

# MISSILES



FROM CONCEPT

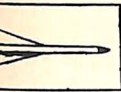
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## A HISTORY OF ROCKETS AND MISSILES

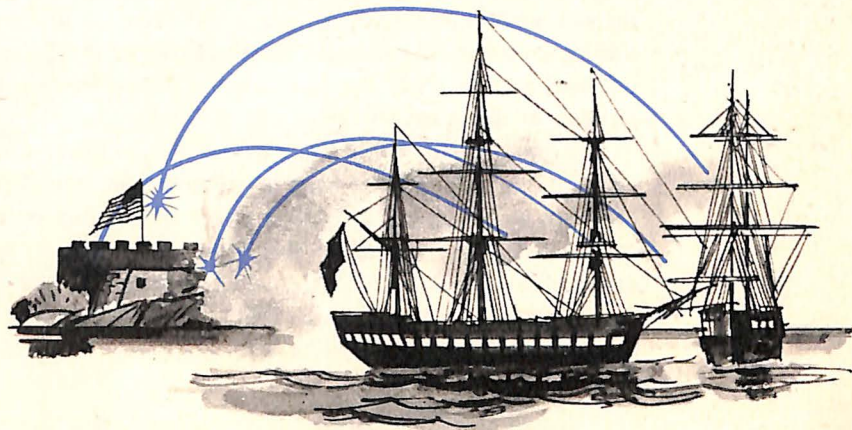
The guided missile is frequently termed a “new” method of destruction. Certainly the massive airframes, the thunderous power plants and the elaborate guidance mechanisms of modern automatic weaponry are new. In the broader sense, however, the concept of unmanned and self-propelled weaponry dates back more than two centuries before the astronomer Copernicus laid the foundation for modern space cartography.

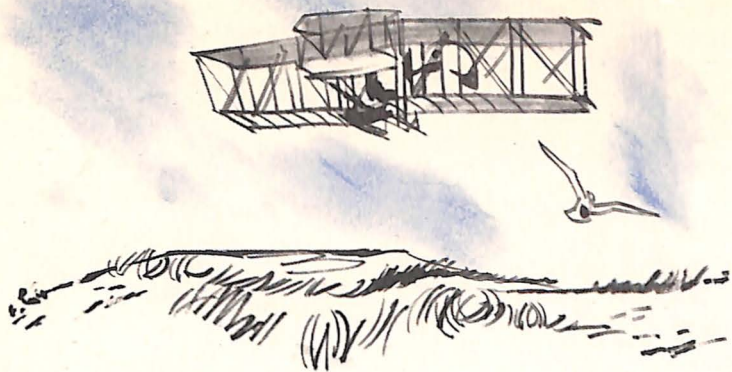
The earliest authentic records tell us that in 1232 A.D. the Chinese used rocket missiles, or “arrows of flying fire,” against the Mongols in the siege of a city named Kai-fung-fu. About the same time, rockets were introduced in Europe, where they gained wide acceptance by the military forces of various Middle Age belligerents.

A rocket of a more advanced type was developed in India circa 1780 and in the second Mysore war (1792) rockets were used to considerable advantage by troops of Tipu Sultan of Mysore against British forces under Lord Cornwallis in the battle of Seringapatam. At the turn of the 19th century a new development in propellants credited to Britain’s Sir William Congreve gave the rocket a considerably increased range capability and led to its wider use as an artillery weapon.

The most notable 19th century employment of rocketry occurred during the War of 1812 when British forces attacked Fort McHenry with ship-launched rockets. A brief historical reference to this incident was preserved for posterity by Francis Scott Key in his masterwork, the Star-Spangled Banner:

*“And the rockets’ red glare,  
The bombs bursting in air,  
Gave proof through the night  
That our flag was still there.”*





About 1830, an American named William Hale added an element of stability to the rocket by providing it with nozzle vanes which caused it to spin rapidly. Within the next two decades, however, other ballistic engineers came up with great advances in the range and accuracy of conventional artillery. As a result, the popularity of the rocket declined and in 1866 the last rocket artillery force, an element of the Austrian army, was disbanded.

The researches of Orville and Wilbur Wright in the first years of the 20th century were of utmost importance to missilery. Although the Wrights were not thinking in terms of automatic weaponry when they built their "Flyer," the memorable first powered flight at Kitty Hawk started a continuing program of research and development in aerodynamics and propulsion which later contributed in great measure to missile progress.

The *guided* missile, as opposed to the aimed rocket, came into being in 1915 as the result of a cooperative program between the U. S. Navy and a private contractor. Known as an "aerial torpedo," the missile flew a pre-set course. Later, radio control was used as guidance.

During World War I, the Army sponsored a series of experiments with a radio-controlled pilotless aircraft known as the "Bug." Although successfully test flown, the Bug did not see war duty. It did, however, demonstrate the potential of radio-controlled missiles and started a chain of development work in that area which continued into the thirties.

In the period between World War I and World War II, a good deal of research work was accomplished on power plants for missiles, although most of it was aimed primarily at aircraft power. In addition to the piston engines used in the early radio-controlled missiles, there was the turbojet engine, developed during the thirties by Frank Whittle in Great Britain and Hans von Ohain in Germany.

There was also the ramjet engine, first proposed and patented in France as early as 1913. In the late twenties and early thirties, experiments with ramjet power were conducted in France and Hungary without success, largely due to lack of information about high-speed air flow. The first successful ramjet was developed in the United States by the Applied Physics Laboratory of Johns Hopkins University and test flown in 1945.

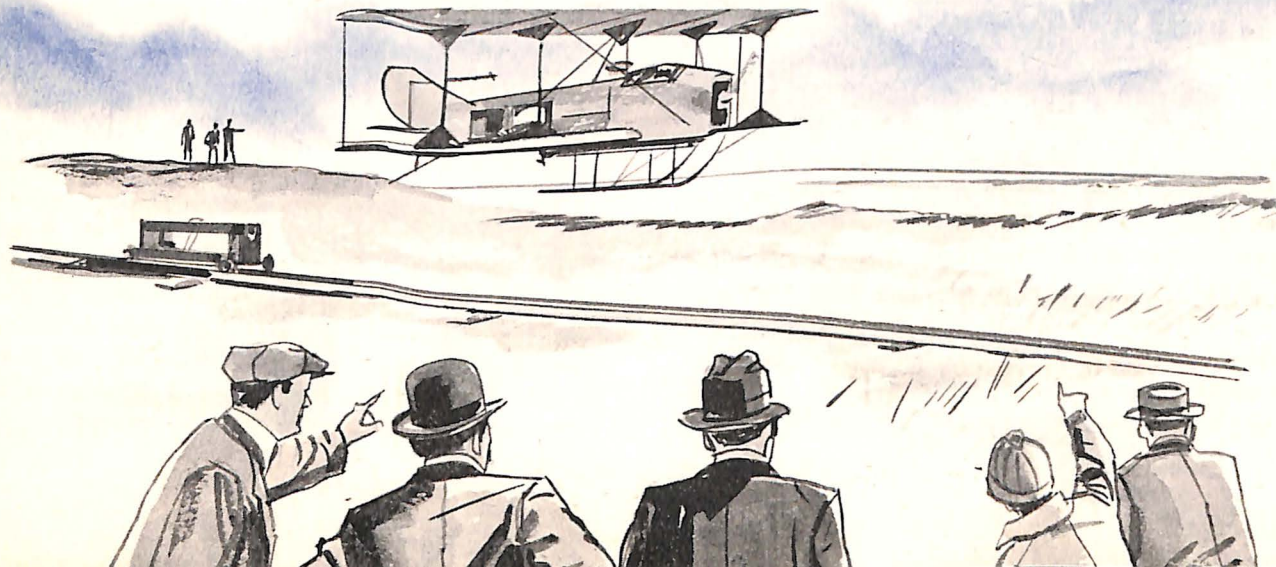
During the thirties, the Germans experimented with another type of power, the pulsejet. This engine was perfected during World War II and it became the power plant for the V-1 "buzz bomb."

Modern rocket research started in the late days of World War I when Dr. Robert H. Goddard introduced a new and more powerful solid propellant than had previously been available. During the thirties, several nations developed powerful solid-fuel artillery rockets which saw considerable use in World War II.

Searching for still greater power, Dr. Goddard turned his attention toward liquid propellants, and in March, 1926,

he flew the world's first successful liquid rocket. The Germans were conducting parallel liquid fuel research in the late twenties and made a successful flight in March, 1931.

The following year, a German army captain named Walter Dornberger (later a major general commanding the experimental missile test station at Peenemunde and now with an American aircraft and missile manufacturer) secured approval from the German government to develop liquid fuel weapons. In 1936, the famed "Peenemunde Project" was organized and the Germans built a large rocket research establishment staffed for the most part by members of the German Rocket Society. Of special interest was



the specification laid down by the German army and transmitted to Dr. Dornberger at the start of the German rocket program. A model of simplicity and directness, it read: *"To develop in military facilities a liquid fuel rocket, the range of which should surpass that of any existing gun and production of which would be carried out by industry. Secrecy of the development is paramount."*

Some of Peenemunde's products became frighteningly well known during World War II, for instance, the "Vengeance Weapons": the V-1 buzz bomb and the deadly V-2. Others, in various stages of development and test, were not as well known.

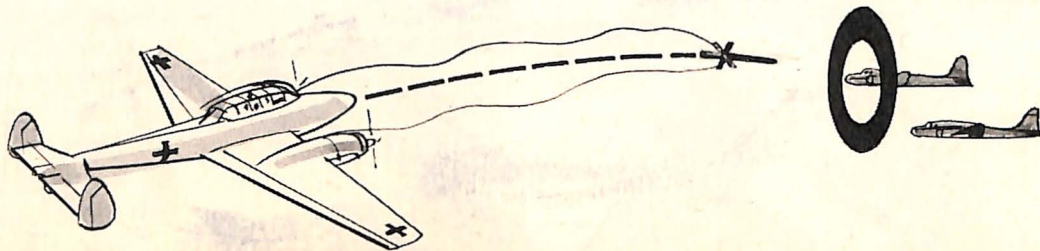
They included the Rheinbote, a surface-to-surface missile with a smaller warhead and less range than the V-2; the Wasserfall, a radio-controlled supersonic surface-to-air missile; the Schmetterling, a subsonic surface-to-air weapon with a proximity fuse; the Enzian, a liquid-plus-solid booster rocket designed for use against bomber formations; and the X-4, an air-to-air missile which was controlled by signals from the launching plane transmitted through wires

which unreeled from the "mother" aircraft as the missile sped on its way.

On the Peenemunde drawing boards even at that early date were such projects as submarine-launched missiles and boost-glide rocket bombers with very long range capability.

Although the Germans were concededly most advanced in missile development, they had no corner on the market during World War II. The Japanese experimented without much success with rocket glide bombs launched from the air and controlled by radio. The Japanese also developed the rocket-powered gliding "baka bomb," controlled by the best guidance system yet discovered: a human pilot.

Although not as far advanced as Germany, the United States made some efforts toward developing guided weapons during World War II. As early as 1941, work was initiated



on controllable bombs. In 1943, the Azon, a vertical bomb which could be controlled in azimuth (laterally) but not in range, was placed in production. The Razon, controllable both in azimuth and range, was started in 1942 but not completed until the war's end. Both were Army Air Corps projects.

The Navy developed a glide torpedo which was used in the Pacific in the closing days of the war.

The Air Corps also developed an unmanned explosive-laden bomber guided by remote control, using war-weary aircraft. The "Weary Willies" saw limited service in the battle against Germany.

Other wartime projects included advanced versions of the Razon, a guided jet-propelled flying-wing bomb, an American version of the V-1, a radio-controlled ramjet missile, several types of glide bombs, experiments in heat and light seeking missiles, and research in television control. Practically all of these projects were dropped at the end of the war.

In the postwar era, both the United States and the Soviet Union profited from research data accumulated by the Germans in Peenemunde and other centers. The Soviets apparently concentrated from the start on long range ballistic missiles, while the United States leaned toward rocket-powered air defense weapons. The U. S. continued development of the German V-2, which was used as a booster for upper air research experiments.

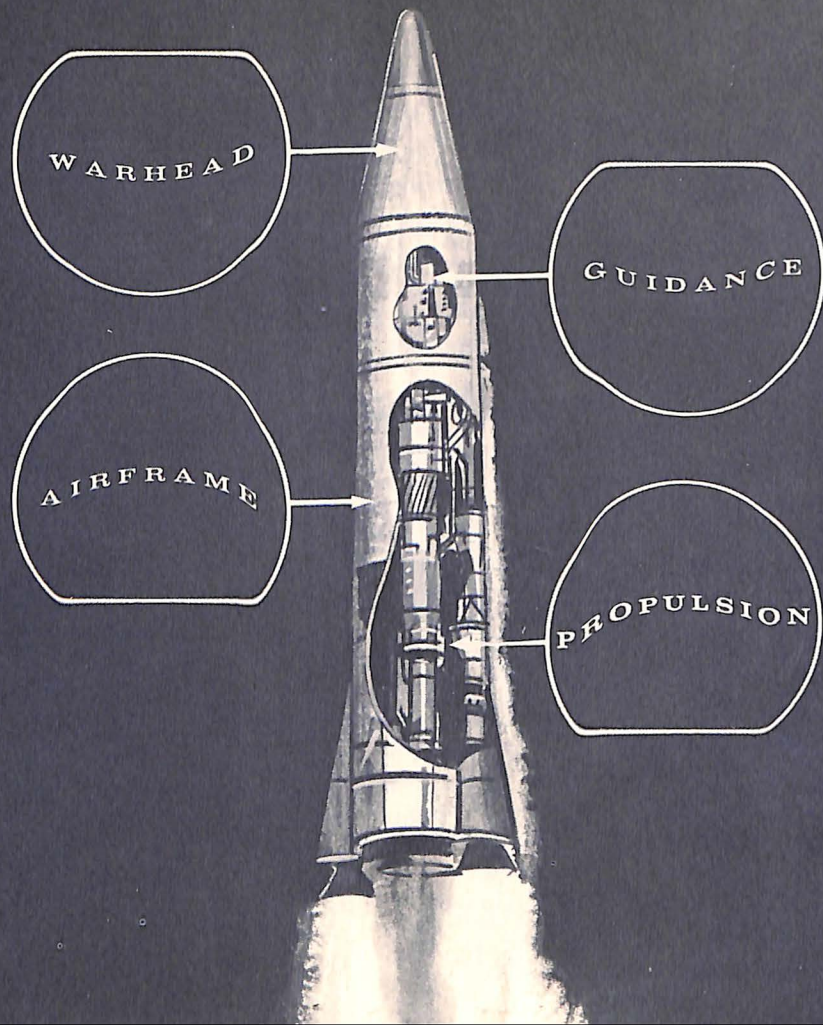
In 1946, the USAF started work on an intercontinental ballistic missile program known as MX-774, but this work was terminated in the sweeping defense budget cuts of 1949. An aircraft company carried on the project on a study basis with its own funds.

Development by the Atomic Energy Commission of lighter and less bulky atomic warheads gave impetus to America's long range missile program in the early 1950's. At the same time, work was accelerated on a wide variety of other missiles, offensive and defensive, with rocket, turbojet and ramjet power plants.

Today, there are scores of active missile projects in various stages of progress, and we are drawing heavily upon missile data in the development of our infant space technology.

A study of guided missile history makes one point clear: this weapon emerged through an evolutionary, rather than a revolutionary, process. It evolved slowly, over a long period of time. The development cycle accelerated rapidly in the last two decades, and this acceleration was due in large part to the wealth of information on aerodynamics, propulsion and guidance obtained through development of the airplane. This is evidenced by the fact that, of the prime contractors handling current missile projects, 80% are associated with the aircraft industry. Similarly, tomorrow's spaceplane will evolve from the solid store of aeronautical knowledge buttressed by new data provided by the missile.

## COMPONENTS OF

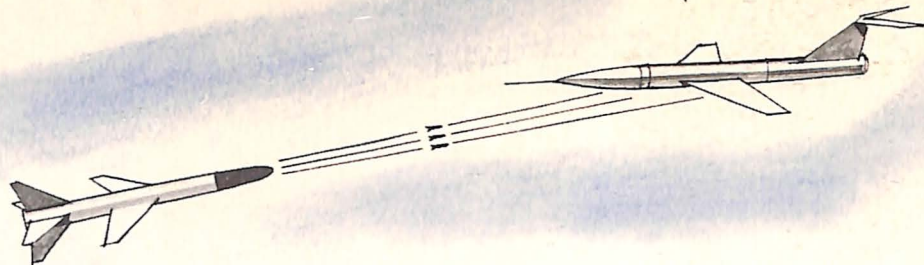


The first guided missile of 1915 bore only the most remote resemblance to the automatic weapons we employ today, but it had certain elements in common with the most advanced missile on the drawing board. All missiles, of whatever vintage, of whatever type, for whatever military purpose share a basic set of components: they need a warload to achieve their destructive purpose, an airframe in which to encase the warload, a power source to move the airframe at its designed speed, and a method to guide the whole package to its target.

The missile shares this set of components with the manned military airplane, with the single exception that in most cases the warload is integral to the missile where it is payload to the airplane. The missile, then, is not really a new weapon; it is a system in which automation is substituted for man's muscular, sensory and brain power. For the most part, the reason for the substitution is not the humane consideration of saving aircrew lives through automation, but rather the achievement of performance values currently beyond human tolerances.



# THE MISSILE



## WARHEAD

No one of the four missile components can be termed the most important, because no combination short of the total can obtain the design result. From the standpoint of military use, however, the warhead is the focal point of the assembly.

In general, a warhead is an explosive charge designed to eliminate a military objective, and there are as many types of warhead as there are varieties of target. Depending upon the use for which it is intended, a warhead may detonate on impact or it may be fuzed to explode near, above or below a target. It may destroy by direct contact, by concussion, by fragmentation or by fall-out. Its destructive load varies over a wide range of force application, ranging from the relatively light explosive charge in an anti-tank missile to the awesome package of mass elimination contained in a thermonuclear warhead.

Half-forgotten, rarely discussed, but still an active consideration in defense development is a warhead whose deadliness is unrivaled even by the thermonuclear load, one in

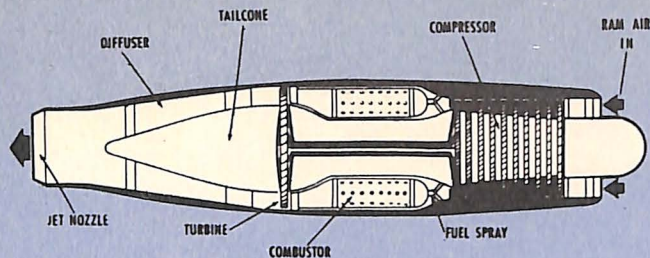
which the explosive charge serves only as a disseminator of the real destructive agents: poison gas or killing bacteria.

## AIRFRAME

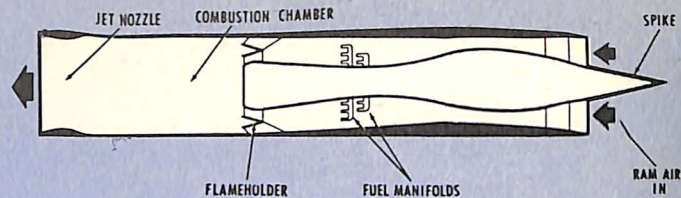
The airframe is the shell which unites the components and protects them from the aerodynamic forces encountered on their journey to the target. Like the other major components, it comes in a variety of sizes and shapes. Anti-tank and air-to-air missiles are usually only a few feet in length; missiles of strategic capability range up to about 90 feet. The airframe may be a simple tube without external fittings; it may have one or more sets of fins for stability and control; or it may have wings and empennage like an airplane.

## PROPULSION

For purposes of simplicity, modern missile power plants can be grouped under the general heading "jet propulsion." By definition, a jet is a system which provides motion by ejecting a stream of gas. Thus, a rocket is a jet. The other two types are the ramjet and the turbojet, the latter being



TURBOJET



RAMJET

very familiar to the layman through its years of service in military aircraft and its recent application to commercial aircraft.

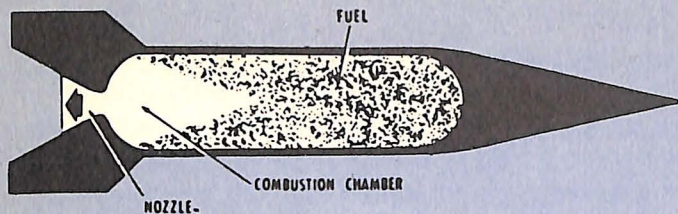
The source of momentum in a jet propulsion system is explained by Newton's Third Law of Motion, which states that for every *action*, there is an equal and opposite *reaction*.

The *action* is the high-velocity stream of gas escaping through the exhaust nozzle. It is created by burning and expanding a substance within the engine. The expansion forces the gas created by the burning to seek an outlet, which is provided by the exhaust nozzle. In the process of its escape, it creates a *reaction* in the opposite direction, that is, in the direction in which the vehicle is flying. The degree of force provided by this reaction depends upon the amount

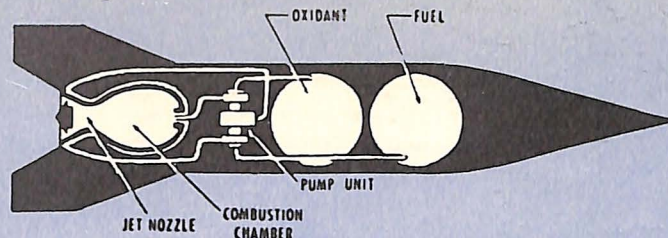
of substance which is burned and expanded and the speed at which it passes through the exhaust nozzle. This force is measured in pounds of thrust.

All three types of jets operate on these general principles, but they differ in the method by which the jet exhaust is created.

The turbojet uses fuel and air to create the exhaust gas. Air is drawn into the fore part of the engine and passed through a compressor, which consists of one or more bladed wheels which rotate at high speed. These compressor rotors accelerate the air particles and compress the air mass for more efficient burning. In a combustion chamber located behind the compressor system, fuel is mixed with the air and ignited, producing the *action* and hence the propelling



**SOLID FUEL ROCKET**



**LIQUID FUEL ROCKET**

*reaction.*

The ramjet also burns air, but instead of a mechanical rotor system, it compresses the air by means of its own high forward velocity, or by "ram" effect. Obviously, for efficient compressions, the tubular engine must move at very high speed, which means that another form of propulsion is required to accelerate it to efficient ram velocity.

In both these systems, the air serves as the "oxidizer," or the substance which provides the oxygen needed to burn the fuel. The rocket engine is self-contained; it needs no outside air for combustion. Instead, it carries its own fuel and oxidizer, which are burned in a combustion chamber and exhausted through a nozzle.

A rocket power plant may have either solid or liquid

propellants. Each has certain advantages. The liquid propellants are injected into the combustion chamber from storage tanks within the missile system, while the solids are stored within the chamber.

Each of the three types of jet propulsion systems has its own area of utility. Because it must carry its fuel and oxidizer along with it, the rocket engine is limited in duration of firing time, but it also provides great thrust in a relatively small package. It is the ideal system for short range, high-velocity weapons. Since it can operate independently of atmosphere, it also powers long range ballistic missiles, which can coast thousands of miles on the momentum provided by a short-duration, extremely high thrust burst of power. Its extra-atmospheric operational capability has

earned it the assignment of powering today's space probes.

There are other types of missiles wherein the other jet types are best applied. In service, for instance, are weapons of the "pilotless bomber" variety which are designed to fly long distances within the atmosphere. The turbojet is the logical power plant for this type of missile.

Another interceptor missile operates within the atmosphere but its mission requires much higher speed than contemporary turbojets can provide. In this case, the ramjet is used, with a rocket booster to accelerate it initially.

### GUIDANCE

Guiding an unmanned weapon to a target is an extremely difficult job. In general, the missile's function dictates the type of guidance employed and there is a wide variety of types available. There are two major guidance classifications: systems which use electronics and those which do

not. They might also be grouped into short range and long range systems. Some examples of the former are:

*Pre-set guidance:* Information as to the course to be flown and the distance to be traveled are fed to the missile's computer, and equipment within the "bird" senses deviations and automatically makes corrections.

*Command Guidance:* In this system, the missile is radio controlled on the basis of information the "bird" sends back regarding its position. A computer on the ground swiftly compares the missile's position with its desired position at all times during the flight and makes corrections if it is off course by sending radio impulses to the weapon's control system.

One type of command guidance is the *Wire Rider*, in which a wire connected with the missile's control system unreels as the weapon flies toward its target. Control impulses are sent through the wire from the command station. This system is used in very short range anti-tank missiles.

Another type in wide use is the *Beam Rider*, in which a radar beam remains fixed on the target and the missile "rides" the beam. In a missile launched from a plane at another plane, the weapon is provided with sensing instruments which determine its position relative to the beam and make corrections. A two-beam system is employed for weapons launched from the ground at attacking aircraft. One beam tracks the target, the other the missile. A ground computing system determines the error and corrects the

missile's course until the two beams coincide at target.

*Infrared Homing:* A method whereby equipment in the missile detects the heat radiating from a target, such as an invading airplane, and corrects the weapon's course to fly directly at the heat source.

Two important types of long range guidance are Inertial Guidance and Celestial Navigation.

*Inertial Guidance:* For simplicity, this type of guidance might be called a course-and-distance measuring system. A set of gyroscopes, which maintain their orientation in space, provides a reference. A complex set of equipment measures the sideward and the fore and aft movements of the missile in flight. This information is relayed to a computer, which continuously measures velocity, distance traveled and course. The computer compares this information with the position it "knows" it should maintain and makes corrections through an autopilot.

*Celestial Navigation:* Like a human airplane or ship navigator, automatic equipment takes continual sights on pre-selected stars, measures the angle from star to missile and computes its position. This system may be used by itself, but it has also been assigned the job of double checking the inertial system, should the gyroscopes in the latter not function perfectly. The combined system is known as the Stellar Supervised Inertial Autonavigator. It is interesting to note that a system of this type originally developed for a long range missile is now used in nuclear-powered submarines.



## TYPES OF MISSILES

The individual types of missiles in research, development, production or operational service now number in the scores, a fact which frequently causes the layman to ask: Why do we need so many?

The need for the wide variety of missiles arises from the variance in the types of targets. There are targets on the surface, beneath the surface and in the air. They may

be moving, or they may be stationary. They may be known before the start of an action, or they may be discovered in the course of battlefield reconnaissance. They range in size from a single piece of armored equipment to a large city or a military complex.

Such a range of targets obviously precludes development of an all-purpose missile. The battle commander must have at his disposal a weapons inventory as versatile as his targets are variant.

The most general breakdown of missiles types would include two areas: those which are launched from the surface and those which are launched from the air. Turning that around to signify destination rather than point of origin, there are missiles which are fired at a target on the surface and others which are fired at a target in the air. Generally, the former are offensive weapons, the latter defensive.

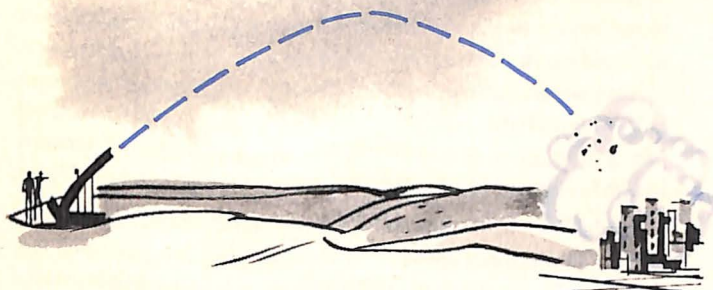
There is a slight variation of these categories: in the case of sea warfare, some missiles are launched from beneath the surface and others are directed at targets beneath the surface. For simplicity, we can couple sub-surface and on-surface into one group. With that alteration, we can put all missiles into one of four major categories which embrace both launching point and target:

Surface-to-surface.

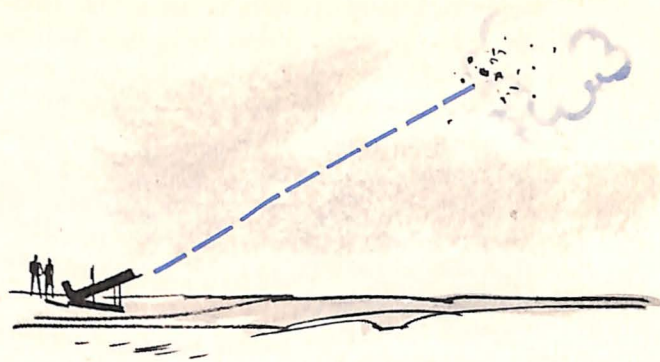
Surface-to-air.

Air-to-surface.

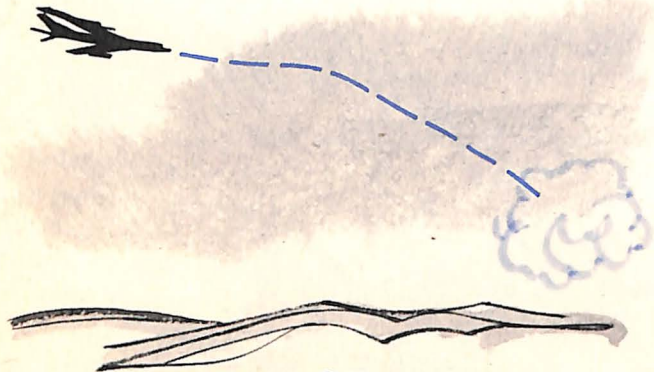
Air-to-air.



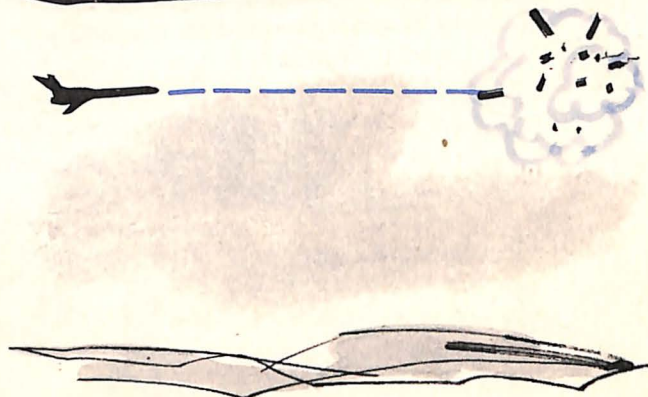
SURFACE-TO-SURFACE



SURFACE-TO-AIR



AIR-TO-SURFACE



AIR-TO-AIR

Within each category, there is still a wide range of diversity. Let's, for example, take the surface-to-air category. In general, all weapons in this category are designed to defend against attacking weapons systems. Such an attacker might be a single bomber; or it might be a formation of bombers. The attacker might invade at high altitude, or it might come in at minimum altitude to increase the difficulty of radar detection. It might be a missile launched from an airplane; or it might be a missile fired from a base thousands of miles away.

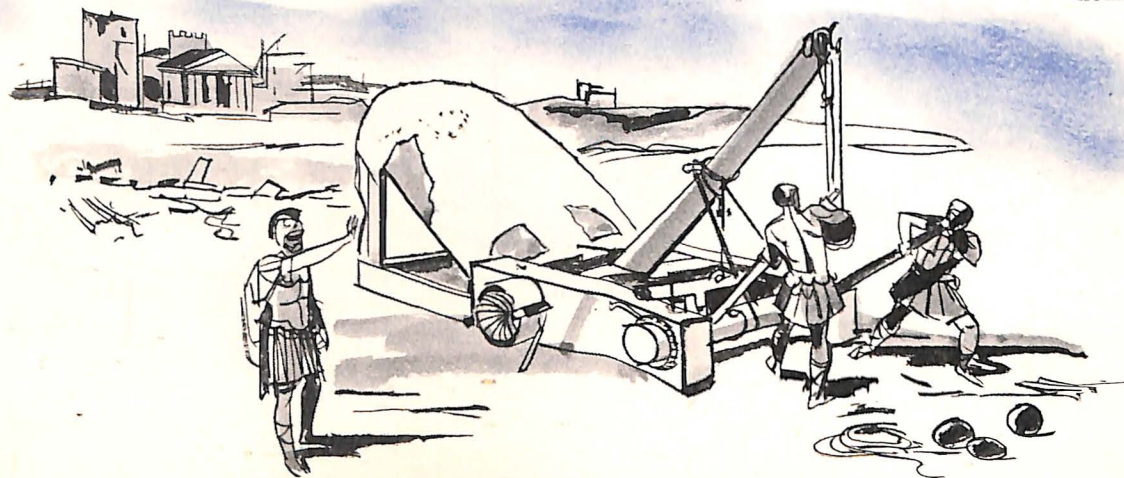
A system for defense against this latter contingency is under development. In the other cases, countering weapons are in being. They include high altitude missiles and low altitude missiles of varying ranges and different types of warheads. They are propelled for the most part by rocket

power, but the ramjet system is also used for longer-ranging defense missiles.

In the surface-to-surface category there is a division of types which needs definition. This is the ballistic missile as opposed to the pilotless bomber.

The word *ballistic* comes from the old Roman war machine named the *ballista*. This was a device which hurled heavy stones at the enemy by the sudden release of tension in the launcher; in effect, it was a king-size sling-shot. Upon release, the stone followed a parabolic trajectory to its target. Directional guidance was achieved by pointing the ballista; the amount of tension and the size of the stone

Basically, the ballistic missile operates in the same fashion. The rocket power plant provides the initial momentum; its



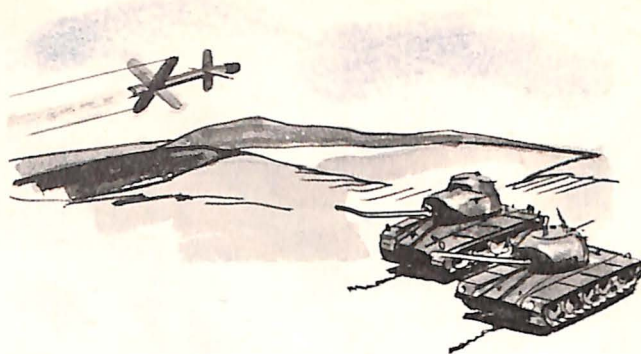


thrust output and burning time, together with the arc into which the missile is fired, contribute to the distance factor. The vast improvement of the ballistic missile over its Roman counterpart lies in the tremendous destructive capability of its warhead, the incomparably superior initial momentum imparted by high-thrust rocket systems, and the sophisticated guidance equipment.

In simplified terms, we can describe the ballistic missile as a weapon which coasts to its target in a parabolic trajectory after its rocket power has been exhausted.

The pilotless bomber variety of missile flies a target course like an airplane under continuous power. Since rockets are power plants of brief duration, it follows that this type of weapon must be propelled by "air-breathing" engines. Thus, the term "air-breathing missiles" is sometimes applied to this category.

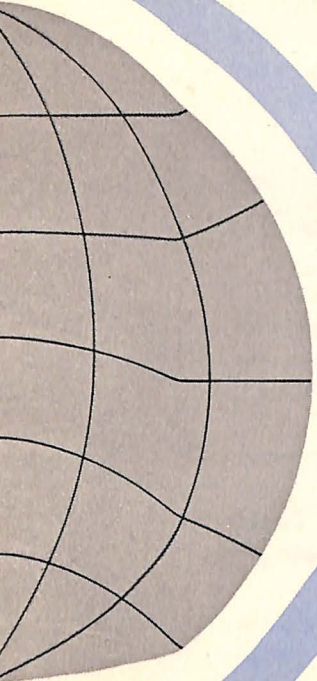
Other than performance, the difference between the two types is in the direction from which they may approach a target. The ballistic missile is relatively inflexible; once its rocket power is expended, it cannot change its direction. The air-breather can be rigged to approach from any point of the compass and at any altitude within performance capabilities. The speed of the air-breather, which must overcome the resistance of the air it is breathing, is limited to manned-airplane velocities. The speed of the ballistic missile operating in very thin air or in space, with little or no resistance, is measured in thousands of miles per hour.



From the standpoint of penetration of enemy defenses, one type utilizes speed to thwart detection and interception, the other relies on maneuverability, particularly in low level attack. Each has its role to play in mass retaliation.

The air-breather and ballistic categories do not embrace all surface-to-surface missiles. There remains the short range weapon which attacks its target in a line-of-sight path like a rifle bullet. An anti-tank missile is an example of this group.

Two final types of missiles bear mentioning. One is the decoy, whose job it is to confuse enemy detection equipment and increase the difficulty of intercepting another weapon. The other is the reconnaissance missile or drone, which "looks over" the battlefield and relays important tactical information to the battle commander.



# THE MISSILE

The guided missile has so captured the fancy of the lay public that it is sometimes regarded as a panacea for all the complex problems of defense. It cannot fill that bill.

An efficient defense organization requires a great deal of versatility, hence a wide range of weapons systems. The missile is one such system. It offers performance values of an order vastly superior to more conventional weapons and in that respect it is an extremely important member of the defense arsenal. It must be remembered, however, that missile performance was achieved by eliminating man and his natural attributes from the flying vehicle.

As a result, the missile lacks certain elements of importance to the conduct of a war, notably human judgment and the ability to make decisions. Although the missile is employable in a wide variety of operational applications, there are other factors which might dictate use of a different weapons system in a specific situation.

To understand where the missile fits in the overall battle program, and particularly where its assignments replace, supplement or overlap those of the manned airplane, let us consider each of the main areas of air warfare.

The task in air defense is to defend the homeland and overseas areas under our protection from enemy attack.

Such attack might come by manned bomber, by ballistic missile, by a marriage of bomber and missile, or by all of these in combination. Such versatility of attack potential must be matched by an equally versatile defense force.

If the attack comes by ballistic missile, it must be neutralized by a missile. Such a defense does not exist today, but it is in development.

A bomber, with either a nuclear bomb or missile payload, might penetrate the outlying defenses and reach the neighborhood of its target. In this case, the defense is the "local" air defense missile which guards the target area.

The prime objective is to destroy the invader as far from the target areas as possible, to prevent his losing his payload of destruction. For this purpose, there are long-ranging "pilotless fighter" missiles of very high performance and quick reaction time. These, again, are valuable members of the arsenal, but they must be launched from fixed bases. Barring a massive construction program of such bases all over the free world, an economically unfeasible program, there will be areas beyond the range capabilities of these weapons.

This calls for use of the long range manned interceptor, with performance approaching that of the missile, but with

the advantage of flexibility in that it can cover undefended areas by shifting from base to base as the changing air battle situation dictates. In this case, the missile and the airplane supplement each other toward a common purpose. The manned interceptors, in turn, carry air-launched missiles, a combination wherein the advantages of each are mated.

Tactical operations are designed to support friendly ground forces in a battle zone and to inflict damage to enemy forces opposing them. In this area, the missiles have provided ground troops with greatly increased firepower. At the start of a battle, they are vitally important in the destruction of targets selected in advance.

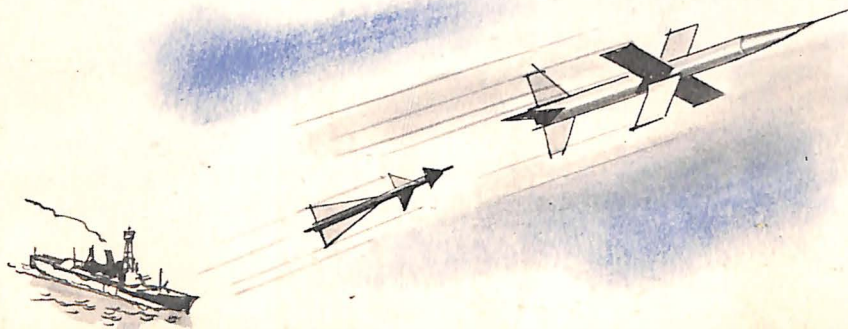
Later, when enemy troops and armored equipment are on the move, they are still useful if intelligence can pinpoint the new locations of the moving targets. Even more useful, however, are the manned fighter-bomber and reconnaissance-bomber, which can locate a target and destroy it in a single operation. Under development are sophisticated reconnaissance drones which can provide the needed in-

telligence and enhance the effectiveness of the mobile missile. Such equipment does not eliminate the requirement for manned aircraft; it is a supplement which increases versatility.

In strategic warfare, the destruction of targets within the enemy homeland to decrease his capability to wage war, the guided missile is particularly important because its performance characteristics afford a greater chance of successful penetration. It is primarily useful against large targets where a minor error in impact point will still achieve the desired degree of obliteration. For pinpoint precision on smaller targets, or on targets which intelligence can locate generally but not exactly, the manned bomber-with-bomb or bomber-with-missile supplements missile operations.

There is also the need for strategic reconnaissance, the determination of the effectiveness of an assault and an evaluation of the remaining objectives. This job calls for vision, which can be artificially duplicated to some extent, and judgment, which cannot, so it remains primarily a function of the human-with-carrier, or the manned airplane.

Thus, in all areas, the missile has certain advantages and disadvantages, as do all other weapons systems. No single type of weapon possesses the degree of versatility requisite to modern defense. A combination of weapons must be used in concert for maximum effectiveness. The belief, or hope, that the missile can assume all the functions of waging war has little foundation in military fact.



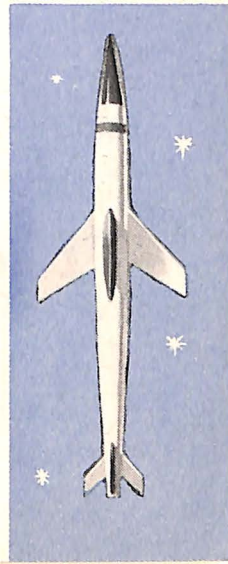
## GROUND SUPPORT OF THE MISSILE

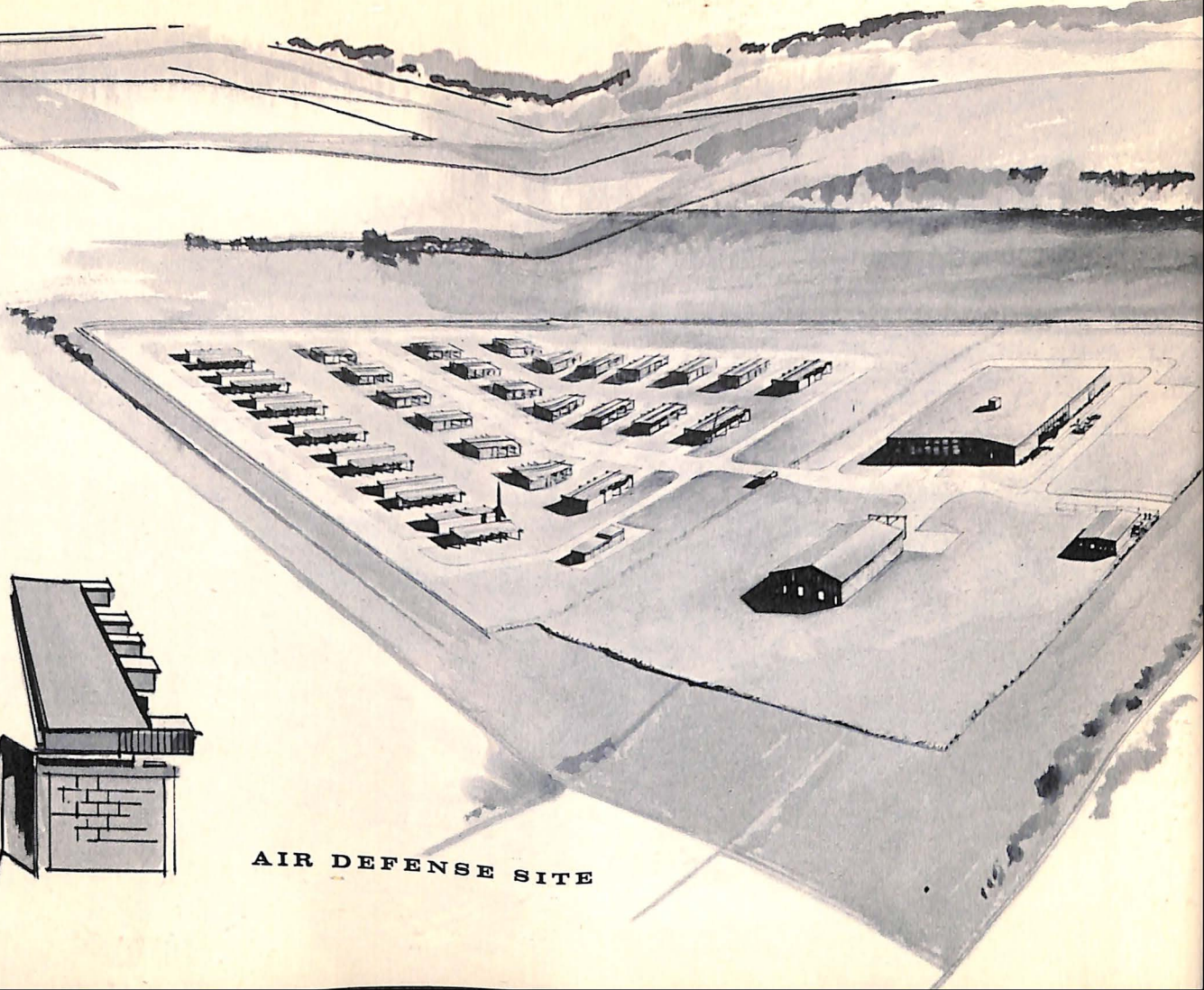
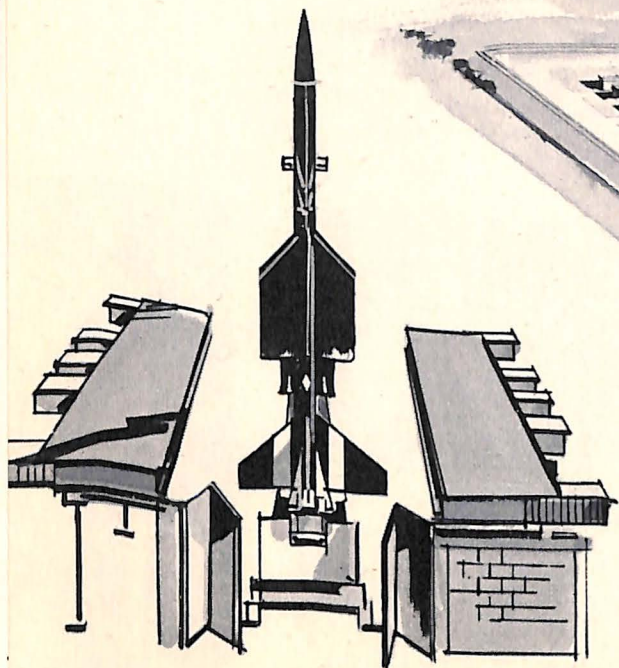
The airplane and the missile share another common requirement, and that is the need for extensive support equipment and facilities on the ground to insure their effective operation in flight. In the case of the missile, the equipment required is much more elaborate than that needed by the airplane.

Both types of vehicles must be fueled with whatever is to provide the source of their power, and here there is a

degree of similarity in the type of ground equipment needed. Solid propellant missiles can be stored with their fuel already packaged, but liquid propellant types need rather complex fueling systems.

Once fueled, the airplane can taxi out to a runway and take off. The unmanned missile needs a transporter to move it about in the firing area, a device to fix it in position and a launcher. In some of the more simple missiles, these





AIR DEFENSE SITE

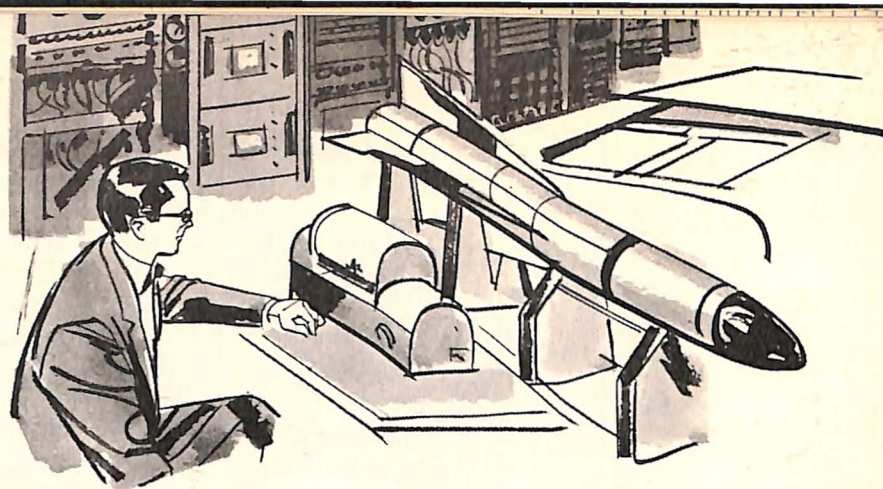
elements can be combined in a single system; in others, they are separate units of considerable size.

Before take-off, the pilot of an airplane makes certain checks to insure that his equipment is functioning properly, a fairly simple procedure in most cases. In the missile, every single one of the thousands of parts in its system must function perfectly. This requires a very extensive complex of checkout and test equipment, and the missiles must be checked not only prior to launching but periodically while they are in storage.

Maintenance of the missile, to insure that all its parts are ready to function when it is needed, is similarly a much more complicated task than maintaining an airplane. In the manned aircraft, the pilot can compensate for certain types of malfunction, but in the missile even a very minor failure can cause a target miss. Therefore, reliability of all the working parts of the missile system is an extremely important factor in its operational use. Maintenance must be continuous and precise to insure that reliability.

For a closer look at the types of ground support equipment needed in the missile program, let us take a single air defense missile, a rocket-and-ramjet powered pilotless interceptor, and consider some of the major pieces of ground equipment it requires.

First, there is the *missile exerciser*, which checks out the control system before the missile is moved to the launch site. It consists of a mechanical system for moving the



missile while it is in a "captive" position. It makes the missile roll, pitch and yaw and perform other motions simulating actual flight, and determines whether there is any error in the control responses.

Next, there is the *checkout bench*. This is a very complicated system, composed of a number of devices which test the electronic equipment on board the missile. It is used in all phases of missile inspection and test, both in the *assembly and maintenance hangar* and at the launch site. It performs 100 tests on the missile's equipment, and, in addition, it makes 40 checks on itself to be sure that it is functioning properly.

There is a launch shelter with a movable roof which slides to either side during an alert. To get the missile from the assembly and maintenance hangar to the launch shelter, a

*straddle transporter* is used. The transporter places the missile on a *launcher erector*, hydraulically actuated equipment which lifts the missile to a vertical firing position.

The next item is the *jet fuel cart*, which services the liquid booster rocket with fuel which combines with the oxidizer to provide the initial launch power. This missile also has two ramjet engines for sustained power, so it needs a *gasoline fueler*, which fills the tanks with high octane gas.

Helium is used in the propulsion system, and it is forced into the missile by compressed air, so this calls for a *compressor plant*, containing the helium and high and low pressure air equipment necessary to move the gas through a distribution system to the shelters.

To start the booster rocket, acid is employed. This calls for an *acid trailer* which supplies the acid fuel to the booster's fuel lines.

In the individual shelters are *missile beacon test equipment* and a *launch control console* for a final test of all the missile's parts and its launch sequences. Another highly complex system, it checks out all the equipment, prepares for launch and fires the missile within two minutes of the initial warning.

These air defense missiles are kept in their shelters on continuous alert, so there is also a *cycle checkout van* which visits each shelter, tests the combat readiness of the missile and its equipment, and permits on-the-spot maintenance for minor defects. If it detects a major malfunction, the

missile must be returned to the assembly and maintenance hangar and another substituted.

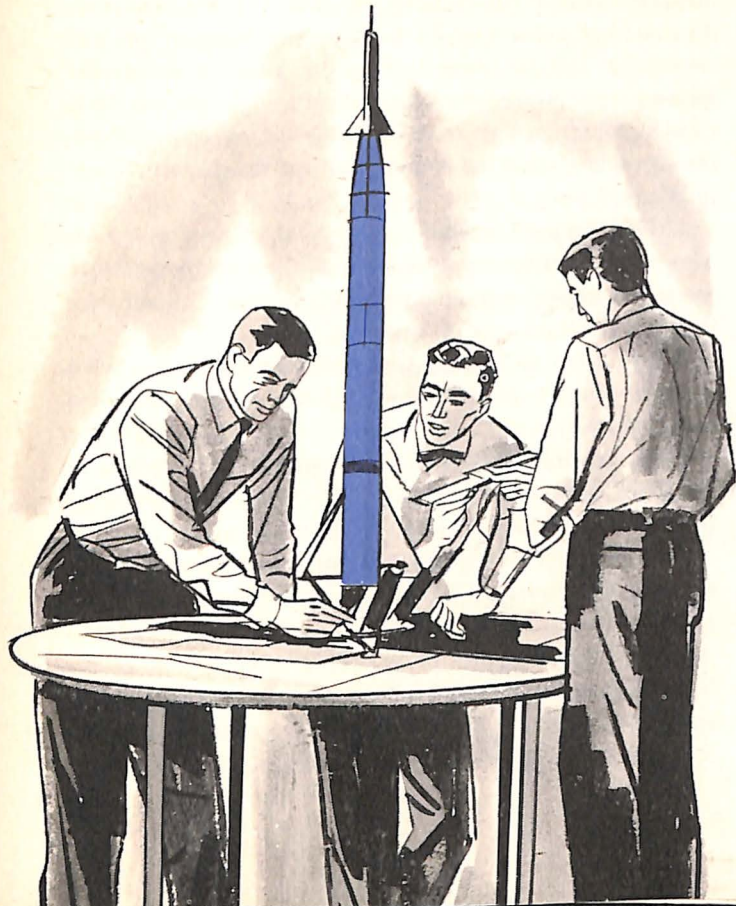
The foregoing include only the major items of ground support equipment for a particular missile. There are a great many other pieces of equipment and facilities. Consider the "push-button" which energizes a propulsion system and starts a flight at a missile test center. It is considerably more than a simple switch like the one which turns on an electric light. It is a maze of wiring connected with all of the components of the test range, hooked up to a huge console containing a series of colored lights which signify the degree of readiness of each section, with built-in automatic safeguards which prevent a premature firing. So even the push-button is an extensive system.

In general, the amount of ground support equipment is proportional to the size of the missile and the complexity of its gear. Some of the smaller missiles have rather simplified ground support, designed for mobility in the field. The larger, ballistic-type missiles require ground equipment infinitely more complex than the system described for the air defense missile.

In some cases, a single piece of checkout equipment is almost as complicated as the missile it supports. It follows that such equipment is expensive. Ground support equipment has become a billion dollar a year program for the Air Force alone and it usually represents the major portion of a missile system.



## MISSILE MANUFACTURE



Reliability is the key word in all phases of missilery, from design to launching, but nowhere is it more important than in the actual construction of the weapon. The achievement of an extreme degree of reliability in an automated product which substitutes electronic, hydraulic and mechanical devices for man's brain and motor impulses, and which demands in addition performance values of a new order of magnitude, is a task which challenges technological ingenuity to the utmost.

To meet the challenge, missile builders have developed a whole new line of manufacturing processes involving new techniques and new equipment, some of it as ingenious and as fascinating as the end product, the guided missile.

The number of parts in a given missile system may run into the thousands. Each part must be precisely manufactured in itself, but it must also work in perfect coordination with the adjacent part. A combination of individual parts may function as a system, and this system must again operate flawlessly in conjunction with a companion system. Failure of any part of any system not only causes the loss of a valuable piece of equipment, but also decreases the combat potential of the unit charged with the operation of the weapon.

To illustrate the manufacturing challenge, let us consider



a specific system, the inertial guidance system for a long range ballistic missile. The heart of this system is a set of floated gyroscopes. These gyros are floated in a heavy fluid to keep friction at an absolute minimum and to provide a cushion against shock and vibration. For proper flotation, a precise fluid density is required. This density in turn depends upon near-perfect temperature control, which requires a thermostat to keep the fluid temperature within three-tenths of one degree of the design requirement.

Production of this very precise gyro system is accomplished in an environment of cleanliness which rivals, and in some aspects even exceeds, that of a surgical theater.

When the first floated gyros were manufactured in the early fifties, industry itself was in the know-how kinder-

garten. There were frequent rejections for malfunctions as foreign objects, like infinitesimal dust particles, penetrated the system and contaminated the fluid or the gyros. Economical volume production was not feasible. Industry decided that know-how on building the systems was not enough; it had to research even the areas in which the systems were put together, so teams of engineers were put to work to design a series of assembly rooms. A team from one company spent an entire year on this aspect of the problem alone.

Today, the gyro assembly consists of a series of rooms where control of temperature, humidity and dust is a science in itself. A rejection in final test is the exception rather than the rule.

Taking a typical leading gyro manufacturer, here is what the design engineers took into consideration in constructing their facilities:

First, new foundations for the assembly rooms had to be built within the main factory to still vibration effects from other plant operations and from street traffic.

Plumbing and wiring had to be arranged so that maintenance could be handled from spaces between the "clean" rooms.

Overhead lighting had to be designed flush to the ceiling. Since maintenance workers cannot be permitted in the clean rooms, they had to be provided a crawl space in the roof for bulb replacement.

Elimination of dust particles in the rooms called for an atmospheric control system which utilizes charcoal filters. This system insures that 99.8 per cent of airborne particles larger than 12 millionths of an inch are excluded from air entering the rooms.

Temperature in the rooms had to be constant; not more than two degrees variation could be allowed, and in one case this was reduced to one degree. In this critical room, normally occupied by four men, the accidental entry of more than one additional worker would cause a disruption of the rigid temperature control system because of body heat, and production would have to be halted temporarily.

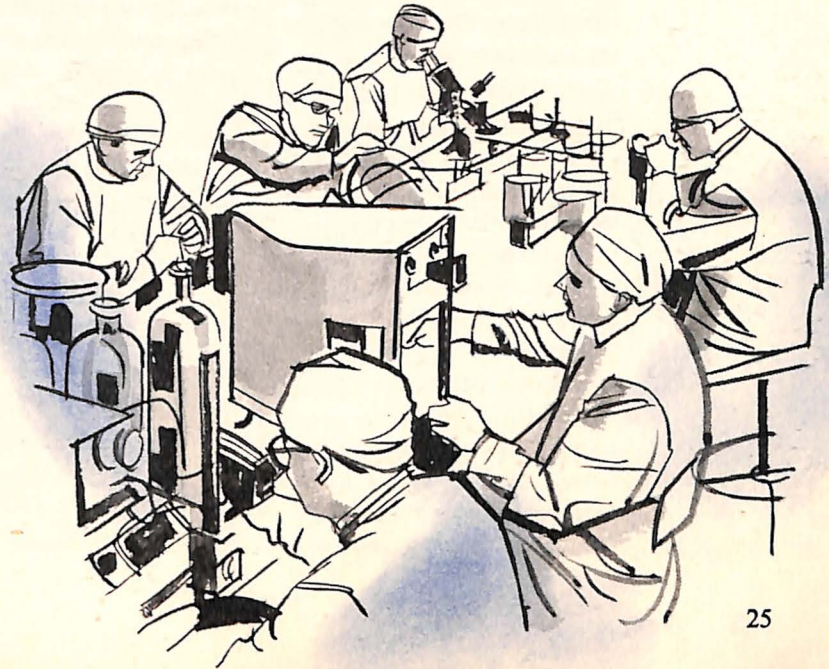
To forestall dust collection, the interiors of these rooms could have no corners; they had to be rounded off. Walls and ceilings were covered with a special vinyl sheeting that must be washed every other day. The work benches, built of stainless steel, were extended from the walls in a cantilever design to eliminate leg supports, another possible source of dust collection. The floors must be cleaned daily by a special wet vacuuming process using liquid freon.

Clean room design called for construction of air locks, through which parts to be assembled are passed. These parts must be cleaned prior to their entry into the assembly room; they must also be polished and examined under 45-power microscopes to permit detection of infinitesimal metal burrs. Dental drills are used to eliminate such burrs.

Once inside the assembly room, the parts are cleaned

again by ultra-sonic vibrations in water and detergent solutions. After the final cleaning, the parts are not touched again by human hands; they are handled mechanically by tweezers and medical-type tongs. These tools are subjected daily to the same cleaning process.

Along with these precautions, equal care is taken to insure that working personnel entering the assembly rooms



do not introduce dust. Entry is made in two stages. The worker must first doff street clothing and scrub his face and hands. He then enters a final dressing room where he puts on a "flying suit," a hair covering and shoe boots, all made of lint-free nylon. Next, he passes through an "air shower," which removes loose particles of matter.

Such employees are carefully screened. A worker with dandruff, for instance, would be automatically eliminated.

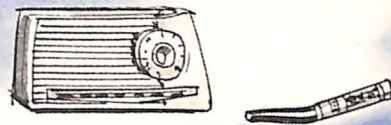
Conventional blueprints and paper pads for noting data are not allowed in the clean rooms, because the paper might shred. Paper has been replaced by special plastic sheets. At the same time, the pencil has been eliminated in favor of the ball-point pen, because tiny pieces of graphite might find their way into a gyro assembly.

In the earlier stages of manufacture of a missile component, there is less need for these extreme precautions for cleanliness, but here there are other problems. For instance, the precision and tolerances of each part are such that, by comparison, a watch factory would look like a locomotive repair shop. Measurements in tenths of thousands of an inch are crude and completely unacceptable for some parts. The scale is in fractional millionths of an inch.

To get the utmost in missile performance, missile engineers must continually design new parts which are smaller, lighter, more efficient and more reliable than their predecessors. At the same time, the designer must keep in mind the fact that the part must also be produced on an assembly

line, so production engineers work alongside design engineers to build producibility into the component.

Continued emphasis on reducing size, or micro-miniaturization, has produced some astounding results. For instance, engineers have been able to take the commercial pocket-size transistor radio, itself a marvel of miniaturization, and reduce it to the size of a fountain pen.



Micro-miniaturization poses new problems for the manufacture and assembly of the parts. Manual production in quantity is no longer possible. Instead, tools and techniques have been developed which permit elimination of the human operator and assembler.

A system called numerical control is now entering missile manufacture. Machining instructions are placed on punched or magnetic tapes and fed through a computer. A series of servomechanisms control the machining processes as dictated by the taped instructions. Thus, extremely complicated machining processes can be reduced to a single roll of tape, and engineers feel that very soon an entire manufacturing operation of a complex weapon can be contained in a small

filing cabinet of tapes.

The manufacturing divisions of most missile plants have very large staffs of production engineers who concentrate solely on devising new equipment and techniques to keep pace with the design engineers' demands for size reduction and reliability. Even the old blueprint, a long time fixture in all manufacturing plants, is on the way out. In missile plants, it is being replaced by microfilm slides which project part drawings on a screen before the operator. In the future, it is expected that this method will in turn give way to a television system in which a central controller will transmit drawings to each operator.

In the process of manufacturing individual missile parts and putting them together in a compact assembly, testing has assumed a much greater degree of importance. To meet the new requirements, it became necessary to devise automatic test equipment, because studies showed that costs rose sharply and quality dropped when the old manual test methods were applied to complex missile assemblies. The addition of such automatic equipment was, of course, costly, but it produced a lower unit cost for assemblies, and, more important, it increased reliability.

Testing operations are normally carried out in an area immediately adjacent to the wiring and assembly areas. Test procedures start with the individual part and there is a continual checking process as each part moves toward final assembly of the whole system.

Automatic testing equipment can be run by relatively unskilled workers. An assembly is inserted in the machine, which is pre-set to make the required test operations. During the checkout, a series of lights on a console indicate "Accept" or "Reject." When the "Reject" light flashes, the machine tells the operator the precise nature of the fault. The machine not only checks the assembly, but runs simultaneous checks on its own equipment to eliminate possibility of error.

In one specific complex assembly, checkout time is now one hour, compared with 32 hours by the manual method, wherein there was an average error factor of 14 per cent.

Today, the entire missile component manufacturing process must be one of extreme flexibility. There is no longer a sharp dividing line between development and production. Both continue simultaneously, and as the design engineers come up with new technological advances, they are cranked into the production line. At the same time, mass production of a given item has given way to short, low volume production runs.

Thus, the production engineer must anticipate and make provision for the inevitable and continuing changes in the product. This he does by working closely with the design engineer and by preprogramming his production line to maintain a built-in capability for rapid change absorption. This flexibility is one of the most effective antidotes to rising production costs.



## MISSILE COSTS

Any discussion of weapons costs is necessarily an extraordinarily complicated one. Any high performance weapons system, manned or unmanned, is more expensive than a lower-performing predecessor. The question of costs is largely academic; the criterion for modern defense must be what systems are needed to stay abreast of a developmentally-aggressive foreign power.

This is not to intimate that costs are a minor consideration. Quite the contrary, they are one of the paramount elements of any defense system. The military programmer knows that only a certain portion of the national economy can be diverted to defense funding. His job is to come up with the best possible overall defense system for the lowest possible cost. In so doing, he must consider a great number of factors, of which cost is an important one, but not necessarily the predominating one.

At the same time, the manufacturer is very interested in costs. He realizes that in a highly competitive environment the budget-conscious military programmer has no place for a high-cost supplier. The manufacturer also recognizes his responsibility as a member of the defense team: the degree of effective defense the available dollar will buy is to

a great extent dependent upon his ability to produce at lowest possible cost. As a result, the industry is adopting ever-more-stringent measures to combat rising costs.

Despite all efforts in this direction, missile systems are and will continue to be expensive. The reasons are manifold:

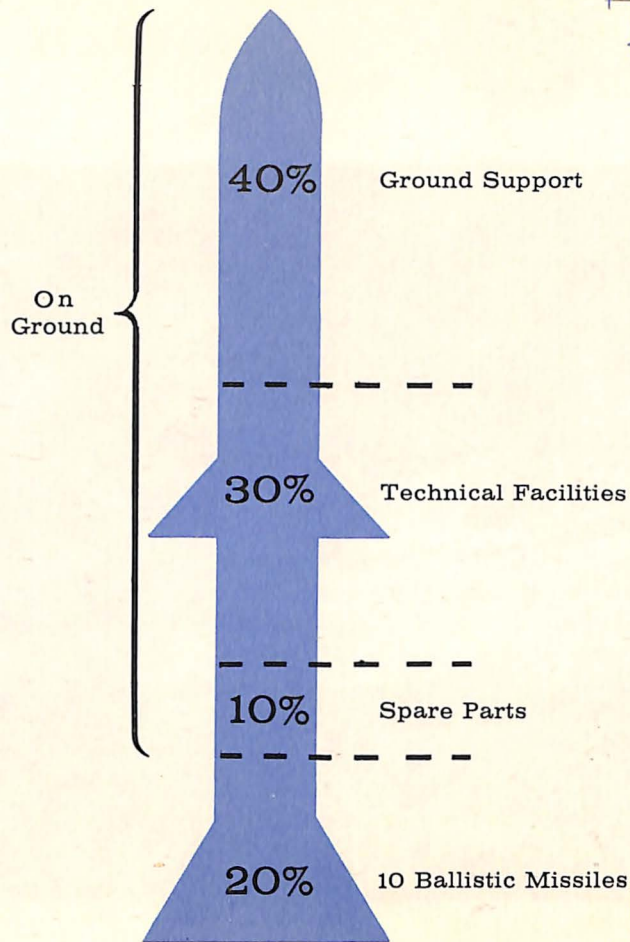
- The United States' position as leader of the free world's defense requires that it match or better the technological advances of the potential aggressor, which demands increasing outlays for research and development.
- The combination of eliminating man and increasing performance dictates a high order of complexity in missile systems, and complexity means cost.
- The reliability demanded of unmanned weaponry increases costs all along the line, from research through production to operational use, in facilities, equipment and personnel.
- Government demands for a great many experimental items at the expense of quantity prevent achievement of low unit cost.
- The greater destructive potential of the missile, coupled with its high rate of obsolescence, produces a requirement for shorter production runs which negates economy of production achieved through experience and refinement of a repetitive operation.
- Finally, the automated weapon demands support equip-

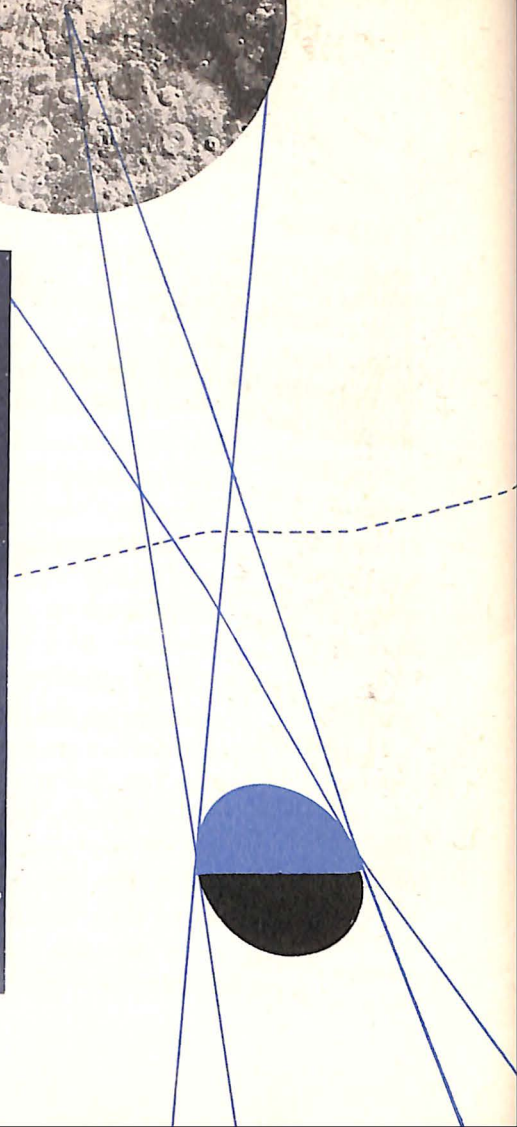
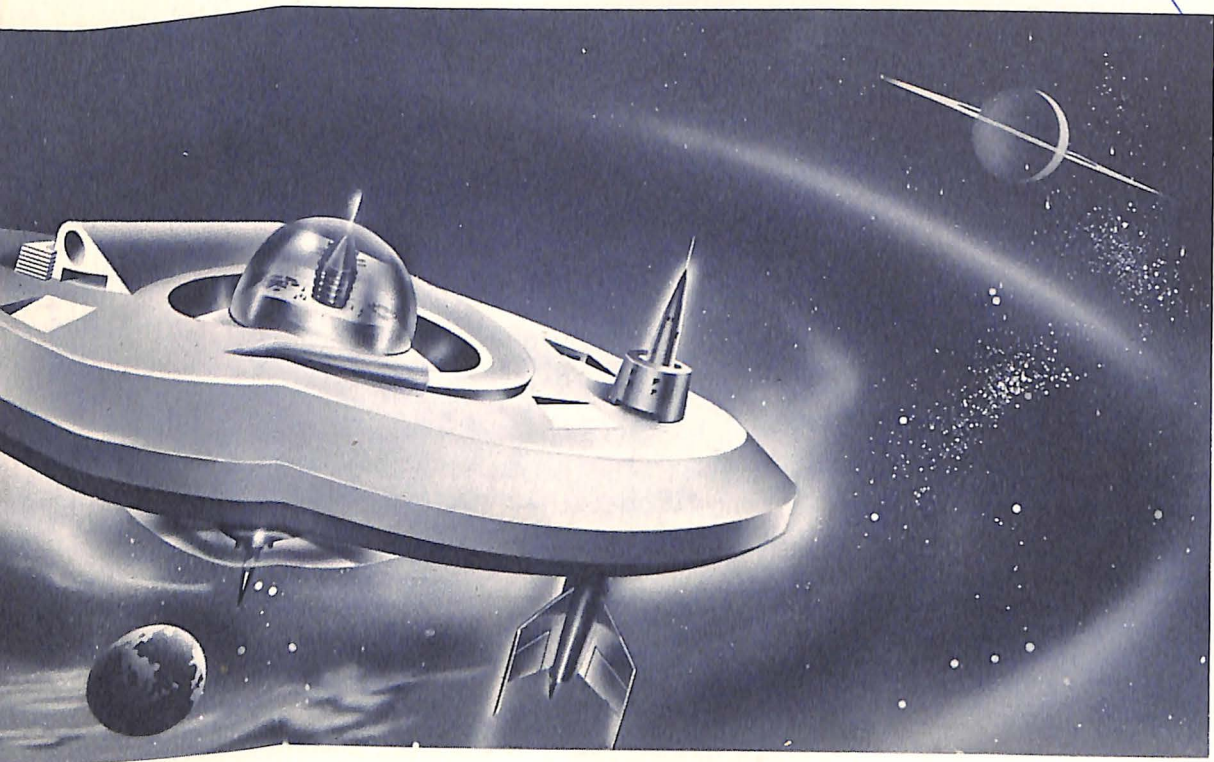
ment larger in volume and infinitely more complex than previous manned weapons systems.

In this latter connection, a long range ballistic missile site provides an example. It consists of 10 basic missiles, each running about \$2,000,000, but this is less than 20 per cent of the cost of the site. Spare parts for all the flight equipment are valued at 10 per cent. The technical facilities to operate the site comprise another 30 per cent. The remaining 40 per cent is in ground support equipment.

The elaborate test requirements constitute another example. Missile engineers estimate that if a commercial consumer item like a vacuum cleaner were subjected to the same painstaking testing as a missile assembly it would cost several hundred dollars on the market. Or, in the automobile field, one of the "low-priced-three" would carry a price tag of \$25,000 if each manufacturing step and each part were subjected to the extremely rigorous missile test procedures.

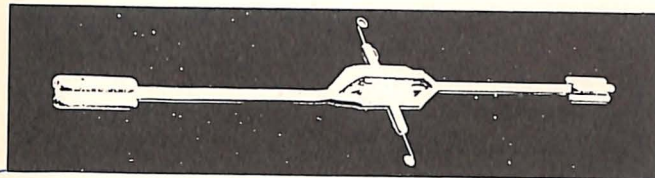
There is one final element in the matter of costs. In considering the achievable destruction per unit of cost, or "dollar per megaton on target," the guided missile is cheaper than World War II weapons systems. However, the degree of destruction inflictable *after* the start of a war is moot. The more important consideration is the degree of deterrence to such a war. Within that guide line, there is no option as to economics. Like bread and meat, the price of defense has gone up—and it will continue to go up.







# SPACE EXPLORATION



As the leapfrogging technology of the post World War II era picked up momentum, the builders of aircraft and missiles inherited a new and important responsibility: the construction of vehicles for the exploration of space.

The vast storehouse of knowledge accumulated by the industry in more than five decades of airplane and missile manufacture provided an incalculably valuable foundation for this new task, because even the fantastic space ships designers are now contemplating share the same basic set of components with the airplane and the guided missile. They need a structure, a power plant, a method of guidance, and, if they are to be used for defense, a warload.

In specific, these components will differ considerably from predecessor types. The first American manned space machine is markedly similar in design to a modern jet fighter,

but as man moves farther into the universe, there will of necessity be radical changes in the shape of the frame, in types of propulsion and in the type of navigation and guidance equipment employed.

It remains for the designers to demonstrate the degree of change. One thing, however, appears inevitable: the order of complexity will increase, and as it rises there will be a compounding of all the current problems.

With its foundation laid, the industry is prepared to start on this challenging venture, but its scientific and management leaders are well aware of the magnitude of the job they are undertaking.

The early achievements of the Space Age have captured the imagination of the lay public and produced, perhaps, a rather exaggerated view of man's current capabilities. Or-



bital satellites, lunar probes, and circumsolar satellites are fantastic accomplishments of contemporary science, but they are the most feeble of baby steps when one contemplates the vastness of the space void.

Man presumes a great deal when he talks of the "conquest of space." He is the inhabitant of the fifth largest planet in a system revolving about a minor star. That star, our sun, exerts a gravitational influence extending unbelievable distances. Pluto, a "neighbor" within our solar system is more than three and a half *billion* miles away.

Yet this entire solar system is infinitesimally minute as a portion of the universe. The star nearest our sun is four and a half light years away, a light year being the distance traveled in one year at the speed of light, which is roughly 186,000 miles per second. That speed is more than 26,000 times greater than the maximum velocity yet achieved by a man-made object.

These two stars are members of a galaxy we call the "Milky Way," a grouping of an estimated 100 billion stars so immense that it would take 100,000 years at the speed of light to traverse its length. And this galaxy is but one of uncountable galaxies moving through the universe.

Even the exploration of our own solar system involves distances which boggle the imagination. Earth's closest neighbor, Venus, is a scant 26,000,000 miles distant. A round trip at the speed of light is a matter of only a few minutes, but at the best speed yet attained (seven miles a

second) it is a three month journey.

Consider the technological demands for a manned vehicle capable of making such a trip: a propulsion system to sustain the initial speed for a long period; an airframe far sturdier than any ever built to protect the crew from the disastrous effects of hull puncture by space matter; a guidance system of incredible accuracy; a complete, built-in, Earth-like environment for the crew; and a degree of reliability which will permit every component of the system to operate for long periods independently of assistance from Earth.

It should be obvious that space will not readily submit to "conquest." Even a limited exploration of space will require a tremendous technological effort, a long period of time, and a very great deal of money.

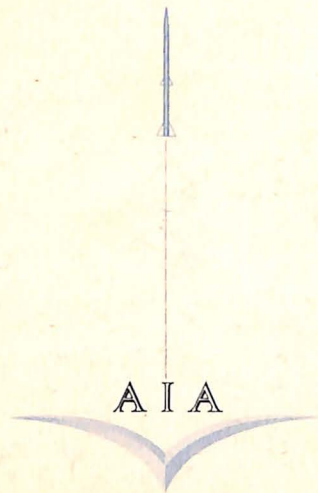
The projected probing of the universe is man's greatest challenge, but the industry, its management, its scientists and engineers and its Government supervisors are all ready and eager to accept it. Despite the enormity of the task, there are few who feel that man will forever remain shackled to his minor planet.

There is one predominant requisite to the accomplishment of this great venture: an enlightened public which recognizes the importance of space exploration and which is determined to support it. With that support, anything is possible, as the achievements of the first half century of powered flight have already demonstrated.



## AIA MEMBERS

- Aero Design & Engineering Co.  
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Aeronca Manufacturing Corp.  
Allison Division, General Motors Corp.  
Aluminum Company of America  
American Airmotive Corp.  
Avco Manufacturing Corp.  
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