RAILGUNS: WILL THEY GIVE THE BEST SHOT?

Electromagnetic launching of all kinds of missiles may someday surpass traditional chemical explosives

BY DIETRICK E. THOMSEN

People have always liked to launch missiles—for fun, for profit or for hostility. Not only people, apes get a charge out of it too. For many millenia the force that accelerated such missiles at their launching was the strength of the human (or simian) arm.

In ancient times people learned how to amplify the launching force with throwing sticks, slings, the tension of bowstrings and the ropes of ballistae. The object was always higher launch velocities and so longer flight of heavier missiles for greater impact or more distant communication. Then came the application of exploding chemicals. Now we seem to be on the verge of practical application of electromagnetic forces for the propulsion of missiles of many kinds. The change could mean greater muzzle velocities for generally heavier projectiles and thus greater penetrating power if penetrating power is what is needed. It also means longer flight paths and greater accuracy of shooting. In space applications it would mean the shooting of projectiles containing mostly payload. The current practice is that a rocket's weight is overwhelmingly fuel destined to be burned at one stage of the launch or another.

The force that might provide all these things is called the Lorentz force after Hendrik Antoon Lorentz, a Dutch physicist who flourished during the last decades of the nineteenth century. If an electric current is moving through a conductor in a direction perpendicular to the orientation of a magnetic field in the space surrounding the conductor, the conductor will experience a force perpendicular to both the current direction and the field direction. This geometry is often illustrated by the so-called right-hand rule: Extend the thumb sideways for the current, the index finger upward for the magnetic field and the middle finger forward for the Lorentz force.

A device to use the Lorentz force in accelerating missiles is easy to draw up. It consists of two parallel steel rails connected to some power source. The electrical circuit is completed by a sliding armature that spans the distance between the rails. The electric currents generate a magnetic field as they flow, and its direction is generally perpendicular to the current. The Lorentz force engendered in this case is felt by the armature as a thrust parallel to the rails. Not being fettered, the armature slides down the space between the rails.

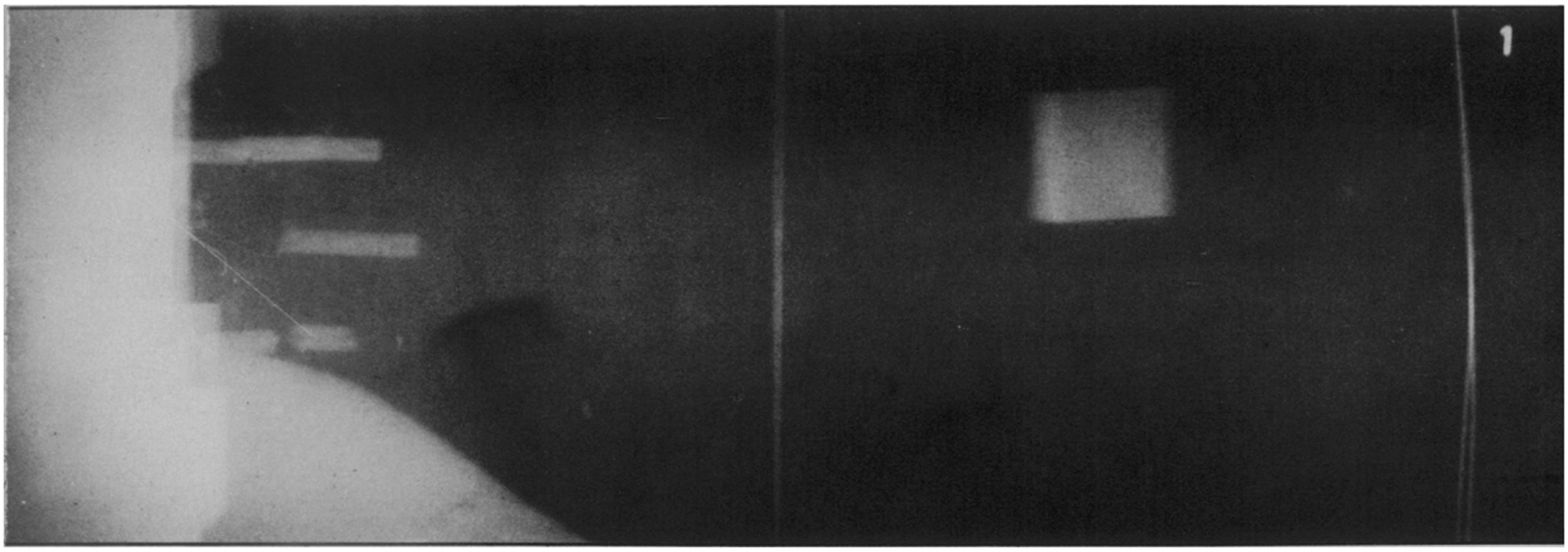
This sort of arrangement is known as a railgun in spite of the possibility of confusion with Big Bertha and lesser forms of artillery that have been mounted on railroad cars for quick maneuvering. Considering military interest in the experiments on the subject, the device could someday be a railgun in both senses.

Experiments aimed at using the Lorentz force for propulsion, at least on a laboratory scale, may go back to the days of Lorentz himself. The first that ever launched anything, so far as Henry H. Kolm of the Francis Bitter National Magnet Laboratory is aware, was fired in 1937 by Edwin Fitch Northrup, a professor at


Los Alamos National Laboratory

Standing: Craig Wozynski (Livermore), Dennis Peterson (Los Alamos). Kneeling: John Scudder (Litton Labs), C. M. Fowler (Los Alamos), Ron Hawke (Livermore), R. A. Marshall (Univ. of Texas). On the sandbags is the firing end of a railgun (encased in a cylindrical cast of dielectric). Rag-filled garbage can receives the projectile.

Los Alamos National Laboratory



The cubical pellet, 50 mm on a side, emerges from the muzzle of the gun. Flash X-rays like this are used to record shot data.

Princeton University and founder of the Leeds Northrup Co. in Philadelphia. It threw projectiles across the Princeton campus. During the 1940s Westinghouse built an electromagnetic catapult for the launching of aircraft from naval ships, but it did not perform as well as conventional ones powered by steam or compressed air.

The first reason for these disappointing performances, as everyone now in the business says, was that the power supplies available in those days could not deliver an intense enough current to engender a strong enough Lorentz force to accelerate the projectile better than a chemical charge or even a blast of steam. The first reason for today's revived interest in electromagnetic propulsion is that modern power sources seem capable or have the potential of being capable of providing the necessary current. If the experiments going on now should produce a practical missile thrower, it would be — as several participants in the research assert — the first real revolution in missile launching since the Chinese invented gunpowder.

Participants trace the current interest to a demonstration by R. A. Marshall at the Australian National University in Canberra that respectable projectile velocities could be achieved with modern power sources. "Dick's power source was the Canberra homopolar generator, one of the large console things you find around an accelerator lab," says C.M. Fowler of Los Alamos National Laboratory. The comment indicates how recent developments —accelerators were tabletop affairs in the 1940s — incidentally aid the business. A homopolar generator is basically a charged wheel rotating in a magnetic field directed along its axis. Brushes pick off the current at the wheel's edges. Fowler's own interest as a power source is something he was working on before railguns seemed feasible, magnetic flux compression devices.

This interest fermenting among scientists aroused the Department of Defense. About three years ago DOD began steps to examine electromagnetic propulsion to see whether it might be a feasible candidate for the despatch of warheads. Harry D. Fair Jr., chief of propulsion technology at Picatinny Arsenal in Dover, N.J., assembled an army advisory committee including Kolm, James Powell of Brookhaven National Laboratory, William Weldon, then at Texas Technological University, Marshall (who was in from Australia), Philip Thulin of Los Alamos, and Peter Mack of Princeton University.

They decided that the technology was worth supporting and watching. DOD supports Weldon's work at the University of Texas on railguns powered by homopolar generators, and it funds the work of Ian MacNab at Westinghouse to make a device with a megajoule power supply and the capability of getting a ⅓ kilogram projectile to a muzzle velocity of 3 kilometers a second. Fair points out that this is (for a start) more than usual in chemical propulsion, which can go about as high as 1.5 to 2 kilometers per second. Later on MacNab's work will be transferred to Picatinny Arsenal.

Fair stresses that, contrary to some reports that have appeared, there is "no interest in making a rifle ... no interest to focus on a weapon." Possible uses include impact thermonuclear fusion (the smashing together of two pieces of fuel so that they undergo nuclear fusion and release energy), space launching, transport, defense against weapons and aircraft launching.

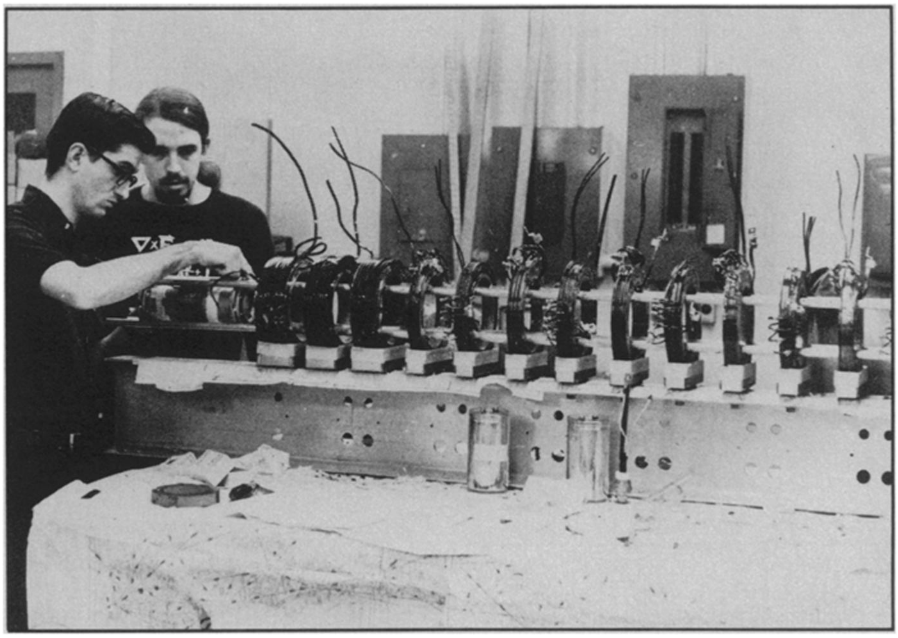
Impact fusion is also mentioned as an application by members of the group of scientists from Los Alamos and the Lawrence Livermore National Laboratory who are working jointly on the development of railguns powered by magnetic flux compression devices. So are equation-of-state studies (that is, investigations of what happens to the internal structure of a solid when it is pinged by a hard, fast-moving projectile). Work of both sorts has been going on in both laboratories for years.

Laid open on a table in Livermore the object hardly looks like a gun. The first oddity is that the bore is square instead of round like that of a proper gun. The two lateral rails that give the thing its name are joined by bottom and top plates. The top plate is now removed. The bore is maybe a centimeter or so across. The whole device is a few meters long, but half of what is lying there is not gun. It is the magnetic flux compressor, part of the powering device. The top plate in this part is covered by an explosive. An outside source delivers a current pulse to the device. Then the explosive is detonated so that it crushes this long narrow box sequentially from the outer end to the inner.

The initial current pulse, which is the discharge of a bank of capacitors, sets up a magnetic flux inside the long box. The crushing of the box gradually compresses this flux into a smaller and smaller space. This compression tends to induce an electric current in the rails. The induced current increases so as to maintain the total level of current first established by the capacitor discharge. Without the contribution of the flux compression the capacitor current would decay very quickly. The flux compression feature maintains it for long enough to do a significant acceleration.

The projectiles used by the Livermore-Los Alamos group are made of Lexan plastic. They are driven by a conductor consisting of a small puff of ionized gas that closes the electric gap between the rails. The ionized gas is produced by a fuse that vaporizes when the current first hits it. It is this gas that feels the Lorentz force, and it pushes the projectile. This is a method developed by Marshall, and the Los Alamos-Livermore group feel that it avoids several difficulties with the electric circuitry. Others in the field, according to Fair, believe that the structural simplicity of having electrically conducting projectiles outweighs the advantages of the plasma-driven Lexan, and they are working on such.

The railguns that are built at Livermore are test fired in Ancho Canyon in Los Alamos. For firing, the gun part proper is covered in a protective casting of dielectric material, one purpose of which is to hold the railgun together during firing. In five shots fired in 1979 and 1980, velocities up to 5.3 kilometers per second were measured. Two, in which the measuring devices malfunctioned, are officially scored as "probably large" with an estimate of 9.9 by Livermore people. Everyone in this field will tell you that, in theory, an electromagnetic gun is limited only by the speed of light, although in practice a number of mechanical and electrical effects lessen that significantly. Still, a chemical gun is limited to the velocity of sound in the gas, something about 2 kilometers per second.


Francis Bitter National Magnet Laboratory

Bill Snow and Eric Drexler, associates of H. H. Kolm, work on mass driver one.

Fair's comment is that you can't use one of the Livermore-Los Alamos arrangements a second time. Not even the part that doesn't explode. The Los Alamos-Livermore group acknowledges this. "Because we're interested in very high velocities," says A.L. Brooks of Livermore, "it is necessary for us to immediately concern ourselves with megampere railguns. Primary emphasis is what effects there are on rails and dielectric." The effects are severe enough to preclude reuse. The experimenters are working on ways to lessen that damage, but even if they don't succeed in designing a reusable gun, disposable guns still may be useful in equation-of-state experiments or in impact fusion studies. In the latter, samples of thermonuclear fuel might be loaded into projectiles and banged together to induce fusions.

Fair says what the DOD wants is a repeating gun and one that will throw much heavier projectiles than the 3 grams characteristic of the Livermore-Los Alamos experiments. A portable infantry weapon is not desired. Anyone who visits Ancho Canyon and sees the size of the capacitor banks that supply the initial current (and the other kinds of current sources are not much smaller) will realize that no future version of this, however miniaturized, is likely to be loaded on the back of the all-suffering grunt.

Fair says we may see a spacecraft launcher before we see a successful electromagnetic launcher of small projectiles. So does Kolm. So does Gerard K. O'Neill. Why should he not? O'Neill is famous for his vision of a future involving artificial colonies with large human populations in interplanetary space. Both Kolm and O'Neill will say that this kind of space economy, with large amounts of goods and people going constantly back and forth among the earth, the moon, O'Neill's Lagrangean-point colonies and maybe the asteroids cannot be achieved by chemical propulsion. Kolm points out that the recently fired Ariane rocket took 136 pounds of fuel to hoist one pound of payload into orbit. A mature space economy could not stand the expense or the inconvenience.

What Kolm and Chul Park and Stewart Bowen of the NASA-Ames Research Center in Mountain View, Calif., are working on instead is an electromagnetic launcher based on coils within coils, two sets of concentric coils. The outer coils are fixed. The inner coil, called the "bucket," is free to move inside the outer coils. The bucket accelerates the projectile, throws it in the desired direction and then returns to the beginning.

When the two coils are energized, the bucket is levitated by the effect of eddy currents, which are secondary effects of the passage of the main currents. The bucket is then free to move up and down the common axis. The force that thrusts the bucket up the axis comes from the mutual inductance of the currents in the two sets of coils. This is a somewhat more complex situation than that of the sliding armature, but it too can be analyzed in terms of the Lorentz force.

Kolm proposes that a version of this arrangement 7.8 kilometers long could launch 1,000 tons with a velocity of 12 kilometers per second. That is escape velocity from the solar system and so sufficient for all spaceflight uses. It would take 76 gigajoules in energy. This amounts to a minute or two of power from a sizable, but conventional, power station. The installation is estimated to cost about $10 million.

If that seems too rich, Kolm can offer trade-offs: Make only the first and hardest launch stage electromagnetic. The rest can be chemical. That cuts the expense of the electromagnetic launcher part while retaining its efficiency where it makes the biggest difference.

Smaller versions of this kind of launcher could be used for terrestrial purposes. Mounted on special wheeled transporters, they could be used to send goods or people to inaccessible places for applications in forestry, firefighting, mining, military tactics, etc. At the moment Kolm, Park and Bowen are working on benchtop models of the idea. Someday they hope it will be launching from the moon. ☐