The U.S. and Russia are engaged in a race whose outcome may determine the course of history. The goal: development of the most frightful weapon conceived by man—a virtually unstoppable 16,000-mph intercontinental ballistic missile that can drop a hydrogen warhead on a city 5,000 miles away. At stake is not only the security of the free world, but our position as the world's leading technological and industrial power. On the next page begins the full, dramatic story of the . . .

ICBM

IT WILL not be long. In ten years—five years, perhaps only two or three—the historic count-down will start: "Ten—nine—eight—seven—six—five—four—three—two—one—" At zero a new era will open up on the earth—the era of push-button war. A giant rocket, 100 to 135 feet high, will lift slowly from its launching pad and, with voice of thunder, tongue of flame, disappear into the stratosphere. Some 20 to 30 minutes later and 5,000 miles away, the world's first intercontinental ballistic missile will plunge toward the earth.

Where will it come from?

It *could* be launched from Cape Canaveral, Florida, at the U.S. Air Force Missile Test Center, to splash harmlessly into the South Atlantic near Ascension Island. . . .

Or, the missile might be launched from a Russian desert to arch—in unseen ellipse—high above the uninhabited tundra of the north. . . .

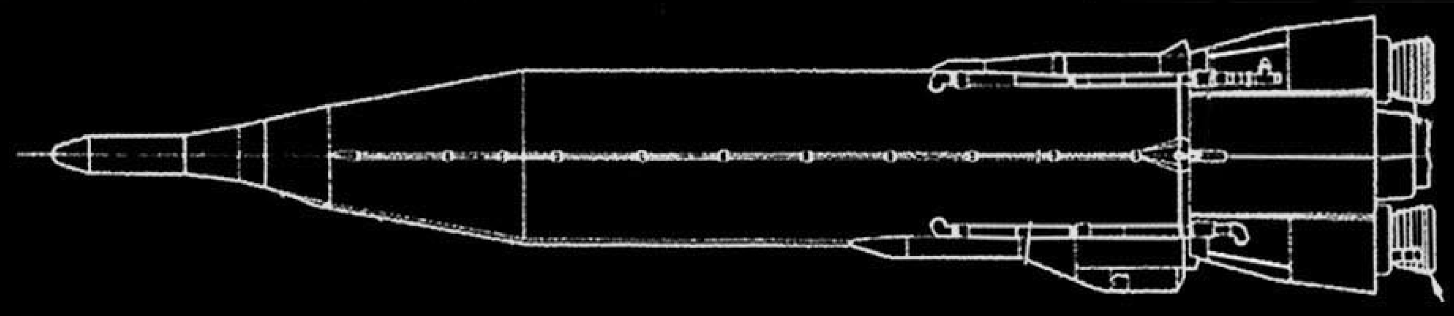
It will make a difference—at most, the difference between peace and war; at least, the difference between added security for the West and possible Communist domination of more of the world.

Dubbed ICBM in our research laboratories and Pentagon offices, the intercontinental ballistic missile has been called "the ultimate weapon." This giant ocean-spanning, mountain-leaping rocket—mated to a hydrogen warhead with a destructive capability of megatons (millions of tons of TNT)—is a supreme instrument of offense. It arches so high (600 to 800 miles above the earth), and moves so fast (12,000 to 16,000 miles an hour) that, once it has been launched, defense against it will be nearly, if not entirely, impossible. The German V-2, the small 200-mile range forerunner of the ICBM, bombarded London during World War II, and even the conventional explosives then used in the warhead caused thousands of casualties and blew whole buildings apart. The ICBM will—when developed—threaten every city on earth, not merely with damage but with destruction.

The implications are frightening—and sobering. In the early period of the coming ICBM era, before radar missile-detection and possible antimissile defenses are developed, an enemy could probably devastate the United States with a surprise ballistic missile bombardment before we could even detect the attack—much less before we could launch a retaliatory attack. One or two missiles for each of our 50 biggest cities might cause 10,000,000 to 50,000,000 casualties, knock out perhaps a third of our industrial capacity, and turn parts of America into radioactive deserts.

But if we beat Russia in the race to develop the first practical ICBM, the weapon could be still another deterrent to nuclear war and to overt, large-scale armed aggression of any sort. Our capability of retaliation against aggressors would be considerably increased; the aggressors would have certain knowledge that they might have to pay a very high price indeed.

How is the race going?



Atlas Rocket

No one—in Washington or Moscow—can answer that positively. "We just don't know," a high U.S. official says.

But many of our Intelligence officials and some of our scientists believe Russia leads today. The Communists are *not* ahead of us across the whole broad band of the missile spectrum. We don't think Russia has anything to equal our Nike or Terrier antiaircraft guided missiles, or the Army's short-range surface-to-surface bombardment missile, the Corporal. We are "fat" with other good missiles—air-to-air and ship-to-shore.

But in the field of long-range bombardment missiles—in which the ICBM is the ultimate objective—the Russians seem to be off to a head start. There is unmistakable evidence that last year they tested an intermediate-range ballistic missile—a bombardment missile of unknown accuracy but with a range of at least 800 miles, far greater than that of anything we have yet fired; a missile which is clearly a first cousin to the ICBM. Moreover, Senator Henry M. Jackson, chairman of the Military Applications Subcommittee of the Joint Congressional Committee on Atomic Energy, warned in the Senate last month that "there is a danger" the Soviets may fire a 1,500-mile ballistic missile before the end of this year. Possession of even these two intermediate weapons would give Russia the means to bombard from her own territory most, if not all, of our allies in Europe and Asia—the means perhaps to blackmail them into throwing in their lot with the Soviet bloc, denying us their bases and isolating the United States.

The truth is that the Russians have emphasized the finished "hardware," and they are getting it. We have emphasized research and "refinements," and ultimately this approach may pay off. However, our policy has been questioned within the administration itself; last month Trevor Gardner, who has urged a bigger, faster missile program, resigned his post as Assistant Secretary of the Air Force for Research and Development as the culmination of his long disagreement with the Pentagon on that subject.

Policy disputes aside, there is little doubt that time is important. We are coming into the homestretch of the race. In a year or so—perhaps less—the first earth satellites will be launched into outer space, and Russia may put hers upstairs first. The earth-satellite program, despite the general scientific knowledge it will produce for all, is really a dress rehearsal for the ICBM so far as the launching phase of the program goes. It will supply, too, some data—much needed for calculating accurate ballistic trajectories—about nature's unknowns in space. So the heat is on.

Last month Defense Secretary Charles E. Wilson took cognizance of the need for speeding up our efforts by announcing that he shortly would name a special assistant to direct all our various ballistic-missile projects.

"We have always been under pressure," a missile scientist working on the ICBM says—"only more so now. We cannot afford to believe in a twenty-year peace; we have to pace our development as if war were just around the corner."

We must learn, then, whether we like it or not, to live with the ICBM, and hence we must understand not only what makes it tick and how it fits into our military armory, but what effect its development will have upon war and peace, strategy and society.

Let's suppose, for a moment, that the worst happens and Moscow does win the race for the most powerful offensive weapon known to man. The Soviet advantage would be temporary—and brief. No matter who wins the race, the other power will not be far behind—six months, one year . . . three years. Moscow, then, would have a transitory advantage in offensive delivery capabilities, a temporary monopoly of long-range ballistic weapons. But this could not be an "absolute" advantage; the ICBM won't cancel out all other offensive and all defensive systems, both active and passive. It won't mean world domination for the Kremlin—unless Russia also develops a virtually airtight defense against all other nuclear-explosive delivery systems, well-nigh an impossibility.

But Russia with an ICBM would be like a bully (*Continued on page 74*) with a really big stick. Regardless of whether he used it, he would have the means to throw his weight around dangerously—and the other boys in the block might go out of their way to avoid offending him.

To the present Communist advantage of superior land power, then, the ICBM would add a temporary—though definite—qualitative superiority in the air offensive.

I don't agree with those prophets of doom who hold that a Russian monopoly of the ICBM—even though short-lived—would enable Moscow to accomplish her objective of absolute world power. It is true, and it is a

Is the ICBM the ultimate weapon?

How destructive is it?

Is there any defense against it?

What will happen if Russia gets it first?

frightening thought, that if Russia wins the ICBM race, some of the tough men in the Kremlin might (figuratively) push a button and destroy New York. But Moscow has the capability of destroying New York today—though with far more difficult and less certain methods. And Russia could not hope to escape heavy retaliatory damage, whether or not we had developed the ICBM, for the intercontinental ballistic missile will not automatically replace all other ground, ship and air-based weapons. Short- and intermediate-range missiles and piloted planes, some of them firing air-to-ground missiles like the Rascal, would still pack a powerful offensive punch. Some of these would get through, no matter how good the Russian defenses.

WHAT MIGHT HAPPEN if Russia wins the ICBM race is suggested by the events that followed her conquest of the atom, when she broke our atomic monopoly. Her diplomacy became bolder; the Reds were more willing to take a chance. They started a war in Korea, got tough in Indochina and off Formosa. Right now, they are getting tough in the Middle East.

In other words, the Soviet political and psychological offensive would be greatly strengthened. Many of the world's peoples are band-wagon jumpers: they want to be on the side they think will win. We can depend on Soviet propaganda to exploit to the full a Soviet victory in the ICBM race. The Russians would be certain to hammer on the theme that the Soviet Union had displaced the United States as the most advanced industrial and technological nation in the world. The resultant loss of face for the U.S. could be damaging for the cause of freedom.

Furthermore, just as Soviet diplomacy would be strengthened by the new weapon, so ours—if we didn't have it—would be correspondingly weakened. Without the power of full retaliation, it would take a bold President and a bold Secretary of State to stand completely firm against Communist aggression and Soviet demands if our military leaders advised them that Moscow could destroy 20 major U.S. cities and pulverize our industrial plant in half an hour!

So, in my opinion, while a Russian victory in the ICBM race wouldn't mean all-out nuclear war or Communist world domination, it *would* mean a very critical period, indeed, in which U.S. diplomacy—already behind the eight ball in many parts of the world—would be still further handicapped. The danger would be that during this period Russia might make very large political-economic-psychological gains which would prejudice our future global position. The danger would be that Russia might press her campaign for the world to a point where another small war—like Korea or Indochina—might start, with unknown ultimate consequences.

What is the story behind the development of this amazing missile which can change the course of history?

The arms race today and tomorrow is centered around carriers of nuclear weapons rather than the weapons themselves. The world already has a whole "family" of A-weapons; it has about maximized weapons of destruction. The race now goes to the side that first develops the most efficient carriers for nuclear weapons: planes, ships, submarines—and missiles.

If any one man deserves the title of "Father of the Ballistic Missile," he is Dr. Wernher von Braun, a dynamic young German-born scientist. During World War II, he headed the German scientific team at Peenemünde which developed the granddaddy of the ICBM—the V-2 rocket, used against London. He and many of his countrymen were recruited by the U.S. Army after the war and brought to the United States to help develop our missiles. Now American citizens, they are an important part of the Army's missile-development team at Redstone Arsenal, near Huntsville, Alabama.

The men behind the ICBM; top, physicists Simon Ramo (left) and Dean Wooldridge, advisers and technical directors for the Air Force program; bottom, Convair's team includes (from left) Thomas G. Lanphier, Jr., vice-president and management's top man on so-called "Atlas" project; Karel Jan (Charlie) Bossart, project engineer; and James R. Dempsey, director of missile project

To this group's pioneering research has been added a vast volume of basic and developmental work by U.S. scientists and engineers. As a result, the United States is already flying medium-range and long-range surface-to-surface bombardment missiles—all of them to date, however, operating in the earth's atmosphere and hence relatively easier to intercept than the space-flying ICBM. The U.S. Navy's Regulus, the Air Force's Matador—both of them small pilotless planes, with ranges of about 500 miles—are much improved versions of the German V-1 pilotless aircraft which bombarded London prior to the development of the V-2. Drone planes—really a form of guided missile—have flown coast to coast with their own self-contained navigation system.

The Snark—the first of this nation's intercontinental-range guided missiles—has been test-fired at Cape Canaveral on Florida's east coast, and Northrop Aircraft Company, its developer, is reported to be about to receive a production contract. The Snark is a pilotless plane, powered by a turbojet engine, and it flies at aircraft altitudes and speeds (under 50,000 feet, 500 to 600 miles an hour) for about 5,000 miles.

The Navaho, North American Aviation's contribution to the armory of intercontinental war, is still in the development stage. Powered either with a turbojet or with a ram-jet engine, it is designed to fly higher and faster (50,000 to 75,000 feet and 1,000 to 2,000 miles per hour) than the Snark.

But all these missiles are really pilotless bombers, not intercontinental artillery like the ICBM. In fact, the wingless ballistic missile differs from a conventional artillery shell only in that it has its own integral propulsion system and can be guided from the ground in at least the initial stages of its flight. The path of a long-range artillery shell is an arc looping high into the air, then curving downward toward the target. A long-range ballistic missile follows the same elliptical trajectory—but loops into outer space and covers a few thousand miles instead of a few thousand yards.

By contrast, the long-range winged missiles now in use all follow so-called "cruise" or flat trajectories. Like piloted planes, they take off from run-ways, ramps, catapults or other launching rigs, climb to cruising altitude and level off. They are limited in speed, altitude and trajectory by the need of their engines for the oxygen in the atmosphere and by their dependence on their stubby wings for lift. These limitations mean that missiles like the Snark and Navaho can be intercepted—by fast piloted planes or by other missiles.

The ICBM—because it follows a ballistic trajectory outside the earth's atmosphere, because it flies so high and so fast—may become the world's first unstoppable weapon. Scientists envisage, in theory, a system of automatic tracking and intercepting missiles which might in time make possible a small "kill rate." But the time between launching and impact is so short, the technical difficulties so immense, that any such defensive system is a long way off. Furthermore, even when it is developed it can never be more than fractionally effective—and that just wouldn't be good enough. Only a few ICBMs would have to get through to knock out our own principal cities—and a good part of our war-making potential.

IMAGINE TRYING to hit an artillery shell in mid-flight with another artillery shell. This is—in minuscule—the problem of intercepting an ICBM. The expensive and extensive radar, interceptor and missile-defense system we are now so hastily and painfully erecting will be of little use against the ICBM. We cannot even track a giant rocket through its entire ballistic trajectory with our present early-warning and control radar—much less intercept it. The ICBM represents, for the immediate future at least, the ultimate triumph of the offensive in war.

Russia's probable lead in the ICBM race can be traced in part to the way in which the Soviets were able to capitalize on the preliminary work done by the Germans in World War II. While Von Braun and a number of his colleagues came over to the West, the Soviets seized the Peenemünde station itself and found a number of V-2 production lines more or less intact. Recruiting those scientists who had not already fled to the West, the Reds started up the production lines again, stockpiled V-2s and, as time went on, gradually improved the range, accuracy and performance of the missiles.

On the other hand, our immediate postwar effort in missile work was centered on basic research and preliminary development. We carried out a series of test-firings of V-2-type rockets and other research vehicles at the White Sands Proving Ground in New Mexico, and awarded research contracts to a number of companies and universities. Not until the Korean war started did we attempt to turn basic knowledge into finished "hardware," and even then the emphasis was more on the pilotless-plane-type missile than the ballistic kind.

Then, more than two years ago, Assistant Air Secretary Trevor Gardner "built a fire" under the ICBM. Such a missile had been under consideration ever since World War II, with Convair doing research and design studies, part of the time at its own expense. But a missile is very different from an airplane, and rather "early on"—as the British put it—Convair encountered some of the same difficulties other aircraft companies have since met in attempting to adapt to missile work. The ICBM studies, therefore, were more or less inchoate until Gardner appointed a scientific committee in 1953 to study the project and make recommendations. This committee—and another later—not only found that an ICBM was feasible, but laid the groundwork for the present high-priority organization.

THAT ORGANIZATION is centered around a specially created Western Development Division of the Air Research and Development Command, with headquarters at Los Angeles. Here, Major General Bernard A. Schriever of the Air Force, with the aid of a sizable staff and of the Ramo-Wooldridge Corporation, is directing the development of the ICBM. (Dean Wooldridge and Simon Ramo are two brilliant young physicists who did some trail-blazing work in electronics, while with Hughes Aircraft, on the Falcon air-to-air guided missile and on various Air Force fire-control systems.) An advisory committee, including Brigadier General Charles A. Lindbergh and headed by the famous scientist Dr. John von Neumann, "kibitzes" and monitors progress.

Last year, the effort was broadened to a dual and competing approach. While Convair continues to develop its "Atlas" project, the Glenn L. Martin

Company is attempting a different approach to the air-frame and configuration problem in a separate program. Companies working with Convair or Martin on propulsion matters include North American, Aerojet-General division of General Tire & Rubber Company, and Reaction Motors; while General Electric, Bell Telephone Laboratories, Sperry Rand, Bendix, AVCO, AC Spark Plug Division of General Motors, and American Bosch Arma Corporation are among firms assisting in solving guidance and other problems.

The United States has also entered—belatedly—the intermediate-range ballistic missile race. The Air Force has a project of its own under way, and the Army and Navy have begun a joint high-priority program centered at Redstone Arsenal under Major General John Bruce Medaris and Dr. von Braun; their missile will be for both ground and shipboard launching.

All these competing projects will exchange technical data; a great increase in funds is to be provided in the next fiscal year, starting July 1st, and in mid-1957—the year, incidentally, in which the U.S. hopes to launch some earth satellites into the upper atmosphere—the entire project will be reviewed. After considerable hesitancy and delay, the U.S. ballistic-missiles program at last appears to be in high administrative gear.

But the technical problems are still immense, especially as they apply to the ICBM. Imagine a giant rocket—a Gargantuan version of a Fourth of July skyrocket, more than 100 feet high, weighing more than 100 tons—hurled to an altitude 600 to 800 miles above the earth into a region of no air. Then envisage, if you can, the warhead or nose of this huge gadget slanting downward through the denser atmosphere—speeding at 15,000 miles an hour toward a target a couple of thousand miles away. How can you hit anything with such a long-range weapon? How do you even get this great mass to budge from the earth?

It can be done. One expert has said, "The missile can be built with the scientific knowledge now available, but basic research will enable us to do the job better. The work ahead is chiefly engineering."


A Titan Missile Silo.

There are three primary problems (and thousands of subsidiary ones) that collectively make up the problem of the ICBM. These are propulsion, guidance, and heat or re-entry.

"It is going to take much or most of the engine development of the country to get the ICBM upstairs," a scientist predicted in outlining the propulsion problem.

The world's fastest rocket today probably loafs along at 4,000 to 5,000 feet per second. The Atlas (Convair's name for the ICBM), if it is to travel 5,000 miles, will have to be moving in its first stages five to six times as fast, or 20 to 25 times the speed of sound.

The engines that will give the ICBM this "oomph" are rocket engines; they spew hot gases out of an exhaust in the tail and the reaction lifts the rocket. They differ from other jet engines in that they run on chemicals and carry their own oxygen with them to permit combustion. The fuels can be either liquid or solid. The V-2 used a combination of alcohol and liquid oxygen; the Army's Corporal guided missile—a battlefield weapon with a range of under 100 miles—uses an acid-aniline combination.

Liquid fuels—chemicals in all sorts of combinations—produce a higher impulse, a greater thrust, than solid fuels, and they can be more easily "cut off" (combustion stopped) at a desired point in flight. But they are volatile, explosive and hard to handle, and the rocket engines that use them require a lot of "plumbing" in the form of piping. Solid propellants—really powder in various forms—haven't yet equaled the "kick" of the liquid fuels, and cutoff control is more difficult. But they are simple, reliable, rugged and give promise of providing a somewhat slower but more even acceleration.

Another potential fuel of great promise for the future (but unlikely for the first models of the ICBM) is fissionable material. A very small nuclear pile to heat and expand some type of gas might ultimately prove to be the most efficient type of propulsion for an ICBM.

But the ICBM's first rocket engines are likely to be powered with liquid fuels, or perhaps with liquids and solid propellants in combination.

A single rocket motor big enough to lift a hydrogen warhead sufficiently high for a 5,000-mile range has not yet been built. On the other hand, engines now under development could be used in multiple to provide the total thrust needed. The earth-satellite program (which really serves—in its launching phase—as a sort of "dry run" for the ICBM) will depend upon a multistage rocket for launching. Two liquid-fuel rocket engines will be connected in tandem. The first "stage" will lift the entire device rapidly into the skies; when its fuel is exhausted, a servomechanism will detach it from the main body, and the second "stage" will take over. Finally, at the apogee (top) of the trajectory, some 200 or 300 miles above the earth, a solid-propellant engine will tilt the satellite on its side and give it a final "kick" up to 30,000 feet per second in a path parallel to the earth's orbit. Thus, the earth-satellite launching program will probably involve what is called a "three-stage" rocket—three rocket engines connected in tandem, one behind another—the power of all of them used successively to get the satellite to the required speed and altitude.

The advantage of the staged rocket for the ICBM is obvious; speed increases as bulk and weight decrease, until finally the warhead—on its own and with all its propulsion mechanism dropped behind it—follows a ballistic trajectory, like an artillery shell, to its target.

ROCKET MOTORS thus can be linked in tandem, or stages, to provide the boost needed to put the warhead upstairs. Each stage would function successively; as each used its fuel and was detached the rocket would become lighter and lighter and its speed greater and greater.

But rocket motors can also be linked in parallel—or radially, like the cylinders of a radial gasoline engine. This so-called "honeycomb mesh," or "six-shooter-revolver" configuration, could also be arranged so that one or more of the engines would be detached from the central cylinder and would drop off when it had done its job.

No one yet knows which configuration—tandem or parallel motors—offers more promise; both can and probably will be used. But the ultimate ICBM will almost certainly be—as experts see it now—a staged rocket, perhaps one and a half or two propelling stages with the warhead on top.

That brings us to the second major problem—guidance. Like the jabberwockian talk of Alice in Wonderland, there have been a lot of semantics used to define *guided* missiles. One might ask: When is a guided missile not a guided missile? The answer would be: the ICBM. It will be guided only for about the first 300 miles of its 5,000-mile flight.

Imagine a gun barrel about 300 miles long. This represents the "guided" part of the ICBM's trajectory—the burning time when the rocket motors are functioning and accelerating the warhead for its 4,700 miles of free flight. Up until the last rocket-motor stage falls off, some control, some guidance is possible; after that, no human effort is likely to modify the ICBM's trajectory.


USAF Master Missle Maintenance Badge

The "guidance" of the ICBM simply endeavors to put the warhead on a proper course at a proper speed at a fixed predetermined point in space. This is done primarily in two ways. The course and speed required to reach a fixed and known target are precalculated (as they are prior to the firing of an artillery shell), the amount of fuel and acceleration needed is determined, and the servomechanisms which will automatically cut off the fuel supply at the right point are adjusted before firing. Similarly, control mechanisms which will tilt the rocket toward the correct great-circle course can be preadjusted. These mechanisms can take two forms. The German V-2 rocket used graphite control vanes which were set in the blast of the jet stream; the angle at which these vanes were set deflected the jet blast and tilted the rocket. The U.S. Viking rocket, on the other hand, changed the angle of the jet blast by tilting the entire rocket motor.

IN ADDITION to careful prefiring calculations and adjustments (called "programed guidance"), some electronic control over the rocket during its climb into the blue-black emptiness of outer space is possible. The rocket is fitted with a so-called "transponder," or radar beacon, and its course during the 300 miles of guidance is tracked by ground radar. The data recorded is fed into computing machines, which immediately determine whether or not the rocket is on its predetermined course. If it is not, a new course is calculated by the machines, the correction flashed by electronic waves to the rocket, and servomechanisms deflect the jet stream and tilt the rocket, shut off, open or regulate the fuel flow. If the rocket promises to be a "wild" one (like one of our test V-2s which went the wrong way at White Sands Proving Ground and landed across the border in Mexico), a self-destroying mechanism can be activated.

This limited guidance for the ICBM may in time be supplemented. A system of so-called inertial guidance, or automatic self-navigation, now applicable to cruise-type missiles like the Navaho, can be tailored to the propulsion stages of the rocket, and—perhaps—to the warhead to keep it in the proper flying "attitude" during its free flight. A so-called "terminal guidance system," which would take over when the missile was approaching its target and would "attract" the missile to the target by light, heat or infrared, might also have some future application to the ICBM. But the difficulties would be enormous.


Left: Maj. Gen. Bernard A. Schriever heads the AF ballistic missile program. Right: Trevor Gardner, dissatisfied with Pentagon policy on ICBM, resigned as Assistant Air Secretary

The ICBM as now envisaged, therefore, is subject in free flight to the whims and vagaries of nature. And some of these are irregular and variable —one reason why the ICBM will never be a "bomb-in-a-pickle-barrel" weapon, but essentially a weapon of limited accuracy for area bombardment.

There are three groups of errors which affect the guidance of an ICBM, and none of them is easily susceptible to correction.

The first of these categories might be called "errors due to nature." There is a constant and unpredictable fluctuation in the thickness of the ionospheric layers of the atmosphere which influences the propagation of radio waves through space, and hence the accuracy of any electronic guidance systems. There is, moreover, no way to predict variable changes in the direction and strength of gravitational forces, which could tend to pull an ICBM off course. And, finally, the earth's rotation—long considered a constant—has been found to change unpredictably and without uniformity; such a change could cause a missile properly launched to score a clean miss.

The second category of errors are instrument errors. These are more susceptible to human control, but will probably never be eliminated completely. Tiny errors at launching—and during the 300-mile gun-tube guidance phase—are multiplied geometrically by the long range to enormous errors on impact. An error in speed of one foot per second at the time of combustion cutoff could cause an error of one mile on impact.

The third category of errors are errors of mapping and surveying. To put it baldly, we don't know where true north is, or where, say, Sverdlovsk is. The ICBM follows a great-circle course from launching point to target. If it is to hit we have to know exactly where—on the earth's surface—the two points are. This is not as simple as it sounds; one of the great problems of missile warfare is the incorrect co-ordinates of many of the cities and points on earth, particularly those in Russia. Many of the world's maps are in error, especially those that show the vast area of the Soviet Union east of the Urals.

If the co-ordinates given on your maps and charts are in error you will miss. This may be one reason, incidentally, why the Russians are hostile to President Eisenhower's mutual aerial inspection proposal. They know we don't know the exact location of cities and industries east of the Urals, and they know there is probably no good way for us to find out except by a great remapping job.

All these categories of errors—many of which appear unpredictable—mean that the ICBM will have to compensate for its inaccuracy by the frightful power and the extensive destructive effect of the explosive it carries—the hydrogen warhead. Just how "inaccurate" it will be no one now knows; the first ICBM obviously will be far less accurate than later models. An error of one per cent in 5,000 miles—a figure once discussed—could mean that the missile might fall 50 miles from the target. That, scientists and military men agree, is not good enough. Scientists seem to believe that ultimately they may be able to reduce the circular error at 5,000 miles' range to five to 10 miles—provided the target is where it is supposed to be.

Dwarfing the tremendous—though soluble—problems of propulsion and guidance, virtually all scientists agree, is the problem of heat generated by skin friction when the missile re-enters the earth's atmosphere. Meteors that constantly bombard the earth nearly all burn up and disintegrate long before they reach the surface; the tremendous heat generated by their passage through the earth's atmosphere destroys them. The ICBM will be, in effect, a meteor; it will be hurled into upper space, and then fall back at high speeds into the denser lower atmosphere. The denser lower air will slow it up—perhaps down to Mach 2 or 3—but also it will heat and perhaps burn it up. In fact, the skin friction caused by the passage through the atmosphere will be so enormous that until some way is found of absorbing, or draining off, or neutralizing this heat, no intact ICBM will reach the earth.

This is a problem for metallurgists, chemists, physicists and half a dozen other specialists with long names—like aerothermodynamicist. It is a giant problem—in fact, the major problem of the ICBM today. Re-entry temperatures might, for example, reach 6,000 degrees or more, and today most of our low-carbon alloy steels lose their strength at about 1,000 degrees.

THERE ARE several approaches to this problem—and they are all being tried. You can try to slow the missile up—with wings or spoilers or some similar devices—and thus reduce the temperatures. You can plunge right on through, reducing the duration of heating, though increasing the temperature. You can try ceramic "skins," or porous or sweating jackets, which exude moisture for liquid cooling. You can devise higher-temperature alloys. Or you can take a leaf from the lesson of the larger meteorites that sometimes reach the earth; you can increase the thickness of your missile's skin (and hence the bulk and weight) and provide a "heat sink." This is the so-called "brute force" or boiler-plate approach; it obviously takes longer for a thick metal skin to melt than a thin one. But the "brute-force" approach has its disadvantages; it increases the weight of the missile and thus greatly increases the problem of the propulsion engineer.

Today, there is no clear-cut answer in sight to the heat problem—though one will be found. But again, as in the guidance problem, the power of the weapon that the ICBM will carry—the thermonuclear explosive—reduces somewhat the importance of the re-entry factor. You don't have to design a missile that will remain intact all the way to earth. It can "miss" vertically as well as horizontally and still do tremendous damage.

Here, then, is what some military men have called "the ultimate weapon," "the absolute weapon"—"the weapon that will rule the earth." It will tower perhaps 100 to 135 feet above its launching pad. Its gross take-off weight—with fuel—may be between 100 and 120 tons. It will lift, slowly at first, virtually straight into the air, burning thousands of pounds of fuel in 60 seconds. It will slowly tilt toward its great-circle course. Probably under

100,000 feet its first stage will break away; the second stage will ignite and the smaller rocket will continue its climb toward the stars. At 300 miles—above the earth's thin envelope of air—the second stage will be detached and the great warhead, perhaps 30 feet long, four feet in diameter, will streak on alone toward outer space under the tremendous momentum given it. It will reach its apogee between 600 and 800 miles above the earth and will then start its elliptical fall—perhaps tail first (for there is no bite of thin air to straighten it out). It may "tumble," particularly as it gathers speed and reaches the upper atmosphere; it should nose down under the resistance of thicker air—but erratic gyrations are possible. Finally, glowing white and slowed down to Mach 2 or 3, it will burst like a violent meteor above some unsuspecting metropolis of man.

The ICBM will be an awesome weapon—with frightening capabilities. It is well named Atlas; truly it carries man and his future on its shoulders.