Medical and Biological Problems of

SPACE FLIGHT

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Preface

It is of interest to mention here the history of the Bahamas Conferences. The late Dr. Bruno L. Frank visited the Bahamas in 1949 and the peace and relaxed atmosphere of Nassau appeared to him to be the ideal environment for scientific contemplation. He decided, therefore, to organize a series of medical meetings which would bring together basic scientists and clinicians specialized in various fields. It was believed that minds would work better, and fresh approaches to research problems would seem easier against the background of the peace and beauty of the Bahamas, removed from pressure and from the tension of the daily routine—with ample time to present work and studies and with unlimited time for discussion. Informal and closer contact with colleagues than possible elsewhere would lead to cross fertilization of ideas. In past conferences this atmosphere of serendipity has led to speculation and a reassessment of accepted views. It has been the prime object of the Bahamas Conferences to attempt something new or to stimulate thought and discussion. The advantage of Nassau for these conferences is its unique atmosphere, perfect climate, and convenient geographical position.

Of all the subjects now being studied, those dealing with life support in spacecraft are probably subjected to the greatest pressure. It was considered that Nassau would be an excellent place to hold a conference, and a limited number of individuals who were key figures in the research being carried out in this field were invited to discuse their work ad libitum. We regret that some investigators were so pressed for time that they were unable to participate in the proceedings to such an extent as would have been beneficial to them and their associates as well.

It was impossible to cover, in one conference, all the many subjects involved in the medical and biological problems of space flight, but some outstanding problems were discussed. The preliminary articles in this volume deal with the vehicles and advanced manned space systems which will be involved in launching man into space, and, coming as they do from the George C. Marshall Space Flight Center and the Douglas Aircraft Company, they are of an authoritative nature. Subsequent chapters deal with space vehicle simulators, problems of weightlessness (especially cardiovascular adaptability), machines and attempts to simulate the weightless state on earth. Nutrition, the use of *Chlorella* as food, and water recovery in a space vehicle are also considered; problems of radiation in space is the subject of another chapter. While it has not been possible to deal here with extraterrestrial life, this volume does include a fascinating account of the "Chemical Origins of Protein" which is after all the prime constituent of life.

November, 1962 G. H. BOURNE

Contents

CHAPTER 1

The Development of Manned Space Vehicles

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Less than 60 years have passed since man first hesitatingly took to the air in a primitive flying machine. Since that epochal moment in history we have witnessed the amazingly rapid growth of military, commercial, and private aviation with the result that the airplane has become an accepted, and widely used, mode of transportation. Today, we can travel at high speed virtually anywhere on our planet with a feeling of comfort and security that early aviators would have thought unattainable.

Now we are reaching out into space in a fashion somewhat analogous to the way in which, decades ago, man commenced probing the then mysterious atmosphere. The next 60 years may produce wonders in flight as far above our prognostications of today as the scheduled trans-Atlantic jet airliner would have been to the imaginations of the Wright brothers.

As the science and technology of space flight unfolds before us we observe the emergence of three vehicular categories, themselves conveniently divided into corresponding unmanned and manned types.

Unmanned	Manned
1. High altitude sounding rockets	1. Air/space vehicles
2. Satellites	2. Satellites and space stations
3. Probes	3. Spaceships

* Saturn Apollo Office.
† Space Systems Information Branch.

Vehicles in category 1 are designed to probe the outer atmosphere and borders of space. Category 2 vehicles carry instruments and men into orbit around the Earth; instrumented unmanned satellites can remain for very extended periods in space, but flight times of manned satellites are limited by the capability of life systems to sustain their human occupants. Large satellites with multiman crews are usually referred to as space stations. In category 3 are those vehicles created to fly deeper into space than artificial satellites; they are launched along departure trajectories characterized by the velocity imparted to them by the launching or carrier rocket, e.g., less than escape, or greater than escape velocity.* We can think of the probe as being to the spacehip what the unmanned satellite is to the manned satellite.

Today, programs designed to assure man's ability to undertake extended flights into space are following three main lines of development that correspond to the three vehicular categories mentioned above. First, there are experiments involving winged craft capable of leaving and reentering Earth's atmosphere. They use both aerodynamic and reaction controls, and glide to landings in much the same manner as conventional airplanes. Second, there are a number of relatively simple artificial satellites that can carry man for flights lasting for hours or at most a few days. Third, extrapolations of artificial satellite technology are permitting rapid progress to be made toward the realization of manned flight to, around, and onto the Moon, and eventually to the planets beyond. This line of development is exemplified by the spaceship.

America's X15 rocket air/space plane and the Dynasoar orbital glider, together with a rumored Dynasoar counterpart under development in the Soviet Union, are characteristic of category 1 vehicles. The second approach is being followed by the Mercury, Gemini, and Apollo† satellites, all in various stages of use or development in the U. S., and by theVostok program in the U. S. S. R. The only known vehicle in the third category is America's Apollo lunar spaceship. No manned interplanetary vehicle has advanced beyond the design stage.

Air/Space Vehicles

The X15 rocket-powered air/space plane and the Dynasoar orbital craft are both winged vehicles that utilize the atmosphere to a very considerable extent in the performance of their missions. Hence, they are

* The velocity selected for a given vehicle depends on the nature of the mission.

† Early Apollos will be placed into orbit around the Earth and hence are artificial satellites; advanced Apollos will be launched along lunar trajectories and consequently are considered to be spaceships.

examples of air/space vehicles, which are defined as craft that can operate both in the atmosphere and in space.* The X15 does not take off from the ground but is launched from a modified four-engine bomber at high altitude. Under rocket power it subsequently flies out of the dense atmosphere into near-space conditions, later reentering along a controlled glide path. The Dynasoar, on the other hand, is boosted into orbit by a large space carrier vehicle, reentering the atmosphere upon completion of its orbital flight.

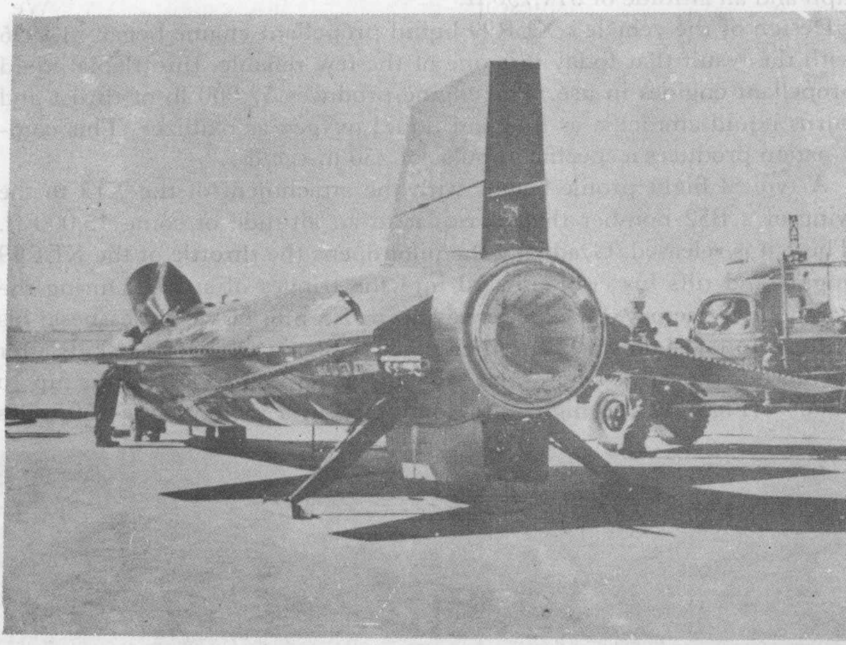

FIG. 1. Rear side view of X15 airplane showing single chamber XLR99 rocket engine. Courtesy of U.S. Air Force.

X15

The X15, shown in Fig. 1, is a research craft intermediate between the airplane and the spaceship. It is America's oldest combination air and space project, having been initiated in 1952. The 50-ft long plane is the latest of a series of high-performance rocket-powered airplanes that began in 1947 with the X1, the first manned plane to fly faster than the speed of sound. The X15 project is sponsored jointly by the U. S. Air Force,

* Or, in the case of the X15, at the borders of space. While it is not capable of orbital flight, it can "poke its nose" into the space frontier as it arcs over a parabolic trajectory. The Dynasoar, however, is as much at home in space as it is in the atmosphere.

the National Aeronautics and Space Administration, and the U. S. Navy,* and is undertaken by North American Aviation, Inc.

The X15 has little resemblance to the conventional jet aircraft. Highly streamlined, it is specifically designed for speeds greater than 4000 mph and altitudes between 50 and 100 miles where reaction controls must be utilized to establish and maintain attitude. The attitude control system is based on reaction jets that use steam produced by the catalytic breakdown of hydrogen peroxide. By mid-1962 the ship had reached a speed of 4159 mph and an altitude of 314,750 ft.

Design of the vehicle's XLR99 liquid propellant engine began in 1956 with the result that today it is one of the few reliable, throttlable liquid propellant engines in use. The engine produces 57,000 lb of thrust and burns liquid ammonia as fuel and liquid oxygen as oxidizer. This combination produces a specific impulse of 250 lb-sec/lb.

A typical flight profile begins with the attachment of the X15 to the wing of a B52 bomber that carries it to an altitude of some 45,000 ft. There it is released. Gradually the pilot opens the throttle of the XLR99 engine and tilts his craft upward into the fringes of space. During the parabolic trajectory, he experiences up to 2.5 min of weightlessness; his entire trip takes only 10 min. The plane lands on wire-brush skids after reentering the atmosphere and sustaining aerodynamic heating up to 1200°F (Fig. 2). X15 flights are conducted in a region some 450 miles

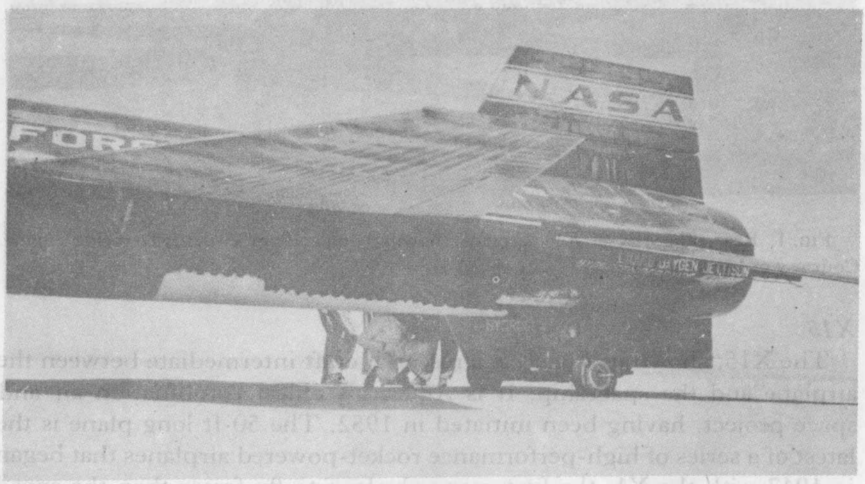

FIG. 2. Thermocolor paint is seen under wing of X15. This paint indicates temperatures encountered during September 28, 1961 flight. Maximum reading was 1050°F. Courtesy of NASA.

* It was originally begun by the National Advisory Committee on Aeronautics, the organization from which the National Aeronautics and Space Administration was formed.

long and 50 miles wide between Wendover, Utah, and Edwards Air Force Base, California. Since this area contains a number of dry lake beds, there are ample landing strips in case emergencies unexpectedly terminate the flights.

From a biological point of view, it makes little difference that the pilot flies in the outer atmosphere and lower fringes of space, and not in 100 per cent space itself. He must be protected as if he were in a spaceship on an interplanetary mission. Once above an altitude of approximately 80,000 ft, the human body must be completely sealed in a cabin that affords it a reasonable facsimile of the atmosphere of Earth. For this reason, the X15 pilot wears a special pressure suit to protect him from the explosive effects of sudden decompression should the sealed cabin of the craft develop a leak. The cabin itself is pressurized by nitrogen, but the pilot's suit is pressurized by oxygen. He sits in a special ejection seat that has aerodynamic controls to stabilize it in case an emergency arises and he has to bail out. The seat also contains a parachute that deploys automatically at a preset altitude.

Dynasoar

Dynasoar, the U. S. Air Force's manned orbital glider vehicle, is a unique project within the U. S. space program. Its name derives from the words *dynamic soaring*, which best describes its mode of operation.

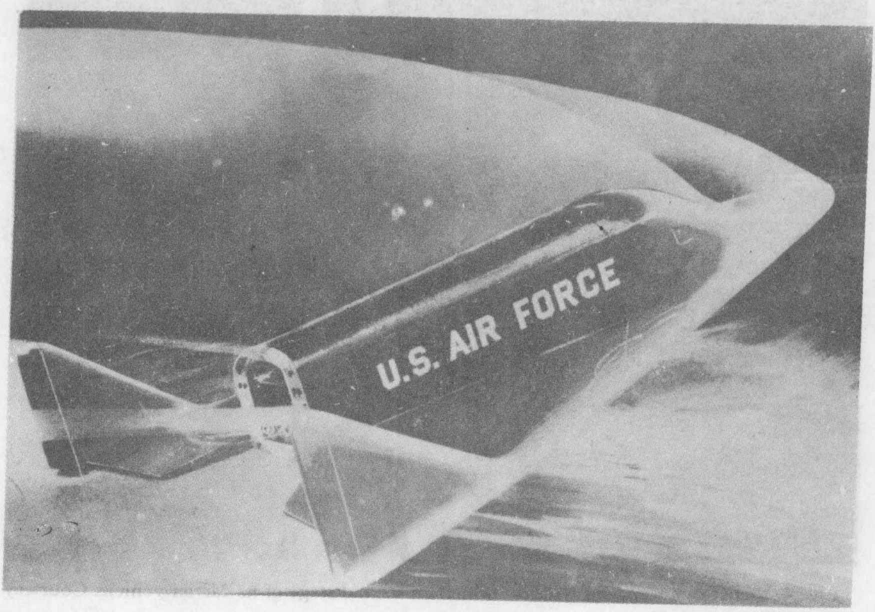

FIG. 3. Artist's concept of Dynasoar glider. Courtesy of Boeing Company.

Basically Dynasoar is designed as a manned, delta-winged glider (Fig. 3) capable of orbiting Earth at velocities of more than 18,000 mph, re-entering the atmosphere under pilot control, and landing on conventional airfields or landing areas at velocities no greater than those of modern jet fighters.

The Boeing-developed Dynasoar glider has a special adaptive control system (proven out on the X15) that permits the aerodynamic control surfaces to be utilized to the fullest extent, since they require less energy than the reaction control system that maintains vehicle attitude in space. Essentially, this system is an automatic gain changer tied into a self-evaluating control loop. The output of this arrangement is inversely proportional to the effectiveness of the aerodynamic controls. Thus, the

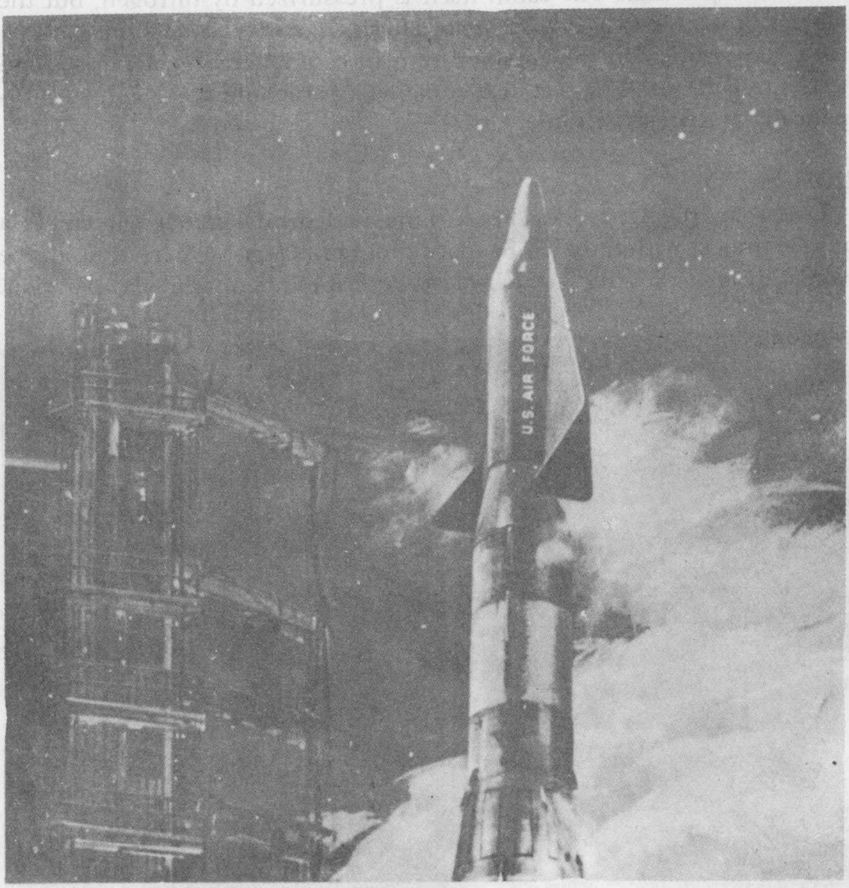

FIG. 4. Artist's concept of Dynasoar seated on second stage of its carrier vehicle. Courtesy of Martin Company.

reaction control system functions only when the output of the adaptive control system exceeds a certain level.

Another important aspect of the Dynasoar glider is an "energy management" concept, also tested and perfected during X15 flights. At all points along Dynasoar's trajectory it is necessary that the amounts of kinetic and potential energy remaining be correlated. If the pilot is to have maximum descent and landing maneuverability, these energies must be used or dissipated in a very precise manner and ratio. This problem is solved on board by a computer.

The carrier vehicle for the Dynasoar is the Titan 3, developed by the Martin-Marietta Co. Following the decision in early 1962 to streamline the Dynasoar program by eliminating suborbital flights, a plan was devised to boost the glider into orbit by a more powerful version of the Titan family of ICBMs. Capitalizing on recent advances in the development of large solid propellant rocket motors, the Titan 3 carrier was selected. This carrier consists of a 430,000-lb thrust Titan 2 liquid-propelled stage to which are attached two solid propellant rocket motors each 120 inches in diameter. Figure 4 is an artist's impression of Dynasoar, atop the upper stage of its carrier.

To test such features as flight dynamics, structural integrity, and aerodynamic characteristics, the Air Force plans to use a 7-ft scale model of the Dynasoar glider that will be flown at velocities above Mach 20 by a Blue Scout carrier vehicle. The program, scheduled for early 1963, is a part of the Air Force's Project Asset.

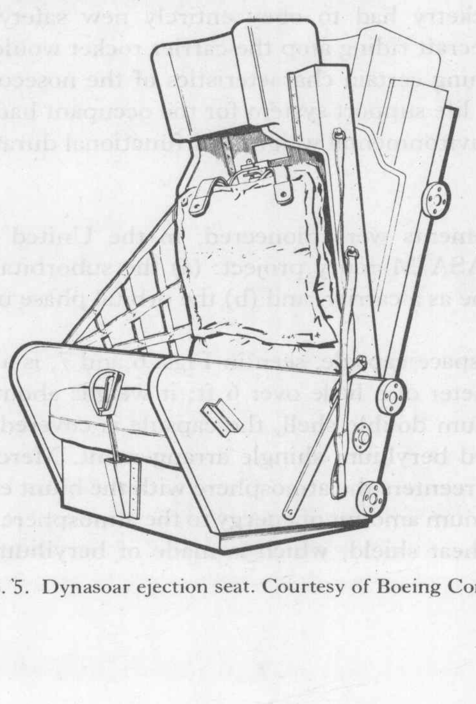

FIG. 5. Dynasoar ejection seat. Courtesy of Boeing Company.

Full-size unpowered gliders will be proof-tested by dropping them from B52 bombers at high altitudes, a technique that was utilized and perfected in the X15 program. This will give pilots the opportunity to check stability and control characteristics of Dynasoar at low velocities and to practice landing. Later, rocket-powered gliders will be drop-tested and will fly in the supersonic speed regime. Finally, the craft will be launched from the Atlantic Missile Range into orbit to test all phases of flight operation, from in-space controllability to reentry dynamics. Like the X15, Dynasoars will be fitted with ejection seats, illustrated in Fig. 5, to insure pilot escape in the event of vehicle malfunction. Landings will be at Edwards Air Force Base, California.

Manned Satellites and Space Stations

Two manned satellite programs have proven to be successful, the U. S. Mercury and the Russian Vostok. Both involve one-man capsules that are boosted into orbit by large space carrier vehicles and, after making a number of orbits, are recovered. The U. S. Gemini capsule, now under development, will be able to carry two men. Following Gemini, three-man Apollo capsules will be placed in orbit to test the reaction of crews to from 1 to 2 weeks in space. The satellite portion of the Apollo program will precede attempts to make a lunar landing.

When manned flight into space first became a serious project it was clear that success would depend on three new technological developments. First, rocketry had to obey entirely new safety requirements. Second, the spacecraft riding atop the carrier rocket would be a new type of vehicle combining certain characteristics of the nosecone and the airplane. Third, the life support system for the occupant had to work under unprecedented environmental weight and functional duration conditions.

Mercury

These developments were pioneered, in the United States, by two phases of the NASA Mercury project: (a) the suborbital phase using a modified Redstone as a carrier, and (b) the orbital phase using a modified Atlas carrier.

The Mercury space capsule, seen in Figs. 6 and 7, is a truncated cone with a base diameter of a little over 6 ft; it weighs about 4000 lb. Consisting of a titanium double shell, the capsule is covered by a heat-protecting corrugated beryllium shingle arrangement. Mercury is a typical drag vehicle that reenters the atmosphere with the blunt end first in order to impart a maximum amount of energy to the atmosphere. This blunt end is covered by a heat shield, which is made of beryllium for suborbital flights.

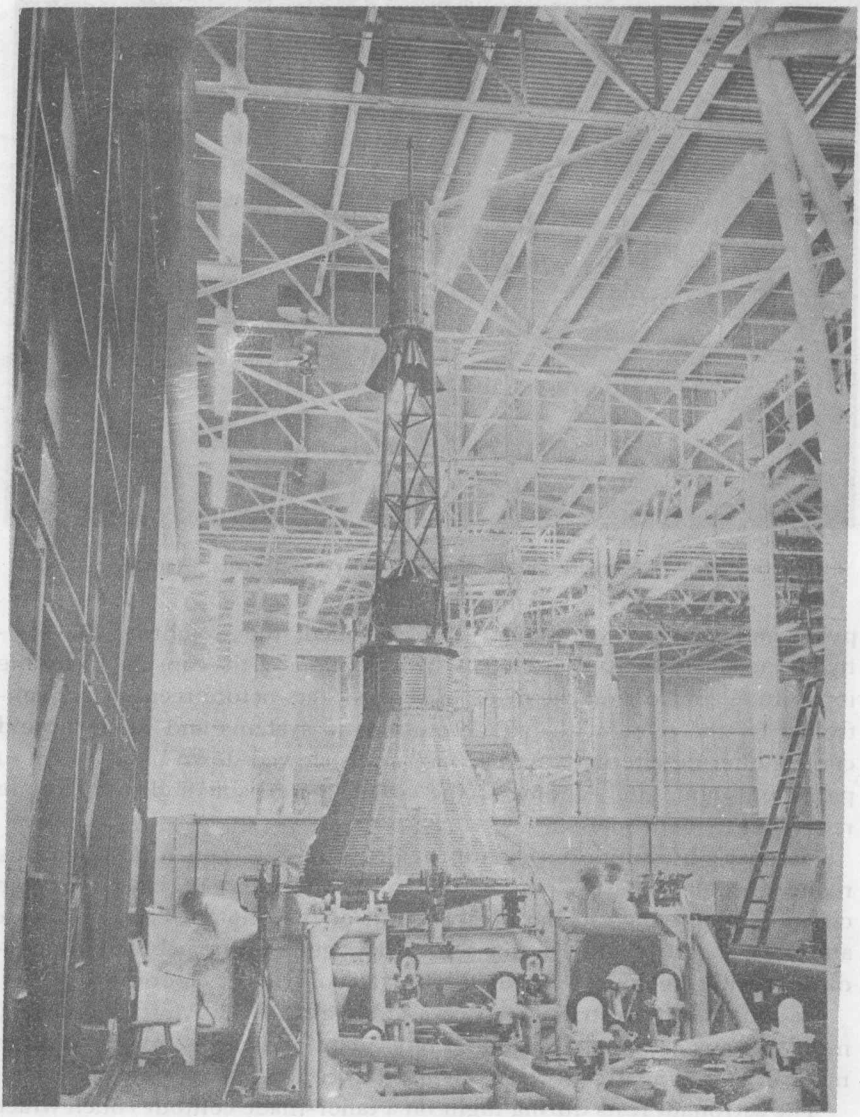

FIG. 6. Operational Mercury capsule at McDonnell Aircraft Corporation.

A pylon on top of the space capsule carries a 56,000-lb thrust escape rocket (weighing 1,100 lb) designed to quickly propel the capsule from the carrier rocket in case of an impending explosion or emergency. The flight is guarded by an automatic failure detection system. Once the escape

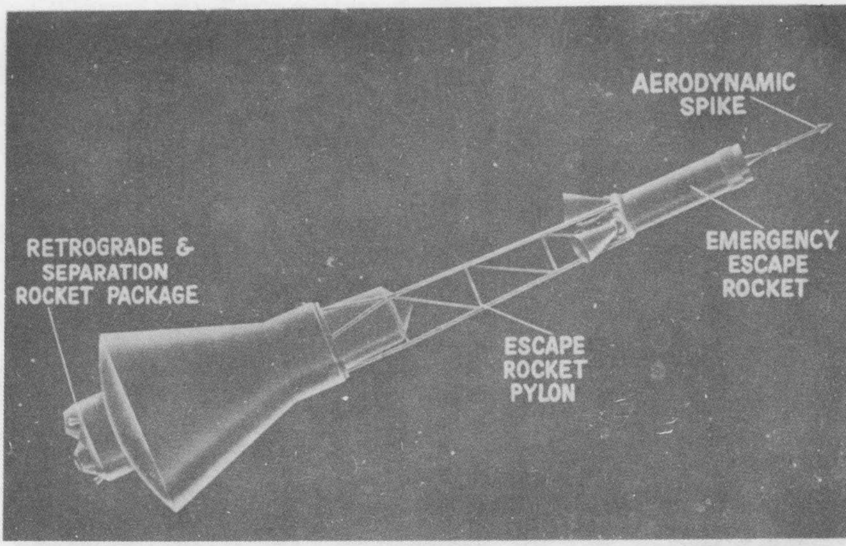

FIG. 7. Side view of Mercury capsule showing major components. Courtesy of NASA.

pylon and auxiliary equipment are jettisoned, the weight of the free-flying capsule is reduced to 2900 lb. Most systems of the capsule, including its attitude control and the firing of retrorockets before reentry, are controlled by the pilot, with parallel automatic systems and radio ground control offering alternatives. The capsule is slowed down by a system of parachutes and, after landing in the ocean, the capsule and the pilot are recovered by helicopters.

Mercury's life support system provides a pure oxygen atmosphere at a reduced cabin pressure. In addition, an independent closed oxygen circuit is maintained in the pressure suit of the pilot. A carbon dioxide and odor absorber and a water separator regulate proper breathing conditions, while cooling is provided by means of water evaporation.

In spite of the restrictive space and weight of the Mercury capsule, most systems are single or double redundant and can be operated automatically or manually as well as by ground command.

The astronaut rests during flight on a tailor-made contour couch which alleviates the acceleration loads in the initial and final flight phase. Both during liftoff and reentry he lies with his back toward the ground. Capsule attitude is controlled by hydrogen peroxide reaction jets. Horizon scanners and gyroscope equipment serve as attitude sensing devices.

For orientation and observation purposes, the astronaut has a periscope and a large window in addition to numerous navigational devices. While most of the measurements are telemetered to the ground, the astronaut is