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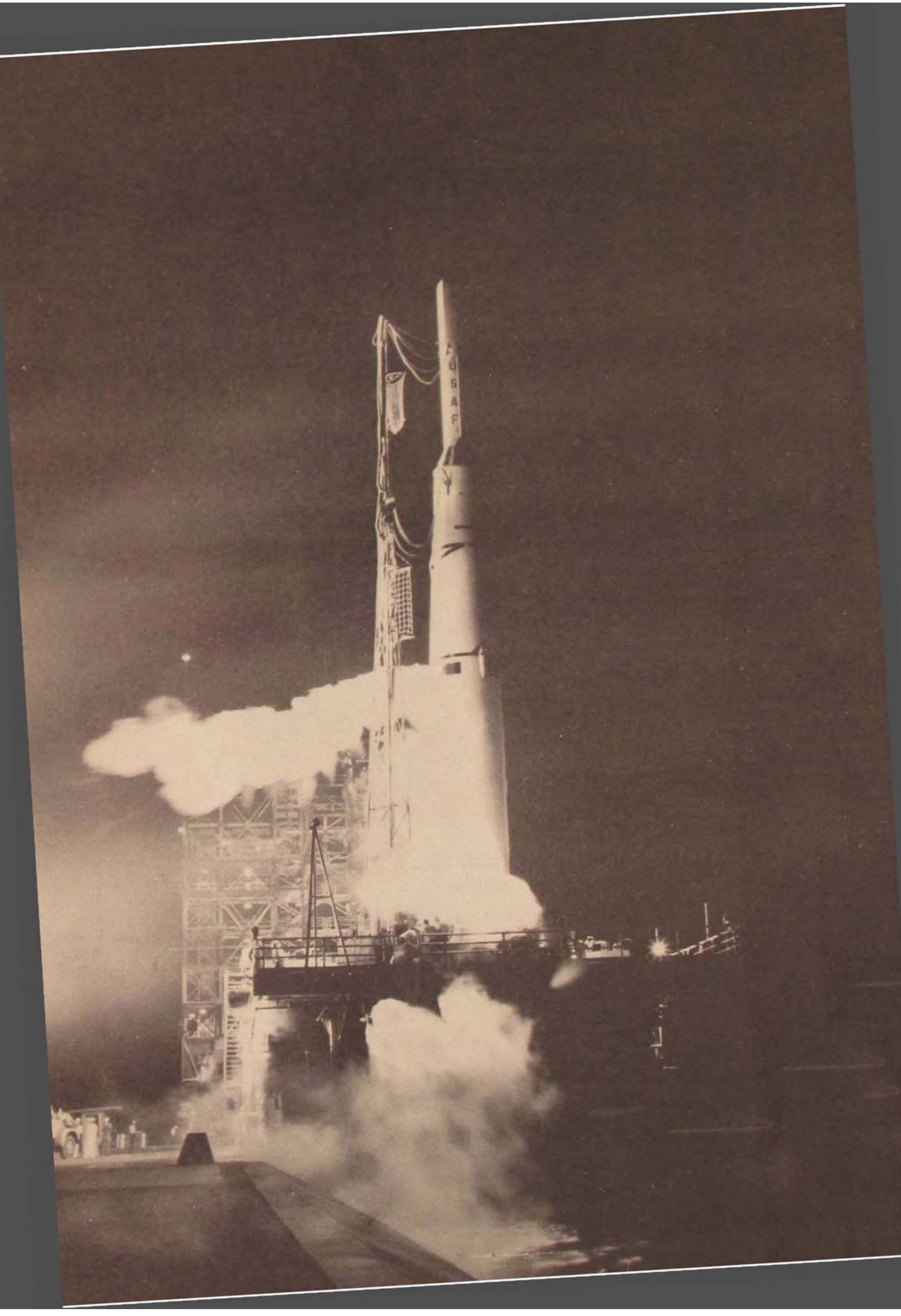

USAF

Science, Liberal Arts, or Both?

Brigadier General Cecil E. Combs

NOT many years ago, the part that education played in the career of the officer in the Army or the Navy was fairly simple. The service academies provided what, at the time, seemed an adequate grounding in the liberal arts, a degree of scientific literacy adequate to the operation of the weapons of the day, and enough experience with the hardware to permit a graduate to function effectively as a junior officer in a tactical unit or aboard ship.

Upon this basic education, actual service experience built a high degree of competence for the employment of troops, planes, and ships in action, and professional service schools provided specialized instruction in the art of logistics, planning, and the command and employment of larger units. Only a few officers finally attended the higher institutions of learning, such as the Army and Navy War Colleges where for the first time, and somewhat late in an officer's career, he was exposed to problems that went outside the field of military and naval operations.

This pattern, which I admit is oversimplified, has not met the requirements of the Air Force, even back in its early days. From the beginning, the problems of flight have required men who, if not in themselves scientists or engineers, were men with the scientific spirit of inquiry, and with an understanding of scientific method and an awareness of technical potential. We must remember that the phenomenal growth in military aviation has not been a technical advance forced upon unwilling military aviators but rather has been a response to the demands of these aviators, and, I might add, a response that has always been behind the requirement. Whatever one may say about the conservatism of the military mind, there can still be no question that the impetus to the development of military aviation has in large measure come from the farsighted recognition of its possibilities by the military aviators themselves—and this during a long period in which they were considered little better than visionary enthusiasts.

If this was true during the years of adolescence of air power, it is certainly even more important today. For example, the Air Force today expends annually for research and development a sum of money which exceeds the average annual appropriation to all the military services during the thirties. The administration of research and development programs of this size obviously requires on the part of the officers engaged a higher level of scientific competency than was ever heretofore necessary. Even though we contract with civilian institutions of learning, with research foundations, and with industry to perform most of our basic research, we cannot let, administer, or evaluate such contracts without a great deal of knowledge of what we are about, what results we hope to obtain, and what chances we have of success. True enough, we have many able and devoted civil servants working for the Air Force who help in these deliberations; but we must not forget that the Air Force Chief of Staff bears the ultimate responsibility for the military decisions that have to be made and that he must depend upon the decisions of his officers at all levels. This is the responsibility which today requires that many of these officers be trained as scientists and engineers.

As weapon systems have grown so much more complicated, the operational readiness of these systems becomes more and more dependent upon the technical efficiency of maintenance. The desired technical competence seems to approach very nearly the quality of scientific know-how of the engineer who built the equipment. There are those who say that for this reason we should contract with the industry that builds the equipment to maintain it. Whenever we do so, we are to a certain degree passing on by means of a financial contract an essential part of our responsibility to defend the country. There is certainly a limit to which this process can be carried without an abrogation of that responsibility.

Education for a military career can no longer be confined to military operations. Many officers must have a high level of scientific competency to enable the Air Force to perform the roles and missions with which it is charged. Even the nonspecialized line officer must have sufficient scientific literacy to handle management functions that have been complicated by radically new weapon systems. Also leadership in the Air Force must rest on a broader base than narrow specialization. Military affairs are now so intertwined with national affairs that military leaders must meet dual demands: professional competence and real statesmanship. Brigadier General Cecil E. Combs, Commandant, Air Force Institute of Technology, sets the course of Air Force education toward both science and the humanities to prepare for "the continuing and increasing demands placed upon Air Force leadership."

It seems clear to me therefore that, to whatever degree technical readiness demands, we must possess those technical engineering skills within our own ranks or we cannot perform the roles and missions with which the Air Force is charged.

So much for the scientific and engineering aspects. I do not believe that these remarks will be considered exceptional by other than those fanatics who might wish to turn over the defense responsibility entirely to private industry. These remarks do not, however, entirely dispose of the problems. There is the related question of the degree of scientific and engineering emphasis that is needed in an officer's basic education. Some years ago, for example, the B.S. degree from West Point and Annapolis was considered by the engineering profession equivalent to a civil engineering degree from a good engineering school. This has changed as the service academies have broadened their curricula to include more needed breadth and coverage of the humanities and as the engineering schools have loaded more heavily the pure engineering content of their curricula. The same situation will probably hold with respect to the graduates of the Air Force Academy.

What is the degree of scientific literacy required of an average officer? By that I mean not a specialist but one who, like most of us, has spent most of his time in operational units or in general rather than special staff duty. Will the Air Force of ten years hence have a continuing need for the generalist? We know we will need specialists in great variety, but what about that traditional Jack-of-all-trades, the line officer?

A clue from industry and from our own experience may indicate the answer: the more complex the problem, and the greater the specialization, the more demanding has become the problem of management. Look at the vast increase of staff work that has resulted from more complicated weapon systems. This is not the mere operation of some Parkinson's law—there has been an actual increase in the problems of planning, coordinating, organizing, and supervising. These jobs may be assisted by mechanization, but, as usual, this will merely produce greater accuracy or speed; it will not lessen the load. To put it another way, we may hope for better quality from these processes, but we can only foresee a continuing increase in quantity.

These management functions, once simply considered part of the tasks of a commander, along with actual combat, have always been in the traditional fields of the line officer. The requirements for them have always largely determined what we might call the military virtues, with emphasis on those qualities which produce leadership and integrity and devotion to the task. These requirements will always exist, but are they enough? Simple courage and loyalty, rare nevertheless, might once have sufficed to make a general officer. These are things, by the way, which educators do not know too much about. But what are the things that education might do something about? What will these line officers and commanders need to know about things scientific in order to command and coordinate complicated scientific weapon systems? (I have left out the task of "employing" these systems on the assumption that if we are ever forced to that point the next task will be one of rebuilding a shattered world, and our current problem will have been replaced by a greater one.)

Such questions lead into problems which ultimately are explored by Headquarters USAF in its determination of the educational requirements of the airman. These are exceedingly difficult determinations, and in the process a great deal of consultation must take place. Some of the needs are immediately known to the commanders in the field and are obviously current needs. Others are equally apparent to the various staffs. Some needs are clearly tied to future requirements where the specific educational preparation involved is much more difficult to estimate. In addition, as I have implied, the matter of the general educational requirements for an officer in today's Air Force is an open question. Selected individuals from the professions are more and more called upon to exercise leadership at high levels where professional specialization is usually less important than the ability to lead and direct large enterprises. Thus we are faced with the growing need for more professional specialization in scientific areas, while at the same time the problems facing our leadership are such as will require a broader comprehension of national and international problems than is compatible with specialized courses of education.

For one thing, it seems possible that a baccalaureate degree, even in one of the sciences, may not provide a sufficient breadth of understanding of the various scientific disciplines which coalesce in a weapon system. For another, there is the alternative danger that breadth alone may be associated with a very superficial knowledge that could be more dangerous than ignorance. This danger lies in the fact that the nature of an officer's responsibilities limits somewhat the extent to which he can depend on outside advice. We do not hesitate to turn our medical problems over to a doctor, and when we do so we freely put ourselves in his hands and pass on to him the complete responsibility. At the various decision-making levels we must at least know our own limitations.

It is still an open question, therefore, and only a great deal of open discussion, to include a consideration of the kinds of jobs that line officers will fill, may help us to an answer.

On the other hand, we can easily foresee requirements which necessitate a continued or even greater emphasis on the study of the humanities. In those good old days of which I spoke the Army and Navy officers of the country had few occasions to be concerned about the impact of the cost of defense upon national resources. Not only were the military problems seemingly less urgent but the implications of those problems to the rest of the nation were very minor. This also, of course, has changed tremendously. We cannot open or close the smallest military installation anywhere in the country without immediate far-reaching political and economic repercussions. We cannot calculate our requirements without realizing that their magnitude nowadays is such as to compete materially with other aims and expectations of a free people. We can no longer go before Congress and talk of a pure military requirement. Should we do so, we would find ourselves so far out of the ball park that our budget estimates would be worse than useless. On the international scene more and more of our officers are put into positions in which they and their men are in a very real sense representatives of the Government of the United States in a foreign land.

With considerations such as these in mind there appears to be at least one conclusion we can accept without question: that any educational program designed to meet the needs of the Air Force must be designed to meet the continuing and increasing demands placed upon Air Force leadership. There was an old saying that West Point did not train second lieutenants—it trained generals. There is an element of truth in this statement which explains what I am talking about.

The educational program of the Air Force must be, in my opinion, sufficiently inclusive as to be concerned with what the Chief of Staff of the Air Force needs to know and what he needs to be able to do. No career development plan or career educational program can serve the needs of the Air Force and the nation unless it produces at least once every four years an officer qualified to hold down that job—not only that job but the two or three dozen other top jobs which call for three- or four-star generals. Few of these positions can be filled by narrow specialists, no matter how highly trained. Moreover, if these men are to be adequate and if the Air Force is to be able to count on adequate leadership, they must be the few best selected from the many potentially qualified. The choice of these leaders is obviously based on what men they are rather than on what they know. But what they are and what they know add up to what they will be able to do; and what they will have to be able to do is very clearly to be seen in the tremendous demands inherent in these jobs as we see them today.

This represents a change from past tradition, or rather an addition. The art of generalship used to be dependent on the knowledge of the capabilities and limitations of men and weapons under the varying conditions of land warfare. Despite the rules or principles of war, it was finally those heights of accomplishment and daring and sacrifice to which men could be led, driven, or inspired that really measured generalship. In aerial warfare it has been a similar story with an added emphasis on example. Men followed where they could not have been driven. This will still be a major criterion of the special knowledge required of our leaders. The leader must know what the job is, what the plane or other weapons will do, what the obstacles are to be overcome, and how. In short, he must have been there.

But aside from this problem, which is ageless, let us look again at the demands placed upon our leaders. Much argument has been made in recent years about civil-military relationship. Our government was deliberately designed to separate major governmental functions and powers and to provide that the major divisions of government should serve as mutual checks and balances. This system, while somewhat weakened by the experiences of two world wars, still exists both in form and in fact, and in peacetime it creates problems which were never foreseen by the Founding Fathers for the simple reason that they never contemplated the existence in peacetime of such large and permanent military forces as our security demands today. This system puts our military leadership in the middle between two opposing forces. It makes demands upon our leaders that seem to require not merely great professional competence but also a great measure of real statesmanship. Each Chief of Staff must be a great Chief of Staff, and in a sense this means he must have a great staff.

Recent thought-provoking studies have shown the magnitude of this problem. One such would see the answer in a complete withdrawal of the professional military from all save professional military interest. Another school of thought urges wide recognition of the fact that there are no purely military aspects of our problem and that the military must be citizens first and officers second.

How can such a problem be solved? Not by the edict of a Chief of Staff—or even of a President, but only eventually by the concurrence of the views of officers themselves on their duties as citizens and officers. And upon what can such a concurrence be gained soundly except upon a liberal and comprehensive understanding of historic forces and the realities of power and opinion? In short our professionalism like all others requires a liberal education—one broader than ever before and not to be found in any undergraduate curriculum. It is a need too great to be so easily met. It can only be met by a continuing process of education—self-education.

A great amount of this continuing education is going on, some of it formally and measurable, a great deal informally and on the job—a process of learning by living. Much of it, however, is without direction and lacks purpose and goal.

One of the purposes of this paper has been to indicate that this goal is not an easy one to discover. The problems indicated here can only be answered out of the breadth of experience of our most experienced people, as well as from the soundest intuitions of those who have pondered most about the future of the Air Force. It is my hope that such analysis of our experience and speculation as to our future bring to bear on this problem the wide attention and interest which alone can lead us to a wise solution.

Air Force Institute of Technology

The Spiral Toward Space

A QUARTERLY REVIEW STAFF STUDY

THE DAWN of the space age—at least for the general public—came on 4 October 1957 with the launching of the first earth satellite. Here was tangible, occasionally even visible, proof that man could put a vehicle outside the earth's atmosphere and use the laws of nature to keep it there.

To the airman the promise of the space age had perhaps been apparent some years earlier. But even he, caught up in the events of the present, is apt to lose sight of the broader patterns that mark more clearly the means by which man will expand his activities into interplanetary and eventually interstellar space. Even he, caught up in the almost concurrent development of the big missile and the application of this missile's power plant to the purposes of the earth satellite program, is apt to lose sight of the two parallel strands of vehicle development—the missiles and the aerodynamic systems. At their present stage both are married to the rocket engine for propulsion. As long as man must depend on the rocket's brief, violent surge of power to spring free of the earth's atmosphere or its field of gravity, probably both the missile and the aerodynamic vehicle will have useful roles.

But as the next major cycle of propulsion comes into being, perhaps in the form of packageable atomic power, and as a true space combat capability comes within reach—in terms of being able to operate in space against other craft in space as well as against ground targets—then it would seem that the aerodynamic vehicle would soon crowd the missile to the wall. For then the requirements that molded the airplane will be superimposed on those dictated for space flight by the laws of nature. The vehicle will have to be able not only to re-enter the atmosphere but to land at any of a number of points on the earth's surface. The vehicle will have to be able not only to fly a trajectory in space but to maneuver with intelligence and versatility, to make judgments and choices of a kind that come better from a human pilot than from the memory bank of a computer.

The first flight of the X-15, now scheduled for early 1959, serves as a reminder that the aerodynamic vehicle is moving apace the ballistic missile in controlled space flight. This is by no means an accident of technological timing, for the X-15 is the culmination of a distinguished family of rocket-powered research aircraft. Designed to fly at hypersonic speed and at altitudes up to 100 miles, the X-15 is a test not only of a machine but of man in a machine in space. The major objectives of the X-15 flights will be to study the effects of frictional heat during re-entry into the earth's atmosphere, the problems of stability and control at high speeds and altitudes, and the psychological and physiological effects on the pilot of weightlessness and of rapidly accelerated and decelerated flight processes. The X-15 may well be an historic landmark in the development of the aerodynamic space vehicle.

research concepts

In considering the point now reached in the state of the art of research aircraft, we might well think first of the role of research aircraft in relation to such ground test facilities as wind tunnels, high-speed sleds, and free-flight models. Although these ground facilities provide much valuable information, they have definite limitations in simulating the conditions of actual flight. For example, wind tunnels, now capable of surpassing for a fraction of a second the minimum speed necessary to propel a vehicle beyond the earth's gravity into space, provide important data on the heat problem of atmospheric re-entry; but it is impossible

The X-15 research aircraft, recently unveiled at the Los Angeles plant of North American Aviation, Inc., is undoubtedly a major milestone in man's aeronautical progress toward space travel. As part of the cooperative flight research of the USAF, the Navy, and the National Advisory Committee for Aeronautics, the X-15 will be used to study the aerodynamic, thermodynamic, and human problems of space flight. With the assistance of Major Arthur Murray and Mr. Chester McCollough of the X-15 Weapon System Project Office of Headquarters, Air Research and Development Command, the *Quarterly Review* considers the potential use of winged vehicles for space flight (as opposed to ballistic missiles), reviews certain concepts underlying research aircraft and their past application, sets forth the background of the X-15 program, and concludes with a word about "follow-on" projects.

to duplicate the size of the vehicle in wind-tunnel tests. Also, high-performance data are obtained only for short durations. Sled tests are useful in investigating such problems as escape at high speeds, but here limitations are imposed by the length of the track, which requires high starting and stopping accelerations in order to achieve the necessary speeds. Free-flight models provide helpful aerodynamic and thermodynamic information, but operations are on a small scale and yield only limited data.

Larger unmanned test vehicles, which are extremely expensive, may be used for essentially one data point in each experiment, and recovery of the vehicle for re-use is sometimes impossible. With the possible exception of sophisticated, remote-controlled vehicles, which would have the disadvantage of great expense and unwieldy complication, none of these tools is capable of investigating the flying qualities of an aircraft with a human input in actual environmental conditions.

Manned research aircraft obviously are not limited in full-scale simulation of flight conditions, since the craft actually enter the environment of flight. They do, however, have certain limitations. To design and build a research aircraft and to maintain the organization necessary for research testing are expensive operations. The amount of data recorded is somewhat restricted by the space and weight that may be devoted to instrumentation. Since research aircraft are to probe certain unknown areas of flight, there is some risk involved for the pilot. Electronic devices cannot be substituted for a human being because there are no practical means of adapting the equipment to the flight situation until the environmental conditions and the characteristics of the vehicle in flight have been explored.

In the evaluation of the advantages and disadvantages of the various methods of obtaining data discussed thus far, the need for the manned research aircraft is clear. The main attraction of such an aircraft is that by no other means can the effects of the actual operating environment on piloted vehicles be accurately determined. This is considered justification for the expense and risk to human life involved. Manned research vehicles have been accurately described by E. Kotcher of Wright Air Development Center as "necessary full-scale flight laboratory facilities to confirm, supplement and consolidate the model data obtained from ground test facilities before undertaking prototype development of manned operational vehicles."

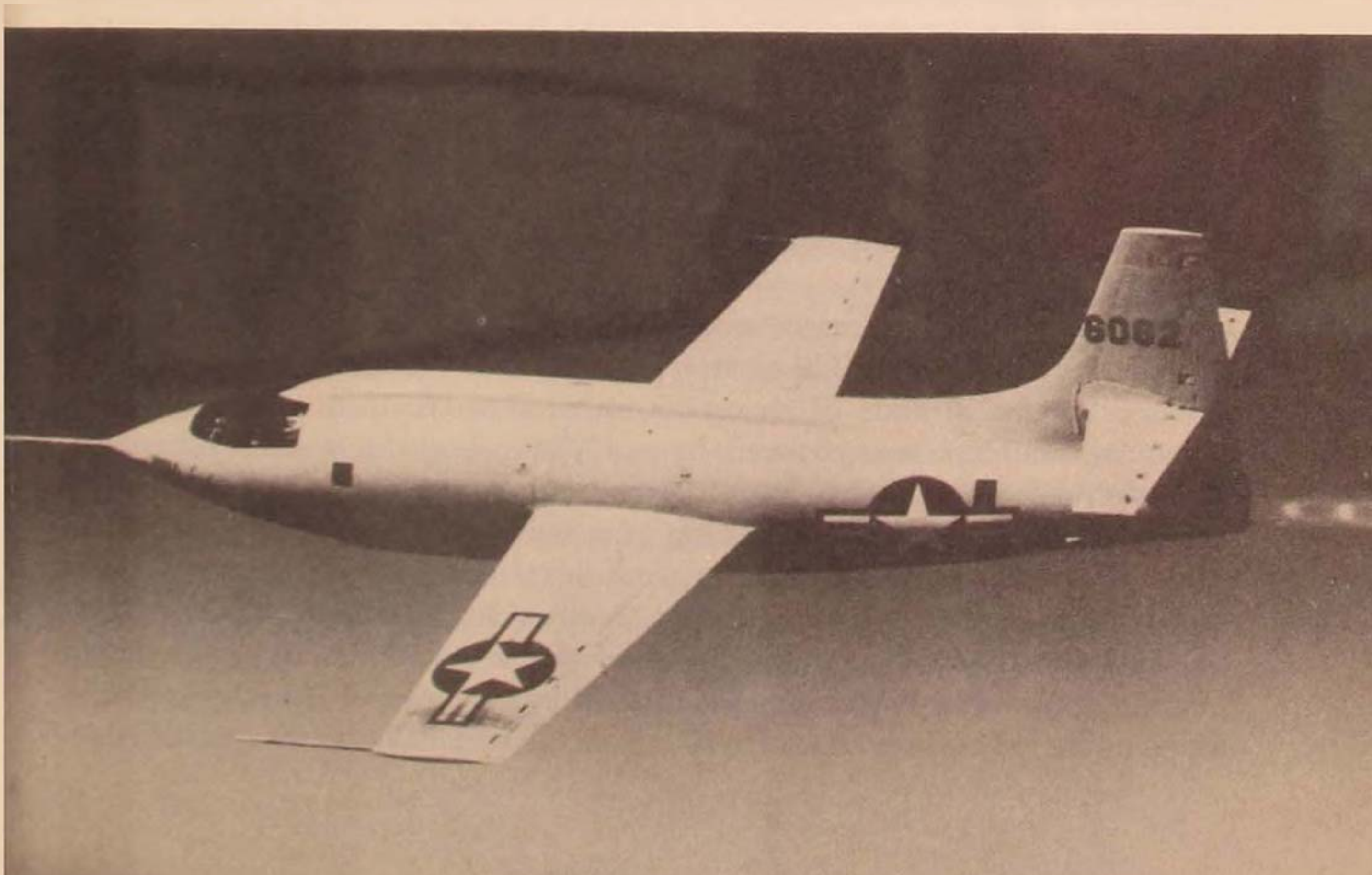
In the design and construction of research aircraft, many of the requirements of operational aircraft are subordinated to obtaining research information. The payload is the instrumentation required to bring back the information. Range is of no importance and flight duration is important only at the points of flight being investigated. The brute force of rocket propulsion necessary to get the craft to desired speeds can be built into the vehicle at the expense of ordinarily important features. The research aircraft is designed to operate in one vicinity only (Edwards Air Force Base, California, in the case of the X-15). Consequently there is no need for the aircraft to be able to withstand certain conditions such as high humidity and salt spray. The pilot obviously does not need equipment for arctic, tropic, or other unusual conditions. Lengthy flight preparation is acceptable in a research aircraft. It may be air-launched at high speeds and altitudes, thus offsetting the high propellant consumption of rocket vehicles. The flight plan may be selected so that dry lakes are available for landings. This feature, together with the fact that once landed the craft may be picked up by auxiliary equipment, permits the use of skid-type landing gear.

background of the X-15 project

Toward the end of World War II the United States embarked upon a series of projects for the development of manned aircraft designed to probe the unknown areas of aeronautical technology. This program led to the historic breaking of the sound barrier in 1947 by the Bell X-1. The German V-2 guided missile had exceeded the speed of sound, but the Bell X-1 was the first inhabited aircraft to accomplish the feat. Like the others of the series, this airplane was designed for the purpose of pure research. It was a rather conventional aircraft except for the liquid-rocket engine, which developed a thrust of some 6000 pounds. An alcohol-water mixture was the fuel and liquid oxygen the oxidizer. Major problems in development were making the plane strong enough to withstand the rigors of supersonic flight and crowding the necessary equipment, especially instruments, into the limited space available. It is interesting to note that the Bell X-1 was the first of the research aircraft projects in which the National Advisory Committee for Aeronautics (NACA), the military services, and the aircraft industry participated.

The Bell X-1A attained a speed of two and one half times the speed of sound

Powered by a Reaction Motors liquid-rocket engine that developed a thrust of 6000 pounds, the Bell X-1 on 14 October 1947 became the first aircraft to break the sound barrier, reaching a speed of mach 1.06. The wing span was approximately 28 feet, the length 35 feet, the height 10 feet, and the aircraft weighed some 16,000 pounds. The original Bell X-1 is now in the Smithsonian Institution.



The Bell X-1A, approximately five feet longer than the X-1, weighed about the same and was powered by the same engine as the X-1 but modified to afford some 4.2 rather than 2.5 minutes of powered flight. It was flown at a speed of 1650 mph at an altitude of about 70,000 feet in December 1953; and in May 1954 a height of 90,000 feet was reported. Both the X-1 and the X-1A were air-launched from a B-29.

in 1953 and the following year exceeded an altitude of 90,000 feet. This plane had a skin of duralumin and the general contour of a .50-caliber bullet. It was approximately 35 feet long with a wing span of some 28 feet. The craft was powered by the same type engine used in the Bell X-1 except for the use of a pump feeding device instead of high-pressure propellant tanks. A big problem with this plane was aerodynamic control in the rarefied atmosphere of high altitudes. Aerodynamic heating was no special problem because flights were made at altitudes where aerodynamic heating is not acute in speed runs of short duration. The altitudes and speeds of the Bell X-1A necessitated the wearing of a partial-pressure suit.

New records in both speed and altitude were set by the Bell X-2 in two flights in September 1956. The aircraft reached more than three times the speed of sound and an altitude of almost 25 miles. Pencil shaped with swept-back wings, the Bell X-2 was powered by a 15,000-pound-thrust, double-barreled Curtiss-Wright rocket engine. With this aircraft, altitudes and speeds were such that the effects of aerodynamic heating presented a considerable problem to the design engineers. So the aircraft was constructed primarily of K-monel, a new metal at that time which possessed good qualities of heat resistance.

The latest research aircraft to be developed is the X-15. The origin of this program may be traced to a resolution passed in the spring of 1952 by the Committee on Aerodynamics of the NACA directing the laboratories of NACA to

The Bell X-2, powered by a Curtiss-Wright liquid-fueled rocket engine with 15,000 pounds thrust, reached an altitude of some 126,000 feet, just under 24 miles, and a speed exceeding 2000 mph at about 70,000 feet, in two flights in September 1956. This swept-wing aircraft weighed 18,000 pounds, had a wing span of some 32 feet, and a length of 37 feet. The X-2 was air-launched from a B-50 carrier.

initiate studies of the problems likely to be encountered in space flight and of the methods of exploring them. Ground facilities, missiles, and manned airplanes were considered. By the spring of 1954 the NACA had a team at work to determine the characteristics of an airplane suitable for exploratory flight studies. This work led to an NACA proposal for the construction of an airplane capable of investigating aerodynamic heating, stability, control, and physiological problems of hypersonic and space flight.

When on 9 July 1954 NACA representatives met with members of the Air Force and Navy research and development groups to present the proposal as an extension of the cooperative research airplane program, it was discovered that both the Air Force and the Navy were already actively interested in similar types of research. This fact made for early acceptance of the NACA proposal for a joint effort and eventually led to the X-15 project.

Areas of responsibility were designated by a memorandum of understanding signed in December 1954 by the Special Assistant, Research and Development, of the Air Force, the Assistant Secretary of the Navy for Air, and the Director of the NACA. Technical direction of the project was assigned to the Director of the NACA acting with the advice and assistance of a Research Airplane Committee composed of one representative each from the Air Force, the Navy, and NACA. The Air Force was charged with the responsibility of developing the X-15, which included establishing the contract as well as coordinating the various development phases of the program. The responsibility of conducting flight research after acceptance of the airplane as an airworthy article was assigned to NACA. The Director of the NACA and the Research Airplane Committee were to inform the military services and the aircraft industry of the progress and results of the program. The memorandum concluded with the statement that this project was a matter of national urgency.

After Department of Defense approval was obtained, the Air Force was authorized in December 1954 to issue invitations to prospective contractors to participate in the design competition for the X-15 airplane. Approximately one year later North American Aviation, Inc., was awarded the contract.

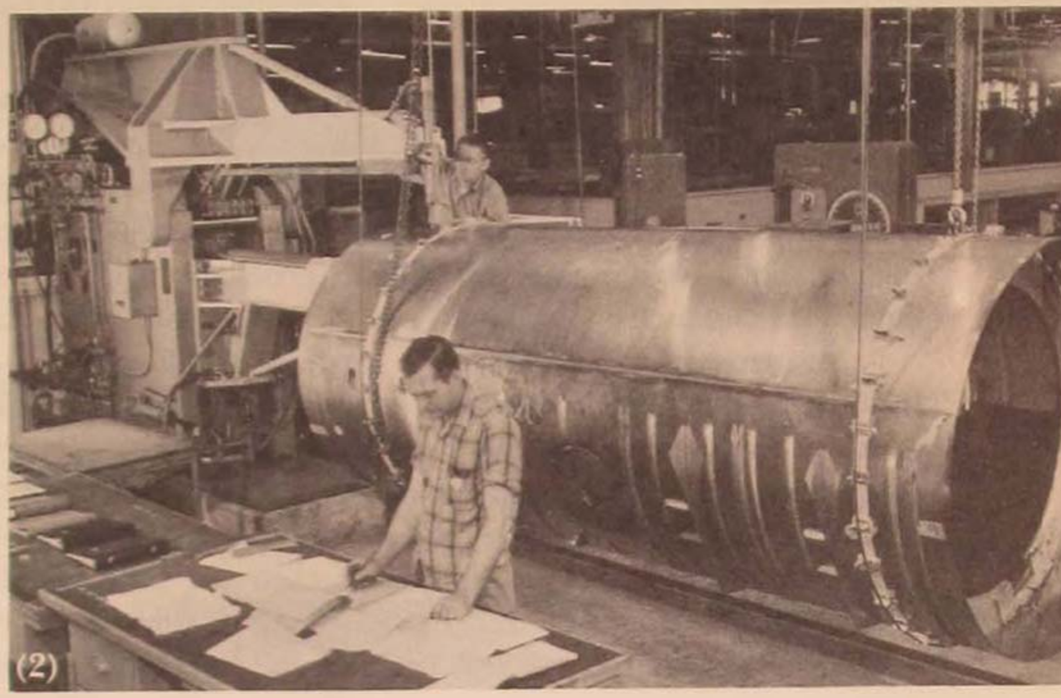
development and flight of the X-15

By October 1955 it was fairly certain that the development contract would be awarded to North American. In that month a meeting of representatives of this company, NACA, and USAF was held to establish the requirements and features of the aircraft and to coordinate generally the X-15 program. A list of customer comments and requests concerning the configuration submitted by North American was presented and discussed. Most of the items were quickly settled when contractor representatives agreed to the proposed changes. In those cases not settled, it was agreed that the contractor would provide studies to enable more accurate evaluation of the questions. At this point in the program, one of the more difficult problems was the type of escape to be used. A second meeting was held in November 1955 to discuss the results of the contractor studies. Important among the results of this meeting were evaluations of possible engine and propellant variations.

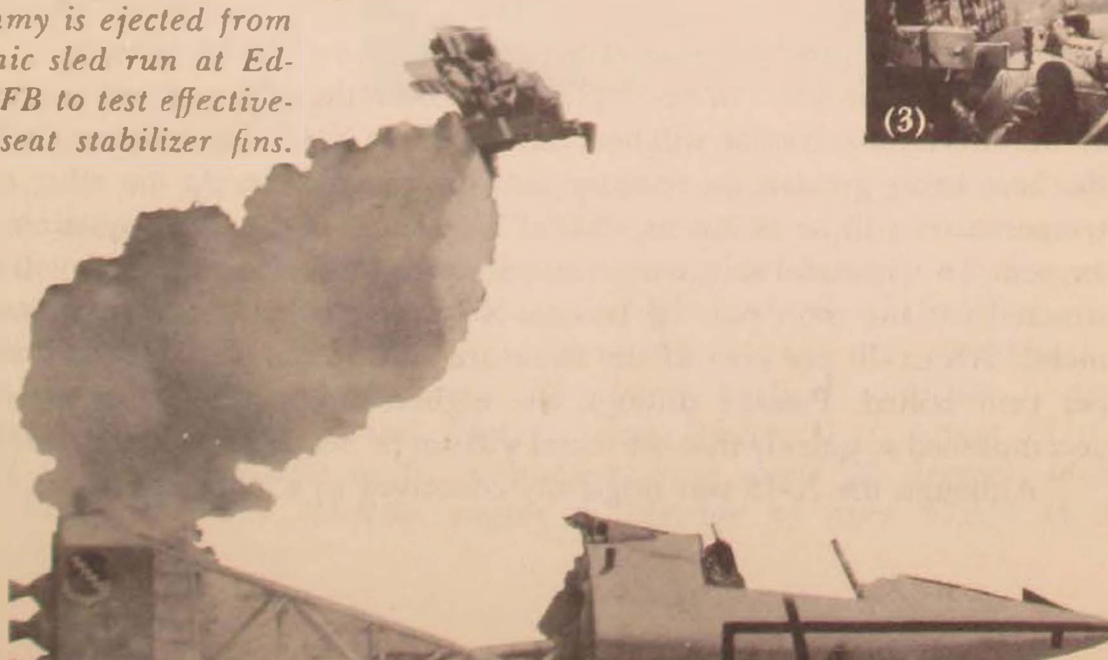
In February 1956 a letter contract was executed with Reaction Motors, Inc., for development of the XLR-99 throttleable liquid-rocket engine. Anhydrous ammonia was chosen as the fuel, with liquid oxygen as the oxidizer. The propellants account for well over half of the iaunch gross weight and are contained in tanks which form an integral part of the fuselage. Separator baffles counteract the surge of the liquid propellant in flight. Sustained firing time of the engine, at varying thrust, is up to six minutes.

By July 1956 the cockpit arrangement had been established and the decision had been made to use a full-pressure suit for altitude and acceleration protection. This lightweight, flexible suit is considered one of the significant accomplishments of the program thus far and will doubtless be of value to pilots of our present high-speed and high-altitude aircraft. The instrumentation bay and pilot's compartment will be pressurized to 35,000 feet and cooled by expansion of liquid nitrogen. A stabilized ejection seat will be used for emergency escape.

Of the human problems, the physiological and psychological effects of weightlessness and of acceleration and deceleration forces are the areas where new information is most needed. A condition of weightlessness, in which the gravitational pull of the earth is nullified, will be experienced by the pilot of the X-15 for several minutes as the plane coasts over the peak of the flight path. Recently pilots of other high-performance aircraft have been subjected briefly to this condition without serious impairment of their ability to function properly. Though the effects of weightlessness seem to vary considerably with individual pilots, some



Research and development of the X-15, one of the most extensive projects in aviation history, involved innumerable steps. For example, (1) wind tunnel testing of X-15 model reveals high-speed-flight shock waves. (2) To produce the Inconel-X fuel cylinder of the X-15, North American developed new techniques for welding this high-strength, thermal-resistant metal. (3) X-15 test pilot undergoes centrifuge tests at U.S. Navy Aero Medical Laboratory, Johnsville, Pennsylvania, to simulate extreme g-forces anticipated for maximum performance flights of X-15. (4) Dummy is ejected from supersonic sled run at Edwards AFB to test effectiveness of seat stabilizer fins.



becoming nauseated and others experiencing a feeling of exhilaration, the duration of this condition in the X-15 flight trajectory is thought to be insufficient for it to be one of the severe human problems of the program.

It is felt that the pilot of the X-15 will have good control over the forces of rapidly accelerated and decelerated flight processes. He will be subjected to about 2 g as the engine is ignited and the plane begins to climb. This force, roughly comparable to that experienced in a catapult launching of an aircraft, will tend to immobilize the pilot but not to the extent of preventing him from performing the tasks necessary to control the aircraft. As the fuel load is rapidly consumed, the speed is increased and the g-forces become stronger. Maximum g-force is reached as the engine burns out prior to the peak of the flight path. It is in the latter stages of the flight, however, that deceleration and pullout forces can combine with atmospheric disturbances to give the pilot most trouble in controlling the X-15. An entirely new control design has been created to avoid involuntary pilot inputs. To study this problem area a series of simulation tests have been conducted in the Navy centrifuge at Johnsville, Pennsylvania.

An inertial flight-data system is being built into the X-15. The equipment includes a lightweight computer and a three-axis gyrostabilized platform on which accelerometers are mounted. The output of the accelerometers is fed to the computer, which derives speed, altitude, rate of climb, and other data. This information is supplied to the pilot through conventional instrument presentation. Built to withstand accelerations more than ten times the force of gravity, the system has the advantage of being adaptable to other space experiments.

Aerodynamic control will be accomplished by movable outboard portions of the upper and lower vertical stabilizers and by differentially operated, all-movable horizontal tail surfaces. The movable portion of the lower vertical stabilizer will be jettisoned before landing. One of the surprising features of the X-15 is the wedge-shaped vertical tail, which measures no less than 12 inches thick at the trailing edge. These surfaces are moved through an irreversible hydraulic control system, with the pilot using a control handle on his right console along with conventional rudder pedals.

Small peroxide rocket motors will provide control at altitudes where aerodynamic controls become ineffective. Two motors controlling movement about the pitch axis and two motors controlling movement about the yaw axis are mounted in the nose of the aircraft in the form of a cross. Movement about the roll axis is controlled by a motor mounted in the tip of each wing. The pilot will operate these motors by means of a single control on the left console.

A difficult problem in development has been the effects of high temperatures on the aircraft. Air friction will heat the skin of the X-15 to approximately 1000° F, the heat being greatest on re-entry into the atmosphere. At the other extreme, temperatures will be as low as −300° F in sections of the plane containing liquid oxygen. To withstand skin temperatures up to 1200° F the aircraft will be constructed for the most part of Inconel-X, a new metal consisting primarily of nickel. About 70 per cent of the structure will be welded, with only about 30 per cent bolted. Passage through the highest temperature is expected to be accomplished so quickly that the metal will not be heated beyond the design point.

Although the X-15 was originally conceived as a "state-of-the-art aircraft"

Four views of the X-15 taken upon its first public showing, 15 October 1958. Built by North American Aviation to attain speeds over 3600 mph and altitudes above 100 miles, it will permit exploration of problems of aerodynamic heating, stability and control, and the psychological and physiological effects on the pilot of hypersonic space flight. The configuration features short, square-tip, swept-back wings and wedge-shaped vertical stabilizers. The lower vertical stabilizer is removed while the X-15 is on the ground. Specifications: length 50 ft, height 13 ft, wing span 22 ft, wing area 200 sq ft, swept-back wing angle 25 degrees, launching weight 31,275 lb. The XLR-99 engine is capable of over 50,000 lb thrust.

(i.e., built with the materials, techniques, and knowledge available at the time of requirements), there have been many difficult technical problems in the development phase of the program that required new techniques and new knowledge. One such problem was in the area of structure. Like K-monel, of which the Bell X-2 was constructed, Inconel-X had never before been used in building an airplane. A pioneering effort was necessary, a type of activity which in itself is of value to the aircraft industry.

Other landmarks in the development phase of the program that should be mentioned include the two industry conferences, one in October 1956 and the other in July 1958, to review progress on the program; and a development engineering inspection of a mockup of the vehicle in December 1956 at which comments and suggested changes were presented. Also there was the decision in the summer of 1957 to use a B-52 as the carrier instead of a B-36. By the end of that year the basic design configuration had been established and manufacturing had begun.

The first powered flight of the X-15 is expected to take place on schedule in early 1959. The B-52 carrier will take off from Edwards Air Force Base and fly northeast toward Wendover Air Force Base, Utah, some 500 miles distant. Just before drop, the pilot will carry out final preparations such as checking electrical circuits. In the vicinity of Wendover the X-15 will be air-launched at approximately 40,000 feet from beneath the right wing of the carrier. After launch the engine will be started and the aircraft will then fly a semiballistic path, during which research data will be recorded both internally and by telemeter at the three stations of a special radar range. Early in the flight the X-15 will be trailed by a jet "chase plane" from a nearby base. Re-entering the earth's atmosphere at the correct angle will be one of the critical tasks of the pilot. Two aft skids and a nose wheel will permit landing the X-15 on the dry lakes around Edwards Air Force Base. Because of delays in development of the XLR-99 rocket engine, an interim engine package of two XLR-11's from the Bell X-1 program will be used for initial flights. The program of demonstration flights by North American will continue until the fall of 1959 when the aircraft is expected to be accepted by the Government and turned over to the NACA–Air Force Flight Test Center Joint Operating Committee for initiation of the flight research program.

Research flights of the X-15 will be flown by pilots from the NACA, the Navy, and the Air Force. These pilots will take the airplane through the full exploration of its performance capabilities.

the future

Just as the accomplishments of earlier research aircraft paved the way for the design of aircraft now operating in our first line of defense, so it is expected that the information obtained from the X-15 flights will be useful, mainly to the aircraft industry, in the design and development of more advanced vehicles for atmospheric and space flight. Data pertaining to all the major areas of interest in the program—the aerodynamic, thermodynamic, and human problems of space flight—will be of value in conjunction with information obtained from ground test facilities. This phase of development must precede the prototype development of manned operational aircraft. Technical reports regarding the results of the project will be disseminated to interested concerns in accordance with the memorandum of understanding mentioned above. North American Aviation, Inc., will retain no proprietary rights concerning the techniques and devices developed and the information gained through the program.

The project which is perhaps closest to a continuation of the X-15 program is the development of a boost-glide aircraft called Dyna-Soar, a name derived from "dynamic soaring." The Air Force and the NACA are now engaged in developing this advanced test vehicle, thus continuing the productive partnership that resulted in the earlier research aircraft and the forthcoming X-15.

Preliminary investigations indicate that it will be possible to vary the original thrust and thus the velocity of Dyna-Soar, enabling the pilot to complete one or more orbits around the earth and make a normal landing. The vehicle will operate from space altitudes down to well within the atmosphere where it can maneuver and be recovered undamaged. It will utilize both centrifugal effect and aerodynamic lift.

The Martin Company and the Boeing Airplane Company have been selected as development contractors for the Dyna-Soar. These companies will each head a team composed of five or six of the ablest contractors in the aircraft industry. Martin will draw heavily on the aeronautical pioneering experience of the Bell Aircraft Corporation. The specialized abilities of contractors throughout the country will contribute to development by both teams. Early efforts of the two teams will be competitive to ensure that the Air Force receives the most advanced and complete designs. The Air Force, NACA, and the aircraft industry have been obtaining and assessing data and knowledge on the boost-glide concept since 1951.

Possible operational craft following the test version of Dyna-Soar will be capable of various missions, including bombing and reconnaissance. As a weapon this vehicle promises to have some of the best features of both guided missiles and aircraft. It will have long range and great destructive capability, especially with nuclear payloads, and the judgment of the pilot will make for reliability and versatility. Such a weapon would be particularly useful in case of loss of our overseas bases.

It would naturally be almost impossible to predict the exact course that space technology will take. We can say with some assurance, however, that the information gained from flights of the X-15 and similar aircraft will be extremely valuable. In fact, later craft in this same line of development may well play the predominant role in the conquest of space.

Air University Quarterly Review

That "Military Mind"

Brigadier General Harold W. Bowman

IN THEIR penchant for oversimplification, Americans tend to lump all people into categories: you have good guys and bad guys. In the Western movie, it is always the hero versus the villain. The public servant is either a politician or a statesman, depending on the plus or minus sign on his public esteem. If one lends money, he is a loan shark or a financier. The owner of a factory is a tycoon if dogs bark as he slinks past, an industrialist if children climb on his knees. Just as a news photo is worth more than a thousand words, the nickname given to a public figure depicts his reputation far more accurately and quickly than a Gallup poll could do it.

The professional military man has not escaped his sobriquet. As a group we are tagged as "military minds." The number of our profession referred to as military strategists or leaders, indicating a high level of public esteem, is discouragingly small.

Like most such nicknames, "military mind" is never accurately defined but we know it is uncomplimentary and we cringe when we hear it. By this term our critics seem to imply that we are inflexible, rigid, unimaginative, uncreative. While recognizing loyalty as a virtue, they see military loyalty as a fierce and narrow chauvinistic quality bounded by the confines of the individual's own organization—sometimes at the expense of a higher obligation. They think of a little mind, limited in vision to what one can see with the naked eye.

How did we in the military get that way? We are impaled on the horns of a serious dilemma.

Horn #1. We must develop disciplined minds immediately responsive to authority. We must have standardization. We must have consistency and continuity and long lead times in order that development, procurement, training, and the budget can all progress in an orderly way on a scale never before needed in peacetime. Our weapons and methods must be tested and proved before we risk lives and gamble on victory.

Horn #2. Our efforts to attain perfection along these lines lead toward the undesirable qualities of inflexibility, lack of imagination, and resistance to change. We tend to become overconservative conformists. Today we are witnessing the greatest technological revolution in the history of warfare. More radical changes in the art of war have taken place in the last thirteen years than in all previous time. Unfortunately there has not been a comparable breakthrough in the art of thinking.

But we are not hopelessly impaled on these horns. There is a way of escape and I am happy to say that many of those recognized as national and international military leaders have found the way. Just as the politician must break out of the confines of his local district and think in terms of tomorrow, of the country, and of the world before he becomes a statesman, so the military man must raise his sights and broaden his horizon before he can join the more exclusive group of highly respected leaders. He can become bigger than his combat unit or the problems of today without sacrificing his loyalties, his discipline, or his fine ideals and sentiments in any echelon. Fortunately this growth can come from the development of capabilities which are inherent in the professional officers of our services. There are five qualities which the military man must cultivate if he is to escape being labeled a "military mind":

1. *Breadth of Viewpoint.* If one's horizon is limited to his own level of responsibility or current duty assignment, the "big picture" will forever remain an undeveloped negative. Every organization has a purpose bigger than itself. The squadron is the means to an end—not the end. The Air Force exists to support national policy. Our national policy exists as an expression of the ideals of free men. There is always a higher force to motivate and guide our thinking. Only when we keep our eyes on the higher purposes of our responsibilities can we function in harmony with the ideals we are employed to support.

2. *A Fertile Imagination.* The habitat of imagination is a mind that is wide open to new ideas and capable of fitting old ideas

A high level of public esteem for the professional military man is lacking in the United States. One evidence of this is the frequent charge that there is a "military mind," the product of authoritarianism and standardization which result in inflexibility, lack of imagination, and resistance to change. Brigadier General Harold W. Bowman, Deputy Commandant, Air Force, Armed Forces Staff College, advances five qualities which, if developed, can help lift a military man above military parochialism and into the realm of public respect: breadth of viewpoint, a fertile imagination, an analytical mind, boldness, and intelligent loyalty.

into new relationships of time, space, and hardware. That does not mean throwing out everything old merely because it is not a new model. Everything we possess should be subject to continuous questioning, adapting, and testing, since victories are not won by any second-best combination of ideas and gadgets. Imagination must be tempered with wisdom and discipline.

3. *An Analytical Mind.* The rose-colored glasses of tradition and party lines do not lend themselves well to scientific investigation and logic. We must develop the capacity to separate in our own minds fact from fantasy, doctrine from party line, logic from sentiment. Placed in proper perspective, there is a legitimate place for them all. But we must develop the mental habit of listening, of attempting to understand the viewpoints of others, and of accepting or rejecting proposals on the basis of logic. What action we take is another question and that brings us to the fourth quality.

4. *Boldness.* It takes courage to be a nonconformist, to stand up and be counted when one's ideas are unusual. Just as the satellite needs tremendous thrust to escape from the earth's envelope, so man's mind needs a special force to carry his ideas beyond his conventional mental atmosphere. Boldness is the mental propellant that carries a new idea into higher echelons.

5. *Intelligent Loyalty.* I stress the word *intelligent* because here is the area of greatest confusion and misunderstanding. Military men are generously endowed with loyalty. Far too often it is misdirected. We tend to develop an "either-or" philosophy wherein we limit our attention to the wheel that is closest and squeaks the loudest. We are inclined to feel that we cannot support a sister service without hurting our own. But just as sister Suzie can love her parents, all five brothers, and the boy next door with equal fervor, an infinite number of focal points merits our favors.

Logical thinking and boldness are not at all inconsistent with loyalty. No good commander wants a bootlicking yes-man around. He wants and depends upon solid, logical thinking, and loyalty demands that we give it to him. Loyalty also demands that once the commander has made his decision, it be fully accepted and carried out. That is the difference between the teamworker and the martyr. They may both have imagination, analytical minds, and boldness. The teamworker can see the other person's viewpoint and, when appropriate, can subordinate his own. The martyr can not. Martyrs have an honored place in the world. They have added luster to history. Their shock effect has spurred progress and reform. But if the spirit of martyrdom were a criterion for selection of military officers, our organizational responsiveness to the national will would be nil.

Since boldness and loyalty are not incompatible, where should the courage of our convictions leave off and loyalty take precedence vis-à-vis the boss? The answer is quite simple. Courage and boldness take precedence within the framework of our own responsibilities and prerogatives. But when the focal point for decision resides elsewhere, then loyalty demands our support and our willingness to "render therefore unto Caesar the things which are Caesar's."

If our contrary convictions are so strong that we cannot bow to the responsibility and authority of others, then it would not be disloyal to step out of the organization; it would be disloyal to stay in. Since martyrdom reaches its flower only in personal sacrifice, then if convictions are strong enough to justify it the logical step is—out. Sabotage from within is not even honorable martyrdom.

Yes, multiple loyalties—in proper balance and relative priorities—are legitimate and necessary.

Only to the degree that we as a group shed our parochial viewpoints and take on more of the qualities that distinguish the esteemed military leader will our directors, the American public, drop the tag of "military mind" which they have ascribed to the officer corps of the armed forces.

Armed Forces Staff College

Industry and the Military in the United States

Colonel Edward N. Hall

Defining large, amorphous organizations is always difficult. The definition of the relationship between two such entities is even more so. The meaning of the term "military" is fairly clear and is intended to imply all the organizations comprising the armed forces of the nation. Industry, however, is generally seen to consist of a heterogeneous mixture of producing organizations, both light and heavy, service organizations, development organizations, and possibly scientific organizations. To a surprising extent the fate of all these diverse elements of industry is materially influenced by their relationship with the military. Because of this fact the definition of this relationship, although beset with difficulties, is believed to be a worthwhile exercise.

In addition to the amorphous nature of the organizations under discussion, another obstacle which must be surmounted in this effort is found in the changing nature of this relationship through the years. The interaction of one upon the other was of little significance in the days of Xerxes, grew somewhat in importance during the long period of dominance of the British navy, became really significant if poorly understood during and after World War I, and has now become a crucial issue. That it remains singularly poorly understood is attested by the comments on this subject of many informed people. Our news media are replete with statements to the effect that the military budget is too large, that it is too small, that the military should be run in a businesslike fashion, that no profit-making organization could stay in business if it were run on this pattern, that all military expenditures are a dead waste, that military aid to industrial research and development is the key to economic health for the nation's economy. Some of these must be wrong.

Our efforts to define this significant relationship may be considerably aided by reviewing some aspects of this problem as they existed in the past. The elements of this relationship which seem worthy of careful examination include the needs of the military as a function of time; the driving forces enabling industry to expand and remain healthy under varying social conditions; the manner of transmission of military requirements to industrial organizations—in brief, the way in which industry may best be guided by the military to ensure defense of the nation with economic good health.

History of the Relationship

Chronologically the periods under discussion can be divided arbitrarily into the era preceding World War II, and the time from the conclusion of World War II to the present.

before World War II

The story of humanity from the dawn of recorded history is largely a saga of the dominance of mass land armies. It is true that interposed between periods of vigorous activity of these mass armies there were times of relative peace. These, however, were of limited duration and seem to have served primarily to provide sufficient time to generate enough steam to reinvigorate the mass armies.

In the time of Xerxes the activities of these mass armies broke down, as they do today, into operational and technical elements. The relative importance of the two at that time was heavily weighted in favor of the operational. The act of providing Xerxes with a large number of catapults built to the best designs of Archimedes might possibly have reduced his manpower requirements by a small percentage.

As the air-jet age bridges into the space-rocket age, technology looms larger and larger in the shaping of strategies and the nature of warfare. Hence the importance of the proper balance between a healthy, forward-looking industry and the capability within the Air Force to keep industry pushing the frontiers of the state of the art, to evaluate the proposals advanced by industry, and to monitor the development and production of each new weapon system to the end that it best satisfies the military requirement. Colonel Edward N. Hall, Director of Weapon System 133A (Minuteman), Air Force Ballistic Missile Division, Hq ARDC, points out that even a recognition of the need for such a balance is relatively recent and that the actual achievement of such a balance has been rather spotty. He analyzes the various systems that have been used and are being used to try to achieve this balance, and points up the importance of the military development engineer.

The advent of gunpowder had a small but material effect in slightly increasing the relative significance of the technical element of military activity, but operational considerations still comprised the transcendent aspect of military activity. The defeat of Napoleon at Waterloo presents an early illustration of the rapidly increasing importance of the role of technology in military action. Napoleon organized his forces in his traditional pattern, completely ignoring the development and potential use of shrapnel on the part of the British. His troops were cut to ribbons by Colonel Shrapnel's invention, and the outcome of the battle was determined to a large extent by proper use of this technical development.

In many ways the American Civil War can be considered as the first modern conflict. In numbers of casualties and particularly in numbers of deaths, it was a long step from its predecessors. This was the result of a number of factors, among which was a more effective exploitation of technical development than had occurred previously. Here for the first time we find arms requirements building up to a level constituting a respectable part of the total industrial potential of the nation. The industrial load was an extremely variable one, going from next to nothing before the war to a tremendous requirement in certain fields at the height of the conflict, and receding to insignificance after its close.

Because of this, as well as a lack of previous knowledge in handling the delicate relations between the military and industry, the pattern of the relationship which developed can only be described as random. Out of an appreciation that standardization makes for high production rates and that any development effort inevitably becomes a disrupting influence, General Ripley, Union Chief of Ordnance, insisted that any deviation in battlefield use from the standard smoothbore, muzzle-loading musket would be accomplished only over his dead body. So strong were his and his subordinates' convictions on this point that the terrific effectiveness displayed by Spencer rifles at Gettysburg was completely ignored, and the Spencer company obtained government contracts only through the illicit activities of various state government officials and the pressure of President Lincoln.

With the conclusion of conflict most of the small industrial organizations which had contributed to the war effort converted to peaceful pursuits and lost contact with the military entirely. The small continuing burden of research and development was carried on within the armed services. Two elements of this type of activity which have since become of critical importance, the cycle time from concept to use of a weapon system and the lead time for its production, were not recognized as important in that era.

During the course of World War I for the first time, the significance of technical as contrasted with tactical activity became paramount. Masses of men were of little avail against well-emplaced machine guns. Machine guns were of limited value against tanks. In no case involving these weapons could the issue be decided by employment of mere masses of men with hand weapons, regardless of how superlatively trained.

During the period between World Wars I and II our nation was slowly and reluctantly forced to recognize that we were no longer immune to attack from abroad, that wars would probably never again be initiated in a gentlemanly fashion, and that the maintenance of a sizable minimum state of military preparedness might become an unhappy necessity. This period, an interval of peace preceding a great conflict, is in some ways similar to the situation in the world today, so a careful study of selected events might be highly rewarding. Because my field of activity has been most closely connected with engine development and because I really believe that the story of engine development in the United States during this period is most significant, most of the history which I shall now cover will involve propulsion.

The great questions that dominated military research and development during the 1920's and 1930's and that still remain unsolved in important aspects include the following: How do we balance a program between the Scylla of potential rapid obsolescence and the Charybdis of extreme technical difficulty? How much effort should be put into analyses and paper activity as compared to empirical hardware exploration and consequent scrap-heap generation? How is industry to be guided into development rates not in consonance with profitable civilian patterns? A considerable amount of light is cast on these questions by the episodes which follow.

After the conclusion of World War I the United States found itself in a position where the major part of its aircraft engine production was in the form of a foreign engine of limited performance, built under license. This situation seemed a comfortable one, in that the small number of relatively low-performance airplanes possessed by the military were able to fly and the organization producing the engines and maintaining them operated at a profit. A certain amount of military pressure was brought to bear on the producer of this engine to develop and produce higher performance power plants, but the effect was zero. There was no commercial interest which could be served by the development and production of superior power plants and the only excuse for such development work lay in armed services requirements.

Late in the 1920's a very small organization had begun to produce air-cooled radial engines radically different in design from the foreign units produced under license. It was evident that this product of native talent had the potential of far outstripping its foreign competitor in power-weight ratio, but large engine producers were extremely reluctant to undertake its development and production. Small companies were not capable of meeting military requirements imposed upon a prime contractor. This unfortunate situation was resolved in an apparently unorthodox manner. The government agreed with the producer of the obsolescent foreign power plant that he could indeed continue to produce these devices as long as he saw fit, but it was difficult to see how further contracts for support of military aviation could be placed with his organization unless vigorous efforts were made to exploit the newer technology of the radial air-cooled engine. Very reluctantly the larger firms moved in the direction indicated, and achieved great success in the development of these power plants, resulting in profits to their stockholders and engines to the Air Corps.

The lesson here is a subtle one—the Air Force strongly feels, and has traditionally felt for many years, that American industry is its partner. To use properly the talents of this partner, the service is loath to interfere in direct managerial prerogatives. Yet to ensure the defense of the nation, military development must inevitably occur at a pace faster than that characterizing the civilian economy, and some military pressure must be brought to bear to accomplish this. Too much pressure is rightly regarded as an invasion of managerial rights; too little inevitably leads to the development of a second-rate military force. The objective in this instance was achieved through exercise of careful discretion which did not infringe unduly upon the rights of the company but indeed reacted beneficially to it while attaining the ends deemed necessary for the defense of the nation.

Toward the end of the 1930's a highly significant phenomenon was taking place in Europe. The Otto-cycle engine, which for many years had held the center of the stage in several forms for aircraft propulsion, was being challenged. In Italy, Germany, France, and England other cycles were recognized and were being investigated. Heinkel had built and operated an axial-flow turbojet and had vigorously investigated about half a dozen other seemingly promising approaches. The Italians had operated the ductedfan reciprocating engine combination of Campini-Caproni, and the Englishman Whittle was well advanced in the development of the centrifugal-compressor turbojet.

In the United States our engine contractors and most of our development people regarded these advances with contempt. In the field of rocket engines during the 1920's the key approaches leading to the large engines of today were recognized and vigorously and successfully pursued by Professor Robert H. Goddard in the United States. During the entire period of the 1920's and 1930's he labored with very considerable success in this field. When at the close of the 1930's he offered his work gratis to the military services, he was refused and little effort was made to exploit the brilliance of this individual in engine developments aimed at the prosecution of World War II. The Germans on the other hand, enjoined from development of conventional aircraft by the terms of the Versailles Treaty, sponsored the development of the rocket engine which ultimately led to its successful exploitation in the V-2.

These instances clearly are symptoms of the same disease. Traditionally the United States has turned out large numbers of extremely reliable power plants over the years. This has been accomplished through very effective employment of high-quality, complex tooling requiring very large capital investment. A natural corollary of the existence of this tooling is the desire to use it as extensively as possible to write off the large original investment. Thus we find in the instances above that the United States has a greater stake in the retention of the status quo than other nations less extensively tooled for production of existing engines. High-class, expensive tooling therefore should be regarded as both a blessing and a curse in that it enables us to turn out large quantities of high-quality power plants at reasonably low cost but tends to inhibit rapid acceptance of radical departures in technology, even when significant gains may be achieved.

Another phenomenon which came to light during this period pertains to the difficulties involved in the transfer of a design developed by one agency to some other agency for production purposes. As the devices of war become ever more complex, involving ever finer tolerances, clearances, surface conditions, etc., the ability of man to precisely identify these things by means of drawings and specifications becomes ever more deficient. One could be fairly confident that the spears handled by Xerxes and turned out by the brass shop of Xantippe could be equally well produced by the metalworkers of Aristophanes II. Not so the complex devices of modern warfare. Early in World War II a certain admiration was felt for the performance of the Rolls-Royce Merlin engine and it was decided that the engine would be put into production in the United States. Little difficulty was contemplated, since it was a device in massive production and well proved in service. In actual fact, in spite of the transfer of tens of thousands of drawings from Rolls-Royce to Packard, it took years to iron out the low-tolerance, highly specialized techniques required to produce reliable power plants. Similarly the initiation of production by the Ford Motor Company of the B-24 airplane at Willow Run was quite painful. The airplane had been designed, developed, and was in production by Convair, but again the generation of a competence to produce this proven device by some other agency was a task of no small magnitude.

The significance of these two illustrations rests in the conclusion that the transfer of complex engineering entities between production organizations is a difficult, time- and dollar-consuming process. The transfer of devices which have yet to be completely developed and thoroughly checked out to production agencies is naturally even more painful, time consuming, and dollar consuming. It is for this reason that the U.S. Air Force has remained firmly convinced that the best way to obtain efficient military materiel without this painful and expensive transition is to employ balanced teams of industrial organizations to accomplish the development and production tasks consecutively within one organizational complex.

since World War II

During the period since World War II a pattern of relationship between industry and the military has evolved which still defies precise definition but the significance of which seems obvious. The provision of large masses of advanced engineering equipment upon which the military security of the nation must depend has become a task of tremendous and continuing economic significance. The highly seasonal character of this operation, typified by the Civil War period, has largely disappeared, and a requirement has emerged in its stead for systematizing the development pattern of this equipment to exploit scientific potentials expeditiously while maintaining a healthy economy at all times. The development-cycle time for these massive weapon systems from concept to military inventory has become paramount. We are concerned now not merely with the exercise of adequate discretion to ensure that each development program neither reaches too far into the blue of the technical unknown nor sits in the gutter of technical complacence and inevitable rapid obsolescence, but also that the proper steps in improving our complex of weapon systems are taken on a rational and timely basis to ensure that we neither lose ourselves in a forest of dissimilar prototypes nor luxuriate in a sea of standard muzzle-loading muskets.

A survey of major development programs conducted since World War II indicates that this critical time cycle has averaged something like eight to ten years. Is this kind of extended effort essential? Does it save money? Does it enable us to do our jobs better? I think the answer to all three is no. This excessive time cycle stems from many things, not the least of which are lack of skill in budgeting and programing as exercised by both military and industry; failure to prosecute simultaneously facility, production, test, and training, as well as vehicle development aspects; and the pains involved in attempted transitions from government to industrial organizations.

Among the notable exceptions to this pattern of extended-time-scale development are the programs which led to the large liquid-rocket engines available to the United States today, and the Thor missile. These have been singled out not so much for their uniqueness as for my own close involvement in them which has permitted some light to be cast on how these time scales can be cut. In the case of large liquid-rocket engine development a quite significant sum of money had been spent by the armed services prior to 1951 with very limited results. The feasibility of many propellant combinations had been established and several rocket designs, some employing advanced mechanical features, had been explored. But no large rocket engine had been developed to the point where reliability and safety had been demonstrated sufficiently to permit its inclusion in the military inventory.

The primary reason for this sad state of affairs was a failure to realize that the major elements of development programs for engines and missiles are not demonstrations of feasibility after the execution of much analytical work but instead are extensive component test and rework followed by even more extensive engine test and rework over wide ranges of combinations of adverse marginal conditions. This philosophy had long been applied to reciprocating and turbojet engines, but until the time period in question most of the rocket engine development programs in this country were set up by scientifically oriented souls possessed of a great disdain for empirical procedures.

The unique success of the Air Force large liquid-rocket development program can be traced to application of development procedures directly based upon successful operations in reciprocating and turbojet engines. It is of interest to note here that the application of these development principles necessarily had to be pressed by the Air Force itself, since its industrial contractors in the rocket field had little or no knowledge of the general philosophies of development employed for reciprocating engines and turbojets.

In the case of the Thor missile development program the Air Force found itself in a very nearly classical position to exploit properly the development of components which had been sponsored independently of this program and were ripe for use. Because of this situation it was possible to lay out a preliminary design in a very short time, followed by a detailed test schedule developed very early in the program, with great confidence that momentous changes would not have to be made. The use, from the inception of the program, of the team of industrial contractors selected to ultimately produce the missile precluded the loss of significant amounts of time for transition into production at some later point in the program. Moreover, efforts to employ final production specifications and acceptance test procedures as early as possible paid off handsomely in excellent definition of the items tested. On the other hand, tests performed on model shop items are frequently inconclusive in nature even when excellent instrumentation is used, because of lack of clear definition of what has been tested. Even when the items to be tested are sharply defined, unless procedures in fabrication and assembly are identical to those anticipated in production their significance with relation to production items is questionable.

The speedy success achieved with the Thor program, then, stemmed largely from no loss of time in transition from model shop to production tooling, early establishment of production specifications and techniques, exploitation of reasonably well-developed components at the inception of the program, complete elimination of dead-end testing of so-called test vehicles which generally have little bearing on final configurations, and a realistic appraisal of the budgeting program. This last element is of great significance, in that the typical military program budgeting procedures involve preparation and justification in great detail of all major items required for development by men intimately familiar with the task at hand, followed by arbitrary cutting of these amounts at various levels by people much less familiar with the programs in question. Such cuts are frequently expensive.

Patterns of Military-Industrial Relationships

There is considerable alarm and confusion today on the part of the American public concerning the effectiveness of our military activities. This is completely understandable and stems in no small degree from the fact that the military task has changed profoundly since 1940. Today we must recognize that the only constant in the military picture is that technical changes will continue at an ever accelerating pace. To resist this is suicidal, while intelligent accommodation to it can yield many benefits. The criterion of success for a military service has become the ability to conceive, develop, and operate effective, complex weapon systems at a pace to exploit efficiently the ever increasing rate of scientific advance.

With these thoughts in mind, then, it should be profitable to explore patterns of military and industrial relationships which have been tried. These include the arsenal concept, the service-industry team concept, and operation by committee.

the arsenal concept

Inspection of the arsenal concept, largely adhered to by the United States for a good part of its history, reveals certain difficulties. If it is agreed that indeed the massiveness of the industrial base to support the military precludes placing it all in the hands of the government, employment of this arsenal concept necessarily involves some split between the activity of private industry and that of the arsenals. It would seem most rational that this be effected in a pattern permitting research, development, and limited production to be conducted largely by arsenals, while massive production would be accomplished by private industry. This indeed has frequently been the pattern followed. A significant advantage of this system lies in the fact that development up to the prototype stage can probably be conducted more rapidly than through most other systems. However, production of large numbers of complex units of any given weapon system can be accomplished more favorably by teams of large private industrial contractors.

Can we take advantage of both circumstances by using arsenal-type installations and industry each for the task for which it is best suited? I think the answer is sometimes yes, with the proviso that the point of compromise between the activities of one and the other of these entities be very carefully selected. Inevitably the use of this combination involves a transition at some time from arsenal fabrication, assembly, etc., to the execution of these activities by teams of private contractors. Unless this occurs very early in the program, or unless the program is limited to few or simple devices, the operation can be extremely time-consuming and expensive. It should also be pointed out that such a pattern of operation generally fails to make best use of the management, test, and engineering competence of American industry and tends to force the use of highly integrated industrial facilities along courses of fabrication and assembly which are not optimal for their particular layouts, equipment, and skills.

Another adverse aspect of this manner of operation relates to the potential exploitation of military development by the civilian economy. One of the key elements in ensuring continued prosperity in our nation is the unceasing development of newer, more attractive commodities to support an ever expanding population of increasing industrial efficiency. Without these new commodities, techniques, and materials our economy would stagnate or shrink. Of primary significance in this advance of the nation's economy is the ratio between expenditures upon effective research and development and those for production and services. It is through this medium that the armed forces can contribute very effectively to the civilian economic health of the United States.

the service-industry team concept

The service-industry team concept, which is the typical pattern of Air Force research and development, is like the others in that it is not perfect. To be effective, it requires the exercise of discretion and inspiration. When handled properly, this concept can be most effective; but its distinction from the arsenal concept when that is handled properly need not be great.

A development program from its inception until the prototype assembly stage can almost certainly be accomplished more rapidly by specialized job shop than by closely coordinated teams of massive industrial contractors. Generally, however, the total elapsed time and cost from inception of program to delivery of first production items can and probably will be very considerably shorter in most cases when the service-industry principle is employed than if development through prototype were isolated. This system also facilitates to the maximum the exploitation by civilian industry of military development of commodities, techniques, finishes, and materials and thus contributes most effectively, if handled properly, to the civilian economy of the nation.

The major potential weakness of the service-industry system lies in the fact that it will operate in an apparently healthy pattern even without the exercise of adequate technical discretion on the part of the military service employing it. Thus unless a definite effort is devoted to the training of military project engineers, the possibility exists that military engineering competence could be reduced to a dangerous level before the deficiency is recognized. Since a contractor industrial organization is necessarily and appropriately profit oriented, it inevitably attempts to propose to the military what it thinks the military would like to do. This may or may not be what is best for the nation. Under these circumstances sufficient technical competence must be available within the military to provide these contractor teams with adequate guidance to develop and produce militarily profitable devices. It is exclusively within the military that the peculiar synthesis of technical feasibility and military attractiveness can best be made.

operation by committee

During the last decade it has become increasingly more fashionable in the United States to use large numbers of committees for the control of many diverse activities. In the case of military development this seems to be particularly true. Large numbers of learned scientific committees continually circulate within Defense Department activities. Where do these fit into the scheme of things?

It is very proper that scientific committees evaluate the technical feasibility of approaches proposed by the military, but it does not follow that scientific committees are necessarily competent to adjudge the validity of development programs with respect to facility requirements, dollar requirements, time scales, etc. While history has occasionally demonstrated that an individual completely unversed in a specified art may exercise competent judgment, this is rarely so. Most frequently the man best qualified to estimate the validity of development schedules and requirements for facilities and hardware is one with extensive experience in this particular field.

Although a steady trend away from pure line organizations has existed since the turn of the century, it may well be that the exaggerated staffs and committees employed by typical development organizations today have become too large and that much good could come from some reversion to the coupling of authority and responsibility in the hands of single program managers. Even the best of committees composed of individuals with expert skills in all activities under consideration should not be expected to contribute more than good general advice on most aspects of complicated development programs.

What Have We Learned?

We have covered a somewhat extensive history of military development activity as related to industry. It is a haphazard story of an unfortunately seasonal relationship which has developed to gigantic proportions under the same laws of growth that covered the well-known Topsy. Can the implications of this story be reduced to simple general terms? Can these observations provide signposts in the apparently trackless morass of future military activities? I am firmly convinced that the answer to these climactic questions is yes. Intelligent application of the answers to these questions, however, is completely contingent upon a determined effort to shake off prejudices and dogmas which have extended back thousands of years to mankind's obscure past.

Much discussion has raged regarding the nature of the next war. Shall we direct our defense efforts primarily along the lines of massive retaliation? Shall we prepare mainly for a series of so-called fringe wars? Shall we go back to developing superior species of horses and better streamlined spears? In the light of hard, cold fact all these are almost equally irrelevant. It would hardly have seemed appropriate when we were in the midst of World War II, fighting for our lives, that a ponderous public debate should break out occupying many acres of magazines and newspapers with questions of what we will do in the next war. Surely it was evident at that time that the first business of the nation was to win that war.

We are at war today. It is called cold. We will be in this kind of war for an indefinite period into the future. While it is of philosophic interest to consider massive retaliation versus fringe efforts versus heavier spears and larger horses, it must be recognized that these are all of secondary importance. The matter of primary importance is to win this war. It is understandable that many of us have not recognized that we are at war. It is a very different type of war than any in which we have engaged previously. For all that, this war is not merely as deadly but much more so; we are fighting not merely for our survival as a nation but for the very lives of every one of our citizens. For the first time we are confronted with potential enemies who can destroy us totally. The objective of this war, in contrast with that of previous conflicts, is not to gain a decision on the battlefield but to avoid going to the battlefield. The use of the battlefield by the combatants involved would probably ensure the annihilation of both sides, a feat which could hardly be regarded as victory. Under these circumstances it would seem that the objectives stand out very clearly. We must demonstrate to potential enemies clearly and continuously that a decision to take to the battlefield would inevitably result in suicide.

The means we have at our disposal for accomplishing this objective are limited. Any threat on our part that an attack on this nation would be met with the landing on foreign shores of hordes of men equipped with rifles, spears, bean-shooters, or atomic cannon would be completely futile. In fact it would constitute a tempting invitation to disaster. It must be made clear to potential enemies that any openly hostile act will result in rapid, inevitable, effective retaliation against the sources of the aggression.

The objective of a military force, then, is to continually demonstrate that attack cannot be profitable. This can only be achieved by coupling the rapid exploitation of scientific progress, through development of high-performance weapon systems, with an obvious capability to deploy and use the results effectively. In short the military tasks during the kind of war in which we find ourselves boil down to technical development, planning, and training.

Acceptance of this concept of warfare necessarily calls for a revision of past military values. Far from being a seasonal venture, the prosecution of this type of war is a long-continuing process and must be planned to support a healthy civilian economy as well as to provide the primary means of survival. It is not merely with respect to the nature and duration of war, however, that our concepts must change radically. Even more importantly we must reconsider the type of people necessary to achieve success at this new kind of war.

Traditionally the military services have been combat-oriented; their major task has been operational, and everything else has been treated as an unfortunate diversion to be delegated whenever possible to appropriate civilian agencies. The acceptance of technical development as a task equal in significance to that of plans and training radically alters this position. It seems manifestly absurd to contemplate contracting for the defense of the city of Oshkosh by some civilian agency, while direction of the development of essential weapon systems frequently is blithely contracted for with a minimum of guidance provided by the military services. In our current kind of war it is fully as important to demonstrate to potential enemies the ability to develop advanced major weapon systems in the shortest time from concept to inventory as to display the competence to deploy and operate these systems about the city of Oshkosh. Perhaps more so.

Continuing development of weapon systems to short time scales inevitably involves selection and guidance of the most competent industrial contractors available. The direct guidance takes the form of discussions, visits, formal technical meetings, and, most significantly, the definitions provided by exhibits in requests for proposals. It is in the preparation of these exceedingly important exhibits as well as in the evaluation of the ensuing proposals that the need for technical competence within the military becomes paramount. Gresham's law classically relates to the driving of sound currency out of circulation by unsound during economic disorders. That this law works equally well to drive out technically competent contractors in favor of gifted advertisers is appallingly evident when the technical evaluation competence within the armed services dips below a threshold value.

Allusion has been made to the steady loss of competent development engineers from the armed services. If the function of these men is as critical as indicated previously, why does this exodus continue? Can it be stopped or reversed? The reasons for these conundrums are fairly obvious, and they tie back to the profoundly changed nature of war as it is fought today. We still regard the military as primarily combat services; we still regard development engineering as an unfortunate adjunct having no legitimate place in military activity. While it seems quite reasonable to expend hundreds of millions of dollars on training men to navigate, fly airplanes, and shoot guns and many millions on the continual conduct of exercises through which proficiency in these skills may be maintained, equivalent expenditures in the engineering development fields are generally regarded as completely unwarranted, although they would only amount to a small fraction of what is involved on the operational side. Development engineering is not regarded as a military profession. Doctors, dentists, lawyers, navigators, pilots, preachers are all professional men and recognized as such, but not development engineers.

The significance of this statement lies not merely in the psychological snub implied. but far more importantly in the fact that this lack of status has prevented the formulation of a professional career pattern whereby such men can be acquired, trained, and effectively exploited. It is only by good fortune that occasionally an engineer is employed over a period of years as an engineer, becomes highly competent in his field, and contributes to the nation's defense in his professional capacity. This in spite of the enormous significance attaching to these activities during the indefinite span of this new kind of war.

It has often been said that the armed services cannot retain engineers under any circumstances because of the miserable pay scales offered. This is a very questionable statement. If a good engineer wished to become rich he would cease to be an engineer; in fact he would never have been an engineer in the first place. Good engineers, in common with good professional people and craftsmen the world over, usually seek more than pecuniary recompense. No doubt there is a financial threshold value below which engineers are economically forced out of the service, but this is not very high. The lure of the service to the professional development engineer lies in the opportunity to participate meaningfully in great engineering adventure.

It is the failure to recognize the significance of development engineering as a constituent of military strength, and the consequent failure to set up any career plan to develop and exploit the engineer, that have caused the deplorable exodus of these key people. Without competent military development engineers there can be no stable relationship between industry and the military, for without these men the power to exercise technical discretion with regard to where we go, how we do it, and when it can be done ceases to exist. For the reasons dwelt upon above, this discretion cannot be contracted for.

The key to the dilemma of the relationship between industry and the military during extended periods of a new type of war lies, as we might have suspected from the beginning, in people. I have spent a good deal of time of late listening to organizations debate their relative merit in terms of how many Ph.D.'s or M.S.'s are found on the company payrolls. That such fatuous discussions can take place at all is a sad commentary on our modern sense of values. A massive program will prosper or die as a result of the vision, drive, technical skill, and ability to handle men of a handful of people in key positions. Organization can never substitute for inspiration. The man does not exist who can manage a complex task without a deep and abiding knowledge of the arts and sciences involved. The existence of mere ability to "manage" as a skill unrelated to specific endeavor is questionable. The modern tendency to refer the conduct of difficult programs to committees and teams is merely a convenient way to shirk responsibility. No team is worth anything without a captain, and the captain is the man responsible.

It seems quite clear that a delicate but well-defined and effective relationship can indeed be set up between industry and the military which will provide both the defense of the nation and continued industrial good health. The military services must recognize development engineering as a profession and undertake enough engineering work on their own to ensure a supply of competent development engineering officers at all times. In doing so, they should not go into competition with massive American industry but rather should investigate technical approaches with a marginal chance of payoff, largely under conditions not appropriate for contract work, and undertake test evaluation of massive contractor-developed equipment. In this way our numerous military graduates from engineering schools can be developed into the high-class engineers required to make the momentous decisions involved in military development activity. By this means also, significant contributions are sure to be made over the years in the state of the art, thus generating and sustaining the prestige of the military development officer. These officers, then, through their ability to combine the potentially militarily useful with the technically feasible, can act to inspire, stimulate, and guide industry along lines to best exploit its own skills for military programs. The numbers of men involved need not be large. It is surprising how rapidly the point of diminishing returns is reached in any organization.

The industry-military team thus formed would be enormously benefited by the return of many learned scientific scholars to science—for this country is proportionately weaker in straight scientific research than any other advanced country on the face of the earth—and by return of administrative politicians to politics.

Air Force Ballistic Missile Division (Hq ARDC)

. . . a searching look at the philosophy and management of research and development

The Stever Report

A Quarterly Review Staff Report

On 21 November 1957, some six weeks after the launching of Sputnik I, General Thomas D. White, Chief of Staff, USAF, sent a memorandum to the Chairman of the Scientific Advisory Board, calling for a "searching review" of the Air Force research and development program:

DEPARTMENT OF THE AIR FORCE
OFFICE OF THE CHIEF OF STAFF
UNITED STATES AIR FORCE
WASHINGTON, D. C.

21 November 1957

MEMORANDUM FOR CHAIRMAN, SCIENTIFIC ADVISORY BOARD

SUBJECT: Review of Air Force R&D Accomplishments

1. Eight years ago, the USAF Scientific Advisory Board surveyed the research and development program of the Air Force at the request of General Vandenberg, then Chief of Staff. Their recommendations, combined with similar recommendations from the Air University, resulted in our establishing the Air Research and Development Command and the Deputy Chief of Staff, Development. Clearly, the Air Force program of research and development is today far ahead for having taken those steps.

2. To insure our best contribution to the national technological effort, I should like the Scientific Advisory Board to conduct an impartial and searching review of the organization, functions, policies and procedures of the Air Force and ARDC in relation to accomplishments in research and development over the past seven years. After completing this review, I would expect the Board to make recommendations as to how we can do our job better in the future.

3. Lt. General D. L. Putt, the Deputy Chief of Staff for Development, and Lt. General S. E. Anderson, the new Commander of ARDC, will welcome this study. I regard it as a most important task and an opportunity for the Scientific Advisory Board to make another significant contribution to the progress of the United States Air Force.

/s/ *THOMAS D. WHITE*
Chief of Staff

Approximately seven months later the report of the Scientific Advisory Board's Ad Hoc Committee on Research and Development was submitted by the Chairman, Dr. H. Guyford Stever of the Massachusetts Institute of Technology. The letter of submittal summarizes the major findings and recommendations of the Committee:

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS UNITED STATES AIR FORCE
WASHINGTON 25, D. C.

20 June 1958

Dr. James H. Doolittle, Chairman
Scientific Advisory Board
United States Air Force
Washington 25, D. C.

Dear Dr. Doolittle:

In his memorandum of 21 November 1957, General Thomas D. White, Chief of Staff of the United States Air Force, requested the Scientific Advisory Board to investigate the manner in which the Air Force conducted its program in research and development and to recommend methods by which the Air Force might improve its management of research and development. You assigned responsibility for fulfilling this request to the Ad Hoc Committee on Research and Development, appointed especially for this task.

The Committee's report is herewith submitted. Its recommendations are based on a few broad concepts which are considered most important and are noted briefly below:

a. In all of its activities the Air Force will continue to experience at a growing rate the impact of advancing technology. The research and development phases will enlarge and become of greater importance. Though in the past the Air Force has introduced major changes to adjust to this increasing role of research and development, it has not yet kept pace with the need.

b. In order to handle its increasing technological problems, the Air Force will need a higher percentage of better trained, more capable technical personnel—officers, civilians, and airmen.

c. There is a growing lack of trust in the capability and performance of individuals at the working level in research and development, not only in the Air Force but throughout the government. This growing lack of trust has resulted in taking away from the working level the authority, but not the responsibility, for research and development projects, and diffusing this authority in a host of organizations and individuals in higher echelons; it has resulted in an increase in staff work of all sorts on matters of minutia; it has resulted in increasingly detailed technical direction from higher policies and planning echelons to lower working-level echelons in the research and development organizations; it has resulted in an increase in the constraint on the use of money, people, facilities, and on the resources required at the working level to do the research and development job. The lack of trust is extended into the contractual relations with industry, academic, and other private organizations.

Unless trust is restored and these symptoms of distrust eliminated the Air Force can never hope to reduce the length of its development cycle to that required to maintain technical superiority in weapons over our potential enemy.

d. Many of the changes needed to improve management and conduct of research and development in the Air Force depend upon other governmental agencies, such as the Department of Defense, the Bureau of the Budget, the Congress, and the Executive Office of the President.

In 1957 the Chief of Staff, USAF, requested the Scientific Advisory Board to review the Air Force's research and development organization with the view of ensuring that it was providing the nation with the best weapon systems in the shortest lead time. The result of the investigation is the Stever Report, which derives its name from the chairman, H. Guyford Stever, of the committee appointed by the Scientific Advisory Board to make the study. Concisely written and pointed in its language, the Report finds much to be done in reorganizing Air Force research and development and indicates that many of the same problems are present in governmental handling of research and development on levels above the Air Force. Because of the widespread interest that the Report evoked at the time of its release, the *Quarterly Review* offers an abridgment of the text of the Report. Its findings are still under study by the Air Staff and none of its controversial recommendations have yet been implemented by the Chief of Staff. But its distinguished authorship and its depth of perspective on problems of Air Force research and development make it an important document for the thoughtful air officer.

The Committee's recommendations, too numerous to list here in detail, are designed to eliminate to the maximum extent possible the undesirable conditions in research and development which are indicated above. The major recommendations are summarized briefly here, as follows:

a. The Air Force must sharply reduce excessive administrative controls and detailed technical direction which are exerted by higher echelons both within and without the research and development chain of command over the working-level project engineers, laboratories, and contractors. Authority and responsibility must be delegated together and concentrated at the working level.

b. Air Force must make clear to higher authorities the necessity for a reorientation of those activities of government above the Air Force that prevent the Air Force from doing the most effective job in research and development.

c. The Office of the Deputy Chief of Staff, Development should concentrate its efforts along the important staff lines of research and development requirements, policies, resources, program integration, and program evaluation. These tasks can be accomplished in such a way that the total number of staff personnel is reduced and detailed technical direction of the Air Research and Development Command is eliminated.

d. The Air Research and Development Command should be reorganized along the distinct functional lines of the research and development program, i.e., research, technical development, weapon systems, and testing. There should be Deputy Commanders in Air Research and Development Command in charge of each of these areas, who not only have responsibility for the program, but also are in charge of the Centers, laboratories, and other facilities which are directly engaged in their activity. An objective of this reorganization is to consolidate and reduce the staff and overhead personnel of the Headquarters, Air Research and Development Command and its Centers. This change should be accomplished in a way that the detailed research and development program is carried out directly at the working levels in the Centers and the laboratories.

e. Those portions of the research and development budget used for research, state-of-the-art development, and the development of radically new weapons should be substantially and immediately increased.

f. All operating funds for research and development should be consolidated within the research and development appropriation and placed completely under Deputy Chief of Staff, Development–Air Research and Development Command control, with Air Research and Development Command designated as a procuring activity.

g. The ponderous procedures for funding, approving, designing, and constructing research and development facilities must be streamlined.

h. The concept of giving the operating research and development agency packaged resources—funds, facilities, and personnel—should be followed more frequently, particularly for weapon systems development.

i. The budgetary and financial controls for research and development should be made more flexible.

j. Some research and development programs, particularly the exploratory research program, should be provided longer-term funding and greater stability.

k. Contracting procedures should be changed to give contractors greater incentive to do research and development work more efficiently.

l. The Air Force should raise the technical qualifications of its research and development personnel by increasing opportunities for higher education in technical fields.

m. The Air Force should attempt to obtain and retain better qualified research and development personnel by improving its career management and rotation policies.

n. Qualified civilian personnel should be given greater authority and responsibility in research and development work.

The Committee is strongly of the opinion that the Air Force research and development activities will be substantially and immediately improved and the total Air Force missions will be better discharged if the spirit of these recommendations is accepted and their sense is effected by the Air Force.

Sincerely,

/s/*H. GUYFORD STEVER*, Chairman
for the Ad Hoc Committee
on Research and Development

Mr. Bennett Archambault
Dr. W. Randolph Lovelace, II
Dr. Clifford T. Morgan
Professor Courtland D. Perkins
Mr. Perry W. Pratt
Dean Ralph A. Sawyer
Dr. Teddy F. Walkowicz
Mr. Raymond J. Woodrow

Because of the widespread public interest in the Stever Report and because of the important implications which its recommendations may well have for the future organization and functions of Air Force research and development activities, the *Quarterly Review* offers a summary of this outspoken and controversial document.

The Report begins by reviewing the events which led up to General White's memorandum. When the Deputy Chief of Staff for Development, Hq USAF, and the Air Research and Development Command were established, six months had passed since the first Soviet atomic explosion in August 1949. The Stever Report states that, even so, "the Soviet ability to master modern science and engineering was still not widely understood or appreciated. . . . In June of 1950, however, as a result of the Communist aggression in Korea, major support was given to all military activity, including research and development. . . ."

With these additional funds ARDC improved both its facilities and its products. This rate of progress was short-lived:

> Hardly three years after the initiation of these changes, when these improvements in USAF R&D were beginning to bear fruit, a new and less favorable environment emerged to give them a serious setback. Toward the end of the Korean War, the government moved to reduce the cost of the military establishment by placing greater reliance on modern weapons and technology. This policy should have called for increasing R&D budgets to develop the more modern weapons. Instead, because of overall economic considerations, the Air Force R&D budget levelled off, then declined.
>
> At the same time, the greatly increased interest in the military economy brought about stricter administrative controls, particularly in R&D. Project direction was often carried to much higher administrative levels than before. Decision-making became more ponderous as did procedures for providing the resources—people, dollars, and facilities—required to get the R&D job done.
>
> These two general factors, limited budgets and excessive administrative controls, together with some evident reservations within the Air Force about either the capability of the R&D organizations, or the importance of R&D, have partially vitiated the early accomplishments of the new R&D operation within the USAF. . . .

Nevertheless, the Report goes on to say, the USAF R&D organizations have done an effective job in many areas, most notably perhaps in accelerating and giving direction to the ballistic missile program.

Philosophy of Operations

After the introductory remarks concerning mainly the history of DCS/D and ARDC, the Stever Report considers in rather general terms the Department of Defense R&D program and the changing nature of the Air Force.

". . . another national awakening"

> There has been an intense research and development rivalry as each of the services has worked hard to establish its future in the air defense, guided missile, and space fields. In this competitive process, the Defense Department has been unable to limit interservice competition to that essential to most rapid progress. As a result, the roles and missions of the services have become competitive rather than complementary.
>
> This situation has imposed an additional burden on top of the already heavy cost of modern weapons. Because of it, budget agencies outside the R&D management structure have sought to reduce costs by themselves intruding into the detailed R&D phases of management. From the point of view of the USAF, the situation has been further aggravated by a lack of understanding of sciences related to air power at levels of government above that of the Air Force.

We have just gone through another national awakening to the importance of science and technology. In its aftermath, the President has taken two steps of major importance: first, he has presented a reorganization plan for the Department of Defense, including the establishment of the Advanced Research Projects Agency; second, he has appointed a Special Assistant for Science and Technology and revitalized the President's Science Advisory Committee. It is hoped that these steps will lead promptly to major improvements in military R&D management, and that the appointment of a number of officials throughout the decision-making structure of government who understand the dominant technologies of our time will come about. As the needed improvements in R&D management are studied by the higher echelons of government, the USAF has a major responsibility to make known its problems, needs, and recommendations.

". . . an increasingly complex technological Air Force"

The USAF is now faced with dividing its efforts amongst the continuing needs for manned aircraft, the growing needs for missiles, and the emerging, though not clearly defined, needs for space technology. Guided missiles and electronics already amount to approximately one-half of the total USAF R&D and Materiel budget. The USAF must face the problems inherent in this rapid trend toward an increasingly complex technological Air Force without having the strength in depth of scientific and technical personnel that is required to discharge its responsibilities. Over the past eight years the increase in the technical education and training of company grade Air Force officers has been somewhat impressive but still inadequate. In the field and general officer grades, only about one-third have technical degrees, rather less than in sister military services, and the percentage has been sliding slowly downward over the past eight years.

The USAF must come to understand that its ability to do its job depends to an ever greater degree on having a far greater proportion of its personnel trained in science and technology; otherwise, it will fail first to carry out its expanding R&D responsibilities, and eventually, to operate effectively its increasingly complex weapons.

"this separation between authority and responsibility . . ."

The past decade has seen a growing tendency within the government and the military to centralize authority, thus removing it from the operating units which still have the responsibility. This philosophy has seriously affected R&D. The typical Air Force R&D project officer, who has the responsibility for bringing a technical development or weapon system into being, has above him too many officials who have or assume authority for controlling critical portions of his resources and for approving in detail his project decisions. This separation between authority and responsibility, which is widespread, has been bogging down the R&D program, and in many cases it is dangerously lowering the competence of the R&D operating staff. . . .

The Committee is convinced that a principal reason for the long weapon development cycle, which must be of such a serious concern when we compare our military progress with that of our potential enemy, is this failure of each echelon and organization to trust lower echelons and other organizations, and to discipline itself to do its own job well and not to meddle with others. The maze of communication channels, the excess of paper work, the continual reviews and justifications, the diffusion of decision-making responsibility and authority, which are prevalent throughout the Air Force R&D program and which constitute a most formidable single barrier to its success, are manifestations of this lack of trust and discipline.

The trend of the past few years must be reversed. Authority and responsibility must be delegated together. The authority must include control of all resources required to get a job done, and the opportunity to stand or fall on the basis of competence to make sound decisions. Higher headquarters must limit the direction which they give the operating echelons to general policy and fiscal guidance. The operating levels must be freed from the present unending demands for information on all minutiae of all phases of their activity. . . .

Organization and Program Management

THE heart of the Stever Report is the section recommending a reorganization of DCS/D and ARDC. It begins with the problems of the existing system:

There is frequently a lack of clear understanding of the intended functions of each of the several echelons of the Air Force concerned in R&D. Even in cases where such understanding exists, there sometimes is poor discipline in confining the actual functions to those intended. In addition, direction is too detailed, and authority is too confused from the higher echelons to those beneath them.

The organization of DCS/D does not appear to be optimum for the important functions it has to carry out. The ARDC Centers are organized primarily along geographical, rather than functional, lines. Staff activity is duplicated to excess among the Centers, Headquarters ARDC, and DCS/D.

"DCS/D should direct and guide ARDC . . . avoid detailed project direction"

DCS/D should be responsible for five primary functions: generating R&D requirements, formulating R&D policies, obtaining the resources for conducting the R&D programs, integrating these R&D programs into the total Air Force and governmental programs, and evaluating and analyzing progress on R&D programs in order to facilitate the decisions of the Air Council, Weapons Board and other Headquarters USAF organizations. . . .

The generation of R&D requirements, presently is participated in by both the Directorate of Requirements and the Directorate of Development Planning. These organizations must hear and weigh the opinions of military planners, scientists, and engineers from both within and outside the Air Force, including the USAF operating Commands, in order to formulate requirements that are meaningful, obtainable, and worthwhile. Because these two Directorates have such similar objectives and activities, we recommend that they be combined.

The Committee is informed that consideration is being given to removing the requirements function from DCS/D and placing it in DCS/Operations. The Committee strongly believes that this would not be desirable, since it is convinced that the continuous development of the optimum in advanced requirements must be based primarily upon considerations of technical feasibility. Clearly, Operations personnel must have an important voice in the establishment of forward requirements, but leadership in this function should be the responsibility of the R&D organization.

The Air Force can only have the most advanced weapon systems by making maximum use of the state-of-the-art developments taking place in industry, scientific institutions, and its own laboratories. It requires technically trained people from the R&D structure to evaluate these developments and to know what is feasible. To be sure, any requirements group must have inputs from Operations personnel, who are often in the best position to point out deficiencies in the existing weapon systems, and to indicate what they consider to be desirable in future weapon systems. Even so, what should be possible often depends on new developments not familiar to Operations officers. So in the final analysis, the stating of requirements must remain in the hands of those who are most competent to judge the possibility of meeting any particular requirement. To put it elsewhere is to insure that our technological progress will be slowed at a time when it is essential to our survival that we do everything possible to speed it up.

There is at present no organization within DCS/D with specific responsibility for the formulation of R&D policies, the second function of DCS/D listed above. This function is so important that a separate office within DCS/D should be responsible for it. Such office should, among other things, monitor the effectiveness of the USAF R&D organizations; develop policies and plans to improve the quality and utilization of R&D personnel; work toward the improvement of R&D contractual relations with industry, academic, and other research and development organizations; insure that R&D activities and problems receive proper consideration in all Air Force policies and regulations; and, in general, be responsible for the formulation of optimum policies with respect to all R&D activities in the Air Force.

At present, within DCS/D the third and fourth functions listed, those of securing resources for the R&D program and of integrating the R&D program into overall Air Force activities, are carried out by the Directorate of R&D and the Assistant for Development Programming. In this area greatly increased emphasis must be placed on providing fully integrated resources for all major R&D programs.

The necessity of an adequate evaluation organization within the Air Staff is recognized. The Committee recommends the establishment of a separate office within DCS/D responsible for continuous evaluation and analysis of all present and planned weapon systems. This organization can provide the Air Staff authorities in the Weapons Board and Air Council with continuous and competent evaluation to help in their day-to-day deliberations and decisions.

In summary, it is recommended that DCS/D concentrate its efforts along the important staff lines of requirements and development plans, research and development policies, resources, evaluation, and program integration. It is firmly believed that these functions can and should be carried out by fewer people than at present.

for ARDC—"functional Deputy Commanders"

The ARDC should be organized primarily along functional rather than, as at present, geographical lines. More specifically, the Committee recommends that ARDC be organized with Deputy Commanders placed in charge of all distinct functional areas of the R&D program, these areas to be research, technical development, weapon systems, and testing. These Deputy Commanders should be responsible for overall program guidance and direction as well as the packaging of resources which are required for the execution of the programs. These functional Deputy Commanders may or may not be located at Headquarters ARDC but will control their programs within any Center where capabilities for such work exist. The operation of each Center will be directed by the Deputy Commander to whom the Center is assigned, presumably the Deputy Commander whose function dominates the work at the Center. Deputy Commanders will carry out their work at a Center directed by another Deputy Commander on a tenant basis.

The basic objectives of such a reorganization would be:

(1) To eliminate the excessive costs and confusion that now result from unnecessary duplications in staff work at Headquarters and at the Centers;

(2) To provide an improved basis for achieving the packaging of resources needed to expedite the entire R&D program;

(3) To minimize the present costly and wasteful tendencies toward "empire building" both at the Centers and at Headquarters;

(4) To eliminate to the maximum possible extent confusions in management authority and mission responsibility;

(5) To reduce sharply the redundance which now exists in many areas of Center activities, and thereby make feasible contractions in the activities of certain Centers and, possibly, the eventual elimination of some Centers.

With determined and sustained effort all these objectives—and the Committee regards them as essential to the future success of R&D in the Air Force—can be accomplished by means of the type of reorganization discussed in detail below, and with reductions in headquarters personnel.

In addition to believing that circumstances require a reorganization of ARDC along the lines proposed in this report, the Committee also believes strongly that clear criteria need to be established to govern the functions and methods of operation of Headquarters ARDC. The Committee recommends that these criteria include:

(1) Delegation of the maximum reasonable authority to the functional Deputy Commanders;

(2) The concentration of Headquarters ARDC's efforts toward providing:

(a) Overall program guidance that is specific, directive, and consistent with the operational plans and requirements of the USAF;

(b) In cooperation with the DCS/D, resources adequate for the execution of the programs planned;

(3) Emphasis upon the continuous appraisal of all major projects and programs to insure that they are consistent with the objectives of the Air Force;

(4) Emphasis upon the continuous assessment of technical progress and management effectiveness;

(5) The avoidance of short-term project guidance or control.

1. RESEARCH. The research program of the Air Force is widely scattered through various Centers and other offices and badly compromised by confusion as to the purpose of this research program and its overall direction. Research is interwoven with technical development and even weapon system projects, usually to the detriment of the research program.

In order to provide a sound basis for improving this situation with respect to research, the Committee recommends the establishment of a Deputy Commander for Research (DC/R).

Before considering the mission of the DC/R and of the other functional Deputy Commanders to be discussed in these organizational recommendations, certain definitions need to be established:

a. For purposes of this discussion, basic research is divided into two categories:
   (1) Basic research which is completely nondirected, has no specific end item in view, and is oriented only toward increasing the sum total of human knowledge is referred to as exploratory research;
   (2) Basic research which is directed toward a definite problem area is referred to as supporting research.

b. Applied research (and development) is also considered in two categories:
   (1) Applied research which is not oriented toward a particular weapon system and concerned only with improving the state-of-the-art is referred to as technical development (state-of-the-art);
   (2) Applied research which is oriented toward some specific Air Force equipment problem (e.g., the development of components for a particular weapon system) is referred to as technical development (supporting).

In terms of these definitions the unique mission of the DC/R would be responsibility for the entire exploratory research program of the Air Force. It is desirable that this responsibility be separated and placed under a Deputy Commander in order to ensure that exploratory research is given adequate attention and not neglected in favor of the much larger technical development program. The DC/R should be responsible for exploratory research in the USAF wherever located, and whether such research is performed in-house or by contract. It is desirable that the DC/R be located in or near Washington in order to operate in close proximity to Headquarters USAF, the Department of Defense, and such governmental agencies engaged in exploratory research as Office of Naval Research, National Science Foundation, National Advisory Committee for Aeronautics, and the Atomic Energy Commission.

The Air Force exploratory research program should be concentrated under the cognizance of the DC/R, and his office should both advise the Commander ARDC and represent the Air Force in all matters relating to exploratory research.

The DC/R should have under his jurisdiction the present Office of Scientific Research, and supervise such in-house laboratories of ARDC as are engaged primarily in exploratory research. Believed to be in this category are the Aeronautical Research Laboratory of Wright Air Development Center, the Geophysics and Electronics Research Directorates of the Cambridge Research Center, the Aeromedical Field Laboratory of Missile Development Center, the Brussels Office of ARDC, and the nonclinical research laboratories of the School of Aviation Medicine. The DC/R should supervise and implement all requests for contract exploratory research which might be generated at other ARDC laboratories or at other Air Force Commands, e.g., the contract program of the School of Aviation Medicine. Consideration should be given to placing the Armed Services Technical Information Agency under the DC/R.

Under the DC/R there should be separate divisions for physical and life sciences. This is to ensure that life sciences (medical science, biology, psychology, and social sciences) are given proper recognition and emphasis in the total Air Force program of exploratory research. In-house work in life sciences is dispersed throughout Centers and laboratories primarily concerned with development and testing. It tends therefore to be subordinate to the physical sciences and engineering. Yet in the advancing technology of the space age, human factors of all kinds are becoming increasingly important. To see that they receive the priority they deserve, they must be represented at a high level in DC/R on a par with the physical sciences and not subordinate to them. . . .

2. TECHNICAL DEVELOPMENT. Technical development embraces three fields defined earlier in this report as supporting research, technical development (state-of-the-art), and technical development (supporting). All are vital to the acquisition by the Air Force of continuously superior weapons and equipment.

ARDC has within its Centers both a substantial competence for conducting in-house technical development and for contracting for technical development work to be performed by others. Each of these capabilities is essential to the successful conduct of new weapon development and, in many respects, the two are complementary. Much attention must be paid, however, to the emphasis to be placed on each, and this emphasis will necessarily change from time to time. With few exceptions, however, the levels of competence in technical development are somewhat higher outside than within the Air Force. Nevertheless, the Air Force must maintain some in-house capability in technical development because at times it may be either impossible or impractical to have certain highly specialized types of development performed under contract. Clear criteria, however, should be established with respect to the types and scale of technical development work to be done within ARDC. Such in-house work is now too extensive and the present policies are not too clear. Such criteria might include these considerations:

(1) Can the work to be done effectively by one or more outside contractors, without the necessity for duplicating important facilities already available within ARDC?

(2) At what point in the development can the responsibility be transferred to an outside contractor?

(3) Is direct participation by ARDC in the development work essential to providing ARDC with sufficient competence to monitor contract efforts in this or in some closely associated field?

The greatly increased emphasis which has been placed during recent years upon both weapon systems project management and Category I procurement has tended to ignore the technical competence which is available within the Air Force. As a consequence, competence is decaying and morale is sinking in many important areas of the Air Force technical development effort. In addition, technical development directed toward the support of specific weapon systems is increasing at the expense of the state-of-the-art development.

The competence of the Air Force to conduct effective technical development in a particular field has been acquired over many years. Yet, present practices in the procurement and management of research and development on weapon systems largely bypass this competence. There appear to be at least four undesirable consequences:

(1) The Air Force may frequently fail to obtain the benefits of the optimum state-of-the-art developments in its weapon system programs;

(2) The cost of such programs may be unnecessarily high;

(3) The incentive for intensive state-of-the-art development is sharply reduced;

(4) The basic competence of the Air Force R&D organization declines.

The present organization of ARDC does not provide means for correcting these deficiencies. In order to do so, the Committee strongly recommends that the entire Air Force program in technical development, wherever located and whether conducted in-house or by contract, be placed under the direct supervision of a Deputy Commander in ARDC for Technical Development (DC/TD). The DC/TD should control all ARDC Centers and laboratories which are engaged primarily in technical development. The Committee believes that the following Centers should be considered for inclusion in this category: Wright Air Development Center, Rome Air Development Center, possibly Special Weapons Center, and probably Arnold Engineering Development Center. While the Arnold Engineering Development Center has substantial activities in testing, these activities are primarily concerned with development testing. For that reason, Arnold Engineering Development Center might be placed under the DC/TD. In addition to his direct supervision of certain Centers, DC/TD should also be responsible (on a tenant basis) for all important technical development work conducted at other Centers, whether done in-house or by contract. . . .

3. WEAPON SYSTEMS. The weapon system concept is relatively new, and in some respects it has been carried too far. In theory, it is desirable; but a practical means must be found for taking advantage of its inherent capabilities. Although the Air Force faces many difficult problems in this area, it must nevertheless become more effective in the development of complex new systems—all depending, in the end, upon the successful development of critical components. This concept has helped simplify the management of large weapon system programs, but at the same time has generated new management problems. These problems arise partly through the advent of weapon systems that employ new technologies with which ARDC has had little experience, and partly for other reasons outlined earlier in this report. In the development of airborne weapon systems, for example, ARDC has available many competent people capable of providing effective technical management. This competence has been acquired over several decades. In electronics, however, Air Force experience is narrower, and ARDC's competence is limited largely to the management of major air defense systems development; hence,

ARDC has relied greatly on outside organizations, particularly for systems planning. The Air Force had even less experience in the development of ballistic missiles, and realizing this it decided to contract for outside technical assistance in the management of this program.

The weapon systems divide themselves naturally into two major categories: flying vehicle systems, and ground environmental (i.e., air defense) systems. The present ARDC organization for weapon systems project management recognizes these categories but separates the management responsibility for flying vehicle into ballistic and aerodynamic systems. This separation arose because of the high urgency of the ballistic missile program and the decision to contract for its technical management. It has already caused some confusion and may well cause even more as the differences between the characteristics of aerodynamic and ballistic systems become less clear. The Committee, therefore, recommends that ARDC work toward the consolidation of management authority over the vehicle weapon systems development program, while at the same time it recognizes the current need for separate management of the aerodynamic and ballistic systems.

a. The Committee recommends that a Vice Commander be placed in charge of all aerodynamic and ballistic weapon systems and under this Vice Commander there be a Deputy Commander for Aerodynamic Weapon Systems and a Deputy Commander for Ballistic Weapon Systems. The establishment of this Vice Commander will aid in handling the overlap of vehicle systems to be managed by the respective Deputy Commanders for Aerodynamic and Ballistic Systems. Obviously, the missions and authority eventually assigned to the Advanced Research Projects Agency and National Aeronautics and Space Agency will bear directly upon the decisions as to which types of weapon systems will be managed in these different organizations; but we presuppose that the Air Force will continue to have R&D responsibilities in both areas. . . .

b. *Deputy Commander for Air Defense Systems Management* (*DC/ADS*). The equivalent of a Deputy Commander for Air Defense Systems has recently been established, and the Committee believes this action most desirable. The DC/ADS should have complete authority with respect to the management of the development of all major ground environmental systems. The Committee notes with approval the Air Force's decision to obtain for this Deputy Commander the assistance of a contract-operated technical management organization.

In making the foregoing recommendations with respect to the organization of weapon systems project management, the Committee wishes to emphasize again the importance of ensuring that these systems managers utilize to the maximum possible extent the full capabilities of the entire ARDC technical development organization. Attainment of this objective obviously will require, among other things, that the choice of procurement policy (e.g., Category I versus Category II) be given the most careful consideration on a project-by-project basis.

4. TESTING. A major task facing ARDC is to clarify and strengthen the management of the Air Force testing program. It must utilize more effectively its test facilities and ranges. Testing is the largest single functional activity of ARDC in terms of funds, personnel, and facilities. The present system of organization does not provide for an effective management of these major Air Force resources.

It is recommended that there be established a Deputy Commander for Testing (DC/T) who has complete responsibility for all phases and types of evaluation testing for the Air Force wherever conducted. It is the intention of this recommendation that operation of ARDC's extensive test ranges should be under one authority and that responsibility for evaluation testing be independent of those responsible for research, technical development, and weapon systems development.

The DC/T should have direct responsibility for the operation of Flight Test Center, Missile Development Center, Air Proving Ground Center, Missile Test Center, and possibly, Special Weapons Center. The DC/T should be responsible for providing facilities and services, as requested, for developmental testing, but the conduct of all such developmental testing should be under the supervision of the DC/R, DC/TD, DC/AWS, DC/BWS, or DC/ADS, as the case may be. It would be desirable for the DC/T to be located at a major test Center. For the long term, APGC seems the most likely to be suitable, however, FTC might be a preferable location during the present phase of testing requirements.

The concentration of authority over all evaluation testing in the hands of a Deputy Commander can assist greatly in the achievement of several of the essential objectives. These are:

(1) Clarification of the missions of the Center now engaged in evaluation testing activity;

(2) Improved utilization of testing resources;

(3) Elimination of duplications in testing resources;

(4) Substantial reductions in the testing resources now being employed, including the possible eventual disposal of certain major physical facilities; and

(5) Better planning with respect to future requirements for testing facilities. . . .

5. CENTER COMMAND AND ORGANIZATION. The reorganization of ARDC in accordance with these recommendations will have the obvious effect of greatly reducing the authority and responsibility now held by the Center Commanders, reducing or eliminating Center staffs, and possibly eliminating certain Centers. This seems to be essential to more effective performance of the research and development mission. Many of ARDC's present problems appear to stem directly from the natural tendency of Centers to broaden their missions and resources to the extent of serious overlap; these attempts have not been effectively controlled under the present system of organization.

Under the proposed system, it is the Committee's conception that the Centers themselves would, in most cases, be operated by Base Commanders having no authority or responsibility beyond that required for facilitating the technical activity, and that all authority with respect to program management would reside in the respective Deputy Commanders. . . .

Budgets, Accounts, and Control Expenditures

AFTER the recommendations for reorganization, the Report focuses attention on R&D budgetary matters. Reviewing past R&D budgets, the Committee notes that in the period 1946–50 the Air Force R&D budget remained constant at around $200 million, despite repeated efforts to get it raised; that the Korean War period boosted this figure considerably but it was again sharply cut after the war ended; that with inflation and allocation of certain operating expenses out of R&D money, funds available for development contracts have dropped to less than 50 per cent of the total, this in a period when both ballistic and aerodynamic systems must be developed. To halt this "debilitating process," the Report lists the following basic points that must be recognized:

(1) So long as the Soviets engage us in an armaments race, we dare not fall behind in quality of aerial weapons;

(2) So long as the technological complexity of weapons continues to increase, a steady increase in the emphasis on the R&D as compared with production programs should be expected;

(3) So long as the Soviet technological threat exists, and so long as the numbers of scientists and engineers to meet it are available, the overall R&D effort should increase:

(4) The commercial aircraft manufacturing and transport industries cannot appreciably support the military R&D program. The entire net worth of these industries would keep the program going for less than one year. Thus, the growing budgetary demands of the USAF R&D program must be met by the government.

These four points, it is believed, lead to the conclusion that those portions of the R&D budget which are used for research, state-of-the-art technical development, and development of weapons of entirely new concept should be increased substantially and immediately. The Committee readily grants that there may be some unnecessary duplication and some marginally useful projects in the R&D program; but this is true of all R&D programs and "squeezing the water" out of these areas is not the important problem. Though every effort should be made to spend R&D funds efficiently, it is still necessary to increase the size of this portion of the R&D budget. Required savings of money should be achieved by a sharper selection of weapon systems for production, with a quick and final elimination of those that are technologically clearly behind the times.

R&D budgeting should be "the servant and not the master"

> The Committee understands . . . that approximately 80% of the funds employed in the research and development activities in the Air Force are not under the direct control of DCS/D-ARDC, but come from procurement, construction, and military personnel appropriations. DCS/Materiel-Air Materiel Command, are responsible for representing to the funding authorities budgetary information concerning by far the largest portion of the R&D operating budget, after having exerted an important influence on the character and size of the items going into this portion of the budget. In addition, DCS/M-AMC also have control over the obligation and expenditure of these funds once they have been appropriated. As a result, DCS/D-ARDC are in a position of having responsibility for the R&D program of the Air Force, but only a very limited authority over the budgets and expenditures involved. Even with respect to R&D appropriations—the bulk of which are spent through contracts with industrial organizations, educational institutions, and independent laboratories—ARDC may contract only on the basis of delegated authority from AMC and is subject to its review and control of important contracts and contract terms and procedures.
>
> The Committee further believes that the present budget categories for research and development do not correlate sufficiently with a sound organizational structure for R&D management, particularly with respect to appropriations for technical development not directly related to specific end products such as aircraft or missiles. Present budget categories do not provide sufficient flexibility to accommodate the rapidly changing science and technology of air warfare. Nor do they fit the need for a firmer foundation of stability and continuity of funds for most basic research and certain technical developments.
>
> In general, there should be greater emphasis on the philosophy that the R&D budgeting and accounting structure should, within the sound limitations of Executive and Congressional control, be the servant and not the master of those managing R&D. This is not to say that the managers of R&D should not be interested in economy or reduction in costs, but that they should be held responsible for *total costs* in major areas of performance in terms of results produced, not told in detail how their dollars should be spent. . . .

The Report considers these points in some detail and makes recommendations for substantial changes in the handling of Air Force R&D funds, including those for R&D facilities construction. For example, it is proposed that all operating funds for research and development be placed under DCS/D-ARDC control. The Committee further urged that ARDC be designated a Procuring Activity, as is Air Materiel Command, having "the authority commensurate with such a status." Also that the funding system should be reorganized to provide greater flexibility in fund management on the one hand and greater stability and continuity on the other. Another important recommendation is in regard to R&D contractors. The Report strongly emphasizes the need for greater incentives, such as higher fixed fees, for industrial contractors to undertake research and development.

Personnel

THE final section of the Report deals with R&D personnel. Primary attention is given to the problems of obtaining men who can fulfill the ever changing technical requirements of the modern Air Force and of making an Air Force R&D career attractive enough to retain them.

> The problem now is not so much one of numbers but of the technical training and capability of officers and civilians manning the Air Force R&D effort. In all of its comments concerning the capabilities of the officers and civilians in the USAF research

and development effort, the Committee recognizes that some really outstanding individuals, both in uniform and in Civil Service, are doing the Air Force's R&D work. The Committee, however, views with alarm the inadequate numbers of such personnel and the apparent absence of serious plans to eliminate the shortage.

"notable shortcomings still exist"

While the Air Force has improved certain aspects of its management of technical personnel, there are other areas in which notable shortcomings still exist. To understand these shortcomings, it is necessary to consider the following impacts of the current technological revolution in weapons on technical personnel requirements:

(1) Weapons of all kinds have become more complicated. To appreciate what a weapon does, or may be capable of doing, now requires a level of sophistication and technical knowledge far higher than it did only a few short years ago.

(2) With the advent of the missile age the flyer is becoming relatively less important and a technical knowledge of weapons is becoming relatively more important. Hence, the Air Force needs more and more officers who need not be pilots but who are highly competent in technical matters. . . .

The Air Force has made an effort to improve the supply and quality of its technical personnel without success. In regard to officer personnel, the following changes have taken place since the Ridenour Report:

(1) The fraction of general officers with technical degrees has gone down about one per cent.

(2) The fraction of field-grade officers with technical degrees has decreased about four per cent.

(3) The fraction of company-grade officers with technical degrees has increased about ten per cent.

The level of training of senior officers was too low to begin with, and the trends are in the wrong direction. With regard to junior officers the level of training was seriously inadequate eight years ago, and the commendable progress made since then must be further accelerated if the Air Force is to have technical leadership equal to the challenge of its increasingly complex tasks. Much of the improvement in numbers in the junior officer ranks is a result of getting for only a short time ROTC officers from technical schools.

As regards civilian personnel, red tape, unequal opportunity between officers and civilians for senior positions of authority and responsibility, as well as the more commonly recognized handicaps of government employment are depriving the Air Force of the services of highly qualified civilians.

The Air Force must make a herculean effort to recruit, retain, and utilize effectively greater numbers of technically qualified R&D personnel.

"a bachelor's degree is not enough"

At the present time only a small percentage of officers in the R&D assignments do not have a bachelor's degree. Although the holding of such a degree does not in itself guarantee technical competence, and some can achieve such competence without a degree, it is believed that, as a general rule, officers in technical and supporting assignments should hold at least a bachelor's degree in technical fields. The data given to us indicate that currently 93.5 per cent of ARDC officers in technical assignments have at least a bachelor's degree.

In many technical areas a bachelor's degree is not enough. Rather, a master's degree or doctor's degree should be the minimum qualification for the officer holding an assignment. To spell out such areas and assignments is not possible in this report but, in general, the more an officer is concerned with the use or application of science or advanced technology, the higher should be his educational qualifications. The number of officers holding master's and doctor's degrees should be substantially increased. The statistics with respect to ARDC technical officers indicate that 32 per cent have master's degrees and 2.5 per cent have doctor's degrees. In all R&D assignments in the Air Force the statistics are 31.1 per cent for master's degrees and 2.9 per cent for doctor's degrees.

The Air Force has been doing an impressive job of sending officers back to school in order to raise their educational level and hence their technical qualifications. For example, this year the number of officers sent to the Air Force Institute of Technology for additional schooling at bachelor's and master's levels is 82 and 90; to civilian technical universities the numbers for bachelor's, master's, and doctor's are 497, 230, and 4. For this the Air Force should be complimented. It is noted, however, that, despite these efforts, the number of officers in ARDC who hold bachelor's and master's degrees is not increasing rapidly enough to meet the demand. For that reason the program of sending officers to schools of higher learning, particularly the civilian technical universities, should be expanded and certain changes in the present program should be made. More specifically, the following is recommended:

a. Officers should be permitted to apply for training and to learn the result of their applications *before* obligating themselves to a specific tour of duty. The present practice, of requiring such an obligation before applying for and being accepted for training, discourages many company-grade officers (ROTC) who might otherwise remain in the service. Having been accepted for and having received training while in the service, the officers in the Air Force ought to be required to obligate themselves for post-training active duty on a scale adjusted to the amount and level of training received. Something like three years of duty for each year of training at the Air Force's expense seems to be a reasonable figure, and it would be more equitable than the flat three-year rule now in force.

b. Where university facilities are in the neighborhood of R&D installations, the Air Force should do even more to improve the opportunities for officers to do part-time graduate work by contributing to the tuition that must be paid and by giving the officer some time off from regular duties.

c. The Air Force provides a limited number of duty assignments at universities or research laboratories so that its more capable, highly trained officers might bring themselves up to date in the latest scientific and engineering developments. If the Air Force broadened this program, it would help considerably to raise the level of capability of the R&D officers.

d. Experience of some of the Committee members indicates that the Air Force does a good job of reassigning R&D officers to R&D positions after they have completed additional schooling in the technical subjects, and in keeping them there after the completion of their training. Even an occasional deviation from this practice, however, represents a serious loss in technical potential, both directly and by discouraging those who want to be assured of an R&D career.

e. At present the Air Force requires that an Air Force flying cadet need have only two years of college training. Since many of these young officers are highly motivated to remain in the Air Force, including in R&D, this requirement should be increased as soon as possible to a bachelor's degree, preferably an engineering or scientific degree, prior to starting flying training.

Such steps are essential if the educational level throughout the Air Force is to be improved to the extent necessary for manning the technologically complex Air Force of the future.

The Committee then offered a number of recommendations on R&D personnel management, designed to make careers more attractive and to get maximum use from trained personnel.

Air University Quarterly Review

Atlas Launch Crew Proficiency

Major Edward H. Peterson

THE SM-65, the Atlas, will soon become the first operational intercontinental ballistic missile in the USAF inventory. The integration of this weapon into the operational structure of our air units opens up an entirely new set of organizational, maintenance, operational, and employment concepts. As with most new weapons, the problems of the maintenance of the hardware will probably constitute the bulk of the shakedown effort. But in this system there will be other problems scarcely less new. Operationally the immediate objective of the Strategic Air Command is to get the missiles and their crews up to operational readiness as quickly as possible. Secondly, having achieved this, we must keep them there. The big new problem here is how launch crews can be trained and their proficiency maintained without deteriorating the constant combat alert that must be maintained, and with only very rarely carrying the training to its logical culmination—the full launching of the ICBM.

In reviewing the progress that has been made on the problem of Atlas launch crew proficiency, let us first consider the factors that serve to frame the training of launch crews—the weapon, operational posture, the limitations of the hardware, and the simultaneous phasing requirements; then review the analysis of the various types of training that were considered possible under these conditions; and finally discuss in broad outline the launch crew training program as it now stands.

the molding factors

The Weapon. The Atlas is a liquid-fueled, one-and-one-half-stage rocket designed to place a nuclear warhead on a target 5500 nautical miles from the launch point. This is accomplished by firing three large rocket engines at take-off, jettisoning two engines (the boosters) after part of the fuel is consumed, continuing to gain speed and altitude on the sustainer engine, and trimming the final velocity vector with low-thrust vernier motors. Since the final control of velocity is applied relatively early in the flight, the bulk of the flight is free fall—hence the term ballistic trajectory. To complete the flight requires about one half hour; this, coupled with ability to rapidly invoke this weapon system, provides an extremely fast retaliatory system.

Operational Posture. The capability of fast reaction presents a series of operational difficulties. On the manning side we must have a perpetual alert status—a crew standing by at all times. Various schemes of "fire-house" manning versus shifts have been considered, but under any plan each job must be multiple-manned. This manning increases the loads in all training phases and generates a greater demand for proficiency exercises to be conducted within the operational unit. Another complication arises from the fact that the weapon is beyond recall shortly after its launch. To preclude an accidental triggering, the control procedures must be fast, accurate, and foolproof.

The combination of long alert periods and tight command control are presently under study from a morale and motivation point of view. In addition, there is a dual requirement on the launch procedures themselves: (1) the development and refinement of the operational procedures to provide maximum effectiveness when and if implemented, and (2) the continuous exercise and evaluation of the launch crews' proficiency in performing these functions.

Hardware Limitations. The hardware limitations that affect this weapon system can be defined in four main categories: single flight, high performance, weight penalty, and irreversibilities. First, single flight simply means that ballistic missiles are non-recoverable vehicles. Second, missile components must meet very

Reconcile such diverse operational ingredients as perpetual alert status, multiple-manning, proficiency exercises, and tight command control—and one has some measure of the ICBM launch crew proficiency problem. Added complications lie in hardware limitations and in requirements that crews be trained and proficiency maintained within the operational unit without lowering constant combat readiness and without launching the ICBM. Major Edward H. Peterson, Headquarters SAC Mike, surveys the Atlas launch crew proficiency problem and some of its possible solutions. These include (1) a simulated operational environment (mockups of launch control consoles) to analyze launch crew procedures, and (2) the same simulation circuitry, capable of being quickly switched in and out of the missile system, to practice on-site operations. This approach "will permit the full-scale exercise of the ballistic missile force or the exercise of any desired element."

high quantitative and qualitative performance requirements. Third, all components must be reduced to minimum weight because any excess weight causes a sizable penalty in range. Fourth, these hardware parameters cause certain irreversibilities: a launch means the expenditure of a missile; a static firing saves the missile but requires a period of cleanup and rechecking that costs wear and tear plus some hours' loss in readiness; a practice countdown short of firing still causes a recycle period. Essentially these conditions permit the missiles to be brought to the fully ready state and then kept at this level by periodic functional checkouts. Any attempt to practice procedures beyond this readiness point means system stand-down.

Simultaneous Requirements in Phasing. Complicating the phasing of ballistic missiles into the operational inventory is the requirement for the three elements of the system—hardware, skills, and techniques—to be developed simultaneously. Several development actions in the area of skills are presently under way. The Qualitative Personnel Requirements Information (QPRI) defines the skills required of the individual members of ballistic missile units. The individual training program develops these skills in the personnel. The Integrated Weapon System Training (IWST) program welds these individuals into launch, checkout, and maintenance teams. It is during this training period that the launch crews receive their initial practice as a complete team. To establish these launch crew procedures a thorough analysis process was required.

the analysis

The hardware test program was examined for the possibility of serving as the source of information on pure operational procedures. There are certain inherent drawbacks with this approach: (1) the compressed schedules that limit personnel research and practice in the test program; (2) the overlay of telemetry and instrumentation to the point where the test countdown bears little resemblance to the anticipated operational countdown; and (3) the quantitative and qualitative superiority of manning in the hardware test program over that in an operational unit. (This is to be expected. Since the purpose is equipment testing, it is essential to remove all possible human variables.) To satisfy the requirements of procedures analysis, it was necessary to design a program specifically aimed at investigating the operator variables.

The mockups of launch control consoles constructed for the

Atlas development engineering inspections offered an economical means of creating a simulated operational environment in which to conduct such an analysis. After the addition of a communications system and certain recording devices, this set of launch control consoles represents the future operational system and has the capability of presenting normal and abnormal situations. These mockups consist of the control consoles of a blockhouse, a guidance station, and a squadron command control console. With this facility Air Force crews can practice and test the countdown procedures in a controlled environment. Similarly we can test alternate schemes of organization, manning, procedures, communications, controls, and information displays. Certain information derived from this analysis will be fed back into the hardware development to assist the continuing improvement of the product. The bulk of the information derived is centered around the personnel in the system. It suggests answers to such problems as validation of predicted personnel requirements, exercise frequency and content, evaluation standards, and future personnel economies.

After the analytical program is completed, this set of console mockups will augment the operational equipment used in the Integrated Weapon System Training program. The IWST program calls for four launch crews, plus a proportionate number of maintenance crews, to be trained on each of two shifts. The training equipment consists of one complex of operational launch equipment. This training load requires a separate facility to augment the basic complex for the practice of crew procedures.

unit proficiency training program

After operational personnel have completed individual and IWS training phases and have been deployed in operational squadrons, frequent exercises must be continued to build and maintain launch crews' effectiveness. There must be periodic evaluations, since neither individuals nor crews can be considered combat-ready unless they periodically demonstrate their capability. The hardware factors previously mentioned are the limiting ones in this exercise and evaluation program. It is presently planned for each Atlas squadron to expend a limited number of missiles per year in actual launches. This number is determined by various factors, including economic and force modernization considerations and the progress of the training programs. These launches are essential for the proofing of the man-machine relationships of the system. Because of the limited number of actual launches expected, the operating crews will not be able to continuously sustain and demonstrate their proficiency by this means alone. To the actual launchings there must be added simulated forms of launch training.

Static firings and aborted countdowns have also been explored for their possible use as an exercise and evaluation method. Unfortunately these processes also involve penalties in system wear-out and readiness degradation. The conclusions reached in an early study of operational launch equipment are presented in chart form. The checks indicate the kinds of exercises that can be conducted under three approaches involving different types of equipment. The top three exercises in the left column provide the best evaluation of men and equipment, but they are also costly. The day-to-day practice must be done by some synthetic means, and this exercise can be combined with a true command control exercise under the second approach. Also a Unit Simulated Combat Mission (USCM) can be conducted realistically in the first two approaches. A simulation capability at the operational site will permit more frequent and less costly exercises of this sort. The principal conclusion reached by this study was that a means should be provided to practice operational procedures within the

Exercise vs. Equipment

type of exercise	operational equipment only	operational equipment plus simulator and recorders	separate simulator
combat training launch	√	√	
static firing	√	√	
aborted firing	√	√	
simulated launch		√	√
command control	√	√	
unit simulated combat mission (emergency war plan)	√	√	

job environment without impairing the readiness state of the missiles. This means adding sufficient simulation to the primary system to prevent activating critical or delicate parts of the missile. So as not to hamper the system readiness criteria, this simulation circuitry must be capable of being quickly switched in and out of the system. To evaluate the performance of the operational crews it is necessary to determine standards against which these crews should be measured and to provide a means for recording the essential data to be compared against the standards.

At the present time the analysis and development of this Unit Proficiency System are in process for the Atlas and the other ballistic missile systems. These Unit Proficiency Systems are scheduled to go into the field at the time the weapons become operational. Concurrent with the development of the proficiency systems and standards will be the generation of the methods and techniques to be employed in these exercises. The manned bomber system of SAC has a series of regulations and manuals defining the periodic training requirements for the personnel of the bomber systems; the corresponding regulations and manuals will be developed for these ballistic systems.

The approach being followed will permit the full-scale exercise of the ballistic missile force or the exercise of any desired element. It will permit the exercise of the command communications from Headquarters SAC down through the elements of command to the operational crews, the implementation of a typical Emergency War Plan by the crews, and the flow of data back through the command channels for decisions at the higher levels.

The launch crew proficiency problem, then, can be divided into two main areas: the development and refinement of the procedures to yield maximum effectiveness; and the capability to train, exercise, and evaluate the crews in these procedures. The first part of the problem is being solved through the use of a dynamic simulator designed with the flexibility to test experimentally a variety of organizational, manning, communications, data-flow, and decision-rendering functions. The training of the launch crews during the Integrated Weapon System Training phase will be accomplished on operational equipment augmented by the same simulator used in the analytical program. The continued proficiency practice in the operational units will be accomplished through the addition of the necessary simulation and recording equipment to conduct the exercises on-site. This approach will permit the exercise and evaluation of the complete Atlas force or of a wing, squadron, or individual launch crew. The frequency and content of each level of exercise must be designed to bring the manned system to maximum effectiveness. Adding this capability to an otherwise static set of hardware is the only acceptable manner for the SAC units to build, maintain, and prove their constant combat readiness.

Headquarters SAC Mike

. . . Air Force Review

THE HUMAN SIDE OF THE BERLIN AIRLIFT

Dr. W. Phillips Davison

THE Berlin airlift of 1948-1949 has been widely recognized as a masterpiece of improvisation and organization. When the Soviets completely severed land communications between Berlin and West Germany in the last days of June 1948, British and American aircraft were suddenly called upon to supply all the necessities of life to nearly two and a half million persons in the beleaguered city. This feat was accomplished with a speed and efficiency that caused many observers to label it a technical miracle. During July 1948, with almost no advance preparation for a large-scale operation, the Western powers were able to fly in an average of somewhat over 2000 tons per day. This figure rose steadily, although with fluctuations caused by bad weather, and by April 1949 more than 8000 tons per day were arriving in West Berlin via the airlift.

Considerable attention has been given the technical lessons learned from the Berlin airlift, especially in regard to aircraft and airspace utilization, training procedures, cargo handling, and so on. Less attention has been given the human factors involved in the airlift's operations, although these were certainly no less important to its success or failure than were the material and organizational aspects. The following pages are devoted to a discussion of some of these human factors: the importance of enthusiasm as a spur to improvisation, the way in which a clear definition of the mission helped ensure coordination among the numerous agencies concerned, the strains that the grueling pace of the operation placed on the morale of aircrews, the compensating motivations that combined to ensure high performance in spite of these strains, and the spontaneous contributions to good public relations made by individuals who took part in the airlift.[1]

enthusiasm and improvisation

On the American side, the first steps toward establishing a large-scale airlift came on 29 June when temporary headquarters for a Berlin Airlift Task Force were set up under the command of Brigadier General Joseph Smith. General Smith was given this assignment by General Curtis LeMay, at that time commander of the U.S. Air Forces in Europe, when he stopped in at General LeMay's office "on the way back from lunch." Instructed to fly as much food as possible into Berlin starting immediately, General Smith mobilized all available transport aircraft, manned those planes that did not have assigned crews by taking flying personnel off desk jobs in USAFE headquarters, and began transporting supplies for the Berlin civilian population on the same day. Many of the officers were flying "in addition to their other duties," and suddenly found themselves working sixteen to eighteen hours out of each twenty-four. But the airlift was expected to last at the most a few weeks, and many of the personnel regarded the sudden demands on them as a lark.

British aircrews of the Royal Air Force Transport Command had a similar exhilarating experience when ordered to start a large-scale airlift to Berlin. A British account describes the operations of the first few days as having been conducted in a carefree, almost a haphazard manner:

> Pilots full of doughnuts and tea went forth to seek any aircraft which happened to be fueled, serviced, and loaded. Hot was the competition, and great was the joy when one was found. Soon the summer skies were full of . . . aircraft heading in the general direction of Berlin.[2]

Much the same situation prevailed in organizations responsible for procuring supplies to be transported. Since as yet there were no provisions for moving large quantities of food to the airfields, American and British Army officials commandeered shipments of foodstuffs wherever they could find them and rushed them to the planes. German and military stocks were thus diverted to the airlift for several weeks before a more systematic procurement system was set up.

Stories about the confusion and also the enthusiasm of the early days of the airlift are legion. One tells of a C-47 that was carrying an eminent diplomat on a tour around Europe. This plane landed at Wiesbaden and the machine was left unattended while crew and passenger had lunch. When they returned, they found the plane loaded with three tons of flour.[3]

The peculiar problems of the airlift called for considerable ingenuity, both in utilization of aircraft and airspace and in operations on the ground. For instance, some of the heavy machinery required for airfield construction in Berlin had to be cut into manageable pieces with a blowtorch before it could be flown in; once in Berlin, it had to be welded together once more.[4] Again, to facilitate bad-weather landings at Tempelhof, it was necessary to construct towers of up to seventy-five feet on which to mount approach lights. After searching the city for materials, engineers decided to try to build them out of welded-steel landing mats, and the experiment worked perfectly.[5] New methods of cargo handling were devised, ways were found of scheduling aircraft at closer intervals than had previously been considered possible, and numerous other innovations helped speed the operation.

Transportation of supplies from Berlin airfields to storage depots was accomplished largely by German civilian trucking firms under the supervision of mili-

More often than not the Berlin Airlift is acclaimed as either a technological triumph that confirmed the role of aviation in big-time transportation and logistics, or a psychopolitical victory in the cold war. Less spectacular but equally valuable are the hard-earned lessons in human morale, endurance, teamwork, motivation, ingenuity, enthusiasm, and spontaneity that are the heritage from the human side of this airlift. These human factors have been closely studied by Dr. W. Phillips Davison, Research Scientist, Social Science Division, The Rand Corporation. He concludes that "human limitations should be taken into account" along with hardware considerations in undertaking any such large-scale operation.

tary transport agencies, but fuel economies were effected in several ingenious ways. U.S. Military Government, for example, put into operating condition a small, privately owned railroad extending some six miles from Tempelhof airfield to one of the city's canals, and thereby saved substantial quantities of gasoline. Two locomotives and twenty freight cars were "borrowed" from the Russians for this purpose, and were then credited against the railway-car debt that the Soviets owed the West German bizonal area.[6] The British, for their part, constructed a pipeline from Gatow airfield to an oil-barge loading point on Berlin's canal system. They were able to do so only because there happened to be available in Berlin some lengths from the oil pipeline that had been laid on the floor of the English Channel during the war to pump oil supplied from England to the armies on the Continent.[7]

Those who were involved in the operation of the airlift reported that the atmosphere was favorable to ingenuity and improvisation. The emphasis was on getting the job done rather than on doing it according to the book. Although this emphasis was sparked by the speed and enthusiasm with which the undertaking was launched, some of it persisted to the very end. Anticipated bottlenecks again and again failed to materialize, and the airlift broke its own records week after week. The atmosphere was summarized by a U.S. Air Force officer who was trying to explain the success of the airlift to an inquiring reporter: ". . . if you run across anyone in the theater who tells you that he knew we could do it all the time, pass him up. We didn't know all the answers all the time. We kind of astounded ourselves."[8]

definition of mission as an aid to coordination

Successful operation of the airlift required not only smooth teamwork within the American and British air forces, and between the two, but also coordination among French, British, and American military governments, Berlin's German officials, and civilian agencies in West Germany. All these authorities played a vital role in assuring the supply of West Berlin and without full cooperation from all of them the success of the mission would have been in doubt.

Since many of the agencies that vitally aided the airlift did this in addition to their many other functions, it was impossible to place all of them under a single command. Coordination was ensured in part through a complicated network of air-ground, inter-Allied, and Allied-German committees, but even more by the fact that everyone understood the mission and appreciated its importance and urgency. When U.S. airlift units first started using airbase facilities in the British zone of Germany, for instance, it was found that certain vital supplies had not yet been brought forward from the U.S. zone. The British immediately furnished the necessary supplies, in spite of the absence of any agreement calling on them to do so. Similarly Army personnel diverted supplies that had been allocated for other purposes and shipped them to West German airfields so as to maintain an adequate flow, and German officials cheerfully cut across formal administrative channels to help both in planning requirements and in distributing supplies.

All of these arrangements might very well have necessitated time-consuming negotiations and conferences. That such negotiations ordinarily were not necessary was in large part because the significance of the airlift was clearly understood by all personnel at all echelons. As a German supervisor at Rhein-Main Air Base said afterwards with reference to the performance of his maintenance crew: "We didn't have to explain to the men the importance of what they were doing; this they saw every day in the newspaper."

The experience of the airlift thus suggests that a clear definition of objective, which is understood by all personnel, may on occasion do as much to ensure good coordination as a streamlined organizational setup.

the strain of the long haul

On 20 October 1948 the British and American units engaged in the airlift were brought under the direction of a Combined Airlift Task Force, with Major General William H. Tunner as commander and Air Commodore J.W.F. Merer as deputy.

General Tunner recognized that the airlift's success might depend on whether minutes, or even seconds, could be shaved off the time necessary to perform each individual operation. This called for clocklike, standardized efficiency at all the air bases. In General Tunner's own words:

> The basic concept of the lift was to pace the entire procedure to a steady, even rhythm with hundreds of planes doing exactly the same thing every hour, day and night, at the same persistent beat.[9]

The soundness of this concept was clearly demonstrated by the results achieved during the ensuing ten months.

Maintenance of this steady rhythm over a longer period, while it ensured optimum utilization of available equipment and airspace, imposed serious strains on personnel, and morale problems were inevitable. Some of these were caused by physical and mental fatigue; others were brought on by inadequate base facilities, uncertainty about the length of time the operation would continue, and domestic worries.

Soon after the novelty of the airlift wore off, fatigue began to be reported. The major causes of fatigue were reported by British aircrews in a study conducted by medical authorities:

Major Causes of Fatigue Reported by British Aircrews in Response to a Medical Questionnaire[10]

Problem	*Per Cent**
Lack of sleep or lack of undisturbed sleep	57
Waiting about between trips	46
Unsatisfactory living conditions	40
Unsatisfactory ground-crew organization	28
Long working hours	28
Aircraft design	26
Irregular meals and poor food	23
Extra flying involved	20
Domestic worries	20
Lack of recreation	10

*Figures add to more than 100 per cent, since many respondents cited more than one cause of fatigue.

This study also found that, while the men at first suffered principally from mental fatigue resulting from the unaccustomed pressure, they gradually began to suffer predominantly physical symptoms, induced not only by the work itself but also by the fact that many men had to sleep wherever they could whenever they had the opportunity.

Studies of U.S. crews, of which the principal one is by Lt. Col. Harry G. Moseley of the Air Force Medical Corps, disclosed similar findings, with problems of scheduling, inadequate base facilities, and domestic concerns the greatest threats to morale and the chief causes of fatigue.

The necessity of operating the airlift twenty-four hours a day and seven days a week required exhausting schedules for the individual men. Many varying schedules were tried at one time or another by different units. For the most part, crews were on duty about fourteen hours and off twelve hours. U.S. Air Force personnel maintained this schedule for three days, followed by two days of rest. For Navy personnel it went on for fifteen days, with five days off before the next round. A period of day flying for any given crew was ordinarily followed by a period of night flying.[11] RAF crews usually flew two round trips, followed by twelve hours off duty. After about two weeks of this they were sent to Britain for five days' leave.[12] Toward the end of the airlift a rotation scheme was devised for RAF crews which called for three months in Germany followed by two months in England.[13]

There were many variations in these patterns, however, since scheduling was left to squadron and group commanders, with little guidance from above, and schedules were changed frequently. Most men actually had to work more hours than their schedules called for and were on duty at least as much time as they were off duty.[14] As a result flying personnel rarely were able to get enough rest, and efficiency was cut down by fatigue and illness. To complicate matters still more, laundry, medical, and post exchange services usually were not available around-the-clock, so inevitably some of the men were off duty only at hours when these services were closed.

The airlift's rapid expansion strained air base facilities for housing and feeding personnel almost to the breaking point. The water supply at Wiesbaden was inadequate at first and Fassberg and Celle had recurrent water shortages which were bound to interfere with personal hygiene. Inadequate mess hall facilities, manned by untrained personnel, often created unsanitary conditions. None of the bases had proper refrigeration facilities. Only the relatively cold climate kept spoilage from becoming a major problem.[15]

Air personnel felt the extreme housing shortage keenly. Every type of shelter had to be exploited and even distant barracks were renovated for use. Heating and lighting were often primitive and some dormitory rooms could hold no furniture besides doubledeck bunks. Because the men were not segregated according to the shifts they worked, there was a continual traffic problem, especially in the larger rooms, and sleepers were constantly disturbed. Colonel Moseley concluded from his survey that, at their worst, conditions at the airlift bases were comparable to those found in Nazi concentration camps in 1945.[16]

The morale of air personnel was affected also by domestic worries and uncertainty about the future. All the men sent to Europe during the first months of the airlift had come on temporary duty, expecting to return to their home bases within weeks. As temporary duty assignments were extended first to 60, then to 90, and finally to 120 days and beyond, personnel problems multiplied. Seldom, even in wartime, had personnel been removed so abruptly and unexpectedly from their homes and communities. Some men left their families in tourist courts, others parked their cars at some airfield of embarkation, and many had to leave all kinds of legal or financial problems dangling in mid-air. As assignments were prolonged, the uncertainty and the unsolved personal problems became magnified to the point where the men could concentrate on little else.[17] Morale of U.S. airlift personnel improved sharply following the establishment of a rotation plan, but this could not be put into effect until early in 1949.

Some men were able to have their families sent to Europe to join them, but even then their situation was scarcely improved. With barely enough family housing available for the regular occupation forces, airlift personnel often had to resign themselves to having their families one hundred or more miles from the air bases and to seeing them only once or twice a month, even then at the sacrifice of rest and sleep. One man wrote in response to a questionnaire that his family was living out of suitcases in a hotel 100 miles away from his base and that he was anxious about the effect of the insecurity on his children. He concluded: "I feel that we have been let down by our service very badly."[18] The fact that many of the regular occupation personnel in Germany lived in comparative luxury did nothing to ease the situation.

compensating factors

A number of factors helped to counterbalance the physical and psychological pressures under which airlift personnel lived and worked. Most important among them were the growing spirit of competition, a sense of the importance of the job to be done, and the ability to see humor in every situation. Airlift headquarters did everything possible to strengthen these factors, one of its devices being the publication of a vigorous little daily, the *Task Force Times*.

Numerous observers of the operational side of the airlift have commented on the spirit of competition among the various units. In the opinion of a Navy medical officer, many aggressions were sublimated in the keen competition among the squadrons:

> There was no failure on the part of our personnel to recognize the humanitarian aspect of their activities, and the international importance of the operation; but rather it seemed that the competitive aspects overshadowed the global aspects in immediate concern.[19]

The editor of *Air Transportation*, who visited most of the units engaged in flying the lift, relates his experience on coming into the operations room at Celle Air Base where an officer was shouting angrily into the phone.

> "What's he yelling about?" I asked the sergeant at my elbow.
>
> "Figures," he replied wearily. "Everybody's tonnage-whacky. He's claiming the tonnage high for the day. Somebody in Wiesbaden gave it to the 313th or some other group. You'd think this was the Kentucky Derby."[20]

The same newsman noted that the spirit of competition carried over to German workers who loaded and unloaded the planes. At Celle the 317th Troop Carrier Group claimed a record for loading a C-54 aircraft: a 12-man German crew had stowed 19,580 pounds of coal in 5 minutes and 45 seconds. (The normal time for such a job was considered to be 16 minutes.) A lieutenant colonel told the inquiring editor: "Just tell loaders at other airlift bases we believe Celle loaders can't be beat."[21]

To some extent morale was aided by the sense of humor with which most personnel were able to view their working conditions. The airlift was well served by two excellent cartoonists: Technical Sergeant John Schuffert, an American whose creations appeared regularly in the *Task Force Times*, and British Flight Lieutenant "Frosty" Winterbottom. Their incisive caricatures became familiar to a wide audience. Jokes about the disagreeable working conditions abounded. A typical one dealt with the almost incredible mud that hampered operations at most airfields during the winter. An officer, the story went, was sloshing along through the mud at Rhein-Main airfield when he saw a sailor's cap lying on the ground. He stopped to pick it up and found that a sailor's head was underneath it. "What are you doing here?" asked the officer. "Everything under control, sir," replied the man. "I'm just trying to start my jeep."

More bitter is the humor of the "Fassberg Diary," an imaginary chronicle of half-starved, coal-blackened airmen at Fassberg Air Base. After having been on 30-day temporary duty for several years, these men, now in rags and tatters, are visited by a newspaper reporter. He is immediately pressed into service as a "replacement," the first they had ever seen. The "Fassberg Diary" was widely circulated in typescript; its unrestrained language rendered it unprintable.[22]

There were enough of these counterbalancing factors to keep morale from slipping to a point where operations would have been seriously hindered. But there is no denying that fatigue and poor morale prevented the fullest utilization of available personnel. Every month 10 per cent or more of the aircrews at airlift bases had to be removed from flying, as compared to 2.5 per cent at nonairlift bases. Respiratory diseases, the most frequent cause for such removals, were five times as common at airlift bases as at others. Colonel Moseley in his medical analysis notes however that it was not unusual to assign respiratory disease as the cause for removal when the real reason was some type of subclinical fatigue. This seems to be corroborated by the fact that other disabilities did not appreciably exceed normal expectations.[23] Colonel Moseley points out further that flying itself was not the principal cause of exhaustion, that there was indeed surprisingly little operational fatigue. In his opinion it was the combination of other pressures that led to periodic breakdowns.[24]

As far as can be determined the great stress on personnel and consequent loss of human efficiency did not lead to a lower performance than would have been possible had human resources been used more conservatively. In the Berlin airlift the supply of personnel was adequate to allow for some loss of human efficiency without lowering the volume of supplies transported.

The experience of the airlift does suggest that in situations where the fullest utilization of aircrews is a critical factor it would be desirable to achieve greater stability in each individual's time schedule, to give him as much time as possible in which to make advance preparations, and to try to secure more adequate base facilities. Given these adjustments and the existence of a healthy spirit of competition, even very intensive peacetime flying at low altitudes does not appear to be detrimental to health or efficiency.

public relations

Throughout the airlift a handful of public information officers in the military forces did their utmost to assist newsmen in assembling material that would provide a picture of the total operation. Most of their efforts were directed toward international news media serving the free world, but they also gave attention to the information requirements of the German public.[25]

Early in the airlift Hq USAFE approved a plan by which, for a period of one month, German correspondents, photographers, and radio commentators were permitted to fly aboard airlift planes so that they might give eyewitness reports of the operation.[26] British authorities adopted a similar procedure and newsmen from both West Germany and Berlin took advantage of the invitations. In addition some of the airfields were occasionally thrown open to German visitors. Thus on 12 September 1948 about 15,000 Germans, most of whom had arrived on foot or bicycle, swarmed over Wiesbaden and Rhein-Main airfields to watch the operations. An American observer described their reaction as one of "I see it but I don't believe it."[27] On the same day some 150 prominent Berliners, representing government, business, schools, and welfare organizations, were invited to inspect operations at Tempelhof.[28] As time went on "open house" days attracted ever larger crowds and the airlift received ever wider coverage in the German press and radio.

The airlift's most effective contribution to public relations lay in several unplanned, informal activities, all of them spontaneous gestures of friendliness on the part of Allied personnel. The most extensive of these was Operation Little Vittles, originated by a U.S. Air Force officer, First Lieutenant Gale S. Halvorsen. In the summer of 1948 Lieutenant Halvorsen happened to be talking with some German children on his day off at Tempelhof. Embarrassed because he had no candy to offer them, he promised that on his flight into Berlin the next day he would drop some candy as he came in for a landing. His first drop consisted of a few candy bars with parachutes made out of pocket handkerchiefs.[29] This caught the imagination of Halvorsen's former military unit, the 521st Air Transport Group, whose men undertook to supply candy and handkerchiefs in quantity from their own rations. Within a few weeks Little Vittles had received so much publicity that the lieutenant was called to New York to appear on "We the People" radio program. On his return to Rhein-Main he found his quarters overflowing with 800 pounds of candy, 1000 handkerchiefs, and nearly 1000 letters and packages from military and civilian well-wishers in the United States. "We the People" arranged to send him 40,000 candy bars and 25,000 pieces of bubble gum. In addition the vice president of the Huyler Candy Company offered to supply at least 10,000 more bars per week, and the wife of the company's owner undertook to provide ready-made midget parachutes.[30] Little Vittles thus became a large operation. When Halvorsen was returned to the United States in January 1949 his project was carried on. As time passed there were further refinements. For example, every two weeks 2500 of Berlin's underprivileged children were invited to a camp on Peacock Island in Wannsee Lake and the candy drop was made on the island.[31]

Two similar projects also received considerable publicity. The first of these was Operation Schmoo, originated by a group of airmen at Rhein-Main airfield who suggested the idea to cartoonist Al Capp. As a result arrangements were made to drop approximately one hundred Schmoo balloons, to each of which was attached a card that could be exchanged for a Care package.[32] The second was Operation Santa Claus, organized at Fassberg Air Base by British and American personnel. They collected twenty-four tons of assorted sweets for Berlin children and flew them into the city just before Christmas of 1948.

A number of other activities, large and small, were aimed at spreading cheer among the children of Berlin and West Germany. One airlift unit adopted an orphanage. Another gave a series of parties for 1300 children in the British zone. The snack bar at Gatow airfield once had to be closed temporarily because two officers had purchased all available edibles in an attempt to feed a crowd of hungry-looking children. Few if any of these ventures were conceived as public relations gestures. Yet in terms of publicity and good will their effect was appreciable.

THE Berlin airlift thus offers a number of illustrations of the important contribution that individual enthusiasm, energy, ingenuity, understanding, and humanitarianism can make to a large-scale operation. It also suggests that human limitations should be taken into account, along with the capacities of machines and other physical or organizational factors. One of the principal problems in planning such an operation is certainly to allow for human limitations while at the same time providing full scope for the unfolding of both suspected and unsuspected human capabilities.

The Rand Corporation

NOTES

1. This article is a by-product of a larger study of the political and psychological aspects of the Berlin blockade and airlift undertaken by the Rand Corporation and published by the Princeton University Press in 1958 under the title: *The Berlin Blockade—A Study in Cold War Politics*. Observations made here are based on interviews with personnel who were involved in the operation of the airlift, both Allied and German, as well as on published sources.

   For information on the technical lessons learned from the airlift, see especially: *Berlin Airlift—A USAFE Summary*, published by Headquarters U.S. Air Forces Europe, 1949; "A Special Study of Operation 'Vittles,'" published by *Aviation Operations* magazine, April 1949; *Berlin Airlift: An Account of the British Contribution*, prepared by the Air Ministry and the Central Office of Information, with text by Dudley Barker, H. M. Stationery Office, London, 1949; *A Report on the Airlift, Berlin Mission: The Operational and Internal Aspects of the Advance Element*, prepared by Headquarters Combined Airlift Task Force (no date); and Charles J. V. Murphy, "Berlin Air Lift," *Fortune*, November 1948.
2. *Berlin Airlift: An Account of the British Contribution*, *op. cit.*, p. 18.
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13. "One Year of the Berlin Airlift," *Fighting Forces*, August 1949, p. 145.
14. Lt. Col. Harry G. Moseley, USAF (MC), "Medical History of the Berlin Airlift," *U.S. Armed Forces Medical Journal*, November 1950, pp. 1256–57.
15. *Ibid.*
16. *Ibid.*, p. 1254.
17. *Ibid.*, pp. 1252–53.
18. *Ibid.*, p. 1255.
19. Nauman, *op. cit.*, p. 11.
20. Richard Malkin, "From Hot to Cold War," *Air Transportation*, October 1949, p. 11.
21. *Ibid.*, p. 38.
22. "The Valley of Taegu," an account very similar in spirit and phraseology, emerged from the Korean campaign several years later.
23. Moseley, *op. cit.*, pp. 1258–61.
24. *Ibid.*, p. 1256.
25. In addition all Allied military governments maintained offices which attempted to provide for the needs of the German mass media. In the case of U.S. Military Government this was the Information Services Division.
26. *Berlin Airlift—A USAFE Summary*, *op. cit.*, p. 156.
27. *Task Force Times*, 13 September 1948.
28. *Ibid.*
29. *Ibid.*, 9 September 1948.
30. *Ibid.*, 27 and 28 September 1948.
31. *Ibid.*, 18 May 1949.
32. *Ibid.*, 14 October 1948.

Lunar Flight Dynamics

Dr. Robert W. Buchheim and
Hans A. Lieske

THIS PAPER presents a brief survey of the general subject of lunar flight with particular reference to flight trajectories, including discussion of the general nature of the trajectory problem, classes of trajectories, initial conditions, and sensitivities to initial conditions. The associated subjects of orientation control and launching requirements are also introduced.

I. Lunar Flight Environment

1. Environment Components

The study of any vehicle system requires an examination of the complete physical environment in which it is to operate. The environment in which a rocket fired to the moon will operate is generally similar to that for an earth satellite. However some factors, such as the gravitational attractions of the sun and the moon, for example, will be of greater importance in the present discussion. Other factors, such as the drag produced by the earth's atmosphere during free flight, will tend to be of less importance.

The various components of the environment must be investigated for their influence on:

a. Vehicle operation
b. Trajectory
c. Vehicle orientation

In this treatment the chief area of interest is the trajectory problem.

Effects of the earth-moon environment on vehicle operation and orientation will be considered briefly. The principal components of the environment are:

a. Gravitational fields
b. Electromagnetic and particle radiations
c. Static electric and magnetic fields
d. Material bodies

2. Gravitational Environment

Of these items the one of greatest interest is the gravitational environment, which is the dominant factor in the trajectory problem.

The gravitational environment can be developed by setting up an analytical model describing an idealized earth-moon system and then by considering the discrepancies between this "ideal" world and the "real" world as corrections to the model.

Roughly speaking, the earth-moon system can be described as follows: The earth and moon are separated by a distance of about one quarter million miles. The diameter of the earth is about 8000 miles and that of the moon about 2000 miles. The mass of the earth is about 80 times that of the moon, and the acceleration of gravity at the earth's surface is about six times that at the surface of the moon. The center of mass of the earth-moon system is inside the earth, about 3000 miles from the center toward the moon. Both earth and moon revolve about this common center of mass at a rate of one revolution per month.

In setting up the analytical model it will be assumed that the earth and moon are spheres isolated in space, separated by a fixed distance, revolving around their common center of mass at a constant rate. A diagram of this system is shown in Fig. 1. The system can be numerically specified by the consistent set of parameters shown in the Table of Nomenclature.

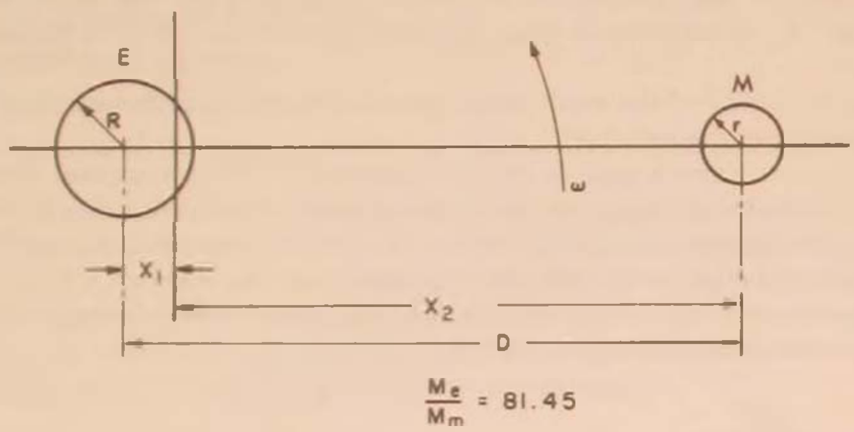

Figure 1. The earth-moon model. E, *earth;* M, *moon* (M_e = *mass of earth;* M_m = *mass of moon*).

Since it is convenient for most purposes to use a unit system that does not require very large or very small numbers to describe the variables, numerical values are expressed in a system using one day as the unit of time and a "lunar unit" as a unit of distance, the lunar unit being defined as the distance between

Recent interest in the possibilities of lunar flight has perhaps not fully appreciated the complexities of such an undertaking. At the request of the *Quarterly Review* two Rand Corporation scientists—Dr. Robert W. Buchheim, project leader of space flight studies, and Hans A. Lieske, head of the Flight Mechanics Group of the Engineering Division—explore the subject of lunar flight with emphasis on the problems of flight trajectories. Trajectories for six missions a vehicle can perform in the earth-moon system are discussed: impact on the moon, landing on the moon, escape from the moon, circumlunar flight, lunar satellite, and flight from the moon to the earth. To facilitate the reading of this technical article two different type sizes are used: large type to distinguish the general discussion which can be read as an entity and with profit by the person interested in the broader aspects, and small type for the part containing the more difficult mathematical explanations that might interest the more technically minded reader.

the centers of the earth and moon. Thus a lunar unit is taken to be 239,073.7 statute miles in length.

ω = 0.22997084 radians per day
D = 1 lunar unit
K = 0.052886587 (lunar unit)^3/day^2
R = 0.01655926 lunar unit
$|x_1|$ = 0.012128563 lunar unit
$|x_2|$ = 0.98787144 lunar unit

The sources of these parameter values range over a considerable variety of measurements and deductions.

The mean radius of the earth is derived from geodetic survey data, and is consistent with the dimensions of the International Ellipsoid of Reference.[1]

The mass product (product of the gravitational constant and earth mass) is computed from this radius and an authoritative figure for the mean value of gravitational acceleration at the surface of the earth,[2] after removal of the centrifugal acceleration due to the earth's rotation. The mean value of g is determined from world-wide gravity surveys with precision pendulum apparatus.

The angular velocity of the earth-moon system is based upon astronomical determination of the mean duration of the month.[1]

The value for the moon's mass in terms of the earth's mass is computed from estimates of the location of the center of mass of the earth-moon system; and this location is determined from fluctuations in the apparent orbits of asteroids as referred to the earth's center.[3] The nominal value used in this discussion is that adopted in the American Ephemeris.[1]

The distance between the centers of the earth and moon has been computed from the other constants mentioned above to satisfy the relation

$$D^3 = \frac{gR^2}{(1-\mu)\omega^2}$$

which is a necessary consequence of the following expressions for the angular velocity of the moon and the acceleration of gravity:

Table of Nomenclature

R = mean radius of spherical earth
= 6.371221 (10^8) centimeters
= 3958.885 statute miles

ω = angular velocity of earth-moon system
= 2.6616995 (10^{-6}) radians per second

K = product of the gravitational constant, G, and the total mass of the earth and moon, M_o
= 4.035187 (10^{20}) cm^3/sec^2

D = distance between the centers of the earth and moon
= 3.847527 (10^{10}) centimeters
= 239,073.7 statute miles

μ = ratio of the mass of the moon, M_m, to the total mass of the earth and moon, M_o
= 1/82.45

$|x_1|$ = distance from the center of the earth to the center of mass of the system
= $D\mu$
= 2899.622 statute miles

$|x_2|$ = distance from the center of the moon to the center of mass of the system
= $D(1-\mu)$
= 236,174.2 statute miles

$$\omega'^2 = \frac{GM_0}{D^3}$$

$$g = \frac{GM_e}{R^2} = \frac{GM_0(1-\mu)}{R^2}$$

The quantity D is derived rather than adopted from observation in order to establish a set of parameters that are internally consistent. This somewhat artificially contrived consistency is necessary in the construction of a model that is to be simple yet useful. This derived value is 239,073.7 st mi, whereas the observed mean distance is 238,857 st mi, a difference of about 0.09 per cent. The model parameters cannot match observed reality exactly, because the model does not include all the factors that contribute to the real situation. The physical quantities that are included in the model are known to degrees of precision that are adequate for most of the applications we are going to consider.

Relevant factors that must be treated as corrections to the idealized gravitational model are:

a. The gravitational field of the sun
b. The oblateness of the earth
c. The eccentricity of the moon's orbit
d. The inclination of the moon's orbit to the earth's equatorial plane

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An observer at the center of mass of the earth-moon system would not detect, by dynamical measurement, any force field due to the sun. The force due to the sun's attraction would be exactly canceled by the reaction forces due to his orbital motion about the sun. He could, however, detect a gravitational gradient due to the sun, and would encounter a net gravitational acceleration due to this body as he moved away from the center of mass of the earth-moon system. The maximum value of the gravitational effect of the sun is approximately

$$g_{sm} = 2\Omega_e^2 r_0$$

where Ω_e = angular rate of the earth in its orbit around the sun, $\approx 2(10^{-7})$ rad/sec

r_0 = distance of vehicle from center of mass of earth-moon system.

At the distance of the moon the space vehicle would be acted on by an acceleration due to the sun that is never more than about 10^{-4} ft/sec^2. The integrated effect of the sun's action over a typical earth-moon trajectory implies a shift in vehicle projection velocity at the earth of roughly 10 ft/sec out of about 35,000 ft/sec.

The oblate figure of the earth causes the gravitational field of the earth to depart from the ideal inverse-square law assumed in the model. At the moon's distance the effect of the earth's oblateness is of the order of 10^{-11} ft/sec^2. The integrated effect over a typical earth-moon trajectory is roughly comparable to that of the sun's field.

The eccentricity of the orbit of the moon causes its actual distance from the earth to vary over a range of some 30,000 miles about its mean value. This also produces a change in angular velocity to keep the total angular momentum fixed. Rough estimates of the net effect of these changes indicate a possible shift in projection velocity of roughly 50 ft/sec out of about 35,000 ft/sec.

The effects of the inclination of the moon's orbit away from the earth's equatorial plane are associated only with the oblateness of the earth; the magnitude of the effects, therefore, should be no more serious than those indicated above.

But none of these factors neglected in the model is likely to alter substantially the nature of the motion in most applications. However, some of them will alter specific numerical results by an amount sufficient to require their inclusion in trajectory computations for actual flight programs.

The proper utility of the simplified gravitational model lies in exploring the nature of the problem of earth-moon trajectories by analytical treatment and preliminary computational programs. An actual lunar flight program must be based upon machine computations with all relevant effects included. Since the motions of the system are not entirely periodic, each computation can really only apply to a single flight date—each try is a computer problem of its own.

3. *Radiation Environment*

The physical environment discussed thus far has been concerned with the gravitational fields in which the vehicle will operate. The components of the acceleration acting on the vehicle can be written and result in the classical equations of motion for the "Restricted Problem of Three Bodies." In addition to these gravitational forces another source of vehicle acceleration is that produced by radiation pressure.

The radiation environment in earth-moon space is very largely that due to the sun. Forces on the vehicle due to the pressure of this radiation may or may not have an appreciable effect on the trajectory, depending upon the nature of the vehicle. Generally speaking, the effect will be small on vehicles of conventional density, but it could be quite large on low-density objects like "balloons."

The pressure on a perfect absorber due to solar radiation at about the earth's distance from the sun is

$$p = 4.49 \times 10^{-5} \text{ dynes/cm}^2$$

On a nearly perfect reflector this pressure is about twice p, so the total force due to radiation pressure that can act on a bright vehicle with a projected area A is $2pA$, and the acceleration a_r produced in a vehicle with an earth-weight of W lb is

$$a_r = 6.04(10^{-6})(A/W) \text{ ft/sec}^2$$

with A in sq ft. If we represent the vehicle, for rough estimating purposes, as a body with the projected area and volume of an equivalent sphere of radius R_v and mean density ρ_v, we can write a_r as

$$a_r = 1.81(10^{-5})(\rho_v R_v)^{-1} \text{ ft/sec}^2$$

If we assume that the vehicle radius lies in the range

$$1 < R_v < 1000 \text{ ft}$$

and that its mean density lies in the range

$$10^{-3} < \rho_v < 10^2 \text{ lb/ft}^3$$

a_r will lie in the approximate range

$$2(10^{-10}) < a_r < 2(10^{-2}) \text{ ft/sec}^2$$

This acceleration will, over a flight time of about 2.5 days, produce a velocity change v_r that lies in the approximate range

$$4(10^{-5}) < v_r < 4000 \text{ ft/sec}$$

Clearly, for the wide range of R_v and ρ_v postulated, the consequences of solar radiation pressure can vary from negligible to very serious. As a more specific example, consider the case of a possible space vehicle discussed in Ref. 4. This vehicle has a projected area of about 10 sq ft and a weight of about 300 lb. For this case

$$a_r \approx 2 \times 10^{-7} \text{ ft/sec}^2$$

and, over 2.5 days,

$$v_r \approx 0.04 \text{ ft/sec}$$

which is undoubtedly negligible for most purposes.

Similar effects would be produced by radiations from the vehicle, such as radio transmissions, heat discharge, etc.

4. *Static Fields*

It appears that the known static fields of earth-moon space, specifically the earth's magnetic field, will have negligible effect on the trajectories of vehicles of conventional construction. It also seems highly likely that any other static fields in earth-moon space are substantially smaller in magnitude than that of the earth.[5]

5. *Material Bodies*

Apart from the earth and moon themselves (and, eventually, man-made space trash), the material content of earth-moon space consists of meteoroids of widely varying size and mass. These bodies, if encountered, can influence the trajectory.

If a vehicle of mass M_v encounters a meteoroid of mass m with a relative velocity V, and all the momentum of the meteoroid is delivered to the vehicle, the vehicle will experience a velocity increment which will cause its trajectory to be disturbed. The amount of trajectory disturbance will, of course, depend upon the energy of the vehicle in its trajectory and also upon the distance of the collision point from the earth. For example, a meteor collision near the earth will change the apogee distance of a near-minimum energy trajectory to the moon by about 800 mi for every 1 ft/sec change in the vehicle's velocity. Since this distance is of the order of the moon's radius, it is reasonable to investigate the magnitudes and frequencies of meteors which will cause a vehicle velocity change of only 0.1 ft/sec.

The vehicle velocity increment δv is given by

$$\delta v = \frac{mV}{M_v}$$

The kinetic energy U_k of the meteoroid will be

$$U_k = \frac{1}{2} M_v V \delta v$$

If the vehicle velocity increment δv is to be 0.1 ft/sec or less, and the meteor velocity is assumed to be 40 km/sec,[6] the energy U_k must be

$$U_k \leq 6.08(10^6)\, M_v \text{ ergs}$$

or

$$U_k \leq 2.76(10^9)\ W \text{ ergs}$$

with W the earth-weight of the vehicle in pounds.

It is usual to relate the kinetic energy of a meteoroid to the visual magnitude M it display upon entry into the earth's atmosphere. This relation is given approximately by Ref. 6,

$$U_k = pq^{-M} \text{ ergs}$$

where $p \approx 10^{13}$ ergs and $q \approx 2.5$

Using this relation, we find that $\delta v \geq 0.1$ ft/sec will be imparted by encounters with meteoroids that display visual magnitudes equal to or less than M_o, with

$$M_o = 8.94 - 1.091 \log_e W$$

A plot of M_o against W is shown in Fig. 2.

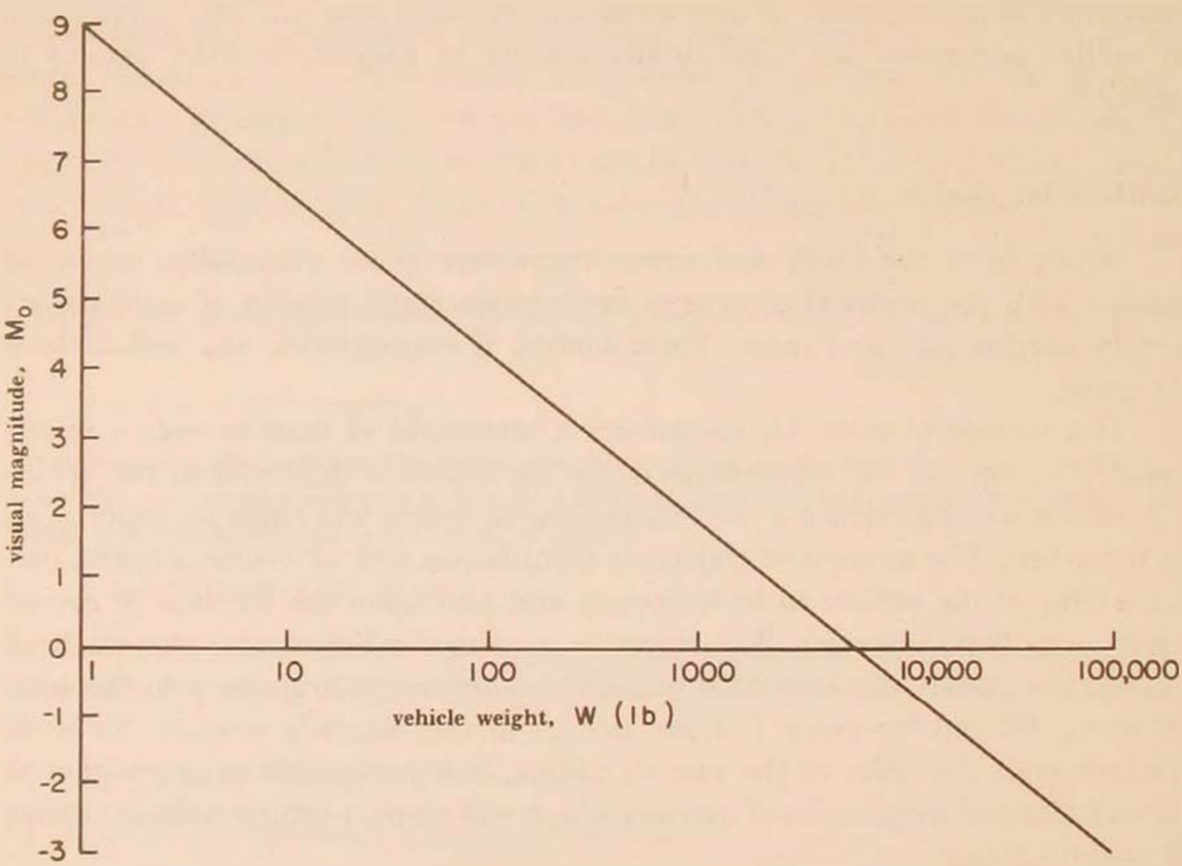

Figure 2. Limiting magnitude of meteoroids that will impart a velocity of 0.1 ft/sec or more to the vehicle.

The number of meteoroids entering the earth's atmosphere per day of visual magnitudes ($M - 1/2$) to ($M + 1/2$) can be approximated by the empirical relation

$$N(M) = gb^M$$

with g and b dimensionless figures which are determined by observation.

Thus the number N_o with $M \leq M_o$ is given by

$$N(M \leq M_o) = \frac{gb^{M_o + 1/2}}{b - 1}$$

For $g = 1.21(10^6)$ and $b = 2.69$ (see Ref. 7), we find

$$N = 7.16(10^5)\left[(2.69)^{(9.44 - 1.091 \log_e W)}\right]$$

This is the number, with $M \leq M_o$, entering the earth's atmosphere per day. Since the earth's surface area is about $5.59(10^{15})$ sq ft, the number per day passing through a surface with an area of one sq ft is about

$$n = 1.28(10^{-10})\left[(2.69)^{(9.44 - 1.091 \log_e W)}\right]$$

This is the average number of meteoroids per day, per sq ft of surface area, that will impart a velocity increment of 0.1 ft/sec to the vehicle. A plot of n against W is given in Fig. 3.

We see from Fig. 3 that the 300-lb vehicle of Ref. 4 will encounter, on the

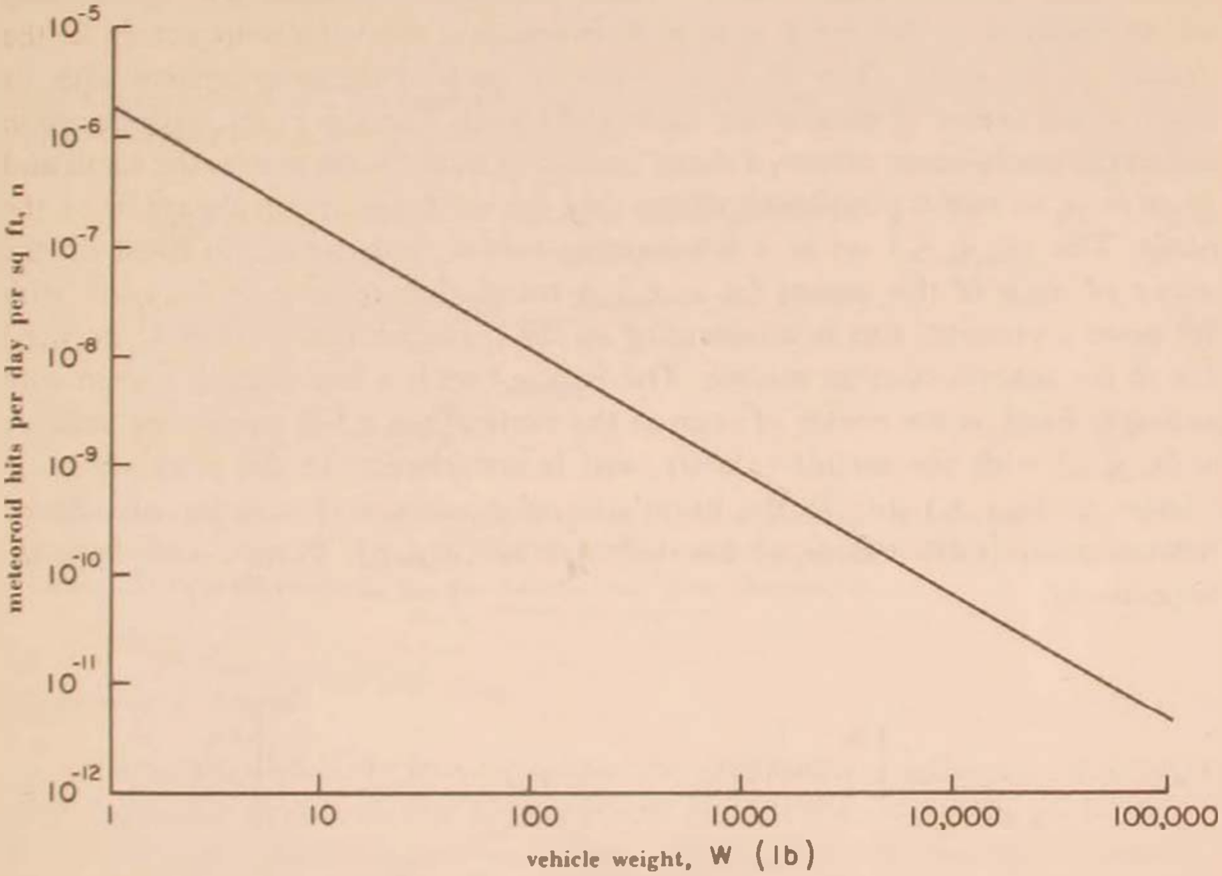

Figure 3. Frequency of hits by meteoroids that will impart a velocity of 0.1 ft/sec or more to the vehicle.

average, 3×10^{-9} meteoroid hit per day per square foot that would generate a $\delta v \geq 0.1$ ft/sec. Since this example has a vehicle surface area of about 10 sq ft and the total flight time from earth to moon is about 2.5 days, we find that the vehicle will receive, on the average, about 8×10^{-8} "serious" hit per trip, or one hit in each 10,000,000 trips.

II. Analytical Relations

1. Coordinate Systems

Prior to discussing the equations of motion of the vehicle in the earth-moon system, the various coordinate systems should be reviewed. Those of principal interest are shown in Fig. 4. The equations assume a convenient form in a coordinate system fixed at the center of mass of the earth-moon system. Two coordinate systems are of chief importance. The first is an inertial system, and the second is a coordinate system which rotates to keep the earth and moon on the x-axis.

For analysis of the trajectories relative to the earth, a nonrotating coordinate system fixed at the center of the earth is convenient. Similarly, a nonrotating system centered at the moon is used to investigate the vehicle trajectory in the vicinity of the moon. The (x_o,y_o,z_o) set is an inertial reference system with its origin at the center of mass of the earth and moon. The (x,y,z) set, with its origin also at the earth-moon center of mass, is rotating at the same rate as the earth and moon from an initial position chosen so that the earth and moon always lie on the x-axis. The (x_m,y_m,z_m) set is a nonrotating system with its origin fixed at the center of mass of the moon; (x_m,y_m,z_m) is translating relative to (x_o,y_o,z_o) with the moon's velocity, and is accelerating in the $(-x)$ direction relative to (x_o,y_o,z_o) due to the moon's circular motion. The (x_e,y_e,z_e) set is a nonrotating system with its origin fixed at the center of mass of the earth; (x_e,y_e,z_e) is translating relative to (x_o,y_o,z_o) with the earth's velocity, and is accelerating in the $(+x)$ direction relative to (x_o,y_o,z_o) due to the earth's circular motion. The polar coordinate systems (r,ϕ), (r,θ), and (r_1,γ) are referred to (x_o,y_o,z_o), (x,y,z), and (x_e,y_e,z_e), respectively.

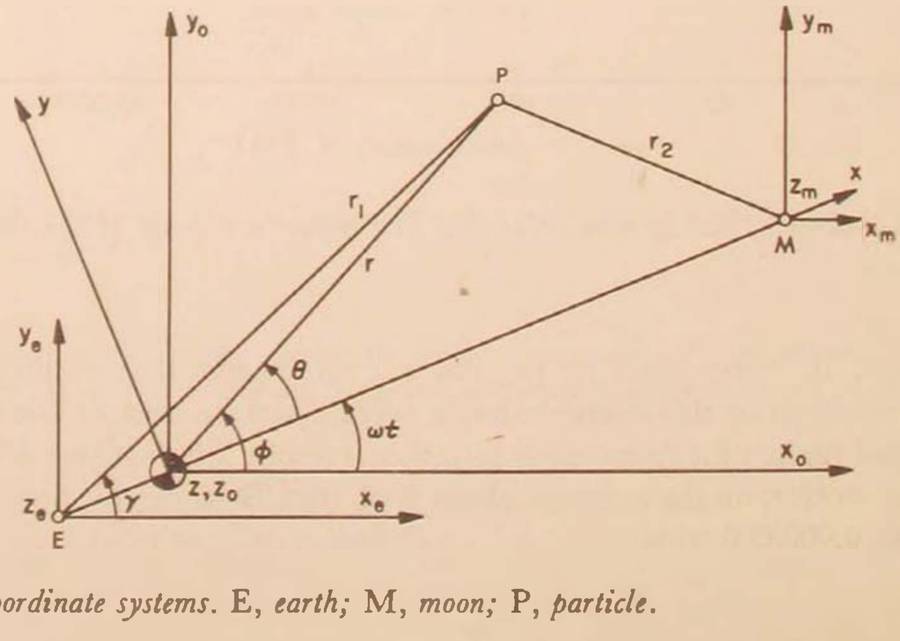

Figure 4. Coordinate systems. E, *earth;* M, *moon;* P, *particle.*

2. *Equations of Motion*

The equations of motion of a small body in earth-moon space can be written most directly in the (x_o,y_o,z_o) system. The x_o, y_o, and z_o components of acceleration are given simply by the corresponding gravitational attractions of the earth and moon.

These equations are

$$\ddot{x}_o = \frac{-K(1-\mu)(x_o - x_{01})}{r_1^3} - \frac{K\mu(x_o - x_{02})}{r_2^3} \tag{1a}$$

$$\ddot{y}_o = \frac{-K(1-\mu)(y_o - y_{01})}{r_1^3} - \frac{K\mu(y_o - y_{02})}{r_2^3} \tag{1b}$$

$$\ddot{z}_o = \frac{-K(1-\mu)z_o}{r_1^3} - \frac{K\mu z_o}{r_2^3} \tag{1c}$$

where K is the product of G, the gravitational constant, and the total mass of the earth and moon.

Transforming to (x,y,z) coordinates these are

$$\ddot{x} - 2\omega\dot{y} = \omega^2 x - \frac{K(1-\mu)(x - x_1)}{r_1^3} - \frac{K\mu(x - x_2)}{r_2^3} \tag{2a}$$

$$\ddot{y} + 2\omega\dot{x} = \omega^2 y - \frac{K(1-\mu)y}{r_1^3} - \frac{K\mu y}{r_2^3} \tag{2b}$$

$$\ddot{z} = \frac{-K(1-\mu)z}{r_1^3} - \frac{K\mu z}{r_2^3} \tag{2c}$$

The terms $2\omega\dot{y}$ and $2\omega\dot{x}$ are the Coriolis accelerations, and $\omega^2 x$ and $\omega^2 y$ are centrifugal terms. The advantage of form (2) over form (1) lies in the fact that equations (2) do not contain time as an explicit variable since x_{01}, x_{02}, y_{01}, and y_{02} have been eliminated.

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3. *Jacobi's Integral*

In the case of a body moving under the gravitational influence of a single point mass, the equations can be integrated completely to define, analytically, the velocity and position of the body. For a body moving under the influence of two bodies like the earth and moon, however, only one integral to the equations —Jacobi's integral—is known.

Jacobi's integral to the equations of motion can be constructed as follows:

If we write

$$W(x,y,z) = \frac{1}{2}\omega^2(x^2 + y^2) + \frac{K(1-\mu)}{r_1} + \frac{K\mu}{r_2}$$

then the equations of motion (2) can be written

$$\ddot{x} - 2\omega\dot{y} = \frac{\partial W}{\partial x}$$

$$y + 2\omega x = \frac{\partial W}{\partial y}$$

$$z = \frac{\partial W}{\partial z}$$

Multiplying these by $2x$, $2y$, and $2z$, respectively, adding, and integrating, we obtain Jacobi's integral:

$$(x)^2 + (y)^2 + (z)^2 = v^2 = 2W - C$$

or

$$v^2 = \omega^2(x^2 + y^2) + \frac{2K(1 - \mu)}{r_1} + \frac{2K\mu}{r_2} - C \qquad (3)$$

where v is the magnitude of the velocity of the vehicle in rotating (x,y,z) space; and C is the "Jacobian Constant."

This single integral is of great importance since it will provide us with a great deal of general information about motion in earth-moon space.

4. Energy Relations

The first piece of information provided by Jacobi's integral is the fact that the total energy of an unpowered vehicle in earth-moon space is not constant. Rather it can be shown that a linear combination of total energy and angular momentum about the z-axis is conserved. This lack of energy conservation makes the lunar trajectory problem markedly different from terrestrial ballistic flight and earth-satellite orbit problems. The energy changes along an earth-moon trajectory are large enough to add great complexity to trajectory computations but are not great enough to have any substantial significance in a propulsion sense.

III. General Characteristics

1. Regions of Possible Motion

The chief utility of Jacobi's integral lies in the fact that it provides a broad specification of the possible types of ballistic flight which can be achieved in earth-moon space and also a partial definition of the projection conditions required for these various types. Thus, it provides a preliminary guide to more detailed computations.

Following the reasoning employed by G. W. Hill in the development of his lunar theory [8,9] we recognize that v^2 in Jacobi's integral, Eq. (3), can take on positive values only in real motion. Thus, for a given value of the constant C, if substitution of the coordinates of a given location in Eq. (3) results in a positive v^2, that location lies in a region of possible motion; if the resulting v^2 is negative, the given location lies in a region in which motion of the body is not possible. The boundaries between regions of possible motion and excluded regions are contours on which $v = 0$; these are called curves of zero relative velocity. A real particle cannot cross one of these curves.

Several such sets of contours in the (x,y) plane are shown in Fig. 5 (these contours are intended only to show the form of the regions; they are not drawn to scale). The C values of Fig. 5 are numerically in the order $C_1 > C_2 > C_3 > C_4 > C_5$. For initial conditions corresponding to $C = C_1$, the body can move either in a closed region about the earth or in a closed region about the moon—it is forever restricted to the neighborhood of its parent and cannot travel from earth to moon. The International Geophysical Year satellites are bodies of this kind—restricted to the neighborhood of earth. Conventional ballistic missiles also fall in this class.

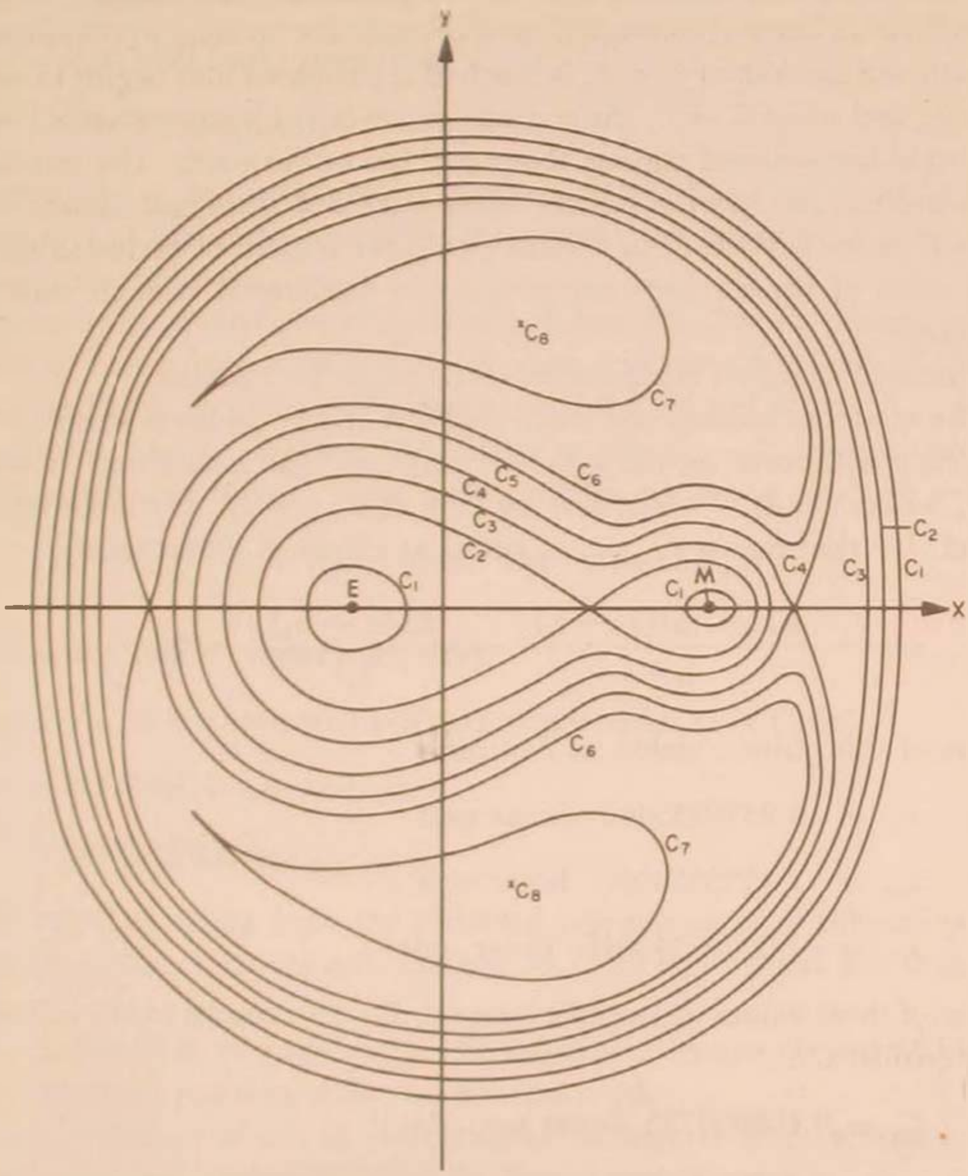

Figure 5. Contours of zero relative velocity in (x, y) *plane.* E, *earth;* M, *moon.*

For a set of initial conditions corresponding to $C = C_3$, the body is restricted to a closed contour around the earth-moon system but motion from one body to another is now possible. $C = C_2$ represents the limiting case separating situations in which motion between earth and moon is possible from situations in which it is not possible.

For a case where $C = C_5$ the contour delimiting the region of possible motion is open behind the moon, indicating that the body can escape entirely from the earth-moon system. $C = C_4$ is the limiting case marking the onset of this condition,

In addition to these contours within which a particle is bound, there are. for the same C values, outer boundaries around the earth-moon system, as shown in Fig. 5. A particle which starts at a great distance from the earth-moon system with $C > C_4$ cannot approach these bodies more closely than the corresponding outer $C = C_4$ contour of Fig. 5.

At $C = C_4$ the inner and outer branches of the curve of zero relative velocity coalesce, and for $C < C_4$ a particle starting near the primary bodies can escape from the system. One starting at a remote point can reach either body.

As C varies from C_4 through C_5 and beyond, the opening in the contour behind the moon widens. When $C = C_6$ is reached the contour also begins to open behind the earth, and when $C = C_7$ the contour in the (x,y) plane consists of two branches enclosing kidney-shaped regions above and below the x-axis. The interiors of these regions are the only portions of the plane excluded from real motion for $C = C_7$.

As C varies beyond C_7 to a value of C_8, the regions of exclusion shrink to two points, each of these points completing an equilateral triangle with the earth and moon.

Where $C < C_8$, no region of the (x,y) plane is excluded.

The contours around the earth and the moon coalesce when $C = C_2$. This coalescence will occur on the x-axis at point x_{ci}. The coalescence of contours for $C = C_4$ will occur at $x = x_{cm}$, and for $C = C_6$ at $x = x_{ce}$. It can be readily shown (see Ref. 10) that points x_{ci}, x_{cm}, x_{ce} occur at values of x that satisfy

$$\omega^2 x - \frac{K(1-\mu)(x-x_1)}{r_1^3} - \frac{K\mu(x-x_2)}{r_2^3} = 0 \quad (4)$$

Solution of this quintic yields, as real roots

$x_{ci} = 0.8370235445$ lunar unit

$x_{cm} = 1.155597403$ lunar unit

$x_{ce} = -1.00505347015$ lunar unit

Use of these values in Jacobi's integral, Eq. (3), results in the following values for the critical C's:

$C_2 = 0.168609735$ (lunar unit/day)^2

$C_4 = 0.167755543$ (lunar unit/day)^2

$C_6 = 0.159301018$ (lunar unit/day)^2

2. *Corresponding Initial Conditions*

To indicate the significance of these values more directly we can calculate the velocity of a vehicle near the earth that corresponds to C values of C_2, C_4, and C_6. For this location, a standard position must be adopted; the one arbitrarily chosen will be on the x-axis, 4300 st mi from the center of the earth, on the side of the earth adjacent to the moon. With the lunar unit D = 239,073.7 st mi, the standard position is then at x_s = 0.00585752 lunar unit. Using the coordinates of this position in Eq. (3) and, successively, $C = C_2, C_4, C_6$, we find the corresponding velocities v_2, v_4, v_6 to be

$$v_2 = 2.375333 \text{ lunar units/day}$$
$$= 34{,}703.76 \text{ ft/sec}$$
$$v_4 = 2.375513 \text{ lunar units/day}$$
$$= 34{,}706.39 \text{ ft/sec}$$
$$v_6 = 2.377292 \text{ lunar units/day}$$
$$= 34{,}732.38 \text{ ft/sec}$$

It can be seen that v_4 is lower than v_6, and therefore that it is easier to escape from the vicinity of the earth by projecting toward the moon than it is by projecting away from the moon.

The rather great qualitative difference between the $C = C_2$ contour and the $C = C_4$ contour arises from a difference in projection velocity of only 2.63 ft/sec out of about 34,700 ft/sec, or a difference of only 0.0074 per cent.

The points in the (x,y) plane that make up the $C = C_8$ contour are equidistant from earth and moon. Thus their coordinates are $x = (1/2 - \mu) =$ 0.487871437, $y = (\pm)\frac{1}{2}\sqrt{3}$, in lunar units. The value of C_8 is

$$C_8 = 0.1580261 \text{ (lunar unit/day)}^2$$

and the velocity v_8 at the standard position required for $C = C_8$ is

$$v_8 = 2.377560 \text{ lunar units/day}$$
$$= 34{,}736.30 \text{ ft/sec}$$

Thus a vehicle starting from the standard position could reach any point in the earth-moon system if its velocity exceeds 34,736.3 ft/sec (and if it is properly directed).

These velocities are all rather near the velocity of escape V_e = 35,214.52 ft/sec from the standard position above an isolated earth.

The general nature of the intersections of surfaces of zero relative velocity with the (x,z) and (y,z) planes is shown in Figs. 6 and 7.

3. *The "Zerogravity" Point*

One interesting use of Jacobi's integral is to examine the validity of the proposition frequently suggested in the popular literature that getting to the moon is a matter of projecting a vehicle beyond the point of balance of the gravitational fields of earth and moon, the "zerogravity" point. According to this notion, we must project the vehicle from the earth with initial conditions suitable to reach beyond a point about 90 per cent of the distance to the moon, this point being determined by equating the Newtonian fields of earth and moon. That is, we

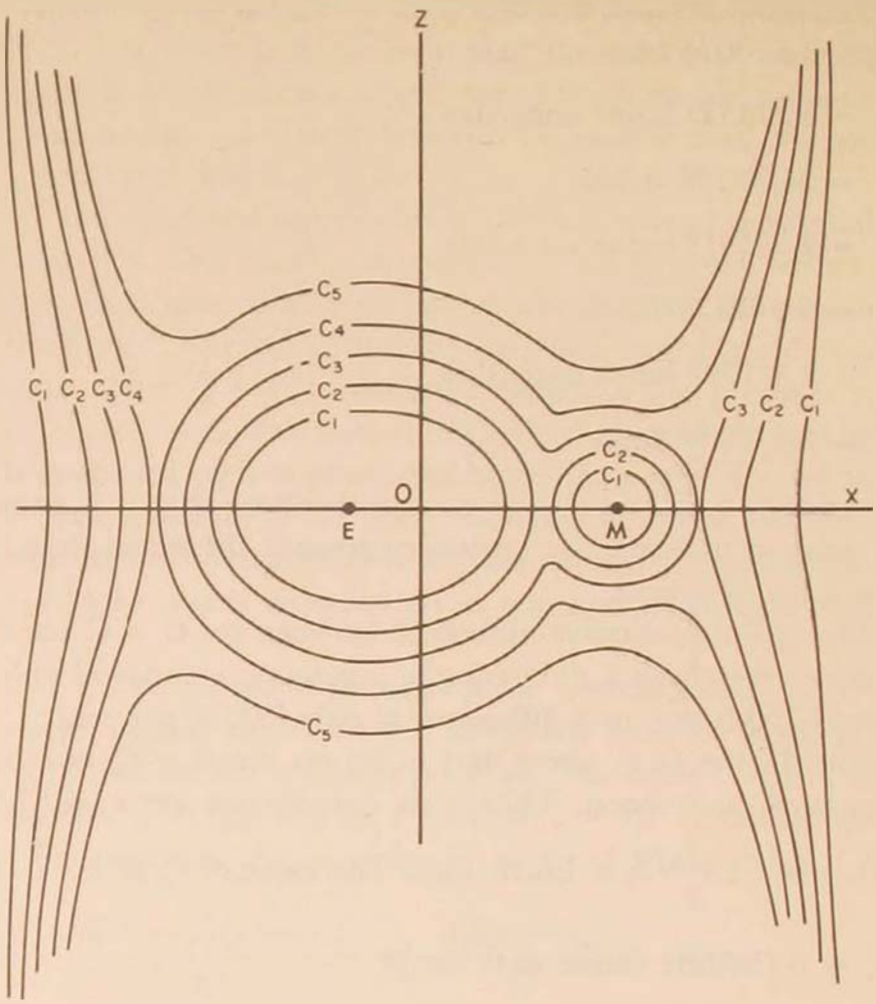

Figure 6. Contours of zero relative velocity in (x, z) *plane.* E, *earth;* M, *moon.*

must achieve a distance from the earth greater than P, with P such that

$$\frac{M_e}{P^2} = \frac{M_m}{(D - P)^2} \tag{5}$$

Now, according to the discussion based on Jacobi's integral, the critical point of transition from contours that do not permit earth-moon passage to those that do permit such passage is found to occur at a distance that is 84.9 per cent of the distance from earth to moon. The difference between these two approaches lies in the fact that the simpler scheme, based on Eq. (5), neglects a very important detail, the effect of the motions of earth and moon about their common center of mass. The difference appears small enough to be relegated to the category of a detail, and perhaps for some purposes it is; however the minor appearance of this difference is an accident of the system. On an interplanetary scale the fallacies of the simple balancing of Newtonian fields become large indeed. If we consider the earth-sun system, the balancing of gravitational attractions would lead to the result that we can jump from the earth to the sun just by getting to a point more than about 165,000 miles from the earth. Our moon—at about 240,000 miles from the earth—is itself good evidence that the theory is faulty. Jacobi's integral shows that we must achieve a distance of nearly 1,000,000 miles from

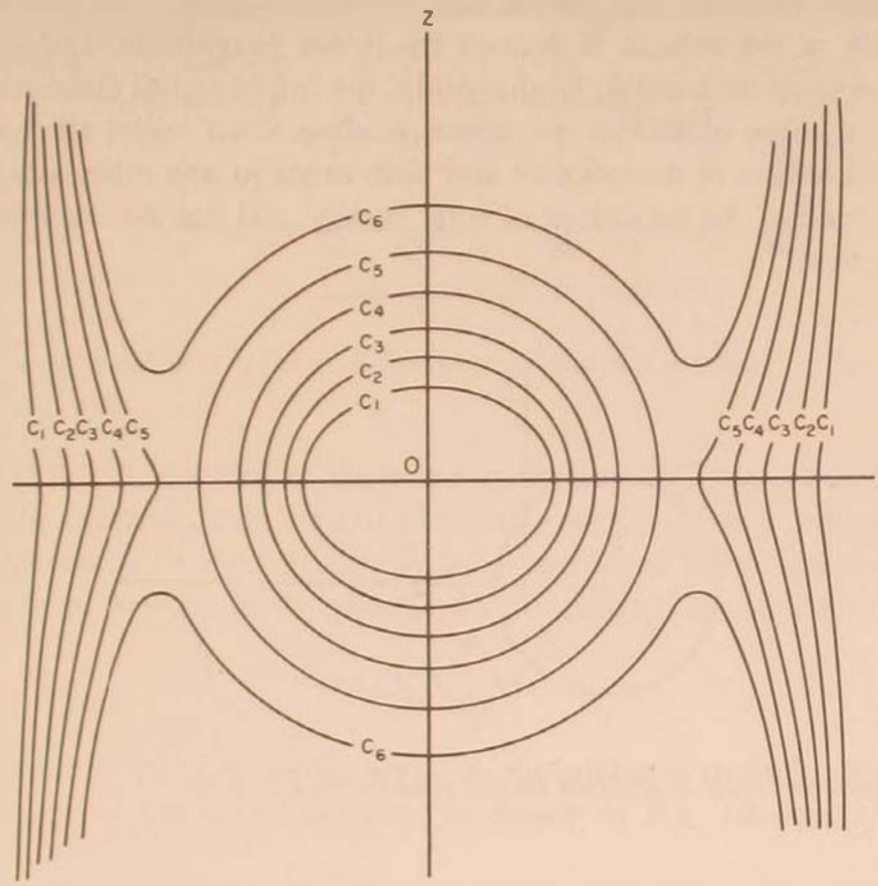

Figure 7. Contours of zero relative velocity in (y, z) *plane.*

the earth before we are really operating in terms of departing from the vicinity of the earth.

IV. Trajectory Types

The various ballistic, or unpowered, trajectories which a vehicle can follow in the earth-moon system will now be discussed in terms of mission types.(11) Since complete analytical solutions to the equations of motion are unavailable, numerical methods must be used in these investigations.

The various types to be considered are:

- Impact
- Landing
- Lunar escape
- Circumlunar flight
- Lunar satellite
- Moon-to-earth

The vehicle's trajectory and the moon's orbit are assumed to be coplanar. In this two-dimensional problem, therefore, a set of four initial conditions, shown schematically in Fig. 8, is required to define the trajectory of the vehicle. The origin of the coordinate system denotes the center of mass of the earth-moon system, with the moon located on the positive x-axis. The initial position of the trajectory is defined by r, the radial distance from the center of the earth, and by ϕ, the angle between this radius and the initial position of the moon. The initial velocity of the vehicle is defined by V, the magnitude, and γ, the angle relative to the local horizontal. In this study, the initial radial distance r has been held fixed at a value of 4300 st mi, corresponding to an initial altitude of about 350 st mi. The values of the velocity and path angle at any other altitude can be computed by use of the equations of total energy and angular momentum for a central force field.

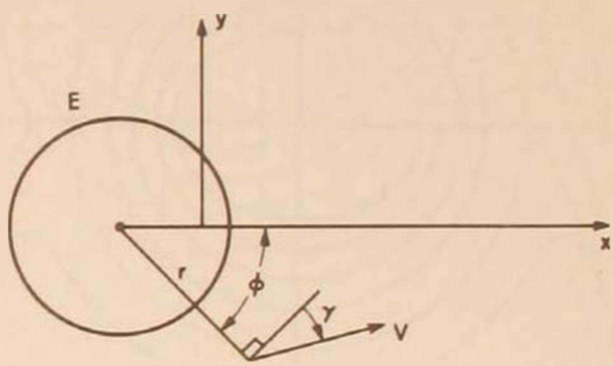

Figure 8. Parameters used to describe initial conditions. E, *earth.*

The motion of a body is considered to be direct if its angular velocity is in the same direction as that of the system, and retrograde if the angular velocity is opposite to this direction. Thus trajectories with initial positions around the lower edge of the earth in this diagram will be launched in direct motion relative to the earth-moon system.

The general combinations of initial conditions for trajectories launched in direct motion relative to the earth-moon system and impact on the moon are given in Fig. 9. The curves of initial path angle as functions of the velocity are shown for several values of the initial position angle of the trajectory relative to the moon. The minimum velocity required to hit the moon on the first "pass" is found to be about 34,800 ft/sec referred to the rotating coordinate system, and the curves are extended initial velocities up to 37,000 ft/sec. Velocities below about 34,800 ft/sec, down to the minimum value indicated by Jacobi's integral, will also lead to impacts on the moon but only after the vehicle has made a large number of revolutions around the earth.

The curves shown in this graph actually represent narrow bands of initial velocity–path angle combinations, because the moon has a finite diameter. Since the slope of the curves changes from nearly horizontal (variation in path angle) to vertical (variation in velocity), the relative size of the tolerances in each of these quantities will vary as a function of the magnitude of the initial velocity.

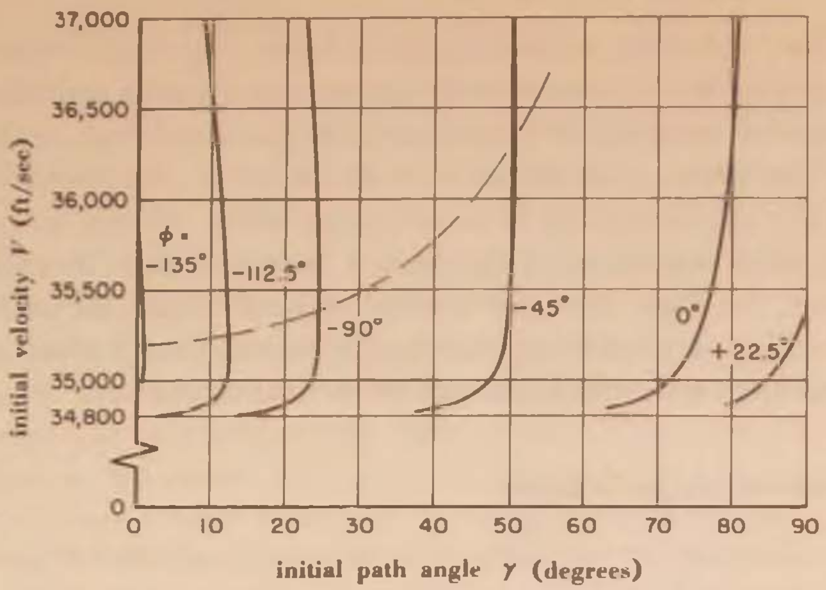

Figure 9. Initial conditions required to hit the moon—direct motion.

The dashed line is included to show the variation, with respect to initial position angle, in the magnitude of the initial velocity which corresponds to a maximum velocity tolerance. As the initial velocity is increased beyond this dashed curve, the curves bend over again and the allowable velocity tolerance decreases slightly.

1. Transit Time

The time of flight from the earth to the moon is strongly dependent upon the magnitude of the initial velocity, as shown in Fig. 10. Actually, this curve

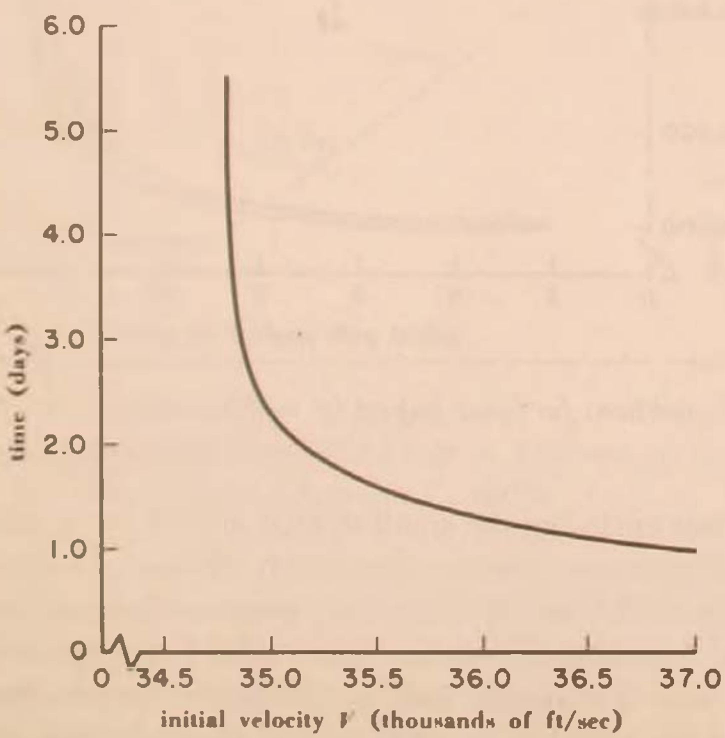

Figure 10. Transit time from earth to moon.

also represents a relatively narrow band of values, since the transit time to the moon is a function of the location of the lunar impact point and also of the initial trajectory position relative to the moon. At near-minimum velocities, 34,800 ft/sec at the standard initial distance from the earth, the transit time is about 5.5 days. As the initial velocity is increased by about 1.0 per cent, to a value of 35,150 ft/sec, the transit time is reduced to a value of 2 days. At an initial velocity of 37,000 ft/sec, the flight time is decreased to about 1 day. As the initial velocity is increased further, approaching infinity, the transit time is given approximately by the ratio of the earth-moon distance to the initial velocity.

2. *Initial Tolerances for Impact*

In order to discuss the variation of the tolerances of initial conditions for lunar impact in more detail, and also to define the various other types of trajectories which are possible in the earth-moon system, Fig. 11 presents an expanded graph in the vicinity of the curve for an initial trajectory position angle of −112.5 deg relative to the moon.

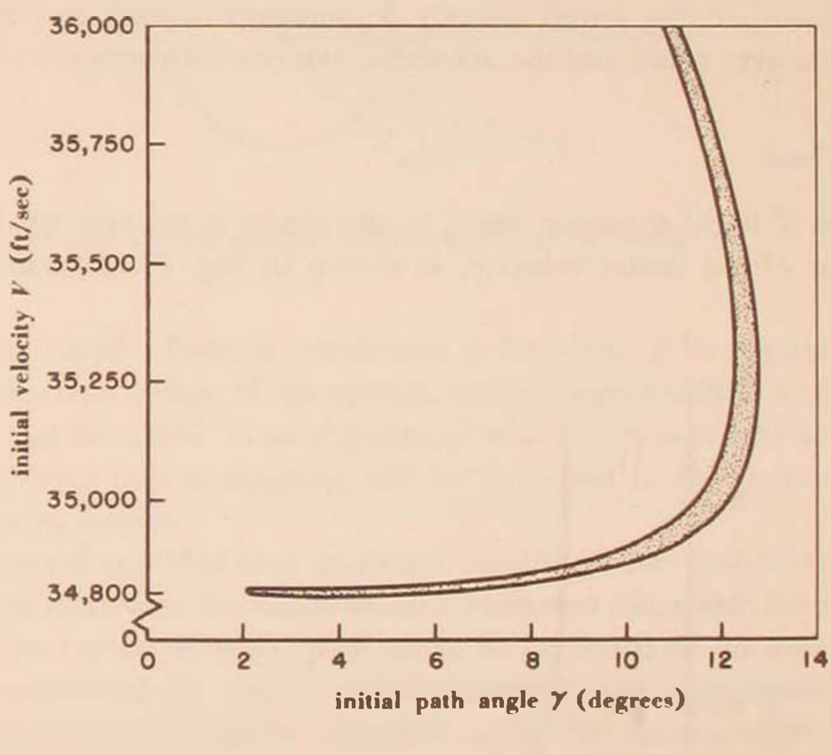

Figure 11. Initial conditions for lunar impact (r = *4300 miles;* ϕ = *−112.5 degrees*).

The solid lines enclosing the small shaded area of the graph define combinations of initial conditions of trajectories which hit somewhere on the moon. The upper solid curve (left edge) leads to hits near the leading, or eastern, limb of the moon; while combinations on the lower solid line (right edge) define trajectories which hit near the western limb of the moon. A curve lying approximately midway between the solid lines would give the locus of initial conditions resulting in trajectories which impact normal to the surface of the moon. Points to the left of the hit band will give the combinations of initial conditions for trajectories which pass ahead of the moon in its orbit. These, typically, could be used as transit trajectories to establish a vehicle as a satellite of the moon if its velocity is reduced at the point of closest approach. Trajectories defined by a set of initial conditions to the right of the hit band will intersect the moon's orbit after the moon has passed. This type of passage may result in increasing the energy of the trajectory of the vehicle by action of the moon's gravitational field, and thus be thrown out of the earth-moon system.

The reflex curvature of the hit band, mentioned earlier, is more pronounced in this graph (Fig. 11). Also, the relative variation in the magnitude and path-angle tolerances can be seen more easily. Some typical combinations of tolerances to hit somewhere on the moon are: $\Delta V = \pm 5$ ft/sec and $\Delta\gamma = \pm 2$ deg at an initial velocity of about 34,800 ft/sec. As the magnitude of the initial velocity is increased to about 35,000 ft/sec, the tolerances are $\Delta V = \pm 50$ ft/sec and $\Delta\gamma = \pm 0.3$ deg. The maximum velocity tolerance for this initial position angle has a value of nearly ± 300 ft/sec.

For initial velocities above this portion of the curve, the tolerance in the magnitude of the velocity gradually decreases again as the band curves over. The corresponding angular tolerance also decreases slightly.

A typical transit trajectory resulting in an impact which is normal to the surface of the moon is shown in Fig. 12. This trajectory is plotted in an inertial coordinate system fixed at the center of mass of the earth-moon system. The elliptical character of the trajectory relative to the earth is evident. The trajectory

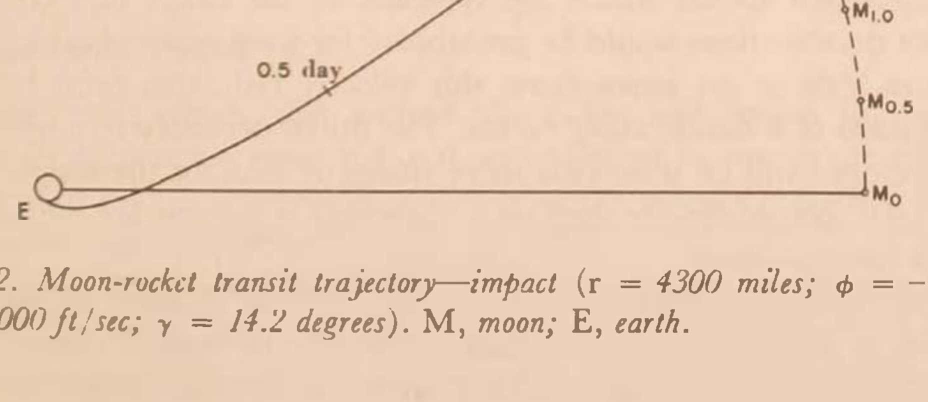

Figure 12. Moon-rocket transit trajectory—impact (r = *4300 miles;* ϕ = *−108 degrees;* V = *35,000 ft/sec;* γ = *14.2 degrees*). M, *moon;* E, *earth.*

is noticeably perturbed by the moon's gravitational field only during approximately the last 0.5 day of the 2.3-day transit time. The initial velocity and path-angle tolerances around this particular trajectory design point are about ± 40 ft/sec or ± 0.25 deg to hit somewhere on the face of the moon which is visible from the earth. In the immediate vicinity of this point, however, the sensitivity in impact location is about 25 st mi/ft/sec or 4500 st mi/deg.

The terminal portions of several trajectories, differing only in the values of the initial velocity in vicinity of the nominal case, are shown in Fig. 13. The central curve, for $V = 35{,}000$ ft/sec, corresponds to the trajectory shown in Fig. 12. It can be seen that the minimum sensitivity of the impact location to initial errors occurs in the vicinity of the trajectory which impacts normal to the

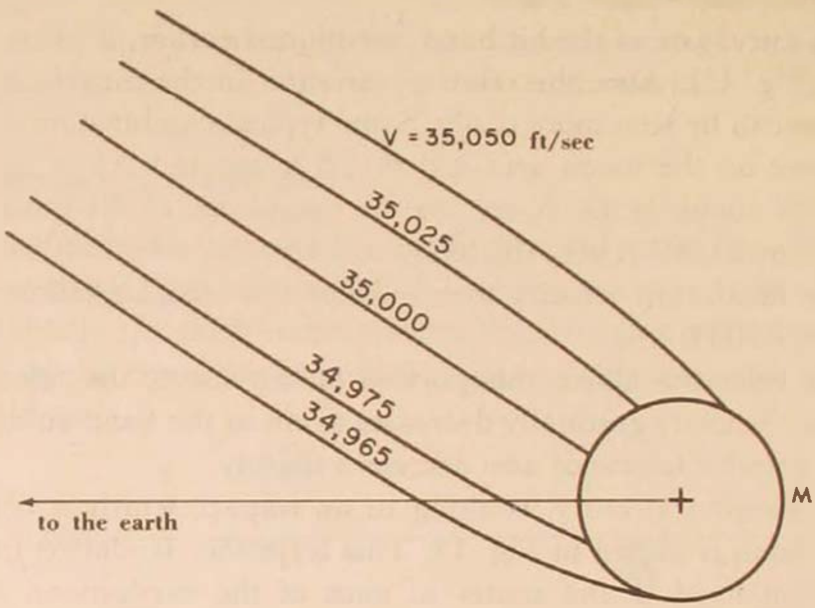

Figure 13. Effect of varying V *on impact location* (r = *4300 miles;* ϕ = *−108 degrees;* γ = *14.2 degrees*). M, *moon.*

lunar surface. The initial conditions for the family of trajectories shown in this diagram correspond to a vertical cut through the hit band shown in Fig. 11.

3. Lunar Landing

The transit trajectories leading to lunar impact described above will result in vehicle approach speeds which are typically in the range of 10,000 ft/sec. The resultant decelerations would be prohibitive for most types of vehicles. Since the moon has little or no atmosphere, this velocity reduction must be accomplished by means of a decelerating rocket. The initial accuracy requirements for landing trajectories will be somewhat more stringent than for the simpler impact cases if a nearly perpendicular approach trajectory is needed for the particular landing-gear arrangement.

Since the typically high approach velocity must be reduced by means of a rocket motor, a provision must be made to orient the vehicle correctly. This could be accomplished either by spin-stabilization of the rocket when the correct orientation is achieved after booster burnout, or by some means of terminal attitude sensing and control system.

4. Lunar Escape

Another type of unpowered trajectory which the vehicle could follow is to use the moon's orbital motion and gravitational field to accelerate it out of the earth-moon system.

The initial conditions for trajectories of this type are located to the right of the hit band shown in Fig. 11. The vehicle, on a trajectory of this type, will reach the moon's orbit shortly after the moon has passed. The vehicle will be accelerated and its trajectory deflected by the encounter with the moon for relatively close approaches, as shown in Fig. 14. This type of maneuver might be used to gain an effective initial velocity increment of several hundred feet per second for interplanetary flights if the required initial trajectory accuracies could be achieved.

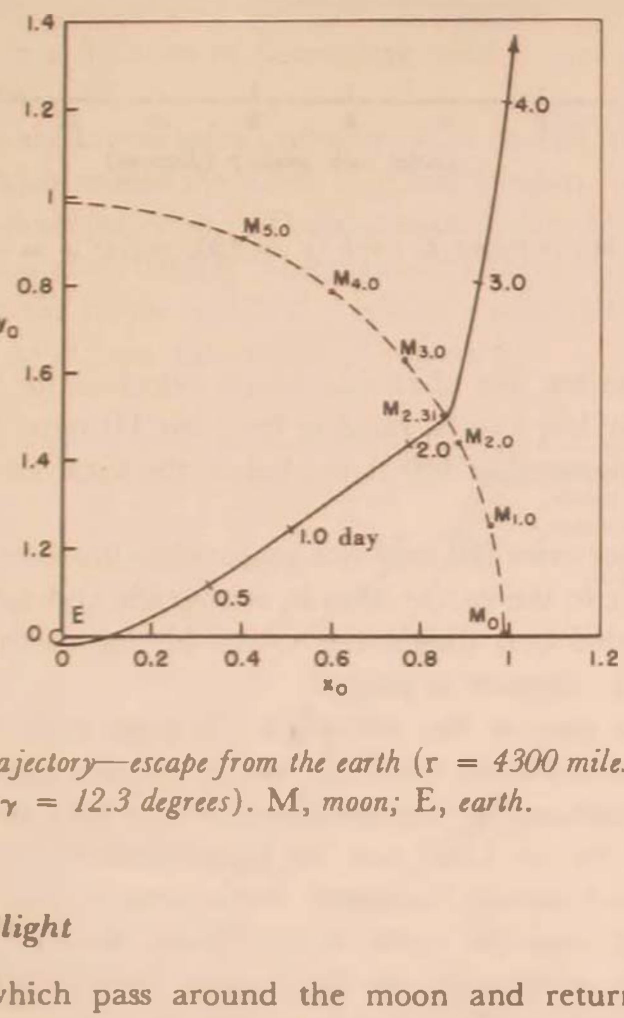

Figure 14. Transit trajectory—escape from the earth (r = *4300 miles;* ϕ = *−112.5 degrees;* V = *35,000 ft/sec;* γ = *12.3 degrees*). M, *moon;* E, *earth.*

5. Circumlunar Flight

Trajectories which pass around the moon and return to the immediate vicinity of the earth are restricted to those which are in retrograde motion relative to the moon; that is, trajectories which cross the moon's orbit shortly before the moon reaches that position.[12]

In order to show the development of the various types of trajectories which return to the earth, Fig. 15 presents a further expansion of the $V - \gamma$ plot for the same position angle ($\phi = -112.5$ deg) shown previously (Fig. 11). The curved, shaded band again indicates the initial combinations for trajectories which hit the moon. The trajectories which return to the earth are defined by initial conditions lying to the left (smaller path angles) of the hit band.

The dashed line near the top of the graph defines the locus of initial conditions for trajectories which reach a maximum distance (apogee) from the earth equal to twice the lunar distance after being deflected by the moon's gravita-

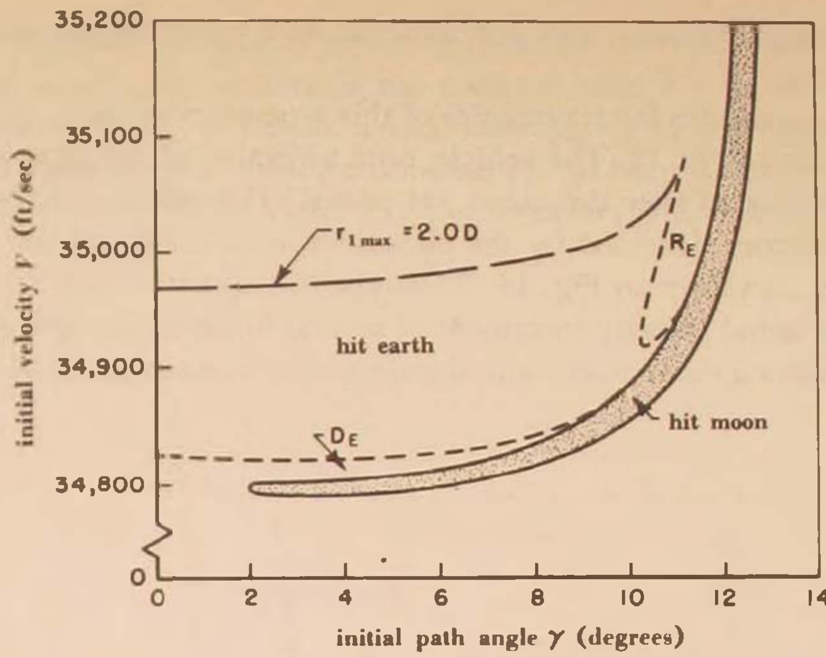

Figure 15. Initial conditions to return to earth (r = *4300 miles;* ϕ = *−112.5 degrees*).

tional field. As we can see, the allowable initial velocities for return trajectories are restricted to rather low values, ranging from the hit band to values of about 35,000 ft/sec, which is roughly 100 ft/sec below the local escape velocity from the earth.

These return trajectories fall into two major classifications as defined by the type of motion relative to the earth—that is, retrograde and direct. Each of these classes is further divided into trajectories which hit the earth and those which miss the earth by some distance at perigee.

The short-dashed lines to the left of the hit band show the boundaries of initial conditions for trajectories which hit the moon and miss the earth on the return. Trajectories defined by combinations in the area between the nearly horizontal portion of the hit band and the lower dashed line, labeled D_E, will miss the earth in direct motion. Similarly, trajectories defined by points in the region labeled R_E will miss the earth in retrograde motion. The dividing line between trajectories in retrograde and direct motion which hit the earth on the return lies approximately halfway between these two curves. A trajectory defined by $V - \gamma$ combination lying on this curve will return to the earth on a nearly straight line—a rectilinear trajectory whose eccentricity is 1.0.

From this graph we can quote a set of allowable initial tolerances to merely go around the moon and return to the earth. These values, which are approximately $\Delta V = \pm 80$ ft/sec and $\Delta\gamma = \pm 5$ deg, do not really have much significance, since the distance of closest approach to the moon will vary from zero to about 80,000 mi within these tolerance values. For any reasonable missions, such as photographing the far side of the moon, this extreme variation of lunar approach distances would not be acceptable. Thus these tolerances would be reduced to more realistic values. Lines of constant minimum distance to the moon are roughly parallel to the line defining the limit of hits on the moon (left edge of the hit band) as mentioned earlier, so that the sensitivities of closest approach distance will be functions of the magnitude of the initial velocity.

An interesting conclusion to be drawn from this graph is that, according to these calculations, a close approach to the moon and subsequent return to hit the earth is possible only for a relatively limited variation in the magnitude of the initial velocity. Values below the lower limit result in misses of the earth in direct motion, while values above the upper limit result in misses of the earth in retrograde motion.

Typical examples of trajectories which pass the moon's surface at about the same minimum distance are shown in the following set of graphs (Figs. 16–18). The initial velocity is increased through the set, and the initial path angle is selected to result in a distance of closest approach to the surface of the moon of approximately 3000 st mi.

Figure 16, for the lowest initial velocity (V = 34,825 ft/sec) gives an example of a trajectory which misses the earth in direct motion. This path is similar to the classical "figure-eight orbit." The minimum altitude at the earth is about 1300 mi at 7.4 days after launch. The trajectory is continued to a flight time of 9 days to indicate the ellipse which the vehicle would follow if no powered maneuver were used to recover the vehicle at the earth.

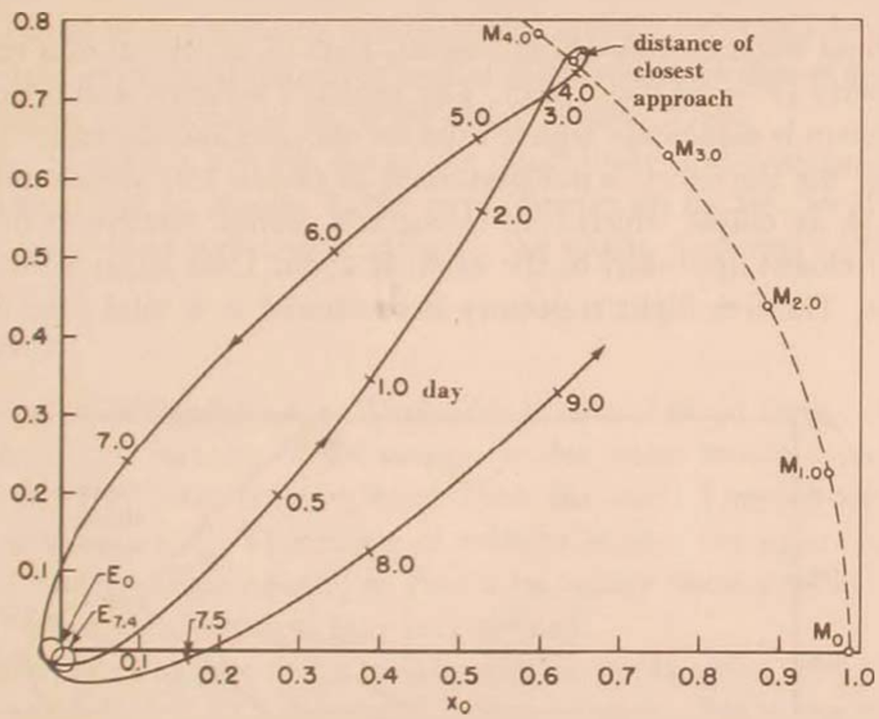

Figure 16. Return near the earth after passing near the moon—direct motion (r = *4300 miles;* ϕ = *−90 degrees;* V = *34,825 ft/sec;* γ = *17.0 degrees*). E, *earth;* M, *moon.*

An example of a trajectory with a nearly radial return to the earth is given in Fig. 17. This trajectory is typical of those defined by a value in the middle range of initial velocities. The distance of closest approach to the moon is also 3000 mi and the time of return to impact on the earth is about 7.1 days after launch.

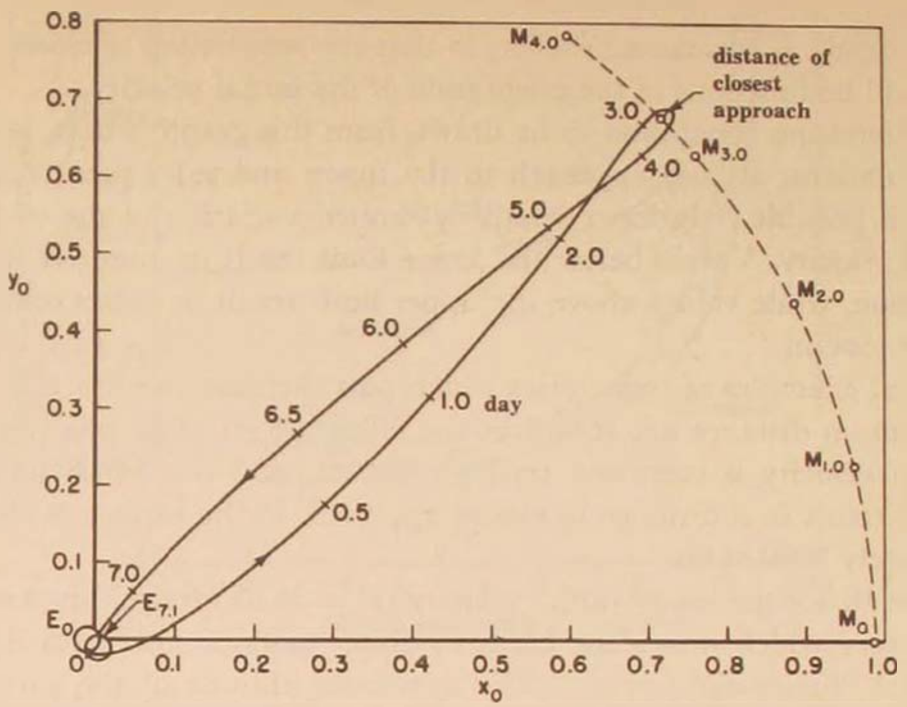

Figure 17. Return to hit the earth after passing near the moon—direct motion (r = *4300 miles;* ϕ = *−90 degrees;* V = *34,850 ft/sec;* γ = *19.25 degrees*). E, *earth;* M, *moon.*

The final trajectory shown in this set, Fig. 18, is typical of a relatively high initial velocity (V = 34,950 ft/sec). The vehicle's velocity, and hence its energy, near the moon is somewhat higher than for the previous examples (Figs. 16 and 17), so that the trajectory is not perturbed as much. The vehicle returns to miss the earth on an ellipse which is in retrograde motion relative to the earth. The distance of closest approach to the earth is about 1500 mi at a total flight time of 9.9 days. The free-flight trajectory is continued to a total time of 12 days to

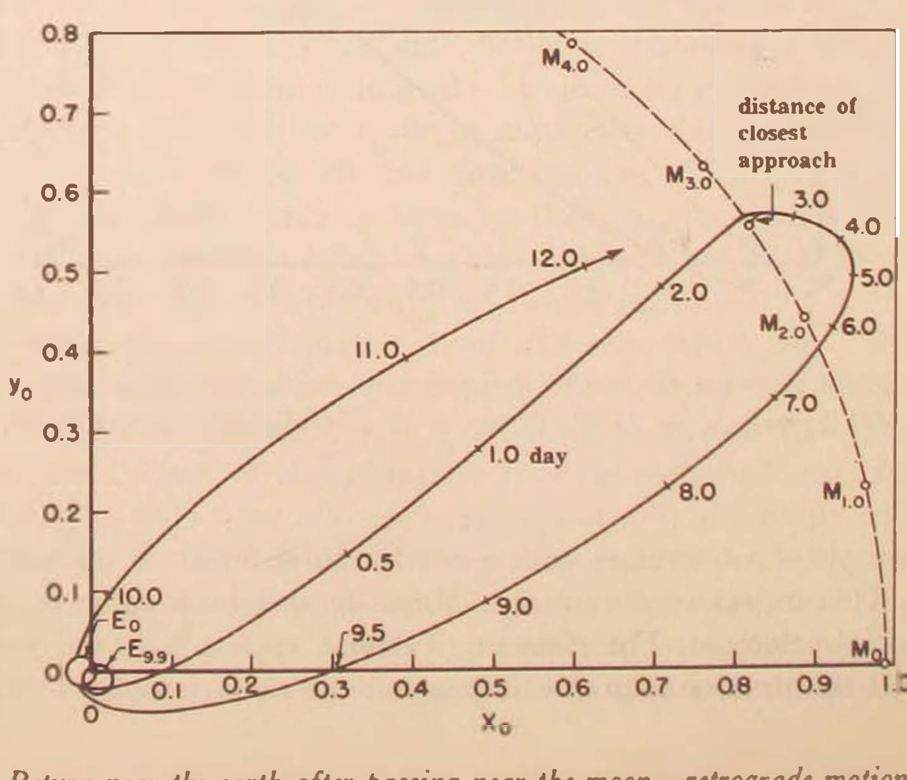

Figure 18. Return near the earth after passing near the moon—retrograde motion (r = *4300 miles;* ϕ = *−90 degrees;* V = *34,950 ft/sec;* γ = *22.0 degrees*). E, *earth;* M, *moon.*

show, once again, the ellipse on which the vehicle will move until, at some future time, the moon may possibly perturb the trajectory again.

6. Lunar Satellite

It might be of interest, for some scientific experiments, to establish a vehicle as a satellite of the moon.[13] The transit trajectory for this type of mission could be the same as the earth-to-moon phase of either the circumlunar (Figs. 16–18) or lunar-escape trajectory (Fig. 14) discussed earlier.

A transit trajectory like that shown for a circumlunar mission will pass ahead of the moon in its orbit and will therefore result in a lunar satellite which is orbiting in a clockwise direction, and be in retrograde motion. Conversely, a trajectory like that shown for a lunar-escape mission will pass behind the moon in its orbit and thus will lead to a lunar satellite which is in direct motion. Preliminary investigations indicate that lunar satellites orbiting in retrograde motion may be more stable.

Since the moon cannot capture a vehicle on a trajectory from the earth, the vehicle's velocity at the point of closest approach to the moon must be reduced by an increment sufficient for it to remain in a circular or elliptical orbit around the moon, that is, enough to produce conditions corresponding to a curve of zero velocity (Fig. 5) which is closed around the moon. The magnitude of the velocity increment required to establish the vehicle in the satellite orbit will be a function both of the initial velocity at the earth and of the distance of closest approach to the moon. Typical values would be of the order of 5000 ft/sec.

The requirement on the control of the magnitude and orientation of this velocity increment will be similar to the requirements on the decelerating rocket which is used for a nondestructive landing on the moon, discussed earlier.

7. Moon-to-Earth

The final type of mission we will consider is that of flight from the moon to the earth. The initial velocity of the vehicle at the moon would typically be of the order of 2000 to 5000 ft/sec greater than the local lunar escape velocity (7800 ft/sec at the surface). This range of velocity is near the upper limit of the capabilities of a single-stage missile, so that a two-stage booster, which will give good payload–gross weight ratios, may be required.

The transit time from the moon to the earth for the range of velocities quoted above will vary from about 2.5 down to 1.5 days—comparable to the earth-moon case discussed earlier.

The tolerances on the initial velocity and path angle at the moon will be quite large if the vehicle is merely to return somewhere on the earth, because of the earth's larger diameter and stronger gravitational attraction. A typical set of tolerances might be ± 1000 ft/sec or ± 5 deg to return to a point somewhere on the earth.

The sensitivity of the location of the impact point on the earth (vacuum entry) is determined by the variation of the geometrical location (on a nonrotating earth) with respect to initial velocity vector errors plus the sensitivity of total flight time to the initial errors, since the earth is spinning on its axis.

Because the moon's period of rotation on its axis is equal to its orbital period around the earth, the launch time will be determined by the angular location of the desired impact point on the earth at that future time.

The thermal protection requirements for the vehicle entering the atmosphere will be quite severe, since the earth-approach speed will be of the order of escape velocity. If the vehicle enters the atmosphere vertically, the aerodynamic deceleration will be about 300 g's. This high g-load can be reduced either by entering the atmosphere at a somewhat shallower angle or by using a decelerating rocket to reduce the entry velocity.

8. Launch-Time Tolerance

One of the operational considerations for a lunar shot is the allowable tolerance on the instant of launching the vehicle. Since the earth rotates on its axis and the moon moves in its orbit, the launch site is moving with respect to the "target." The decision to launch the vehicle at a given time on a specific calendar date is, therefore, equivalent to defining the instantaneous orientation of the launch site relative to the sun and the moon. For any particular booster vehicle there will be a specific powered ascent trajectory which is optimum for the desired lunar mission. The powered ascent trajectory is determined by the thrust vector orientation as a function of powered-flight time. This thrust vector function will, of course, determine the final burnout path angle for a given vehicle. The allowable tolerance on the instant of launch will, therefore, be given by the time increment required for the earth to rotate through a position angle increment corresponding to the allowable path-angle tolerance for trajectories whose impact points on the moon vary from one limb to the other. For a trajectory defined by an initial velocity of 35,000 ft/sec, the allowable path-angle tolerance is about ± 0.3 deg, which would correspond to a launch-time tolerance of about ± 2.5 min.

If, on the other hand, the thrust vector function of burning time can be continuously reprogramed as a function of the instant of launch, the plus and minus launch-time tolerances will be determined mainly by the propellant allowances in the booster stages or the aerodynamic drag during ascent. For moderate propellant reserves, the launch-time tolerance could be increased to several minutes.

V. Orientation Control

Proper alignment of the vehicle with respect to inertial space is important for several applications, such as retro- or decelerating rockets, or instrument orientation.

The principal sources of orientation errors in the free-space environment of unpowered lunar flight are:

Initial alignment errors
Initial angular rates
Internal moving parts
Fluid exhausts
Solar radiation

Vehicle radiations
Gravitational gradients
Meteoroid impacts

The initial alignment errors at the start of ballistic flight must simply be held within acceptable tolerances. Initial angular rates must either be removed by application of control torques or be absorbed within acceptable precession angles by adequate angular momentum due to vehicle spin.

As a result of the law of conservation of angular momentum (for the vehicle as a rigid body, and not to be confused with the nonconservative momentum situation encountered in the trajectory problem), any movement of masses internal to the vehicle, if not internally compensated, will lead to complementary rotations of the vehicle body. Thus internal moving parts must be arranged so that every rotating component is matched by a suitable counterrotating part, or the vehicle angular momentum capacity must be large enough to absorb these disturbances without excessive displacement.

Fluid exhausts are, in essence, rockets and can therefore produce couples if the exit flow lines are off the center of mass of the vehicle.

Solar radiation pressure will produce a torque if the center of radiation pressure of the vehicle, in the aspect presented to sunlight, is not coincident with the center of mass. Similarly a torque can be produced by the pressure of any radiation emanating from the vehicle, such as radio transmissions or temperature-control heat radiators.

The gradient of the gravitational field in which the vehicle operates can produce a torque. The portions of the vehicle nearer to the earth are attracted more strongly than the portions that are farther away; from this difference in attractive force a couple can be produced.

If a meteoroid strikes the vehicle along a line off the center of mass, its impact will impart an impulse of angular momentum to the vehicle, and thus produce an attitude disturbance.

All these sources of orientation disturbance are small, or can be made small, but all are important enough to require consideration.

For most instrumented flights, the most convenient stabilization measure is spin. If spin is not an acceptable stabilization method for a particular application—such as manned flight, perhaps—then an active control system based on jet exhaust or other reaction devices would be required. Some of the torque sources listed above as disturbances, such as fluid exhausts and radiation pressure, can also provide useful control forces.

VI. Heat Protection

The heat-protection provisions for vehicles on most of the lunar missions discussed earlier will be similar to the requirements for the present scientific satellites. That is, the lunar vehicle must be protected from the aerodynamic heating encountered during the powered ascent trajectory. During the free-flight portion of the trajectory from the earth to the moon, the main source of heat input will be solar radiation. For lunar vehicles which are spin-stabilized, a solution to the temperature problem would be alternating stripes of paint and bare metal so that the absorptivity and emissivity will result in an acceptable internal temperature.

Vehicles which are to be recovered from circumlunar trajectories, or which are fired from the moon to the earth, must be protected from the aerodynamic heating during entry into the atmosphere. The use of some type of parachute to produce a high drag-weight ratio will cause the heating to be reduced and to occur at higher altitude. The payload itself could be protected by means of either a heat sink or an ablating type of re-entry body.

VII. Ground Facilities

Lunar flight ground facilities include facilities for launching, observation, communication, and recovery. While each space activity will have unique features of its own, there are some general characteristics that cast light on the nature of the ground problems.

Since flights in space take a long time and involve flight paths completely separate from the earth, the earth's rotation will carry ground stations in and out of view of most space vehicles in daily cycles. Thus, continuous reliable observation and communication can be maintained only if ground stations are distributed around the entire globe. Such stations must be built, supplied, and operated. This, of course, also involves securing real property and rights of access. A world-wide communication net will also be needed for coordination of the operation of ground stations.

Uncertainty in the arrival points of some experimental payloads from space—for example, returning circumlunar vehicles—indicates need for world-wide tracking, search, and recovery operations with the attendant need for rights of access or international agreement for cooperation. This requirement will become most pressing with the advent of manned flight.

Launching of some space rockets will involve hazards that severely limit freedom of choice of launching sites; and, further, the ground range covered by these vehicles during the launching phase will generally be very long, so that the launching site must include a long, clear ground path—in general, many hundreds of miles long—with adequate tracking communication and guidance stations along its length. Vehicle efficiency is generally enhanced by launching in an easterly direction to take advantage of the speed of rotation of the earth; however, access to a wide range of firing directions is required for certain operations, including lunar flight. Lunar flights require firing in different directions at different times because of the natural changes in the moon's position over an 18.6-year cycle.

The physical necessities of the situation clearly indicate a trend toward launching rockets that will be very large by present standards, particularly for manned flight. The great propellant load in greatly enlarged rockets may raise the level of hazard from accidents to an extent that may require some unusual measures to adequately isolate the launch site from populated areas, indicating a severe reduction in the freedom of choice of geography for ground stations.

These "earthy" problems are an intimate and vital part of astronautics.

VIII. Scientific Utilization

Briefly, some of the purposes to which lunar rocket experiments might be turned include measurements to advance our knowledge in the following areas:

1. A better determination of the mass of the moon. The current estimates of this quantity may be in error by as much as 0.3 per cent, and substantial inconsistencies exist between mass estimates based on asteroid observations and those implied by data on the motions of the earth's polar axis.

2. Measurement of the moon's magnetic field. At present we have no knowledge whatsoever of the moon's magnetic field. Data on the magnetic field of the moon would allow us to make some progress in theories about the history of the moon, the processes of its formation, etc.

3. Determination of the composition and physical properties of the lunar atmosphere.

4. Determination of the composition and properties of the lunar crust.

5. Measurement of lunar surface temperature and its variation with time and depth.

6. Measurement of surface radioactivity and atmospheric electricity.

7. Seismic properties of the lunar interior.

The Rand Corporation

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including a lot of little people—still fight wars, there is much to be learned from books like Wiley's *Johnny Reb* and *Billy Yank*, Marshall's *The River and the Gauntlet*, and Edmond's *They Fought With What They Had*.

Finally, no matter what or how much he reads, the wise student will keep always in mind that he must never allow himself to be bound by the past. He will not forget that we cannot fight today's war with the specific strategies, tactics, and weapons of yesterday's war. How then will he use the record of the past? He will use it to understand the present and to plan for the future. He will use it for information and background. He will use it to take advantage of experience and success, to avoid errors, and to learn from failures. He will not allow history to be his master; instead, he will make it his servant.

Research Studies Institute, Air University

The Air Force Historical Foundation

TO fulfill a felt need for the perpetuation of the annals of air power, the Air Force Historical Foundation was organized by a group of senior Air Force officers, active and retired, and a significant representation of distinguished civilians who have a continuing interest in air power problems. Its primary and overriding purpose for its creation is to treat with the historical features and factors of air power growth.

The Foundation is an independent, incorporated, nonprofit organization, supported wholly by its membership. It operates in close contact with the official Air Force historical program and for that reason is located in Montgomery, Alabama, on Maxwell Air Force Base, where liaison may be maintained with the Historical Division of the Research Studies Institute of the Air University. The Foundation is able to complement the activities of the Institute in those areas where the Air Force cannot engage because of budgetary, legal, or policy limitations. A reasoned interpretation of the lessons of historical experience is one of its major objectives in this field.

Because the men who make history are frequently not conscious of the tremendous importance of their contributions to the solutions of military problems, it usually becomes the task of others to appraise and evaluate the significance and meaning of these historic contributions. Although the layman in this nuclear age possesses a natural and expanding interest in air power, he must rely on the interpretations of specialists if he is to appreciate realistically the significance of the evolutionary growth of weapon systems as they relate to the current and continuing welfare of Western civilization. Since air power is directly related to the atomic age and in a sense fostered it, air power must be treated accordingly.

The voice of the Foundation is a quarterly publication entitled, *The Air Power Historian*, distributed only to members of the Foundation. One of the guiding editorial beliefs of *The Air Power Historian* is that our civilization cannot survive if the people who enjoy its blessings and favors display weakness of conviction and lack of courage.

Another editorial belief is that history must be studied for its flaws as well as its merits and achievements. Examples in history are to be treated for their causative factors and not treated solely in terms of final accomplishments. Final results can be, and often are, the product of enemy errors and weaknesses, as well as successful action on the part of the victors.

For the midnight oil

With the airman now reaching out for the stars he must take a broadly diverging knowledge for his province. From time to time *Air University Quarterly Review* will recommend volumes ranging from undergraduate textbook and advanced amateur's handbook to tool sharpeners for the serious initiate. Concept and term, technique and operation are expanding in the Air Force like the exploding universe some of these books will talk about.

Discovery of the Universe, by Gerard de Vaucouleurs, 328 pp, Macmillan, $6.—An excellent narrative history of the development of astronomy from the origins to 1956, from mystical speculation to scientific comprehension: the rise of classical astronomy, the study of the stellar system and the solar system onward from the end of the eighteenth century, the upgrowth of modern astrophysics. Compact and readable. The author has done two excellent summaries of what we know about the red planet Mars: *The Planet Mars*, for the general reader, and *Physics of the Planet Mars*, for readers more specially interested and equipped. The general reader will also like to be reminded of *The Green and Red Planet*, by Dr. Hubertus Strughold, Professor of Space Medicine, School of Aviation Medicine, USAF, a brief, lucid consideration of the biological possibilities of Mars. De Vaucouleurs, a distinguished French areologist, is now Research Associate, Harvard College Observatory.

The Planet Venus, by Patrick Moore, 132 pp, Macmillan, $3.—A summary of what little is known about the planet Venus and its physical aspects. There are two chapters on the surface of the planet and the possibility of life upon it. Suitable for the amateur astronomer. Bibliography. "Popular interest in astronomy is focused mainly on the planet Mars. In view of the fact that Mars has always been considered as a possible abode of intelligent life, this preoccupation with it is not surprising; and even now, when we are to all intents and purposes certain that the 'Martians' do not exist, the interest remains. Yet the fascination of Mars must not lead us to neglect other equally intriguing planets. Venus, in particular, will repay close attention from the amateur as well as the professional astronomer. Here we have a world almost the same size as our own, comparatively close to us and yet virtually unknown." Twilight and evening star! A world so brilliant-close yet so swathed in dense, cloud-charged atmosphere that the prying telescope has never seen its surface. Moore is Director of the Mercury and Venus Section of the British Astronomical Association.

The Planet Jupiter, by Bertrand M. Peek, 283 pp, Macmillan, $8.50.—A curiously interesting book in the once-impactive meaning of the adverb. A survey of what learning we have slowly accumulated about the Great Planet, but for all its detail and conscientious exposition it is permeated with the enticing firsthand observations of the devotee. Written by the Director of the Jupiter Section of the British Astronomical Association.

Modern Chemistry for the Engineer and Scientist, edited by G. Ross Robertson, 442 pp, McGraw-Hill, $9.50.—For understanding of the latest developments in theory and practice and for review of forgotten fundamentals. A collection of lectures delivered originally to graduate engineers and scientists in university extension courses. A knowledge of the fundamentals of chemistry is assumed.

Deals with such topics as chemical thermodynamics, photochemistry, and chemical synthesis in organisms.

Vector Analysis, by Louis Brand, 282 pp, John Wiley, $6.—Intended for a short undergraduate course, this text provides a good introduction to a valuable tool in the solution of problems in mechanics and dynamics.

Elements of Pure and Applied Mathematics, by Harry Lass, 491 pp, McGraw-Hill, $7.50.—A text intended for upper-division undergraduate courses for physical science, engineering, and mathematics majors—but not in the minor leagues. The reader dives into this one fast with the summation convention first introduced by Albert Einstein.

Mathematics for Science and Engineering, by Philip L. Alger, 360 pp, McGraw-Hill, $5.50.—This is a very good one for the man who has "forgotten" his college math. A revision of the famous review book written by Charles Steinmetz, its successive chapters take up arithmetic, trigonometry, algebra, calculus, probability, etc. Intended to contain "about 80 per cent of the mathematical procedures and methods which an engineer or technician will need to use in the course of his career."

Modern Introductory Physics, by Ira M. Freeman, 497 pp, McGraw-Hill, $6.—A good beginners' physics text on the college freshman level.

Microbiology, by Michael J. Pelczar, Jr., and Roger D. Reid, 564 pp, McGraw-Hill, $8.—An introductory text on the undergraduate level, but nicely sophisticated in text and illustration contrary to the educational specialists and their "living-in-our-world" style. In short, a text that does not talk down to the juvenile malcontent but is clear and to the point. Simple and easy to understand, but it still means business.

Vistas in Aeronautics, First Annual Air Force Office of Scientific Research Astronautics Symposium, edited by Morton Alperin et al, 330 pp, Pergamon Press, $15.—Proceedings of the Astronautics Symposium convened at San Diego in February 1957. The first technical meeting of its kind and sponsored by the USAF Air Research and Development Command with the General Dynamics Corporation. Papers in the technology of astronautics for the very serious.

The Quarterly Review Contributors

BRIGADIER GENERAL CECIL E. COMBS (USMA; M.A., George Washington University) is Commandant of the Air Force Institute of Technology, Wright-Patterson AFB. Previously he served as Deputy Commander of the Crew Training Air Force, Air Training Command. Other assignments have been as Commander, Officer Military Schools, Lackland AFB; Assistant Chief, Plans Division, Hq USAF; member of the War Department General Staff; Commander, India Task Force; Commander, 19th and 7th Bombardment Groups; and Deputy Commander, 58th Bombardment Wing.

BRIGADIER GENERAL HAROLD W. BOWMAN (University of California) is Deputy Commandant, Air Force, Armed Forces Staff College. His military career began as a flying cadet (1928), followed by assignment to the 7th Bombardment Group. He was sent to the Philippines (1934), to Langley Field (1937), and became Chief of the Technical Data Branch, Wright Field (1938). He was Assistant Executive to the Chief of the Air Corps (1939), Commander of the 401st Bombardment Group (1943), and Deputy Chief of Staff for Public Relations of the U.S. Strategic Air Forces in Europe (1944). He became Chief of the Office of Information Services, Hq AAF (1945), and Deputy Director of Information for the Army Air Forces (1946). After graduation from the National War College (1948), he became Chief of Staff of the Ninth Air Force, Vice Commander in February 1950, and Commander in July 1950. In August 1950 he was appointed Deputy for Personnel, Tactical Air Command, and in 1951 assumed command of the 62d Troop Carrier Wing at McChord and Larson AFB. He became Deputy Director for Plans, Plans and Policies Division, Hq U.S. European Command, in 1954.

COLONEL EDWARD N. HALL (M.S., California Institute of Technology) is Director of Weapon System 133A (Minuteman), Air Force Ballistic Missile Division, Hq ARDC. He has been in the Air Force since 1939 and during the war served in England in engineering assignments in aircraft repair. He got his start with missiles at the end of the war when he led an Air Force Propulsion Group through German rocket plants and later assisted in the division of captured missile equipment between the U.S. and Great Britain. In a second tour of Europe he covered further propulsion developments. He then became Assistant Chief, Non-Rotating Engine Branch, Power Plant Laboratory, Wright-Patterson AFB, where he helped in the development of solid and liquid rocket power plants. In 1954 he joined AFBMD as Chief, Propulsion Development, where he was responsible for the programs leading to engines for the Atlas, Titan, and Thor missiles.

MAJOR EDWARD H. PETERSON (B.S., M.S., Massachusetts Institute of Technology) is Chief, Operations and Training Procedures Analysis Division, Directorate of Manpower and Training, Plans and Operations, Headquarters SAC Mike. Called to active duty with the Corps of Engineers in April 1943, he later attended USAAF OCS and was commissioned in May 1944. He served as aircraft maintenance officer and flight engineer both as an instructor at Lowry AFB and as aircrew with the 509th Bombardment Wing, SAC. He attended the Air Intelligence Officer Course in 1948 and was a USAFIT aeronautical engineering student in 1948-50. He was Technical Supply Officer for Project Casey Jones (photo mapping of Europe) and from 1951 to 1954 served primarily as a special-weapons-course instructor, AFSWP, Sandia AFB.

DR. W. PHILLIPS DAVISON (A.B., Princeton University; M.A., Ph.D., Columbia University) has since 1948 been engaged as a Research Scientist, Social Science Division, The Rand Corporation. During 1957–1958 while on leave from Rand he served as Visiting Professor, Department of Economics and Social Science, Massachusetts Institute of Technology. He has also since 1954 been a Professorial Lecturer at the American University, Washington, D.C. In 1947–48 he was a Research Associate, Council on Foreign Relations, New York. From 1948 to 1951 he was Editor, *Public Opinion Quarterly*, Princeton University. Dr. Davison's publications include numerous articles and book reviews on propaganda, communications, and public opinion; as a contributor to *Public Opinion and Foreign Policy* (edited by Lester Markel); *West German Leadership and Foreign Policy* (with Hans Speier); and *The Berlin Blockade—A Study in Cold War Politics*.

DR. ROBERT W. BUCHHEIM (B.E., M.E., Ph.D., Yale University) is Project Leader of Space Flight Studies at the Rand Corporation. Previously he was an instructor in the Electrical Engineering Department, Yale University. Before joining Rand in 1954 he was with North American Aviation, Inc., as Project Engineer on a guidance system for the Snark missile. He is the author of numerous reports in the fields of electronics and space flight.

HANS A. LIESKE (B.S., Massachusetts Institute of Technology) is head of the Flight Mechanics Group of the Engineering Division, The Rand Corporation. As an ensign in the United States Navy he was assigned to the Naval Air Development Center, Johnsville, Pennsylvania, where he conducted airplane and missile performance studies. In October 1946 he joined Project Rand at the Douglas Aircraft Company and in November 1948 transferred to the Rand Corporation.

DR. ALBERT F. SIMPSON (Ph.D., Vanderbilt University) is the Air Force Historian and is Chief of the Historical Division, Research Studies Institute, Air University. He has been with the Air Force since 1941, first as a senior instructor and assistant director of the Academic Division of the Pre-Flight School at Maxwell Field. He was historian for the Mediterranean Theater, Air Service Command, prior to assuming his present duties in 1946.

ATTENTION

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