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THE AIR FORCE BALLISTIC MISSILE

SUMMER 1957

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While the ballistic missile itself is less flexible than the manned bomber when comparing weapon with weapon, its addition will definitely add a considerable measure of flexibility to our forces as a whole. Its reaction time and speed of flight are very valuable characteristics in a situation requiring immediate response to an attack. The ballistic missile will also permit greater versatility for our forces by relieving the manned bomber of those heavily defended targets where the cost of attacking with bombers would be too high and where precise accuracy is not mandatory. In considering the characteristics of the bomber and the ballistic missile, it appears that for many years to come an optimum force will make best use of both weapons.

The creation of the ballistic missile has been a tremendous undertaking, surpassing even the Manhattan Project in scope and goals. In the not too distant future the ballistic missile will enter our forces as an operational weapon. We must be ready to receive it and use it effectively. It is sufficiently different in almost every phase of Air Force experience to create many problems. Some of the problems which we are facing and will face in the future are discussed in this issue of the *Quarterly Review* so that Air Force members may see them in context and begin thinking about them.

With each passing year the ballistic missile will become more important as an instrument of national policy. As the missiles take their place alongside manned bombers, we in the Air Force must bend ourselves to the task of creating for our country the best possible air power we can produce. Our problem is to exert a steady, unremitting pressure against war over the years ahead. We must hold ready, night and day, for every day of every year, a counterstroke so powerful, so swift, and so deadly that no aggressor could resort to war against us and expect to survive.

Headquarters United States Air Force

The USAF Ballistic Missile Program

MAJOR GENERAL BERNARD A. SCHRIEVER

THE USAF ballistic missile program is the largest military development program ever undertaken by this nation in peacetime. Compared to previous programs, it involves many simultaneous technical advances in the state of the missile art. Among these are development of equipment to produce high engine thrusts, great accuracy of guidance, and equipment to resist high speeds and temperatures. It also requires greater expansion of production and test facilities than has been true of any other Air Force program. It is a single, integrated program, based upon years of Air Force missile and aircraft experience. From it operational weapon systems will emerge for the intercontinental mission and the intermediate-range mission. The Air Force with its firm belief in utilizing all elements of science and industry has assembled the strongest scientific-industrial-military development team that it could to perform the complex and vital development-operational task for these missiles.

Program origins

The Air Force has been actively interested in ballistic missiles since the closing days of World War II, beginning with our knowledge of the German V-2 program. The V-2, remarkable development that it was in view of the time allotted for development and operations, had notable shortcomings. Its payload was small and its accuracy questionable. Economically, as a military weapon, it was costly. Its range was far less than that of aircraft, which could deliver more payload with greater accuracy. It was only resorted to when the Allied air forces drove the Germans from the skies.

These facts were well known to us. Consequently Air Force ballistic missile development work following World War II concentrated on first extending the state of the missile art, particularly in propulsion and guidance.

In 1946 the Air Force began an orderly and systematic missile development program. Contracts were negotiated with North American Aviation for rocket propulsion and long-range missile (Navaho) development, and with Consolidated-Vultee Aircraft (now the Convair Division of General Dynamics Corporation) for study and investigation of missile guidance and control, rocket engine swiveling, and lightweight missile structures.

Our most advanced rocket power plant today is a direct result of this North American contract. Similarly our current ballistic missile program profited heavily from Consolidated-Vultee design and testing under Project MX-774.

The Air Force ballistic missile program benefited during the postwar years from other Air Force long-range guided missile programs such as Matador, Snark, and Navaho, and from air defense missile developments. All contributed to the solution of ballistic missile propulsion, guidance and control, and structural problems. Also aircraft and engine programs contributed advances in turbopumps, heat-resistant materials, combustion theory, autopilots, radio-inertial and all-inertial guidance, and so forth. Such progress was cumulative and did much to solve outstanding technical problems of long-range missiles.

The Air Force ballistic missile development program was kept at a relatively low level until 1950, because more conventional guided missiles appeared to offer the best and easiest solution to the range/payload/accuracy problem which faced long-range strategic missile designers. Economic factors related to the

Major General Bernard A. Schriever, Texas A&M: M.S. Stanford University, is Commander, Ballistic Missile Division, Hq Air Research and Development Command. Receiving a reserve commission in the Field Artillery upon graduation from college, he completed flying training in 1933. In 1937 he reverted to inactive status and became a pilot for Northwest Airlines. Re-entering the Air Corps with a regular commission in 1938, he became a test pilot at Wright Field in 1939. Here he also attended the Air Corps Engineering School. In 1942 he went to the Southwest Pacific with the 19th Bomb Group, where he flew 63 combat missions. In 1946 he became Chief, Scientific Liaison Section, Deputy Chief of Staff, Materiel. After graduating from the National War College in 1949 he served as Assistant for Evaluation, Office of the Deputy Chief of Staff, Development. In May 1954 he became Assistant to the Commander, ARDC, and in August of that year he entered on his present assignment. As Commander of BMD, with his headquarters in Inglewood, California, General Schriever has immediate control and supervision over all aspects of the Air Force ballistic missile program.

cost of development also played a part in this situation. In particular, two inhibiting factors were the lack of an attractive payload in terms of weight versus yield, and concern over how to protect this payload on re-entry. The re-entry problem was considered to be a particularly knotty one.

By 1950 Air Force development agencies felt that enough progress had been made in these areas to warrant study and limited design of an intercontinental ballistic missile. A contract was awarded to Convair* in early 1951 for the development of an ICBM. This was the original Atlas program, on which conservative development policies were followed because of the technical problems still to be solved. By 1953 impending solution of most of these problems allowed design and initial construction of Atlas vehicles.

The "thermonuclear breakthrough"

This was the status of the program when several new factors altered the development picture. The first was the "thermonuclear breakthrough" of 1952-53, when Atomic Energy Commission advances in nuclear weapon technology pointed the way to the design and production of small, high-yield warheads.

To this factor, tremendous in its implications as it was, must be added a second. In 1953 the Department of Defense conducted a vigorous examination of all long-range missile programs. In its report the Department of Defense guided missiles study group of the Armed Forces Policy Council recommended that strategic missile programs could best be evaluated by a special group of the nation's leading scientists. To perform this evaluation, Mr. Trevor Gardner, then Air Force Special Assistant for Research and Development, established the Air Force Strategic Missiles Evaluation Committee, also known as the "Teapot" Committee. It was composed of outstanding scientists and engineers and chaired by the late Professor John von Neumann,** then of the Princeton Institute for Advanced Study and later an AEC Commissioner.

Thoroughly aware of the implications of the thermonuclear breakthrough, and supported by independent studies of organizations such as the RAND Corporation, Mr. Gardner and his group made positive recommendations that a redirected, expanded, and accelerated Atlas program be established. In its report the Com-

*Convair had carried on studies of its own in ICBM areas after completion of its original ballistic missile contract in 1948.

**Other members of the Committee were Professor Clark B. Millikan, California Institute of Technology; Professor Charles C. Lauritsen, California Institute of Technology; Dr. Louis G. Dunn, California Institute of Technology; Dr. Hendrik W. Bode, Bell Telephone Laboratories; Dr. Allen E. Puckett, Hughes Aircraft Company; Dr. George B. Kistiakowsky, Harvard University; Professor J. B. Wiesner, Massachusetts Institute of Technology; Mr. Lawrence A. Hyland, Bendix Aviation Corporation; Dr. Simon Ramo, Ramo-Wooldridge Corporation; and Dr. Dean Wooldridge, Ramo-Wooldridge Corporation.

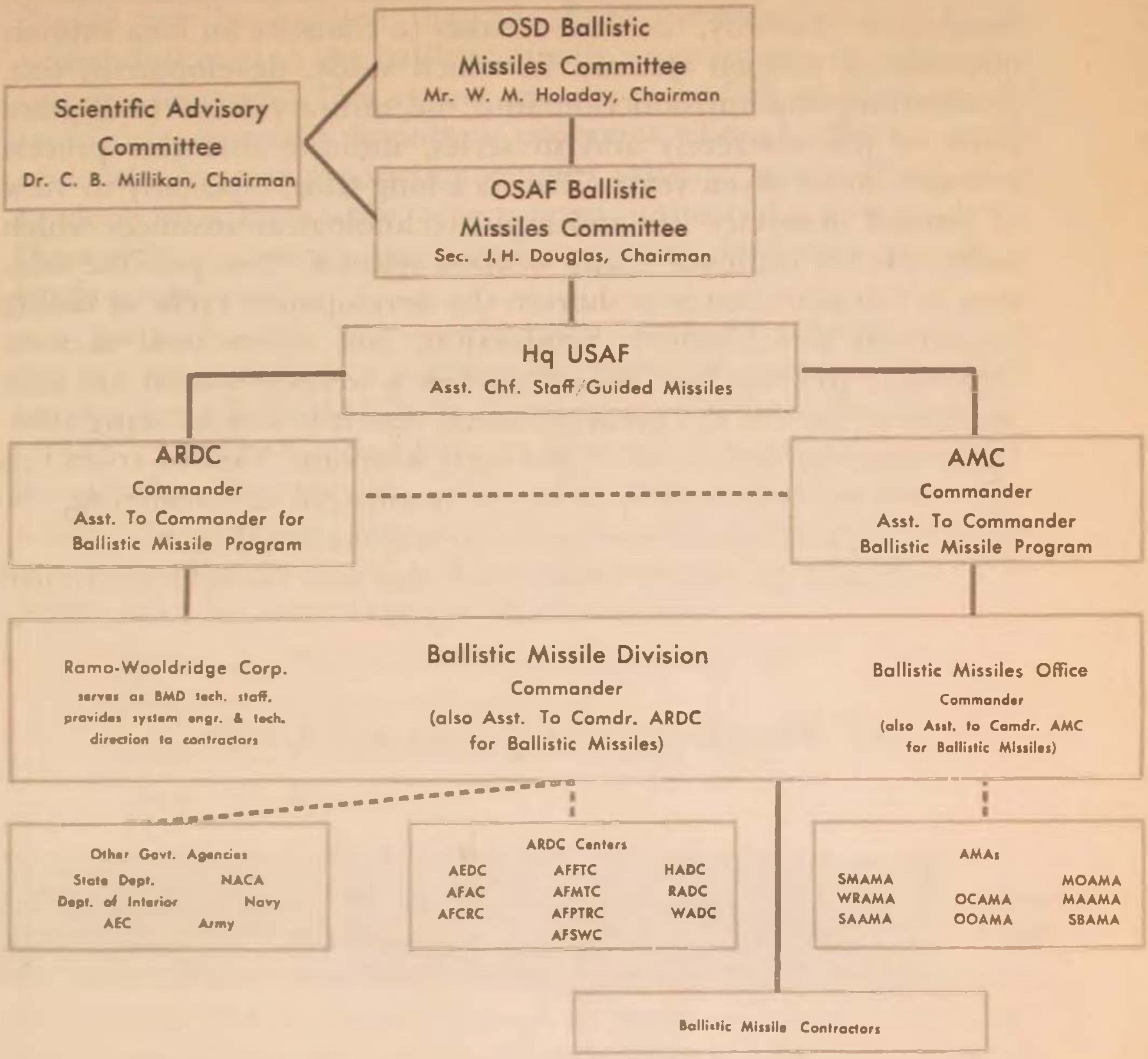
mittee concluded that if the program was given increased priority and funding, and if direction of the program was placed under the control of a strong development-management organization, an operational ICBM could be achieved years sooner than might otherwise be possible.

The Air Force approved the "Teapot" Committee's recommendations in May 1954. Directives were issued assigning the program the highest priority in the Air Force. The Air Research and Development Command was directed to establish a field organization with a general officer in command to exercise complete authority and control over all aspects of the program. Directives were issued that the program was to be reoriented and accelerated to the maximum extent that technology would permit.

In August 1954 the Western Development Division (now the Air Force Ballistic Missile Division of Headquarters ARDC) was established in Inglewood, California, to perform these tasks. At the same time, to perform procurement and contracting functions for the new program, the Air Materiel Command established the Special Aircraft Project Office (now the Ballistic Missiles Office, Directorate of Procurement and Production, Headquarters AMC), at the Inglewood location. This organization, under Brigadier General Ben I. Funk, performs the normal range of AMC functions on an expedited basis.

In early studies of what type of organization should be set up to manage and direct the program, all advisers were insistent that centralized management control of the project was necessary. The task of technical direction and systems engineering was considered more complex than that encountered on the original atom bomb project. After study, the decision was made that the Air Force would retain over-all system responsibility and contract for a technical and scientific staff. Obviously a strong team of scientists and engineers was required to perform these functions. After thorough consideration of this need, the Ramo-Wooldridge Corporation was selected to provide the important systems engineering and technical direction of the associate contractors who made up the development team. They provide the scientists and engineers needed to perform the complex technical and scientific analysis and systems engineering. Together with their counterparts of the Air Force Ballistic Missile Division, the R-W technical and scientific personnel were integrated into a development-management team, with all the elements working on a side-by-side, counterpart basis. This organizational integration permitted close working relationships and saved time in getting on with the job.

Management Structure
AF Ballistic Missile Program

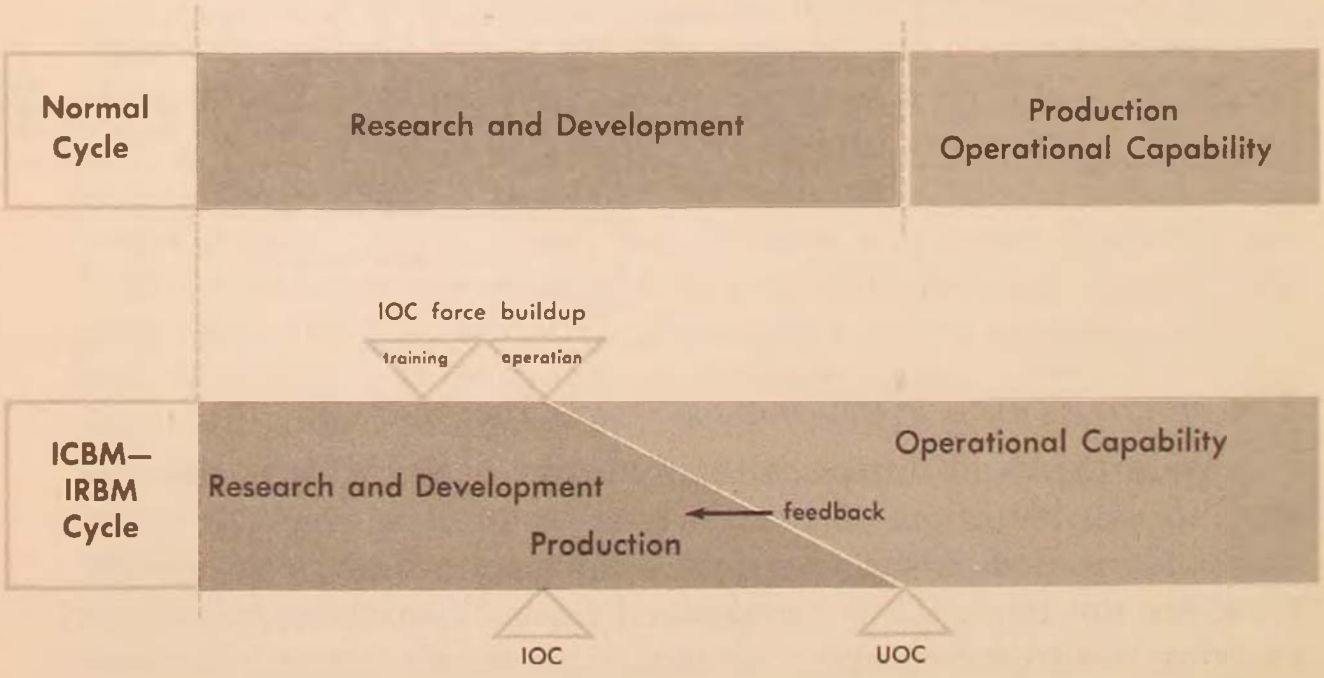


The program development-management concept

With this brief historical background in mind, it is time to turn to consideration of the development-management concept and policies used in the program. Contrary to some impressions, these are not new. They are derived from experiences gained in carrying out other complex research and development programs and from our weapon system concept. As indicated, there are parallels in the Manhattan Engineering District project.

Development concepts and policies used in the past have changed considerably from one weapon system to the next as systems have become more complex and costly. For the past few years we have tended to rely more and more on the "prime contractor" approach to weapon system development in order to speed system development and integration. Studies of the classic development cycle (broadly, the time it takes to translate an idea into an operational weapon system), in which study, development, test, production, and introduction into the military force take place more or less discretely and in series, indicate that this process averages about seven years. This is a long time, especially in view of limited in-service life and rapid technological advances which today quickly outmode many weapon systems. One possible solution to this situation is to shorten the development cycle by taking concurrent development, production, and operational actions. Obviously this can be done only when a weapon system has such promise of success and great potential that it is worth taking risks. Long-range ballistic missiles are such weapons. Viewed from this light, the ballistic missile program is engaged in shortening the normal weapon system development-to-operational cycle.

It should be clearly understood that no criticism is implied



AF Development-Operational Cycle

Comparison of the normal sequence of research and development and operational capability with the sequence of the accelerated ballistic missile program. In an aircraft program the operational capability is not achieved until research and development have been virtually completed. In the ballistic missile program these events had to be considerably overlapped, primarily to save time. Also the characteristics of the weapon required that data from experience with the initial operational capability (IOC) be fed back into the development cycle as soon as possible.

of our normal development policies. They have been carefully evolved and appear to suit normal circumstances. Likewise it should not be implied that the development-management approach followed in the ballistic missile program can be applied to just any program. This system appears to be best applied only to large-scale, especially important programs where it offers a means of developing and producing complex systems, where things must be done on a large scale, where many industrial concerns, many Government agencies, new and expensive facilities, and large funds are involved.

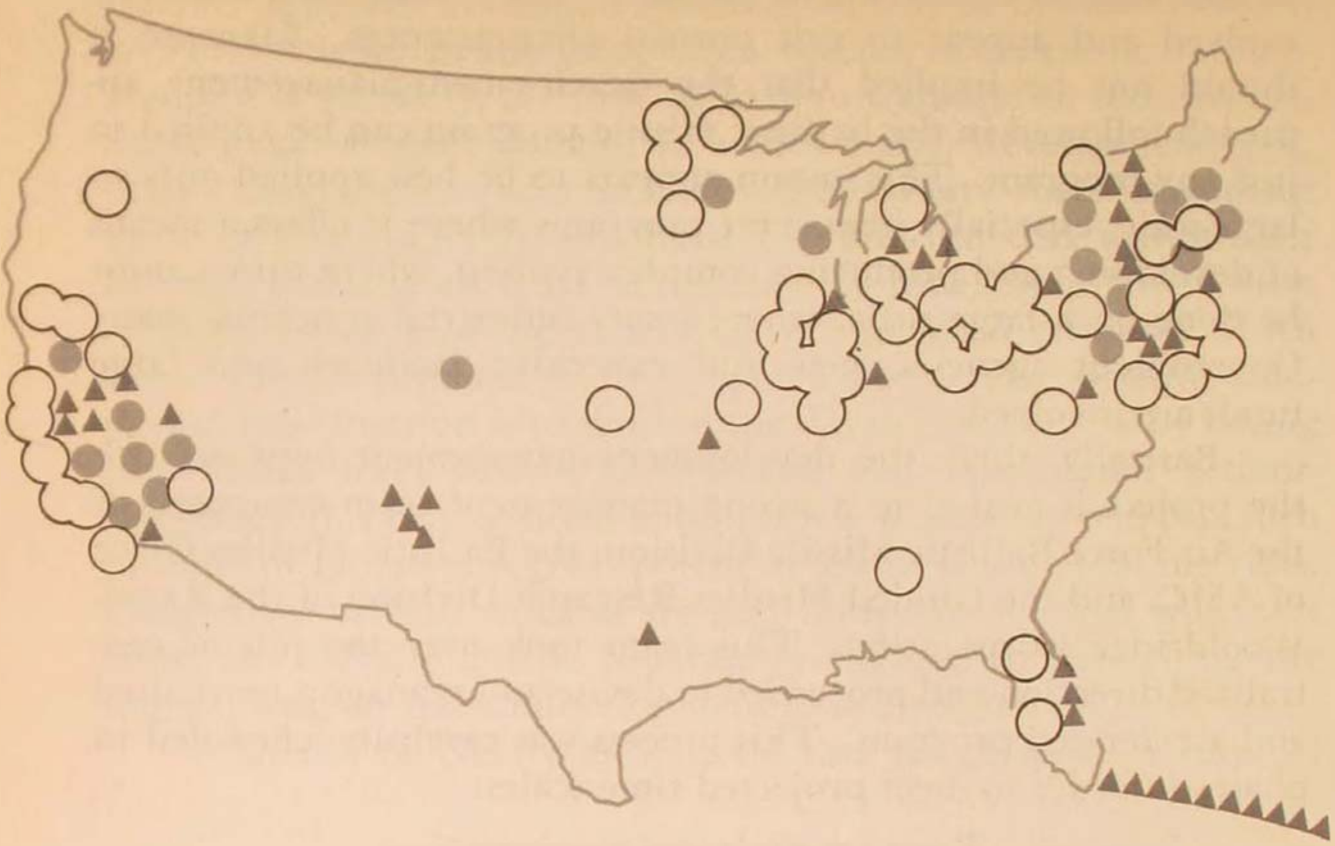
Basically, then, the development-management approach for the project is geared to a strong management team composed of the Air Force Ballistic Missile Division, the Ballistic Missiles Office of AMC, and the Guided Missiles Research Division of the Ramo-Wooldridge Corporation. This team took over the job of centralized direction and proceeded to devise and manage a reoriented and accelerated program. This process was carefully scheduled in phases in order to meet projected time scales:

Phase I	Program study and reorientation
Phase II	Contractor selection
Phase III	Hardware fabrication and test
Phase IV	Missile test
Phase V	Operational capability

The study phase embraced careful program analysis and planning. Scientific and engineering analyses were made of all aspects of the program. From the study, analyses, and planning, certain conclusions and recommendations emerged. The development-management structure for the program was clarified. Steps were taken to reorient the program by scaling down missile size and gross weight, thus simplifying many technical and development problems. A positive conclusion was reached that in order to accelerate the program, to provide competition, and to ensure success, a multiple approach should be used in the development of subsystems. Selective industrial competitions would be used to pick the associate contractors. A third result of the study analysis and planning was an integrated development-test-facility plan.

The selection of contractors marked an important phase of the ballistic missile program. Contractors were carefully chosen, through a highly selective, competitive method that identified the contractors with the highest capability. In this process, the Division management team prepared a statement of the job require-

Ballistic Missile Program



The Air Force ballistic missile program is truly nationwide. The dark circles denote the major contractors, the white circles the major subcontractors, and the triangles the directly participating Air Force installations. The vendors (not shown) who supply the subcontractors are located in every state of the Union.

ments. After study of these requirements, an AMC/ARDC team prepared a recommended list of the best qualified contractors. Then these contractors were given a preproposal briefing, after which they prepared their technical proposals. Concurrently with the contractor preparation of technical proposals, a joint evaluation board with members from ARDC, AMC, and independent agencies was established. This evaluation board prepared suitably weighted proposal evaluation criteria. All contractor proposals were then reviewed and evaluated by board members and specialists. Following this review and evaluation, the board recommended a winner. This recommendation was forwarded to ARDC, AMC, and USAF for approval. By means of this selective competition method, the basic subsystem contractors for the program were chosen.

The outstanding feature of this method was the speed with which the selection of contractors was accomplished. In most cases the entire process from the statement of job requirements through to notification of contractor selection took place within ninety days. Immediately on notification of selection, contractors were put to work through the use of letter contracts. The letter contracts were used in order that no time be lost in definitization of contracts before getting the program under way.

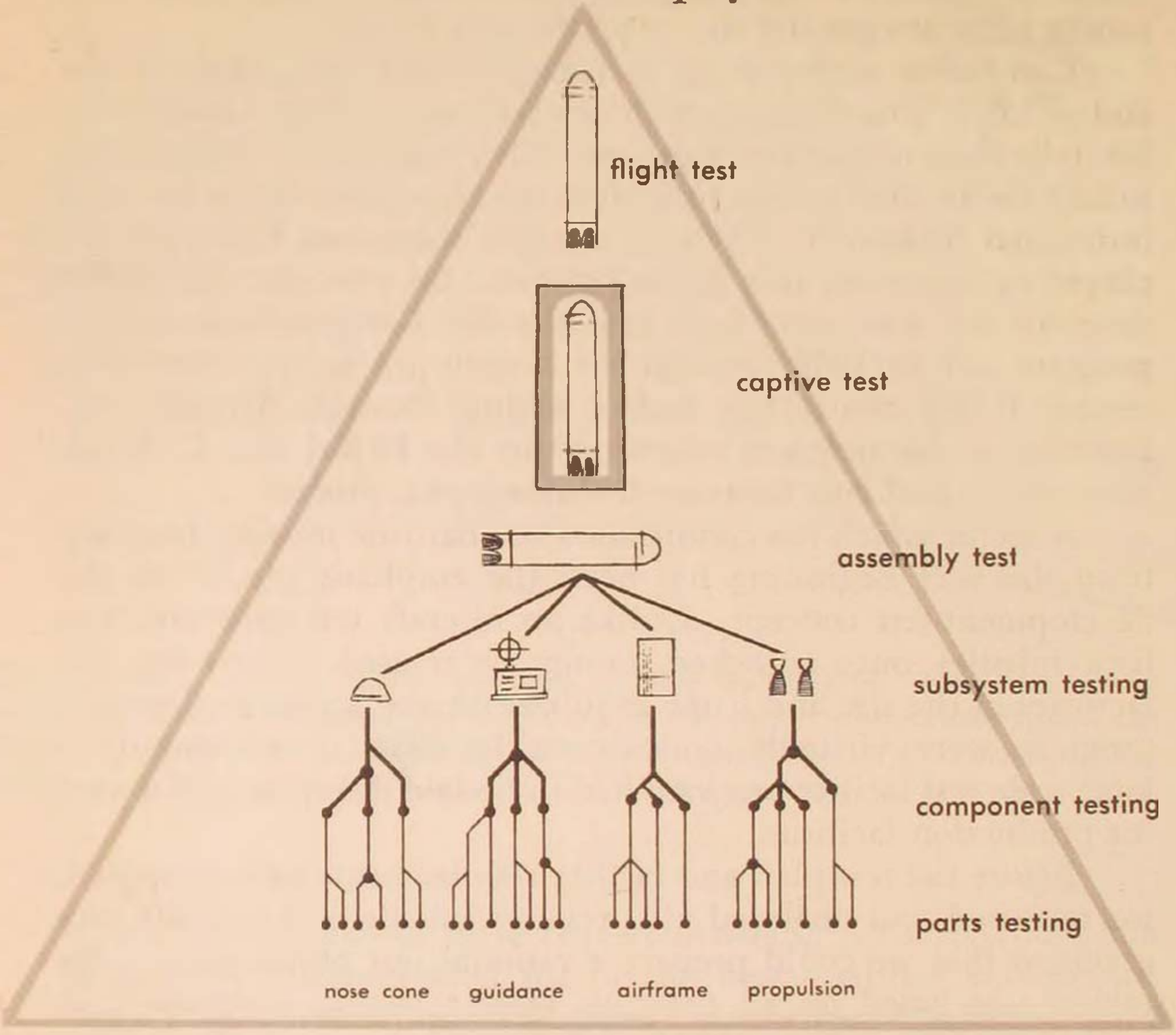
Contractor selection by this process was completed by the end of 1955. The contractors themselves were grouped into teams for individual missile development. This was possible through the utilization of dual-source subsystem development efforts for each individual subsystem. These dual-source subsystem developments played an important role in the program: for example, the IRBM development was introduced into the Air Force ballistic missile program late in 1955 through the simple process of reorienting certain ICBM contractors and of adding Douglas Aircraft Corporation as the airframe contractor for the IRBM No. 1. Much time, effort, and cost were saved through this process.

A factor which has conditioned the ballistic missiles program from the very beginning has been the emphasis placed on the development-test concept. Unlike an aircraft test program, ballistic missiles, once launched, cannot be re-used. Moreover, test facilities of the size and scope required for the accelerated missile program were virtually nonexistent in 1954. Consequently a large-scale test facility program had to be laid down, as well as one for production facilities.

Before the test plan and facility requirements were prepared, we reviewed and analyzed all previous missile and aircraft programs so that we could prepare a rational test philosophy. This review was based on all previous missile testing experience, as well as the requirements of the accelerated program. A test program was planned with the aim of reducing the number of costly "one way" missile flight tests and of getting required information as early as possible. Insofar as possible, components would be thoroughly tested on the ground prior to flight tests. The method utilized provided a step approach, beginning with component tests, then assembly tests, then captive tests of propulsion and airframe, and captive tests of complete missiles prior to flight testing. In this way reliability could be checked at the lowest possible levels and systems interaction tests could be performed as subsystems were mated. This test philosophy was adopted and is in use in the program today.

This plan provides the maximum likelihood that the more advanced and costly systems tests will not fail because of failure of components or minor assemblies and that information on over-

Test Philosophy



all systems interaction will be available before we embark on large-scale flight tests. Another important element of the test philosophy is that there are no special-purpose test vehicles.* In other words, no "dead end" testing would take place. The ballistic missiles themselves will serve as data-collecting test vehicles. Thus development-test effort is all applied to the missiles themselves. Needless to say, such a plan was only possible because of our work with missiles over the past decade.

Having worked out a logical test philosophy, the next step was to apply it. This required careful test facility planning to ensure the availability of such facilities in the numbers and at the time they were needed. At the start of the program practically no facilities suitable for missile or component testing on the scale re-

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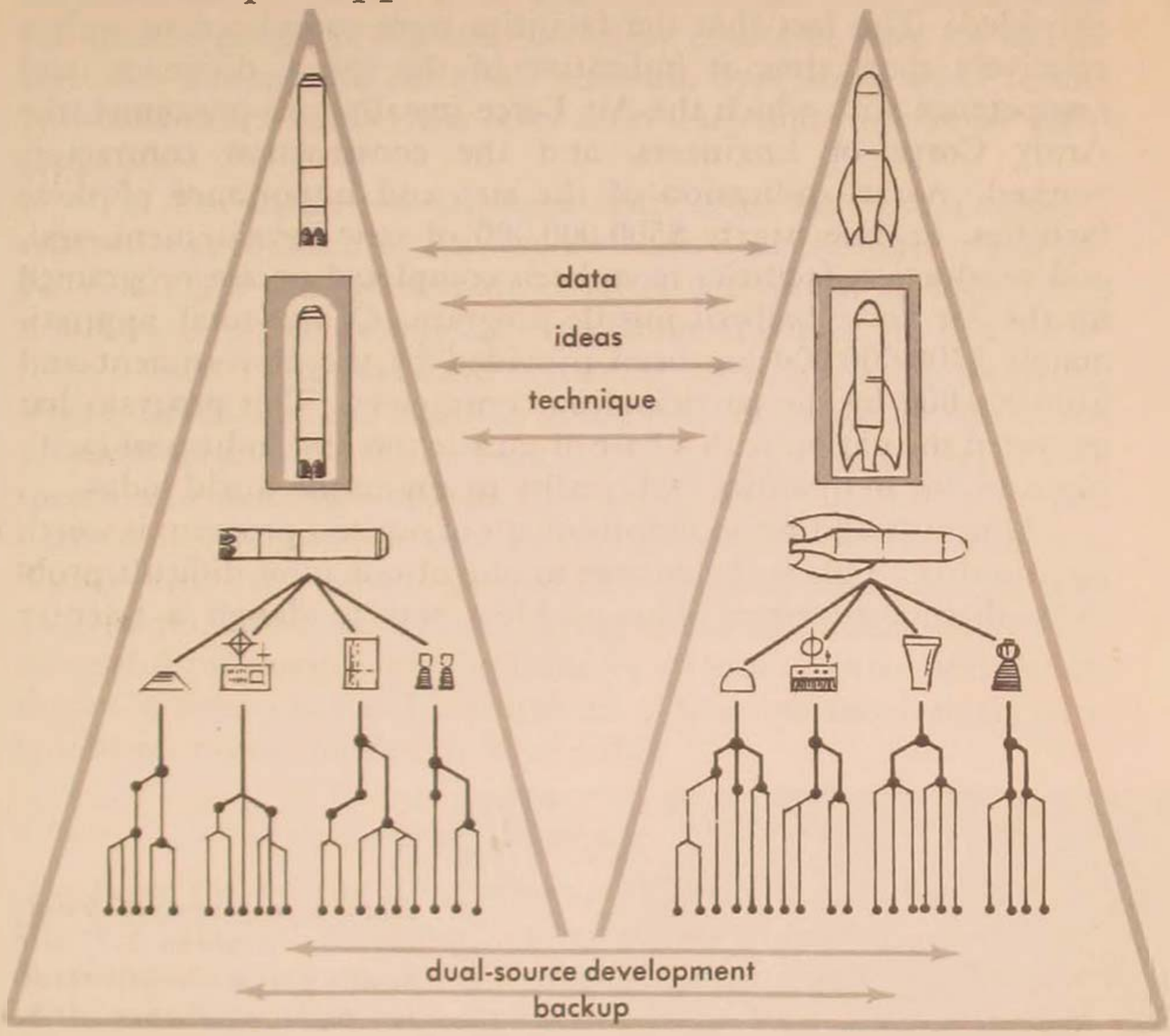
*Except for the re-entry test vehicle to gather nose cone re-entry data.

Multiple-Approach-with-Backup Philosophy



quired for the ballistic missile program existed. Many such facilities were required as quickly as possible—facilities of considerable size, complexity, and cost. For example, large rocket engines had to be developed and tested, requiring new and unique testing facilities; captive tests of complete missiles required large test stands of great strength together with complex instrumentation and blockhouses. The contractors needed industrial facilities for fabrication testing of components. The problem was doubly difficult since unique test facilities of the type desired require a long lead-time to design and build. A plan was evolved that would provide these facilities at the times needed. Unprecedented action on the part of the Air Force and the Army Corps of Engineers was required to accomplish the necessary actions and approvals under expedited conditions. To complete the facilities which had been closely matched to the R and D schedule, the construction contractors in many cases worked on multiple shifts seven days a week.

By such means the necessary test and industrial facilities were provided. The fact that the facilities were completed in such a relatively short time is indicative of the speed, diligence, and competence with which the Air Force installations personnel, the Army Corps of Engineers, and the construction contractors worked. As an indication of the size and importance of these facilities, to date nearly $500,000,000 of new development, test, and production facilities have been completed or are programed for the Air Force ballistic missile program. Of this total, approximately $400,000,000 has been provided by the Government and $100,000,000 by the participating contractors. This program has provided the nation with a base of missile-test and industrial facilities superior in quantity and quality to any in the world today.

One outstanding accomplishment of our test program is worth mentioning. This is the answer to one of our most difficult problems—that of re-entry. The problem was to design a re-entry

High as a four-story building, the Lockheed X-17 test missile points skyward ready for flight at Patrick AFB, Florida. The six-ton, three-stage rocket is saving millions of dollars. Its flights help solve problems connected with ballistic missiles that otherwise might be answered only after many firings of those much more expensive missiles themselves.

body (nose cone) that would not burn up as it re-entered the earth's atmosphere at meteoric speeds. To solve the problem, many extensions into the regions of hypersonic research were required and empirical verification of this research was needed. An intense program was laid on: study contracts were let to conduct shock-tube tests, materials research, hypersonic wind tunnel and ballistics research, nose-cone drop tests, and hypersonic flight tests.

For the latter, the Division contracted with the Lockheed Aircraft Corporation to develop a re-entry test vehicle, called the X-17. Its job was to simulate re-entry conditions at high Mach numbers in order to validate hypersonic theories. It is a three-stage missile. The first stage drives the missile to a high altitude where it falls over and starts its descent; then the second and third powered stages drive the nose cone to higher and higher hypersonic speeds as it descends through the atmosphere. Telemetered data derived from the flight provide the needed design information. This re-entry test vehicle proved to be a quick and accurate way to gain reliable data without flying a full-scale missile. It was successful in proving out the theories of heat transfer and design shapes of nose cones and it reassured us that our theoretical calculations on nose-cone design were valid.

The operational development program

After the missile development program was under way, the Division received additional directives to undertake operational development programs for the missiles. These directives rounded out the ballistic missile program by making the Division responsible for all actions necessary to achieve the initial operational capability (IOC) with these weapon systems. With this assignment, the Air Force ballistic missile program became an integral one. A single agency was now responsible for the entire weapon system development-operational program. Moreover, the two programs are concurrent rather than in series. While missile development and test are under way, so also are all the actions ensuring that when development is completed an operational force will be trained to handle the missiles and that the force will be ready for the Strategic Air Command. This is an unprecedented assignment for the Air Research and Development Command. It has absorbed a great deal of effort, particularly since we are dealing with new weapon systems with which we have little experience. Our operational experience must be gathered out of the development and test program. Again, through this combination of missions the development-operational cycle for the systems should be shortened, since the agency which is accumulating this experience will be able to put it to use quickly.

Integration of this responsibility was aided by the fact that from the beginning BMD had a staff to study system operational planning. With the addition of the responsibility for initial operational capability, the operational planning staff has expanded considerably in both size and mission. From it have come not only the operations, personnel, logistics, and installations concepts which furnish the guidelines for the organization and employment of the IOC force, but the actual detailed plans that are at the present time being put into effect.

Turning these concepts into practical, usable plans and then implementing them have required detailed work and coordination. Organizational structure and composition had to be planned. Facility requirements for operations and training had to be identified and action had to be taken quickly to obtain these long-lead-time items. A procedure for locating and assigning personnel with the abilities and experience necessary to man the units had to be worked out. Programs for training personnel had to be determined to the extent of writing course lesson plans, designing training aids and equipment, and determining training evaluation procedures. This latter process has already produced several changes in the missile and its test and handling equipment to adapt it more closely to the abilities of the airman who will do the job.

Logistics plans are being worked out in detail in coordination with the logistics and missile maintenance concepts. AMC is instituting an entirely new type of logistic system, based upon electronic data processing, for use with the ballistic missile forces. An explanation of this system appears elsewhere in this issue.

BMD could not develop all these details itself and expect them to be realistic. Active participation of other Air Force commands was mandatory. Therefore liaison offices were established at BMD by the Strategic Air Command, the Air Training Command, ARDC's Air Force Personnel and Training Research Center, and Air University. In addition coordination was accomplished with Headquarters USAF, the U.S. Army Corps of Engineers, Air Force Weapon System Phasing Groups, and others. The ballistic missile program is truly Air Force-wide.

Actions in the IOC area have taken place rapidly. Recently the field unit to command the initial operational capability force, the 1st Ballistic Missile Division, was activated. Under it will come the wings and squadrons, some of which are now being formed, as well as ballistic missile bases within the United States. Cooke Air Force Base, California, is the first of these bases, where training will be performed. Facilities are under construction and the base is being manned.

Program control

The ballistic missile program is nationwide in all aspects. The work of seventeen major system contractors located in every part of the United States has to be coordinated and kept in phase. The magnitude of the program is such that if a slippage occurred in any area, the whole program could be delayed. To keep abreast of the entire program, the efforts of all the members of the management-development team are closely monitored in a central place in BMD—the Program Control Room. The joint BMD—BMO—R-W Program Control Room is the nerve center for the project. As a management tool it provides "management visibility" by displaying information on the status of every aspect of the project in graphic form.

This management information is provided through frequent visits with contractors, use of the extensive communications network between BMD and the contractors and field offices, written reports, and periodic meetings of BMD, BMO, and R-W personnel. The information is not displayed until it has been double-checked and coordinated by the offices concerned with that phase of the program. Any problems are spotted early and acted upon quickly. Those that may produce schedule slippages are identified with a "red flag" and carry that identification until they are solved. The "red flag" problems are given immediate treatment and their status is considered each time a review is made.

The program pulse is felt continuously. It is presented formally once a month to key members of the management team. In these presentations, the rule of "management by exception" is followed. There are hundreds of items that could be considered. It would take several days to treat them all. Instead, only progress and problem areas are noted and discussed.

Today we are in the fourth phase of the program, the flight test phase. In all respects this is the most critical phase. We have entered it with confidence that the missiles will indicate the results of the carefully structured test program. Realistically, we must recognize that this is the phase where troubles appear. We think that our careful planning will enable us to meet these troubles. We have laid down careful procedures for their correction. Some setbacks are to be expected, since after all we are in the "Model T" age of missiles. Another way of putting it—we stand today with ballistic missiles where aircraft were forty years ago. However, we have a far superior scientific knowledge of these complex birds than the early aviators had of their aircraft. The application of modern technology to our missile programs will ensure success.

Through rigorous attention to program needs, we have remained on schedule. The bugaboo of most missile programs, slippage, has been pretty well contained. All major milestones for the Atlas, Titan, and Thor development programs have so far been passed essentially on schedule. In addition the IOC force is being built and trained. We are confident that the program will continue to meet its schedule and that the United States will soon have its long-range ballistic missile operational capability.

The future

The Air Force ballistic missile program does put us on the threshold of space travel. The long-range ballistic missile is in fact a space vehicle. The airframe, propulsion, and guidance subsystems developments and the data which will become available as ballistic missile test flights are made will make possible a whole series of follow-on projects.

Take for example the propulsive unit. The same propulsive unit that boosts a heavy nose cone with its warhead to 25,000 ft/sec could boost a somewhat lighter body to the escape velocity of 35,000 ft/sec or to an orbital path around the earth. The same guidance system that enables the warhead of a ballistic missile to reach its target within a permissible accuracy would also be sufficiently accurate to hit a target much smaller than the size of the moon, even at that increased range. These same propulsive and guidance components could also be used for surface-to-surface transport vehicles of various sorts experimentally to carry mail or strategic military material to critical sites. Structural advances of the ICBM have brought us to new heights in the ratio of total weight to structural weight. Perhaps 90 per cent of the *unmanned* follow-on projects that one could visualize for the future can be undertaken with propulsive, guidance, and structural techniques *presently under development* in the Air Force ballistic missile program.

There is one final question—what will we have achieved when we reach our goal—when ICBMs and IRBMs have become reliable, operational weapon systems produced in quantity? Paradoxically, the best we can hope for is that we will never have to use these weapons; that our ballistic missile capability will be so highly respected by all potential aggressors as to indefinitely deter them from attacking us.

This should not imply that the ICBM and IRBM are "ultimate weapons" as they are frequently called, nor that the ballistic missile will replace the manned intercontinental bomber. But it will undoubtedly become one of the most potent and convincing arms in our arsenal of strategic weapon systems.

It is hard to believe that any one single weapon, no matter how powerful, can by itself enforce peace in this uneasy world. But we are confident that weapons like the ICBM and IRBM will help the Air Force to enable the free world to maintain deterrent forces which no aggressor in his right mind dare challenge.

Air Force Ballistic Missile Division, Hq ARDC

Air Force Missile Experience

Colonel Edward N. Hall

IT IS probable that more misinformation has been generated on the subjects of guided missiles, long-range missiles, ballistic missiles, intermediate-range missiles, and intercontinental missiles than on almost any other conceivable subject. What are these devices, how do they differ from each other, why have they come into being, what has been their past history? The answers available to the general public have been fragmentary and frequently misleading, primarily because of their inevitable security restrictions. This has been a highly justifiable policy in the past, but at this time the American public and its high-ranking civil administrators are being confronted with crucial decisions concerning these weapons, their control, and their use and are possibly being forced to conclusions based upon a paltry smattering of factual background. This article is being written in an effort to dispel some of the mists of obfuscation that pervade this field.

Missiles may be divided into two categories: ballistic and airfoil controlled. Both categories have been somewhat arbitrarily further divided into guided and unguided species. The word arbitrary is employed here because it is hard to conceive of any justification today for a truly unguided missile, one deliberately designed to take off and capriciously land, "I know not where." Guided missiles follow trajectories that may be altered by signals from some guidance device well after the moment of launch; unguided missiles are those in which all guidance influence ceases within an extremely short time after launch.

Both ballistic and airfoil-controlled vehicles have been employed by mankind for a very long time. Ballistic weapons as rocks hand cast by primitive man preceded their airfoil-controlled cousins, arrows launched from bows and controlled by tail feathers, by a significant period of time. A greater amount of effort through the years has gone into the ballistic-controlled vehicles than into the airfoil-controlled ones (e.g., rocks thrown by hand or catapult and gun-propelled slugs and shells). Only recently has serious consideration been given to the development of relatively long-range airfoil-controlled weapons. An essential ingredient in the development of relatively long-range ballistic devices was the creation of a basic science of ballistics. Similarly a sizable mass of data in the field of aerodynamics was a necessary precursor to the development of long-range airfoil-controlled vehicles.

Ballistic science is much the older of the two, stemming back pretty directly to Keppler's Laws of Motion, which have been constantly and repeatedly confirmed by such phenomena of celestial mechanics as the motions of the moon, planets, and comets. Aerodynamics could not support accelerated development of long-range devices until late in the 19th century. Exercising these two general sciences man has developed a series of missiles.

In the course of this activity, cross-pollinization in the two fields has occurred to such an extent that the course of individual developments has in many cases become obscure. For many years ballistic missiles, considered apart from their launching devices, were simple. The shell hurled from a big gun, although differing in degree of sophistication, had much in common with the rock launched from the hand of primitive man. Aerodynamic effects in both cases were small. The trajectories resulted largely from the interplay of gravity, conservation of momentum, and, in the case of extreme ranges, centrifugal force. Extremely strong, lightweight structures were not needed.

Significantly the method of propulsion employed in the gun involved the use of very heavy launching devices of a relatively declining effectiveness as muzzle velocities in excess of about 4000 feet per second were reached. Projectiles were guided by accurately aligning the gun in the direction and elevation desired. No

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guidance signals were transmitted to the projectile after exit from the gun barrel. While stability was imparted by projectile spin, even at this relatively early level of missile sophistication a certain degree of hybridization occurred; fin-stabilized gun-launched projectiles were developed, in which a certain amount of aerodynamic science was drawn upon. The serious development of long-range, aerodynamic-controlled missiles had to await the development of the airplane.

Quite early in this saga attempts were made to apply this newer science to long-range missiles. Even during World War I efforts were made to load military airplanes with bombs and direct them without pilots to specified targets. Out of aerodynamic science grew automatic control devices such as autopilots, auto navigation equipment of both radio and inertial varieties, automatic bombing systems, and the advent of reliable, efficient propulsion systems. It became evident that a proper integration of these sophistications could make practical an unmanned, long-range, aerodynamically-controlled missile. During World War II several instances of the operation of such devices took place.

Up to this point a fairly distinct demarkation existed between ballistic and aerodynamic approaches. Ballistic vehicles were dense, unsophisticated structures, most of them propelled by expanding gases generated by combustion of solid propellants in gun barrels. No provisions were made for internal control, guidance, or propulsion equipment. Aerodynamic missiles, on the other hand, sprang directly from airplane experience. In these were automatic control systems, strong, lightweight airframes, sophisticated guidance systems, and advanced propulsion units.

Modern missile beginnings

Until the War the potential performance of long-range missiles was largely misunderstood. The barrier to be overcome was not of sound, or heat, but of the mind, which is really the only type that man is ever confronted with anyway. A traditional approach by the aerodynamic people to the problem of range versus speed had convinced them that an inverse relationship existed between these two parameters and that, consequently, truly long-range, airfoil-controlled vehicles would have to travel at relatively slow speeds. The ballistic advocates, also limited by mental blocks, thought in terms of thousands of yards rather than thousands of miles. Although the latter group had had rockets at its disposal for hundreds of years, it had employed them in a manner highly analogous to the gun. Thus aerodynamicists talked about relatively slow devices capable of ranges up to 10,000 miles or so, employing reciprocating or compound engines with conventional propellers and high-aspect-ratio airfoils. Military ballistic people were thinking in terms of rocket- and gun-propelled projectiles with unsophisticated structures and very limited guidance and control systems capable of ranges of hundreds of thousands of yards.

Between these two placid pools of specialized interest there were several small, disturbing anomalies. Dr. Robert Goddard in the United States and the Weapon Development Group of the German Army were pursuing programs of high-performance rocket development. Dr. Goddard was completely unsuccessful in his efforts to interest the United States armed forces in his work, and the German effort, until a time too late to be of any influence in deciding the outcome of World War II, was similarly ignored. The efforts of both of these groups were aimed at the development of a desirable hybrid in which the sophistication of the aerodynamic approach would be effectively applied to a ballistic vehicle. These efforts incorporated the subtle structural talents of the airframe industry and the highly sophisticated guidance and control mechanisms developed for imparting stability to, navigating, and controlling bomb release from modern airplanes—all this married to a high-performance rocket-propulsion system to produce an entirely new species of vehicle.

Except for the propulsion system all elements stemmed directly from the airplane development art. And the rocket propulsion systems employed on these devices, in the United States at any rate, have also stemmed from the propulsion development programs of the United States Air Force. The problems of heat transfer, turbine operation, combustion, and pumping are intrinsically the same as those that plagued the developers of reciprocating engines, turbojet engines, ramjet engines, and other aeronautical power plants. These rocket engines have been developed by the same U.S. Air Force and affiliated organizations that developed the preceding types of power plants mentioned, using the same basic philosophies. The result is that large liquid-rocket power plants are available today as reasonably reliable, producible items to provide the extreme propulsion requirements of the long-range guided ballistic missiles. The rapid advance of the Air Force ballistic missile program has been predicated upon this rich background of familiarity with, and development of, all the key elements required for success in its field.

The rate of development progress

The rate of progress achieved in ballistic missile development has been limited by two categories of factors: the operational and the technical. That ballistic missile development can only be carried out by the armed services is an accepted fact. Armed services, however, must always seek to justify their development activities in terms of the economic validity of the gains to be achieved. No new weapon, however spectacular, can really be justified unless it promises to perform military tasks at a lower gross cost than will any weapon system preceding it. A rocket-propelled, guided ballistic missile of short range would be questionable from an economic standpoint if compared to the operating cost of the manned bomber. Even a relatively long-range missile of this variety would be questionable until the detonation magnitude of its warhead and the accuracy with which it could be positioned made it less costly per unit of effectiveness than the piloted bomber. Questions would still arise about the methods of reconnaissance and bomb-damage assessment that could be employed as a necessary adjunct to such a weapon system.

A limiting factor in the missile development drive until very recently was the questionable effectiveness of available warheads and guidance systems. Obviously the use of a TNT warhead on a ballistic missile with a range of more than a thousand miles would be extremely costly. With missiles dispersing several miles in the target areas, as they must with today's guidance systems, several thousand would be needed to destroy a specific target of limited size. As the accuracy of the guidance system improves and as the detonation effectiveness of the warhead increases, the numbers of missiles required to perform any specific military task drop—as do comparative costs.

The atomic bomb greatly improved the destructive potential of this type of missile, but even it, when coupled with available guidance accuracies, did not guarantee economies beyond the use of manned bombers. With the atomic warhead such economies could only be achieved by the development of extremely accurate guidance systems. It was the thermonuclear bomb that altered this picture radically. This weapon promised economical dividends in the destruction of military targets by means of long-range ballistic missiles. So it is that from the operational point of view the drive to develop these missiles was compromised by lack of clear-cut evidence that their employment was militarily justified until improvements in warhead and guidance techniques occurred.

A much more basic limitation to the development of long-range ballistic missiles existed up to 1950: adequate propulsion systems. The long-range ballistic missile consists of guidance, control, structure, warhead, and propulsion. Each of these must be adequate if there is to be a worthwhile military missile. The propulsion system is in a somewhat different category from the others. This is the one component without which the missile could not fly at all. In fact the long-range ballistic missiles are so intimately tied up with rocket propulsion systems that frequently the terms missile and rocket are used interchangeably.

A fallacious concept, formerly widely cherished by air power "experts," that the relationship between range and speed was an inverse one has already been mentioned. There was evidence upon which to base this false conclusion in the form of ranges and speeds of the aircraft developed prior to the 1950's. Some of this evidence centered on the assumption that lift for these long-range vehicles would inevitably be supplied aerodynamically.

As soon as one accepts the fact that centrifugal force is quite as reliable as aerodynamic lift—attested to by the degree of assurance man has developed that the moon will not fall down—the picture becomes greatly clarified. While the attainment of Mach 1 speeds was always accompanied by very limited ranges in that era, this limitation was largely a product of the characteristics of air-breathing engines, available conventional fuels, and aerodynamic drag. It was always evident that if one could get out of the atmosphere and reach orbiting velocities, terrestrial range would become unlimited. The problem lay in the development of a power plant and structural system capable of attaining orbiting speeds outside the earth's atmosphere. What structures and what power plants can be used?

A survey of existing power-plant and structural concepts reveals that the choice is a narrow one. The reciprocating engine and propeller combination is only effective at relatively low altitudes and speeds. Propeller efficiencies drop very rapidly at great altitudes unless the blades are extremely large and heavy. The ratio of thrust to drag attainable with this type of propulsion system is very unfavorable for high-speed flight. Turbojet and ramjet engines suffer the same general deficiencies, although the turbojet engine is greatly superior to its reciprocating brother in thrust-frontal area and thrust-weight ratios. But the value of the compressor element of the turbojet approaches zero as forward speeds rise above Mach 3. This is so because the inevitable rise in stagnation temperature brought about by the forward speed of the aircraft, when coupled with the further temperature rise through the turbojet compressor, heats the incoming air to the no-thrust point in this speed range. This limitation is imposed by structural problems stemming from limitations in the strengths of available materials at high temperatures. Advanced cooling techniques and further development of high-strength, high-temperature-resistant materials may push this limit up but not to any useful degree when compared with the speed requirements necessary for orbiting the earth. The case for the ramjet, similar to that of the turbojet, is slightly more favorable. Here we do not have to worry about structural loads on centrifugally stressed turbine and compressor elements. The high stagnation temperature of the incoming atmosphere remains as a severe problem. The twin necessities of furnishing a reasonable static pressure to support combustion and a very high forward speed to sustain flight cause stagnation temperatures in the combustion chambers and discharge nozzles to become limiting at about Mach 5. This is still very far from earth-orbiting velocity.

Only in the non-air-breathing rocket engine does none of these intrinsic limitations bar the way to earth-orbiting velocity. Since the rocket uses no air, high stagnation temperature of surrounding atmosphere is of no consequence to the power plant. Developing thrust more effectively in vacuum than in the atmosphere, rocket-propelled vehicles may approach and exceed orbiting velocities without the problems associated with atmospheric friction. Theoretically, therefore, the rocket power plant should be capable of attaining earth-orbiting speeds and unlimited terrestrial flight ranges at very high velocities. Development of rockets of sufficient specific impulse, structural lightness, and reliability for long-range ballistic application had to await the development of modern metallurgical techniques, of propellant chemistry, and of the thermodynamics required to determine what performance was available from the materials at hand.

Rocket engine development program

At the conclusion of World War II the Air Materiel Command of the Army Air Forces became interested in the further development of the German A-4 type rocket. As a result the rather battered components of three of these engines were shipped from Germany to North American Aviation, the contractor designated by the project office at Air Materiel Command. At this time no large-scale liquid-rocket development facilities existed in the United States. Two large test stands and associated equipment for the development testing of these engines were to be erected at Edwards Air Force Base. Shortly after this, agreements were reached between the Air Materiel Command and the Curtiss-Wright Corporation for the use of Dr. Robert Goddard's patents in the Army Air Forces' rocket development work. Additional work to establish the operational effectiveness of nitric acid as a rocket oxidant was contracted at Aerojet, Bell, and Kellogg.

It was the conviction at this time of the Army Air Forces, which became the United States Air Force in 1947, that the rocket development program should be handled in a manner like that of other engine development programs. Traditionally industry had always been regarded as a partner in these ventures. It was felt that a continuation of this policy would make available the most competent organizations and best brains for rapid exploitation of rocket art. The former Air Corps' engine development programs, dating back to the days of the Hispano-Suiza and Liberty engines of World War I, had attempted to harness available sources of industry to development and production programs. The Air Force feels today that this was a wise decision. The fact that the only successful large liquid-rocket engine programs in the United States have been Air Force programs is in no small measure due to this manner of operation. This policy has greatly eased transition from applied research to development to production and has minimized scientific stagnation.

Since the inception of these rocket development programs the Air Force has spent large sums of money on the development of rocket engines. This expenditure was justified by the belief that only through the development of such power plants could high-speed, long-range guided ballistic and aerodynamic missiles be created. The men entrusted with the development of this device for the U.S. Air Force were experienced in developing successful reciprocating and turbojet engines. They had no delusions about the relationship between demonstration of basic principles and completed development of rocket engines adequate in reliability and simplicity for inclusion in the military inventory. The Air Force understood that preliminary design and demonstration of feasibility of basic principles amounted to less than five per cent of the costs of an engine-development program. Each rocket-development project, in the Air Force view, would be faced with a long period of component tests, engine shakedown, and redesign. This realistic attitude has meant that the activities have seemed unspectacular, and achievements have seemed to be attained at a relatively slow pace.

Air Force Experience in Missile Development

Project	Inception Date	Significant Dividends to the Ballistic Missile Programs
Navajo	1946	Large, lightweight thrust chambers, much design data for large liquid-oxygen-alcohol engines, large injector design techniques, much inertial guidance design data. Illustrated air-bearing gyro limitations, and provided first successful American large liquid rocket engine.
MX-774	1946	Control techniques employing swiveling engines, lightweight structures for tanks, and separation techniques.
Atlas	1951	Ultra lightweight tank structures, feasibility of very high expansion-ratio discharge nozzles, precision guidance and control, development of high specific impulse from conventional propellants, appreciation of propellant utilization problems and techniques of attacking them.
Rocket Engine Advancement Program	1951	Large hydrocarbon liquid oxygen rocket engines, advanced high suction specific pumps, very lightweight gimbaling systems, fluorine rocket technology, techniques leading to extension of stable combustion limits of rocket engines, practical methods of ignition and handling of starting transients, limitations and methods of throttling, very large turbo pumps and thrust chambers. This program has provided the basis for all the large oxygen hydrocarbon rocket engine work in the United States.
Nalar	1951	Extensive propellant performance and ignition work, short combustion chambers, rapid ignition at low temperatures, ingenious positive expulsion tanks.
Shrike	1947	First closely controlled series production of pressurized hydrocarbon nitric acid rocket.
Rascal	1947	Turbo-pump driven, two leveled-thrust engines, automatic control systems, practical acid hydrocarbon gas generators.
X-2	1947	High-ratio, continuous throttling of liquid-oxygen-alcohol engines, early employment of common propellants for thrust chamber and gas generator, tank pressurization by turbine discharge heat exchanger, direct-driven, high-speed propellant pumps, spark plug ignition.
LR-45	1949	Mechanical techniques leading to safe operation of nitric acid hydrocarbon rockets, automatic high-response-rate control systems, high-performance propellant pumps and specialized bearings and lubrication systems.
LR-63	1951	Safe, highly reliable, hydrocarbon acid, lightweight rocket system, effective use of refractory ceramics, highly compact components.
Bomarc	1951	Hot gas pressurization data, large engine application of refractory materials, design techniques for interaction of sloshing and controls, low cost practical low ignition energy propellants and combustion techniques, swiveling engine control system.
Falcon	1950	Quality control techniques for rubber-base propellants, design data for case-bonded grains, aging characteristics of rubber-base propellants.
16 NS 1000	1953	Large-scale exploitation of low-cost rocket potential of ammonium nitrate.
Ohio State Project	1949	Pumping, handling, and combustion of liquid hydrogen and liquid fluorine.
Sergeant*		Large, high-mass-ratio, solid rocket techniques.
Corporal*		Pressurized, nitric-acid rocket techniques.
Nike	1944	Initiated jointly by Ordnance and Air Force. Joint study program led Air Force to development of Gapa and Bomarc for improved performances.

* JPL programs jointly supervised by military services.

By 1949 the first large engines based on the recovered V-2 fragments had been fired at the new rocket facilities of North American Aviation. They developed thrusts and thrust-weight ratios considerably in excess of the German units. But the Air Force and its contractors, with a now respectable background of rocketry, realized that the basic German approach to the power plant was rather limited. During 1950 it was decided that this initial engine effort would no longer meet more ambitious Air Force requirements, and the entire program for large liquid-rocket engines was reoriented toward larger, lighter, higher-performance units. This enlarged program produced rocket engines useful not only to the Air Force but to the Army as well. When the U.S. Army Ordnance Corps, sponsoring the Redstone Missile Development Program, had no adequate engine available within its own facilities, the Air Force made its engine available to Army Ordnance. It has since been successfully employed as the power plant for the Redstone missile.

During this same period, vigorous programs to develop a family of nitric acid—hydrocarbon rockets were being sponsored by the Air Force at various contractor plants. One of these development programs, intended for airplane application, involved subscale unit firings to establish the basic characteristics of this propellant pair. This subscale unit went through many metamorphoses of development and finally provided the basic device around which the current Nike engine is built.

Development philosophy

Although the bulk of Air Force development work is left to industrial contractors, the role played by Air Force engineers should not be overlooked. Air Force development procedures have been designed to receive the most from industry for the taxpayers' dollar—to develop power plants that are practical ventures yet press the current limits of the state of the art. A key element in this development is availability of Air Force officers of sufficient technical competence to recognize real potentials of scientific development, to discard pseudoscientific hogwash, and to apply, through good management techniques, lessons learned on previous engine programs. There is no way in which the responsibility for setting up weapon-development programs can be divorced from the military. If the objectives of such a development program are unreal, the contractor, regardless of his intrinsic competence, will fail. If proper guidance is not supplied by the military, the contractor's program will be so prolonged as to invite exceedingly high costs and produce very little of technical merit.

Because the Air Force was convinced that long-range rocket-propelled missiles would become necessary weapons and that the development of suitable rocket engines would be the pacing factor for these missiles, its rocket programs continued even through the years of lean appropriations prior to the Korean War. As a result when the ballistic missile designers' job was suddenly and dramatically eased by the advent of practical, lightweight thermonuclear warheads, the Air Force was ready to begin matching this development with a ballistic missile delivery vehicle. Rocket-propellant pairs had been selected as best for this job because of economy, availability, performance, and handling characteristics; engine components were in a realistically advanced state of development, and the means of estimating facility, manpower, and dollar requirements to meet accelerated programs had been developed. On the firm foundation of this continuous, vigorously prosecuted Air Force rocket development program, all the long-range and intermediate-range ballistic missiles now in development by the United States have been based. Again at this stage of the development of rocket engines, the Air Force has made available its rocket engines to the Army Ordnance Corps for use in the Jupiter program.

Structure and control

All the components of long-range ballistic and aerodynamic missiles, except for the rocket-engine power plants, are direct descendants of basic components in modern military aircraft. The Air Force and its contractors spent twenty-five years developing structural materials and manufacturing techniques that offer high strength and low weight. A high percentage of the cost of the development of lightweight alloys and high-temperature alloys in this country has been underwritten by the U.S. Air Force in one form or another.

In ballistic missiles, range is an especially sensitive function of the ratio of propellant weight to total weight. Two items essential to long ballistic ranges are high-performance rocket power plants and extremely low weights of structural elements. In recognition of this, shortly after World War II the Army Air Forces started a program with Convair for intensive studies of structure, control, and guidance of long-range ballistic missiles. This program eventually led to impressive advances in control of ballistic missiles through gimbaling of rocket engines, better understanding of the requirements of guidance components, and a lightweight structural concept now employed in the Air Force ICBM program. The basic structures of all the long-range and intermediate-range guided missiles, ballistic and aerodynamic, of the USAF are highly sophisticated and employ subtle techniques coupled with carefully chosen materials to attain strength-weight ratios of a very high order. Each of the Air Force missiles has developed a structure peculiarly suited to the specific purpose. That these structural approaches have produced superior results is indicated by the recent action of the Army Ordnance Corps. After it examined the basic structure of the Air Force Thor missile, Army Ordnance decided to alter its basic structural design of the Jupiter missile to permit employment of the materials and fabrication techniques utilized on Thor.

The extension of missile control systems beyond performance limits of piloted aircraft has not proved as difficult as extrapolations of other elements. In the operational employment of missiles themselves many other conventional Air Force elements must be brought into play. Thus a long-range or intermediate-range missile would be of limited use without Air Force target-system information, reconnaissance, and communication nets, all integrated under central control. Only with these can missile devices be efficiently meshed into the operations of present manned bombers so as to destroy with a minimum effort the most significant items of potential enemy resistance.

The Air Force missile program encompasses both ballistic and aerodynamic types of vehicles designed to cover many applications over both long and intermediate ranges. This program has been based upon a consistent philosophy systematically pursued over a long period of years. The Air Force mission in this field has been well understood, was reiterated in the Key West agreement reaffirming roles and missions of the three services, and further confirmed by the Secretary of Defense in his recent memorandum. This program has proceeded along lines of development demonstrated to be effective through past extensive experience with large airborne vehicles. This program has not been spectacular, but massive and sound. There is every reason for confidence that it will do the job well and on schedule.

Air Force Ballistic Missile Division, Hq ARDC

Notes on Technical Aspects of Ballistic Missiles

TECHNICAL TRAINING AND SCIENTIFIC RELATIONS GROUP
GUIDED MISSILE RESEARCH DIVISION
THE RAMO-WOOLDRIDGE CORPORATION

THESE notes are intended to provide a brief introduction to the technical aspects of the USAF ballistic missile program. Particular emphasis is given to problems that are new or newly critical. Topics are covered in an order suggested by the relationships among them.

The Systems Concept

A BALLISTIC missile system obviously consists of a tremendous number of components and detailed parts that must be designed, developed, and assembled into a working system. Less obvious, perhaps, is the fact that the *systems engineering* devoted to the study and planning of the over-all system is a significant and vital part of the program. Systems engineering is distinguished by its primary emphasis on the relationships of the various portions of a system to one another and to the over-all system performance.

In a systems engineering approach a missile is initially planned in broad outline, essentially in block diagram form, and the interactions of the different parts with one another are studied in detail before any hardware designs are committed to the missile. Necessarily the potentialities of detailed hardware must play an important part in the selection of possible systems for study and in their evaluation, but the emphasis is fundamentally on verifying that the system as a whole can be a practical, reliable, and sufficiently precise solution to the military problem.

In an alternate and less satisfactory initial approach various designs of engines, gyroscopes, airframe structures, and so on might be selected on the basis of their satisfactory performance in previous military developments, modified to meet the more obvious system requirements, and then committed to the new missile. An increasing effort might then be applied to working out further details of the system. Such an approach inevitably would lead to a prolonged schedule, and perhaps even to an inferior missile. As the program moved on, many decisions would have to be reversed or modified because of system requirements that were not understood at the beginning.

Systems engineering evidently must not be confined to the initial planning but must permeate the entire research and development phases, and even production. Although the initial researches must be as thorough as possible, many decisions must be made boldly on the basis of incomplete information. Investigation must continue so as to determine whether further data support the decisions. Any indications of the need for changes must be carefully weighed.

The system cannot be planned initially in complete detail. Within the subsystems the input-output relationships and general configuration of which have been tentatively established, more detailed systems engineering must be carried out. As the development progresses, it must receive continued monitoring from an over-all systems engineering point of view. This is especially important in times of apparent crisis such as may occur in any missile program, because a proposed change in propulsion, for example, might require accompanying radical changes in guidance or other areas. If the initial planning was sound within the limitations of available information and competent engineering is available at both system and more detailed levels, such an apparent crisis ordinarily is quickly resolved by a few minor changes.

Thus it is seen that systems engineering in a ballistic missile or any similar program requires employment of large numbers of specialists and also of an adequate number of competent administrators who can cement them together into a broad-visioned effective team. The over-all systems engineering effort for the present USAF program is carried out primarily in the Guided Missile Research Division of The Ramo-Wooldridge Corporation, in accordance with its responsibilities as technical director of the program and technical advisor to the Air Force Ballistic Missile Division of Headquarters Air Research and Development Command, USAF. The more detailed systems engineering within the various subsystems is primarily the responsibility of the corresponding contractors.

At the request of the Editors for some reasonably nontechnical explanation of the principles and concepts underlying the development of the long-range ballistic missile, Duane Roller (Ph.D., physics, California Institute of Technology) and his staff of the Technical Training and Scientific Relations Group wrote the accompanying "Notes" for the special Ballistic Missile edition of the *Quarterly Review*, where they contribute materially to fuller understanding of the USAF missile program depicted in the various articles. Associated with Dr. Roller in writing the "Notes" were Charles T. Morrow (Ph.D., acoustics and communications, Harvard University), Reed P. Berry (M.S., engineering, University of California at Los Angeles), and John W. Herrick (B.S., aeronautics; B.S., mechanical engineering, Tri-State College). The "Notes" offer a brief but remarkably lucid exposition of the basic concepts of missile systems, subsystems and components, control and guidance, rocket engines, propellants, theory of trajectories, testing, and monitoring.

Systems and Subsystems of a Long-Range Ballistic Missile

A BALLISTIC missile may be considered as an assemblage of a number of interconnected and interacting systems and subsystems that perform distinct functions in the accomplishment of the mission of the missile. In a military missile the payload is a *warhead*—high explosive, atomic, or thermonuclear in nature—that is to be delivered to and detonated at a predetermined target in enemy territory. The warhead, together with its auxiliary equipment, such as a fuzing system, is incorporated in the *nose cone* of the missile.

Delivery of the warhead to a predetermined target requires inclusion in the missile of a *guidance system*. This system regulates the position and velocity of the center of mass of the vehicle during powered flight, with the purpose of establishing a satisfactory trajectory prior to thrust cutoff. A *control system* is also necessary so as to maintain attitude stability of the missile during powered flight, to prevent undesirable responses when overriding guidance signals are introduced, and to correct deflections caused by winds, gusts, and other disturbances.

Electric power is required for the guidance and control systems. This power, as well as any required hydraulic or pneumatic power, is furnished by a subsystem, the *accessory power supply*.

For the *propulsion system*, present-day long-range ballistic missiles utilize rocket power plants with liquid oxidizer and liquid fuel as the propellant. The future may see the development of long-range missiles with solid-propellant rocket engines. The use of nuclear power also is an eventuality.

Flight monitoring equipment, part of which is carried by the missile, is needed to provide sufficient data for each test flight to justify the expense and effort of the firing.

Finally there is the *airframe*, the supporting structure for everything else in the missile. Each of the aforementioned systems or subsystems comprises a number of further subsystems, components, and component parts. For example, the liquid-propellant propulsion system includes not only the rocket engines and propellant tanks but also the turbopumps for forcing propellants into the engines, the propellant utilization system for monitoring and controlling the discharge rates from the propellant tanks, the ignition circuitry for starting the engines, and so on. However it must be emphasized that while all these subdivisions can be studied and discussed individually, their designers must give full consideration to the interactions between them if the missile is to operate successfully. Thus the missile, at every step of its development, must be considered as a complex of closely related and interacting mechanisms.

Powered Flight of the Missile

POWER produced by rocket engines is applied to an ICBM or an IRBM only during the initial portion of its flight, from the *launch point* to the *thrust-*

cutoff point B (Fig. 1). All necessary guidance and control of the missile must be accomplished during the powered flight, for the missile motion cannot be influenced when power is no longer available.

The ICBM and the IRBM are launched vertically, for this simplifies the launcher required for these large vehicles and also shortens the time that they are close to the ground during take-off. After this initial vertical climb the vehicle undergoes a programed turn toward the target. During this turn the guidance system begins to function and continues to do so until the desired altitude h, speed V, and angle γ are attained (at B, Fig. 1), whereupon it gives the signal for cutoff of the propulsive power. Perception and correction of vehicle attitude, exercised by the control system, are continuous during the powered flight. Both the attitude of the vehicle and the motion of its center of gravity relative to the required trajectory are adjusted by altering the direction of the thrust of the rocket engines, for instance, by putting jet vanes in the exhaust stream or by gimbaling the rocket thrust chambers.

There are many sets of values of the speed V, angle γ, and spatial position of B that will put the nose cone on a trajectory terminating at the desired target; but some sets are more favorable than others in respect to amount of propellant consumed by the engines or required precision of aim. It is the function of powered flight to impart to the nose cone, as accurately as possible, a favorable set of these parameters.

The energy expended in propelling the vehicle during the powered flight increases with the weight of the vehicle. Because both the kinetic and the potential energies are approximately proportional to the weight of the vehicle at thrust cutoff, it is desirable that this weight be as little as possible in excess of the weight of the nose cone. This objective is aided very materially by dividing the vehicle into two or more parts, or *stages*, with each stage containing a rocket propulsion system. Launching is accomplished by starting the engines of the first stage and, in some designs, also of other stages. At some time during the powered flight the first-stage engines are shut down, and this stage is jettisoned from the remainder of the vehicle. The engines of the next stage are then started, if they are not already operating, and

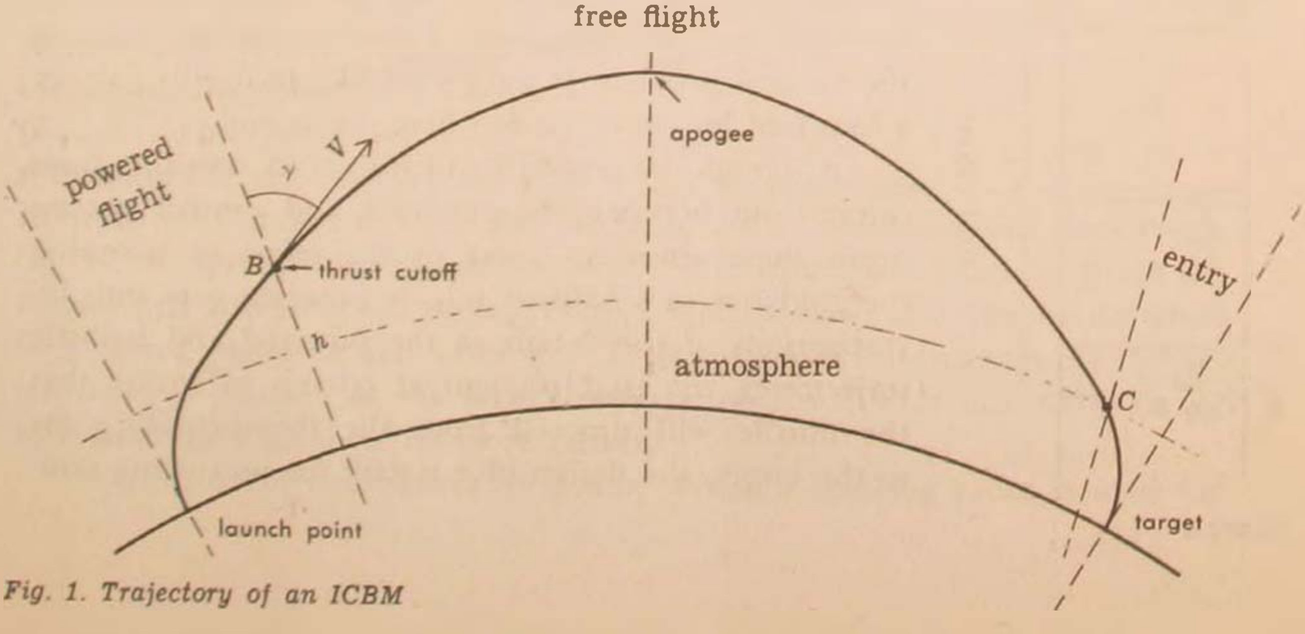

Fig. 1. Trajectory of an ICBM

they propel the vehicle on toward *B*. As the missile nears *B*, the engines on the last stage are shut down, and the final adjustment of the velocity needed to keep the nose cone on a trajectory that will reach the target is accomplished with rocket engines of comparatively small thrust, called *vernier engines*. Thus the term *thrust-cutoff point B* refers, accurately speaking, to the point where the vernier engines are shut down rather than to the shutdown point of the engines of the final stage.

In Fig. 2 is shown a possible configuration of a two-stage ICBM. Each stage incorporates one or more rocket engines *E* and a pair of propellant tanks T_o and T_f. The engine or engines of each stage are supplied with the oxidizer and fuel by pumps P_o and P_f, which are driven by a turbine *T*.

General Aspects of Control and Guidance

In a missile the primary function of the *control system* is to control the attitude, whereas the primary function of the *guidance system* is to establish a satisfactory trajectory. While these two functions are thus clearly distinguishable and are the responsibilities of distinct research and development groups, the two systems themselves interact with each other in numerous ways. Moreover they have certain devices in common, for instance, jet vanes or swiveling engines.

A ballistic missile is dependent on the control system for maintenance of a stable attitude, especially in the low-speed portion of the trajectory immediately after take-off. The control system must prevent the deflection of the missile during and after any disturbance, such as a gust, from becoming unacceptably large and must prevent wobbling in attitude after a guidance command. Because it is difficult to maintain sufficiently tight control without making the missile unstable at frequencies for which it readily vibrates, a significant portion of the control system engineering must be concerned with effects of airframe vibrations, propellant motions, and so forth on the control system. Solving the control problem is somewhat like trying to balance a four-foot length of garden hose on its end.

Although the possibility of instability resulting from interactions between the guidance and control systems needs some attention, most of the effort of planning the guidance in a ballistic missile program goes into investigations of the details of the powered and ballistic trajectories, the establishment of criteria to ensure that the missile will proceed from the thrust-cutoff point to the target, the design of a system for measuring posi-

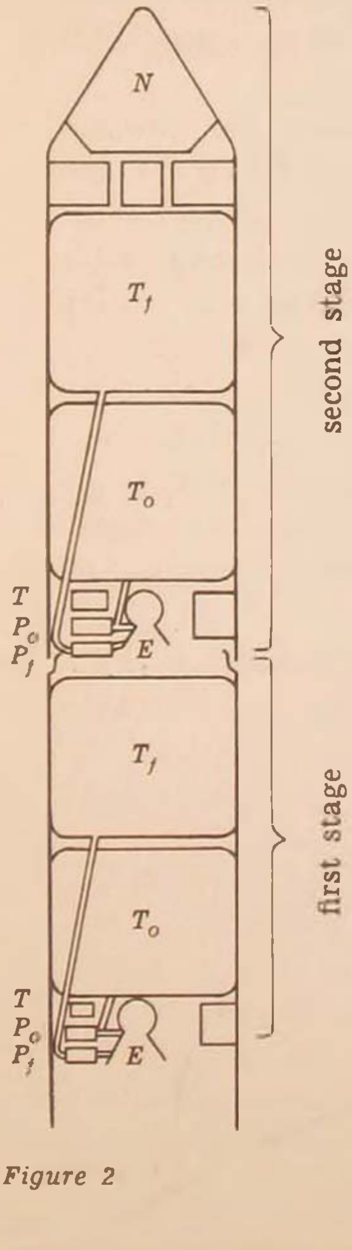

Figure 2

tion and velocity with sufficient precision, and the development of satisfactory computers for generating precise corrective maneuvers.

A choice of trajectory must be made that will ease the problems of propulsion and guidance as much as possible. If the ballistic trajectory is sufficiently understood and if measurements and corrective maneuvers can be made with sufficient precision during the powered flight, the missile will hit its target.

Radio-Inertial Guidance

IN *radio-inertial,* or *radar-command, guidance* the measurement of the position and velocity of the missile is performed by one or more ground-based radars, and corrective maneuvers are computed by a ground-based computer and transmitted to the missile as "commands." Inertial elements, such as gyroscopes, may also be included in the missile, their purposes being to keep it approximately on course during any temporary loss of ground guidance and to prevent impact on friendly territory in case of complete loss of ground guidance. However precision guidance is obtained primarily from the ground.

As in other applications the radars that may be considered are primarily of two types, *pulse radar* and *Doppler radar.* In the pulse radar, pulses of microwave energy are radiated from a ground station, and the time lapses for return of signals from the missile are measured. This measurement provides direct determinations of the slant range, or line-of-sight distance, to the missile at any instant, within limitations imposed by the precision of practical time measurement and the precision with which the velocity of microwaves along the beam is known. The instantaneous velocity of the missile can then be computed in terms of the time-rate of change of slant range. In the Doppler radar, use is made of the fact that the return signal is shifted in carrier frequency by an amount proportional to the velocity with which the missile is moving away from the radar (Fig. 3). Thus measurement of this shift gives the velocity directly, within limitations similar to those for the pulse radar. Instantaneous slant range can be computed from the velocities or by counting the beats between the transmitted and returned signals. Either type of radar can also be designed to measure angles as well as range. Thus complete information on the instantaneous position of the missile may be obtained with one radar or by triangulation with three or more radars.

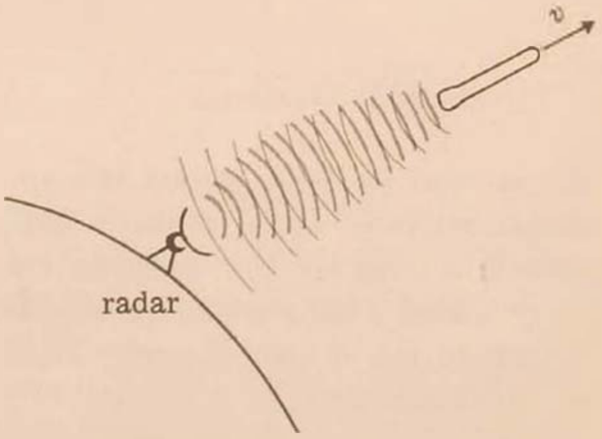

Fig. 3. Doppler Effect

Refraction of microwaves in clouds. When a tracking radar is used for

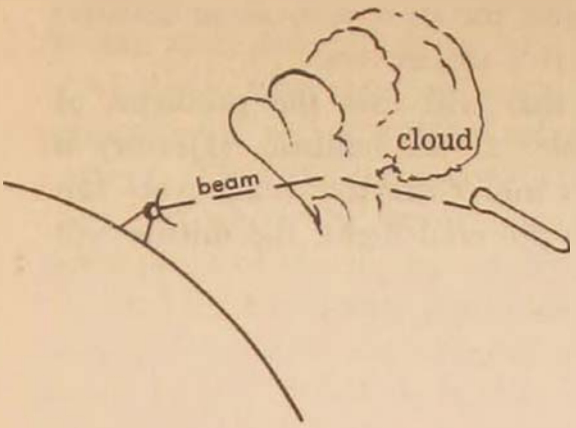

Fig. 4. Refraction in Clouds

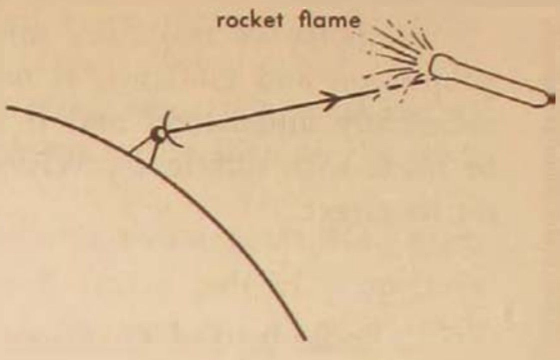

Fig. 5. Flame Attenuation

guidance of an ICBM or IRBM, or for evaluation of the guidance system, an error in apparent direction of the missile can be produced by refraction of the microwaves in clouds (Fig. 4). This problem is under experimental and theoretical investigation. In one of the most promising and convenient types of experiment, a radar and a microwave reflector are used to send beams out and back between stations in a valley and on a mountain in a region where intervening clouds are frequent. The variations in the apparent direction of the reflected beam as the clouds drift by can be studied and described in statistical terms.

Flame attenuation. At high altitudes the exhaust flame from the rocket engines spreads to a large angle. When radio communication between the missile and the ground is necessary, the transmission path may be through the flame, and the ionization of the gases in the flame may attenuate signals to such an extent that reception will be difficult (Fig. 5). This problem is under theoretical and experimental investigation.

Inertial Guidance

An *inertial guidance system* is a special sort of dead-reckoning system that, unlike radio guidance, operates independently of information received from outside the missile. Its computer and sensing instruments—a set of mutually perpendicular accelerometers mounted on a gyro-stabilized platform—furnish signals to the control system. These signals are based on data preset into the guidance system.

The set of accelerometers is used to measure the components of the vehicle acceleration along three mutually perpendicular axes (Fig. 6). Velocities are computable from the accelerations and positions from the velocities. Corrective maneuvers are then calculated by the computer. The orientation of the set of accelerometers must be precisely known, for otherwise the acceleration components will not be interpreted properly by the computer. Furthermore it is necessary that the effect of the earth's gravitational force on the accelerometers be subtracted out. Since this can be done only on the basis of prior estimates of the magnitude and direction of this force, the platform on which the accelerometers are mounted must be stabilized with respect to a known frame of reference by a set of precision gyroscopes and suitable servomechanisms. The reference frames that may be used range from those fixed in inertial space (*see below* "Theory of ballistic trajectories") to those fixed relative to the earth, but each possible reference frame imposes different requirements on the system components.

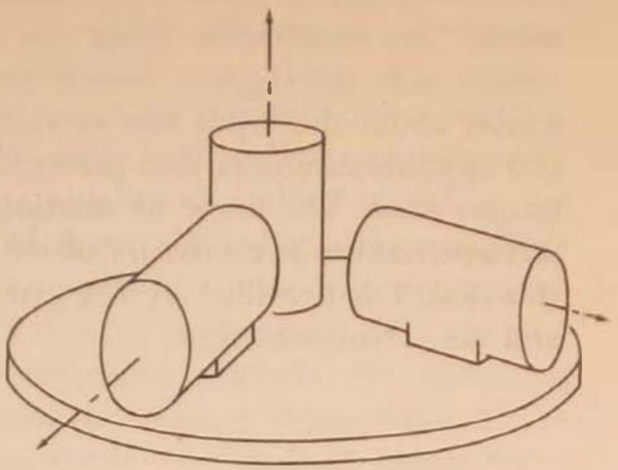

Fig. 6. Orientations of Accelerometer Sensitive Axes

Inertial guidance has the obviously great advantage that interference with the operation of the sensing instruments cannot be accomplished by any means short of destruction by another missile.

Accelerometers

THERE are many accelerometer designs, but all reduce basically to an object of known mass that is subject to some precisely known restraint provided, for example, by a spring or a damper (Fig. 7). In response to an acceleration in the direction of the sensitive axis, the object is displaced with respect to the case of the instrument. This relative displacement is proportional either to the acceleration or to the velocity of the missile, depending on the type of restraint.

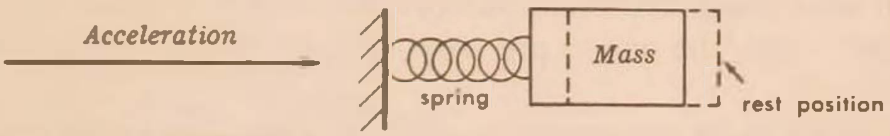

Fig. 7. Basic Accelerometer

One example of the velocity measuring type is the *gyroscopic integrating accelerometer* (Fig. 8). This consists of a single-axis integrating gyroscope

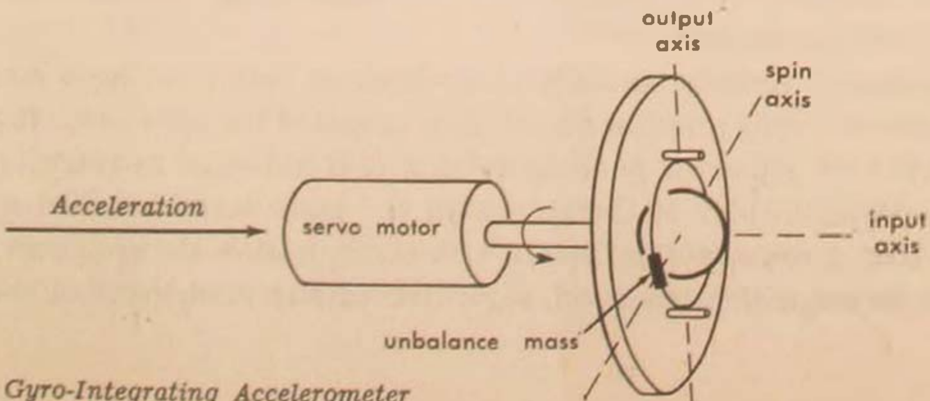

Fig. 8. Gyro-Integrating Accelerometer

with an unbalance mass on the gimbal and rotatable by a suitable servomechanism. An acceleration along the input axis produces a torque about the output axis. In response to this torque the servomechanism rotates the assembly about the input axis so as to generate a torque of equal magnitude and opposite direction, thus preventing any deflection of the gimbal about the output axis. The angle of rotation about the input axis produced by the servomechanism is a measure of the instantaneous velocity. The restraint in this design is provided by the gyroscopic action, the output axis damping, and the servomechanism.

Sled Testing

Sled testing is desirable in the inertial guidance development program because of the difficulties encountered in trying to make laboratory measurements of the errors of accelerometers and gyroscopes under sustained accelerations. In a centrifuge, which may be used for such tests, the acceleration is always directed toward the axis of rotation, and this continuous change in its direction may introduce disturbing effects. In principle a shaker can also be used to provide indications of the errors, but it does not directly simulate the sustained accelerations that occur during powered flight.

The sled, which rides on two rails, is accelerated to a high velocity by rocket engines and then is slowed to a sliding stop by a water brake that picks up water from a channel between the rails; this deceleration can be controlled by presetting the water levels for various stations along the track. The successive positions and velocities of the sled are measured precisely during each run and compared with indications of the inertial elements. The longer the track, the more precisely can the errors of the elements be investigated.

The sled may be accelerated by a liquid-propellant rocket engine or by a cluster of solid-propellant rocket engines. The liquid propellant will be more economical than the solid if a large number of tests is planned.

Gyroscopes in Ballistic Missiles

Gyroscopes may contribute to two basic functions in a missile: control and inertial guidance. The selection of gyroscopes for either of these purposes must take account of the differences in operational characteristics of the various available designs.

A gyroscope consists basically of a wheel, or *rotor,* having a massive rim and capable of rapid rotation about its axis, called the *spin axis.* If the rotor is supported on a pair of *gimbals,* so that it is also free to rotate about the two axes perpendicular to the spin axis, the instrument is called a *two-axis displacement gyroscope* (Fig. 9). In this configuration the spin axis tends to maintain its original orientation, regardless of any maneuvers of the missile.

Position indicators, such as potentiometers, can be attached to the gimbals to measure the gimbal angles and therefore the missile orientation with respect to the preselected, fixed direction of the spin axis.

In other designs there is only one gimbal. The axis of rotation is called the *output axis*. The supports for its bearings are rigidly attached to the missile airframe (Fig. 10). Thus the spin axis is constrained to follow the airframe when the latter rotates about a third axis called the *input axis*. This motion about the input axis is measured by applying to the deflecting gimbal a precisely known restraint provided by a damper or a spring. If a damper, such as a viscous liquid, is used as the rotational restraint, the deflection about the output axis provides a measure of the angular displacement of the airframe about the input axis. This instrument is called a *single-axis displacement gyroscope*, or a *single-axis integrating gyroscope*. In event that a spring provides the major restraint, as in Fig. 11, the instrument measures the rate of rotation of the airframe about the input axis and is known as a *single-axis rate gyroscope*, or simply a *rate gyroscope*.

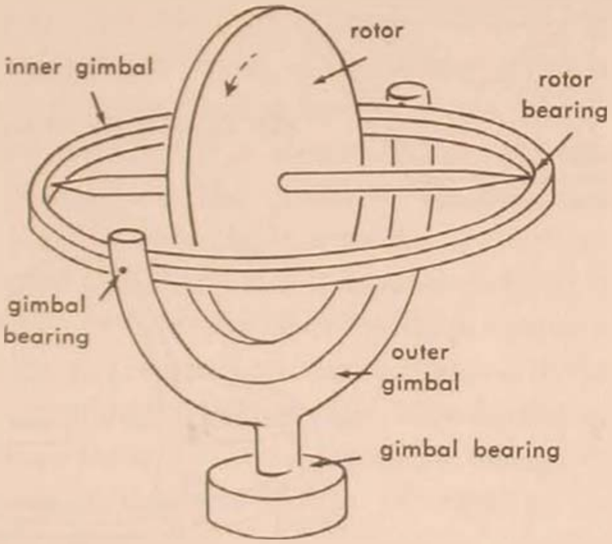

Fig. 9. Two-Axis or Two-Degree-of-Freedom Gyroscope

Control of a missile requires measurement of either the missile attitude or the rate of change of attitude, and the application of corrective torques. To achieve satisfactory attitude control, it is essential that the correcting torque for reducing unwanted oscillation in attitude after a gust be applied when the vehicle is actually in rotation rather than when the next extreme attitude error occurs. Thus the gyroscopes must be capable of rapid response and should provide some anticipation of any change in attitude that is occurring. Rate gyroscopes find good application here. If greater precision over a longer period is desired, integrating gyroscopes may be used to supplement rate gyroscopes or, with modification of the output signal, in place of them.

For inertial guidance of a missile the displacement gyroscopes may find application. Rapid measurement or anticipation is not necessary. But because the stabilized platform of the guidance system must be kept precisely fixed with respect to an inertial guidance frame of reference for a considerable time, the gyroscopes mounted on the platform must be extremely precise and capable of minimum drift over a long period of time.

Errors in gyroscopes. Because of the extreme precision required in gyroscopes for some of the ballistic missile applications, the possible errors of these instruments are of extreme importance. One of the first necessities is that the materials used in the gyroscope must be stable. Likewise any wear that occurs in bearings or rubbing surfaces must be such as not to introduce any play or significant mass unbalance.

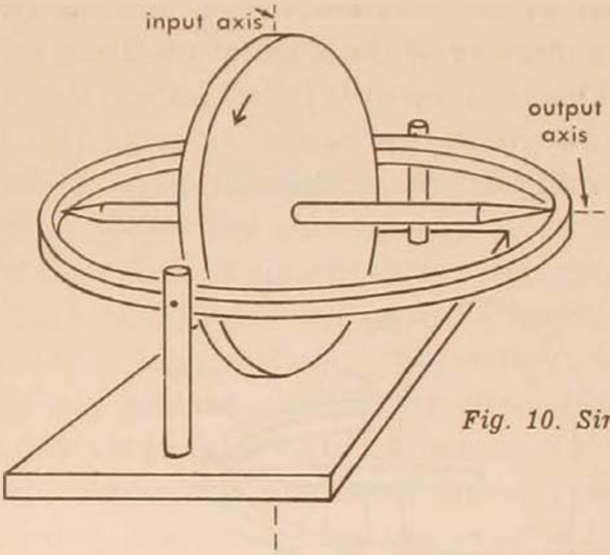

Fig. 10. Single-Axis Gyroscope

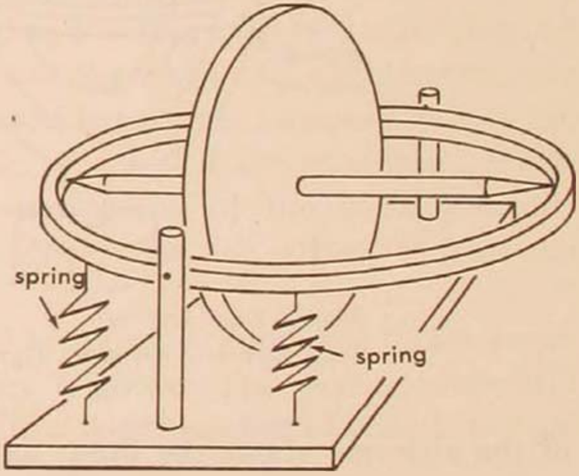

Fig. 11. Rate Gyroscope

The gimbal assemblies must be sufficiently stiff, free from excessive inertia, and precisely balanced about the gimbal axes so that no appreciable torque will be produced on them by gravitational, inertial, or frictional forces. The device for picking off signals must not exert significant torque on any gimbal and must be insensitive to stray fields in the vicinity. The motor used to position the gimbal must not exert any significant spurious torque.

The rotor must be precisely balanced so that its vibration is reduced to a minimum and so that no appreciable drift will result from externally applied vibration that is approximately in synchronism with the rotor.

The gyroscope must be designed for negligible wobbulation and nutation drifts, or else it must be isolated so that these drifts will not occur. Wobbulation drift occurs in a single-axis gyroscope when it is wobbled or vibrated so that its input axis describes a conical surface; this drift, which occurs basically because nonplanar angles do not add vectorially, can be influenced only to small extent by the design of the gyroscope. A wobbling two-axis gyroscope will not drift so long as the spin axis does not tend to follow the motion. However, this may initiate a similar motion of the spin axis, called *nutation*, that persists even after the original excitation ceases. Drift will then result except when the spin axis is precisely perpendicular to the gimbal axes.

Applications of Computers

THE computers of interest in the ballistic missile programs are primarily electrical and are of two types, *analog* and *digital*. The *analog computer* receives its information in the form of voltages that are proportional to corresponding variables of interest, such as the angles expressing the missile attitude, and the forces or torques exerted by the atmosphere. These voltages are applied to a network of electrical elements that are analogous to the mechanical or other elements of the problem at hand or that perform mathematical operations that are analogous to the operations performed by these elements. The output signals of the computer provide the solutions to the problem. The *digital computer* receives its information in the form of counts that are related to the corresponding variables of interest and are made, for example, by analog-digital converters. The digital computer carries out arithmetic operations on these counts or numbers, except that it ordinarily uses a binary rather than a decimal system of numbers to simplify the requirements on its arithmetic circuits. The analog computer ordinarily finds its application where rapid approximate computations are required. The digital computer ordinarily is used where more precise computations must be made.

Computers find application in the systems engineering of the missile as well as in actual guidance. The analog computer finds more application in the study and planning of the control system, and the digital computer finds more in the study of the guidance systems, but there is no sharp dividing line. For extreme realism actual mechanical elements of the control system, such as servo valves or gyroscopes, may be substituted for portions of the computer. Computers may also be used in the study of the effects of various phenomena on the trajectory.

In the guidance of the missile the raw data yielded by its measuring devices are not necessarily expressed with reference to a convenient coordinate system, and so it may be advisable to have the computer perform a coordinate transformation. In addition, the computer must either compute the impact point of the missile or compare the data on the actual trajectory with that for a standard trajectory and decide on corrective maneuvers.

Accessory Power Supply

The accessory power supply (APS) of a modern ballistic missile is a system that furnishes electric, hydraulic, and pneumatic power to other systems of the vehicle on which it is installed. Specifically, on a long-range ballistic missile, the accessory power supply furnishes electric power to the guidance and the control systems during powered flight and, in some cases, during prelaunching and conceivably also after thrust cutoff. It may also furnish hydraulic and pneumatic power to these and other systems of the missile. Fig. 12 is a simplified diagram of a typical APS assembly.

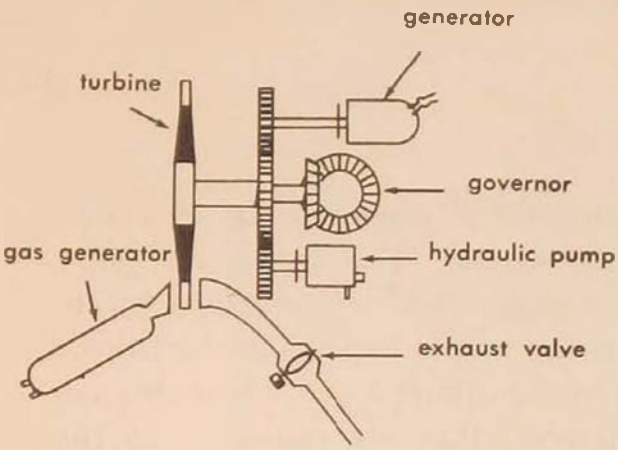

Fig. 12. Accessory Power Supply

The great need for minimizing weight in a long-range ballistic missile indicates the use of a lightweight gas turbine to supply the missile accessory power requirements. The APS would then consist of a hot-gas generator, a turbine with necessary gearing, alternating current and direct current generators, and any required hydraulic and pneumatic pumps. This power unit is installed in the final stage in the case of a multistaged vehicle.

In a multistaged missile it would not be practical to use power from the power plants of the various stages to drive the APS generators and pumps because this would require duplication of the generating equipment on each stage, thus increasing the weight. Furthermore such an arrangement would furnish accessory power only while the engines are operating. A separate APS, on the other hand, can be designed to furnish accessory power for any desired period. Separate liquid or solid propellant for the gas generator might be included in the APS. More commonly, however, the APS would draw propellant from the main tanks.

The well-known battery-inverter type of power supply could be used to supplement the gas-turbine type and conceivably might be developed sufficiently to replace it. Although improvements in batteries will make them more competitive with gas turbines as a primary power source, the choice between the two types still depends largely upon the amount of power to be generated and the duration of the operating cycle.

Problems Associated with Engine Development

The development of liquid-propellant rocket engines for long-range ballistic missiles poses both new problems and problems similar to those encountered on other programs, but now on a larger scale. These problems may be divided into two groups: those related primarily to engine design and operation and those primarily concerned with other systems on the vehicle. Fig. 13 shows the main components of a typical liquid-propellant rocket engine.

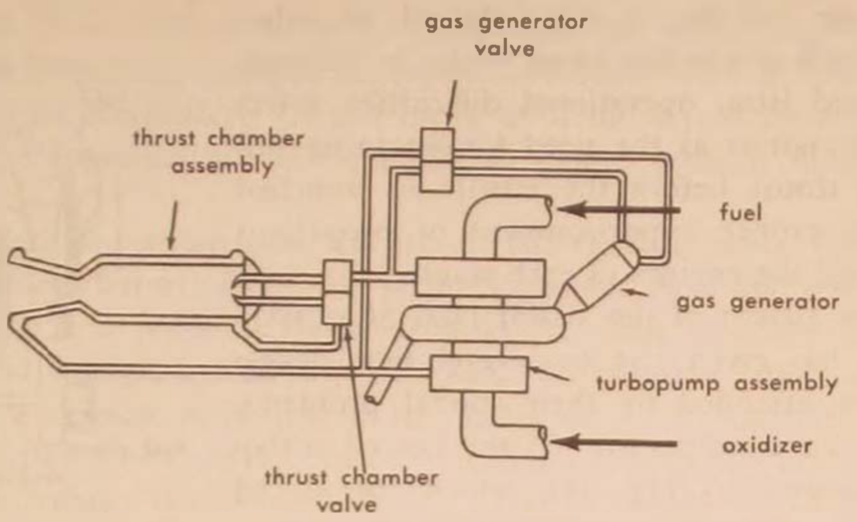

Fig. 13. Components of Liquid-Propellant Rocket Engine

Among the first of the important engine design and operational problems to be solved is the selection of the proper propellant combination for the particular application. This problem is discussed in the following section, but is mentioned here because the characteristics of the propellants are factors in determining engine design, just as in the case of other reaction power plants. After selection of oxidizer and fuel, major design and developmental problems likely to be encountered are conditions of power-plant operation, for example chamber pressure, nozzle area ratio, and type of injection; cooling system for the thrust chambers and gas generators; provision of the necessary degree of thrust control, including shutdown operation; starting of the complete power plant, for example thrust buildup sequence after ignition, simultaneous starting of several chambers, and altitude-start; elimination or minimization of combustion instability; and mechanical design of major components such as the turbopump assembly.

Thrust control is required in a large rocket-propelled ballistic missile so that the thrust may be kept within specified limits during the powered flight and also terminated to achieve the precise thrust-cutoff velocity required to strike the desired target. Reduction of combustion instability presents a problem to the engine designer because such instability gives rise to severe vibrations, over a wide frequency spectrum, that can damage not only the engine but also the airframe and other components, resulting in malfunctions and failures of equipment. Lastly, in multistage missiles, special engine ignition problems result from the low ambient pressures and temperatures existing at the extreme altitudes where stagings occur.

In the second group are those problems of rocket engine development concerned with the entire power plant, with thrust steering, and with operational difficulties introduced by the use of more than one engine in a single stage. The problems of engine installation and steering are intimately related, for if the vehicle is to be steered by swiveling the thrust chambers, the method of mounting the engines will be quite different from that used when the steering is accomplished by other means such as movable vanes in the jet exhaust. The third item, operational difficulties, refers to such matters as the need for attaining full take-off thrust before the missile is launched and the proper apportionment of propellant flow to all the engines of each stage.

The advent of the ICBM class of weapon systems has given rise to several new design concepts, attended by their special problems. The major concepts are (i) the geared turbopump assembly (Fig. 14), which introduced problems concerning gear-train design and a separate lubrication system; (ii) thrust-chamber nozzles with divergent sections of unusual length (Fig. 15) and unique configuration, causing a fabrication problem of considerable magnitude; (iii) propellant-control systems that ensure safe thrust-buildup, an electronics design problem; and (iv) multiengine power plants (Fig. 16). The geared turbopump is more efficient than the older single-shaft design and, in addition, provides extra drive shafts for accessories such as a small hydraulic pump.

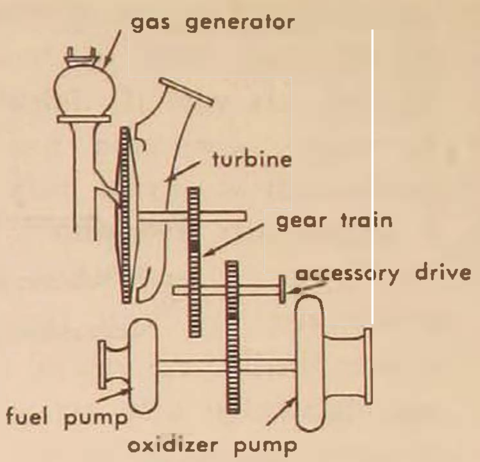

Fig. 14. Geared Turbopump

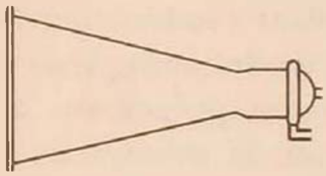

Fig. 15. High-Ratio Nozzle

The need for rocket power plants of very large capacity, to operate at extreme altitudes, is the basis for design concepts (ii), (iii), and (iv). Bringing several complete rocket power plants together to obtain the required total thrust adversely affects reliability, missile control, costs, and reduction of aerodynamic drag.

This listing of engine developmental problems is representative rather than complete; there are many other problems, both major and minor. However, progress in this relatively new propulsion field is rapid, and there are reasons to think that satisfactory solutions to the various problems involved will be forthcoming.

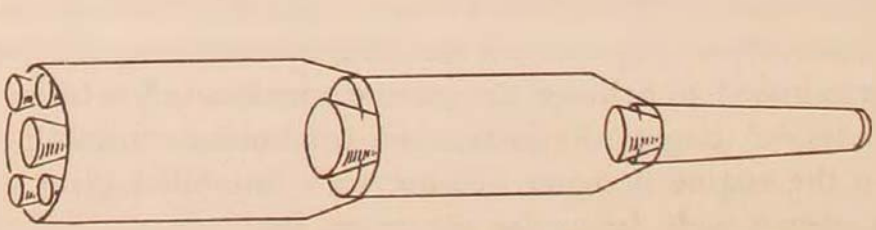

Fig. 16. Multiengine Power Plant

Selection of Liquid Propellants

In the choice of the propellant for a particular application, account must be taken not only of the properties of the propellant components, but also of the purpose of the vehicle to be propelled and the requirements on its power plant. For ballistic missiles, bipropellants—liquid *oxidizer* and liquid *fuel*—appear to be acceptable. Of the many available liquid combinations, however, only a few turn out to be satisfactory, and none is ideal in all respects.

Each propellant combination has its unique characteristics. These include performance characteristics, the physical properties of the component liquids and their end products, and such considerations as safety and ease of handling and storage, availability, and cost. Of primary importance are the performance characteristics; if they are inadequate, the propellant cannot be used, no matter how desirable its other characteristics may be. Furthermore the characteristics that do not directly affect performance can often be compensated for or modified. For instance if a liquid component has a high freezing temperature, thus complicating its use in low-temperature regions, it may be possible to add some substance that will lower the freezing point and yet not introduce unwanted side effects. Again, the corrosive action of a highly active propellant component may be rendered negligible by resorting to tanks and pipelines made of special materials.

One performance characteristic of major interest is *specific thrust,* more commonly called "specific impulse." It is defined as the thrust (in pounds) produced per unit time-rate of flow of propellant (in pounds per second). One can show that the specific thrust may be increased by raising the temperature of the combustion products in the chamber, by reducing the weighted average of their molecular weights, and, to a slight extent, by reducing the ratio of their specific heats at constant pressure and at constant volume. A high gas temperature can be obtained by using a propellant mixture that yields a large quantity of heat per pound of mixture. The average molecular weight of the combustion products is determined both by the nature of the oxidizer and the fuel and by the ratio in which they are mixed.

The specific thrust will also be lowered if the combustion gases dissociate into simpler molecules and atoms, because the dissociation requires energy and thus reduces the amount available for conversion into the translational kinetic energy of the exhaust stream. Where tests indicate that effects of dissociation are appreciable, a change can be made either to a propellant having more stable reaction products or to a lower gas temperature.

In addition to these basic requirements the densities of the propellants should be high, for the tank structure can then be made smaller and lighter and the liquids will also be easier to pump. Other desirable propellant properties include rapid and reliable ignition of the mixture, high rate of reaction, low vapor pressure, and low freezing point. Among the properties creating possible hazards are chemical instability, corrosivity, flammability, and toxicity. In view of these many restrictions, one can see why the search for suitable liquid combinations is a major problem of rocket research.

Significant advances with high-energy propellants may be forthcoming if solutions can be found for the engineering problems of adapting such propellants to rocket applications and of producing them on a commercial basis, at acceptable prices. For ICBM propulsion significant increases in performance and energy would result if reliable and practical rocket power plants could be developed for even the commonly known high-energy propellants, such as liquid fluorine and liquid hydrogen.

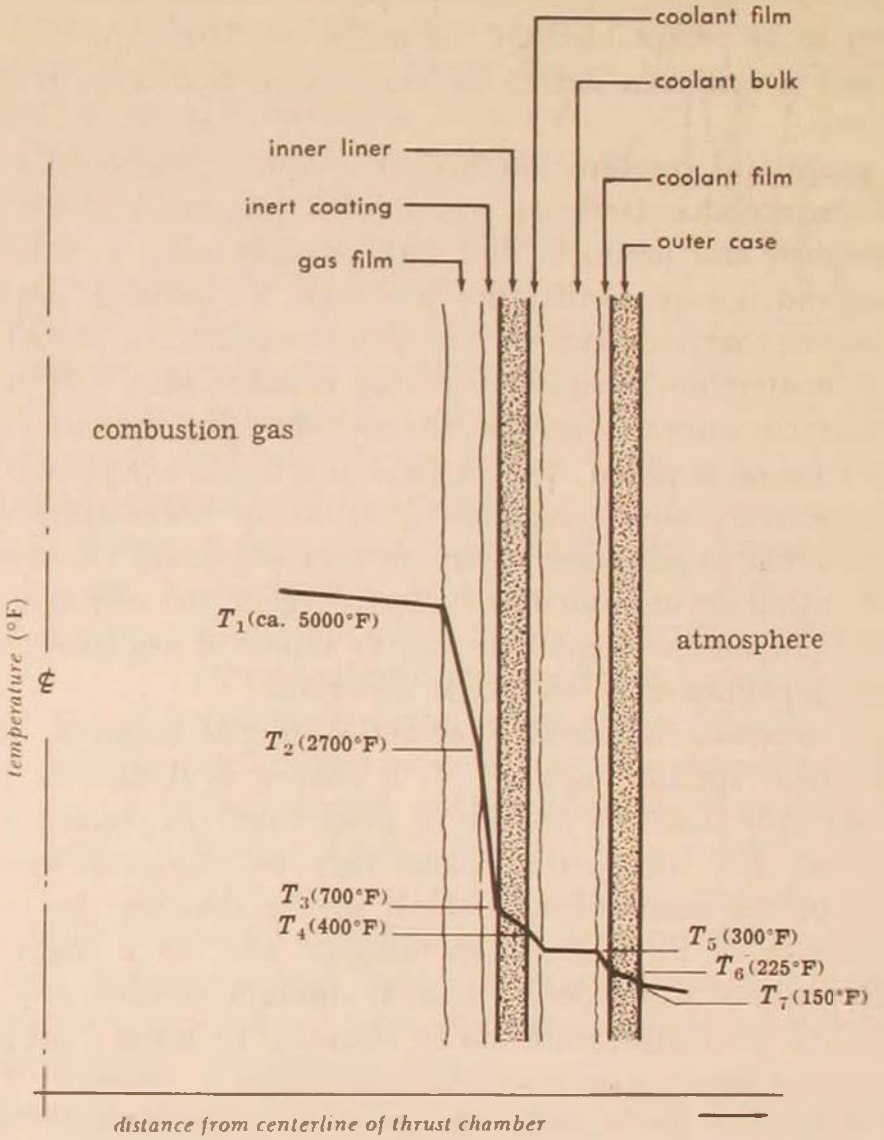

Fig. 17. Temperature Gradients

To reduce the rate of transfer of heat through the combustion chamber walls, which is an acute problem in rocket engine design, several different methods have been devised and are in use. One scheme, still under investigation, is to employ an oxidizer-fuel combination that will deposit on the inner chamber wall an inert coating capable of providing good thermal insulation and also of withstanding the scouring action of the hot gas flow.

The graph in Fig. 17 illustrates the temperature gradients to be expected in a regeneratively cooled thrust chamber provided with such an inert coating.

Propellant Utilization

PROPELLANT utilization is a problem that becomes important when a missile is being fired for maximum range. The problem is (i) to ensure that the maximum amount of propellant available to the rocket engines is consumed by them and (ii) to design the propellant feed system so that a minimum amount of propellant is trapped and hence unavailable for consumption. For the bipropellant rocket engines of current ballistic missiles, the problem is accentuated, since the engines, because of various system and trajectory tolerances, may consume one propellant component at a relatively faster rate. Thus when this component is completely consumed, a portion of the other one remains unburned. The effects of residual propellant can be drastic. For instance, a rough calculation shows that if one percent of the initial propellant weight remains unconsumed in a vehicle designed to have a thrust-cutoff speed of 25,000 ft/sec, the range will be reduced by about 600 nautical miles. Moreover to maintain this cutoff speed of 25,000 ft/sec when one percent is unconsumed, the weight of propellant needed initially would be almost doubled.

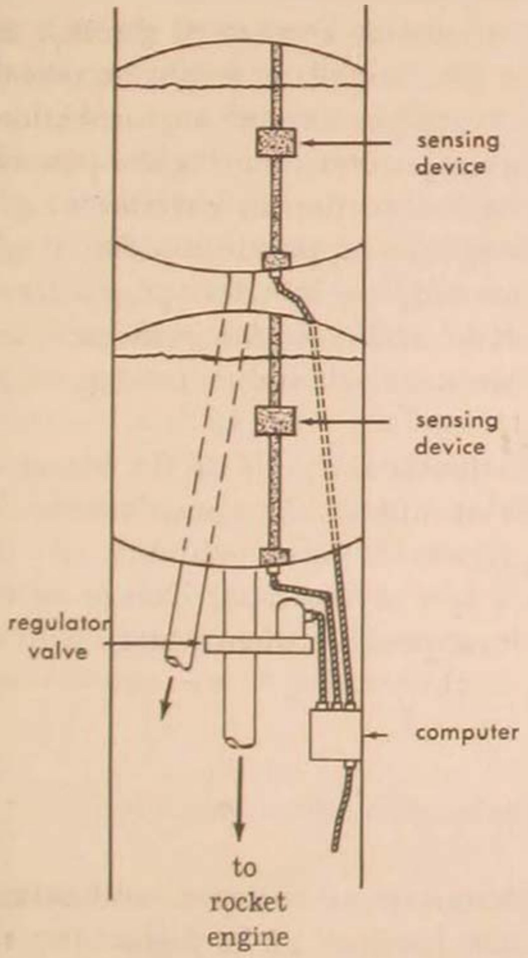

Fig. 18. Propellant Utilization System

Figure 18 shows the main elements of a propellant utilization system. The most difficult problem is how to determine the amounts of oxidizer and fuel in the tanks at successive times during powered flight. When the vehicle is disturbed, as by a gust or by the control system, the resulting accelerations produce in the propellant liquids sloshing that may be appreciable even when the tanks are equipped with baffles or some other damping device. Thus the determination of propellant levels by conventional means is difficult, if not impossible. Measurements depending upon dielectric properties of the tank contents appear to be impracticable because of the severity of the liquid motions. However there are sensing methods that offer promise, and these are receiving extensive study and tests.

Vortices may form in a liquid that is flowing from a tank, and this can result in premature cutoff of the thrust. Thus studies must also be made to gain a better understanding of vortex formation and how it may be controlled.

The Airframe

The design of any airframe involves a continual struggle and compromise in satisfying requirements of both weight and strength. For a long-range ballistic missile, which must be power-accelerated all the way to thrust cutoff, excess weight is a critical problem, for it results in a drastic reduction of maximum range. Yet the airframe at the same time must have sufficient strength and rigidity to support the other components and the propellants without failing under normal static and flight loads. Included in these loads are the stresses caused by vibrations of the engines, propellant sloshing, maneuvers, and aerodynamic heating. The lift developed by the large missile body during a programed turn is an especially interesting problem.

A significant reduction in the mass that must be accelerated through the entire distance to thrust cutoff and also in the propellant weight at take-off is obtained by using a *multistage design,* in which one or more engine sections, with or without associated propellant tanks, are jettisoned during the powered flight. Advanced design techniques also permit reduction in airframe weight.

The development of new materials may offer opportunities for weight reduction. The designer must consider not only the physical properties of the materials, such as strength-to-weight ratio and corrosion resistance, but also such factors as availability and cost of the materials and their adaptability to standard fabrication techniques.

One effect needing thorough investigation is the shift of the center of gravity of the vehicle as the propellant is consumed. This shift relative to the center of pressure is a determining factor in missile stability. In the ICBM and IRBM account must also be taken of the rapid change in the relative positions of the centers of gravity and pressure when a stage with its rocket engines is jettisoned.

Aerodynamics of a Ballistic Missile

The ballistic missile is subject to aerodynamic forces, torques, and related effects during both the initial and the final portions of its flight. For the initial portion—from the launch point to the thrust-cutoff point *B* in Fig. 1—the aerodynamic calculations are conventional. Moreover the choice of aerodynamic characteristics is less critical for a ballistic missile than for other types. On the other hand these characteristics must be precisely known. Unless they are accounted for properly in the design of the control system, the missile may exhibit instability during a portion of the powered flight.

One unconventional aerodynamic investigation associated with multistage engines is concerned with the amounts of "hot drag" and "cold drag," that is, with the drags produced by the open end of the missile body when the rocket engines are firing and when they are inoperative, respectively. Different arrangements of engine clusters and different firing sequences of the exposed thrust chambers yield different values of hot drag. In some cases the low pressure in the engine compartment resulting from the "jet pump action" of the supersonic exhaust streams may create a structural problem.

During repassage through the atmosphere—from *C* to the target in Fig. 1—there are similar problems of stability that have required investigation, and heating effects occur that are not treated in ordinary aerodynamic theory.

The Nose Cone

THE *nose cone* will contain, among other things, an atomic warhead and provision for arming and fuzing. On returning to the earth through the atmosphere the nose cone should be decelerated to reduce the possibility of burning up from aerodynamic heating. It must be contoured for the proper deceleration and for minimizing turbulence over its surface.

The rapid heating of the re-entry body on return to the earth through the atmosphere is under theoretical and experimental investigation. Since the conditions involved in the heating are beyond those readily produced in the laboratory, theory for such conditions must be extrapolated beyond any previous experimental confirmations. Some insight into the problem is provided by shock-tube studies. An instrumented model placed within the tube is momentarily subjected to conditions approaching those of re-entry by means of a shock wave propagated along the tube. Further insight is being obtained through flight tests in which models are accelerated by means of simple multistage rockets to conditions approaching those of re-entry.

In these experiments the important parameters are the atmospheric pressure, the Mach number, and the Reynolds number. The experiments are planned to yield combinations of these parameters such that the desired information can be predicted from the data.

Encounters with Atmospheric Dust and Interplanetary Particles

SEVERAL independent lines of evidence have yielded approximate values for the probability of a collision between an ICBM and a meteoric particle and for the probable value of the meteoric mass encountered. For a single flight there appears to be about an even chance of a collision with a particle of diameter as large as about 0.0001 inch. The mass of particles of all sizes encountered by the surface of the vehicle during a half-hour flight would be roughly 4×10^{-11} lb/ft^2. If the vehicle should encounter a meteor shower, these figures of course would be larger, though still so small that the vehicle's course and range would not be affected appreciably. The damage would be confined to abrasion and pitting of the vehicle's skin. Such damage can also be produced by encounters with atmospheric dust during the initial and final portions of the flight. Pitting of the skin conceivably could result in abnormal heating during passage through the atmosphere, an eventuality that cannot be disregarded. As for the chance of collision with a meteor sufficiently massive to produce a catastropic effect, this turns out to be so exceedingly small that it can be ignored. Incidentally there are practically no interplanetary particles of diameters less than about 0.0001 inch, for smaller particles are blown out of the solar system by radiation pressure.

The density of meteoric dust near the earth is approximately 3×10^{-19} lb/ft^3. This density has been determined by measurements of zodiacal light; the part due to scattering of sunlight by meteoric dust is found by separating from the measurements all other effects, such as scattering from the top of the atmosphere, scattering by electrons in interplanetary space (about 5000 per cubic inch), and the luminescence of the ionosphere. The density of meteoric dust has also been computed on the basis of the rate of accretion of the dust by the earth, 200 lb/sec. This rate of accretion is determined by three different, independent methods: pitting of recovered rockets and of acoustic devices carried on them; collection of micrometeorites and study of deep-sea nickel deposits; computations involving the determination of the optical density of atmospheric dust and the average diameter of the dust particles. The average diameter is found from time-correlation studies between meteor showers and the deposit of material on collecting plates, and between meteor showers and the size of the earth's shadow on the moon.

The values of the density of meteoric dust yielded by the aforementioned methods are about 10,000 times larger than that determined by reflecting radio waves from meteor paths and extrapolating to include particles which are too small—less than 0.0001 inch diameter—to produce reflection.

Exterior Ballistics of a Missile

THE trajectory beyond the thrust-cutoff point *B* may be divided into two segments: the free-flight portion, from *B* to the point *C* of re-entry into the atmosphere; the re-entry portion, from *C* to the impact point *T* (*see* Fig. 1). For a long-range missile the free-flight portion *BC* is above the sensible atmosphere; hence the missile during this phase is a freely falling body, the only force acting on it being gravitational attraction. During the re-entry portion *CT* aerodynamic forces also come into play, and these slow the missile and cause it to become heated.

The length and shape of the free-flight trajectory are determined by the speed V of the missile at thrust cutoff, the angle γ between the local vertical at B and the direction of V, the altitude h of B, and the values of the acceleration due to gravity g along the trajectory.

Considering a given point B and a given target T, one finds that for every thrust-cutoff speed V between the lowest and the highest values needed to reach the target, there are two values of the angle γ that yield trajectories connecting B and T. One of these trajectories is steep, of high apogee; the other is *flat*, of low apogee. As one decreases the thrust-cutoff speed V, these two possible trajectories approach each other, the steeper trajectory becoming flatter, and the flatter trajectory more arched. In the limit, when V attains the minimum value for which the missile will reach the target, the two trajectories merge into a single one of medium height (Fig. 19). Because this medium trajectory requires the smallest speed V, and therefore minimum kinetic energy at thrust cutoff, it is optimum with respect to propellant requirements. It is also more favorable in other respects. For the steeper trajectory the re-entry speed is higher, thus presenting a more formidable heating problem. For the flatter trajectory the re-entry path through the atmosphere is longer. Both very steep and very flat trajectories require a more precise guidance system.

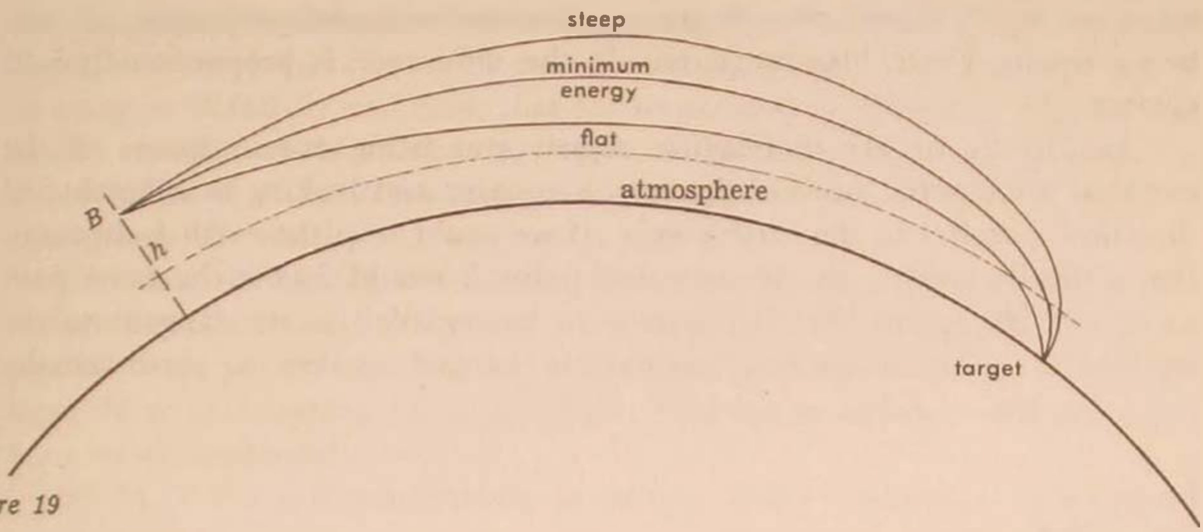

Figure 19

Effect of Earth's Spin and Curvature on Trajectory Length—A Qualitative Approach

A SIMPLE picture of a free-flight trajectory may be obtained by considering first the case where the range and time of flight are so small that the missile can be assumed to be traveling over a flat and motionless earth, above which the acceleration due to gravity g is at every point the same in magnitude and always directed normal to the flat surface (Fig. 20). For this *flat-earth* situation the horizontal range from thrust cutoff to impact is given by the expression,

$$\text{Range} = x + \Delta x = \frac{2V^2 \sin\gamma}{g}(\cos\gamma + \sin\gamma\tan\theta), \qquad (1)$$

where Δx is the additional range gained because thrust cutoff occurs at B instead of on the ground at O, and where θ is the angle between the horizontal and the straight line drawn from B to the point of impact.

As the range is increased, the effects of the earth's curvature and rotation become more and more important. A rough picture of how these effects alter the length of the trajectory may be gained by starting with the short-range flat-earth trajectory (Fig. 20) and adding successive corrections to it. Only the simplest situation will be considered: namely, that of a missile moving in the plane of the equator. Moreover, since the interest here is in a qualitative picture, the mathematical expressions for most of the corrections will not be included. However it is interesting to note that for so short a range as that of a shotput by an athlete at the equator, the range for eastward projection turns out to be about an inch greater than for westward projection, all else being equal. For a long-range missile the difference is proportionally still greater.

In Fig. 21 we are to imagine ourselves as being out in space, off the earth, at some point south of the earth's equator and looking in a northward direction, parallel to the earth's axis. If we could stop the earth from rotating, a missile leaving the thrust-cutoff point *B* would follow the same path as in Fig. 20, except that *OX* is now to be regarded as the tangent to the equator at *O*. Let us see how this path is changed because the earth actually

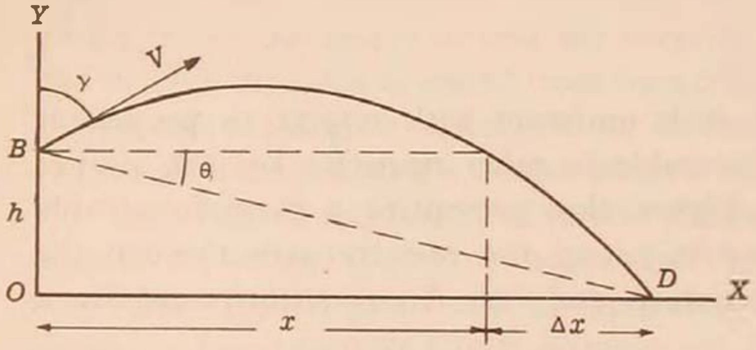

Figure 20

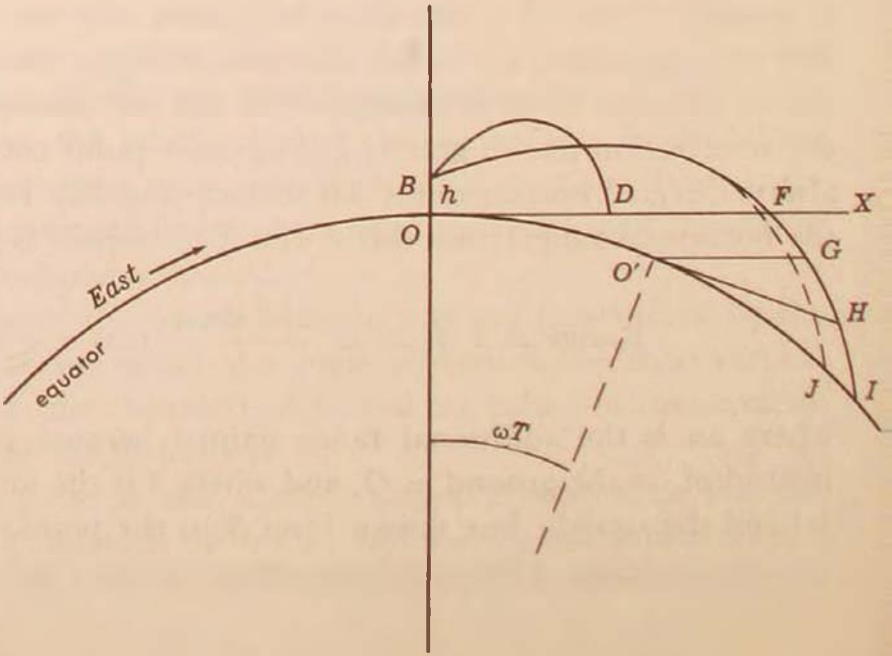

Figure 21

is rotating and its surface is not flat. In Fig. 21 the coordinate system XOY is to be thought of as *fixed in space,* as not participating in the earth's motions. This means that the origin O does not move and that the missile leaves B at the moment when B is vertically above O.

(i) The trajectory is extended from D to F because the horizontal component of the missile's velocity at B is increased from the locally imparted value $V \sin \gamma$ to $V \sin \gamma + \omega R$, where ω is the earth's angular speed of rotation and R is the earth's radius. The circumferential speed ωR, which the missile has before it is launched and retains during flight, is about 1600 ft/sec eastward; this is a sizable correction even for missiles for which $V \sin \gamma$ might be as much as 20,000 ft/sec. Note that for westbound missiles, this effect of the earth's rotation would reduce the length of the trajectory. For motion along any parallel of latitude λ other than the equator, the correction would of course have the smaller value $\omega R \cos \lambda$ eastward.

(ii) While the missile is traveling from B to F, the point on the earth's surface directly beneath B has advanced from O to O'. This extends the trajectory to the point G because the impact area has been displaced downward, from OF to $O'G$, during the missile flight. Such an extension would also occur for a westbound missile.

(iii) At O' the apparent horizon is the line $O'H$, which cuts the trajectory at H, and thus the trajectory is extended to H. Notice that this particular extension results from a downward rotation or tilting of the apparent impact area with respect to OX during flight. For a westbound missile the rotation of the impact area, as observed from O', would be upward, resulting in a reduction of trajectory length.

(iv) The trajectory is still farther extended, from H to I, because of the curvature of the earth, which gives the missile additional time to acquire range. This extension is positive, no matter in what direction the missile is traveling, and would occur even if the earth were not rotating. The longer the range, the greater will be this extension, because the separation of the spherical surface from the plane OX occurs at an increasing rate as the distance from O increases.

(v) The missile would reach point I only if the gravitational force on it were at every point parallel to the Y-axis. Actually this force is directed toward the center of the earth at every instant of the flight. Consequently a backward component of gravitational force sets in as soon as the missile leaves the thrust-cutoff point B, and its magnitude increases steadily with the time since the missile left B. The net effect is to shorten the trajectory, so that impact occurs at some point J, rather than at I. Acually the backward component of the gravitational force is associated with two different factors. One is the displacement of the missile from the fixed point O as a result of its locally imparted velocity V. This part of the backward component increases with the duration of flight, decreases as the distance of the missile from the center of the earth increases, and would exist even if the earth were not rotating. The other factor is the departure of the missile from O because of its velocity ωR resulting from the earth's rotation. This part of the net backward component is always westward, thus reducing eastward ranges and extending westward ranges.

Although our interest has been mainly to show in a qualitative way how the rotation and curvature of the earth affect the range, it should be said that the method used here can be generalized to cover the case of a missile projected at any latitude and in a trajectory the plane of which is directed in any desired azimuth. For any case, however, the approximations involved in deriving the mathematical expressions for the various independent correction, or *perturbation,* terms are least objectionable for missiles having small velocities at thrust cutoff.

Theory of Ballistic Trajectories

ALTHOUGH the foregoing approach is useful for illustrative purposes, computations of trajectories of great length must of course be based on Newtonian dynamical and gravitational theory. One starts with the assumption that the earth is a homogenous sphere and therefore attracts a missile as if all the earth's mass M were concentrated at its center (Fig. 22). We have then a two-particle problem, that of a missile of relatively small mass m in free flight under the gravitational attraction of another particle, the earth, of exceedingly large mass M. Notice that the only role played here by the earth's surface is to provide launching and impact areas for the missile.

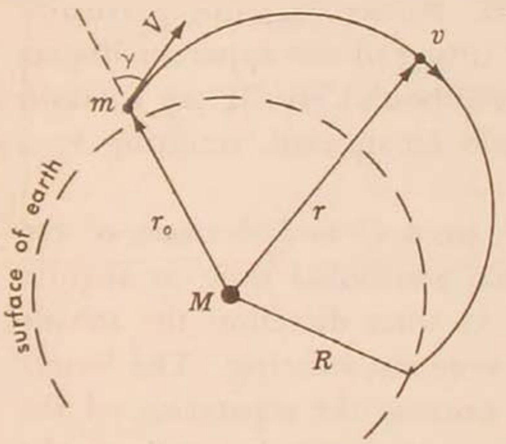

Figure 22

The trajectories to be used in coordinating the preliminary designs of the major subsystems of any particular type of missile are called *reference trajectories.* For this preliminary phase the trajectories will be sufficiently accurate if computed with respect to a nonrotating spherical earth. Thus the earth in Fig. 22 is to be thought of as motionless in an *inertial frame of reference*—a nonrotating set of coordinates in space that, for all present purposes, may be regarded as having its origin fixed with respect to the center of the sun. Newton's equations of motion then apply in their simplest form, and from them an equation for the various possible free-flight trajectories of a missile may be derived. This equation turns out to be the general equation of a conic section. As to whether any particular trajectory will be a parabola or an ellipse is found to depend on whether the ratio of the missile's kinetic energy to its potential energy at thrust cutoff is equal to unity or is less than unity. Knowing this, one can then show that the speed V of the missile at cutoff determines the type of path as follows:

(i) A parabola if $V = \sqrt{2GM/(R+h)}$, where G is the Newtonian constant of gravitation, M and R are the mass and the radius of the earth, respectively, and h is the altitude of the thrust-cutoff point. Inserting in this expression the known values of G, M, and R, and letting h be, for example, 100 miles, we find that V is approximately 6.9 mi/sec. For this cutoff velocity and any value of the projection angle γ (Fig. 22), the missile will escape from the earth along a parabolic path.

(ii) An ellipse with its nearer focus at the center of the earth (Fig. 23) if $\sqrt{GM/(R+h)} < V < \sqrt{2GM/(R+h)}$; that is, if V is between about 5 and 7 mi/sec.

(iii) A circle surrounding the earth if $V = \sqrt{GM/(R+h)}$, about 5 mi/sec, and $\gamma = 90°$. For other values of γ the path will be elliptic, but not circular.

(iv) An ellipse with its farther focus at the earth's center (Fig. 24) if $V < \sqrt{GM/(R+h)}$, that is, less than about 5 mi/sec.

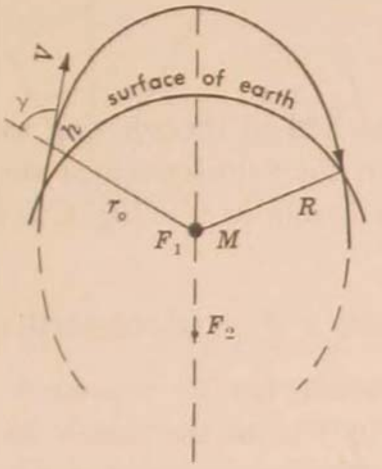

Figure 23

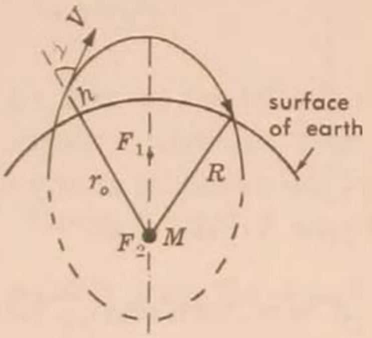

Figure 24

It is Case (iv) that is of interest in the ballistic missile program. For this one can show that to obtain maximum range for any given thrust-cutoff speed V, the projection angle γ must exceed 45°. The maximum possible range is half way around the earth, this being obtained when γ is 90° (horizontal projection), regardless of the altitude h of the thrust-cutoff point. However ranges exceeding about four-tenths of the way around become increasingly impractical because of the extreme sensitivity of the range to the angle γ and speed V. To get one fourth of the way around the earth when h is 100 mi, the optimum values are roughly 70° for γ, 4 mi/sec for V, and 0.5 hr for the flight time.

Effect of earth's motions. In computing accurate *flight test trajectories,* account must of course be taken of the effects of the earth's motions. This amounts to finding how velocities and accelerations measured on the earth, a noninertial frame of reference, can be transformed into data suitable for use in the basic Newtonian equations. Here we will be able to clarify some concepts—the Coriolis acceleration, the static vertical, and so on—that were of less importance a decade or so ago when air vehicle speeds were smaller and the accuracies of navigational instruments were just about equal to the magnitudes of some of the effects to be described.

In Fig. 25, let $X_iY_iZ_i$, represent a set of rigid coordinate axes fixed in inertial space and with its origin O_i located at the center of the sun; and let XYZ be a similar set of axes rigidly attached to the rotating earth and with its origin O at the earth's center. If V_i is the velocity (speed and direction of motion) of the missile m at any moment during its free flight, as seen from the inertial frame $X_iY_iZ_i$, then

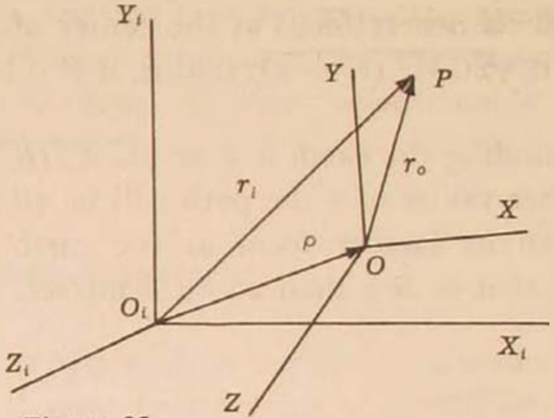

Figure 25

$$V_i = V_{obs} + \omega R \cos \lambda \text{ (always eastward)} + V_{orb} \text{ (along earth's orbit).} \qquad (2)$$

In words, the "true velocity" at any moment can be expressed as the *vector sum* of three components: (i) the velocity V_{obs} of the missile as measured by an observer on the earth; (ii) the velocity $\omega R \cos \lambda$ with which a point on the earth's surface at latitude λ moves eastward in a circle about the earth's axis, where ω is the earth's angular velocity about its axis, and R is the earth's radius; (iii) the orbital velocity V_{orb} of the earth's center O about the sun, of average magnitude about 18 mi/sec and in a direction in space that varies with the time of year.

The expression for the "true acceleration" a_i of the missile relative to the inertial frame $X_iY_iZ_i$ is obtained by differentiating Eq. (2) with respect to the time. The result, omitting unimportant terms, is

$$a_i = a_{obs} + \omega^2 R \cos \lambda + a_{cor}; \qquad (3)$$

that is, a_i is the vector sum of three components: (i) the acceleration a_{obs} of the missile as observed from the earth; (ii) the *centripetal acceleration* $\omega^2 R$ $\cos \lambda$, which is always directed toward and normal to the earth's axis, is possessed by the missile before launching, and is retained by it during flight (Fig. 26); (iii) the *Coriolis acceleration* a_{cor}, which will be discussed in a subsequent section. Omitted from Eq. (3) are two additional components of acceleration that are negligibly small: one is the acceleration of the earth's center in its orbit about the sun; the other involves the angular acceleration of the earth about its axis.

The Acceleration g and the Static Vertical

If the earth did not rotate on its axis, there would be associated with every point on and above its surface a pure gravitational field of intensity (acceleration) a_t. Its magnitude at any point distant r from the center of the earth would be GM/r^2, from Newton's law of gravitation, and its direction would be toward the center O of the earth. But actually the earth is rotating about its axis with angular velocity ω, and any object attached to it is continuously undergoing a centripetal acceleration $\omega^2 r \cos \lambda$ (Fig. 26). This means that the earth's gravitational force on the object must be resolved into two components: one of these produces the centripetal acceleration and is therefore directed perpendicular to the earth's axis; the remaining component produces the acceleration that we call *acceleration due to gravity* g. Thus, as shown in Fig. 27, g at any point is the *vector difference* between the "true gravitational acceleration" and the centripetal acceleration at that point, or

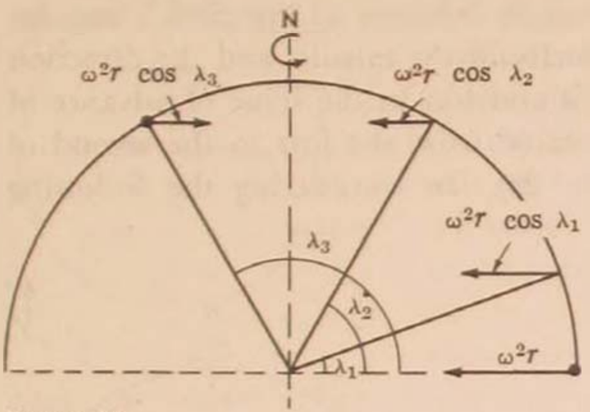

Figure 26

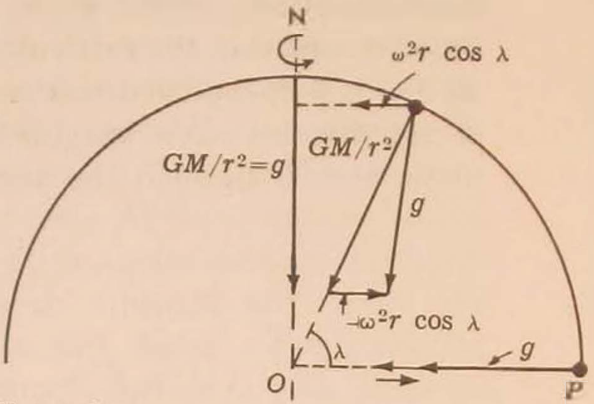

Figure 27

$$g = GM/r^2 \text{ (toward earth's center)} - \omega^2 r \cos \lambda \text{ (toward earth's axis).} \quad (4)$$

This variation of g with r and λ obviously might be a matter of considerable importance for a missile trajectory of great length and height.

The direction of g at any point is called the *static vertical* at that point. The surface of still water on the earth's surface is perpendicular to g, not to GM/r^2; and the earth as a whole, at a time when it was not rigid, similarly tended to adjust itself, taking approximately the shape of an oblate spheroid rather than a sphere. Only at the equator and the poles is g directed toward the earth's center O; and since mg is what we call the *weight* of any object of mass m, it is only at these places that the weight is directed toward O.

Advantages of having the concept g become evident when we solve Eq. (3) for the earth-observed acceleration a_{obs} and then insert into it the value of g given by Eq. (4). The result is

$$a_{obs} = g - a_{cor}. \quad (5)$$

In words, a_{obs} at any point of a missile's free-flight trajectory is equal simply to the vector difference between g and the Coriolis acceleration at that point;

tains, valleys, oceans, and abnormally high or low densities of the materials near the gravity stations. Such departures from the expected values are called *gravity anomalies.* Although gravity anomalies are small in magnitude, varying in different localities from about zero to about ±0.07 percent, they make possible refined determinations of important geodesic quantities: geodesic lines, deflections of the static vertical, and elevations of sea-level points with respect to the surface of the oblate spheroid used as a reference figure.

The Phases of Research, Development, and Production

Any missile program if successful, and in particular a ballistic missile program, involves the three definite but overlapping and blending phases of research, development, and production. There is more blending between research and development than between development and production. Ordinarily there is no abrupt transition between research and development. At the beginning of a program the proportion of research to development is high. Toward the end of the developmental phase, the research may taper off. Research and development are close together organizationally and require frequent and direct interchanges of information.

As in most military contracts, the research carried out is applied research. Its primary motivation is the fact that at the beginning of the program not everything is known that should be known to guarantee success. The scope of the required knowledge is not clear until the objectives and performance of the missile are defined. This usually involves specific advances beyond the state of the art. A secondary motivation derives from the fact that, even in explored areas, the technology on which missiles are dependent is in constant need of improvement. For these reasons a missile program profits by a vigorous and practical research effort at the beginning and a continued research effort to support the developmental phase.

Although it is wise to stay close to the state of the art wherever possible, any new program that promises major advances in military capability inevitably involves some corresponding advances in scientific knowledge and technology. The ICBM and IRBM have requirements of precision guidance that have not previously been reduced to practice in a complete operating system. The altitude attained is greater than that of any other military missile. This not only involves extensions of the current propulsion technology but raises questions about matter that may be encountered on the edge of interplanetary space. Further problems arise because of the wide ranges of temperature and vibration through which the vehicle must be designed to operate satisfactorily and reliably. There is a problem of safe return of the warhead through the atmosphere without overheating. Although a comprehensive discussion of such problems is not possible here, it appears safe to say that nothing has been found to date that would prevent the ultimate success of the USAF ballistic missile program.

If it were feasible for research men to foresee all problems and solve them before missiles were flown and if designers could always design correctly on first attempt, there would be no need for a developmental phase. In practice a missile necessarily must be developed as an extended series of designs, redesigns, tests, and measurements. Developmental hardware differs from research hardware not only in serving to prove out a principle but in being capable of practical use in the missile and adaptable to production with redesign only for changes in tooling or for easier assembly by workers of minimum skill.

The early portions of the research and developmental phases are centered on the attainment of one or more satisfactory designs. Eventually the emphasis shifts toward the demonstration through continued tests and firings that one or more designs are satisfactory. When a design is sufficiently proved out, the production phase begins, but evaluation of the design continues and some further improvements are made.

The production organization must prepare for the eventual full-scale production of the hardware by manufacturing it in gradually increasing quantities while perfecting the product and its method of manufacture. The operation must be relatively flexible at first, to permit necessary engineering changes that were not completed before production began. But the emphasis soon shifts to that of adapting the design as necessary for production tooling, for manufacture in sufficient quantity with plants of feasible size and without excessive demands of skilled labor and for manufacture at a lower cost per item, consistent with the other important requirements on the hardware.

Missile Reliability

THE probability of hitting the target is influenced in part by the dispersion of those missiles whose flights have not been influenced by major malfunctions and in part by the number of missiles that fail because of some internal malfunction or some difficulty in the ground equipment. Although a reliability group is normally concerned with the monitoring of aspects of design and manufacture that contribute both to dispersion and to loss, the reliability of the weapon system in strictest sense is related to the second aspect.

The *reliability* is defined as the ratio of the number of successful firings, with only normal dispersion and no major malfunction, to the total number of firings. The ICBM and IRBM are neither the most complicated nor the simplest of missiles under development. The more complex the weapon system, the greater, in general, is the reliability needed in the various portions of the system. Thus reliability is one of the important considerations in the development of any missile. The absence of a human pilot suggests that the reliability which can be tolerated is somewhat smaller than that for an airplane; but to attain this reliability in an unmanned vehicle is more difficult.

A reliability program is largely a matter of monitoring to ensure that the design techniques applied and the component parts utilized are the best that are available, that the environmental conditions of the missile—temperature, altitude, humidity, corrosive air, vibration, and so forth—have been taken sufficiently into account in the design, that extensive testing is carried out to support the development program, that even more testing is incorporated into the manufacturing process than with hardware for other applications, that adequate control of quality of workmanship is maintained, and that a well-balanced record of environmental conditions and performance histories is obtained from the missile flights. It will be noted how heavily dependent the attainment of satisfactory reliability is on testing, both to ensure that the hardware is built as it was designed and as an aid in perfecting the design. However, as the design matures, it is important that the need for further testing be kept to a minimum.

Extensive testing of hardware will be carried out in environmental chambers. Vibration is notably an awkward environment to analyze and design to, but the most advanced techniques currently known for data reduction and for simulation of vibration will be used. Of special importance is an efficient process for gathering data on reliability problems and ensuring that the diagnoses are used to improve the design or the manufacture methods at the earliest date consistent with maintenance of an orderly schedule.

The Approach to Testing

Any missile development is heavily dependent on testing. The schedule and the success of the development are critically influenced by the planning for the tests. Of special importance are the order in which the various tests are carried out, the relative emphasis placed on them, the complexity of any supporting equipment needed for making each test, and the adequacy of the test facilities.

The approach used in the USAF ballistic missile program is one of parallel or overlapping tests with an orderly progression from simple test items to a complete system. Extensive testing of detail parts, subassemblies, and assemblies is being carried out in the laboratory. However, flight testing is scheduled to begin at the earliest possible date because the optimum conditions for the laboratory tests are never known until a number of flights have taken place. Early flights are also necessary to verify that no important aspect of the problem has been overlooked in the initial planning.

The test vehicles begin with the simplest version of the ultimate weapon that can profitably be flown and gradually progress to a complete system, with no radical redesigns along the way. The only vehicles primarily useful for research are a rocket sled for testing of inertial guidance components and some simple vehicles for obtaining fundamental data on the re-entry problem.

To ensure that the tests progress rapidly, special efforts have been made to provide adequate facilities for testing in the laboratory and in flight. Of particular importance are the elaborate facilities and equipment for static firings and flight tests that have been provided at various centers, especially at the Air Force Missile Test Center, Cape Canaveral, Florida.

Flight Monitoring Equipment

As is true of most other missiles, the USAF ballistic missiles are expendable and nonrecoverable. Since the nominal target for a test flight is in the open ocean, precise location of the impact point is possible only with special techniques. Consequently extensive monitoring equipment is necessary to provide sufficient data for each flight to justify the expense and effort of the firing.

The flight monitoring equipment may be divided into two classes: the missile-borne sensing and radio telemetering equipment, together with the necessary ground-based receivers and recorders; and the ground-based radar and optical tracking devices located along the firing range. The telemetering systems respond to various voltages generated within the missile and transmit a corresponding code to ground receivers. The voltages may be signals of functional importance in themselves or may be generated by transducers as measures of temperatures, engine gimbal angles, vibrations, and so forth. A *transducer* is a device that is actuated by energy from one system—in the present case mechanical or thermal—and that supplies energy in the same or different form to another system—here electrical.

Unless special techniques are used, the information obtained by telemetry about the functioning of the various systems in the missile is only semiquantitative; it provides clues for the diagnosis of malfunctions but does not necessarily permit precise evaluation of performance. The optical tracking devices provide data on missile attitude as well as on position and velocity, but most of them operate only at short range in contrast to the radars. Some of the tracking equipment will have precision comparable to or better than that of the guidance systems, or at least have errors of somewhat different origin, so that a check on the precision of guidance can be made.

As with most missiles, the raw data provided by the telemetry and the tracking devices will not be in the most suitable form for study. Consequently an extensive *data reduction process* is necessary after each flight. This process, which consists of the conversion of the recorded data into meaningful form, such as curves or tables, will be carried on partly at the launch site and partly in contractors' laboratories.

Some Nonmilitary Advances

The effort expended in development of the ICBM will have benefits even when judged by peacetime standards. Significant advances in science and engineering will result.

The advances in science are primarily in those areas that are new or have become newly critical. For the most part they will remain of interest when ballistic missiles are no longer needed for military purposes. The supporting research and the test flights will contribute to geodesic methods and to more accurate geodesic data. Advances in celestial mechanics have been necessary, for instance, in the theory of elliptic trajectories relative to an oblate earth. Also in the general category of physics of the atmosphere and hyperatmosphere are problems associated with ion layers, properties of clouds (such as optical or microwave refraction), flame attenuation of radio signals, and the characteristics of atmospheric and meteoric dust. Extensive investigations have been made in hypersonics—the phenomena associated with motions at speeds large by comparison with the speed of sound—in radio wave propagation through a boundary layer generated by hypersonic flight, and in the properties of materials under extreme conditions of temperature and pressure. Advances have been made in fluid dynamics, especially in connection with vortex formation, and in connection with combustion phenomena and thermodynamics, especially combustion instability, dissociation and reassociation, nucleate boiling, and heat transfer.

Of necessity advances are occurring in engineering areas also, especially in connection with rocket power plants, structures (as in designs to reduce weight and to reduce stresses owing to thermal loads), guidance, control, and design of ground equipment. The development of unmanned vehicles for the purely scientific exploration of extraterrestrial, circumlunar, and interplanetary regions will be aided very materially by the work done in ballistic missile programs. For instance, no longer is it a matter of pure conjecture that eventually we may be able to land instruments on the surface of the moon capable of transmitting physical data back to the earth over a period of many days.

Some progress is being made too on the problems of reliability and operational safety, two areas that are of particular importance in relation to any future attempts at space flight. Reliability is an unwieldy engineering problem when one is dealing with advanced designs. However the efforts made on the ICBM to make it a practical and economical weapon will do much to improve our approaches to the reliability problem in general.

Los Angeles, California

Command and Control of Ballistic Missiles

BRIGADIER GENERAL CHARLES M. MCCORKLE

DURING the past year intensive effort has been devoted to planning for the command and control of guided missiles. I would like briefly to point out some of the problems involved with this planning and to give a few personal thoughts on the likely evolution of command and control of ballistic missiles. By no means do I have all the answers. My primary purpose is to stimulate thinking on the subject.

It is significant that for the first time we are engaged in detailed operational planning for a weapon system that has not yet emerged from the development stage. There is no time to wait for the information we usually have when we plan for the introduction of a weapon into the air inventory. With very preliminary data we must begin to integrate ballistic missiles into the existing Air Force command and control structure, taking into account those unusual requirements stemming from the nature of the weapon.

Since command and control can mean different things to different people, perhaps it is necessary to establish a meaning for the purpose of this discussion. At the very least it must include general considerations of command channels, organizational structure, and the problems of operational control and coordination. Effective control by the commander is absolutely necessary if the ballistic missile is to fulfill its dual function as a deterrent to war and as a devastating weapon if war comes.

In planning for effective control by a commander we can subdivide our task along several lines: defining objectives, preparing plans and programs, developing a suitable organization, establishing policies and procedures, placing into effect a system of reporting, allocating personnel, carefully training and orienting personnel, and adopting strict inspection procedures. It is especially important for ballistic missiles that we establish a means of reserving to the commander final decision in all major undertakings.

We are making good progress in these tasks, but we have by no stretch of the imagination solved all the problems or fully explored all the ramifications these weapons bring to any consideration of command and control. Because there are still many decisions to be made, we must continue the same level of effort that we are applying to the accelerated development programs. The necessity for this approach was implicitly recognized when the responsibility for attaining the initial operational capability was assigned to the Air Research and Development Command along with its development responsibilities.

Differences and similarities

Even without a great deal of study it becomes apparent that we cannot treat the command and control of ballistic missiles as though we were simply integrating additional bombers into our forces. The special characteristics of the missiles bring about a new operational environment and unique operational problems. The dispersed locations of the early units will pose problems of control that do not hamper the tightly knit operations of a compact air base. But I think that perhaps the most difficult problems we have to face are that the primary job of the ballistic missile organization is to *stay ready* year-in and year-out and that instead of "flying" most of the work will be "dry-running."

Not everything is new, however. Some of the problems of integrating the ballistic missile into our forces will be quite similar to those encountered in replacing the B-36 with the B-52. With the passing of any weapon system certain skills are no longer re-

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quired and new ones must be developed. For years, in one way or another, we have been coping with this problem. Nor should we have too much trouble with many of the normal housekeeping functions. Men of the ballistic missile wings will certainly eat and sleep much the same as the men in other organizations.

It is in the operational control and logistics areas that we find the need for substantial departures from established practices. Such characteristics as quick reaction time, the ability to strike an enemy within minutes after launch, the capacity for a high rate of fire, and relative invulnerability once in the air lend a new significance to the ballistic missile.

First let us consider the operational control problem. The nature of the weapon and its potential as an instrument of national policy dictate that the command and control structure be immediately and entirely responsive to the highest national authorities. The initial use of ballistic missiles will likely be closely controlled by the President, both personally and by means of instructions governing actions under various conditions. This circumstance places certain restrictions and requirements on the command and control of ballistic missiles that do not generally apply to other weapon systems. We must be very sure that we are being attacked before launching the retaliatory ballistic missiles. The margin for errors in judgment or information is very narrow. It is with these ideas in mind that the general framework for command and control should be established.

Although ballistic missiles will bring new and powerful capabilities to the Air Force, I think it is necessary that we treat them as part of the family of long-range offensive weapons when considering their application to warfare. This is necessary because for a long time to come it appears that an optimum strategic force will have both manned aircraft and long-range missiles.

In order to gain maximum benefit from the several manned bombers and guided missiles the various elements must be employed with careful regard to coordination of attack. While each weapon has its peculiar characteristics, there are many factors which they have in common. They all have long range; they have heavy warheads for destroying large or hard targets; their design is such that they should be used in strikes at the heart of enemy strength rather than at his minor defenses; for best effect they must be employed in large numbers; they require central planning; and the target examination, evaluation, and assignment process is one that must be centrally and closely controlled.

These features indicate that, while ballistic missiles should have close attention by the highest national authorities, there is nothing which should preclude the use of the existing command and control structure of the Strategic Air Command. The principle of central control of all strategic systems remains valid. I think it is absolutely necessary that all uses of large nuclear weapons, except in the missions of air defense and close support of the surface battle, be coordinated by a central agency. Therefore I believe that the decisions which have been made assigning the ICBM and the land-based IRBM to SAC are wise.

Complications

It is then necessary to examine the structure of ballistic missile command and control in light of two very fundamental ideas: first, close control by the highest national authorities and, second, incorporation of the weapon into the existing strategic air power command and control structure. After consideration of such factors as the effect of specific employment aspects, physical aspects, and support characteristics, it should be possible to determine just how much the existing strategic command and control must be modified.

As opposed to the general considerations mentioned previously, it is necessary to consider certain aspects in some detail. For example, when would ballistic missiles be used—only after an actual attack, or at some other unmistakable sign of aggression? This is not a decision which the military can or should make. It is a decision which should be made only at the highest level of government. Even though the military is not directly responsible for the answer to this question, I offer it as food for thought because we are directly concerned with the answer. In our basic planning for command and control we must build in sufficient flexibility to be able to accept various orders. For example, even if our first warning is the observance of hypersonic blips on Dewline radarscopes, we must be able immediately to launch a counterattack if our orders so dictate.

Since a very obvious advantage of ballistic missiles is their quick reaction time, we must take every precaution to protect our missile sites from crippling damage or destruction. There are two obvious courses we can follow here. The first possibility is to harden the sites so that any nuclear burst other than a direct hit would do relatively little damage. The cost of such a program runs into very high figures. The other approach is to provide protection by dispersal of our sites over wide areas. Although this is a cheaper method, it complicates the problems of organization, communications, and logistics. Initially we may depend upon dispersion to afford us the assurance that we will have a force-in-being at an early date. But there is no doubt that we must also eventually harden our bases to some degree.

The target complexes assigned to the early ballistic missiles must be compatible with their capability. Industrial complexes or large military concentrations are representative of the type of targets that can be most profitably attacked by our early ballistic weapons.

Another complex problem with which we are confronted is that we are unable to divert the ballistic missile after a very short time in the air; and of course the missile, once launched, cannot be recalled. This means, then, that we must have a very tight command structure that does not allow any mistakes. We are dealing here with decisions to be made in minutes rather than hours or days. We must balance the need to react quickly with the equally important need for a system of checks and balances which will prevent premature or accidental firings. Our command and control structure must be devised so as to make it immune to unauthorized firings—such as might be accomplished by saboteurs.

Several other physical aspects of the missile are important to a consideration of command and control. The inability of the missile to tell us what it did after being launched presents a problem. Based upon launch reports, radar track reports, and any other information he can lay hands on, the ballistic missile commander must decide whether enough missiles have been sent against any particular target. This points to the need for concurrent work in reconnaissance systems that will help tell us what the enemy is up to and what our missiles and aircraft are doing to him. Information of this kind will permit us to make much better use of a mixed force. For example, we might want to send several ballistic missiles against a target, knowing that the chances were against a good hit. But we might do it anyway in an effort to avoid high risks to our bombers. Yet without some kind of intelligence as to what happened to the missiles we would not be in a very good position to make a decision as to whether to follow up with bombers against that particular target.

Closely related to this problem is the difficulty of shifting the missile aiming point to any of a large number of targets. This creates the need for more detailed planning than is required for the manned bomber. Sequencing arrangements must be worked out well in advance to cover numerous operational situations.

A matter of logistics

Earlier I mentioned that in the logistics area we should expect to find the need for substantial departure from established practices. Since only a very small part of the workload of ballistic missile organizations will be "flying" and the greatest share will be keeping ready, command and control must reflect this situation. I think it is apparent that logistics will be more important to ballistic missiles than to manned aircraft. The aircraft can usually absorb a large number of malfunctions and still complete its mission or return home. Not so with the missile. We must begin to exploit all the newest techniques and methods developed in the field of logistics. For example, the use of electronic data-processing equipments and methods seems to have great potential for coping with the complex problems of supplying and maintaining ballistic missiles. This system should give the commander a much firmer control over his logistics than he has had in the past.

Communications requirements will be of far greater importance and larger magnitude than any system we have today. The communications system must be capable of handling a vast flow of information in a very short time. It must react instantaneously and transmit orders from one side of the country to the other in a matter of seconds. In addition there must be a backup system depending upon another entirely different means of communication. We may even need a backup for the backup. All of these systems must be completely tamperproof to prevent unauthorized orders precipitating a nuclear war. Without assurance of an effective and rapid communications system, any talk of a quick-reaction weapon system loses a great deal of its meaning. And still we must be prepared to act under prearranged orders in the event communications are knocked out in spite of all our precautions. In effect, we must have a completely foolproof communications system.

The actual sites chosen for the ballistic missile launch areas will have a serious effect on the command and control structure. It is reasonable to assume that Strategic Air Command strike bases would be a prime target of Soviet attack. We cannot afford to site our ballistic missiles on or very near these particular bases. But because of tremendous logistics problems we cannot afford to place them in a wilderness. For this reason and for economy considerations we must compromise and site ballistic missiles near enough to existing military bases so that logistic support is comparatively easy, but still far enough away so that an attack aimed at the base will not destroy the missile launch area.

I have mentioned earlier the problem of maintaining an alert status month after month, year after year. It is worthy of special note that the ballistic missile commander will encounter some fairly difficult personnel problems as a result of this type of operation. Keeping skilled men and maintaining morale in the face of boredom will require exceptionally qualified commanders. Capturing and developing the elusive esprit de corps will be one of their most important jobs.

Command and control structure

Now that I have touched on some of the major factors that will affect the command and control of ballistic missiles, I think it appropriate to consider how our command and control structure could be formulated. To get a clearer picture of what the organization of our ballistic missile structure should be, I want to make a few necessary assumptions:

> That we can develop and produce the necessary communications net for the use of Strategic Air Command.
>
> That the President only will be authorized to direct an attack, either directly or by standing order.
>
> That the missile sites will be widely dispersed.
>
> That the personnel and logistics problems can be solved.
>
> That targets will be assigned.

So far nothing has developed which demands that we throw out the conventional organizational plan of air forces: air divisions, wings, groups, and squadrons. Perhaps it will be necessary to make some revisions in nomenclature, but in the main I think the organizational theory will still apply. Initially I visualize a ballistic missile air division consisting of wings, each with several squadrons. As additional missiles are phased into the inventory, additional wings could be activated. When the quantities of ballistic missiles are sufficient, the entire ballistic missile organization could be placed under the commander of a numbered air force whose sole mission would be the control of ballistic missiles. This concept differs somewhat from the concept that intercontinental air-breathing missiles should be integrated under the same commander who commands manned aircraft.

There are proponents of this latter concept who would extend it to include ballistic missiles. Under this proposal a certain number of ballistic missiles would be assigned to each numbered air force of the Strategic Air Command. Their belief is that integration of these missiles will bring familiarity throughout the Air Force with these new weapons and the transition period will be covered more easily. My own view is that the ballistic missile is so different from other strategic systems in its operational characteristics that it must have special treatment. This can be offered best by a separate controlling organization.

One important aspect is that operational control of actual directions for launching must be placed high in the chain of command. If we are to use effectively the short reaction times being developed into the system we cannot possibly depend upon a system of relaying commands to numerous points in the organizational structure. This becomes even more apparent when we consider the problem of coordinating attacks of other weapons.

One exception to establishing ballistic missiles under separate Air Force commands could be the IRBM. It does appear reasonable to place the overseas elements of this missile under the command of the local Strategic Air Command numbered air force.

Timing

Both for the ICBM and the IRBM we must remember that the manned system and the air-breathing missile system have a longer time of flight to the target area. We must assure ourselves of close coordination between attacks by these forces, with their various characteristics, so that we avoid the possibility of destroying part of our own attacking forces. We must be careful to ensure coordination of attack so that our first wave of supersonic, intercontinental cruise missiles is not destroyed by the explosions of subsequent launchings of intercontinental ballistic missiles. We must bear in mind that the principle of coordination of attack applies nowhere more completely than in air warfare involving strategic weapon systems. We will have to develop means of concentrating our attacks on the various target complexes with minimum danger to the ensuing attacks. I do not visualize one single attack but a series of hammering attacks throughout the first several hours of the war.

A possible solution to the time schedule for this problem is to launch intercontinental ballistic missiles against targets deep in enemy territory. After a few hours the ballistic missile attack would cease, leaving a short period for the initial wave of supersonic cruise missiles to make their penetration to their assigned targets. These missiles would be followed by supersonic manned aircraft, hitting targets of shorter range or flying through corridors between atomic clouds. Following these supersonic manned aircraft would be the remaining portion of our force: the subsonic manned aircraft and subsonic missiles.

After the last wave of subsonic aircraft has departed for their bases the ballistic missile attack would commence anew, to be followed by the second wave of supersonic missiles and so on until our entire weight of attack has been laid down.

In summary, these are the elements we must have in an effective command and control structure for ballistic missiles:

- A safe, dependable, and rapid communications system.
- A time-phased plan for the use of ballistic missiles in conjunction with other weapons.
- A tight, well-knit command structure running from the highest national authorities to the launch position.
- A well-trained, dedicated nucleus of personnel upon whom the effectiveness of the launch operation will depend.
- A logistics system which is entirely rsponsive to the stringent demands of the weapon system.
- An effective means of maintaining esprit de corps in the missile organization.

Our problems are difficult but not insurmountable. Many of the problems we faced a year ago have been solved. No matter how they are finally settled, it is clear that the ballistic missile is arriving fast, that it is a potent weapon, and that it is here to stay. In the command and control function it will demand of our leaders and planners imagination, objectivity, and a freedom from preconceived ideas that can only be compared with the demands made upon military men when they first became the possessors of our old friend the airplane.

Headquarters United States Air Force

Organizing and Manning Ballistic Missile Units

LIEUTENANT COLONEL WILLIAM L. ANDERSON

ALL THE Israelite judges were instructed by Moses to decide the small matters, saving only the hard causes for the prophet. In the law this great organizational principle survives to this day. Despite its durability this ancient precept may be of little use in ballistic missile organizations. Ballistic missile leadership is characterized by the demand for prompt decision-making at all levels. The commander of a missile complex with his mighty responsibilities or the antenna specialist in his narrow area must face this challenge, each in his own way. This conclusion caps all our ballistic missile organizational studies to date. It promises to be a reliable rule for the future.

When the Air Force Ballistic Missile Division began operational planning concurrently with ballistic research and development activities, all the usual weapon system building blocks were missing. There was neither manpower nor personnel information. Organizational data was nonexistent. Hence this project was at once a test of and a stimulus to existing weapon system procedures. As with many new weapons, there was a tendency to overemphasize the complexity of the system, to exaggerate the difficulty of training, and to suspect the adequacy of the personnel identification system. For the most part these difficulties have not materialized. In fact the adaptability of existing manpower and personnel staff procedures has been a real asset.

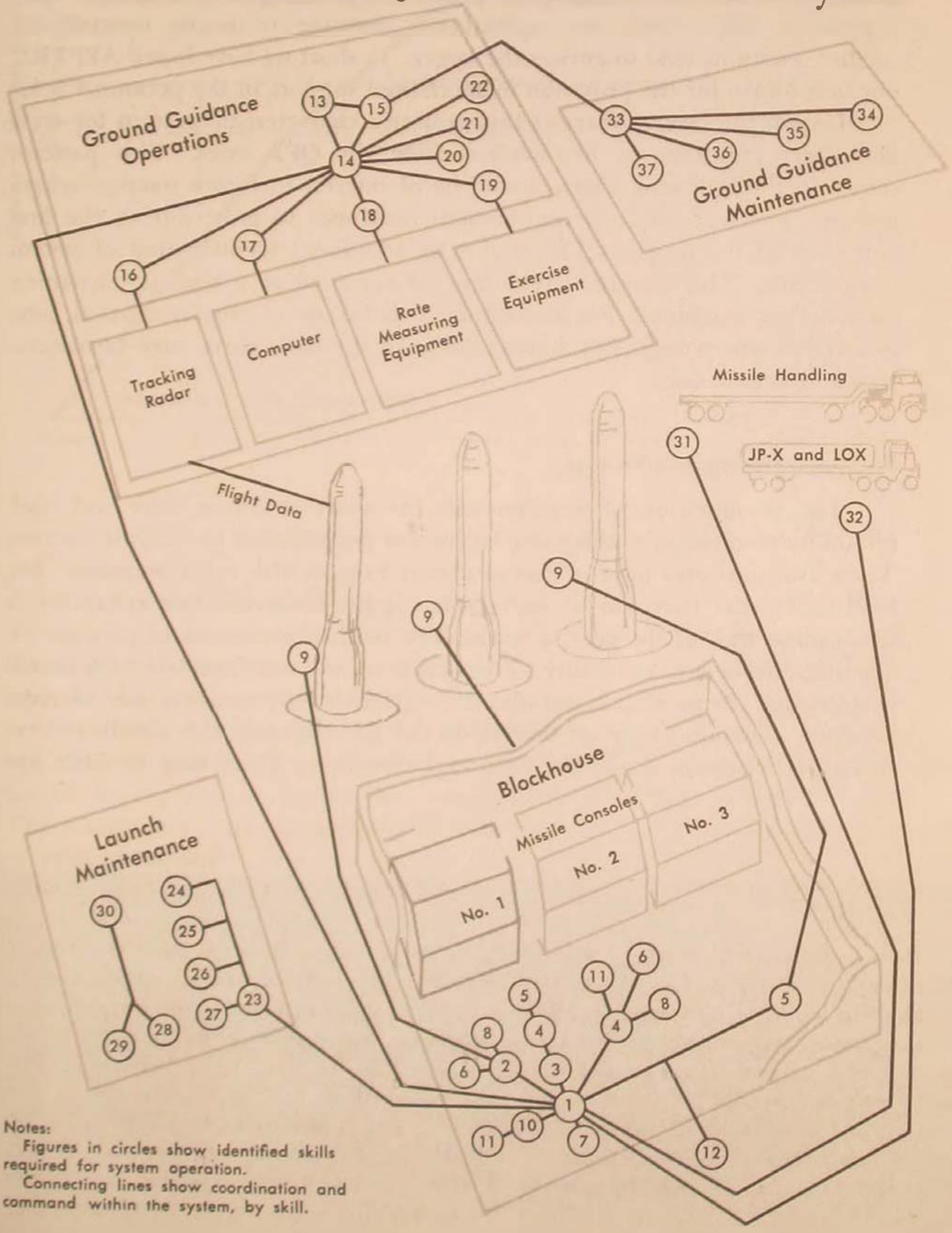
Developing operational criteria when a weapon is still in the rudimentary research and development stages involves the planner in a struggle to obtain basic information. In this search we have been greatly assisted by the Technical Training Air Force of the Air Training Command. The TTAF training-requirements specialists have shown admirable professionalism in supporting BMD planning. In future projects of this type it will serve the responsible agency well to consult with the Air Training Command at the outset.

Role of Air Force Personnel and Training Research

As has been mentioned, operational building blocks have been the scarce article. The difficulty here cannot be overestimated. The contractors are of course the sources of such data as may be available. But conversion and evaluation of contractor information require time and experience. Hence early in the program we turned for assistance to the Air Force Personnel and

Training Research Center (AFPTRC). This has proved profitable. By timely employment of qualitative personnel information (QPI) reporting procedures, we have enjoyed the use of excellent data reflecting job functions, and specifying training depth and equipment.

To provide qualitative personnel information for our schedules, AFPTRC has a direct working relationship with the weapon system contractors.



Initial Forecast of Job Functions for Atlas System

Notes:
Figures in circles show identified skills required for system operation.
Connecting lines show coordination and command within the system, by skill.

This allows the freest flow of information via AFPTRC to the Ballistic Missile Division. Prior to our receipt of job function and ancillary data, conversion and editing are accomplished by AFPTRC. The QPI has become a principal operational building block, the source for much organizational and manpower plans.

An example of the QPI application is shown in the foregoing chart. This is an early illustration of the Atlas (SM-65) crew requirements. Note the arrangement of crew members with respect to equipment and the resultant organizational logic. The use of this preliminary information, with occasional revisions, has facilitated operational planning of good quality. Our experience also teaches that operational planning is usually upward—the smaller questions tend to answer the larger. In short we have found AFPTRC our best source for the provision of specialized support in the personnel field.

During the several years of this project a characteristic pattern for crew manpower requirements has evolved from the QPI series. This pattern, shown in the following chart, should be of interest to future weapon system groups. The forecast crew requirement continues to grow during the first two years of the project. This is due to additional identification of system components. This growth period may be regarded as a time for matching men against machines. For the future a shrinkage of requirements is forecast as the system engineers, having designed the basic parts, turn to integration and automation.

Human Performance Factors

The combination of requirements for short readiness time and high reliability emphasizes a dimension of human performance in ballistic systems. These two measures have of course always existed with other weapons. For ballistic missiles they will be indivisible. It has been said that reliability is the leading trait of the good airman. The ballistic environment presages an equality of time and reliability. The missile countdown is replete with timed-performance demands. Naturally the various crew members are interdependent. The knowledge of how to do the job, together with timely and reliable performance, marks the successful crewman. There may be little op-

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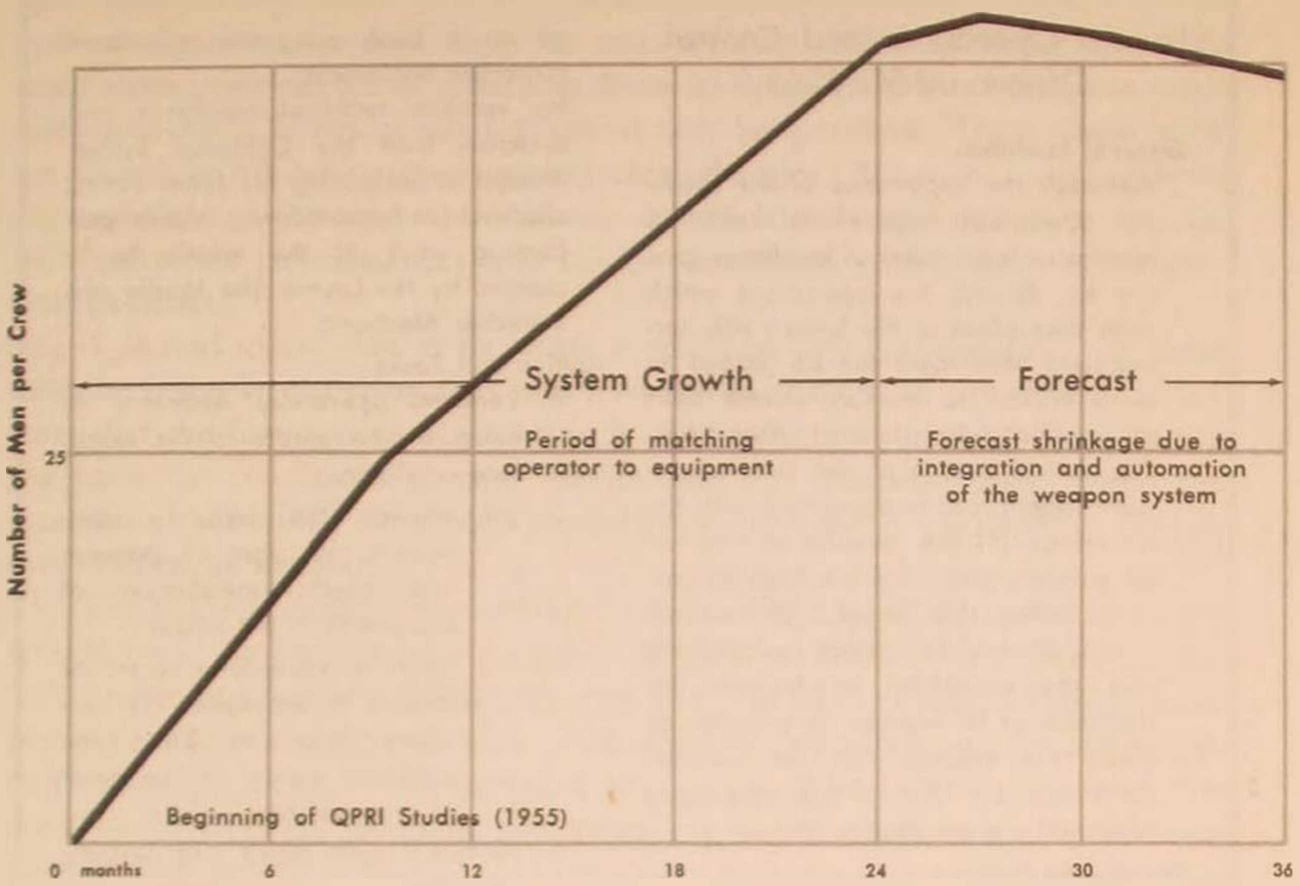
Forecast of Atlas Crew Requirements

Derived from QPR Information



portunity to check individual performance when the serious game is being played.

The timed-performance demand is abetted by a second major influence. This is standardization. Not only must standard crew operational procedures be established, but their rigid implementation is essential. With a crew several times as large as the largest bombing crew, we cannot hope to maintain total crew integrity. The ability to replace a crew member on short notice depends largely on standardization. This conclusion has also been reported as a principal operations rule from air-breathing missile systems. There are other forces of standardization. The launch officer will find his exercise of ingenuity largely restricted. The target is preselected. Weather is no longer a major factor. Where once military leaders implemented battle doctrine even at small unit level by varying their techniques, there is no requirement for this in ballistic systems. All this will mean a loss of the customary incentives. The missileman will be a student of standard methodology. The highly individualistic personality, capable but unorthodox, loses his special value in this rigid situation. There is a new market for the compatible person, capable of accepting the most uniform behavior pattern.

Monotony should flourish in this atmosphere. Indeed we expect monotony to increase directly with the growth of standardization. Crew mo-

Typical Officer and Airman Job Descriptions in Ballistic Missile Unit

Launch Operations and Control Officer—AFSC 3265

General Features:

Although the importance of the checkout operations required to hold the missiles at their states of readiness cannot be denied, the operations which must take place at the launch site during final countdown can be judged as more critical to mission success than those which take place at other times. The critical nature of the final countdown operations is associated with the following: (1) the pressure of time on all persons who have functions to perform during this period, (2) the lack of opportunity to correct malfunctions and the associated requirement for decisions as to whether to override or abort the mission, (3) the hazards generated by the fueling operations which take place at this time.

Duties and Tasks:

1. Prepares for a launching and operates Master Operations Console during an actual or simulated final countdown.
    - 1.1 Receives launching instructions from a higher headquarters.
    - 1.2 Instructs guidance station of launch requirement.
    - 1.3 Coordinates ongoing maintenance and servicing activities with launch requirement.
    - 1.4 Initiates a final countdown by instructing blockhouse personnel to perform the checks.
    - 1.5 Monitors and evaluates the status of subsystem checkout, fueling, and firing sequence.

Guidance System Specialist (IGS)—AFSC 31450

General Features:

The guidance system components are checked out at the launch site on a go no-go basis using the countdown controller equipment.

He receives technical assistance and direction from the Guidance System Analyst in performing his duties during checkout and countdown. When performing work at the missile he is assisted by the Launch Site Missile and Launcher Mechanic.

Duties and Tasks:

1. Performs operations necessary to bring a new missile to the readiness condition.
    - 1.1 Inspects the airborne components for signs of damage and checks installation of equipment in the missile.
    - 1.2 Operates countdown controller console to accomplish the necessary steps to bring the guidance system to the point of irreversibility.
2. Performs unscheduled and periodic maintenance of the ground equipment and airborne system.

Launch Site Propellant Handling and Storage Specialist—AFSC 64350

General Features:

The functions of this incumbent are principally those of operating and maintaining propellant transfer equipment.

Duties and Tasks:

1. Operates propellant transfer equipment during countdown or simulated countdown.
    - 1.1 Defuels missile at the direction of the operator of the Master Operations Console or the Launch Site Operations and Control Officer.
2. Performs maintenance and servicing functions of propellant transfer equipment.

notony is regarded as an ominous threat to system performance. To counter this, the commander will seek effective motivation. But how? First by crew exercises, using operational equipment together with simulation gear. The crew must be kept busy. Problems of every description must be fed into the system. Crews at random must be unexpectedly called to bring a missile from some lesser degree of readiness down to firing condition. In some exercises hold-down firings of short duration may be specified. These alerts must be flashed at all hours, even during crew changes. Surprise is an essential characteristic of the motivation effort. Actual launch of obsolescent missiles in appropriate circumstances will be the occasional culmination of motivation exercises.

A second motivation is to create a spirit of crew excellence. The crew must be brought to realize that it is a foremost element of the defense structure, that the functioning of the crew is of supreme importance. Considering the probable conditions of crew service and the irregular duty hours, the creation of this spirit is a harsh challenge to leadership. No sterner test of commanders is foreseen.

The ballistic commander, unlike a conventional weapon commander, has several crews for each missile complex. This is occasioned by an earlier Air Staff decision to preserve in ballistic systems the normal number of work hours per day. This normalcy for crew work-schedules promises to forestall major motivation problems. It is regarded as a great improvement over the "30 days on—30 days off" schemes previously suggested in some quarters. Some hope is even held that this normal crew shift will improve the bleak prospect in personnel turnover. It is interesting to note that those officers most likely to receive crew assignments have been the leading proponents of an eight-hour crew shift.

An eight-hour day and a sense of importance do not answer all the commander's needs. He must have an adequate physical plant to do the full job of motivation. He needs good barracks and good quarters. The level of intelligence required for effective crew members is one that will instinctively expect adequate living conditions. Ballistic missiles are not to be located within easy commuting distance of a pleasant city. Saving defense money by ignoring the requirement for personal accommodations simply will not work in this case. If we do not spend the money for quarters and barracks, we will spend it again and again in personnel turnover—a cost that few private enterprises could long endure.

Organization and Internal Communications

When one looks at the planned ballistic missile organization, one can see a layering of integrated interests. True organizational unity of action is demanded by the interdependence between job site centers. To achieve this unity of effort, it has not been necessary to derive a new type of organization. The launch complex is a performance-functional element, and its compatibility with traditional Air Force organizational concepts is self-evident.

Since the complex is functionally oriented, considerable effort has been devoted to the exclusion of nonoperational elements. The projected organization is designed to be a functional package, totally executive in character.

No matter how singular the organizational objective or how functional the unit design, certain practices may dilute and distort the intended pattern of group activities. Within conventional Air Force organizations, there is a marked tendency toward long span of control. Responsible operating officials are often prevented from making decisions on those matters about which they have the most direct knowledge. This is largely attributable to the growth and secularization of staff elements. There is no denying that integrated control of missiles requires that operational command levels be empowered with essential information. Missile status and targeting orders are foremost examples of the data required by successive levels of command. Conversely the launch complex, the lowest entity, must be freed from all unnecessary staff interference. An example of this is safety. Ballistic missiles are inherently so dangerous that safety is an integral element of the operation. The usual activity of a base safety officer, endlessly visiting and writing reports to some safety section in a distant staff, promises little but interference to the launch commander. Advisory safety services from a staff element may be helpful, but the relationship should be simplified and the tendency toward staff supervision of operations eliminated.

It has been said that if a single airman were assigned to sit on a rock in the Pacific, the mere application of existing regulations and policies would soon end in a whole air base springing into existence around him. The vested interests of many staff service agencies decree manning for this or that service, whether required or not. The launch commander must be spared this pressure. The present ballistic organization is relatively devoid of unessential elements. Keeping it clean will require a revision of Air Force documents. In essence effective missile operation means organization in which self-reliant men may freely exercise competence. There is neither time nor circumstance for an appellate relationship to a remote staff. Delegation is the prime rule for success.

All the lines stretching from one operator to another in the first chart would perhaps seem quite a long span of control, but these lines are for the most part merely indicative of the communications pattern. In this communications growth we see a notable characteristic of missile organization. The fueling function may be virtually an independent operation with little or no supervision. Yet the volatile nature of fuels and the importance of rapid fueling make it necessary for the launch commander to know at any point in time the exact status of this function. Rapid communication answers such demands. This example is perfectly compatible with the principle of delegation of function and functionalization itself. Future organizational efficiency may be served by regrouping and thereby shortening communications within a complex. In any event communication is and will continue to be a servant of function.

The growth of communications in the local command of missiles is accompanied by a lessening of informal relationships. By contrast, successful corporate efforts, such as du Pont's, have long prospered on informal relationships and on de-emphasis of the functional chart. Although organized under functional charts, military units in fact operate with unpublished relationships to some extent. The method of operation is bound up in a web of informal relations based upon personalities and accessibility of people. In a ballistic organization the informality is doomed by the physical layout and the personal separations. The flow pattern and sources of information in the launch complex are born on the drawing board. Hardware design determines speaking parties. Missile organization promises to be of unparalleled formality and characterized by intensity of communication.

I HAVE attempted to forecast a few of the ballistic organizational considerations for the future. It may be argued that some of these observations are not organization matters at all. Indeed this may be true. It is exceedingly difficult to separate personnel policies and operational conditions from organization. In the interest of provoking the reader's thought, I am listing a few more preliminary conclusions for him to ponder. Only time and experience will test these conclusions:

- There will be no requirement for a traditional reserve system.
- Airmen to be assigned to missile units will have careers exclusively in such units.
- There will be unusually high personnel turnover in missile units.
- Individual responsibility will be greatly increased, but operating practices will be highly standardized.
- Contractor participation will be greatly enlarged in logistics and maintenance.
- Difficulty will be encountered in the integration of missile units into conventional weapon commands because of differences of hardware, logistical methods, and force deployment.

Air Force Ballistic Missile Division, Hq ARDC

Logistics for the Ballistic Missile

Brigadier General Ben I. Funk

IT HAS long been conceded that combat units must be provided with immediately responsive logistics support if they are to continually maintain a state of peak operational readiness. The advent of missiles in the operational inventory further intensifies the need to streamline logistics actions. The ballistic missile, with its requirement for launching in a very short time after the signal is given, is a case in point.

When the over-all Air Force logistics picture is examined in terms of the requirements of the ICBM/IRBM weapon systems, an incompatibility is evident. The Air Force has embarked upon a program calculated to achieve a fast reacting, reflex logistics system within the next ten years. There are many manifestations of this. Logair, in the transportation field, is a major step toward attaining a proper logistics airlift posture. Air Materiel Command conducts service tests in many aspects of logistics, particularly in electronic data processing. Base supply is undergoing a mechanization program. But these long-range logistics goals, called "jet-age logistics," cannot be attained in the near future for the entire Air Force. The size and inertia of the present complex logistics system simply will not permit it. A streamlined logistics system of this size must be achieved by evolution, by a gradual injection of new and advanced techniques and procedures.

A closer analysis of the problem reveals that if we do not attempt to cure all the Air Force logistics ailments with one dose, the same objectives can be realized in a relatively short time. We can do this by focusing attention on segments of the operational force, thus confining the problem to a manageable size. The ballistic missiles represent such a manageable segment. It may well be that in streamlining logistics support for the ballistic missiles we will find that we have crossed the threshold into a new era of "rocket-age logistics."

The attainment of an early operational ballistic missile capability is obviously a matter of pre-eminent national importance. An extreme concentration of technical and management attention has been invested in this program, resulting in a marked compression of the normal cycle for bringing a new weapon into the operational inventory. Since the Air Force is denied the opportunity of preparing for the logistics-support task at its leisure, many of the present methods of doing things must be critically examined. Further we cannot afford the luxury of errors in preplanning. It is unnecessary to go into a lengthy discourse on planning deficiencies of past programs. One example is that Air Force packaging techniques in the past have not been fully in consonance with weapon design. And how many times have operational units been deployed when they were not fully equipped, thus degrading their capability?

It appears at first glance that there are insurmountable constraints to a proper approach to the ballistic missile logistics problems. Upon closer examination, however, these apparently burdensome conditions change character. It may be that a critical examination of some of the current procedures and ways of doing things, caused in this case by necessity, is a blessing in disguise. The realization that there is not enough time to do the things that must be done will cause attention to be concentrated on quicker and more efficient methods. The realization that a planning error of the order of some committed in the past would be disastrous in a program of this nature is another big step. The very establishment of the Ballistic Missile Division (ARDC), Ballistic Missile Office (AMC), and Guided Missile Research Division of Ramo-Wooldridge Corporation as a management team signifies the awareness of the need to vest the authority and responsibility for prosecuting a high-priority weapon system development program in an organization of unusual competence. This same philosophy must be applied in all of the complementing support areas such as logistics and training.

The problem of having to support operational weapons of quick reaction capability has been briefly touched upon. Ballistic missiles are weapons which can wreak devastation on their assigned targets thousands of miles away within a very short time after they are launched. Most assuredly they cannot be allowed to remain in a state of disrepair for any appreciable length of time. Lack of proper supporting spares and maintenance capability would be sheer waste of the inherent capability which the weapons possess. The tremendous cost of these weapons makes completely unacceptable overprograming of additional weapons, supporting equipment, or spares to compensate for those out of commission.

In our manned aircraft, components may be found to be defective after take-off and still not cause a mission abort. Skilled crew members can often

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take up the slack. In some guided missiles, such as pilotless aircraft, we cannot rely on the human factor but we still have in the guidance system a means for retaining control of the missile for a considerable period of time after launch. Such is not the case, of course, with the ballistic missile. Little time is allowed for correction of errors. The missile is soon beyond a point where we can exert any control over it. Reliability then becomes paramount. This applies not only to reliability of the weapon and its ground support equipment but equally to all contributing elements of the weapon system.

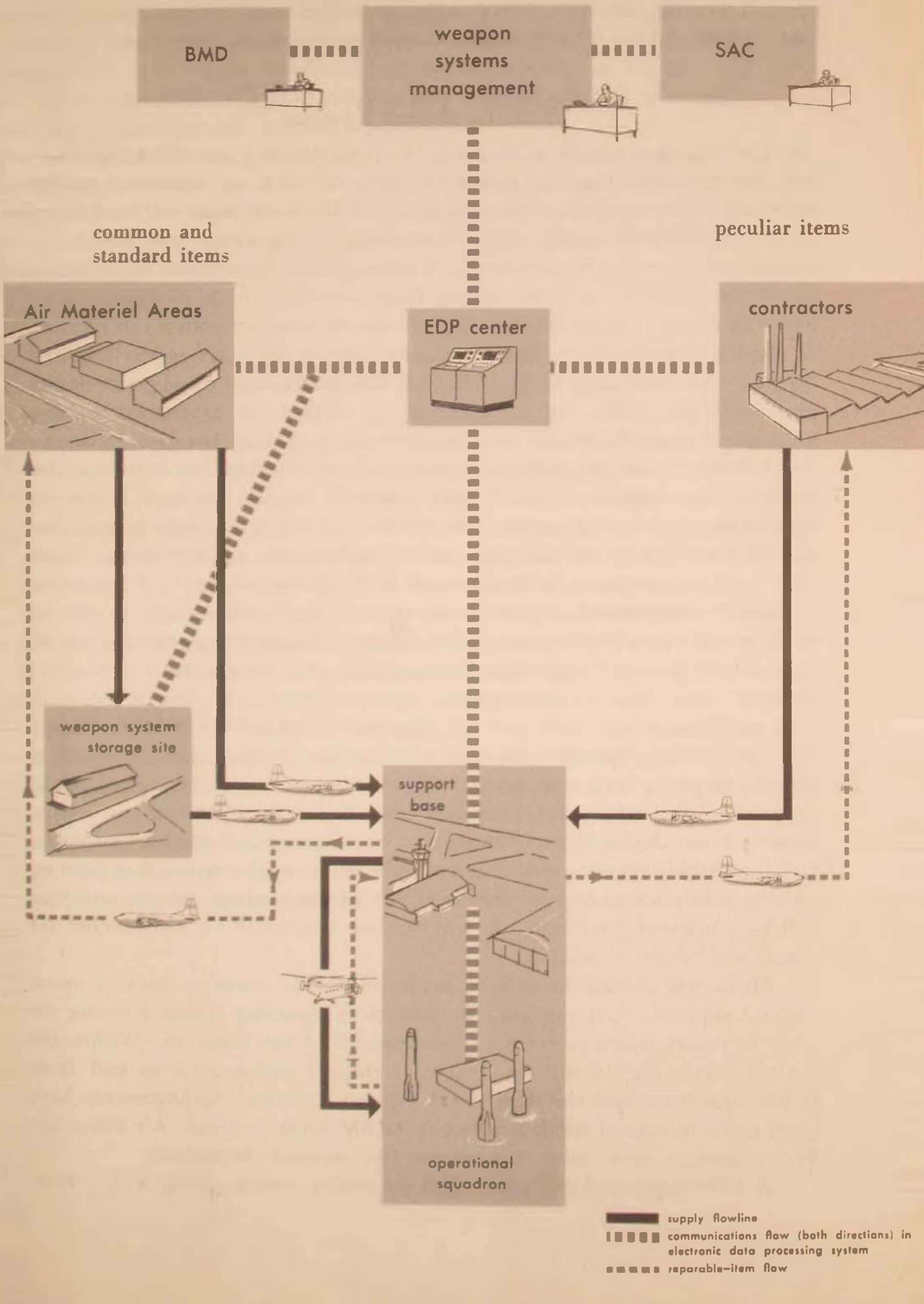
The Logistics Control

If attention is narrowed specifically to ballistic missile logistics it will be noted that many contractors are involved in the development of these missiles. Under the present Air Materiel Area (AMA) depot system many AMC field agencies would automatically, by virtue of the contractor alignment, be involved in the direct support of ballistic missile operational units. With such dispersion a logistics reaction capability satisfying the requirements of the ICBM/IRBM would have to invoke the utmost in cooperation, coordinated planning, and concentrated effort. To preserve the operational effectiveness of the ballistic missiles, the Air Force would have to expect a degree of fully coordinated efficiency that could not possibly be attained in any organization this large and compartmentalized without some form of central control.

The direction to be taken is clear. It has been necessary to delegate to one individual within the AMC structure full responsibility to develop a logistics system fully tuned to the requirements of these new weapon systems. At the same time we would be seriously remiss if we did not, in designing such a system, fully exploit those logistics procedures and techniques of an advanced nature which have been service-tested piece by piece during the past several years. We have an opportunity to give birth to some long-conceived tenets and to shake down in an isolated, yet not insulated, environment a logistics package based upon the weapon system management concept.

In recognition of the need to develop an advanced logistics system in close harmony with the research and development effort and to ensure readiness to operate on the date the first operational unit must be deployed, AMC published logistics plans early in the life of the ballistic missile program. Distributed in November 1956, these documents have the approval of the Air Force Ballistic Missile Division, the Strategic Air Command, the Air Training Command, and Headquarters USAF. They provide for the appointment of a weapon systems manager for ballistic missile logistics, charged with the responsibility of establishing and maintaining a streamlined ICBM/IRBM logistics system. The weapon systems manager has been established as a separate organizational element of Headquarters AMC, responsible directly to the Commander. He has been assigned prime and executive AMC responsibilities for ballistic missiles.

Ballistic Missiles Logistics Plan



The plans prescribe a logistics system that makes maximum use of electronic data processing devices to aid the weapon systems manager in performing the logistics functions connected with mission support of the ballistic missiles. They are based upon minimum stock levels, minimum pipeline time, direct support from source to user, minimum administration at the operational unit level, and optimum use of contractor maintenance.

The Logistics System

Let us examine more in detail the features of this plan. All components required in support of the ICBM/IRBM units and not currently stocked within the Air Force depot system as standard Air Force items will be initially supported for both supply and maintenance by the contractor who is developing the particular subsystem. As soon as such support can be rendered more effectively by an AMC agency, responsibility will shift to the AMA/depot structure. To provide the weapon systems manager with a full measure of control, those items stocked within the current Air Force system required for direct mission support of ICBM/IRBM strategic missile squadrons are also under his jurisdiction. This is not, it should be emphasized, a huge amount of materiel, but rather a small working stock of fast-moving items.

Ballistic missile operating squadrons will be satellited on host bases for housekeeping support. Those items required in the essential day-to-day operations of the squadrons to maintain them in a constant state of readiness will be provided by the weapon systems manager, on a direct basis. There will be no requirement for these items to be accounted for by a base-level, numbered, stock-record account as we now know it. Accountability will be held centrally by the weapon systems manager. Naturally operational squadrons will be provided with the small stock of items they require to perform their mission. Their record-keeping requirements will be held to an absolute minimum. They will not be required to submit formal requisitions through the long-familiar procedures to obtain supplies. On the basis of periodic reports, both emergency and routine, they will be automatically supplied with their needs. They will be authorized to perform such maintenance as can logically be effected with available skills, facilities, and space, and considering system complexity and reliability requirements. Any item requiring maintenance beyond the capability of the strategic missile squadron will be evacuated directly to the appropriate contractor or AMA/depot for repair and return to stock.

Maximum utilization will be made of mobile teams as backup maintenance support. A streamlined unsatisfactory-reporting system is being devised to ensure quick reaction to the demands of the situation. Within the United States Logair will be used to transport components to and from ICBM squadrons and the depot-level support agencies. Arrangements have been made to extend similar service to IRBM units overseas. Air Force airlift capability will be used to transport the weapons themselves.

A fully integrated electronic data processing system, along with a communications system, will link the weapon systems manager, the operating squadrons, a storage site for common items of supply, and the applicable contractor. All activities in this system will be provided with the latest communications terminal equipment to ease the problem of communicating between elements. The heart of the system will be an electronic data processing center which will streamline logistics action by predetermining and placing into a computer as many management actions as possible. All transaction information for the entire system will funnel into this location for proper recording and necessary action.

Considerations of vulnerability have not been overlooked. Backup provisions have been made in the event of any equipment failure. Provisions have also been made for the using command to participate in all levels of the development of this logistics system and in its operation. This will make for immediate responsiveness to the programing and operational requirements of the using agency.

THE system just described has not been planned on an "it would be nice if" basis. The system is attainable in the time period in question, if it is restricted initially to the ballistic missile organization. The ability to react instantaneously to a requirement, coupled with the close inventory control this system will permit, will save countless millions of dollars usually expended to stock larger quantities of spares. This is not to say that the establishment of this system will not be difficult. Highly trained personnel have been assigned to the effort because there is little time for the training of semiskilled personnel in the fields of electronic data processing, supply, maintenance, and transportation. Those personnel chosen for the effort have had to undergo a highly selective qualification review. Full use will be made of heretofore separate and unintegrated electronic data processing research programs recently completed, currently in process, and now being planned within the Air Force and industry. The best talent in the business has been marshaled to the task. There is little doubt that the service-testing of this support concept and of the fully integrated electronic data processing system it uses will provide a wealth of data useful to all echelons of management within the Air Force. It will doubtless become a signpost to the future of the entire Air Force logistics structure. It should point the way for other weapons systems on the drawing board and in early stages of development.

Ballistic Missiles Office, Hq AMC

Impact of the Ballistic Missile on Industry

Brigadier General Ben I. Funk

Part I: From the Air Force's Viewpoint

THE real impact of the development-production of ICBM/IRBM is found in our current position. We are producing in quantity a weapon system that is still in development. Except for this time compression, the problems in converting a development to a production program in ballistic missile systems are similar to those encountered in the development-production of any major Air Force weapon system.

This weapon system, however, is the largest project in point of dollars and ultimate yield in the Air Force program. The reasoning that dictated the time compression of development-production gave the basis for according the ballistic missile the highest Air Force priority and ultimately the highest national priority. The decision by the President that this program was "second to none" has been well publicized.

The original action to make this program "second to none" was to give it top listing among a small number of the nation's vital projects. While this served to establish the program as a vital project, the practical effect was to make it "second to none" but equal to several. All projects in this group had equal priority and the effect of top listing was largely psychological. In many instances the ballistic missile was competing with conventional programs for critical goods and services. Even though red tape was cut, valuable time was lost in justifying diversion of material or effort to the ballistic missile. The conventional industrial priority rating of "DO" was simply not getting the job done.

As the first step in obtaining more emphasis for the ballistic missile effort, particularly in the lower tiers of subcontractors and suppliers, a distinctive ballistic missile stamp indicating "urgency" was devised and its use was authorized by the Department of Defense. Although carrying no priority in itself, its psychological effect was highly beneficial. Contractors and subcontractors promptly applied it to their subcontracts and purchase orders. It had the very practical effect of indicating to a manufacturer that his particular product was destined for a ballistic missile. But despite the benefit obtained from conventional priority ratings and distinctive identification of contractors' orders, something more finite was needed.

This came early in 1957 when the Office of Defense Mobilization decided to award the highest industrial priority rating, the "DX" rating, to the ballistic missile program. Used heretofore as an identification of directive action by the Business and Defense Services Administration (the agency charged with administrating industrial priorities), this rating was now to be applied to all ballistic missile contracts, subcontracts, and purchase orders. The ballistic missile program is now in truth "second to none."

This action has in itself brought an impact on the over-all aircraft and missile industry. When competition for application of effort or time of delivery exists, the manufacturer must now give precedence to the ballistic missile orders over lower priority orders. This may mean that the supplier must devote his effort to smaller or even less profitable orders to honor the high priority of the program. At the same time his other customers must wait in line. The supplier of critical materials may experience delivery conflicts even within the ballistic missile program. These are resolved within the BMD-BMO complex on the basis of in-program urgency.

Principal Contractors

Who, then, makes up the industry that is taking the impact of the ballistic missile development-production time compression, the great costs involved, and the pressures of its primary urgency? There are fifteen carefully selected prime contractors within the ballistic missile complex, three in

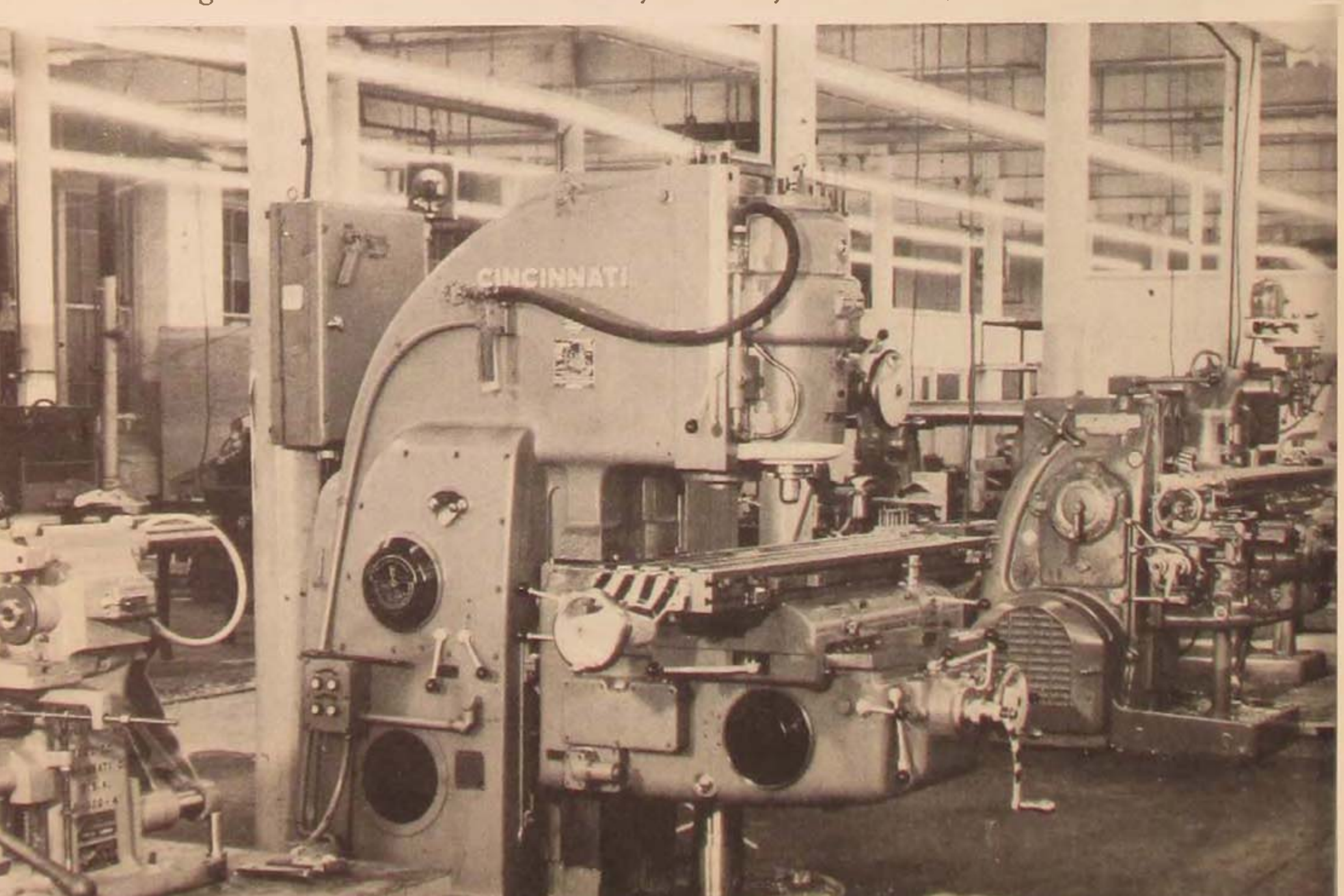
Major Contractual Areas

airframes, three in propulsion, six in guidance, two in nose cones (or warheads), and one contractor with over-all technical guidance. Stemming from these primes are approximately two hundred principal subcontractors in all parts of the country.

The anchor man on the Atlas missile team is the Convair Division of the General Dynamics Corporation as producer of the airframe. Convair, builder of many planes from B-24's to B-58's, certainly needs no introduction. Atlas propulsion is the responsibility of North American Aviation's Rocketdyne Division. North American is best known as the home of World War II's T-6, B-25, and P-51 aircraft and the postwar Sabre series. American Machine & Foundry, a manufacturer of tools and intricate equipment for industry, is furnishing the accessory power supply. The guidance system is the responsibility of the Missile Section of General Electric's Heavy Military Electronic Equipment Department. The accompanying computer is being manufactured by the Burroughs Corporation, a well-known name in business machines. As builder of the nose cone or warhead, the "payload" of the ballistic missile, General Electric's Missile and Ordnance Systems Department was selected.

On the Titan The Martin Company, an aviation industry pioneer, is producing the airframe. The engine as well as the accessory power supply comes from the new liquid-rocket plant of Aerojet-General, a division of General Tire and Rubber Company, well known as producers of solid-propellant assist take-off units for the armed services. Alternate radio-inertial and all-inertial guidance systems are being provided by the Western Electric Company, the communication experts, in conjunction with the Bell Tele-

Milling machines used in the manufacture of nose cone, Avco, Everett, Mass.



phone Laboratories and American Bosch Arma. The latter firm has had long experience in building highly precise diesel injection systems and more recently in supplying gun fire-control systems to the Air Force. The computer on this weapon system is the responsibility of Remington Rand Univac, a leader in the computer field. The warhead on the Titan is being produced by the Research and Advanced Development Division of Avco. Avco, a diversified manufacturer, pioneered the shock tube experiments in connection with the problem of re-entry of the nose cone into the atmosphere.

The Thor, as may be seen, has benefited from experience in other ballistic missiles. The Douglas Aircraft Company was selected as the airframe producer, with North American's Rocketdyne Division manufacturing the engine. Western Electric is providing the guidance system, and the accompanying computer is by Remington Rand Univac. An alternate guidance system is being developed by the A C Spark Plug Division of General Motors, best known to the Air Force as makers of fire-control and bomb-navigation system components. The nose cone is being produced by General Electric in conjunction with its Atlas effort.

In addition, of course, are many research and study contractors, including such well-known organizations as Lockheed, Massachusetts Institute of Technology, and Union Carbide & Carbon.

Finally, to provide technical direction for the entire program, the Ramo-Wooldridge Corporation is on contract as a nonhardware-producing partner of the Air Force. Ramo-Wooldridge is a relatively new but extremely well-qualified engineering and scientific contractor, whose Guided Missiles Research Division provides the integration and coordination of the activities of all separate contractors contributing to the program.

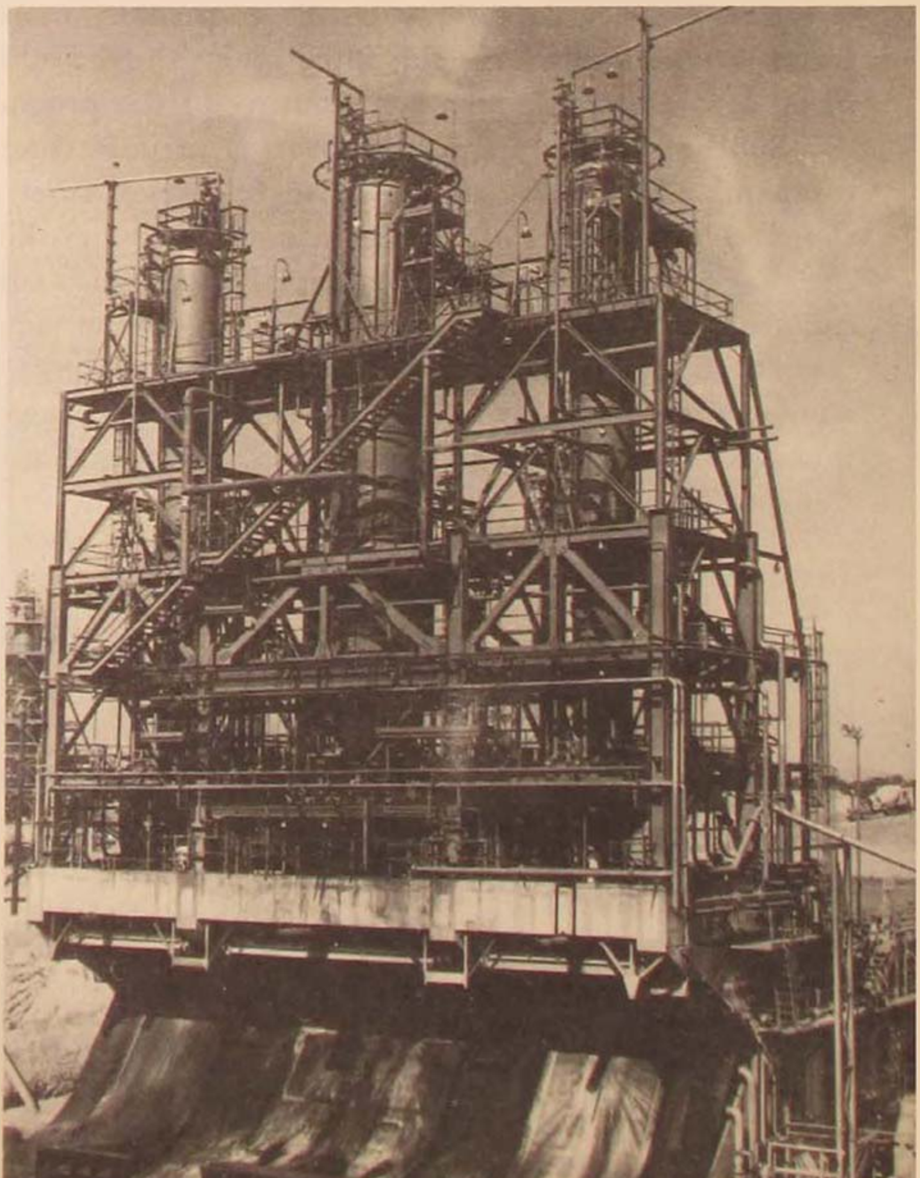
Subcontracting ranges from bearing manufacturers to electric instrument companies, from valve producers to foundries, from universities to machine shops. The resources of experts in every necessary skill have been tapped for the exacting requirements in point of time and accuracy. Beyond these two hundred first-tier subcontractors, and down the subcontract chain, are the myriad suppliers and vendors, producing to tight schedules and in many instances endeavoring to meet simultaneous demands of several ballistic missile contractors for critical material or equipment from highly specialized but limited production.

Industrial Facilities

The advent of the ballistic missile has placed a new impact on industrial facilities, both contractor-owned and Government-owned. The requirements for the highest possible degree of reliability are paramount and inherent to the eventual success of the ballistic missile as an operational weapon system. This demands more exacting manufacturing and prooftesting of a type and scale not encountered in the production of manned aircraft. Additional quantities of precision machine tools had to be manufactured, a huge amount of new laboratory and test equipment had to be created, and an entirely new family of contractor and Government test complexes had to be utilized in testing entire systems and individual components. Most of the major corporations participating in the ballistic missile program have chosen to segregate their ballistic missile activities by establishing separate, essentially autonomous divisions, and have been or are in the process of building new plants to house them.

The magnitude of the impact of the ballistic missile program on industry and on industrial facilities can be best expressed statistically. From late 1954 into 1957 the Air Force has provided contractors participating in the program with industrial facilities amounting to $154,000,000. This figure excludes investments at test sites. By July 1957 the industrial facility investment approached $200,000,000. Contractors have also made substantial investments and have spent about $100,000,000 of their own funds for industrial facilities during these three years. Most of the funds provided by the Air Force have been spent for machine tools and related production equipment, for laboratory and test equipment, and for test stands located in the vicinity of contractors' plants. Included in the contractors' investment are seven new plants built to support the ballistic missile program.

In that program, more than in other defense programs, there has been a demand for highly specialized facilities that would be of no value to a contractor for other work. Defense contractors normally are unwilling to invest large amounts of their own capital under such high-risk circumstances.



View of rocket propulsion engine test stand, Aerojet-General Corporation, at Azuza, California.

Many of them expect the Government to provide all or a major portion of the required facilities. Yet the Government has provided to the total of all contractors in the ballistic missile program a smaller dollar amount of industrial facilities than was previously provided a single Air Force contractor for facilities in support of an aircraft engine program. Contractor investment, as previously shown, has been substantial, in spite of the fact that the work to date has been principally developmental and that no contractor has complete assurance he will be given a contract for quantity production. Program priority reduced administrative lead time in the processing of contractor facilities requests. It has not reduced the requirement to justify Government-facilities assistance. On the contrary, the Ballistic Missile Division—Ballistic Missiles Office—Ramo-Wooldridge complex, as the result of program priority, reviews very carefully each request for Government assistance and requires detailed justification prior to granting such assistance.

Comparison with Conventional Aircraft

We have established a substantial industrial capability which can produce the best engineered weapons that our technicians and industrial complex can provide. Of course the requirement to secure the earliest possible tactical capability has dictated this approach. We have a time-compression situation not duplicated in our previous experience with manned aircraft. With the manned vehicle we have the opportunity of amassing a large number of test hours and data. With the ballistic missile only a few minutes are available to secure test data since the missile is destroyed. Thus we must commit to production substantial quantities of materiel before conclusive test results are available.

As speeds increase, man's natural limitations force us to increasing dependence on electronic controls. The commander of a manned aircraft is becoming more of a "Chairman of the Board," the Board being a control board full of electronic devices. With the guided missile the man has been pulled out of the plane and his cockpit is on the ground. A new zenith of the trend appears in the ballistic missile. Here man and his control board aim the missile at its intended target. Virtually from that point on, a hit on the distant target depends on electronic resources within the weapon. Man, although handicapped by a narrow environmental tolerance, has a high reliability factor and the power to reason. Duplicating this reliability and reasoning, in terms of reaction, in materials and electronics is an awesome assignment. Quality and systems reliability must be stressed.

Obviously with such high goals of reliability and quality accompanied by the peculiar strains and stresses placed on this type of missile, advanced manufacturing techniques must be devised. This impact, not common with conventional aircraft, is being met by industry in design, application, metallurgy, metal working, circuitry, and tooling.

A program of this magnitude and complexity will generate competition for materials, parts, and equipment. The great impact is on lower priority programs competing for the material left after the higher priority needs have been satisfied. This could lead to shortages in other Air Force projects, both in production and field support. To prevent this, contractors on lower priority programs must submit requests for priorities assistance to the government to provide the needed material delivery. Ballistic missile contractors are also being limited in acquiring materials to a minimum rate consistent with their delivery schedule.

Another national resource subject to impact is manpower. In July 1957 approximately 40,000 people were employed in the prime contractors' plants for this program. This is an area less sensitive to priority ratings and directives but more reactive to company policy and skill availability. Considering the complexity of a weapon of this kind, it is understandable that a proportionately large part of the manpower must be devoted to engineering. The competition for engineering and scientific skills is further compounded by the speed necessary in manning the program. As development breakthroughs occur, they must be quickly engineered into the design. At the same time production people must incorporate the changes into the product with the least possible delay. Again time is the crucial element.

Part II: From an Airframe Manufacturer's Viewpoint

The Martin Company

On first examination it appears that the impact of the ballistic missile on the airframe industry would necessitate little change in manpower or facilities. However the efficient production of the ballistic missile requires methods, techniques, and engineering concepts not previously encountered by the airframe manufacturer. This impact becomes evident only when the entire concept of the ballistic missile is compared to that of the manned aircraft.

The military aircraft has evolved from engineering knowledge and new concepts of manufacturing into a highly complex weapon system composed of mechanical, electronic, structural, and electromechanical subsystems and components. Its weight empty can be as much as fifty per cent of its take-off weight. Most of the elements that make up the system are designed to be directly operated or controlled by men—at least the crew of the aircraft can monitor the performance of the subsystems. The military aircraft is designed for repeated use, with provisions for maintenance and repair between missions. It is also designed for operation with other aircraft—thus the failure of one aircraft in a flight usually does not completely abort a given mission.

A ballistic missile is also a highly complex weapon system composed of the same basic elements as a manned aircraft. In fact, without the engineering knowledge and manufacturing skills developed for the production of manned aircraft, the evolution to missiles would not be possible. But the ballistic missile is significantly different in some respects. Its weight empty should not exceed ten per cent of its take-off weight (ninety per cent must be devoted to fuel). The subsystems of a ballistic missile cannot be directly

Site of new ballistic missiles plant, The Martin Co., Denver, Colorado

controlled or monitored by man. The ballistic missile is a one-shot weapon—it either functions properly or the mission is aborted and an expensive vehicle is a total loss. Therefore the need for extreme reliability becomes the key to the success of any ballistic missile.

Reliability a Must

The demand for extremely reliable components and subsystems in the ballistic missile has its most obvious effect on the personnel requirements of the airframe manufacturer. These requirements show a change in three respects. The general level of technical knowledge throughout the organization must be of the highest; the distribution of technically trained people between engineering, manufacturing, and testing functions shows a marked change; and the total number of people required to produce a ballistic missile is slightly less than that required to produce a manned aircraft.

The reliability requirements of the ballistic missile affect every item that goes into the final product from the smallest bolt to the most complex guidance system. The implications of any variation from quality standards must be recognized by every individual in the organization—designer, machinist, inspector, assembler, and test engineer—and require greater technical skill and knowledge in each individual. This demand for greater technical qualifications has been gradually increasing as the complexity of airborne vehicles has increased. The transition from manned aircraft to ballistic missiles increases the demand almost as much as the transition from wood-and-fabric to metal airplanes.

The greater technical skill and knowledge of each individual in the organization naturally tend to reduce the total number of people required to do the job. Here again reliability plays a part. By reducing the number of people concerned with a particular item, the chances of maintaining its reliability are increased throughout the production process.

The third point of impact of missile production on the airframe organization's personnel is in the distribution of people between engineering and testing functions and manufacturing operations. The higher speeds, new environments, and greater reliability of the ballistic missile will require a higher percentage of engineering effort, at least until the art of missile production becomes as familiar to us as the production of manned aircraft.

The impact of the ballistic missile on airframe manufacturing facilities can be illustrated many ways. The machine tools used to produce manned aircraft are also used for missiles. However, since ninety per cent of the ballistic missile's take-off weight is devoted to fuel tankage, there is an increase in facilities for welded sheet-metal construction. The reliability of the tankage is a function of the design, the quality of the material, the number of joints, and the finish of the metal. Thus the facilities for heat-treating, plating, and cleaning large sheet-metal units have increased. The need for automatic welding and nondestructive testing equipment is also greater in a missile production plant. But basically the ballistic missile only requires closer tolerances and more attention to reliability factors throughout the manufacturing process.

Testing

In the field of testing, the ballistic missile demands facilities not required by the production of manned aircraft. For convenience let us consider three basic types of testing—laboratory, captive, and flight testing.

The laboratory test facilities for ballistic missiles must be equipped to simulate environments whose characteristics are still conjectural. Materials, components, and subsystems must be subjected to extremes of temperature, pressure, acceleration, radiation, and shock. These conditions and the reliability requirements create a formidable quality control problem for the laboratories. Completely new facilities must be constructed.

The captive, or field, test facilities for ballistic missiles are of course vastly different from those required for manned aircraft. No airstrips are needed for taxi tests, but captive test stands capable of simulating all launch conditions and limited flight conditions must be available. The instrumentation required to test a ballistic missile is far greater than that for a manned aircraft. The nature of the missile and its behavior defy the direct human observation which is so valuable in the testing of conventional aircraft. In fact test personnel must be protected in concrete structures at some distance from the test firing. Yet the reliability requirements of the missile demand closer control of test conditions and more data recording than the ground testing of manned aircraft. The ballistic missile also multiplies the noise-suppression problem a hundredfold. The development of effective noise suppressors for jet engines is progressing rapidly but it will be years before a suppressor will be developed for the tremendous blast of a ballistic missile's rocket engine.

There are new problems in the handling of fuels in the test areas. We have been handling gasoline for years, and the safety precautions have become routine. The hazards in handling missile fuels and oxygen supplies are new and quite different in many respects. New facilities for the safe storage and handling of large volumes of these materials must be constructed.

The production of a ballistic missile obviates the need for any manufacturer's flight-test facilities. The Air Force Missile Test Center, with its range over the Atlantic, is the only available flight-test facility for long-range missiles. This is in contrast to the desirability of having a flight-test facility adjacent to the manufacturing operation for manned aircraft.

In general, then, it can be said that the impact of the ballistic missile on the airframe industry expresses itself in the need for more highly skilled and technically trained personnel, more exacting control of manufacturing processes, and more complex testing facilities. This effect is certainly consistent with the effects of all technical advances. As we gain the knowledge to conceive (and increased ability to construct) more technically complex products, our need for such skill, knowledge, and products increases by geometric progression.

Part III: From a Rocket Engine Producer's Viewpoint

Rocketdyne Division, North American Aviation Company

The development and production of high-thrust propulsion systems for ballistic missiles have created an industry at once similar and dissimilar to those producing conventional reciprocating and turbojet engines. Producers of rocket engines have built their industry with engineering and manufacturing skills essentially the same as those used in the production of other engines. But the engine itself—the high-thrust, liquid-propellant rocket—has created unique developmental and testing problems and has demanded concentrated effort to advance the state of the art.

With rocket engines the development engineer faced a propulsion system employing a liquid rather than a gaseous oxidizer for combustion. More important, his engine was required to produce 100 to 1000 times the thrust of conventional engines of comparable size and weight. At the same time his engine was required to operate through errorless, automatic sequences for brief durations. These factors created testing requirements that demanded new concepts in facilities and methods.

Engine Reliability

The development engineer early encountered reliability problems that varied substantially from those encountered with conventional engines. Ballistic missiles demanded that the engine start without error and operate automatically, rather than that it run for thousands of hours after it started. Also it was apparent that this reliability had to be achieved largely through testing at the manufacturer's plant rather than through service use of the engine in operational vehicles.

With conventional reciprocating engines, for example, crews can run up an engine on the ground as often as necessary to gain proper operation. Failure of the engine to start the first, second, or third time the starter button is pushed usually produces no more of a trouble report than a swear word by the mechanic. Early coughs and sputters also go unreported if the engine clears and develops full power within a few minutes. Minor adjustments, such as plug changes, also fall in the category of unreported incidents unless they develop a pattern of frequency. Should the engine fail during runup prior to take-off, the pilot can taxi back to the flight line for service. While this could abort a military mission, such a failure in transport or liaison flying results in nothing more serious than a delayed take-off.

For the ballistic missile the rocket engine must start and operate smoothly and develop full thrust within less than a second after the start button is pushed. Any malfunction during the start or buildup of thrust could destroy both the engine and the missile. Furthermore the only preflight checks that probably can be made by the ground crew will be electrical, hydromatic, and pneumatic checkouts made with simulated test equipment. It may well be impractical to run the engine without flying the missile.

In a ballistic missile any malfunction of the power plant, which must be completely automatic, since there is no pilot, will cause an abort and loss of the missile. In a multiengine missile the malfunction of any one of the engines will cause the loss of the complete missile. Where a conventional engine must run many hours on a single flight and is expected to operate over and over again for thousands of hours before the engine is overhauled, the engine for the ballistic missile must operate only in durations measured in seconds and must fly only once.

These comparisons point out the differences in the nature of the reliability problem for the rocket engine compared to the conventional aircraft engine. Similar differences exist in testing.

Conventional engines normally are run for a large number of hours in test cells to develop sufficient endurance capability for safe operation in an airplane. Additional reliability is developed during flight tests. At a reasonably early date in their development, engines are installed in substantial numbers of aircraft to develop many hours of service operation within a

Rocket propulsion test stand, Rocket Propulsion Laboratory, Santa Susana Mountains, Rocketdyne Division, North American Aviation, Canoga Park, California

relatively short period of time. This safely serves as an excellent means of uncovering design and manufacturing "bugs." As the service hours build up, a steady stream of reports flows back to the engine manufacturer. In the vast majority of malfunctions the engine is available for analysis by the user and the manufacturer. This information is invaluable to the engine developer in evolving the reliability desired in his product.

With rocket engines, feedback from service use is extremely limited. While they may be subjected to numerous simulated ground checks, rocket engines fly only once. And the engine is almost never available for analysis after flight whether it malfunctioned or not.

In view of these considerations it was evident that the reliability of liquid-propellant engines had to be developed by the manufacturer through extensive testing on static stands. With the pressure imposed upon the ballistic missile program to achieve operational dates as early as possible, it also became apparent that this testing had to be carried out with a minimum of elapsed time.

As a result new statistical techniques were developed to minimize the number of tests required to achieve a given reliability with a given confidence level. By varying many parameters of the test simultaneously to off-design-condition operating points, failures were induced more rapidly. These methods appreciably reduced the number of tests that were necessary.

Test Facilities

One of the first problems faced by industry in the development of propulsion units for ballistic missiles was the design and construction of suitable test facilities. The requirements for operating and testing these engines have resulted in the construction of completely new test facilities differing radically in design concept and scope from those for aircraft engines. The first characteristic of the engine affecting the test facilities is its size. Developing thrust in the order of 100 to 1000 times that developed by conventional engines, rocket engines require test structures of massive proportions and create major civil and structural engineering design problems.

One of the most severe problems in the design of these test stands has been the handling of the flame after it leaves the engine nozzle. Missile engines are started and tested in a vertical position. Exhaust flames are 75 to 100 feet long. Early test stands were designed to hang engines over the side of a cliff, providing about 100 feet of free drop for the hot gases. Even at these distances, however, the flame cut out ground and concrete at the rate of an inch or more per run.

To remedy this, the flame deflector was developed to turn the flame approximately 90° almost immediately after it left the nozzle of the rocket engine. The flame deflector consists of a large steel elbow cooled by large quantities of water. Thanks to it, test stands are now built much smaller, simpler, and much less expensively than before, making it practical to build sufficient numbers for extensive and rapid reliability testing.

In the testing of conventional, air-breathing engines—both piston and turbojet—a major portion of the facilities is involved in the apparatus to provide the quantities of air required to run the engines. This equipment becomes quite large and complex as the size of the engines increases and as it becomes necessary to simulate the temperatures and densities encountered at high altitudes.

None of that type of equipment is required in rocket-engine testing, but test stands must provide tankage and associated feed systems for both liquid oxidizer and fuel. The flow rates of both propellants are so large—measured in thousands of gallons per minute—that the sudden starting and stopping of these tremendous flows create fluid dynamic transients that can materially affect the operation of the engine. The test apparatus must approximate the configuration of the missile in the size and the location of the propellant run tanks and of the propellant feed-system piping.

Even though the engine operates for only a few seconds at a time, large quantities of propellants are consumed. Each test entails the supply and handling of extensive quantities of propellants. The quantity of liquid oxygen required, for instance, soon exceeds that available from commercial sources. For this reason plants to produce considerable quantities of liquid oxygen have been built in the immediate vicinity of rocket-engine testing facilities.

Similarities and Differences

Although some unique production problems have been encountered with the rocket engine, most have been conventional. Many of the parts for the rocket engine are quite different from conventional engines, but production methods and machinery have been developed through conventional industrial engineering and tool engineering practices. In some cases these have involved the use of new materials and the development of new welding, forming, and processing techniques. Generally the work has been within the scope of existing technology and manufacturing skills. Tolerances and quality requirements on certain parts have been severe but within the scope of good aircraft and engine practices.

Primarily affecting production operations has been the unique requirement that performance parameters of the rocket engine be held within very narrow maximum and minimum tolerances. Conventional engines must meet only a minimum performance requirement. With a conventional engine the

Liquid oxygen plant, Aerojet-General Corporation, Azuza, California

user is only interested in assuring himself that the engine will develop a given power with a fuel consumption less than a specified amount while certain other minimum requirements are met. Performance exceeding these requirements, even by a large margin, is a bonus and users seldom complain.

In a ballistic missile, however, excess power can cause the missile to follow a different ballistic trajectory or otherwise produce missile performance for which the guidance and control system cannot correct.

Another very severe problem for the production organization in the rocket-engine field has been that of producing the large amounts of experimental hardware for the fast-moving development programs. Such hardware, designed for short duration in order to minimize weight and maximize performance, is subject to high attrition. In developmental testing it is not at all unusual to wear out components that would never wear out in service use. Secondly, much of the developmental and reliability testing on the engine is done under operating conditions purposely intended to induce malfunction. With the tremendous levels of power being developed in such lightweight components, there is a high probability of considerable damage when failure does occur. Thirdly, there is a high level of obsolescence of parts during the development phase, where the very purpose of the test-evaluate-redesign-fabricate-test cycle is to evolve quickly the necessary design changes. Large quantities of experimental hardware must be produced in a minimum of time to support the developmental and reliability testing program.

The problem of production is further complicated by the accelerated schedule of the ballistic missile program. Production must be carried on concurrently with development. This means that extraordinary techniques must be adopted by the manufacturing organization to handle the large numbers of production changes that result from concurrent development and product improvement.

Part IV: From the Electronic Industry's Viewpoint

An Electronic Industry Symposium

The ballistic missile program, superimposed on an already rapidly expanding electronic industry, has created an added impetus to expansion in specific fields. The urgency of the program dictated the need for compressing normal research and development time cycles to the barest minimum. Development time has been reduced from years to months in all areas of engineering effort. Great strides were required almost immediately in the state of the art as it applies to adaptation and improvement of existing equipment and the development of new equipment and materials to meet the environmental conditions, high reliability standards, and accuracy requirements. The need for highly complex ground and missile-borne equipment to ensure the accuracy of the ballistic trajectory of the missile has created a challenge which is presently being met by the electronic industry.

Possibly the greatest challenge to the industry is the need for developing and manufacturing electronic equipment capable of continuous, accurate performance under the extremely harsh environmental conditions in ballistic missile operations. Acceleration, altitude, speed, vibration, heat, and other environmental requirements are radically different than those we have had to cope with in other military programs.

These difficult operational requirements and the high accuracy and reliability requirements under which the missile must operate mean that an extensive test program must be established. This has been done and testing of electronic equipment is presently going on. The test program has had a significant impact on the manufacturers of test equipment. Many small companies producing telemetering equipment, vibration equipment, and other standard and special components of environmental test equipment have suddenly found the demand far beyond their ability to produce. They have rallied valiantly, and principally through their own efforts these problems are being met and the program has continued without delay.

The accelerated research and development required by the ballistic missile program have to a limited degree necessitated new manufacturing processes and created demands for new materials. They have greatly increased the need for items such as transistors and diodes. This is particularly true in computer design and production. Because of the extremely critical accuracy requirements the rejection rates for certain types have been very high, so that production rates have had to be increased to ensure an adequate yield. At the same time work has continued to improve the product and also lower the cost.

To meet the development schedules for electronics, it has been necessary to provide certain facilities. These facilities generally fall in the category of long-lead-time tools and test equipment that are immediately required to support the environmental test program. It is conceivable that the program might have suffered serious delay had not a great number of facilities items been readily available from Government inventories early in the program.

No Great Effect

The ballistic missile program has not as yet had any great effect on the over-all production capacity of the electronic industry. In terms of the national average, requirements are small. The additional productive effort attributable to this program is easily absorbed by existing industry. As indicated earlier, there has been a temporary effect on the portion of the industry that manufactures test equipment. This was caused by the need for significant quantities of equipment during a relatively short period of complete developmental testing and does not represent a continuing requirement, except in a very few specific areas.

In terms of utilization of available materials and existing resources, there is no significant impact in the electronic industry similar to that attributable to the requirement for huge quantities of liquid oxygen. There is a minor impact with respect to requirements for materials or components such as tantalum and diodes.

In short the ballistic missile program has had no significant impact on the electronic industry as a whole, in terms of greatly increased requirements. It has had a significant effect on certain specific portions of the industry, notably the manufacturers of electronic test equipment.

The greatest impact has been in the area of engineering as a whole. The great urgency of the program has resulted in rapid strides in the application of engineering theory to existing problems and their early solu-

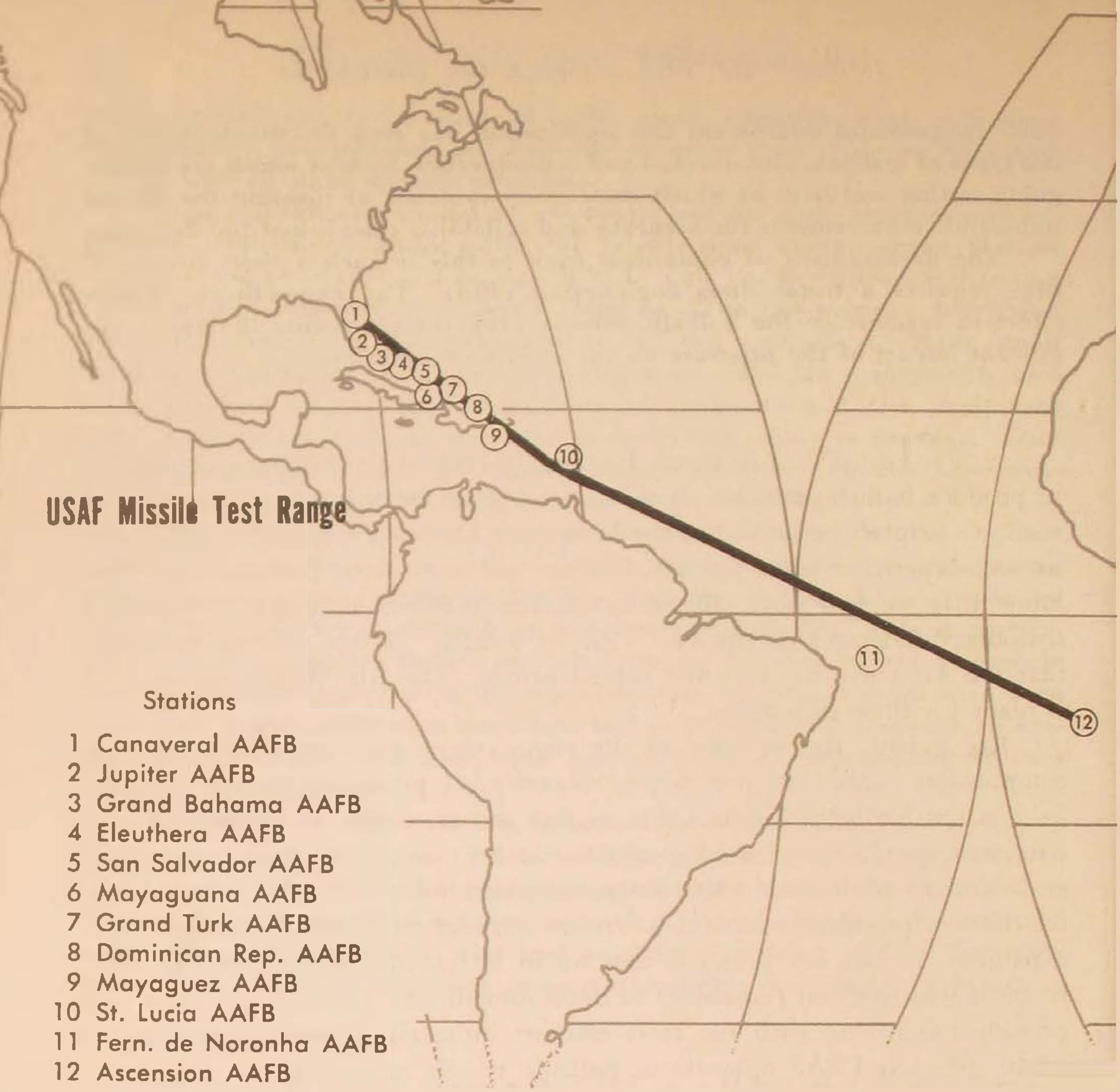
tion. In guidance equipment this application has seen the development of two types of systems, pure-inertial and radio-inertial, both of which are undergoing testing and both of which show every evidence of meeting the almost impossible requirements for accuracy and reliability established for their use.

The development of equipment such as this in such a short period of time requires a tremendous engineering effort. The expenditure of this effort in support of the ballistic missile program represents the most significant impact of the program on the electronic industry.

THE U.S. AIR FORCE has largely created the industrial capability to produce ballistic missiles. The materials have been isolated, the machine tools are in place or on order, the manpower has been hired. We know that we will experience some failures, but we will learn from these failures. We know that we will have difficulties—strikes, material shortages, or possibly temporary shortages of the best kind of tooling. These are the problems that the Air Force has met and solved before. The Air Materiel Command is ready for these difficulties.

Recognizing the urgency of the requirement and the impact of time compression, AMC assigned highly experienced personnel in the materiel field to the Ballistic Missiles Office so that our maximum experience in procurement, production, and logistics would be brought to bear on the program and its problems. AMC has participated with BMD and R-W in the selection of production sources to ensure the highest order of selectivity and capability. In fact our policy is that we in BMO, in a supporting role, will be most sensitive and responsive to development and jointly with BMD will provide the nation with the most efficient industrial capability possible to secure an early USAF operational ballistic missile capability.

Ballistic Missiles Office, Hq AMC



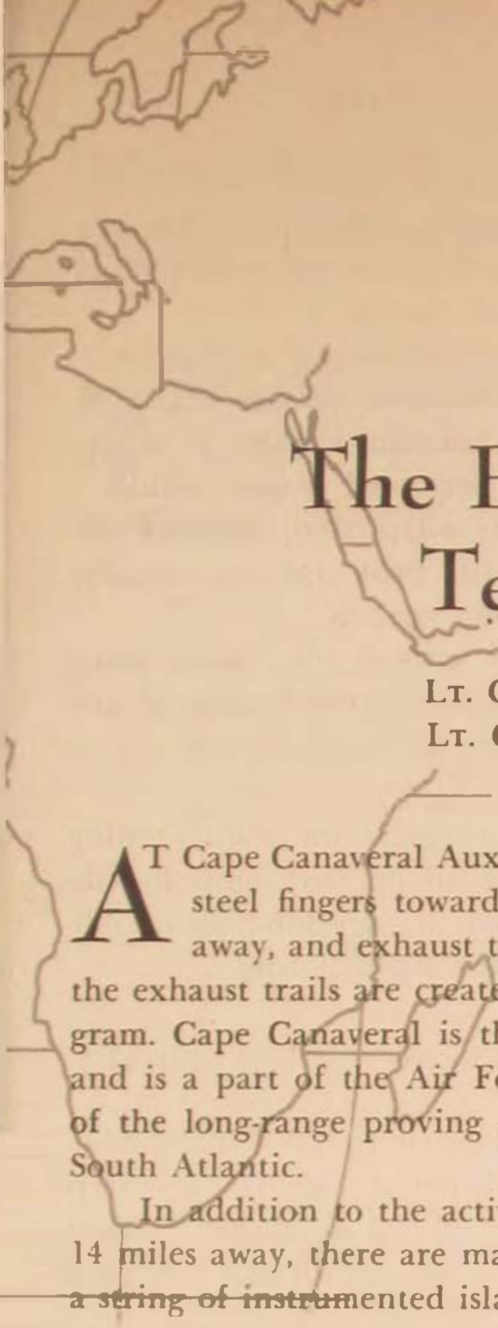
USAF Missile Test Range

Stations

1 Canaveral AAFB
2 Jupiter AAFB
3 Grand Bahama AAFB
4 Eleuthera AAFB
5 San Salvador AAFB
6 Mayaguana AAFB
7 Grand Turk AAFB
8 Dominican Rep. AAFB
9 Mayaguez AAFB
10 St. Lucia AAFB
11 Fern. de Noronha AAFB
12 Ascension AAFB

Cape Canaveral, 1954

Cape Canaveral, 1957



The Ballistic Missile Test Program

Lt. Col. Edwin A. Swanke *and*
Lt. Col. Richard K. Jacobson

AT Cape Canaveral Auxiliary Air Force Base, Florida, weird gantries push steel fingers toward the sky, wisps of vapor from LOX tanks drift away, and exhaust trails crisscross the sky. More and more frequently, the exhaust trails are created by and are symbols of the ballistic missile program. Cape Canaveral is the site of all ballistic missile flight test activities and is a part of the Air Force Missile Test Center. It constitutes the start of the long-range proving ground which stretches out 5000 miles over the South Atlantic.

In addition to the activities at the Cape and at Patrick Air Force Base, 14 miles away, there are many other mainland sites for instrumentation and a string of instrumented islands extending to tiny Ascension Island some 500 miles south of the equator. The ballistic missile program has changed the face of Cape Canaveral as new facilities have been identified and programed to support this effort. These will further change the Cape until it has the highest concentration of missile activity in the country.

Guided missiles are the daily business of the Air Force Missile Test Center. There missile testing is a concrete reality, and more than ten thousand Air Force, Civil Service, and contractor personnel are engaged in it daily. Approximately one third of these people are directly supporting the Air Force ballistic missile program and the number will increase.

This activity at the Air Force Missile Test Center represents only a part, and a small part, of the ballistic missile test program. It is the visual evidence of progress in the program and certainly the final culmination of any test effort. Flight testing in this program has been compared to the visible portion of an iceberg. The major portion of the test effort is conducted at numerous sites throughout the country.

To understand the magnitude of the ballistic missile test program, it is necessary to understand the test philosophy of the program. At the outset several factors were recognized as having an important relationship to any philosophies specifically oriented toward rocket ballistic weapons. These factors included consideration of the following:

- The test philosophy for manned aircraft, which was well established and has been demonstrated to be effective, seemed applicable to ballistic missile testing. This philosophy includes comprehensive testing of individual components up to and including complete weapon systems.
- The Unsatisfactory Report System which has contributed so heavily to the successful development and improvement of manned aircraft is not directly applicable to the missile program, since the constant scrutiny of equipment by pilots, crew members, and maintenance personnel is unavailable.
- The vast complex of test facilities uniquely adapted to manned aircraft had not been duplicated in the guided missile field and was virtually nonexistent for the rocket-powered ballistic weapon systems.
- Guided missiles were to be highly complex systems comprising many complex subsystems. More so than in manned aircraft, the failure of any part could mean the failure of the entire missile. All these systems are in series as regards over-all reliability.
- The aircraft-testing practice of relying primarily on flight testing could not provide the data on which to base needed improvements in missile design. Simulation of potential difficulties and the development of reliability would have to be done on the ground before flight testing.

The Testing Philosophy

These factors were summarized in a letter written by the Commander, Air Research and Development Command, to the Chief of Staff, Headquarters USAF, in which he recommended a philosophy of testing rocket ballistic weapons. This philosophy as established and operating in this program establishes three general principles:

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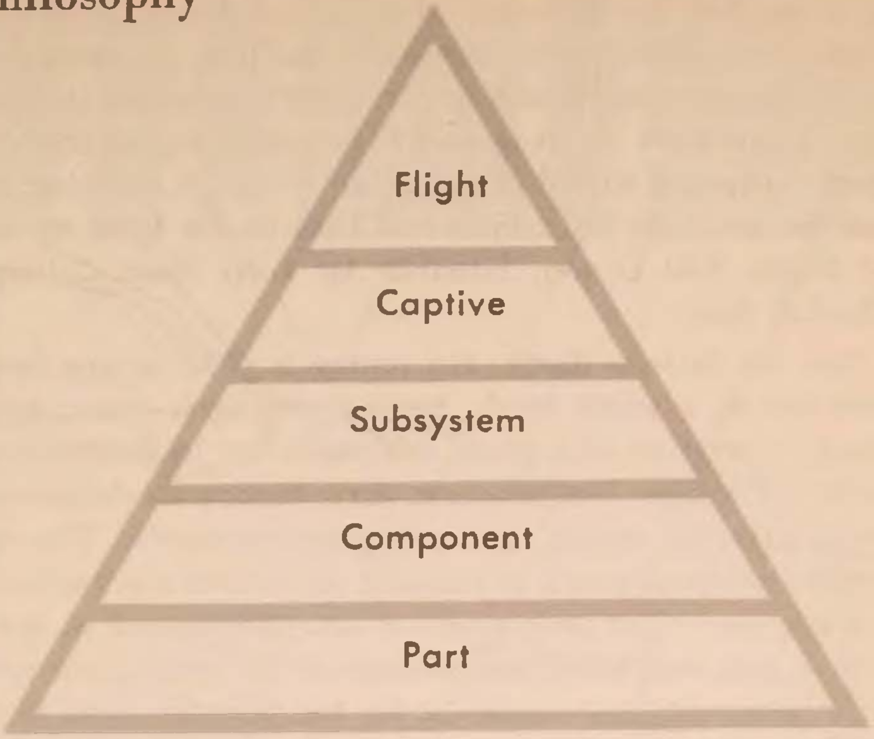
Ballistic Weapon Test Philosophy



"Testing will be accomplished at the lowest possible level"

Avoid Dead-end Testing. Within the ballistic missile program no components are designed and tested unless they are ultimately to be a part of the system. Accordingly the first missiles are in the final configuration, minus certain components. As the program progresses and as our knowledge increases, the complexity of the test program increases. While the first series encompasses test of an airframe, autopilot, and propulsion system only, the minimum capability for flight, these components are designed as portions of the ultimate operational missiles. As the test program progresses, guidance, auxiliary power, nose cone, warhead, and other subsystems are successively added.

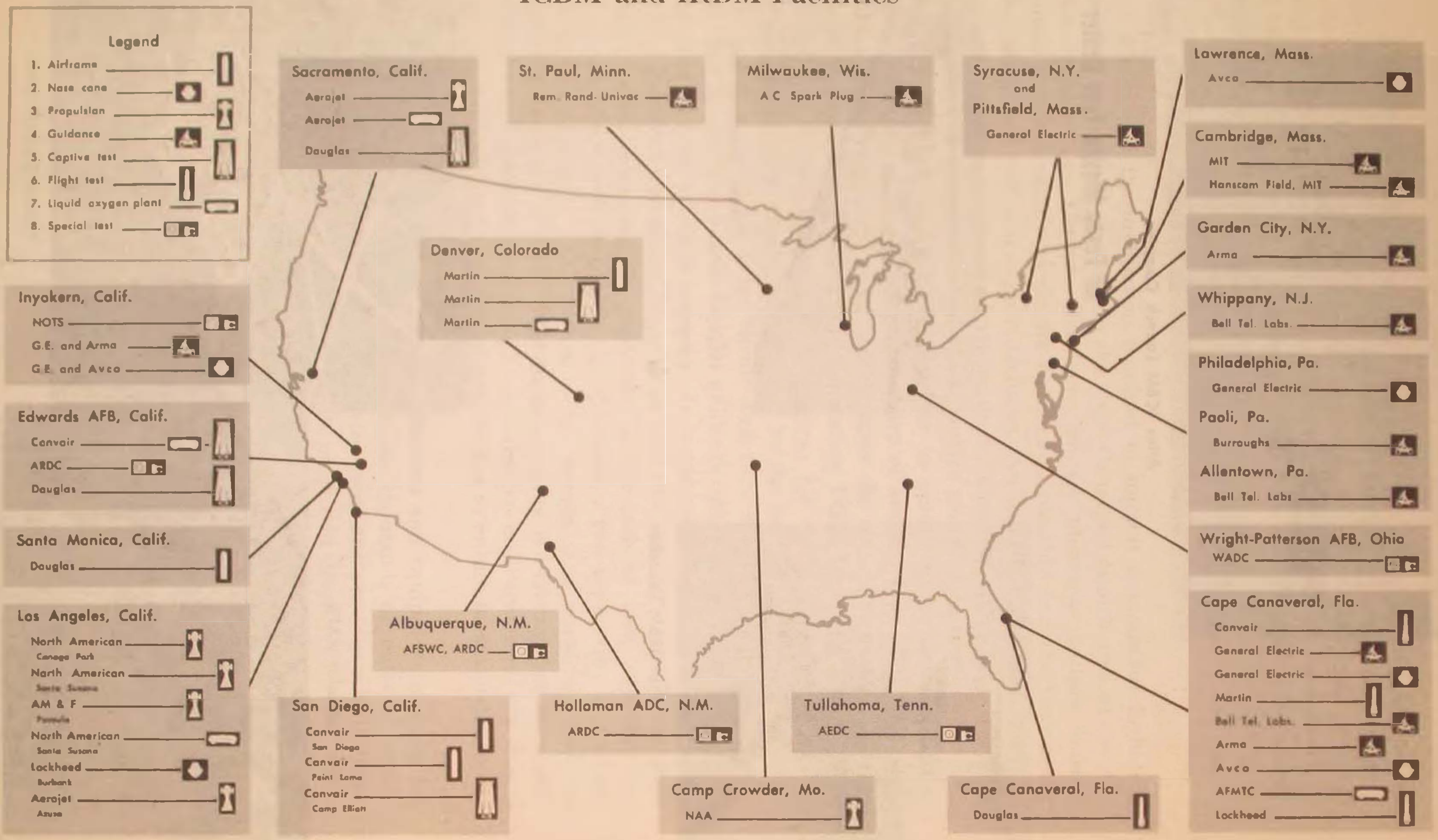
Rely on Ground Tests. Primary dependence on flight testing for rocket-powered ballistic weapon development is inadequate and extremely expensive. Consequently a comprehensive ground test program is a prerequisite to flight testing. It has been proved that captive vehicle testing can be effective and economical. Thus in the ICBM program the first missile of any series is assigned to a captive test stand. Facilities similar to the launch complexes at Patrick can be found at Edwards Rocket Base, California, and in the "backyard" of various contractors. The number of these systems test facilities exceeds the number of the launch complexes at AFMTC. In this type of testing the missiles may be run many times, providing masses of statistical information to aid in the development of a reliable system. Because of the hazards involved in such testing, each program has in it a so-called "battleship facility." This stand has heavy tanks of battleship steel built in the exact configuration of the actual missile tanks for use in repeated testings. In addition to the battleship facilities the ground test program includes hydrostatic test stands to check the reaction of the missile to pressurization. To measure the reaction of the missile to fast servicing and to determine the potential hazard of any given missile, a complete facility for checkout of fast-servicing procedures and hazards has been developed at the Air Force Flight Test Center, Edwards Air Force Base, California, adjacent to the Rocket Base.

Test the Systems Early. No testing is done at any level if it could be carried out at a lower level. Systems testing is never designed merely to check the operation of a given subsystem but to determine the relationship between subsystems. For example, early flight tests demonstrate the compatibility of airframe, engine, and autopilot subsystems. The operation of each subsystem has been tested in advance on its own test facilities. Likewise testing of engines is not programed to test components of the system. Turbopumps, valves, and other components of the propulsion system are checked out independently. Schematically the test program looks like a pyramid. Relating the efforts to the flight test program, we find that numerically flight testing represents only a small part of the total test effort. Captive tests will number an order of magnitude greater than the programed flight tests. Tests of the rocket engine will number to an order of magnitude greater than the captive tests and several orders of magnitude greater than the flight tests. Component tests will exceed by several orders of magnitude the programed subsystem testing. Thus any flight test represents tens of thousands of tests on captive facilities, subsystems test facilities, and components testing facilities.

This philosophy determines the requirement for facilities to support the test program. In recognizing this philosophy and its translation into specific test plans and programs, one must examine the installations and facilities requirements that it dictates. The Air Force Missile Test Center, where missiles are actually flight tested, rests on a broad base of support facilities throughout the United States required for the success of its flight-test mission. The test plans have established the scope, number, character, and location of our test facilities.

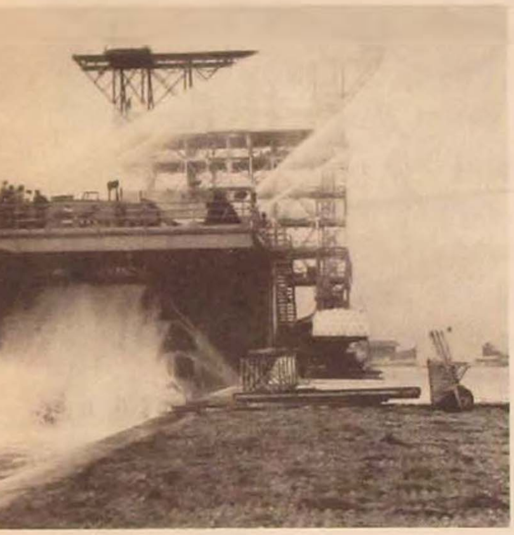
Since the ballistic missile program was accelerated in 1954, approximately $500,000,000 has been made available for new test installations and contractor plant expansions. A substantial percentage of this total, over $100,000,000, is privately financed by both prime contractors and subcontractors. The impact of a test program of this magnitude at installations like Patrick and Edwards Air Force Bases has called for a considerable expansion of the technical, administrative, and support facilities to handle the significant increase in contractor and Air Force equipment and personnel. Such a buildup of testing effort can obviously only be supported by substantial expansion in

ICBM and IRBM Facilities



Atlas ICBM Launch Complex

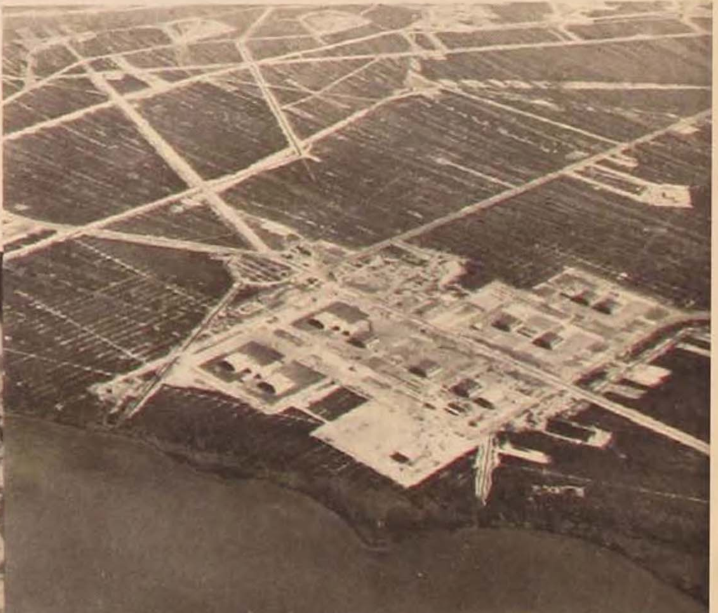
Air Force Missile Test Center



Thor IRBM Launcher

Ground Guidance Unit

San Salvador AAFB



Typical Support Area

the industrial facilities to support the fabrication of test hardware and to provide a development and engineering capability at contractors' plants. Laboratory test equipment, such as environmental test chambers, random-noise vibration equipment, and data-reduction equipment, has been installed at contractors' plants for the extensive developmental and reliability testing required to support this major effort.

Flight Test

The size of the installation required to support a successful flight-test program is readily appreciated in the Cape Canaveral launch area of the Air Force Missile Test Center. Here one can see numerous ballistic missile launch stands flanked by guidance complexes, assembly and checkout areas, and the related technical support facilities. An Atlas ICBM launch complex includes blockhouse, instrumentation ducts, elevated ramp, launch stand, LOX, fuel, and gas systems, and gantry service tower. The stand is elevated to provide a water-cooled flame deflector to permit preflight static testing prior to the actual launch. Representative of another type launch stand is a Thor IRBM launcher. It too encompasses the major features of a blockhouse, elevated launch stand, and supporting LOX, fuel, and high-pressure gas systems. Design criteria and site layout for these unique facilities are based on the safety conditions required at the launch area and the range safety criteria of the Air Force Missile Test Center.

The ground-based radio-inertial guidance system being used on tests of the Atlas weapon system is complex. It encompasses the major elements of central guidance operations, Doppler radars, and the rate transmitters—with the rate receivers accurately positioned at the ends of four 5000-foot legs of a cross. No operations could succeed without a vast supporting area where the assembly hangars, LOX plants, shops, storage, data reduction, and engineering space are located. This entire complex is tied together by a network of roads, communications, and water and power distribution, and dotted with a myriad of range instrumentation devices to ensure maximum effectiveness of the test program.

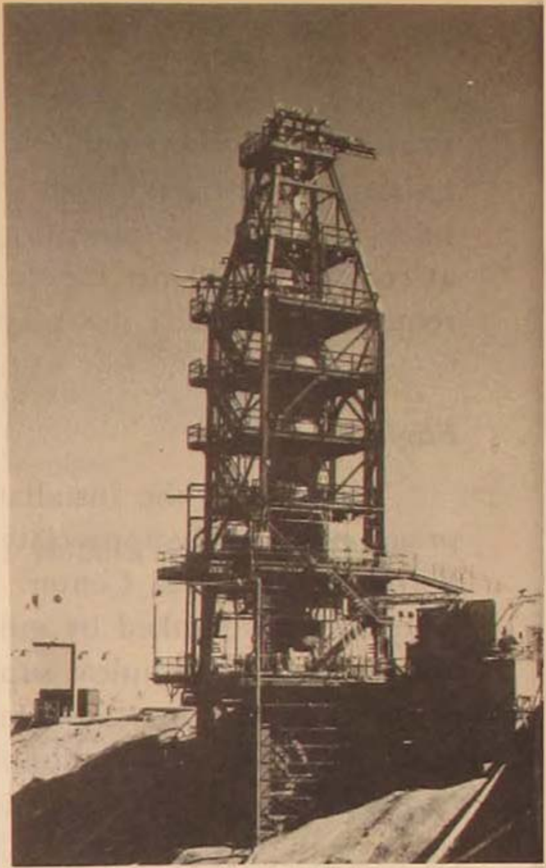
Range. Included in this huge installations and equipment buildup for testing of the complete weapon systems are thousands of miles of instrumented range whose scope and complexities dwarf any previous missile effort. There is not space here to cover this vast project in detail.

A typical range station is on San Salvador. It is manned and operated by the range contractor (Pan American Airways and RCA) for the Air Force.

Captive Test

Of significant importance is the static testing of the complete weapon system, which the test philosophy requires in support of a successful flight-test schedule. For example, at the Edwards Rocket Base both the Atlas and Thor weapons are undergoing captive testing. Representative of this test

Captive Test Stand

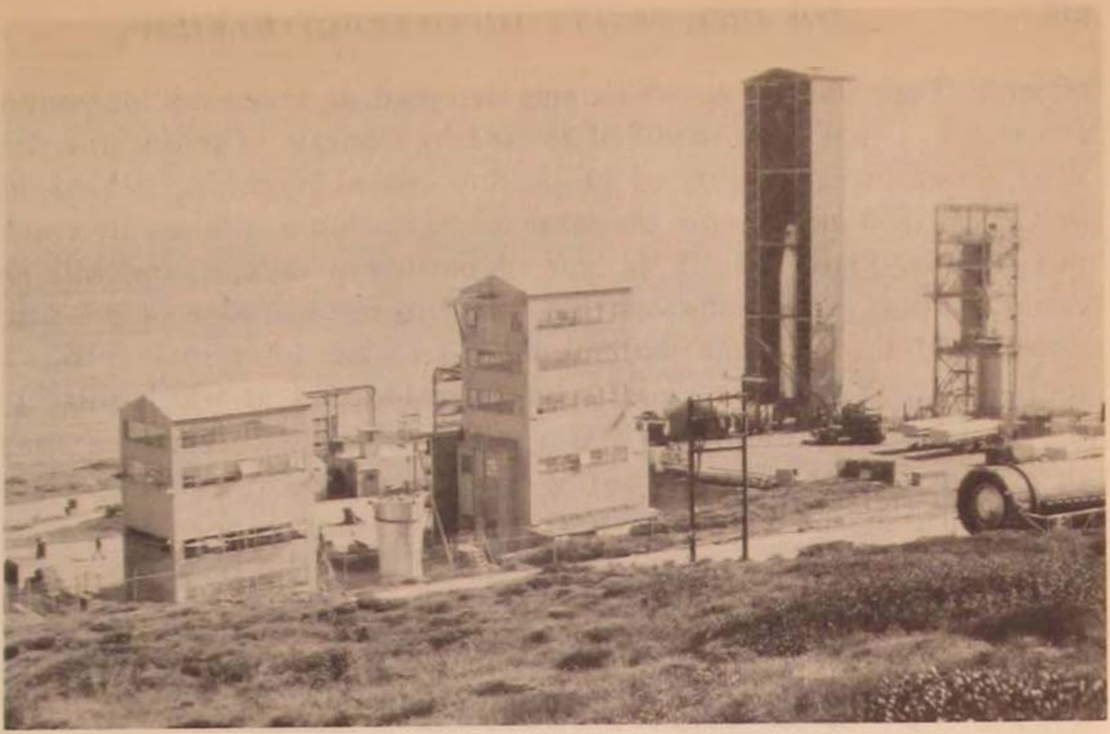


Battleship Test Stand

Support Equipment Test Facilities

Convair Test Stand, Sycamore Canyon

Martin Test Stand, Denver



Convair Airframe Component Testing, Point Loma

Martin's Denver Facilities Cover a Vast Area

North American Test Stands

effort is Test Stand 1-A, which was designed as a one-million-pound-thrust test stand. It has been modified for use by Convair in testing the Atlas missile. To ensure reliability of propulsion system plumbing, a tank made of battleship steel and having the same configuration as the missile tankage was put on Test Stand 1-4. This type of battleship tank testing will permit a determination of those factors that relate to the marriage of the propulsion system and the airframe without having to use an actual missile for this testing. The stand also permits an early location at which some test-crew training can be accomplished. Also at the Edwards Rocket Base other facilities are in place to support testing of ground-support equipment and other tests which in themselves have a high risk and cannot be done at other locations.

Since additional captive testing is done in the contractor's backyard, one will see static test stands at the airframe contractor's plant for the Thor, Titan, and Atlas weapon systems. The proximity of this type of test stand to the engineering and fabrication facilities of the contractor makes for rapid fixes during development and the efficient use of highly trained personnel responsible for the conduct of these activities.

Subsystem Testing

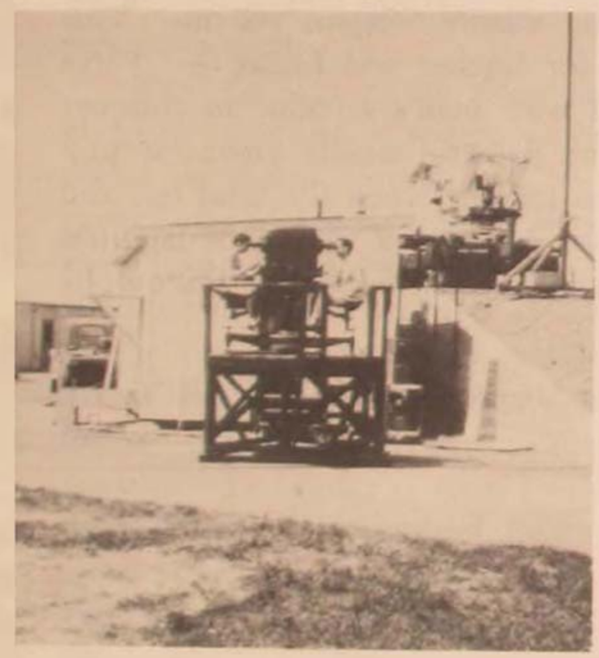
Weapon system testing cannot be successful within the terms of the test philosophy without a broad capability for subsystem testing and individual component testing.

Airframe. The Air Force ballistic missile program involves the development, fabrication, and testing of three airframes: namely, Atlas by Convair, Titan by Martin, and Thor by Douglas. Support of this development effort has called for a considerable expansion of engineering laboratories, fabrication facilities, and environmental test facilities. Representative of this type of activity is the Convair Point Loma test area, where components and elements are tested prior to assembly of the missile airframe.

As in the case of other contractors a large area adjacent to the engineering and fabrication facilities is required in the interest of safety, security, noise suppression, and other problems arising in ballistic missile testing. Martin, for example, has moved to the Denver region and established a new plant with associated facilities.

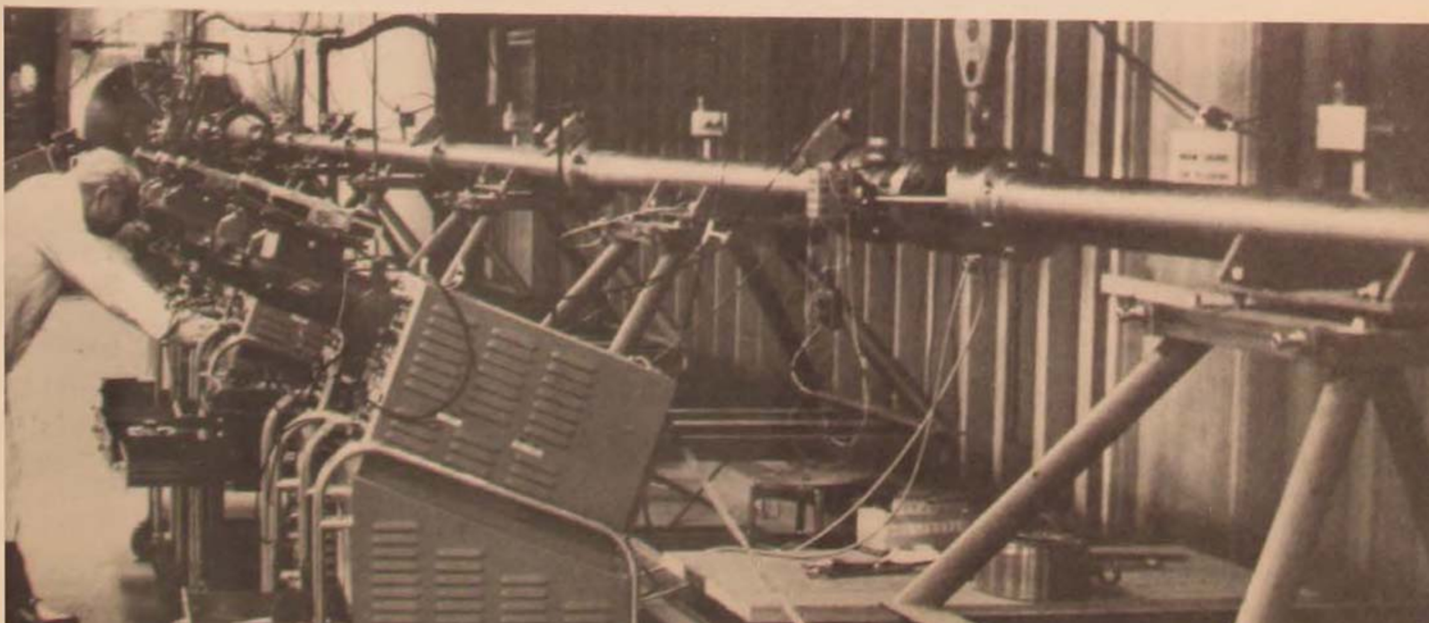
Propulsion. In all probability, the most impressive facility buildup to support a development and test program was accomplished in the propulsion area. The Rocketdyne Division of North American Aviation, with Air Force assistance, has established a Field Propulsion Laboratory in the hills above San Fernando Valley. At North American are an engineering development facility, a cold-flow calibration laboratory, environmental testing fixtures, and a battery of eighteen rocket-engine test stands. Similarly, at Aerojet-General in Sacramento, a sizable facility buildup can be noted. These two contractors are obviously large users of liquid oxygen. The Air Force

Aerojet's Engine Test Area, Sacramento



General Electric's Hancock Field
Guidance System Test Site

The Avco Shock Tube, Used in Nose Cone Work



considered it economical to provide on-site LOX plants and such facilities have been constructed.

Guidance. Perhaps the best example of subsystem and component testing can be seen in the guidance-system testing. There are approximately eight prime contractors working in guidance, and their test capability buildup has been tremendous. A tour through their facilities would reveal environmental test equipment, data-processing equipment, reliability test facilities, and backyard field test setups.

Nose Cone. The remaining subsystem of the ballistic missile weapon system is the nose cone and its warhead. Here also a substantial buildup of laboratory, fabrication, and test equipment and facilities can be observed. This subsystem requires a considerable amount of systems analysis equipment to ensure, insofar as possible before flight test, the nose cone's ability to operate satisfactorily under actual flight environment.

In the small space of two years this half-billion-dollar facility expansion program has been more than 75 per cent completed and represents to the Air Force, and to the nation, a significant milestone in the progress made toward the development of effective ballistic missile weapon systems. This effort also forms the basic building block for further and future Air Force investigation into the problems associated with man's attempt to conquer space. One can readily appreciate that the ballistic missile flight-test program is in fact like the visible portion of an iceberg, when the total test and facilities support of test objectives is backed by so vast a base of facilities and testing effort, the architecture of which was shaped by the test philosophy established.

Air Force Ballistic Missile Division, Hq ARDC

Impact of the Ballistic Missile on Warfare

Colonel Alexander Sheridan

THERE have been immense changes in the art of warfare within the past century. The use of mass, the substitution of artillery, rifle, and machine gun for massed troops, the entrenchments of the Civil War and World War I, the swing back to movement with the panzer thrust of early World War II have each had profound effects. The advent of the air-delivered nuclear weapon is so big and so different that many planners, still bound by the traditional thinking of the last war, have yet to fully appreciate this weapon system.

Now we are on the threshold of the ballistic missile. This event has given rise to a host of writers and publicists, and some military planners, who might be called "futurists." These people often evaluate future expected capabilities of a new weapon system within the present-day framework, with everything except their new weapon system remaining at today's state of development. These futurists are so bemused and enchanted by the ultimate possibilities of the ballistic missile with the nuclear warhead that they are prone to lull the United States into a false sense of military prowess. The futurist is just as dangerous to the security of the United States as the traditionalist. The latter is rooted firmly in the rut of the past; the former has his feet well off the ground, floating off ten years into tomorrow.

Sound planning for this future master-weapon system is imperative, and some good work is being done. For the most part, however, it has been done only by a small group intimately associated with missile development. Proper evaluation and full utilization of the ballistic missile, within the perspective of the political climate anticipated, are tasks of the greatest importance for United States leaders today.

Initial Impact

The initial capability of the first ballistic missiles will set neatly into the U.S. philosophy of modern warfare. The philosophy of modern warfare evolved in the United States since World War II is based upon the ability to mount an immediate and decisive attack against enemy forces and heartland. This philosophy embraces the proposition that the sheer potential destructiveness of such an attack will deter enemy aggression. Since the avowed policy of the United States leaves the initiative in the hands of the enemy, our ability to launch quickly and decisively a counterstrike against the enemy requires a force-in-being. This ready force must be secure from enemy attack and capable of winning the decisive phase of the war, should its deterrent effect fail. Such a force will be an effective deterrent to an enemy only if the enemy has knowledge of the force's capability and invulnerability and, at the same time, knows of the intention to exercise this force.

The primary deterrent to enemy aggression since World War II has been the U.S. strategic air forces equipped with manned bombers. The deterrent effect of this force is being slowly diminished by improved counterbomber defenses. The early ballistic missiles, if handled properly, will have the characteristics to assist in the deterrent task. The manned bomber will be an important part of the total deterrent force for a long time to come, and the first ballistic missiles will supplement the bomber and help restore the effectiveness of the deterrent force.

The relationship of the ballistic missile newcomer to the family of strategic weapons will be determined by capabilities and limitations. The tremendous speed of the weapon is possibly the characteristic most important to its strategic role. The quick reaction to enemy threat and the improved ability to penetrate enemy defenses are two attributes of the missile's hypersonic speed which make the missile far superior to aircraft. The possibility of hardening and camouflaging the launching site of the missile will make it less vulnerable to surprise attack than the large runway complex of the aircraft's ground environment.

Certain conditions must be met to capitalize on the advantages of fast reaction and improved ability to penetrate defenses. Some changes in operations or tactics will be mandatory, and as capabilities of the missiles increase with the advance of technology, more profound operational changes will be indicated. Advance planning and detailed targeting information, including postshot reconnaissance, will be a necessity. Intelligence information, always a prerequisite for a successful aircraft strike, will be most important since the missile's entire mission will be predicated on this information. Extensive logistic support will be required. The unusual nature of fuels used, the intricate instrumentation and electronic gear will all demand unique facili-

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ties and highly skilled personnel. This materiel and manpower will have to be prepositioned and made secure to ensure prelaunch survivability.

Aside from imposed operational requirements the early ballistic missiles have inherent limitations that must be considered for a full appreciation of the missile's initial employment. One such limitation will be an inability to attack fleeting targets and targets on which detailed information is lacking. Initially even its fixed targets will be large-area ones, because of expected inaccuracies in the guidance systems. Selectivity of warhead size to fit the tactical situation will be restricted. It would not be profitable to deliver small-yield warheads, because the use of the totally expendable missile can only be economically justified if the damage effected is in favorable ratio to the cost involved. Too, there are those who feel the first missiles will be limited in effectiveness by the restricted size of the warhead that can be carried. Considering the accuracy allowance for guidance error in the first missiles, the yield may not be great enough to destroy the target. With its one-shot performance the weapon will be limited to priority targets commensurate with its delivery yield and guidance accuracy. Also reliability must not be ignored. Estimates on the reliability of the first ballistic missile force vary, and it will probably take considerable testing and practice firing to establish a dependability that could be termed "combat ready."

Even the ballistic missile's extreme speed, the characteristic that has the greatest potential, is somewhat modified by limitations imposed. The first missiles will be so limited in terms of accuracy and yield that it will be impossible to take advantage of speed to hit enemy forces and thus eliminate the enemy's capability to retaliate. The restriction of the early missiles to large-area targets, control centers, or industrial areas compromises the advantages of speed. These large-area targets are impossible to hide and are completely immobile. Warning time or preparation for expected attack will have little effect. Certain precautionary means can be taken to save life through passive defense, shelters, and evacuation; any enemy government initiating hostilities presumably would take these steps before attacking. Destruction to the target area itself cannot be evaded, but speed of attack in this instance would be of little consequence.

Even with its known limitations the ballistic missile lends itself ideally to some of the missions now performed by the long-range manned bomber. Within the next two decades it appears that the ballistic missile will become the primary means of conducting offensive strategic operations against an enemy, superseding the conventional manned bomber aircraft. In the interim, substitution of the missiles for the more conventional systems will be made as rapidly as technical progress permits. The transition period will see a gradual change, with the ballistic missile and the long-range manned bomber being used concurrently.

Initially the ballistic missile could best supplement the strategic aircraft force by providing a very fast reaction to any enemy war action. The psychological effect of even the relatively inaccurate early missiles falling on the enemy heartland within a matter of minutes of the first outbreak of general war would be considerable. The shock generated by such an attack would facilitate the application of other forces. Fast missile strikes in advance of the aircraft could aid the more accurate manned bomber attack by causing general confusion, disruption of communications, and possible damage to enemy defenses, particularly point defenses adjacent to the large-area missile targets. Enemy defenses against aircraft attack are improving considerably. It is conceivable that there might be some important, heavily defended targets that would be almost impossible to destroy with manned bombers without unacceptable losses. In such a situation the ballistic missile may be the only practicable method of destroying these vital targets. Salvos of the early ballistic missiles could be used to compensate for inaccuracies and limited yields. Immediate missile retaliatory strikes, assistance to manned-bomber penetration, and attacks on heavily guarded, large-area targets will be the contributions of the early missiles to the bombardment force in the execution of the strategic mission.

Future Impact

The eventual long-range impact of the ballistic missile on warfare is difficult, if not impossible, to ascertain. No armament of warfare is ever static in its development or application. The eternal swing of the pendulum from offensive weapon to counter defensive measure alone could conceivably render this seemingly master weapon of the future obsolete before it is ever used in warfare. In the present stage of development any defense against the ballistic missile in flight, with its extremely high altitudes and speeds, appears to be a task of gigantic proportions. Yet the very nature of the ballistic trajectory, a path that is unvariable and easily and quickly computed, may be its undoing. The political ramifications of the use of nuclear-armed ballistic missiles may decide whether this weapon will have any impact at all on active warfare or any influence in peacetime. There is evidence of growing concern with the coming of "atomic parity" and the possibility of acts that some have termed bordering on "mutual suicide." World political conditions change and so does the U.S. national policy of which the military is an instrument. Any projection of warfare embracing the use of new weapon systems must also take into account the probable political-military grand strategy.

In endeavoring to understand the future impact of missiles it would probably be better not to try to probe too far into the future. The changes wrought by their introduction will be great, and the changes in warfare after the next twenty years, when the missiles will have reached their advanced capability, will be revolutionary. For the purpose of discussion and to establish some terms of reference, the advanced capability of the ballistic missile may be described as extreme accuracy, unlimited range, and the carrying of a variable warhead. Other assumptions about the perfected ballistic missile must include a high degree of dependability, an adequate stockpile, and a continuing reconnaissance sufficient to supply accurate and detailed target information. The future ballistic missile described here may never be realized; but if the advanced weapon approximates the capabilities assumed on the basis of today's technological promise, it will be a formidable weapon indeed.

The paramount characteristic of this future weapon system will be its compression of firepower in time and space. This compression effect on the long-revered principles of war and on the more recent doctrinal decrees of the present-day services will be great. Adjustments will be difficult. The old, tested principles and much of the modern-day doctrine will still be valid from the purist viewpoint, but the time compression by the weapon will give them new significance and altered emphasis.

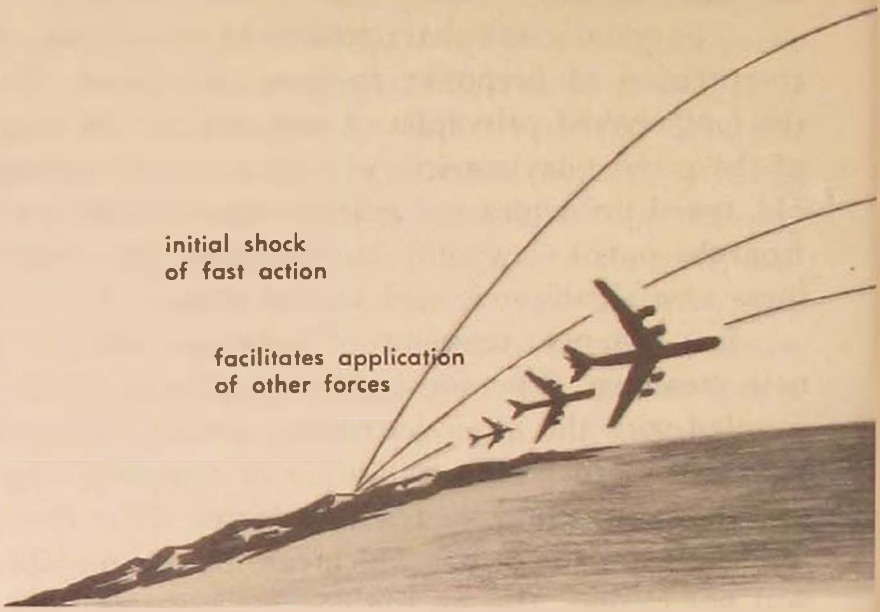
For instance, economy of force and concentration of force will have new meaning. The inevitable completion of the ballistic missile mission coupled with the large destructive power of the nuclear warhead will make possible an orderly neutralization of complete target systems performed with the utmost economy to friendly forces. The free disposal or placement of forces, a principle of war which can include mobility, flexibility, and surprise, will not change, though the concept of operations will be greatly modified. The new weapon, prepositioned as it must be, gives new meaning to mobility and flexibility. Because of the weapon's speed, range, and accuracy any target system selected could be hit with any degree of intensity desired. With movement of forces at the rate of 16,000 miles per hour, the surprise to be effected will be achieved in a matter of minutes. Disposition of forces and security are principles that will govern even national survival in the compressed time phasing of the new atomic-ballistic age. Force deployment and force-in-being will have to be on immediate, battle-ready vigilance at all times. The security of the force will determine its potential destructive power and in turn its deterrent effect, for this will also be the age of counterforce operation. With each combatant holding quick life or death over the other by virtue of superarmament, the superarmament itself becomes the prime target. The destruction of an enemy national capital is small gain when traded against the annihilation of the friendly nation's own capital. The new era will demand disposition of forces in instant-ready position, relatively secure against enemy action, and aimed at countering the enemy offensive power.

The grand strategy of the United States—the maintenance of ineluctable force with destructive power unacceptable to an enemy—will not change with the coming of age of the missile. The compression of time, the ability to react very quickly to any act of aggression, will become increasingly important as universal improvements are made in the ballistic missile weapons. Until an enemy is assured that the United States' nuclear-armed ballistic missile capability can be destroyed, or until an enemy creates an impregnable defense against the missile, there seems little danger that all-out war will be deliberately initiated except as an act of irrationality. Immediate ballistic missile retaliation reduces the initiation of unlimited war to sheer adventurism. Calculation of risks becomes unreal; the cost of miscalculation becomes

Growth of Ballistic

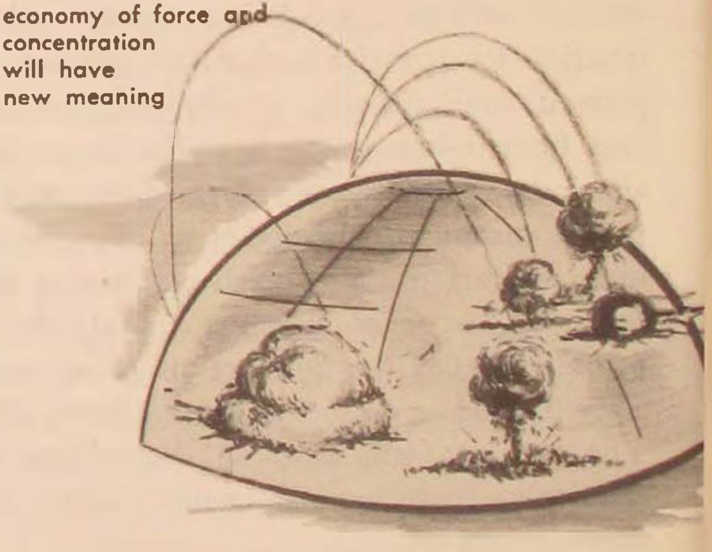
Initial Capability

supplement to manned bombers



Mature Capability

missile force spearheads offense

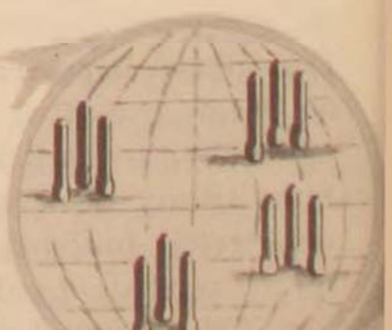


Mature Capability Requirements

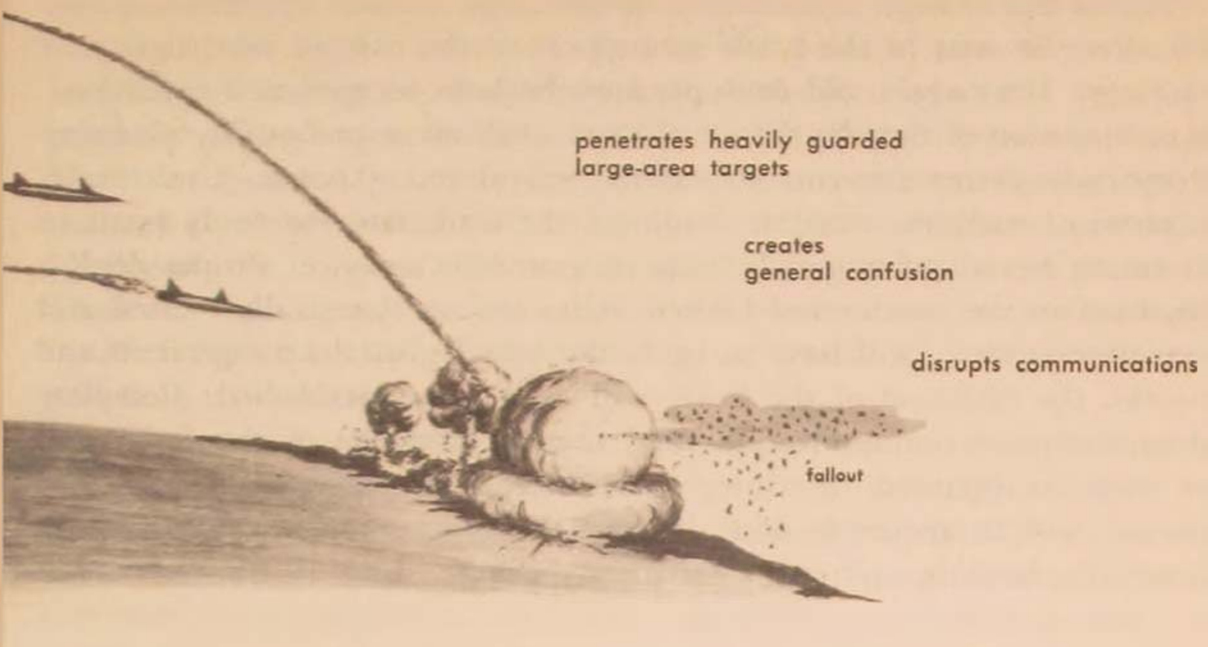
effects of compression of time and space

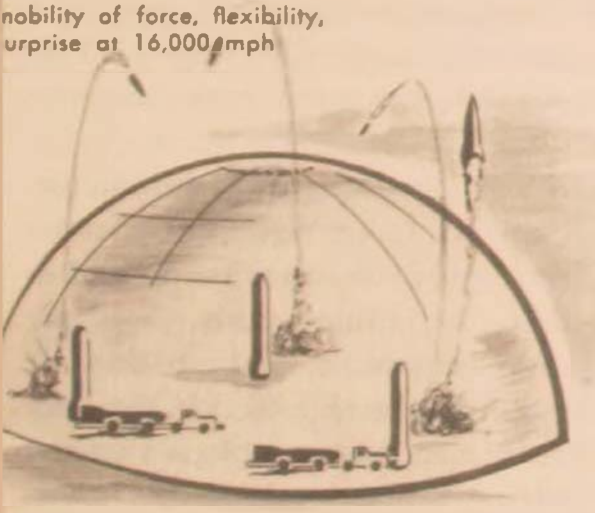
prehostility planning

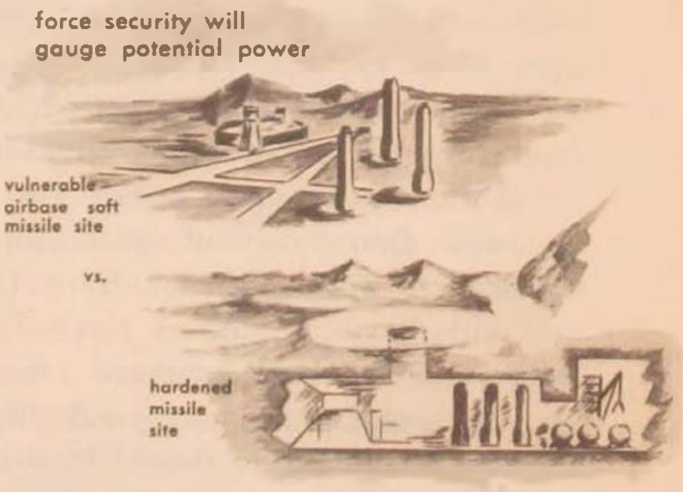
world-wide battle station deployment

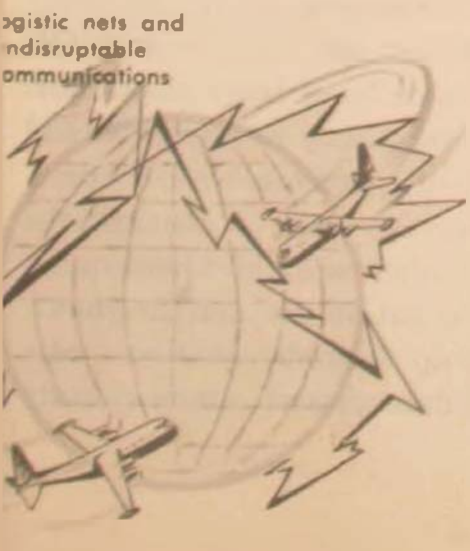


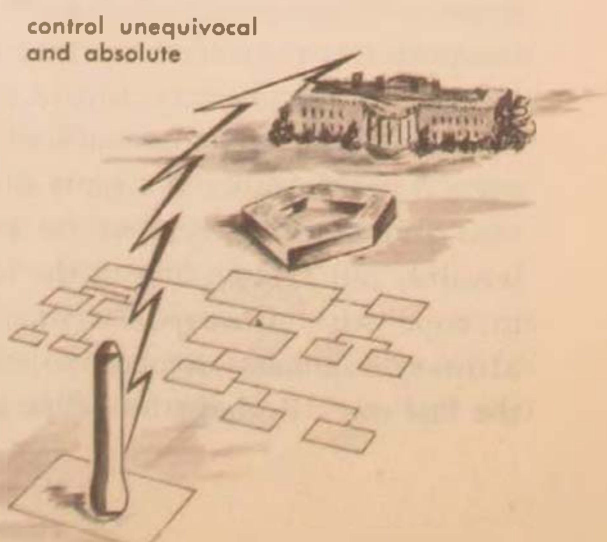
Missile Effectiveness











unacceptable in logic. The strategy will strengthen to such an extent that general all-out war, always abhorrent in the eyes of reasonable men, may become a thing of the past.

Tactics will change. Conventionally the term "tactics" applies to actions taken after the start of the battle in support of the over-all campaign plan or strategy. Here again, old concepts must be bent to meet new conditions. The compression of time by the new weapon will mean prehostility planning and operational readiness to an extent heretofore unknown. Under such conditions of complete wartime readiness, the force must be ready to strike vital enemy heartland targets literally at a moment's notice. Proper deployment, both in the continental United States and in stategically located and secure sites overseas, will have to be made. Vast logistical arrangements and networks, the lifeblood of the force, will have to be established. Complete and undisruptive communication nets, the nerve system of the force, will have to be maintained. Training, placement, and management of skilled personnel will be required; and all these things must be functioning on a full wartime basis in any period of uneasy peace.

Future Control

Control of the force will have to be unequivocal and absolute. In this field of control, perhaps more than in any other, changes will be most difficult. New technology produces new hardware, and new hardware requires new operational concepts. These, in turn, require new supporting logistics and new skills and training of personnel. These things, for the most part, are readily recognized and accepted within the military.

Unfortunately this is not always true with anything approaching organizational or command and control arrangements designed to fit new modes of warfare. These subjects, fraught as they are with interservice prejudices and with service traditions, rarely receive objective military study. A purely military solution to command arrangement is impossible, and, in the last analysis, perhaps this is a good thing. Any arrangement affecting the very survival of the nation should be the concern of all. The trouble is that too many people have honorable interests and individual loyalties that sometimes conflict with the hard, clear-cut decision that would give the United States military the kind of control it needs if it is not to vitiate the time-compression characteristic that makes the new weapon so potent. The changes to our military control structure will have to be of large magnitude, stemming from the commander-in-chief and on down. The luxury of several agencies performing the same tasks, the gentlemanly agreements of cooperation and noninfringement on traditional prerogatives—real or fancied, the leisurely talk-talk ending in the innocuous compromise, will all be inadequate to cope with a weapon system that can kill a nation in half an hour. Military command structure should be arranged to fight the next war, not the last one. Perhaps no other problem is more deserving of our best study and early resolution than the one of organization and command control necessary to fight the advanced ballistic missile in tomorrow's battle.

The controlling element transcends the military. Any weapon that has the potential of starting and ending a conflict in one action will be the concern of the highest authority. Because the political aspects involved will be great and lasting, any decision to unleash the future ballistic missile force can be made by no less than the President with the consent of the Congress. Since our national policy is firmly dedicated to preventing war and our military capability geared to reacting against aggression, there appears little likelihood that Congress will be confronted with the decision to declare war. Thus, any decision will undoubtedly come from the President as Commander-in-Chief, in a situation clearly requiring and receiving public endorsement and Congressional approval.

The use of offensive weapons of the caliber of the nuclear-armed ballistic missile against enemy territory, regardless of the provocation, is an unmistakable invitation to unlimited war. Authority to launch such weapons, even when we are confronted with imminent attack, is not very likely to be delegated by the President. Decision to launch an attack will probably have to depend upon strategic warning that an enemy attack is imminent and inevitable. Warning of this nature is difficult to obtain. When obtainable it could easily be misinterpreted. A country no longer will have the advantage of observing the conventional intelligence signs: stockpiling, troop build-up, maneuvers—all the paraphernalia of former preparation for war. Rather preparations will be made months and years in advance, with the final preparation nothing more than topping off fuel containers and final choice from among preselected targets. Long-range or advance intelligence, by its very paucity, will not be reliable enough for decision. Short-range intelligence reports of a positive nature, e.g., missiles in flight, will be available for only a few minutes and be practically worthless as a means of buying time for decision.

Although administrative and technical procedures have been established to keep the President fully informed, there is always the danger that an enemy surprise attack could destroy communication facilities. Since this will be a counterforce attack, even the means of retaliation may be destroyed before a decision could be rendered. Thus national survival under the conditions of complete surprise attack will depend upon prearranged rules of engagement as well as upon military readiness. There is a distinct requirement for the formulation of automatic rules of engagement approved by the President and the Congress and made known to the world.

The initial capability of the ballistic missile will assist the United States strategic air forces in performing the deterrent mission. The advanced nuclear-armed ballistic missile, with its extreme accuracy and range, will not change U.S. basic philosophy of war but it will revolutionize operations as the missile becomes the principal instrument of offensive force. The key to the weapon's impact, in either its initial or ultimate role, upon warfare and thus upon the nations of the world is its terrific compression of time and space. This capability in the hands of an enemy nation bent on domination may be the very incentive for aggression. Its possession by an enemy becomes even more dangerous if it happens to be in the hands of those who would not mind the destruction of a million lives or a dozen cities to obtain their objectives. In any evaluation of the future of the ballistic missile, one fact is clear: the United States should keep as far in advance as possible in the development of both the ballistic missile and the defensive measures against it. An enemy is not likely to launch an attack that has small chance of a quick success. Means of missile defense bear directly on the problem of deterrence.

THE ERA of the missile will make war more unattractive than ever. The very great and immediate destruction envisaged on both vanquished and victor—if indeed one side could be called a victor—may be so great as to spark some system of international control and settlement of differences short of all-out war. American morality has been reaching for such a goal for some time. The benevolent if quixotic disarmament attempts of the past are proof of good intention. It is further a fact that the United States has not used its preponderance of force in the recent past to gain any kind of dominance over other nations, even in the face of extreme provocation. This too was at a time when American power was supreme and could be applied without thought or danger of retaliation to the United States. Although not indicated in the foreseeable future, public opinion in support of a world authority may bring about an eventual understanding and acceptance of the implications of the ballistic missile era. The United States, by all means, should encourage any overtures in this direction.

It is probably agreed by all that any sort of firm universal limitations on the use of weapons could be achieved only under a supranational government that, in turn, would have to be armed with the latest, most powerful weapon —the nuclear-warhead ballistic missile. There is no indication that sovereign states will relinquish such power to a supranational government in the present or foreseeable future. It seems that the best the world can expect from the ballistic missile's impact on warfare will be a period of uneasy, mutual deterrence.

Evaluation Staff, Air War College

Impact of the Ballistic Missile on Defense

Colonel Harvey W. Shelton

FEW areas of military and scientific thought are more beset with conjecture, as opposed to fact-based logic, than is that concerning defense against the ballistic missile. One hears the cliché that no offensive armament in the history of warfare has long existed without effective counters to it being devised. But it is also true that no competent scientific or military authority will today confidently predict that any particular defensive scheme against the ICBM is really practicable. Be that as it may, there is an abiding urgency about the threat which demands that we not simply ignore it and hope that it will go away.

Before we examine some of the possibilities in defense against ballistic missiles it might be well to review some of the principles of defense against any military threat, if only to fix a few terms that will be used from time to time in this writing.

A defense against military threat must be rooted in a recognition of the threat, including a knowledge of the enemy's strategic intent. Logically the attacker's strategic intent is consistent with the capabilities of his weapon system, so the defender—armed with knowledge of that intent—is equipped to make appropriate strategic preparations. That is, the defender can now devise the best possible defensive system and formulate concepts and, to a degree, plans for its employment. Traditionally the defense function to this point proceeds at a comparatively leisurely pace and draws more on technical and political skills than on classical military skills. It has been common, as well, for the resultant defensive capability to lag behind the offensive capability, sometimes by a pretty frightening margin. This is the case with the ballistic missile.

Once the attack is launched the relative pace of the defensive effort increases greatly, and it is at this time that the classical military skills—notably tactical judgment—come into play. Again speaking historically, superior tactical judgment has often succeeded in spite of poor strategic preparation; faulty tactical judgment has often dissipated an apparent strategic advantage. Tactical judgment on the part of the defender involves such actions as gathering necessary information, waiting until the essential bits can be had and not wasting further time once they are available, divining the attacker's tactical intent while there is still time to frustrate it, and vigorously proceeding with the indicated counterstroke. Defense has always placed a high premium on sure knowledge or shrewd guess, and has imposed a severe penalty on uncertainty.

Application to the Missile

We shall see that all these classical functions and principles must play their part in the defense against the ballistic missile. Our problem can be stated as one of determining how to alter and adapt them. This current consideration will examine some of the characteristics of the ballistic missile system itself that must shape the defense against it. This effort may limit the area of our ignorance of how to fashion an effective defensive effort. It may then be possible to point with some confidence toward the avenues that more explicit scientific and military exploration must follow.

Looking first at pertinent characteristics of the ballistic missile system itself, I realize that all these will have been covered rather extensively elsewhere in this issue. It seems useful, though, to note them here and now so that they may be borne in mind in our further considerations.

Flight Time. One of the most frightening aspects of the ballistic missile is its extremely short flight time. Even people who routinely deal in the art of air battle at a thousand miles per hour or so tend to blanche when they think of doing battle with a vehicle whose entire tactical life span is of the order of a half hour or less. Certainly the opportunities for bringing human judgment and tactical skill to bear in such a duel are to be fantastically more limited than we have ever encountered before, even in the fast-evolving air age. Somewhat on the other side of the coin, however, is the relative inflexibility of the ballistic missile system. For instance, it may be that a prepared missile cannot be shifted from one target to another or among a large variety of targets without some rather time-consuming preparations. More to the point—once committed, a missile is destined for only one target, and its trajectory, while short-lived and far-flung, is also rigidly constrained by laws of nature.

Trajectory. An unaccelerated body, such as the ballistic missile becomes

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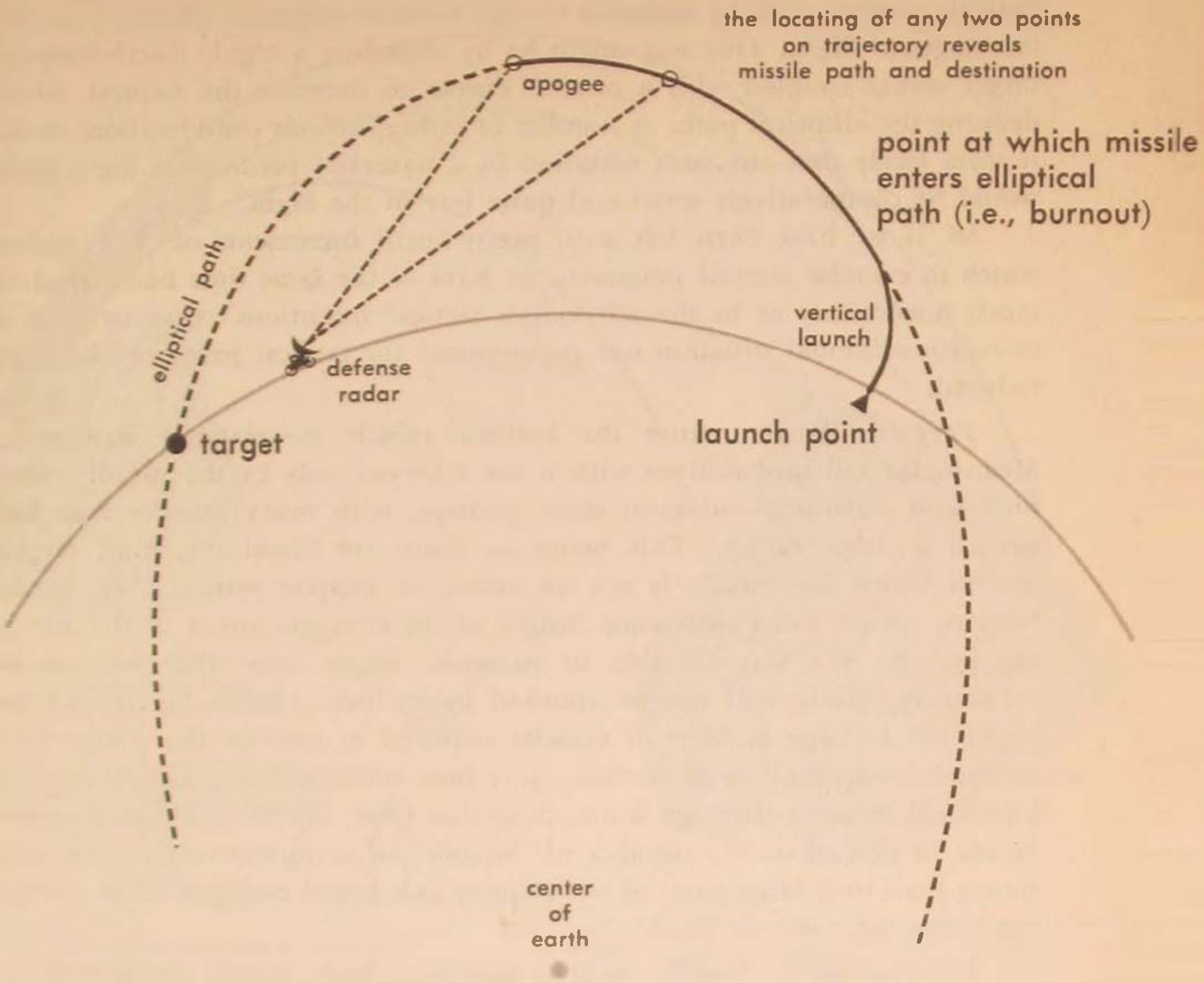
Ballistic Missile Trajectory



after fuel burnout, must travel in an elliptical path which intersects the earth's surface at two points. If we neglect atmospheric friction, the ellipse containing the flight path to a particular target is determined by two factors: the velocity of the body and the fact that the nether focus of the ellipse is at the center of the earth's gravitational field, i.e., at the center of the earth. The greater the velocity, the more elongated will be the ellipse, which is to say the higher above the surface of the earth will be the apogee of the trajectory. For any given range between two points on the earth's surface there is a minimum apogee corresponding to the minimum velocity which will propel a missile that far. This minimum velocity may be said to define the optimum flight trajectory, since even small increases in velocity exact relatively enormous penalties in the interrelated factors of thrust and weight. Actually, of course, a ballistic missile's flight does not take place in a true and constant vacuum, but the deformation of the elliptical trajectory from atmospheric effects is both minor and predictable. It can be seen, then, that if any two points on the missile's trajectory can be determined, its destination is also known, as well as every other point in space through which it must pass; it is not even necessary to "track" the missile in the ordinary sense to fathom its precise intent. In making this statement we ignore the possibility that a ballistic missile could be designed to vary from its elliptical trajectory in the last stages of flight. One way might be by including a highly discriminating target seeker coupled with a control system to override the natural forces defining the elliptical path. A number of rather obvious considerations make it seem likely that any such variation in a naturally predictable flight path would be comparatively small and quite late in the flight.

So, if we have been left with pretty small increments of time within which to exercise tactical judgment, we have at the same time been freed of much uncertainty as to the adversary's tactical intentions. Compared to a more conventional situation our requirement for tactical judgment is vastly reduced.

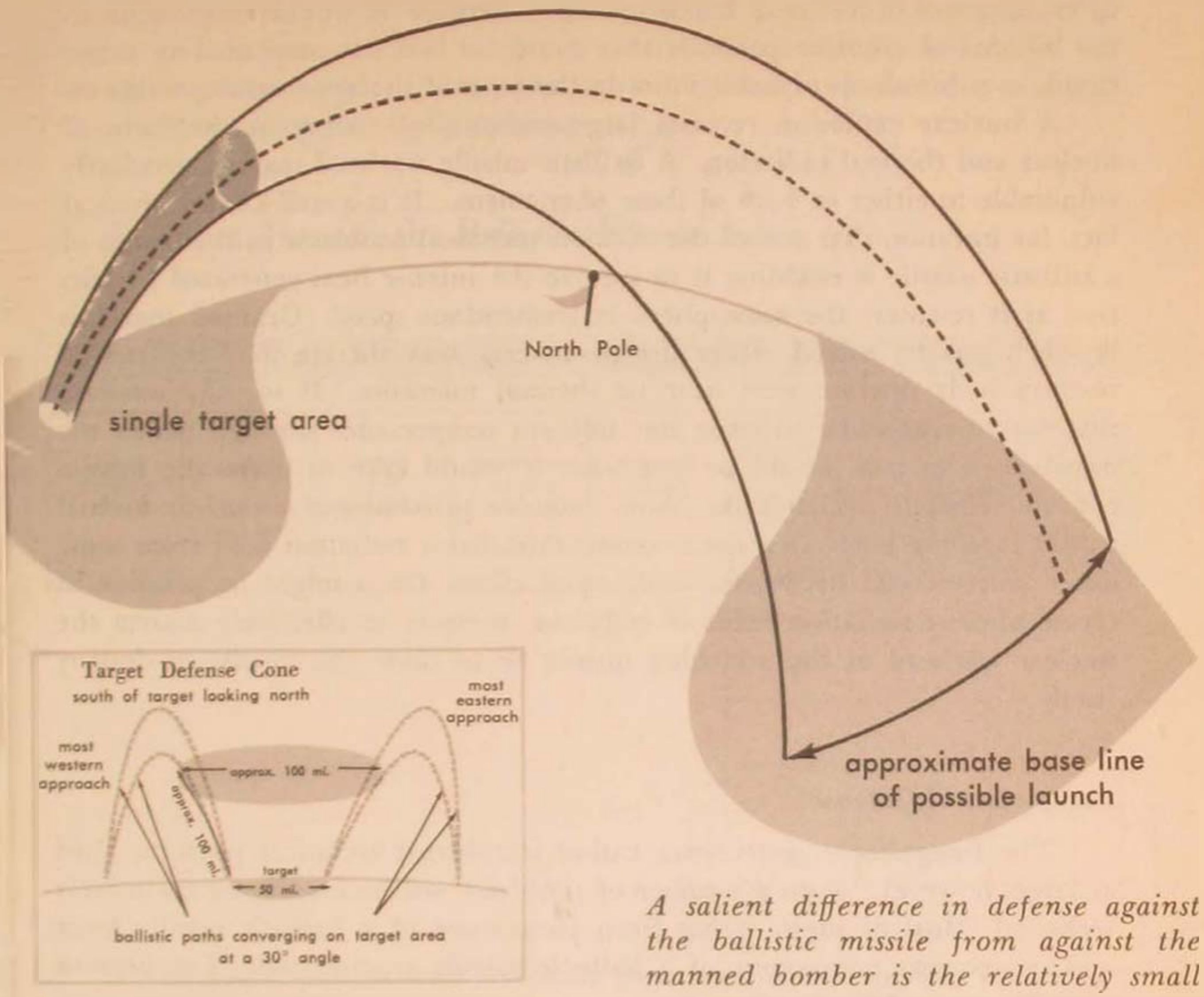
Targets. By its nature the ballistic missile is relatively inaccurate. Meaningful kill probabilities with it are achieved only by the use of rather high-yield warheads and even then, perhaps, with many missiles launched against a single target. This being so, there are broad classes of targets against which the missile is not an attractive weapon system. We, as defenders, are provided with some insight of the strategic intent of the attacking system. We may be able to recognize target areas that we can be reasonably certain will not be attacked by ballistic missiles because of the prohibitively large number of missiles required to provide the enemy with acceptable expectation of success. Just how much this foreknowledge can be turned to our advantage is not altogether clear, but we could conceivably decide to defend only a number of "islands" of comparatively modest area rather than such large parts of the country as a broad east-west band extending across the northern border.

Vulnerabilities. Finally, in this superficial look at the missile system's characteristics, let us consider some of its other unique vulnerabilities. It seems clear that a ballistic missile's support and launch facilities must be extenive, expensive, elaborate, and interdependently important to the successful launch of the weapon. Because there will always be sharp constraints, economic if no other, on the number and variety of such facilities, it appears that even behind an iron curtain their existence and location will not long remain a mystery. If one knew when to act, pretty straightforward techniques should be highly effective in destroying the nests before the birds fly. Many will be quick to point out that this Achilles' heel of a ballistic missile system seems well beyond the reach of a nation committed against aggression. It is too early to decide to ignore this potential vulnerability of the ballistic missile.

Assuming now that attacking missiles will be in flight before we can institute any defensive measures, how can we get at the missile itself? What does it take to kill it?

The commonest techniques of military destruction, whether the target be a man, a fort, or an aircraft, have been blast and physical impact. At first glance the incoming ballistic warhead seems singularly invulnerable to both.

Ballistic Missile Angle of Attack



A salient difference in defense against the ballistic missile from against the manned bomber is the relatively small approach corridor to be defended for each target. The bomber can attack from any direction. All the missile trajectories that could hit any particular area-target in the U.S. from any point in the U.S.S.R. would describe an envelope looking rather like a "wilted funnel," of roughly elliptical cross section and inclined toward Soviet Russia at an angle of about 30° from the target surface. Any defense system that could bring the "funnel" under surveillance and intercept the missile coming down through it would suffice.

The tremendous acceleration and other forces of its normal regime would require a design that should be highly impervious to blast overpressures—not to mention the warhead's vast kinetic energy and the fact that during most of its flight it is in a region where blast has little or no medium in which to operate. It is hard to imagine a body more difficult to strike with another body than this warhead hurtling toward us at twenty-odd thousand feet per second.

The very speed of the warhead that makes its interception such a problem may contain the seeds of solution. Recent investigations have suggested that at very high impact velocities very small "projectiles" have a rather explosive effect completely out of proportion to the impact effect normally to be expected from their kinetic energy. Perhaps it would be possible to use billions of sandlike particles that could be laid in comparatively dense clouds over hundreds of cubic miles in the path of the approaching warhead.

A nuclear explosion releases large amounts of energy in the form of nuclear and thermal radiation. A ballistic missile warhead may be peculiarly vulnerable to either or both of these phenomena. It is a well-known physical fact, for instance, that one of the trickiest technical problems in the design of a ballistic missile is enabling it to survive the intense heat generated by friction as it re-enters the atmosphere at tremendous speed. Granted that this problem can be solved, other design criteria may dictate that the missile re-entry body operate very near its thermal tolerance. If so, any measure that would materially increase the ambient temperature through which the missile had to pass would be just what it would take to make the missile consume itself in a meteorlike blaze. Suitable proximity of a nuclear fireball would turn the trick. It is even conceivable that a radiation field from some other source could be devised with equal effect. Or it might be possible to create nuclear radiation fields of sufficient intensity to effectively disarm the nuclear warhead of the attacking missile or to cause the missile to destroy itself.

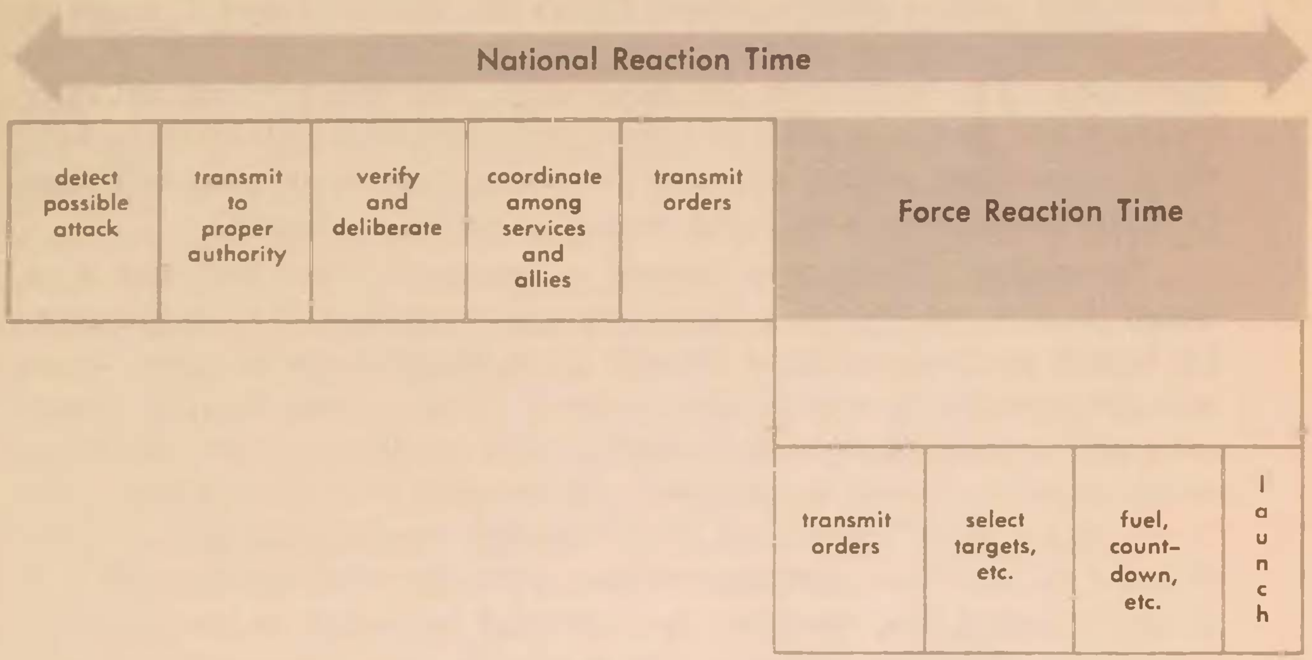
Parameters of Defense

The foregoing suggests some rather formidable technical pursuits. Just as large, however, looms a number of problems not necessarily or exclusively technical. Most of these spring from parameters of a ballistic missile force and consequent parameters of a ballistic missile counterforce. Let us now consider some of these.

Reaction. A signal characteristic of a ballistic missile force is its inherent capacity to launch a truly massive attack with a very high degree of simultaneity. It seems completely feasible to cause a large fraction of a very large attacking force to cross a defense net or strike a wide variety of targets in concert within one or two minutes. The defensive system obviously must have high resistance to saturation and, since its reaction time is one of the important parameters of any defense force, it is apparent that a missile defense force requires a very rapid reaction capability indeed.

It may be useful to coin two definitions at this point: "*force* reaction time," the period from the time competent military authority orders commitment of the force until active defense measures are brought to bear; and "*national* reaction time," the longer period from the time when a threat is first recognized or suspected, including all necessary gathering of information, making of decisions, and passage of orders and ending again when active defense measures are brought to bear. Up to now there has been little occasion to make the distinction drawn by the above definitions. If the *force* reaction time is and can afford to be several hours, the fact that *national* reaction time is an hour or so longer is not particularly alarming. But if the *total reaction time available* is in the order of a half hour, the distinction becomes vastly more important for this reason: it probably is comparatively easy to reduce *force* reaction time; but even if this is pared to near-zero we are still in deep trouble if the other factors that make up *national* reaction time have not been drastically reduced.

Reaction Time in the Ballistic Missile Age



Today *force* and *national* reaction times can be concurrent to a considerable extent. That may not be the case in the ballistic missile era. Today, for example, if the President received information on an apparently imminent attack, he could immediately order all necessary preparations, knowing that at any time in the next several hours he could abort or recall the retaliatory strike if further developments proved his initial information to be misleading. On the other hand a retaliatory ballistic missile system ideally would be designed so that its force reaction time would be in the order of a quarter hour. Once that quarter hour had begun to run its course, quite likely very little could be done to recall the commitment, at least without jettisoning a large part of the force. The implication is that the supreme authority could not start the force reaction time until the other elements of the national reaction time had proceeded to an irrevocable conclusion of commitment.

Warning. Compounding the reaction-time difficulties of a ballistic missile attack is the glum outlook for strategic warning. It probably is true that we will have strategic warning in the sense that we will know of the existence of a threatening missile force before it is prepared to attack, but the likelihood that we will know much more than that until missiles are actually fired is rather remote. A manned-bomber force of significant size represents a far-flung operation. Its launching involves many elaborate preparations such as assembly of people and fuel in conspicuous quantities, intricately timed deployments, and a number of other such activities that differ observably from the routine activities of a bomber force *not* on the eve of a strike. The result is that, even with the low-order intelligence we suffer on doings behind the iron curtain, it is hard to believe that a really significant bomber strike could be launched against us without some days' foreknowledge, at least to the extent of learning that such a thing *could* happen. By contrast, in a ballistic missile force all the materiel and people that must be deployed for it to attack must be deployed continuously. Thus the pattern of activity around and about a ballistic missile facility on "H-hour minus 2" is apt to be completely indistinguishable from that on "D-day minus 200" or any other time. This underlines the requirement that whatever our defensive measures are, they be capable of moving from long-term alert status to fully effective operation within minutes. Naturally there is an extremely high premium on learning of an attack as early in its life as possible.

Automation. There now emerges a parameter of the defensive force design: it must incorporate a high degree of automation. The requirement for human judgment must be brought to an irreducible minimum. Means must be provided to assemble the problems which human judgments must solve and present them with negligible delay to those centers where the necessary judgment can be exercised. At the same time the old adage that "haste makes waste" never had more dreadful import. The defense force designed for near-instantaneous reaction cannot be so designed at the risk of implementing false decisions, particularly if retaliation in kind must be part of the defensive measures. Imagine a two-way, intercontinental exchange of ballistic missile forces that was triggered off by one radar which could not tell the difference between a meteorite and an ICBM!

Cost. Yet another parameter of the required defense force is suggested. It is a foregone conclusion that our current air defense force is of little value against ballistic missiles. For just the reasons that this is true, the converse is probably true: a countermissile defense force will have limited value against other threats. Since for at least several years to come a ballistic missile force will confront us as part of a *spectrum* of threats, it follows that any ballistic missile defense force we fashion must be in addition to, rather than instead of, such air defense forces as we now have. Indeed ballistic missile defense measures will tend to compete economically with other necessary defensive measures in an era when the missile is by no means the most fearsome threat. This could serve to make countermissile measures that are technically feasible practically infeasible from a cost standpoint.

What We Must Do

What can we now recognize as the net impact of the ballistic missile on air defense? What can we say of the defense force that must be fashioned for the era ahead?

We must take steps to reduce national reaction time while designing force reaction time to a minimum. There must be foolproof and delay-free organizational machinery to inform the highest levels of government of an imminent or possible attack and to transmit top-level decisions to the force or forces concerned. There may be a requirement in this connection for reviewing the laws, traditions, and policies governing who can act under varying circumstances "for and in the absence of" the President and other high officials. There also is a requirement, whether or not it is apt to be met, for extensions of international law. Clearly, for example, moves falling far short of what is now internationally recognized as aggression could in fact foretell the virtual annihilation of a major nation within an hour or so.

It almost goes without saying that the more we know about a ballistic missile attack, including the intent to launch it, the better off we will be in countering it. Any improvement we can make, then, in our intelligence gathering or preattack reconnaissance is certainly to be sought. Perhaps we shall have to devise entirely new types of "indicators," such as the widespread evacuation of the enemy's urban populations—a predictable course for him to take if he were about to launch a strike and thus expected a retaliatory strike. A reconnaissance satellite or other technique that could detect the launching of a ballistic missile or fix its trajectory at an early stage of the flight would be invaluable, if we could learn of these things almost as soon as the satellite did. This communication problem might dictate a whole system of satellites capable of almost instantaneous relay of information. A next, obvious line of defense would be suitable radar or other detection devices that could be home based yet able to detect the existence and path of an incoming trajectory, presumably not much before apogee but hopefully not much after.

Rather involved computing and informing systems would have to be married to the detection systems and somewhere between them positive identification, with appropriate human judgment exercised, would have to be effected. That accomplished, the force reaction could be preplanned and made nearly automatic, quite possibly aided by a tentative alert status dating from initial detection.

It is less clear what active defensive measures, if any, should be provided to take advantage of the knowledge gained and the decisions made. There are a number of technical investigations in the realm of nuclear weapon effects, for example, to be pursued. For other suggestions the frontiers of scientific knowledge must be examined as they move forward.

It is entirely possible that for a long time to come the only really practical defense against the ballistic missile threat will be the passive one represented by our deterrent retaliatory force, including our own ballistic missiles. Even if that proves true, there is much to be done to fit ourselves for defense in the missile age.

Command and Staff School

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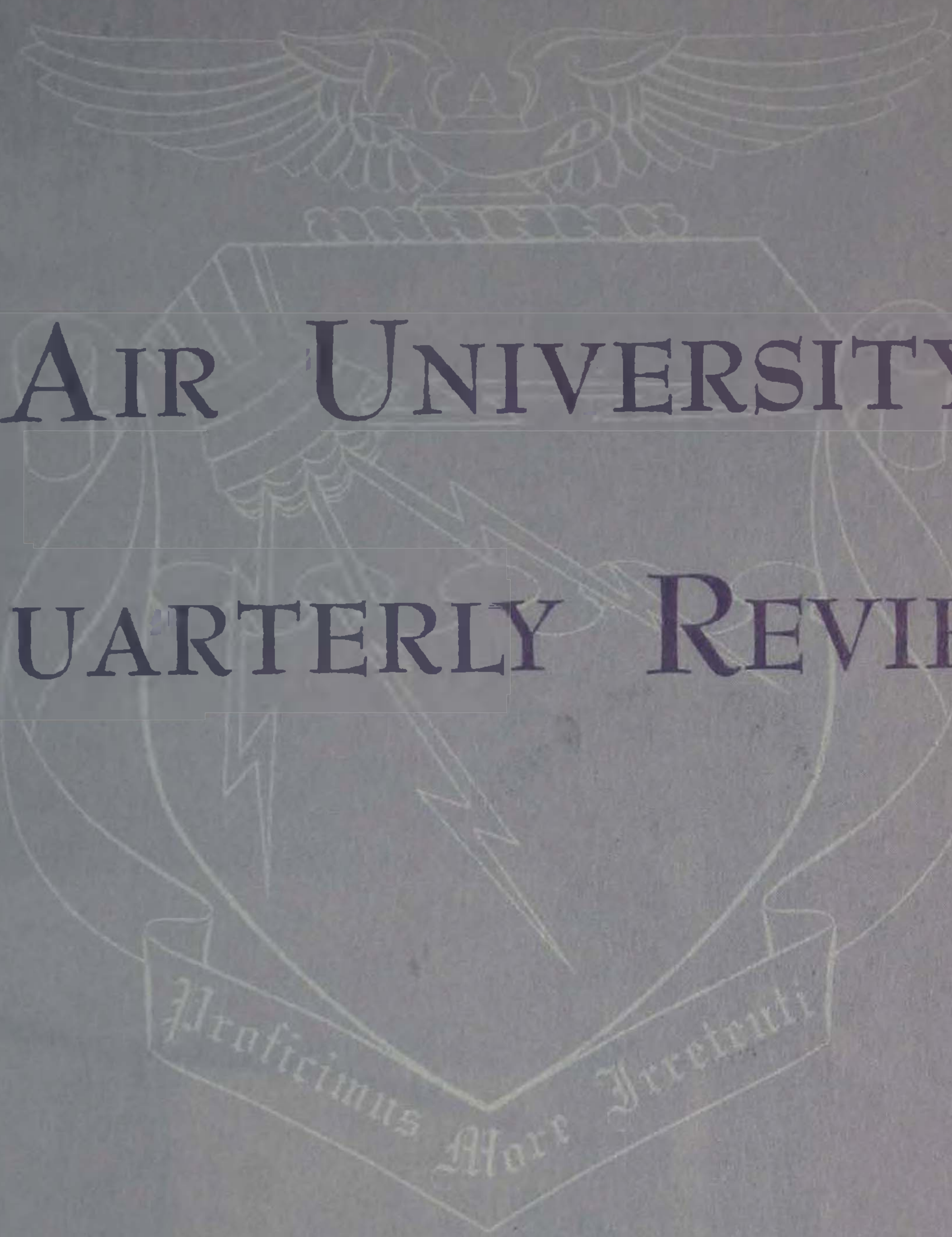

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