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Space Handbook:

ASTRONAUTICS AND ITS APPLICATIONS

By ROBERT W. BUCHHEIM
and the Staff of
THE RAND CORPORATION

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FOREWORD

This handbook was prepared by The RAND Corporation for the Select Committee on Astronautics and Space Exploration, House of Representatives.

In the words of the committee, "A real need has been felt for an authoritative study in lay terms which would set forth clearly the present and definitely foreseeable state of the art of space flight. The committee, after careful consideration of alternatives, requested The RAND Corporation of Santa Monica, Calif., to undertake such a study. Under contract with the United States Air Force, RAND scientists and engineers have been in the forefront of objective investigation of such problems since World War II. RAND's reputation for integrity and independence particularly commended this nonprofit organization to our attention.

"The report which follows . . . represents the most comprehensive unclassified study on the subject now available. The report is confined to technical and scientific analysis, avoiding expressions of opinion on policy and administrative matters. It studiously avoids borderline speculative judgments on the pace of future development."

In accepting the report, the Select Committee passed a special resolution commending The RAND Corporation.

Preparation of the report was under the direction of Robert W. Buchheim, now head of the Aero-Astronautics Department in the Engineering Division of The RAND Corporation.

The report was forwarded on December 29, 1958, to the Honorable John W. McCormack, Majority Leader, and Chairman, Select Committee on Astronautics and Space Exploration, by the Committee Director and Chief Counsel, George J. Feldman, and Assistant Director Charles Sheldon II. The present volume has been revised, corrected, and brought up to date in the light of developments during the first two months of 1959.

The work of preparing this report was undertaken by The RAND Corporation with its own funds in the public interest. The views expressed in this handbook are not necessarily those of the United States Air Force or of the committee or any of its members.

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Introduction

A. Historical Notes

The early history of space flight is really the history of an idea deeply imbedded in the general stream of development of human thought about the nature of the universe. The notion of flight to the Moon followed almost instantaneously upon the arrival of the idea that the Moon might be another solid sphere akin to the Earth. The evolution of these speculations from ancient times is treated in a fascinating manner by Willy Ley, an acknowledged historian of astronautics.[1]

The first glimmer of a chance to convert fanciful notions of extraterrestrial flight into an idea with engineering significance came with the invention of the rocket.

The first applications of rocket propulsion were, with little doubt, military, and rockets have had a long and varied career in military service, mostly as on-and-off rivals of artillery.

The current feasibility of space activities is clearly the product of modern weapons developments, the first substantial step having been taken in the German V-2 program.[2] This beginning has been greatly extended in the intermediate range (IRBM) and intercontinental ballistic missile (ICBM) programs in the United States and the Soviet Union.

For most of their long history, military rockets were viewed as "gunless artillery" and estimates of their merits were based on comparisons of their performance with that of competing artillery pieces. Only rather recently have rockets been looked upon as devices applicable to a class of activity far removed from anything achievable by artillery projectors; they are now more nearly rivals or companions of long-range bomber aircraft.

It is interesting to note that Maj. J. R. Randolph, an officer of the United States Army Reserve, deduced 20 years ago that the rocket has two likely applications: as gunless artillery, and for bombardment over intercontinental ranges.[3] His assessment, with respect to the application now labeled "ICBM," was based on data developed by investigators interested in interplanetary flight.

Major Randolph also suggested the possibility of using large liquid-propellant rockets of ICBM class as boosters for manned intercontinental bombing vehicles—a notion now being implemented in the Dyna-Soar program (see p. 178). These ideas about rockets are a strikingly good broad outline of the more detailed program developed at Peenemünde for extension of German rocket development to intercontinental scope.[4, 5] There have been suggestions that this general theme has also been operative in U. S. S. R. development planning.[6]

Military and peaceful application of rockets was pioneered in the United States by Dr. Robert Goddard, who was in charge of War Department rocket work during World War I. Dr. Goddard advanced the state of the rocket art in many ways in the twenties and thirties, and saw the great potential for scientific experimentation inherent in rocket propulsion as a means of reaching altitudes otherwise unattainable.[7]

The principal early work in the technological field of space flight was done in Russia, Germany, and the United States. The chief United States effort was that of Goddard. The early German work was done by H. Oberth, beginning in the 1920's. Russian efforts commenced at a substantially earlier date, giving them a clear and valid claim to a "first." Russian activity began with the work of Meshcherskii and Tsiolkovskii near the end of the 19th century.[8, 9] Tsiolkovskii is generally recognized as the father of astronautics. Considerable work, both theoretical and experimental, was accomplished in the U. S. S. R. in the 1920's and 1930's.

Serious and substantial Government-sponsored rocket-research programs were established in Germany in about 1930, in the Soviet Union sometime in or before 1934, and in the United States in 1942. The astronautical activities of the

United States and the U. S. S. R. will be discussed in greater detail below.

B. General Nature of Astronautics

Even in its present early and uncertain state, astronautics has important implications for a very wide variety of human activities.

In the most immediate and practical sense, astronautics is a very large engineering job. Equipments and facilities, often requiring substantial advances over current practice, must be designed and built. Severe environmental conditions and demands for high reliability over very long periods of essentially unattended operation will require uncompromising thoroughness and extensive testing. Bold imagination and painstaking attention to detail must be the twin hallmarks of engineering for space flight.

Engineering action can be founded only on scientific knowledge. The scientist must support the engineer with adequate data on the many aspects of space environments, and with a growing body of fundamental knowledge. Astronautics can furnish unparalleled new opportunities to the scientist to explore and understand man and his universe. Space vehicles can carry the scientist's instruments—and eventually the scientist himself—to regions otherwise not accessible to gather information otherwise unattainable. Astronautics presents the life sciences with two particularly challenging prospects: the problem of maintaining human existence outside the narrow living zone at the Earth's surface, and the possibility of encountering living things on other planets.

The departure of man and his machines from the very Earth itself is bound to have a profound influence on human thought and the general view of man's place in the scheme of things. His findings on other worlds can be expected to influence the broad development of philosophy to a degree comparable to that resulting from the invention of the telescope, whereby man discovered that he was not actually the center of the universe. Perhaps astronautics will show man that he is also not alone in the universe.

These and other aspects of the revolutionary nature of extraterrestrial exploration have prompted serious theological discussion. Implications of space flight with respect to Christian principles are matters of lively interest. As early as September 1956, Pope Pius XII formally stated that space activities are in no way contradictory to Church doctrine.[10]

The statesman, endeavoring to promote world peace, can see both a hope and a threat in astronautics. International cooperation in space enterprises could help to promote trust and understanding. Astronautics can provide physical means to aid international inspection and, thereby, can help in the progress toward disarmament and the prevention of surprise attack. Astronautics can also lead to military systems which, once developed and deployed, may make hopes of disarmament, arms control, or inspection immeasurably more difficult to fulfill.

International cooperation in astronautics is imperative simply as a matter of efficiency. Scientific space exploration cannot reasonably be done in isolated national packages. The long history of astronomy as an international science clearly demonstrates the point. Observation of natural celestial bodies, which (as viewed from the Earth) are permanent and relatively slow moving, has required the closest kind of international collaboration. The observation (not to mention creation and retrieval) of artificial celestial bodies, transient and fast moving, will place even heavier, more urgent, demands on international cooperation.

There is also obvious need for international cooperation in such matters as agreement on radio frequency allocations for space vehicles; and on rights of access to, and egress from, national territories for recovery of vehicles, particularly in cases of accidentally misplaced landings of manned vehicles.

Astronautics raises substantial questions of law, both international and local. The important issues of international agreement on space access and use must be afforded the most thoughtful sort of attention. Legal factors of a more conventional nature are also inherent in astronautics. Large tracts of real estate will be required for operations and testing, for example. The physical needs of astronautics are, therefore, a matter of important concern also to the civic planner—somewhat in the manner of airports and marine facilities.

Astronautics is inherently a high-cost activity that will clearly have an important impact on Government expenditures, taxes, corporate profits, and personal incomes. For the future, it may hold considerable promise of substantial economic benefits—astronautics is an entire new industry.

In astronautics lies the possibility of improved performance in important public and commercial service activities: weather forecasting, aids to navigation and communication, aerial mapping, geological surveys, forest-fire warning, iceberg patrol, and other such functions.

For national security and military operations, astronautics holds more than new means for implementing standard operations like reconnaissance and bombing. It suggests novel capabilities of such magnitude that entirely new concepts of military action will have to be developed to exploit them. As an obvious parallel, airplane technology has come a long way since Kitty Hawk; but the military thinking that determines the role of aircraft in national arsenals has also come a very long way indeed. A similar companion development of technology and military concepts can be expected to occur in astronautics also—but we can no longer afford the comparatively leisurely pace of adjustment that characterized the thinking about aircraft.

Astronautics has another important military dimension if "military" is interpreted in the broad sense of an organized, trained, and disciplined activity. It is hard to conceive of space exploration efforts such as manned voyages to Mars, involving many months of hazard and hardship, being undertaken by any but a "military" type of organization.

Astronautics is the sort of activity in which anyone can find means for satisfying personal participation. The work of amateurs in optical and radio observation of satellites has already been of great value, and there is no reason to believe that amateur activities in astronautics will not take a place alongside and within such vigorous hobbies as amateur radio and amateur astronomy.

Astronautics is bound to have an important impact on education. The broad nature of the problems to be faced will require not only specialists, but minds trained to cut across and exploit various classical disciplines.

C. Current State of Space Technology

The physical assets of the United States and other countries in astronautics now reside in large measure in military activities. More specifically, these current assets lie mainly in ballistic-missile programs.

The space flight capabilities that can be built on ballistic-missile assets are very extensive, indeed. The greatest of these are derivable from ICBM hardware. Adaptation of these vehicles to accommodate specially developed additional equipment will permit us to do the following:

(*a*) Orbit satellite payloads of 10,000 pounds at 300 miles altitude.

(*b*) Orbit satellite payloads of 2,500 pounds at 22,000 miles altitude.

(*c*) Impact 3,000 pounds on the Moon.

(*d*) Land, intact, 1,000 pounds of instruments on the Moon.

(*e*) Land, intact, more than 1,000 pounds of instruments on Venus or Mars.

(*f*) Probe the atmosphere of Jupiter with 1,000 pounds of instruments.

(*g*) Place a man, or men, in a satellite orbit around the Earth for recovery after a few days of flight.

All of these and other feats can be accomplished by starting with basic rocket vehicles now in development in this country. None, however, will come from the ballistic-missile programs directly. All require additional work of a very substantial nature. With diligence and reasonable luck, the overall rocket machinery necessary to attempt any of these flights could be available in a few years—probably less than five. Rocket capabilities of roughly the same order can reasonably be assigned to the U. S. S. R. in this period also—perhaps more.

At some point in the next 5 years the effect of larger engine developments should make itself felt; so we can already look forward to the day when the payloads listed above will be five to ten times greater.

These basic vehicle capabilities reflect the status of (*a*) chemical propulsion systems (mainly systems using liquid oxygen and kerosene); (*b*) vehicle structural materials, design techniques, and fabrication methods; and (*c*) vehicle flight stabilization (autopilot) methods. Much remains to be done in these fields, but a solid footing has been established.

Other fields, in various states of advancement, must also be considered, however, to obtain a full view of our current standing.

While knowledge of the space environment is uncertain in many respects, no important barriers stand in the way of unmanned flights. So far as manned flight is concerned, no such definite statement can be made—partly because the requirements for human survival are much more severe than for instruments, partly because instrument flights can be one-way while manned flights must be round-trips, and partly because the human risk attached to mistakes is great for manned flight.

Accurate guidance of space vehicles over interplanetary ranges may require improvement in current knowledge of basic astronomical constants.

Performance of current guidance and navigation equipment is probably adequate for most satellite and lunar flight missions, but probably not at all adequate for flights to the planets.

Systems to control the orientation of space vehicles during free flight are (except for spin stabilization) in the untested and uncertain category.

Communication between space vehicles and Earth stations is rather easy to maintain in satellite or lunar flights. Communication as far as Mars seems reasonably attainable, but at much greater distances current possibilities become questionable.

Observation and tracking of vehicles will also be comparatively easy on satellite and lunar flights, and possible, with decreasing precision, to about the same ranges that apply for low-capacity communication systems—Venus and Mars, or beyond—with today's technology.

Techniques for high-speed penetration of the atmosphere, based on ballistic-missile re-entry developments, are adequate for nondestructive landings of instruments on Earth, Mars, or Venus. Methods are available for withstanding the shock of landing on planets or on the surface of the Moon.

Internal power sources now available are probably adequate for low-power applications over extended periods of time, or for short-time operation at moderate power levels. Sources suitable for large amounts of power over long periods of time are yet to be developed. Supply of internal power is one of the major problem areas.

A problem area that cannot be overemphasized is that of reliability. It is utterly meaningless to talk about flights to Mars if the equipment to be sent there has no reasonable probability of continuing to work for the duration of the flight and for a useful period after arrival. Keeping modest amounts of equipment working, unattended, for many months is possible, but it requires good knowledge of the environment, careful design, and extensive testing.

Electrical propulsion systems that can provide continuous thrust in the space environment are being investigated. All of these require extremely large amounts of electrical power—thousands of horsepower—making the already important problem of internal power supply even more prominent by consideration of such devices. Until one of these electrical propulsion systems is developed, all flights in space will be unpowered ballistic flights, with perhaps occasional spurts of corrective thrust from conventional chemical rockets.

The broad needs for sustained manned flight in space can be stated rather simply: Large launching rockets, extensive and highly reliable space-vehicle equipments, a great deal of experimentation and study, and, above all, actual flight trials in manned satellites or similar vehicles.

D. Action Considerations

A brief appreciation of the above remarks on technological status would be just this: Large-scale space exploration is imminently feasible with the beginnings now in hand; its actual accomplishment will require a great deal of work.

The value of a vigorous space program—and the urgent need for one—rests on many considerations, including moral, economic, scientific, defense, and international cooperation. The various objectives pertinent to these areas are closely related in themselves and in the kind of devices needed to implement them. A class of device that is "scientific" when it is originally planned may be "military" when it becomes a reality, and vice versa. There are, of course, always distinctions that can be drawn on the basis of primary intent. This is a matter of human choice—the machinery itself may not be changed much by shifts in purpose.

In trying to assess the value of a given space effort it is important to recall that new devices and methods must be examined not only for what they can do better than existing devices, but also for what they can do that now cannot be done at all. It is quite likely that astronautical devices will be found to be very poor competitors for many current conventional devices; much of the benefit is likely to lie in the doing of new kinds of things through astronautics. Practical realization of these ends is dependent upon our recognizing the unique capabilities in the field and developing (inventing, perhaps) the applications that make them useful. This is true in all the possible areas of interest. A space weapon will make no real contribution to national defense unless it is accompanied by a clear concept of useful employment—an innovation in military science must be sought in some cases. The physical capability for worldwide live television by satellite relays is a hollow thing without a complex set of plans and agreements that put suitable receiving sets in the homes on the ground and attractive program material into the transmitter. The opportunity to put scientific instruments into space is of only minor importance if it is not adequately supported by attention to basic theory and laboratory research on the ground.

Some of the unique opportunities that seem to lie in astronautics and are of obvious importance include the ability to do the following:

Carry scientific instruments out of the atmosphere and away from the Earth's magnetic field to permit greatly improved observations of remote regions of space, to advance basic understanding of some of the great fundamental questions about the nature of the universe and its large-scale processes.

Carry scientific instruments, and eventually people, to the planets and other bodies in the solar system for direct exploration of their physical make-up and, perhaps, of their indigenous life forms.

Permit studies of the behavior and evolution of terrestrial biological specimens in environments grossly different from that on Earth.

Enhance understanding of the physical properties of the Earth by viewing it from the vantage point of space to supplement surface observations.

Provide meteorological observations of global scope to improve understanding of weather processes, with a long-range hope not merely of better forecasting but eventually of some form of weather control.

Provide useful navigation beacons with global coverage independent of weather and time of day.

Provide large-scale radio broadcasting facilities, long-range point-to-point communications without elaborate, slowly constructed ground facilities; reliable communication at low power levels with fixed or vehicular stations; and point-to-point communication over long ranges at low power levels to conserve the already crowded radio frequency spectrum.

Conduct detailed military reconnaissance of vast areas in a short period of time.

Conduct international inspection of vast areas in a short period of time.

Make possible various forms of interference with military attack-warning systems.

Deliver nuclear weapons from remote regions of space.

Opportunities for international inspection through astronautics could be of incalculable value to world peace and security. The military potentialities are vast—and they can be exploited for good or ill by any power with the resources and will to try. The more scientific-seeming applications may, in the long run, exert a more profound influence on the future than any of the others. The massive importance of early research in nuclear physics in the laboratory and observatory is now apparent beyond doubt.

Notes

[1] Ley, W., Rockets, Missiles, and Space Travel, The Viking Press, Inc., New York, 1957.

[2] Dornberger, W. R., V-2, The Viking Press, New York, 1954.

[3] Randolph, Maj. J. R., What Can We Expect of Rockets? Army Ordnance, vol. XIX, No. 112, January-February 1939.

[4] See footnote 2.

[5] Dornberger, W. R., The Lessons of Peenemünde, Astronautics, vol. 3, No. 3, March 1958, p. 18.

[6] See footnote 5.

[7] Goddard, R. H., A Method of Reaching Extreme Altitudes, Smithsonian Institution publication No. 2540, 1919.

[8] Krieger, F. J., A Casebook on Soviet Astronautics, The RAND Corp., Research Memorandum RM-1760, June 21, 1956; A Casebook on Soviet Astronautics—Part II, RM-1922, June 21, 1957.

[9] Krieger, F. J., Behind the Sputniks: A Survey of Soviet Space Science, Public Affairs Press, Washington, D. C., 1958.

[10] Address of Pope Pius XII to the International Astronautical Congress, Castel Gandolfo, September 20, 1956. See L'Osservatore Romano, September 22, 1956.