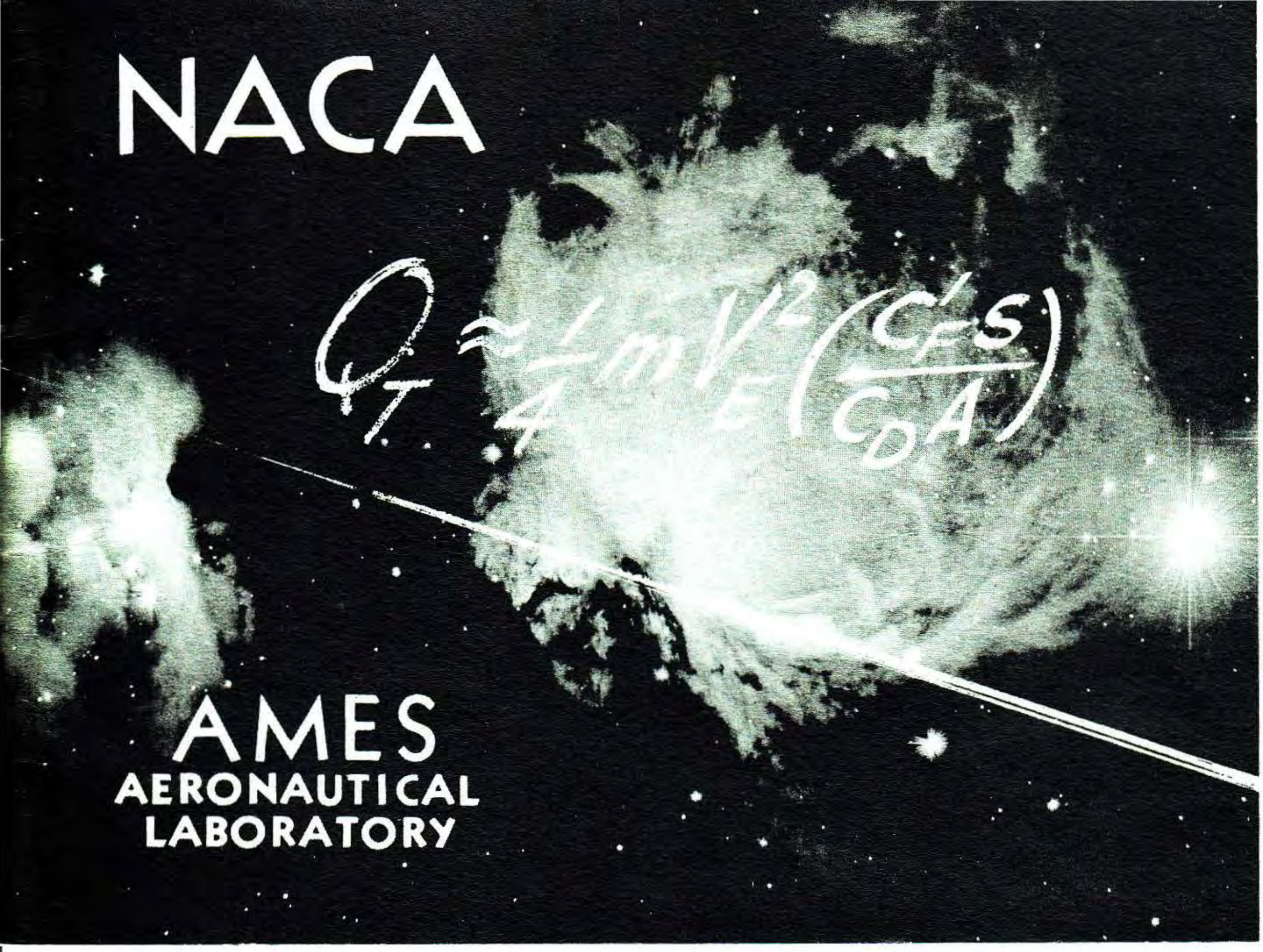

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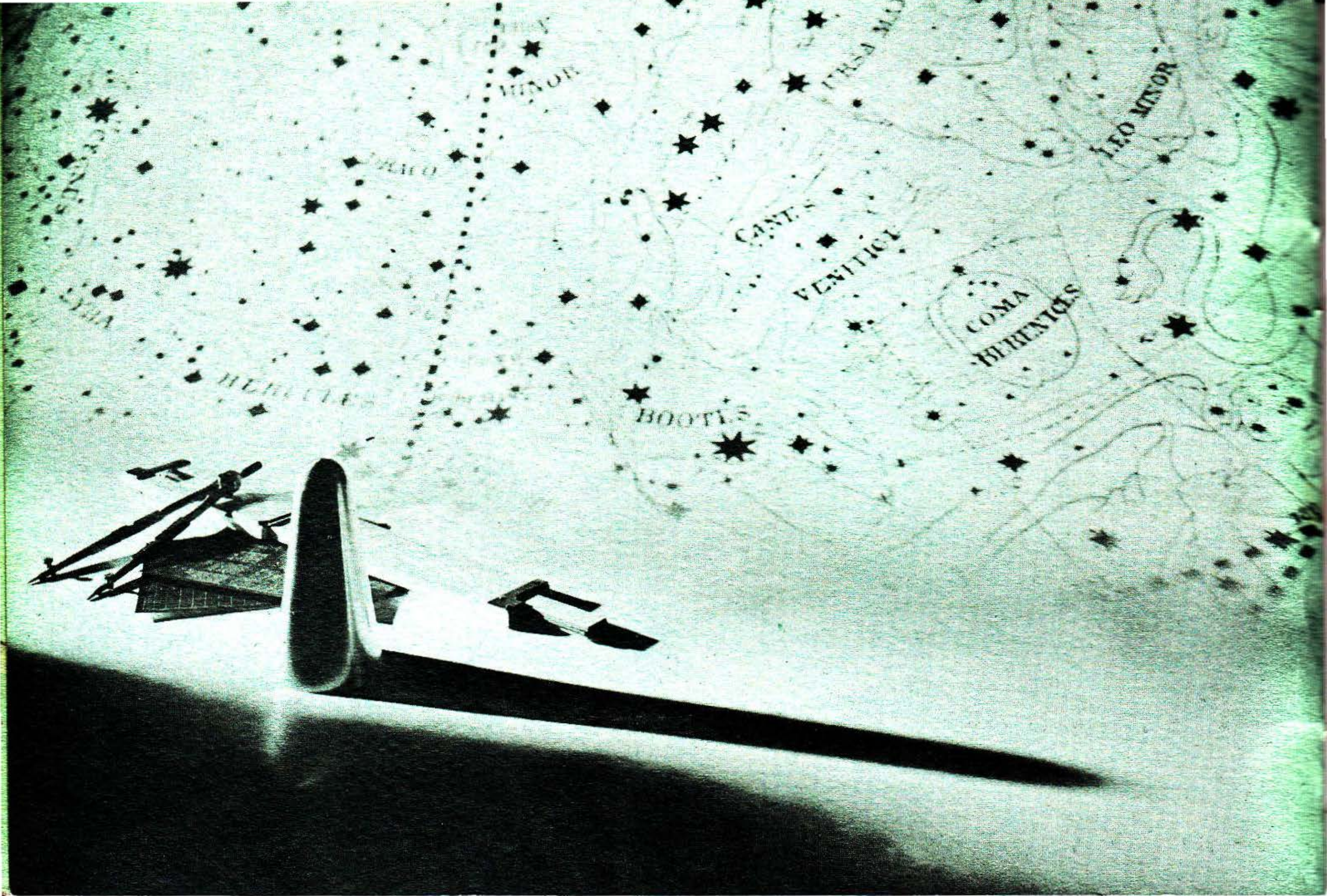
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"The ultimate potentialities of space flight cannot now be fully grasped."

DWIGHT D. EISENHOWER
April 2, 1958

THE COVER . . .

MATHEMATICS IS THE language of physical science. The equation seen against the background of the heavens expresses a basic physical relationship, that the total heat absorbed by a body during entry into the atmosphere can be kept to a minimum if a space craft has a high total drag in proportion to its friction drag. From this derives the principle of blunt shapes for re-entry. Application of the principle permits the far-traveling space vehicle to return to Earth in safety. The equation thus merits attention as we look outward to the universe and prepare for the splendid adventure ahead, the conquest of space.

WELCOME . . .

The National Advisory Committee for Aeronautics is honored by your presence today for the 1958 Triennial Inspection of the Ames Aeronautical Laboratory.

More than six years ago in this Laboratory an NACA scientist worked out the principle of the high-drag blunt nose cone to reduce to a minimum the aerodynamic heating experienced by a body entering the Earth's atmosphere at high speed. All current ICBM and IRBM warheads employ this concept. From this and even earlier beginnings NACA's work in space technology has grown in orderly fashion until it now receives half of our research attention.

As the United States prepares a national policy for the peaceful exploration of space, we invite you to join in the interchange of ideas and concepts from which there will surely grow a human endeavor surpassing in boldness and grandeur man's long struggle to master the land, the sea and the air. It is a privilege to meet here again with old friends and to greet those who have come to know us for the first time. We shall do our best to make your visit stimulating and enjoyable.

J. H. Doolittle,
Chairman
National Advisory Committee for Aeronautics

The Thrust into Space

The United States has the resources, the knowledge, the will — and above all, the responsibility — to pioneer in the Space Age. If the manifold possibilities of space are to be realized for the benefit of all mankind, it is imperative that this country lead the way.

The President's Science Advisory Committee has stated the situation this way:

"It is useful to distinguish among four factors which give importance, urgency and inevitability to the advancement of space technology.

"The first of these factors is the compelling urge of man to explore and to discover, the thrust of curiosity that leads men to try to go where no one has gone before. Most of the surface of the Earth has now been explored and men now turn to the exploration of outer space as their next objective.

"Second, there is the defense objective for the development of space technology. We wish to be sure that space is not used to endanger our security. If space is to be used for military purposes, we must be prepared to use space to defend ourselves.

"Third, there is the factor of national prestige. To be strong and bold in space technology will enhance the prestige of the United States among the peoples of the world and create added confidence in our scientific, technological, industrial and military strength.

"Fourth, space technology affords new opportunities for scientific observation and experiment which will add to our knowledge and understanding of the Earth, the solar system and the universe.

"The determination of what our space program should be must take into consideration all four of these objectives . . ."

As every scientist and engineer knows, we will reach these objectives step by fully tested step — not by eye-catching stunts. We will be building upon more than half a century of development in aerodynamics, propulsion, structures, electronics and the human factors involved in airplane flight through the atmosphere. Such development must continue as we move forward into space.

Design and development need to proceed along two parallel lines: manned and unmanned space vehicles. The earliest vehicles will be progressively larger unmanned satellites capable of carrying the instrumentation to perform more and more complex scientific tasks. Once we have demonstrated that we can bring man back safely, we can send him on flights into space, even to the planets within the solar system.

The ingredients for success in this challenging adventure are the time-honored ones: intelligence, application, hard work. We have a long way to go. The journey will be one of the most exciting in man's history.

Aerophysics

The International Geophysical Year finds this small planet taking a close scientific look at itself. The result will be an organized body of knowledge gathered by many scientists in many nations to provide the detailed understanding we must have to essay manned flight in space.

Men have long been interested in the gaseous film clinging to the surface of our planet. As their awe merged into comprehension they learned first to use the air and its energy, later to achieve some command over the atmosphere. The history and science of flight show the extent of understanding we have attained.

It is imperative to increase and deepen our knowledge of the atmosphere if we are to succeed in launching a man into space with his safe return assured. It is further necessary to know more about atmospheric properties to refine the design of vehicles which will use the air as a drag brake and landing cushion. Finally, the new knowledge of gas dynamics which must be attained will aid in solving the landing problem as it occurs on other planets whose atmospheres are composed of different gases.

Air density is one important quantity to be measured. The artificial satellites already launched are telling us much of value. They indicate that the atmosphere at 140 miles altitude is about 10 times more dense than some had thought, a fact of consequence to space technology and hypersonic vehicle design.

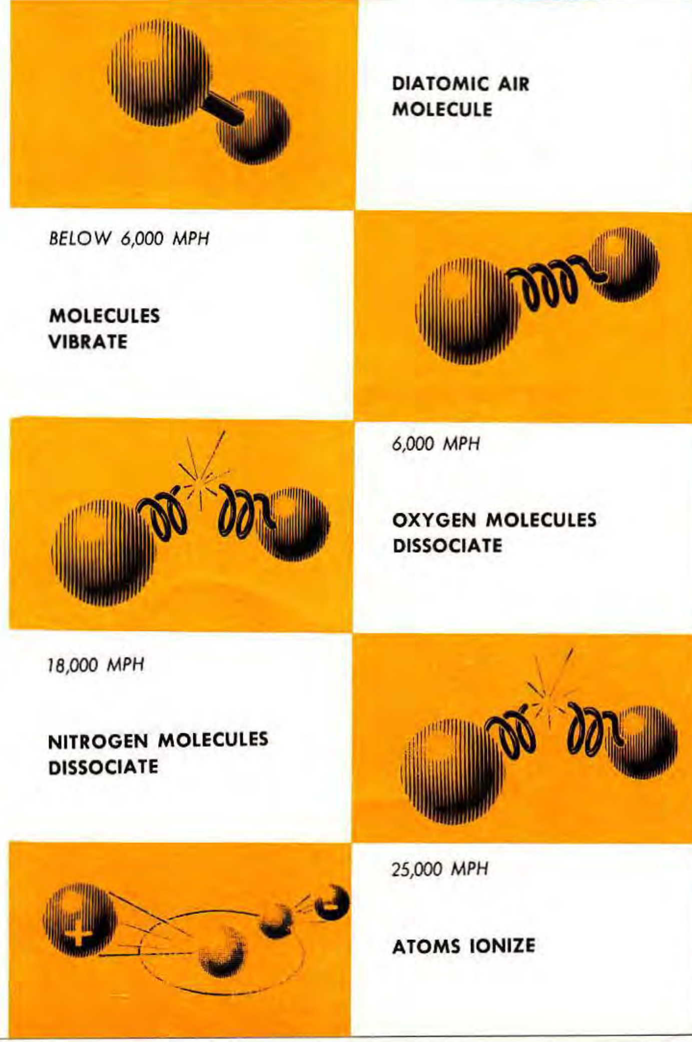
Next, the energy properties of air are of concern. As a space vehicle enters the Earth's air blanket at a speed that may range from 15,000 to 25,000 miles per hour a complex process of energy exchange occurs. In a very brief span of time, the kinetic energy of the entering vehicle is transformed into heat energy with violent results to the air and to the vehicle as well if it is unprotected. Clearly the vehicle designer must know in detail what *can* happen if he is to forestall what must not happen.

The oxygen and nitrogen molecules of which air is mainly composed are jammed together as the entry vehicle approaches. Density is instantaneously increased and the well-known shock-wave phenomenon results. Temperature is simply a measure of the energy of molecular motion, and the violent transformation of the vehicle's kinetic energy into energy of molecular motion raises the air to white heat. Much of the heat is radiated to the surrounding air. Some of it passes into the vehicle when high-energy molecules collide violently with its skin.

Examining more closely the molecules thus energized, we find that each is formed by two atoms linked by a bond of electrical energy. At 6,000 miles per hour sufficient energy to break this bond may easily occur in the system and we find the atoms separating. The process is called dissociation. The reverse, recombination, adds further complications. An atom of nitrogen may combine with an oxygen atom to form nitrous oxide, a gas not originally present in air. How a chemical change of this kind may affect a space vehicle's surface material is something we must know.

At higher speeds, near 25,000 miles per hour, the structures of the atoms are disturbed. Individual electrons receive so much additional energy that they are knocked free of the paths in which they normally spin around the atomic nucleus. An atom which loses one or more of its electrons is known as an ion. It possesses a positive electrical charge. Energy is absorbed when the electrons are ripped away, released when they snap back into place.

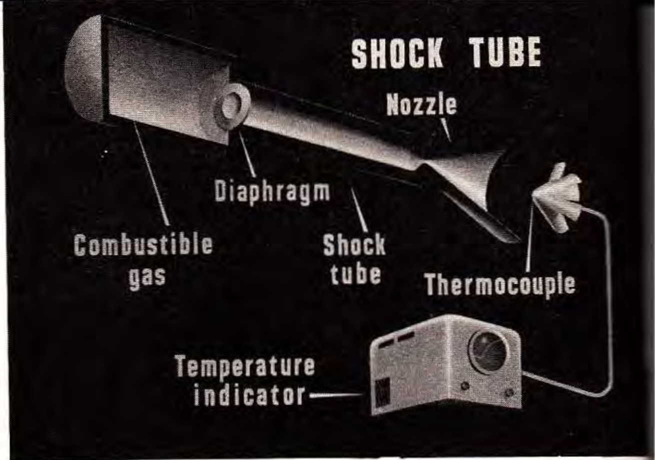
But while the particle remains ionized, new phenomena which science calls magnetogasdynamic effects, appear when charged ions and free electrons



are influenced by magnetic and electrical forces. Much research remains to be done in this area before we will know whether the principles of magnetogasdynamics can be usefully employed to maintain smooth flows over a vehicle's surface or to reduce heat transferred to the outer skin.

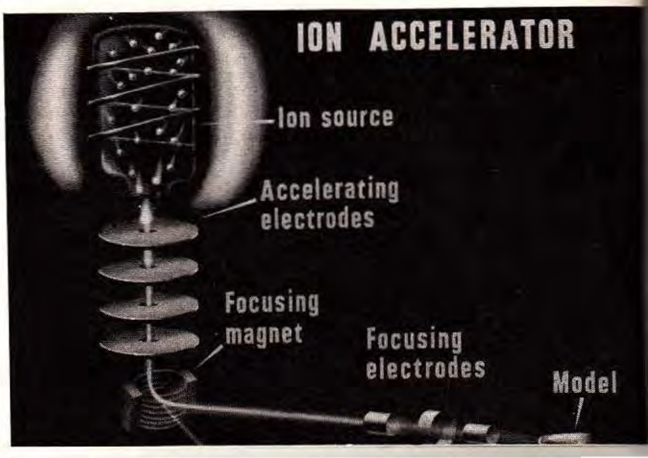
These and other physical processes take place with great rapidity during the energy exchange between an entering space vehicle and the air through which it moves. Laboratory research is rapidly filling in areas where only partial knowledge exists. New tools of research come into play while older methods are sharpened and expanded. Shock tubes at all three NACA Laboratories are performing high-temperature experiments. At the Ames Laboratory a new shock tube—actually a smooth-bore cannon 40 feet long—terminates in a nozzle followed by a one-foot test section capable of mounting models two feet long. Temperatures of 25,000° Fahrenheit can be developed in the apparatus to duplicate heating on models and the energy changes brought about during dissociation and ionization. In terms of speed, the conditions of a satellite entering the Earth's atmosphere can be reproduced.

A new application of the particle accelerator now in use at the Ames Laboratory is exploring the erosion which occurs when ionized particles



SHOCK TUBE PRODUCES 25,000° TEMPERATURES

MAGNETS FOCUS BEAM OF IONS




ION ACCELERATOR STUDIES
EROSION BY PARTICLES

strike metal surfaces at speeds of 15,000 miles per hour or faster. Nitrogen or oxygen ions generated by high-frequency electric waves are accelerated electrically to very high velocities, then focused by a magnet into a beam of ions impinging on a sample of the material being tested. Surface pitting caused by the ions is like that which will occur on the skins of space craft.

No single organization can hope to provide all the detailed knowledge that we will require about physical changes in the atmosphere. The careful coordination of many scientists' contributions will give the designer and engineer the facts they must possess.

Satellites and Orbits

Perhaps the most startling, single research instrument ever conceived and put to use is the artificial Earth satellite. The initial social and emotional impact of the first satellites has subsided and we can thus take a more nearly balanced view of their purposes and probable usefulness.

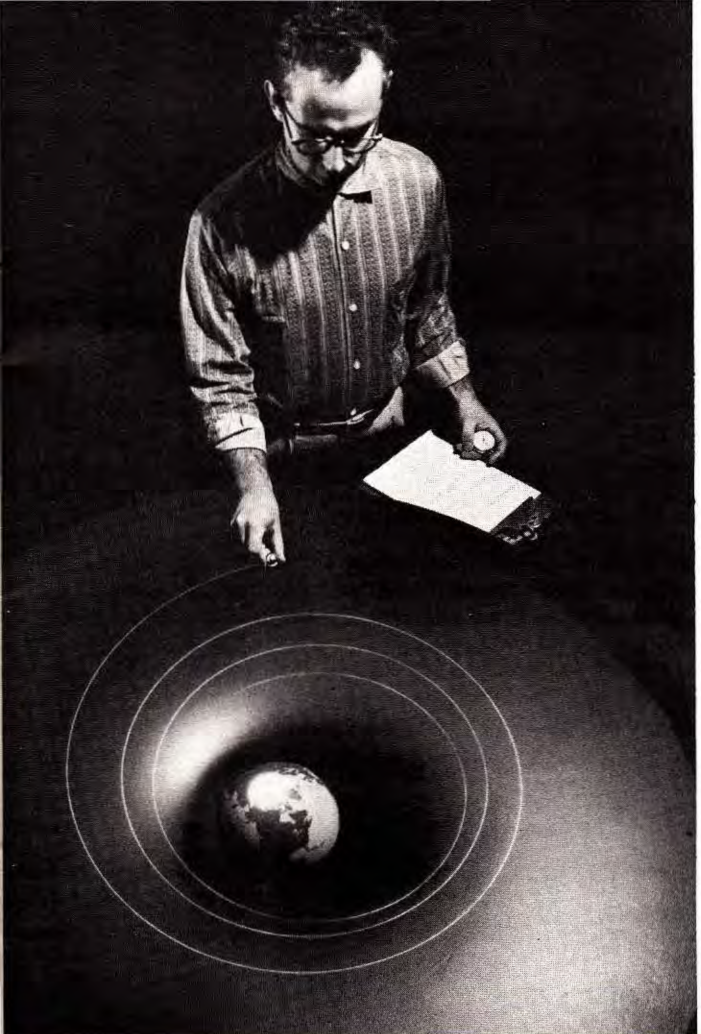
As originally conceived for the International Geophysical Year, the satellite was designed to examine directly regions in the upper atmosphere unreached by man himself. It has performed well, so well that in the months to come scientists face a formidable task to make useful order out of the great volume of satellite-gathered data.

Even a simple, inert satellite bearing no instruments can enlarge man's knowledge of the Earth and the Earth's atmosphere. From careful observations of the satellite in orbit distance measurements over the Earth's surface can be made more accurately. Small variations in orbit speak of the way the Earth's density is distributed; drag measurements disclose new facts about the upper air density.

Add an elementary radio and the satellite can be tracked when it cannot be seen. Radio measurements on the ground can be interpreted to compute the number of charged particles in the ionosphere, a matter of great importance in long-range communications.

More elaborate instruments in the satellite itself greatly magnify its usefulness. We now get detailed information about the atmosphere — its composition, pressure and density — at many different altitudes. Solar and cosmic particles and radiation become measurable. Hypotheses about the Earth's magnetic and gravitational fields and their complex interaction with solar radiations may be tested. The Earth's reflectivity can be accurately determined and we expect to attain new insights into the little-appreciated fact that our planet sends back into space over a period of time exactly as much heat

ORBIT DEMONSTRATED ON CURVED TABLE



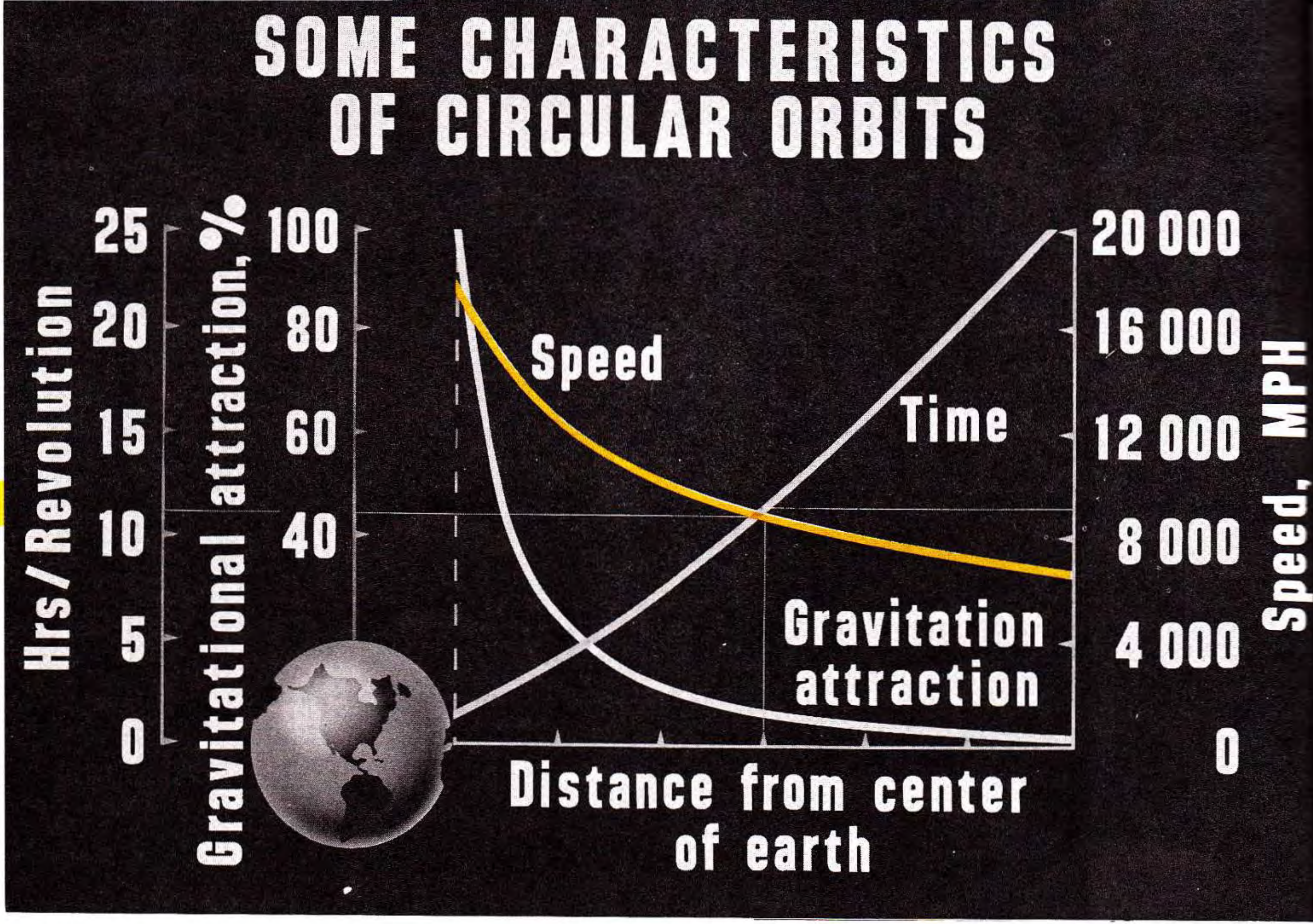
energy as it receives from the sun. Weather, with all its economic and social impacts upon man, will be open to more rigorous analysis than ever before.

Turn the eye of the satellite toward the depths of space and for the first time the universe around us will be seen, undimmed by the atmosphere. Fit the satellite with biological and medical research equipment and it becomes a space medicine laboratory, scene of many experiments precedent to man in space.

So many useful jobs for satellites have already been determined that their future value, expanded many-fold, is beyond question.

A satellite is held in orbit by precisely balanced forces, gravity acting toward the center of the Earth, centrifugal force acting in an opposite direction. The latter force is established by the speed imparted to the satellite as it enters its orbit. In a sense, the satellite is constantly falling, but the surface of the Earth curves away from a straight line at the same rate and an orbit results. Weightlessness of the satellite and all objects within it arises from the balanced forces.

The variety of orbits in which it is theoretically possible to establish a satellite enlarge its useful functions. Thus far, all actual orbits have been elliptical, but there seems to be no reason why a circular


SOME CHARACTERISTICS OF CIRCULAR ORBITS
Hrs/Revolution
25
20
15
10
5
0
Gravitational attraction, %
100
80
60
40
Speed
Time
Gravitation attraction
20 000
16 000
12 000
8 000
4 000
0
Speed, MPH
Distance from center of earth

orbit or a specific ellipse cannot be achieved provided very accurate guidance and thrust control are attained.

Selecting the proper launching path sets the plane in which the satellite orbits. At the Florida site all U. S. satellites have thus far been launched at an angle of 35° to the equator in order to begin the flight over an existing tracking range and to assure that spent rocket stages will not drop on inhabited areas. The resulting orbit carries the satellite over a band of the Earth extending 40° to the north and 40° to the south of the equator.

When we are ready to observe weather over the entire planet by satellite cameras, we shall launch in a polar orbit. This will permit total coverage of the Earth. It is, however, not the orbit we might choose if we hoped to land the vehicle at a selected site, because a satellite circling the Earth every 90 minutes in a polar orbit will pass over the same spot on Earth only twice every 24 hours.

Least Earth coverage is provided by an equatorial orbit, but it has the compensating virtue of simplifying landing. Launch must be from the equator, but the satellite will pass over a given landing spot on every revolution. A complication, nevertheless surmountable, is the fact that most of the Earth at the equator is either ocean or jungle.

The science of communications finds promise in a satellite in a circular orbit at the equator at an altitude of 22,000 miles. Such a satellite would take 24 hours to complete one revolution, hence would appear to hang motionless in the skies. Three equally spaced satellites in such an orbit might provide radio or television relay stations capable of covering the whole Earth for broadcasts.

Research is concerned with further requirements, one being the orientation of a satellite with respect to the Earth. If the satellite carries optical instruments, we must be able to point them at the objects they are meant to observe. If unwanted motions take place when the carrier rocket breaks free from the satellite, we must be able to stop or control them. If a human crew is aboard, it is quite essential to bring the satellite to the correct attitude for entering the atmosphere. The questions are those of stability and control in an environment where the conventional aerodynamic forces to provide lift or damping are lacking.

We must therefore place within the satellite vehicle means for providing control. Fortunately, there exists a well-developed body of knowledge about gyroscopic controls and the elaborate uses to which they have been put; for example, the so-called "stable platform" which can provide a fixed reference in space regardless of disturbing forces acting on its carrier vehicle.

Space Propulsion Systems

Flight progress has always been paced by propulsion. The technical revolution from which the modern high performance rocket engines evolved had its beginnings in the chemical rocket experiments of Dr. Robert H. Goddard as early as 1926. The work of German scientists and engineers culminating in the V-2 ballistic missile removed any doubts that rocket engines could be made practical. High-thrust engines developed during and since World War II ultimately made possible earth satellite experiments lifting the prospect of travel beyond this planet out of the realm of science fiction.

Before extensive manned flight in space is accomplished, a very large effort in propulsion research and development must be made. Propulsion systems now suitable for ballistic missiles must be greatly improved to deliver larger payloads more economically, to operate for longer periods and to achieve greater vehicle speeds. New methods in addition to chemical rockets must be brought into service. NACA research is moving forward on these and other concepts as a key element in the space technology program of the United States.

Three rocket propulsion systems are currently of foremost concern. They are chemical, nuclear and nuclear-electric. Each has applications to which it is best suited; indeed, any well-conceived program of space exploration may use the advantages of all three.

Discussion of rocket power usually includes the term "specific impulse," which by definition is the amount of thrust measured in pounds produced by an engine for each pound of propellant consumed each second. Thus, it is a measure of the effectiveness of the propellant being used. For example, rocket engine propellants such as kerosene and liquid oxygen yield about 250 pounds of thrust for each pound of propellant consumed each second. Other chemical rockets, solid or liquid, range in specific impulse from 200 to about 400. Nuclear rockets are theoretically capable of specific impulses from 500 to 1,000 or more depending upon the temperatures permissible in the nuclear reactor. Electric propulsion systems can have specific impulses up to 20,000 or more.

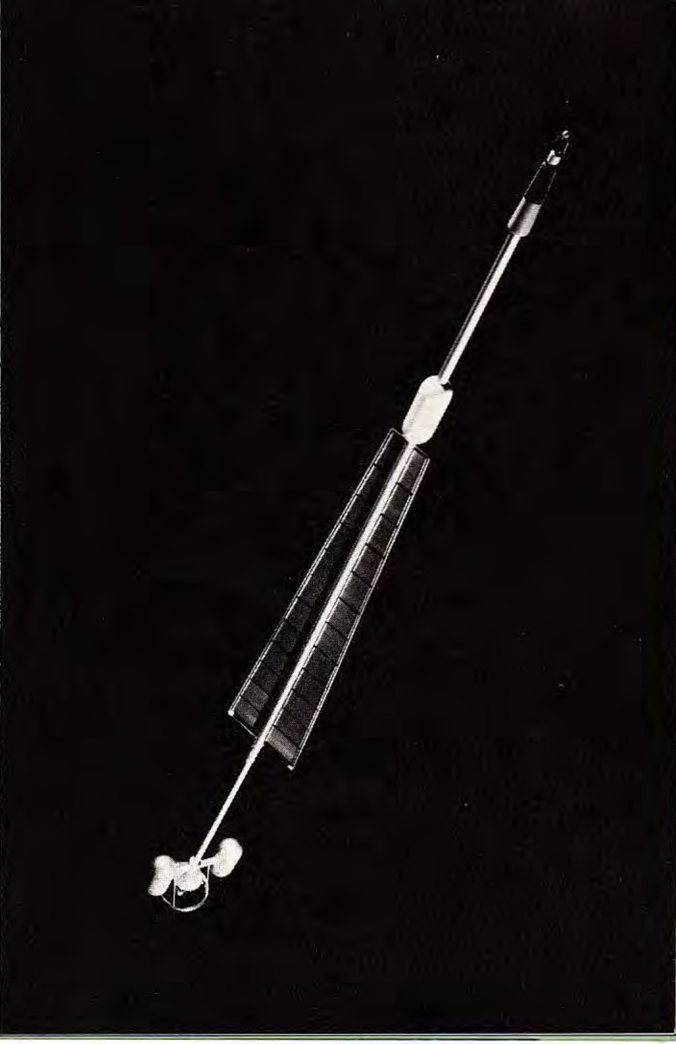
To achieve the high speeds and large payloads desirable for flight in space, the designer seeks to combine high specific impulse with low structure weight. Chemical rockets produce high thrust with light weight engines, have good acceleration for take-off and landing and are generally suitable for satellite launchings and Moon trips. More important, they are available now in useful sizes. Nuclear rockets produce high thrusts with lower rates of propellant discharge than chemical rockets. They will probably find their best uses in delivering large payloads to the Moon or nearby planets. Nuclear-electric rockets have low ratios of thrust to engine weight resulting in such low accelerations that they would be useless for Earth take-off but well suited to outer space.

Liquid-fueled chemical rockets present many research and design problems. The combustion process in which the fuel and oxidant burn to produce thrust takes place under extreme pressure and temperature conditions. Many questions concerning proper injection, combustion, and expansion of propellants require solution. Propellant pumping and control techniques must be improved. Engine reliability, which is affected by starting, cooling, and combustion stability, is of concern. By no means least important are very difficult problems of storing and handling fuels which often are explosive, poisonous, corrosive or otherwise intractable. The difficulties to be overcome and real opportunities for making important gains require maximum effort.

Analyses have shown that the take-off weight required to accomplish manned flight to another planet becomes extremely large with the use of a chemical rocket for the entire flight. For this reason other means of propulsion must be considered.

The nuclear rocket shows promise as a power plant capable of fulfilling the requirements for

HYPOTHETICAL NUCLEAR SPACE CRAFT



manned interplanetary flight. It consists of a nuclear reactor which heats a propellant, perhaps hydrogen, to very high temperatures and generates thrust by expanding the hot gas through a nozzle.

The temperature at which the reactor can be permitted to operate governs the amount of thrust a nuclear rocket generates. Materials must be found and developed for fabrication into reactor fuel elements and moderators usable at the highest possible temperatures. Such materials as graphite and beryllium are useful moderators but may require cooling. Possible materials for fuel elements and internal structure range from nickel based alloys, molybdenum, and tungsten, to such compounds as the carbides of hafnium and tantalum.

For space operation the nuclear rocket must be made to withstand numerous starts and shutdowns. Further, it must be capable of efficient operation for much longer periods than current chemical rockets.

Electric propulsion systems accelerate the propellant by electro-static or electromagnetic forces. They can produce very high specific impulses at the disadvantage of requiring large amounts of heavy machinery to supply electric power. It is possible to obtain this power from a nuclear reactor carried with the vehicle, or perhaps from solar energy, but development of a truly practical system demands a large research effort.

PLASMA ACCELERATOR GENERATES THRUST IN LABORATORY

Electric propulsion systems are particularly attractive because of their ability to operate on much smaller propellant requirements than either chemical or nuclear rockets. They are believed best suited for interplanetary travel or space craft control.

Stability Vital to Successful, Safe Recovery

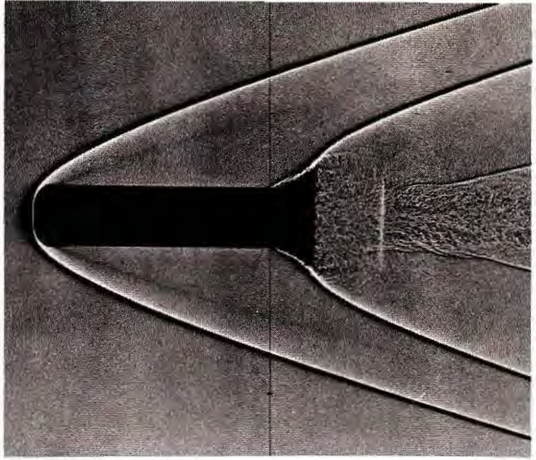
Without stability there can be no satisfactory, safe, successful return to Earth of satellites, ballistic missiles or space craft. It is one of the tasks of research to determine what kinds of stability are acceptable for space vehicles and how much stability must be provided to make a given design amenable to control.

Stability, defined broadly as the tendency of a system to maintain a given equilibrium and to reestablish itself if disturbed, has been studied by aerodynamicists and scientists in other fields for many decades. Although the stability demanded by conventional airplanes at low speeds and altitudes is well understood, and workable solutions are available to the design engineer, much new knowledge is needed to deal with the complications brought about by the speeds and altitudes implied by space flight. Much of NACA's research effort is being devoted to this problem. In particular, a number of facilities of the Ames Laboratory are being used to obtain quantitative measurements of stability characteristics by flight tests in air at hypersonic speeds.

If space craft are to be controlled for approach and landing on return to the Earth, adequate stability must be provided for them. Without it a definite flight program during atmosphere entry and descent cannot be followed, nor can the pilot maneuver effectively or bring himself safely to Earth. A landing point, for example, must be guaranteed within reasonable limits or a re-entry flight programmed to land at Rogers Dry Lake in California might end far out in the Pacific Ocean. For like reasons, stability is necessary to the accurate flight and landing of ballistic missiles and other unmanned vehicles.

A second consideration applicable to manned satellites or space craft is buffeting which would certainly occur in tumbling, unstable flight. Buffeting could injure the pilot and seriously damage the vehicle and its equipment. If we consider a programmed ballistic entry for a manned satellite as some have suggested, buffeting is intolerable when added to the already severe deceleration forces a man would have to survive. At best the pilot might be expected to withstand decelerations of eight times the force of gravity — boosting his effective weight from 200 to 1,600 pounds for a short period. The rough ride added by buffeting probably would be disastrous.

Stability and vehicle heating are importantly interrelated. To protect a recoverable satellite or space craft from destructive heat during entry, designers will provide it with a heat shield selected for the specific flight conditions to be encountered. They will try to keep the weight of material devoted to heat protection as small as possible, restricting the area covered to the frontal surfaces. Thus the vital heat protection will be in front of, but not behind the enclosure for instruments, payload and in some cases the human crew. Any lapse into instability would expose unprotected portions of the vehicle to destructive heating during re-entry.

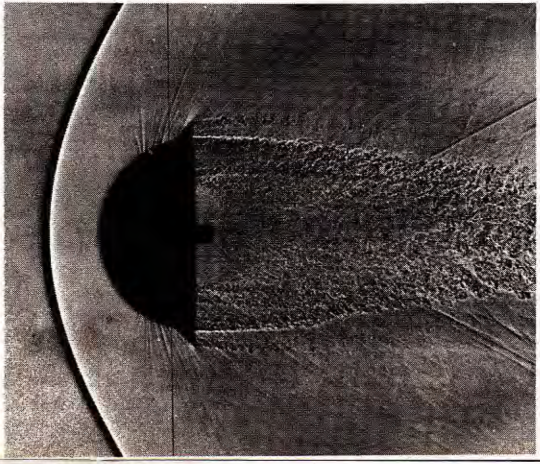


SHADOWGRAPH OF FREE FLIGHT STABILITY MODEL

Flight stability is primarily determined by two factors — shape and center of gravity. These essentials must be judiciously balanced in the design and engineering process along with many other considerations.

The compact shapes which presently seem best suited to survive atmosphere entry tend to instability and, without counteraction by proper design, may wander, tumble or even assume a rearward flight attitude. The center of gravity — or point of balance — is also the center of rotation for oscillations that may occur in flight. The designer has a measure of choice in locating the center of gravity for a given vehicle; when the center of gravity is moved forward, stability is increased. But other

STRONG SHOCK WAVE CHARACTERIZES BLUNT SHAPE



considerations of design may dictate a compromise in center-of-gravity location. One urgent objective of stability investigations is to determine the precise location of center of gravity required for particular families of space craft and re-entry vehicles.

New Problems for the Pilot

Every space vehicle we intend to recover must be brought through the Earth's atmosphere to some sort of landing. Great difficulties must be overcome to accomplish this end, whether the vehicle is controlled by a human pilot or by a mechanism.

Landing problems have occupied a large share of research attention through the entire history of flight. But these problems of the past shrink in significance when we consider the new complications we undertake to master for successful recovery or landing of space craft.

For a manned satellite or space craft the landing approach begins in airless space when the pilot, human or automatic, aligns the vehicle properly to begin atmosphere entry. Reaction controls or internal gyroscopic devices will be used to accomplish the task.

In a vehicle which depends on aerodynamic lift for controlled flight in the atmosphere, a transition is made from space controls to aerodynamic controls as it enters the Earth's envelope of air. Then effective command over the vehicle must be maintained through a very wide range of accelerations and rapid changes in air density and dynamic pressure while speed is reduced from 18,000 miles per hour or more to some safe landing value.

In consequence, a whole new family of piloting and control problems appears, and the cost and complexity of flight operations multiply.

Satellites and space vehicles will have greatly reduced damping compared with familiar airplane-like vehicles. They will be designed to survive the intense heating attendant upon high-speed atmosphere entry. The compact shapes that will result will be such that damping—the tendency for angular motions of the vehicle to subside—will not occur naturally and thus tend to keep the vehicle on a constant flight path. On the contrary, blunt, stubby space craft may have such poor damping qualities that they will tend to diverge from a steady course and will require every possible design refinement plus artificial stabilization to accomplish controlled flight in the atmosphere.

Another problem area for the pilot lies in the upper atmosphere when a transition must be made from a control system suited to flight in space to a control system adapted to aerodynamics. Use of conventional aerodynamic control surfaces in the dense atmosphere appears necessary, but these, depending as they do on physical reactions with the air, will have no effect in airless space. To shift from one control system to another during the rapid course of re-entry flight while speed, altitude and pressure are all changing each second will require extraordinary piloting skill and all the mechanical assistance we can provide.

Once inside the sensible atmosphere the pilot will have to adjust himself to unfamiliar and very rapid changes in control effectiveness. Aerodynamic controls respond quickly to changes in dynamic pressure, and at the speeds we are considering those changes can be very large and very swift.

Much needs to be learned about unwanted and perhaps intolerable interactions between individual controls. Experience with high-performance conventional airplanes disclosed new and unsuspected ways in which a control motion by the pilot can lead to an undesired response. Low damping is one factor in the problem, and, unless corrective measures are provided, complete loss of control is the penalty.

The human pilot performs his task by responding to information of various sorts presented to him on the faces of dials and instruments and by the physiological ability to perceive motion which each of us

ELECTRONIC SIMULATOR EXPLORES PILOTING PROBLEMS

possesses. For space and re-entry flight many new types of flight instruments will be needed, all able to give the pilot accurately and usefully the information he requires. At the same time, flight data must be presented more rapidly than ever before to keep pace with the speed and altitude changes associated with re-entry flight.

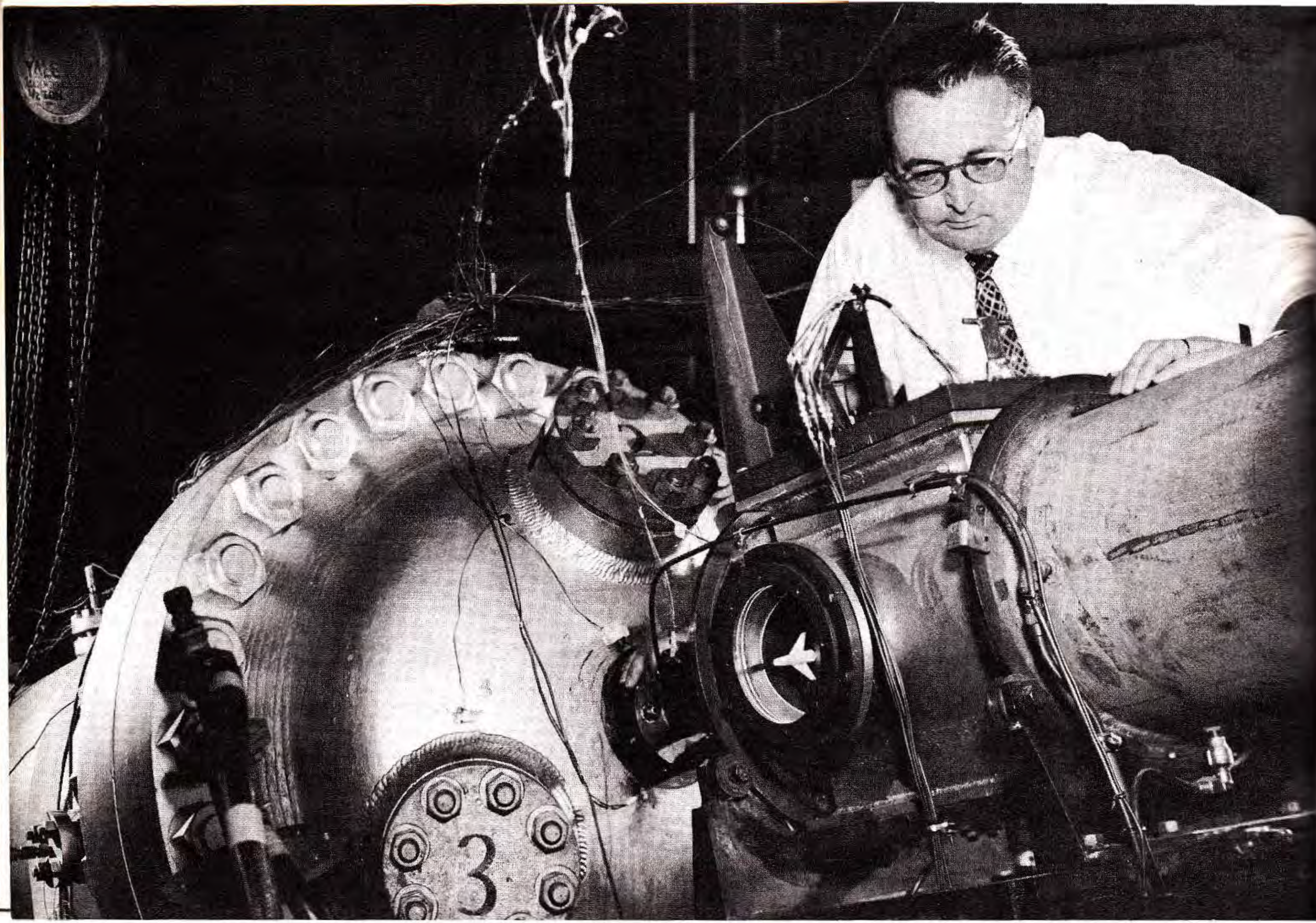
Research attacks on all of these problems are in progress and the knowledge being gained will apply whether control is maintained by an automatic pilot, by remote guidance or by a human being.

The use of simulators for much of the research in these problem areas is mandatory, since test flying of space craft will be more hazardous, sometimes less effective, and always far more costly than with the conventional airplane. For identical reasons, simulators will find increased use and importance for training pilots and flight crews.

New Tools for Research

The kind of flight path followed by a ballistic missile or a satellite descending through the Earth's atmosphere has a most important bearing on the type and magnitude of the engineering problems imposed by re-entry. The flight path in turn is dictated by the kind of vehicle and mission being considered.

It is expected that recoverable satellites and other space craft will begin entry at a tangent to the Earth's surface, using the upper atmosphere as a drag brake for gradual deceleration from speeds of about 19,000 miles per hour. As the flight progresses the path will steepen and the decelerating vehicle will lose altitude more rapidly. In contrast, the ballistic missile is intended to begin entry at a quite steep angle with an initial speed of some 15,000 miles per hour. All types of entry vehicles exchange their kinetic energy for heat energy during the entry process. The ballistic missile does so in a very brief time; the carefully programmed entry paths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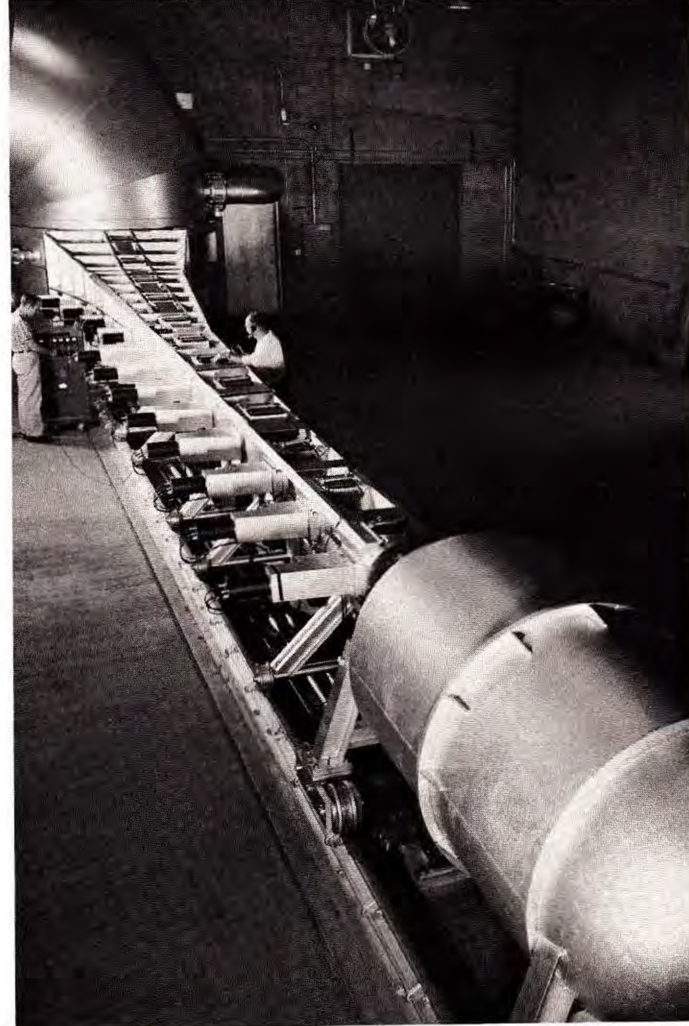
for more complex vehicles extend the process over a longer period. But in all cases aerodynamic heating due to the enormous speed presents major engineering problems, with destruction the penalty for unsatisfactory solutions.

In the NACA Laboratories new tools of research have been brought to bear on the heating problem to find materials and structural concepts capable of meeting the severe requirements.

At the Ames Laboratory, ultra-high speed guns make possible model launchings at actual re-entry speeds. A choice of environments is available for model flights duplicating a wide variety of test conditions. In the new Ames Hypervelocity Ballistic Range models can be shot at 16,000 miles per hour into a 500-foot long pressurized tank to duplicate atmospheric conditions at different altitudes. By substituting suitable gas mixtures, flight through atmospheres of other planets can be studied.

The Ames Atmosphere Entry Simulator represents another specialized use of high-velocity guns for research. Here a special trumpet-shaped nozzle accelerates a flow of high-pressure air so that it duplicates accurately the way the Earth's atmosphere becomes less dense with increasing altitude. At the widest part of the nozzle, air thins to the very low densities typical of the region where reentry flight begins. As the nozzle narrows, the den-

◀ *HIGH SPEEDS AND TEMPERATURES ARE POSSIBLE IN CERAMIC JET*



AMES ATMOSPHERE ENTRY SIMULATOR ▶

sity increases, and if the test conditions require it, the narrowest section can duplicate sea-level air density. When a gun-launched model flies at full re-entry velocity into the simulator nozzle, it experiences during a few thousandths of a second the decelerations, stresses, pressures and temperatures of actual entry. Thus the simulator can quickly and economically determine whether a specific design will survive atmosphere entry or perish.

Finding materials which can withstand high temperatures without melting or burning is only a part of the task. We must know whether their strength characteristics are preserved for a useful span of time. Actual vehicle entries to the atmosphere will not be completed in a few seconds and there must be no question, when a manned satellite is committed to space, about the vehicle's ability to return its pilot or crew safely to Earth.

Thus, the study of materials and structures at high temperatures is more than merely determining strength under severe heating. Evaluation of materials for re-entry use demands that real air, under proper conditions of speed and pressure, be duplicated. In the Langley Structures Laboratory, for example, an electric arc-powered air jet creates an air flow at temperatures between 12,000° and 15,000° F. In it all types of materials can be studied under realistic conditions.

TEST HEMISPHERE GLOWS AT 2,000° F

For experiments with larger objects — nose cones and leading edges of wings or fins — devices known as pebble-bed heaters are in service at the Ames and Langley Laboratories. Air under pressure is forced through a column of ceramic or refractory "marbles" previously brought to white heat by a gas burner. The same air is then accelerated through a cooled nozzle to the supersonic speeds required in the working section where the model under test is placed. Much useful information is being obtained from these facilities and they are showing designers ways to build even more effective tools of research.

Exploring Re-entry in Flight

Flight testing, with or without pilot, alone yields final proof of the research results obtained in the laboratory and the way they are applied in vehicle design. Some full-scale flight tests are today, as always in the past, imperative. But the cost of full-scale tests of missiles and space craft is so great that other means of flight testing are essential.

Since 1945, the NACA has been exploiting an economical, reliable way of obtaining high speed, large-scale test results in the actual atmosphere. Working from the Pilotless Aircraft Research Station at Wallops Island, Virginia, NACA engineers and scientists have acquired a steadily growing body of experience with rocket-propelled model tests at progressively higher speeds. At the outset, the program was aimed to gather aerodynamic information in the transonic speed range unattainable by conventional wind tunnels. In more recent years higher speeds and higher altitudes have been the goal.

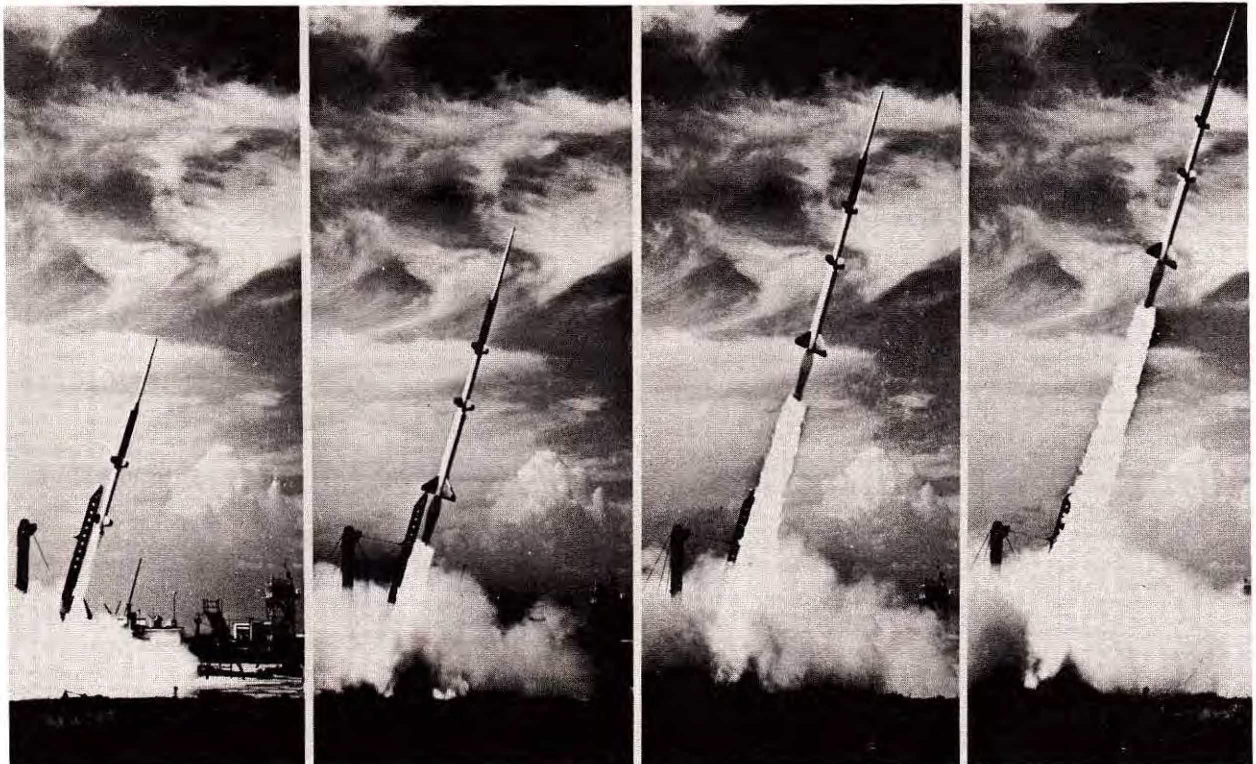
Speeds of more than 11,000 miles per hour—Mach number 16—have been reached. Solid fuel rockets, developed for military purposes and readily available at relatively low cost, are used for propulsion. Multi-staging, the device of piling one rocket on top of another and firing stages in sequence, has been developed to the point that five-stage vehicles are now considered routine. The results obtained apply directly to the larger vehicles to be launched later as ballistic missiles, satellites or space craft.

Remarkable versatility characterizes the multi-staging method. The angle from which the test vehicle is started on its flight can be adjusted to select a number of different flight paths. Then the firing times of the various stages can be arranged to cover a wide variety of flight programs. In all cases, stages One and Two are fired early in the flight to obtain altitude. To simulate an atmosphere entry, it is possible to delay firing the third stage until the assembly has reached a re-entry angle. Then stages Three, Four, and Five fire to drive the test body at very high speeds down through the dense atmosphere.

A more extended test period at high altitudes can be selected by igniting the third stage just as the rockets pass over the peak of their trajectory, then firing the fourth and last stages in rapid sequence. The result is a relatively horizontal flight path such as a hypersonic rocket glider might follow.

For extreme altitude work all stages are fired in sequence as the rocket is ascending; it is this method that has produced altitude results as high as 200 miles.

Paralleling the work of developing reliable methods for multi-staging solid fuel rockets has been a growing program for refining telemetering techniques so that information from test models flying



at extreme speeds and altitudes can be reported accurately to the launching station. The models and spent rockets are lost at sea but a steady flow of data is reported by telemetering devices sturdy enough to withstand accelerations as high as 150 times the force of gravity.

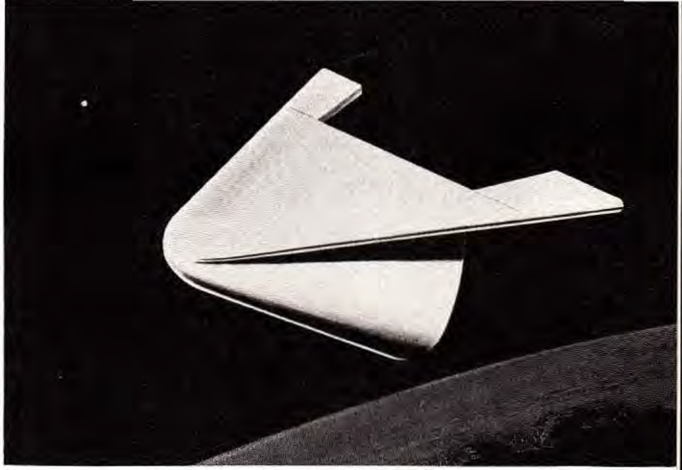
Heating and Cooling

Known methods for dealing with the intense heat of high-speed atmospheric entry exist. The principle of blunting, originated by H. Julian Allen of the Ames Laboratory, places in the hands of design engineers a practical aerodynamic method for dumping a large measure of heat into the atmosphere.

A second way to keep the surface temperatures within tolerable limits is to use aerodynamic lift during entry. In this way the vehicle remains longer at higher altitudes and the retardation which generates heat is more gradual. Use of lift for re-entry permits lower decelerations, a most important consideration if human occupants are aboard.

Lift, however, has its price. To obtain it, the blunt, high drag forms known to permit successful ballistic re-entry must be altered. As greater lift is required, the vehicle becomes more flattened and the amount of blunting that can be tolerated gradually diminishes.

FIVE-STAGE ROCKET POWERED MODEL TAKE-OFF



STUDY VEHICLE FOR LIFTING ENTRY

Varying both lift and drag during atmospheric entry promises marked reductions in heating rates and in total heat absorbed. It has been suggested that a variable lift-drag ratio vehicle might begin entry without lift but with high drag provided by some form of braking device, perhaps a parachute. When a sufficiently low speed has been reached, the drag device would be dropped or retracted, leaving a lifting vehicle to complete the flight. Worthwhile results in lowered heating are promised by such a method, but at the cost of mechanical complications which might be unacceptable for particular vehicles.

Thus far we have been talking about aerodynamic means for controlling re-entry heating. In every case, the best aerodynamic solutions obtainable will require some internal provision for keeping the re-entry vehicle cool or for dealing with the quantities of heat which must inescapably be absorbed.

The specific method or combination of methods will vary with the conditions of re-entry, the shape of the vehicle and the flight path it follows. In some cases, the rate of heat absorption during entry is the crucial factor; in others, lengths of time of exposure to heating become more important and the total heat demands attention. It appears now that no single, simple answer to all entry situations is likely to be found.

Several well-tried cooling systems and some less familiar are receiving research attention. One system uses a cooling fluid which is pumped through passages next to the skin to absorb and carry away incoming heat.

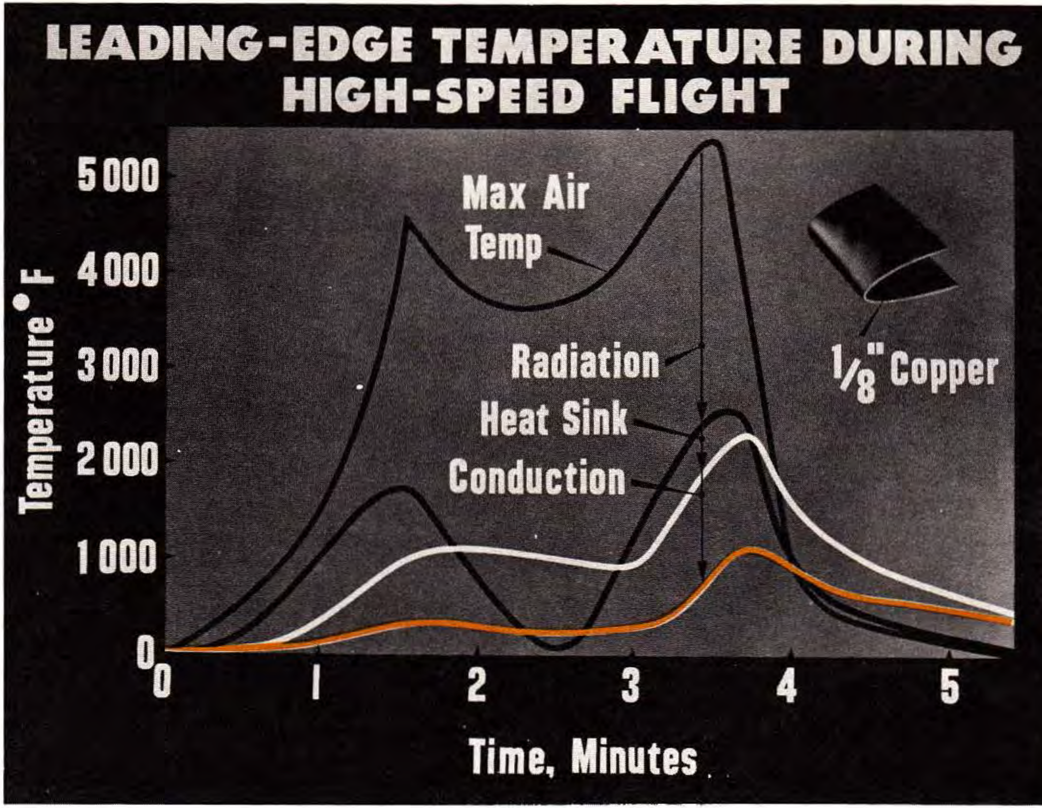
Transpiration cooling, which has worked for countless generations of humans, may have applications to returning space vehicles. A coolant liquid pumped through a porous skin absorbs heat and then flows rearward over the vehicle, insulating the surface from the hot layer of adjacent air.

A third method useful for re-entry is called ablation cooling. The surface of the entering vehicle is coated with a substance which progressively vaporizes during heating. The vaporizing process absorbs heat and the gases produced insulate the skin over which they flow. The ablating material used will eventually be consumed, but a half-inch coating of some materials could protect a rocket-glider through a 20-minute hypersonic fllight.

Radiation provides valuable cooling during an entry flight. A moderate increase in surface temperatures relative to the surroundings can yield a large increase in the quantity of heat radiated away from a vehicle. If surface materials can withstand high enough temperatures, radiation will supply all the cooling needed. Unfortunately, the hot skin radiates inward as well as away from the vehicle, implying additional internal protection for crew and equipment.

Heat sinks are useful for accepting and storing re-entry heat but they become heavy if they must protect a vehicle for long periods. They are simply thick walls of metal. They were used with success on the German V-2 ballistic missile during World War II. Beryllium, a rare metal, has excellent heat-absorbing qualities: it is five times better than copper for this purpose. It may find re-entry applications if certain fabricating difficulties are overcome.

Finally, conduction can be useful for cooling when used in combination with a heat sink. A good



LEADING-EDGE TEMPERATURE DURING HIGH-SPEED FLIGHT
Temperature ° F
5 000
4 000
3 000
2 000
1 000
0
Max Air Temp
Radiation
Heat Sink
Conduction
1/8" Copper
0
1
2
3
4
5
Time, Minutes

conductor will carry heat from the hottest surface regions of a re-entering vehicle and transmit it to cooler areas where it can be stored, but the weight penalties of this method are severe.

Possibly every method described will find employment in the variety of space vehicles envisioned.

Long Range at Supersonic Speeds

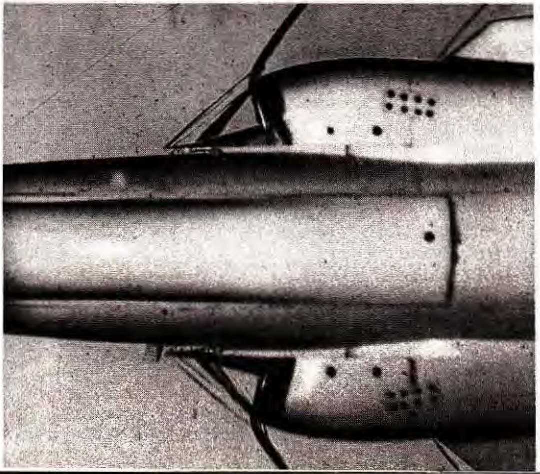
As our program of research into space is intensified, it is more than ever necessary that we maintain a judicious balance between the effort we put into space technology and the continuing improvement of flight inside the atmosphere. Through the cooperation of the nation's aircraft industry, the military services and the NACA, supersonic flight has been made routine in fighter and research airplanes. Now it appears possible to extend these speed gains to transport and bombing airplanes.

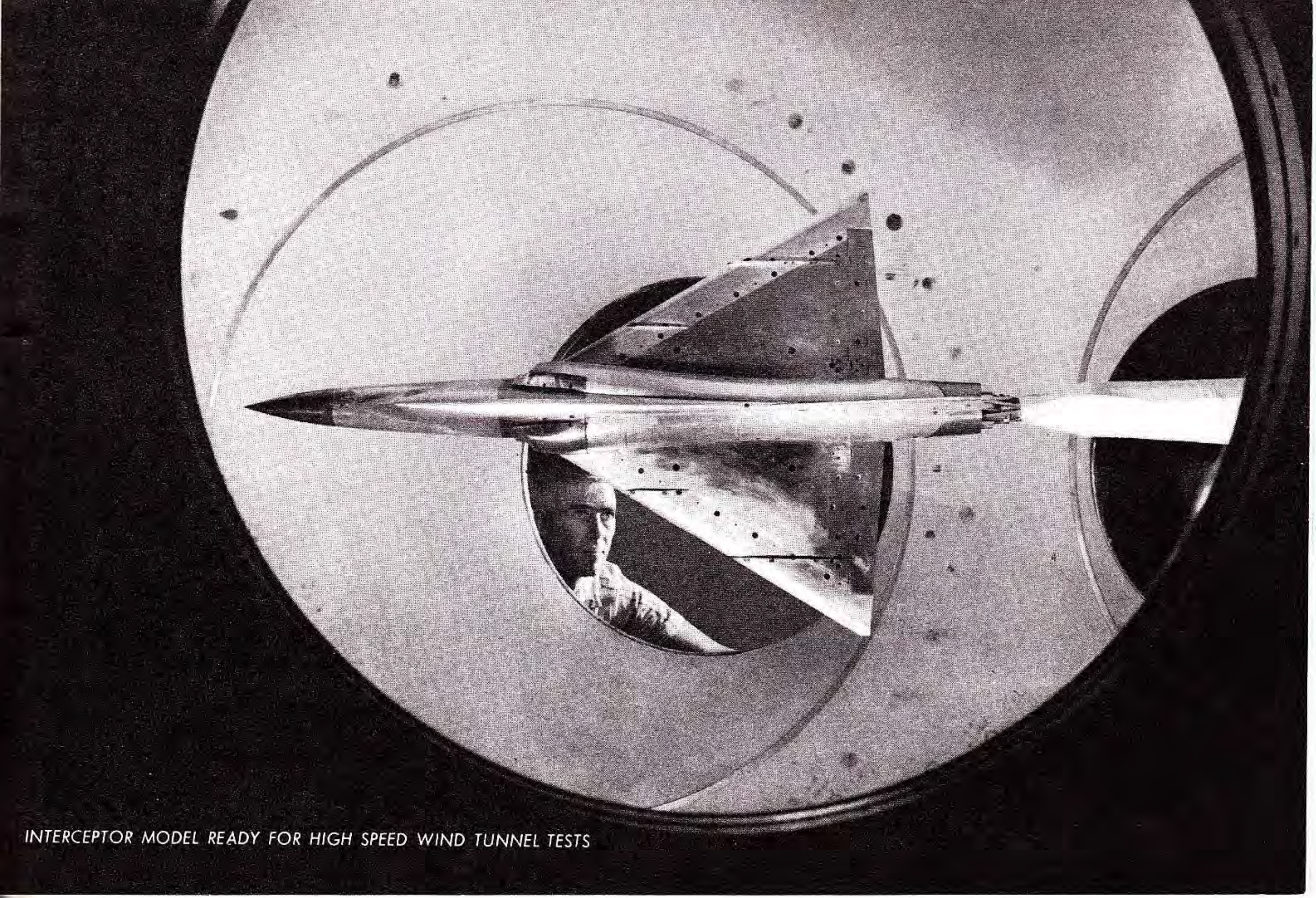
With new knowledge of aerodynamics, powerplants and structures, aeronautical science can be extended to provide a heavy, efficient airplane capable of flying large useful loads at 2,000 mph over intercontinental distances.

The aircraft designer expresses range in terms of efficiency. Aerodynamic efficiency obtains when the airframe is shaped to generate sufficient lift with least possible drag. Propulsive efficiency requires an air-breathing engine together with intake and exhaust systems yielding the greatest possible thrust for the lowest consumption of fuel. Structural efficiency seeks the lightest weight at greatest strength, for highest possible proportion of gross airplane weight made up of payload rather than structure.

For the past 43 years a large share of NACA's research effort has been directed toward these ends. At the Ames Laboratory, aerodynamic studies have provided the designer with new ways to increase lift and to reduce drag. Research on inlet systems best suited for supersonic airplanes has found more efficient means to utilize the tons of air ingested

SCHLIEREN PHOTOGRAPH OF INLET SHOCK WAVE PATTERNS





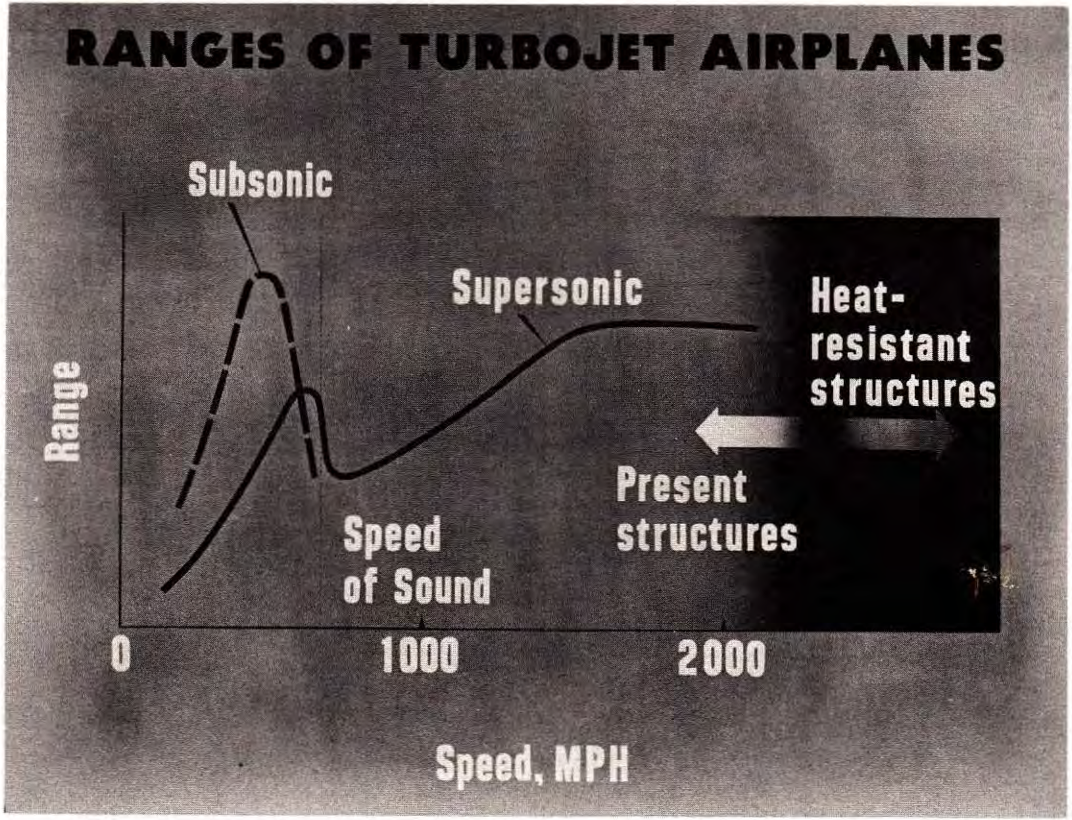
INTERCEPTOR MODEL READY FOR HIGH SPEED WIND TUNNEL TESTS and expanded by the turbojet engine. At the Lewis Flight Propulsion Laboratory the engine and all of its components have been improved to deliver higher efficiencies. Finally, the structural studies pursued at the Langley Laboratory have played an important part in the marked decrease in airframe weights achieved in the past 20 years.

High-speed wind tunnels have been used advantageously to exploit the potential drag reductions suggested by supersonic wing theory. The benefits of sweepback have been systematically analyzed and new studies have revealed methods to accomplish an elliptical distribution of lift over the wing surface which, in theory, is required for the least drag that is due to lift. The advantages of cambering and twisting wings have been well established, and several supersonic airplanes now in operational use incorporate these principles.

New studies are investigating the matter of interference pressure fields which shows promise in supersonic design application. As an airplane moves through the atmosphere it creates pressure changes. By properly shaping the airplane, these pressure changes resulting from interference between the various parts can be made to react on other parts so as to increase lift.

Inlet problems, too, are of great importance in any supersonic aircraft. The turbojet engine requires that air entering the combustion chamber be flowing at subsonic speed. The inlet must be able to accept large volumes of air at supersonic speed and reduce the flow to a subsonic value with the least loss in pressure. If the air is slowed too abruptly, pressure losses are high, and engine efficiency suffers. Through proper design, ways have been found to set up oblique shock wave systems at the inlet, with the result that the air is decelerated at little loss of pressure.

Information on all the elements of supersonic flight applicable to the heavy transport or bomber airplane is continuing to be developed by the NACA. Some of this knowledge is being applied to the Air Force's new chemical bomber, the North American B-70.


RANGES OF TURBOJET AIRPLANES
Subsonic
Supersonic
Heat-
resistant
structures
Present
structures
Speed
of Sound
Range
0
1000
2000
Speed, MPH

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