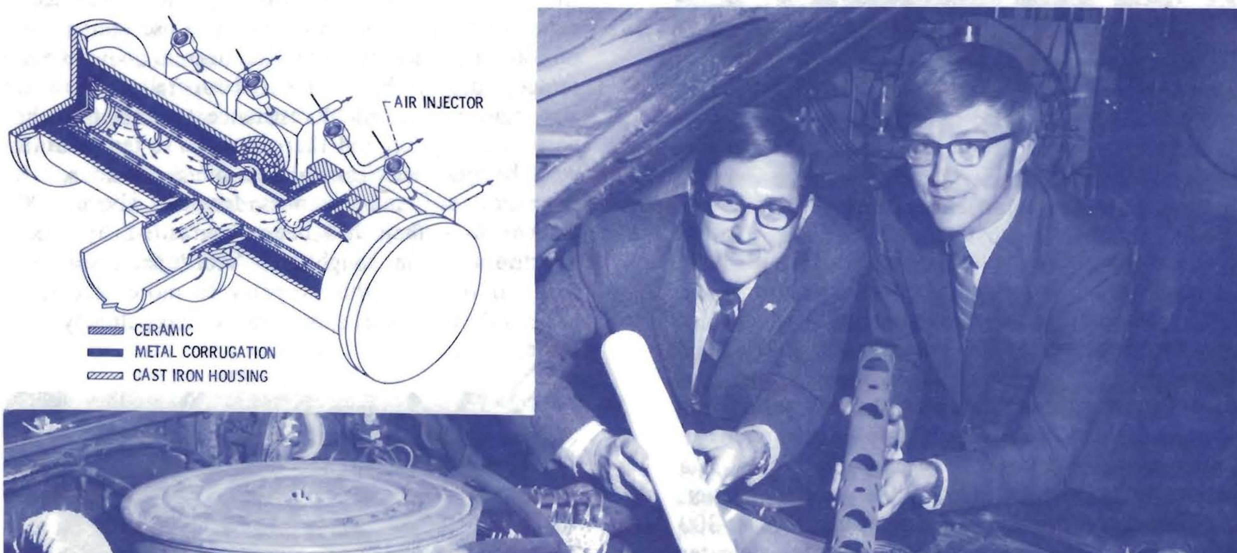
A comparison with metals shows that the projected price of a ceramic part in comparison to the same metal part is only one-thirtieth that of the metal. Also, a 60 percent weight savings results with the use of the ceramic. A further major advantage of ceramics such as silicon carbide is a use temperature of 3000 degrees fahrenheit, 800 degrees above the use temperature of the best coated superalloy. Ceramics also maintain excellent resistance to oxidation, hot corrosion, erosion and thermal stress to temperatures well beyond the capabilities of superalloys. The superiority of the ceramics for use above 2000 degrees fahrenheit has been augmented by recent improvements in toughness. Additional research is required to bring this property to more acceptable levels although significant advances have already been made.

Scanning Electron Microscope

Stator vanes made of ceramics are already being considered for use in stationary ground power turbomachinery. Because they are cheap, lightweight, and can withstand very high temperatures, ceramics are also finding very practical and important application in antipollution devices for automobile engines. In the conventional internal combustion engine, exhaust gases contain objectionable quantities of carbon monoxide and unburned hydrocarbons. Oxidation of the carbon monoxide and unburned hydrocarbons can be completed in thermal reactors employing ceramics. Lewis has been testing materials for thermal reactors in a test program for the Environmental Protection Agency, and ceramic thermal reactors have been built and evaluated. Silicon carbide operating at temperatures up to 2000 degrees fahrenheit has performed excellently in the thermal reactor of a laboratory station wagon for more than 20,000 miles.

Plastics, because of their light weight and low cost, are found in many consumer products, as well as in aerospace and industrial applications. Lewis researchers are developing fire retardant polymers to reduce the danger of fires in products that use plastics. Polymers are chains of interconnected molecules composed principally of carbon and hydrogen, plus other elements such as oxygen, nitrogen, halogens or silicon. Most polymers can burn or decompose to form toxic by-products. To minimize toxicity, Lewis and other NASA centers have been developing nonhalogen-containing fire retardant polymers such as the polyphosphazenes.

Under the sponsorship of the Johnson Space Center in Houston, Texas, the Monsanto Corporation developed a fire retardant polymer known as Durette 402, which was used to weave the fabric for the astronaut coveralls and sleep restraint equipment used



Experimental thermal reactor for automobile pollution control in the Skylab mission. A polyphosphazene that Lewis is developing for use as a binder or matrix material for fiber reinforced plastics also has an excellent flame retardant potential.

Lewis is also attempting to synthesize polymers with increased toughness, strength, and use temperature capability up to 600 degrees fahrenheit, as well as other properties needed for use as the binder or matrix material in fiber reinforced plastics for all types of structural applications. These fiber reinforced plastics are called composite materials. Because they are lighter, stronger, and stiffer than metals such as aluminum and titanium, Lewis is developing a whole new technology of these composite materials so that they can be substituted for many metals in turbine engine fans and compressors and in aerospace structures. Their applicability to nonaerospace use is constantly growing also. One example is lightweight, substantially safer pressure vessels for a variety of ground installations.

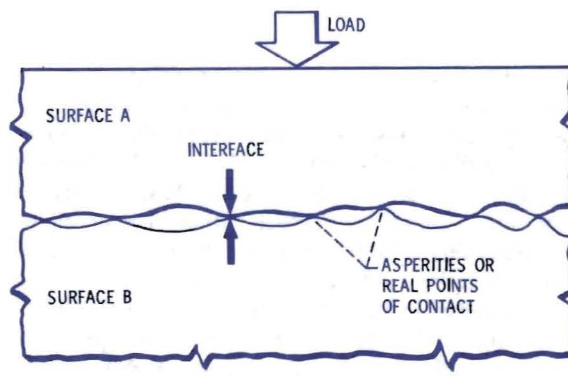
THE IMPACT OF WEAR

Among the artifacts in the ancient tombs, archeologists have found animal tallow and other solids that were used as axle lubricants. From this it is clear that our forebears appreciated the value of lubricants and understood that axle lubrication made the wheel a practical device. Without lubrication, high friction demands a considerable effort and high wear decreases the useful life of moving parts.

As man developed labor saving devices, he encountered lubrication problems. The early simple tools have been replaced by complex machines. Automobiles, aircraft and rockets have supplanted the chariot. The problems of lubrication are, however, still with us and have become a very critical element in today's technology.

Endurance test area for bearings, slip rings and lubricants

A study in England a few years ago indicated that billions of dollars were being lost annually because of improper or inadequate lubrication. An awareness of this loss initiated a large scale research and development program in lubrication in that country. Based on the British figures, we can say that the annual loss in the United States today due to inadequate or poor lubrication practices easily exceeds 10 billion dollars.



The microscopic nature of metal surfaces

Much of Lewis work has been directed toward discovering and defining the fundamental principles of performance in mechanical components, continuing advanced work on the mechanisms of lubrication, pioneering work on lubricant additives, and research on bearing materials at the atomic level.

Some of the specific contributions from this broadly interdisciplinary research are the discovery of the effects of metallic crystal lattice and atomic spacing on friction and wear; the conception and development of graphite-fiber, polyimide composites; the pioneering work in ion plating and sputtering of lubricant films; the demonstration of benefits of sulfur and chlorine additives (now widely used); and the discovery of the effect of the differences in hardness of metals used in the races and rolling elements on bearing life.

Among other things, this advanced technology has made possible reliable, efficient, long life bearings in high temperature, cryogenic, vacuum, and liquid-metal environments.

The first step in solving a problem such as bearing wear is to understand the way in which it starts. The problem starts with contact between two solid surfaces. In recent years, surface analysis tools have become available that have allowed giant strides to be made toward a better understanding of wear and to really define the problems. One of these tools is the Scanning Electron Microscope (SEM). Previous microscopes have not had the depth of focus to give an adequate picture of the wear process, but the SEM produces a clear picture of wear as it occurs with magnifications from 7 to 77,000 times.

Microscope pictures show that contact between bearing surfaces is really between high spots or asperities on the surfaces. The highest magnifications of normal bearing finishes make it appear that the Alps have been placed upside down on the Rocky Mountains. This means the real area of contact between the peaks is a very small percentage of the total surface area. The very high pressures brought to bear by the peaks sometimes break through any protective film on the bearing. When the film breaks, it is possible for completely clean base metals to come into contact with each other. Under these conditions almost all engineering materials will adhere or stick together. With the continuing motion of the bearing, these junctions fracture and frequently a protruding particle breaks off. The broken particles may be work hardened and act as an abrasive to wear the surface further.

In minimizing wear a protective film or lubricant on the surface is always preferred, but the base material itself should be capable of minimizing the damaging effects of friction and wear.

One Lewis approach to this problem has been based on how atoms move due to shear in various types of crystal. The arrangement of atoms and the spacing between planes of atoms in crystals determine the planes in metal crystals where slip and fracture can occur. Lewis engineers have found that hexagonal closely-packed crystals give far better performance as slider bearing materials than the more common cubic crystal structure. By alloying to get greater spacing between the hexagonal planes, friction can be further reduced. Also, alloying can insure that the hexagonal structure will not change to cubic, which normally occurs at higher temperatures.

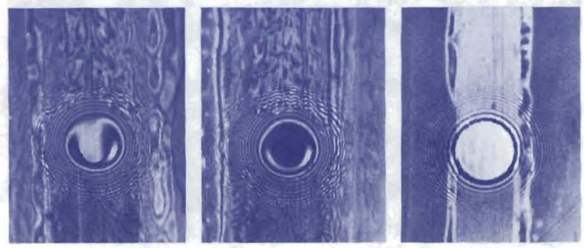
Another approach to improving the wear resistance of the base material is to employ segregation or diffusion mechanisms to develop surface layers on materials that influence those performance factors. The basic structure of a bearing alloy can still be established to meet mechanical, thermal, or other requirements; but the surface layer that dominates the adhesion, friction and wear processes can be designed to give needed performance in lubrication.

In addition to diffusion and surface segregation of desirable elements to reduce adhesion, friction and wear, there are other properties or characteristics of materials that can be exploited to accomplish similar effects. One of these is texturing which is causing the crystalline slip planes to become almost parallel to the surface. The texturing process is one that occurs with careful run-in. If the material can be textured to the point that the slip planes are nearly parallel to the surface, the particles of wear may be only a few atomic layers thick and give reduced wear as well as reduced friction.

There are two ways to reduce adhesion, friction and wear with any solids in sliding, rubbing or rolling contact. One, already mentioned, is to take advantage of material properties such as segregation or texturing. The other is to lubricate the solid surfaces.

Oxide films present on material surfaces serve as lubricants that prevent contact of clean metals and thereby are helpful in reducing adhesion, friction and wear.

Solid lubricant materials chosen on the basis of easy shear can provide much lower friction than the oxides. Most people are familiar with oils and greases as lubricants, but the use of solids to lubricate surfaces is not quite so well known. A solid that lubricates and is familiar to most because of its



Photomicrograph of progressive lubricant starvation of bearing

usefulness around the home is graphite. Lewis has been active in developing solid film lubricants over the last three decades. It has been demonstrated that excellent performance can be obtained with solid lubricants like graphite, molybdenum disulfide, Teflon, lead monoxide, calcium fluoride and graphite fluoride under extreme conditions where liquid lubricants cannot function or survive. Solid lubricants are now commonplace in industrial products like automobiles.

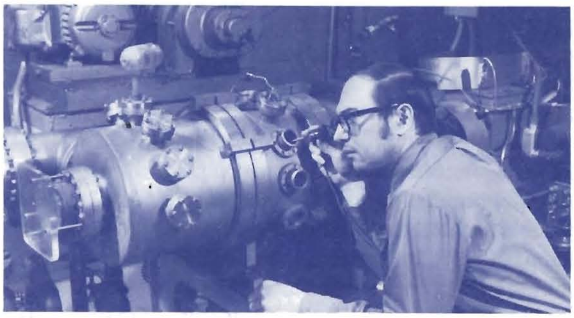
Solid lubricants have a limited wear life. In some cases they can be incorporated into the bulk structure of composite materials to extend the wear life. The wide use of thin films, however, dictates that improved methods of application be developed for extending wear life.

The life of a solid lubricant film is very often determined by how well the solid adheres to the coated substrate. Lewis has pioneered in the use of the vacuum system processes of ion plating (soft metal films like gold or silver) and sputter coating (compounds like molybdenum disulfide). Both methods can produce highly adherent films that have good lubricating properties.

Despite the long history of their use, we are still learning new things about oils. In recent years, one of the more significant additions to the science of lubrication is the concept of elastohydrodynamics (EHD). As the name implies, it involves the hydrodynamic formation of an oil film between surfaces that become elastically deformed under high loads. These oil films are very thin, on the order of 10 or 20 millionths of an inch. This method of lubrication occurs in many applications including the lubrication of ball and roller bearings.

One of the tools now available to study EHD lubrication is optical interferometry. This technique uses the wavelength of light, about 8 millionths of an inch, as a basic unit of measure for determining the thickness of these thin oil films.

The fluid in the contact area can encounter very high pressures. In ball bearings the maximum pressures are usually 200,000 to 300,000 psi. It has long been known that oils get more viscous at high pressures, that is, as we force two surfaces together under a load the oil becomes less fluid. New data show that the oil in the contact is essentially solid and glass-like at very high pressures. From such studies, engineers learn about the types of molecule that give this behavior; thus they can also design lubricants to provide useful film thickness, high film strength, and traction to prevent skidding in bearings at high speeds.



Shaft seal testing facility

Additionally, engineers are relating the lubricating and cooling of the lubricants to properties such as surface tension which is the ability of the lubricant to wet a surface, vapor pressure, stability at high temperatures, shear stability and other characteristics.

Some of the first wearing parts in man's existence were the parts of his own body - hip joints or knee joints. For example, there are many people today with diseased or worn out hips. The orthopedic uses of surgical implants of total hip prostheses (artificial joints) have been spectacular successes. Patients have almost complete relief of pain and achieve mobility many have not known for years. There may be as many as 100,000 such operations performed each year in Western Europe, Canada and the United States. One of the factors most doctors now use for considering such surgery is advanced age, e.g., 65. That is because present prostheses are considered to have a wear life of only 10 years and reoperation, while done, is not desirable. Thus, surgical implants of artificial joints are generally only done on younger persons when it is absolutely necessary. Extending the lives of such prostheses by reducing wear is urgently needed. Lewis believes some of the results from space-oriented materials studies can be applied to implanted orthopedic devices.

The metals most commonly used for prostheses are cobalt-chromium base alloys with cubic crystal structures. One of Lewis' hexagonal alloys is a cobalt, molybdenum chromium alloy. The chemistry of the two alloys is sufficiently similar so that Lewis engineers thought the hexagonal alloy would also be compatible with living tissue. Furthermore, wear and friction data were obtained that suggested substantial improvements are likely.

Another material from space programs that seemed applicable was the polyimide plastic. It has good self lubricating properties and can be used in a variety of difficult seal and bearing applications.

Lewis engineers believe there are potential advantages to replacing the presently used high density polyethylene in several types of prostheses with polyimides.

In cooperation with the University of California at Los Angeles Medical School, hexagonal metal alloys and polyimide plastics are now under study for possible application to orthopedic implants. Tissue compatibility implants in rabbits have been continuing and present results are favorable. Additionally, some dogs have total hip prostheses of experimental materials and are being studied for functional capabilities.

Results with conventional materials have given some immediately applicable information. Aerospace experience with rocket and aircraft engines showed that wear of a bearing with plastics in contact with metal depends on the development of a transfer film of the plastic on to the metal. The formation of that transfer film is influenced by the roughness or texture of the metal surface. Presently used artificial joints have the section that is implanted in the upper leg finished to extreme smoothness. Increasing the roughness from 1 to 4 or 8 microinches can almost cut the wear in half. Thus, the life of a hip joint also might be extended by using another well established concept from aerospace lubrication technology.

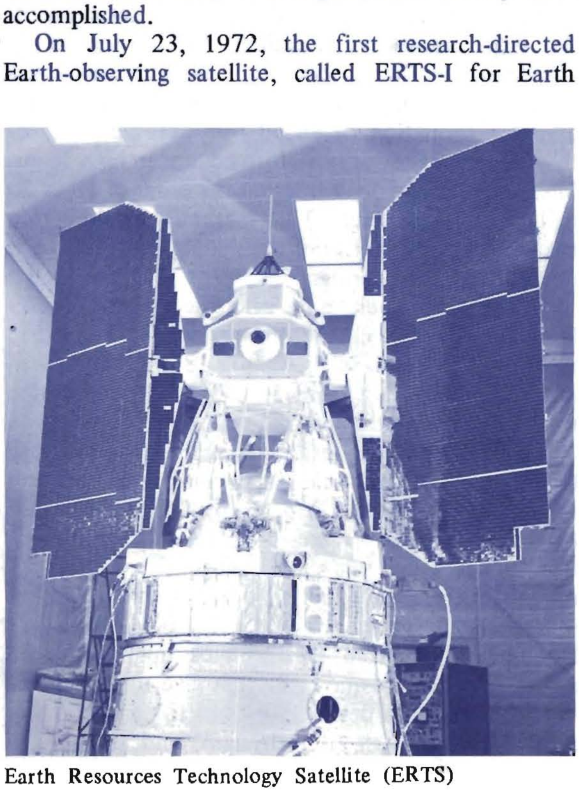
SERVANTS IN SPACE

Among the many uses of spacecraft are communications, weather forecasting, scientific data gathering in space, solar observation, exploration of the Moon and planets, and perhaps surprisingly exploration, inventory, and management of terrestrial natural resources and the activities of man on Earth.

Almost from the beginning of the agency, NASA experimented with photographing the Earth from rockets and from unmanned and manned satellites. The results were both spectacular and practical. These photographs demonstrated the special characteristics of space imagery; tens of thousands of square miles of the Earth's surface could be shown in single scenes, giving uniformly illuminated coverage of whole regions and containing a wealth of detail.

After viewing these pictures, experts in many fields recognized the potential of Earth-observing systems from orbiting platforms for those applications that prove too difficult or expensive to do by most conventional methods. Consider as examples, rapid and repeated inventory of crop production in areas as large as the entire Great Plains, updated mapping of national forests throughout the Rocky Mountains, assessment of changes in large metropolitan areas, statewide mapping of major land use patterns, recognition of geologic conditions favorable for possible concentration of ore minerals, continual checks on the status of water reservoirs serving millions of people, examination of vast stretches of open ocean for conditions favorable to feeding grounds for fish, monitoring of air and water pollution, determination of the extent to which the land is scarred by strip mining or mineral extraction, and surveying of great masses of sea ice to establish shipping lanes, and monitoring the development of icebergs. All of these tasks can be done effectively from satellites and, to a degree, have already been accomplished.

On July 23, 1972, the first research-directed Earth-observing satellite, called ERTS-I for Earth


Earth Resources Technology Satellite (ERTS)

Resources Technology Satellite, developed under the management of the Goddard Space Center, was launched in a near-circular, almost polar orbit at an altitude of 570 miles. This satellite carries several image sensors including a multispectral scanner that produces an image 115 miles on a side or more than 12,000 square miles. The scanner, by examining the Earth at different wavelengths, yields photoimages that represent light reflected or radiated from the surface in green and red in the visible light range and in two wavelengths in the near infrared. The satellite reoccupies the same orbital path and covers the same large area every 18 days. Depending on cloud cover, up to 20 different images of each scene are obtained in a year. This allows for seasonal coverage to monitor changes in vegetation, snow cover, water supply, land development, and the like. So far, over 75 percent of the earth's surface has already been examined by ERTS.

How practical is ERTS? Here are a few examples of this powerful new space tool.

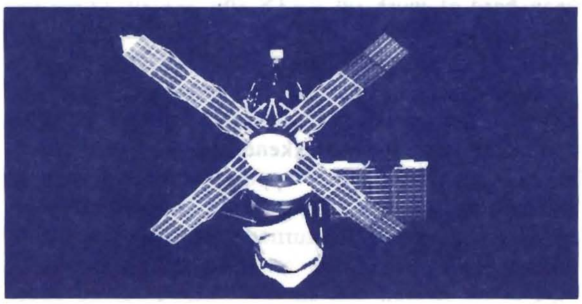
In the rugged inaccessible Wind River Mountain range in west central Wyoming a scientist had been mapping for 5 years the great faults and fractures, which are important features because they may concentrate mineral deposits. He had, after thousands of hours by pack mule and foot completed about 10 percent. One aerial flight added some new information. But after he got the ERTS image, he was able to complete the fractures map for the whole range in just 3 hours (including coffee break time).

Inventory of croplands during a growth cycle takes particular advantage of the repetitive coverage afforded by ERTS. A pilot study of ERTS' effectiveness in crop recognition was carried out in a small area of the Sacramento Valley. While the naked eye has difficulty in discerning small differences in the color tones for some of the fields, careful measurements show the differences to be real and to represent the influence of different crop types. For the number of categories selected, the computer-generated ERTS classification has proved to be about 90 percent accurate. From data like these, it is possible to derive such useful information as total acreage planted in each crop type, estimates of total harvest, approximate times of anticipated crop maturity, and, in some instances, an indication of possible crop disease or weather damage. At present, the only alternatives to getting this information are to send county farm agents out to count the crops or to ask each farmer to send in monthly reports.

State legislatures trying to develop sound land use legislation require as an essential base a series of use maps, whose costs of initial preparation and continual updating are monumental. ERTS can do the job for a fraction of this dollar outlay.

Skylab is an experimental space station which was launched on May 14, 1973. The station is a 100-ton complex of highly versatile laboratories being used for multipurpose scientific, medical, and technological investigations. At 234 nautical miles above the Earth, Skylab crisscrosses every section of the world between 50 degrees north latitude and 50 degrees south latitude every 5 days.

One of the prime objectives of the Skylab Program is to improve man's ability to better understand Earth resources in such fields as geology, forestry, oceanography, and especially agriculture.



Skylab I

The Earth Resources Experiment Package (EREP) aboard Skylab is composed of a group of instruments including cameras, radar, microwave and infrared radiometers, and a multispectral scanner that can record photographic and thermal infrared information of the Earth's surface at numerous wavelengths. These data are stored on photographic film and computer tape and are being analyzed by some 150 U.S. and foreign scientists. Additional data are also being acquired by electronic microwave sensors aboard Skylab. This is the first time such microwave sensors have ever been used to view the Earth from space.

One photograph, taken over southwestern Utah, shows an excellent view of the San Rafael Swell, a large structural feature on the Earth's surface called an anticline. The feature, defined by rock units of varying color and composition, is the surface expression of subsurface conditions, which in many cases are reservoirs of oil and gas accumulation. Similar structural conditions observable on the Earth's surface may contain copper, silver, and other minerals.

Scientists analyzing these types of EREP photographs are developing and applying the use of space photography to help locate hydrocarbon and mineral deposits throughout the world.

Another photograph, taken in June 1973, shows the city of St. Louis, and the confluence of the Mississippi and Missouri Rivers. These data will be used by the U.S. Army Corps of Engineers to study the extent and effect of the recent major flooding along these rivers. It will also be analyzed for groundwater supplies in the vicinity of St. Louis.

The investigations which are being conducted with ERTS-I and EREP data will pave the way toward the development of future Earth orbiting systems to conduct operational crop acreage and other Earth resources inventories over extensive areas of the Earth's surface.

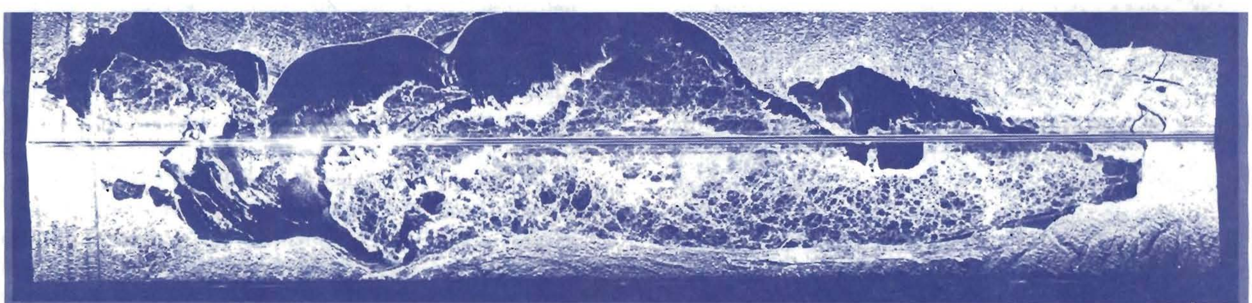
While Goddard and Johnson Space Centers have been hard at work on ERTS and Skylab, Lewis has been advancing the art of Earth observation by tackling some local problems from aircraft.

Strip mining in Ohio has left great scars across the southern part of the state. Miners as well as environmentalists have been awakened to the problems of rehabilitating the land. Mapping the overall damage and advance of strip mining is not enough, however. Many types of soil are turned up during the mining process and part of the general problem is one of making an overall soil survey. Such a survey could take years if conducted from the ground. The question Lewis scientists undertook to answer was, "Can the strip mined soil types be identified remotely and at the resolution required?" The answer is yes. A general soil survey also can be done remotely. Surveys of counties in Ohio can be done in days or weeks by automatic processing. Maps could then be provided with speed and accuracy to land use planning commissions at the county, regional, and state levels.

Seasonal loss of jobs and under-utilization of equipment and facilities result from the Great Lakes being closed to shipping for 4 months out of each year. This problem has been recognized for some time, and a combined effort involving 10 Federal agencies is attempting to assess the situation and determine the feasibility of extending the shipping season to the full 12 months of the year. The many aspects of the problem are aided by information concerning the distribution of the type of ice and thickness on the lakes at regular intervals. Unfortunately, ERTS looking in the visible and near infrared portions of the spectrum cannot help much here because it is only very rarely that the lake area is not cloud covered in winter. Lewis has been using Side Looking Airborne Radar (SLAR) to produce a picture of the entire Lake Erie, for example, with one pass. SLAR's big advantage is that it makes a clear picture of the ice conditions on the lake whether there is cloud cover or not, daytime or nighttime. In the wave length used by radar, clouds are transparent, and radar provides its own illumination.

During the winter of 1972-73, Lewis worked with the U.S. Coast Guard to flight test all of the instruments to be used in the program. In addition to SLAR, short pulse radar was used to measure ice thickness, and a thermal infrared mapper was used to read the Lake's surface temperature. At the same time, the Coast Guard measured ice thickness and made observations on the ice to compare with instrument measurements.

During the winter of 1973-74, Lewis will try to reduce the entire procedure to a fast, efficient, remote system. At the same time, the maps being produced will be made available to shipping companies on as close to an operational basis as possible. Such maps will allow captains to choose the path of least resistance through the ice and be a major step in bringing year-round navigation on the Great Lakes closer to reality.



ICE COVER ON LAKE ERIE FEB 22, 1973, AS RECORDED THROUGH CLOUD COVER ON SIDE LOOKING RADAR BY NASA LEWIS AS PART OF A MULTI-FEDERAL AGENCY EFFORT TO EXTEND THE GREAT LAKES SHIPPING SEASON.

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