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THE NEXT TEN YEARS IN SPACE

1959–1969

STAFF REPORT

OF THE

SELECT COMMITTEE

ON

ASTRONAUTICS AND SPACE EXPLORATION

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(Created by H. Res. 496, March 5, 1958, 85th Cong.)

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LETTER OF TRANSMITTAL

HOUSE OF REPRESENTATIVES,
Washington, D.C., February 3, 1959.

Hon. SAM RAYBURN,
Speaker of the House of Representatives, Washington, D.C.

DEAR MR. SPEAKER: By direction of the Committee on Science and Astronautics, I submit the enclosed staff report, "The Next Ten Years in Space, 1959–1969," with the recommendation that it be printed as a House document.

As indicated in the original letter of submittal, this report was prepared for the use of the former Select Committee on Astronautics and Space Exploration, and it was approved by that committee for public release. The public demand for copies has been very large. Those of us who were members of the select committee now serving on the Committee on Science and Astronautics urged the new committee to sponsor the printing of this report we had previously approved, and they have so agreed.

OVERTON BROOKS, *Chairman.*

LETTER OF SUBMITTAL

JANUARY 2, 1959.

Hon. JOHN W. McCORMACK,
Majority Leader, Chairman, Select Committee on Astronautics and Space Exploration.

DEAR MR. CHAIRMAN: There is forwarded herewith for your consideration and submittal to the Congress a staff report, The Next 10 Years in Space, 1959–69.

This report is one of the most fascinating studies ever prepared for the Congress. It is not the fanciful creation of this staff, but rather a summary of the thinking of the leading scientists, engineers, industrialists, military officials, and Government administrators concerned with our national space program. These are men whose training and responsibility have made them careful, sober, and accurate in what they say. The sum total of their assessment of the next 10 years adds up to an astonishing technological preview of the world of tomorrow.

One word of caution is required. All the plans, programs, and projections these qualified men present will count for little unless the United States decides to meet this challenge with the mobilization of its private industry as well as public facilities, its resources, manpower, materiel, and money, which the national space effort requires. The indications are the Soviet Union is prepared to make such commitments. For reasons developed in earlier reports of this staff, our effort should have the help and partnership of other countries of the free world.

This report consists of two principal parts. The first is a staff summary of the commentary from the men and institutions answering the chairman's questionnaire. The second part includes the full texts of the statements received.

The views expressed in this report do not necessarily conform with the views of the committee or any particular member of the committee.

GEORGE J. FELDMAN,
Director and Chief Counsel.
CHARLES S. SHELDON II,
Assistant Director.

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CONTRIBUTORS

H. Res. 157

IN THE HOUSE OF REPRESENTATIVES, U.S.
April 20, 1959.

Resolved, That there be printed as a House document the staff report entitled "The Next Ten Years in Space, 1959–1969" (heretofore printed as a committee print for the use of the Select Committee on Astronautics and Space Exploration of the House of Representatives), and there shall be printed for the use of the Committee on Science and Astronautics of the House of Repreesntatives ten thousand additional copies of such House document.

Attest:

RALPH R. ROBERTS,
Clerk.

86TH CONGRESS } HOUSE OF REPRESENTATIVES { DOCUMENT
1st Session } { No. 115

THE NEXT 10 YEARS IN SPACE, 1959-69

Mr. McCORMACK, chairman of the Select Committee on Astronautics and Space Exploration, submitted the following

STAFF REPORT

[Pursuant to H. Res. 496 (85th Cong.)]

INTRODUCTION

Evidence of a keen desire on the part of the American public to learn what discoveries and advances may be ahead in the new space age has prompted the House Select Committee on Astronautics and Space Exploration to make a special effort to sample informed opinion.

At the direction of the chairman, the views of experts in this field have been diligently sought over the past several months. Requests for information and predictions were dispatched to eminent authorities in the United States, Great Britain, Germany, Italy, and the Far East, to American corporations engaged in space projects, to United States military leaders and to Government agencies.

The experts were asked what they see in the future for space development—and particularly what scientific progress they think may evolve in the next 10 years.

Will man reach the Moon or begin to use or colonize it? Will he probe the planets by instrumented vehicles? Will he be able to land on Mars or Venus? What kind of vehicles must he have at his disposal to do these things? Will his space research result in precise weather forecasting or control? Will rockets become a standard mode of travel and transportation?

Answers to these and many other questions allied with the space age are contained in the accompanying replies from half a hundred of the most knowledgeable of today's space authorities. Names and identification of these contributors are listed beginning on page V.

I. THE TENOR OF THE FINDINGS

Where does fantasy end and reality begin?

Is it fantasy to say that man may set foot upon the Moon in 1965? Upon Mars and Venus 3 years later? Dr. Herbert F. York, Chief Scientist for the Defense Department's Advanced Research Projects

Agency (ARPA),* says these goals may be achieved if sufficient priority is assigned them.

Is it fantasy to say that man may be traveling almost 670 million miles an hour within 40 years? Perhaps. But Dr. Eugen Sänger, Director of the Institute of Jet Propulsion Physics at the Technical University of Stuttgart, Germany, thinks it quite possible.

"There are concrete indications," he says, "that the technical application of new knowledge in physics gained during the last 30 years will permit such a rapid development that manned top-speed aircraft [i. e., spacecraft] will approach the velocity of light by the turn of the century."

But long before the year 2000 a businessman in New York will probably be able to write a colleague in Paris in the morning and receive a written reply by noon the same day. Dr. Glauco Partel, founder of the Italian Rocket Association and a propulsion expert, views postal rockets in the near future as a certainty.

And before the next decade is out, predicted scientists of the Dow Chemical Co., man will be able to fly continuously for many months.

"Our scientists feel," wrote Tyrone Gillespie, assistant to the president, "[that] * * * nuclear fuels will make possible continuous flight either within or outside the Earth's atmosphere for any desired period of time * * * as much as a year."

The space age will engulf the world so rapidly, says another authority, that it will bring with it an industrial revolution within 10 years. "From the astronautics effort will arise the greatest industrial complex in the history of the world," predicts Andrew G. Haley, president of the International Astronautical Federation. "The combined number of production workers in the automotive field of the entire world and the dollars spent on the automotive industry will soon, in each case, be equal to only a fraction of the astronautics industry."

"The time is now appropriate for serious space exploration and * * * many things previously considered in the realm of fancy can now be accomplished," said Donald W. Douglas, chairman of the board of the Douglas Aircraft Co.

"Prediction in science is a most dangerous and often foolhardy occupation * * * [but] progress in space research seems to have outstripped the predictions of the past," commented the noted physicist, Dr. Joseph Kaplan, Chairman of the United States National Committee for the International Geophysical Year. "While we should try to be realistic and reasonable, we should also remember that science and technology now move faster than most of us dare predict and that the setting of difficult and ambitious goals brings with it many unexpected rewards."

"Mail may become almost as swift as the telephone," said Lt. Gen. James M. Gavin, former Army Deputy Chief of Staff for Research and Development.

Gavin, now a vice president of Arthur D. Little, Inc., declared that the missile industry is producing such reliable, accurate, miniature parts that some may one day be used "to replace wornout human parts."

*Dr. York has since been appointed Director of Defense Research and Engineering, Department of Defense.

"There may well come a day," he predicted, "when rocket valves will be at work in the human heart—and we'll be thanking missiles that our hearts beat."

* * * * * * *

Here, then, is presented the thinking of practical, dedicated, and knowledgeable men about the future development of space exploration.

The conquering of outer space is no longer fantasy. Today man-made satellites circle the globe at more than 17,000 miles an hour, to be followed in the near future by manned space stations, by lunar bases, by exploration of Venus, Mars, and Mercury. After that, in the more distant future, will come flights beyond the solar system, to other worlds, to other galaxies.

That is the consensus of those who proffered their views to the committee. There was some difference of opinion as to when these epochal events would occur, but there was little disagreement that they would, in the course of time, come to pass. For the most part, the outside time limit was set at 20 years.

Some authorities stressed that there were many things which should and could be done within the next 10 years, but whether they would be accomplished depended in good part on just how great an effort was expended by the people, the Congress, and the Government.

There were those who expressed confidence that the United States would soon take its rightful place in the forefront of space development. There were others who hoped for the best, but expressed alarm over a general feeling of complacency which they felt still existed

II. The Moon

When man first began to reason, he looked upon the Moon with awe. There were those who worshiped the Moon as a deity and over the ages many were sacrificed to appease it.

But as man's reasoning power increased and with it his knowledge of the universe, there came a longing to know what was on the Moon. Was there any life, even in a very primitive stage? Was there any air? What was obscured on the "other" side of the Moon?

Today, man looks to the Earth's natural satellite as once Christopher Columbus and the early explorers looked to the west, to new worlds to explore. We dream now of setting foot upon this object which whirls about the Earth some 240,000 miles distant.

It is noteworthy that not one authority questioned the possibility of man's reaching the Moon. The only question appeared to be when.

According to Dr. York, in views endorsed by Roy W. Johnson, and Rear Adm. John E. Clark, Director and Deputy Director of ARPA, respectively, man can first set foot upon the lunar dust in "just about 10 years (perhaps in as little as 7, if a very high priority were placed on this goal.)"

The prediction that man may reach the Moon in 10 years is not confined to the military. "Certainly within 10 years manned flights around the Moon and return can be accomplished," said Donald W. Douglas, "and possibly during that time manned landings on the Moon and return will be possible."

Wernher von Braun, scientific chief of the Army Ballistic Missile Agency, also thinks this is possible.

"It is my opinion," he wrote the committee, "that manned flight around the Moon is possible within the next 8 to 10 years, and a 2-way flight to the Moon, including landing, a few years thereafter."

Dr. Fred L. Whipple, Director of the Smithsonian Astrophysical Laboratory, predicted that during the next decade "Equipment will have been safely landed on the Moon to set up a remote-controlled observatory" and "the back side of the Moon will have become as well known as the near side."

There were several who felt it would be the following decade (1969–79) before man first set foot upon the lunar terrain. Among these was Capt. R. C. Truax, of ARPA, who has devoted more than 20 years to rocketry, and who expressed belief that a circumlunar shot, to return a picture of the far side of the Moon, should be possible around 1968–69. He saw no reason why almost identical equipment, thrown into an orbit around the Moon, could not map the entire lunar surface "in fine detail."

"Such a feat," he stated, "will require several attempts, even with largely proven equipment, but should be possible before the end of the decade for a total added expenditure of less than the Vanguard program. [in the neighborhood of $111 million]."

"Manned circumlunar flight," continued Captain Truax, "falls into the same category of exploitations of military equipment for scientific and cultural purposes. The million-pound vehicle will be developed primarily to put large unmanned, and later manned, satellites into orbit. With minor modifications, the same vehicle can send a manned expedition round the Moon. Such a voyage would be a prelude to a manned lunar landing within the following decade."

In summing up, Truax listed these achievements as possible during the period 1959–69, at an estimated expenditure of $20 billion during the decade:

Numerous small unmanned single-purpose satellites, one large manned multipurpose space station, circumlunar instrumented flights, a soft-landing lunar craft instrumented to make numerous surface measurements critical to a later manned landing, and a manned circumlunar flight.

"These accomplishments," he stated, "are real and solid, though they are considerably below some glowing predictions."

Dr. S. Fred Singer, University of Maryland physicist, thought it probable that existing ICBM rocket development would make it possible "to design and operate a manned vehicle around the Moon which will again return to Earth."

"Judging from the probable state of ICBM rocket development," he stated, "it should be possible to design and operate a manned vehicle around the Moon which will again return to the Earth. This is probably the ultimate that can be done without new developments in rockets and, therefore, without large additional expenditures of money and effort. Such a project would * * * be * * * a real step in the direction of manned space travel."

Singer described how it would be done. He said:

"The vehicle would have to start from the Earth with about escape speed, 7 miles per second. Its occupant could operate a small 'vernier rocket' to put him on the correct precalculated orbit after the main rocket has burned out. Once in the correct orbit, no further adjustment will be necessary; the Moon's gravitational field will again 'reflect' the vehicle after it has passed around the far side."

Recovering the first astronaut would be a difficult task. "Probably the best method," Singer asserted, "is to use the Earth's atmosphere again to slow the vehicle down to satellite speed. By reentering fairly deeply on the first pass, enough energy would be expended so that the vehicle is thrown into an elliptic orbit, and as energy is expended on each pass, the ellipse shrinks quite rapidly into a circle. From there the reentry would proceed as in the case of a manned satellite."

Scientists of the North American Aviation Co. predicted that the first manned expedition will be of short duration.

"The logistic problems of boosting the large tonnages needed to sustain life for extended periods will dictate only a transient stay on the surface," they said. "But in this short time we should learn infinitely more about the Moon than all the unmanned lunar probes have been able to provide before.

"Men will be able to select samples of the Moon's crust to be taken back for analysis to determine the degree of identity with the Earth's crust. One provocative theory holds that life has been distributed throughout the universe by minute spores traveling on meteorites. The first men on the Moon will be equipped to prove or disprove this theory.

"They will also be able to determine firsthand facts that will ease the problems of succeeding expeditions. Thus, they may find fissures of frozen water or minerals containing readily available oxygen, which will make the sustenance of life very much easier. We cannot discount the presence of unknown perils that will make life hazardous for man on the Moon. Terrestrial exploration has always revealed unsuspected hazards, and we can expect that the first manned lunar expedition will provide experience that will make life safer for succeeding efforts."

III. Mars and Venus

Man's age-old dream of leaving the confines of the Earth has not been limited to reaching the Moon. The planets, especially Mars and Venus, have been perhaps even stronger magnets.

Ever since astronomers first reported "canals" and polar snow caps upon Mars, man has speculated about it. Is it a dead planet? Is it strewn with the remnants of ancient civilizations? Does life exist upon this world? For the first time now, a positive answer to this age-old riddle may lie ahead.

As for Venus, what mysteries lie behind its swirling clouds? Does it hide a lush tropical climate, as some believe, is it a watery waste, or is it a desert swept by duststorms?

The closest Mars will come to the Earth in the next decade will be approximately 35 million miles in 1971, the nearest approach since 1924. Venus is about 26 million miles from the Earth at its closest approach.

Dr. York foresees manned expeditions to these planets "a few years after 1968," but added that they could, perhaps, be made "in just about 10 years, if a very high priority were placed on this goal."

To von Braun "It seems unlikely that either Soviet or United States technology will be far enough advanced in the next 10 years to permit man's reaching the planets." But he declared that instrumented probes to Mars and Venus "are a certainty" within that period.

National Aeronautics and Space Administration scientists look to the "eventual establishment" of scientific bases on Mars and Venus, as well as the Moon. They do not predict just how soon, but they foresee during the next decade the mapping of the surfaces of the two planets by space probes, as well as attempts at "soft landings" of instrumented payloads "to determine many surface and atmospheric properties of these bodies and whether life in some form exists."

Although the civilian space agency did not anticipate that landings on Mars and Venus would occur by 1969, its scientists advised the committee that "an active program should be underway" by then for a manned expedition to circumnavigate Mars or Venus. This would be the prelude to a landing on the planets.

Krafft A. Ehricke, chief of astronautics for Convair, foresaw during the coming decade "Interplanetary space probes exploring the region between Mercury and Earth as well as between Earth and Mars and beyond in the asteroid belt between Mars and Jupiter."

"These probes can be of low-flight accuracy," declared Ehricke, "since they do not have to meet another body in space. They require no optical equipment and no navigation equipment. The messages which they transmit back to Earth on meteoritic material, interplanetary gas, electric and magnetic phenomena, etc., require low power. Therefore their overall weight can be comparatively small, between 200 and 1,000 pounds." He added that during the next 10 years there will be only 5 opportunities to launch a Mars probe and 7 occasions for a Venus probe. The best opportunity for a Venus probe will be in 1959 and 1967, while the most favorable opportunity for a Mars exploration would be provided in November 1962 and November 1964.

With the advent of the 1½-million-pound booster vehicle, on which plans are now underway, Ehricke said it will become possible to transmit a probe to the planet Jupiter, 387 million miles from the Earth at its closest approach.

Ehricke said the Jupiter probe is a difficult project which "may not be practical" until the end of the sixties. The vehicle would take a year to reach its destination, but would be of "considerable scientific interest."

George L. Haller, vice president of General Electric Co., proposed this 3-year program beginning with a Venus probe in 1959.

"(1) a Venus satellite;
(2) a Mars satellite;
(3) a close lunar satellite;
(4) a lunar soft landing;
(5) a trans-Mercury (solar) probe;
(6) a trans-Mars (outer planetary) probe;
(7) a Venus slow descent;
(8) a Mars soft landing."

Haller said that the missions to the planets could carry, as on the lunar probes, payloads of 50 to 250 pounds, sufficient to enable them to learn, among other things, "what the clouds that blanket Venus consist of, whether or not Venus rotates, and whether or not there is any form of life on Mars."

"A common error [in forecasting progress]," Haller also said, "is that of being too optimistic about what can be achieved in a few years and too cautious about the developments to be expected in 20 to 30 years * * *.

"Man's venture into space is the great enterprise of this century * * *. tremendous progress has already been made. Yet in the light of what remains to be done, all that has been accomplished so far is no more than a tennis ball as viewed in relation to the Earth."

Andrew Haley said the coming decade "should see the successful launching of Mars, Venus, and Moon probes and the establishment of many heretofore undreamed of orbits."

But he maintained that the exploration of Mars and Venus by manned expeditions will probably have to wait until the development of "propulsion systems capable of delivering millions of pounds of thrust at speeds in the order of one-third the speed of light," about 62,000 miles a second.

He warned that the exploration of outer space will not be without ts sacrifices in human lives.

"Biological hazards arising from travel in outer space will be diagnosed and largely overcome [but] the penalty for these investigations will be the sacrificing of numerous warm-blooded animals and, in time, of numerous human beings. The sacrifice of human beings will be roughly a little higher than was incident to man's conquest of the air."

IV. Man in Space

When will man fly in outer space? His first sustained flight in outer space will probably be in a space vehicle which will orbit the Earth—and the consensus of some of the experts is that this event is not far distant. The biggest problem still to be overcome, apparently, before man can circle the globe as a human satellite, is bringing him back safely to the Earth.

Rear Adm. John T. Hayward, Research and Development Chief for the Navy, put it this way: "Perhaps the key to man in space, Moon flights, etc., can be stated as follows: manned space flight will be practicable when there is *reasonable* chance for survival and rescue." Hayward predicted that man will fly in space orbit within the decade.

At least one expert believes man will orbit the Earth in 1959 and that man will be a Soviet citizen.

"I believe," stated Frederick C. Durant III, former president of the International Astronautical Federation, "that the U. S. S. R. will continue to shock this country rudely, pressing their current advantageous lead. I believe they will send man into orbital flight and recover him several times during the next year."

What is the consensus of the experts as to when man will spring from a speed of something like 2,000 miles per hour (performed for a brief period of time in experimental planes) to something like the 18,000 miles per hour at which the average satellite orbits?

While, with the one exception already noted, none would predict the step would be taken in 1959, others felt it would be accomplished within a few years.

Aeronutronic Systems' scientists foresaw a manned satellite in orbit within a few years which would remain aloft for possibly months.

Dr. Eric Durand, Aeronutronics' head of space sciences, stated:

"The present Atlas booster is capable of putting a man in a satellite orbit for a limited period, and provide for his safe return. This capability will be improved with the Titan, particularly through the use of advanced propellants, such as fluorine-hydrazine or fluorine-ammonia in the second stage.

"The advent later of a 1-million-pound-thrust booster will make it possible to put a large satellite in orbit with a crew of 2 or more men, and durations measured in weeks and possibly months." Durand estimated the 1-million-pound-thrust booster would be operational by 1961.

Predictions varied among the other experts who gave the committee the benefit of their views as to when man would orbit the Earth. Some emphasized that this would merely be another step in the direction of controlled space flight, necessary before man could really explore outer space.

Brig. Gen. H. A. Boushey, Air Force Director of Advanced Technology, foresaw such quick advances in space technology that within 4 to 5 years orbital refueling or restaging will be underway. "By such means," he stated, "the severe heating and deceleration problems of reentry can be completely avoided. * * * I think the first manned, orbital restaging or refueling flight will be accomplished within 4 or 5 years, and I fully expect that the necessary priority and emphasis will be placed on this key phase of space exploration." He told the committee that by 1965 manned maintenance, repair, and resupply space vehicles will be in use for military, commercial, and scientific purposes.

Roy K. Knutson, chairman of North American Aviation's space committee, thought the "initial flights would probably consist of a single orbit of the Earth, [with] the environmental system * * * capable of sustaining life for at least 24 hours in order to provide for emergencies."

"The capsule," continued Knutson, "would be decelerated out of orbit by a retrorocket. Speed of descent would be checked by speed brakes and, later, a ribbon parachute. The point at which the retrorocket is fired would be carefully controlled so that the recovery trajectory would land the capsule on the North American Continent in daylight hours.

"A manned capsule will provide a rapid means of getting man into orbit and for studying physiological effects, such as weightlessness."

NASA scientists cautioned the committee that a manned vehicle cannot be placed in orbit about the Earth until three basic questions have been answered regarding (1) high-energy radiation, both primary and cosmic ray and the newer plasma type discovered in the IGY satellite series, (2) man's ability to withstand long periods of loneliness and strain while subjected to the strange environment of which weightlessness is the factor least evaluated, and (3) reentry into the atmosphere and safe landing. They added that the reliability of the launching rocket must also be increased before a manned capsule is used as a payload.

V. Space Stations—Controlled Flight

The development of space stations and controlled space flight will follow successful manned orbit in the opinion of the astronautical authorities.

Many of the experts stressed the need for space stations in fixed positions in relation to the Earth, from which expeditions could be launched to the Moon and possibly beyond. Some regarded a space station as a necessary prerequisite to a successful assault upon the Moon.

The development of a space station, it was generally felt, would be accompanied by controlled space flight. The spaceman of science fiction would then become a reality.

General Boushey listed the early use of spacecraft, piloted by man, as "the most important" of the goals which must receive attention before there can be true exploration of space. The others were propulsion, orbital staging or refueling and the early matching of vehicles and boosters.

Boushey explained: "By piloted spacecraft, I refer to a vehicle wherein a pilot operates controls and directs the vehicle. This is quite a different concept from the so-called man-in-space proposal which merely takes a human 'along for the ride' to permit observation of his reactions and assess his capabilities.

"The high-speed flight experience of the National Advisory Committee for Aeronautics and the Air Force has shown that piloted craft return research data more effectively and more economically than do unmanned vehicles.

"While there is a place certainly for automatic, instrumented vehicles, I believe *man* himself will prove 'the essential payload' to the full utilization of space. Orbital rendezvous, controlled landing after reentry, and space missions other than the simplest sensing and reporting type, will require man."

Near the end of the period 1959–69, Boushey foresaw the construction of a large space station. He said it will be assembled "section by section as the result of numerous individual firings from an equatorial launching site. Final joinup of these sections will be accomplished by piloted 'space tugs' which will operate in orbit during their entire useful life. In addition to the 'tugs,' manned resupply and maintenance spacecraft will shuttle from the Earth's Equator to the orbiting satellites. Of course, military spacecraft will police the near vicinity of the Earth to prevent the use of space for aggressive purposes."

With the development that will by now have taken place, said Boushey, "a piloted spacecraft, taking full advantage of outgoing and returning refueling in the equatorial orbit, will land on the Moon."

T. F. Morrow, vice president of Chrysler Corp., did not anticipate the construction of space stations until after the next decade, but predicted that "manned flights of limited duration will be commonplace. Flights will exceed the few minutes of the current planned programs and, toward the end of the decade, will include space trips encircling the Earth and the Moon. The means of establishing space platforms will be developed, but operations from space platforms are not contemplated in this period."

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Morrow, whose firm is instrumental in the manufacture of the Army's Redstone missile, added however:

"The essential instruments of scientific investigation to make this space exploration fruitful are available now. The most difficult problem to be solved is attainment of safety and reliability. Our success in conquest of space will be measured, not in terms of brilliance of technical innovation, but in terms of attaining through sound basic concepts, product engineering, and manufacturing control an indispensable high degree of safety and reliability in large rocket vehicles as indicated by Redstone reliability of more than 90 percent."

Dr. Walter R. Dornberger, rocket expert for Bell Aircraft, viewed as one of the most important achievements of the next 10 years "The development of manned and unmanned space vehicles, maneuverable in space and able to rendezvous with permanent satellites or space systems."

The main area for space vehicles during the 1959–69 period, predicted Dornberger, "will be mainly up to 650 miles this side of the radiation cloud at operational times of up to 2 to 3 weeks."

The next decade, he said, will see the following developments: manned and automatic space astronomical observatories; manned space laboratories; manned and automatic filling, storage, supply and assembly space facilities; manned space maintenance and supply and rescue ships—all climaxed by the first manned flight to the Moon.

General Gavin said that "in the near future—when guidance devices permit—soft landings, rocket cargo and passenger transport will become feasible.

"We will probably reach the time," he predicted, "when we can consider rocket transport superior to airplane for anything over a thousand miles or so—just as we have long since reached a point of recognizing that planes are superior to automobiles for distances over a hundred miles."

Alexander Kartveli, vice president of Republic Aviation, predicted that by 1968, 3 years after man orbits the Moon, a space station will be established for staging flights to the Moon and planets.

"Manned space stations," he said, "have been suggested as a staging area for further exploration of space. The present man-in-space programs planned for the near future offer considerable hope that in a 10-year period the first operational space stations will have been placed in orbit."

He cautioned, however, that the launching of any manned system "requires a period of testing with similar unmanned systems to assure reliability."

VI. Other Uses of Space

Communications, television, weather, astronomy

Many space authorities believe that the first big economic payoff from advancement of astronautics will arise from the "fixing" of satellites in a 24-hour "stationary" orbit approximately 22,000 miles from the Earth.

Some felt it was the next big step in satellites and one which would affect the lives of the great mass of people on the Earth more than anything in the way of spectacular feats which might follow.

Arthur C. Clarke, English scientist and author, foresaw the day when stationary satellites would make television available to everyone on Earth. He declared that "Of all the applications of astronautics during the coming decade, I think the communications satellite the most important. * * * it is now widely conceded that this may be the only way of establishing a truly global TV service. The political, commercial, and cultural implications of this, however, do not yet seem so thoroughly appreciated.

"Living as I do in the Far East, I am constantly reminded of the struggle between the Western World and the U. S. S. R. for the uncommitted millions of Asia. The printed word plays only a small part in this battle for the minds of largely illiterate populations, and even radio is limited in range and impact.

"But when line-of-sight TV transmissions become possible from satellites directly overhead, the propaganda effect may be decisive, especially if it is coupled with a drive to produce simple and cheap battery-operated receivers.

"There could be few communities which would be unable to afford one set (in Ceylon there are dozens of radios blaring in every village) and when we consider the effect of TV upon our own ostensibly educated public, the impact upon the peoples of Asia and Africa may be overwhelming. It may well determine whether Russian or English is the main language of the future."

"The TV satellite is mightier than the ICBM," he concluded.

The possibilities of employing fixed satellites for weather observations have proven equally intriguing to space authorities. While none would predict that they would someday make of weather forecasting an exact science, the general belief was that a tremendous improvement would result.

Dr. F. W. Reichelderfer, Chief of the U.S. Weather Bureau, told the committee: "The development of meteorological satellites and the application of new observations and data from this source to the problems of meteorology offers promise of one of the most revolutionary advances in the history of the science. It should make possible the immediate detection of new storm formations—hurricanes, extratropical cyclones, etc.—any place over the globe. Its worldwide weather-observing potentialities are of utmost importance in human welfare relating to weather and climate."

It is generally agreed that billions of dollars would be saved and many deaths prevented if sudden onslaughts of bad weather could be predicted sufficiently in advance so that the necessary steps might be taken to protect people and industry.

Reichelderfer said the prospects of being freed from the various limitations which make accurate and advance weather forecasting difficult "is no longer just a dream of the meteorologist and researcher.

"Earth satellites can serve as global weather-observing platforms." he said. "Studies clearly indicate that Earth satellites fitted with television cameras, radiometers, and radar could telemeter to ground stations sufficient data on the weather as seen by the satellites to make it possible for man to actually achieve weather surveillance and analysis on a global basis.

"Satellites could televise to Earth stations in considerable detail direct photographic observations of the cloud systems of the globe, particularly those associated with major storms. Similarly, the extent of polar ice caps and snow-covered surfaces bearing on processes in the atmosphere could be determined."

Admiral Hayward told the committee that "there is every reason to expect the development of a navigational satellite system that will provide the required accuracy to ensure the safe navigation of all ships of the world in all oceans of the world—regardless of the weather. It may even be possible to extend this system to the safe navigation of aircraft on long extended flights. Additionally, such satellites could provide for the accurate measuring of the Earth, its islands and mountains."

Dr. Louis G. Dunn, president of Space Technology Laboratories, expressed optimism about communications satellites. "It is safe to predict," he said, "that this particular use of rocket vehicles will have more direct effect on the man in the street than any other development in space technology. He will now for the first time be able to see, as well as hear, an English cricket game, the shelling of Quemoy, the coronation of a Pope."

As for costs, Dr. Dunn says: "A careful analysis of the relative costs of satellites and of more conventional communication systems shows that even at today's costs the communications satellite costs less than the underseas telephone cable per cycle of band width and is comparable in cost with that of the overseas radio system."

The National Aeronautics and Space Administration also predicted many beneficial uses for satellites, including meteorology, communications, geodetics and navigation.

"A system of meteorological satellites," Dr. Glennan said, "will some day provide continuous worldwide observation of cloud cover, storms, heat input and other meteorological measurements which can be used for improved forecasting, and perhaps, at some future date, control of the weather."

Scientists of the Dow Chemical Co. predicted that in addition to satellites, nuclear-powered ramjets, flying continuously, will "undoubtedly" record the cloud cover and the upper atmospheric conditions at all points around the world to permit accurate short-range weather forecasting.

Ehricke saw instrumented satellites providing a global post office and television relay, improved weather and navigation aids, with the latter "acting like a radio star for ships in the case of overcast," and an early warning system against enemy attack, especially with long-range missiles.

L. Eugene Root, missiles systems expert for Lockheed Aircraft, predicted that distances of several hundred million miles will be spanned by pictures and other media. He commented that: "in the next decade, communications systems capable of spanning planetary distances of several hundred million miles, such as will be involved in planetary probes, solar probes and artificial asteroids, will be developed for transmission of complex data, including pictures."

Root described what he thought the next 10 years would bring in communications. "In addition to the frequency bands now in use, new systems using presently untapped portions of the entire frequency spectrum, from X-ray frequencies on up, will begin to be evolved for extraterrestrial space-to-space transmission. Erectible or unfurlable antennas, dishes, and mirrors, possibly steerable and highly directive, will have been evolved for space vehicles and communications satellites. New methods of information coding and processing will permit compact reliable low-power drain communication links capable of handling much more complex information than at present."

Root predicted that astronomy, too, will greatly benefit from new developments. During the next decade "astronomical observations from space vehicles will be an accomplished fact (and) will revolutionize conventional astronomy."

He raised the possibility that future astronomical techniques may bring the answer to the evolution of the universe. Radio telescopes will look into space for much greater distances than is now possible. "If at these much greater distances the distribution of galaxies in space is much more dense, then we would have an argument for an evolutionary theory of the universe where galaxies are created once and for all and simply expand from some point in time. If, on the other hand, the distribution of galaxies remains uniform, we would have an argument for continuous creation of galaxies with no necessity for supposing creation at some finite time in the past."

This speculation was similar to that of Prof. A. C. B. Lovell, noted British astronomer, who has long believed that radio-telescopes may solve some of the main mysteries of the universe. Lovell suggests that any telescope, if carried in an Earth satellite, will reach space-time distances of much greater magnitude than is possible today and thus obtain information of the state of the universe as it existed billions of years ago.

Dr. Harold C. Weber, the Army's Chief Scientific Adviser, implies that it will be difficult to evaluate the magnitude of knowledge to be obtained from the study and exploration of outer space, although certainly it will be great.

Immediate results, he said, will include more accurate maps of the Earth to replace the surprisingly "inaccurate" maps we now have; worldwide communications "on a reliable scale" through the use of satellites; greatly increased amounts of information concerning weather and the formation of weather patterns which may result even in some slight control over weather; greatly increased knowledge concerning the composition "and probably the life history of the universe"; and "ability to perform quantitative experiments on a grand scale in outer space which will contribute new knowledge to our understanding of matter, energy and time. * * *"

VII. Propulsion, The Key to Space Travel

Since the time of Jules Verne men have envisioned journeys to distant worlds in interstellar space ships which cruise at fantastic speeds. More recently, science fiction has been replete with stories of space travel. In many such journeys the space voyager travels in comfortable craft, unencumbered by unusual or heavy garments until he prepares to leave his ship. He has at his command suitable propulsion systems, including auxiliary ones, which blast him from Earth swiftly and efficiently. He is generally at ease in his spaceship, protected by heat, air, light and other conveniences and necessities.

This view by science fiction assumes that a variety of serious technical problems have been solved, which often is not the case today.

Scientists have little doubt that these obstacles can be overcome. But how and when? Will nuclear power be available for propulsion and auxiliary uses before the next decade ends? Will ion rockets be practical? What of solar boiler rockets? Plasma jets? Photon rockets? Magnetic propulsion and braking? Solar sails?

The predictions and speculations embrace virtually all the levels of human imagination.

Technicians of the Thiokol Chemical Corp. said the problem of developing engines of very high thrust is responsible for a "serious lag in space technology in the United States." However, they thought that solid propellant engines developing 10 to 100 times a million-pound thrust "present only straight-forward engineering problems." Within 10 years they predict large solid propellant engines for the first stages of space vehicles capable of lifting gross loads of over 10 million pounds.

What is really needed, they say, "is a way to contain a fluid having a temperature of 10 million degrees Kelvin. Such a rocket would permit space travel with a fuel-mass ratio of about 2 pounds per ton at takeoff. Space travel could then be accomplished with all the comforts of a voyage on an ocean liner."

The company concluded that such achievements probably lie beyond the next decade but felt they could crystallize "if we, as a nation, want them enough to put forth the effort needed for their attainment."

Concerning the feasibility of nuclear propulsion for space vehicles, Chairman John A. McCone of the Atomic Energy Commission said that investigations over the past 3 years "have made us confident that nuclear energy will play a prominent role in the conquest of space." He pointed to projects Rover and SNAP as examples of experiments going on in this field. "Rover is concerned with the application of nuclear energy to rocket propulsion," he explained. "SNAP is concerned with the development of small, lightweight nuclear auxiliary-power units for use in space environment. Both radio-isotopic and reactor energy sources are being exploited for this application."

Assuming the necessary effort and support, McCone said the decade ahead should:

(1) Demonstrate by full-power ground test a nuclear rocket engine capable of boosting extremely large payloads into space. (2) Operate for many months an electricity-producing, satellite-borne, nuclear auxiliary power unit. (3) Develop and test nuclear electric drive units capable of providing propulsive power for space probes. (4) Develop and test units which will convert nuclearly developed heat directly into electricity without resort to rotating equipment.

Dr. T. C. Merkle, nuclear power expert at the University of California, suggested that there is not yet developed a "complete conceptual design" for the "space cruising" stage. Therefore, he said, from the propulsion standpoint it is necessary to develop some of the systems now being explored in a tentative manner to a high degree of practicality "before we can be truly said to be in the space age." He said nuclear energy will be necessary to accomplish these results and foresees in the next 10 years heat-exchanger rockets, mainly for booster use; light reliable reactor systems for space-station powerplants and, eventually, for use by landing parties on the Moon or planets; and ion rocket schemes to be used as the last stage of planetary probe vehicles.

Dr. Raemer E. Schreiber, Los Alamos scientist, said the actual operation of the experimental high temperature rocket reactor will probably take place this year. The reactor is known as KIWI–A and is a heat-exchanger device, blowing propellant gas through channels in solid fuel elements and exhausting it through a nozzle.

He emphasized that even though such reactors have "attractive performance for orbital missions and limited interplanetary exploration" they make use of only a small part of the nuclear potential.

"Basic studies are therefore being made on nonconventional reactor concepts in which the temperature and specific impulse of the system are much less limited by internal structural considerations. In addition, rather encouraging results have been obtained in the study of direct electrical power generation from fission heat. The generation of electricity by thermoelectric effect in metals has been known for many years, but is a relatively inefficient process. The similar effect in a gaseous plasma potentially has a much higher efficiency."

Schreiber disclosed that solar sailing has been investigated and shows some promise as a method of orbit-to-orbit propulsion. The technique would use pressure from the Sun's radiation to generate motion. "This is very minute, but is adequate for maneuvering a space craft into various Earth orbits and to do rather leisurely interplantetary exploration. A thin sail some 500 yards in diameter is needed for a space capsule weighing 500 pounds. * * * Control of orientation is accomplished by counter-rotating the sail and the payload and making use of the resultant gyroscopic action."

Dan A. Kimball, president of Aerojet Corp., thought that present propulsion systems developed for the military intercontinental ballistic missiles can be clustered to provide boost thrusts of from 1 to 1½ million pounds. Clustering existing powerplants beyond this level, he said, would be impractical from the standpoint of reliability and complexity. However, he thought single-engine thrust of this magnitude should be developed within 5 years. By clustering these more powerful engines, he continued, total thrusts of 10 to 15 million pounds might be achieved.

Missions beyond the next decade, in Kimball's view, will require still larger boost systems for which nuclear rockets may provide "significant advantages in reduced gross weight * * * and a single stage configuration." He pointed to charged colloidal propulsion systems as a means of vernier control and navigation in sustained space flight, and added "* * * our engineers visualize that a recombination power plant can also be developed. This powerplant would utilize energy available in the upper atmosphere and would be particularly suitable for manned flight in the regime of Mach 10 or more and at altitudes of 50 to 100 miles. To date, the studies and experimentation on these advanced propulsion systems show promising indications of their feasibility."

Dr. W. H. Pickering, Director of NASA's Jet Propulsion Laboratory, felt that space technology will have advanced during the coming decade to the point where the following developments will be likely:

(1) Reliable chemical engines having thrusts of several million pounds; (2) prototype models of atomic rocket engines undergoing static tests; (3) ionic propulsion systems in the advanced experimental stage; (4) more efficient and reliable solar-energized power sources having an almost indefinite lifetime.

Dr. H. Guyford Stever, associate dean of engineering at Massachusetts Institute of Technology, thought the accomplishments of the next 10 years would be restricted mainly to current or slightly improved forms of conventional liquid- and solid-propellant rockets. He predicted that "no new forms of propulsion will challenge the conventional rockets in their accomplishment by the end of the (first decade)," but added that nuclear and ion propulsion would advance "in experimental form" during that time. On their development, he said, may hang the long-term future of distant solar-system travel and travel beyond.

Robert P. Parker, research chief for American Cyanamid Co., stated that "tailormade" chemical propellants will play important roles in many aspects of missile and space exploration systems in the next 5 to 10 years. Parker explained that his colleagues believed "future advances in propellant systems will necessitate the discovery of entirely new chemical substances designed for a specific purpose."

VIII. Long-Term Speculations

While the potentials of space are too vast for accurate prediction, assumptions, conjectures, and speculations have been made.

"In an estimate of the probable progress to be made in space technology during the next decade," remarked Dr. Weber, "one can be sure he will be accused of being either too conservative or too radical, so great is the spread of opinions even among those technically competent."

An example of the long-range, controversial type of conjecture is the possibility of an ultimate space weapon similar to the "death ray." Professor Sänger described such a device as a "stationary ultraviolet searchlight" which might exert a radiation pressure by means of high-energy beams and thus be capable of "destroying flying objects up to a distance of several hundreds of miles in a fraction of a second."

"Perhaps," said Sänger, "this would lead to the ultimate elimination of all warlike tendencies from research in aeronautics and astronautics."

One of the most exciting prospects of the future from the scientific standpoint is the possibility of checking out some of Einstein's theories of time and relativity.

NASA scientists say that "a relativity check with atomic clocks in orbit" may have been made before the next decade is over. Such a clock, placed in an Earth satellite, might measure gravitational fields in certain areas of space. Compared with the gravitational fields of Earth, this could provide verification of the time-gravity aspects of relativity.

Sänger has provided a description of how the theory would work on a space flight from Earth to some star a thousand light years away, using photon power and traveling close to the speed of light.

It might take the crew, he said, 11 years by spaceship time to reach the star. On Earth a thousand years might have passed. If, upon reaching the star, the voyagers immediately began their return trip, they would arrive back on Earth 22 years from the time they left it. During that period 2,000 years would have gone by on Earth.

Dr. Partel, Italian rocket expert, foresees, as an offshoot of space exploration, the rise of a new technological branch—space architecture—to handle projects for "lunar bases, Mars stations, etc."

He predicted that there will be progress accompanying space development in what he termed "alien fields." Thus there should be research on ion rockets for traveling *through* the Earth and artificial ball lightning for mining ore. He said the latter could prove an extremely speedy and economical process since the lightning could cut into the ground almost instantaneously, forming mine shafts with solid, streamlined walls.

Partel also foresaw (1) both civilian and military jet underwater craft which could be converted into aircraft, (2) underwater cargo ships, (3) studies on plankton as the fuel of the future for hydro-ramjets, (4) the use of ocean depths as "the biggest launching pads in the world, having the huge advantage of being concealed."

IX. Space Policy for the Future

It is an interesting commentary that most of the scientists questioned by the committee suspected that the biggest space problem of the future might lie less with technology than with the attitude of the people.

George S. Trimble of The Martin Co., put it graphically: "The hero of this age will not be the space traveler, but rather the man or men who successfully figure out how to motivate 170 million American people actively to do battle with a part of their environment that they just began to hear about, that they really did not know was important * * * SPACE."

Dr. Arthur Kantrowitz, director of AVCO's research laboratories, urged "that we take courage from the fact that we can already see how space will pay for itself to move on to much bolder adventures * * * we should not allow those who see only the immediate expenditures to stand in the way of progress in a field which is not only essential to our survival through military and scientific strength, but also promises to constitute an important segment of our civilian economy."

Maj. Gen. John B. Medaris, Chief of the Army's Ordnance Missile Command, emphasized that in view of the tremendous Soviet effort in space, the United States cannot afford not to keep pace. But, he added, this country must not lose its "more profound motivation than the mere pressures of recent Soviet successes—the classic challenge of space." He quoted Einstein as believing that "the most beautiful thing we can experience is the mysterious; it is the source of all true art and science."

Moreover, in investigating space, for whatever reason, there are those who emphasize the necessity for international cooperation with other people of the free world.

"We should afford these peoples," said Vice Adm. Hyman G. Rickover, "the opportunity to learn on a completely free and open basis, giving them all the information we possess. Such a step will insure that our space effort will remain thoroughly productive because it will benefit from using the brains of not only our own people, but also those of all our friends."

Von Braun qualified his predictions with this thought: "It is utterly essential that we now commit our resources likewise to a long-range integrated national program and sustain that program even if public interest in it temporarily abates. For if public opinion again becomes lethargic, it will, of course, be reawakened by Soviet accomplishments. The resultant stop-and-go method would be neither economical nor successful."

Dr. Weber may have put his finger on the crux of the issue when he told the committee:

"Space experiments offer a whole new vista to scientists * * * and what science uncovers is eventually put to practical use by man. Our only question is whether the use is for practical good or practical evil."

STATEMENTS OF CONTRIBUTORS

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PREPARATION FOR SPACE COMMUNICATIONS

The recent rapid advances in rocketry and in other developments leading to a probable early achievement of space travels and the use of satellites and space vehicles for numerous purposes has created an awareness that provision must be made for adequate space communications. This awareness has arisen at all national and international levels of those agencies charged with the responsibility of insuring the orderly use of communications, as well as in the scientific and engineering community.

Just what is meant by adequate cannot be stated at this time, particularly with regard to quantity. The communication requirements will continually develop as more and more is learned about space vehicles and the uses to which they are put. Some general requirements as to the characteristics of the radio frequencies which would be useful can be outlined as a result of recent studies which have been made. These preliminary judgments as to the required frequency characteristics will be further refined and modified in accordance with future experience and information. Although present information is fragmentary, the important thing is that the situation is under study so that the proper steps can be taken at the proper time to make available the communication channels necessary for space communication.

It should be emphasized that these studies are in a preliminary phase. No radio frequency bands have been set aside for this purpose. The preliminary information indicates that the frequency bands which have the proper characteristics for some requirements of space communication are now assigned to, and widely used for other purposes. Thus no virgin frequency bands are awaiting these requirements. Insofar as the civilian uses are concerned, it will be incumbent upon the proponents to justify both the locations and the amounts of space which are allocated, in competition with other new and existing services. This will be done through established procedures at national and international level, during which the proponents will be afforded full opportunity to justify the extent and importance of their needs as compared to the needs of terrestrial communications, radio astronomy, and other uses of the radio spectrum.

The following are some of the steps which have been taken to date to assure an orderly consideration of the problems which will arise in connection with space communications. These steps involve the accumulation of preliminary factual information and the establishment of procedures whereby new information will flow into the proper channels as it becomes available.

The first instance involved official action to make available a frequency for use in space communication.

In 1957 the frequency of 108 megacycles was made available for communication with satellite vehicles, by the action of the Interdepartment Radio Advisory Committee, with the concurrence of the FCC. This frequency was confirmed for international use at a meeting of the Special Committee for the International Geophysical Year (CSAGI) in Madrid, and was subsequently used in communicating with American satellites. A comparison of the use of this frequency with the use of the 20-megacycle and 40-megacycle frequencies by the Russian satellites has yielded valuable data as to the relative suitability of the 3 frequencies for various purposes.

At the Eighth Plenary Assembly of the International Radio Consultative Committee (CCIR) held in Warsaw in 1956, a representative of the American Rocket Society requested that the matter of the reservation of frequencies for space communications be placed upon the agenda for discussion. The assembly declined to accede to the request because no decision could be reached in the absence of a comprehensive factual study preceding consideration by the Assembly. In Moscow, during the interim meeting of CCIR Study Group XI on Television in May 1958, the same person now representing the International Astronautical Federation, requested that the group adopt a proposed set of television standards for space use. The group felt that the proposal for standards was premature. It felt that the initial problem was to study the general communications requirements and the radio frequency bands having the proper characteristics to satisfy the requirements. Consequently, the group assisted in the drafting of a study program to accomplish this. After proper endorsement by the official delegations of the countries attending the meeting, the program was assigned by the Director of the CCIR to Study Groups V and VI which are concerned with radio waves and their characteristics.

The formulation of this program was called to the attention of the International Scientific Radio Union (URSI), so that any scientific information bearing on the problem which is known to URSI can be made available to the CCIR. This matter was taken up at a meeting of URSI held in October 1958, and the members of URSI Commissions II and III, dealing with radio waves, agreed to forward pertinent information to the CCIR Study Groups. The first information from URSI was received by CCIR about November 3, and was considered at a special meeting held at the National Bureau of Standards in Boulder, Colo., on November 7. Members of the FCC staff are active in both URSI and CCIR and are contributing to the program being made in this study.

As an aid to the development and dissemination of information on space and other new forms of communication by radio, a symposium on extended range communications was recently held in the Lisner Auditorium of the George Washington University and some very valuable ideas were developed. This is not an isolated case, but is cited as an example of the wide interest and activity in this subject at technical levels.

An international radio conference, looking toward improvements in the radio allocation established at Atlantic City in 1947, is to be held in Geneva beginning August 1959.

The Department of State Government-Industry Preparatory Committee responsible for the development of international frequency allocation recommendations has under consideration a paper prepared by the American Rocket Society which is essentially the same paper introduced into the Warsaw CCIR meeting. This paper was also filed with the FCC as the recommendation of the above society.

FCC staff representatives are in active consultation with the Interdepartment Radio Advisory Committee on all frequency allocation problems, including the ones raised in connection with future space communication requirements.

In summary, it may be stated that—

(*a*) It is generally recognized that there will be future requirements for space communications, and there is present activity looking toward the orderly satisfaction of these requirements.

(*b*) The future requirements for these communications are in the process of being developed, but insufficient experience has been had as yet to be able to forecast, with any reasonable accuracy, the amount of spectrum space or the portions of the spectrum needed to meet the requirements.

(c) At the present time, all space-vehicles projects of the United States have been under complete control of the Federal Government. Irrespective of the technical and engineering requirements which may be presented for space communications, these ultimate requirements may depend upon the extent to which the Government may establish control. In other words, one of the ingredients which will determine these requirements will be the determination of whether the Government assumes complete control over satellites, whether private industry is permitted to control them, or whether a combination of these controls will emerge as the United States policy.

Dr. Lloyd V. Berkner, President of Associated Universities, Inc.

(An address to the annual dinner of the American Geographical Society, January 20, 1959, Plaza Hotel, New York)

Man's conquest of space in year 2 A. S. (after sputnik or after space, as you like) has become the fastest developing drama of human history. Hardly 4 years ago, in September 1954, at scientific meetings of the International Scientific Radio Union at The Hague and of the International Union of Geodesy and Geophysics at Rome, serious scientific resolutions were adopted by sober and responsible groups of scientists asking for launching of instrumented Earth satellites. Only a few days later, as a direct consequence of these resolutions, the plan for launching Earth satellites was incorporated into the International Geophysical Year. Then came the electrifying announcements of July 1955 and of September 1956 that the United States and the U. S. S. R. respectively would attempt to launch the first artificial Earth satellites for scientific observations during the IGY. With these resolutions and announcements, by responsible scientists and governments, space science began to acquire an air of respectability—an attitude whose absence before the year 1954 had influenced more conservative citizens to shun serious thought of the potentialities of space. In fact, serious studies as late as 1952 failed to arouse serious government interest. Buck Rogers of the comic strips had so shrouded space exploration in fantasy that men were hard pressed to believe that the space age was here.

But on October 4, 1957, that air of fantasy was rudely and finally exploded by Sputnik I. The "beep-beep-beep" of the first artificial satellite of planet Earth became the symbol that is now the prelude to announcement of important news. The age of space had come—fortunately in a peaceful role, as a part of a planned international program of scientific research under the world auspices of the International Geophysical Year. Man had made his first escape from his imprisonment on planet Earth into the space of the universe. Even more than nuclear energy, the satellite has symbolized the cohesive force of science in bringing together and cementing political, social, and economic elements of man's civilization.

Now, more than a half dozen instrumented Earth satellites have circled the Earth, and a Soviet Sun satellite with an 800-pound payload is making a cometlike orbit around the Sun. The drama brings a sense of reality to the notion that our home is an isolated planet of decidedly limited size and importance as it whirls through the surrounding maze of heavenly bodies. As the drama unfolds, it provides an exhilaration arising from the demonstration of the strength of man's mind that has enabled the conquest of space; but, at the same time, it provides a new perspective from which to view the more petty differences among men on Earth, and to focus with better proportion on the more critical aspects of our existence.

Space exploration falls naturally into two parts—the exploration of the Earth and its immediate surroundings by means of artificial satellites, and the exploration of celestial bodies: the Moon, the Sun, the other planets with their moons, and the stars. Certainly, the study of the Earth, using satellites, falls squarely in the realm of geography and geophysics in the strictest sense of the word. But as one travels to other heavenly bodies the prefix "geo" to geography, geophysics, geology, geodesy, geomorphology, and on through the long list of geo-scientific terms, no longer carries the proper connotation with respect to similar studies on the Moon or planets other than to remind us, perhaps, of man's excessive and introspective preoccupation with his own planet during his 6,000 years of historical imprisonment. In the search for words to fit the needs of the space age, we are reminded of Hevelius's "Selenographia" of the 1600's, a magnificent atlas of the moon's features, which gives us the words:

Selenology: The branch of astronomy dealing with the Moon, and

Selenography: The *science* of the physical features of the Moon.

Going on to the planets and stars we find the dictionary defines:

Uranology: A discourse or treatise on the heavens or celestial bodies, and

Uranography: The *science* of describing the heavens and celestial bodies.

Our language begins to sound pretty useful after all. We begin to imagine an American Geographical Society becoming the American Geographic and Uranographic Society until we read on and find uranography also defined as "a description of heaven."

One shudders a little at coining the words "selenophysics" or "uranophysics" to generalize geophysics to the Moon and planets, but we are stopped completely in trying to generalize such words of delicate meaning as "geology," since both selenology and uranology are already preempted for other connotations. Clearly, until the philologists get to work on their space etymology, we must be strongly tempted to speak, though quite incorrectly, of the "geology" of Mars or the Moon, and to indulge in other linguistic improprieties.

Turning now to the scientific implications of space, we can begin to speak with a considerable confidence. Certainly, as a scientific tool, the space vehicle is a device of superb potentialities comparable to other great scientific instruments such as the telescope, microscope, or nuclear accelerator. Under our almost insulating atmosphere we can sense the nature of the universe only through one octave of light, a few octaves of radio waves, the interaction of a few very energetic particles on our atmosphere, and examination of a few meteorites. The result is an almost monochromatic view of the universe.

The simple satellite, as we now know it, extends our scientific capabilities beyond this insulated view. It now permits us to see the universe for the first time in its full range of "color," in the special sense that the satellite broadens the range of our vision from a narrow spectrum to the whole spectrum of nature—from the shortest to the longest wavelengths, from the lowest to the highest particle energies.

To try to outline the full range of scientific experiments that can now be foreseen in artificial satellites would take a very thick volume. In fact, such a volume is now being prepared by the Space Science Board of the National Academy of Sciences, and late this afternoon I have returned from Cape Canaveral, from a 4-day meeting of the Board as it worked on this very task. But to cite a few scientific implications is useful in grasping the real significance of even elementary space science.

We have said that the satellite views the universe in the full range of chromaticity. To the astrophysicist this means that the word "color" takes on new meaning in speaking of the universe. Through his access to the whole range of color of radiations and of spectral distribution over this whole range, he can now view the complete manifestations of atomic behaviour in the stars and gaseous plasmas in space. Certainly, our knowledge of the origin, evolution, and destruction of the matter of the universe will be revolutionized by such information obtained from suitably instrumented satellites. Eventually, an inhabited astrophysical observatory on the Moon may become desirable and necessary to enjoy fully the advantages of space astronomy. This would, incidentally, be a fine international objective rather than a competitive effort among nations.

Closely related to general astronomy are observations of our own Sun—the origin of the energy for life. Our knowledge of the physics of the Sun, its changes and the causes of those changes is surprisingly scant. But above the atmosphere where we can see the Sun in its full glory, and where we can enter the corona at will and even approach the Sun's surface, we can study the radiation distribution, the spectral phenomena, the magnetized plasma, and their changes with time, phenomena that are major clues to the Sun's behaviour.

Turning to the Earth itself, satellites have already given us a new figure for its ellipticity, 298.3, so we are learning of its real figure.

Much more accurate mapping and geodetic surveying is already in sight with ultimate precision of perhaps 10 feet that will permit critical tests of such hypotheses as continental drift. But perhaps the most important contribution to the Earth sciences will come in the field of meteorology. I will stress meteorology at some length, since it illustrates so clearly the great new power that the satellite provides to geography and geophysics by its ability to scan the whole Earth quickly.

We learned in high school that the Earth's atmosphere can be regarded as the gas of a kind of heat engine. The equatorial region is the firebox that receives a net gain of energy from the Sun and stores much of the energy in water vapor that is evaporated. The polar regions are the condensers of this great heat engine, where the atmospheric gas suffers a net loss of energy by an excess of radiation of heat into space. Thus, the Earth's atmosphere is the only great heat engine that uses a radiator as a condenser.

The circulation of the atmosphere that brings us our weather arises from the transfer of heat from the equatorial fire-box to the polar condenser. Unfortunately, the heat input and the output to the engine are not constant. The input changes as variation of equatorial cloud cover reflects more or less of incident heat from the Sun back into space; the output depends on the reabsorption in the atmosphere of heat radiated from the surface, as the gases within the atmosphere that reabsorb the radiated heat are redistributed. Furthermore, a small change in rate of overturn of the oceans by changing winds can change supply of the heat to or from the atmosphere, locally.

Moreover, the equatorial energy is collected by the trade winds and carried to the meteorological Equator where it is piped up through huge equatorial thunderstorm cells to the troposphere to be circulated into the temperate zones. Perhaps 5,000 of these equatorial thunderstorm pipes normally occur each day. But occasionally such cells may fail to form locally or conceivably may direct their energy into the wrong hemisphere to produce temporarily hemispheric unbalance of stored heat. All of these localized changes in input and output may upset the already doubtful stability of the atmospheric flow.

The circulation of heat from the equatorial regions toward the poles is not as simple as it would be through a series of pipes. Instead, the heat is conveyed through couplings between a series of vertical circulation cells successively in the equatorial regions, in the temperate zones, and in the polar regions in each hemisphere. Sometimes, these cells do not transfer heat from one to another as expected, with a resultant delay in the heat transfer and consequent buildup of unusually hot and cold spots, or a rerouting of the ordinary flow patterns. The delay may extend for a considerable time, but when the breakdown does occur, the effects on the weather may be catastrophic. Such gross effects cannot be traced or understood until the whole Earth is observed at very frequent intervals with appropriate measuring devices.

Viewing meteorology in this way, it is not surprising that, through inability to make fundamental global measurements, our present methods of forecasting are far from perfect. By itself, limited observation from a few poorly distributed points on the surface cannot possibly provide the basis for the continuing global description of atmospheric circulation and underlying heat balance and exchange that is the very basis of our weather and of climatic change.

The satellite holds promise of revolutionizing our powers of observation in the field of meteorology. Among the early satellite experiments will be a measure of the heat balance of the Earth and the variation of that heat balance from place to place, i. e., the map of input and output radiation and the changes of that map with time. For the mapping of the hot and cold spots in the sense of excessive input to or output from the atmospheric heat engine is certainly feasible with the Earth satellite. Not far behind will come experimental mapping of the cloud and storm systems over the whole Earth. This involves delineation of changes and movements of storm systems at frequent intervals, and the observation of cyclogenesis. It should not be difficult to count thunderstorms by flash-frequency of lightning on the dark side of the Earth or "radiostatic" discharges produced by lightning on either the sunlit or dark hemisphere, and to map development and movements of active frontal areas. I could go on to many other powerful experiments critical to meteorology. To what extent do meteoric dust particles of microscopic size vary in density from place to place as they are swept up by the Earth as it courses along its orbit? Are such particles of meteoric dust of the kind and numbers that can influence rainfall, as Prof. E. G. Bowen has suggested?

In the field of pure physics are a whole range of experiments, but we might mention positive test of the general theory of relativity through measurement of gravitational red-shift in the lower gravitational field enveloping the satellite. This involves comparison of an atomic clock in a satellite with one on the ground, a comparison involving a measurement to one part in a billion-billion. Yet this certainly will be done in the next few years, since it is so fundamental to progress in the whole of science, and we now have atomic clocks capable of the necessary precision.

Likewise, the sampling of meteoric dust in space will add to our knowledge of the universe, its mass, and the processes of formation of matter. The interaction of cosmic rays with the particles of space can give us knowledge of the age of such material.

I could go on to describe experiments involving primary cosmic ray particles themselves, zodiacal light, character of the ionosphere, propagation of those strange phenomena known as whistlers, and a hundred other studies in physics. Already Van Allen has discovered the curious "radiation belt" of high energy particles extending over some 700 miles in a band around the Earth between the two auroral zones. This belt seems to arise from upward flying debris of cosmic ray collisions, technically called cosmic-ray albedo, that is trapped by the Earth's magnetic field. The discovery of this Van Allen region suggests a host of experiments related to geomagnetism, the aurora, and particle streams from the Sun and from space that will greatly illuminate our knowledge of the Earth's environment.

But aside from their great power to science, satellites are of almost immediate commercial utility. The recent Christmas message of President Eisenhower highlights the potentiality of satellites for relaying communications. Certainly, a variety of schemes can be used to provide tens of thousands of new channels of communications over great distances using satellite relays powered by energy from the Sun.

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The value of such channels for all purposes, including international television, far exceeds the costs of the satellites; they are certain to become regular features of our economy. Of particular interest for communications is the hovering satellite launched eastward to a little more than 22,000 miles in height. Circling the Earth at the rate of its rotation, it will remain continuously in the same line of longitude or can be made to hover stationary over a fixed point above the Equator. The advantage of a hovering satellite for communication relay is obvious. And so, in a number of ways, space activity will extend our economic potentialities in the immediate future.

But we are already looking beyond mere satellites to interplanetary travel, and all of you are aware of the attempts to circle the Moon and examine it intimately. Certainly, science looks eagerly to the data collected by the close passage of the Lunik to the Moon. This is but the first step toward man's dream to visit other planets. Over and above the adventure itself, and quite apart from the unevaluated advantages of occupying other planets, the scientific knowledge to be acquired in such exploration is prodigious. That there are some forms of life on Mars, for example, seems quite certain, since Mars' temperate zones get green in summer and even brown in winter. But there is no free oxygen and little free water on Mars, so the sources of life there are something of a puzzle. Yet we know that life requires only a source of energy, a solvent, and an oxident, so perhaps life on Mars has utilized quite different evolutionary paths, since a variety of usable solvents and oxidents are conceivable. Thus, the difference in evolutionary patterns under presumably independent circumstances might easily provide basic keys to the origin of life itself and might give us some striking surprises. This is but a single instance of tremendous range of extraordinary scientific vistas that will be opened to the interplanetary voyager in every aspect of science. Certainly the surface character under different conditions of erosion and oxidation would have immense geological significance, and the circulation and weather of a different atmosphere would be fascinating.

Interplanetary travel imposes an immense complex of difficulties to be overcome and problems to be solved. Yet, theoretically, all of them can be solved within the framework of our present basic capabilities with time, effort, experiment, and patience. The pattern of development of such space explorations will probably be:

1. Lunar, interplanetary, and solar probes to circle the Moon, Mars, Venus, and perhaps penetrate close to the Sun, to transmit back their scientific findings.
2. Hard landings of certain durable experiments on the Moon and planets.
3. Soft landings of permanent or semipermanent experiments that transmit their data back, with possibly automatic return of such vehicles to Earth with samples. This would amount to a mechanical space man.
4. Short range experiments of man in space, perhaps in a few satellite orbits.
5. Soft landings of man on planets with reasonable probability of return. By this stage, a wide range of safety measures must have been developed and tested.

6. Establishment of planetary bases. Such bases could conceivably be manned by a series of soft landings without immediate expectation of return.

This is a long and difficult program, and it will require many years for completion. Yet it certainly seems capable of completion in the remaining years of this century, that is within the first 40 or 50 years of the space age.

So far I have talked of the capabilities of space activity in the constructive sense. But what problems of international politics are such vehicles likely to impose?

Certainly the space vehicles of one nation can be made to behave in a fashion that another nation does not like, a behavior that seems inimical to its national interest. Certainly, satellites crossing boundaries can collect a variety of intelligence data concerning surface features and construction, movement of transport, and communications information. They can jam communications accidentally or deliberately, or preempt communications channels. Imagine the psychological impact of a Soviet satellite steadily hovering over the United States, on any task, without U.S. concurrence. Satellites can be made to broadcast voice or television into the territories of others quite beyond their present control, and in a way very difficult to jam. Unpredicted satellites can trigger early-warning systems and create fears that might cause wars.

Any instrument of one nation that can be used contrary to the interests of another certainly has military capabilities and can be used as an instrument of war. Therefore, occupancy of space has clear military implications. Certainly, the presence of unregulated satellites in the near future will require development of military capability of nations to knock them out or disable them in some way. Consequently, man is faced with the prospect of agreeing on rigid international space-launching supervision and control or, alternatively, developing a space military capability for disabling space objects that appear to operate contrary to national interest. Certainly an effective agreement on control is to be fervently desired, not only to avoid constant military friction and action in space, but also to optimize the benefits that space can provide to mankind. In the field of communications, for example, agreement on channels, and on cross use of one another's relay satellites is imperative, if the great new benefits to communications are to be enjoyed by all.

But in considering the problem of regulation and control we can well avoid one pitfall. In creating such an international agency, politicians will almost inevitably attempt to endow such an international agency with operating as well as with regulatory functions. In this country of individual initiative, we know well the conflict of interest of the operating as contrasted to the regulatory function. Our own system recognizes regulation as a proper governmental or international political function, but equally recognizes operation as a function for individual enterprise and enthusiasm. The success of the IGY, in my opinion, arose from its organization as an international scientific enterprise, operated *by scientists*, with the consent, cooperation, and aid, but not the direction of governments. Therefore, an agency for regulation and control should be just that—it should leave the scientific and commercial enterprise to those most competent and willing to do the job, within the framework of regulation and control established by the international governmental agency. Only by this clear separation of function can we avoid a kind of international socialism of a pattern that has never yet been found successful. For regulatory bodies tend to be reactionary and conservative and will kill off useful applications unless legally pushed by those who know how to do things.

A second troublesome problem is that of secrecy. Because of the inevitable failures accompanying man's first space attempts, there has been widespread feeling that no account of advance planning for attempts in space should be made public. Rather we should, as a nation, play the Russian game of acting the strong silent giant who hides his failures and surprises the world with his successes.

This attitude seems to me to be infantile and even insulting to a moderately adult world. Certainly, men everywhere view failures with understanding and even respect for the attempt to solve problems at the very forefront (I almost said vanguard) of man's capability. Men everywhere have the right to share in the plans, attempts, failures, and successes in the halting steps toward the conquest of space. Indeed, the very people who must foot the bill certainly have the privilege of some voice in the debate on what should best be done.

But we might be a little careful on how we formulate and publicize our objectives. If Pioneer I had been projected as a very high shot with the scientific objectives that it indeed achieved, it would not have been listed as a failure. The nice clean miss of the Lunik on the Moon was still a great success as a "solar satellite." Nevertheless, as a people, we should not take ourselves too seriously, and become "stuffy" in trying to create this illusion that failure never occurs to us.

On the contrary, widespread advance public information can encourage new brains to join in our efforts. The world will respect our successes all the more if it can share with us our problems. For to achieve these striking objectives, the base of our space program among our scientific brains must be broadened.

Because of the fantasy that has surrounded space in the past, many reputable men have avoided association with space thinking for fear of being branded "space cadets." But reality puts this era behind us, and our universities and institutions must accept boldly the capabilities of the future in fashioning their programs of scientific thinking and research. It makes no sense at all to waste lifetimes on observations from our earthly prison, when the same lives could fashion far more powerful and effective scientific methods from the space capabilities now at hand. For many of you, this means a sharp break with your scientific pasts, with all the effort and discomforts that such breaks imply. Yet the rewards are now certain. The achievement of man's destiny must be earned by the pursuit of objectives fashioned to his most advanced capability.

BRIG. GEN. H. A. BOUSHEY, DIRECTOR OF ADVANCED TECHNOLOGY, UNITED STATES AIR FORCE, WASHINGTON, D. C.

* * * In my position on the Air Force staff, I am, of course, vitally concerned with the question of our Nation's future space role. Therefore, I welcome the opportunity to express my personal views, and hope these will be of interest to you and your committee.

Based on my assumptions that we will steadfastly support a vigorous scientific and military space program, I believe the following space goals will be achieved during the next decade.

Mission	Achieved	Purpose
Unmanned space probes (and lunar probes)	1959	Scientific and military.
Unmanned communication satellites	1960	Military and commerciall
Unmanned geodetic survey, reconnaissance, and attack-warning satellites.	1961	Military and scientific.
Unmanned weather reporting satellites	1961	Military, commercial, and scientific.
Unmanned navigation satellites	1961	Military and commercial.
Unmanned lunar and planetary satellites	1963	Scientific and military.
Manned maintenance, repair, and resupply space vehicles	1965	Military, Commercial, and scientific.
Unmanned lunar surface vehicles (soft landing capability)	1965	Scientific and military.
Manned lunar circumnavigation (and return to Earth)	1966	Do.
Manned defensive offensive space vehicles	1967	Military.
Manned "all-purpose" space station (astronautical observatory, Earth surveillance, weather reporting, and communication relay).	1968	Military, scientific, and commercial.
Manned lunar vehicle (landing and return to Earth)	1968	Scientific and military.
Manned lunar base (start construction)	1969	Military and scientific.

To achieve the above goals, I believe four key areas must receive emphasis. They are: Propulsion, orbital staging or refueling, the early matching of vehicles and boosters, and the early use of space craft piloted by man.

Propulsion is fundamental to all space effort. The perfection of a reliable, million pound thrust rocket engine during the next 3 years would not only give the United States a significant launching capability, but it would also lower the total costs of our entire national space program. Launching costs would be further reduced by development of fully recoverable boosters in 2 sizes of approximately 1 million, and 4 million pounds thrust. These will be developed as a matter of urgency during the next 5 years. In addition, the advantages of nuclear rocket propulsion are so great that I believe this type rocket engine will also receive priority emphasis and will be developed within and 8- to 10-year time period.

Next I think storable liquid fuels and oxidizers having good specific impulse will be used for the upper stages. The perfection of a storable liquid oxidizer within a 4-year period is vital to orbital restaging or orbital refueling. Therefore, I fully expect that rocket engines which develop thrusts of less than 200,000 pounds will generally utilize storable, fuel-oxidizer combinations. Hydrazine in combination with nitrogentetroxide appears to be a promising candidate. By the use of clustering techniques, almost any space mission could be performed, yet the number of individual rocket engine developments could be kept to a minimum. Such a degree of modified standardization will occur, I expect, during the next 3 years.

Last, I believe practical electrical propulsion devices will be developed during the next 5 years. Whether they be ion, plasma, or particle type units, they most probably will require small, nuclear reactors for their source of electrical energy. Since only relatively low thrust outputs are necessary for these type reaction engines to be extremely useful, the nuclear reactor can be small and of low power, and, even for manned space flight, would not entail intolerable shielding weights. I expect such electrical propulsion devices and their necessary nuclear power sources will be in use within 6 years.

Orbital staging and refueling will, in my opinion, prove to be the best means of placing large payloads in orbit and sending the required weights to the Moon and the nearer planets. The process of refueling or restaging in orbit (at an altitude of perhaps 150 to 350 miles) has been thoroughly described and does not require repetition. However, three elements of orbital staging have not been stressed sufficiently. These are: The great advantage of equatorial launching, the use of man as space craft pilots to effect orbital rendezvous and final contact, and the utilization of long duration reverse thrust during reentry. The latter technique of course is practical only if orbital refueling or staging is employed, and by such means the severe heating and deceleration problems of reentry can be completely avoided. For these reasons, I think the first manned, orbital restaging or refueling flight will be accomplished within 4 or 5 years, and I fully expect that the necessary priority and emphasis will be placed on this key phase of space exploration.

Early matching of vehicles and boosters should be accomplished. The development of large rocket engines and large boosters is already underway. This work should be coordinated with the design of the vehicles which will use them, and concurrent vehicle development should be initiated immediately so as to preclude a crash program at a later date. I expect the establishment of such an integrated, national engine-booster-vehicle program will be one of the early tasks of the National Aeronautics and Space Policy Council during calendar year 1959.

The early use of space craft, piloted by man, while listed last among my four "key areas of space flight," is nevertheless, the most important. (By "piloted space craft," I refer to a vehicle wherein a pilot operates controls and directs the vehicle. This is quite a different concept from the so-called man-in-space proposal which merely takes a human "along for the ride" to permit observation of his reactions and assess his capabilities.) The high speed flight experience of the NACA and the Air Force has shown that piloted craft return research data more effectively and more economically than do unmanned vehicles. While there is a place, certainly, for automatic, instrumented vehicles, I believe *man* himself will prove "The essential payload" to the full utilization of space. Orbital rendezvous, controlled landing after reentry, and space missions other than the simplest sensing and reporting type, will require man. If for no other reason than that of reliability, man will more than pay his way. For the establishment of a useful space station or a lunar base, man is essential. Therefore, I believe we must intensify our efforts to design and develop piloted spacecraft. Granted such emphasis, I expect the first piloted space flight will occur within 4 or 5 years.

In summary, within the next 10 years we can expect numerous unmanned satellites in orbit—about the Earth, around the Moon, and even reporting the distant conditions during rotation around the

Sun. Those unmanned vehicles which circle the Earth will greatly improve the geodetic knowledge of our planet; will enhance our weather forecasting techniques; will aid the cause of peace by promptly detecting and warning the free world of potentially hostile activity; will revolutionize the worldwide systems of communications and navigation; and will give scientists unmanned observation sites far removed from the disturbing influences of our atmosphere. The unprecedented worldwide interest in space evoked by the earliest satellites will be minor indeed compared to that which is certain to occur when numerous satellites, some of which will weigh over 10 tons each, are visible to the unaided eye during both day and night. The psychological effect will extend to all peoples, and will exceed in impact any of man's previous accomplishments.

We can also expect, during the next 10 years, that piloted spaceflight will become routine, and will be followed by not only a manned circumnavigation of the Moon, but near the end of the 10-year period, the start of construction of a large space station which will be assembled section by section as the result of numerous individual firings from an equatorial launching site. Final join-up of these sections will be accomplished by piloted "space-tugs" which will operate in orbit during their entire useful life. In addition to the "tugs", manned resupply and maintenance spacecraft will shuttle from the Earth's equator to the orbiting satellites. Of course military spacecraft will police the near vicinity of the Earth to prevent the use of space for aggressive purposes.

Prior to the end of the decade, I firmly believe that a piloted spacecraft, taking full advantage of outgoing and returning refueling in the equatorial orbit, will land on the Moon. This remarkable feat will signal the beginning of construction of a lunar base—the advantages of which will only become fully apparent as we recognize the enormous difficulties of supporting men and machines in space for long term periods. The lunar base will become our foremost scientific space observatory and will provide the jump-off site for interplanetary exploration. That it will also have military potential seems beyond argument, for almost every mission which can be accomplished by an earth-orbiting vehicle can also be performed from the Moon, where materials abound and where man can exist in a gravity environment equaling one-fifth that of our Earth. The lunar base, I believe, will eventually become the cornerstone of our space capability.

In conclusion, I must point out that in making these speculations I have assumed that we will find it both desirable and possible to commit relatively large resources and efforts to gain supremacy in space. The time estimates in particular are dependent upon the consistent support over a period of years of the development effort necessary to achieve this goal. If we find that we are unable to place the required emphasis on space due to our many additional requirements, then these schedules will, of course, slip accordingly. * * *

ARTHUR C. CLARKE, AUTHOR AND EDITOR, AMATEUR ASTRONOMER, MATHEMATICIAN, PHYSICIST, LECTURER ON ASTRONAUTICS, FELLOW, ROYAL ASTRONOMICAL SOCIETY, FORMER CHAIRMAN, BRITISH INTERPLANETARY SOCIETY, MEMBER, BRITISH ASTRONOMICAL ASSOCIATION, COLOMBO, CEYLON

* * * In the decade 1960–70 I think we may expect the following with a very high degree of assurance, almost amounting to certainty:

Automatic probes to the Moon, Mars, Venus.

Establishment of meteorological and communication satellites, possibly manned, certainly visited by servicing teams.

Manned flights around Moon, without landing.

Robot landings on Moon.

Flight tests of nuclear propulsion devices.

The following are possible but much less likely in 1960–70:

Probes to Mercury, asteroid belt, outer solar corona.

Manned flights around Mars and Venus without landing, except on Mars' moons.

Landing of manned spaceship on Moon.

I consider the latter unlikely before 1970 owing to limitations of technical manpower and the need to assimilate the results of the first period of astronautical research. It would be unhealthy to force the natural pace of development and attempt too much, too soon.

Of all the applications of astronautics during the coming decade, I think the communications satellite the most important. The use of satellites for TV and radio relaying was, I believe, first suggested by myself in the British journal Wireless World in 1945, and it is now widely conceded that this may be the only way of establishing a truly global TV service. The political, commercial, and cultural implications of this, however, do not yet seem so thoroughly appreciated.

Living as I do in the Far East, I am constantly reminded of the struggle between the Western World and the U. S. S. R. for the uncommitted millions of Asia. The printed word plays only a small part in this battle for the minds of largely illiterate populations, and even radio is limited in range and impact. But when line-of-sight TV transmissions become possible from satellites directly overhead, the propaganda effect may be decisive—especially if it is coupled with a drive to produce simple and cheap battery-operated receivers. There could be few communities which would be unable to afford one set (in Ceylon there are dozens of radios blaring in every village) and when we consider the effect of TV upon our own ostensibly educated public, the impact upon the peoples of Asia and Africa may be overwhelming. It may well determine whether Russian or English is the main language of the future.

The TV satellite is mightier than the ICBM; this is the fact which I would most earnestly bring to the attention of your committee. * * *

DR. JAMES H. DOOLITTLE, MEMBER, NATIONAL AERONAUTICS AND SPACE COUNCIL, WASHINGTON, D. C.

* * * regarding the next 10 years: I believe that we can, if we will, in the next 10 years, establish reconnaissance, communication, meteorological, and astronomical satellites. We can put a man in orbit. We just may put a man on the Moon and get him back. We can "see" Mars and Venus close up first by means of instrumented space vehicles and then by man-carrying vehicles.

Chemical propulsion, including high-energy fuels, will be used for the first part of the next decade, but nuclear-rocket propulsion can be developed and in practical use before the end of the next 10 years.

The principal determinant in whither we go in space in the next 10 years is not science and technology but rather our national sense of urgency and willingness to sacrifice. * * *

DR. WALTER R. DORNBERGER, TECHNICAL ASSISTANT TO THE PRESIDENT, BELL AIRCRAFT CORP., BUFFALO, N. Y.

A. The next 10 years of the Space Age *will* fundamentally be characterized by 5 important achievements leveling the road to the ultimate utilization of outer space for mankind.

1. The establishment of an exact scientific model of the space environment up to Mars and Venus, achieved by scientific space probes.
2. The safe return of manned and unmanned space vehicles to predetermined bases on the Earth.
3. The development of manned and unmanned space vehicles, maneuverable in space and able to rendezvous with permanent satellites or space systems.
4. The establishment of a permanent automatic weather-predicting satellite system.
5. The establishment of a permanent automatic communication satellite system supplementing, later replacing oversea cables, and covering the entire globe.

The exploration of space by automatic space vehicles will have extended in this time period up to Mars and Venus. Circumnavigation of these planets, as well as soft landings on the surface of the Moon will have been achieved. The main area in space of manned vehicles, however, will be mainly up to 650 miles this side of the radiation cloud at operational times of up to 2 to 3 weeks.

B. In the powerplant field the following *will* be achieved:

1. The successful development of operational first-stage booster powerplants with millions of pounds of thrust, however, using cheap and conventional propellants.
2. The successful development of operational upper stage high-energy propellant powerplants (hydrogen-oxygen, fluorine-hydrogen).
3. The successful development of nuclear powerplants for the upper stages. This powerplant will be used for maneuvering in space.

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4. The successful development of air-breathing recoverable manned first-stage boosters (turbojet-ramjet combination) taking off horizontally and launching the upper stages at altitudes of about 60,000 feet and at speeds of about Mach 5. For economy reasons we will have later in that time period no expendable first-stage boosters any more for civilian and scientific space flights.

5. The successful development of secondary powerplants (auxiliary power supply) guaranteeing an economical operation over weeks in space.

6. The successful development of ion rocket space powerplants may be achieved.

With these boosters and powerplants available and using them in different combinations we will be able to get in this time period about 50,000 pounds of payload in orbits and about 30,000 pounds to the Moon.

The progress in powerplants (first and secondary) and in guidance and navigation systems, besides large and well-equipped scientific probes into outer space, even beyond Mars and Venus, *may* push forward the accomplishment of the following feats in the time period in question:

1. Space astronomical observatories, manned and automatic.
2. Space laboratories, manned.
3. Space television transmitting stations, automatic.
4. Space filling, storage, supply, and assembly facilities, manned and automatic.
5. Space maintenance, supply, and rescue ships, manned.
6. Lunar exploration, automatic.
7. First manned flight to the Moon.

C. The preceding achievements and goals mainly deal with our national effort for the peaceful use of space. However, it would be foolish and nothing else than putting the head in the sand, if we would not consider the military use of space. Defensive weapons becoming stronger and stronger will force our military to look at space as an extension of their field of military operations into a vertical direction. As long as there is no enforced international agreement about the peaceful use of space, we better have all possible space weapons at hand in order to avoid our national defeat.

My personal feeling is, therefore, that we will see within the next 10 years the following space vehicles in our weapon arsenal:

1. Reconnaissance satellites, optical, radar, infrared, and ferret, automatic.
2. Reconnaissance and bombing space gliders, manned.
3. Unjammable weather stations, automatic.
4. Unjammable communication satellites, automatic.
5. Military maintenance, supply and rescue ships, manned.
6. Antisatellite space weapon system, manned and automatic.
7. Satellite defense systems, automatic.
8. Bombing devices, automatic.

What these weapons systems will finally look like, up to which altitude they will operate, I don't know yet, but I know, we have to have them sooner than our potential enemy.

DONALD W. DOUGLAS, CHAIRMAN OF THE BOARD, DOUGLAS AIRCRAFT CO., SANTA MONICA, CALIF.

* * * I would first like to point out that speculation as to what the next decade holds in the field of astronautics and space exploration is difficult to make. It is possible to predict the first few years with a certain amount of confidence, but the rapid rate of progress in scientific fields makes 10 years a long time for prediction. It is my general feeling, however, that the time is now appropriate for serious space exploration, and that many things previously considered in the realm of fancy can now be accomplished.

It is certainly possible, within perhaps 2 years, to send instrumented probes to the Moon, Mars, and Venus with sufficiently large payloads landed softly on those bodies to permit obtaining really useful scientific information. It appears that techniques for communication, in space, at least as far as the near planets, can be developed also within a few years. As for more far-reaching achievements, certainly within 10 years manned flights around the Moon and return can be accomplished, and possibly during that time manned landings on the Moon and return will be possible. As to types of propulsion to be developed, there are a large variety of possible useful systems. In the past history of aircraft, different types of propulsion units were developed for different applications, and the same would be expected of space propulsion systems.

It seems clear, that some utilization of nuclear energy will be a requirement to achieve the very high performance for really practical space operations.

Exactly which method of utilizing nuclear energy will be most appropriate is yet unclear. In fact, one of the most difficult items of prediction is the rate of progress of nuclear rocketry since so much depends on the test programs now getting underway. They should be watched with great interest. * * *

Although this represents a relatively short list of future predictions, I do not feel that a more elaborate discussion is really justified in view of the uncertainties involved. * * *

DR. LOUIS G. DUNN, PRESIDENT, SPACE TECHNOLOGY LABORATORIES, INC., LOS ANGELES, CALIF.

* * * I am summarizing my extrapolation into the next 10 years as based on our present knowledge of space technology. Progress in space exploration can be measured in a general way against four broad technical areas:

I. Communications
II. Propulsion
III. Guidance and Control
IV. Reliability

It is my opinion that the most significant development that will emerge out of the various space programs is the use of satellites for a *worldwide communication system.* Such a system can have a profound effect on our daily lives. Thus I shall discuss communications in somewhat more detail than the other three areas.

I. COMMUNICATIONS

A. State of the art

The first demonstration of the use of a satellite for communications occurred during the flight of Pioneer I. This relatively crude transmission is the precursor of what should become the most important peaceful use of rocket vehicles. Communications satellites can now be placed in orbits ranging in altitude from 1,000 to 25,000 miles and with periods of revolution about the Earth ranging from 2 hours to more than 24 hours. It appears possible to develop adequate controls so that the altitude of the vehicle may be maintained constant over very long periods of time. It is also clear that present missile guidance and space-tracking systems are adequate to establish circular orbits with the requisite accuracy. Solar power supplies are available for supplying moderate powers to the satellites; if higher powers are required, a development program for nuclear electric power sources will be required. The actual electronic components for repeaters and other portions of the communications system are available and need only be adapted to the rocket vehicle environments. It is only in the area of the actual environment to which the satellite will be subjected that there is considerable uncertainty—an uncertainty which will require a number of specially instrumented satellite test flights to resolve.

B. What the actual communications satellite will look like

The communications satellite of the near future will be unlike most of the artists' conceptions I have seen. Factors such as the relative motion of the Sun, the requirement for directional antennas at particular points on the Earth, and guidance and attitude controls dictate a design which will consist of a central, small, spherical body with limbs jutting out from the surface to support and orient solar cells and directional antennas. Inside the sphere will be storage batteries, communications repeaters, horizon or star seekers, control circuits and energy source, and the guidance subsystems. This complex system must be designed to operate without attention for years at a time, an accomplishment only recently made possible by transistors and other ultrareliable components.

The structure of the satellite will be of Fiberglas and magnesium honeycomb for light weight, strength, and rigidity. The paddle-shaped limbs stowed along the rocket's sides during ascent will automatically spring open outside the Earth's atmosphere. The sphere and the surfaces of the paddles, including the solar cells, will be treated to provide the proper balance of heat received from the Sun and heat radiated by the electronic circuits inside the sphere.

C. Passive satellites

A first step in the development of intercontinental satellite communications might well be a passive satellite. A large metallic balloon placed in a circular orbit by a rocket can serve as a reflector from which powerful ground stations can bounce energy to a second ground station thousands of miles away. The principal disadvantage of this scheme, whose advantage is that it does not require airborne electronics and other complexities, are the relatively narrow band widths of the system and the very large ground power and receiving antennas required.

D. Trajectories

The trajectories that must be flown to place a communications satellite into orbit require more attention than do the trajectories for the scientific satellites already launched. Because a satellite can serve as a communication relay between two ground stations only while it is in line-of-sight of the two stations simultaneously the usefulness of the satellite is determined to a large extent by the nature of its orbit. Although several types of orbit are of interest for communication purposes, one of the most promising is the equatorial circular orbit with a period of 1 day, so that it has the unique property of appearing to hover constantly above the same point on the Earth. Accurate positioning of the satellite at the appropriate altitude, which is about 22,000 miles, requires more sophisticated guidance systems than used to date but can be accomplished by combining existing missile guidance components with recently established space-tracking stations.

Because the propulsion system cannot burn continuously until the satellite is actually in orbit, a combination of firing periods and coasting periods is required. The simplest sequence consists of a normal launch phase followed by coasting on a transfer ellipse to the desired altitude. An engine then is fired to place the satellite in orbit. Final vernier corrections may be required to insure the precise orbit. Throughout the time from launch until final orbit establishment, some element of the guidance system must be measuring the path of the satellite to provide the basis for proper control signals.

E. Economics and exploitation

A careful analysis of the relative costs of satellites and of more conventional communication systems shows that even at today's costs the communications satellite costs less than the underseas telephone cable per cycle of band width and is comparable in cost with that of the overseas radio system. But what is of utmost importance is that it will do what no other device will do: it will provide the wide band widths required for television, for multichannel telephone, and for secure communications. Literally, it opens a new era of reliable long-band communications that may well revolutionize our life. It is safe to predict that this particular use of rocket vehicles will have more direct effect on the man in the street than any other development in space technology. He will now for the first time be able to see, as well as hear, an English cricket game, the shelling of Quemoy, the coronation of a pope.

II. PROPULSION

In the area of propulsion we have made substantial progress during the past 10 years in the understanding of chemical systems and in the building of chemical propulsion systems of large thrust. I believe that, within rather narrow limits, we clearly understand the performance which we can expect from various chemical systems, the advantages and disadvantages of the various chemical systems, and the time and effort required to develop a propulsion system of a given size. We also know rather precisely the size of vehicles and the total thrust required for various space missions.

Other new types of propulsion, such as nuclear, thermonuclear, and ion, are still in an exploratory state. However, these systems offer sufficient promise that research should be continued in these fields, although it is unlikely that any one of these systems will be developed in the next 10 years to the degree necessary to replace chemical systems. For this reason, it is my opinion that the Nation's space program during this period will have to rely heavily, if not exclusively, on chemical systems. However, a concentrated effort is needed in the development of chemical propulsion systems using propellants of higher energy than those presently used.

III. GUIDANCE AND CONTROL

Space missions require precise control of position and velocity of the vehicle during powered flight. As a result of the intensive effort in the ballistic-missile program, a great deal of progress has been made in the past 10 years. I believe that the technical problems are sufficiently well understood and that actual hardware is available to the extent that I foresee no real difficulty in accomplishing most of the desired missions.

One of the improvements which need to be made during the next 10 years is reducing weight. For example, in our present Thor-Able system, we find that to place 1 pound of payload in the vicinity of the Moon requires about 1,800 pounds total vehicle weight at takeoff. Although it is true that this ratio will be greatly improved in the near future, nevertheless, in those flights in which guidance is required in the last stage so that its weight effect is equivalent to payload, the guidance weight becomes an important consideration from a standpoint of the final payload which can be carried. In addition to the guidance requirements during the initial powered flight, certain space missions require precise position or velocity corrections at distances which may be millions of miles from the Earth. Although this can be broadly considered as part of the guidance and control problem, it is related to the general problem of communications previously discussed.

IV. RELIABILITY

The basic technical understanding today exists to proceed in an orderly fashion with space exploration. One of the most difficult problems that will continue to face us during at least the next few years and on a continuing basis is that of reliability. Because of the complexity of the systems and the necessity that they must all interact with a high degree of precision, it will continue to be a difficult problem to exercise the proper quality control, by inspection assembly, acceptance testing, and so forth, to insure success of the entire system. I believe certain steps can and should be taken to improve the chances of success, namely:

A. A greater appreciation by industry of the vital necessity of quality control of a type considerably more rigorous than any which has been used to date.

B. An application to the maximum extent possible of the very large effort which has gone into the ballistic-missile program.

This comment applies to the actual use of hardware as well as the large body of experience which has been gained.

C. A deliberate and strong effort to make the equipment in the total system as simple as possible consistent with the particular experiment. We know from experience that it requires great effort and technical ingenuity to make a system simple. Such effort will pay off heavily, however, in terms of success, and maximize the returns for the dollars spent.

These specific points are in no way the only ones, but I believe they are of major consideration.

In summary, I foresee no real technical barriers which will hamper any program for the scientific exploration of space. We can have the ability to send humans to or around the Moon and back; we can achieve a more fully integrated understanding of weather conditions around the world, which in turn may lead to weather forecasting as a more nearly exact science. I will not even disagree with those who feel that once we understand the basic causes underlying our weather we may be able to control it.

The extent to which such achievements will become realities, and the degree to which the United States will be a pioneer in these new fields of knowledge, will depend more upon the support which the American people are willing to give to the space program than upon any technical problem that I can foresee. Clearly, the very nature of this work causes it to be a costly undertaking and can be vigorously prosecuted only if it is given the proper financial support.

DR. ERIC DURAND, MANAGER OF SPACE SCIENCES, SPACE TECHNOLOGY DIVISION, AERONUTRONICS SYSTEMS, INC. (SUBSIDIARY, FORD MOTOR CO.), GLENDALE, CALIF.

A realistic estimate of progress in space flight in the next decade requires an evaluation of three principal factors: The effort made (budget), the objectives selected (missions), and the component developments to be expected (state of the art). These will be discussed in the above order.

BUDGET

It is clear that future rate of progress in space flight will be closely tied to the effort expended which, in turn, is determined primarily by budgetary considerations. Except, perhaps, in the area of communication relays, all space operations for at least the next two decades will have to be Government sponsored, and the funds therefor will have to come out of the Federal budget. How much we spend, therefore, is a matter of national policy.

Our view as to what the space budget level will be and should be is as follows. First, we do not hold to the view that this country is hard up economically, and must curtail Government expenditures to the bone. Nor do we believe that unbounded spending of Government funds is the answer. Consequently, our estimates of future progress are based on what we consider a median view—an active, well-funded, but not unlimited program of development outside of the military budget.

The order of magnitude of budget we consider reasonable is as follows. For the next 2 years, the expenditure rate would be about $1 billion per year. This would be stepped up during the succeeding 3 years to perhaps 4 to 5 billion dollars, where it would be held constant for the rest of the decade.

This budget does not include expenditures for purely military development or production. It does, however, include the development of propulsion systems and certain other components which would be used for both military and civilian purposes.

It seems to us that the key to the question at hand—what the next decade will bring—lies mainly in the state of the art of propulsion systems. Specifically, while we believe that work on radically new propulsion schemes should and will proceed, we do not see these as entering the picture in practical vehicles during the next decade. In other words, our ability to perform difficult space missions will be determined by the improvements which will be made in our present propulsion systems, particularly in the area of larger booster engines.

While solid-propellant rocket motors are improving rapidly, it does not now appear that they will be able to compete with liquids for the main stages of difficult space missions because of their inherently lower specific impulses even compared to the current liquid oxygen-kerosene systems. The disadvantage is more pronounced in comparison with such advanced liquid propellants as fluorine-ammonia, which should become operational within a few years at least in the smaller sustainer motor sizes. Solid rockets will, however, be useful for such auxiliary functions as braking to bring a satellite out of orbit or to establish a lunar satellite.

Our predicted timetable for the development of operational boosters is as follows:

Type	Thrust pounds	Operational date	Remarks
3 motor, 1½ stage	360,000	1959–1960	Atlas.
3 motor, 2 stage	300,000	1960–1961	Titan.
6 chamber, 1 stage	1,000,000	1961	Underway.
1 chamber, 1 stage	1,000,000	1963	In development.
6 chamber, 1 stage	6,000,000	1965	In planning.

If this estimate holds, then missions using gross takeoff weights of the order of 4 million pounds should take place within the decade.

MISSIONS

The principal question with respect to missions is whether to concentrate or to diversify the effort. For a country with a highly limited budget, concentration on a single mission would undoubtedly be necessary. The budget we have just discussed, however, permits a considerable degree of diversity in missions. Accordingly, we would recommend the support of several programs, most of which would see fruition within the decade.

Three groups of missions are either under way or should be started immediately with the expectation of accomplishment within the next decade. These are:

1. Improved instrumented satellites

A family of satellite vehicles ranging upward from the present Vanguard and Explorer size to the largest obtainable with a 6 million pound booster will be developed. These will serve both military and nonmilitary functions such as reconnaissance, experimentation, communications, relay, and weather forecasting. An important mission will be to establish a satellite space telescope.

2. Manned (recoverable) satellites

The present Atlas booster is capable of putting a man in a satellite orbit, for a limited period, and provide for his safe return. This capability will be improved with the Titan, particularly through the use of advanced propellants, such as fluorine-hydrazine or fluorine-ammonia in the second stage. The advent later of a 1 million pound thrust booster will make it possible to put a large satellite in orbit with a crew of two or more men, and durations measured in weeks, and possible months.

3. Lunar probes

A successful lunar firing may be accomplished in the next few weeks—in any case, within a few months. Larger probes with larger payloads and greater accuracy will be developed. These will include one-way shots with and without impact, the establishment of a satellite around the Moon, and circumlunar shots with destructive return to Earth. A circumlunar shot with safe return may well be achieved also, although this involves the solution of some difficult guidance problems.

Another type of mission will probably be accomplished within the decade, although its initiation on a large scale should probably await experience with lunar probes. This is:

4. One-way interplanetary probes

Attempts will undoubtedly be made to fire rockets to Mars and, perhaps, Venus. It is not clear yet whether the guidance problem can be solved within the decade, nor whether we will be able to prove that the planetary vicinity was actually reached because of the communication distance involved. It is unlikely that we will be able to fire such a probe with return to Earth in less than 15 to 20 years.

It is significant, perhaps, to note which missions we feel will *not* be accomplished in this decade. These include the following:

1. Manned lunar flight (assuming man to be nonexpendable).
2. All missions using nuclear-powered motors and "low thrust" propulsion systems.
3. Interplanetary flight with return (and hence, by implication, manned interplanetary flight).

We do believe all these missions will ultimately be achieved. The first two might be accomplished in the next following decade, and the other two in the third decade.

The foregoing discussions have dealt with generalized missions. Four specific missions involving the use of artificial satellites should be mentioned. Each has a highly practical value, and each should be attained within the decade. These are:

1. *Reconnaissance satellite.*—This program, already under active development, will provide invaluable military reconnaissance and surveillance data.

2. *Weather satellite.*—Great improvements in weather forecasting will become possible with a satellite providing rapid overall data on cloud coverage and atmospheric transmission, albedo, and emission. Weather forecasting may not become an "exact science," but it will be greatly improved. This has tremendous implications, both military and civilian. As a special point, there will be great benefit to military and commercial aircraft if it proves possible to recognize jet streams from satellites.

3. *Communications satellite.*—A system of satellites will offer tremendous advantages, both military and civilian, in the fast handling of bulk communications, greatly relieving the available radio channels, which are already severely taxed. The areas here include both message traffic and entertainment (radio and TV).

4. *Navigational buoy system.*—A set of satellites equipped with beacon transponders will serve to provide accurate navigational information. Continued tracking will establish their orbits to within a matter of feet, and long-term ephemerides can then be computed. This system will be useful to sea and air navigation as well as to space navigation. These or other satellites will be used for the geodetic purposes of establishing accurately the figure of the Earth and the various intercontinental ties.

SUPPORTING PROGRAMS

Various supporting programs must be activated, not only to accomplish the missions suggested for the next decade, but also for those which will follow later. A broad list of program support areas follow:

1. Vehicles.
2. Propulsion systems.
3. Guidance and navigation.
4. Structures and materials.
5. Environment control—manned and unmanned flight.
6. Instrumentation—scientific and operational.
7. Earth space range.
8. Orbit theory.
9. Communications.
10. Power sources.

Some of the results to be expected from such programs will now be discussed.

1. *Vehicles.*—Within the decade, a family of booster vehicles should become available including the present Jupiter, Thor, and Atlas, the coming Titan, and new 2-stage boosters based on the previously mentioned 1,000,000- and 6,000,000-pound thrust engines. With various upper stage and payload packages, a variety of missions of the types already discussed will be accomplished.

2. *Propulsion.*—Our prediction with respect to high-thrust propulsion units has already been covered. In addition, much progress should be made in the ion-propulsion systems, although these probably will

not be operational except on a small scale for more than 10 years. The adaptability of nuclear propulsion to space flight is not yet demonstrated. It may prove unsuitable because of the shielding requirement. On the other hand, a breakthrough in heat-resisting materials could make it highly competitive with chemical systems. It may prove useful either as a heat source for a reaction motor working on hydrogen, or as a prime power source for an electrical propulsion system such as ion propulsion.

Work on other advanced concepts, such as frozen radicals, "solar sails," and photon-propulsion systems will continue, and a fair evaluation of their potential should be possible within a few years.

3. *Guidance and navigation.*—Great improvements will be achieved in inertial guidance components and in lightweight guidance computers. Also, techniques will be developed for in-flight observation of position, both from onboard and ground-based equipment. Typical devices will be star trackers and associated navigation computers. Techniques for midcourse and terminal trajectory control will be developed and used for satellite and lunar missions, possibly to a point where safe return is possible from a lunar flight (requiring grazing the atmosphere within a band a few miles wide). Use will be made of simple onboard computers processing preflight computed orbits. See also item 8 below.

4. *Structures and materials.*—Many advances will be made along the lines of better honeycombs, light metals, resin-bonded glass, and quartz fibers and other lightweight structural materials. Advantage will be taken of the absence of stress in a free-fall condition. Large use of plastic film inflatable devices (balloons) can be anticipated for antennas, energy collectors, solar sails, and possible structural elements. Improved reentry materials and insulation will appear.

5. *Environment control.*—The principal improvements here will have to do with manned flight. Ways will be found of the economical maintenance of breathing air, temperature, and humidity. True closed-cycle systems may appear, although this may require over a decade. Alternately, efficient food sources and devices for extracting usable water and other substances from human waste will be developed. The problems of radiation in space will be studied, but the solution cannot be predicated until the magnitude of the hazard is known, which should be very soon. (It may be noted that ultraviolet radiation, often quoted as a hazard, is readily stopped by the thinnest sheet of black paper or by paint!)

6. *Instrumentation.*—One area where extensive development will be required is that of the vehicle-borne instrumentation. Along the scientific front, we need, and may expect to obtain within the next decade, numerous types of lightweight scientific apparatus. Among these are:

(*a*) Improved magnetometers to measure all three coordinates of the magnetic field;

(*b*) Radiation detectors which can determine the type, energy, and direction of the radiation;

(*c*) High-resolution ultraviolet and soft X-ray spectrometers;

(*d*) Ionization and electrostatic field meters to observe electrostatic winds, ion clouds, etc.;

(*e*) Mass-spectrometer gas analysis devices;

(*f*) Optical devices for measuring Earth's albedo as a function of wavelength over the range from the ultraviolet to the infrared. Such devices will also be able to measure the albedo of selected regions such as cloud masses, oceans, deserts, etc.;

(*g*) Devices for measuring the size, frequency, energy, and composition of meteorites and interplanetary dust;

(*h*) Space telescopes operating in the ultraviolet, visible, and infrared for numerous applications including mapping of the skies in wavelength regions now obscured by the atmosphere, twinkle-free studies of the Moon and the planets, and spectral studies of the Sun;

(*i*) Retrievable devices for collecting samples of the high atmosphere to determine its composition and for measuring the accretion of solar material;

(*j*) Devices for making synoptic measurements of upper atmospheric winds and of the related general circulation;

(*k*) Electromagnetic propagation and ionosphere fine structure.

Similar advances are required and will be made with respect to operational instrumentation. The areas of guidance and navigation, environment control, communications, and power sources are discussed as separate items. In addition to these, advances are required and will be made in numerous areas including the following:

(*a*) Attitude reference and control, including the development of minimum roll-rate systems to permit high-resolution photography;

(*b*) High-gain stabilized antennas with programed or servo-controlled orientation;

(*c*) Reconnaissance and weather-observation devices including photographic and electronic scanning cameras working in various spectral regions and ferret systems. Many of the scientific experiment instruments will also be adopted and used operationally;

(*d*) Various types of monitoring, display, and control devices for manned vehicles and for unmanned vehicles using telemeter and command data links to ground stations;

(*e*) Beacons for aiding ground tracking;

(*f*) Orbit and attitude correction devices.

7. *Earth space range.*—The extensive space operations in the next decade will require a well-coordinated worldwide network of stations for keeping track of the vehicles, for receiving data from them, and for issuing commands of various types. For economic reasons, a single network should be used for all vehicles, both military and nonmilitary. Various types of stations are needed. Some will be mainly for tracking—optical and radio; others will deal with data transmission, while still others will perform decision functions. Generally, 1 master station will combine all 3 functions, while auxiliary stations will handle either tracking or data transmission only, or both.

An elaborate interstation communications link will be required, as well as extensive computing equipment for orbit determination and data processing. The question of on-station computation with narrow-band communications versus centralized computation with wide-band communications requires further study.

Associated with the foregoing station complex will be several launch complexes—notably at Patrick, on the west coast, and probably in the far Pacific. There will also be one or more recovery ranges with provision for locating and retrieving space vehicles, including manned ones. The more distant future will see maneuverable vehicles which can be steered to conventional landing fields such as airports, but most or all of the recoveries of the next decade will be unguided, the recovery area being determined by the vehicular orbit and the choice of time of initiating a return-to-Earth command signal.

8. *Orbit theory.*—Extensive work will have to be done on orbit theory. Most of the analyses done to date have been of the "feasibility" type using inefficient "brute force" computational methods. Precision space flight requires precision orbital analysis, which is so complex that brute-force methods are too slow and often too inaccurate even with large digital computers. (Work at Aeronutronic Systems, Inc., has already shown that tremendous improvements in computational speed, efficiency, and accuracy are possible by the use of advanced forms of some of the elegant techniques used in classical celestial mechanics.)

A whole new, untouched area that will be opened up in the next few years is that of on-board orbit determination for in-flight guidance purposes. This will certainly be necessary for interplanetary flight. Precision may be secondary, since presumably later correction for early errors can be made, but extreme emphasis will have to be placed on computational efficiency to reduce the weight of the onboard equipment.

9. *Communications.*—One of the most urgent and difficult of the problems to be solved will be that of communications, which are required for the transmission of commands to the vehicle; for the telemetry of vehicle-generated data to the ground; for intervehicle communication; and for intelligence exchange in cases of manned flight.

Important advances will be made in the following areas:

(*a*) Efficient modulation methods to obtain the maximum transmission of information for the power expended.

(*b*) Efficient, lightweight vehicle-borne transmitters.

(*c*) Low-noise receivers.

(*d*) High-gain directional antennas for both ground and vehicle use.

(*e*) General reduction in weight, size, and power consumption of vehicular equipment, together with improved reliability.

10. *Power sources.*—The increasing complexity of vehicle-borne equipment will call for larger power sources, with great emphasis on size, weight, and lifetime. Advances will be made on solar and nuclear power sources.

The initial work will be directed toward the use of power for control and instrumentation, with demands ranging from a few watts to a few kilowatts, and durations ranging from a few hours to a year or more. Later, power sources in the megawatt range will be required to drive ionic, photonic, or other advanced propulsion units. Here, the durations will range from a few days for lunar missions up to many months for interplanetary missions. More modest power demands will also occur for cases where such propulsion systems are used for orbit correction rather than main propulsion, but even here, the range will be tens or hundreds of kilowatts.

FREDERICK C. DURANT, III, FORMER PRESIDENT, AMERICAN ROCKET SOCIETY, FORMER PRESIDENT, INTERNATIONAL ASTRONAUTICAL FEDERATION, EVERETT, MASS.

*** * * The dissertation which follows is divided into three general categories: administration of space research, technical accomplishments, and international cooperation. Some of the concepts mentioned have been originated by others. I put them forward, perhaps in different words, not as mine but because they seem important at this time.**

ADMINISTRATION OF SPACE RESEARCH

As others have recently stated, what will occur in space technology during the next 10 years will depend not upon the feasibility of accomplishment, but rather upon the continuing interest and support of the people.

Federal-sponsored research in recent years has been plagued by "off again, on again" funding. A common result of such sporadic funding is discouragement and disillusionment among many scientists.

For a healthy climate in which to nurture research, a constant level of support is necessary to attract and hold competent workers.

There is another requirement for the research environment which will produce rapid steps forward in the ceaseless quest for a better understanding of nature. This requirement is an administrative system which will permit bold new concepts to be heard, judged, and considered carefully for the funding of an investigative program. The critical administrative evaluation which I speak of should be of the ability, creativity, and record of progress of the individual who originates these programs, rather more than the program upon which he wishes to work. Too often, research advisory committees, even though composed of brilliant scientists in their own right, deliver ultraconservative opinions when acting in concert. This "lowest common denominator" type of review and guidance can reduce national scientific programs to mediocrity and attract mediocre researchers only.

In a technology which is vital nationally and because we face a formidable competitor, I am convinced that we must cultivate a research atmosphere conducive to the origin of adventurous ideas as well as methodical, straightforward programs laid out years before. Certainly, such adventurous programs will not all bear fruit, but a sufficient number will.

It seems to me that such a course is the only way in which we can close the current gap in space capability that exists between the United States and the U. S. S. R. Unless this gap can be closed within the next few years, the United States may face most serious consequences if the U. S. S. R.'s technical superiority in space is utilized for military purposes. This possibility, if not probability, is so apparent that we dare not risk the consequences.

Money judiciously and continuously supplied to a national effort in bold new concepts will see the United States match and surpass the U. S. S. R. in overall space capability and accomplishment within 10 years.

TECHNICAL ACCOMPLISHMENTS

As to technical milestones along this path, my opinions beyond the next year or so are only guesses, naturally. First of all, I believe that the U. S. S. R. will continue to shock this country rudely, pressing their current advantageous lead. I believe they will send man into orbital flight and recover him several times during the next year.

By 1968 I am certain that we shall have worldwide communications systems, based upon the so-called 24-hour or stationary orbit at about 22,000 miles from the Earth. Practical, economic advantages of this first, Federal-funded system will have been proved and a commercial system will be established. A network of lower altitude weather-monitoring satellites will transmit detailed cloud-man movement information to international computing centers for transmission of evaluated meterorological data around the world. Eight-hour weather forecasts will still be subject to error, but weekly and monthly forecasts of inches of rainfall and sunshine will be surprisingly accurate.

Man will have made several trips around the Moon by now—and find the other side quite similar to the one we see. A program to land on the Moon will be in the last stages of completion. Orbiting space laboratories will be conducting research at various altitudes. Such research laboratories will be one of the first proofs of man's superiority to black boxes and electronic gadgetry. Pound per pound, automated equipment will never be able to compete with man where judgment is to be exercised and unanticipated facts are to be recorded and transmitted.

Another role to be filled by man in space is that of repair and maintenance—replacement of inoperative or faulty electronic equipment, batteries, adjustment of equipment, and modification of earlier design equipment such as in communication relay satellites.

INTERNATIONAL COOPERATION

As an early fist pounder for the values and benefits of international cooperation, I am particularly pleased by the House committee's general acceptance and refinements of the "four-point program" which I was privileged to discuss with the committee last April. These concepts were ratified and unanimously approved by the delegates of the Ninth Annual Congress of the International Astronautical Federation in Amsterdam in August. The IAF represents, as you know, the rocket and astronautical societies of 26 nations. As this is written, I have just learned that the International Committee for Space Research, meeting at the Royal Society in London, has obtained agreement in principle between the United States and the U. S. S. R. in the concept of sharing test space in research satellites and space vehicles with scientists of other nations. In my opinion, this is an important start along the road to eventual wide international cooperation.

Within 10 years I foresee a number of logical outgrowths of a workable relationship between nations capable of launching space vehicles and the rest of the world community—to the mutual benefit of all.

I anticipate that a program of exchange students will be organized, fellowships and scholarships awarded, which will train the astronautical scientists and engineers on the job. Some of this will be financed by Federal funds, some by private foundations, grants, and bequests, and some by popular fund raising.

We shall, by 1968, have at least three internationally used and manned launching sites. Perhaps 2 will be near the Equator—1 in the Pacific Ocean and 1 in Somalia (Africa). The technical advantages of equatorial launchings for many space missions make such sites highly desirable. Recent technical appreciations make it possible to launch from a point near the equator and guide the vehicle to an equatorial flight path during latter stages of powered flight.

Another international launch site will probably be located near the true South Pole in Antarctica. Current belief among key scientists indicates advantages in such launchings in the zone of minimum radiation from the "Van Allen Belt."

There will be perhaps 2 or 3 dozen tracking stations, internationally used, manned, and operated. Some will be optical tracking, some radio (e. g., minitrack), some radar. All will be linked by communications to one or more computing stations for reduction of tracking data.

CONCLUSION

The above-prognosticated events are to some extent wishful thinking, certainly those which relate to international cooperation. Political events will be governing factors. It is not possible to predict in what manner these things will come about—nor the many more fabulous discoveries and economic returns which will come from space research.

I am not sanguine over the possibilities of the United States leading the way into space. There is far too little appreciation by the authorities of the complexities of rocket development, space medical factors, and reliability, as examples. The working press has still to develop a strong coterie of knowledgeable, sympathetic, and understanding writers and news analysts. There has not yet been enough time.

But in the back of my mind is a gnawing concern that the United States will *not* meet the challenge—will *not* forge the leadership which there is still time to create. The great majority of the people of the world—both educated and uneducated—are watching closely the two most powerful nations. They look to see which is the more capable in demonstrating its prowess in space research; which nation will be the leader and which one will follow.

In the year following the first sputnik there was some funding of earlier planned programs, such as Dyna-Soar, X-17, the Sentry, and Army and Air Force space vehicles, but the United States spent essentially nothing on new concepts—new creative space programs. In my opinion, the relative space technical capabilities of the two nations changed little, if any, in 1958.

I do not argue the "case for panic." I state simply that the United States has not yet faced the challenge as presented by the U. S. S. R. We are forming set patterns of thinking and relaxing in unwise confidence that the NASA will be the guiding light into space. Our scientific planners are overconservative, in my opinion, and a change must occur if the United States is not to meet defeat. Defeat not in hot war—but, humiliatingly, at our own game: **Creative, industrial,** technical enterprise; the bold scientific program.

The United States forged its international reputation in technical feats such as the east-west railroad, the Panama Canal, the transatlantic cable, the airplanes of the twenties and thirties, and in dozens of other real feats that no other nation matched. In all of these examples there was a triangle of a goal, a technique, and an adventurous spirit—a will to accomplish that would not accept defeat.

With a few exceptions of outstanding industry and governmental teams, I don't see this combination of qualities, determination, and financial support in the United States today.

Maybe we have to get mad. Maybe we need a Pearl Harbor in space.

I think we'll get one. * * *

Krafft A. Ehricke, Assistant to the Chief Engineer, Convair, San Diego, Calif.

1. THE BACKGROUND

During the year 1958, the Government has become increasingly aware of the necessity to actively and consistently sponsor a national space-development program. The prime motivation for authorizing the considerable financial effort involved, derives from the concern of Congress for the economic welfare and military strength of the Nation. Leadership in science and technology and in the exploration of our micro and macrocosmic environment is one of the prerequisites for assuring this condition and therewith also for gaining the right and the ability to shape a better world for all mankind. The United States possesses this leadership in many areas. Missile technology and, even more so, space technology are in their infancy. Temporary setbacks in this initial phase are not critical, if accepted in the spirit of determination to support consistently and adequately a long-range program for refining our missile technology and developing a space technology. With its concentration on the development of a long-range missile technology dating only as far back as 1953–54, the United States has made progress at a rate which is far greater than that of the U. S. S. R. This is clearly evidenced by the fact that the United States has the greatest and most diversified missile arsenal, that the quality of its long-range missiles appears in many instances to be at least as good as that of their Russian counterparts, that the United States appears to be in the process of gaining a stalemate in the field of intermediate-range ballistic missiles and that this country may be only about 2 or 3 years behind in the establishment of a consequential operational capability in intercontinental ballistic missiles.

While the Soviet Union appears to have a military lead in ICBM's in the critical years 1960–63, and while every effort should be supported by Congress to reduce the length of this period, Russia's lead—if viewed in the context of the overall military and industrial capability of both nations—is unlikely to reach sufficient proportions to tempt launching a nuclear attack on the United States, should this otherwise be regarded as desirable. After this period, the United States will be able to develop its second generation of long-range missiles behind the protective shield of SAC's and the Navy's first generation of missile systems.

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The missile and space planners find not only large booster rockets available or in the advanced state of development (in the liquid as well as in the solid field), but also a large variety of test facilities to speedily develop follow-on systems. The American missile industry is, in the opinion of this writer, the world's most advanced institution of its kind, in terms of missile production capability and scientific engineering ability. There is an abundance of good ideas accompanied by a unique capability of translating them into practice. The problem of the American planners is one of making the right choice, so as to guarantee maximum rate of progress at reasonable cost to the Nation. In planning for the future, the increasing complexity and cost of some of the contemplated weapon systems and of practically all future space flight operations must be taken into account.

Against this background, the purpose and goals of space flight during the next 10 years are reviewed.

2. PURPOSE OF THE NEXT 10 YEARS OF SPACE FLIGHT DEVELOPMENT

2.1 Definitions

In astronautics one may distinguish between terrestrial, cislunar, lunar, interplanetary and planetary systems and/or operations. Although the first three of these all lie within the realm of the Earth's gravitational dominance (geocentric space), they represent three distinct zones of activity, in terms of performance, complexity of the space vehicles and purpose.

Terrestrial vehicle systems operate in terrestrial space, roughly between the Earth's outer atmosphere and 10 Earth radii or 40,000 miles out. Instrumented terrestrial space vehicles are referred to as (Earth) satellites; manned satellites are often called space stations.

Cislunar vehicle systems operate in cislunar space, ranging roughly from 10 Earth radii to about 50 Earth radii (40,000 miles to 200,000 miles), that is, the major portion of the space between Earth and Moon. Instrumented vehicles are referred to as cislunar probes. Manned vehicles are unlikely to stay in cislunar space. They pass through it on the way to the Moon.

Lunar vehicle systems operate in the vicinity or on the surface of the Moon (in lunar space). The operations comprise lunar encounter (passage near the Moon, followed by arbitrary orbit, not necessarily returning to Earth), circumlunar flights ("nonstop" round trip Earth-Moon-Earth), lunar satellite flights (vehicle "stops" near Moon, by becoming a satellite of the Moon, either temporary or permanently) and lunar landing operations. The latter may consist of hard landing (high-speed impact at about 5,000 to 6,000 miles per hour, semihard landing (some braking of the fall by retrorockets with subsequent low speed impact, using a spike or an elastic, shock-absorbing rubber ball-type structure to protect equipment) and soft landing (vehicle is set down gently on the Moon's surface by means of retrorockets). Instrumented vehicles are referred to as lunar probes (impact probe—etc.). Manned vehicles are often designated as Moon vehicle or manned lunar vehicle.

Interplanetary vehicles operate in the space between planets. They escape the Earth entirely and become tiny planets of the Sun. Instrumented vehicles are called interplanetary probes. Manned vehicles will not stay in interplanetary space, but pass through it on their way to another planet.

Planetary vehicles aim to get near, or on the surface, of another planet. Again, one distinguishes here between a planetary encounter, satellite mission and landing mission. In the latter case, the planet's atmosphere brakes the fall. Instrumented vehicles are called planetary probes, manned space vehicles as manned interplanetary vehicles (Mars ships, Venus ships, etc.).

Cislunar, lunar, interplanetary and planetary instrumented spacecraft are sometimes losely designated as *deep-space probes.*

To *orbit* means to circle the Earth in a near-circular or elliptic orbit.

Entry or *reentry* means to return from space through the atmosphere.

2.2 Purpose

Clearly defined *military purposes* are so far associated only with terrestrial space systems. This is unlikely to change in the near future. The systems and their purpose are:

(1) *Manned systems.*—Temporary orbit or near-orbit capability.

(1a) Dyna-Soar-hypersonic glide vehicle, eventually to have bombing capability.

(1b) Manned orbital reconnaissance system for special radar and/or optical reconnaissance missions.

(2) *Instrumented satellites.*—Long-term orbit capability in the altitude range between 400 and 22,000 miles. Purpose: Early warning of enemy attack, especially with long-range missiles

Communication
Reconnaissance
Weather service
Navigation (acting like a radio star for ships in the case of overcast)

Manned orbital systems will be limited to a small altitude region between about 140 and 350 miles. Atmospheric resistance prevents lower altitude, intense radiation endangers human life at higher altitude, unless heavily shielded. The ensuing weight penalty is prohibitive for the boosters of the earlier systems, at least until boosters with 1 million pound thrust or more will be available. Instrumented satellites are not restricted to this belt. They can operate at higher altitudes.

Potential *economic utilities* are so far also restricted to terrestrial space systems.

(1) *Manned systems.*—No utilities clearly defined. Reason: Even after the problems of manned orbiting and entry are solved, the maintenance and protection of man in space, and the requirements for getting him into orbit and back will be so costly in the near future (primarily as long as chemical rockets are used) that it turns out to be more economical to let instrumented satellites do the job, even if they have to be replaced once or twice a year. In addition, instrumented satellites are not restricted to the relatively narrow, low-altitude belt, defined above. For many utilities, especially weather service and communication, the satellites should be much higher (between 4,000 and 22,000 miles).

(2) *Instrumented satellites.*—

Communication (global post office, global TV-relay).

Weather service.

Navigation.

All other space flight projects have so far no clearly outlined objective other than space research and space exploration. These objectives are of fundamental importance for the acquisition of knowledge from which alone an advanced space technology and new utilities can be derived.

The above-defined purposes and the objectives of space research and exploration determine to a large extent the goals which appear achievable during the next 10 years.

3. PLATEAUS OF ACHIEVEMENT

Aside from the alinement with the above purposes, the plateaus of achievement which can realistically be expected must be consistent with the vehicular capabilities estimated to be available during the next 10 years. These are, briefly:

ICBM booster rockets.

Upper stages with advanced chemical propulsion systems.

Large boosters with 1.5 to 3 million pounds of thrust.

Upper stages with nuclear heat exchanger powerplants.

The first small ion-propulsion systems, not for propelling space vehicles, but for keeping high-altitude satellites in a prescribed place in their orbit (orbital stabilization).

The payload capabilities of the above vehicles are summarized in tab 1. On the basis of this vehicular capability, space technology may be expected to reach the following plateaus of achievement during the coming decade:

(1) Terrestrial space

(1a) Instrumented satellites for the purpose of communication, weather service, navigation, and research. These satellites will mostly be at higher altitudes and will weigh between 1,000 and 5,000 pounds.

(1b) Establishment of manned orbital flight and reentry, for space-medical purposes and to develop a reliable *short-term* (a few revolutions) *life-support system* for man.

(1c) Establishment of hypersonic near-orbital flight capability in a maneuverable (glide) system at altitudes between 250,000 and 100,000 feet.

(1d) Establishment of one or more small experimental manned space stations of the general size of the Atlas space station "Outpost" proposed before (cf. fig. 1) for the purpose of developing a reliable *long-term* life-support system for orbital operations and manned deep-space vehicles, for selecting suitable space crews and condition them through orbital flight training.

(2) Cislunar space

(2a) Research satellites to further explore the outer limits of the high-intensity radiation belt, to study the distribution of meteoritic matter, the propagation of material expelled from the Sun, the magnetic and electric phenomena in cislunar space and to observe the Earth from great distance.

(3) Lunar space

(3a) Exploration of the Moon with instrumented probes. The first phase involves lunar encounter probes of between 30 and perhaps 1,000 pounds. The second phase will establish lunar satellites of the order of 2,000 pounds with optical and television equipment for detailed study of the lunar surface. The third phase will involve lunar landings, hard to soft. It is generally recognized that the latter phase involves special precautions in order not to contaminate the Moon with terrestrial organic or inorganic (radioactive) material and thereby destroy inadvertently priceless scientific evidence for later manned expeditions.

(3b) Development of the capability for manned reconnaissance flights around the Moon (4 to 6 day missions).

(3c) First manned lunar landings.

This may be a marginal goal for the period 1959–69. However, the technical possibility cannot be discarded.

No dates have been affixed to these plateaus for security reasons. The vehicular correlation is given by tab 1.

(4) Interplanetary and planetary space

(4a) Interplanetary space probes exploring the region between Mercury and Earth as well as between Earth and Mars and beyond in the asteroid belt between Mars and Jupiter. These probes can be of low-flight accuracy, since they do not have to meet another body in space. They require no optical equipment and no navigation equipment. The messages which they transmit back to Earth on meteoritic material, interplanetary gas, electric and magnetic phenomena, etc., require low power. Therefore, their overall weight can be comparatively small, between 200 and 1,000 pounds.

(4b) Planetary probes. The time periods at which these probes can be aimed specifically at Venus and Mars in the period 1959–71 are presented in tab 2. It is seen that during the next 10 years there exist only a maximum of 5 opportunities to launch a Mars probe and 7 occasions for a Venus probe. Especially favorable for the establishment of a satellite of Venus, because of low-transfer energy requirements, are the constellations in June 1959 and June 1967. Unfortunately, in June 1959, the existing vehicular capability for establishing a Venusian satellite is quite marginal. However, this date is attractive for present hardware, because it permits a low-energy transfer. A somewhat less favorable occasion for establishing a satellite of Venus exists in November 1965. During all other constellations, that is in 1961, 1962, and 1964, the opportunity will exist for sending an encounter probe to Venus. In the case of Mars the best opportunities for establishing a Martian satellite are in November 1962 and November 1964, although none is as favorable as the years 1959 and 1967 are for Venus. All other dates during the coming decade offer the possibility of sending an encounter probe to Mars. With the advent of a 1.5 million pound booster vehicle it will become possible to transmit a probe to the planet Jupiter. The opportunity for this arises once almost every year. The transfer time would be in excess of 1 year. A Jupiter probe would be of considerable scientific interest, but is a difficult project which may not be practical until the end of the sixties.

It is most unlikely that during the next 10 years manned spaceships will leave the Earth's gravitational field for another planet.

4. ADVANCED PROPULSION SYSTEMS

Advanced astronautic concepts, such as the manned lunar base and manned flights to other planets must await the harnessing of nuclear power for spacecraft propulsion. The two most attractive and realistic concepts using nuclear energy are at present the nuclear heat exchanger rocket and the nuclear energized ion rocket. Of these two, the former is more universally usable, since it is capable of a sufficiently strong acceleration (0.2–0.02 g) to establish fast cislunar transfer and lunar landing as well as takeoff. In addition, fast transfers to Venus and Mars, as well as fast round trips, can be flown with a fraction ($1/10$–$1/20$) of the mass consumption of the best chemical rocket for the same mission. Ion propulsion allows only accelerations of the order of 1/10,000 g. As it leaves its assembly orbit near the Earth, it follows a slow spiral orbit leading it deeper into space. However, its long stay time in the radiation belt as well as its long flight time makes the ion system in its presently conceived form unattractive for lunar operations. For interplanetary operations to Mars and Venus much longer transfer times and round-trip times must be accepted than with the nuclear heat exchanger drive. An advantage of the ion rocket, however, is that it uses only about $1/100$ of the mass of the best chemical system for the same mission. Consequently, its payload carrying capability is far better than that of either the chemical or the nuclear system.

Propulsion research and development will therefore concentrate on nuclear drives, ion drives, and other potentially promising methods of propulsion. It appears reasonable to assume that a nuclear heat exchanger drive will have been perfected and flight tested in cislunar space by the end of the next 10 years. Ion-propulsion research can be expected to be in an advanced state.

5. TRACKING STATIONS AND LAUNCHING SITES

The use of lunar and interplanetary probes demands the establishment of a global net of tracking stations. In the field of sharing tracking systems, coordinate transmission frequencies and joint evaluation of scientific data lie probably the greatest practical possibilities for international cooperation in astronautical research and development in the next 10 years. They can represent a practical step-by-step approach to more sweeping international space agreements.

Among the presently available launching sites, AFMTC in Florida, is primarily geared for eastern, northeastern, and southeastern flights. The Pacific Missile Range at the Vandenberg Air Force Base in California is primarily suitable for the establishment of north-south orbits. The amendment of those capabilities by a mid-Pacific equatorial launching site is highly desirable, especially for the establishment of a small manned space station. The reasons are:

1. Very good accessibility of the station from the surface from only one space station.

2. Vehicles returning from the space station will land in a relatively narrow belt around the globe. This belt is presently well outside Communist-controlled territory and is generally in the fair-weather zone. It can be easier monitored than any other area of

landing pertaining to an orbit which is inclined with respect to the equator.

3. The Moon and the planets are relatively most conveniently accessible from the equator.

From the viewpoint of location, Howland and Baker Islands (both United States territory), just east of the 180th meridian and very close to the equator, appear most attractive. Hawaii, about the distance San Francisco-Detroit away, can serve as major supply base.

6. CONCLUSIONS

By the end of the next 10 years we can thus expect the following state of development in astronautics:

1. Communication and television relay satellites at very great altitudes, probably as high as 22,000 miles (24-hour orbit) in equatorial and inclined orbits.
2. Global weather monitoring on a routine basis from optical satellites circling the globe in polar or highly inclined orbits some 4,000 to 8,000 miles high.
3. Radio-navigation satellites some 1,000 miles high, serving the ships on seas in equatorial and inclined orbits.
4. One or more relatively small manned space stations some 300 miles high in the equator plane for orbital flight training, life support systems development and man-conducted research in space.
5. All or many of these satellites and space stations will be equipped with nuclear auxiliary power supply systems.
6. Satellites of the Moon will have been established and landings with instrumented probes on the Moon will have been accomplished. Probably, the first landings by man will have been achieved.
7. Man will have circumnavigated the Moon using vehicles launched directly from the Earth's surface without orbital assembly or fueling.
8. Interplanetary probes will have covered the entire inner solar system from inside the orbit of Mercury to the asteroid belt beyond Mars. Encounter probes will have been sent to Venus and Mars and instrumented satellites of these planets will have been established. Probes may have been sent out as far as to the planet Jupiter.
9. All these projects will have been carried out essentially on the basis of chemical rockets, such as the ICBM boosters with advanced chemical upper stages and the 1.5 million pound thrust booster with chemical upper stages. However, at the end of this decade nuclear powered upper stages, boosted beyond the atmosphere by chemical first stages, will be available.
10. Research in auxiliary power systems, energy conversion, materials, and electrical propulsion systems will have made great strides.
11. Close international cooperation in the scientific and practical usage of satellites, as well as in monitoring and tracking of space vehicles and in control of transmission frequencies, will have been established. At least one new launching complex for space vehicles will have been built, located in the mid-Pacific on or near the Equator.
12. Man will have sufficient information to decide for or against a permanent lunar base and will begin to look to the planets Venus and Mars as his goals for the decade to come.

TABLE 1.—*Development of space vehicles*

[Dash (—) means no useful capability]

Class	Designation	Stages	Propulsion	Thrust (pounds)	Launching from—	Weight of instrument probe carried into space (no return) (pounds): Earth orbital 300 to 500 nautical miles	Lunar circumnavigation	Lunar satellite	Lunar landing	Venus or Mars	Mercury or Solar probe	Jupiter or Asteroid probe	Manned space flight (return): Space station	Moon flights	Venus or Mars	Outer solar system
1	Juno 1	4	Chemical: Stage 1 liquid; stage 2–4 solid.	~80,000 pound (stage 1).	Surface	Tens	—	—	—	—	—	—	—	—	—	—
	Vanguard	3	Chemical: Stages 1, 2 liquid; stage 3 solid.	~25,000 pounds (stage 1).	Surface	Tens	—	—	—	—	—	—	—	—	—	—
2	Thor or Jupiter (modified).	2–4	Chemical: Stage 1 liquid; upper stages liquid or solid.	140,000+ (stage 1).	Surface	Hundreds	Tens	—	—	—	—	—	—	—	—	—
					Space station.	----------	Thousands [1]	Thousands [1]	Hundreds [1]	Thousands [1,3]	Hundreds [1,3]	—	—	Circumnavigation with small crew.[2]	—	—
3	Atlas or Titan (modified).	2–3	Chemical: Stages 1, 2 liquid; stage 3 liquid or solid.	200,000+ (stage 1).	Surface	6,000 to 8,000	Thousands	Thousands	Hundreds	>1,000 [3] or Hundreds [4]	Hundreds [3]	—	Small space stations (1 to 4 people).	—	—	—
					Space station.	----------	>10,000 [1]	Thousands [1]	Thousands [1]	>10,000 [1] or Thousands [4,5]	Thousands [1]	Thousands [1,3,6]		Lunar landing with small crew.[2]	—	—

4	Growth versions of present chemical vehicles (first stage winged and recoverable).	3	Chemical: All stages liquid.	1,500,000 (stage 1).	Surface	$\sim$40,000	$\sim$8,000	$\sim$6,000	$\sim$4,000	$\sim$7,000 [3] or 3,000 [4]	Thousands	—	Large space stations.	Temporary lunar satellite with small crew.	—	—
				3,000,000 (stage 1).	Surface	$\sim$90,000	$\sim$20,000	----------	$\sim$9,000	18,000 [3] or 7,000 [4]	Thousands	Thousands [5] [6]	Large space stations.	$\sim$16,000 pounds for circumnavigation.	—	—
5	Helios (winged first stage).	2	Chemonuclear: Stage 1 chemical; stage 2 nuclear-heated.	3,000,000 (stage 1). $\sim$230,000 (I=800 seconds) sp (stage 2).	Surface	$\sim$160,000	----------	----------	$\sim$22,000	$\sim$30,000	>20,000	Thousands [4] [6]	----------	Lunar bases.	Fast reconnaissance flights (high-energy orbits).	—

[1] Single basic vehicle (modified).
[2] Clusters of basic vehicles.
[3] Hyperbolic encounter; no capture.
[4] Capture into satellite orbit.
[5] Landing on planet.
[6] Parabolic transfer orbit to Jupiter.

TABLE 2.—*Launching schedule of probes to Venus and Mars (1959–71)*

Target planet	59	60	61	62	63	64	65	66	67	68	69	70	71
Venus	June 3–16 [1]	----------	Jan. 11–25	Aug. 8–22	----------	Mar. 18–Apr. 1.	Oct. 27–Nov. 11. [2]	----------	June 7–21 [1]	----------	January	August	----------
Mars	----------	September, October	----------	October, November. [2]	----------	November, [2] December. [2]	----------	December.	January	----------	January, February.	----------	February, March.
Jupiter [3]	----------	----------	----------	----------	----------	----------	June	September.	November.	----------	January, February.	April	June, July.

[1] Constellations especially suited for low-energy transfers and for the establishment of instrumented satellites near the target planet.
[2] Constellation relatively favorable for low-energy transfers and planet satellite establishment.
[3] Firings in earlier years than given in table are possible but probably not practical. Dates apply to very fast (parabolic) transfer to Jupiter with 1.15 years Earth-Jupiter transfer time.

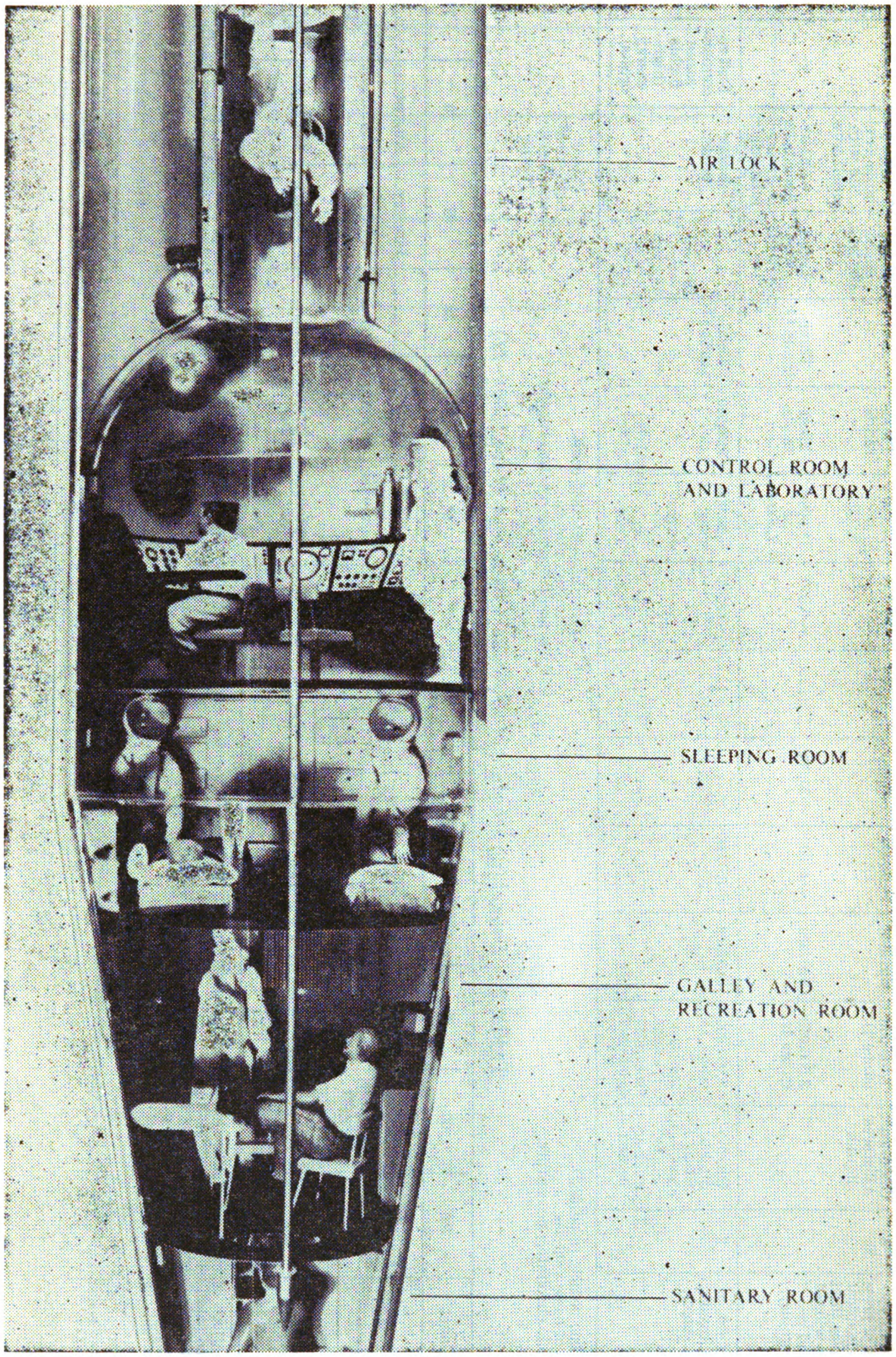

Figure 1: Living quarters—Inboard profile

LT. GEN. JAMES M. GAVIN (RETIRED); FORMER DEPUTY CHIEF OF STAFF, RESEARCH AND DEVELOPMENT, ARMY; VICE PRESIDENT, ARTHUR D. LITTLE, INC., CAMBRIDGE, MASS.

THE DECADE OF DECISION

[An address by James M. Gavin, vice president, Arthur D. Little, Inc., to the American Rocket Society, New York City, November 19, 1958]

Much has been written and said lately about the decade of decision—the period between 1955 and 1965. The latest contributor was Mr. Nikita Khrushchev when he announced last week a plan that he anticipates completing in 1965. It is the new Soviet 7-year plan for the period 1959 to 1965, the most ambitious document ever unveiled by the Kremlin. Describing it, last Sunday's New York Times said, "Russia last week mounted one of the most intensive political, economic, and diplomatic offensives it has ever directed against the West."

Some time ago, you may recall, Mr. Khrushchev said, "I declare war on you, forgive the expression, in the realm of trade." So this now seems to be his war plan, and he anticipates that within 7 years he will have settled for all time who, whether the United States or the U. S. S. R., shall, in the words of Alexis de Touqueville, sway the destinies of half the globe.

It is well that we realize the significance of Mr. Khrushchev's announcement, for one of the clear implications of the space age is that the world has shrunk very much indeed. Shrunk so much in time and space, in fact, that space is now the realm of strategy, and its new dimensions are economic, technological, and psychological. And the perfect strategy is one that will bring victory to the nation that is frugal and hard working, plans well, and develops a strategy that will win without ever a shot being fired. This touches upon the heart of our problem.

There will be those who would say that with a higher gross national product, the superiority of the West is assured. This, at best, is very misleading and at worst, critically dangerous. Carthage was a flourishing economic entity when it was destroyed by a young and warlike Rome. Many hundreds of years later, Rome had a gross national product without precedence. Its wealth and opulence surpassed even the wildest dreams of the barbarians north of the Danube who in a short time were to sweep the Empire from end to end. Neither Rome's great engineering skills, its architectural grandeur, its great laws, nor, in the last analysis, its gross national product, could prevail against well-led, warlike, frugal, and hard-fighting barbarians. No, a gross national product is not any insurance of survival. In fact, quite the contrary. I believe I could make a case to indicate the contrary. Only industry, imagination, a sense of dedication, a sense of dedication on the part of each of us, and all of us collectively, can prevail in this contest.

Fortunately, those now members of, and associated with the rocket and missile industry, have been men of vision, and the contributions that they have made to our Nation's programs in the last several years have been tremendous. The rocket and missile industry of the United States has made gigantic steps forward in the past couple of years. I think, too, that the armed services have all evidenced an awareness of the importance of these programs to a degree that is most reassuring. I believe that in our top national defense team, Secretary McElroy and General Twining, we have a splendid combination of an excellent businessman and a first-class military professional. Their support of our space programs has been most significant. I believe, however, that we really need more than these things, more than good leadership, a greater investment of our gross national product in national defense, which, goodness knows, we need, and an awareness and dedication on the part of each of us. In order that our missile and space programs shall move ahead, we need more than all of these things.

I think that this vast field is in a position comparable to the aircraft industry of about 40 years ago. The reasons that prompt us to work so hard today are many: the natural desire, as Dr. Stever has expressed it in the current issue of Astronautics, "the natural desire of men for exploring both physically and mentally, and his desire to improve his lot," as well as the obvious and compelling reason, a superior national-defense position. But, as with the aircraft industry many years ago, what we really need for this field to grow is a widespread application of much of the technology to commercial and industrial needs.

I remember a conversation I had with one of our nuclear scientists when I was a member of the Weapons Systems Evaluations Group almost 10 years ago. We were talking about the possible peaceful applications of fission. We really could think of little that could be done with it other than making fissionable material into a form of destructive power. There had been some discussion about harnessing the power of fission, but this seemed to us to be quite remote. It seemed difficult to conceive of the atomic bomb as anything but sheer power used for destructive purposes. Yet today the products of fission applied to peaceful uses are many. The use of isotopes in industry, medicine, agriculture are well known. Food irradiation, nuclear power reactors, now reactors for shipboard use, are with us, and it is hardly the beginning. I frequently ask myself, of late, what 10 years from now will be the commercial, shall we call it, applications of our missile and rocket programs. This is the problem to which I should particularly ask that you would give your attention. May I point out a few of the significant applications that have already taken place.

In this month's Astronautics, Dr. Theodore von Karman comments: "It does not take a crystal ball to appreciate that major scientific discoveries will occur over the next 25 years. Whole new fields of science will open up as we investigate high-energy fuels, ionic, and electromagnetic rockets, and study the use of solar energy, plasma jets * * * Techniques, structures, and materials as yet undreamed of will be found * * *."

There are many, new technological developments in the missile industry that can be used with profit in industry and many consumer markets. These applications can and should be gotten underway now. For example, a large company in the missile field has asked us, in Arthur D. Little, to make a preliminary evaluation of licensing opportunities that might exist among a selected sample of developments. Our initial exploration shows real possibilities for at least three.

The first of these comes from scientific advances and substantial know-how in the field of plasma technology, which—we believe—can be translated into new thermal industrial processes.

The second is a reliable flow meter which has no packings or bearings, and was first developed for measuring liquefied gases. This, we feel, will have a very wide industrial usefulness, and may even lead to improvements in marine devices for measuring distance and velocity.

The third opportunity arises from materials research. We believe a specific development may lead to a family of new plastic materials with a variety of industrial uses.

These are applications under study. Many others are already in use. Several companies were involved in an effort to produce missile electrical coils that would be lighter, smaller, and possess better heat-dissipating qualities. Under Government sponsorship, they developed a flat ribbon conductor coil. Because these coils have real cost advantages, the automobile industry has put them to use.

The control display panels for missile testing and firing are so elaborate that it is not possible to physically present sufficient separate colored lights to indicate changing prelaunch conditions. Under Government sponsorship, several companies developed a display board that shows changing colored lights without separate bulbs for each color. These panels are on the market for use in powerplants and similar applications.

Ground-to-air missiles that ride a beam to their targets must measure the distance to the target plane with an accuracy of a few feet in several miles. This principle, now being applied to surveying techniques, has revolutionized the surveying industry.

The solenoid valve, which seats itself softly enough to eliminate vibration, has been applied very satisfactorily to home-heating systems.

The use of the jet drilling for mining is another, and worthy of amplification. Missiles are already working the economically unminable taconite ore of the Mesabi Range, have helped build the St. Lawrence Seaway, and are bringing down costs in quarrying.

It is estimated that taconite will be supplying about a third of our ores in less than 20 years. Until 1947 we were unable to mine this very hard rock, and then suitable rotary and churn drills were produced. Jet drilling, now available, cracks and crumbles stone layers by thermally induced expansion and is somewhere between 3 and 5 times faster than rotaries.

Jet piercing can take us far deeper into the Earth than we have been able to go so far, to new sources of ore and hydrocarbons.

In stone quarrying, jet spalling and channeling are proven techniques· Stone quarrying has been expensive and wasteful heretofore. Rocket flame equipment allows cutting along the natural cleavage planes, or crystal boundaries—hence cuts stone thin without danger of cracking, and in addition, produces a fine finish that cannot be obtained when cutting by steel or abrasive tools.

Research and development on missiles will lead us to a workable method of processing beryllium which, with its high heat resistivity and unique physical qualities, could be ideal on leading edges and high-drag surfaces of future space and manned reentry vehicles. It may have many other applications.

Scientific literature is beginning to contain speculations on using the principle of the missile engine to save unstable intermediate products of chemical processes. The high heats achieved in the rocket engine can, perhaps, be utilized to produce desired products that would be lost by slow cooling. But the high rate of cooling accomplished by expanding gases through the engine nozzle, it is thought, would save these unstable compounds. Exploration in this direction is worth pursuing.

In the course of testing missiles a "rough combustion cutoff device" was created. It measures vibrations, and cuts off the operations before the vibrations reach destructive proportions. Although destined for this particular use, the cutoff device could be modified for many industrial applications.

Infrared has come into its own through missile electronics. Infrared, which—since it cannot be jammed—appears to be challenging radar for use in guidance devices, tracking systems, and reconnaissance vehicles. Infrared is being used industrially to measure the compositions of fluids in complex processes of chemical petroleum refining and distilling. Infrared cameras are used in analyzing metallurgical material processing operations—to aid in accuracy and quality control. The entire infrared field should be significantly assisted in its growth and application through our missile-space programs.

Another very promising outcome from missile development is a computer converter that can quickly transform analog signals—such as pressure measurements—into digital form.

Out of the missile industry, with its need for reliable, accurate, miniature parts, have come mechanical gadgets, valves, so small and so reliable that one might foresee their use in medicine—perhaps to replace wornout human parts. If our lives continue at their present pace, there may well come a day when rocket valves will be at work in the human heart—and we'll be thanking missiles that our hearts beat.

Experimental work in psychology and physiology—study of the human body under accelerations, weightlessness, in absence of all external stimulation—will also feed into our medical knowledge—and therefore our medical skills.

In the near future—when guidance devices permit—soft landing, rocket cargo and passenger transport will become feasible. Mail may become almost as swift as telephone.

We are making rapid progress in the economics of space travel that is both assuring and promising. Payload costs for Vanguard were about $1 million a pound. For Explorer the cost dropped to somewhere between eighty and a hundred thousand dollars—for the Soviet sputniks and the near-future United States launchings, based on Atlas and Titan, the cost should be about $1,000 a pound. Ultimately payload costs may be trimmed to about a hundred dollars a pound, and then we may expect commercial space flight. It is quite likely that this payload economy will come from nuclear propulsion. We will probably reach the time when we can consider rocket transport superior to airplane for anything over a thousand miles or so—just as we have long since reached a point of recognizing that planes are superior to automobiles for distances over a hundred miles.

So far I have avoided the obvious application with which many of you are familiar. May I briefly state them; the use of a satellite as a communications vehicle. It shows every promise of providing worldwide communication at a faster, more reliable, less expensive rate than present terrestial communications. Furthermore, it will very likely be more secure. Meteorological satellites, satellites to contribute to our navigation systems, reconnaissance satellites, and satellites to provide worldwide TV networks are all in the offing.

At the outset, this evening, I quoted Mr. Khrushchev's declaration of war and pointed out that in the realm of space, and in missiles and rocketry associated therewith, and in the economic and technological realm of the problems of all of these together, will be fought the great strategic battle of the decade. The battle is now joined, and you, each of you, are very much in it.

Much could have been said this evening about specific pieces of hardware and about, for example, our defense program. But I have avoided these out of the conviction that the greatest incentive that can be given to our programs is through a *widespread* awareness of the multitudinous applications of missile and space technology. Through a development of this awareness we will acquire an increasing backing from our people, from industry, and from our Government. I could add, "much the same as we *once* did in the aircraft industry," but I believe that would be a serious understatement. For the application of ideas and technology from our missile and space programs will far overshadow and outnumber the things that we have learned and applied through the history of our dynamic aircraft industrial growth.

Now, it is not too difficult a thing to summarize our shortcomings and enumerate specific technological advances. It is another thing to recommend specific steps that may lead to a solution of our problem. Nevertheless, I would like to touch upon a few of these.

First, in this strategic competition in which we are joined, we are dealing with an opponent who has integrated all of the resources of science and industry of the U. S. S. R. and all of its satellites. Prices, material costs, working hours, all are carefully controlled. The rewards for success are bountiful, capitalistic incentives are commonplace, and the Soviet achievement has been impressive. There has been a tendency, on the other hand, on our part to move in a fragmented effort. I believe that it is of the utmost importance that we integrate our scientific effort. The scientific resources of the West are tremendous, and sometimes I think that we have hardly tapped them. For reasons characteristic of our economy, and sometimes out of an understandable concern for national security, we have tended to compartment our work. Now it is imperative we move toward the ultimate objective of a completely integrated scientific and technological effort. The scientific community of one nation, or one area, may, for example, contribute significantly to the solution of a particular problem. It should be allowed to do so while the scientists of another area deal with another aspect of the problem or another problem rather than having duplication of both groups working on the same problem. The implications of this are many, as I know you will realize, and I see no reason to belabor the point further. The key to the solution is to get the maximum return for our investment of scientific man-hours in terms of not one industry, nor one industrial area, nor one country, but in terms of the free world. We, in the United States, should sponsor such an integration.

Closely akin to the success or failure of such an integration program is the problem of national security. This needs constant scrutiny. I am convinced, from long personal association with national-security problems, that much information is being denied our allies by each other that if shared would enable us all to move ahead more rapidly without in any way aiding the Soviet programs.

My association with industrial research has impressed me with the cost consciousness and marketing orientation of civilian management. If we are to succeed in the economic as well as the technological competition that we are now in, if we are to achieve the technological integration in our country and in the free world, we must use the thinking and skills of the market-centered economy as well as our defense-oriented technology.

The man who is highly skilled and experienced in the latter field cannot prove equally skillful in the ways of civilian industry at a moment's notice. To bring about this integration, we need men from both groups working in double harness with constant communication between them. This suggests a parallel research and development group staffed with plenty of creative imagination to seek out civilian applications such as we have noticed earlier. Armed with their knowledge of markets, industrial needs, and the primacy of costs, these running mates can speed up the scientific and technological integration—and perhaps feed useful ideas back in their turn. Thus we can work toward greater economic strength.

As a final comment, and it is closely related to what I have said so far, we must continue to conduct meetings such as those conducted by the American Rocket Society through which an exchange of information can be realized to our mutual benefit. It would be well if these could be extended beyond the geographical limits of the United States. Perhaps through the American Rocket Society we may be able to achieve a further degree of the integration of the scientific and technological community.

These are simple things, but their achievement can set us well on the course to the early exploration of space and the betterment of the lot of mankind. I am personally convinced that a capability in space will clearly presage a lasting peace. A space program under the auspices of the United Nations can, for the first time in the history of mankind, guarantee peace. For this reason, if no other, our effort deserves the full measure of each of us. We must get our minds, in part at least, off the petty problems of everyday concern. As businessmen and military men, we must lift our eyes not to the horizon, but to outer space, and we must constantly search for ways and means to contribute to a more effective space program, be it commercial or military. Thus we must take counsel from our loftiest aspirations and not from any transient concern with the vain boastings of the itinerant occupant of the Kremlin.

On us the burden falls to lead the nations
Out of this frightful wilderness of steel;
On us depends the course of that which is
To come hereafter—whether freedom was
A stolen dream from Heaven, or is the truth
On which to found the future of mankind.[1]

[1] My Country, by Russell Davenport.

TYRONE GILLESPIE, ASSISTANT TO THE PRESIDENT, DOW CHEMICAL CO., MIDLAND, MICH.

* * * true scientists * * * are reluctant to establish a too specific timetable in predicting progress. However, our people do anticipate considerable progress in the next decade and are agreed on these likelihoods:

Unmanned space vehicles powered by nuclear energy will probably explore the Moon and nearer planets and return to Earth under instrument control.

Satellites and nuclear-powered continuously flying ram jets will undoubtedly record the cloud cover and the upper atmospheric conditions at all points around the world to permit accurate short-range weather forecasting.

Manned flights into space and return will be made experimentally. Such flights will probably be in gliders launched from high-flying ram jets and powered by solid- or liquid-fueled rockets. Directional control will also be achieved by small rocket jets. Return to the Earth will be accomplished by simple gliding. Such short-term experimental flights will determine man's capabilities, both physically and emotionally, to adapt himself to space flight.

Our scientists feel that the major developments in propellants will be in higher energy fuel for ram jets, solid and liquid for rockets, and nuclear propulsion both with reactors and with fission products. These new chemical fuels may be expected to give from 50 to 100 percent more rocket range than available at present. Nuclear fuels will make possible continuous flight either within or outside the Earth's atmosphere for any desired period of time * * * as much as a year.

Such continuously flying craft will make possible many new types of worldwide communication. Information through the medium of television pictures could be transmitted to such crafts as they fly overhead, stored electronically, and relayed to other Earth stations on arrival. Direct aerial photographs could be taken and delivered by mechanical drop to any other station. Such continuously flying planes could pick up and deliver mail from the ground or through transfer from other planes.

These are the best predictions our people can make in terms of available knowledge. I suspect that the collective opinions obtained by your committee will point to important developments in this field for the next decade. * * *

ANDREW G. HALEY, PRESIDENT, INTERNATIONAL ASTRONAUTICAL FEDERATION; GENERAL COUNSEL, AMERICAN ROCKET SOCIETY, WASHINGTON, D. C.

The age of exploration in outer space will not become a reality until propulsion thrust is improved by a factor of several thousand. In other words, man cannot undertake the exploration of regions beyond the Moon, and perhaps Mars and Venus, until he has achieved pro-

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pulsion systems capable of delivering millions of pounds of thrust at speeds in the order of one-third the speed of light.

The situation is not so critical with respect to the limited area of *exploration of Earth* from a not distant point in outer space. The Russians for some time, and the United States during recent months, have undertaken the design of powerplants in the order of a million pounds of thrust. These propulsive systems will be able to launch into orbit comparatively large satellite vehicles containing 3 to 5 human observers and capable of return to Earth through retrorocket and other deceleration devices. This latter certainly will be an achievement of the next 5 years.

But to get back to the main point, namely, the true exploration of space, I must say this is a problem that has bothered me since I organized Aerojet in 1941—and more importantly when it came into active existence in 1942. I believe that during all this time our propulsive objectives were far too shortsighted. Thrust of 6,000 feet per second obviously can only provide for limited areas of operation. Rockets of up to 100,000-pound thrust can eject only the equivalent of Indian canoes into outer space. This problem has been so worrisome that when I finally had the greatest opportunity—namely, outlining the scientific program for the Ninth Annual Congress of the International Astronautical Federation held in Amsterdam from August 25 to 30, 1958—I arranged for the main theme to deal with propulsion systems and propellants. I believe that history will show that the scientific papers read at the lecture program were epochal in importance.

Here are some of the papers: Theodore von Karman, United States, "Magneto fluid dynamics in relation to space-flight problems"; Eugen Sänger, West Germany, "Sources of radiation for photonic rockets"; J. Ackeret, Switzerland, "The use of gas turbines for rocket propulsion in space"; L. R. Shepherd, England, "Electrical propulsion systems for space flight"; B. Lewis and B. Karlovitz, United States, "Space propulsion by interstellar gas"; J. Vandenkerckhove, Belgium, "Notes on the optimum design of solid-propellant powerplants for missiles systems engineering"; B. Heim, West Germany, "The contrabaric effect"; E. E. Buechner, West Germany, "Liquid and solid fuels for rockets"; W. Peschka, Austria, "On utilization of atomic hydrogen as fuel for liquid-fuel rockets"; H. J. Huth, United States, "Electric power for space flight"; F. Cap, Austria, "Gröbner's general and exact solution of the astronomical *n*-body problem and its application to astronautics"; I. Sänger-Bredt, West Germany, "Working fluids for rockets heated by nonconventional chemical energy"; W. H. Bostick, United States, "Plasma motors: The propulsion of plasma by magnetic means"; E. Ostinelli, Italy, "Limit performances of spaceships employing fission power of uranium nuclei or fusion power of deuterium nuclei"; D. Altman, United States, "Chemical propulsion in the new Space Age"; K. R. Stehling, United States, "Solid-propellant rockets for space flight"; H. Bednarczyk, Austria, "Acceleration of conducting parties by magnetic fields"; F. Winterberg, West Germany, "The attainment of exhaust velocities up to 20,000 miles per second by means of isothermic expansion in nuclear rockets"; O. K. Rice, United States, "The recombination of atoms and other energy-exchange reactions"; G. C. Szego, United States, "Similitudes and limitations in transconventional propulsion systems"; L. G. Napolitano, Italy, "Magneto fluid dynamics of two interacting streams"; J. H. Houtman, Netherlands, "Efficiency and ram-rocket start of self-tanking multicoupled rocket"; O. Wolczek, Poland, "On the artificial sources of nuclear energy in space"; E. Stuhlinger, United States, "Advanced propulsion systems for space vehicles"; J. J. Barré, France, "Physiothermic autopropulsion units—radioactive process of heat transfer permitting acceleration of mass particles"; F. Schütte, West Germany, "Influence of speed vector precision at time of flameout on the orbit of a satellite"; R. P. Haviland, United States, "The solar probe"; R. John, R. Schweiger, J. Yos, M. E. Malin, United States, "Electric-arc plasma generators applied to propulsion"; B. R. Noton, Sweden, "Materials and constructions for rockets, missiles, and satellites."

Despite our limited propulsion facilities, nevertheless within the next 10 years, man will achieve the following fairly basic objectives:

(1) Biological hazards arising from travel in outer space will be diagnosed and largely overcome. The penalty for these investigations will be the sacrificing of numerous warm-blooded animals and, in time, of numerous human beings. The sacrifice of human beings will be roughly a little higher than was incident to man's conquest of the air.

(2) The problem of controlled reentry of Earth-orbital vehicles will certainly be achieved, and it is even possible that the reentry of lunar vehicles also may become a reality.

(3) The whole field of space communications will receive detailed investigation and use—and should result in the most productive aspects of the entire astronautics effort.

(4) An area most often overlooked, namely, the advent of rocket transportation from point to point on the Earth's surface, will achieve great impetus and within the decade we will have rocket communications between distant points such as Moscow and New York, Melbourne and London, and so on. This new form of transportation will create vast international problems and vast new requirements for facilities. The great central pine-laden plateau of New Jersey will be cleared to become an immense landing and launching field for rocket ships. From here cargo and human beings will be transported to London in half an hour and to Moscow in 45 minutes. This type of transportation is quite inevitable.

(5) The coming decade should see the successful launching of Mars, Venus, and Moon probes and the establishment of many heretofore undreamed of orbits. The instrumentation on these probes undoubtedly will supply mankind with information of immense value.

(6) From the astronautics effort will arise the greatest industrial complex in the history of the world. The combined number of production workers in the automotive field of the entire world and the dollars spent on the automotive industry, will soon, in each case, be equal to only a fraction of the astronautics industry. During the next 10 years the peoples of the Earth will finally be faced with an industrial revolution never before realized—even on a prorated basis and taking into consideration all elements of finance, population, and industry.

International agreements to bring about peaceful regulation and encouragement of astronautics must be achieved in the very near fu-

ture, or this unprecedented potential boon to human welfare may well become a most efficient means of self-destruction and the degradation of mankind.

GEORGE L. HALLER, VICE PRESIDENT, GENERAL ELECTRIC CO., SYRACUSE, N. Y.

INTRODUCTION

From the standpoint of technological feasibility, certain advancements in space exploration may be predicted with some confidence, inasmuch as the state of the arts in space technology is already sufficiently advanced to achieve them.

Certain other potential achievements, predicated on anticipated advances in technology, may be forecast on the assumption of an adequate national effort. The assumption pertains to the selection and management of space programs, the amount of money allocated to them, the degree to which the enormous research and development capability of the United States is put to work on them, and, perhaps most important in the long run, the extent of public understanding and support.

This paper endeavors to furnish the committee with estimates of the achievements which now are, or should become, technologically feasible in the next 10 years.

GENERAL ELECTRIC'S EXPERIENCE IN SPACE TECHNOLOGY

As a way of indicating the experience underlying the views expressed in this paper, it may be of interest to review briefly the company's background in defense work as related to space problems.

For a number of decades the company has been pleased to help solve difficult military technological problems such as those encountered in building nuclear reactors for aircraft propulsion, specialized communication systems, giant radar units, and improved jet engines.

The company also devotes a part of its manufacturing facilities to the production of military equipment and materiel. In recent years defense work has accounted for about 20 percent of total sales. The highly technical nature of this work can be seen in the fact that nearly 50 percent of the company's technical manpower is assigned to defense product departments.

America's first industrial guided missile contract was signed in 1944 between General Electric and Army Ordnance. Since then the company has worked continuously on missile problems, participating in at least one phase of the research, development, and production of many major missile projects undertaken in the United States.

Work conducted under contract covers virtually all aspects of missile development, including propulsion, guidance, fire control, warhead arming and fusing, reentry (nose cone) vehicles, space cabin design, as well as other work both classified and nonclassified.

Example of company's research and development missile work

The successes of the reentry vehicles developed by General Electric may be of interest.

For the Thor missile the company is producing reentry vehicles which have been proven in a classified number of flight tests. A more advanced type of reentry vehicle for the Thor-Able missile was successfully flight tested just 7 months after developmental work began in December 1957.

A valuable byproduct of the successful Thor flights is of extreme significance to the scientific world. Data capsules developed by General Electric and bearing instruments to obtain, record and store scientific information have been successfully recovered for analysis in the laboratory. This marks the first time that scientific data has been physically recovered from hypersonic missile flights.

The range of the company's interest and involvement in space work is perhaps illustrated by the fact that 17 separate departments made substantial contributions to a recent company space-flight symposium. General Electric operates 42 research and development laboratories, all of which have complete research and scientific facilities for their particular purposes. Their work is either directly or indirectly contributing to progress in space problems, and the cross-fertilization of technologies within the company is of immeasurable help to all departments engaged in this work.

Progress requires contributions of many organizations

A point to be stressed is that no single organization can hope to progress by itself very far or for very long in space technology. General Electric is but one element of a large complex of brainpower that industry, educational institutions, Government agencies, and the military bring to bear on space problems.

In the future development of space technology, it is clearly of first importance that all organizations capable of making significant contributions be employed so as to enable their personnel to keep pace with current advances.

Within industry itself, the subcontracting process should be maintained. It broadens the base of technological competence and establishes a ready potential for maximum production under emergency conditions. General Electric maintains close working relationships with thousands of suppliers. On just one missile contract, for example, the company has more than 600 suppliers. They receive more than 50 cents of every dollar paid under the contract, and about 85 percent of them fall within the "small business" classification. This kind of arrangement, we believe, is one that in the long run will best serve the national interest.

POTENTIAL SPACE ACHIEVEMENTS OF THE NEXT DECADE

The pace of technological achievement accelerates year by year, making accurate forecasting increasingly difficult even for short periods. A common error is that of being too optimistic about what can be achieved in a few years and too cautious about the developments to be expected in 20 or 30 years.

Perhaps the only certainty is that space exploration and research will lead to new knowledge whose origins and applications cannot now be predicted. That is a lesson which the history of science teaches. It is also the reason that the quest for new scientific knowledge must be vigorously supported.

Research is the pursuit of the unknown, and we Americans have learned to expect the unexpected from it. We fear—and with good reason—that a potential enemy may come into possession of potentially dangerous scientific knowledge unknown to us.

Being the first to learn about the unknown—the unexpected that cannot be foreseen—has a payoff in terms of insurance against surprise which perhaps alone justifies the tremendous costs entailed in space exploration and research. This point is particularly cogent when the cold war situation is taken into account. Scientific achievement has become one of the foremost determinants of national prestige and a potent weapon in what is called the battle for men's minds.

Utilitarian benefits of space technology

Fortunately, there are other more immediate kinds of return to be anticipated from advancements of space technology. Man has long demonstrated great ingenuity in making useful applications of new scientific knowledge. There is every reason to have faith that the unknowns of today—the new scientific knowledge of tomorrow—will have useful application to man's peaceful goals and aspirations.

Some of the directly utilitarian uses foreseen as resulting from further progress in space technology include better weather analysis and forecasting and, ultimately, limited weather control; safer, more accurate navigation over the surface of the Earth; improved point-to-point communications; global television; and, when the world is ready for it, the possibility of international surveillance and policing.

These are some of the benefits that may realistically be expected from but the first step into space. Substantial progress could occur within the next decade with respect to all of them. Dr. Hugh L. Dryden, Deputy Administrator of NASA and an eminent scientist in his own right, stated recently:

> I think that in a relatively short time the economic payoffs of our civilian space effort will have been so large as to make the entire space effort fully self-financing.

Looking further ahead, there are possibilities of still other benefits beyond anything presently conceivable. Dr. Richard W. Porter of General Electric, who, among other responsibilities, serves as chairman of the earth satellite program of the United States National Committee for the International Geophysical Year, has put this thought in these words:

> If our scientists can obtain extended knowledge and a clearer understanding of the Earth and its atmosphere; of the external environmental effects which control so many material phenomena on Earth; of the Moon, the Sun, and the neighboring planets; of the dependence of living things on the gravitational field; of whether and how life has developed on other planets and therefore how it came into being on Earth; and eventually, perhaps, of the innermost

secrets of the universe, such as the interplay between mass and energy, the continuing creation and destruction of matter, and the size and age of the universe, we may hopefully expect that out of this new knowledge and understanding will come developments far beyond our present imagination.

Payoff in advanced military capabilities

Still another form of return lies in the development of military weapons and devices. The United States cannot afford to risk losing the deterrent power that comes from being able at least to match the Soviet's military capability.

On the basis of the company's experience in defense work, we respectfully suggest consideration of several changes in approach to defense research and development that would, we believe, result in improved performance.

1. The idea should be rejected that no research is worthwhile unless it is tied to a weapons system. This is costly nonsense, particularly in view of the fact that events of the past year have demonstrated dramatically that every experiment in space produces results which had not been anticipated—evidence of the need for a great deal more exploratory research.

2. Research decisions should be decentralized in order to assure the application of the best and latest information. Technological advances occur so rapidly today that inflexibility in a research program, which frequently occurs under centralized decision-making, is practically a guaranty of inferior results.

3. Researchers should be granted greater freedom to chance possible failure in the bold pursuit of high-risk ideas. Bold ideas, if successful, are generally the ones that yield high-potential results.

4. Costs should be reduced by cutting down on some of the elaborate machinery that is set up to prevent mistakes and avoid duplication. This machinery, in the form of numerous review committees and redtape procedures, consumes time and money that might otherwise be devoted to research itself. Safeguards are necessary, of course, but they may be carried too far when it costs more to police the expenditure of money than can be saved by the policing effort.

A current trend emphasizes the importance of adopting such changes as are suggested here. It is that as we undertake more elaborate systems and supersystems, time and costs tend to increase, while the useful life of the product or process is shortened by accelerating technological obsolescence. Permitting late design changes and other adaptations while work is in progress may serve in some degree as a means of extending the useful life of costly hardware.

It may be recognized, also, that defense research and development does not necessarily parallel the work that must be done in meeting space-flight requirements. To date, space-flight research has largely employed castoff military equipment or has hitchhiked on military tests. It is encouraging to anticipate that under NASA, as well as under other agencies, increased attention may be given to space research conducted independently of defense requirements.

It is to be hoped that research and development will increasingly come to be recognized as worthwhile ends in themselves and that they will be put on a sound basis and managed with skill and purpose.

Advances that present technology will permit

It should be self-evident that the rate at which potential benefits are realized from space technology depends largely upon the speed with which necessary new technology is acquired. The scientific knowledge possessed by the United States right now is adequate to implement a number of space probes and satellite launchings that would be of inestimable scientific value.

Beginning with a Venus space probe in 1959, a 3-year program might include a Venus satellite, a Mars satellite, a close lunar satellite, a lunar soft landing, a trans-Mercury (solar) probe, a trans-Mars (outer planetary) probe, a Venus slow descent, a Mars soft landing.

These missions could carry instruments in packages ranging from 50 to 250 pounds, which would be sufficient to enable us to acquire a great deal of knowledge we do not now possess. We could determine the astronomical unit in terms of Earth units, such as meters or feet. We could study the density and characteristics of interplanetary matter. The radiation environment in space could be more extensively studied. We could learn considerably more than we now know about the electric and magnetic fields in space. We could study radio propagation through interplanetary space. And the study of the effect of space environment on living organisms could be advanced.

Of perhaps more popular interest, the suggested satellites and probes would enable us to learn, for example, about the composition and physical characteristics of the surface of the Moon, what the clouds that blanket Venus consist of, whether or not Venus rotates, and whether or not there is any form of life on Mars.

Closer to home, there are a number of things we could be doing that would enable us to acquire new knowledge about the Earth and our atmosphere. We could, for example, orbit around the Earth a satellite that would carry a light to illuminate on signal, permitting pinpoint photographs to be made from different positions on the Earth. Such an experiment might enable us to map the gravitational fields of the Earth. The density of the upper atmosphere and other valuable information could be obtained by sending up an inflatable sphere that would be large and light enough to register air drag at an altitude of 500 to 1,000 miles.

A critical shortcoming in space research

There is literally no end to the things scientists would like to know and to the experiments that might be conducted. Every research project suggests new areas of investigation. Obviously, not all desired or desirable studies can be conducted at once. The problem is to make the wisest possible use of available funds.

With this thought in mind, it might be appropriate for us to point out that one area of research—applied research to advance the state of the arts in space-vehicular technology—is largely neglected. There is little seed money with which to replenish the technology we are continually harvesting. Unless corrected, this could prove to be a critical shortcoming in the Nation's space effort. It is highly desirable that provision be made so that creative scientists and engineers can do concentrated work in specific areas of inquiry in advance of an actual need for the particular knowledge sought.

Advances required in space technology

It is possible, and indeed probable, that a manned spaceship might circle the Moon within the next decade. Before other space travel possibilities can progress very far, however, a number of technological advances will have to be made.

In general the major barriers to space travel lie in the technological problems of propulsion, auxiliary power systems, structures, and human factors. The latter is already being given considerable study by the military. Development of the necessary knowledge in structure should present no serious difficulties that can be foreseen now. But years of work will be required on propulsion plants and auxiliary power systems before true spaceships with cruising power become operational.

Both propulsion powerplants and auxiliary powerplants are of continuing and active interest to General Electric. During the past 2 years, the company has been conducting intensive engineering studies to identify potentially feasible and attractive space propulsion systems.

Booster powerplants

Our studies indicate that early attempts to launch spaceships will depend upon separate booster vehicles to accelerate the ships into orbit. Orbit corrections will be attained by vernier rockets, but otherwise the spaceships will be unpowered.

Early booster vehicles could utilize present rockets arranged in a cluster to achieve adequate thrust. A second generation of recoverable first- and perhaps second-stage booster vehicles designed for a variety of different payloads might be developed as the key to operational economy. These recoverable booster vehicles would probably be manned. They would be powered by self-accelerating air-breathing booster powerplants, possibly in combination with advanced liquid-propellant rocket engines.

Nuclear heat transfer rocket

A type of rocket now being considered for space vehicles is a high-temperature nuclear reactor through which is passed a low molecular weight propellant such as hydrogen or ammonia that is heated by the fission process and is then exhausted through a rocket nozzle to produce thrust. Since the nuclear rocket would not have to carry a high molecular weight oxidizer, it could theoretically have a specific impulse at least double that of the best chemical rocket.

The nuclear heat transfer rocket might prove attractive for putting large payloads in orbit (on the order of 25,000 pounds or more) and for space missions to the Moon, Mars, or Venus. General Electric's aircraft nuclear propulsion department is presently under contract to the United States Air Force and the AEC to develop a nuclear turbojet powerplant for aircraft propulsion. The development of related powerplants for space propulsion is a logical extension of this work.

Other propulsion possibilities

In addition to advanced chemical rockets and the research and development required for a nuclear heat transfer rocket, other propulsive techniques are clearly not to be overlooked. These include plasma jet engines, nuclear engines of other types, and photon and ion propulsion. The latter appears to hold some promise as the cruise powerplant or at least as a means of attitude control of a spaceship over a long period of time.

A relatively large investment in research and development funds is believed to be a necessity during the next 10 years in order to achieve true capability for interplanetary space travel.

As we reported to the committee earlier this year, the company is ready at this time to undertake a comprehensive development program of an electrical space propulsion system. Such a system is likely to be especially attractive for those applications requiring large quantities of electrical power, since the generating equipment could be used for nonpropulsion functions. For example, it should be extremely effective in controlling the orientation and movement of a communications unit in space, at the same time providing the power required for the operation of the radio equipment.

Auxiliary power system

The present lack of an adequate technology for devising a suitable auxiliary power system for space vehicles constitutes a very critical limitation on this country's ability to advance into interplanetary space. A continuous source of electrical power, capable of operating without any maintenance for long periods of time, will be necessary for communication and radar equipment. It must also produce energy for electrical propulsion devices needed for orbit corrections and for the many supporting functions on which a human crew is dependent.

Several nuclear auxiliary systems appear possible, such as (1) a nuclear reactor, or (2) a radioactive heat source with a steam or closed-cycle gas turbine generator set, or with (3) a thermoelectric converter. Still another approach to the auxiliary power problem lies in the development of solar-energy converters.

Research and development effort will be necessary throughout the next decade to perfect and refine auxiliary power systems suitable for space vehicles.

NONTECHNOLOGICAL PROBLEMS REQUIRING ATTENTION

In the final determination of the rate of progress the United States makes in conquering space, nontechnological problems will prove at least as difficult as the technical problems faced by scientists and engineers.

It would not appear appropriate to present here extended arguments about the problems to be anticipated. But this paper would not seem complete without mention of them.

Indemnity

General Electric, like other firms engaged in missile and space work, is concerned about the question of indemnity as it pertains to unusually hazardous risks arising from missile space programs. An indemnity provision should be included in the Space Act. Participation by industry in space development in the coming years will increase the need for protection against liability claims too large to be assumed as business risk and for which adequate insurance is not available.

The programs that can be foreseen in the future would dictate against limiting indemnities to research and development work or to indemnities effective only within the territorial limits of the United States. The need is for authority to indemnify without limits as to place of occurrence of loss, particular stages of work, or range of activity.

Patents

We are seriously disturbed by the sweeping authority of the patent provisions of the Space Act. As written, the act grants the Government exclusive ownership of any inventions conceived or first put to use under any contractual or other arrangement between a company and NASA. Apparently, these exclusive rights might attach to inventions made with private funds in advance of and independently of a contract proposal, or even to inventions stemming from noncontractual research and development that a company might undertake for commercial purposes, if the inventions related to one of the scientific fields also being investigated for NASA. Provisions having such effects obviously penalize severely those corporations that draw upon nonspace research and technologies to facilitate space work.

We believe that in these respects the act dangerously undercuts the incentives which ought to apply to the field of space activity. We suggest also that there are serious public policy implications in the concentration within a Government agency of patent control over what may well prove to be the major proportion of a new technology to be developed in the next few decades.

For these reasons we believe that Congress should immediately initiate remedial legislation. It is felt that industry, given a hearing, can suggest amendatory provisions which will better serve the presumed objectives of the Space Act than do the patent provisions which the act now includes.

Procurement practices

To better meet changing conditions arising from the fact that industry is now continually involved in defense work and to better satisfy the need for technological advances on a broad scientific front, certain changes in procurement practices are worth consideration. Specifically, we suggest that:

1. Greater incentive profits in return for good performance and reliability might enable private companies to invest more of their own funds in exploratory research and needed facilities, thus achieving greater decentralization of initiative.

2. Steps might be taken to permit greater freedom and latitude in the management of those research-and-development contracts which are essentially scientific in character, as contrasted with those for limited military purposes only.

3. It would be a saving of time and money if there were fewer review committees and fewer, but better qualified, project supervisors. The latter might serve more usefully if authority to approve proposals and changes existed at lower levels than at present.

4. Several advantages might be attained by elimination of situations in which approval of proposals rests with the same Government personnel who advance competing proposals of their own.

5. The scope and complexity of space programs to meet scientific and defense requirements are so demanding that there is a clear need for the development of legislative guidelines which will permit industry to work together in making available the full range of its technical competence without risking unwitting violation of the antitrust laws.

Public support

There is gratifying evidence that Congress and the public are aware of the promise of space research and exploration. While every advance made in space is likely to have military applications, we hope the realization will grow that the justification for spending the people's money on space research and exploration extends far beyond the question of military use.

CONCLUSION

Man's venture into space is the great enterprise of this century. It calls for a concerted effort by many people and organizations. In view of the complexity and the scope of the problems involved, tremendous progress has already been made. Yet in the light of what remains to be done, all that has been accomplished so far is no more than a tennis ball as viewed in relation to the Earth. At this point we must continue to proceed largely on faith that the enormous effort and expense required will yield worthwhile returns. There is every reason to believe that in time—perhaps sooner than most people would believe—that faith will prove justified.

REAR ADM. JOHN T. HAYWARD, ASSISTANT CHIEF OF NAVAL OPERATIONS (RESEARCH AND DEVELOPMENT), WASHINGTON, D. C.

* * * Your theme, "Whither the Space Age in the Next Decade," is indeed timely and worthy of the most careful consideration of everyone engaged in astronautics and space exploration. The "whither" is the key, in my opinion, to ultimate success; whether we take the high road of spectacular stunts or whether we take the low road of step-by-step, mile-by-mile basic scientific exploration to first acquire and extend our knowledge of space. Obviously, the most logical course of action is the latter—the low road. Unfortunately, this does not seem to be the case at present. The sputniks created the great "race into space"—the challenge for a race to the Moon, the planets, and stars—with as many unanswered questions as there are miles to bridge the enormous distances. Dr. Wernher von Braun recently stated in a presentation "the first specification that we now receive is the launching date." So, regardless of our current knowledge of the difficulties of space or the lack thereof, we launch! We have only a very few pounds of payload material in orbit, and we have gained valuable information. However, with the possible exception of Vanguard, orbits have been achieved by brute force; in all cases orbit predictions have been sketchy. Yet we immediately hit the "high road" for lunar probes and glowing accounts of man-in-space; the race to the Moon.

On the other hand, we must acknowledge the great contribution that we gained from the sputnik hysteria in awakening this country to the need for prompt action to meet this oncoming Space Age. Perhaps we have been overanxious and hasty in attempting a variety of approaches to "win the race," but now we should carefully consider our future course.

Aside from basic scientific experimentation and technical development that are immediately recognized, two important factors must be considered. First, the tremendous cost of a successful space program, and, secondly, maintaining the interest and wholehearted support of the American people. The cost factor demands the earliest formulation of a fully integrated national space program. In this connection, I do not mean a listing of projects, but rather a detailed plan to conquer space by a series of experiments to resolve its mysteries and thereby determine the probability of success for later more sophisticated ventures. We must face the fact that we will have failures, as we have had in the past. Repeated failures will discourage the most ardent supporter. Consequently, it is most important to maintain the support and interest of the American people by publishing facts concerning the difficulties of space flight and the low probability of success, rather than attempting to "sugar coat the pill." The American public must become scientific minded to accept a series of failures and not expect a Yankee dollar's worth of results for each appropriated dollar. The continued cross-examination of scientists as to why their complicated apparatus failed will eventually drive our imaginative scientific ability into stereotype efforts.

The future of space development in the next decade will depend in a large measure on the support and interest of the American people and their willingness to go along with a basic scientific effort that may not win immediate victories in the race in space, but whose ultimate success will be accomplished. I sincerely hope that the United States will continue its maximum effort to resolve the mysteries of space, to the end that man will, one day, explore outer space.

"Whither the Space Age in the Next Decade." In our present state of progress in facing the multiplicity of problems and unknowns of space, it would seem most pretentious to venture any predictions as to the accomplishment in space developments within the decade. I would be far more inclined to follow the example of the President's Science Advisory Committee in defining a space timetable in terms of scientific objectives as "early," "later," "still later," and "much later still." In passing, I would recommend the President's Science Advisory Committee explanatory statement "Introduction to Outer Space," as a departure point for your report on space development.

Will man reach the Moon in the next decade? Plans are being made and work is being undertaken on the assumption that it will be possible and desirable for man to fly in orbit about the Earth, to the Moon, and eventually to the planets. Although it is understood that unmanned devices must precede the man it is not possible at present to be certain that it will be feasible for man to journey into space. I refer to the so-called Van Allen radiation belt around the Earth. Nor, indeed is it yet possible to say whether it would not be more sensible to try to explore space with automatons as an alternative to attempting to solve the problems of sending man's environment with him. Either approach will require the solution of immensely difficult engineering problems. I would say that man will fly in space orbit within the decade but the successful achievement of man reaching the Moon will take more than 10 years. Man successfully reaching the planets within a decade is extremely doubtful—almost certainly not. Perhaps the key to man in space, Moon flights, etc., can be stated as follows: "manned space flight will be practicable when there is a *reasonable* chance for survival and rescue." The number of unknown quantities to be resolved in order to satisfy the term "reasonable" may well determine the question that man will ever travel through space.

Operational liquid fueled rockets have existed for 13 years. Great difficulty still attends their use—especially where reliability is concerned. Propulsion systems must be improved to have a very high degree of reliability in order to have manned space flight with a "reasonable safety factor." High-thrust systems are required to escape the Earth's gravitational environment whereas relatively low-thrust systems are required while the vehicle is in orbit or in flight between planets. In nuclear rockets it seems that liquid hydrogen is best as a working fuel. However, nuclear power is not so attractive right now as improved chemical power. The development of the practical use of fuels other than kerosene and oxygen is in a very early state. It might be stated that as the space project or flight becomes more ambitious, the nuclear power system becomes more attractive.

In my opinion, our greatest achievement within the next decade will be unmanned satellites filling the vital needs of communication, navigation, and weather forecasting or meteorology. Weather forecasting as an exact science requires more than just the ability to observe the atmosphere from outside. Observation from satellites should lead to a better understanding of what the atmosphere does, but unless the new knowledge leads to a comprehensive theoretical development it may not add very much to the precision of practical meteorology.

There is every reason to expect the development of a navigational satellite system that will provide the required accuracy to insure the safe navigation of all ships of the world in all oceans of the world, regardless of the weather. It may even be possible to extend this system to the safe navigation of aircraft on long-extended flight. Additionally, such satellites could provide for the accurate measuring of the Earth, its islands and mountains.

Satellites can provide a communication system that will permit continuous worldwide color television. This can be done within the decade if the proper emphasis and funding is provided.

The infant steps in space have been taken by Sputnik, Explorer, and Vanguard. Undoubtedly, the future will provide man his first real flight into space to other planets; perhaps not in this decade, but surely in the next. I should like to close by repeating the last sentence of the report of the President's Science Advisory Committee on Outer Space, "It therefore appears wise to be cautious and modest in our predictions and pronouncements about future space activities * * * and quietly bold in our execution." * * *

DR. ARTHUR KANTROWITZ, DIRECTOR, AVCO RESEARCH LABORATORY, EVERETT, MASS.

* * * The interest in space flight will, in my opinion, be greatly advanced by a development which is currently completely within our scientific horizons. This is the communication satellite.

Communication satellites will produce an entirely changed attitude toward space flight simply because it will be clearly seen how space development will pay for itself. Communication satellites will make possible worldwide communication far more perfect than any we know today. Thus, for example, it is possible to establish many TV channels and innumerable voice channels between any points on the Earth's surface with the use of 3 satellites in the so-called 24-hour orbit. These satellites would receive and rebroadcast signals from and to the Earth's surface. It now seems clear that such relay stations can, in the not too distant future, provide a vastly superior communication system to the one we now possess. Note that our current expenditure for electronic communications (radio, telephones, etc.) runs into many billions of dollars annually. It is apparent, therefore, that a superior communication system via satellites will be worth much more than this per annum.

It is a remarkable fact that, although our adventures in space are only about a year old, we can already see clearly how they will pay for themselves. In the communication satellite we see a concept which, though it is not new in the sense that it was first proposed many years ago, has come into its own because of the enlargement of our vision brought about by the actual achievement of artificial satellites.

It seems clear that, when we make the further step of putting a man into space, some of the many propositions which have been put forward which man can do in space will make similar tremendous impacts on our economic system. I should like to urge that we should take courage from the fact that we can already see how space will pay for itself to move on to much bolder adventures, and that we should not allow those who see only the immediate expenditures to stand in the way of progress in a field which is not only essential to our survival through military and scientific strength, but also promises to constitute an important segment of our civilian economy. * * *

DR. JOSEPH KAPLAN, CHAIRMAN, UNITED STATES NATIONAL COMMITTEE FOR THE INTERNATIONAL GEOPHYSICAL YEAR, PROFESSOR OF PHYSICS, UNIVERSITY OF CALIFORNIA AT LOS ANGELES

Prediction in science is a most dangerous and often foolhardy occupation and yet, unless some of us try to predict, it is impossible for those who plan legislation and budgets to prepare for the future. The International Geophysical Year, which will come to a formal end on December 31, 1958, is an excellent example of what can happen when the ideas of scientists and their supporters in Government and industry are combined into an actual program. Parts of the program that appeared to have been impossible to accomplish by December

1958, are now not only matters of record, but the basis for carefully thought out and ambitious programs of the future.

The space science program in the International Geophysical Year appears now to be a conservative one, particularly when one realizes that progress in space research seems to have outstripped the predictions of the past. It is my feeling that while we should try to be realistic and reasonable, we should also remember that science and technology now move faster than most of us dare predict, and that the setting of difficult and ambitious goals brings with it many unexpected rewards.

The principal developments in space science in the next 10 years will probably be the results of experiments performed in manned and unmanned satellites. The proposals that were made to the United States National Committee for the International Geophysical Year, and then subsequently extended and reexamined by the Space Science Board of the National Academy of Sciences, represent a great challenge to the combined efforts of all of the nations that might conceivably cooperate in one phase or another of this great scientific enterprise. It is my strong belief that for the next 10 years at least we should set as our goal the solution of those space problems that are essentially tied to operations on the Earth. Satellites for better communications; satellites that will literally revolutionize astronomy; satellites, for weather prediction and for many other scientific and applied purposes, will add much to both science and industry and what may be as important, to the vision and hopes of a harassed and confused civilization. One should not forget the new opportunities and challenges that space research has given to the life sciences. The results in these fields are bound to be notable during the next 10 years.

In planning the space science program, it must always be kept in mind that space research is, by its very nature, international in character. The scientists who have been the pioneers in space research have already acted on this by the recent authorization and quick organization of a Committee on Space Research (COSPAR), by the International Council of Scientific Unions (ICSU). It was ICSU that set up the committee that in turn organized the International Geophysical Year.

The composition of COSPAR represents clearly the scientists' concept of the large variety of interests that space science will eventually generate. It is made up of representatives of nine scientific unions, as well as of countries that are vitally concerned with space research. ICSU, through COSPAR, can become a powerful force for bringing together world science in a way that will make most effective the large space efforts now underway or contemplated. It will do much more than this, by uniting scientists of the world in another great and imaginative enterprise, and in this way putting into action one of the most significant aspects of the relationships of our country to the rest of the world.

ALEXANDER KARTVELI, VICE PRESIDENT, RESEARCH AND DEVELOPMENT, REPUBLIC AVIATION CORP., FARMINGDALE, LONG ISLAND, N. Y.

A. TIMETABLE OF SPACE ACHIEVEMENTS

The listing below is a logical sequence of significant events in the conquest of space. The dates assigned are a rough assessment of the difficulty of the tasks. It presumes a realistically large unified development effort.

1957: First sputnik.
1958: Explorers and Vanguard.
Moon probe.
1959: Planetary probe.
1960: Manned Earth satellite.
1961: Instrumented lunar hard landing.
1962: Instrumented planetary hard landing.
Instrumented lunar soft landing.
1963: Instrumented planetary soft landing.
1965: Man in orbit around Moon.
1968: Space station for staging to Moon and planets.
1969: Man on Moon.
1970–75: Moon base.

B SCIENTIFIC SPACE SYSTEMS

1. Propulsion

1. Propulsion is, of course, the key to movement in space. For several years, more efficient and reliable means of launching greater weights into orbit and of in-space propulsion for maneuver, orbital shifts, and interplanetary travel have been under development. Recoverable boosters now being developed can provide a more economical means of launching small satellites, and nuclear boosters should reduce the ratio of launch pad weight to weight in orbit from the current figure of over 100 to 1 to less than 10 to 1. Ion- or plasma-jet propulsion, using a nuclear power source, appears to be a highly promising technique for in-space maneuver. Intensive effort is now going on in this field. A technological breakthrough in either of these regions would give a great impetus to all space programs.

2. Moon Missions

The present Moon probe shots will shortly prove successful and be followed by unmanned landings on the Moon. These will be followed by manned circumnavigations of the Moon in a few years. Considerable progress in our current state of knowledge will be required before a manned landing on the Moon can be attempted, but 10 years is a long time and there is every reason to believe that it is time enough for the purpose. Actual Moon stations may take more than 10 years.

3. Planetary missions

Test probes of neighboring planets will start within a year. Unmanned hard landings will probably take place shortly after similar missions to the Moon. Instrumented soft landings on the neighboring planets should follow after similar missions to the Moon. Manned landings on the nearby planets will take more than 10 years and will involve more elaborate expeditions in terms of numbers of personnel and vehicles.

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4. Space stations (manned)

Manned space stations have been suggested as a staging area for further exploration of space. The present "man-in-space" programs planned for the near future offer considerable hope that in a 10-year period the first operational space stations will have been placed in orbit. It must be realized that the launching of any manned system requires a period of testing with similar unmanned systems to assure reliability. Only in this way can a sufficient degree of confidence be attained.

5. Weather

The ability to obtain a global weather picture by the use of weather satellites combined with modern computing machines and techniques will definitely bring us near to the goal of making weather forecasting an exact science. Scientific institutions are now studying control of weather. With improved knowledge of meteorological phenomena, a degree of control can well become feasible, as an important economic and military objective.

6. Geophysics

The current interest in space systems will result in a considerably expanded effort in this field and many new systems will be proposed for scientific as well as military uses. The degree of success and efficiency which will be realized for any of these space systems will depend largely on a detailed knowledge of the operational environment. Republic foresees an extensive satellite program in the near future to extend the current knowledge through basic research. Not only will the upper atmosphere and space be extensively explored and defined in the next 10 years, but geographic relationships on Earth itself will be accurately determined.

7. Astronomy

Optical Earthbound systems are severally limited by atmospheric interference so that other means for exploring the heavens are being sought. Many elaborate radar "telescopes" are being designed and built today to overcome this difficulty. Operating beyond atmospheric interference offers an escape from this confinement and we may expect considerable activity in the field of astronomical satellites and great strides in improving our knowledge of the universe.

8. Communications

New techniques for launching satellites cheaply, in the study of which Republic is now engaged, will provide the ability to keep systems of orbiting satellites in operation. A network of this kind will provide a reliable communication relay system. Intercontinental television will be a reality, and the disruptive effects of sunspot activity on communication will be circumvented.

C. MILITARY SYSTEMS

Historically, whenever man has conquered a new medium for exploration or transit, there has followed an immediate need for military means to control it. Thus the development of sea and air transport led to the evolution of navies and air forces. This military power comprises means to insure safe transit in the new medium to deny its use for hostile purposes, and to conduct reconnaissance in and from the new medium. The ultimate purpose of these new military forces is to influence conditions and interactions on and between the land masses of opposing homelands. Military operations may be broadly categorized as reconnaissance, offense and defense.

1. Reconnaissance includes detection of activities and conditions in space and terrestrial mediums. Among intelligence targets are military actions, transport movement, electromagnetic radiations (ferret), and meteorological phenomena. All of these observations in peace or cold war have a deterrent effect by precluding surprise attacks. They also lead to contemplation of specialized modes of limited war by some degree of control of electromagnetic communication and detection, and of weather. These systems will precede the offensive weapons.

2. Offensive operations in space may comprise attack and control of terrestrial systems from space, destruction or neutralization of hostile space vehicles and the occupation of the Moon and planets. The first may be achieved by a combination of orbital vehicles and ballistic missiles with the former exercising guidance over the latter. All of these systems appear feasible in a 10- to 15-year time period.

3. Defensive weapon systems usually follow closely the development of offensive means. One of the first defensive satellite missions is to detect and counter intercontinental ballistic missiles. The next task is to destroy enemy orbiting vehicles, or to counteract their influence on terrestrial systems. In the limited war aspects of control of weather and electromagnetic radiation, it may be necessary to neutralize the influences of satellites without destroying them. A further extrapolation of defensive effect is to attack hostile installations on the Moon and planets.

D. CONCLUSIONS

1. Progress in launching and in space propulsion will have a profound influence on what can be accomplished in exploration and utilization of space in the next decade.

2. Aside from exploration there are many practical uses for space vehicles to improve the welfare of man on Earth.

3. Utilization of space for scientific purposes will lead to the development of military or police systems to assure safe transit in space and to prevent its use for purposes detrimental to national interests.

Dan A. Kimball, President, Aerojet-General Corp., Azusa, Calif.

* * * I am pleased to submit my views on prospective developments in space exploration.

Let me first review my concepts of the status of propulsion and auxiliary power as they relate to the space program.

BOOST ROCKETS FOR SPACE VEHICLES

Present propulsion systems developed for the military intercontinental ballistic missiles can be clustered to provide boost thrusts in the range of 1 to 1½ million pounds. Clustering of existing powerplants beyond this level would be considered impractical from the standpoint of reliability and complexity. However, programs now under consideration for developing higher thrust single engines should, if given proper support, make such single engines of 1 to 1½ million pound thrust range available within 5 years. Clustering of these larger engines could then provide total thrusts of 10 to 15 million pounds, adequate for the missions which seem feasible within this decade. All these booster powerplants would utilize chemical propellants and, since manned flight will be involved, maximum emphasis should be placed on safety and reliability. Considerations of safety and reliability should generally outweigh those of reduced size or weight. Extrapolation of missions beyond the next decade could conceivably require still larger boost systems. It is in this area that the nuclear rocket would provide significant advantages in reduced gross weight, and the further advantage of a single stage configuration. It is for the missions requiring very large payloads that the nuclear rocket holds particular promise. Continued effort in the nuclear area, however, could well produce a better booster engine for lower payload missions as well as for space exploration requirements. Significant progress can be made if we have continuous development of the nuclear rocket throughout the next decade which will insure its future availability for extended and increasingly ambitious space programs.

PROPULSION FOR SUSTAINED FLIGHT IN SPACE

Advanced propulsion systems with extremely high performance in terms of specific impulse would provide the optimum propulsion for space vehicles. These systems, classified under the general term of charged particle propulsion systems, eject particles with very high energies and can operate continuously for months or years. One of these systems, the charged colloidal propulsion system, gives promise of being useful for vernier control and navigation in space. This high performance system will be relatively light and compact. Another system, ionic propulsion, would give higher performance than the colloidal system and is considered desirable for sustained flight. In addition to these systems, our engineers visualize that a recombination powerplant can also be developed. This powerplant would utilize energy available in the upper atmosphere and would be particularly suitable for manned flight in the regime of Mach 10 or more and at altitudes of 50 to 100 miles. To date the studies and experimentation on these advanced propulsion systems show promising indications of their feasibility. Extensive development of many components such as ion sources, heat exchangers, controls, basic materials, and large electrical sources will be required to bring these advanced systems to a stage at which they would be useful in space programs. Full support of the development of these systems during the next 10 years will insure their availability for space applications.

AUXILIARY POWER

In the field of auxiliary power there are immediate requirements for systems of low output for short durations. Available chemical turbines, electrical batteries, and solar-cell systems satisfy these requirements. For missions of longer duration, particularly manned missions, power output requirements will be considerably above 1 kilowatt. For these applications nuclear auxiliary power will be the surest and most satisfactory means of obtaining reliable power sources. We believe that such units can be developed within 5 years, and will be available for space missions in this decade.

The nuclear system for auxiliary power is particularly attractive because it provides a possibility that the same reactor may be used as part of the propulsion system as well as for the auxiliary power system. This would apply to the ion-propulsion system in which a large electrical power source is required. It also would apply to the nuclear heat exchanger rocket, although, as previously noted, these developments are not expected to be completed within this decade.

SPACE MISSIONS IN THE NEXT DECADE

The above discussed booster propulsion and auxiliary power systems can definitely be available within the next decade *provided they are vigorously pursued.* Assuming their availability, and in answer to your question "Whither the Space Age within the next decade," we can visualize the following specific accomplishments:

Large satellites for observation, communication and meteorological purposes.

Lunar instruments surveys.

Landing of equipment on the Moon.

Initial attempts at manned landings on the Moon.

Manned orbiting of the Earth.

Initial attempts to establish manned space stations orbiting the Earth.

Exploratory flights to nearby planets such as Mars and Venus.

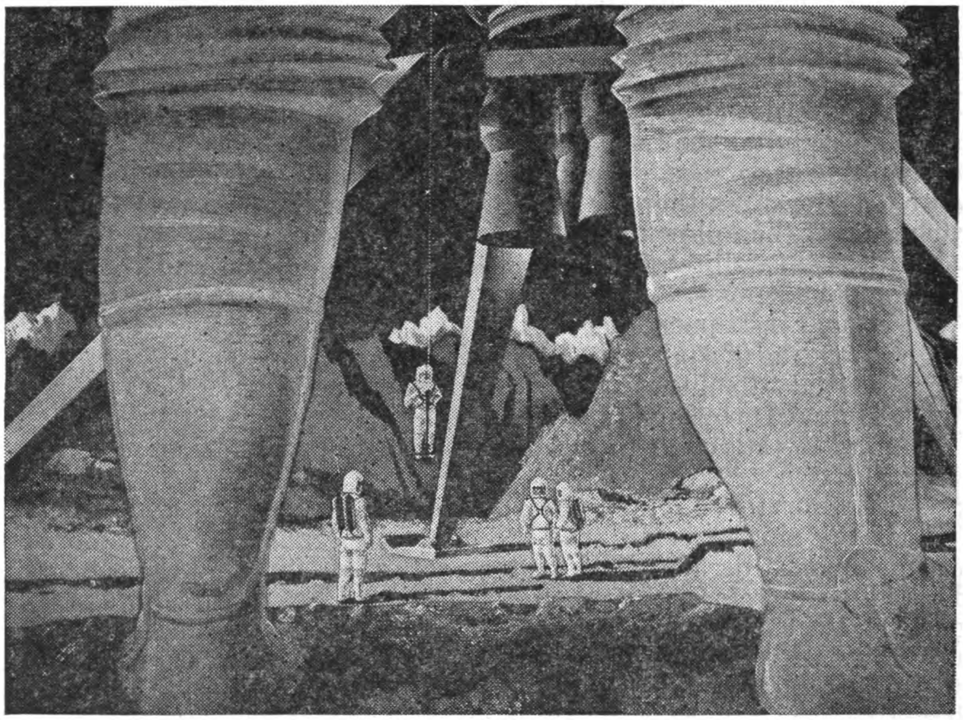
It is my sincere belief that the above programs can be achieved within the next decade. The importance of research and the benefits derived therefrom are no longer questioned or disputed. Consequently, the exploration of space for basic research should be inexorably pursued. Space flights can provide the necessary environment of gravity, atmosphere, pressures, etc., where many special research investigations can be uniquely carried on. Meteorology and communication are but two areas which can benefit in these space programs. There are numerous other new and as yet undiscovered areas, including the entire biological field, where the results of our research in space will yield benefits to present and future generations. The impetus that has been given the space programs by the successes over the past year with satellite and lunar probe projects places a challenge on all of us associated with the future space programs to justify the fullest national support. * * *

ROY K. KNUTSON, CHAIRMAN, CORPORATE SPACE COMMITTEE, NORTH AMERICAN AVIATION, INC., LOS ANGELES, CALIF.

FOREWORD

* * * Prediction of future events is always a risky enterprise. So at this, the very inception of the Space Age, we can form only tentative conclusions about what the years ahead may hold in this exciting new field. The layman asks, "Why go to space at all?" But as with the classic explorations of the Earth, it is reasonable to expect that the

conquest of space may unlock the door to physical discoveries of the greatest value to the human race. The effect on this and future generations of the extension of our knowledge of the Earth on which we live, the sun and the solar system, the universe around us—even, possibly, the origin of life itself—is difficult to visualize at this time. Space exploration will be a vast and expensive undertaking. However, as the select committee stated in an early report, "* * * the decision to enter into the Space Age is not one the United States can ignore or defer. Our national survival requires it."



Man sets foot on the moon.

All illustrations from North American Aviation, Inc., motion picture The Widest Horizon.

THE NEXT DECADE

The Space Age dawned spectacularly in the latter half of 1957 with the launching of the Russian sputnik. This and subsequent feats, both in Russia and the United States, have been likened in their effects on human history to the development of the atomic bomb in the previous decade. It is appropriate to ask the question, "Whither the Space Age in the next decade?" A variety of individuals and groups have come forward with answers to the question according to their own particular interests or experience. Military men have tended to regard space as a simple extension of the terrestrial military arena. The astronautic enthusiasts, encouraged by the early steps that have been taken, urge massive lunar and interplanetary exploration programs by men in fantastic spaceships. The scientists see an opportunity to expand knowledge of the Earth, solar system, and the universe around us. And the statesmen want spectacular achievements to symbolize our technological superiority in the battle for international prestige. The result has been a profusion of space recommendations, grandiose in concept and of incalcuable cost. At best these recommendations provide an uncertain and confusing picture of the years ahead in space exploration; more basic considerations are obviously required if a credible projection is to be made.

The technological state of the art is one such consideration. However, although a necessary condition, technological feasibility is not a compelling reason for any space undertaking. As with most human endeavor, we must determine if the cost of any particular space project is commensurate with the return, or if greater benefit would result from a like amount of effort expended in another direction. Since space flight requires the application of the highest levels of our technology, it will always vie for manpower, money, and material with other projects involving perhaps a greater urgency. For example, it would undoubtedly be technically feasible to place a man on the Moon and return him safely to earth within considerably less time than a decade. However, such an undertaking would require a massive effort involving a considerable proportion of our best scientists and engineers, a budget representing a sizable percentage of the yearly defense expenditure, and the priority utilization of hardware and material otherwise required in the national defense effort.

This is the crux of the problem in projecting the timetable of space activity in the next decade. Space is important and we will see exciting and important developments in this field in the years ahead. But we cannot neglect the manned bombers and interceptors, the missiles, the submarines and carriers, and all the other military hardware so necessary to our survival in this era. The picture of space flight progress assembled in the following pages attempts to maintain a balance between what is technologically feasible and what may be practicable in terms of the Nation's economy and security.

THE MISSIONS

The next decade can see a large number of space missions for widely different purposes. A broad classification of these missions may be made under three categories: Vicinity of Earth; Lunar; Interplanetary.

Initially, the missions will be mainly unmanned, but in the latter half of the period manned missions in the vicinity of Earth may be almost commonplace. And toward the end of the decade, a program aimed at placing man on the Moon should be underway. Manned interplanetary flight will certainly await this Moon mission; it appears that such flights may be as much as two decades removed.

Most missions in the period will be oriented toward scientific research and exploration. However, a number of military missions may attain increasing utility and importance. Generally, it is expected that space flight in the decade will serve the following main purposes:

NONMILITARY	MILITARY
Increase knowledge of Earth, Moon, Sun, and planets; astronomical research; global communication; weather forecasting.	Reconnaissance; global communication; satellite neutralization; military research.

VICINITY OF EARTH

SCIENTIFIC SATELLITES

Upper atmosphere research

Scientific satellites have already provided much new knowledge about the Earth and its atmosphere. Important additional discoveries undoubtedly lie ahead as this effective method of examining the Earth from arm's length, so to speak, is utilized. This knowledge will greatly extend our understanding of the mechanisms influencing weather, radio communication, and the radiation reaching the Earth's surface, for example. A list of the necessary areas of measurement would include the following:

Density of atmosphere, temperature of atmosphere, composition of upper atmosphere, structure of ionosphere, heat intake versus outgo of Earth, upper atmosphere motion, magnetic field of Earth. Charged particle density, cosmic ray research, high altitude radiation, density of micrometeorites, exact shape of Earth, composition of the Sun's corona, and magnetic fields of the Sun.

Astronomical research

Earthbound astronomers must be content to examine only the small fraction of the radiation emitted by the stars that penetrates the atmosphere. Furthermore, the resolving power of even the most powerful telescopes is limited by turbulence in the atmosphere. A telescope at satellite altitudes will reveal secrets of the universe in infinitely richer detail than is presently possible. Initially, small telescopes in unmanned vehicles will perform specialized tasks. With the advent of a manned space station a large telescope with a human observer can greatly extend the astronomers' capabilities. Our notions of the universe will undoubtedly be profoundly affected by the knowledge obtained with such instruments.

COMMUNICATIONS SATELLITES

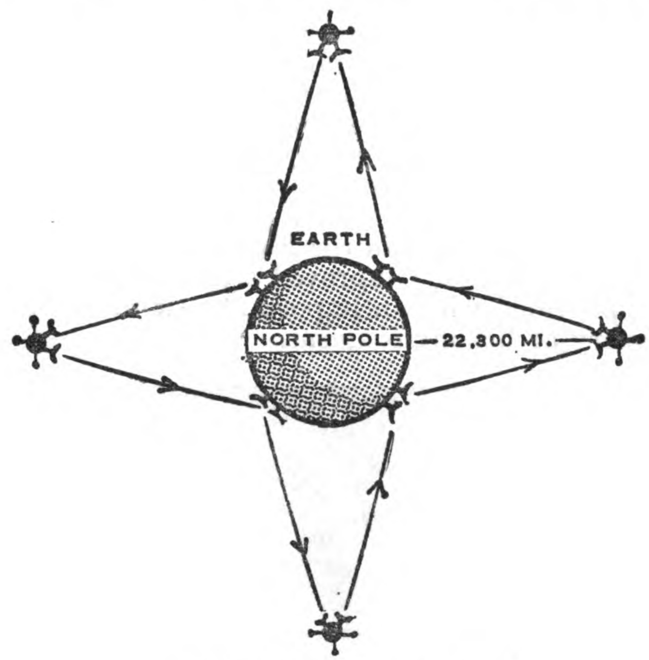
Stationary orbit

A satellite at an altitude of approximately 22,300 miles has a period of rotation about the Earth of 24 hours. Since this coincides with the period of rotation of the Earth about its axis, such a satellite will remain above a fixed point on the Earth's surface. Three or four satellites in stationary orbits will then provide a global capability for high-frequency radio communication, which is ordinarily limited to line-of-sight at the surface of the Earth. These satellites may be of the passive type, in which case they simply serve as reflectors for radio waves much as a mirror reflects light. Or they may be active with a small receiver-transmitter installed to receive the transmission on one antenna and rebroadcast it on another. Such a system would permit global communication with smaller transmitters at the Earth station, but would require very reliable electronic equipment and an internal power supply.

Projecting a satellite into a stationary orbit will require very accurate guidance and a vernier propulsion system. Because of the difficulty inherent in this process, stationary communication satellites are not expected to appear until the middle of the next decade.

Nonstationary orbit

Because of the importance of global communications, both for military and nonmilitary applications, it is probable that a system utilizing nonstationary satellites will be used initially. These will be used in a passive sense in which the earth transmitter tracks the satellite and bounces energy off it. The receiving antenna at the distant site must simultaneously track the same satellite. It is estimated that 35 to 50 satellites will be required in a 3,000 mile orbit to assure a 99.9 percent probability of transmission. However, these could be simple inflated spheres requiring no stabilization or guidance once they were launched. The economics of this system would probably compare quite favorably with alternative schemes using more conventional techniques.



Stationary orbit system.

RECONNAISSANCE SATELLITES

Military reconnaissance

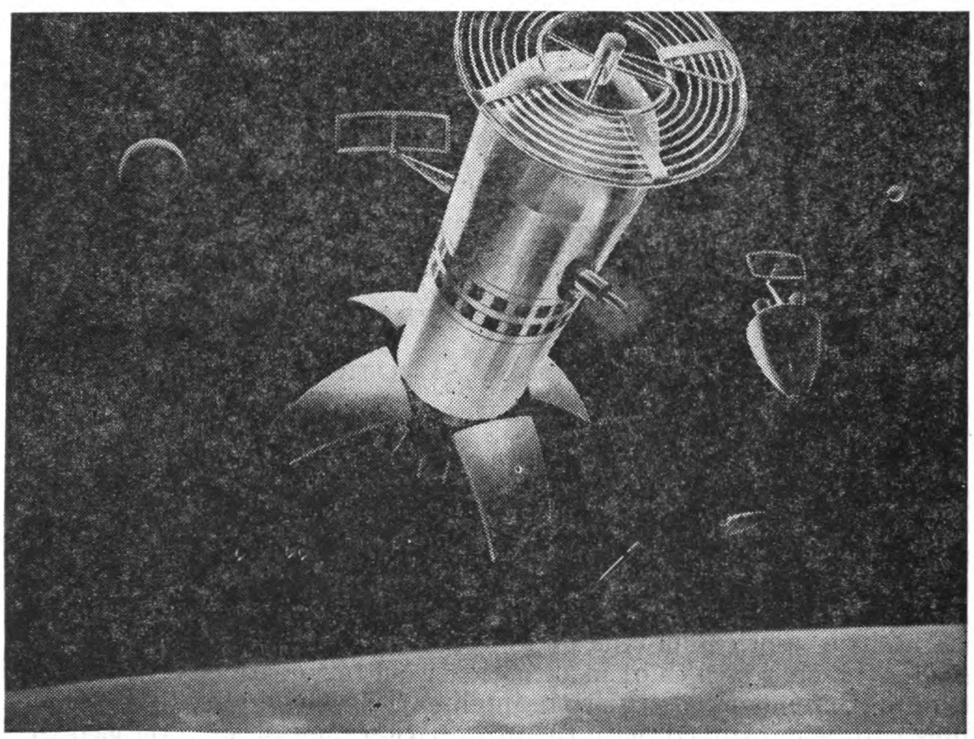
One of the few significant military applications of space that are presently apparent is the reconnaissance satellite. As a Nation, we are faced with a curiously unsymmetric situation in which other major powers have vastly more information on military objectives within our country than we within theirs. A reconnaissance satellite in a polar orbit might make several daylight passes per day over a country, mapping a swath hundreds of miles wide. Within the lifetime of such a vehicle a wealth of information would be obtained that would tend to eliminate the disparity in intelligence. Originally these satellites will be unmanned, with the information they pick up radioed to receivers in friendly territory. For extreme resolution, camera techniques may be required, necessitating recovery of film. Recovery of ICBM nose cones intact indicates that this is a feasible technique.

The reconnaissance satellite program might involve a considerable number of vehicles operating at different altitudes depending on the resolution required. Thus for highest resolution, vehicles in short-lived 150-mile orbits might be used with subsequent recovery of the payload. For large area coverage and modest resolution satellites in more or less permanent orbits at altitudes of 300 miles or more can be envisioned. Recovery of data from such vehicles will almost certainly be accomplished through a radio link.

Eventually, for certain reconnaissance missions, it will probably be desirable to use manned reconnaissance vehicles operating in low orbits and capable of landing at designated spots under control of the pilot.

Weather reconnaissance

An important satellite function will be the forecasting of weather by observation of cloud patterns from high altitude. A foretaste of this capability has already been obtained in a photograph taken from a Viking rocket at 125 miles altitude, in which an incipient tropical hurricane was detected. For greatest economy it is probable that these weather satellites will be unmanned, with the pictures relayed by a television link. At present the scarcity of weather reporting stations over much of the globe makes weather reporting difficult. The graphic representation of disturbances in the Earth's atmosphere on a global scale would provide greatly improved weather forecasting. Thus, man would be provided with an important new tool to assist him in obtaining mastery of his environment.



Reconnaissance satellite in orbit.

MANNED ORBITAL FLIGHT

Manned capsule

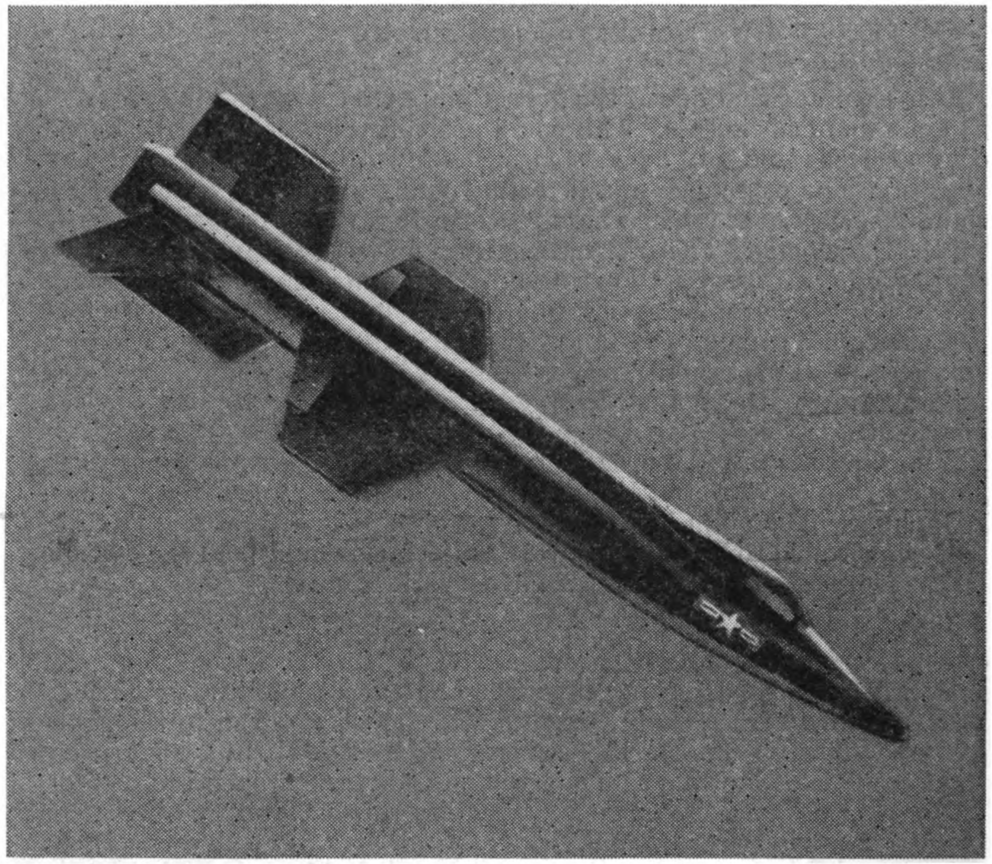
It is expected that one of the first attempts to place man in orbit will be via a manned capsule. This could probably consist of a ball-shaped compartment that will be boosted into a low orbit by a large military booster. The passenger would recline on a form-fitting couch, which could be oriented so the maximum acceleration would pass transversely through his body. The internal environment of the capsule would be controlled with respect to pressure, temperature, and oxygen content to provide a reasonable approximation of conditions at the surface of the Earth. Although the initial flights would probably consist of a single orbit of the Earth, the environmental system would be capable of sustaining life for at least 24 hours in order to provide for emergencies.

The capsule would be decelerated out of orbit by a retrorocket. Speed of descent would be checked by speed brakes and later a ribbon parachute. The point at which the retrorocket is fired would be carefully controlled so that the recovery trajectory would land the capsule on the North American Continent in daylight hours.

Winged vehicle

A manned capsule will provide a rapid means for getting man into orbit and for studying physiological effects, such as weightlessness. Ultimately, however, consideration must be given to the problem of reentering the Earth's atmosphere from orbit in a winged vehicle capable of landing at a designated spot under control of a pilot. The utility of many future space missions depends on carrying out this operation reliably and economically. The X–15 is a forerunner of vehicles of this type and will provide much information of value in solving the reentry problem.

A large rocket booster would be used to boost the vehicle to high altitudes. Then a rocket engine installed in the ship itself would be ignited to provide further acceleration up to the 25,000 miles per hour required for orbiting. In a low trajectory the vehicle would pass halfway around the Earth in 45 minutes. A retrorocket would start the ship out of orbit at perhaps 10,000 miles from the landing point. As the vehicle enters the denser atmosphere, the nose and leading edges of the wing and tail will glow like iron in a blacksmith's forge. The structure will be built to withstand this extreme condition, however, and the pilot will glide down to a dead stick landing.



Orbital vehicle reentering atmosphere.

SATELLITE NEUTRALIZATION

Unmanned

Military reconnaissance satellites launched by unfriendly powers would pose a serious threat to our security. Means must be provided to neutralize such vehicles as they intrude on the space overlooking our territory. This is a problem of extreme difficulty. Detection of a strange satellite is, by itself, a nearly impossible problem, since it is relatively simple to make the vehicle nonreflecting to light and radar. Assuming that such detection is made, the orbit of the satellite must be exactly determined. Neutralization could then presumably be effected by firing an unmanned missile into an intercepting orbit. This scheme presents many problems, however. It would be desirable to be able to identify the type of unfriendly satellite and its probable mission before initiating neutralization. Decoy satellites might be used in large numbers to confuse the defenses. Attacks on every one of these might be economically infeasible, particularly if atomic warheads are used in the interceptor. Also, terminal guidance in the interceptor satellite would be required to close the trajectories. This implies a highly sophisticated system with its attendant problems of reliability.

Manned

The difficulties inherent in the unmanned interceptor satellite may dictate the use of manned vehicles for this purpose. Such vehicles would resemble the winged manned orbital vehicles previously described. The intercept would be analagous to intercepts by more conventional aircraft, with the pilot supplying judgment to make final closure with the target satellite. By means of vernier rocket propulsion, the pilot could make actual contact for close examination of the unknown vehicle. Positive neutralization measures could then be instituted. An interceptor satellite of this kind would probably be feasible in the latter half of the decade.

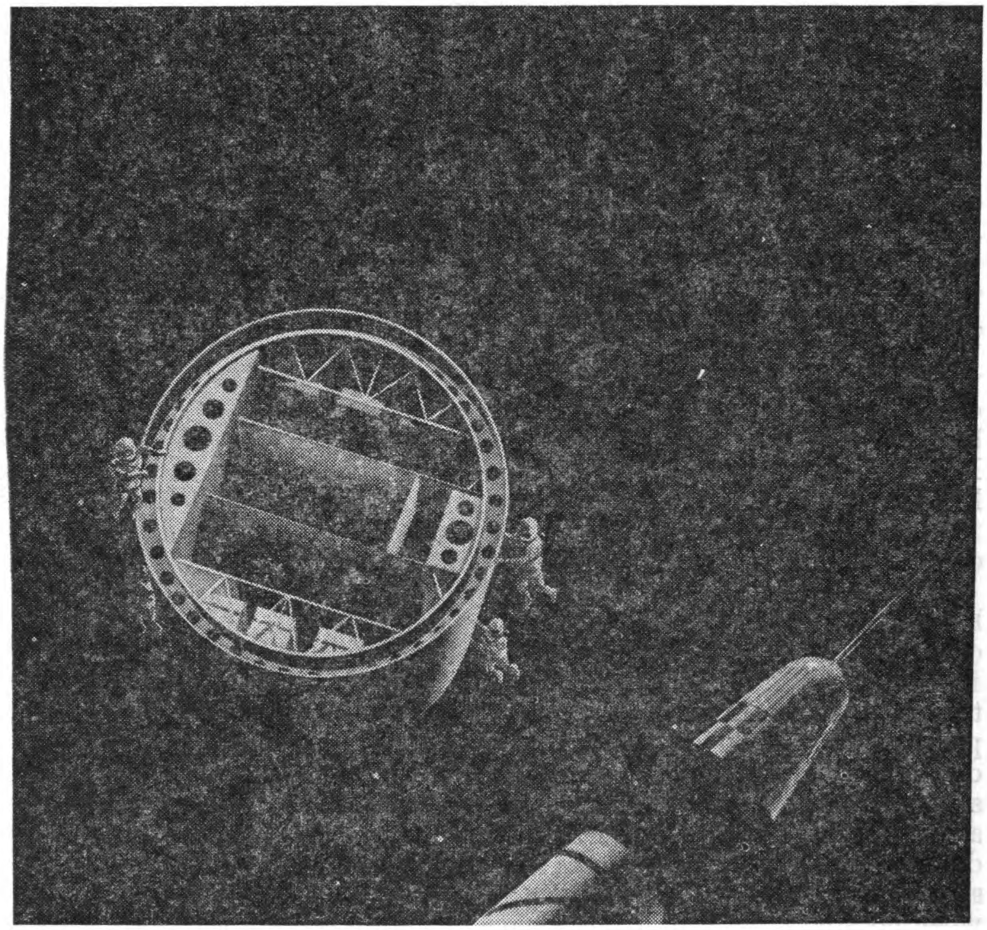
MANNED SPACE STATION

The ultimate objective of manned space flight within the vicinity of Earth will be a satellite large enough to permit occupancy by a number of men for extended periods of time. Manned space stations will probably represent the highest attainment of space technology within the decade ahead. Realization of such devices will depend on advances in the state of the art in a number of fields. Large rocket boosters must be developed, producing millions of pounds of thrust. New environmental control systems must be designed to maintain human life. A reliable orbital-shuttle vehicle must be developed to ferry men and supplies. And a host of subsystems, large and small, of hitherto unattainable reliability must be built.

The first space station will probably be a single integrated assembly boosted directly into orbit with a large rocket booster and several succeeding stages. One such design envisions a cylindrical vehicle 7 feet in diameter and 50 feet long, boosted into orbit by a 6 million pound thrust booster. A complement of 5 men would man the station for a period of 30 to 60 days. Larger space stations will ultimately be desirable. These could be accomplished by the assembly of modular sections boosted into orbit by boosters similar to the one described above. Advanced guidance techniques would be required to assure delivery of the component parts into the same position in orbit. Each subsection of the station would necessarily be complete within itself when boosted from Earth, and clever fastening techniques would have to be employed to minimize the difficulties of assembly in orbit.

It is anticipated that manned space stations will have many uses. Scientific observations incapable of performance in unmanned vehicles will be possible. And a space station in a stationary orbit would provide greatly increased capability for nationwide television, global communications, and weather forecasting. Useful though these functions are, perhaps the most important function of the stations would be to provide a step in the direction of manned exploration deeper into space. The station will be invaluable in determining the human factors necessary to survival in a strange environment for extended periods. Men selected for future lunar and interplanetary missions will train in space stations, where they will become accustomed to long periods of weightlessness and the physical and mental problems associated with confinement in small quarters in a hostile environment.

The space stations may also serve as bases for the assembly of the large vehicles required for manned exploration of the Moon and the near planets. Component parts of the vehicles could be boosted to the vicinity of the station and assembled by crews based in the station. This method would permit the assembly of a space ship of very large size, utilizing boosters no larger than those used to assemble the space station itself.



Assembling the large space station.

LUNAR

LUNAR PROBES

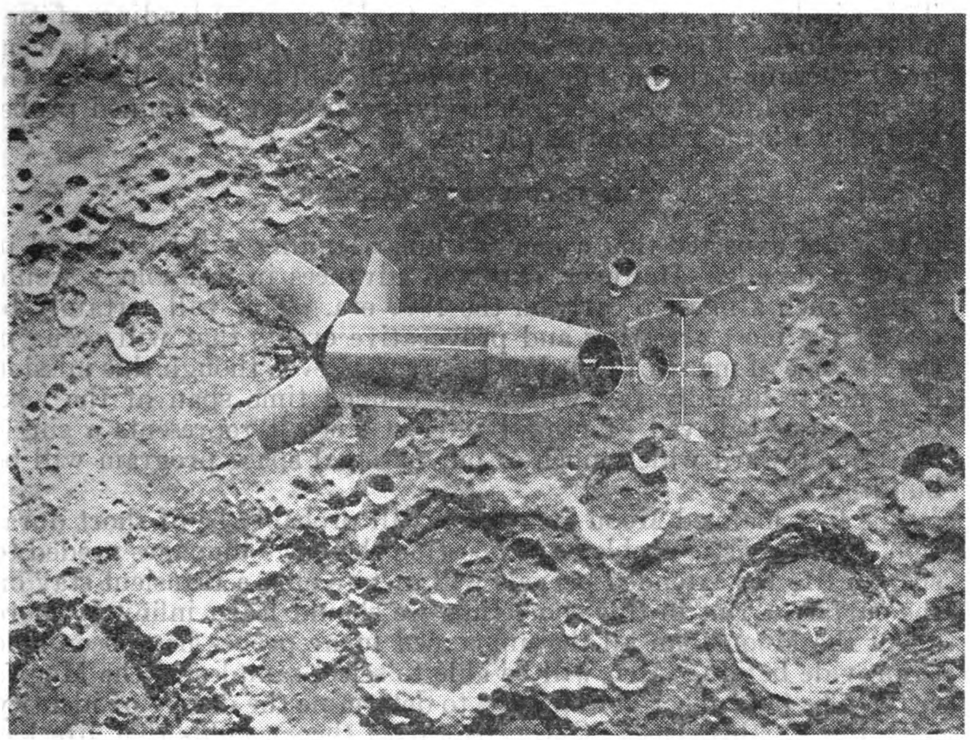
The year 1958 has seen the attempt to place a small instrument carrier in orbit around the Moon. The near success of this launching indicates that circumlunar probes will soon be an accomplished fact, at least, with payloads up to 50 pounds. The most publicized aspect of this program is the attempt to obtain a crude picture of the back side of the Moon for transmission back to Earth. However, a vast amount of scientific data of greater importance will be obtained with circumlunar probes. For example, it will be possible to accurately measure the mass of the Moon and determine if it has a magnetic field and a tenuous atmosphere. Data of this nature will reveal much about the history of Moon and, possibly, of the Earth and other planets.

As space technology progresses, it will be possible to project larger and larger payloads into precisely controlled orbits about the Moon. Then a very careful mapping of the details of the Moon's surface will be possible. This will require a large number of vehicles operating over a considerable period.

Many of the fascinating questions which have engaged the attention of astronomers for a long time may be answered. Are the obscurations occasionally seen on the bottom of Moon craters really clouds of carbon dioxide, thus indicating a low level of volcanic activity? What is the nature of the crater known as Linné which "disappeared" in 1866? Are the dark streaks radiating from certain craters due to low forms of vegetation, as has been conjectured?

The end result of the program of mapping the surface of the Moon will be an atlas nearly as detailed as that available for our own Earth. This will be a necessary adjunct to the landing of unmanned instrument carriers and, eventually, manned spaceships on the surface of the Moon.

Midway in the decade space technology will permit a daring venture to be carried out—a circumlunar voyage by 1 or 2 adventurous astronauts in a small spaceship launched directly from Earth. This, however, would be a risky and expensive undertaking. It is more probable that such a journey would await the construction of a space station, which could serve as both launch and recovery point. Thus, the mission would not take place much before the end of the decade.



Orbital vehicle mapping lunar surface.

UNMANNED LUNAR LANDING

Probing the secrets of the Moon with circumlunar or orbiting vehicles will provide a wealth of new information about our neighbor in space, but eventually we will want to land instrumented vehicles on the lunar surface. In the first stages of this program it is expected that payloads of something less than 100 pounds will be lowered to the Moon's surface, using retrorockets to brake the descent. These relatively crude devices will then sample such lunar conditions as temperature, radiation level, and the incidence of micrometeorite strikes, and radio this information back to Earth.

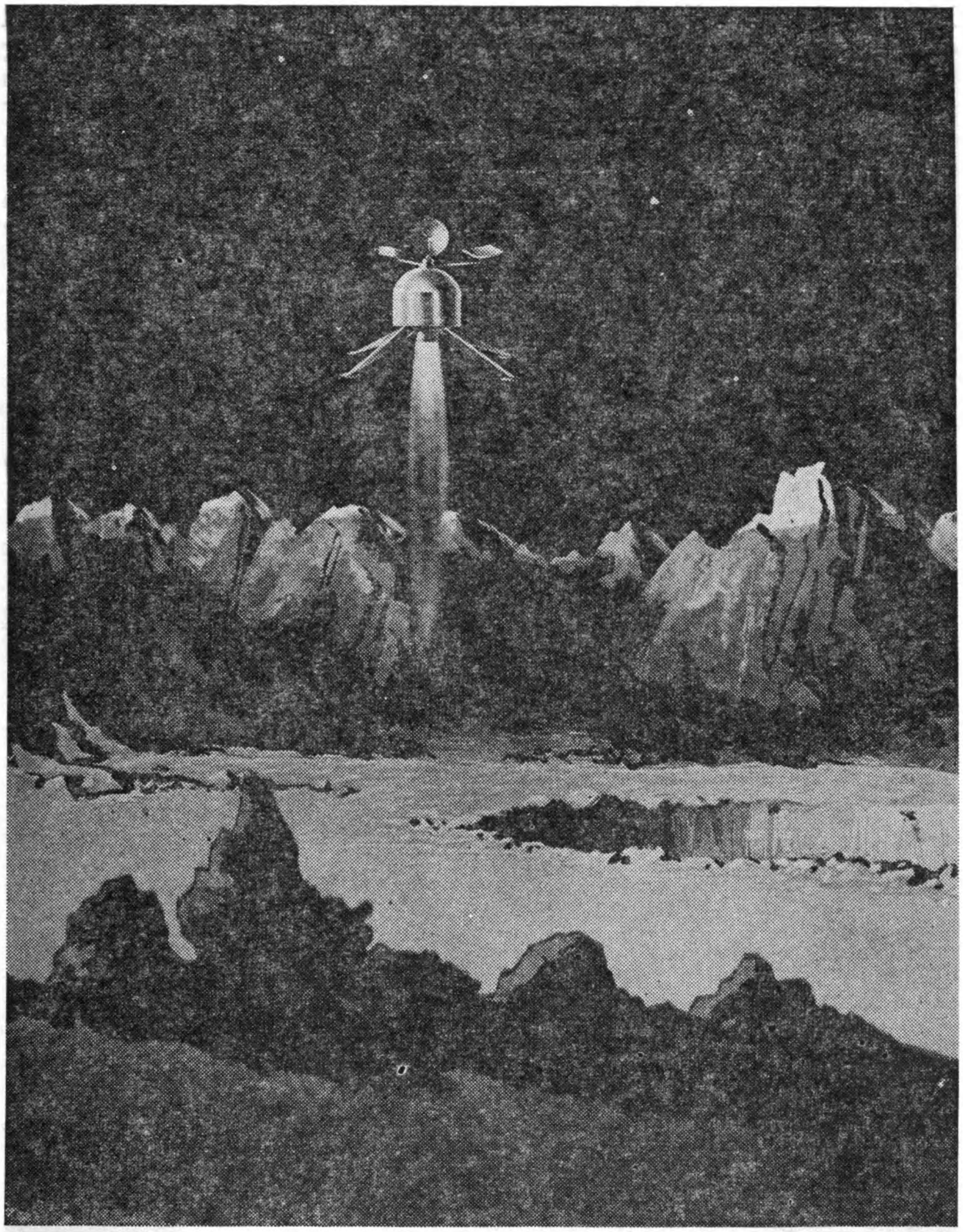
Progress in the technology of large rocket boosters should ultimately permit the "soft" landing of instrument carriers of perhaps several thousand pounds gross weight. This will permit a surface-testing program of considerable sophistication. Trainable television cameras will relay on-the-spot pictures of the lunar terrain. Core drills will test the hardness of the surface and settle the famous question of the depth of the dust layer. Explosive charges projected out from the vehicle in conjunction with a seismic pickup will reveal details of the subsurface structure. Samples of the surface may even be subjected to crude chemical and physical analysis by automatic instrumentation within the vehicle. And, of course, a very detailed record of the environmental conditions at the Moon's surface will be obtained.

A very extensive program involving many "soft" landing instrumented probes can be in progress during the last half of the decade. This will be a very necessary prelude to the eventual landing of men on the Moon. The cost of the manned lunar expedition will be very great; therefore, the most detailed planning will be required before the attempt, and, of course, the relatively inexpensive unmanned probes will play a large part in this picture.

MANNED LUNAR LANDING

It is not expected that a manned lunar landing will be realized in the next decade. However, expected advances in technology would permit such a mission early in the 1970 era. This will certainly be one of the most arresting and provocative events that will occur in the lifetime of many of us. For this reason, even though this mission does not technically fall within the defined time span of the next decade, it is believed of utmost interest since it represents a single objective toward which much of our national space program will be building.

The first manned Moon expedition will probably be of short duration. The logistic problems of boosting the large tonnages needed to sustain life for extended periods will dictate only a transient stay on the surface. But in this short time we should learn infinitely more about the Moon than all the unmanned lunar probes have been able to provide before. Men will be able to select samples of the Moon's crust to be taken back for analysis to determine the degree of identity with the Earth's crust. One provocative theory holds that life has been distributed throughout the universe by minute spores traveling on meteorites. The first men on the Moon will be equipped to prove or disprove this theory. They will also be able to determine firsthand facts that will ease the problems of succeeding expeditions. Thus,



"Soft" landing of lunar surface probe.

they may find fissures of frozen water or minerals containing readily available oxygen, which will make the sustenance of life very much easier. We cannot discount the presence of unknown perils that will make life hazardous for man on the Moon. Terrestrial exploration has always revealed unsuspected hazards, and we can expect that the first manned lunar expedition will provide experience that will make life safer for succeeding efforts.

It is difficult to imagine all the benefits that will accrue from the first manned Moon expeditions. But it appears likely that sufficient unanswered questions will remain after the first transient stays on the

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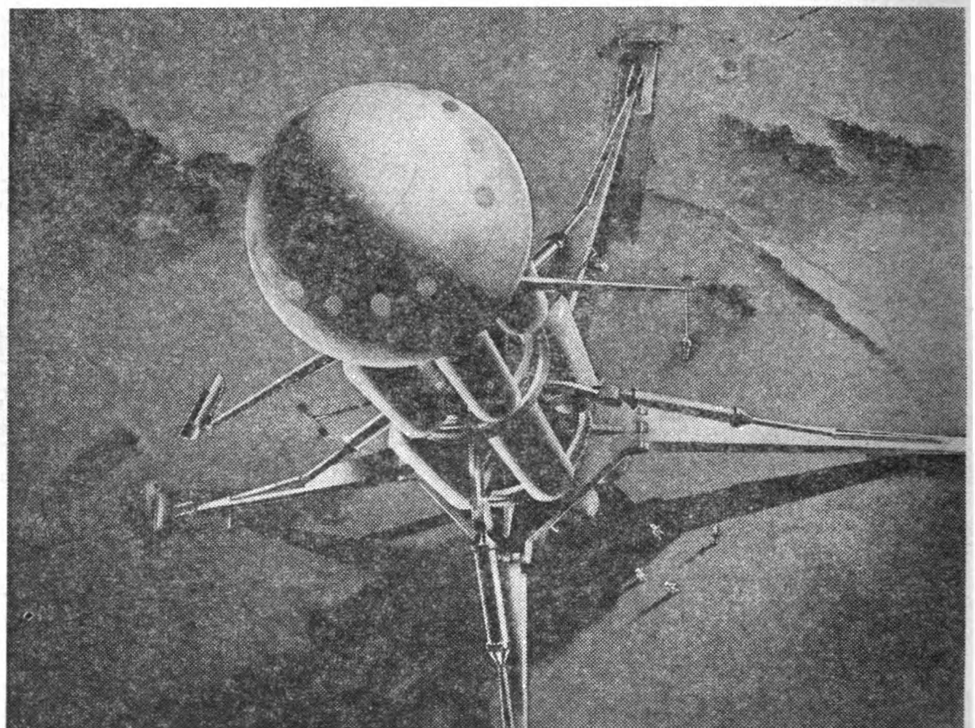
Moon so that we will wish to construct a permanent base for extended occupancy. Mobile surface vehicles will permit the men occupying the base to extend their explorations further and further with the passage of time. Thus it will be possible to assemble an increasingly comprehensive picture of Earth's natural satellite. The construction of the permanent base will be a vastly more complex and costly operation than our exploration of Antarctica, for example. It does not seem unreasonable that we will be prepared to take this step in the latter half of the 1970 period, however.

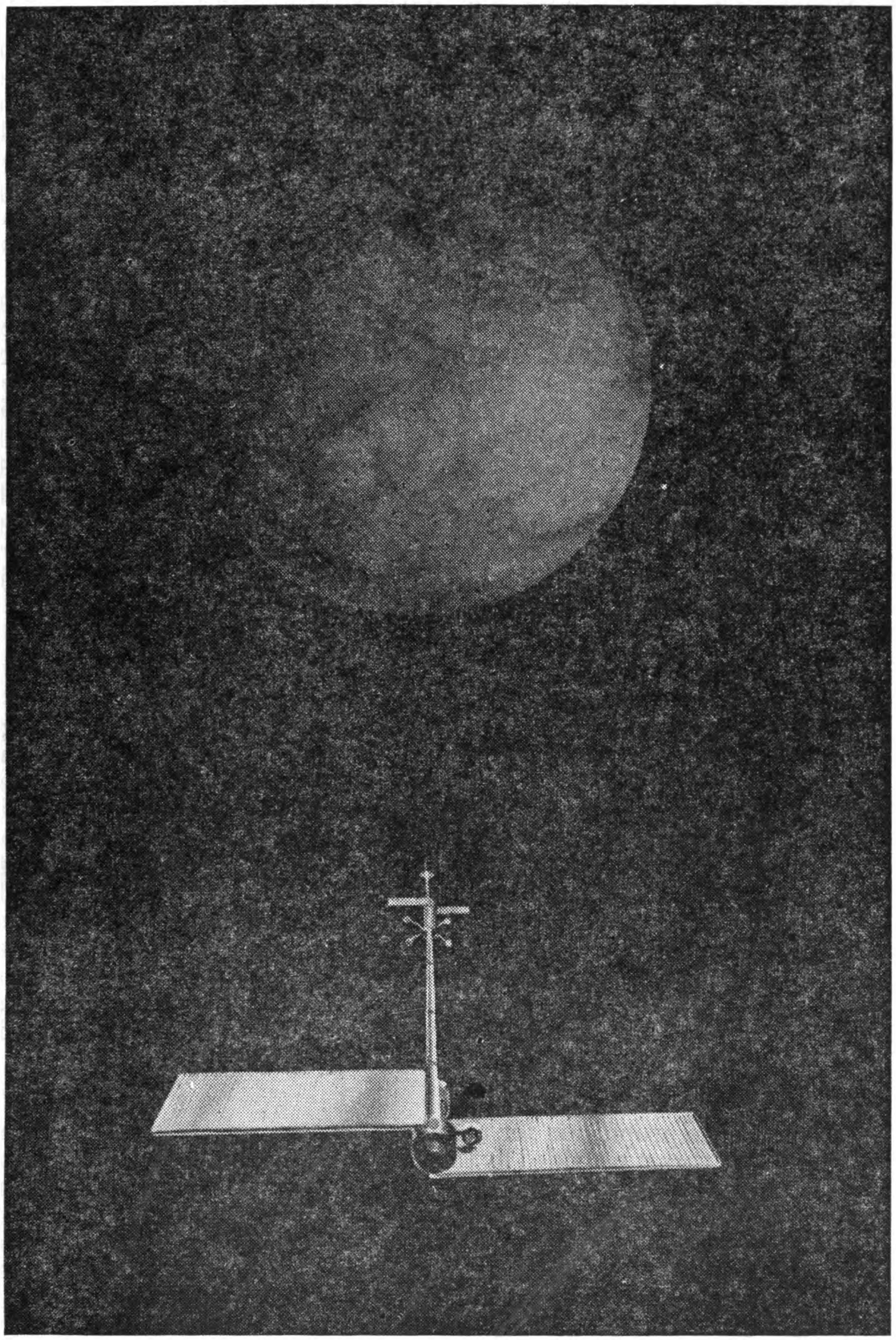


The first men land on the Moon.

INTERPLANETARY

PLANETARY PROBES

While the lunar program is proceeding, the first tentative probings of the near planets could be made with unmanned vehicles. At first, these would be of relatively small payload capacity and, because of this limitation, they would be programed only for a close pass at the planet of interest. During this transit, much information on the physical properties of the planet would be obtained for transmission back to Earth. Venus and Mars will be the planets of greatest interest initially. A more exact determination of the size and mass of Venus would be obtained. And a close pass at Mars will reveal surface details through television linkback to Earth. But such probes will not answer the questions of greatest interest; for this purpose orbiting vehicles and ultimately "soft" landing vehicles will be required.



"Snooper" ion-propelled interplanetary probe.

A vehicle orbiting Venus could obtain information regarding the composition of the Venusian atmosphere and would solve the riddle of the composition of the clouds that shroud that planet. A Mars orbiting vehicle would reveal, for example, whether oxygen exists in the atmosphere. And a television camera would give the first detailed closeup of the Martian surface. Toward the end of the decade, a fairly comprehensive picture of the surface of Mars should be available. The presence of life on Mars, in the form of vegetable matter of a low order, has long been a provocative conjecture. The orbiting vehicle may provide answers to the question. And of course, the nature of the famous "canals," if, indeed they exist at all, might be settled by a close look at the Martian surface.

Study of a typical Mars mission reveals the magnitude of the problem of interplanetary flight. The minimum and maximum distance between Earth and Mars is 34,797,000 and 340 million miles respectively, so the flight must be planned in such a way that a distance nearer the minimum is obtained. Because Mars requires approximately 2 earth years to complete 1 orbit of the sun, only certain launch periods are feasible. These will occur at 2-year intervals—1962, 1964, 1966 * * * for example. Using the best available chemical propulsion, a one-way trip would require about 260 days. If a round trip is considered, the return must be initiated almost immediately; otherwise a wait of 2 years in the vicinity of Mars is required. This indicates the problem attendant upon a manned landing expedition.

TECHNOLOGICAL DEVELOPMENT

PROPULSION

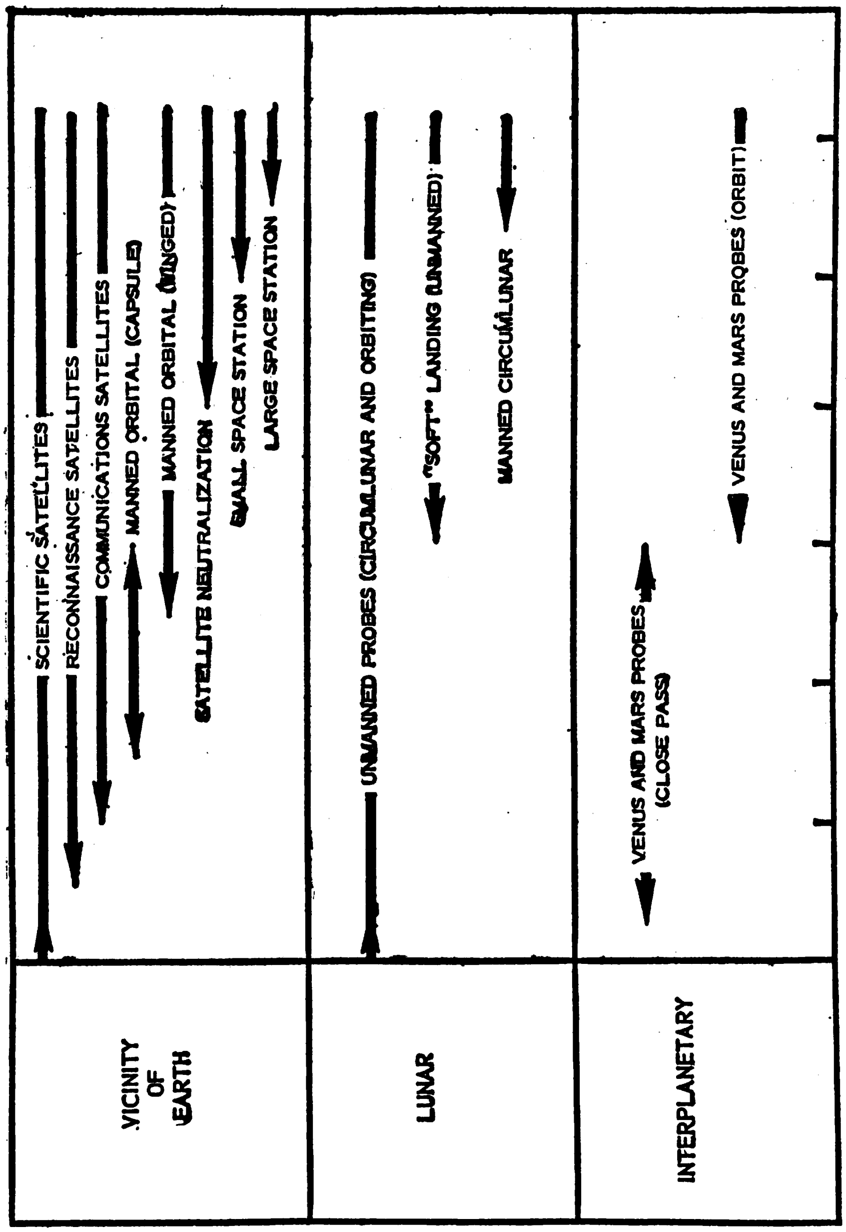
The pace of the national space program will be limited to a large extent by advances in propulsion. Two general areas of development are of importance. First, the more advanced space missions will require boosters with as much as 5 or 6 million pounds thrust. This implies the development of single-thrust chambers with capability of 1 to 1½ million pounds thrust in order to avoid the necessity of ganging an excessive number of engines. Second, improvements in propulsion efficiency, particularly for the upper stages of multistage vehicles, will be required. A measure of this efficiency is the specific impulse, defined as the pounds of thrust produced per pound of fuel consumed per second. Three types of propulsion systems now under consideration for space flight, in ascending order of specific impulse, are chemical, nuclear, and electrical.

Chemical propulsion

First stage propulsion for all current space projects is based on the propulsive thrust provided by the energy released in the combustion of two fluids, such as jet fuel and liquid oxygen, in an open chamber. Very large thrusts are obtainable with such systems and it appears entirely feasible to build an engine in the million-pound class in the time period of interest. This probably represents a desirable limit for single-thrust chambers, although it is possible to gang at least 3 or 4 such engines to provide a corresponding multiplication of the thrust. Comparatively conventional fuel-oxidizer combinations will probably be used in first-stage boosters of this size because of their reliability and relatively low cost. This latter item is an important consideration since a million-pound-thrust booster may burn 800,000 to 900,000 pounds of propellant for a typical mission.

SCHEDULE

SPACE TIMETABLE



Most space missions will require staging, in which a number of rocket stages are placed in series, with the lowest stage providing the initial boost before the succeeding stage is lighted off, and so on. The expended stage is dropped off to avoid having to accelerate the mass of its tank and engine. The upper stages are successively smaller in thrust capability and weight, and it is here that exotic propellants of high specific impulse will be employed to increase performance.

The theoretical specific impulses that can be provided by possible combinations of propellants vary between 220 and 365, with jet fuel and liquid oxygen yielding 260 at sea level. The more than 30 percent increase in performance possible with the better fuel-oxidizer combinations is an important consideration in space missions, and it can be expected that a considerable amount of effort will be expended in the development of practical engines using such propellants.

Nuclear propulsion

The use of a nuclear reactor in place of a chemical combustor to provide the energy required for propulsion is an attractive concept. In this system, a fluid such as liquid hydrogen is pumped through a reactor where it is vaporized and heated to a high temperature. Expansion of the resulting gas in a nozzle provides thrust. Theoretical calculations show that, if the working fluid can be heated to a high temperature, specific impulses of the order of three times those possible with chemical energy can be obtained. The difficulties of operating reactors at the temperatures required limit the practicality of the nuclear rocket engine at present. Authorities in the field believe that such systems may be practical in the next decade, however.

Nuclear rockets have an inherent disadvantage, particularly for manned space flight. This is the requirement for heavy shielding, which may partially negate the performance advantage afforded by high specific impuse. One solution is to boost the nuclear rocket out of the atmosphere with a chemical stage. If the reactor is not activated until it passes beyond the atmosphere, a lightweight "shadow" shield will provide protection to the crew, particularly if the inhabited space cabin is towed by the nuclear rocket by means of a long cable.

Electrical propulsion

Space flight has stimulated interest in the thrust-producing capabilities of a stream of charged particles accelerated by electrical or magnetic forces. Specific impulses measured in the tens of thousands are theoretically possible with such devices. Practical engines of this kind might have a total thrust of something less than a pound. For vehicles weighing several thousand pounds, the resulting acceleration would be extremely low. Obviously, such a vehicle would not take off from Earth under its own power but would require boosting to at least orbital speed with a chemical booster, for example. For an interplanetary mission, the electrical propulsion system could accelerate the vehicle from orbital speed to escape velocity if sufficient time were allowed. Such propulsion would be useful in orbiting about a planet such as Mars where a slowing down through application of reverse thrust is required.

Electrical propulsion technology is in its infancy, However, its attractive properties in certain space applications have engendered a considerable amount of effort currently, and practical systems embodying this principle may become a reality in the next 10 years.

GUIDANCE AND STABILIZATION

Guidance

Space-flight guidance can be divided for convenience into three phases: ascent guidance, midcourse guidance, and terminal guidance. During the ascent phase, inertial guidance techniques developed in the military missile program are adequate for most missions. A number of missions—satellite, circumlunar moon impact, and moon orbit—require guidance only during the ascent phase, and the accuracy provided by ICBM systems is sufficient. For interplanetary missions, midcourse and terminal guidance will be required. Here inertial guidance must be teamed with optical systems using fixes on the sun, stars, and planets to provide corrections for the errors that would result from such long trajectories if only pure inertial systems were used. Again, techniques borrowed from the long-range missile field can be used. From the standpoint of function alone, no radical advances in the state of the art appear necessary to accomplish the missions described on the preceding pages. However, for interplanetary flight where systems must operate over considerable periods of time, current technology does not assure sufficient reliability to accomplish the mission. For example, if, on a one-way mission to Mars, an overall probability of failure of the guidance system of 1 percent is the maximum permissible, a so-called mean time to failure of 600,000 hours would be required. Current practice with similar equipment yields a mean time to failure of only 2–3,000 hours. This appears to pose a serious problem for long space missions. However, several things can be done to solve the problem. New guidance concepts utilizing vastly simplified equipment can be devised, duplicative standby systems can be incorporated, and guidance programs requiring operation of the equipment for only a fraction of the total time can be devised. At any rate, designers of current guidance equipment feel that the problems are not insoluble and that equipment adequate for the first unmanned interplanetary flight in the latter half of the next decade will be available.

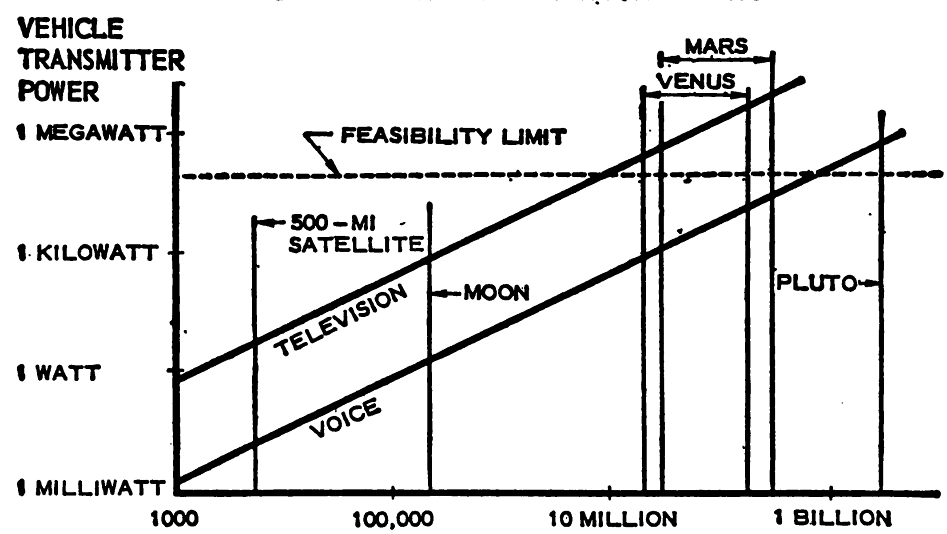
Stabilization

Unlike an airplane, which utilizes aerodynamic forces to maintain its attitude, a space vehicle subjected to even minute torques will tumble unless stabilization is provided. In many applications the attitude of the space vehicle with respect to a reference direction is important, as in a reconnaisance satellite, for example. Techniques for stabilization are fortunately relatively simple. The guidance system senses deviation from the reference direction. Small flywheels in the vehicle can then be accelerated in one direction or the other to produce a torque to restore the desired attitude. Thus, if the guidance problem is solved, attitude stabilization is believed to be well within the state of the art.

COMMUNICATIONS

Reliable communication with Earth satellite vehicles is an established fact. But when lunar and interplanetary distances are considered, the question naturally arises as to the adequacy of communication techniques. Simple computations show that, even across interplanetary distances, we can expect to maintain communication with relatively modest amounts of power in the space vehicle. True, the bandwidth, which is related to the rate at which we can transmit intelligence, must be restricted at the longer ranges, but techniques analogous to slow motion movies can be utilized for the purpose. Of course, the same reliability considerations discussed for Guidance Equipment apply. However, communications technology is not expected to place any limitation on accomplishment of the missions discussed in this report.

COMMUNICATIONS POWER REQUIREMENTS



LIFE SUPPORT

The first manned space missions can be accomplished with comparatively simple systems to maintain life, since they will be of short duration. Provision must be made to counteract the crushing effect of acceleration on the pilot during the boost and reentry phases, but this problem appears amenable to solution with proper body support and orientation. The maintenance of an atmosphere suitable for the human occupant within the vehicle will require only open-cycle systems similar to those provided for the X-15 research aircraft, for example.

As man extends his stay in outer space, the logistical problems of providing the elements necessary for human existence will become critical, and open cycle systems in which no attempt is made to conserve life supporting materials will not longer be feasible. For example, a normal adult male will consume 2 pounds of food, 5½ pounds of water, and 3 pounds of oxygen per day with the ambient temperature at 70° F. When it is considered that each pound of material placed in orbit requires perhaps 50 pounds of takeoff weight, the formidable nature of the problem of supporting life in space is evident.

The simplest closed loop systems will process the atmosphere in the space ship to recover water released in breathing and perspiring.

This can be done by freezing and subsequent thawing of the water ice that is produced, a process that will also remove the poisonous carbon dioxide produced in breathing.

Some work has begun on closed ecological systems in which algae are fed on waste products in the presence of radiant energy, such as light. Oxygen would be derived in this process and it has even been suggested that the algae could be used as food. The progress to date is not sufficiently great so that the feasibility of such schemes can be evaluated.

It can only be concluded that when we remove man from the environment to which he has become adapted through many generations, we are faced with problems of considerable magnitude. For this reason each phase in manned space flight will be preceded by an extensive period of activity involving unmanned probes. The ultimate objective is manned exploration of space, but the penalty imposed by the life-support system that man must carry with him will demand planning of the highest order before the more extended space missions are undertaken.

AUXILIARY POWER

The various systems for life support, instrumentation, guidance, stabilization, and communication will require a considerable amount of electrical energy that must be generated on board space vehicles. Three general types of systems have been considered—chemical, solar, and nuclear. While invention does not appear to be required to solve the problem, a considerable amount of work is necessary to develop practical systems, particularly for the longer missions.

Chemical

The simplest embodiment of this system is a turbogenerator, burning a fuel and oxidizer which might be one of the conventional rocket propellant combinations. This system is heavy and requires the expenditure of materials that must be boosted against the pull of gravity at considerable expense, as previously noted. An improvement in this type of system would be afforded by a fuel cell in which two gases, such as oxygen and hydrogen, are directly combined in an electrolytic cell to produce electrical current. Water is also produced in this process, which might be useful for life support, for example. Fuel cell development is a new technology, but it may well find application for future short range missions.

Solar

The Sun provides a continuous source of energy equivalent to about 1.5 horsepower per square yard of illuminated surface. Converting this energy to electricity is a problem. The straightforward method would be to employ a steam boiler and turbogenerator, but this scheme is heavy and complicated. Solar cells provide a method for converting solar energy directly to electricity. They will produce about 0.12 electrical horsepower per square yard of surface (approximately 8 percent efficiency) and weigh about 9 pounds per square yard. These devices, of course, power our satellite transmitters. Where large amounts of power are required, the areas involved become unwieldy. Furture developments can be expected to approach the 22 percent theoretical efficiency of such cells, which will make them desirable for many applications.

Nuclear

Where large amounts of power are required more or less continuously, small nuclear reactor powerplants are indicated for space missions. Initially, these will employ a fairly conventional conversion cycle in which the heat of the reactor is used to vaporize a fluid, which can then be used to drive a turbogenerator. Again, this system is heavy and complex. Of greater promise is the development of thermoelectricity, in which heat is converted directly to electricity, using recently discovered semiconductor materials. The relative newness of this development makes extrapolation of future potential difficult. However, it is expected that thermoelectric converters capable of transforming 20 percent of the heat energy they receive into electricity without recourse to intermediate machinery will be available for space projects in the last half of the decade.

PROF. A. C. B. LOVELL, PROFESSOR OF RADIO ASTRONOMY, UNIVERSITY OF MANCHESTER; DIRECTOR, JODRELL BANK EXPERIMENTAL STATION, LOWER WITHINGTON, MACCLESFIELD, CHESHIRE, ENGLAND

* * * I can only give you a general comment in that I believe the next decade in space research will see developments in astronomical work which were inconceivable only a short time ago. During this period one can confidently expect that both radio and optical telescopes will be carried on Earth satellites so that the universe can be studied from above the interfering regions of the Earth's atmosphere. One can even hope that remotely controlled telescopes may be operated from the Moon within this period. In connection with space probes, it seems clear that such vehicles will be able to approach and possibly sample the atmospheres and surfaces of some of the planets. The contributions which can be expected to result to our knowledge of the conditions and evolution of the solar system are at present almost incalculable. * * *

JOHN A. MCCONE, CHAIRMAN, ATOMIC ENERGY COMMISSION, WASHINGTON, D. C.

* * * It would be inappropriate for me to forecast space missions per se which might be brought to fruition in the next decade since such predictions properly are the responsibility of the Department of Defense (DOD) and the newly created National Aeronautics and Space Administration (NASA). As you know, however, one of the Commission's responsibilities is to provide technical support to the various Government agencies in response to nuclear requirements they place upon us. To this end, we have been pursuing space oriented nuclear programs in accordance with stated DOD and NASA requirements for the past 3 years. Our experience to date in these advanced projects has made us confident that nuclear energy will play a prominent role in the conquest of space.

I have specific reference to Projects Rover and SNAP. Rover is concerned with the application of nuclear energy to rocket propulsion. Work on the project is centered at the Los Alamos Scientific Laboratory. Ground tests of experimental devices are scheduled in the near future at the Nevada test site where a test complex is being established. SNAP is concerned with the development of small, lightweight, nuclear auxiliary power units for use in the space environment. Both radioisotopic and reactor energy sources are being exploited for this application. The SNAP units will provide electric power in significant amounts, over long periods of time, for a DOD satellite application. Results thus far on both the Rover and SNAP projects have been very promising. It must be recognized, however, that the field is new and development of the necessary technology is difficult.

The aforementioned projects can be regarded as initial steps in the development of two basic, but markedly different, nuclear propulsion systems which are considered necessary to reach, navigate and explore space. The two systems may be described as a "boost system" to accelerate large payloads in appropriate vehicles from the Earth's surface to escape velocity and an auxiliary propulsion system (electric drive) for navigation and maneuver, once the payload is boosted into space. The nuclear boost system, which in principle functions in a manner similar to existing chemical engines, must produce high thrust for relatively short periods of time (5 to 15 minutes). The auxiliary propulsion system, of which ion propelled devices are an example, must produce low thrust over long periods of time (days or years). Such an accelerator-type propulsion device requires large amounts of electric energy which, because of the space operation environment, appears best derived from nuclear sources. It is my view that the Rover project can, with continuing support, lead to a nuclear boost system with performance capabilities far surpassing any known or foreseeable systems. The SNAP work, if broadened in scope at the appropriate time, can lead to a long lived, reactor powered, electric drive system for space propulsion application as well as the current goal of providing nuclear derived electric power for satellite instrument operation.

It is of significance to note that even in current advanced reactor systems only a very small fraction of the available nuclear energy is converted to useful work. The development potential for more effective use of this energy in space applications is therefore enormous and is limited only by technology. Accordingly, the Commission is confident that the advanced nuclear development programs currently underway will lead to technological advances which will play a prominent role in the establishment of the Nation's space capability. Based upon our ability to obtain the necessary support and guidance, the next decade should allow us to:

(*a*) demonstrate, by full power ground test, a nuclear rocket engine capable of boosting extremely large payloads into space;

(*b*) operate for many months an electricity-producing, satellite-borne, nuclear auxiliary power unit;

(*c*) develop and test nuclear electric drive units capable of providing propulsive power for space probes;

(*d*) develop and test units which will convert nuclearly developed heat directly into electricity without resort to rotating equipment. * * *

Maj. Gen. J. B. Medaris, Commanding General, United States Army Ordnance Missile Command, Redstone Arsenal, Huntsville, Ala.

* * * The coming decade will undoubtedly be chronicled by history as the birth-era of the Age of Space, for the decade is certain to be marked by phenomenal technological achievements; however, any attempt to second guess the extent of these achievements must be tempered by the realization that there is almost always an unfortunate gap between that which is possible and that which is probable.

The Soviet Union has announced a long-range space program through the president of the Soviet Academy of Sciences. The program's sequence is:

First, Earth satellites of such lifetime as to be practically permanent orbiters.

Second, recoverable satellites.

Third, manned Earth satellites.

Fourth, rocket flights to the Moon and other celestial bodies.

Fifth, satellites of very high apogee orbits.

Sixth, interplanetary space stations which could support a considerable number of personnel over extended periods of time.

Seventh, manned flights to Mars and Venus.

The logic of the sequence is obvious, of course. It simply arranges chronologically the order of difficulty. The undertaking is ambitious, requiring marked advances in science and technology, with emphasis on the latter. The possible and probable time scales for this Soviet program are subject to debate, but I have yet to meet an informed person who doubts that the program will be pursued by the Soviet Union with all the technical vigor it can muster. It should also be remembered that practically all of these undertakings could serve military purposes.

The House Select Committee on Astronautics and Space Exploration recently invited the comments of various members of the Army Ordnance Missile Command on the following space program:

1. Orbital vehicles with payloads in the order of thousands of pounds within 5 years.
2. Payloads of 100 to several hundred pounds placed on or around the Moon within 5 to 10 years.
3. Payloads of several hundred pounds into interplanetary space as far out as the orbits of Venus and Mars within 5 to 10 years.
4. Manned orbital vehicles within 10 years.
5. Manned flight around the Moon within 15 years.
6. Manned two-way flight to the Moon, including landing, within 20 years.

There was not a dissenting comment on the possibility of accomplishing this program within this time frame. In fact, AOMC presented its recommendations to the committee on how this program could be most efficiently realized. In each comment, however, there was a warning note: having decided what is possible we must take a look at those conditions in our national space effort which breach the possible and the probable.

I would list the following:

1. We must establish a long range, national program which takes advantage of all available resources, military and civilian.

2. We must then fund that program on a long-range sustained basis so that our technology does not suffer a hand-to-mouth, fits-and-starts existence from one fiscal year to the next.

3. We must empower our program managers with the legal capability of making decisions when they are needed.

4. We must spend more money for applied research. Specifically in this regard, I would like to briefly discuss the following technical problems:

A. PROPULSION

In this field we are faced with two problems, one the engineering of larger powerplants of conventional types for the initial phases of our national space program, and, two, developing new types of propulsion systems which are more attractive for space exploration. Examples of the latter include propulsion by the acceleration of a gas by heat energy from nuclear reactors, electric arcs or the Sun, and propulsion by means of an electrical system in which the propellant is converted to ions which are accelerated by electric fields. Research should also be accomplished on the feasibility of such theoretical systems as the photon rocket.

B. GUIDANCE, CONTROL, AND COMMUNICATION

The development of accurate, reliable, and lightweight guidance, control and communication equipment is absolutely essential and will require tremendous technical effort. The accurate guidance of Earth-bound ballistic missiles is a reality, but space guidance is infinitely more complex. In this area there must also be much more micro-miniaturization, or reduction in size and weight of components.

Much work must also be done in the field of communication in order to equip communications satellite systems and to achieve a satellite system of precise weather forecasting.

How close we come to the mark which history has set for us—how closely the probable approaches the possible—depends primarily on the quality and quantity of money, men, and material which we are willing to expend toward this end. Given the resources, we know how to accomplish the necessary economy of action, and here I would defer to Plutarch's definition of economy, which, he said, is but money-making in things inanimate—but when exercised over men becomes policy.

Fortunately, we are blessed with a more profound motivation than the mere pressures of recent Soviet successes—the classic challenge of space. "The most beautiful thing we can experience is the mysterious. It is the source of all true art and science." The man who wrote these words was no mystic—he was Albert Einstein. * * *

DR. T. C. MERKLE, NUCLEAR PROPULSION DIVISION LEADER, RADIATION LABORATORY, UNIVERSITY OF CALIFORNIA, LIVERMORE, CALIF.

The major problem facing those wishing to explore "space"—that is, the volume of space lying between the orbits of Mars and Venus—is as it has always been, the problem of developing a suitable propulsion plant. It is clear that chemical systems for such a task would be enormously expensive, vastly hazardous, and in the last analysis too unreliable. It is equally clear that the nuclear heat-exchanger rockets of the Rover type, while technically feasible as second stages for space exploration rockets, have two serious operational disadvantages:

(1) Liquid hydrogen must be stored in the thin-walled tanks for long periods for the return trip. This problem is indeed formidable.

(2) All the impulse the machine will obtain on a given one-way trip is given in a few hundred seconds. This means high accelerations (in the order of six "g") and also makes corrections to the flight trajectory difficult.

In view of these comments it is possible to state that while both large chemical rockets and nuclear heat-exchanger rockets are good for putting objects on an orbit around the Earth, and as first stages for interplanetary "spaceships," we do not now have a complete conceptual design for the "space cruising" stage.

From the propulsion standpoint it is necessary, therefore, to develop some of the systems now being explored in a tentative manner to a high degree of practicality before we can be truly said to be in the Space Age.

NEXT DECADE: NUCLEAR ENERGY DEVELOPMENTS FOR SPACE TRAVEL APPLICATIONS

Nuclear energy will turn out to be necessary.

(1) Large heat-exchanger rockets will be developed and will probably be used for boosters only.

(2) Light reliable reactor systems will be developed for space station powerplants.

(3) Light reliable reactor systems will be developed for use by parties wishing to land on the Moon, Mars, and Venus. Such landings will *not* occur during the coming decade, but somewhat later.

(4) Ion (and similar) rocket schemes of some sort will become practical, and hardware systems will be constructed to one degree or another during this period. First *manned* flights will be after the coming decade, but a simple unmanned flight may take place within the decade. Such rockets will be used for the final stage in Moon rockets, Venus and Mars rockets, replacing presently considered nuclear heat-exchanger rockets and super-chemical rockets. First-stage boosters will probably be chemical.

(5) The key to space exploration lies in the development of materials suitable for reactors, ion guns, plasma guns, cooling loops and radiators, etc. Nuclear physics cannot be expected to contribute much that is new during the coming decade. High-temperature solid-state physics and chemistry must be strongly encouraged.

T. F. MORROW, VICE PRESIDENT, CHRYSLER CORP., DETROIT, MICH.

INTRODUCTION

Man will explore space. The exploration will be rewarding—in terms of weather forecasting, communications, aid to terrestrial navigation, surveillance of natural phenomena, and valid scientific knowledge. The foundation for the exploration of the universe around us is the transportation of man and instruments devised by man.

CHRYSLER QUALIFICATIONS AND INTEREST

For more than 30 years, Chrysler has been devoted primarily to the concept, development, and production of superior vehicular transportation—passenger, commercial, and military. For the past 6 years, Chrysler has been heavily engaged in the development and production of large rocket vehicles which are the established foundation for space transportation. The outstanding success of the Redstone and Jupiter programs, which Chrysler manages as principal contractor to the Department of the Army, attests to effectiveness of application of Chrysler's broad transportation skills to the special problems of space transportation.

The extension of transportation into space involves an extremely broad range of scientific and engineering disciplines. To provide the best possible background for possible space contribution to transportation plans, Chrysler has established a Scientific Advisory Council consisting of outstanding United States scientists to supplement the skills already available within the organization.

Space transportation is not a thing apart but is closely related to advanced means of transportation from place to place on the Earth. The space ship is a brother to the rocket ship for terrestrial transport. Space programs will have, as valuable byproducts, contributions to development of extremely rapid Earth transportation. The two developments must be planned together.

GENERAL COMMENTS

The rate of progress in space programs is in large degree subject to human control and may be compared with the tremendous accomplishments in atomic energy. The forecast of progress must assume the continuous support by the United States Government of a carefully planned overall space program under present world conditions throughout the decade. The constitution and activity of the Select Committee on Astronautics and Space Exploration support confidence in the continuing progress and increasing success of American space programs.

Based on the foregoing assumptions, we contemplate major progress in space transportation within the decade. Manned flights of limited duration will be commonplace. Flights will exceed the few minutes of the current planned programs and, toward the end of the decade, will include space trips encircling the Earth and the Moon. The means of establishing space platforms will be developed, but operations from space platforms are not contemplated in this period. Exploratory flights by instrumentation packages to the vicinity of the nearer planets and the Sun will be achieved, and will provide essential information for later manned journeys.

The technology essential to this development is within or at the boundary of the present state of engineering knowledge. The essential instruments of scientific investigation to make this space exploration fruitful are available now. The most difficult problem to be solved is attainment of safety and reliability. Our success in conquest of space will be measured, not in terms of brilliance of technical innovation, but in terms of attaining through sound basic concepts, product engineering, and manufacturing control an indispensable high degree of safety and reliability in large rocket vehicles as indicated by Redstone reliability of more than 90 percent.

The characteristics in terms of which space transportation systems are measured are essentially the same as those for other forms of transportation. They are—

(1) Performance—payload, range, speed, maneuverability, human engineering.

(2) Safety and reliability, environmental protection—which must in space systems be considered together.

(3) Cost.

Our analysis of the development of space transportation is in terms of these criteria.

Performance

The starting point in concept of a transportation system is the determination of what is to be carried. Current programs in space by the United States have been limited, essentially, to transportation of instrumentation packages. These are good devices—guidance, measuring, and communication equipment, all in miniature—and the initial exploration of the new environment of space must be performed by such machines. Instrumented flights are stepping stones. Our real progress in the exploration of space must be measured in terms of the transportation of men.

Safety and reliability

Safety and reliability, the biggest challenges in attaining manned space flight, will be obtained by major concentration on three factors: First, the reliability of which the basic design is capable must be attained in production and operation. The outstanding success of the Redstone reflects enforcement by the Army and Chrysler of the strictest discipline in all phases of fabrication and testing. Second, basic flight testing to have, throughout, adequate margins of safety. Third, there must be major emphasis on "fail-safe" systems where the pilot can safely return despite a system failure which prevents accomplishing the planned mission.

Cost

The costs of space programs will be related to the economic health of the Nation and survival as a first-rate power. Costs will depend on the overall space program and are a consideration in the analysis which follows.

In the discussion of technical aspects of the contemplated space vehicle which follows, a number of choices of system specification affecting performance, safety and reliability and cost, are brought out and our analysis of the possible development of space transportation considers these necessary characteristics.

TECHNICAL ASPECTS

To accomplish a determined mission—measured in terms of performance of safety—the space vehicle system must possess certain essential elements. The principal ones are: (1) the physical structure; (2) the propulsion system; (3) means of guidance, and (4) means of control. The vehicle must be capable of operating successfully in a number of distinctly different phases of flight. The flight may conveniently be divided into five phases: (1) takeoff and climb through the atmosphere; (2) acceleration to minimum orbital speed; (3) flight in orbit and between orbits; (4) return to the atmosphere of the Earth; and (5) descent through the atmosphere and landing. The flight phases and system elements provide a reference for our remarks on the probable form of space vehicle development in the decade.

In phase one, takeoff and climb, guidance and control may be by the ground station in connection with mechanisms on board the vehicle. The pilot will not actively participate. Radio links permit utilization of extensive sophisticated equipment and skilled personnel which the vehicle cannot carry. The vehicle will be tied down until the engines are started and satisfactory operation is assured. Missile equipment will be as simple and robust as possible; the ground system will have adequate redundancy to assure reliable operation.

In phrase two, acceleration to minimum orbital speed, there is a continuing need for high thrust. Aerodynamic control is no longer possible. With the high accelerations involved, the pilot will not have time to make decisions. Ground information as to course and speed will permit continuation of course and attitude control from the ground station. Attitude information on board is presumed throughout.

Phase three: once minimum orbital speed is attained, there is no longer either need or justification for high propulsive thrust. The pilot's reflexes will permit adequate control over the very low thrust space propulsion unit, with the assistance of servo devices as convenient. As the vehicle recedes from the earth, information available by observation from the vehicle will gradually improve with respect to that available by radio contact with the ground station. Information available to the pilot by direct observation may be used, first to bias the control of the vehicle from the ground stations, and, at greater distances to substitute as the basic information for navigation of the vehicle. Remote from the Earth, navigation references will be sights on the Sun, Earth, Moon, and planets with automatic inputs into an automatic navigation system under the surveillance of the pilot. The pilot will have overriding control over the vehicle attitude in space—to permit observations, to regulate temperature by varying the surface offered to radiation, and to alter course as a prelude to embarking on a change of orbit.

In phase four, returning to the sensible atmosphere of the Earth, the implications of the vehicle trajectory, with respect to successful reentry become of critical importance. Evaluating the vehicle's position and speed in term of reentry must be entrusted to the large computers available at the ground station. Observations from the pilot will be an input, but navigation responsibility must be transferred to the ground station.

Phase five: As the vehicle approaches the outer reaches of the atmosphere, aerodynamic heating is for a time the critical problem. The rate of descent must be automatically controlled—by means on board the vehicle—until the danger of overheating is past. Thereafter the pilot will operate the vehicle and should be able to land at a place of his own choosing.

It should be made clear at this point that we are describing a space *vehicle* toward the end of the decade. Earlier in the period, a manned space *capsule* will be feasible and is expected. We should expect a space capsule to be much like the Jupiter reentry test vehicles which have been publicly described, conical in shape with ablation protection on the conical surface, the velocity being checked by parachute or retrorockets. The space capsule would be adequately buoyant, with flotation gear to assure an erect attitude in the water. The manned space capsule must be regarded as but an interim step, however.

SPACE VEHICLE SYSTEM ELEMENTS

Important elements of a system to perform the mission just described are available now or are readily attainable. Guidance, control, and communications are in this category. Essential aerodynamic information, materials and means of providing a tolerable atmosphere within the vehicle for the period of a week or so are also available now. In all these categories, means are available for multiple approaches to the optimum solution, any one of which can be adopted at a relatively late stage of the program of overall space vehicle system development. Much remains to be done, but we are already moving forward on a broad front. We do not look on guidance, control, or the structure and configuration of the space vehicle as being the critical area in limiting realization of true manned space flight within the decade. As the key element—because of the development time required, the enormous facilities for testing, and the prohibitive cost of several parallel programs—we identify the propulsion system. Inseparable from consideration of the propulsion is the broad configuration of the overall space vehicle system. The remainder of this paper is restricted to these critical areas of devision.

This emphasis does not reflect any lack of interest or energetic application on the part of Chrysler in such other essentials of space transportation systems as aeromedicine. We do believe that key program decisions will have to be made early in the propulsion-configuration area, which must be completely confirmed by instrumented unmanned test vehicles while basic scientific knowledge is being accumulated for future manned flights.

CONFIGURATION

It has been implicit in the foregoing discussion that we expect the space-vehicle system to be essentially a multistage device with a final stage in the form of a space craft capable of control in orbit and return to Earth. Further, it has been implicit that we contemplate booster stages devised from large ballistic missiles.

A specialized air-breathing vehicle may be economically useful for *first phase* operation. Two-thirds of a typical rocket propellant weight is oxygen, a material abundantly available in the sensible atmosphere. An air-breathing first-phase engine thus, at given efficiency, saves two-thirds of the propellant. This saving is compounded by consequent reduction in total vehicle weight, and related reduction in propellant energy requirements.

The contemplated configuration is a piloted space craft atop 1 or 2 intermediate rocket-powered booster stages, with a first stage that may be either rocket or air-breathing engine powered. The booster stages would consist of large fuel tanks with multiple engines and suitable control means, derived from large rocket boosters currently in production or in advanced stage of development. These boosters would be provided with recovery means. Our studies lead to a preference for parachute recovery system at this time.

PROPULSION

The choice of powerplants for the various stages of this space-vehicle system is of the greatest importance. It is necessary to know that the main engines are running and running properly before takeoff. It must be possible to shut down all or any part of the propulsion system on command. Otherwise a faulty start would be disastrous. Also, in the boost phases, in the event of failure of some part of booster system, clean disengagement and safe return of the space vehicle may depend critically upon immediate shutdown of the powerplant.

The powerplants should have good growth potential so that it is not necessary to start anew to take advantage of improvements in propulsion technology. A high powerplant specific performance is desirable, particularly in the upper stages. In the first stage, emphasis must be on thrust. In the final stage specific impulse is of the greatest importance; the thrust may be quite small, but it is necessary that the powerplant be capable of starting and stopping repeatedly in flight.

In the rocket engines there is a choice between liquid propellants, solid propellants, and more exotic systems. In the next decade liquid-propulsion engines appear to have advantages as prime boosters supplemented by solids in after stages. Within the class of liquid engines, a selection may be made between the currently popular cryogenic oxidizers and storable propellant systems. The current employment of liquid oxygen (cryogenic) oxidizer traces directly back to the German V–2 and earlier American experience. Programs for investigating characteristics of storable liquids are now bearing fruit. The advantages of being able to hold the missile fueled in a ready condition for extended periods associated with the storable propellants are substantial in a large space-vehicle system. The simplified ignition possible with available storables and the elimination of requirement to protect against distortion of components subject to cryogenics also favor the employment of storable propellants. We anticipate an expanding use of storables in application to the lower stages.

A major consideration is the choice of number of engines to provide the required thrust for a given stage, and indicates a preference for a multiplicity of thrust chambers as opposed to a single large one. This choice is favored by considerations of (1) reliability, (2) safety, (3) cost, (4) flexibility of application, and (5) performance.

Reliability

There is no substitute for a great deal of testing to establish a reliable machine. The know-how gained from the Army's successful Redstone program shows that there is no substitute for man-hours and testing hours to secure component reliability. Building up the required very large thrust of the booster stage for the space vehicle from a number of smaller engines currently under development automatically insures components in a more advanced stage of development and reliability.

Safety

The possibility that a single engine of the several employed in a given stage may fail must be contemplated. With proper instrumentation on board, the failure can be sensed and the engine shut down without disaster. The more engines that are employed in that stage, the smaller percentage disturbance there will be and the less hazard to the controllability of the vehicle. Under some circumstances, an engine might, under these ground rules, be lost, and yet the vehicle fully accomplish its mission. The remaining engines would just operate a little longer.

Cost

The production quantities of elements of space systems will in the next decade be extremely minute in comparison with such familiar objects as trucks and automobiles. The major expense is in research, development, and testing. With the employment of larger numbers of smaller engines, a broader base for amortizing these costs is utilized. Very substantial savings should be realized through employment of larger quantities of established thrust units.

Flexibility

An engine of given thrust can be applied only to missions requiring this trust or greater thrust. Smaller engines can be grouped in various numbers to meet a variety of mission requirements, with consequent increased total requirement and further benefits therefrom.

Performance

Scaling factors favor the performance per unit weight of relatively smaller units. Further, performance improvements through development in the state of the art will naturally accrue more rapidly to a system which utilizes a large number of relatively more advanced individual elements.

CONCLUSION

The foregoing analysis is broadly qualitative, and touches upon only a few high spots of the probable direction of space-vehicle development. Continued analysis of available facts and consideration of facts which will become available will doubtless lead to modification of these views. Our convictions, based on Chrysler's experience over the past 6 years in conduct of the Redstone and Jupiter programs, give us full confidence that space exploration is feasible in the decade.

E. V. MURPHREE, PRESIDENT, ESSO RESEARCH & ENGINEERING CO., LINDEN, N. J.

Of the many important technological advances that will accompany our vigorous space exploration program during the next decade, there are two on which I would particularly like to comment. These are propulsion and weather forecasting.

Greater propulsion capability is the first requirement for successful space exploration. Powerful rocket engines are required to launch space flight vehicles or satellites; and, in addition to these huge powerplants, smaller highly efficient propulsion systems for trajectory and speed adjustment during long trips and for landing are required. Clusters of the largest military engines now available may allow launching of a manned satellite vehicle in the next 10 years. In any case, much information can be obtained from larger unmanned, suitably instrumented satellites. While many problems of reliability and accuracy will need solution, with our active satellite and space probe program we can expect that these problems will be solved through experience. Clusters of the million-pound-thrust rocket on which we are starting development should be available in the last half of the next decade and will allow launching of much larger vehicles. It is possible that sufficient reliability and performance may be achieved toward the latter part of the decade to send manned craft into outer space. Here again, however, much can be learned from large suitably instrumented, unmanned probes.

The huge first stage rockets will probably continue to use propellants such as liquid oxygen and hydrocarbons or other related systems because of the large quantities required and because of relative safety. For the final rocket stages, however, the premium for higher performance is so great that we must make every effort to extract the ultimate in thrust per unit weight from these rockets. The importance of high efficiency is illustrated by the fact that, even for an ICBM, saving 1 pound in the final stage reduces overall weight by around 50 pounds. An even greater multiplying factor will probably apply to space vehicles. Since the ultimate potential of the oxygen-hydrocarbon type fuel now used is nearly realized, use will probably be made of propellants containing fluorine as the oxidizer, along with hydrogen or materials rich in hydrogen. The highest performance can be obtained with liquid hydrogen and liquid fluorine, and it is expected that continued development of this propellant system will be carried out for use in intermediate stages. The great difficulty of handling these materials makes development of high-energy solid rocket propellants which also make use of fluorine as well as light metals of great importance. Such rockets would give more impulse per unit weight than present liquid rocket systems and because of their simplicity, they would contribute a great deal to the reliability. The large solid propellant research program sponsored by ARPA should lead to development of such simple high performance rockets.

The rockets developed during this period will come close to realizing the potential that exists in ordinary chemical propellants. A very significant breakthrough in chemical propulsion would come through use of highly energetic materials such as hydrogen free radicals. While some of these materials can be stabilized in low concentrations near absolute zero temperature, attempts to concentrate them and to stabilize them under more practical conditions have not been encouraging. However, one can hope that continued research will find a solution to this problem in the next decade.

A propulsion system based on use of nuclear energy holds great promise for space exploration. Where very large amounts of propulsive energy are needed, the use of nuclear energy will probably give the lowest weight propulsion system. To utilize nuclear energy, as at present pictured, a nuclear reactor heats up a gas such as hydrogen under pressure and the expansion of this hot gas gives the thrust. Nuclear propulsion when used in this way, therefore, does not eliminate the need for carrying a propellant such as liquid hydrogen or ammonia. The use of nuclear propulsion for the large first stage rockets offers a considerable number of hazards, and it may be more desirable to use this form of propulsion for other than the first stage. In addition to the need of large rockets to get space vessels off the ground, there is need for units of smaller energy capacity to give small amounts of thrust for long periods of time and also to furnish power for instruments, particularly radio transmitters. For these applications nuclear energy looks extremely attractive. Research and development based on the use of nuclear energy for various space uses should be emphasized and continued as a long range need.

Exploration of space and the upper atmosphere will provide us with information needed for a more complete understanding of the factors that determine weather on the Earth. While it is optimistic to expect that precise long-range weather predictions will come as soon as 10 years, it is believed that the new information provided and the continuous worldwide observations available from satellites will aid a great deal in improving our ability to predict weather weeks or months in advance instead of a few days.

The incentive for long-range weather prediction is very large. For the petroleum industry alone more efficient operation due to improved inventory planning would save $100 million per year. The economic incentive is much greater, several billion a year, when agriculture and other industries are involved. To be able to predict rainfall and long-range temperatures, much more information must also be available on the oceans and the lower atmosphere, as well as the upper atmosphere. Vigorous support of the sciences of oceonography and meteorology as such will also be necessary to attain accurate long-range weather predictions.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, DR. T. KEITH GLENNAN, ADMINISTRATOR; DR. HUGH L. DRYDEN, DEPUTY ADMINISTRATOR; DR. ABE SILVERSTEIN, DIRECTOR OF SPACE FLIGHT DEVELOPMENT; DR. JOHN P. HAGEN, CHIEF, VANGUARD DIVISION; DR. HOMER E. NEWELL, JR., ASSISTANT DIRECTOR FOR SPACE SCIENCES

The United States has the resources, the knowledge, the will—and, above all, the responsibility—to pioneer in the Spage 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. With this in mind, the President and Congress created the National Aeronautics and Space Administration and, thereby, formally declared their desire and intent that the United States should undertake a vigorous long-range program of space exploration and exploitation. Accordingly, the program is now being formulated both to gain a better understanding of our universe through scientific investigations in space and to apply our newly gained understanding and capabilities for the benefit of all. The work is being carried forward with a deep sense of urgency.

The motivations for so ambitious an undertaking are many, and it is in the sum total that the undeniable compulsion to press onward may be found. The scientist is satisfied with the search for knowledge for its own sake and the historical validation that scientific progress has never failed to better the lot of man. The realist is perhaps most interested in direct application of space technology to improving his own welfare, and watches with interest the current progress with meterological and communication satellites, for example. The economist is most intrigued by the thought of indirect benefits to be derived from the stimulus such an advanced technology is certain to have on our industrial complex. The educator rejoices as students give up the television set for the textbook and as teachers tackle the new disciplines required of them. The military planner looks forward to applications to the defense of the free world.

The political scientist is concerned with the fact that, in order to hold a position of world leadership in an area of intellectual awakening, it is essential that the United States maintain a position of scientific supremacy. The challenges and rewards of space research are such that the scientific prowess of the Nation will be measured by its contributions in this field for many years to come. To apply less than our best effort consistent with out national capability represents an open invitation to other scientifically oriented nations to seize supremacy in the space-science field, and, with it, world leadership.

To sustain this great undertaking, we must have the interest and enthusiasm of the people of this country. If we are going to capture and maintain this enthusiasm, we are going to have to let them know what we are doing in the clearest, most interesting way possible. It will not be sufficient merely to release new findings as they occur.

However much scientists might wish to confine their prognostications, they must be shared with those who are called upon to back the research. In this spirit, this document attempts to outline the current NASA program and look into the future.

PROGRAMS

The NASA is implementing a three-part approach: (1) a strong space-science program, (2) a program aimed at the application of space-flight capabilities to the national welfare, and (3) a forward-looking program of research and development in advanced technological areas which will further the national capability in space.

Scientific

Scientific space investigations include the use of high-altitude soundings, earth satellites, and space probes to explore the upper atmosphere and outer space in order to gain a better knowledge of our universe. These investigations include measurements of the constituents of the upper atmosphere and space; particles and micrometeorites; primary and secondary radiations of all types; aurora and ionospheric characteristics; electric, magnetic, and gravitational fields; astronomical data; and relativity checks, as well as biophysical experiments.

Space vehicles launched to date have contained a minimum of instruments for the collection of scientific information. Already, however, these vehicles have yielded important data leading to new or modified theories about the makeup of the atmosphere and near-space regions around the Earth. It is the long-range goal of the NASA to extend these scientific measurements in size and scope until sufficient data are amassed to give man an understanding of the total environment in which he exists.

Many of the proposed projects will explore new areas of the solar system. The types of experiments initially conducted in orbits around the Earth will, later on, be carried out in the vicinity of the Moon and planets. Knowledge of the Sun as a typical star can be vastly improved by measurements gathered with a probe. But not all the scientific projects will have this quality of newness. A sound program requires that many measurements be made repetitively so that a continuous picture of the space environment can be attained.

Manned space flights are an important part of the scientific program. Man will certainly play a significant role in the exploration of the Moon and the planets. In order to achieve the capacity of prolonged manned space flight, many preliminary steps have to be taken.

To begin with, scientific experiments both in satellites and in the laboratory must be performed to determined under what conditions it is possible to send a man safely on a space mission and have him return. The problems known to exist include (1) high-energy radiation, both primary and cosmic ray and the newer plasma type discovered in the IGY satellite series; (2) man's ability to withstand long periods of loneliness and strain while subjected to the strange environment of which weightlessness is the factor least evaluated; and (3) reentry into the atmosphere and safe landing. The reliability of the launching rocket must be increased before a manned capsule is used as a payload. Once these basic questions have been answered, then we can place a manned vehicle in orbit about the Earth.

Later, an an Earth satellite laboratory will be established and space rendezvous techniques for supplying it will be developed. Physical and biophysical experiments requiring longtime human operations will be conducted and the resultant knowledge of the behavior and reaction of man to space flight environments can be expected to add extensively to the biological and medical understanding of man. The results of manned space flight research will be applied to developmental studies of suborbital and orbital transportation techniques as well as to the manned exploration of the Moon and nearby planets with eventual establishment of scientific bases on these bodies.

Applications

The area of satellite applications already foreseen includes meteorology, communications, geodetics, and navigation. A system of meteorological satellites will someday provide continuous worldwide observation of cloud cover, storms, heat input, and other meteorological measurements which can be used for improved forecasting, and perhaps at some future date, control of the weather.

Communications satellites will permit transmission of far greater quantities of information between widely separated points on the Earth than is now possible. Overseas television, reliable overseas telephone and cheaper long-range communication should result. In addition to this application, they will eventually serve to relay information from other satellites and spaceships. Geodetic satellites will permit improved mapping of the Earth's surface.

The NASA program in these areas is aimed at the solution of the scientific and technical problems inherent in each system and the demonstration of practical applications of the systems.

Advanced technology

The programs of the NASA can only be partly conducted with the present technological space flight capabilities. Many of the projects already in the preliminary planning stage will require propulsion systems dwarfing those currently available. Some of the contemplated missions cannot easily be accomplished with the relatively low energy fuels in current usage. The guidance and control systems now available will be quite inadequate for many space flight missions. The weights and power requirements of the present satellite and space probe communication systems both need reduction. Instruments do not now exist to measure directly many of the physical quantities which are of interest. The NASA advanced technology programs in these areas have as their goal the development and improvement of advanced components and systems prior to their need in space flight programs.

EXPECTED PROGRESS

This, then, is the broad program. There is no doubt that the Nation has the technological capability to undertake such a program successfully. How much of it can be achieved in the next decade depends in a large measure on the funding provided. The following appraisal assumes vigorous national support of the program.

Scientific

The many physical measurements listed earlier, and some yet to be discovered, should have been quite well mapped as functions of space and time to a distance of at least 10 Earth diameters. Beyond this distance to the vicinity of the Moon and the planets, the observations will be less complete although a relatively large number of deep-space probes will have been successfully launched. A number of these probes should successfully go into orbit about the Moon or planets and hence we will have commenced mapping physical quantities of interest in the vicinity of these bodies. Soft landings of instrumental payloads will have been attempted on the Moon, Mars, and Venus to determine many surface and atmospheric properties of these bodies and whether life in some form exists. It is marginally possible that samples of the Moon's surface may be transported to Earth.

The astronomical unit and the solar constant should be more accurately known. A relativity check with atomic clocks in orbit will have been made. Remotely operated astronomical and radio telescopes will be operating in orbit and relaying new information on the stars back to Earth. Furthermore, it seems likely that new subatomic particles will be discovered in our studies of cosmic radiation and one can only guess at the advances in theoretical physics which might derive from analyses of these particles.

In the area of manned space flight, the orbital reentry vehicle of both the ballistic and the lifting types will be relatively well developed to return the occupants of space laboratories in orbit about the Earth. The space rendezvous problem should be successfully solved so that logistic support for these laboratories could be supplied from the ground. Experiments conducted within the orbiting laboratories should have done much toward improving the comfort and safety of space travellers. Although space transportation from point-to-point on the Earth is not expected in this time, we should have a much more accurate appraisal of its possible future.

There is a good chance that space scientists may have circumnavigated the Moon without landing and an active program should be underway to attempt a similar flight to Mars or Venus along an excess energy flight path resulting in reasonable flight durations. Manned surface exploration will be receiving serious research and development effort.

Applications

The applied areas of meteorology, communications, geodetics, and navigation should realize notable success in the next decade. It seems possible that a fully operational meteorological satellite system having worldwide coverage could be in operation. The presently conceived elements of the complete system include stabilized satellites in polar orbits of 500 to 1,000 mile altitude and "stationary" satellites in equatorial orbits of 22,000-mile altitude, all feeding information into a national weather center managed by the United States Weather Bureau. The satellites would make use of radiation detection equipment, including television, infrared detectors, and radar to measure such things as cloud cover, storm location, precipitation, temperature, wind direction, heat balance, and water vapor. The large amounts of data will probably require satellite-to-satellite transmission and special computing machine techniques on the ground. A worldwide tracking and telemetering network will be required.

Although it would be a mistake to imply that such a system will eliminate our meteorological limitations, there is no doubt that it will supply a tremendous amount of useful meteorological data not now obtainable. It will do this not only because of its ability to give worldwide coverage to some meteorological parameters, in contrast to the current 5 to 10 percent coverage, but also because of its unique vantage point above the atmosphere which will make new measurements possible. Basic scientific understanding, climatology, forecasting, and weather-control techniques should all benefit.

The benefits to be derived from improved capability in meteorology include convenience in planning personal activities, protection of life and property from weather disasters; safeguarding transportation, crop planning, control and protection; industrial planning of weather-dependent products, outdoor enterprises, and heating and cooling loads; eventual limited weather control; and good will in return for providing these services to other nations of the world.

In the area of communication satellites, extensive research and development will be sufficiently complete to permit establishment of practical worldwide systems relaying ground-to-ground, ground-to-satellite, and satellite-to-ground transmission of data, messages, voice, and television. The research and development required includes (*a*) passive relays which reflect radio waves omnidirectionally, as with a sphere, or directionally, as with a corner reflector which must be aimed; (*b*) active relays which repeat messages immediately or at some delayed time; (*c*) high-power directional antennas for ground and satellite installation; (*d*) sensitive "low noise" receivers; (*e*) stabilizing and aiming devices; (*f*) lightweight power supplies; (*g*) "stationary" satellites in equatorial orbit; (*h*) propagation of electromagnetic radiation, and (*i*) world communication needs.

Long-range communication in the form of telephone, telegraph, and television networks is now accomplished by means of land lines, cables, long- and short-wave radio, and microwave relay stations. The total band width of land lines, cables, and low-frequency radio is limited. Shortwave radio bands are crowded and are unreliable because of atmosphere interference and ionospheric irregularity. Ultrashortwave and microwave radio is usually limited to line-of-sight range; long-distance communications at these frequencies is commonly achieved by means of repeater stations.

Satellites should make possible in this time period worldwide communications by ultrashortwave or microwave radio because the line-of-sight range at satellite altitudes is very large. The band width or channel capabilities at these wavelengths are sufficient for television and most other foreseeable communications needs.

Navigation satellites should be in use by specially equipped ships. Geodetic satellites will have been used to improve our measurements of the earth and the relative location of its land masses.

Advanced technology

The next 10 years should see tremendous advancement in the technology which supports our space exploration. Advances will be in the form of improved reliability of old equipment as well as in the development of new equipment.

In the area of propulsion, the following booster rockets probably will be available, in addition to those now existing: (1) A 1-million-pound-thrust rocket; (2) a 6-million-pound clustered rocket; and (3) high-energy-fueled (hydrogen-oxygen) upper stage rockets in the 10,000 to 100,000 pound thrust levels. In addition, a nuclear rocket space engine should have been developed. Electric propulsion systems suitable for maintaining a 22,000-mile equatorial orbit satellite in a "stationary" overhead position may also be in use. Solid propellant technology will result in a much wider variety of such rockets for use in advanced systems. Relatively inexpensive solid propellant booster assemblies will be regularly used for placing small experiments in orbit.

Auxiliary power supplies for electronic equipment will be very advanced, making strong use of fission and solar heat sources combined with turboelectric, thermopile and thermoionic converters. Large power output and long life will be the outstanding characteristics. Solar batteries will remain prominent.

Guidance, navigation and control equipment will be quite advanced over present day systems. Midcourse and terminal guidance for lunar and planetary orbits and soft landings will constitute major operational accomplishments. In the area of control, efficiently stabilized platforms will have been developed for a wide number of applications in satellites and space probes.

Communication equipment for use in the satellite will include large erectable and directable antennas, light and powerful transmitters and low noise receivers using master technology. Lastly, a host of new scientific instruments will evolve to cope with the unique measurements which face us.

Support facilities

The country will have established in 10 years the personnel and supporting equipment for a large sustained effort in space exploration. Although it would be foolish to imply all necessary facilities will have been acquired, it seems probable that the major portion of the buildup will be complete with additional facilities required only to meet the needs of unforeseen developments.

CONCLUSION

All this, and more, can be visualized as being accomplished in 10 years, with a sustained adequate level of support. One must not forget in assaying the merits of these projected accomplishments, that the unknown will, as always, yield up many yet-undreamed-of rewards. We must not fail to meet the challenge.

Dr. W. Albert Noyes, Jr., Department of Chemistry, University of Rochester, Rochester, N. Y.

* * * The questions asked are difficult ones to answer with any certainty. It is almost certain that fairly good sized space vehicles will be put into orbit around the Earth in fair numbers. With proper instrumentation they should do much to improve both short- and long-range weather forecasting. They will also provide valuable data on radiation, possibly on the reactions of atoms, radicals, and molecules under very low pressure conditions. The fields of exploration are limitless, but at present there are problems of power sources and instrumentation which must be solved before the data can be gotten in large quantity.

As for reaching the Moon and putting vehicles into orbit around it so that all sides of it can be explored, one may only guess that these things will be done before long. A certain amount of luck will be required and one predicts many failures. The dangers of contaminating the Moon are real but probably have been exaggerated. Conditions on the Moon are such that organic material would hardly persist.

Propulsion methods are under active study and I am far from an authority on them. One might guess that ultimately atomic power will be necessary to achieve consistent and long-range results, particularly if attempts are to be made to reach other planets. When one considers the small margin between success and failure in reaching the Moon, one must realize that the difficulties will be even greater in reaching the planets. If success is achieved, it will result from many attempts, but the scientific data to be obtained would be of immense interest. One could use one's imagination in describing what to look for, but for the moment one can only say that the engineering problems of reaching other planets are tremendous. * * *

ROBERT P. PARKER, GENERAL MANAGER, RESEARCH DIVISION, AMERICAN CYANAMID CO., NEW YORK, N. Y.

* * * American Cyanamid Co. has recently been selected by the Advanced Research Projects Agency as one of four companies to be granted contracts for long-range research in the area of advanced solid propellants * * *.

With few exceptions, up to the present these chemicals used as propellants have been known and commercially available, being simply combined and otherwise adapted to use by suitable formulation. It is generally believed that future advances in propellant systems will necessitate the discovery of entirely new chemical substances designed for a specific purpose. Such tailormade chemical propellants will certainly play important roles in many aspects of missile systems and space exploration in the next 5 to 10 years.

We believe from theoretical considerations that it should be possible to predict and discover chemical substances which will serve more efficiently, and it is with this belief that we undertake these rather fundamental researches for the Advanced Research Projects Agency. Since our work has just begun, it is impossible to predict where it may lead us. However, our past experience gives us faith in the fundamental research approach to a chemical problem of this nature, and makes us confident that new chemical systems for propellants will be forthcoming and that these will contribute importantly to the future of space development. * * *

DR. GLAUCO PARTEL, FOUNDER, ITALIAN ROCKET ASSOCIATION, ROME, ITALY

In discussing the matter of space developments in the next 10 years, it is necessary to survey also the alien fields which are somehow connected to our progress in general. Therefore, I give hereunder my views on what I believe can be expected during the next decade, separating the different fields for convenience.

I. EARTH

(*1*) *Underground*

(*a*) Research on the chemistry of silicon and silica.

(*b*) Feasibility designs of jet and rocket engines to travel through the solid Earth. Production of chemicals reacting with the Earth.

(*c*) Research on ion rockets for traveling through the Earth.

(*d*) Artificial ball lightning for ore mining with an extremely speedy and most economical process. Such lightning, already under research, would, with extraordinary speed, cut into the ground and form mining shafts with solid, streamlined walls.

(*e*) Design of vehicles utilizing engines under (*b*) and (*c*), above, for traveling underground.

(*2*) *Underwater*

(*a*) Research on chemics, hydrodynamics, communications, cavitation, propulsion, control in the underwater field.

(*b*) Operative jet torpedoes with underwater jets of both the rocket and ram-jet type. Underwater-to-underwater applications. Operational underwater missiles with speeds of 300 knots.

(*c*) Jet underwater craft: civilian and military. Experimental hydroaircraft: boat convertible into aircraft by a suitable engine (both independent and connected to the hydrorocket or hydro-ram-jet type, with a common fuel).

(*d*) Electron transfer reactions to be applied in an "ion" underwater propulsion system. A photoelectric cell can be envisaged to reduce water to hydrogen and oxygen gases which burn together. Ceric ions and cerous ions, in a solution of water and perchloric acid, form the basis for the conversion process. When the light from the cell strikes the solution containing ceric ions and cerous ions, the ceric ions are converted into cerous ions, giving off oxygen from the water; at the same time, the original cerous ions are changed into new ceric ions, liberating the hydrogen. Since both ceric ions and cerous ions remain in the solution, the process can be continued as long as a sunlight source is available.

(*e*) Manned underwater rockets will be developed to provide data about the effect on a human being of underwater rocket motion; to gain experience of conditions required to maintain manual control of rockets in underwater motion; to experiment with pressure cabins and occupants at extreme depths; to carry out experiments in connection with transmission and communication from extreme depths; to obtain records and pictures of the sea bottom; to explore the sea bottom in an autonomous way; to operate underwater attacking boats.

(*f*) Construction of underwater cargo ships.

(*g*) Realization of submarines with hydrodynamic boundary layer control (laminar flow).

(*h*) Feasibility and experimental studies on plankton as the fuel of the future for hydro ram jets.

(*i*) Testing of nuclear hydrofuels (e. g., lithium-aluminum and lithium deuterides).

(*j*) Systematic study of fishes to gain know-how on greater maneuverability, cavitation, propulsion, drag, flow phenomena underwater.

(*k*) Development of underwater means of detection and escape.

(*l*) Antitorpedo torpedo.

(*m*) Feasibility and experimental studies on artificial gills for human use.

(*n*) Systematic study of oceanography.

(*o*) Ocean depths used as the biggest launching pads in the world, having the huge advantage of being concealed.

(*p*) Development of underwater operational launching sites.

(*q*) Experimental research on underwater supersonic "flight."

(*r*) Evaluation of preliminary ideas of underwater mining, roads, towns. Feasibility studies on same.

(*3*) *Surface*

(*a*) No substantial improvements are foreseen for the surface transportation vehicles (cars, trains, ships), except some applications of atomic energy.

(*b*) Operation of atomic-power stations to supply electric energy.

(*c*) Better know-how of application of isotopes in medicine and discoveries of new medicals.

(*d*) Cohesion of atoms in a metal obtained by development of fine crystal filaments called "whiskers." In this way it could be possible to get the highest strengths in materials, thus realizing also light and strong spaceship structures.

(*e*) Development of the superperoxide chemicals.

(*f*) Construction of an equatorial big launching base for satellites and space vehicles.

(*g*) Further investigation and utilization of Antarctica.

(*4*) *Atmosphere*

(*a*) Development of civil supersonic aircraft, utilizing ram jets.

(*b*) Ram-jet and rocket postal service. (See enclosure 1.)

(*c*) Further utilization of plastic balloon astronomy.

(*d*) Systematic world survey by sounding rockets.

(*e*) Experimentation and development of atomic oxygen ram jets, ram jets utilizing excited particles available in the upper atmosphere, ram jets suitable to start a space flight, ionized gas and magnetic ram jets.

(*f*) Systematic investigation of upper atmosphere and related phenomena.

(*g*) Operation of manned orbital bombers.

(*h*) Development and testing of reentry and landing techniques. Operation of same in automatic and manned space vehicles.

(*i*) Evaluation of ion-magnetic braking.

(*j*) Operation of antimissile missiles.

(*k*) Studies on radiant energy to substitute antimissile missiles.

(*l*) Improvement of navigation equipment.

II. SPACE VEHICLES

(*1*) *Satellites*

(*a*) Development of satellite recovery processes.

(*b*) Development of long-range weather forecasting by utilization of satellites.

(*c*) Reconnaissance satellites in operation, both manned and unmanned.

(*d*) Realizations of manned satellites, mono- and pluri-seated.

(*e*) Television and radio communication by satellites.

(*f*) Satellites utilized as physical, chemical, biological labs.

(*g*) Astronomical satellite.

(h) Satellites used to disturb and jam enemy ICBM's.

(*2*) *Instrumented probes*

(*a*) Realizations of Moon, Mars, Venus, solar, and solar-system instrumented probes.

(*b*) Landing of probes on the Moon and the neighbor planets.

(*c*) Improvement of guidance, control, navigation equipment for probes and space vehicles. Development of instrumentation for same.

(*d*) Realization of lunar satellites.

(*e*) "Boomerang" flight around the Moon and back.

(*f*) Evaluation of the energies available in space.

(*g*) Improvement and advances in celestial mechanics and cosmology.

(*h*) Development of communication techniques in space.

(*i*) Expansion of optical and radio astronomical facilities on the Earth.

(*3*) *Manned vehicles*

(*a*) Exploratory flight by manned vehicles in space, connected to development in landing techniques.

(*b*) Extensive development of biological, medical, and psychological research and experimentation to support manned space flight, both on simulators on the Earth and on board actual vehicles in space.

(*c*) Development of measures against weightlessness, acceleration, deceleration, waste; shielding against nuclear radiation, meteoritic hazards, boredom.

(*d*) Training techniques to prepare men for space flight.

(*e*) Development of emergency escape procedures.

(*f*) Assembling and realizations of small space stations.

(*g*) Probable landing of manned vehicles on Mars before the Moon, because of easier landing problems and less severe temperatures. The same holds true for Venus.

(*h*) Full exploration of the Moon by manned vehicles without landing.

(*i*) Problems of survival and operations upon landing on the Moon or other planets to be solved (air supply, shelter, power energy, local resources, appropriate means for travel on the surface and in the "atmosphere").

(*j*) Space architecture: New technological branch to be evolved (projects for lunar bases, Mars stations, etc.).

(*4*) *Propulsion*

(*a*) The total design of the vehicle must incorporate economy of construction and operation. These factors, coupled with a reasonable payload, are essential if we are to perform useful military or civilian tasks. The ideal is a single configuration. In this respect, I agree with Colonel Davis' "conceptual design." The main propulsion unit might be a large ram jet surrounded by auxiliary turbojets. The ram jet would be activated as soon as optimum speed and altitude are reached. On attaining an altitude of 150,000 feet, some means of electromagnetically accelerating particles of ionized atmospheric constituents would gradually be introduced, thereby making use of the magnetohydrodynamic properties of ionized gases. As the flight progresses into the ionosphere and the density of the atmosphere decreases, the electromagnetic propulsion system will be of increasing importance. At the top of the atmosphere, density approaches zero, and it is necessary to introduce a source of ions into the propulsion system. This may be supplemented, to a small extent, by ionized particles that occur naturally in space. During the cruise, a combination of ion source and electromagnetic propulsion will provide a continuous but low acceleration. Rotation of the vehicle about its axis will be achieved by deflection of part of the exhaust stream, and artificial gravity achieved. During the descent to Earth, the electromagnetic propulsion system can be reversed and the kinetic energy of the vehicle converted into stored electricity or dissipated as heat within controlled limits. At an altitude where charged particles are no longer available, the ram jet can again become operational and, for the final landing, control can be gained by starting the turbojets.

(*b*) Plasma engines, atomic rockets, free-radicals rockets, chemical rockets with the utmost performance will all be developed and tested. It is my opinion, however, that all these propulsion systems are only interim devices. The same holds true for hybrid rockets.

(*c*) Ion propulsion systems are one of the most prominent, even if not the best, powerplants to be widely utilized in space vehicles. Ion systems, however, will be replaced by magnetic propulsion because the electrostatic method of ion propulsion, whereby a large voltage difference is created, is somewhat unattractive in its practical possibilities.

(*d*) Magnetic propulsion systems look as one of the most promising field, particularly for manned vehicles, primarily because they do not require high voltages.

(*e*) Development of solar energy not only to generate electricity but also to drive vehicles with large "sails."

(*f*) Experimental evaluation of the "dynamic contrabaric" principle. To prove experimentally how, in certain conditions, the radiant energy can be immediately converted into mechanical motion.

(*g*) Evaluation of "electrogravitativity." Apparently, changes in direction and velocity variations could be realized by an alteration of intensity, polarity, and sense of the charge.

(*h*) Development of some basic elements for photon rocket propulsion.

(*i*) Development of propulsive force by the acceleration of interstellar matter.

III. SOCIAL AND CULTURAL IMPLICATIONS

(1) Creation of an international body, with permanent liaison facilities devoted to the encouragement of cooperative arrangements with other countries; to foster the development of promising scientific talent in space sciences, regardless of national origin; to integrate and possibly coordinate the work in international space cooperation already academically and absolutely insufficiently accomplished by the IAF and other organizations; to evolve a functioning international organization for space development at the level of governments as well as individuals; to assist materially and efficiently the individual initiatives.

(2) A big international conference on "rockets for peace," such as the one held in Geneva for the atomic applications. It is not thought, however, that such a conference would strengthen the overall relationships between West and East.

(3) The law of space will be greatly enhanced in the next decade. However, this will have no practical effect as far as the Soviet Union is concerned. The United Nations will take care of the relative legislation.

(4) Agreements on the use of frequencies, signal codes, communication in space.

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(5) Shortage of management talent will emphasize the need for personnel with know-how and ideas. Education will improve.

(6) A drawback to be carefully avoided is the increased rivalry which could exist among different bodies and agencies, between civil and military organizations, and top executives of different agencies.

(7) Publication of important works for international use such as the decimal classification for astronautics, an up-to-date documentation, and a multilanguage dictionary of rocketry and astronautics.

(8) Agreements and establishment of an international equatorial launching base. To foster such a base will eventually lead to a better international relationship in the astronautical field and to the management of practical solutions for the exploitation of the outer space in a peaceful way.

POSTAL ROCKETS

From a survey of the type and the amount of transportation which should be carried out in connection with a mail service, it results that the vehicles and the assistance facilities are formed by elements derived from the rocket technology, which are mostly existing and tested or are in a stage of advanced design and experimental research, so that the section to be developed ex novo is limited to some particulars.

The evolution of rocketry has provided all the essential elements required for the realization of a rapid automatic mail service with rockets.

The mail service can be considered under two aspects, as follows:

(*a*) a continuous service connecting different main points of a net, so as to insure the forwarding of correspondence in quite shorter times than any other service at present in existence.

(*b*) a discontinuous service providing, in the points of interest, launching and receiving stations from where upon request a vehicle can take off and carry some pounds of valued goods in a short time to another equipped station.

Requirements for the continuous-type service

Irrespective of the velocity by which it will be possible to connect two far-away main points, the gain of time by the higher speed of the rocket is small compared to the times required for collecting and sending out the mail. Therefore, the continuous service is worthwhile if inhabited centers are connected, capable of supplying the postal line and having a relatively small distance between them (e. g. 300 to 1,000 miles), with a service of vehicles having a very high frequency. The main points of the net which are distant many thousand miles may have a minor frequency.

Designating by T_a the time necessary for an aircraft to cover the distance between two main points, and considering that the letters carried by the rocket vehicle undergo the maximum waiting time, while the waiting time for the letters carried by the aircraft is zero (most unfavorable limiting case for the rocket vehicle), we have:

$$T_a = \frac{24}{n_r} + T_r$$

or

$$T_a = \frac{24}{n_r} + T_a \cdot \frac{v_a}{v_r}$$

then

$$n_r = \frac{24}{T_a\left(1 - \frac{v_a}{v_r}\right)}$$

where

n_r=number of rockets per day (launchings are considered as equidistant in time),
v_a=speed of aircraft,
v_r=speed of rocket,
T_r=time employed by the rocket.

Example of application

In order to connect America to Europe by a postal service, it is advisable to establish first a net for collection and concentration of the mail in Europe and a similar net in America. The requirements for the vehicles and traffic frequency are obviously very complex and necessitate a painstaking study based on statistical elements provided by the existing mail services. As an example, the new service can be envisaged as follows:

Connection to be carried out by ram-jet vehicles for the main European cities (Rome, Vienna, Berlin, Stockholm, London, Paris—this last city to be used as collection center).

A similar net can be established in America.

As the flying times of the ram-jet are on the order of 20 minutes, and taking a frequency of one vehicle every 0.5 hour, adding 15 minutes to transport the mail from the central office downtown to the launching site, the correspondence in the worst case takes 1 hour 5 minutes from the postal office downtown to the launching site in Paris. In case of inner European communications, the mail would take 1 hour 20 minutes from the postal office of a European town to the postal office of another town.

The connection from Paris to the American center (e. g., New York) should be carried over by a rocket glider which could take about 1 hour to cover the distance in question. In the worst case, then, the correspondence shipped from the postal office of a European town would take 2 hours 44 minutes to reach the American launching site, assuming that the transatlantic postal vehicles have a frequency of one vehicle every hour.

It is clearly evident that a system like this will allow a European businessman to write to America and receive in the same day the answer.

Considering that, due to the higher cost, the service in question will take over only a part of the present airmail traffic; evaluating the present one-way daily traffic on the order of 22,000 pounds mail; taking into account a not uniform distribution of the load in the 24 hours, the payload of the transatlantic vehicles can be foreseen to be on the order from 50 to 200 pounds, while the payloads of the European net can be of the order from 10 to 20 pounds.

Therefore, it is obvious that these vehicles cannot be manned and the convenience of the whole system is inherent to the possibility of carrying out the service with electronics-guided vehicles.

The European vehicles have an order of magnitude of a target drone.

The guidance technique is of course of the type of automatic navigation or missile guidance, facilitated in the application concerned by the fact that the guidance equipment can be also located in the place which would constitute the target of a missile.

The only technique which maybe is not yet completely set up is the landing of vehicles without damaging or destructing same.

Apparently, a difficulty of the project in question is due to the fact that it can work out only if applied integrally. However, it can also be possible to manage economically even the only connection between two European main points.

P. S.—A feasibility project of this nature, much more detailed, is presently underway by Dr. G. Partel and Dr. A. Angeloni.

Dr. W. H. Pickering, Director, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Calif.

Before attempting to predict the specific achievements which the free world should be capable of accomplishing in the realm of space exploration within the next 10 years, I believe that it is important to recognize several controlling factors which, in my opinion, may well determine the difference between what can probably be accomplished and what will be accomplished.

The most fundamental of these factors is that having to do with the motivation stemming from our national will to gain and sustain an ascendancy over the totalitarian world in the exploitation of space either for military or for humanitarian purposes. If we are content to continue in our present position of lagging the U. S. S. R. in the orbiting of scientific satellites or if we are prone to rest on our laurels once we may have achieved a major "first" in space, I would regretfully predict that a wide margin will exist between our inherent capability in this field and our actual accomplishments in the next 10 years.

Assuming that it is the desire of this Nation to take the lead in the Space Age, it would then appear that the only limitations which will prevent our being able to do so are those relating to our scientific and engineering competency, the efficient utilization of this competency, the adequacy of our planning, and the financial investment which the Congress is willing to authorize on a continuing basis.

I have no particular concern that the first of these will prove to be a serious limitation, for I believe that the scientific competency intrinsic to the free world is equal, if not superior, to that existing in the totalitarian countries. I would remark, however, that this Nation might well benefit from the establishment of closer working relationships with the scientists of our allies. I also seem to now detect an awareness on the part of the public to recognize the necessity of giving greater support to our educational institutions, and to encourage the development of the latent scientific and creative abilities existing in our younger generation. I am hopeful that this awareness will continue on a sustaining basis and that it will result not only in the development of fine scientific minds but also in a broader and deeper understanding on the part of the layman of the profound changes which the advent of the Space Age must ultimately have on the economics and the culture of our society.

I am rather more concerned on the point of making efficient use of our scientific ability. I believe that a potentially serious danger exists if we fail to recognize that a dearth of fundamental knowledge must eventually result if there is inadequate sponsorship of basic and supporting research in our universities and laboratories. There are forces in play which are conducive to our neglecting these vitally important areas. Among these are the tendency of industry to lure, by attractive financial rewards, gifted scientists from our universities, and a failure to recognize that funding for successful research effort cannot generally be done on a short-term basis which is geared to the attainment of specific achievements at predictable intervals.

PLANNING

Inadequacy of planning, particularly that of a long-range nature, may well prove to be our most serious handicap in attaining significant breakthroughs in the next 10 years of the Space Age. Impractically conceived missions having little chance of success because of premature scheduling which is based on the use of unproven components in the very early stages of development can have a most demoralizing effect on those involved in a program. Experience in the field of missilery and rocketry has shown that significant achievements come about as the result of the orderly planning of supporting research and a step-by-step advance in the engineering of new vehicles. Such an approach offers a reasonable expectation of constructing equipment having the necessary degree of reliability to permit the successful accomplishment of planned missions.

This experience supports the thesis that basic and supporting research must be conducted on a sustained basis if we expect to have a continuous reservoir of technical knowledge on which we may draw to further our tangible accomplishments in space exploration.

FUNDING

Over or under funding of programs may also lead to the inefficient utilization of our scientific talent and engineering facilities by creating instability in the market for scientific talent and by placing localized segments of our Nation in the ironical position of suffering sporadic economic setbacks. Attempts to avoid such setbacks by unwarranted subsidizing of outmoded programs or by the initiation of poorly conceived expedient programs is extremely wasteful in both technical manpower and money. Unwarranted duplication of effort on similar programs among competing organizations may also result in a needless dissipation of talent and funds with an attendant loss which could be avoided by concentrating on single, well-conceived programs.

I cannot overstress the need for adopting a sound attitude in regard to the funding of space programs. This attitude, I believe, should reflect the fact that for some time to come, it should be recognized that considerable funds must of necessity be invested in supporting research, in facilities, and for experimental equipment with the realization that the accomplishment of the early missions may not necessarily result in any immediate or significant dividends in terms of tangible gains to the economy. This attitude, of course, discounts any dividends having a psychological or propaganda value which might accrue to the free world from having achieved significant "firsts" in the exploitation of space. It is conceivable that the prestige value to the nation of achieving these "firsts" may well prove to be one of the most economical means of carrying the cost of a cold war.

NEXT DECADE

Within the coming decade the science of space technology should be advanced to the state where the following feats have a reasonable expectation of being achieved.

1. Reliably performing chemical rocket engines having thrusts of several million pounds will be available as propulsion systems.
2. Prototype models of atomic rocket engines will be undergoing static testing and ionic propulsion systems will be in the advanced experimental stage.
3. Highly reliable guidance systems will be perfected which are capable of permitting satellites to be established in precise orbits and space probes to be launched on predictable trajectories.
4. Improved structural materials capable of better meeting the new requirements imposed by space exploration vehicles will be developed.
5. More efficient and reliable solar-energized power sources having practically indefinite life will be in use.
6. Improved vehicle communications and tracking facilities to permit the accurate location of space vehicles and their remote control from the Earth will be in use.
7. Communication relay and navigational-aid-type satellites will be placed in orbits, stationary with respect to the Earth, and experiments leading to the establishment of a worldwide video and audio communication links will be in process.
8. A man-carrying satellite will be successfully placed in orbit and returned to Earth.
9. Instrumented devices will be successfully landed on the Moon so that information regarding the characteristics of the lunar surface can be transmitted to Earth. It is also very probable that an unmanned vehicle will be landed on the Moon and returned to Earth.
10. The characteristics of Venus and Mars will be investigated by instrumented space probes to obtain the answers to such questions as: "Does life exist on Mars?" and "Will it be possible for human beings to survive on Mars?"
11. Scientifically instrumented space probes will be launched into deep solar space and considerable knowledge of the environment in the interplanetary regions will be gained.
12. Weather observation satellites will be placed in orbit and the science of accurate weather forecasting on a global scale will be undergoing considerable refinement.

13. Experimental models of remotely controlled celestial observatories will be placed in orbit.

As to whether the free world or the totalitarian world will achieve the majority of these "firsts" within the next 10 years, I cannot predict. I know of no valid reasons, however, why this Nation should not be the leader in accomplishing a large number of these feats if the will exists to do so and if the controlling factors which I mentioned earlier are recognized.

Dr. F. W. Reichelderfer, Chief, United States Weather Bureau, Washington, D. C.

SATELLITE METEOROLOGY

The development of meteorological satellites and the application of new observations and data from this source to the problems of meteorology offers promise of one of the most revolutionary advances in the history of the science. It should make possible the immediate detection of new storm formations—hurricanes, extra tropical cyclones, etc., any place over the globe. Its worldwide weather-observing potentialities are of utmost importance in human welfare relating to weather and climate.

PART I. SATELLITES AND METEOROLOGY

Meteorology is still in its scientific infancy. Remarkable new developments could revolutionize the methods for determining the state of the atmosphere, making possible for the first time truly global analyses of its complex and interrelated circulation and contribute immeasurably to man's knowledge of the weather.

The Nation's population, economic, and technological growth over the last several decades has brought about increasingly greater dependence on weather information in the conduct of human activities.

It is only within the last 1 or 2 decades that weather data have been available to permit charting of the weather on a hemispheric basis. Even so, data available from the vast ocean areas covering some 70 percent of the Earth's surface are limited largely to points along the principal sea and air lanes. These data limitations have permitted only the broadest types of hemispheric weather charting and this only for the Northern Hemisphere. Very little is known of the relationship between the weather of the two hemispheres and the effect of the high atmosphere on the weather observed in man's present environment.

Probing of the vertical structure of the atmosphere remains sketchy. Of necessity, meteorology still relies on an observational system permitting only momentary atmospheric samplings once or twice daily at points separated by hundreds of miles over land and thousands of miles over oceans.

The prospect of becoming freed from these limitations is no longer just a dream of the meteorologist and researcher. Earth satellites can serve as global weather observing platforms. Studies clearly indicate that Earth satellites fitted with television cameras, radiometers, and radar could telemeter to ground stations sufficient data on the weather as seen by the satellites to make it possible for man to actually achieve weather surveillance and analyses on a global basis. Satellites could televise to Earth stations, in considerable detail direct photographic observations of the cloud systems of the globe, particularly those associated with major storms. Similarly the extent of polar icecaps and snow-covered surfaces bearing on processes in the atmosphere could be determined.

Satellite-carried instruments measuring the radiation emitted and reflected by meteorological features around the Earth could yield information on cloud types and their structure. Measurement of the total atmospheric moisture content would identify air masses and trace their movement and changes. Knowledge of the radiation balance of the Earth and its atmosphere could lead to an improvement in long-range forecasts.

OZONE

The total ozone content of the atmosphere and the variations in ozone could be measured by satellite-borne instrumentation. Such information on ozone, a gas which plays a vital part in protecting mankind from an excess of ultraviolet radiation from the Sun, would contribute greatly to the understanding of atmospheric circulations and heat exchange processes.

Satellite determinations of the horizontal temperature gradient at the base of the stratosphere would yield important clues on the position, extent, and intensity of the jet stream, particularly over ocean areas where data are difficult to obtain. Other radiometric measurements of Earth and atmospheric temperatures would provide information on the stability of the atmosphere.

The development of satellite radar would permit global tracking both day and night of storm areas with an accuracy and detail hitherto unknown.

Earth satellites could also provide a means for relaying surface meteorological data on a global basis. The surface data could be transmitted to the satellite for storage and subsequent ultra-high-speed retransmission over predetermined areas. Thus, world exchange of perishable meteorological information would be accomplished in a matter of minutes.

These satellite measurements are scientifically substantive and technically obtainable.

The Weather Bureau is actively interested in the field of space meteorology to better meet its present obligations and be in a position to satisfy future meteorological requirments.

The Weather Bureau, in the course of making measurements of the atmosphere necessary to perform the basic responsibilities assigned it as the National Meteorological Service, supports the fundamental meteorological needs of military operations, particularly with regard to the continental United States area.

The proposed satellite and rocket observations outlined in part II will provide (*a*) an immediate observing program utilizing existing satellite instrumentation, (*b*) the development of advanced instrumentation to give more detailed information than now available, (*c*) rocket soundings at regular intervals at several locations to determine environmental conditions in the upper atmosphere, (*d*) analyses of these data and their application to meteorological forecasting and research.

PART II. THE PROPOSAL IN DETAIL

The development of the Earth satellite makes it possible for the first time to survey characteristics of the Earth's atmosphere on a global scale. No longer will the meteorologist be plagued by large blank areas on his global weather maps.

New types of data will result in a better understanding of the workings of the atmospheric heat engine which, in turn, is prerequisite to the improvement of forecasts and the development of large-scale weather control. Frequent observations, rapidly received, of storm movements will materially aid short-range forecasting to the benefit of transportation, commerce, the military, and the general public.

The utilization of meteorological rockets as well as satellites will provide environmental data required for high altitude flight, correlation of satellite data with conventional meteorological observations, and assist studies of solar-terrestrial relationships.

The following sections outline proposed research and development designed to meet present and future needs of meteorology.

A. *Global cloud cover and storm distribution*

The satellite makes possible for the first time a truly worldwide survey of clouds and storms. Clouds are visual indicators of atmospheric motion and enable the detection and location of most high- and low-pressure areas and storm centers. This information will be useful in improving weather forecasts, particularly over the important ocean and sparsely populated land areas from which few observations are now received. Even forecasting for the continental United States, where numerous reports are now available, would be improved by having a more complete global picture of the weather.

In the following, a photocell scanning system is described which is currently available for use on satellites. It is proposed that a television camera system and infrared cloud detection equipment be developed for use within a year or two.

1. *Photocell cloud detector.*—The Army Signal Agency has developed for the International Geophysical Year satellite program a photocell system for detecting global cloud cover. This equipment employs two photoelectric cells which scan the Earth from a spinning satellite. The data are stored by a small tape recorder during the orbit of the satellite and rapidly played back when interrogated by a ground station. This equipment has a resolution of 1°. For a satellite 300 miles above the surface of the Earth the instrument sees at any one time approximately 40 square miles, indicating whether this area is "cloudy" or "clear." Certain modifications to this experiment may enable it to give the average Sun illumination over 5 seconds, together with the character of the cloud cover such as overcast, broken, or scattered. The information received will enable the meteorologist to follow the movement of the large storm centers and the large undulations in air movement known as planetary waves.

The instrumentation for the photocell system, including data storage and transmitters, weighs a total of about 20 pounds.

It is proposed that 6 to 8 such instruments be flown during fiscal year 1959.

2. *Television scanning of clouds and storms.*—Increased resolution in cloud observations will provide for more detailed observations of

smaller scale wind systems and phenomena such as hurricanes, squall lines, and other severe weather. Conditions for the initial formation of hurricanes are poorly understood at present. Detection of hurricanes by convective or "spiral nebulae" cloud patterns in their early stages over the tropical oceans far from present observing stations will aid materially in hurricane research and prediction. Location during successive satellite revolutions will permit hurricane tracking in areas where few or no observations ordinarily exist. The tracking of all severe storms over the whole globe on a continuous basis has important implications in military as well as civilian applications.

Two TV systems are proposed. The initial system would have a resolution of approximately 10 miles. This unit is presently under development by the United States Army Signal Agency and should be available for satellite use before the end of fiscal year 1959. The weight of this system would be approximately 100 pounds including data storage. Without data storage the payload would be reduced to about 50 pounds. In this case, a "snapshot" picture would be obtained upon demand from a ground receiver. Such a transmission could furnish a picture of an area of about 1,200 miles square, for example, over the United States.

It is proposed to develop an improved television camera and data storage system which would give worldwide cloud distribution with a resolution of at least 2 miles. The project would include the development of a data playback and presentation system. A payload of about 300 pounds will be required for this system. The minitrack system of ground receivers would be utilized for data reception.

3. *Infrared cloud detector.*—The television cameras and photocells view only sunlit clouds. By viewing the Earth in the infrared with detectors sensitive to a wavelength near 10 microns, it would be possible to detect clouds on the night side of the Earth. The resolution obtained with this system will not be as great or as detailed as that obtainable with the TV systems but the information will be adequate for detection of nocturnal storms and extended cloud systems.

Certain byproducts may also accrue through the use of the infrared system. Since in many areas of the Earth air temperature in the troposphere varies monotonically with height, it may be possible to estimate cloud top height both day and night from infrared measurements. This would give added information on atmospheric stability and the severity of storms.

The resolution of the infrared system would be approximately the same as that of the photocell scanning system. The instrumentation is expected to weigh about 20 pounds. It is proposed that this development project be started immediately with the expectation of using the equipment in 1960. The possibility of developing a high resolution infrared TV system would also be investigated.

B. Solar–terrestrial energy measurements

The atmosphere is a heat engine which is driven by energy received from the Sun. The heating and cooling of the Earth and its atmosphere control the large-scale motions in the atmosphere. Radiant energy, both terrestrial and solar, in different wavelengths, have varying effects upon atmospheric circulation. At present, meteorologists have only a general idea of the distribution of radiant energy and the heat budget of the earth and its atmosphere. Only fragmentary information is available on the geographic distribution and time variation of the heat budget. Measurements of radiant energy fluxes for the entire Earth at frequent intervals by means of satellite observations would be a basic contribution to meteorology.

Other energy measurements can be used by indirect analyses to determine the distribution of various meteorological parameters and to study, perhaps even forecast, changes in the atmosphere resulting from changes in radiation from the sun.

The following projects are currently available for satellite use or require a minimum of additional development work. It is also proposed that a basic project be initiated to examine additional radiation measurements and analyses which can be used to determine other meteorological parameters.

1. *Energy distribution and heat budget.*—The development of suitable instrumentation to measure the energy received by the Earth from the Sun, the solar energy reflected by the Earth to space, and the infrared energy emitted by the Earth has been completed by Professor Suomi of the University of Wisconsin. The total instrumentation, including telemetering, weighs 8 pounds, allowing it to be used in the smallest of satellites. The sensors used in the instrumentation are omnidirectional, resulting in limited detail when operated in high-flying satellites.

It is desirable to increase the resolution of Suomi's instrumentation to permit measurement of the energy budget of the Earth over individual areas about 600 miles square. It appears to be possible to modify the equipment by placing the sensors in shields. This would probably require a prearranged satellite spin axis. To use a more general spin axis, instrumentation using a shutter that can be made to open each time the sensor faces the Earth could be developed. Such instrumentation might require a 175-pound payload. It is proposed to initiate the development of this equipment during fiscal year 1959 for use in 1960.

The data obtained from these instruments, particularly the directional unit, will be of special value in forecasting for periods of a week or longer. It will also be valuable, after data have been collected for many years, in determining long period changes in climate.

2. *Solar ultraviolet and X-ray measurement.*—Instruments for measurement of X-rays and the Lyman-Alpha line in the solar ultraviolet radiation have been developed for satellite use by the Naval Research Laboratory. The 3-pound weight of the combined instruments permits their use in small satellites or in combination with other instrumentations. Five-second average values of ultraviolet and X-ray solar radiation would be obtained at 2½ minute intervals and stored for the whole orbit of the satellite.

These measurements will aid in verifying a recently proposed hypothesis. This hypothesis states that the more intense emissions from the Sun occurring during solar flares may heat the upper stratosphere unequally, setting up or amplifying air motions in this region. Such motions are then believed to cause the amplification of storms in the lower portions of the atmosphere. This may be one connecting link between unusual solar emissions and weather. To study such effects quantitatively we need measurements of the variations in solar energy which reach the outer limits of our atmosphere.

It is proposed that eight sets of instruments be obtained for use during fiscal year 1959.

3. *Additional radiation measurements.*—By the measurement of various wavelengths of radiant energy emitted by the Earth and its atmosphere, it is possible to determine the amount of certain gases, such as water and ozone, in the atmosphere and to infer certain atmospheric temperatures. The following projects are advocated:

(*a*) *Temperature.*—There is a concentration of water vapor at the base of the stratosphere (the tropopause). By proper selection of wavelength in the infrared, the intensity of the measured radiation will be a function of the temperature at the emission level. The geographical distribution of this tropopause temperature can assist in defining the location of the jet stream and certain types of storm areas. The tropopause temperature also correlates well with the height of the tropopause. From tropopause height it is possible to determine the type of air mass present.

If several other wavelengths of differing absorption characteristics are also measured, it may be possible to infer the three dimensional temperature distribution in the atmosphere. These data would give information on the stability of the atmosphere and some knowledge of the wind field.

(*b*) *Total water-vapor content.*—By measuring the ratio of reflected solar radiation at 2 wavelengths, 1 of which is absorbed by water vapor and the other of which is not, the total amount of water vapor in a column of the atmosphere above a reflecting surface can be determined. This information on a global basis will assist in identifying and following various air masses and determining their characteristics.

Ground-based instrumentation of this type has been developed by the United States Weather Bureau. Miniaturization of this equipment for use on small meteorological rockets is now being planned.

(*c*) *Total ozone and distribution.*—In a manner similar to that for water-vapor content, but using different wavelengths, total ozone in a column of the atmosphere can be measured. Ozone maxima tend to be correlated with high-altitude pressure troughs which are often associated with storm areas. Thus, measurements of ozone will aid in analysing the position and movement of these important atmospheric features.

An ozone instrument suitable for use on small meteorological rockets is now being developed under the sponsorship of the Office of Naval Research. It is probable that little modification will be required for use on a satellite.

(*d*) *Spectrum of solar radiation.*—In studies of the ionosphere and solar-terrestrial weather relationships it is desirable to measure the total solar spectrum and variations in this spectrum during unusual solar activity. The X-ray and Lyman-Alpha measurements only represent two points in this spectrum. Further development work should be carried out to ultimately permit measuring the solar spectrum at more wavelengths. The Naval Research Laboratory has done considerable work in this field. It appears that with a payload of about 100 pounds, measurements in several wavelength bands of the solar spectrum could be made.

C. Meteorological rocketsondes

The maximum altitude generally attained by present rawinsondes [1] is in the vicinity of 100,000 feet. The altitude usually attained is less than this.

Some meteorological information at higher altitudes has been obtained from rocket flights; however, meteorology has suffered on two counts. First, most of the rocket observations which have been made resulted in data at high altitudes above 200,000 to 300,000 feet. Only limited observations have been made in the past of temperature and wind. Second, because of the cost and difficulty of handling rocket systems used heretofore only infrequent observations have been made. Therefore, there is a great meteorological void between about 100,000 and 300,000 feet.

Meteorological information from this region of the atmosphere is urgently needed to determine conditions to be encountered in space flight, to assist in determining the design and performance of space vehicles and to assist in correlating satellite observations with those obtained by more conventional means.

The meager information presently available on winds at high altitudes indicates that they are often very strong and that there is *a systematic* reversal in the general flow from winter to summer. The development of strong winds usually leads to large vertical wind shears. At a certain point instability occurs, resulting in turbulence and a breakdown of the circulation. This sudden change can influence the circulation through a considerable depth of the atmosphere. Only limited data are presently available on these processes at high altitudes. Information on these winds would provide an important link in our understanding of atmospheric motions as well as provide a climatology of the environment being encountered in space flight.

During the International Geophysical Year extremely low temperatures have been observed at the South Pole. The loss of heat by radiation during the long winter night results in low temperatures at the surface and in the stratosphere. Atmospheric motions are largely dependent upon the horizontal temperature gradients which exist between the equator and the poles. In the polar areas, particularly during the long winter night, we are not able to obtain high altitude temperature and wind data because of the low maximum altitudes reached by balloons. Meteorological rocket soundings appear to be ideally suited for obtaining these data which are important in predicting atmospheric motions and understanding atmospheric mechanisms.

Ozone is known to play a role in the radiation balance of the atmosphere. As mentioned earlier, one hypothesis is that significant changes in atmospheric motions occur following solar flares due to sudden warming of the ozone layer. Observations of the amount and distribution of ozone are few. No simultaneous observations of ozone, temperature and wind in the region of the ozone maximum are available. Recent balloon observations to 100,000 feet have indicated the possibility of sudden stratospheric warming which appears to be followed by a complete breakdown of the strong winter circulation at lower altitudes in the atmosphere. Data now available indicate that the level of greatest warming is above the maximum altitude reached

[1] Combined wind, temperature, humidity, and pressure sounding.

by present soundings. By extending our observations vertically using a rocketsonde we can determine the onset of this warming and whether the temperature maximum is coincident with the ozone maximum. In connection with simultaneous satellite solar radiation measurements, these observations will materially aid the study of solar-terrestrial relationships and their effect on the changing weather.

Because of the continuing changes in the atmosphere the meteorologist requires frequent sampling both in time and space. To accomplish this a rocketsonde program must utilize relatively low cost components to permit taking frequent soundings on a regular schedule. The following proposal is based on this need.

1. *Wind measurement to 250,000 feet.*—Presently available instrumentation will permit the measurement of wind between 100,000 and 250,000 feet. A small rocket is used to transport radar chaff or a radar beacon to the maximum desired altitude and the target is tracked on its descent by radar. The changing horizontal position of the target during its descent is a measure of the wind. Because of the immediate availability of this equipment it is recommended that an observing program be established as soon as possible at a minimum of four stations in North America. Soundings would be made three times a week with extra soundings during periods of special interest.

2. *Complete rocketsonde system.*—Although not available for immediate use, development work is well underway on a rocketsonde for measurement of temperature and density as well as wind. Because of present limitations of the temperature and density sensors, it is expected initially that observations of these two parameters can be made only to 200,000 feet. It is proposed that a system be assembled which would permit observations of all three variables by the end of fiscal year 1959. The complete rocket system, including all instrumentation, should cost less than $1,000 each. As most of the development work is now well underway, a minimum of development funds will be required. Upon completion of development work it is proposed to substitute this system for the winds only system outlined above.

3. *Ozone and water vapor measurements.*—Work is underway to develop suitable lightweight instruments for the measurement of ozone and water vapor utilizing the same small rocket planned for the rocketsonde system outlined above. Little or no development funds will be required for completion of this work. It is expected that this instrumentation will be available in fiscal year 1960. At that time it is proposed to make ozone and water vapor measurements to 200,000 feet at the same stations where the rocketsonde observations will be made. One sounding a week would be made at each station with additional flights during periods of special interest such as in conjunction with satellite observations and during unusual solar activity.

4. *Soundings to 500,000 feet.*—The rocketsonde proposals above are limited in altitude due to the present state of the art. It is very desirable to extend these soundings to an altitude of at least 300,000 feet and perhaps a maximum of 500,000 feet. This must still be accomplished at a reasonable cost to permit frequent observations. Some limited feasibility studies have been undertaken. However, increased funding is required. It is proposed that further development work be sponsored.

D. Instrumental developments for the future

Much new data are already being received from rocket soundings and satellites. These data indicate new fields of exploration and are stimulating thought on new instrumentation. It is proposed to study the feasibility of new type of measurements and their application to meteorology and allied sciences. Promising projects will receive further development. Some examples follow.

1. *Radar precipitation measurement.*—It may be feasible to record areas of precipitation over the whole globe utilizing a satellite borne radar. Such measurements would be of extreme value providing the meterologist with direct information on the severity, size, and movement of storms, air mass characteristics and, indirectly, information on atmospheric motions and stability. These data are directly applicable to forecasting in areas where few radar or other meteorological observations are now received. Even over the continental United States it would provide a rapid "bird's eye" view of all important precipitation areas. This would be invaluable when used in conjunction with detailed observations from ground-based radar.

2. *Atmospheric composition-solar emissions.*—The recently observed high levels of cosmic-ray activity indicate that they may be sufficiently intense to be of importance in meteorology, particularly as related to their effect on the composition of the high atmosphere. A study should be made of techniques to permit the measurement of the composition of the high atmosphere, such as injecting known gases into the atmosphere from a satellite and observing chemical reactions which ensue. Studies of the atmospheric composition and the effect of solar emissions on this composition would contribute to the advance of meteorology and the study of the physics of the ionosphere.

E. Data analysis and observational development

The Weather Bureau has been active in planning for the meteorological phases of the current Earth satellite program. The Bureau has an active research and development program in all phases of meteorology, including those which bear on the proposed program. One group has been engaged in high altitude research, including solar-terrestrial relationships and stratospheric circulation. Map analyses for levels up to 100,000 feet are being made regularly as basic research material for this and other projects.

The Weather Bureau's National Meteorological Center constructs daily weather analyses and prognoses for the Northern Hemisphere and has an IBM 704 computer used solely for meteorological problems.

In addition to the more than 90 regular Weather Bureau upper air sounding stations, we have been cooperating in the operation of many additional stations from pole to pole during the International Geophysical Year. Many of these stations will be continued during the post-IGY period.

The Bureau's Satellite Meteorology Group is collecting and analyzing the data now being obtained by Earth satellites. It is proposed that this group be expanded to participate in and supervise analysis of data obtained from future satellites. Many of the facilities of the Weather Bureau would be used in the analyses of these data and their ultimate application to forecasting. The specialized capabilities of universities and private research organizations would be utilized in this work through contracts.

The Bureau's Observational Test and Development Center would monitor the development of the observing systems, operate the rocketsonde systems and coordinate the satellite observing program. The Instrumental Engineering Division would provide engineering support.

Close coordination would be maintained between the analysis and observational development groups to expedite the entire research and development program and permit efficient operation.

JAMES A. REID, EXECUTIVE VICE PRESIDENT AND GENERAL MANAGER, ASTRODYNE, INC., MCGREGOR, TEX.

* * * The challenge of space resides both in the exploration of virgin territory and in the benefits and controls which can accrue from better understanding and use of space. As in all scientific explorations, the "unknowns" being dealt with not only add to the challenge of the investigation, but make impossible an accurate depiction of the final results. Thus, although many guideposts and indications of what space exploration will generate in the next 10 years are already at hand, it is possible that new facts will be discovered which could have applications far beyond our present concepts.

From this viewpoint, it is most important that the United States and the free world proceed in a well organized, but accelerated space exploration program with the goal, as stated by Senator Lyndon B. Johnson, "of dedicating outer space to peaceful purposes for the benefit of all mankind."

The propellants and powerplants for unmanned Earth satellites, lunar probes, and limitedly controlled nonreturn space probes are now in development. Much of the benefits over the next 10 years will result from increased size, efficiency, and reliability of our chemical powerplants, to be used in sending fully instrumented vehicles on exploratory missions from which complete environmental and observational information will be communicated to Earth centers. The information communicated by these satellites and probes can give us such results as:

(1) Continuous surveillance of action on the Earth's surface (dependent upon instrument developments) including construction, movements of people, clouds and atmospheric disturbances. (The latter observation will permit greatly improved weather forecasting.)

(2) Continuous record of changes in chemical and electrical composition and properties of the Earth's upper atmosphere and adjacent space, and use of the information in understanding the effects of solar and other radiation on our communications, long-range weather, Earth energy balance and temperature trends, etc.

(3) Establishment of radio and television relay stations for greatly improved communications.

(4) Better scientific understanding of the environment in our solar system, with knowledge of radiations, magnetic fields and

composition, with exploration of the use of these properties and forces.

(5) The environment, composition and other properties of the Moon will be fully explored by Moon orbital vehicles which may well be recovered.

NEXT DECADE

As a result of experience gained in successful unmanned operations, manned Earth orbital vehicles will be launched and recovered. With modest extensions of our present powerplants and instruments, Moon landings and returns can also be accomplished. Thus, with adequate funding, the instrumented rockets may be sent on almost unlimited exploratory trips and manned rockets at least to the Moon and return. In view of the greatly increased complexities and costs of placing man in space, it is anticipated that by far the greater effort and benefits will be gained from unmanned space vehicles.

Whereas chemical powerplants will generally be satisfactory in Earth orbital and lunar travel for at least the next decade, new power systems are essential for interplanetary space flight. Extensive exploratory research is presently in progress on electrical and nuclear propulsion systems. With anticipated scientific advances, energy sources for space propulsion, guidance, and power generation (for environmental control and communications) for manned travel to outer space can be achieved. Chemical rockets may be used for lifting the space capsule substantially out of the Earth's gravitational field, with electrical-nuclear propulsion being used in space.

We can be much less definite about the results of outer space exploration, in part because we know so much less about it. Much more specific information about the Sun and its radiations, the material and energy content of "space," the composition and atmospheres of the planets in our solar system and other solar systems, may be obtained. With sufficient distance from the Earth, many of the questions in relativity theory could be tested. The progress and expenditures in outer space will require review and judgment as the studies progress.

Although not within the scope of the title of your study, it is desirable to point out that much pioneering research, as well as engineering and development, must be accomplished in order that the space age objectives be accomplished. In addition, from these studies in chemical energetics, nuclear-electrical power systems, and most fabulous electronics and instrumentation, there will result numerous developments having major value and application *outside* the space programs. * * *

Vice Admiral Hyman G. Rickover, Assistant Chief, Bureau of Ships, for Nuclear Propulsion, United States Navy; Assistant Director for Naval Reactors, Atomic Energy Commission

* * * (1) INTERNATIONAL ASPECTS OF THE EXPLORATION OF SPACE

I am in thorough accord with the Staff Report of the Select Committee on Astronautics and Space Exploration, dated October 15, 1958. This is a well-reasoned and concise statement of the problem. I am also in agreement with the draft resolution on the "Control of

Outer Space" submitted in the General Assembly of the United Nations by the United States and 19 other nations on November 13, 1958.

One of the chief reasons it is not possible for the peoples of underdeveloped countries to advance more rapidly than is now the case is because they have not had the opportunity to become educated to the extent which has been found necessary in the West to improve science and industry. By permitting these peoples, and the peoples of all nations that cooperate with us, to share our knowledge of space in an unrestricted manner, they will be assisted in achieving that degree of education which, under modern conditions, is a prerequisite for their welfare. We should afford these peoples the opportunity to learn on a completely free and open basis, giving them all the information we possess. Such a step will insure that our space effort will remain thoroughly productive because it will benefit from using the brains of not only our own people but also those of all our friends.

Conversely, one of the problems in underdeveloped countries is the presence of a number of people who have been educated in the West and can find no productive outlet for their knowledge and abilities in their own lands. Ability to engage in useful scientific and engineering work will tend to alleviate this situation and with it some of the causes for unrest. We must show definitely not only by our *words* but also by our *actions*, that we believe in the peaceful exploration of space.

(2) SECURITY ASPECTS OF THE EXPLORATION OF SPACE

I believe that we should from the start conduct the research and development of the space agency without secrecy. I also believe that the United States Atomic Energy Commission could have conducted its research program in reactors from the very beginning of that agency in 1946 on an open basis and with no resultant harm to the security of the United States. I believe that it would have been possible to disclose in this manner all of the knowledge and technology we developed. The details of the design of military reactors such as dimensions of fuel elements, reactor cores, etc., must, of course, be maintained a secret, as well as the status and plans of the various military reactor programs, but not so the details of the technology involved. At the present time we are declassifying essentially all of this technology without apparent harm to the United States. Let us not repeat this turnabout with the space technology; let us achieve the benefits of good will which come from free giving when it is still voluntary.

(3) ASSUMPTION OF AUTHORITY BY THE SPACE AGENCY

The above opinions lead me to a consideration of what I believe should be the chief function of the new agency. It was amply developed during the hearings of the select committee and in subsequent legislation that Congress did not desire that agency to become a large, powerful organization controlling all work on space matters and itself operating many laboratories and facilities. Should the agency shift its interest in this direction, it would soon become involved in a mass of routine operating problems and its energies would necessarily largely be dissipated in the attempt to take care of these problems rather than in setting up the broad aspects of the program and seeing to it that they are carried out.

In this regard you will realize that the views which I expressed before your select committee concerning the management of a single military development *project* of course cannot be applied in toto to a permanent agency controlling the development of an entire technology. Such an agency cannot hope to control the technical details of all aspects of the work in the same manner which is essential to effective project management. The agency should take steps to insure that its various projects are being managed effectively and should concern itself primarily that the program which these projects and their supporting research programs comprise is well considered.

From what I have said it follows that the agency should not attempt to take over functions which any other governmental agency is now performing or can perform. It should not attempt to secure for itself the detailed direction of such activities. The attempt to do so is generally the hallmark of an inexperienced administration which equates accomplishment with the magnitude of its "empire."

I am aware that what I have written probably adds little to what your committee already knows. I do feel strongly, however, that the space agency can be of great importance to the advancement of science and technology as well as contribute immeasurably to the peaceful solution of present world tensions. * * *

H. W. Ritchey, Vice President, Thiokol Chemical Corp., Huntsville, Ala.

* * * It is my opinion that our achievements in the development of space travel will be controlled much more by the degree of support of the American public than by any technological factors. If we expect to make any appreciable progress in the next 10 years, we will need very strong public opinion behind space projects and the support by an adequate budget. The degree to which these can be achieved is a far greater imponderable than the extent of our technological progress over the next 10 years.

It is for these reasons that I believe that strong support of our national statesmen is extremely important * * *.

PROPULSION

About 15 years ago, in the midyears of World War II, the propulsion of weapons by rocket power was first achieved by the United States. At this time, the Russians were well in the lead in the field of solid propellant rocketry, and the Germans were making astonishing strides with their liquid-propelled V–2 weapon. Our failure to recognize the need for better weapons during the pre-World War II period had led to such a restricted research budget that there was no opportunity to develop weapons based on the new forms of propulsion. Let us hope that complacency never again achieves such predominance that our very existence as a Nation is placed in dire jeopardy.

In order to discuss future advances in the field of rocketry, it would be well to examine the factors that make a good rocket engine. If we are interested in achieving very high velocities for such applications as long-range missiles and for space travel, then there are only two fundamental criteria. We want to use propellants with as high energy as possible, and we want the mass fraction of propellant in the rocket to be as high as possible. Other factors such as cost and reliability are important, of course. No matter how good the design is on paper, it is of no value if the rocket does not work when the button is pushed.

The importance of the second of these two factors, that of propellant mass fraction, has been frequently overlooked. Our World War II rockets used propellants with respectable energy, but were, in general, quite crude devices from the standpoint of mass fraction. The development of the cast-in-place, case-bonded solid propellant rocket removed this limitation, and also the limitation on size. Our solid propellant rockets can now perform most of the military missions with an advantage in cost, reliability, and field handling. The development of more dense propellants, better insulations, and higher strength-to-weight ratio structural materials will probably enable solid propellants to retain their lead in military applications. On the other hand, the liquids are still alive—research in the field of noncryogenic propellants might eliminate many of their current disadvantages.

PROPELLANTS

Significant advances will be made in the field of propellants, both solid and liquid. The nature of these advances are already characterized by the work that has been done in high energy fuels for air-breathing engines. For example, the boron hydrides, although relatively expensive, may enable a given mission to be performed at an overall lower cost. Fuels with heats of combustion in the range of 28,000 B. t. u. per pound may be economic, even at 10 to 100 times the price of hydrocarbons having heats of combustion of around 18,000 B. t. u. per pound.

Since the oxidizing agent is the largest component of a rocket fuel, it is essential that more dense and storable oxidizers be developed. Improvements in oxidizers will, in the next 15 years, yield marked improvements in the performance of both solid and liquid rockets.

Since we are interested in space travel, the moving of very large loads must receive attention. The problem of developing very high thrusts is responsible for a serious lag in space technology in the United States. Although a 1 million-pound thrust liquid combustor may be feasible, solid engines developing thrusts 10 to 100 times this figure present only straightforward engineering problems.

Rockets powered by nuclear fuels are worthy of our consideration. If advantages are to be had, as compared to chemical-fueled rockets, then much must be accomplished to improve the impulse yield attained from the working fluid. This can be done only by increasing the working-fluid temperature, or reducing its density. What we really need is a way to contain a fluid having a temperature of 10,000,000° Kelvin. Such a rocket would permit space travel with a fuel-mass ratio of about 2 pounds per ton at takeoff. Space travel could then be accomplished with all the comforts of a voyage on an ocean liner.

Such an achievement probably lies beyond the next decade of development.

NEXT DECADE

Some predictions can be made with a reasonably high degree of certainty. Within the next 10 years we can have:

Both solid and liquid rockets with a fuel mass fraction of over 95 percent;

Propellants, both solid and liquid, delivering sea level specific impulses in the range of 325 to 375;

Large solid engines for the first stages of space vehicles, capable of lifting gross loads of over 10 million pounds;

Liquid engines, powered by storage propellants, with all of the control features needed by manned vehicles;

Rocket engines, both solid and liquid, that are reliable and that can perform complex missions at costs very attractive in comparison to today's figures.

These things we can have—and perhaps much more. The greatest uncertainty in these predictions is the question: Do we really want them?

Such achievements can be made only if we, as a Nation, want them enough to put forth the effort needed for their attainment. Better rockets, like better anything, are obtainable only by a lot of hard work. Man's movement into space is a vast undertaking—efforts that are less than vast will not get us there.

L. EUGENE ROOT, VICE PRESIDENT AND GENERAL MANAGER, LOCKHEED AIRCRAFT CORP., MISSILE SYSTEMS DIVISION, SUNNYVALE, CALIF.

In asking the questions—what can be the accomplishments of the next 10 years of space research and exploration and what can be the impact of these accomplishments on our intellectual and social horizons and on our way of life—we must recognize that it is easier to prophesy what can be rather than what will be, because what will be depends on the sacrifices that we are willing to make and what wealth, skill, and labor we are willing to devote to explore this new frontier in the absence of the promise of early returns on the investment. We have been fortunate, in that the past year has been a momentous one in the history of astronautics—it has seen man take his first steps into space and it has brought with it a growing acceptance of Soviet competence, possibly even superiority, although hopefully momentary, in an area we have until recently tended to regard as our private domain. This past year has brought about recognition of the pressing need for vigorous prosecution of a space flight program on a national level. Above all, the past year has made the entire world aware of astronautics, and, in so doing has given rise to an environment in which space exploration has become a major technological and political issue. With this background it is reasonable to asume that developments in the next decade will be even more rapid than they have been in the last year. On this premise, and accepting the uncertainities of prediction, this is a general summary of some of our views on what can be accomplished in the next decade in the space age.

SECTION 1. ADVANCES IN COMPONENT TECHNOLOGY AND NEW TECHNIQUES IN THE NEXT DECADE

Propulsion

High-thrust liquid propellant engines of 1 to 1½ million pounds of thrust are now undergoing development and will be used for space exploration well within the next decade. Subsequently, within the next decade, such engines may be ganged to 2, 3, or up to 10 million pounds of thrust, depending on the success of the nuclear engine and the economics of assembly in space of several smaller basic vehicle structures. High-energy liquid propellant engines in various thrust levels are also being developed. These, when used in upper stages of the space vehicles, will increase payloads by 50 percent or more. Fission reactors are undergoing development. Basic tests will begin very soon in Nevada, and successful flight use will very likely be demonstrated substantially before the end of the next decade. Although there will be many development difficulties in this area, nuclear-fission reactors promise major increases in space capability and great increases in payload. Various kinds of low-thrust engines suitable for travel in regions far removed from major gravitational fields will undergo development and possibly successful realization. These may include plasma jets, ion propulsion, or the use of solar boilers. Basic problems of energy conversion from either solar or nuclear power will have been resolved during the next decade. A successful technique for solar sailing, using the sun's radiation pressure may be developed; this method of propulsion does not require the consumption of fuel. Finally, declassifying of the Sherwood project on controlled thermonuclear energy release will make new techniques in magneto hydrodynamics generally available for propulsion development. Direct conversion on a large scale of nuclear energy to electrical energy to provide fundamental increases in power-to-weight ratio for propulsion systems utilizing electrical energy will be an extensively explored problem area in the next decade.

Guidance and control

In the next decade, development of precision initial guidance systems for establishment of precise satellite orbits and for starting lunar and interplanetary vehicles on the approximately correct trajectories will have been developed. Development of terminal guidance to enable space probes to make precision soft landings on the Moon or planets will also have been accomplished. Development of new kinds of guidance systems to permit satellite rendezvous and maneuvers will have been successfully realized. Means will have been developed for enabling vehicles to hold a stable orientation in space even while moving steerable antennas or mirrors, or while personnel motion is present, and to change this orientation at will. This will be accomplished by use of gravity stabilization, angular-momentum controls, or jet-reaction controls. Such attitude stabilization will be imperative for manned flight and for the sophisticated experiments of the future. Work will continue to be keyed toward the development of compact reliable equipment with low-power drain.

Space navigation

For actual rendezvous with a planet, a pre-set or initial guidance system would have to have system accuracies far beyond those attainable at present even if masses and distances in the solar system were precisely known. Therefore, space navigation systems will be developed which measure the vehicle's position and velocity in the solar system and, by computers on board the vehicle, establish the appropriate corrective maneuvers. For this automatic course correction new sensing devices and compact reliable computers with large memory systems will be developed. Such systems may also be used to accomplish Earth recovery of vehicles for lunar circumnavigation.

Communication

The recent Pioneer flight demonstrated the feasibility of communications at distances approaching lunar distances. In the next decade communications systems capable of spanning planetary distances of several hundred million miles, such as will be involved in planetary probes, solar probes, and artificial asteroids, will be developed for transmission of complex data including pictures. In addition to the frequency bands now in use, new systems using presently untapped portions of the entire frequency spectrum, from X-ray frequencies on up, will begin to be evolved for extraterrestrial space-to-space transmission. Erectible or unfurlable antennas, dishes, and mirrors, possibly steerable and highly directive, will have been evolved for space vehicles and communications satellites. New methods of information coding and processing will permit compact reliable low-power drain communications links capable of handling much more complex information than at present. Passive satellite communication relays using large reflecting surfaces or chaff can be established. Continuing developments in such components as tubes and low-noise receivers will eventually permit signal transmission at usable information rates anywhere within the solar system at acceptable vehicle-power levels, especially at the higher frequencies where the natural noise background will not be limiting. Communication systems capable of long time unattended, continuous reliable operation will have been evolved. Fortunately, the payload capacity of space vehicles in the next decade will make it unnecessary to compromise these characteristics to an excessive degree for the sake of weight minimization. This will be especially important in communication satellites operating as active microwave relays with great channel capacity and wide band widths. Such systems may require conservative designs, redundancy of components, and duplication of circuitry.

Computers

The present continuing program for development of more complex computers capable of operating at increasingly faster speeds and having high capacity memory storage systems capable of rapid access is expected to provide the computing tools needed for precise tracking and control of future space vehicles. New techniques in logical design will assist in these developments. Research on artificial neurons will provide means for developing new classes of computers—self-programing computers, computers which can react and adjust to new environments or computational demands, or true thinking machines. Fully automated very rapid data processing systems will record, analyze, interpret, and convert to readily understandable form the results of the highly complex experiments which will be carried out in the next decade.

Astronomy from space vehicles

During the next decade, astronomical observations from space vehicles will be an accomplished fact. Such developments will revolutionize conventional astronomy. Instead of being restricted to very narrow frequency bands from terrestrial observations, we can have a true omnifrequency observatory which can record, analyze, and process experimental observations over the entire frequency spectrum; recovery of film for detailed examination will be possible. In this way we will avoid the limitations placed on terrestrial observatories—limitations imposed by atmospheric absorption, atmospheric scintillation, and the night sky background. Observations over a very wide frequency range, from X-ray on up to fairly low-megacycle frequencies, will permit exploration of features not accessible to terrestrial observatories. New advances in fundamental problems of cosmology—of the nature and origin of the solar system, of the structure of planets which will be inaccessible for some time to our space probes, and of other basic questions of astrophysics—can be obtained from space vehicles.

Two typical problems of astronomy for which definitive experiments may first be carried out from observations in space are the following:

(*a*) *The evolution of the universe.*—It has been determined from optical investigation that the light from more distant galaxies shows a progressive reddening with distance, a fact which is interpreted as a recession of the distant galazies in an expanding universe at velocities increasing directly with distance from us. Optical investigations of this theory are inconclusive since the largest terrestrial telescope cannot see to distances at which the recession velocity should be close to light velocity, for a number of reasons. On the other hand, colliding galaxies in the universe are known to be very prolific producers of radio noise and the combination of large antennas and the ability to receive radio frequencies forbidden to terrestrial radio telescopes because of atmospheric limitations—both factors which could be used to advantage in astronomical observations in space—together with the intrinsically intense radio emission of these sources, will permit these space radio telescopes to "look" to much greater distances. If, at these much greater distances, the distribution of galaxies in space is much more dense, then we would have an argument for an evolutionary theory of the universe where galaxies are created once and for all and simply expand from some point in time. If, on the other hand, the distribution of galaxies remains uniform, we would have an argument for continuous creation of galaxies with no necessity for supposing creation at some finite time in the past.

(*b*) *Investigation of nearby stars for planetary systems.*—On an astronomical laboratory in space, optical studies with mirrors some 3 to 5 times as large as the largest terrestrial mirror could examine the regions near those of the 100 or so closest stars comparable to our Sun and detect planets, if such exist, of size, reflectivity, and distances to the central star comparable to those in our own solar system.

Boosters and structures

To accompany future propulsion developments, we will have to develop much larger boosters than have heretofore been built. This will require refinements and new design techniques in the design of rigid yet light structures, new methods of material fabrication, and new methods of assembly and transport. Problems associated with these new requirements will have been resolved during the next decade so that vehicles compatible with the new propulsion systems can be built. We will determine the materials and develop the techniques providing for lightweight structure suitable for space vehicles with special emphasis on complex reliable mechanical systems, and on large lightweight surfaces required for such things as solar power units, communications, tracking, and the possible use of solar sailing.

Recoverable boosters

The cost of larger booster systems for launching space vehicles will continually increase as the size of the vehicle is increased. More sophisticated and complete experiments will require ever larger structures. In order to reduce the cost of such vehicles, a means for recovering and reusing boosters will be developed. Such boosters may be manned and may be capable of being flown back to launch base immediately after accomplishment of the boosting operation in order to save transport costs and recovery costs.

Space structures

Once a space vehicle is out of the atmosphere and in free fall, the forces on structures are exceedingly small. Methods will be devised for the fabrication of collapsible and unfurlable structural members for space use as well as the fabrication of special structural members designed specifically for assembly in space. In this way structures of much greater size than those attainable by Earthbound installations can be achieved. Techiques for actual assembly of structures in space will be developed.

Solid state physics and associated fields

Continuing studies in solid state physics will contribute to development of low-power drain reliable electronic systems and also to the area of highly sensitive radiation sensing systems needed in space exploration. New developments in solid state physics will influence the entire gamut of electronic systems from the design of low-noise receivers to the design of vehicle-borne computing systems utilizing superconductors for highly complex systems such as would be required for automated space exploration. Developments in solid state physics will also continue the trend towards microminiaturization of certain components of complete electronic systems.

Auxiliary power supply

The use of batteries and solar power cells has been shown to be feasible as a result of our various satellite flights. Successful exploration of space out to planetary distances will require power supplies capable of much longer time of operation and much higher allowable power drain. The development of compact nuclear reactors for furnishing electrical energy through a turboalternator system will have been accomplished. The development of fuel cells to provide higher power-to-weight ratios for auxiliary power will have been accomplished; such cells may also have great impact on the small station power technology. Reactors employing isotopes will have been developed. Problems of efficient thermoelectric devices and of direct conversion from nuclear energy to electrical energy on a large scale will undergo extensive investigation during the next decade and one of several possibilities may be successfully realized. Such a development will overcome a major obstacle in the development of advanced power supply and propulsion schemes utilizing electrical energy in some form.

Space biology

Beyond the immediate requirements of the current man-in-space program, we will establish a program leading to the evaluation of manned biological requirements in space and to the development of systems providing a satisfactory environment for man in space for extended periods of time. We will investigate in great detail closed ecological systems permitting very long sojourns in space vehicles and will be able to make man survive in space for periods of months rather than hours. Acceptable solutions to the problems of shielding personnel and equipment against natural or nuclear radiation for extended periods will be available.

Celestial mechanics

During the next decade the machine solution of the classical problem of astronomy—the N-Body problem—will have become a routine matter for computer solution. The trajectories of space vehicles simultaneously influenced by all the natural bodies in the solar system and by the application of thrust and other nongravitational perturbations will have been investigated in great detail and optimum trajectories under various conditions established. These fundamental computations will enable us to predict the orbit of any body propelled in the solar system and will also serve to establish the required navigation maneuvers for correcting orbits once they have been shown to depart from the planned orbit. The required computations will be capable of being performed on either Earth-based or vehicle-borne computers.

New instrumentation

Instrumentation research and development will improve the sensitivity, range, and reliability of existing devices and techniques and bring to an acceptable point of development those techniques and instruments which are required for future scientific studies in space but which have not yet been reduced in size and/or weight, environmental tolerance, or power drain to acceptable values. Using these new instruments, we can begin to compile a complete compendium of the solar system environment suitable for application to manned flight in the solar system. We will have mapped the major features of the electromagnetic, radiation, and the particle fields and will have determined the fundamental masses and distances of the solar system. As a result of our space probe experiments, we will have compiled a reasonably accurate atlas of the surface geology, chemistry, mineralogy and climatology of the Moon and nearby planets. Special knowledge requiring experiments with fully instrumented solar probes or artificial asteroids will also have been undertaken.

Reentry into planetary atmospheres

During the next decade we will successfully develop techniques for reentering the Earth's atmosphere or entering a planetary atmosphere from satellite, circumlunar, or interplanetary orbits. Means will have been developed for accomplishing such reentry at decelerations and heat inputs which can be tolerated by man. The problem of landing instrument packages into planetary atmosphere will then have automatically been solved since these instrument packages can tolerate greater environmental ranges than can man. A long step toward successful accomplishment of this capability has been demonstrated by the recent successful Thor-Able flights and several techniques are now known which make it feasible to enter the atmospheres of the smaller planets in this fashion. In the case of bodies with little or no atmosphere, such as the Moon, techniques for precision rocket braking will have been achieved which will also permit soft landing of instrument packages, or possibly man, on the lunar surface.

Orbital rendezvous and maneuverable satellites

During the next decade techniques will become available for allowing satellite rendezvous in order to build or assemble larger structures in space or effect transfer of equipment or personnel. Guidance systems, computers, and propulsion will have been developed which can automatically accomplish orbital rendezvous so as to bring the several objects involved in this operation in contact with zero relative velocity. At the same time maneuverable satellites will have been developed which, by proper application of thrust, can change their orbits at will to accomplish new missions as circumstances dictate.

Automated remote laboratories

The demands of future space exploration will require that much more sophisticated and complex unmanned laboratories be established on the Moon or on the surface of planets. Such laboratories may assess the chemical, mineralogical, or geophysical features of the surface of the planet or Moon. Such automated laboratories when landed on the surface of a planet or the Moon will automatically, and in great detail, record, analyze, and transmit the nature, physical or chemical, of the surface material, or in the cases of planets with atmosphere, also that of the atmosphere.

Peaceful uses of satellites

During the next decade we may expect to have communications satellites in orbit which will be either passive relay or active relay stations providing for point-to-point worldwide microwave relay communications systems for teletype, telephone, and television transmission. We may expect to have navigational satellites in orbit which will permit ships or aircraft to establish their positions with great precision irrespective of the weather. We may expect to have geodetic satellites in orbit which will permit more and more accurate mapping of the precise figure of the Earth and we may expect to have weather surveillance satellites which will continually measure fundamental inputs such as temperature, snow and cloud cover, thunderstorm, and precipitation areas required for machine computation of short-range weather forecasting. These techniques can be expected to lead to more and more precise prediction of weather. Such satellites will also function as a storm patrol and as a collector of basic research information for solar and geophysical studies including long-term weather changes and climatic variations. These are, of course, in addition to those purely scientific satellites such as the astronomical observatory.

New fabrication techniques

Because compact reliable electronic systems are so fundamental toward future advances in space flight capability, the next decade will see a great increase in attempts at microminiaturization of electronic circuits. Microminiaturization will be accomplished for information handling circuits such as those of the type found in digital computers and communication systems. It will be possible to pack many thousands of parts into a cubic inch. Many techniques will become available for this purpose; for example, microminiature construction based on electron microscope techniques will allow automatic machine design, assembly, and fabrication of special purpose computing and data processing machines.

SECTION 2. ADVANCES IN SPACE CAPABILITY WHICH THESE NEW ADVANCES CAN EFFECT

It is clear that successful realization of many of the advances in components and techniques described in the previous section can lead to many different kinds of space vehicles with differing missions and levels of sophistication. Rather than attempt to discuss all of these, we can select what appears to be a reasonable and promising vehicle development goal, and assess the capability of this specific case for various space missions.

The workhorse vehicle during the next decade, and the backbone of our space exploration efforts, will still be the chemical rocket. Although we anticipate the successful development of some versions of the more advanced propulsion methods during the next decade, such as the nuclear rocket and the low continuous thrust propulsion systems, the development of the large chemical rockets will very likely antedate these more sophisticated developments and will so be the basis of a major portion of our early space ventures, both manned and unmanned, during the next decade.

Even for these large chemical rockets there will be a number of alternatives possible to perform the more advanced space missions. We can, for example, build very large rockets, perhaps in the thrust level of 5 million to 10 million pounds, and perform the missions directly with these large vehicles. Alternatively, it may prove to be desirable and more economical to remain at somewhat more moderate thrust levels of 1 million to 3 million pounds, and assemble larger vehicles in low altitude satellite orbits by appropriate rendezvous techniques, and use such space-assembled vehicles for the more demanding missions.

There are arguments for both alternatives—arguments which can be fully evaluated only when we have some development experience such as we will be obtaining during the next decade.

We can consider the following vehicle as being a demanding and reasonably ambitious development goal; a booster using present fuels in a 3-million-pound thrust engine, and several upper stages using high energy fuels. Such a vehicle would perform the missions with the corresponding payloads as shown in the following table:

Expected payloads

Optimum staging with dual burning. Thrust, initial=3x10⁶ pounds (Isp=248 sec.) second and third stages have high energy propulsion systems (Isp=420 sec.)

Mission:	Payloads, tons (maximum)
800 mi orbit	50
24 hour or 22,400 mile orbit	15
Lunar, circumnavigation or hard landing	14
Lunar, satellite	10
Lunar, soft landing	6
Lunar, landing and return to Earth with gasdynamic braking	2
Mars	12
Mars, gasdynamic entry	8
Temporary satellite of Mars and return	2
Jupiter or near solar probe	8

MAN IN SPACE

The role of man in the preceding missions can at present be assessed in only a few cases; all of these assume the development of highly reliable systems which will be possible only by a vigorous and intensive shakedown program. It is believed possible to enable a man to be placed into—and to survive in—a very low altitude satellite orbit, and to be recovered from such an orbit after a flight duration of a few hours, with a payload expenditure of not more than approximately 2,500 pounds. To enable this man to perform a lunar circumnavigation and be recovered safely on Earth may not increase the required payload weight by a factor much different from about 2 or 3, although this factor must be continually reviewed as new and more complete information on the radiation fields near the Earth and in cislunar space become available. In the absence of such information, and in the absence of ground rules for determining what the permissible radiation exposure is for a man on such a mission, the payload weight must be considered conjectural. In any event, the preceding table indicates that a manned circumlunar navigation could be possible with the assumed vehicle, while a number of men could survive and be safely recovered from the low altitude satellite after relatively extended orbiting times. On the other hand, it would probably not be possible to land and recover a man on a lunar flight, nor from a nearby planet. Such missions would appear to involve still larger chemical rockets, or the use of some of the more advanced propulsion systems. For manned planetary missions, there are many more unknowns—the problem of sustenance, provision of the appropriate environment for periods of many months, and the like. In the absence of actual realization of the advances in components and techniques discussed in the previous section, attempts to assess the capability for manned flight in these more demanding missions would seem highly conjectural at present.

SECTION 3. THE OUTLOOK

It is not possible today to foresee in great detail the byproducts of the extensive advances in technology and techniques required for a successful program of space exploration. We know intuitively, however, that the vigorous prosecution of such a program, requiring as it does great strides in many fields of science and engineering, cannot fail to have important benefits to our intellectual, social, commercial, and industrial growth on Earth. While many services to society as a whole will accrue directly from our endeavors in space exploration (as, for instance, worldwide benefits from communication, navigation, and weather satellites), there will inevitably be many byproducts from which we can, if intelligently used, derive indirect benefits equally important or more important than the direct products of our program for advancing a space capability. Such indirect benefits will lie in many possible areas affecting our knowledge and well-being, from promoting research on man himself and his capabilities and limitations, to the continued successful exploitation by use of that new powerful tool in international relations—the demonstration of technological competence and leadership.

Finally, impressive as the advances of the next decade will seem, they will still be only a prelude to the emergence of the real space age. Much additional work will have to be done to make man a true three-dimensional creature capable not only of surviving in space for a short time, but perhaps capable of growing and flourishing in remote permanent or semipermanent colonies on the Moon or nearby planets. This work will carry us far beyond the next decade, but, although we cannot today predict in detail the drives and motivations which will inspire man to take the next step, it will be only then when we will have the true space era—an era in which population centers away from the Earth may be in existence, though still linked to the Earth by communication, logistic, and transportation links.

PROFESSOR DR.-ING. EUGEN SÄNGER, DIRECTOR, INSTITUTE OF JET PROPULSION PHYSICS, TECHNICAL UNIVERSITY OF STUTTGART, STUTTGART, FEDERAL GERMAN REPUBLIC

THE FUTURE OF SPACE FLIGHT [1]

Space flight is, in the first place, a matter of flying speeds. Aircraft which have been constructed by man may be divided into the following three major categories for the purposes of this article, and particularly in view of the chronological order in which certain flying speeds will be attained: unmanned missiles, manned high-speed aircraft, and long-range transport aircraft.

It is an undoubted fact that in the development of aeronautics unmanned missiles have always pioneered the way for fast piloted aircraft, and these in turn for long-range transport planes of comparable speeds. This is true today more than ever before, and, owing to the inherent causes of this process, may be expected to hold also in the future.

Looking at the development of aeronautics in this century, three great major periods appear to stand out. First the period between 1900 and 1940, now history, characterized by the propeller-reciprocating engines. Second, the period between 1940 and 1960, at the end of which we now stand, whose main feature seems to be chemical jet propulsion. Finally, the period between 1960 and 2000, still ahead of us, the major gifts of which are in the lap of the Gods, but which may be expected to be dominated by nuclear jet propulsion.

[1] EDITOR'S NOTE.—This article is reprinted from Universitas, a German review of arts and sciences published by Wissenschaftliche Verlagsgesellschaft m. b. H., Stuttgart, Germany.

1900–40

The three types of aircraft mentioned above have been known during the first four decades of this century.

Unmanned missiles, in the form of projectiles, had reached several times the speed of sound by the beginning of this century, and, during World War I, five times the speed of sound was reached with the German Paris gun. The practical development of piloted high-speed aircraft was commenced at around 1905, carefully approaching the speed of sound by 1940 mainly with record-breaking planes and fighters. Long-distance transport planes began their ascent toward greater speeds as bombers in World War I, then with civilian airplanes this development was speeded up, although top speeds reached remained well below those of record-breaking planes. Firing from a gun remained the favored method of propulsion for unpiloted missiles during this period, while propeller-reciprocating engines were used for airplanes.

The basic sciences to be first of all developed were ballistics, aerodymanics, the statics of airframes. Interior ballistics and the technology of propulsion units stayed at a mainly empirical stage. The military usefulness of these flying devices in waging war on human beings doubtlessly very much accelerated their technical development, a fact of which we feel today that we have very little reason to be especially proud.

1940–60

In the two following decades two essentially new technical factors made their appearance: jet propulsion and automation. These new features were quickly applied to unmanned missiles with a corresponding rapid increase in the top speeds achieved. The German A–4 rocket was flying at 6 times the speed of sound in 1942, intercontinental ballistic missiles with around 20 times the speed of sound are in design, and the first small Earth satellites, promised for 1957–58, will do 17,500 miles per hour, i. e., Mach 26, referred to stratospheric temperature. (The Mach number is the ratio of the velocity of the body to that of sound. Mach 1=670 miles per hour.)

This stupendous progress in speeds during contemporary times has important implications with regard to the military use of aircraft. While earlier military requirements had shifted from unmanned missiles, particularly artillery, and concentrated on airplanes, the development today is quite the reverse. Jet-propelled, automatically controlled missiles are superior as weapons and are increasingly replacing piloted planes for military purposes. Piloted planes, now obsolete as weapons, will then gradually become available for civilian use. The time when the last manned fighter and bomber will have disappeared for good will depend merely on the perfection of automatic controls for unmanned missiles. This will mark the first great step toward the dedication of aviation to peaceful ends.

Experience with missiles has in these two decades led to a tempestuous increase in the top speeds of manned aircraft also. The speed of sound was exceeded in 1947, and at present the maximum Mach numbers reached are about 3, while by the end of this decade, that is by 1960, manned high-speed aeroplanes are expected to have reached Mach 6 and over. These are no longer military planes, such as fighters, or sporting planes for breaking records, but purely experimental aircraft designed for scientific purposes. In the period from 1940 to 1960 the speed of transport planes will have followed that of the top-speed aircraft at the distance of the corresponding safety factor. While in 1940 there existed hardly any bombers or passenger planes capable of more than 0.5 times the speed of sound, the fastest bombers have in the meantime considerably exceeded the speed of sound in some cases, and passenger planes may be expected to follow suit, at any rate the prototypes, by the end of this decade. The types of power units responsible for such increases in speed were in the main turbojets, turboramjets, ramjets, and chemical rocket units. New sciences, apart from aerodynamics and statics, which are involved here are the theory of thermochemical flow, the theory of combustion, electronics, fuel chemistry, geophysics, and others.

1960—2000

So far there has been a continuous development of flying speeds of our three types of aircraft. Our attempts to extrapolate this development into the future is prompted by a technical requirement. Experience shows that even in countries with the most efficient coordination of research and development an essentially novel type of flying device will require a period of development of from 5 to 10 years and will swallow up to thousands of millions of man-hours. The decision to develop a new type is therefore in every way as weighty as used to be the resolution at one time to go in for the building of a new type of battleship. There is, however, the difference that here this new development will result directly or indirectly in something of permanent value. The trend of development with the competitor 5 to 10 years ahead must be known at the beginning, with a high degree of certainty if the new device at its future time of completion is to be competitive in a military or commercial sense.

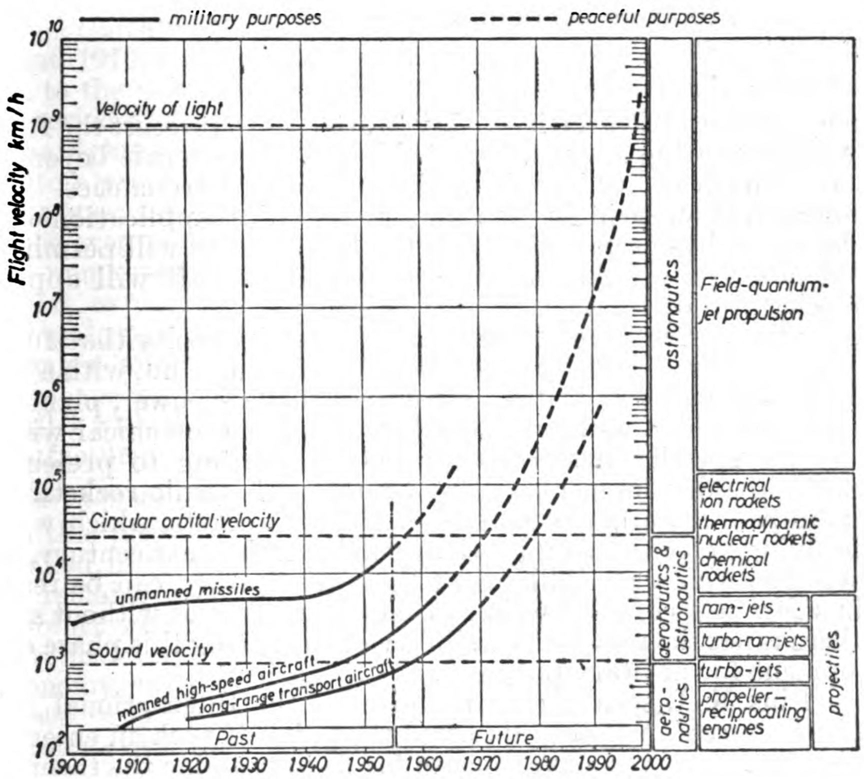
Research must deal with these problems very much ahead of time, or else run the risk of being laughed at and reduced to the mere handmaiden of technological progress. Engineer and politician are under an obligation to be aware of the future trends in space flight and aviation as far ahead as 1970 and 1980. This is a grave responsibility since many factual elements of the future development can not be known today and science can quickly present us with completely fresh situations.

The present stage of aeronautics and research into space flight enables definite predictions to be made as to the possible technical development to be expected within the next decades. The introduction of nuclear energy may even at this stage be assumed to constitute an important new factor.

Space travel

It may reasonably be expected that unmanned missiles, by the end of 1960, will have reached the circular orbital velocity (around 17,500 miles per hour). Now, there are good reasons why after having exceeded even this velocity, further development of these unmanned missiles as instruments of pure research into space travel will result in yet even greater increases in flying speeds. The main reason is that, owing to the gradual disappearance of the atmosphere, aerodynamic and thermal problems (heat barrier, etc.) will have become of minor importance, so that the problem of speeds increasing further is now purely one of powerplant technology. As yet, at this stage, nuclear power can be expected to play a minor role, while chemical rockets are being explored up to their very limits.

It is a remarkable fact that unmanned missiles which had become the sole object of weapons research in aviation and space flight become useless as instruments of war on our tiny Earth as soon as the circular orbital velocity of 17,500 miles per hour is exceeded because their trajectories will then no longer return to Earth. This trend towards peaceful ends, which is ultimately dictated by the laws of nature, begins to make itself felt in space flight too. These trans-orbital unmanned craft will at first be employed for exploratory journeys within the planetary system of the Sun, such as circumnavigation of the Moon, Mars, and Venus, etc. The velocities required for this purpose will not substantially exceed 60,000 miles per hour, and it is to be expected that when speeds of this order of magnitude have been reached further development of speed will probably have to cease. It is hard to say what possible use still faster unmanned craft might have anyhow at this juncture.



flying speeds in the 20th century

With regard to piloted aeroplanes we have noted already that by 1960 they may be expected to have exceeded top speeds corresponding to Mach 6. This rapid rise in speeds will have followed in the wake of missile development, and soon after 1970 the appearance of the first small manned space stations can be expected.

Three important points should be noted in connection with a development, taken almost for granted today. Namely, one, that this phase will serve not military but peaceful aims, since the primary object of these top-speed planes will be to transport personnel to the outer space stations and, in the second place, they will provide prototypes for very fast passenger and transport planes. The toning down of war-like tendencies in aviation is therefore seen to extend also to the intermediate region between aviation and space flight.

Secondly, it is becoming clear that manned space travel will not be via the wingless rocket, but will rather be realized by means of rocket-propelled planes, although here the final method of launching is still open to discussion. At present, these experimental planes start horizontally from special carriers which represent a kind of first stage of the actual rocket aircraft. It seems possible that this method can be perfected so that the entire aggregate will take off horizontally from the ground as is the case in the present experimental stage. Thirdly, nuclear power will not be made use of in the development of top-speed aeroplanes up to the circular orbital velocity, and one may expect that chemically driven rockets will be utilized because these happen to be the only kind of propulsion available and present the surest method to avoid contamination of the atmosphere with radioactive substances.

Approaching the velocity of light

It may appear rather daring today to attempt to forecast the further course of pioneering human flight with manned aircraft beyond the circular orbital velocity into the region proper of astronautics. There are, however, concrete indications that the technical application of new knowledge in physics gained during the last 30 years will permit such a rapid development that manned top-speed aircraft will approach the velocity of light by the turn of the century.

It is in the region beyond the circular orbital velocity that full use will be made of atomic energy for piloted fast planes and, with a better transmutation factor of matter into energy nuclear power, plants will come into use which will gradually become more economical with respect to the specific mass consumption. According to present-day knowledge the development will be via thermal atomic rockets, ionic rockets to field-quantum rockets, e. g., photon rockets, which will result in flying velocities so high that, maybe in the next century, fixed star systems, which are millions of light-years away, can be reached within a few years of the lifetime of the crew. It goes without saying that there is not the remotest possibility of exploiting this phase of the development for military purposes.

Pope Pius XII, speaking to members of the International Astronautical Congress in Rome, discussed the point of such an enterprise. He said: "Some of you have gone so far as to examine the theoretical possibilities of a flight to the fixed stars, this being the professed aim of your endeavors as indicated by the term astronautics. We will not enter into details, but it will not have escaped your attention, gentlemen, that an undertaking of such magnitude involves intellectual and moral aspects which it is impossible to overlook. Such a project involves a certain concept of the world, its meaning, and purpose. God who has planted within the heart of man the insatiable desire for knowledge, when He made man the Lord of all creation, did not in-tend to put a limit to man's endeavor. It is the whole of creation which has thus been entrusted to man so that his spirit might gain an evermore profound knowledge of the infinite greatness of the Creator." Thus spoke the Pope.

Returning now to the technical problems, let us look at those connected with long-range transport aircraft. The tendency toward higher speed in the development of missiles and fast piloted aircraft, as well as the history of transport aviation until 1960, enables certain predictions to be made regarding the probable turn of events in the last four decades of the 20th century. Supersonic turbo-ram-jet passenger aircraft may accordingly be expected with fair certainty in the first half of the next decade.

This is borne out by the news that such aeroplanes are already on the drawing boards of American and British aircraft firms, however undesirable this may be from the point of view of many air transport companies who have invested huge sums in subsonic jet-turbine transport machines. These would, for reasons of economy, have no doubt preferred a pause in development lasting some 20 years.

The first space stations

Assuming further continuity in development, the appearance of ram-jet transport planes with Mach numbers around 4 may be expected around 1970, and about 1980 we ought to have the first space stations open to the public. The number of propulsion methods used during this period of development will be very comprehensive, and in the case of the flying devices considered here, it will range from ram jets to quantum propulsion.

The increase in the number of types of flying devices themselves will be even more impressive. Added to the present variety, we will have unmanned earth satellites, supersonic turbo-ram-jet passenger aircraft, exploratory unmanned interplanetary rockets, ram-jet supersonic passenger aircraft, manned artificial satellites, rocket express passenger aircraft, manned interplanetary rockets for exploration, public space stations, and manned interstellar research rockets. Parallel with this a corresponding increase in research, development, manufacturing, and operational installations may be expected.

No further weapons of war

In this phase of development practically the whole of science will be called in to assist aviation and space travel. Hardly a scientific field remains which will not be made use of directly or indirectly in the solution of the problems which arise here. The list is headed by theoretical physics, atomic and nuclear physics, astrophysics and astronomy, space medicine and space law, all of these will be added to the basic sciences previously used in aviation and space flight.

Looking over the list of new types of flying devices expected to come into existence between 1960 and 2000, it will be seen that there is not one machine of war amongst them. Moreover, the statement will be recalled that the perfection of automatic controls for unmanned devices will bring about the disappearance of piloted fighters and bombers. This may be assumed to have already taken place in the phase of development considered here. Insofar as air or space craft for war purposes are going to be developed at all during this period they will represent a continuation of those invented during 1940 to

1960, and will involve improvements other than in flying speed; for example, in economy, safety, firing accuracy, and in maneuverability, etc.

As yet there is no guarantee that reason will prove to be a match for the remnants of the semianimal battle instinct making even these latest air and space weapons—unmanned missiles with speeds up to the circular orbital speed—superfluous. After the quite automatic elimination of all warlike aims from all other branches of aeronautics and space flight, it would appear very desirable if the powerful means of technology could now be employed to take the sting out of intercontinental rockets with atomic warheads and the unpiloted bombers, which against the background of interplanetary and interstellar research rockets must appear like a serious blot on humanity. Various quarters have tackled this problem, which must appear almost hopeless today, by setting unmanned missiles to fight against each other, i. e., the so-called anti-missile-missiles. As an almost as realistic possibility we may consider—in connection with work on the photon rocket—the development of stationary ultraviolet searchlights, exerting a radiation pressure of many tons, which, by means of their high-energy beam, are capable of destroying flying objects up to a distance of several hundreds of miles in a fraction of a second. These would represent a very effective weapon against any threat from the air or from outer space. Perhaps this would then lead to the ultimate elimination of all warlike tendencies from research in aeronautics and astronautics.

The matter-of-fact reality

It will be realized at all events that as far as the increase of speed in air and space travel is concerned, war will no longer be the father of all things. Instead mankind will demonstrate that the search for new horizons can provide an equally strong and more ethical motive for aeronautical progress, a fact which has already emerged from the building of the first artificial satellite.

These remarks have shown in how far space travel has already become a matter-of-fact reality and how, in spite of all mental resistance, it will develop from aeronautics, and that its dramatic progress, standing upon the shoulders of its sister science of aeronautics, will become the first really great cooperative effort for good which humanity has made and which no civilized nation can afford to ignore today.

These remarks should, however, also foster the conviction that he who wants peace on earth must also want space travel. This conviction was underlined by Pope Pius XII when he said: "This joint effort by all mankind towards the peaceful conquest of the universe must serve to impress even more strongly upon the minds of men the feeling of belonging together and the feeling of being one community so that the conviction will grow that we all belong to God's great family and are the children of the same Father. But the realization of this truth requires just as much respect for truth and a facing of reality as scientific research itself."

SPACE-TRAVEL AND THE EXPLORATION OF OTHER WORLDS

As a consequence of the introduction of the reciprocating engine, of aerodynamics, light metals, and gasoline during the first part of this century the old Ikarus dream of a flight to the stars was brought a stage nearer to realization by aviation. Then there were the great dreamers of space flight: the Russian Ziolkowski, the American Goddard, the German Oberth, the Frenchman Esnault-Pelterie, who thought up the rocket vehicles of the engineers. Today, it is necessary to remind ourselves of these deeply human origins of space flight, and the fact that these technical pioneers never gave a thought to nationality, war, or weapons of war, but thought only of man and the sky above him.

At the beginning of this century, the speeds of these flying objects lay around several thousand miles per hour. In the First World War, the shell of the well-known German Paris gun reached a speed of nearly 4,000 miles per hour, while in the Second World War, the German A–4 rocket attained similar speeds. Owing to this lag in the development of further great advances in speed, piloted military planes, especially bombers, assumed the lead as being temporarily the most important weapons of war. Several years later, technical progress in the development of jet-propulsion and automatization was responsible for a steep rise in the top speeds of unmanned flying devices. By 1952, these had exceeded speeds of 6,000 miles per hour, and they have now reached speeds around the 15,000 miles per hour mark.

It is merely a question of the perfection of their automatic systems. Piloted fighters and bombers will be completely replaced by these unmanned craft, and will then at this stage have ceased to be competitive in a military sense, and be returned for good to their peaceful destination as research and transport machines.

Unmanned flying devices capable of the speeds just referred to will then become the so-called ultimate weapons in the form of intercontinental rockets and will give us cause for serious reflection. This development was initiated by the responsible rocket engineers themselves, when in 1950 in Paris they formed an international world federation for the advancement of rocket science for peaceful purposes.

The increase in the flying speeds of unmanned craft will not stop at the figures quoted above. In 1957, the Russians already sent off two unmanned satellites with speeds of 17,500 miles per hour, and in February 1958 the United States also sent aloft an Earth-satellite. Much work is in progress to push the speeds of unmanned space craft into the neighborhood of 60,000 miles per hour.

A novel technical situation confronts us here: at velocities near or above the so-called orbital velocity of 17,500 miles per hour (28,000 kilometers per hour) inertia will not allow these craft to return to Earth and will force them into the depths of interplanetary space. Unmanned flying missiles, which have finally become the latest objects of weapons development in aeronautics and astronautics, will then become useless as technical weapons of war in the fights between men on our little Earth. The natural process of aviation settling down to peaceful pursuits will in this way be extended to space flight, too.

Much discussion has taken place about the probable military value in a present-day sense, that is, for wars among mankind, of satellites which are flying devices with speeds of 17,500 miles per hour. From a technical point of view there seems to be no danger of this, for owing to their extraordinary vulnerability and the astronomical regularity of their orbits they are much easier to destroy than, for example, the intercontinental rockets or rocket planes.

The erection and operation of extraterrestrial stations, as well as other human pioneer flights, will nevertheless be military tasks in a new sense, inasmuch as military organizations or organizations of a military character are certain to be entrusted with them, and will be assigned more and more to the carrying out of pioneering work in these fields as aviation and space flight become more peaceful in character. There are even now definite indications of this in some instances. The meaning of the word military will become increasingly less associated with the atavistic menacing of men by men, and more and more, in a much more heroic sense, with the active conquest of the barriers set us by nature, the conquest of which is the goal of all scientific endeavour.

The first indications of the breakthrough to peaceful space flight are clearly evident in our time, and we believe that the transition to peaceful purposes could be particularly accelerated by the greatest possible speeding up of the technical development, in particular also by the speedy erection of extraterrestrial stations which may even be manned. This task is clearly in direct line with past development of high-speed aeroplanes, which in its turn has benefited from experiences gained through unmanned flying devices.

This development began in 1905 with the first power-driven aeroplane, but soon became enmeshed in military applications to which, however, it owed great progress. By 1940, the speed of sound was cautiously approached, and exceeded in 1947, which was only 10 years ago. Today, there are experimental aircraft with speeds of almost 2,500 miles per hour. Because of the military technical superiority of unmanned flying devices, this development will serve mostly peaceful and scientific aims and in all probability the speed of 17,500 miles per hour will be reached about 1970 with the extraterrestrial stations or manned satellites.

We may therefore expect the first extraterrestrial stations around 1970. Only from this stage onwards can we speak of space flight proper and turn to the exploration of other worlds.

About this time, too, at the earliest—that is from 1970 onwards—provided, this was desired, and the recovery of European aviation and space flight with respect to both material and personnel were pursued with the necessary vigor, European industry and technical science could be able to play again a leading role in this competition, which is now turning to more peaceful aims. The material exertion required can best be gaged from the fact that today the leading aviation and space-flight nations of the world are devoting annually some 10 percent of their national incomes to this sector. Translated into German conditions, this would correspond to an annual expenditure of more than 5 billion deutschemark. There is no doubt that even at this rate leadership would remain for the next 10 years exclusively in the hands of those nations who are in the forefront today, notably the United States and Russia.

As the first interplanetary phase of manned space flight begins—probably around 1970—man will be entering the cosmic age.

Proper space craft will not be likely to touch into the atmospheres of the Earth and other planets, and will instead be moving amongst the external stations of the planets in empty, interstellar space. For this reason the classical disciplines of aeronautics, such as aerodynamics, aeroplanestatics, flight mechanics, air-breathing jet engines, meteorology and similar things will not be important here. Instead, the emphasis will be on a whole new array of disciplines, in particular rocket propulsion, nuclear physics, chemical and nuclear combustion technology, thermochemical and thermoelectrical hydrodynamics, radiation physics, boundary surface physics, cybernetics, telecommunication technology, astrophysics and astronomy, space medicine and space law, and so on.

Space flight is first and foremost a matter of flying speeds. The fact that the aircraft industry is largely changing over to space travel today is due only to the rapid development in flying speed during the last decades which has in its turn be made possible by the production of increasingly faster propulsion aggregates.

This is perhaps the place to recall the long list of propulsion systems in aviation and space flight which are today partly in use, partly only in the developmental stage, or being tested out in the research stage, and to state their approximate top speeds:

	Kilometers per hour
Propeller reciprocating engines, up to	600
Turbopropeller engines, up to	800
Turbojet engines, up to	2,000
Turbo-ram-jet engines, up to	3,000
Ramjets, up to	6,000
Chemical solid-fuel rockets, up to	28,000
Chemical liquid-fuel rockets, up to	50,000
Thermal atom rockets, up to	100,000
Electric ion rockets, up to	500,000
And photon rockets without speed limits.	

Of these 10 most important propulsion systems the first 4—from the reciprocating engines to the turbojet engines—employ moving parts, such as pistons, propellers, compressors, gas turbines, and so forth. For that reason, they are referred to as machine-jet-propulsion systems. The last six systems, on the other hand, from the ramjets to the photonic engines, are without essential moving or rotating structural elements, and are therefore grouped with the apparative jet engines.

Rocket engines will, of course, play the decisive role in spaceflight, and their most important property is the fuel consumption, because of the immense distances to be covered. This fuel consumption here is not measured in working units such as horsepower hours, but is referred to impulsion units, e. g., ton-seconds. This is the product of the thrust of the motor in tons and the time of action of the thrust in seconds. It is not impossible that the first manned space vehicles may still be equipped with chemical rockets whose specific fuel consumption will approximately be around 4 kilograms per section and which will therefore only be capable of limited speeds and have limited ranges in space.

In pure space flight, however, the atomic rocket will come into its own. Here, there are two competing systems in particular which have claimed the attention of research workers: The so-called thermal atomic rockets using the same thermodynamic process as chemical rockets, which instead of heating their working gases by means of chemical reactions, do so by means of nuclear energy, and which may have a specific fuel consumption as low as about 0.3 kilogram per section. Then there are the so-called electric ion rockets which accelerate their electrically charged jet masses by means of electric fields, avoiding in this way high gas temperatures and achieving a specific fuel consumption which is perhaps as low as 10 grams per second-ton.

Whatever system may eventually succeed, all of them will enable man to undertake journeys through the entire solar system, including all the planets. Thus, the exploration of all the neighbouring planets and their moons will become technically possible. It appears, however, that very inhospitable conditions will be encountered there: moons without an atmosphere, Mars like the Pamir plateau, Venus perhaps an endless ocean, Mercury a searing desert, and the more distant outer planets all night and ice. It is unlikely that in our solar system there will be a flourishing paradise awaiting us to become a new home for man, but it is quite possible that certain raw materials might be found which will be of economic importance; quite certainly, however, an inexhaustible mass of new knowledge will come to light. Merely the erection of a major astronomical observatory upon our Moon, which is without an atmosphere, would, according to the astronomers, be responsible for a similar extension of all our knowledge of the universe as were the invention of the telescope and the introduction of the spectroscope into astronomy long ago; but interplanetary flight will hardly be able to provide new living space for man. For this to happen, it will take the next step of interstellar space flight which will carry us into the regions of new solar systems in our galaxy where, according to the opinion of many astrophysicists, other planets, some of which may resemble our Earth, may be expected to exist. These are questions which in the first instance can also only be decided by the extraterrestrial observatories.

This second interstellar phase of space-flight today is still in the first stage of research where the technical foundations for it must be prepared. Since interstellar space flight is almost entirely a problem of propulsion units, current opinion is that research will have to be done primarily on ion rockets and especially on photonic rockets. These photonic rockets are the last member of the family of jet units. The jet speeds of this member will have exhaust velocities approaching the upper physical limit, the velocity of light, and they will be without any restrictions on their cruising speeds in a technical sense owing to the relativistic effects which are encountered here. The very low fuel-consumption—at best it is only 33 milligrams per second-ton—enables spaceships equipped with photonic rockets to stretch the periods during which they are traveling under power by means of the fuel reserves carried on board. Thus the acceleration of the ship in interstellar space can be maintained over years. This acceleration will equal the acceleration due to gravity of 32 ft/sec^2 so that, in the first place, the crew are living under conditions of acceleration which they were used to on Earth, while secondly the top-speed of the ship relative to the Earth could come close to the velocity of light.

With such space ships it is then possible to aim for places outside the solar system, such as for example other fixed stars in our galaxy, or even in other galaxies. We are thus entering the region of interstellar, and perhaps even of intergalactical, space flight.

On such journeys through space, the laws of the special theory of relatively will begin to make themselves felt, leading to some very strange conditions which perhaps are best illustrated by a concrete example of such a journey.

Supposing that such a craft were to start from an extra-terrestrial station in the direction of some other star, perhaps a thousand light-years away. It will be assumed that, for the better comfort of the travellers, the ship is traveling with an acceleration which is measured on board and physiologically felt to be equal to the acceleration of 32 ft/sec^2, and which remains constant as measured by board time. During the whole time of the journey, the crew will keep their eyes, or rather their navigation instruments, trained on their star of destination. Because of the Doppler blue-shift of the light received from the terminus-star the crew will notice that the original colour of the star, which might at first have been yellow, is gradually changing, owing to the increasing velocity, via green and blue to violet, to disappear finally in the invisible ultra-violet region, so that now the star of their destination can only be observed with the aid of instruments. By means of the Doppler effect the crew would also notice that after about 1.4 years they are approaching the terminus-star with 90 percent of the velocity of light. If the rocket-motors are continued to be used, the crew would find in the same way that after 5.6 years they are approaching their star of destination with 99.999 percent of the velocity of light. Meanwhile the light from this star has ben reduced in wave-length from perhaps an original 5,900 Å to a mere 11 Å and would now be in the X-ray region.

If at this stage, i. e. after 5.6 years from the start, it were possible for the crew to make a measurement of the distance of the terminus-star, this would turn out to be only 5.5 light-years, instead of a few light-years less than 1,000 light-years they might have expected to observe. Because of a velocity relative to the Earth and to the terminus-star, which is so close to the speed of light, interstellar distances at rest in the galactical system, but moving relative to the ship with close to the speed of light, are now subject to the relativistic contraction of distances (Lorentz contraction) and appear to the crew to have been considerably shortened, in the last example, by a factor of two hundred. Even without further acceleration the ship in our example would, in another 5.5 years, 11 years in all from the start, have flown past the terminus-star whose distance before the start had been measured by the crew to be 1,000 light-years. This means that the light from this star, measured according to the terrestrial time scale, would require 1,000 years to reach the Earth.

While, according to the correct indications of their clocks, the crew has been traveling for about 11 years, to people on the Earth more than a thousand years will meanwhile have passed according to their likewise correct clocks. The two time-measurements have experienced a dilatation which is completely analagous to the Lorentz contraction of distances.

If, during their journey to their star, it were possible for the crew to observe details upon the star they are aiming at, then prior to their start from the extra-terrestrial station they will have observed the conditions on their star of a thousand years ago. As they are approaching the star with high speed, the last thousand years of the history of their star would be spreading out before their eyes in quick motion, and having arrived there after 11 years, measured by their proper time, they would look upon what could be studied there as the present-day history of the star. Within 11 years, they would have witnessed a little more than the whole last thousand years of their destination star, that is almost a hundred times faster than an inhabitant of this star could have done. Meanwhile, during their journey to this star, a thousand years would have elapsed on the Earth as well as on the destination star.

If, looking backwards to the Earth, during their journey, conditions there could also be observed, then the light coming from the Earth would appear to the crew to grow gradually redder in color, and finally it would have the wavelength of radio waves. Essentially these long waves would keep them informed about terrestrial history during the 11 years of their absence since their start, so that upon their arrival on their destination star they would be seeing the Earth almost in the state it had been in at their departure from it. Meanwhile, on Earth, a little more than a thousand years would have passed. If the crew were to stay on their star for a longer period, they would be observing the terrestrial events in a terrestrial rhythm, but displaced by a thousand years into the past as compared with crew-time.

However, if after their arrival at the destination star the crew were to turn around and to fly back to Earth in the same manner, a little more than another thousand years would once more pass on Earth, whereas on the ship only another 11 years would go by. Could the crew observe terrestrial events during their return-journey these would appear to them also to be sped up to quick motion tempo, a hundred times faster. On their return to the Earth a little over 2,000 years would have gone by since their start; aboard the ship only 22 years.

The layman has generally great difficulties in understanding these relativistic effects. Particularly, the phenomenon that time intervals on board a vessel traveling with almost the speed of light appear to be dilated to an observer on Earth. In part, these difficulties are due to the fact inherent in the general character of modern physics that its concepts do not lend themselves easily to vivid illustration, and, furthermore, to the circumstance that we are here dealing with phenomena which are outside our everyday, accustomed range of experiences. We have to grow used to these in much the same way as we had to get used to the idea of wireless or human flight.

In part, however, the difficulties are also due to a concrete misunderstanding. The layman in physics mistakenly suspects a direct influence upon, or rather a slowing down of, the biological course of life of the crew, while, in fact, neither the processes of life of the crew nor the rate of working of clocks or of the rocket motors is affected in the least. The time dilatation is only an *observational effect* for the terrestrial observer and would, consequently, present an entirely different aspect to any other observer; for example, one upon a fast-moving star observing the same ship. If our crew never again had an opportunity to contact their planet of origin they would never become aware of the time dilatation, and would only experience the shortening of distances as reality.

The physical reality of the relativistic time dilatation is, of course, no longer disputed. Almost 20 years have passed since it was first measured in the laboratory with the aid of the quadratic Doppler effect, which has also formed the basis of our earlier statements regarding the change in color of the terminus star. In these measurements, full agreement was obtained with the predictions made by *Einstein*, and, since then, research on cosmic rays, which also travel with almost the speed of light, has brought further complete confirmation, so that the mechanics of the special theory of relativity is today quite as much a reliable foundation of interstellar space flight as *Newtonian* mechanics for interplanetary space flights, such as, for example, the Earth satellite, which, incidentally, is still disbelieved by some.

There are but two technical consequences which are new in this situation which naturally still appears strange to the general public: Firstly, it will really be possible to bridge arbitrarily large astronomical distances in the universe within the limited natural lifetime of an individual human being. In other words, cruising speeds can be increased without any limit if astronomical distances measured from the Earth are compared with clocks on board the rocketship. For a photon traveling with the speed of light, this cruising speed would even be infinite. New is, secondly, that the fuel consumption required to traverse these immense astronomical distances is remarkably low. Of course, this fuel consumption is still high enough by comparison with present rocket-engineering concepts. In order, for example, to attain the earlier described approach to the speed of light to within a thousandth part of 1 percent, the initial mass of the spaceship must be 447 times its end mass, which will, however, be entirely within the technical and constructional possibilities of astronautics.

Regarding the technical details of the manner in which the photon rockets are to be realized in practice no very definite ideas exist at present. All one can say at this stage is that, to the crew, the photon rays will probably consist of ultraviolet rays produced by hot metal vapors similar to the ones produced in mercury lamps today. However, these metal vapors, or, better, metal plasmas, will probably have temperatures of the order of 150,000°. These luminous metal vapors will form a fixed part of the aggregate and are permeated by the energy obtained from the fuel. This energy is, in turn, obtained from a more or less complete transformation of matter into energy, which is a process that is being realized with increasing perfection by atomic science.

The technical preparations toward the photonic rockets are finally taking us back to the field of the intercontinental rockets which we had left earlier on. This is because it is hoped that the intensive photon rays can be employed as almost inertia-free weapons of defense against all types of flying devices. They will take the form of stationary ultraviolet searchlights which will direct an intensive energy ray against flying objects and will be capable of destroying them in fractions of a second up to distances of several hundred miles.

In this way, very effective weapons of defense against any threat from the air or from space might result which will, perhaps, initiate the last act of complete dedication of aviation and space flight to peaceful ends.

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ON WORKING FLUIDS FOR ROCKETS NOT HEATED CONVENTIONALLY

A systematic review has been made concerning the various rocket types possible and their attainable arc specific impulses, as well as a definition of the term "working fluid" and its functions. Following this, the values of the functions of thermodynamic mixtures as a partial result of an extensive computation program are published, at equilibrium setting for some hydrogen-oxygen working-fluid mixtures. Mean molecular weights, degree of ionization, and specific impulses obtainable for processes of heating up and flow are derived therefrom, with equilibrium setting free of delay.

Thereupon the processes are considered which take place while the working fluids are heated up through bombardment by corpuscular beams, and which do not permit a complete equilibrium adjustment, a systematical investigation program is suggested. In this connection, some numerical results are given, resulting from a first estimate.

Summarily, there may be stated that the working fluids rich in hydrogen contents still appear to be the best for the heating up to combustion gas temperatures whose heat transfers to the combustion-chamber walls can be controlled by purely thermodynamical means without taking recourse to electric or magnetic fields. This is due to the low radiation of hydrogen, its low ionization degree, low molecular weights, as well as to its high specific impulses. Wherever one wishes to make use of the advantages offered by a high degree of ionization—as, for instance, with ion rockets—alkali metals, the compounds of or mixtures with these metals, appear to be superior to mixtures with oxygen.

(Editor's Note.—The complete German text of Dr. Sänger-Bredt's paper is in the committee's files and is available for inspection.)

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The importance of nuclear-rocket propulsion in space flight was discussed by a number of witnesses in the hearings of the select Committee on Astronautics and Space Exploration during April and May of 1958, so it does not seem necessary to repeat these statements. Project Rover was established by the Atomic Energy Commission about 3½ years ago to investigate the feasibility of nuclear-rocket propulsion. The technical work is primarily centered at the Los Alamos Scientific Laboratory, and is continuing in accordance with the plans outlined in the author's testimony before the select committee (pp. 586–601). With the formation of the National Aeronautics and Space Administration, support for nonnuclear aspects of the Rover work previously supplied by the Air Force is being transferred to the NASA. Also, agreements have been reached between the NASA and the AEC with regard to the administration of the program.

A substantial portion of the Los Alamos Rover effort is now being devoted to the testing of an experimental high-temperature reactor known as Kiwi-A. This is a heat-exchanger device operating on an open cycle; e. g., the propellant gas is blown through channels in solid-fuel elements and ejected to the atmosphere through a nozzle. As of the time of this writing, Kiwi-A is being put through its final assembly checks at the Nevada test site of the AEC and the instrumentation and checkout of the test facilities are being completed. The actual operation of Kiwi-A probably will take place early in 1959. The plan is to operate the reactor through cycles of increasing power and temperature in order to study its response and to check out the diagnostic and control instrumentation. It will then be brought up to rated power and operated for a few minutes. After this run, the reactor will be dismantled in a shielded area and the components will be subjected to post mortem examination. If successful, the Kiwi-A test will be the first concrete step in the practical evaluation of this class of propulsion reactor.

Design work has also been started on two more test reactors that will be put through the same cycles of detailed design, component testing, fabrication, and power operation at the Nevada test site. These reactors will explore the use of new materials or new internal structures.

Since the performance of a nuclear propulsion system depends strongly upon the exhaust temperature of the propellant, there is a strong incentive to develop reactor core materials capable of very high temperatures. Research work on fuel elements based on graphite, refractory metals and refractory compounds is being continued.

Even though reactors of the Kiwi-A type have attractive performance for orbital missions and limited interplanetary exploration, they fall far short of utilizing the potential capabilities of nuclear energy. Basic studies are therefore being made on nonconventional reactor concepts in which the temperature and specific impulse of the system are much less limited by internal structural considerations. In addition, rather encouraging results have been obtained in the study of direct electrical power generation from fission heat. The generation of electricity by the thermoelectric effect in metals has been known for many years but is a relatively inefficient process. The similar effect in a gaseous plasma potentially has a much higher efficiency. Calculations and experiments performed at Los Alamos indicate that specially designed nuclear reactors driving plasma thermocouples may be a means of obtaining the lightweight electrical power supplies needed for ion and plasma propulsion of space vehicles.

Solar sailing has been investigated briefly as a method of orbit-to-orbit propulsion and seems to offer some promise. By solar sailing is meant the use of the pressure from the Sun's radiation as the propulsive force. This is very minute but is adequate for maneuvering a spacecraft into various Earth orbits and to do rather leisurely interplanetary exploration. A thin sail some 500 yards in diameter is needed for a space capsule weighing 500 pounds. Studies have been made of "tacking" operations and of methods for maneuvering into various interplanetary trajectories. Control of orientation is accomplished by counterrotating the sail and the payload and making use of the resultant gyroscopic action. This preliminary study suggests that solar sailing should be considered seriously for propulsion systems requiring very small accelerations.

Any forecasts of progress in space exploration during the next 10 years are necessarily speculative. A prerequisite for effective space exploration would appear to be the ability to place large payloads into permanent orbits about the Earth. One of the applications of nuclear propulsion is certainly in this area. The establishment of quite large unmanned "robot laboratories" capable of collecting and transmitting a variety of inner space data would appear to be a logical initial major objective. Later versions of these vehicles could be used as the launching bases for smaller exploratory vehicles probing more distant space. The development of nuclear systems for propelling such vehicles and supplying auxiliary power is also an important area.

MAJ. GEN. BERNARD A. SCHRIEVER, COMMANDER, AIR FORCE BALLISTIC MISSILE DIVISION, INGLEWOOD, CALIF.

* * * I consider it important that I also outline the general philosophy and assumptions which condition my reply.

Your inquiry fundamentally is directed toward our total national capability, and therefore our reply is similarly couched. When you see the words "we" or "our" in our summary, I imply a national capability rather than a project or program peculiar to the Air Force or any other service or agency. I do not think such a broad approach is presumptuous on our part, since our activities at the Air Force Ballistic Missile Division have brought us into contact with essentially every current space effort in the country.

Our summary is based on an assumption that our national effort will be based on an orderly integration and sequencing of appropriate development programs, each of which supports the more advanced efforts of follow-on programs. Our time predictions in particular could be very much in error if necessary basic and preliminary work is not accomplished.

It is especially worthwhile to note that our forecasts suggest only that "such and such *can* be done" rather than "such and such *will* be done." Difficult decisions will face us regarding the amount of the nation's resources which can and should be allotted to the space program. Aside from this, high national interest and motivation must persist over a period of many years if rapid progress is to be made. Our summary is based upon the assumption that relatively large amounts of resources will be committed to the space program.

Finally, it seems to me that we are in one of the few periods of history in which the direct application of hardware developed for the military is useful and probable indispensable for peaceful purposes. I refer to the fact that the large airframes, propulsion units, and launch facilities developed for missile applications will probably be by far the earliest, most reliable, and most economical means for providing within the time periods we indicate a routine booster capability for our nonmilitary programs. My reason for mentioning this is that a disservice would be done the nation if unwarranted apprehension or biases were allowed to interfere with the massive help the military services can provide to nonmilitary programs. I am happy to say that to date I have seen no difficulties of this kind. * * *

The following estimate of national space development capabilities during the next decade is based on evolutionary extension of the present scientific state of the art, at a rate which appears quite feasible in view of the rapidity of technological progress in recent years. The scope of these capabilities is immensely broad and varied, ranging from experimental unmanned space probes (of which the Pioneer was but a crude beginning) to manned landings on the Moon and safe return to Earth. From this wide variety this summary has selected examples only of the major sequential steps which can be made.

These developments will be made possible only by simultaneous advances over a broad scientific front: guidance and electronics, aerodynamic and structural design, bioastronautics, and varied methods of rocket propulsion—to mention but a few. All these advances are within our reach, but in this paper those in the rocket engine area only will be stressed. More so than in any other technical area, improvements in rocket thrust—our lifting capability—will be a direct determinant of our overall rate of progress. This emphasis on propulsion, therefore, serves only to confine this discussion to basic considerations, and detracts neither from the importance of nor feasibility of concurrent progress in other technological fields.

The significance of increasing thrust capabilities will become obvious as later in this summary the reader notes the sharp decrease possible in the ratio of gross space vehicle weight at launch to payload package weight at mission destination. This decreasing payload ratio is indicative of increasing economy of overall mission accomplishments.

Another primary factor in assessing our possibilities for space exploration will be reliability—reliability of the complete space vehicle and its Earth-based support facilities and equipment, all functioning as an integrated system. Sustained usefulness of space missions will only be achieved when systems operation can be called "routine." We shall use the term "mission reliability" to identify this status of operational dependability. At present the status of our space capabilities is what we shall refer to as "test reliability"—indicating the lower probability of complete accomplishment of mission objectives during developmental phases. The indication of "test reliability" versus "mission reliability" is an important criterion to apply in assessing the significance of the space capabilities which will be outlined in ths summary.

SPACE DEVELOPMENT POTENTIAL

Before turning to a forecast of the future, it is worthwhile briefly defining our starting point—our present space capabilities—and what major national resources have made them possible.

Today's potential for space development rests directly on the Nation's missile programs: their broad industrial base, their assembled scientific and technical knowledge and skills, their test and operational facilities, and their already proven hardware. These programs have now provided us the Thor, Jupiter, and Atlas ballistic missiles as basic booster packages, not to speak of the Vanguard and numerous other rockets which can be used in various combinations. Ballistic missile guidance systems can satisfy the accuracy requirements of terrestrial orbits or lunar probes. And the intensive reliability programs conducted in our development of ballistic missiles will pay off heavily in their space applications.

A major portion of our space ventures for the immediate future—roughly the 1958–59 time period—can be centered around our capability with present ballistic missile boosters to place increasing payloads into low-altitude orbit around the Earth, or smaller but respectable payloads into orbit or space probes at far greater distance. Examples of such possibilities would be the orbiting of as much as a one-and-a-half-ton vehicle at a height of over 100 miles; or of a 500-pound payload at approximately 1,000 miles. Lunar flights of payloads up to roughly 50 pounds are possible, though at a payload ratio of over 2,000 to 1. Other highly instrumented space probes can explore the vicinity of our nearest planetary neighbors, Venus and Mars. All these space mission capabilities would be in the "test reliability" category.

During approximately the next 2 years—say into 1961—the space missions mentioned in the previous paragraph should move into the "mission reliability" category due to presently feasible development of specialized guidance and control and as a result of intensive missile firing and improvements.

With the increasing availability of ICBM's as boosters, and with added stages, greater payloads can be carried, or satellites can operate at greater distances from the Earth. For example, orbital vehicle weights can increase to the order of 5,000 pounds at over 100 miles altitude, or over 1,000 pounds at heights of roughly 1,000 miles. Lunar flight payloads during this period should increase to possibly 500 pounds, with their payload ratio decreasing to something over 400 to 1.

Concurrently with the developments already mentioned, today's recovery techniques—notable in the successful Army retrieval of their Jupiter nose cones—can have progressed to the point first of demonstrating successful recovery of capsules from space, and then quite probably to the recovery of low-altitude satellites of weights up to a ton-and-a-half. This will greatly enhance our capability for exploiting the results of our early exploration of our space environment and for initial experiments with manned space flight.

WEIGHTS IN ORBIT

As we look further into the future, the need to place greater weights on orbit or onto space trajectories becomes more pressing. With proper emphasis on the further development of stages using exotic fuels such as liquid fluorine and hydrazine, additional booster capabilities can be provided during the 1961 time period. These fuels present the advantage of greater thrust per pound of fuel. Initially they will be of small propulsive power (about ten to twenty thousand pounds thrust), but can serve as added stages—on a "test reliability" basis—to roughly double the weight which can be carried on lunar or interplanetary trajectories (up to three to five hundred pounds).

To meet ever greater payload requirements, it is feasible that by, roughly, the end of 1963 a booster of one to two million pounds thrust can be developed utilizing liquid oxygen and hydrocarbon rocket fuel. On its initial flights such a booster used as a first stage will provide a major increase in our payload capability, on a "test reliability" basis.

Concurrently, large (roughly, 100,000 pounds thrust) exotic-fuel stages can be achieved. These, employed with the improved ICBM boosters which will by then be perfected, will further reduce the payload-weight ratio (in the case of the lunar flight, down to a figure of approximately 70). In addition, their payload capabilities will permit a more advanced series of space missions which will be most important ground breakers for later manned exploration utilizing the million-pound thrust class of booster.

As examples, a combination of the improved ICBM booster and large exotic-fueled second stage could be able to orbit 12,000 pounds of payload at over 100 miles altitude, or 3,000 pounds at 20,000 miles (the so-called 24-hour or stationary orbit). As "mission reliability" is achieved some time about 1965, satellites carrying 1 to 3 men could be established in weeks-long low-altitude orbits. This in turn can lead to bringing to "mission reliability" status the first techniques of space rendezvous. As another example, some 3,500 pounds could be carried around the Moon and back, sufficient capability for initial manned circumlunar flight. This lunar payload should also be sufficient to experiment with remote-controlled unmanned lunar landing and takeoff techniques which can be available by then, and which could return to the Earth a payload of some 750 pounds from the surface of the Moon. Concurrently with these developments, of course, the payloads which could be placed on interplanetary flights would also be steadily increasing, to some 3,000 pounds for flights to or in the vicinity of our nearer planetary neighbors. These flights will be essential developmental steps in the perfection of longer distance guidance techniques, but because of their duration (anywhere from 8 to 16 months) would preclude manned versions.

MISSION RELIABILITY

Attainment of "mission reliability" for the very large boosters of the million-pound thrust category, and coupling with them the large exotic-fueled boosters, should also lead to dramatic increased capabilities commencing in the 1965 time period. The payload for 150-mile orbit can jump to a 10- to 12-man carrying capability. Rendezvous techniques could begin to pay off with usable space stations formed from the pooled resources of several vehicles. Advances in the science of bioastronautics, however, will be an important factor in the realization of such capabilities. These very large boosters also make theoretically possible a 20,000-pound payload to the Moon and useful Moon satellite vehicles to further prepare for later manned landing operations. As vehicle reliability is attained, and as lunar landing and takeoff techniques are perfected, it should be possible by 1968 to return to the Earth from the Moon a payload capable of carrying a crew of 1 or 2 men.

During the period from about 1965 to 1968 corresponding advances in interplanetary flight seem feasible. Some 18,000 pounds could be carried to the nearer planets on a minimum-energy trajectory (some 8 to 16 months' round trip), or—as a more attractive possibility then entering the picture and also utilizing the very large boosters—the round trip to Venus could be shortened to roughly 4 months by reducing weight to about 10,000 pounds. These trips refer to the possibility of using manned vehicles, particularly on flights of shorter duration which are by far the more probable in view of the biomedical aspects of the longer duration trip. Even by such increased capabilities, however, the prospects for going beyond the nearer planets of Venus, Mars, and Mercury seem dim if propulsion developments are limited to those of the chemically fueled rockets. A round trip to Jupiter, the next planet out, would require more than 2 years.

PROPULSION

This serves to emphasize our future requirement for a powerplant which can deliver modest thrust for much longer duration than can chemical fuels—a "sustained-thrust" rocket engine. Only thus can we build up the great velocity necessary to shorten interplanetary flights. There are several possibilities for the 1968 period: in most probable sequence, the nuclear-heat exchanger, the ion-beam rocket, and the thermonuclear-plasma rocket. It is not unreasonable to postulate test missions by the end of the decade, using the very large chemical boosters for initial propulsion into orbit, and an ion-beam or thermonuclear-plasma rocket to continue the mission. Nor is it unreasonable to predict that by 1968 we may have perfected techniques of recovering and reusing our chemically fueled boosters after burnout, thus permitting the salvaging of high-cost components and providing the basis for more economical space operations. Such developments would be the preliminary steps into an entirely new phase of space exploration.

The specific applications and the scientific findings which lie within our reach during the next decade of space development present alluring prospects, indeed, and are the fitting subject of a separate study. Actually, these potential bounties have been quite fully presented to the committee during its initial months of evaluation of this Nation's capabilities for space exploration. In the interest of brevity and adherence to fundamental considerations of capability, therefore, no attempt is made to present them in this summary.

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A REPLY TO SPUTNIK [1]

The launching of the sputnik satellites by the Soviet Union has caused apprehension among many people. Even to those who had known of the great strides which the Russians have taken in science and in technology, achievement of the satellite comes as a reminder of the advanced state of missile sciences in Russia. The evidence

[1] EDITOR'S NOTE.—Dr. Singer's paper was written November 18, 1957. In submitting it, he wrote the committee: "I have reread it and find that the developments predicted in this paper have been realized in about the order in which they were expected. I am, therefore, confident that the extrapolations for the future which are contained in the paper will also come true."

suggests that Sputnik I was rushed along in an effort to beat us—by a time difference of only a few weeks, it seems—to a history-making step in mankind's exploration of space.

Here we would like to take a more positive view and ask the question: "How can we use the psychological blow produced by sputnik to best advantage?" In the last few weeks it has already produced a closer reexamination of our missile programs, of our science-education program, and even our whole defense strategy. Perhaps we should even be grateful to the Russians for giving us dramatic and adequate warning of their capabilities so early. The reaction to sputnik cannot but help advance the United States both militarily and technologically; we can only hope that the improvements will be long lasting and bring about a fundamental change in our attitude to the value of basic research and scientific education.

One of the beneficial consequences of sputnik will undoubtedly be a revitalization of the American program for outer space research. This program has never been centrally organized, but was pushed by interested persons within the separate military services. This haphazard approach and its resulting inefficiencies and competitions will now be replaced by a directed approach which organizes all available talents and facilities to pursue a really imaginative space-flight program in the United States.

Why we need a well-directed space-flight program

There are various reasons why such a development is inevitable. In the first place, it is now generally realized that we could have launched a satellite earlier if such central direction had been present. Further, it is realized that a space-flight program, in addition to its scientific value, has a tremendous impact on the imagination of people and, indeed, on their aspirations and is, therefore, inevitably a vehicle of propaganda, as well. In the present age, this cannot be divorced from foreign policy and, therefore, the United States space-flight program, its direction, its quality, its results, will become the object of examination by other nations and will reflect on America's scientific and technical abilities. We are forced, therefore, to undertake a really topnotch program, staffed with the best scientists and carried out in a free and unhampered atmosphere. Its results should be unclassified and available to scientific workers and the interested public. The impact of such a program might produce more favorable results, particularly among uncommitted neutral nations, than a rattling of sabers which is only slightly louder than that of the Russians.

Finally, from a practical point of view, such a space-flight program can be based entirely on rockets, which are either available now or will be developed, in any case, as part of our missile program. A space-flight program can, therefore, be carried out with little extra cost. Far from interfering with our military missile program, a well-conceived space-flight program can serve to test out our rocket engines, launching techniques, guidance systems, and reentry systems.

Why are we lagging in satellites

If viewed from this point of view, one wonders why we are not already in the midst of such a program. It is not for the lack of ideas but because of the lack of a single central focus where these ideas can be evaluated and put into operation. The greatest delay occurs not in the conception of a project, but in its travel from office to office, in its examination by committees at a low level, and in the involvement of personalities which are attached to a program of perhaps a different type. Also because of our policy of classification in missile development, with its requirement of a "need-to-know," one office never knows what another office is doing or planning. Just the dissemination of this information therefore takes many months, leads to parallel plans, even parallel research programs, and by that time of course competition has developed to the extent where a choice can no longer be made on the basis of merit alone.

Space flight must pay its own way

There has been opposition on the part of cost-conscious Government officials to space-flight projects probably because they are often developed without any detailed justification. Fortunately, there is a very good justification. Many space-flight projects give important scientific results which cannot be had in any other way. A good example is the scientific satellite which observes the radiation conditions in the vicinity of the Earth. Aside from the scientific aspects, there is certainly the problem of learning as much as we can about the environment of the Earth for more advanced space-flight programs and for economic and possible military reasons, although the latter have in many cases been considerably overstated. It is important, therefore, that people concerned with space-flight programs have a good appreciation of its scientific value, in other words, a basic understanding of astrophysics, meteorology, and space medical problems.

Space flight projects can be arranged logically on the basis of increasing weight, which means increasing size of rockets and increasing cost and difficulty. There are ideas for some imaginative project which do not fit the pattern; but since this is a highly competitive world we live in, it seems wisest to do them first and to discuss them only afterward.

It makes sense to talk about two types of projects: Orbital flight and extreme distance flight; e. g., close to or beyond the Moon. In the first category we have satellite vehicles which operate at a speed of about 5 miles per second, close to the Earth and within its strong gravitational field; while the other class of vehicles operate with escape speed, about 7 miles per second, and travel so far that distances are measured in terms of the Earth's radius (4,000 miles) instead of miles. The Moon, for example, is at a distance of 60 Earth-radii.

Instrument-carrying Earth satellites

The simplest satellite is certainly a small luminous object which can be seen by its own light or by reflected sunlight. A large metal balloon, for example, will be easily visible at twilight by reflected sunlight, but in order to last for an appreciable time this balloon has to be at a fairly high altitude so that the atmospheric drag will be of no importance. But its simplicity and easy visibility can give it a special popular appeal; and if launched in proper spirit, it could become a symbol of world friendship. The sputnik achieved the opposite effect of a sinister object, largely because of the secrecy surrounding its function and construction. We can learn a lesson from this contrast.

As soon as we add a transmitter and proper instruments to a satellite, it becomes a scientific observatory. We can then detect almost any of the important radiations which rain down on the Earth from outer space, from the highest energy cosmic rays of the galaxy on down to the low energy particles from the Sun which produce the aurora; we can measure the intensity of the ultraviolet and X-rays from the Sun which are so important for the conditions of our own upper atmosphere. Such outer atmosphere observations, of course, connect very closely with other International Geophysical Year observations made at sea level. Both sputnik and Vanguard fall into the category of instrumented satellites. Even though the sputnik is much heavier than the Vanguard satellite, there is every indication that our satellites will be just as effective scientifically, or perhaps more so, depending of course on what the Russians put into their future sputniks.

A large satellite has one clear advantage, however: It can carry small animals. At this point the satellite field branches off into satellites which carry more and more complicated instruments, culminating perhaps in a television camera which can automatically scan all of the Earth's surface, while the other branch pursues animal experiments and attempts eventually to recover these animals. The latter research, of course, leads very naturally to the establishment of a manned satellite which will be the ultimate achievement in the satellite field with our present rocket techniques.

Let's consider first the instrumented variety of satellite. Beyond the very simplest satellite which carries just a transmitter and some instruments some important refinements are indicated. At the present time the limit to useful satellite life is given by the life of the chemical batteries. A solar battery, however, would keep the satellite in operation until it is finally destroyed by atmospheric friction or by impact from a meteor, or until its components just wear out. If we want the satellite instruments to make certain types of observations, e. g., to point at the Sun, or to look down to study the Earth's weather, we need "attitude control" which tells the satellite what is "up" and "down," and provides a definite orientation in space. One can use a very simple system such as the spin stabilization principle of the Mouse satellite, or a more sophisticated system based on a means of sending the orientation and then transmitting this information to a piece of machinery which puts the satellite into the desired attitude. Once these refinements become possible, then it pays to put up a much heavier satellite carrying a television camera. Now we can obtain really detailed information about the Earth's weather, degree of cloud cover, motion of clouds, and location of storms. But by that time, probably, the solar power supply is no longer adequate so that a small nuclear reactor is necessary to provide electric power. This is a satellite which will more than pay its way; weather information which leads to accurate long-range prediction is of tremendous economic importance.

At this stage also, Earth satellites which can act as economical television relay stations become of practical interest; they can receive weak signals from a ground transmitter and retransmit them across oceans. In this way we eliminate the need for expensive submarine video cables or transcontinental microwave links. Newton's laws of planetary motion tell us that a satellite operating at an altitude of about 22,000 miles will make its orbit in 24 hours. Such a satellite could, therefore, remain stationary with respect to the Earth's surface and could be used essentially as a permanent radio and TV reflector.

A manned satellite

But the real desire for space flight will not be satisfied until a manned satellite is successfully developed. This will take much preparatory work. Certainly animals will have to be flown many times to test not only normal biological functions, such as heart beat, respiration, body temperatures, but also psychological reactions to various stimuli and their ability to make intelligent decisions.

Except for weightlessness, the other parameters, such as vacuum and temperature conditions, tight and uncomfortable surroundings, can all be simulated on earth. Balloon-borne capsules, used in Projects Man-High and Strato-Lab, simulate the cooped-up feeling which the first space traveler will get, as well as the very real danger of not coming back alive. Interestingly, cosmic ray effects can be checked at balloon altitudes so that weightlessness remains the only real unknown. Now, near-zero gravity has been produced for short periods of time, of the order of 30 seconds or so, by flying airplanes in near-ballistic arcs. Investigators report that some pilots like the feeling of weightlessness while others definitely do not. Perhaps this indicates that there are people who have a basically positive disposition to weightlessness and therefore to space flight. The sputnik dog seemed to survive the zero-gravity effect; we may never know if she liked it.

The main problem then is to bring the man back through the atmosphere not only in one piece, but preferably "underdone" and not "medium rare." This is a very tricky problem, because in slowing the satellite its kinetic energy has somehow to be dissipated. A simple calculation shows that direct dissipation of the energy will vaporize the satellite, as well as the inhabitant. Probably the reentry operation should be done automatically, so that the scheme can be checked out on animal satellites. Future months will undoubtedly see an effort in that direction: attempts to bring animals back by intricate wing arrangements, coupled with parachutes, and perhaps more subtle techniques which are still in the research stage of our physics laboratories.

We may, however, expect that the objective of a manned satellite will be achieved with existing rockets of the ICBM variety in something like 2 to 5 years. The time scale here is set by the amount of effort which we are willing to put into this problem. There is no doubt that this is an effort in which the Russians also will attempt to be first, and they may very well succeed since their launching rockets are further advanced. But, no matter who is first, the time difference will not be more than a few weeks or a few months, perhaps. Again, the real payoff will be mainly scientific, rather than military or economic. Astronomers will probably be first in line for a trip lasting a few hours. They may experience the same great thrill as Galileo when he first viewed the universe through a telescope. With perfect "seeing conditions" in the absence of a turbulent atmosphere, even a simple telescope can give information of outstanding importance about the planets, the Sun, and even the distant stars.

Moon rockets

On space-flight projects which attempt to get away from the Earth, we have made an impressive start. The Air Force's Far Side project has sent up a small $3\frac{1}{2}$-pound payload to an altitude of the order of 3,000 miles, and there is good indication that the same system will achieve much higher altitudes in the near future. The basic design which uses cheap solid-propellant rockets mounted on a large balloon is so efficient that the cost per firing is of the order of $50,000.

Our military missiles can also give us extremely high altitudes, and we can, therefore, expect a larger research effort in that direction with instruments being flown to greater and greater heights to determine as much as we can about the surroundings of the Earth. The velocity required to get to the Moon, or out of the Earth's gravitational field, is close to the escape velocity, about 40 percent higher than the orbital velocity of 5 miles per second. This means that a rocket which can put a certain payload into an orbit will be able to send up a rather smaller payload to the Moon or away from the Earth.

The argument can be stated in reverse: To escape from the Earth's gravitational field we don't need a large rocket, but then we can only send up a small payload. However, as the Far Side vehicle has shown, with some ingenuity such small payloads can give us a great deal of scientific information.

Scientific problems in cislunar space

The justification for extreme high-altitude work is primarily scientific. The properties of the space around the Earth are not at all well known; we know little about the amount of gas, its chemical nature, its state of ionization. One of the intriguing questions is: How far up does the atmosphere rotate with the Earth; at what point does the general motion of the interplanetary gas take over? These questions and many others, which are so important for space flight, such as the space intensity of meteors and cosmic rays, will be solved by exploratory flights to great distances from the Earth.

Once we operate near the Moon, some intriguing orbit maneuvers become possible; e. g., we can make use of the Moon's gravitational field to return the vehicle to the Earth after traveling around the "far side" of the Moon. This operation we have called Moon Bounce, and the Russians, who developed it apparently quite independently, have called it Boomerang. A different class of operations is concerned with impacting on the Moon. Here, we would hardly want to use a manned vehicle at first because of the problem of getting him back again. One of the more spectacular projects would be to explode an H-bomb on the Moon's surface to observe the results of this explosion. Only a very small part of the Moon would be vaporized and we could follow the motion of the vaporized rock from the Earth. A tiny crater would remain as a mark of man's work on the Moon. One important application of such a project might be for testing nuclear devices without producing any hazards to life on Earth.

Manned circumlunar rocket

Judging from the probable state of ICBM rocket development, it should be possible to design and operate a manned vehicle around the Moon which will again return to the Earth. This is probably the ultimate that can be done without new developments in rockets and, therefore, without large additional expenditures of money and effort. Such a project would, of course, be of great scientific interest and a real step in the direction of manned space travel. The vehicle would have to start from the Earth with about escape speed, 7 miles per second. Its occupant could operate a small "vernier rocket" to put him on the correct precalculated orbit after the main rocket has burned out. Once in the correct orbit, no further adjustment will be necessary; the Moon's gravitational field will again "reflect" the vehicle after it has passed around the far side.

The recovery of the man would have to be done with the greatest of care. Probably the best method is to use the Earth's atmosphere again to slow the vehicle down to satellite speed. By reentering fairly deeply on the first pass, enough energy would be expended so that the vehicle is thrown into an elliptic orbit, and, as energy is expended on each pass, the ellipse shrinks quite rapidly into a circle. From there, the reentry would proceed as in the case of a manned satellite.

The manned circumlunar operation appears to be the most ambitious and challenging one which can be done with existing "hardware." From the way things are going, it would seem that the United States and Russia will proceed to this stage independently. But for any space flight operations which go beyond this stage the rockets used would have to be so large that their military significance might well be negligible, in the same sense in which there is a practical upper limit to the size of a hydrogen bomb. This point is easy to prove. An ICBM rocket may not even be quite big enough to put a man on the Moon; there is the problem of reducing his impact velocity, probably with a retrorocket, to a value which the human frame can stand. In addition, getting him off the Moon and back to Earth again requires more rocketpower. The operation would be easy, indeed, if the Moon's surface were elastic, or if we were clever enough to devise a way of storing the kinetic energy of impact and of releasing it when needed.

Perhaps at this point, then, there could be a meeting of the minds between East and West so that man's further exploration of space, including a manned landing on the Moon, can be done as a joint international effort. The cost would be high. But, if the major powers devoted only a fraction of their defense budget to this purpose, how simple it would be. And isn't the prospect of an interplanetary voyage much more appealing than a devastated Earth? A worthy goal for humanity.

DR. H. GUYFORD STEVER, ASSOCIATE DEAN OF ENGINEERING, PROFESSOR OF AERONAUTICAL ENGINEERING, MASSACHUSETTS INSTITUTE OF TECHNOLOGY, CAMBRIDGE, MASS.

The first decade of the Space Age will see space scientific research firmly established, with many important results obtained before the end of the decade, and with a host of techniques developed for carrying out new important scientific experiments. It will also be marked by the beginnings of manned exploration of the nearer reaches of the solar system and by important applications of space technology to man's daily life.

Taking the last of these first, what are the applications of space technology in man's daily life that can be expected in the next decade? Almost certainly the greatest influence on our daily activity will be from the employment of satellites as communications relay stations. Though we sometimes think all the different forms of radio and wire communications have given us close contact with all parts of the work, our communications are, in fact, quite unreliable, as well as unable to handle efficiently the great volume of business which in modern life is generated for the communication system. The potentiality of using passive reflecting satellites for one-way transmission of radio waves, as well as active repeating satellites for electronic communication, promises that the method of communicating around the world will be completely revolutionized. Furthermore, the technical development required for this advance is not very great and should be accomplished long before the first decade of the Space Age is over.

In addition to giving most benefits to mankind, this Space Age achievement of improved communication by satellite relay stations will also pose to the governments of the world the greatest problem of regulation and control. Unilateral undisciplined action by one country can seriously impair the benefits of this advance to all countries. We would do well to plan at an early date for international control of communications as aided by space vehicles.

WEATHER FORECASTING

Another benefit to the daily life of man from the achievements of the first decade of the Space Age will come in the field of weather forecasting. Improved gross-scale weather data always will be available on a daily basis from the flights of space vehicles. There must be work in the general field of meteorology to vitalize to the maximum the improved data-gathering capability that the techniques of space technology will provide. Probably there will still be much to desire in weather forecasting at the end of this first decade because of the tremendous complexity of the entire field, though, surely, our forecasts will be improved by our space-data-gathering techniques.

The accomplishments of the first decade of the Space Age will depend entirely on current or slightly improved forms of conventional liquid- and solid-propellant rockets. These rockets, of course, will become more advanced, with improved control of stopping and starting; they will be more reliable; higher energy propellants will be used, such as hydrogen and fluorine; there will be much greater range of size of rocket motors available. All these are obtainable by a vigorous research program. No new forms of propulsion will challenge the conventional rockets in their accomplishment by the end of the [next decade]. Naturally, a research and development program is justified in the field of nuclear-rocket propulsion and also in the field of ion propulsion. However, the first decade will see these in experimental form only. They will certainly not become workhorses of space flight in only one decade of development. The long-term future of distant solar-system travel and travel outside the solar system may depend completely on the successful evolution of these more advanced forms of propulsion, and so the vigorous pursuance of their development is essential to the first decade of the Space Age.

MANNED SPACE FLIGHT

Though man will successfully fly in space in a very few years, the first decade of the Space Age will probably be one of acquiring capability in manned space flight, rather than great accomplishment in the more difficult flights of man to the Moon and the planets. By the end of the decade, the capability should be so good that the second and ensuing decades can be characterized by long-range expeditions and elaborate exploration missions. Almost certainly, man will have considerable experience in satellite flight close to the Earth. There will be attempts, probably partially or completely successful, to reach the Moon in a manned space flight in this first decade.

As far as scope of real accomplishment is concerned, the program of scientific research employing space vehicles will advance the fastest. Clearly, a great deal can be accomplished with the vehicles that we now have or are about to have. When we add to these other vehicles propelled by much larger rockets with greater payloads, our potential will surely be great for doing scientific experiments, such as exploring the environment, probing the near planets, and getting better information with respect to the radiations from the Sun and from outer space. All of these things can easily be done without manned vehicles. By the end of this decade, there will be very few sciences not influenced by the techniques of space flight and the result of scientific research carried out in space.

MILITARY TECHNOLOGY

Paralleling the nonmilitary applications of space technology mentioned above, there will be an equally impressive program in the field of military technology. Ballistic missiles, semiballistic missiles, and rocket-propelled aircraft of all sorts can be developed in this decade. The capability of satellites for reconnaissance, for surveillance of enemy action, and for early warning can be realized by our military services within this decade. Space military weapons of a type which today brand their military proponents as dreamers will probably be commonplace by the end of this decade.

Naturally, the accomplishments of the first decade depend upon the enthusiastic support of a vigorous program by the people and the leaders of this country.

George H. Stoner, General Manager, Dyna-Soar Weapons System, Boeing Airplane Co., Seattle, Wash.

INTRODUCTION

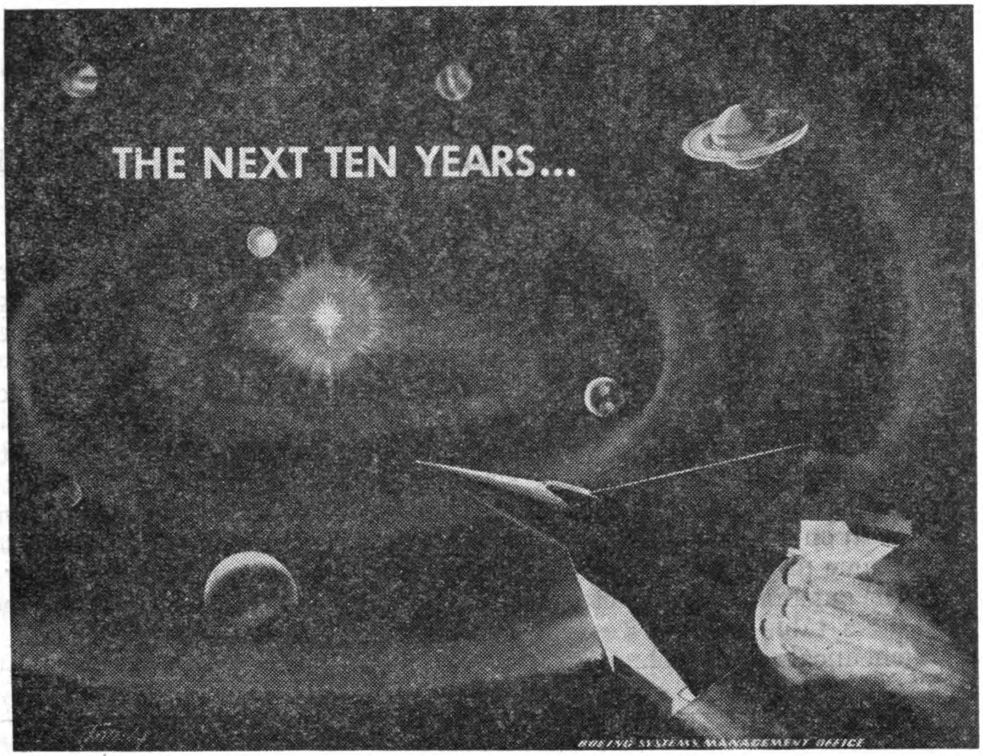
Before discussing possible developments in the United States space technology during the next 10 years, a few comments on factors which influence our rate of progress may be helpful.

Our progress into space will depend on the conflicting influence of four primary factors. Compelling the advancement of our space technology are:

(1) Scientific curiosity.
(2) National defense.

Balanced against these are two extremely important limiting factors:

(1) Available manpower and money.
(2) Available knowledge and techniques.



Scientific curiosity, depending only on individual intelligence, has essentially no limit. National defense is, of course, unalterably linked with our political and economic environment. At present the need for development of near-Earth space systems for defense seems imperative. As the distance from the Earth increases the military utility of space, *as presently conceived*, declines and scientific aspects become of prime importance. Although advances in military science are essential, the cultural impact, particularly on the world scientific community, of purely scientific achievements and endeavors by freemen cannot be underrated.

Large-scale space exploration will require enormous expenditures of money and technical manpower. The civilian space agency, NASA, can be expected to fund a space program which of necessity will be limited to those experiments most likely to advance our knowledge. The great bulk of our effort must be supported by the Defense Department.

By "available knowledge and techniques" as a limiting factor we mean new technology, heretofore unavailable, which will allow us to expand our space activities more rapidly. These technological developments will, in large measure, also be dependent upon research and development activities supported by the Defense Department.

The foregoing is intended to underline the great influence which future policy decisions in the Defense Department will have upon our space program. This discussion of the developments to be expected in the next 10 years is based upon the assumption that the military will recognize the importance of extending our knowledge in all phases of space technology and provide the necessary support for a strong, active program.

PRESENT TRENDS

The developments during the next 10 years may be expected to reflect the space planning and research now being proposed. Consequently, a brief summary of our capabilities in several important technological areas will serve to focus attention on trends which will strongly influence our future progress.

Propulsion

The chemical rocket is the foundation of our space capability today. The liquid propellant rocket has been the backbone of our strategic missile systems. However, liquid-propellant rockets are extremely complex, due to the necessity of metering and controlling large flows of cryogenic or corrosive liquids. This complexity results in low initial reliability and a long development cycle.

The solid-propellant rocket offers increased reliability and shorter development time through simplification. Recent advances in the technology of solid propellants have enabled new and improved weapon systems to be developed using solid-propellant rockets as the prime propulsion system. Table I is a point-by-point comparison of the outstanding characteristics of solid- and liquid-propellant rockets. This table summarizes our current and anticipated capabilities in chemical rocket technology.

TABLE I

Point of comparison	Liquid rocket	Solid rocket
Specific impulse (experimental 1,000 per square inch absolute):		
Current	263 (LOX-JP4)	Approximately 225.
1960–65	313 (F_2–N_2H_4)	Estimated 240–260.
Propellant loading fraction:		
Current	0.92–0.94	0.85–0.92.
1960–65	0.96–?	0.92–0.95.
Specific gravity	1.01 (LOX-JP4)	1.85 (most solids).
Maximum burning time (1958)	No limit	Approximately 1 minute.
Practical storage time	Minutes (LOX, F_2)	Years (most solids).
Thrust vector control	Good (Gimballed Thrust Chamber).	Under development.
Thrust termination	Good (propellant valves)	Do.
Thrust programing	Fair (throttle propellant flow)	Limited; must be designed into motor.
Environmental limitations	As required to store or produce volatile, toxic, or corrosive liquids.	Temperature control probably required during long-term storage.
Special launch-site facilities required by propulsion system.	Tank farm, tank trucks and propellant generator (LOX, F_2).	Erecting equipment.
Degree of complexity of preflight service and inspection.	High	Low.
Count-down time on propulsion system.	Moderate; may involve top-off of volatile propellants.	Very short.
Propellant utilization	Unavailable propellant due to boil-off, poor mixture control, and tank residue.	Sliver loss (can eliminate by design).
Transportation	Volatile propellants require special equipment.	Large rockets require special equipment; ultimate size limit.
Reliability (1958–60)	Good (80–99 percent)	Excellent (95–99.9 percent).
Costs:		
Development	5	1.
Production	1	1.

Unfortunately, neither solid nor liquid propellant rockets may be classed as an ideal space-propulsion system due to inherent energy limitations of the chemical-combustion process. Figure 1 indicates expected improvements in specific impulse for chemical and nuclear rockets. Specific impulse is the pounds of thrust produced by a flow of 1 pound of propellants per second. There is a definite limit to the energy obtainable from chemical combustion. This limit is a specific impulse of about 400 seconds.

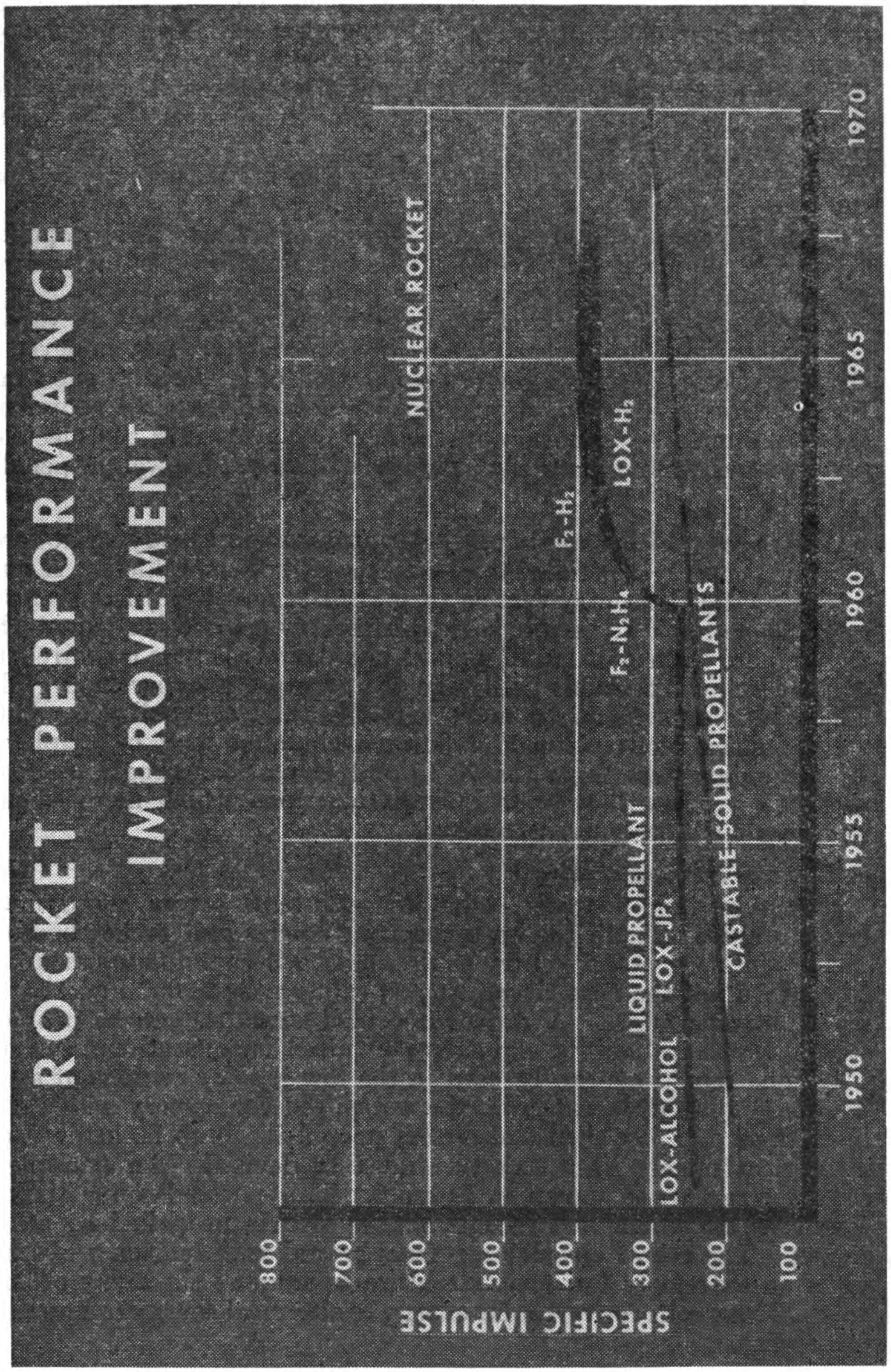

ROCKET PERFORMANCE
IMPROVEMENT
SPECIFIC IMPULSE
800
700
600
500
400
300
200
100
1950
1955
1960
1965
1970
NUCLEAR ROCKET
F₂-H₂
LOX-H₂
F₂-N₂H₄
LIQUID PROPELLANT
LOX-JP₄
LOX-ALCOHOL
CASTABLE SOLID PROPELLANTS

FIGURE 1.

Nuclear energy is the most promising new energy source on the horizon which may be utilized for rocket propulsion. Component development work now underway will provide the foundation for future advances in this field. "Conventional" nuclear rockets using a nuclear reactor as a heat source will provide essentially twice the performance obtainable from our best chemical system. By the end of this decade, the nuclear rocket can provide the large thrusts needed to accelerate heavy payloads through planetary gravity fields if the program receives sufficient support.

Efficient space travel will also require a rocket with very high performance which is capable of providing low thrust for accelerations and maneuvers in the low-gravity regions of space. The propellant or working fluid expenditure of this device must be extremely low to achieve practical, long-duration interplanetary flight.

Theoretical and experimental research has been started on various electrical propulsion schemes where high performance is achieved by electrostatic or electromagnetic acceleration of a working substance. Future effort is directed toward development of practical propulsion hardware and the discovery of methods of providing the electrical energy required to operate these devices without undue weight penalty.

Aerodynamics

As a space vehicle enters a planetary atmosphere, aerodynamic forces must be properly controlled to ensure survival of the vehicle. A pure-drag or ballistic reentry vehicle (e. g., ICBM nose cone) has been successfully tested. In certain cases this reentry method is adequate, but where more control of landing point, speed, and altitude is desired, the reentry vehicle probably will take the form of a hypersonic glider. The glider appears to be more versatile than the ballistic reentry vehicle since "conventional" landing techniques may be employed. Aerodynamic data from the X–15 and Dyna-Soar programs in the next few years will provide information upon which more efficient reentry vehicle designs can be based.

Structures and materials

Structures and materials able to withstand severe aerodynamic heating are available for both reentry vehicles and rocket boosters. A successful uncooled reentry vehicle must withstand temperature up to 3,500° F. at the nose, decreasing to values near 2,000° F. on highly swept leading edges. A radiation-cooled structure can be provided which has the reliability and safety required for operational systems.

Unique structures can be used in the low gravity regions of space. They are quite different from those required for reentry and booster operations. If low-thrust electrical propulsion is to be utilized efficiently, extremely light structure must be devised. An example of such a structure is shown in figure 2. This is the Boeing Martian Explorer, an unmanned reconnaissance vehicle propelled by an ion rocket. The use of circular members braced with tension wires provides an extremely low-mass structure to support the array of solar cells. These cells convert solar energy to electrical energy to power the ion rocket.

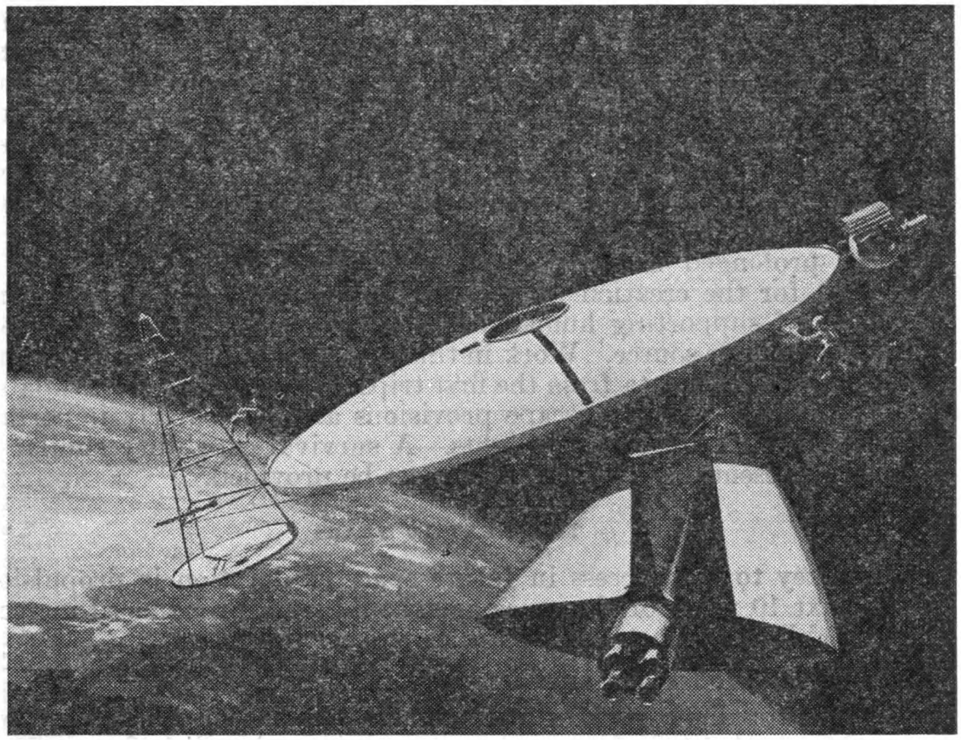


FIGURE 2.

Guidance and communication

Intertial and radio-guidance systems with satisfactory performance are available for placing satellites in orbit and for relatively short flights into space. For longer flights or for return from orbital flight after extended periods, celestial-inertial systems are being developed to provide the required accuracy. It is likely that early unmanned probes will be ground-tracked and guidance information relayed to the vehicle from an Earth-based control center. For manned applications, automatic guidance starting at launch will in general be provided and the pilot will act as monitor for the automatic guidance system.

Communications can be carried out at present from as far away as the Moon with a modest amount of radiated power and reasonably sized receivers such as the large directional antennas presently in use at Cape Canaveral. For interplanetary distances and beyond, very large and highly directional antennas are required. Development of new techniques, such as modulated light beams, are required to provide a satisfactory communications system for interplanetary travel.

Human engineering

The first voyages into space will be accomplished by unmanned probes, but man will soon reach the point where he must see for himself. The two main problems facing the designers of manned space vehicles are (1) providing a suitable environment, and (2) providing adequate escape provisions.

Designs for crew compartments of space vehicles have been proposed and tested that will allow man to exist and function efficiently for periods of up to several days. Outstanding problems needing further investigation include the effect of prolonged weightlessness on man's psychological and physiological efficiency, and the effect of cosmic radiation on his health. In the X–15 and Dyna-Soar projects, man will be exposed to these influences and the data from these trips into space will be used to develop more effective vehicle designs.

For prolonged interplanetary travel, ingenious designs must be evolved for the creation of a self-contained, artificial environment, capable of supporting human life for years without refurbishment from an outside source. Work in this direction is just beginning, and will accelerate as data from the first trips into space become available.

Adequate safety and escape provisions are particularly important for our first manned space flights. A survival capability similar to that of present-day flight testing must be provided.

THE NEXT 10 YEARS

The key to our success in future space exploration is propulsion. The next 10 years of the space age should see a pronounced increase in our ability to penetrate space with rocket power.

Unmanned probes and satellites

Solid-propellant rockets will assume the major burden of our strategic and tactical weapon system. Storable liquid-propellant rockets will also find application. The large liquid rocket engines now under development for Atlas and Titan ICBM weapon systems will continue to be improved until safe, reliable systems are achieved on an operational status. These engines, using inexpensive liquid oxygen and JP4, will become the bulwark of our probe experiments. Larger LOX–JP4 engines, with thrusts up to 1.5 million pounds, will be developed in 3 to 5 years, and will allow larger payloads to be placed in orbit.

High-energy chemical systems using fluorine and hydrogen will become operational, but because of higher propellant costs will probably find widest use in the smaller upper stages of the new space probes.

Manned space vehicles

Early manned orbital vehicles will probably employ solid-propellant rocket clusters to take advantage of their higher safety and reliability. As the safety and reliability of the liquid rocket is improved, its greater payload capacity will dictate its use as a booster for the larger manned vehicles.

The next 10 years will see work started toward the establishment of a manned satellite space station. This and similar space stations will serve as an assembly area for low-thrust, lightweight interplanetary probes, as well as a signal-relay station for terrestrial radio and television signals, and as a weather scanner and astronomical laboratory. These manned satellite stations will be preceded by numerous orbital flights of smaller manned vehicles which will supply the vital data needed for the successful operation of a full-scale space station.

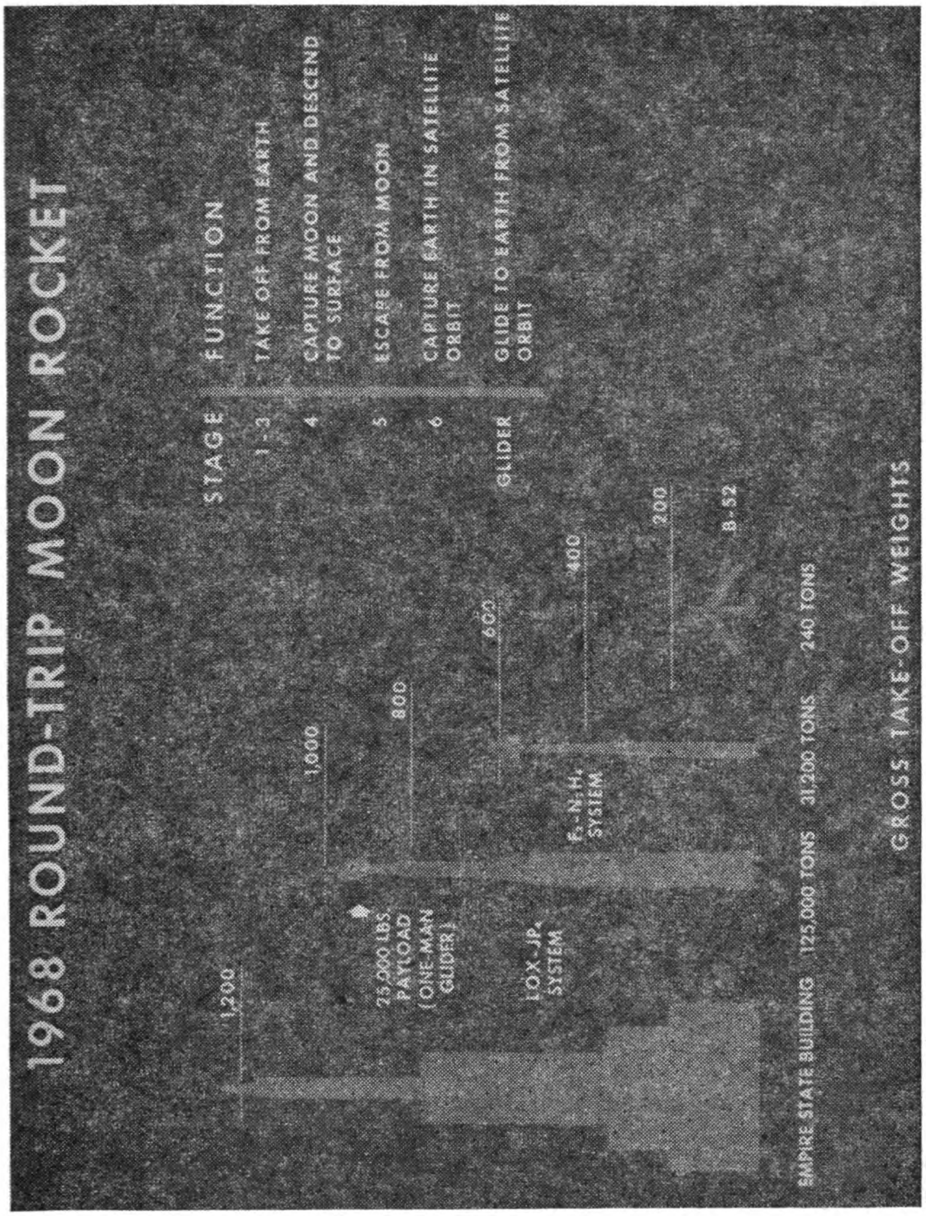


FIGURE 3.

39608°—59——14

One of the outstanding problems facing the United States in space technology is the theoretical calculation and practical execution of precise satellite boost and interception maneuvers. The science of satellite and space-vehicle flight mechanics requires increased emphasis on the problems of computing and achieving precise orbits and trajectories.

It is quite possible that man will make a landing on the Moon within the next 10 years, provided there is sufficient support for this venture. However, a round trip to the Moon, whether starting from an orbital space station or directly from the surface of the Earth, is a formidable task. Figure 3 compares the sizes of round-trip manned Moon rockets using conventional and high-energy liquid rocket propellants. Using LOX–JP4, the booster needed to send a 25,000-pound payload to the Moon and return is almost beyond the realm of practicality. When a manned satellite space station becomes a reality, a more efficient method of getting to the Moon might involve the assembly of the lunar vehicle on the space station. This space station, though probably not available in the next decade, will allow the use of numerous smaller Earth-to-orbit ferry rockets.

The nuclear rocket

The nuclear rocket will allow us to reduce the bulk of these lunar and satellite booster systems by a factor of 8 or 10, at least. However, a great many problems must be solved before the nuclear rocket will realize its full potential. Besides the obvious technical problems of the reactor and propellant system, there are the problems associated with the testing, development, and operational use of highly radioactive equipment. The physiological radiation hazard is a very critical problem. Can we design a manned nuclear rocket for use in the atmosphere where radiation scattering is a hazard, and avoid the weight penalties of standard shielding techniques?

A possible solution might involve the use of unmanned nuclear ferry vehicles to transport large payloads to the satellite space station. A different type of nuclear rocket with a relatively light shadow shield could then be used in space to transport men to the Moon and back. In any case, our space efforts will be rather limited in the next 10 years unless the rapid development of the nuclear rocket receives increased emphasis.

With strong support, the nuclear rocket could be available for operational use by 1968, though unexpected problems in the testing and development of flight hardware could lead to delay.

Advanced propulsion

The next 10 years should see important advances in the development of electrical propulsion techniques. The achievement of full-scale operational systems will depend heavily on laboratory research now under way on the problems of producing and manipulating ions and plasma.

The application of electrical propulsion systems to unmanned probes will depend upon the establishment of a manned orbital space station. The use of solar and nuclear energy to provide electrical power for these advanced propulsion schemes is a critical development problem which could well determine the overall applicability of these techniques.

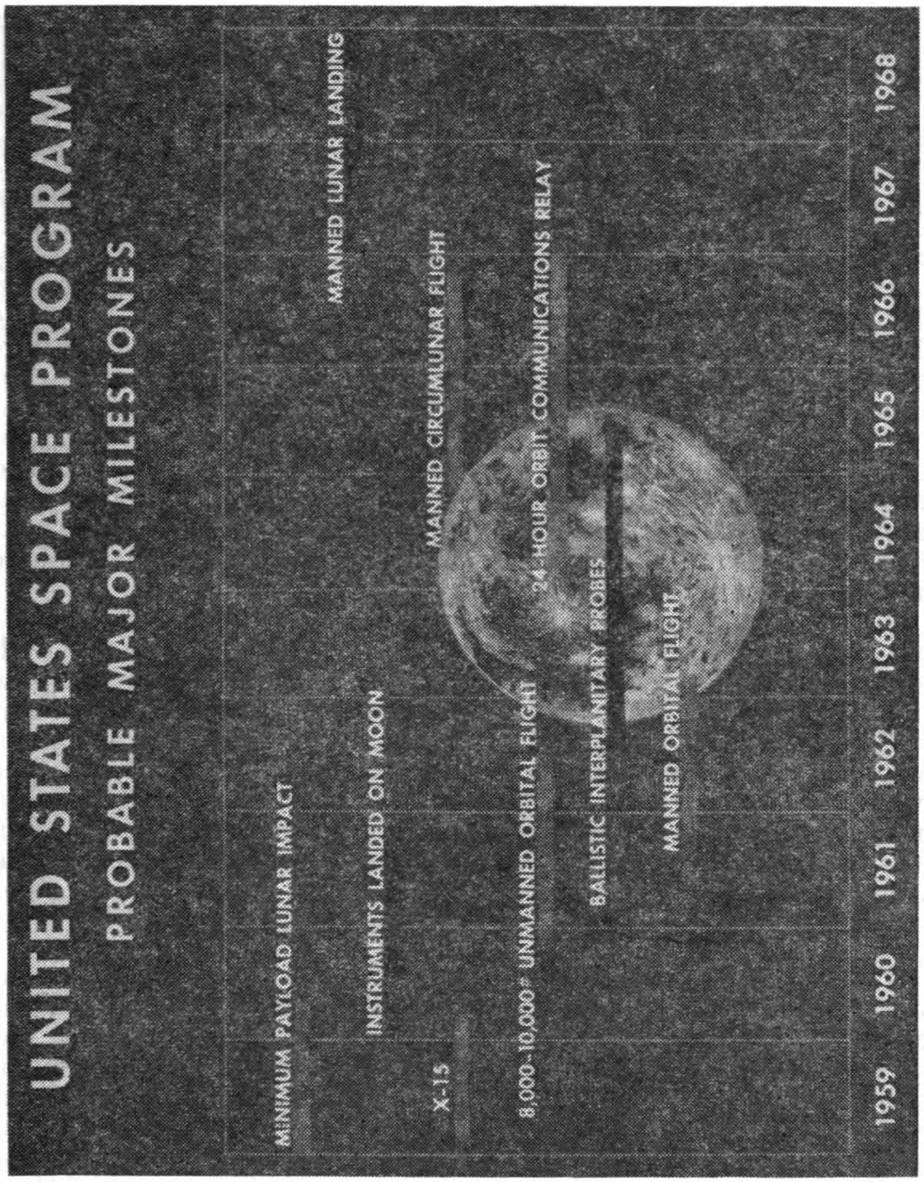

UNITED STATES SPACE PROGRAM
PROBABLE MAJOR MILESTONES
MINIMUM PAYLOAD LUNAR IMPACT
INSTRUMENTS LANDED ON MOON
X-15
8,000-10,000# UNMANNED ORBITAL FLIGHT
BALLISTIC INTERPLANITARY PROBES
MANNED ORBITAL FLIGHT
MANNED CIRCUMLUNAR FLIGHT
24-HOUR ORBIT COMMUNICATIONS RELAY
MANNED LUNAR LANDING
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968

FIGURE 4.

MAJOR MILESTONES

The probable major milestones of the United States space program during the next decade are shown in figure 4.

The exploration of space in the next 10 years may be roughly classified in three major categories:

I. Unmanned satellites and probes
II. Manned orbital vehicles
III. Manned lunar expeditions

We may summarize the foregoing discussion by means of a brief comment on these three areas of endeavor.

I. Unmanned satellites will be launched at an average rate of 2 or 3 per year by both the United States and Russia to obtain geophysical data and data on the upper atmosphere, radiation, meteoric dust, etc. Other satellites will be placed in orbit for more practical reasons, including reconnaissance, weather mapping, and communications relaying. Payloads will increase to several tons when new LOX–JP4 liquid propellant rocket engines in the million pound thrust range become available. The nuclear rocket will be used for boosting larger unmanned satellites into orbit if its rapid development is pushed now.

II. Hypersonic glide vehicles like Dyna-Soar will precede more elaborate manned orbital vehicles. The unmanned reconnaissance and manned reconnaissance or bombardment orbital systems are important military applications of the space age. Although not within the next decade, the manned orbital space station will become a vital link to interplanetary space when manned exploration commences.

III. Manned lunar expeditions which do not land but which orbit about the Moon one or more times before returning to Earth will probably occur within the next decade. The first landing on the Moon by man could also be accomplished within the next 10 years if sufficient support for this vast undertaking is provided. As shown in figure 3, a round trip to the Moon directly from the Earth's surface will require an extremely large chemical rocket. Hence, the first man may not step on the lunar surface until a manned orbital space station has been established which will allow the voyage to be broken into convenient stages.

POSTSCRIPT

* * * Not mentioned in the enclosed paper is the need for a global test range for fostering the experimental evolution of space flight activities. In stating this problem, I can draw an analogy to the implementation in 1947 by Congress of the long range proving ground, which has permitted in the past decade the testing of missiles of increasing range, such as Matador, Bomarc, Atlas, Thor, and the various space exploration probes. The long range proving ground has gone through a series of name changes, and is currently known as the Atlantic test range.

Just as the long range proving ground was established with a variety of projects in mind, it would appear that a global test range needs to be implemented to support a variety of projects on the horizon, such as the man in space program, the Dyna-Soar hypersonic boost glide program, the system 117L satellite program, and other projects yet unnamed, but sure to materialize, all of which require extensive global facilities for proper test support. These facilities include worldwide networks of communication stations for transmission and receipt of messages, telemeter stations, optical and radar tracking stations and landing and recovery sites.

Many existing and planned test sites would readily be incorporated in a global test range, for example, the Atlantic test range the Pacific test range, tracking stations in Hawaii, Australia, and England, certain pertinent Edwards Air Force Base facilities, and many others. However, the need is strong for an appropriation and designation of the agency to tie all the existing facilities together, to procure or negotiate use of international land and facilities as required for this purpose, to standardize upon and achieve international agreements for radio frequency allocations, and to integrate in a broad way all of the requirements for a global test range.

It is inefficient and misleading to require that any single project carry the responsibility for justifying, planning, funding, and implementing an appropriate global test range, especially when any space flight activity will require the essential elements.

Properly handled in the diplomatic sense, it would appear that the implementation and use of a global test range for hypersonic and space flight experiments could be a concept capable of growing to an "open skies" system of inspection. As a minimum result, the existence of such an integrated test range would go a long way to insure that the free world wastes no time in developing the full scientific and military potential of space flight activities. * * *

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Before we attempt to outline anticipated advancements in space technology within the next 10 years, as seen from the viewpoint of space medicine, or bioastronautics, the following three considerations may be useful concerning the definition of space, the definition of various types of space flight, and of the corresponding various types of vehicles.

1. *Definition of space.*—Space, in common usage called outer space, begins at the end of the aerodynamically effective atmosphere around 200 kilometers (120 miles) (extra-atmospheric space). With regard to certain physiological factors, however, space reaches down as low as 20 kilometers (about 12 miles) (intra-atmospheric space-equivalent region). From 200 kilometers (120 miles) on the potential satellite space of the Earth's gravisphere begins, and its satellite-holding power reaches as far as 1½ million kilometers or about 1 million miles. Beyond this region, which may be called "deep space," the Sun's gravitation becomes predominant. In the direction of the line Earth-Moon, the gravitational divide between these two celestial bodies lies at a distance of 332,000 kilometers (193,000 miles) from the Earth, or 58,000 kilometers (35,000 miles) from the surface of the Moon. These average figures indicate "where a rocket leaves the gravitational field" of the Earth and enters that of the Sun or the Moon, which in both cases requires escape velocity.

2. *Present and future basic phases of manned space flight.*—These are enumerated in table I, with a definition of the vehicles and a description of the characteristics of the space environment and of space flight dynamics. These basic phases include atmospheric flight, atmospheric space-equivalent flight, satellite flight, and the category of space operations that require escape velocities such as lunar, interplanetary, and planetary space operations.

3. *Various types of space craft.*—These are shown in the form of a genealogical family tree of rockets and space vehicles in figure 1. On the left side are found unmanned rockets, research satellites, and probes; on the right side, the corresponding manned atmospheric, aerospace, and space craft.

ANTICIPATED DEVELOPMENTS WITHIN THE NEXT 10 YEARS

General considerations.—Since the writer is a physician and physiologist, his discussion on this subject matter will be confined to manned flight, i. e., to the aspects of space medicine. Unmanned research vehicles have to be considered, too, but only to the extent of their supporting role of manned space operations. It lies in the nature of the conquest of space that the timetable of the advancement on this vertical frontier will be determined by space technology. It is the task of space medicine to sense in advance the coming developments and make its research plans accordingly, not so much on the basis of an anticipated timetable, but rather immediately on a broad, all-embracing research scope to meet the necessities of any extension and any duration of space flight foreseeable at least 10 years ahead, or even more. For certain problems will require many years of basic research work before it can be applied to space flight. A typical example in this respect is the use of plants (photosynthesis) for recycling of body wastes in a closed ecological system. Therefore, all of the medical, physiological, and psychological problems in all conceivable types of space flight have to be considered in the "man in space" program at the same time, and this time is *now*.

Specific considerations.—In the following, some specific space medical remarks will be made concerning the various phases of human flight to be anticipated within the next 10 years.

I. Atmospheric flight

A discussion of this now 50-year-old type of human flight is beyond the scope of these comments; however, it should be mentioned that due to the higher altitude range in air transport (20,000 to 30,000 feet) rapid decompression of passenger cabin, and with regard to the 600 mile per hour speed range in jet service, safety of air traffic, especially in the crowded airport areas, will demand special attention in the years ahead.

II. Atmospheric space-equivalent flight

In short-time experimental forms, this type of human flight has been with us for a number of years (Bell Aircraft X–1 and X–2). It will reach its climax with the X–15 and similar craft based on the Dyna-Soar principle. A successful development of this typical example of space-equivalent flight which has been for several years a subject of frequent consultations between the respective engineers, prospective test pilots, and representatives of space medicine can be expected within 2 to 3 years. Though this category of vehicles follows basically a combination of a ballistic and aerodynamically supported curve, i. e., a suborbital trajectory, it may attain short-time orbital capability. This leads us to the first true phase of space operations: orbital space flight or satellite flight.

III. Manned satellite flight.

This is the type of space flight the achievement of which will dominate the efforts in space technology and space medicine during the first half of the next 10 years. As mentioned before, short-time orbital flight in the order of several revolutions around the earth may be achieved by means of more advanced representatives of the Dyna-Soar principle; i. e., a rocket-powered winged craft. The other line of descent comes from the missile. It is probably the ancestress of long-life orbital vehicles and all further evolutions of space vehicles.

Since October 1957 unmanned research satellites are a fact. That animals can survive orbital flight for a number of dozen revolutions has been proven by the Russian "Laika" experiment. Below about 1,000 kilometers (600 miles) altitude manned orbital flight seems to be relatively safe.

Beyond this altitude medical considerations may influence the technical timetable considerably. The source of a certain delay will be the high-intensity radiation belt formed by the geomagnetic field recently discovered by James Van Allen by means of the Explorers.

Further probes eventually with animals are necessary in order to explore to what degree shielding against these ionizing radiations will be necessary. One thing is already certain today, the arena for manned satellite flight will not extend beyond 1,000 kilometers (600 miles). These low-level orbital satellite flights can be expected not later than in 3 to 5 years, provided that a safe return at a predesignated time and location can be achieved.

IV. Lunar, interplanetary, and planetary missions

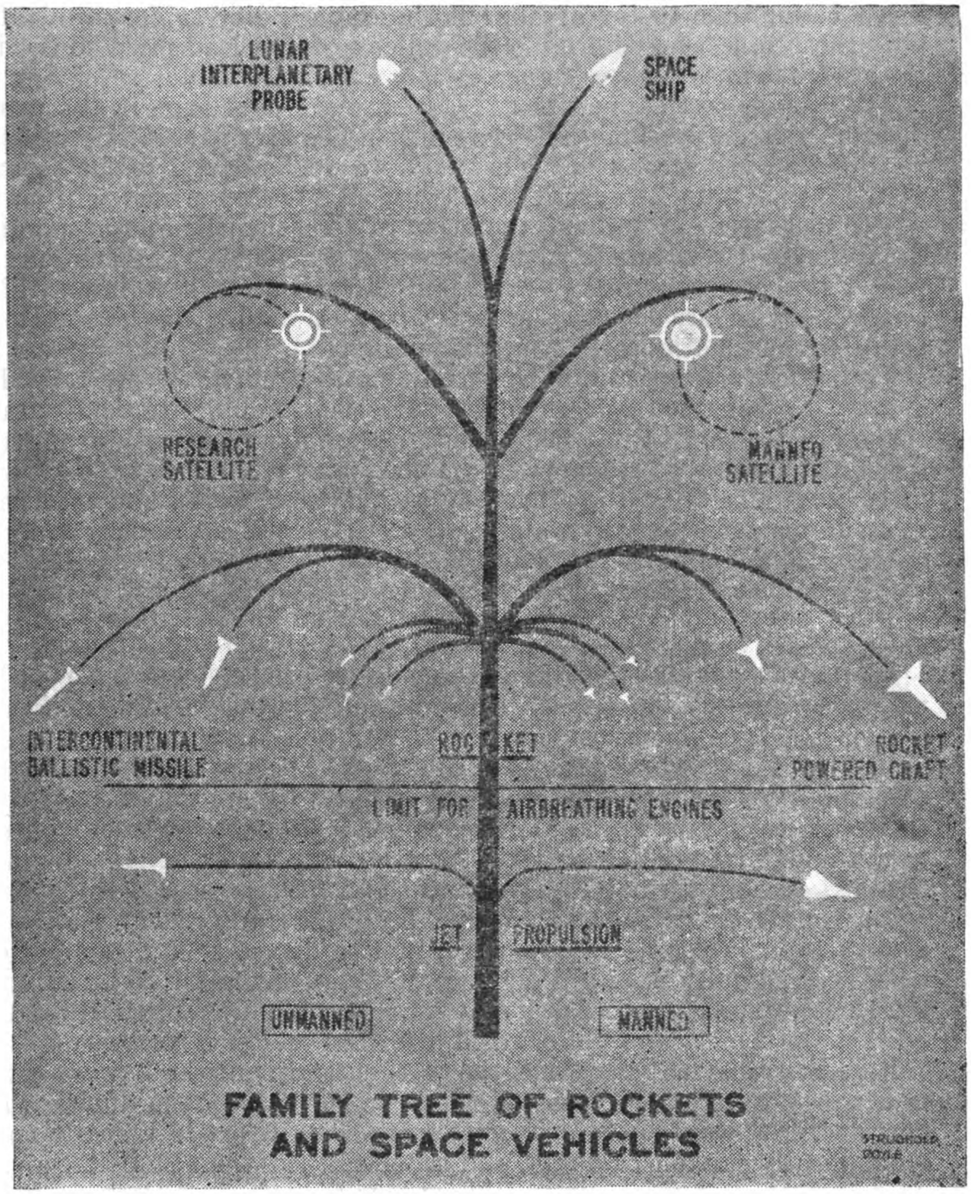
The knowledge of the intensity, extension, and form of Van Allen's radiation belt is of special importance to more extended space operations such a lunar, interplanetary, and planetary missions, because for them this radiation region is a real dangerous obstacle. As can be taken as certain today, only half a year after its discovery, protective measures will be necessary; these are: shielding of the cabin, or avoiding the equatorial danger areas by choosing the less dangerous polar regions as routes for leaving and approaching the Earth, or higher velocities to shorten the exposure time by dashing through the belt. Each of these measures, particularly if a combination of them is necessary, will pose tremendous problems to astronautics and will tend to cause some delay. Before the discovery of this radiation belt it could be assumed that a manned flight into the lunar area would be achieved not later than in 5 to 8 years. Now this estimation may have to be modified by a factor of 2. But it should also be mentioned that the climatization of the cabin (oxygen supply, carbon dioxide removal, etc.) during such an expedition of presumably 5 days, or even longer, could be handled today due to promising medical laboratory work in space-cabin simulators.

More extended manned space operations beyond the Moon and beyond the Sun-Earth gravitational divide (1 million miles) into deep interplanetary space, or even into the region of 1 of the 2 neighboring planets, cannot be expected within the next 10 years unless some drastic improvements in the field of propulsion are made. Nevertheless, space medical studies concerning regeneration of air and recycling of body wastes in a closed ecological system have to be intensified in order to meet the developmental situation in the decade following the 10 years from now. It is equally important to turn our attention to the conditions on the other celestial bodies themselves; however, it seems that the direction has to go away from the Sun toward Mars if it is true that toward Venus the space environment attains more and more the characteristics of the "solar atmosphere" and that the temperature on Venus is too high due to the greenhouse effect of its carbon-dioxide-enriched atmosphere.

In concluding these space medical remarks on anticipated developments within the next 10 years, I would like to emphasize that space medical research will be well prepared to meet the requirements for those space operations that can be expected within the next 10 years. But there are two uncertainties: tolerability of zero gravity over longer periods of time, which will find its answer—and probably a positive answer—in space flight itself. If the answer would be negative, then the engineer would have to provide artificial gravitation by rotating the vehicle. The second uncertainty arises from the geomagnetically caused radiation belt which needs more detailed explorations by instrumental probes. Both of these question marks, especially the latter, may have a delaying effect upon the timetable in the development of manned space operations within the next 10 years.

TABLE I.—*Present and future basic stages of human flight*

	I	II	III	IV
Classification of flight	Atmospheric flight.	Space-equivalent flight.	Satellite flight	Lunar and interplanetary space flight.
Status of vehicle	Airplane	Airplane or projectile.	Satellite	Space ship.
Characteristics:				
Environment	Troposphere, lower stratosphere.	Partial space-equivalent regions of atmosphere.	Total space-equivalent regions of atmosphere and space.	Space.
Dynamics	Aerodynamics.	Aerothermodynamics ballistics.	Celestial mechanics.	Celestial mechanics.
Speed or velocity	Subsonic, supersonic speeds.	Supersonic, hypersonic speeds.	Orbital velocities	Escape velocities.
Gravitational condition.	Normal gravity.	Subgravity, zerogravity.	Zerogravity	Zerogravity.


LUNAR
INTERPLANETARY
PROBE
SPACE
SHIP
RESEARCH
SATELLITE
MANNED
SATELLITE
INTERCONTINENTAL
BALLISTIC MISSILE
ROCKET
ROCKET
POWERED CRAFT
LIMIT FOR AIRBREATHING ENGINES
JET PROPULSION
UNMANNED
MANNED
FAMILY TREE OF ROCKETS
AND SPACE VEHICLES

GEORGE S. TRIMBLE, JR., VICE PRESIDENT, ENGINEERING, THE MARTIN CO., BALTIMORE, MD.

* * * To predict the future is to run an unnecessary risk. There are more famous historians than prophets. Having predicted the future in years gone by, and having been wrong more often than right, I should know better than to try again, but the opportunity to communicate with the people who determine the policies of and lead my country is too golden to miss; so here goes.

The answer to the question: "Whither the Spage Age in the next decade" must be considered in two parts. The first part is "What *can* we do" and the second is "What *will* we do." Part 1 is the easier of the 2 to answer because it is a technical question which will submit to measurement and extrapolation of the scientific and economic disciplines. Unfortunately, the answer is academic. The answer to part 2 is the one we really want, but unfortunately it is impossible to acquire with any degree of accuracy because implicit in the question is the human equation—the American public.

To my knowledge no one has been able to predict, to any reliable degree, the behavior pattern of the American public over a 10-year span even for very simple factors such as population growth or movement, and before we can answer the question "What *will* we do," we must determine what the American people *want* to do, and perhaps more important, why they want to do it. This is the way our country operates, and it is good.

THE AMERICAN PEOPLE

We must recognize that the present desire of the American people to "do something" about space is based totally on their feeling of frustration resulting from losing a race they didn't know they were in—launching Earth's first manmade satellite. The people are reacting to a condition set up by Russia, not acting in their own behalf for their own private reasons. Hence, to get a true answer to our question, I must first predict what Russia will do in the Space Age during the next decade; so that I know what the American people will want to do (how they will react); so that I can determine what the technically capable people will be permitted to do; so that I can judge what will actually happen. This certainly seems to me to be an unfruitful pursuit, and particularly for one eminently unqualified to predict the American public, much less the Russian Government.

Based on this analysis alone, the best tentative answer I could give now to the question "What *will* we do in the Space Age during the next decade?" would be "Considerably less than we are technically and economically capable of doing, and somewhat less than the Russians." This answer is as objective as I know how to make it. Perhaps it is too objective. Perhaps it does not leave enough room for American flexibility. It is but an extrapolation of my observations that groups who are motivated only by reaction to other groups never do their best work and rarely meet the competition. Those who dare to lead and have a reason for it usually lead.

You have every right to expect that my reply to your letter would be focused on the question, "What *can* we do in the Space Age during the next decade?"—as I have said, an academic question. My answer to this would be to ditto what prognostications you have gotten from other qualified people. We in this industry and our friends, the customer, agree quite well on what *can* be done. We may argue about details such as how to do it or who should do it, but, as I have already stated, things scientific and technological are not difficult to predict, and so we find agreement amongst men schooled in the subject. But to believe that what *can* be done *will* be done is to be unrealistic. Perhaps a few examples will clarify my position.

EARLY ORBITING VEHICLE

Almost 12 years ago a group of people with whom I was associated designed a large vehicle capable of orbiting the Earth. We used the materials and knowledge that were available to us. With the clarity of hindsight, it now can be said that the machine would have worked well, that the Space Age would have been ushered in 5 to 6 years earlier and by a different people—by people of the United States of America. My group wasn't the only one with a workable design in 1947. There were several. None of us went ahead with the job because the American people decided not to. We did not know how to sell it to them.

Eighteen months ago, 3 months before Sputnik I, some of my colleagues and I were laughed out of a very scientific meeting for proposing and showing how to build a large military base on the Moon, not because the people at the meeting disagreed with the feasibility of or desire for the scheme, but because the task of selling the need to the American public seemed so impossible to them that consideration of the proposal seemed a complete waste of time. The scientists apparently did not believe the American people would find any sense in such an idea. I cannot agree with this.

You people are better qualified to predict the American people than I. You know how to lead us, because it is your job. You hold the key to the crux of the problem, "Whither the Space Age in the Next Decade," which is "What will the people of the United States of America *want* to do and be willing to support in the Space Age during the next decade." Individuals like me and companies like mine will continue to try to map out and undertake programs that meet your objectives in a timely economical fashion. This is our job. This is how we have elected to make our living. I am confident that we can do whatever the American people decide they want to do: Men to the Moon and return; a base similar to those in the Antarctic on the Moon; a reliable communication system around the entire Earth; reliable weather prediction; but, most important of all, an increase in human knowledge (a commodity that has never gone to waste) concerning our environment in the universe.

ATTAINMENT OF KNOWLEDGE

The attainment of knowledge about our environment has been the major human pursuit for at least 600,000 years. It is the essence of civilization and society. The next big step to take in this pursuit is the exploration and exploitation of space. This step is inevitable. The question is who will contribute the most.

Is it not interesting that this job cannot possibly be accomplished by a few men with a single purpose, such as Columbus and the people who financed that trip must have had. To get the job done we must have an enormous number of human beings, all with the same desire, because the job is so large. Here is a challenge greater than any that has been laid before any people in the past. And the hero of this age will not be the space traveler, but rather the man or men who sucessfully figure out how to motivate 170 million American people actively to do battle with a part of their environment that they just began to hear about, that they really did not know was important—Space.

In this letter, I have done as you requested. I have concentrated my response on the area of my primary interest which concerns "what we *ought* to do in the Space Age during the next decade," and "How do we get the majority of Americans to want to do it." In Public Law 85–568, the National Aeronautics and Space Act of 1958, you have taken a tremendous step forward toward the objective. It remains to be seen how effective the implementation of the act will be. * * *

CAPT. R. C. TRUAX, UNITED STATES NAVY, FORMER PRESIDENT, AMERICAN ROCKET SOCIETY; MEMBER, MILITARY ASSISTANCE GROUP, ADVANCED RESEARCH PROJECTS AGENCY, DEPARTMENT OF DEFENSE, WASHINGTON, D. C.

INTRODUCTION

The role of prophet should always be accepted with great caution. In attempting to predict the accomplishments of the next decade in the new field of space navigation, it is necessary to carefully state the basis for the prediction if one is not to appear completely foolish in the years to come. My remarks here are as much a statement of what I think *should* be done as what *will* be done. To attempt to predict the latter without the basis of the former would be fruitless crystal gazing; of no use in attempting to shape the future along the most rational lines.

Progress in the conquest of space within the next decade will hinge directly on two fundamental items—money and organization. The two are inversely related. The better our organization, both in form and in quality of personnel, the lower the cost of a given measure of progress.

I cite these two elements, rather than the progress of science and invention, as the controlling factors, because developing and exploiting the ability to navigate through space is primarily a problem of rather straightforward application of known techniques. It is engineering more than science. The gathering of scientific knowledge is one of the *ends* of space exploitation, but is not required for the *means*.

New inventions and new scientific discoveries could considerably lessen the cost and accelerate the pace of space flight, but these things can neither be scheduled nor predicted. On the assumption that space flight will be achieved by known means, however, it is possible to predict with some accuracy the results that can be obtained with a given amount of money.

My forecast for the next decade then, is based on the assumption of no major new scientific discoveries, on an amount of money I consider to be reasonable and desirable, and a program which concentrates on the essential elements and eliminates frills and political stunts. It also assumes an administrative organization with the power to eliminate unnecessary waste and duplication and to plan and manage an integrated program of mutually supporting projects. The most important ingredient of all is a top level staff of experienced people, sharing enthusiasm and personal dedication to this great new adventure.

ORGANIZATIONAL PROGRESS

I foresee significant changes in the organization of space effort in the next few years. Firstly, I believe the division of work by project objective (i. e., civilian versus military) will be eliminated for the simple reason that, in many cases, the two types of missions can be performed by the same or similar equipment. The compromises required for such multipurpose use are technical in nature, involving thousand of details. They are not political or policy questions, and as such cannot be properly determined by a Presidential-level council. The later, at present, is the only agency capable of coordinating NASA and ARPA programs, should voluntary measures fail.

A second reason for my belief that all astronautic development will be combined under one agency is that a purely civil effort will collapse for want of financial support, as discussed later. Responsible officials will see the desirability of continuing many nonmilitary projects and will therefore amalgamate these objectives with military ones to insure their continuance.

A second organizational change I believe will take place will be the separation of astronautics from aeronautics. The lack of technical similarity between the two sciences will become more apparent as time progresses. The unsuitability of the old NACA as a space agency nucleus will become obvious as attempts are made to remold the facilities, philosophies and personnel to do the new job. It is usually much more difficult to remodel an old building to suit a totally new use than to build a modern, efficient one from the ground up.

A third organizational change will be to remove all engineering functions of the planning and management organization from the limitations of civil service. While it is sometimes possible to recruit high caliber scientific talent with the promise of excellent facilities and intellectually satisfying work, the kind of people needed most for astronautic development are those having experience in planning large organized engineering efforts. These people are in great demand in the missile industry. Government must pay competitive salaries to get them. To accept second-rate talent for the steering organization is to waste millions to save pennies.

I foresee then, all space research and development, military and civilian, under the direction of an Astronautics Agency, having prosecution of a space program as its *sole* mission.

It may be that a sufficient number of military applications of an offensive implication will be found to justify the formation of a fourth military service. We will then have rounded out our complement by covering all media; land, sea, air and *space*. The research and development aspects will, I believe, be handled by an agency outside the Department of Defense, much as the AEC handles both nuclear weapons development and the application of nuclear energy to peaceful purposes. An alternate possibility would be to extend the mission of the Defense Department to include space exploration, even where military justification is not apparent. The important thing is that there must be *one* agency and *one* program if bickering and waste is to be avoided.

FINANCING

American industry has the capacity, without significant expansion or reorganization, to carry on a space development program of over $2 billion a year. There is some question in my mind as to whether as much money as this can be utilized efficiently in the next few years, but considerably more could be used in the remainder of the decade. I will assume this as the average outlay.

Before building estimates of technical accomplishments around any such expenditure, it is useful to test the reasonableness of the assumption. Two billion dollars a year is a large sum of money. Funds of this magnitude have never been appropriated by the Congress in the past, except for purposes of national defense or other activities of wide general interest. For this reason, it is my opinion that, if the science of astronautics is to be developed, it will be done primarily under military motivation. The closest analogy to cite would be the development of aeronautics, wherein the vast majority of the advances have been the result of military stimuli. One has only to compare the slow progress prior to 1916 with the explosive growth of aviation technology in the 1916–18 period to appreciate the necessity for military justification.

I firmly believe that the military justification for a $2 billion program exists and that very worthwhile cultural, commercial, and scientific gains can be gotten at nominal additional cost as byproducts of a military space program. The types of equipment required for military and nonmilitary ventures are frequently identical. From a vehicle viewpoint the main differences are in final rocket stages and payloads.

Although, in my opinion, the United States is currently well behind the U. S. S. R. in the space race, the exploitation of space for military purposes seems fundamentally to work overwhelmingly to the advantage of the United States. For example, the development of satellite surveillance equipment, to give warning of attack preparation, may completely nullify the present tremendous advantage the U. S. S. R. now holds by virtue of its aggressive intentions and its ability to make preparations in secrecy. In the long run, satellites should prove more effective and more economical than aircraft in the attainment of "open skies" inspection objectives. Furthermore, if we move adroitly in the United Nations, satellites will not encounter the national sovereignty objections now firmly established in international law with respect to "air" space. In short, I view surveillance from space, perhaps with United Nations authorization, but under United States control, as one of the most important means of preserving peace and insuring our national survival. For this reason, if for no other, this country must take the lead in the development of the ability to navigate in space.

These assumptions, primary military justification and a $2 billion per year effort, form the background for my estimate of the progress in astronautics to be expected in the next 10 years.

TECHNICAL ACCOMPLISHMENTS

The single outstanding feature which is common to all space ventures, but present in no other, is that to reach space, except for brief periods, one must climb out of a "gravity well" equivalent to a vertical hole some 2,000 to 4,000 miles deep. This feat requires, even for tiny payloads, very sophisticated rockets. For purposes other than environmental measurements, large payloads are required. Large payloads require enormous, highly engineered rockets. The size and technical excellence of one's rockets represent, in my opinion, the truest single index of space capability. For this reason, I believe that all nations interested in exploiting space, for whatever purpose, will place prime emphasis on the development of large, multistaged rockets. Our present plans call for the development of such a rocket, weighing perhaps a million pounds at takeoff. In 10 years, this rocket will be in full service use, ferrying into orbit, in a single flight, payloads weighing up to 50,000 pounds.

At present, space operations are very costly. Hardware expenditures alone bring the cost of Vanguard payloads to over $25,000 per pound. A larger vehicle, using an ICBM for its first two stages, can bring the cost down to the order of $1,500 per pound. The greatest elements of these costs are contained in the first stage rocket and the complex guidance system. Since only one guidance system is required regardless of the size of the rocket, the largest cost item of a really big rocket is the first stage. There is a good possibility that these first stages can be made recoverable. I believe that this will be done, with an enormous resulting economy. After all, it would be hard to visualize an airline staying "in the black" if every landing were a crash landing. With recoverable boosters of large size, a hardware cost of less than $100 per pound of payload seems attainable. Such a reasonable figure will make economical the performance of many missions for which the use of space vehicles has thus far been considered too costly.

Sophisticated upper stages will be built, probably using very high energy liquid propellants. These will be tailored first to existing ICBM's, then to the new large boosters. The reason for the emphasis on fine engineering and extreme-performance propellants in upper stage rockets, but not in those used for lower stages, is that, for best efficiency, each stage contributes about equally to the total velocity required, but successively differ by a factor of 3 to 8 in weight, and hence differ markedly in cost. We therefore can carry more payload if we lavish care and attention on the smaller stages. Even though this care increases the cost per pound of vehicle, the total cost of the stage is sufficiently small that the overall cost is not greatly affected.

PAYLOADS

In addition to the ability to carry large payloads *into* space, the capability will be developed to *return* payloads *from* space. This ability is required primarily to permit manned space flight. There are few payloads, other than man, that are sufficiently valuable to justify the added cost of the return equipment. At present, the simplest approach seems to be to use an ablative heat shield and recover the payload by parachute after a ballistic or semiballistic reentry. An alternate approach is to develop a high temperature glider. The problem of returning the payload to a predetermined location is primarily one of terminal guidance rather than vehicle maneuverability. In my opinion, adequate maneuverability can be obtained without the use of wings. The latter are needed primarily to effect a safe landing. If it proves simpler and lighter to perform the latter operation by parachute, the technically difficult problem of building high temperature wings can be bypassed. In order to initiate reentry from orbital flight, some type of decelerating device is needed. Large aerodynamic drag devices or retrorockets are the principal means now visualized. Because it is adaptable to a wide variety of missions having varying timing and orbital variations, I foresee the retrorocket ablating heat shield system as being almost universally used.

With retrorockets, ablative heat shields, and accurate navigational equipment, we will be returning payloads to preselected areas no larger than a few miles square. This type of operation should be routine by 1968, up to the full payload capacity of the million pound booster.

PROPULSION

Ion, plasma, and other novel propulsion systems offer some usefulness for special purposes, such as making very fine orbital corrections. The very low thrust-to-weight ratio of these systems tends to confine their utility to very low velocity changes or very long propulsion periods. The vast majority of propulsion requirements in the next 10 years will continue to be met by fairly conventional chemical rockets.

The nuclear rocket is in an anomalous position: It shows up best in very large thrust sizes but is most useful, and most easily used, out in space, where thrust requirements for most missions are generally small. I foresee its first utility in a system which requires a nuclear reactor for electric power production and where useful propulsion can be derived from the same reactor as an extra dividend.

The second technical requirement common to nearly all space missions is the necessity to supply electrical energy for long periods of time. Only two systems hold promise for fulfilling this demand: solar radiation and nuclear fission. Both of these sources will undoubtedly be exploited. Solar energy will probably be used where the power demand is small and the payload sensitive to nuclear radiations. Nuclear reactors will be used when the reverse conditions dominate the situation. Solar arrays, having output power up to 50 kilowatts, and nuclear sources of perhaps 10 times that power should be attained within a decade.

In order to employ space vehicles effectively, a supporting ground environment is required. Essentially this environment consists of facilities to prepare and launch rockets, to recover payloads, and to track and communicate with the spaceborne vehicles.

The location of a launching facility is directly related to the objective of the flights to be made, most specifically to the inclination of the orbit with respect to the Earth's Equator, or to the ecliptic. Both polar and equatorial orbits will doubtless be required. From a launch site located near the Equator, both polar and equatorial launches can be made. Thus one such site might theoretically serve all requirements. Logistic support of such a site, however, is comparatively expensive. Furthermore, problems of electronic and schedule interference arise if a base attempts to handle too large a volume of traffic.

For these reasons I believe that, while an equatorial site will be developed, it will be used only for those launches for which such a site is an absolute necessity. For orbits above 35° in inclination, the Cape Canaveral and Point Arguello locations will be used. Facilities to launch the large booster will be constructed at Point Arguello and at the equatorial site.

At least one general purpose tracking net will be developed, capable of locating and determining the orbit of any vehicle, active or passive, passing within a fairly close distance of the earth. Specialized equipment will be developed for tracking and communicating with special-purpose vehicles.

EQUIPMENT

The final category of equipment to be developed for space is payloads. These relate intimately to the end results to be achieved and will be discussed together with the types of space missions to be accomplished.

As I have stated in the introduction, the most important space mission I see in the near future is worldwide surveillance, to give warning of warlike preparations by any nation. Only by achieving surprise could a world-be aggressor gain victory in this atomic age without enormous damage to himself. Satellite surveillance can greatly increase the difficulty of achieving surprise with either an aircraft or a missile attack. To create and extend such a satellite warning system, special adaptations of photographic, infrared, and radio-spectrum detection techniques will be made. With this equipment installed in satellites, many activities on the ground will be subject to daily scrutiny from above. Radio transmissons of many kinds can be monitored and flights of aircraft and missiles can be detected and tracked.

Initially, this equipment will be installed in small unmanned satellites. Toward the end of the decade, the first large manned space station should be in operation. The motivation for constructing it will again be economic. With the development of long duration electric power supplies, the factor limiting useful lifetimes of space vehicles will be reliability. It will probably be more expensive to repair a small satellite in orbit than to put up a new one. If, however, many equipments are drawn together in one place, such as in a satellite space station, the repairman can be more economically utilized. In fact, it may well be that the prime justification for putting man into space is so that he can act as a servicing technician.

Ultimately, it is my belief that there will be several such space stations. Each will perform a multiplicity of functions. In addition to surveillance of possible warlike activity, these stations will carry electronic equipment to assist surface and airborne craft in navigating. The stations will also act as communications repeaters, handling both military and commercial traffic.

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SCIENTIFIC ACCOMPLISHMENTS

So far, I have not discussed any purely scientific accomplishments to be expected in the next decade. This is because of my belief that there is no such mission sufficiently valuable to justify the outlay required for development of purely scientific space vehicles. As the state-of-the-art in space technology improves under the impetus of military and commercial uses, that is, for surveillance, communication and navigation, the scientific and exploration missions will become possible as relatively inexpensive byproducts.

It is true that sporadic "probes" of various kinds can be *attempted* at reasonable cost, but the chances for success for such efforts are so low that over the long run, the cost per unit of knowledge gained is fantastic. The problem is equipment reliability. Very many flights are required to achieve this reliability. If most elements of the system can be proven in a high-priority military program, then the additional cost for special-mission modifications becomes reasonable.

CIRCUMLUNAR FLIGHT

One of the earliest byproducts of this nature will be a circumlunar shot, using essentially the same equipment developed for Earth surveillance, to return a picture of the far side of the Moon. There is no reason why, in fact, almost identical equipment, thrown into an orbit around the Moon, cannot map the entire lunar surface in fine detail. Such a feat will require several attempts, even with largely proven equipment, but should be possible before the end of the decade for a total added expenditure of less than the Vanguard program. On the same flights, countless other environmental measurements could also be made.

Manned circumlunar flight falls into the same category of exploitations of military equipment for scientific and cultural purposes. The million-pound vehicle will be developed primarily to put large unmanned, and later manned, satellites into orbit. With minor modifications, the same vehicle can send a manned expedition round the Moon. Such a voyage would be a prelude to a manned lunar landing within the following decade.

Perhaps a few further words are necessary on the things I believe will *not* be accomplished in the next 10 years. I foresee no successful interplanetary probes. The problem again is reliability. An interplanetary voyage is a long one. Flight times are long. If other than very simple objectives are to be carried out, the costs of developing the highly reliable equipment required may well be prohibitive. I believe the first really successful interplanetary vehicle will be a manned one. A man is the only really complex mechanism of adequate reliability available. With a man to adjust and service the other equipment, the failure problem is greatly reduced. I do not foresee a manned circum-Martian (no landing) mission accomplished within 10 years, although plans for it may be well underway by that time. Again, most of the equipment required will have been perfected for other purposes.

SUMMARY

To summarize—for $20 billion, spread over the next 10 years, we can have numerous small, unmanned, single-purpose satellites; one large, manned, multipurpose space station; circumlunar instrumented flights; a soft-landing lunar craft instrumented to make numerous surface measurements critical to a later manned landing; and a manned circumlunar flight. Not only is the above list the best attainable with the financing I believe will be available, but it represents, in my opinion, the firmest base on which to build for later, deeper ventures into space. It avoids the pitfall of dissipating efforts on one-shot programs that are foredoomed to failure.

These accomplishments are real and solid, though they are considerably below some glowing predictions. Even these objectives cannot be reached, however, unless we organize efficiently, finance the effort consistently, and, above all, entrust the program to individuals having the experience to understand the problems of space and the personal dedication to solve them.

DR. WERNHER VON BRAUN, DIRECTOR, DEVELOPMENT OPERATIONS DIVISION, ARMY BALLISTIC MISSILE AGENCY, REDSTONE ARSENAL, HUNTSVILLE, ALA.

* * * (*a*) Will man reach the Moon? the planets?

(*b*) Will weather forecasting become an exact science?

(*c*) What types of propulsion will be developed?

In the following I have endeavored to come up with a comprehensive answer which should cover the above subjects.

It is my opinion that manned flight around the Moon is possible within the next 8 to 10 years, and a 2-way flight to the Moon, including landing, a few years thereafter. The launching of manned, Earth-orbital vehicles will have to precede such efforts and can be expected within the next 3 to 4 years. It seems unlikely that either Soviet or United States technology will be far enough advanced in the next 10 years to permit man's reaching the planets, although instrumented probes to the nearer planets (Mars or Venus) are a certainty.

At an altitude of some 22,000 miles, 3 communications satellites spaced 120° apart in the same equatorial 24-hour orbit, will provide a global telephone, telegraph, television, radio, and facsimile transmission system of sufficient traffic handling capacity to serve the entire Earth. Revenues from this worldwide service should be used for the financial support of future deep-space exploration projects.

Meteorological satellites, equipped with television cameras and circling at altitudes of only several hundred miles through near-polar orbits, will provide uninterrupted information on the cloud coverage on every point on Earth. Such information will not only enhance our understanding of the total solar energy absorbed by the Earth (and not reflected by the clouds), but it will also furnish immediate information on impending weather changes, hurricane dangers, and the like. It can be expected that the yearly savings incurred to agriculture and the tourist industry by improved weather forecasting will run into the hundreds of millions.

ROCKET VEHICLES

Rocket vehicles, of course, will be the key to accomplishment in the space age. If we are to expand our capability in space exploration, we must initiate a national integrated missile and space vehicle program which utilizes all existing development teams and facilities. Such a program would permit the development of five generations of space vehicle families within the next 10 years. The first generation, which is now in existence, utilizes short-range ballistic missiles such as Redstone for the boosters and has demonstrated an orbital payload capability of up to 33 pounds. The second and third generations would utilize IRBM and ICBM missiles as boosters, with payload capabilities increasing to 3,000 and 10,000 pounds, respectively. Fourth and fifth generation space vehicles require the development of boosters between 1 and several million pounds of thrust, and will have payload capabilities on the order of 25,000 to 100,000 pounds.

Other requirements for an integrated national space program would be the development of space navigation and guidance systems, crew engineering equipment and techniques, new and improved test and launching facilities, and new and improved satellite and space-vehicle payload compartments to accomplish astronomical research missions based on the idea of look-see.

The extent of United States achievements in the space age's next decade will depend on such a well laid-out national program. The Soviet Union with its traditional 5-year-plans obviously has such a long-range space program in operation. It is utterly essential that we now commit our resources likewise to a long-range, integrated national program and sustain that program even if public interest in it temporarily abates. For if public opinion again becomes lethargic, it will, of course, be reawakened by Soviet accomplishments. But the resultant stop-and-go method would be neither economical nor successful.

I hope you will not think I am begging the question of *where* we are going by answering with another question: *How much* are we willing to pay? * * *

DR. ALAN T. WATERMAN, DIRECTOR, NATIONAL SCIENCE FOUNDATION, WASHINGTON, D. C.

* * * I feel sure it was not your intent that we should attempt to recapitulate the detailed prognostications for the future of space research, which have been so ably set forth by several technical groups during recent months. I refer in particular to the admirable document prepared by the President's Science Advisory Committee, entitled "Introduction to Outer Space," which was released to the press by the White House on March 26, 1958, and to the considerably more technical document, Research in Outer Space, prepared by the Technical Panel on the Earth Satellite Program, United States National Committee for the IGY, National Academy of Sciences, and published in Science, April 11, 1958. As a consultant to the President's Science Advisory Committee, I participated in the preparation of its statement and endorsed both the program which it sets forth and the space timetable attached to it.

The Foundation is, as you know, the agency through which United States participation in the International Geophysical Year has been supported, and we have been in intimate contact with all phases of the United States program, including those in the rocket and satellite area. We find the panel's report on the needs and opportunities for space research within the next 10 years both sound and reasonable.

I shall therefore take this occasion to urge that the United States support a sound program of basic research in all fields that will contribute to the furtherance of space technology. I also urge that as much basic research as possible be included in those projects that have as their principal objective the probing of outer space. In my appearance before your committee last April, I observed that "space exploration will involve essentially two types of research which merge one into the other: (*a*) Research which is necessary to the accomplishment of space exploration; (*b*) pure research employing space vehicles as observing stations."

SPACE RESEARCH

Science does not recognize space research as a separate kind; rather space exploration offers opportunity for wider and more intimate knowledge of matter and the universe. The successful launching of the sputniks by the Russians and our own launching of various types of Earth circling satellites appeared to the general public as an unexpected and dramatic development. The sudden appearance of this new capability seemed to place us upon the very threshold of the Space Age. Scientists, however, pointed out that the satellite was simply the next logical extension of rocket techniques, and that the satellite itself is a form of rocket. It seems useful to emphasize, therefore, that forthcoming developments in space technology—including such items as solution of the reentry problem and recovery of instruments and other objects from satellites; lunar and planetary probes; and the placing of satellite platforms in outer space—will represent the further development of instruments and techniques that are already at hand.

Realization of what at this time appears to be the ultimate objective—namely, manned space travel—depends, also, upon extensive biological experiments which have been only just begun on a small scale. Thus, the aforementioned report of the Technical Panel on the Earth Satellite Program notes:

> Biological experiments should be instituted at the earliest opportunity in the satellite program, since they will be crucial to the eventual attainment of manned space flight. There appear to be two main areas of concern: the biological effects of prolonged exposure to the radiation in space (cosmic rays and the various solar emissions), and the subtle and complicated effects of prolonged weightlessness.

Most scientists are cautious about forecasts. I do not believe that even the most imaginative have allowed their minds to range much beyond the point of manned space travel. That is not to say that such travel represents the upper limits of man's adventuresome spirit, but rather that the more distant future depends on many unknown factors which we are certain to uncover as we achieve these preliminary goals.

The President's Science Advisory Committee wisely observed that—

> Research in outer space affords new opportunities in science, but it does not diminish the importance of science on Earth. Many of the secrets of the universe will be fathomed in laboratories on Earth, and the progress of our science and technology and the welfare of the Nation require that our regular scientific programs go forward without loss of pace—in fact, at an increased pace. It would not be in the national interest to exploit space science at the cost of weakening our efforts in other scientific endeavors. This need not happen if we plan our national program for space science and technology as part of a balanced national effort in all science and technology.

FOUNDATION PROGRAM

The National Science Foundation feels that it can contribute to the future of space technology in a useful way by supporting, as part of its continuing program of basic research, sound and imaginative projects that serve to indicate some of the potentialities of space technology. For example, in my testimony before your committee last spring I commented that—

> undoubtedly the most important opportunity that astronomy has ever had will be the setting up of a fair-sized astronomical telescope on a space platform so as to observe the heavenly bodies for the first time clearly and without interference from our atmosphere, and to study their complete spectra.

STRATOSCOPE I AND II

The possibilities of astronomical research beyond the bulk of the Earth's atmosphere have already been demonstrated in a dramatic way by an Office of Naval Research project, Stratoscope I, in which a special 12-inch Sun telescope camera made two unmanned balloon flights to a height of about 80,000 feet and took photographs of the Sun's surface which were unprecedented in clarity and detail. The success of this venture encouraged the projection of Stratoscope II—a balloon to be equipped with a 36-inch telescope and a television link, with control of the telescope from the ground, for remote-control pointing of the telescopes at celestial objects. The Stratoscope I instrument will continue to be used for solar research. Stratoscope II will be used for high-resolution photography of objects other than the Sun, such as the planets, galaxies, and nebulae. Stratoscope II is now the subject of a design study which will probably require the remainder of 1958 and 1959, with construction to take place in 1960. Stratoscope II's first flight is scheduled to take place in the summer of 1961. The National Science Foundation has made a preliminary grant of $285,000 for the early stages of this project.

STRATO-LAB PROGRAM

Similarly, the Navy's Strato-Lab program is expected to yield important new data regarding the planets. This new program of astrophysical research is currently being inaugurated by a manned, 80,000-foot altitude balloon flight for the purpose of determining the water-vapor content in the Martian atmosphere. A second flight, planned for early 1959, will investigate the oxygen content of Mars, and later flights will observe other planets. Clearly, data about the surface and atmospheric conditions of the planets will prove most valuable in connection with the planning of future flights to these planets. The Office of Naval Research is the principal sponsor of this series, but the Foundation is supporting the initial project to the extent of $40,000. The work being done under the Strato-Lab program is essentially astrophysical, while that being done under the Stratoscope program is optical in nature. The findings of these two programs will undoubtedly complement each other and contribute in a valuable way to our storehouse of knowledge about our nearest neighbors in space.

In anticipating the future of space research and space travel, we should not overlook the significant research that is going on now as a result of the new instruments at hand. The United States can take pride in its work in rocketry and rocket instrumentation—fields in which it has led the world. Explorer III resulted in the discovery of the Van Allen radiation belt, made up of electrons and other charged particles. As a result of these intial observations, we knew such a belt was there but we did not know what it was or how extensive it was. Explorer IV analyzed the nature of the Van Allen belt, and from Pioneer we learned its extent. The importance of these discoveries is, of course, obvious. We now know that the Earth is surrounded by lethal layers of radiation that probably killed the dog, Laika, and would undoubtedly prove equally fatal to human beings attempting space travel. Now that we know the nature of the danger, we can guard against it.

Although the United States still lacks the capabilities for placing in orbit satellite vehicles of the size and weight of the Russian satellites, we are capable of doing this other type of thing any time we wish to. We never know when such research may produce another major discovery.

WORD OF CAUTION

One word of caution may be in order, however. In exploring outer space with the satellites and rockets presently available, it is possible that we may find something on which it would be possible to capitalize in an important way. If we do make such discoveries, however, we must investigate them very carefully before capitalizing on them, in order to be sure that we do not produce some unexpected and cataclysmic effect on nature.

An illustration of this point occurred in the first contemplated experiment of a nuclear explosion. The question was: Is there any possibility of this novel release of energy detonating the atoms of its surroundings, the Earth or the atmosphere adjacent to the bomb? The possibility was examined carefully and the evidence found to be overwhelmingly in the negative. Nuclear scientists could therefore proceed with their research, secure in the knowledge that they were not likely to produce some unlooked for and catastrophic side effect.

One further point has, I am sure, been apparent to you from the beginning, and that is that the whole future of space technology depends in an important way upon the close cooperation of Federal agencies, both civilian and military, and the scientific community. The fact that as a nation we have chosen to place the future of space development under a civilian agency—the National Aeronautics and Space Administration—is a clear indication that our primary interest in exploring outer space is scientific rather than military.

Since, however, we cannot afford to ignore the military implications in the study of the advance of space technology, the creation of the Advanced Research Projects Agency within the Department of Defense assures full attention to those aspects of space research which are directly related to the military defenses of this country. It is likely that we shall continue, for some time to come, to depend on rockets developed by the military services for the propulsion of satellites and space vehicles. The development of nuclear fuels as an addition to, or supplement for, chemical fuels is part of the broad nuclear research program being carried on on many fronts under the sponsorship of the Atomic Energy Commission.

SPACE SCIENCE BOARD

As the result of a recommendation made by the National Science Foundation to the President of the National Academy of Sciences, the Academy appointed, last August, a 16-member Space Science Board within the Academy. Thus we are assured that the scientific community plans to participate actively in "studies of scientific research opportunities and needs opened up by the advent of modern rocket and satellite tools, advice and recommendations on space science to interested agencies and institutions, stimulation of research interest in this area with academies and similar institutions abroad."

The wide diversity of support, as well as the number and variety of agencies and institutions participating in our space research effort, are an indication that it will go forward in an imaginative but balanced way and without neglect of the fundamental research that we must continue to carry on in laboratories on the Earth and by more conventional methods of upper-atmosphere research, such as rockets, rockoons, and manned and unmanned balloons. Meanwhile, I believe we may observe with profit the final admonitory word of the Science Advisory Committee that "it * * * appears wise to be cautious and modest in our predictions and pronouncements about future space activities—and quietly bold in our execution." * * *

Dr. Harold C. Weber, Chief Scientific Adviser, United States Army, Washington, D. C.

In an estimate of the probable progress to be made in space technology during the next decade, one can be sure he will be accused of being either too conservative or too radical, so great is the spread of opinions even among those technically competent.

Possibly the greatest disagreement arises concerning the probability of placing man on the planets, the Moon being the one usually discussed because of its close proximity to the Earth. Although the placing of man on the planets would be an outstanding scientific accomplishment from which much could be learned, such a feat is not necessary to determine many of the facts we wish to learn about the Moon and space in general. Through scientific ingenuity, devices can be built to send back to Earth, either continuously or intermittently, any information desired—even a television picture, if this is deemed worthwhile. It seems quite certain a human passenger will reach at least the vicinity of the Moon during the next 10 years. The psychological importance of such an experiment is, of course, plainly evident.

As of today, we know a great deal about outer space unknown just 2 or 3 years ago. We know the density of solid and gaseous matter out there, the kinds and magnitudes of radiation there present, the magnetic and gravitational fields, the temperature, and a host of other facts.

A lunar-probe vehicle to encircle the Moon and return to Earth will certainly be an accomplished fact in a relatively few years, at the most. Probes to other planets, either to relay information back or, if desired, to return to the Earth, will follow.

IMMEDIATE RESULTS

It is difficult completely to evaluate the magnitude of the knowledge we will get from the study and exploration of outer space. That we must lead in this important new development goes without saying, so important are the results to be obtained.

Immediate results will be:

(1) More accurate maps of the Earth. It is surprising how inaccurate even our best maps of the world are.

(2) Worldwide communications on a reliable scale through the use of properly placed communication satellites.

(3) Greatly increased amounts of information concerning weather and the formation of weather patterns, with the hope that long-range forecasting can be accomplished accurately and that perhaps even some slight control over weather patterns may be exercised.

(4) Greatly increased knowledge concerning the composition and probably the life history of the universe.

(5) Ability to perform quantitative experiments on a grand scale in outer space which will contribute new knowledge to our understanding of matter, energy, and time—concepts so fundamental to our understanding of what goes on around us on our own planet.

Concerning power sources for future space exploration, one finds scientists are already deeply engrossed in discussions and experiments on ion propulsion and atomic power for space craft. Magnetic effects are being reviewed with an eye to using them in space travel. The whole subject of plasma jets is receiving the most careful attention.

Truly space experiments offer a whole new vista to scientists—and remember what science uncovers is eventually put to practical use by man. Our only question is as to whether the use is for practical good or practical evil. Let us make sure it is for the good of mankind by being certain it is the United States and its allies who lead in the development of space technology.

DR. FRED L. WHIPPLE,[1] DIRECTOR, SMITHSONIAN INSTITUTION ASTROPHYSICAL OBSERVATORY, CAMBRIDGE, MASS.

1. Within 10 years, sophisticated weather satellites will observe the Earth continuously and, with the aid of electronic computing machines, will have made possible an improved theory of air circulation to produce a real understanding of weather and reliable methods of forecasting. General long-range forecasting for periods of a month or two over large areas will be fairly well established. Spot forecasting for a specific time and place will still present a great deal of difficulty, and can be attained with considerable precision only with extra effort.

2. Communication satellites will be of considerable value for worldwide broadcasts and, possibly, for transmission of transoceanic television.

3. The Earth's size, shape, and the distribution of its internal mass will have been determined with a precision one order of magnitude greater than present values. This process will include the interlacing of geodetic networks from one continent to another and precision positioning of island masses where gravitationl anomalies are large.

4. The Earth's upper atmosphere and nearby space will be thoroughly charted. We will know the basic facts as to temperature, pressure, density, electron content, and magnetic fields as functions of altitude and longitude. We will also be able to predict variations in these phenomena and possibly, to correlate them with diurnal and seasonal variations, as well as with solar effects. The information will include the knowledge of the danger zone of high-energy electrons, the character and extent of the solar corona, as well as the nature of corpuscular radiation from the Sun.

Solar terrestrial relationships will have been much more thoroughly explored, and certain relationships between broad circulation patterns in the atmosphere and solar variations will have become much better understood.

5. Our knowledge of meteors throughout the entire range from dust to huge fireballs will have been enormously increased, so that we can predict their occurrence, both on the Earth and for space operations, on a sound statistical basis. Such information will have added immeasurably to our understanding of comets, which probably are fundamental bodies in the origin of our solar system.

6. Equipment will have been safely landed on the Moon to set up a remote-controlled observatory which will have told us a great deal about the nature of the lunar surface, magnetic fields, if present, and particularly the origin of the Moon. The back side of the Moon will have become as well known as the near side.

7. Space probes beyond the planet Mars and within the planet Venus will have extended our knowledge, not only of these planets, but also of the interplanetary medium at greater distances from the Earth. The question of the nature of life on Mars may have been settled, although instrumental landings may still not have been fully successful within 10 years. The mystery of the character of the Venusian sur-

[1] EDITOR'S NOTE.—In collaboration with Drs. R. J. Davis, G. S. Hawkins, R. E. McCrosky, G. F. Schilling, and C. A. Whitney of the Astrophysical Observatory scientific staff.

face will have been solved by a combination of high-altitude telescopes, space-satellite telescopes, and space probes in the vicinity of Venus.

8. The great increase in our information concerning the nature of the Earth's interior, the nature of the Moon, and the more detailed observations of Mars and Venus, combined with our more exact knowledge of comets and meteors, will lead to a clear-cut, almost unambiguous understanding of how the plants evolved. This information, coupled with the answers to more basic questions of life on the nearby planets, will be of immense value in philosophical problems concerning man's place in the universe.

9. From the point of view of astronomical "housekeeping," a number of fundamental quantities, such as the solar distance, the lunar distance, the dimensions of the planets, the masses of the planets, and other measurable quantities, will be far better established than today.

10. Telescopes in space, to observe the solar system in particular as well as the stellar universe in general, will have brought in a wealth of new facts that may well revolutionize our concepts of the cosmos. Very possibly, this new information will eliminate large classes of theories relating to the evolution of the universe, and will certainly tell us a great deal more about the growth, development, aging, and death of stars. Similar problems with regard to galaxies will be much closer to solution.

11. A breakthrough in the utilization of nuclear power for space travel can be expected at any time, and may well have developed within 10 years. In any case, our increased knowledge from space telescopes concerning nuclear reactions in stars will be of immense value in peaceful applications of nuclear power on the Earth. Of particular importance will be our increased understanding and the probable solution of some basic problems in magnetohydrodynamics, a field of vital importance from the theoretical standpoint, as well as from the practical viewpoint, of nuclear power.

12. A number of problems in basic physics will have been solved or better understood, particularly such questions as relativity effects, clock rates, uniform time, absolute time and other physical concepts that can be better studied in lesser gravitational fields than those on the surface of the Earth, or those that involve the utilization of gravitational fields in free space.

13. Perhaps the most important advance, for mankind and our modern civilization, will be the improvements in many areas of technology which will result from the development of space science, and from the establishment of the background logistics for space science. These developments will be numerous, although many of the most important will not be revolutionary in character but in the form of improvements; of striking potential is the remote-controlled robot for carrying out dangerous assignments, both on Earth and in space.

14. Unexpected, even unimagined, developments both in technology and pure science will probably overshadow the predictions made above.

DR. HERBERT F. YORK,[1] CHIEF SCIENTIST, ADVANCED RESEARCH PROJECTS AGENCY, DEPARTMENT OF DEFENSE, WASHINGTON, D. C.

The following outline gives my estimate of what we will accomplish over the next 10 years in the fields of space technology, space science, and space exploration. It is based on the assumption that expenditures will average, very roughly, $1 billion per year, and that vigorous related programs of a military nature, such as the missile and high-speed aircraft programs, will continue at more or less their present rate.

This paper does not attempt to justify these goals, but assumes, in line with the writer's firm beliefs, that they are all very much worth while.

I. VEHICLE TECHNOLOGY

A. Payloads

The sequence of maximum low altitude satellite payload capability will be approximately as follows, with the time interval being that in which the payload indicated will first become possible. The figures are based on the assumption that chemical rockets will remain the backbone of our capability, and that, in the later years, "ordinary" fuels will be used in the first stage, and "superchemical" fuels will be used in upper stages:

1959: Maximum *useful* payload about 4,000 pounds
1960 to 1962: Maximum *useful* payload about 8,000 pounds
1962 to 1964: Maximum *useful* payload about 20,000 pounds
1964 to 1968: Maximum *useful* payload about 50,000 pounds

B. Man-in-space capability

Within the next few years we will have achieved, in a minimal way, our first objective of safely orbiting and returning a manned capsule for the purpose of determining man's reactions to the space environment and man's capability of performing useful functions in space. By the end of the next 10 years, we will have developed more sophisticated manned vehicles which are capable of maneuvering in space, making rendezvous with other satellites, and maneuvering in the atmosphere following reentry. The space pilot, on return, will be able to land at an airstrip on the Earth more or less of his own choosing. Man will be performing numerous essential tasks in connection with the various missions and applications given below.

C. Other-than-chemical propulsion systems

Some one or more advanced propulsion methods, such as nuclear rockets, solar boiler rockets, ion rockets, or plasma jets, will probably be coming into limited specialized use toward the end of the next 10 years.

D. Power supplies

Solar batteries, solar boilers, nuclear reactors, and perhaps radioactive heat sources will all be in use during this period.

[1] EDITOR'S NOTE.—Dr. York's paper bears the endorsement also of Roy W. Johnson, Director, and Rear Adm. John E. Clark, Deputy Director, of ARPA.

II. APPLICATION OF SPACE FLIGHT CAPABILITY

A. Practical applications

1. Reconnaissance: The use of satellites for strategic and tactical reconnaissance, and surveillance is obvious and of very great military importance.

2. Communications: The application of satellite relay stations in long-distance communications will begin in the next few years. By the end of the period I expect that satellites will constitute the principal means of intercontinental communications.

3. Very early warning: The use of satellites to supplement, or even virtually replace, ground-based methods of obtaining early warning of a missile attack is also obvious. Well within the next 10 years it should become one of the keystones of our defense system.

4. Meteorology: The use of satellites in the study of meteorology has been much discussed. This application will probably revolutionize the science of meteorology and weather prediction within the next 10 years.

5. Navigation: Satellites can, and will, become one of the principal aids to navigation for sea, air, and perhaps, space craft.

6. (?): Within the next 10 years we may expect other practical applications to be either invented or discovered. One of these presently unknown applications, which may be either civil or military in nature, may very well be more important than any of these listed above.

B. Scientific applications

1. Environmental studies: These will include studies of the Earth's upper atmosphere (composition, ionization, etc.), the chemistry of space, the number and chemistry of meteorites, the details of the Earth's magnetic and gravitational fields, the radiation belt, etc.

2. Studies in which the Earth's atmosphere, magnetic field or gravitational field constitutes a serious interference for ground-based research: These include for example, astronomy, in which case the atmosphere absorbs all of the radiation from the Sun and stars in the ultraviolet and certain other wavelengths of interest; and furthermore, causes the stars to twinkle. It also includes cosmic ray studies, in which case the Earth's atmosphere absorbs or changes the form of the incoming radiation, and in addition, the radiation is greatly perturbed by the Earth's magnetic field. A great many proposals for the use of satellites for this kind of scientific work have been made; no further elaboration is necessary here.

C. Exploration of the Moon and nearby planets

Minimal space probes will be sent out within the next few years to obtain data by closeup observation of the Moon, Mars, and Venus. These will be followed by more sophisticated probes, some of which will orbit and some of which will land, nondestructively, on these bodies. These automated probes will eventually be followed by manned vehicles which can land and return. In the case of the Moon, a manned exploration could take place in just about 10 years (perhaps in as little as 7, if a very high priority were placed on this goal). In the case of Mars and/or Venus, manned exploration will not take place until a few years after 1968 (but could perhaps be done in just about 10 years if a very high priority were placed on this goal).

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