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HUGH L. DRYDEN(*)

National Aeronautics and Space Administration

FUTURE EXPLORATION AND UTILIZATION OF OUTER SPACE

RIASSUNTO - La previsione del futuro dell'astronautica è compito da profeta, una professione non riconosciuta come un ramo ben definito della scienza. I metodi per tali profezie variano da un atto di intuizione e di fede alla più razionale estrapolazione dell'esperienza passata e delle attuali tendenze agli anni futuri. Il secondo procedimento può forse dare risultati ragionevolmente accurati per i prossimi 5 o 10 anni, ma i risultati di ambedue i metodi, a distanza di 20 o 30 anni nel futuro, sono puramente ipotetici. La previsione di una tendenza del progresso tecnico è più attendibile che la previsione dei periodi di tempo necessari alla realizzazione. In effetti la velocità con cui si ottengono certi progressi è legato all'entità dei fondi stanziati, che a loro volta dipendono dall'apprezzamento pubblico e privato del valore dell'esplorazione spaziale.

Questa nota riassume l'attuale posizione tecnica ed elenca le ragioni per l'attuale rapido procedere delle esplorazioni spaziali, come possiamo vederle oggi. I risultati disponibili e le tendenze attuali sono estrapolati per la prossima decina d'anni, con una piccola esemplificazione delle più audaci previsioni per un futuro più lontano. Vengono inoltre presentati alcuni tra i problemi che si prospettano tecnicamente più difficili.

Il futuro dell'astronautica, in ultima analisi, è affidato al talento di una moltitudine di geniali e fantasiosi scienziati, ingegneri e tecnici di tutto il Mondo che debbono dedicare — in comune — il loro talento all'ampliamento delle basi del sapere scientifico ed ingegneristico, senza del quale ogni progresso in astronautica verrebbe rapidamente a cessare.

ABSTRACT - The assessment of the future of astronautics is the task of a prophet, a profession not recognized as an established branch of science. The methods of prophecy vary from an exercise of intuition and faith to the more rational extrapolation of past experience and present trends to the years ahead. The second procedure may give reasonably satisfactory results for five or ten years ahead but the results by either procedure for twenty or fifty years in the future are highly speculative. Prediction of the direction of technical progress is more reliable than prediction of time scale. The actual rate of future progress depends on the magnitude of the resources committed, which in turn are determined by the public and private assessment of the values of space exploration.

This paper summarizes the present technical position as we see it today. The present results and trends are extrapolated to the next decade, with a small sampling of the more

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imaginative speculations for the more distant future. A few of the more outstanding difficult technical problems are described.

The future of astronautics in the last analysis rests with the talents of a host of ingenious and imaginative scientists, engineers, and technicians throughout the world who must join together in devoting their talents to broaden the foundations of scientific and engineering knowledge without which progress in astronautics would soon cease.

Résumé - Il n'appartient qu'au prophète de donner une vue de l'avenir de l'astronautique, mais la prophétie n'a pas été rangée jusqu'à présent parmi les disciplines scientifiques reconnues. Les méthodes d'anticipation procèdent aussi bien par l'intuition et la foi que par une extrapolation plus rationnelle de l'expérience acquise et des voies ouvertes vers les années à venir. Cette seconde méthode peut conduire à des conclusions plus ou moins valables pour les cinq ou dix années prochaines, mais dans un cas comme dans l'autre, les pronostics qui concernent un avenir éloigné de quelque vingt ou cinquante années sont très largement du domaine de la speculation pure. Les pronostics sur l'orientation future du progrès technique présentent un plus haut degré de certitude que ceux qui visent un échelonnement dans le temps. La rapidité avec laquelle ces progrès seront accomplis dépendra de l'importance des ressources qui seront mises en oeuvre, celles-ci étant déterminées par l'opinion des secteurs publics et privés sur l'intérêt présenté par l'exploration de l'espace.

Cet exposé fait le point de la question du point de vue technique et indique les raisons, telles qu'elles apparaissent aujourd'hui, de la rapide avance de l'exploration de l'espace. L'auteur fait une extrapolation, pour la prochaine décennie, des résultats acquis à ce jour et des orientations suivies et présente quelques-unes des vues les plus audacieuses pour un avenir plus éloigné. Il rend compte de certaines difficultés techniques particulièrement importantes.

L'avenir de l'astronautique dépend, en dernière analyse, du succès d'innombrables savants, ingénieurs et techniciens du monde entier qui ont le devoir de mettre en commun toutes les ressources de leur savoir et de leur imagination afin d'enrichir les bases de la connaissance scientifique et technique, faute de quoi tout progrès de l'astronautique deviendrait rapidement impossible.

Introduction.

The assessment of the future of astronautics is the task of a prophet, a profession not recognized as an established branch of science. Prophecy is an art rather than a profession and there are no established methods of procedure. Knowledge of specific developments in progress and past experience give a reasonable basis for extrapolating a few years ahead. For the more distant future, imagination, intuition, and faith are the only tools, and these are inevitably colored by the nature and environment of the prophet. He may be naturally an optimist or a pessimist. The seeker for financial support and the salesman will see the future very differently than the engineer responsible for the success of launching vehicles on difficult missions. Some of the problems of predicting future developments may be appreciated by looking backward in time by 52 years.

1. Aeronautical Prophecies.

WILBUR WRIGHT, at a dinner tendered in honor of the two WRIGHT brothers by the Aero Club of France on November 5, 1908, is reported to have said: « I confess that in 1901 I said to my brother Orville that man would not fly for fifty years. Two years later we ourselves made flights. This demonstration of my impotence as a prophet gave me such a shock that ever since I have distrusted myself and avoided all predictions ».

Scientists did not have good records as prophets of the future of aeronautics. WILLIS L. MOORE, Chief of the U.S. Weather Bureau, stated in an address opening the International Aeronautical Congress of 1907: « Commercially very little is to be expected from either balloons or flying machines. For passenger traffic the number carried will be so small and the cost so great that no competition is possible with existing modes of transit ».

SIMON NEWCOMB in 1908 reported: « The writer cannot see how anyone who carefully weighs all that he has said can avoid the conclusion that the era when we shall take the flyer as we now take the train belongs to dreamland ».

The developments of the first fifty years gave the lie to the pessimists and far exceeded the expectations of the optimists. I do not mean to imply that optimists are always right in every field. For example, in spite of optimism and hard work, the Diesel engine never became successful as an aeronautical power plant. However, I think we may conclude that today amid the great confusion of voices of would-be prophets with their wide range of predictions, some prophecies are bound to be right and with hindsight their authors will in the future be regarded as men of vision.

2. A Prophecy of the Recent Past.

The technology to appear a few years ahead is always latent in the research and development already under way. Thus it was easy for me to write on December 17, 1953, the fiftieth anniversary of the first flight of an airplane, that: « Taking into consideration the speed at which guided missiles travel, that at which models have been propelled, the experimental data available from hypersonic experiments in wind tunnels and ranges, and the theoretical calculations which have been made, we may reasonably suppose that a satellite vehicle is entirely practical now and that travel to the moon is attainable in the next fifty years ».

The first satellite was successfully launched a little less than four years later by the USSR. As of now it appears that travel to the moon will be accomplished in much less than the remaining 43 years. Having thus undermined your confidence in my qualifications, let us consider the present technical position, the developments of the next few years already in the planning and early developmental

stages, and some less solidly founded forecasts of things to come in later years. Prediction of the direction of technical progress is more reliable than prediction of time scale. The rate of future progress depends on the magnitude of the resources committed, which in turn is determined by the public and private assessment of the values of space exploration.

3. Current Technical Position.

Let us then begin with a review of the present technical situation. The heaviest spacecraft launched to date is the 10,000 pound vehicle launched on August 20th/dogs carrying two which were recovered from orbit. The largest distance over which communication has been established is 22 1/2 million miles by Pioneer V. Satellites have been launched which represent major first steps in their application to a new type of global communications system and to greatly improved weather forecasting. Many scientific measurements have been made of the space environment, resulting in new scientific discoveries such as the radiation belts, anomalies in the earth's magnetic field, specific effects associated with solar flares, etc.

From a purely statistical point of view 27 earth satellites have been successfully launched in 49 known attempts. Five lunar and space probes have been successfully launched in nine known attempts, of which one hit the moon, three are in orbit around the sun, and one passed near the moon to return toward the earth. Fifteen of the 27 earth satellites are still in orbit about the earth accompanied by empty final rocket stages and miscellaneous debris such as ejected fairings, etc. Only six are transmitting signals.

It is difficult to assess the scientific and technological results obtained in purely statistical terms. To illustrate the nature of the information already obtained, we may consider as examples Explorer VII, Tiros I, and Echo I.

Explorer VII.

Explorer VII is an earth satellite weighing 91.5 pounds which was launched on October 13, 1959 by a Juno II launch vehicle into an orbit inclined at 50.3° to the equator with a perigee of 345 statute miles, apogee of 678 statute miles and period of 101.3 minutes. This satellite was the last of the satellites planned as part of the IGY program. It carried detectors of Lyman-alpha and X-ray solar radiation, ionization chambers for heavy cosmic rays, Geiger-Mueller tubes, apparatus for measuring the thermal radiation balance of the earth, and micro-meteorite detectors. Data from many of the experiments are still being recei-

ved. Many of the records have not yet been processed and analyzed but many significant results have already been reported by the experimenters.

VAN ALLEN and his collaborators at the State University of Iowa have obtained measurements of time and spatial variations in the outer radiation zone which show interesting correlations with other geophysical observations. For example, a drastic modification of the outer zone occurred on March 31 to April 10,

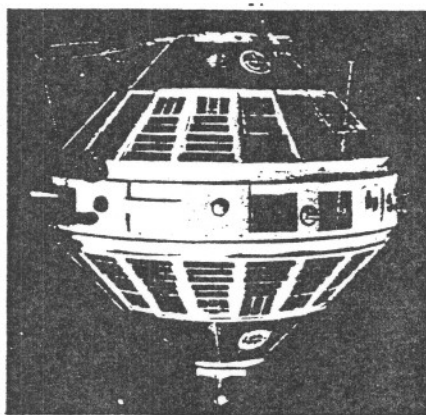


Fig. 1. Explorer VII (October 13, 1959).

1960 beginning with a large magnetic storm on March 31. Intensity levels fell from 200 to less than ten counts/second and rose to over 10,000 counts/second during this event.

Suomi and his colleagues at the University of Wisconsin detected large scale weather patterns in their thermal radiation balance experiments. For example, an area covered with cold air or high clouds shows reductions in heat loss from the average value of the order of ten percent.

Tiros I.

Tiros I is an earth satellite weighing 270 pounds which was launched on April 1, 1960 by a Thor-Able launch vehicle into a near-circular orbit at an inclination of 48.3° to the equator with a perigee of 435 statute miles and apogee of 468 statute miles with a period of 99.2 minutes. Its objective was to measure cloud cover over as much of the globe as possible. The satellite is spin stabilized; hence its axis remains fixed in space. Two television cameras are installed, one wide angle

camera with f 1.5 lens and a narrow angle camera with f 1.8 lens, each providing 500 lines per frame, the axes of the cameras being parallel with the spin axis of the satellite. Hence pictures are obtained only when the satellite is in that part of the orbit where the cameras see the sunlit portion of the earth.

A magnetic tape recorder is provided for each camera with maximum capacity of 32 photographs taken at 30-second intervals. The recorder stores pictures taken out of range of the two ground receiving stations. Timer systems are provided for programming on command. The pictures are transmitted by two 2-watt FM transmitters at 235 mc/s. Two tracking beacons operated on 108 and 108.03 mc/s with 30 milliwatts output. Power is supplied from nickelcadmium batteries charged by 9200 solar cells on the top and sides of the « pill box » 42 inches in diameter and 19 inches high which constitutes the outer shell of the satellite.

More than 22,000 pictures were received during the useful life of the satellite. Each wide angle picture covers an area of roughly 800 miles on a side; each narrow angle picture covers an area of roughly 80 miles on a side within the field of the wide angle camera. Much new information on cloud structures associated with large scale storms has been obtained, particularly the spirally-banded cloud formations whose existence was previously unknown. Frontal systems and storm centers are easily recognizable and their positions plotted accurately. Arrangements are being made to index the photographs and to make copies available through the IGY World Data Centers.

Useful pictures ceased on June 15, 1960 because of equipment failure but the 108 mc/s tracking beacon continues to operate. On the basis of this and future meteorological satellites, it is hoped to develop within a few years an operational system for routine use in weather forecasting. We invite international cooperation in the study of the Tiros data particularly in relation to meteorological data obtained by ground and aircraft observations.

Echo I.

Echo I is a plastic sphere 100 feet in diameter which was launched on August 12, 1960 by a Thor-Delta launching vehicle into a near-circular orbit at an inclination of 47.24° to the equator with a perigee of 945 statute miles and apogee of 1049 statute miles with a period of 118.3 minutes. The sphere was fabricated of Dupont Mylar Polyester film 0.0005 inches (0.013 mm) thick which was then covered with vapor-deposited aluminium on both surfaces to provide radio wave reflectivity of 98 percent up to frequencies of 20,000 mc/s. The sphere is inflated after the satellite is in orbit.

The sphere weighs 136 pounds and contains 30 pounds of sublimating powder (anthroquinone and benzoic acid) to maintain a small internal pressure in spite

of leakage due to puncture by micrometeorites. Two tracking beacons powered by 70 solar cells weigh 1.4 pounds. They operate at a power of 10 milliwatts on 108 mc/s. The container which carries the sphere into orbit weighs 24 pounds.

The primary objective of Echo is to study the transmission of radio signals (including voice modulation and other types of modulation) between distant

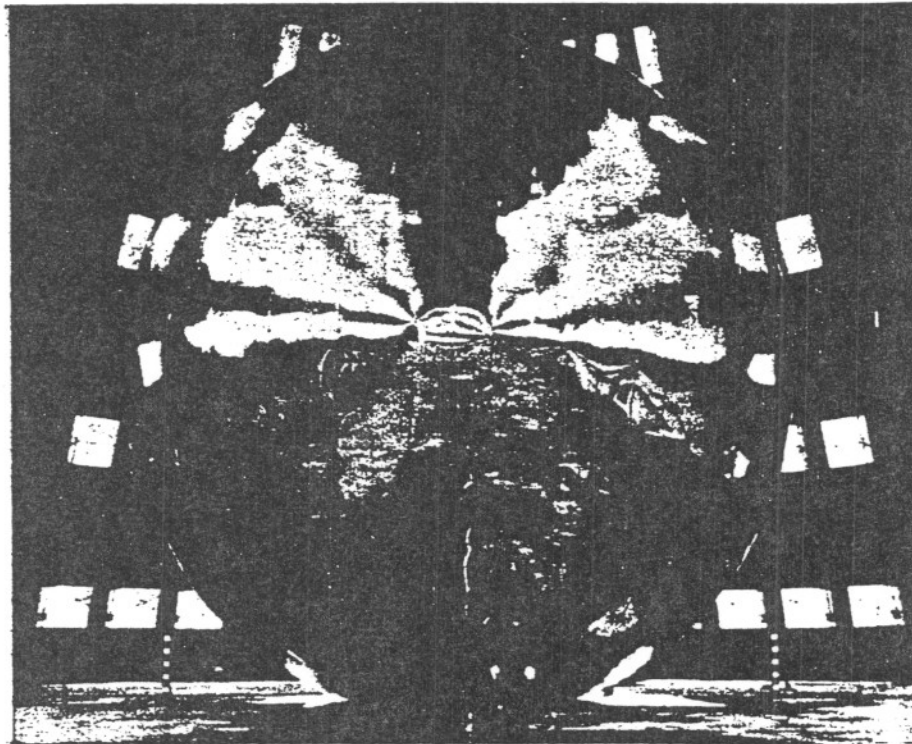


Fig. 6. Echo communications satellite.

points by reflection from the sphere as the first step in the investigation of the feasibility of global communications systems using passive satellites as reflectors. A secondary objective is to study the effects of the residual atoms, molecules, and charged particles and of solar radiation on the motion of satellites at 1000 miles in the hope of learning more about the space environment at that altitude. A third objective is to obtain experience with large light-weight structures in space.

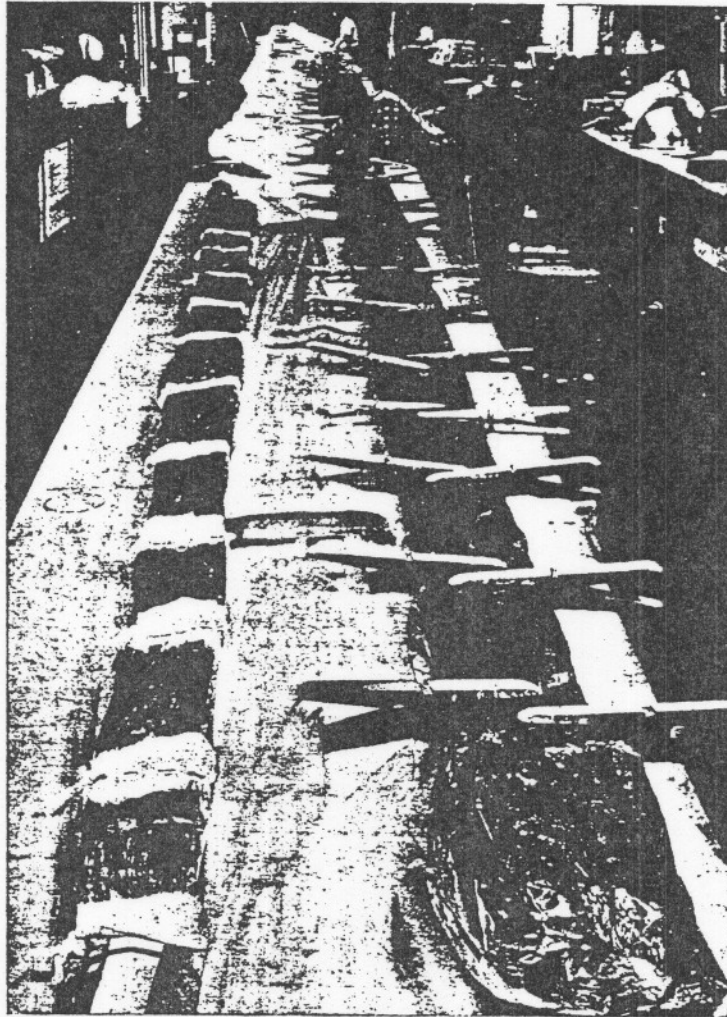


Fig. 7. Method of folding Echo satellite.

There are two primary stations taking part in the Echo communications experiment: Bell Telephone Laboratories' facility at Holmdel, New Jersey, and the NASA-Jet Propulsion Laboratory station at Goldstone, California. BTL transmits at 960 mc/s, JPL at 2390 mc/s. BTL uses a receiver with tracking horn-reflector antenna with maser amplifiers; JPL uses a receiver with 85-foot-diameter

paraboloid antenna with parametric amplifiers. BTL transmits with a 60-foot paraboloid antenna; JPL with an 85-foot paraboloid antenna.

In addition to the two primary stations, independent researchers all over the world have been invited to engage in experiments of their own. Many have

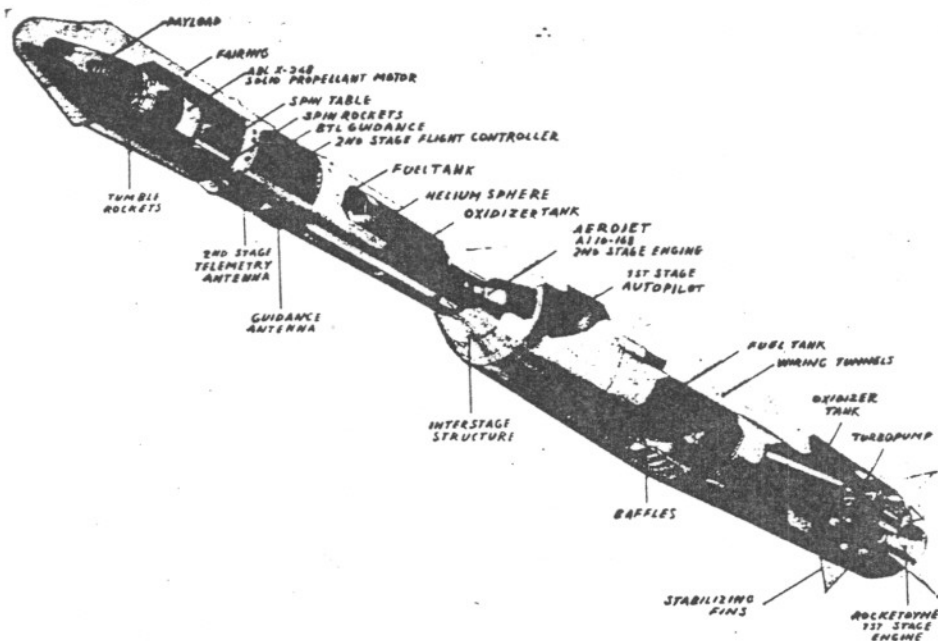


Fig. 8. Thor-Delta launch vehicle for Echo.

engaged in such experiments and the National Aeronautics and Space Administration is assisting them by providing tracking data.

Hundreds of experiments and transmissions have been conducted, using the satellite as a relay. These include teletype, facsimile photographs, voice, music, digitized coded data, and numerous electrical measurements to determine the effects of the ionosphere on signal strength. With the low noise levels of the receivers used, the quality has been exceptional with little variation in signal strength, which corresponds to the theoretically computed values within a few decibels.

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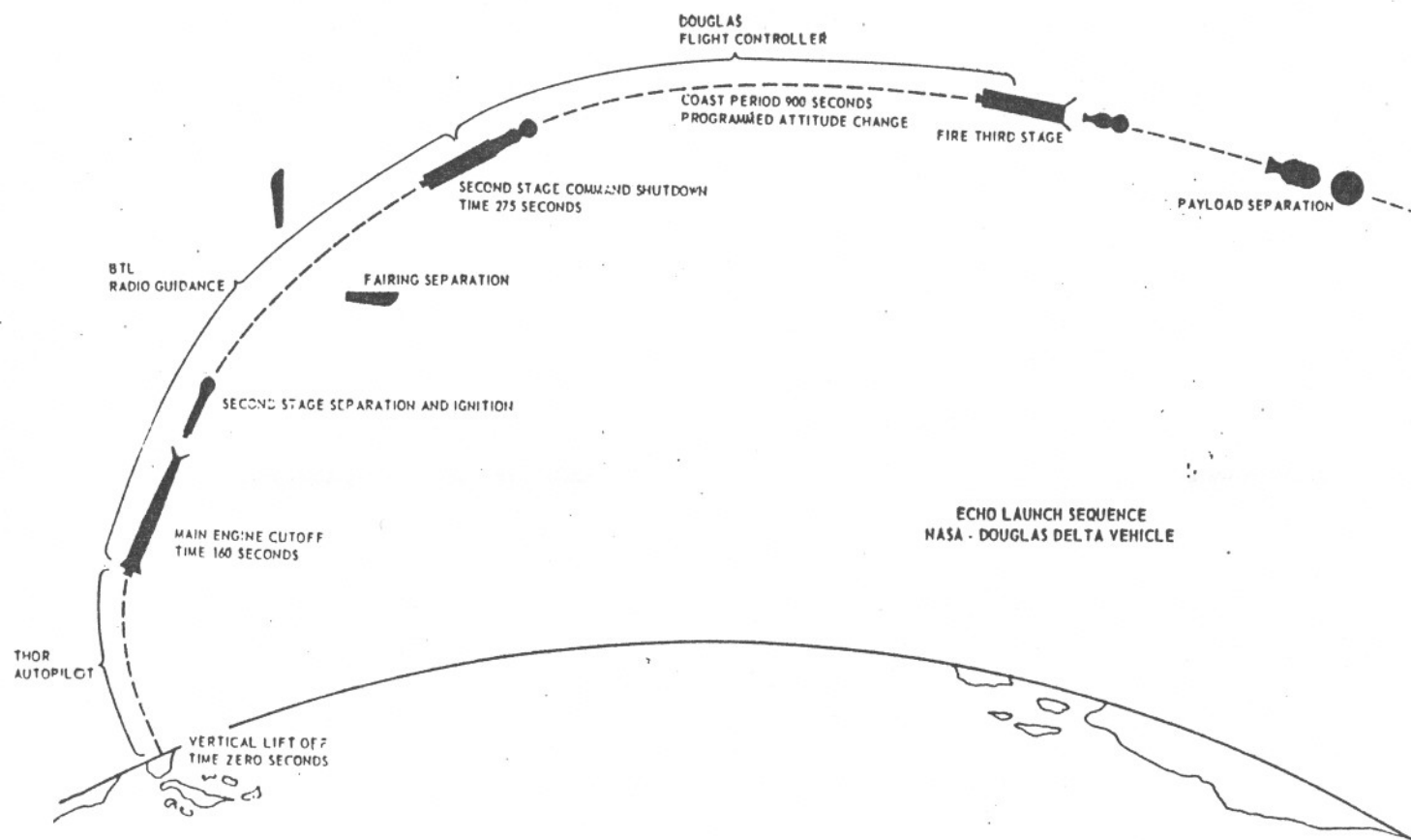


Fig. 9. Echo communications satellite launch sequence.

4. Supporting Research and Technology.

A review of the present technical position would be incomplete without some mention of the foundation of research and advanced technology on which space flight missions are completely dependent. The knowledge available has been built up through the work of countless scientists and engineers of the past and present century and from every nation of the world. Space activities have utilized the basic and exploratory research in such fields as solid state physics, magneto-fluid-dynamics, aero-thermo-chemistry, mathematics of random processes and many others. The technology of rockets, inertial and radio guidance systems, hypersonic aerodynamics, aerodynamic heating, solid and liquid fuels, high tem-

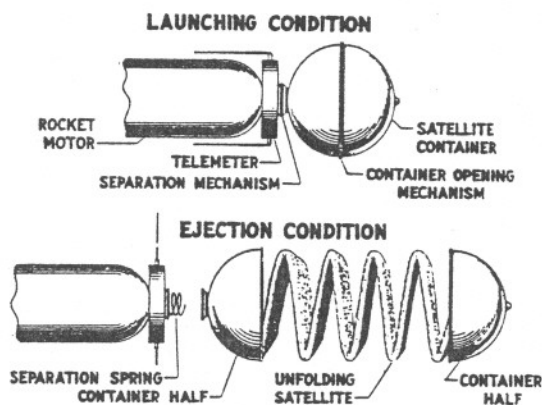


Fig. 10. Echo satellite launch container.

perature materials, thin-walled structures, and many other areas has made possible our present beginning of the exploration and utilization of space.

5. The Near Future.

Beginning on this base let us look at the near future for which plans and development are under way. I can only speak authoritatively for the plans and work of the National Aeronautics and Space Administration, which are reasonably firm for the launchings to be made within the next two or three years. Again we will look only at a few examples of the approximately 28 launchings scheduled per year.

Project Mercury.

We begin with the first step in the manned exploration of space, the orbital flight of man about the earth and safe return. The NASA Project Mercury is well

Fig. 9. Echo communications satellite launch sequence.

VERTICAL LIFT OFF
TIME ZERO SECONDS

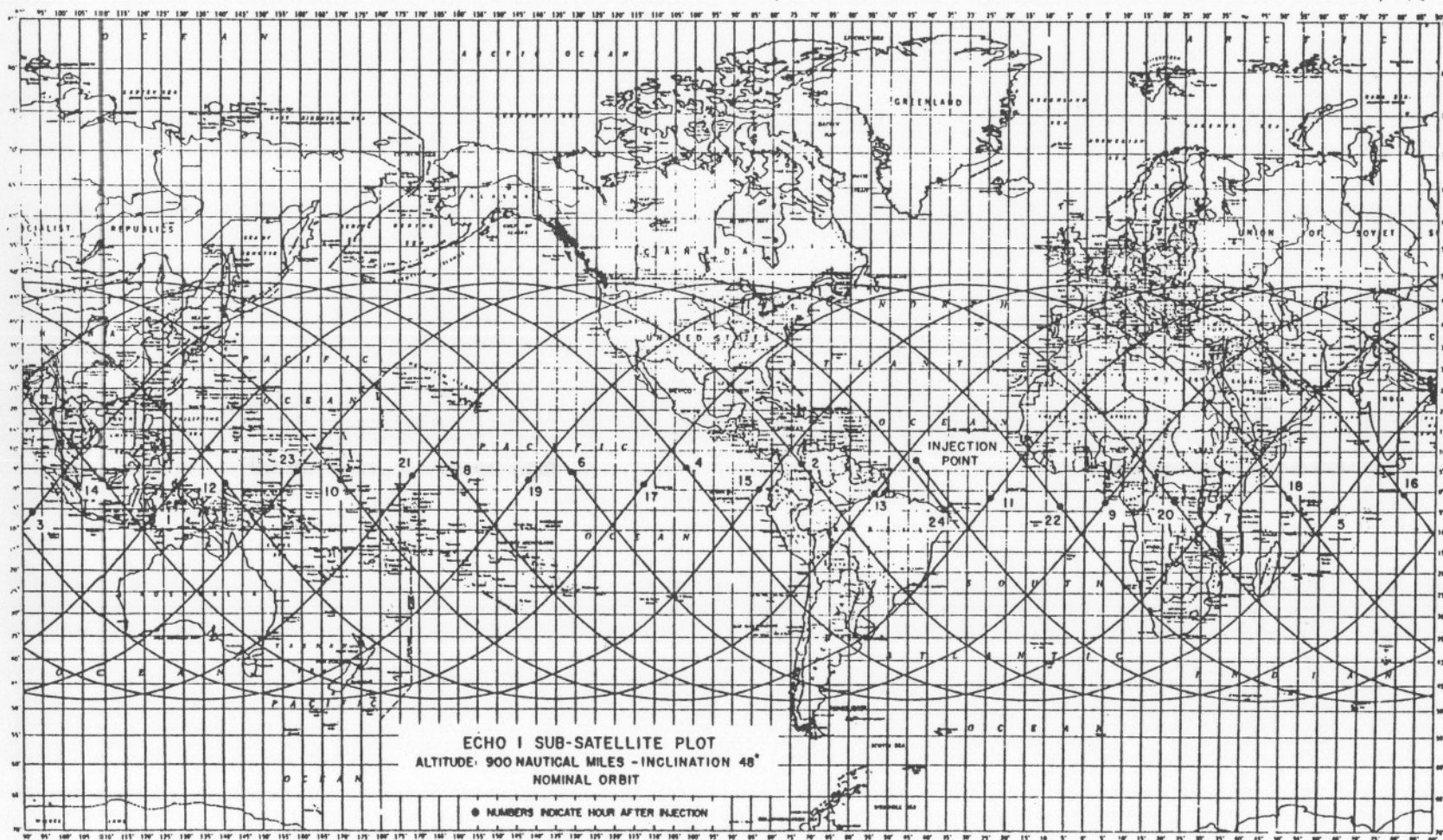


Fig. 11. Sub-satellite plot for Echo.

along in development and is but the beginning step. Its general nature is so well known that I will not describe it in detail, but some aspects of its objective and method of execution are not so widely known.

The primary objective of Project Mercury is to determine the capabilities of man to contribute usefully to space exploration. As such the astronaut in Project



Fig. 12. Echo satellite launch container mounted on Thor-Delta launch vehicle.

Mercury is far more than a passive biological specimen. Provision is made for him to perform the functions of a pilot, flight engineer, navigator, and radio operator. The astronaut can control the attitude of the capsule, initiate reentry, make changes and adjustments in equipment and use alternate systems, determine his position, and communicate with ground stations unless there are

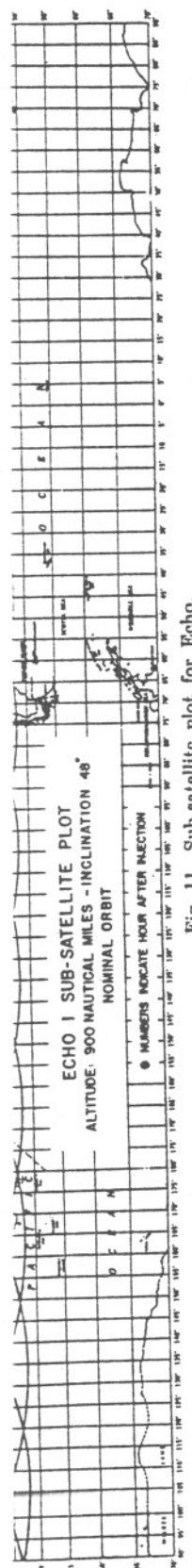


Fig. 11. Sub-satellite plot for Echo.

presently unknown aspects of space flight which incapacitate him for such activities. To assure safety, the spacecraft is equipped with automatic sensing and control devices of the type usually found necessary in high speed military aircraft. Moreover there is being established, with the friendly cooperation in the Mercury project by many countries, a network of ground stations throughout the world with access to highspeed computers by means of which the spacecraft can be controlled from the ground if necessary. An escape system is provided for the pilot for use if the mission becomes unsafe. It is designed to operate automatically, if the rocket fails on the ground or in the air; either the ground crew or the astronaut may actuate it.

Since the astronaut does expect to function as pilot, flight engineer, naviga-

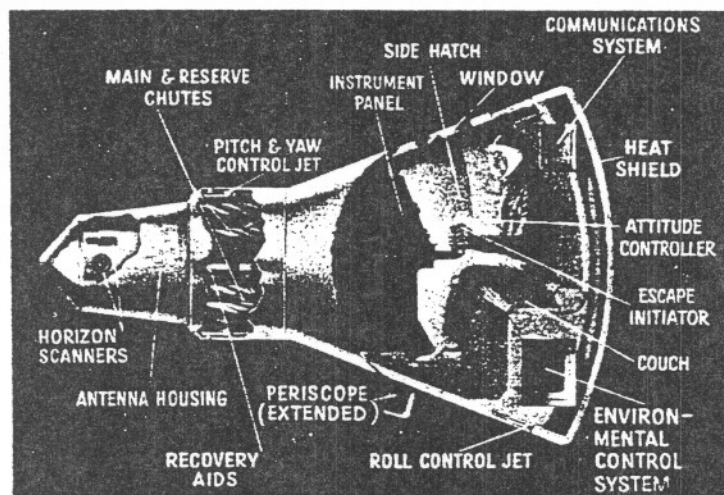


Fig. 13, Project Mercury ballistic capsule.

tor, and radio operator, his training for the flight will be completed by ballistic flights using a Redstone booster to an altitude of 125 miles, and to a distance of 200 miles giving the launch and recovery experience and 5 minutes of weightlessness. It is hoped to accomplish this flight within a few months and the first manned orbital flight during the calendar year 1961. Manned flights will be continued into calendar year 1962. These dates are dependent on satisfactory results in the remaining test program for qualification of the capsule and its equipment, and on satisfactory performance of the tracking and recovery crews in the unmanned flights. The test program provides some redundancy, since, with present rocket reliability, some failures are to be expected.

Nimbus.

The utility of the Tiros meteorological satellite is limited by the spin stabilization which gives the camera axis a fixed position relative to space axes but a changing position relative to the earth. Hence the area covered is limited and photographs can be taken only of sunlit areas.

The Nimbus series now under development will have a stabilization system to keep the cameras pointed earthward at all times. Nimbus will weigh 600 to

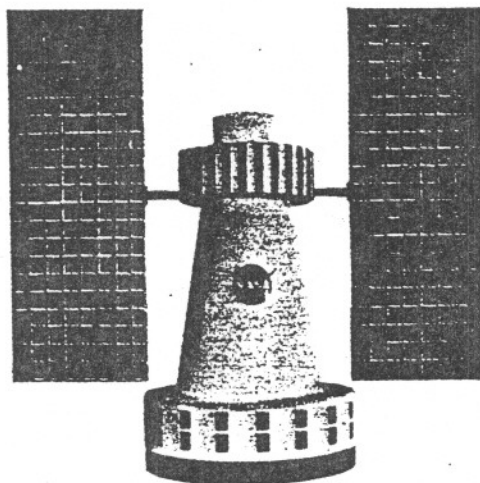


Fig. 14, Nimbus meteorological satellite.

700 pounds and be launched in a nearly polar and nearly circular orbit at an altitude of about 700 statute miles by a Thor-Agena B launch vehicle in mid 1962. Sensors will include television cameras, passive and scan-type radiation-sensing equipment and other experiments. Paddles which are continuously oriented toward the sun carry solar cells to provide power for the satellite subsystems. The present concept visualizes a satellite about ten feet tall and five feet in diameter at the base section. The base section contains the instrumentation. The upper section contains the power and stabilization system mounted on a column to provide clearance for the two paddles carrying solar cells.

Orbiting Solar Observatory.

An orbiting solar observatory is scheduled for launching in the first quarter of 1961 for the purpose of making spectrophotometric studies of the electromagnetic radiation from the sun in the ultraviolet and X-ray regions, with some

additional secondary objectives. The satellite weighing about 350 pounds is to be launched in a nearly circular orbit at an altitude of 300 miles by a Thor-Delta launching vehicle.

The satellite is now under construction. It consists of two sections, a base section ten to sixteen inches thick of large diameter and extended arms to form a gyroscope wheel for spin stabilization and a half disc-shaped upper section carry-

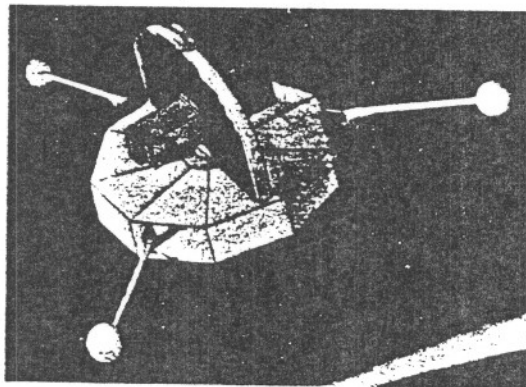


Fig. 15. Orbiting solar observatory,

ing solar cells to charge nickel cadmium batteries. The spin axis of the base will be so oriented as to remain perpendicular to the line joining satellite and sun. The base carries the electronic instrumentation. The arms contain the instrumentation which are pointed to the sun by a stabilization system, consisting of solar sensors and compressed gas jets to precess the spin axis of the satellite.

Orbiting Geophysical Observatory.

With the increase in capacity of launch vehicles it becomes possible to develop large spacecraft with great flexibility to carry forward the scientific program in geophysics. By 1963 we hope to be able to launch with the Atlas-Agena B launch vehicle an orbiting geophysical observatory weighing about 1300 pounds either in a nearly circular polar orbit at altitude of 350 statute miles or a highly eccentric inclined orbit with perigee of 150 statute miles and apogee of 70,000 statute miles at an inclination of 33° to the equator. The standard spacecraft will include the basic structure, electromechanical units, power supply, controls and telemetry. The present concept envisages a cylindrical structure of stacked short cylindrical compartments with large paddles for mounting solar cells.

Orbiting Astronomical Observatory

The first in a series of orbiting astronomical observatories is scheduled for launching in 1963. The satellite is expected to weigh about 3500 pounds and to be placed by an Atlas-Agena B launch vehicle in a 550 mile nearly circular orbit.

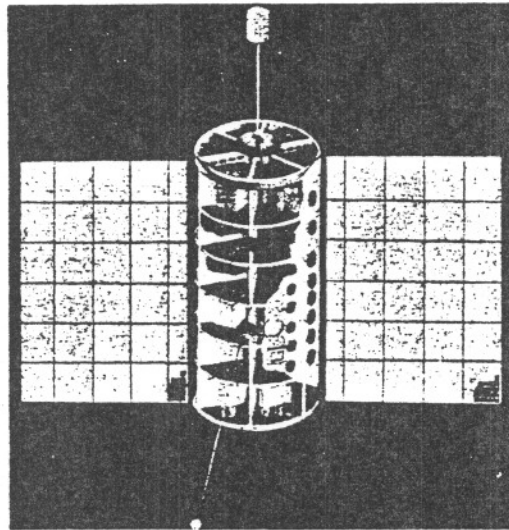


Fig. 16. Orbiting geophysical laboratory.

The principal experiments in the first observatory relate to the emission and absorption characteristics of the stars and nebulae in the ultraviolet.

Ranger and Mariner.

A series of three lunar impact missions are scheduled for 1962 with a spacecraft now under development to which the name Ranger has been given. It is to be launched by an Atlas-Agena launch vehicle. The basic spacecraft consists of a main section carrying guidance and control, telemetry, and propulsion equipment which make it possible to impact the moon within a predetermined area and with attitude control throughout the flight. Two large paddles containing solar cells are extended in flight and oriented toward the sun by solar sensors. A steerable antenna is pointed toward the earth for communication purposes.

The lunar impact mission adds to the basic vehicle a survivable capsule to be slowed by a retro-rocket to an impact velocity less than 500 ft/sec. This cap-

sule will contain a seismometer as the primary experiment. The spacecraft will be provided with a television camera capable of transmitting pictures with a resolution of ten feet during the final moments before impact. A gamma ray spectrometer will also be carried.

The lunar missions will be preceded by several spacecraft development

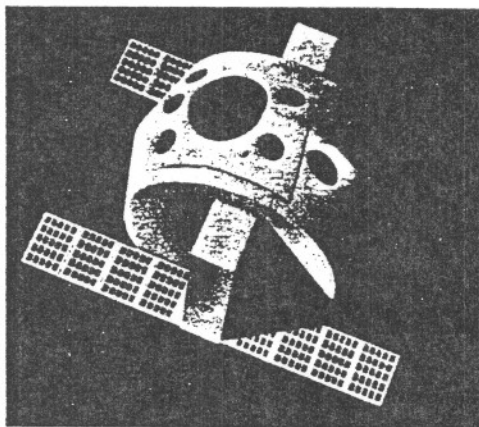


Fig. 17. Orbiting astronomical laboratory.

flights carrying some instrumentation for measurements of the environment of interplanetary space. The same basic vehicle will, we hope, be used with some modifications on early planetary missions to Mars or Venus. In this form it will be called Mariner.

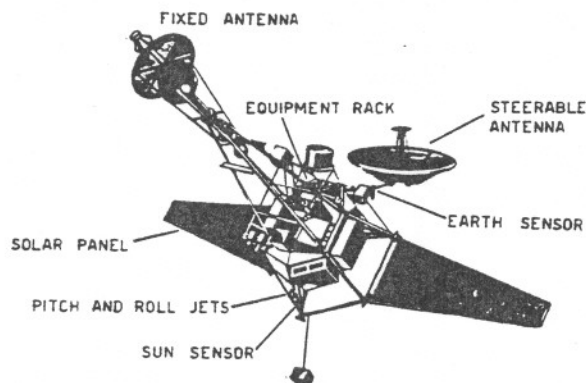


Fig. 18. Spacecraft for Ranger and Mariner series.

spacecraft will
be equipped with a
gamma ray spec-
troscopy develop-
ment

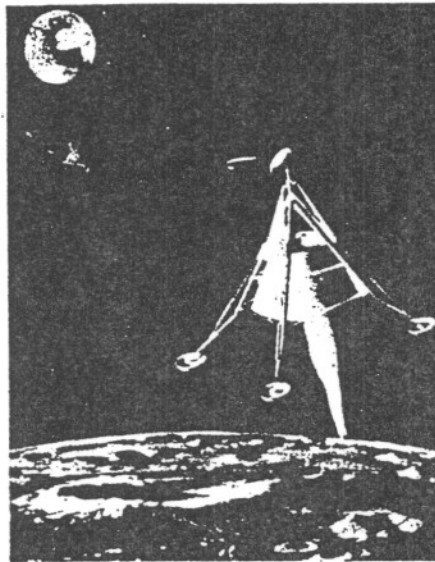


Fig. 19. Surveyor for soft lunar
landing (Centaur).
(Artist's conception).

Surveyor.

Still in the planning stage are spacecraft to be used for the lunar soft-landing mission using a Centaur launch vehicle. This spacecraft will be designed to deposit a scientific payload of 100 to 300 pounds on the lunar surface for examination of radiations, fields, the atmosphere, and the surface and subsurface characteristics with such instruments as television, seismometer, magnetometer, spectrometer, etc. Preliminary design studies are under way.

Longer Range Missions.

Beyond Surveyor there has been some study of spacecraft for lunar and planetary missions using the Saturn launch vehicle of 1 1/2 million pounds thrust which becomes operational in about four or five years. Such Prospector spacecraft might carry a

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with some
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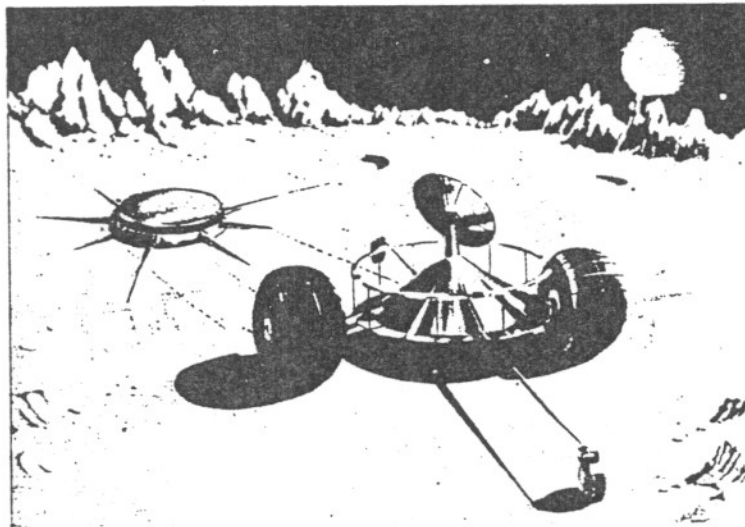


Fig. 20. Prospector for lunar landing (Saturn).
(Artist's conception),

soft landing mobile vehicle capable of exploring a relatively large area of the lunar surface.

Finally, a Voyager series of Saturn-launched spacecraft has been conceived for orbiting Mars and Venus. The spacecraft would be designed to eject an instru-

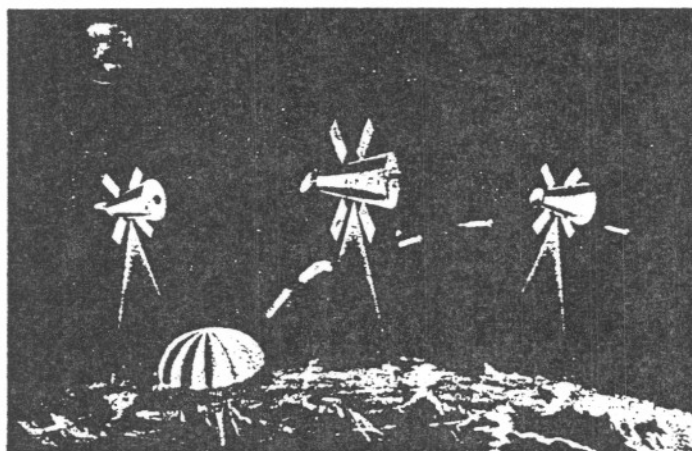


Fig. 21. Voyagers for planetary orbit (Saturn).
(Artist's Conception).

mented capsule for atmospheric entry and perhaps landing. Data from the capsule would be stored and relayed by the mother craft or, technology permitting, could be received directly on earth.

5. The Next Decade.

On January 2, 1959 the Select Committee on Astronautics and Space Exploration of the U. S. House of Representatives published a report entitled, «The Next Ten Years in Space, 1959-69». It contained the views of 56 scientists, engineers, industrialists, military officers, and Government administrators concerned with some aspect of the national space program and a summary by the Committee staff.

There was substantial agreement on the missions which constituted the pathway to space exploration by man. These include manned earth satellites from the first step through manned space stations, circumnavigation of the moon by man and return to earth, landing on the moon and return, and manned expeditions to Mars and Venus. Few carried the pathway beyond Mars and Venus.

Forecasts of time scale varied greatly, but it was generally believed that the circumlunar flight of man would be accomplished before 1969. A few predicted landing on the moon within the decade but the majority thought it would take place early in the following decade.

It is generally believed that applications of satellites to meteorology, communications, and navigation would be commonplace before the end of the decade.

In January of this year NASA presented to the Congress its Ten-Year Plan of space activities. During the next decade, 62 launchings are expected to be required for the development of launch vehicles, 41 for missions related to manned space flight, 96 for scientific satellites, 33 for lunar and planetary scientific missions, and 28 for satellite applications. These numbers correspond to a rate of a little higher than two major missions per month in the total program. The weight of the largest spacecraft that could be launched in a 300-mile earth orbit increases from the 20 to 150 pounds of 1958 and 1959 to more than 50,000 pounds by 1967. Correspondingly the weight capability for other more difficult missions will increase by a large factor.

The early milestones and target dates have already been mentioned. In 1965 the first flight test of a nuclear second-stage rocket will be accomplished if unexpected problems are not encountered. In the 1965-67 time period we are planning the first launching in a program leading to manned circumlunar flight and to a near-earth space station.

Apollo.

The designation Apollo has been assigned to the advanced manned space flight program beyond Project Mercury. Apollo is in the planning and early study phase. Its ultimate objective is manned circumlunar flight, consistent with the planned capabilities of the Saturn vehicle.

Present thinking suggests that the design of a spacecraft for an ultimate circumlunar flight requires the solution of many, but not all, of the problems associated with a manned landing on the moon. These problems include earth reentry from hyperbolic speeds and safe landing, and accurate navigation and mid-course guidance with trajectory control.

6. Major Technical Problems of Manned Space Flight.

A problem of major concern for manned flight beyond low earth orbits is that of radiation in space, including that in the VAN ALLEN radiation belt, cosmic radiation, and solar flares. The trapped radiation in the VAN ALLEN belt is of high intensity but of sufficiently low energy to make shielding feasible, if the manned

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vehicle merely passes through the belt without orbiting in it continuously. Concern is felt in some quarters for the possible effects of the very small fraction of heavy particles.

The energies of cosmic radiation are so high that shielding becomes impractical. However, the peak intensity is sufficiently low to permit the five-day mission of circumlunar flight. For longer periods this exposure may be dangerous.

The most serious problem apparently arises from solar flares whose energy is so high as to require heavy shielding. Studies are in progress on the frequency of their occurrence and the possibilities of prediction.

The radiation problem requires a great deal of study before manned spacecraft can be employed for circumlunar flight. Many of the characteristics of the radiation will be supplied through the scientific satellite and probe programs, but the biological effects of the various types of radiation remain to be more completely determined.

Another major problem area is the effect of the weightless environment of space on man and machine when experienced for long periods. Project Mercury will give some information on this question. Fortunately the gravitational environment of man can be simulated, if necessary, by centrifugal force in a rotating spacecraft. But this solution requires heavier spacecraft and larger booster capacity.

Present state of the art may permit space trips by man of hours or days but when the travel time extends to months and years, a host of new problems arise, associated with the provision of his food, oxygen, and water, waste disposal, and maintenance of a suitable chemical environment. The weight of food, oxygen, and water for long missions becomes very great. In addition his life processes produce carbon dioxide, excreted water and solid matter, and a large number of noxious chemical compounds which must be dealt with in some fashion.

Such considerations lead to the study of closed ecological systems which reproduce on a small scale the carbon, nitrogen, oxygen, water and other chemical cycles that occur on the earth. Knowledge in this area is still fragmentary.

The solution of man's environmental and logistic problems impose the need for additional energy supply and machinery, on whose continued operation over long periods his very life depends. The problem of the design and construction of continuously operating equipment of long life and high reliability has only rarely been solved in our current industrial technology.

7. Speculations for the Distant Future.

I believe as a matter of faith that the extension of space travel to the limits of the solar system will probably be accomplished in several decades, perhaps before the end of the century. Pluto is about 4000 million miles from the sun.

The required minimum launching velocity is about ten miles per second and the transit time is 46 years. Thus we would have to make the velocity considerably higher to make the trip interesting to man.

Travel to the stars is dependent on radically new discoveries in science and technology. The nearest star is 25 million million miles away and requires a travel time of more than four years at the speed of light. Prof. Dr. Ing. E. SÄNGER has speculated that velocities comparable with the speed of light might be attained in the next century, but such an extrapolation of current technology is probably not very reliable.

I quote the following paragraph from the 1960 Penrose Lecture on Prospects for Space Travel which I presented recently before the American Philosophical Society:

« Milestones of space exploration of interest to many are the dates when flight in space, either suborbital to great distances on the Earth, in earth satellite orbits, or to the moon and planets, will be as routine and familiar as the ocean-spanning travel in the jet transport airplanes of today. In my opinion these milestones will be reached but they are too far away to be accurately forecast. I will take refuge in paraphrasing the words of A. F. ZAHM in 1894 with reference to the conquest of the air. "It were vain for us to speculate on the eventualities of the conquest of space, for they are incalculable" ».

Conclusion.

The future of astronautics in the last analysis rests with the talents of a host of ingenious and imaginative scientists, engineers, and technicians throughout the world who must join together in devoting their talents to broaden the foundations of scientific and engineering knowledge without which progress in astronautics would soon cease.

I repeat a statement I made to the United Nations Ad Hoc Committee on the Peaceful Use of Outer Space on May 7, 1959, which I still sincerely believe. Most of all, space research needs to draw upon an entire world for its ideas. Those ingenious insights into the real meaning behind a set of observed facts that lead to real advances in the understanding of our universe are not the prerogative of a single nation or group but come from every quarter of the world where men are seriously occupied with scientific research. So vast is the challenge of space research and exploration and so great is the promise to mankind in the way of increased knowledge and ultimate benefits that no nation can afford to neglect or slight the opportunities that lie before it.

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