10TH ANNIVERSARY

The remarkable thing about the USAF ballistic missile program is that rather than representing great advances in technology it was a classic example of orderly engineering. Although there were differences of scientific opinion as to the feasibility of the program and the time it would take to do the job, there is no question that it had to be organized successfully—and it was . . .

The USAF Missile Program, A Triumph of Orderly Engineering

BY J. S. BUTZ, JR.

TECHNICAL EDITOR, AIR FORCE/SPACE DIGEST

ENGINEERING colleges the world over teach that good order is the foundation upon which all good engineering jobs must be built. The US Air Force ICBM program is the most impressive and best proof of the truth of this precept.

The ballistic missile force operational today is first and foremost a triumph of engineering. An overwhelming portion of its problems involved the practical application to a large and complex problem of scientific and technical knowledge that was already in existence. Very little new research or scientific investigation was necessary; it was a matter of putting knowledge to work.

By virtually every standard of comparison for engineering efforts, the ballistic missile program is the "most" that the nation has completed to date. It set records in terms of dollars spent, people employed, and tasks accomplished in a given period of time.

And the program is the best proof of the axiom that good engineering is orderly engineering. In the very beginning, it was predicted that orderly engineering would be the key to success in developing the ICBM vehicle and the operational complex needed to maintain a large force in constant readiness. The von Neumann Committee, which played a key part in getting the program started, reported in 1954 that technical problems such as target accuracy, warhead weight, reentry, guidance, launch time, and base protection could be handled. It warned, however, that the development objectives must be clearly fixed, that decision-makers must be continually responsive to the needs of the program, and that design teams not be hampered by on-again, off-again decisions.

The fact that the necessary choices were forthcoming represents a victory for decision-making on two levels. First, the basic decision to go ahead had to be made at the highest level. President Eisenhower was the only one who could authorize this multibillion-dollar program. He had to make the decision and stick with it in the face of significant opposition and advice from highly respected scientists and engineers who strongly believed that, if the job could be done at all, it would take years longer and billions more than estimated. It took courage, even though he enjoyed considerable congressional support, to give the program the go-ahead and to provide it with strong continuous backing. And it must be considered a milestone in Mr. Eisenhower's presidency that he made the decision in time to prevent an untenable situation in which the Soviet Union would have been the only power with an ICBM force.

The second vital decision came from within the military. An entirely new organization was formed under Gen. Bernard A. Schriever with the sole mission of developing certain specified ballistic missiles and deploying them in the field by specified dates. General Schriever had virtually absolute authority over — and responsibility for — the ballistic missile program during the first five years until hardware was in widespread production and follow-on systems were in advanced development.

To allow him to move the program ahead as rapidly as technically possible, General Schriever operated outside normal weapon-development channels. He reported directly to the Secretary of the Air Force. Whenever critical problems developed, he was free to discuss them immediately with the Secretary, the Chief of Staff, the Secretary of Defense, and, if necessary, even the President. This policy kept program delays resulting from top-level discussion down to what seems to have been an irreducible minimum. Congressional support never flagged, and essentially the nation's full resources were available as needed.

Instrument package from Discoverer 13, retrieved on August 11, 1960, was the first object recovered from orbit by the United States. It is being shown at left by President Eisenhower during White House display. Generals White and Schriever join top DoD officials in celebrating this most important event.

It was no trick to transfer a sense of urgency and purpose from the high echelons to the low. The strong support and concern at the top of the executive and legislative branches of government were amplified into a state of superb morale and intense dedication at all levels in the military and industrial groups who were doing the development job. As one industry official involved in the program puts it, all problems were approached as joint problems. He says that even after the dismal day when the fifth Atlas in a row exploded at Cape Canaveral, just six months before the missile's scheduled operational date, the Secretary of Defense called General Schriever and the contractors in to a meeting to discuss a solution to "our" problem.

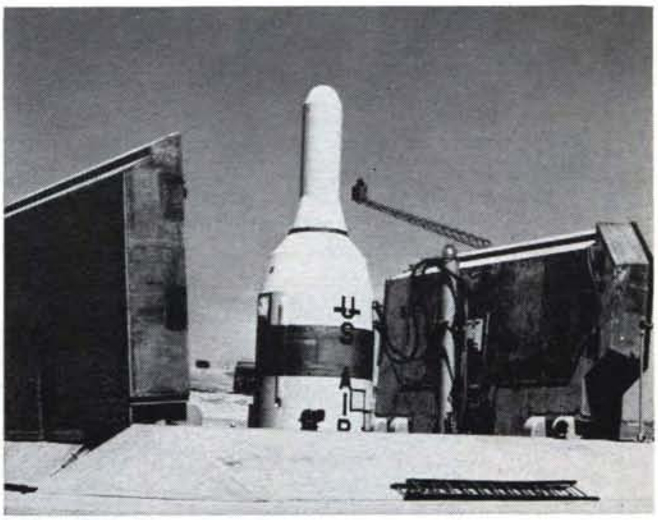
The big trick at the working level was to keep all design groups working at maximum pace on realistic specifications. The short development time available forced adoption of the concurrency concept. This called for the majority of systems and subsystems in each missile to be designed and tested simultaneously, and to be ready for incorporation into a flight-test vehicle on a given date—sometimes years in the future. All ground-support equipment, base facilities, auxiliary apparatus, and personnel were also part of the concurrency package and had to be ready on given operational dates.

Changes were inevitable. Many problems were present in scores of systems at any given time. Any one change could reverberate through the entire missile program, and no one could predict exactly what the final vehicle would look like or guarantee its performance. For example, failure to stay inside original vibration specifications on a turbopump could force major design changes in rocket engines, structure, and all types of auxiliary systems up to and including the nuclear warhead.

Probably the foremost accomplishment of the ballistic missile program is that concurrency worked, and procedures were developed for handling design changes expeditiously and intelligently. These procedures which brought order into a most complicated engineering problem have been refined into the widely used management tool now known as PERT—Program Evaluation and Review Technique. PERT can keep a daily tag on costs, as well as technical progress, and can predict critical problems and major decision points long before they occur. It allows the full consequences of changes to be foreseen, the "best" change to be selected from a group of alternatives, and the adverse impact of all changes to be reduced.

The ballistic missile program also marked the birth of true "systems" engineering. Under this concept, each missile—including all of its flight and ground systems—was designed as an entity under the control

(Continued on page 185)



Titan above is rising out of an operational silo complex at Vandenberg AFB, Calif., where SAC crews, to maintain their proficiency, fire missiles out into the Pacific Ocean. The massive doors that protect this silo are made of steel and concrete, and they weigh approximately 200 tons.

Minuteman being readied for development flight at left is the most efficient weapon to come from the ballistic missile program. It is the most advanced in terms of cost/effectiveness for warhead weight delivered to a target and from a maintenance standpoint.

of one group. Preceding the start of design work, a thorough study was made of the proposed environments the missile could be expected to operate in, as well as the effect that the missile would have on these environments.

Concurrent development is a part, but not all, of the systems-engineering concept. Concurrency was used on all Air Force ballistic missiles, but the degree of systems engineering employed varied. The Atlas, for instance, used rocket engines and other systems which had been developed to their virtually final configurations before the three-engine version of the missile was begun. This development had been accomplished under prior Air Force programs, such as Navaho, and was later continued by Convair with its own funds during a period of government disinterest. The Thor was more of a systems-design job than the Atlas, and the Titan and Minuteman were truly representative of systems engineering.

The new concepts did not have an easy birth and were initially disputed in many ways. In applying ideas of concurrency and systems management, the Air Force Ballistic Missile Division and Ramo-Wooldridge,

(Continued on following page)

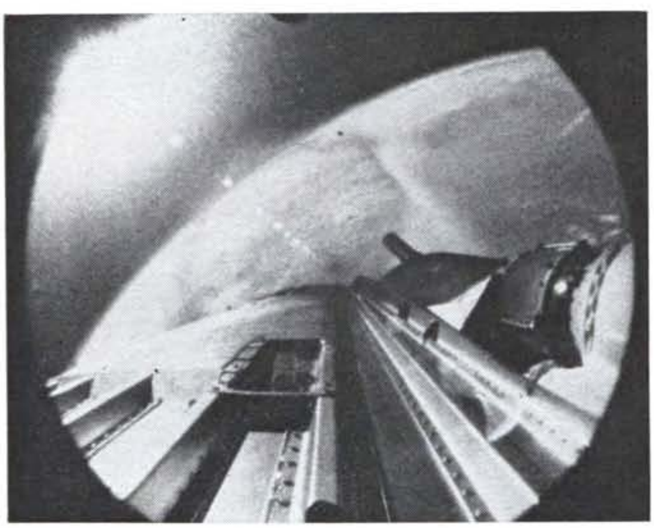
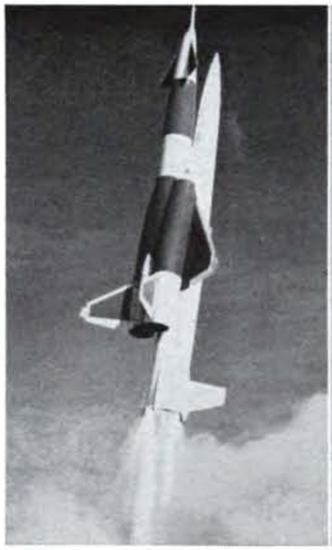


Photo above shows the beginning of stage separation on an early Atlas missile flight. This portion of a missile flight caused great concern at one time. However, it proved to be a manageable engineering problem, as did all of problems connected with the ballistic missile development program.

Minuteman encircled by flame at left illustrates rough conditions of silo firings. But such firings have proved to be much easier than was predicted in many quarters.

Construction of a steel and concrete room for an underground Titan launch complex at Lowry AFB, Colo., is shown in progress above. At one time such complexes were considered to have a very high probability of survival in any possible enemy attack. But the continued improvement in enemy missiles has changed this picture considerably.



Navaho, supersonic intercontinental cruise missile (at left) which was finally canceled in 1957, left a legacy of rocket engines and technology systems that materially aided ICBM development. Titan missile, at right, was originally planned as insurance in case the Atlas failed. Now Titan has grown into a major vehicle in the nation's stable of space boosters.

the contractor which assisted BMD with technical guidance, took over many of the prerogatives that traditionally had belonged to hardware manufacturers in weapon development. The arguments have not completely subsided, but the concurrency and systems-engineering ideas have more than proved their worth.

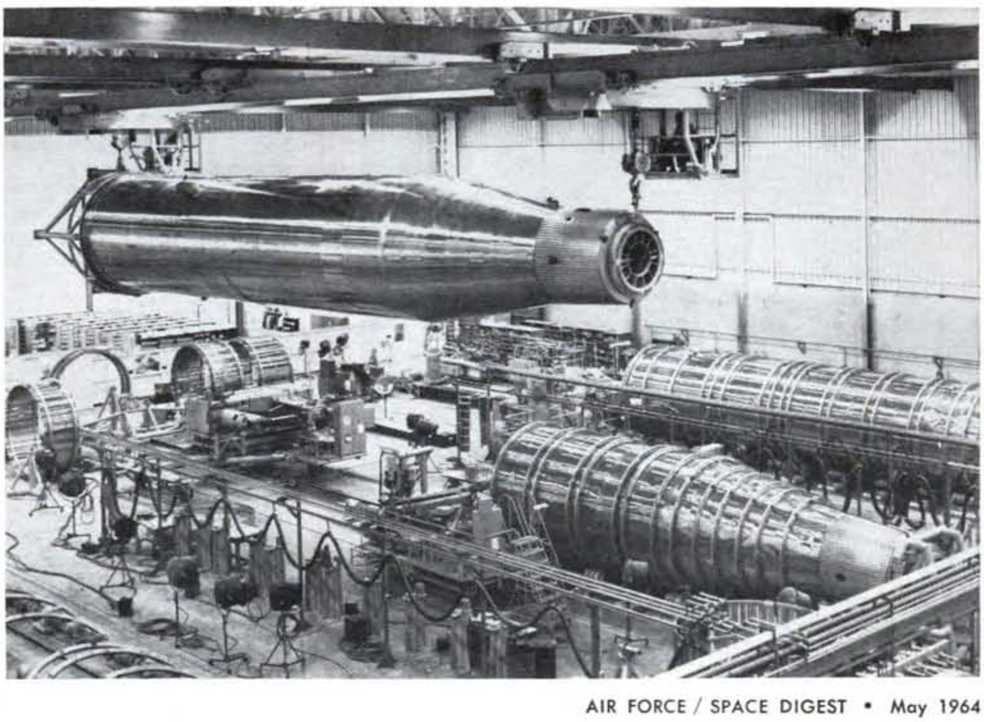
The best proof that the concepts were sound is that the original estimates on development time and missile performance were substantially bettered. The von Neumann Committee thought six to eight years would be necessary to get an operational ICBM after design work had started. Yet the first Atlas squadron was operational in little more than five years.

Performance achievements have been even more impressive. Industry has been able to overcome technical problems in much grander fashion than even the von Neumann Committee imagined. Today's ICBMs can deliver heavier weapons, with greater accuracy, over longer distances, than anyone predicted in 1954.

Reliability of the ICBM in flight test has steadily improved. All types have a cumulative record of better than sixty percent successful firings to date, and there is no doubt that they are fundamentally sound machines. However, estimates on the reliability of an ICBM force and the probability that it could fulfill its assigned mission under all conceivable circumstances are another matter completely. The current public

(Continued on page 189)

Quality control during manufacture of ICBMs has been much more rigid than in any mass-production program of the past. Convair's production record in welding the Atlas' very thin, stainless steel skin has been excellent, even though ten years ago there were many who doubted that proper weld quality could be achieved without very high rejection rate.



Intricacies of Discoverer vehicle instrumentation are explained to General Schriever during briefing early in the ICBM development program. Ability of AF-developed ballistic missiles to orbit Discoverers has been major defense contribution in addition to deterrence role.

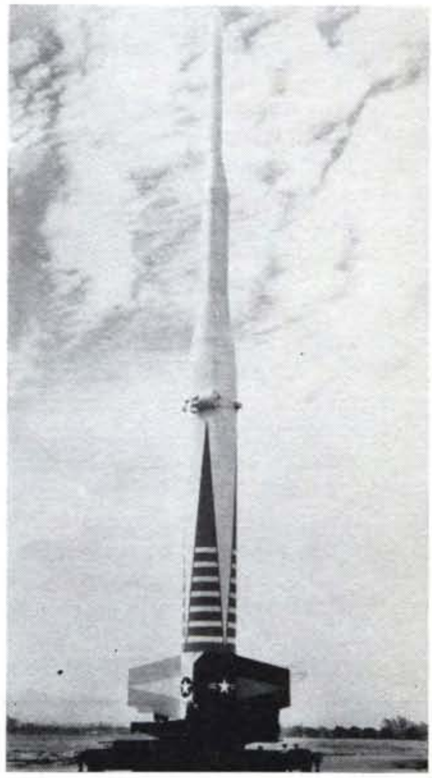
debate about missile reliability undoubtedly will not produce any accurate information or much public understanding.

Certainly the ballistic missile is an immensely potent weapon, but can it be proven reliable enough to assume the full and complete burden of the US strategic mission? This is a matter of judgment, just as the decision to start the ICBM program was a matter of judgment. No one could ever have proved conclusively that the ICBM could be developed until it was done, and no one will ever be able to prove conclusively that the ICBM is invulnerable and unstoppable as long as it sits in a silo in peacetime.

Today, the ICBM is regarded in most technical quarters as a relatively simple vehicle, believe it or not. People who have worked on both aircraft and missile programs say the modern bomber is an order of magnitude more difficult to develop, primarily because it has wings and the ICBM doesn't. This opinion seems to find agreement throughout industry. In other words, the ICBM problem, which looked overwhelmingly complex to many of the nation's best scientists only ten years ago, now has been reduced to a manageable and predictable technology.

H. Julian Allen of the NACA's Ames Laboratory, during the early 1950s developed theories which described the airflow and heat-transfer conditions existing on nose cone during reentry. He was primarily responsible for the blunt nose cones which first proved that high-speed reentry was possible with known materials.

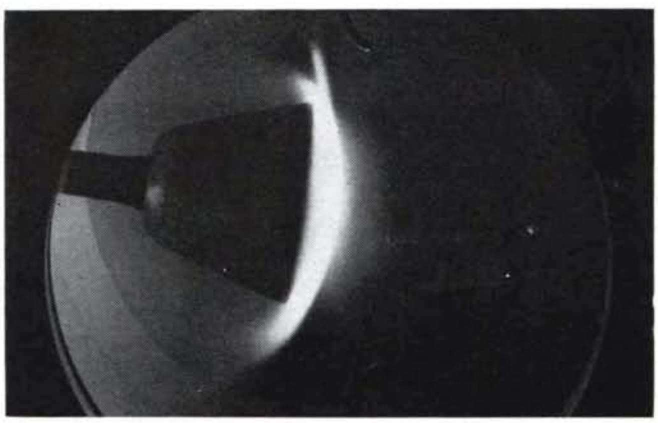
Lockheed's X-17 solid-rocket vehicle provided first large-scale flight data on the behavior of ballistic missile nose cones during reentry at ICBM speeds. This data proved that H. Julian Allen's theory was correct and that a variety of nose cone shapes was feasible.



An insight into how this technology is seen today is given in the paragraphs below, paraphrased from discussions with Allen B. Donovan, a vice president of Aerospace Corp., and Dr. Edward Doll, a vice president of Space Technology Laboratories, Inc., both of whom held responsible positions with Ramo-Wooldridge during virtually all of the ballistic missile development period.

- **Reentry Vehicle**—This was the most difficult new problem. H. Julian Allen, at the NACA's Ames Laboratory, showed analytically that a blunt heat-sink body could survive an ICBM reentry. We needed one bit of research data—flight-test information—to verify the calculations and satisfy everyone that we were on the right track. This was the Reynolds Number (flight condition) at which the flow on various nose-

(Continued on following page)

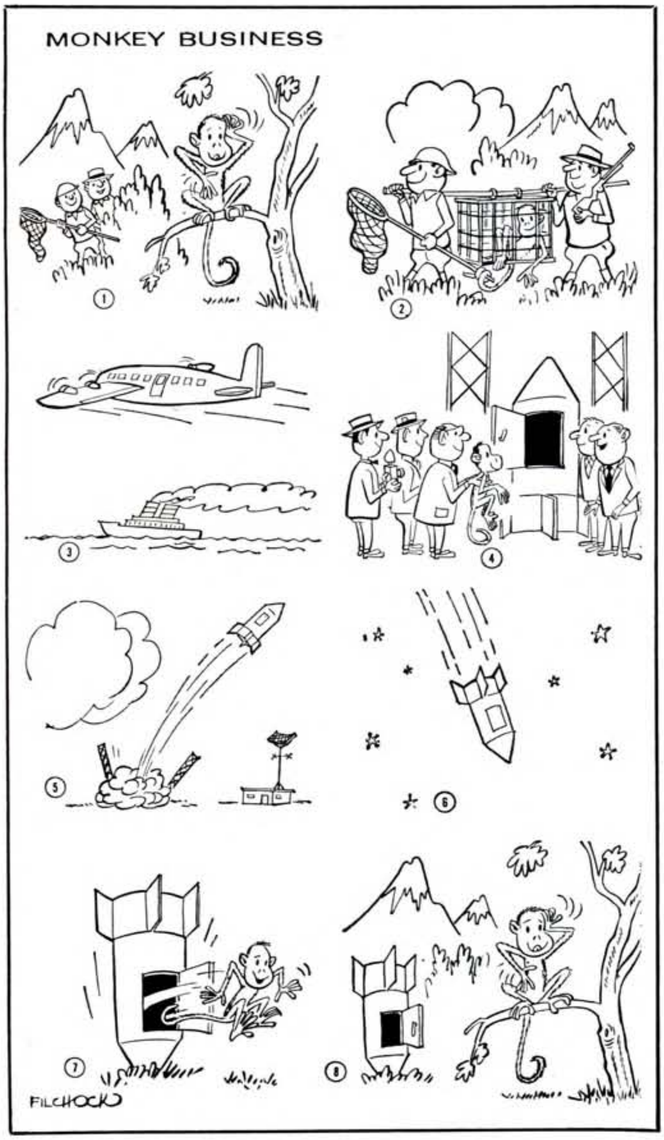


Model of a blunt nose cone during a Mach 20 test is shown in the picture above. Thousands of such tests in the United States during the past ten years have contributed to the building of a powerful reentry vehicle technology.

cone shapes made the transition from laminar to turbulent conditions. The X-17 vehicle got this data on large-scale models, and we were in business. The Thor-Able later was used to prove that the ablation nose cone was practical. In retrospect it seems clear that much of our original concern over heat transfer was without foundation, and we forgot how hard it is to transfer heat when we want to.

• **Quality Control**—Ballistic missiles are manufactured to essentially the same tolerances as aircraft. However, quality control has to be much better because the missile safety factors are lower and they are unmanned, without redundant systems. The main question concerned the ability to make large numbers of sound welds to join the Atlas' thin stainless-steel skin *(see page 100)*. The idea of such a thin, pressurized structure was advanced in the 1930s in papers by von Kármán and Tsien. Convair did a fine job of translating these ideas into a design that could be manufactured reliably and they had remarkably little trouble doing it.

• **Specific Impulse of Liquid Rockets**—The Atlas and Thor engines were straight developments of the Rocketdyne rockets in the Navaho. The only major change was a switch from the Navaho's lox-alcohol propellants to lox-kerosene so the specific impulse could be boosted from 212 to 245 seconds. Some people said this would be difficult, but it wasn't, looking back on it.



• **Guidance Accuracy**—There was some concern about the accuracy of the original Atlas radio guidance because of bending of radio waves in the troposphere. A considerable amount of research was done in this area, and we were able to handle the problem nicely. It also proved possible to develop inertial-guidance systems to much higher accuracies than originally demanded.

• **Materials**—No new or exotic materials have been required for the success of the ICBM program. Steel and aluminum are still the principal airframe materials. Some tungsten nozzle work was instrumental in improving engine performance. The incorporation of a glass-filament-wound rocket case in an upper-stage solid rocket on the later model Minuteman also improved performance.

• **Flight-Test Record**—At one time the program was heavily criticized because of flight-test failures. One of the most trying periods occurred when five Atlases in a row were lost. This was about six months before the system was to become operational. The over-all flight-test record has been good, though. With aircraft, hundreds of development flights often are made before a new model becomes operational. Then several flights often are made in each production aircraft before it is accepted for service use. The missile test record is proof that our quality-control procedures were good. And, in the missile business, quality control is vitally important.

• **Computers**—In many ways computers made the ICBM development tractable. They make it possible to keep track of thousands of items of information, make changes, revise schedules quickly, etc., on large programs. In addition it has been possible to perform a sizable amount of detailed design of engines, structures, and the like, on computers. Apparently this significant capability will continue to grow rapidly and should facilitate the design of any future generation of ICBMs.

The above views on the relative ease of the ICBM development are not those of Monday-morning quarterbacks, and they were not generated with the aid of hindsight. A sizable number of engineers and scientists who were conversant with large rockets had roughly the same ideas from 1950 on. The only problem was that their arguments were drowned out until 1954 by a chorus of opposing experts who were proved to be wrong.

This ICBM experience is not strangely unique. Military technology is not losing its dynamism or heading for stalemate. More so-called "far-out" ideas are said to be on hand than ever before, and if they can be brought to operational status in as good a fashion as that "far-out" idea of the early 1950s—the ICBM—then the ballistic missile may not dominate the 1970s as the Department of Defense now expects.—END