ADVANCED RESEARCH

LANGLEY RESEARCH CENTER

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ADVANCED RESEARCH
key to the future

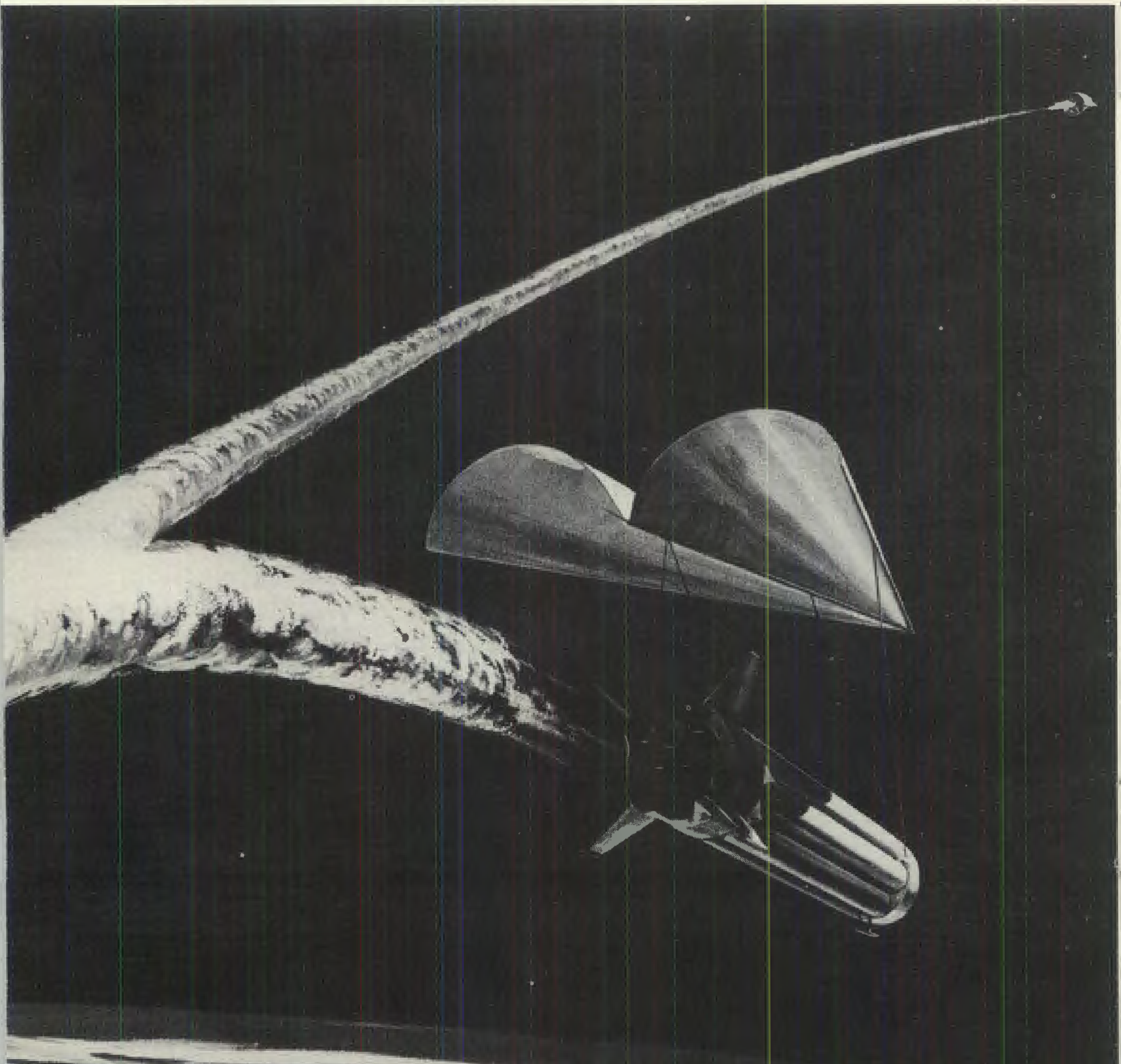
In one minute, approximately the time it takes to read this page, a man-made satellite will travel about 300 miles; a jet airliner may fly 10 miles; an electronic computer can make more than a million different calculations.

These are results of research and technology.

And man, questing for knowledge, determined to satisfy his curiosity, and desiring to improve his life, is continuing and speeding the march of technology. In space technology alone, man has advanced farther in one decade than in all previous recorded history.

For the most part, progress is not born of single moments of inspiration. Instead, advances have evolved from a sustained, gradual, and systematic accumulation of basic knowledge which eventually lent itself to solving the problems at hand and attaining the goals desired. Just as earlier discoveries form the foundation for present United States aeronautics and space technology, NASA's advanced research programs and projects of today are paving the way for aerospace exploration and developments of tomorrow. Descriptions of some of these studies are presented in this booklet.

Parawing recovery of Saturn first stage (artist's conception).

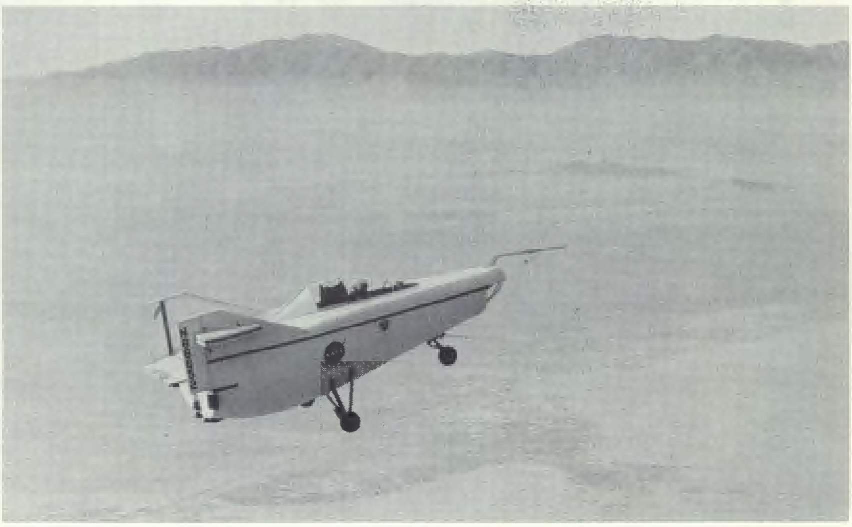


LOW-SPEED RESEARCH

Research in low-speed flight supports both aeronautic and space technologies. For example, it is aimed not only at improving the performance of V/STOL (vertical/short take-off and landing) aircraft but also at incorporating acceptable low-speed flying characteristics into the designs of spacecraft and supersonic airplanes to slow them for safe landings.

NASA is studying numerous types of V/STOL craft. One is the tilt-wing airplane. At take-off and landing, the wings of such craft are rotated to a vertical position so that the propellers provide lift by creating a downward stream of air. For forward flight, the wings are turned to a horizontal position, enabling the craft to fly like a conventional airplane. The tilt-wing airplane is the result of extended research and experiments involved in the search for an efficient plane that combines the high air speed of the conventional propeller-driven airplane with the vertical take-

M-2 during low speed glide flight test.

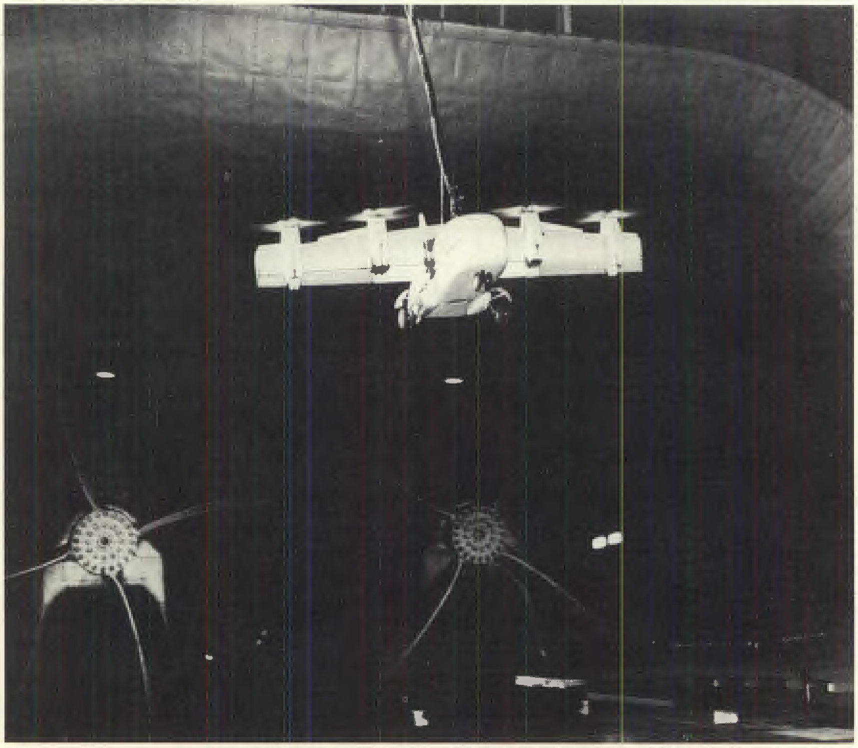


off ability of the helicopter. Tilt-wing work has recently culminated in development of the Tri-Service (Army, Navy, Air Force) XC–142A. When operational, the XC–142A is expected to carry four tons of personnel or cargo and cruise at 300 to 350 miles per hour.

Landing of all U. S. spacecraft recovered to date has been accomplished by means of parachutes. The principal disadvantage of parachutes is that they provide little maneuverability. Techniques are under study that will enable re-entry craft to maneuver over a wide area and land like airplanes.

One method is to use a device such as a parawing which is being considered for some phases of the Gemini manned space flight program and for salvaging costly rocket boosters after they have launched craft into space. A parawing looks and functions

Model of 1/9th scale XC-142A in wind tunnel.



somewhat like a child's folded paper airplane but can be stored and deployed like a parachute.

Another technique is to build the glide capability into the design of the spacecraft. Research results with two such configurations, the M–2 and the HL–10, are so promising that NASA is building two advanced gliders of this type to augment information on the problems of landing spacecraft. Fundamentally, these experimental re-entry vehicles, possible forerunners of ferry craft that will shuttle between future manned space stations and earth (or of future craft that would fly beyond the moon), are designed to withstand the buffeting forces, high pressures, and intense heating of launch and of entry into the atmosphere. In incorporating lowspeed characteristics, care is taken to avoid impairing these capabilities.

HL-10 model being tested in spin tunnel.

SUPERSONIC AIRCRAFT

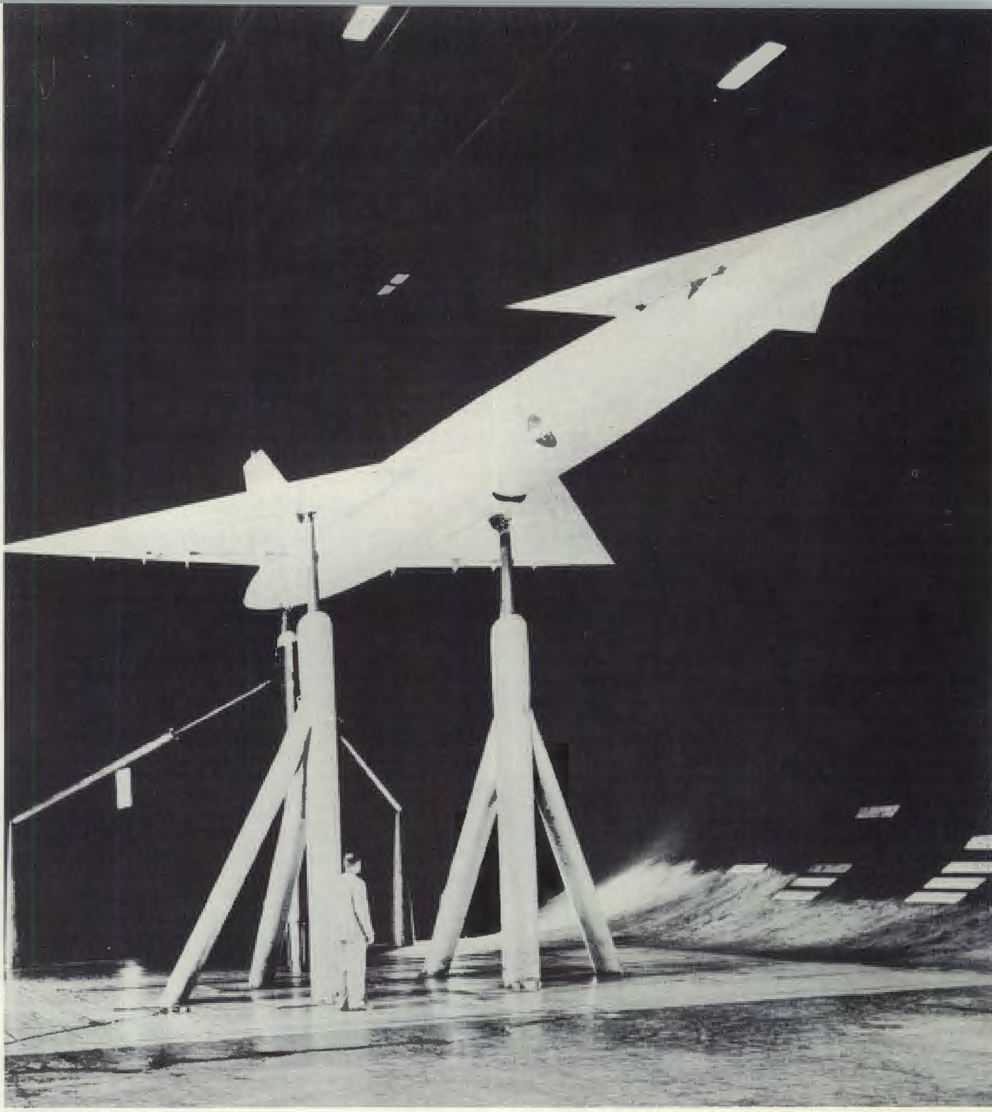
Supersonic flight is flight at speeds faster than sound. Sound travels at 760 miles per hour at sea level and 660 miles per hour at an altitude above 40,000 feet. From the standpoint of efficient supersonic flight, an airplane should be designed so that it is long and slender with thin short wings that are sharply swept back. On the other hand, to take off, approach, and land at low speeds calls ideally for long wings jutting perpendicularly from the fuselage.

Engineers have worked for years on a plane that could operate efficiently at supersonic as well as lower speeds. A research team at NASA's Langley Research Center was the first to solve the problem with the variable-sweepwing concept. In this variable-sweep-wing concept, the wing is extended to provide extra lift for take-off and landing, then can be swept back for efficient supersonic flight. Initial application of the concept was in military aircraft.

For several years, NASA has engaged in a program which has provided United States industry with information basic to construction of a safe and economically practicable supersonic commercial air transport (SCAT). Among the design goals are a speed of Mach 3.0 (three times the speed of sound); a range of 4000 miles; ability to operate from existing jet airports; operating costs equivalent to current subsonic jet airliners; and a useful lifetime of 15 years, or 30,000 to 50,000 hours of operation.

The skin of such a transport must be able to withstand critically high temperatures that can reach 650° Fahrenheit at a speed of 2,000 mph. The heat is generated by compression and friction of air molecules in contact with the plane's exterior. Since aluminum alloys, used in most of today's commercial airlines, lose their strength at this temperature, other metals were studied. Results favor a titanium alloy that has a melting point of about 3000° Fahrenheit.

A significant consideration in the design of aircraft is the air drag on the plane. At subsonic speeds, drag is caused chiefly by friction of air against the plane's skin and by the wing while producing lift.



Model of SCAT-17 in Ames wind tunnel.

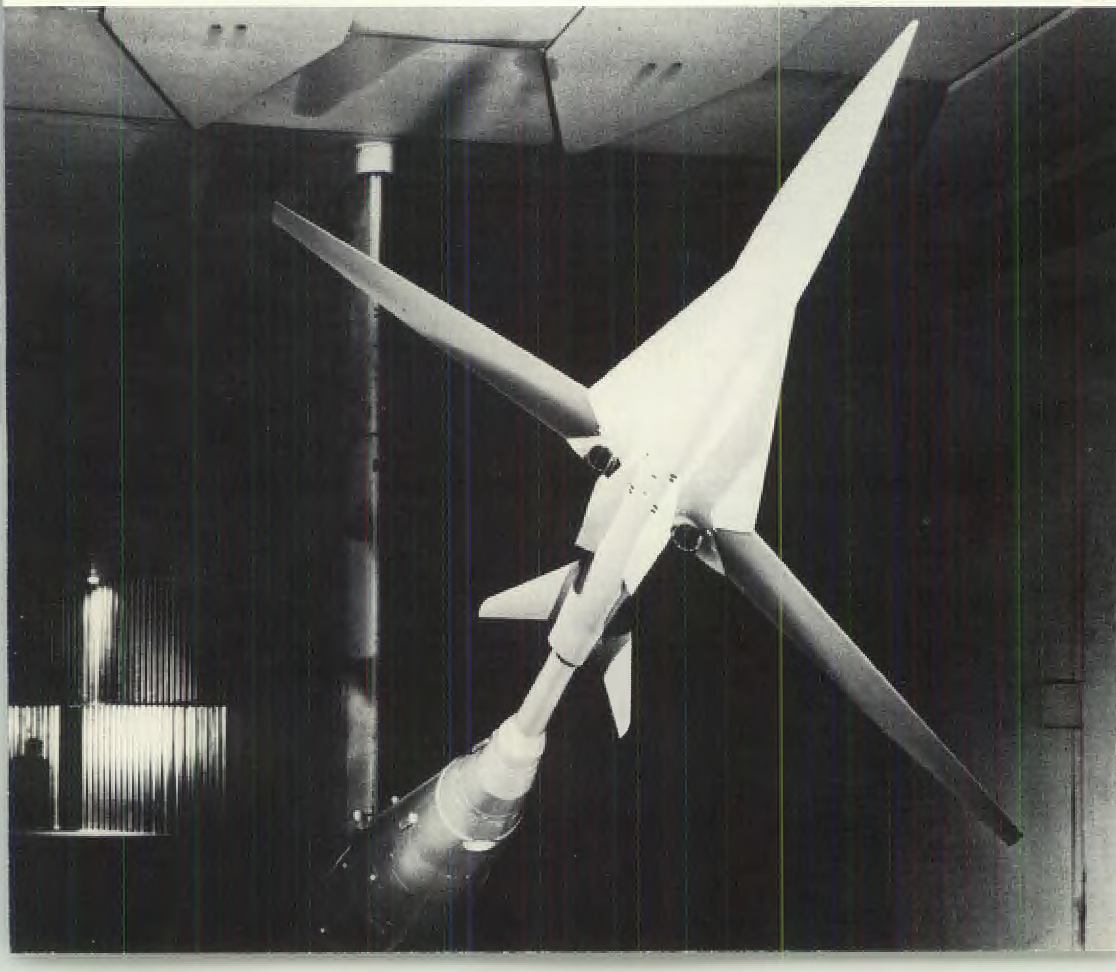
At supersonic speeds, however, the plane is subject to a third type of drag called shock wave drag. The shock wave is produced when an aircraft flies so fast (at supersonic speeds) that it sharply compresses the air about it. The shock wave flows back on each side of the plane like the waves stirred up by the bow of a racing boat, retarding the forward motion of the plane.

Laboratory experiments have demonstrated that shock wave drag can be reduced by constructing a body that is long and thin and by sweeping back the leading edge of the wing. Recent research has shown that the engine nacelles (housings) can be so located that the aggregate drag on the nacelles and airframe together is less than the total of their individual drags.

NASA considers two of a number of supersonic commercial air transport designs studied worthy of further consideration. One, SCAT–16, features a variable-sweep wing, such as described earlier. The other labeled SCAT–17 is distinguished by a long fuselage with a fixed delta (triangular) wing.

Many years of additional study and development will precede the first commercial flight of the supersonic transport. When available, it could cut the best commercial flying time from New York to Los Angeles from approximately 4¼ hours to about 1½ hours.

Model of SCAT-16 in wind tunnel.



AIRCRAFT OPERATING PROBLEMS

NASA is working on problems of general concern that arise in the operation of aircraft, such as fire hazards, collision avoidance, human factors, crashworthiness (protection of occupants in case of crashes), pilot's displays, all-weather flight, noise, air traffic control, and landing and take-off.

As an example, a cockpit of a simulated supersonic commercial airliner has been built at Langley Research Center to examine factors relating to traffic control of such aircraft entering and leaving commercial jet airports. The study ties in the flight simulation capabilities of the center and the air traffic simulation facilities of the Federal Aviation Agency's National Aviation Facilities Experimental Center, Atlantic City, New Jersey.

Research pilots will climb into the ground-based cockpit to simulate future arrivals at and departures from metropolitan air terminals. The controls in the cockpit are linked with a computing system programmed to duplicate anticipated performance and handling qualities of several possible types of supersonic commercial airliners.

Another problem under surveillance is the sonic boom. The sonic boom, or shock wave, is thrown off by supersonic craft like bow waves from a boat. In the atmosphere, it takes the form of a cone with its point at the aircraft. When this cone touches earth, it may be heard as a faint snap or a violent thunderclap.

There is a relationship between the magnitude of the boom which reaches earth and the altitude of the supersonic aircraft. As a result, engineers recommend that such aircraft avoid accelerating to supersonic speed until they reach an altitude above 40,000 feet, then continue to climb and accelerate reaching Mach 3.0 at 65,000 feet.

Studies of the effects of sonic booms over populated areas are being conducted by NASA, the Department of Defense, and the Federal Aviation Agency. Basic purpose is to examine the boom's effects on other aircraft, on buildings, and on people. A study is being carried out over Oklahoma City where supersonic Star-

Supersonic Commercial Air Transport Cockpit Simulator.

fighter jets are being flown so as to duplicate the sonic booms of supersonic airliners. As yet, although reportedly a nuisance to some people, the booms have caused no serious damage to well designed and structurally sound buildings. The booms have caused minor damage such as cracked windows and plaster.

Studies are also being made of factors in aircraft design that would alleviate the boom.

Another area of concern is the noise of jet engines. The roar of the exhaust has been decreased by fan engines which reduce the velocity of the exhaust air.

During the landing approach, inlet noise (caused by the whirling compressor blades) is a problem. Work is in progress to reduce this type of noise.

NASA is conducting research with powered-lift systems (such as boundary layer control) that can substantially increase lift capabilities of airplanes resulting in reductions in landing and take-off speeds. Low speeds are desired from the standpoints of reducing landing distances, lowering bad weather minimums under which aircraft can operate, and obtaining greater safety. NASA flight research in this area is being conducted with both propeller-driven and jet aircraft. Goals are to study low-speed flying characteristics and establish preliminary flying quality requirements for air transports with powered lift systems.

NASA studies have provided new data on reducing the hazards of take-off and landing on rain-slick or slush-covered runways. One problem concerns skidding of airplanes on wet runways. Frequently, the cause of such accidents is hydroplaning, a phenomenon that occurs on wet pavement when a vehicle reaches a speed at which hydrodynamic pressures lift tires clear of the pavement. The vehicle in effect is traveling on a slippery film of water and the wheels are useless for slowing down or turning.

Experiments demonstrate that hydroplaning may occur in water depth of as little as 1/10th inch. They indicate that hydroplaning is influenced by such factors as tire tread design, texture of runway surface, speed, depth of the fluid (water or slush), tire pressure, and runway drainage.

The experiments also showed that straight grooves (ribbed treads) in the tires retard hydroplaning because they furnish a channel for escape of some of the water. The weight of the vehicle has little relation to hydroplaning, but the tire pressure does. Pressure should be as high as possible. Rough textured instead of smooth pavement reduces hydroplaning effects.

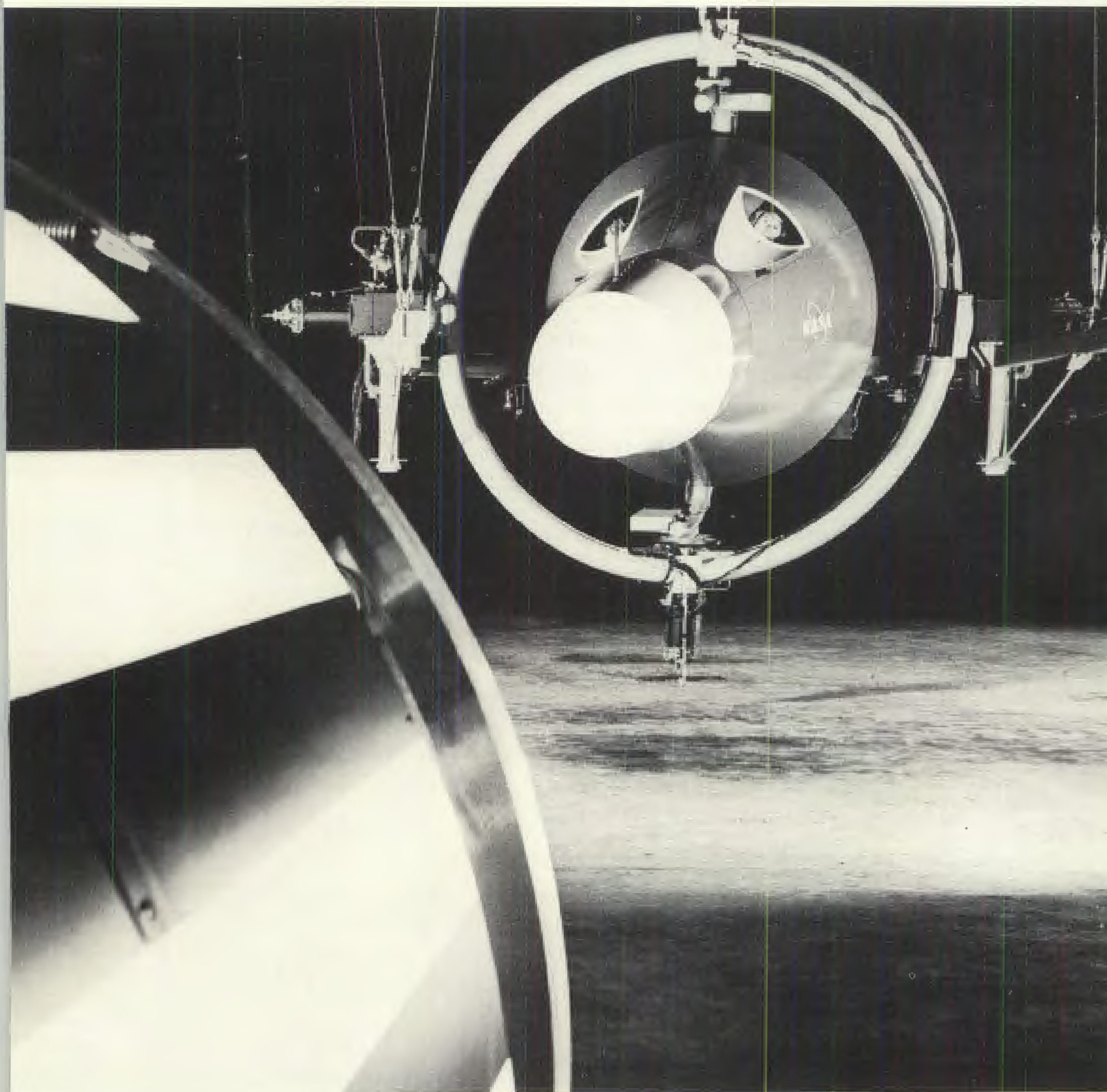
Hydroplaning may also cause automobiles traveling at legal speed limits to lose traction. For example, a car with 30 pounds of pressure in its tires may hydroplane on a wet road at 55 miles per hour. Increasing the tire pressure raises the minimum speed at which hydroplaning can occur.

In addition to hydroplaning, snow or slush creates additional problems on runways. An airplane moving through slush must apply force to push the slush aside. This may prevent the aircraft from reaching flying speed.

Studies of slush on aircraft runways have led to an FAA ruling forbidding take-off of jet aircraft where more than one-half inch of slush covers the runway. NASA is studying techniques that will reduce slush drag on multiple-wheel landing gear.

Transport aircraft used for low speed flight research.

Space Rendezvous Simulator.



MANNED SPACE FLIGHT SIMULATION

In the latter part of this decade, three American astronauts are scheduled to guide their Apollo spacecraft into orbit around the moon. Two astronauts will transfer to an Apollo section called the Lunar Excursion Module (LEM), detach the LEM, and land it on the moon.

After conducting scientific experiments and collecting samples, the astronauts will reboard the LEM, launch it, and rendezvous in orbit with the parent Apollo spacecraft. Then, they will return to the parent craft for the voyage home. The LEM will be cast adrift in lunar orbit.

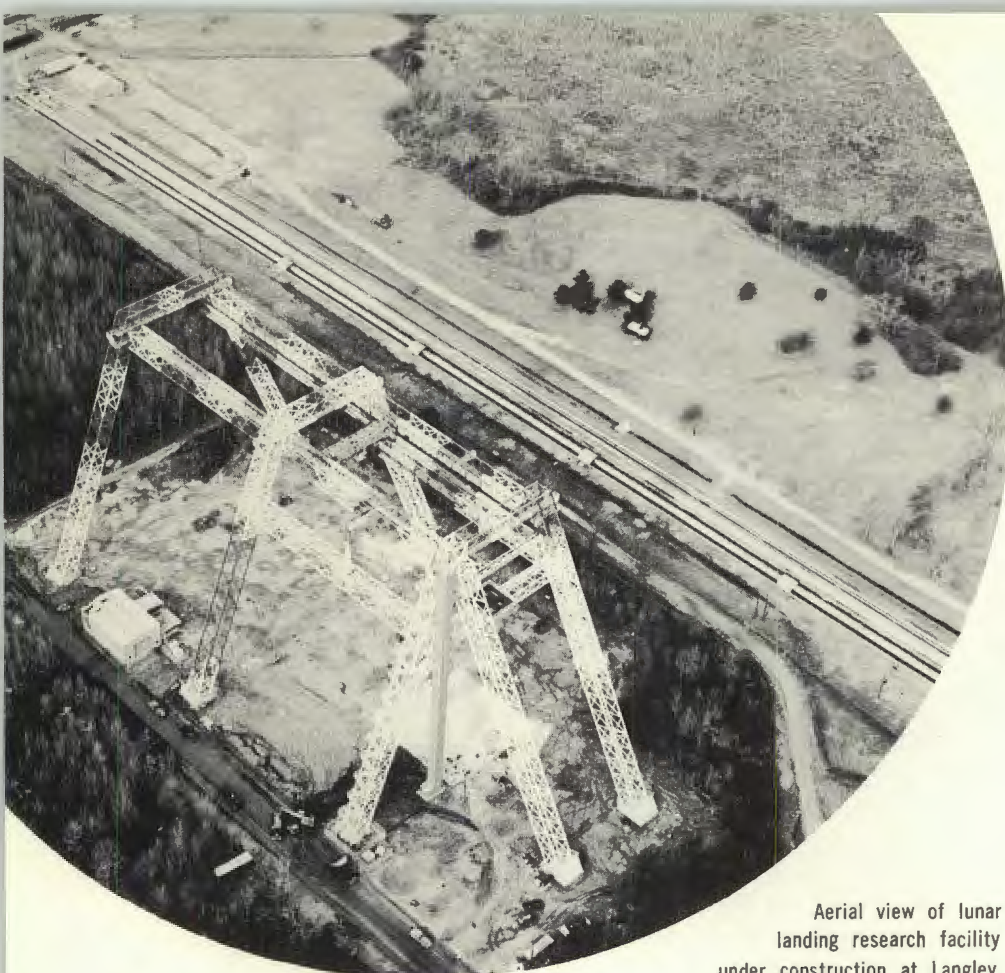
These operations involve many maneuvers never before done by man. For example, the astronauts must learn to rendezvous gently with the parent spacecraft, while both their LEM and the parent spacecraft are speeding at thousands of miles per hour. They must learn to use rocket power alone for both landing and take-off because there is no air to provide lift on the moon.

To prepare astronauts for the lunar journey, NASA has constructed a number of simulators. In them are embodied the ideas, skills, and knowledge of an army of engineers, scientists, and other technologists.

To simulate is to assume the appearance of, without reality. This is exactly what the manned space flight simulators are designed to do. The pilots are made to feel that they are on an actual space mission. In this way also, techniques and equipment are developed for reliable operation in space.

One of the research devices is a saw-horse shaped Lunar-Landing Research Facility at Langley. The facility is 250 feet high, 400 feet long, and 300 feet wide at the base. A research vehicle representing an LEM-type vehicle is suspended by cables that support five-sixths of its weight. The remaining sixth matches the vehicle's weight as it would be on the moon.

The simulator, which provides the appropriate vehicle dynamics during the last 200 feet of landing on the moon, can touch down anywhere within a 20,000-square-foot area. The lander



Aerial view of lunar landing research facility under construction at Langley.

is powered by rockets fueled with hydrogen peroxide. The pilot can control his speed by varying the thrust of his rockets.

For some time, other lunar landing studies have been carried out at the Ames Research Center. Moon landings are simulated by using a vertical take-off and landing aircraft powered by jet engines. Its similarity to a spaceship is neither in its powerplant nor construction but in the way power is applied—by directing the plane's jet exhaust downward to allow the craft to descend or rise vertically like a lunar landing craft.

In a huge hangar at Langley, pilots are practicing in a simulated space environment the techniques for rendezvous, or joining, in space with another vehicle. Advanced electronic equipment and techniques enable a full-size replica of the two-man Gemini spacecraft to behave as if it were in space.

The Gemini project is a bridge between the pioneering Project Mercury and the Apollo program for landing the first American explorers on the moon. A major goal of Project Gemini is to develop and perfect the technology for orbital rendezvous.

In its orbital rendezvous experiment, the Gemini pilots will link their craft with a modified Agena rocket. The Langley Space Vehicle Rendezvous Docking Simulator is designed to duplicate the last two hundred feet of the maneuvers in which craft are joined in either earth or lunar orbit.

The research model is not equipped with the small gas jets that the real Gemini craft will employ for orienting itself. However, computers operating in real time (instantaneously) convert the pilot's actions into motions that would result from jet thrust. Moreover, the computer deliberately simulates malfunctions which the pilot is required to correct.

At the beginning of the experiment, the Gemini and Agena models are 200 feet apart. An overhead suspension system gives Gemini six-degree-of-freedom movement; that is, it can move and turn in any direction.

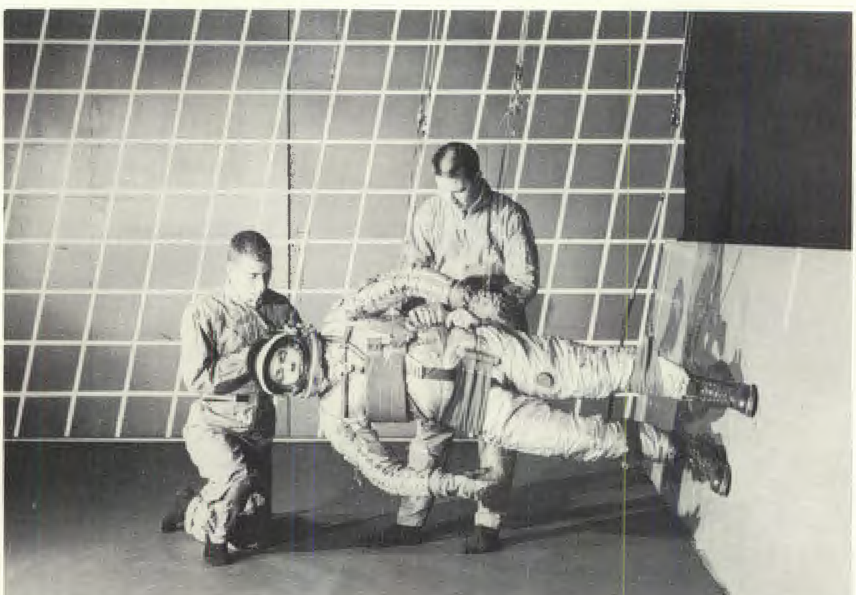
VTOL craft used for moon landing simulation studies at Ames.

In another simulator, called LOLA (Lunar Orbit and Landing Approach), the pilot sits in a dark cockpit which resembles somewhat the cabin of an LEM-type vehicle. He looks out of windows that enable him to see the moon's surface and to judge as he draws closer or pulls farther away how to maneuver his craft. He flies his craft from 100 miles to 200 feet above the moon.

Actually, the pilot's controls are linked to a computer which controls a battery of television cameras pointed at three-dimensional relief maps of the moon's surface. What he sees through his windows are pictures on closed circuit television screens. The relief maps, made of molded fiberglass, are based upon the best photographs taken by telescopes on earth.

A comparable research facility has been set up inside a 53-foot diameter hemispherical planetarium. In this simulator, the pilot has left the parent spacecraft and has started his descent to the moon when he discovers something wrong with his craft. He immediately takes over the controls to rocket his vehicle back to the parent spacecraft which now looks like a moving light in

Lunar Walker being readied for test.

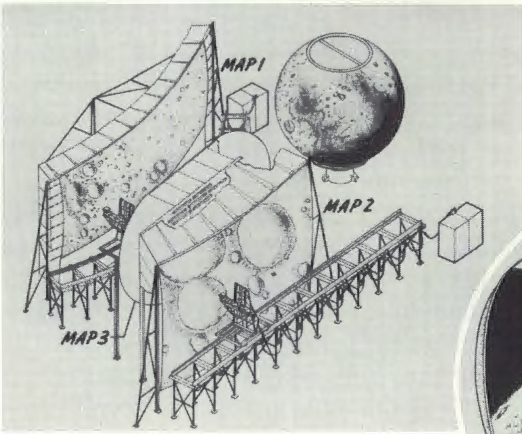


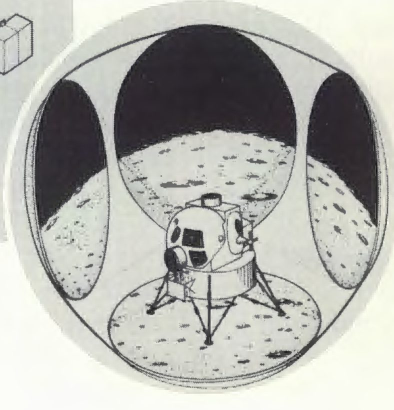
space. The star field, which duplicates the night sky over the moon, moves in response to the pilot's operation of his controls.

In a related program, a simulator is acquainting future astronauts with the physical adjustments, such as in walking and working, they must make in their habits to function effectively on the moon. The apparatus includes an inclined walkway (representing the moon's surface) about 24 feet long and 4 feet wide. The subject, supported by a system of slings suspended from a movable overhead trolley, is tilted about 80 degrees from the vertical so that he can walk "straight" on the inclined walkway. By this means the apparatus removes all but one-sixth of the man's weight from his legs, duplicating the gravity condition he would experience on the moon. The lunar walker is so built that the astronaut is free to run, jump, and even somersault.

Scientists point out that the lunar walker system can be adapted to study the movements of a person at any gravity level. This is done simply by adjusting the angle at which the person is supported.

Drawing of Lunar Orbit and Landing Approach Simulator.





ELECTRONIC COMPUTERS IN AEROSPACE RESEARCH

Electronic computers are flying astronauts on imaginary round trips to the Moon, Mars, and Venus; calculating intricate and lengthy equations of motion for aeronautical and space flights; preparing appropriate vehicle dynamics compatible with air traffic control systems for the advent of the supersonic transport; and enabling aerospace theoretical researchers to do in hours what would otherwise take decades. In effect, computers are speeding the march of technology.

Among NASA's major computing facilities is the 7094 at Langley. The 7094 can perform in a second 250,000 additions or subtractions or 100,000 multiplications or 62,500 divisions of 10-digit numbers.

Computers perform services for all areas of NASA's busy research program. Typical examples are theoretical research to explore new concepts for meeting space flight goals such as plotting trajectories for interplanetary flight; engineering studies in which the topography of the moon is computed from optical and radio telescope studies or in which large volumes of engineering data are compiled and correlated to create the best structural design; experimental research in which wind tunnels and comparable facilities are linked with computers to receive and make preliminary analyses of data; simulation in which the control activities of a test pilot or astronaut are converted to flight results in the form of the model vehicle's movement or in changing the visual cues surrounding him to simulate movement (simulators are used in development of control systems as well as for training); command and control in which a flick of a switch linked to a computer can put a vehicle into the proper motion in the air or space; and monitoring the numerous functions involved in checking out rocket vehicles and spacecraft before launch.

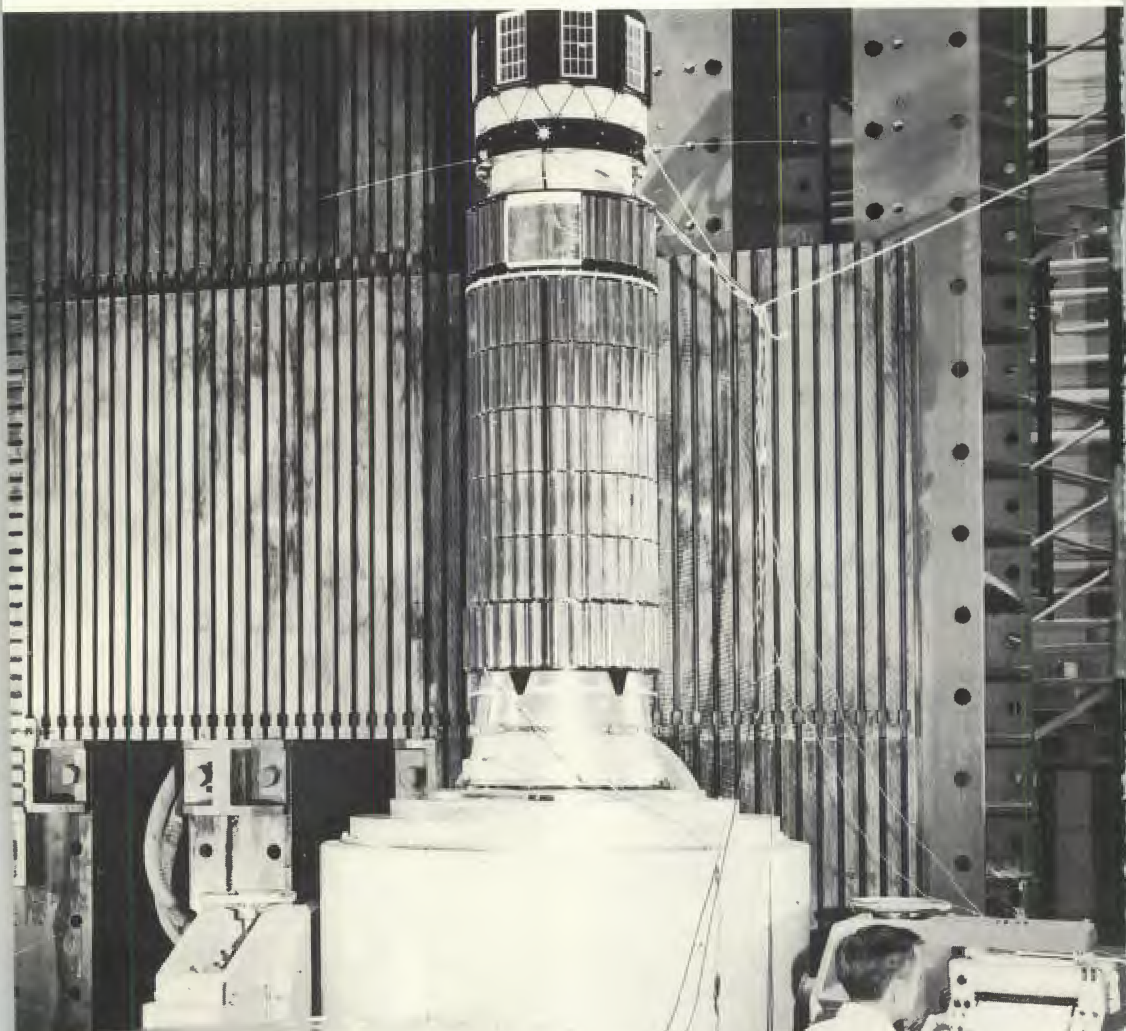
The versatility of computers in any area is manifold. In simulation alone, computers not only create realistic excursions but also invent malfunctions and other emergencies that could take place on the trip. When the pilots have dealt with the emergency, the computer records their corrective action so that similar situations in actual flight can be coped with in seconds.

Computers even now are determining the number and timing of course corrections needed for the Apollo flight to the moon. They are also pinpointing flaws in systems before they are installed in the spacecraft.

NASA engineers, mathematicians, and physicists are constantly evaluating computer installations and carrying out basic research and design studies that will lead eventually to new computing techniques for support of future research.

Computer used in simulation studies.

Vibration test of Explorer XVI satellite.



LAUNCH VEHICLE AND SPACECRAFT DYNAMICS

During its launch and flight through the atmosphere, a rocket vehicle is subjected to many forces such as noise pressures, fuel-dome impact (described below), fuel sloshing, and winds. Since a launch vehicle structurally may be considered thin-skinned, it is basically flexible rather than rigid. As a result, such forces cause the vehicle to vibrate. A goal of dynamics research is to reduce these vibrations to levels that avoid damage to the vehicle. For manned vehicles, there is the requirement of further curbing vibration so that it does not interfere with crucial human activity.

Dynamics research is concerned with: (a) the inputs, or the nature and severity of the forces involved; (b) the system, or physical characteristics of the structure; and (c) the development of the analytical and experimental techniques required to predict the output, or response of the vehicle to the forces acting on it.

The use of models, which has played an important part in development of high performance aircraft and in other research areas, has been extended to dynamics research. Models eliminate the need for many costly and cumbersome full-scale tests. Moreover, it is in models that changes in design can be made most inexpensively. In structure, weight, and other features, dynamic models are small-scale versions of full-size craft. The value of model testing for launch vehicles was demonstrated in preliminary model experiments which contributed to the successful structure of the 1.5 million pound thrust Saturn launch vehicle.

Among the numerous forces acting on a vehicle are winds which act on it while it is still on the launch pad. Whether steady or unsteady, they not only put stress on the vehicle and tie-down mechanism but also trigger a side-to-side vibration such as that which has caused bridges and smokestacks to collapse. The shaking could interfere with launch operations, injure delicate equipment, or cause more serious damage. Gusts, which occur in any kind of weather, intensify this problem.

Another problem receiving research attention is possible damage from rocket engine noise and its associated pressure fluctuations. The sound waves not only reflect back on the vehicle but also pass through the air and ground in all directions and may damage buildings many miles away. This is the reason that areas remote from population centers are selected for launch sites.

As launch vehicles grow larger, the frequencies of the sound waves emitted by their engines become lower. Many sounds may be infrasonic; that is, below the audible range. However, even though they cannot be heard, the sounds may still exert damaging pressures.

NASA is studying low-frequency sound and its effects on man, vehicles, and surrounding structures. A special facility for such study, at Langley, uses a 14-foot diameter speaker driven by a 20,000 pound hydraulic shaker. It can accommodate craft as large as the three-man Apollo command module in which American astronauts will travel during their round trip to the moon.

Sounding rocket studies have revealed regions of intense turbulence and strong wind shears (layers of winds blowing in different directions at different altitudes), particularly at heights in the vicinity of the jet stream (about 30,000 feet).

A complex interaction of the vehicle's structure and control system takes place as it flies through such fluctuating winds. The control system compares the vehicle's actual course with the programmed trajectory and commands the rocket motors to gimbal (turn) to correct the course. However, since, as noted earlier, the vehicle is a flexible rather than rigid body, the winds act to bend it. The control system may confuse the bending motion with the course and send commands that cause the vehicle to oscillate.

Another research problem that has and will continue to receive attention is fuel sloshing which may be caused by a number of course corrections. Sloshing about of massive quantities of fuel could generate damaging forces.

As the vehicle's speed increases to that of sound, randomly fluctuating air flows, or buffeting, are generated. These can produce high-frequency local vibrations of the vehicle's structure and low-frequency vibrations throughout the structure.

At speeds beyond that of sound, panel flutter (vibration) occurs. It originates in the turbulent air surrounding a craft flying at such speeds.

A recent problem of considerable concern is fuel-dome impact. When the thrust of a vehicle accelerating through the atmosphere

Apollo with escape tower in transonic wind tunnel.

is suddenly stopped, aerodynamic drag forces act to reverse the direction of acceleration. When this happens, the remaining propellants are hurled forward, striking the top of the fuel tanks. The consequent force on the dome, or top, of the tank may cause it to burst.

As the payload completes its launch phase, it is subjected to the elements of space such as radiation, vacuum, and meteoroids. Among the NASA facilities simulating the vacuum of space is a huge chamber at Langley that can subject payloads simultaneously to vacuum, vibration, and acceleration. The chamber, 55 feet in diameter and 68-feet high, can be employed for such projects as satellites, space stations, certain military missiles, and problems associated with highly expanded nozzle flows in a vacuum.

NASA has used the chamber to find out what would happen if a lunar landing craft came down on a lunar surface composed of fine materials. The results of the study indicate that the problem of obstruction of pilot visibility is not too critical but that the formation of the resultant crater should be an important consideration in design of landing gear.

MATERIALS AND STRUCTURES

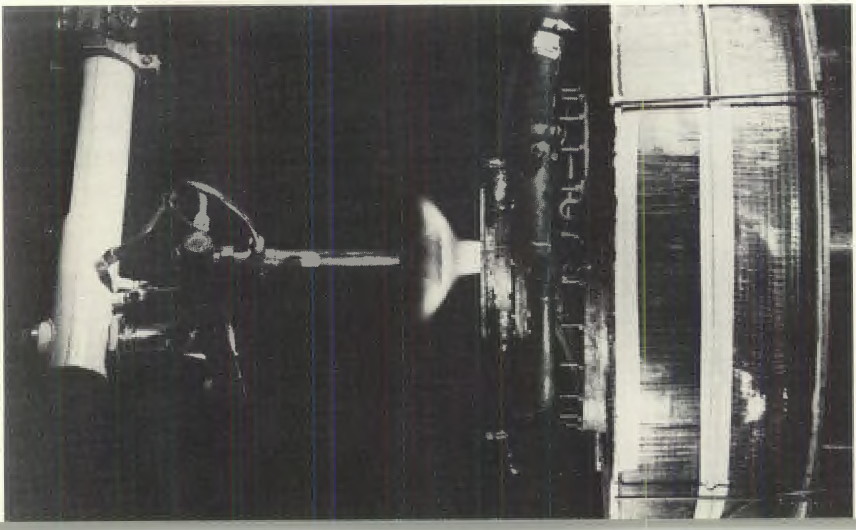
Materials and structures research encompasses a wide range of work for space and aeronautics programs. Several studies are briefly depicted below.

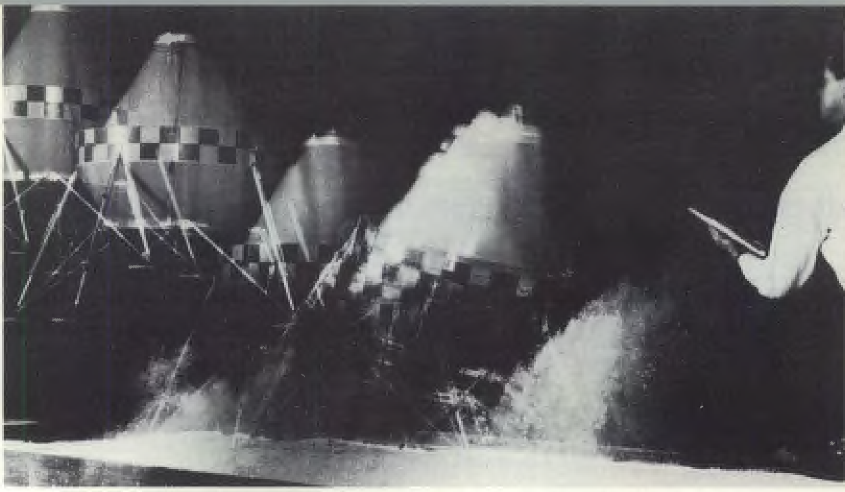
NASA is conducting theoretical, wind tunnel, and actual space experiments in a program aimed at developing spacecraft capable of withstanding the searing heat of re-entry into earth's atmosphere on a return trip from the moon. Such heating will be much greater than the 3000°F which the Mercury spacecraft experienced as it came back to earth.

One facility for re-entry testing of materials uses an arc jet which creates temperatures of about 10,000° F. In an arc jet, a gas such as liquid hydrogen is pumped into a chamber where it is electrically heated to several thousand degrees and then expelled.

In preventing returning spacecraft from burning up, ablation materials show great promise and are receiving considerable research attention. The materials cover the forepart of the vehicle. As the craft enters the atmosphere and heat builds up, the ablative material melts and absorbs some of the heat. As the air becomes hotter, the melting material vaporizes and blocks part of the transfer of heat to the remaining material. Thus, the efficiency of ablation actually increases with temperature.

Electric arc heater tests material considered for ablation.





One-sixth scale model of lunar landing craft, equipped with multiple-leg landing gear, simulates lunar landing in pumice dust.

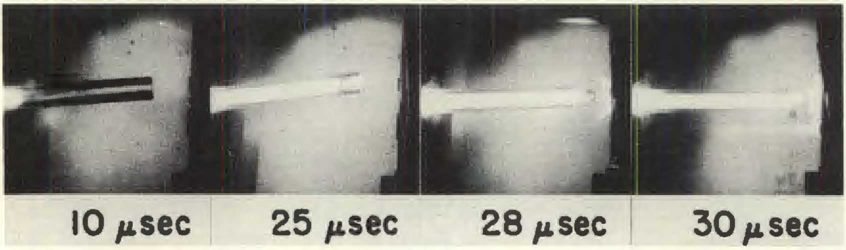
One problem with some types of ablation heat shield designs is that the very speed at which craft rush into atmosphere may build up forces that could tear them away, leaving the spacecraft unprotected. Engineers are studying this problem in arc-jet heated wind tunnels.

NASA researchers have developed theoretical techniques and actual gear for landing a lunar craft upright on the moon. The techniques show the proper combinations of vehicle orientation and horizontal and vertical velocities. Among landing gear under consideration are multiple legs, inflated bags, and foamed material that absorbs shock and adjusts to the terrain.

Experiments with manned spacecraft have shown that the manned space cabin, at least in the vicinity of earth, needs cooling. The heat of the sun alone can keep a sealed space cabin at a 75° F temperature. Reflected heat from earth, body warmth of the crew, and heat given off by equipment in the cabin could create unbearable temperatures. NASA is developing designs that incorporate cooling apparatus within structures.

Considerable work is in progress on developing airtight seals for space cabins. Ground tests with Mercury showed that the spacecraft lost 2.4 pounds of air daily. For Mercury spacecraft, which were in orbit for no longer than 34 hours, the leak was a minor shortcoming. For larger craft on prolonged space missions, the air loss could be serious. Seals must be immune to the damaging effects of radiation, vacuum, and temperature extremes.

Puncture by small meteoroids, which are undefined particles of matter speeding through space, could critically deplete the



Firing sequence of exploding foil meteoroid accelerator. Numbers are in millionths of a second.

air supply of a manned cabin. The problem may be met by double-walled structures which have been shown by laboratory experiments to be far more effective in resisting meteoroid penetration than single walls of the same structural thickness. Self-sealing materials may be developed for closing leaks caused by small meteoroids.

The Explorer XVI satellite verified that small meteoroids can pierce thin metal surfaces. In order to gain more information about the meteoroid hazard, NASA plans to launch giant-size satellites. Each has a test area of approximately 2,000 square feet, as compared with Explorer XVI that exposed a 25-square-foot area. Test materials in the larger satellites will also be thicker. The satellites will be launched by Saturn rocket vehicles.

One of several kinds of equipment for ground laboratory study of meteoroids is the "exploding foil particle accelerator." It can show how meteoroids may penetrate spacecraft hulls and the means for counteracting them. One accelerator at Langley Research Center employs as much as 120,000 volts of electricity to explode a one-mil (1/1,000th-inch) thick section of aluminum foil. The explosion kicks a simulated meteoroid at tremendous velocities against samples of materials or structures.

In aircraft research, engineers are continuing their study of materials and structures for the supersonic commercial air transport. One problem is to determine techniques for abbreviating the time for testing resistance of materials to weakening under the continued high temperatures generated by flight at supersonic speeds. Short-term techniques for testing craft that travel at less than the speed of sound can duplicate in a half year the wear and tear of 4 years of operation. No comparable abridgement has been developed for supersonic aircraft testing.

HYPERSONIC FLIGHT

Hypersonic flight may be defined as flight faster than about five times the speed of sound (Mach 5.0). Interest in hypersonic flight stems from a number of possible applications. Among them are:

a. Studies of entry into the atmosphere from near or far space missions,

b. Developing vehicles to resupply and rotate the crew of possible future manned space stations,

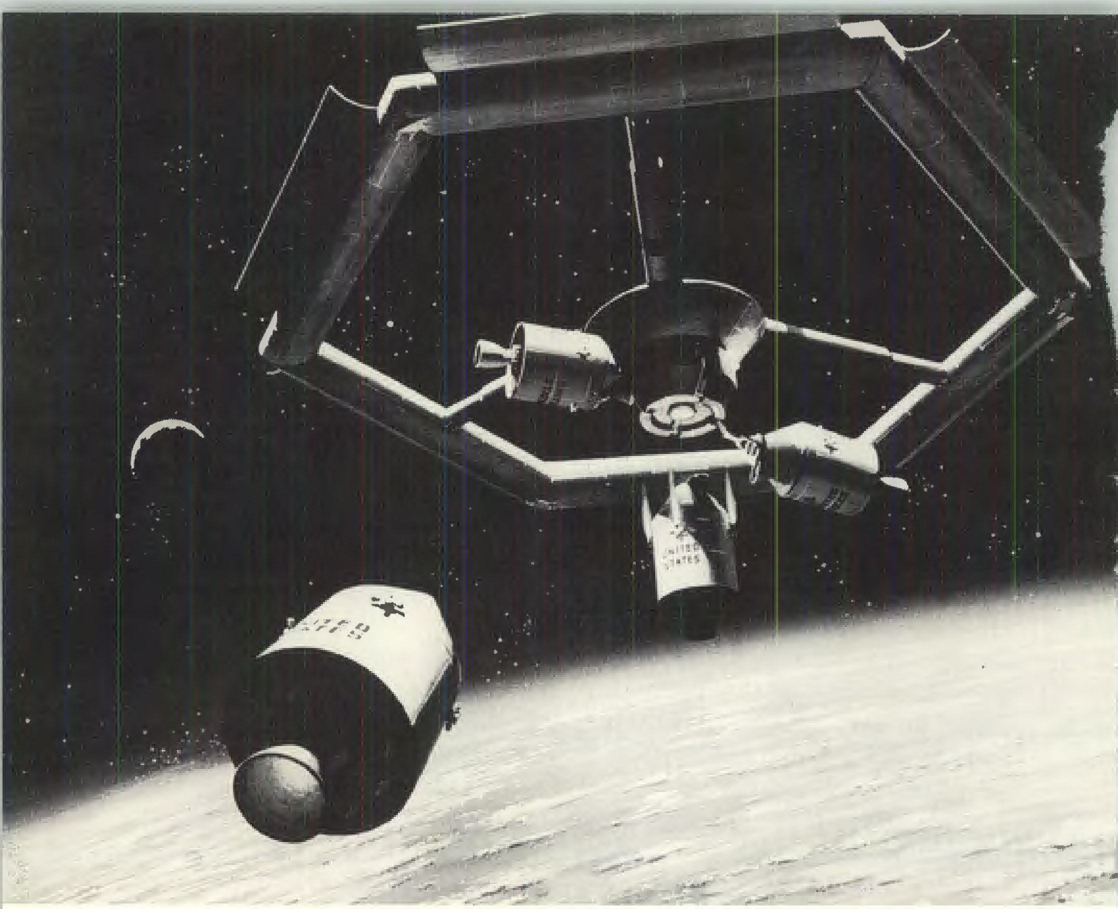
c. Developing systems for recovery of booster rockets, and

d. Studying the technology of vehicles that could take off like an airplane, go into orbit, and then return to and land on earth like an airplane.

A major problem facing the development of hypersonic vehicles is high temperature resulting from aerodynamic heating —compression and friction of air molecules adjacent to and against the craft's surface. However, engineers believe that enough is known about aerodynamic design, cooling of structures, and refractory and ablative materials that resist heat to make hypersonic flight practicable.

The X–15 research airplane conceived and operated by NASA as a joint program with the Air Force and Navy, has provided a focus for studies of aircraft that can fly at hypersonic speeds.

X-15 research airplane.



Logistics vehicle approaching future space station (artist's conception).

It has been flown at speeds greater than 4100 miles per hour and reached altitudes above 66 miles. Essentially a flying laboratory, the X–15 has provided much information for design of high-altitude supersonic and hypersonic aircraft as well as a vast amount of other information advancing the science and technology of aeronautics and space. Project management is provided by NASA's Flight Research Center.

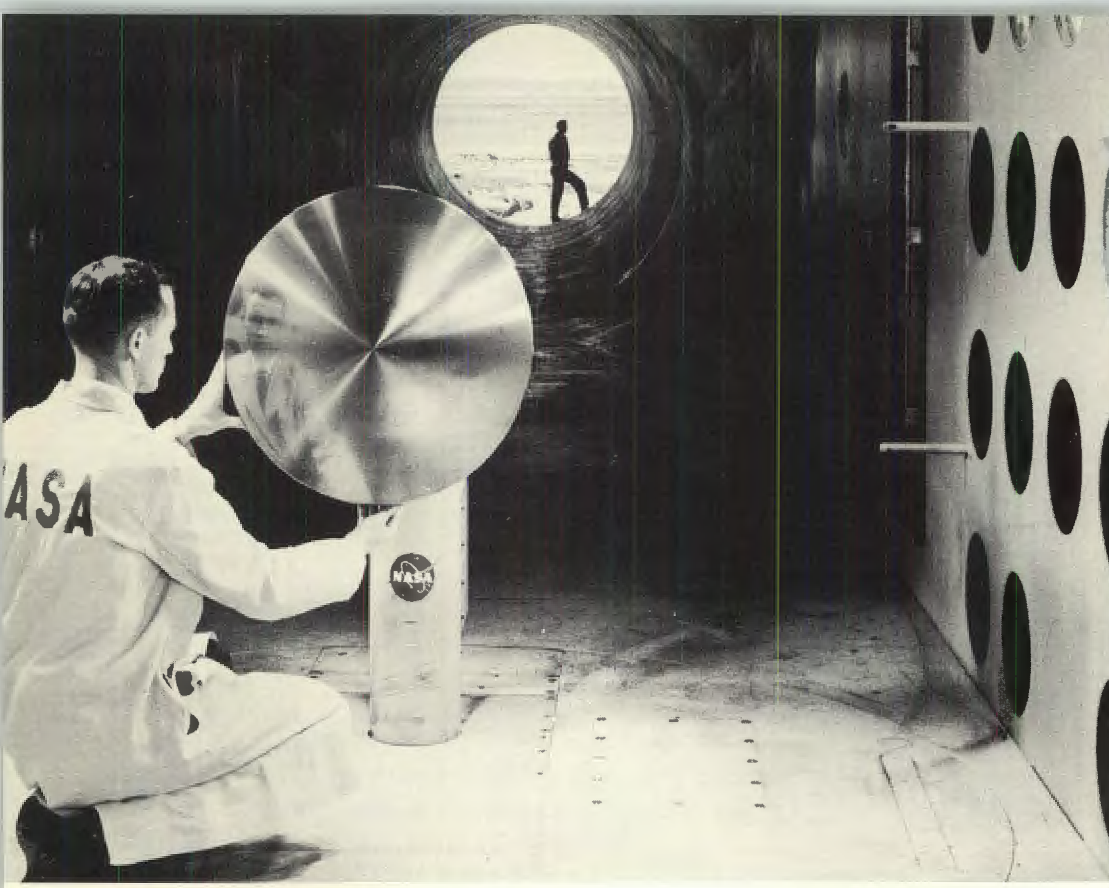
The X–15 is carried aloft by a B–52 aircraft and launched at about 45,000 feet, and, by use of its inboard, liquid propellant rocket, is accelerated to hypersonic speeds at high altitudes. Its attitude is controlled in the thin air of the upper atmosphere with hydrogen peroxide jets in the wings and nose. In the denser lower atmosphere, it uses aerodynamic controls to maneuver. Its landing speed is 210 miles per hour, about 70 miles per hour faster than the landing speed of a subsonic jetliner.

A flight experiment called Projet Fire was designed to supplement analytical and wind-tunnel research on entry into the atmosphere at the lunar return speed of about 25,000 miles per hour. In Project Fire, an instrumented package is launched from Cape Kennedy, Florida, by an Atlas booster, reaches an altitude of about 500 miles, and then after a coast period of 26 minutes, is driven downward by an Antares solid fuel rocket at about 25,000 mph. Instruments in the package radio heating and other measurements and high-speed telescopic cameras photograph the 20,000° F fireball created by the craft. This experiment, successfully flown April 14, 1964, provided the first data at these speeds in the real gas environment.

Although X–15 flight tests and reentry studies such as Project Fire can provide much information, engineers cannot economically build and launch craft every time they want to find out something. The alternative is to bring the conditions of hypersonic flight down to earth. Just as results from wind-tunnel experiments led to design of safe and practicable aircraft, they are also providing essential services in solving the problems of entry into the atmosphere and hypersonic flight.

One kind of wind tunnel is used to investigate basic air flow phenomena and vehicle performance such as stability and control at high speeds. An example of a wind tunnel for such studies is the 22-inch helium tunnel at Langley. The tunnel can create Mach numbers as high as 40. This new facility has already contributed to the knowledge and understanding of what happens to vehicles when they are operated at hypersonic speeds.

Another phenomenon experienced at hypersonic speeds is air chemistry effects. During hypersonic flight, a portion of the kinetic energy (speed) of the vehicle is converted into thermal energy (heat). The heating generated by hypersonic flight is so intense that its energy breaks the diatomic air molecules (molecules made up of two atoms) into two separate atoms. This process is known as dissociation. With further increase of temperature or thermal energy, a process known as ionization takes place. An electron may be knocked loose from an atom, turning the atom into an ion. The ion has a positive electric charge because the loss of the negatively charged electron has unbalanced it. Additional knowledge is required about the chemical and physical changes that take place during the above phenomena and how they influence hypersonic flight.



Project Fire re-entry package in wind tunnel.

New tools of research at NASA centers are being used to find the answers to these and other questions. One such tool is the 4-foot Hypersonic Arc Tunnel. It generates temperatures of 14,000° F and simulates Mach numbers from 10.0 to 18.0. The heater of this tunnel raises the air temperature as the air passes through an electrical arc. This high-temperature air is then accelerated to the high Mach numbers. It is within this high energy flow that various experiments are being conducted to learn more about the dissociation and ionization processes and how they effect hypersonic phenomena.

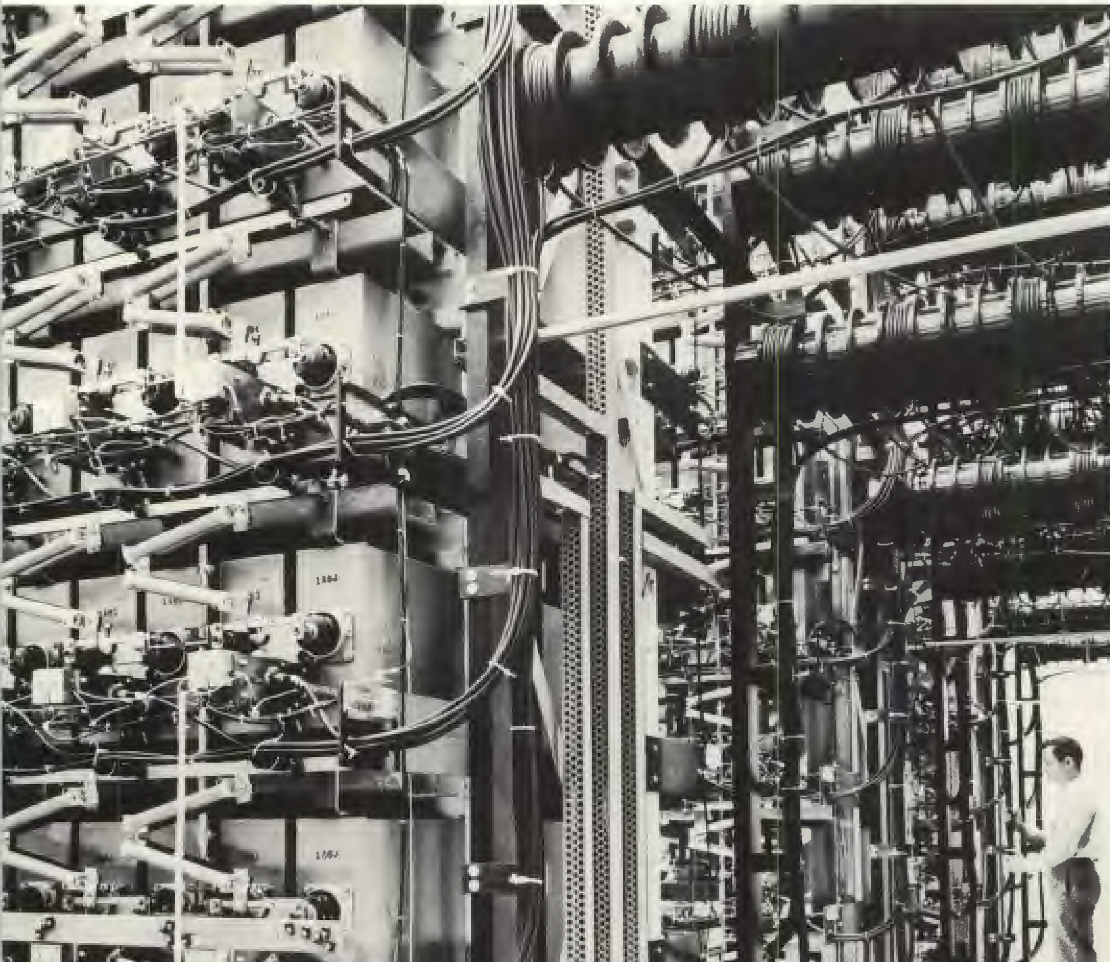
Analytical studies have shown that the trajectory which a nonlifting entry vehicle must fly through the earth's atmosphere is narrow and limited. For example, during a return from the moon, the vehicle will skip out of the atmosphere if the approach path to earth is too high. Conversely, if too low a path is attempted, excessive loads and heating rates will occur. The use of vehicle lift during entry will enlarge the usable range of trajectories; consequently, studies are being conducted of lifting entry vehicles. The advantages and disadvantages of several concepts of hypersonic lifting shapes have been assessed. From these studies have emerged two lifting entry vehicles with considerable merit, the delta (triangularly) shaped HL–10, a Langley concept and the modified half-conical M–2, originated at Ames Research Center.

The HL–10 incorporates an L/D (lift-to-drag ratio) of one. The L/D ratio significantly influences the range of a vehicle flying in the atmosphere. Lift refers to the forces pushing upward; drag the retarding forces. The Langley studies indicate that an L/D–1 vehicle possesses some of the desirable features of both aircraft and spacecraft technology. The studies point out that the L/D–1 vehicle can be relatively low in weight, land like an airplane, and provide the freedom in design offered by use of ablation materials against the intense heat of entering the atmosphere at hypersonic speeds.

Also, with its lifting capability, such a vehicle may return from orbit to a predetermined point on the earth with much less time delay than for the nonlifter. This is due to the fact that a lifting vehicle with its ability to maneuver in the atmosphere does not have to wait until it reaches a precise point in orbit in order to land in a selected area.

Photograph reveals shock wave generated by HL-10 model in hypersonic wind tunnel.

Part of bank of condensers for generation of extremely high temperature plasma.



MAGNETOPLASMADYNAMICS

In a laboratory at Langley, NASA scientists are preparing apparatus to create plasma simulating that which exists in the solar corona. The corona is the outer atmosphere of the sun.

Plasma is a gas containing electrically charged particles. It makes up 99 percent of the matter in the universe. The sun and other stars and a large part of the interstellar matter are made up of plasma. In the home and office, a mercury-vapor plasma fills the fluorescent lamp. Earth's ionosphere, which makes possible long-distance communication by reflection of certain radio waves, consists of a plasma. Lightning creates plasma as the electrical discharge passes through the air.

Plasma is created when a gas becomes sufficiently hot that some of the gas atoms lose electrons. The removal of the negatively charged electron unbalances the neutral atom giving it a positive electric charge. The atom is then called an ion. Plasma contains equal numbers of ions and electrons. (It may or may not also contain some neutrals.) Many scientists consider it a fourth state of matter, distinctly different from solids, liquids, and neutral gases. An essential characteristic of a plasma is that it conducts electricity.

The solar wind, or solar plasma, is made up largely of electrons and protons (ions) of hydrogen atoms. The proton in this case is synonymous with ion because a hydrogen atom consists of a single proton and electron. The solar wind is actually a constant outpouring of plasma from the turbulent surface of the sun.

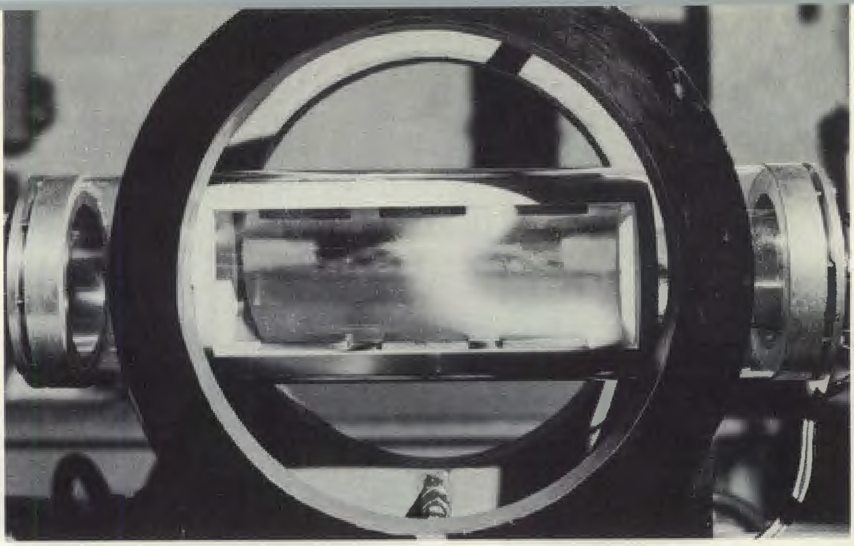
To simulate the corona of the sun in the laboratory, NASA uses a 10-foot tall bank of condensers that provide a 12-million ampere current. The resulting electromagnetic reaction produces for about 25 millionths of a second a column of brilliant plasma that may be as hot as 36 million degrees Fahrenheit. The plasma is made up of hydrogen gas atoms ionized into electrons and protons. Its tremendous heat would incinerate its quartz container but for the simultaneously occurring magnetic field that contains the plasma with a pressure of 15,000 pounds per square inch, a thousand times that of the atmosphere at sea level, and holds it away from the wall of the container. Although the plasma pressure and temperature in the experiment are much higher than in the solar corona, the "scaling" relations (ratios) are known, and detailed atomic and ionic conditions are truly simulated. In the fraction of a second that the 36 million degree heat and 15,000 pounds of pressure are produced, the energy rate or power discharge into the plasma is 80 million kilowatts, equivalent to 80 percent of the total power consumption in the U. S. during this instant.

Spectrographic instruments record the electromagnetic radiations (e.g., visible light, infrared, ultraviolet, X-rays) from the plasma during its creation and return to its neutral gaseous state. Study of these data may reveal much about the nature of the solar system and about the universe.

Magnetoplasmadynamics is the study of the interaction of electric and magnetic fields with plasmas. Basic studies in this new science are being carried out not only by NASA but also by other research organizations. NASA is doing the work in ground laboratories and by means of spacecraft. Among their data, spacecraft reveal that the solar wind carries parts of the sun's magnetic field into space and distributes the parts throughout the solar system.

Moreover, the solar wind compresses earth's magnetic field on the sunlit side of earth to a 40,000-mile altitude and stretches it to as yet undefined limits on the night side. In effect, the solar wind is believed to shape the earth's magnetic field like a teardrop with the part of the magnetic field on earth's night side trailing the planet like the tail of a comet.

Magnetoplasmadynamic research is being conducted on the use of electric and magnetic fields to influence the flow of plasma. The device in which this type of experiment is carried out is called a plasma accelerator. Fundamentally, the accelerator is supplied with plasma formed from a suitable gas and then uses electromagnetic forces (the same forces that run an electric motor) to accelerate the plasma to tremendous velocities—as high as 260,000 mph. Plasma accelerators, when perfected, have potential application for hypersonic wind tunnels and space propulsion. Another application of the same principles uses plasma to generate electric power.



Model plasma generation experiment.

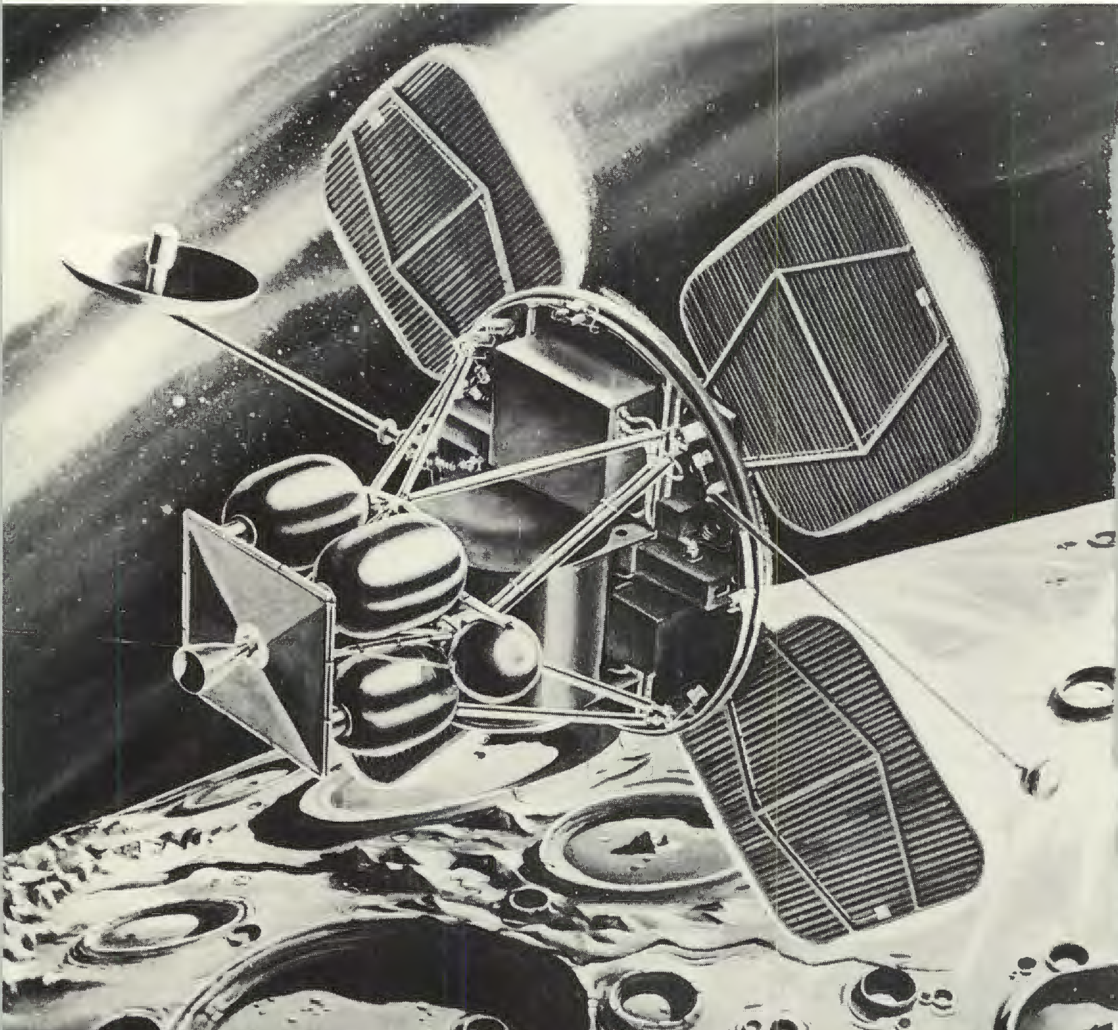
In discussion of "Hypersonic Flight," above, air chemistry effects on a vehicle speeding through the atmosphere are noted. Such air chemistry effects include the formation of a sheath of plasma around the vehicle. The sheath can block radio waves, causing radio blackout. This phenomenon cut off communication during a critical period of the Mercury spacecraft's return to earth.

In the laboratory, scientists are aiming radio waves at plasmas and studying the results. The laboratory studies are being supplemented with information from such flight programs as Projects Fire and RAM (acronym for Radio Attenuation Measurement).

Project Fire is designed to find out what happens to a vehicle returning to earth after a trip to the moon. The return speed under such conditions is about 25,000 miles per hour, as compared to earth orbital speed of about 18,000 miles per hour. Studies of the way in which the radio transmissions of the Project Fire spacecraft varied during its fiery entry into earth's atmosphere and of the changes in the plasma sheath as the craft built up heat will contribute to solution of the radio blackout problem and augment magnetoplasmadynamic knowledge.

In RAM, the spacecraft entered the atmosphere at high velocity and furnished data on properties and behavior of the electrons and ions in the plasma sheath. During the loss of communication, it recorded data and radioed them to earth when communications were reestablished.

Artist's conception of Lunar Orbiter spacecraft about 25 miles above the moon.



MAN IN THE SPACE ENVIRONMENT

Before man can be "at home" in space, he must resolve major problems posed by the space environment. Space is a harsh region of stark contrasts. Because space has no appreciable atmosphere there is no dispersion of light and celestial bodies glow with unusual brilliance. For the same reason, space around celestial bodies is blacker than the darkest night on earth. The sun's heat bakes one side of a spacecraft while the dark side of the same spacecraft freezes in subzero cold.

Space is punctuated by meteoroids. Small ones may pierce the thin hull of a spacecraft or the material of a space suit.

Cosmic radiation, streaming from the sun and from billions of other sources in the vast universe, endangers man. It may modify materials so as to interfere with proper functioning of equipment and structures. Ultraviolet light and X-rays from the sun can deteriorate and degrade materials. Cosmic, ultraviolet, and X-radiation can be lethal to man.

The very high vacuum of space can produce unearthly changes in objects; for example, turning rubber brittle and literally welding together separate items. It can kill a man with a damaged space suit in less than 30 seconds.

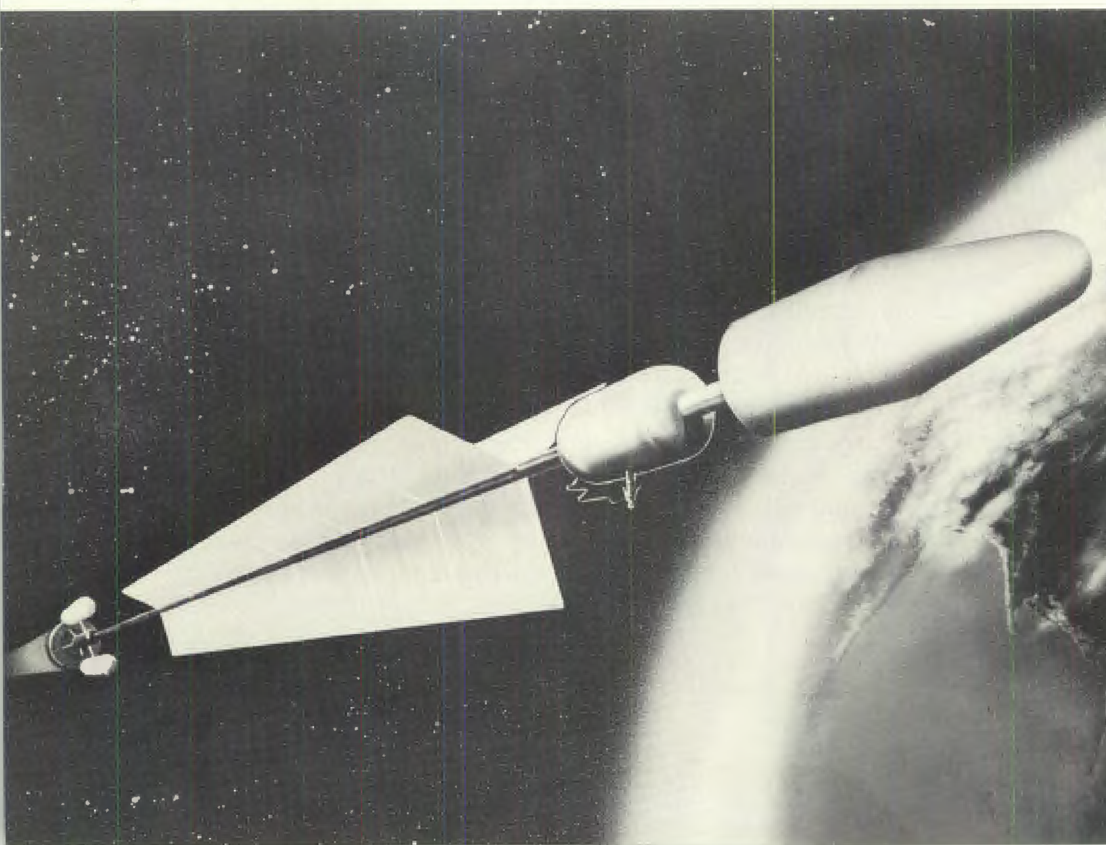
Zero g, popularly called weightlessness, causes liquids to crawl along the walls of their containers, posing problems in storage and pumping of water, of liquid oxygen and liquid nitrogen for cabin atmosphere, and of liquid propellants. Among questions requiring answers are whether prolonged weightlessness will upset delicate biological processes, impair vital organs, and adversely affect man's capabilities for performing his mission in space.

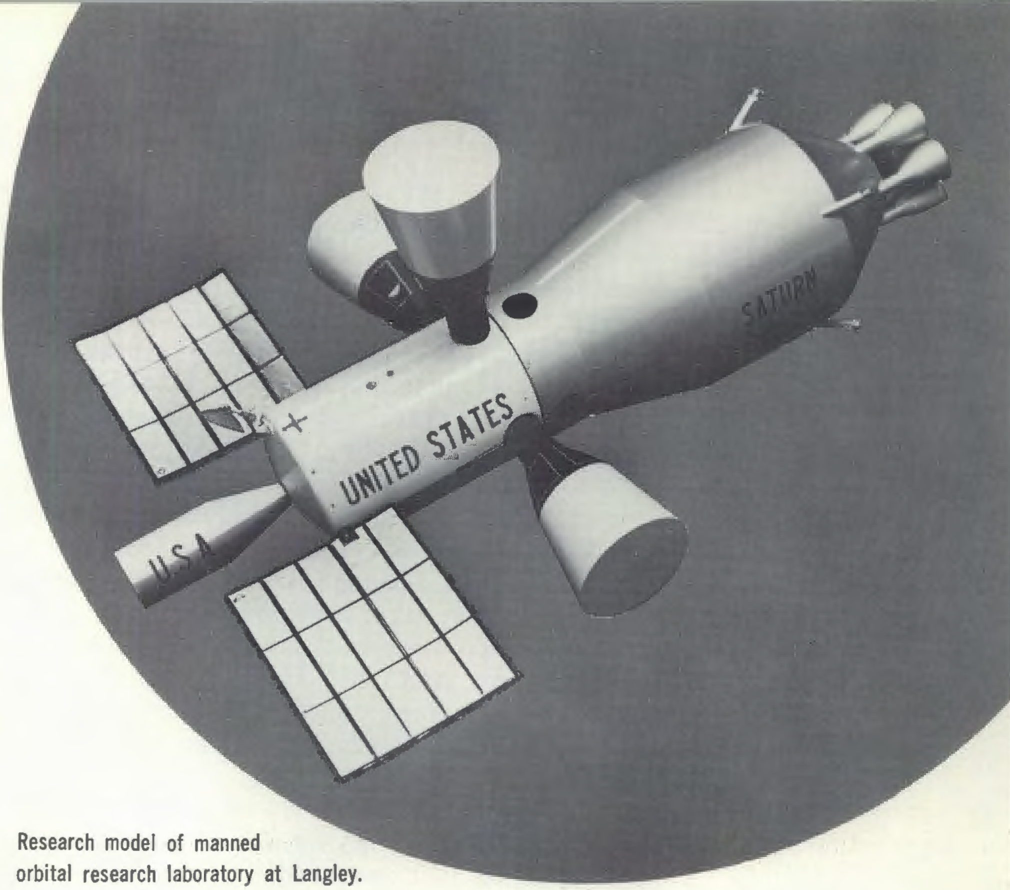
Weightlessness in itself did not appear to trouble the Mercury astronauts during their relatively short space flights. However, particularly in the later and longer flights, the astronauts encountered difficulties upon return to gravity conditions. Their reactions were comparable in a number of respects to those observed in a person who has been bedfast for some time. When he stands, he may become dizzy or faint. His slightest exertion causes his breathing to become rapid and his heart to pound. Among other research projects is an examination of the value of centrifuges for periodic gravity conditioning during prolonged space journeys.

Support of life in space within the confines of a space station poses a number of technological problems somewhat akin to those of submarines designed for long periods under water. Tests are being conducted to learn how man will react and perform during the relative isolation of long space flights. Prototype systems have been developed to purify water and air for reuse and provide for waste disposal and for food. Studies are being carried out on development of compact, lightweight, nutritious, palatable, and morale-supporting meals that require neither heating nor refrigeration.

In April 1964 five men emerged from a chamber where they had been in isolation for 30 days. During that time, they drank water and breathed air that had been purified after use. They

Artist's conception of manned interplanetary spacecraft.





Research model of manned
orbital research laboratory at Langley.

ate foods that had been dehydrated or freeze-dried within small light-weight packets. They reconstituted the foods with water. Except for the lack of zero g, living conditions roughly imitated those that they would encounter in space. This was NASA's first experiment integrating all systems for support of life in space. For the first ten days, the men lived on a diet being considered for the two-man Gemini program.

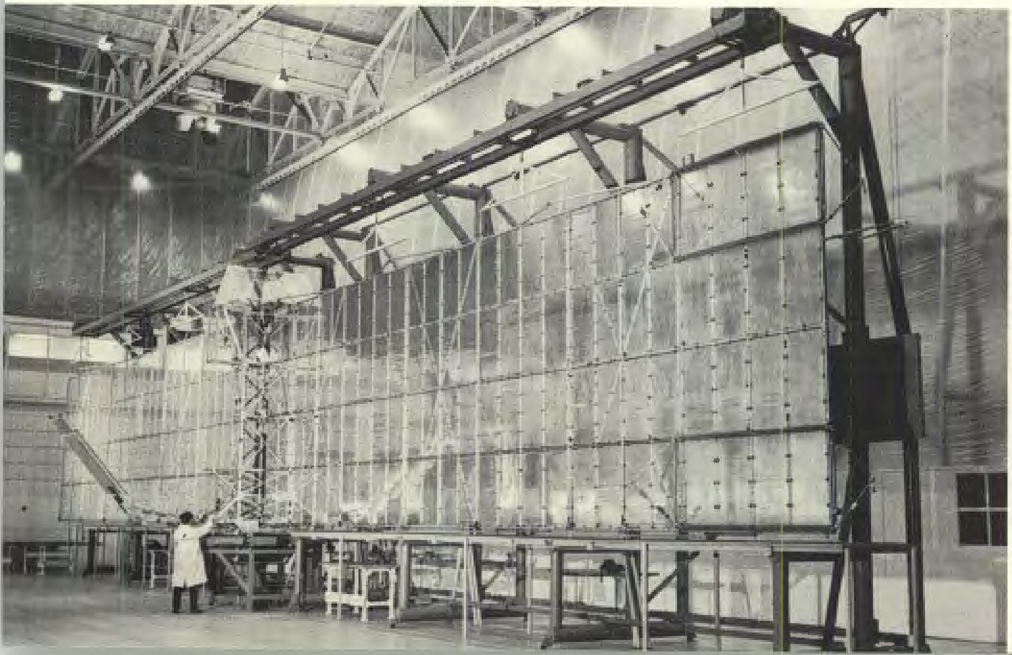
Space suits and spacecraft are being developed that will protect man from high vacuum, temperature extremes, small meteoroids, radiation, and other space hazards. In environmental chambers (space simulation) on earth, they are being subjected to pressures ranging from a near vacuum to that at sea level (15 pounds per square inch), to temperatures from more than 300° above zero F to lower than 300° below zero F; to radiation from the sun such as X-rays, ultraviolet, infrared, and visible light; and to electrified (ionized) atoms of oxygen, nitrogen, hydrogen, and other gases.

Man must vastly expand his knowledge of space if he is to live there for prolonged periods of time. His Orbiting Solar Observatories, bioscience satellites, Pioneer spacecraft, and Explorer satellites are designed to furnish vital data on radiation, meteoroids, zero g, magnetic fields, solar flares, and atmospheric density and other phenomena that may influence manned space flight. Crewless instrumented spacecraft such as Ranger, Surveyor, Lunar Orbiter, and Mariner will precede man to the moon and planets. They will transmit vital information about the dangers he may face during his voyage through the black unchartered regions of space and about the celestial body he is to visit.

Man is going into space to accomplish the work that automatic equipment cannot do. A computer, for example, can be programmed only to report on what we know or expect. It cannot report on the unexpected. And much of what is encountered in space may be unexpected. Moreover, man's observation and judgment is needed to augment, interpret, and enrich the data gathered by instruments.

Experiments with Mercury and the X–15 have demonstrated that man adds to the reliability of spacecraft. When automatic instruments on these vehicles malfunctioned, the men in control not only brought the spacecraft safely to earth but completed their missions before doing so. END

Wings of meteoroid satellite, to be launched by Saturn in its 8th, 9th, and 10th flights, dwarf man. The satellite will probe the meteoroid problem in greater depth than previously possible.



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