Induction for the Birds

NASA and the Navy explore magnetic fields in search of quicker, smoother, and cheaper launches

By Barbara Wolcott, February 2000, American Society of Mechanical Engineers

The U.S. Navy put out word last July that it was interested in a new kind of catapult capable of launching present and future naval fixed wing aircraft, up to 78,000 pounds, from the deck of a carrier. The design goals include a 30 percent reduction in manning, 20 percent reduction in life cycle cost, 20 percent improvement in operational availability, and up to 50 percent reduction in installed size and weight when compared with current steam catapults.

PRT Advanced Maglev Systems built this 50-foot working model of a spacecraft maglifter last fall at the Marshall Center in Huntsville, Ala.

A Navy program based in Lakehurst, N.J., wants to learn if magnetic propulsion is the answer. It awarded two contracts in December for what it calls the electromagnetic aircraft launch system. One award went to Northrop Grumman of Sunnyvale, Calif., and the other to General Atomics in San Diego.

The system would use the same electromagnetic principles as a conventional electric induction motor, but applied with a few differences.

These motors do not rotate; they are linear. The stator is laid out flat and the rotor is replaced by a vehicle that will move in a straight line and achieve sharp acceleration as it pursues ever more rapidly receding magnetic fields.

A subcontractor on the General Atomics team, Foster-Miller of Waltham, Mass., was part of a team that already built a working scale model of an electromagnetic arrestor system, which someday could replace the current arrangement of winches and pulleys that govern the arresting cable on an aircraft carrier's landing deck. The system uses two linear induction motors to control the cable that restrains a landing plane.

Foster-Miller is also competing in a program sponsored by NASA, which is studying magnetic lifters as possible accelerators of launch vehicles. The other contestants in the NASA project are Lawrence Livermore National Laboratory and PRT Advanced Maglev Systems.

The working scale model of an electromagnetic arrestor system which may someday replace winches and pulleys that govern the arresting cable on an aircraft carrier's deck.

According to Mike Doyle, lead technical designer in the electromagnetics program at the Naval Air Warfare Center in Lakehurst, the Navy has been studying magnetic technology for the past 10 years or so, and any possible application of the work done in the electromagnetics project is still some years away.

Design Timetable

The contracts awarded to Northrop Grumman and General Atomics are for the first phase of design and development, which will last almost four years. After 45 months of design and testing, in 2004 the Navy will choose which system it will pursue to completion.

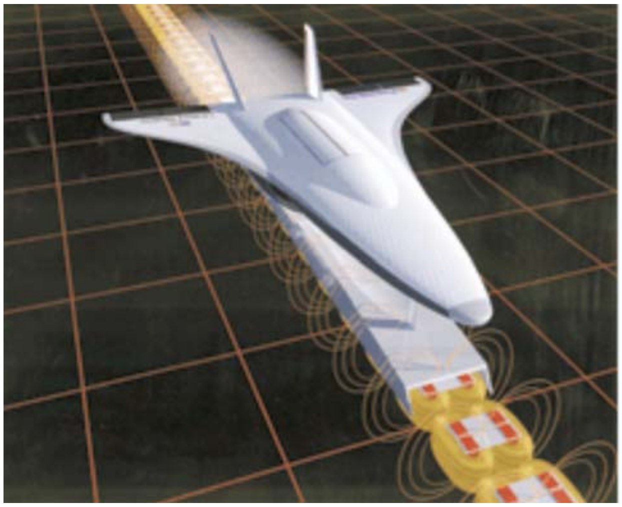
If the Navy decides to deploy an electromagnetic aircraft launcher at sea, the system would be on a new generation of carrier to be launched sometime after 2010.

Another company involved in linear motor research is Engineering Matters Inc. of Boston. Its president, David Cope, pointed out an advantage that electromagnetic linear motors have over the Navy's steam catapults.

Electric motors have the ability to maintain a very uniform force over the duration of the aircraft launch, Cope said. The steady performance would be an improvement over the steam catapult, which has a variable force that rises and falls significantly.

"Initially a steam catapult exerts a high acceleration, about 6 gs, and then weakens to approximately 3 or 4 gs at the end," Cope explained. "It requires that launches increase the g force at the beginning so that the average provides enough velocity for the plane to become airborne. Linear motors take out the peaks and fill in the valleys so that the required force is constant and much less."

Jim Dill, the Foster-Miller program manager for the NASA maglifter project, speculated that one possibility for the Navy catapult might be a linear induction motor to accelerate the aircraft. The plane would be launched from an aluminum or titanium shuttle over a magnetic track. According to Dill, the design will not put magnets or induction coils into the shuttle. Magnetic fields needed to propel it would be induced in the material of the shuttle itself. The design would be considerably lighter than the technology used in Foster-Miller's NASA project.



An artist's conception of a magnetic levitation spacecraft launch. Maglev technologies could dramatically reduce the cost of getting to space.

NASA is in the second year of a three-year program to investigate magnetic launch technology. Sherry Busch-mann, project manager for launch technologies at the Marshall Space Flight Center, called it "an offboard energy source." According to Buschmann, NASA envisions a track a mile and a half long on which a winged craft would ride on a sled that would be magnetically levitated and propelled at an acceleration of 2 gs until it reached a speed of 400 mph. The magnetic shuttle would go from zero to 400 in about 9 1/2 seconds and disengage, when first stage rockets would take over.

Buschmann noted that maglev can accelerate much faster than that, but NASA decided on 2 gs partly because strengthening the wings to withstand a higher rate of acceleration would have added weight. The decision also takes into account the possibility of someday launching a manned craft. According to Buschmann, people are still fairly comfortable with an acceleration of 2 gs.

NASA calculates that using the maglev system, instead of fuel onboard, for initial acceleration can reduce the weight of an orbit-bound vehicle by 20 percent, according to Buschmann.

The systems under study by NASA combine linear induction, to accelerate the vehicle to launch speed, with magnetic levitation, using opposing magnetic fields to suspend the vehicle above its track. The Navy's catapult program does not require magnetic levitation.

Maglev is not new technology, and there are applications of magnetics in parcel sorting, conveyor belts, appliances, and other machinery. Tests have been done of maglev railroads in Europe and Japan. Advocates of the technology say that the scope of its power for controlled lift of thousands of pounds into the air promises to expand its practical influence.

The proposed maglev systems vary in design, but they share the characteristic that magnetic fields keep a vehicle suspended above and aligned with a track. Carriers, or shuttles, for the spacecraft can glide, suspended above the track, even at walking speeds of five miles an hour or less. The carrier rides on auxiliary wheels only until it accelerates to levitation speed and then again when it slows to a stop. At this point, the tracks of working models measure less than 100 feet in length. NASA expects to extend the tests to a track of 350 to 400 feet later this year.

Zero to 60 in Half a Second

PRT Advanced Maglev Systems of Park Forest, Ill., built a 50-foot working model of a spacecraft maglifter last fall at the Marshall Center in Huntsville, Ala. According to NASA, test runs in October of a 30-lb. model spacecraft on the track reached speeds of 60 mph in less than half a second. The model is mounted on a horseshoe-shaped carrier, which levitates magnetically above the track by about half an inch during operation.

According to George Scelzo, president of PRT, the total weight of the carrier and model launch vehicle is 129 lbs.

Richard Wiseman, a Foster-Miller vice president and ASME member, said his company conducted preliminary tests of its maglev launch system in a working model with a 40-foot-long linear synchronous motor. When this article went to press, Foster-Miller had not run tests for NASA at Huntsville, but had shipped the components to the Marshall Center and expected to have the model track and maglifter reassembled sometime in January.

Foster-Miller's maglev launch system for NASA uses two sets of windings on the track. One set forms the stator that propels the vehicle, and other windings, in which magnetic fields are passively induced, levitate the vehicle above the track.

The levitation system, called "null flux," places a system of induction coils wound as figure 8s in the track. If the vehicle has a magnetic field that passes directly through the centers of the 8s, there is no net flux. But if the vehicle's field passes between the 8s slightly below their center, it induces an opposing magnetic field that lifts the car.

The propulsion system uses optical sensors on the track to tell when the car is coming and to turn on the magnetic coils in the appropriate region to accelerate the vehicle.

Dill said that tests so far have reached 58 mph in 20 feet, or three-tenths of a second.

The 40-foot track is in two parts: the first 20 feet contain the drive motor, while the other 20 comprise a magnetic brake. "You have to be able to stop the thing," Dill reminded an interviewer.

This follows the pattern that Buschmann described. She said a full-size maglifter 1 1/2 miles long would use the first half of the distance, three-quarters of a mile, for acceleration and the other half of the track for braking the carrier.

The carrier on Foster-Miller's 40-foot track uses permanent magnets, but Dill said he expects a full-scale version to require superconducting magnets to achieve sufficient magnetic flux.

A Unique Array

Lawrence Livermore National Laboratory in Livermore, Calif., is building a maglifter using permanent magnets, thus avoiding the use of superconductors, which require cooling at cryogenic temperatures.

The Livermore team has developed a maglev design it calls Inductrack, which uses an arrangement of permanent magnets in a pattern called the Halbach array.

Klaus Halbach, a retired researcher from Lawrence Berkeley National Laboratory, invented the array for use in a particle accelerator.

The array combines magnets to create a periodic field that is alternately vertical and horizontal. The interaction causes the magnetic fields to concentrate on one surface, while canceling it on the opposite.

Using Permanent Magnets

According to Richard Post, the Livermore physicist who invented Inductrack, it is this concentration that makes the use of permanent magnets practical. The system allows a 50-lb. load to be lifted with only one pound of magnet.

Inductrack uses permanent magnets of neodymium, a rare earth, combined with iron and boron on the underside of the vehicle, which rides in a guideway lined with inductive coils. As long as the vehicle keeps moving, the permanent magnets induce magnetic fields around the coils, and the vehicle levitates.

The Inductrack can work with many forms of propulsion, Post said. The version being built for NASA uses pulsed drive coils interleaved with levitation coils. According to Post, 95 percent of the track holds levitation coils that work with the horizontal component of the Halbach array's magnetic field. The drive coils, occupying as little as 5 percent of the track, work with the vertical component of the field. The vehicle moves forward as pulsed currents are sent to the drive coils along the track.

So far, Post and his colleagues have demonstrated the principle of Inductrack with a 20-foot-long working model built under internal lab funding. A larger working model of proposed maglifter for NASA is under construction at Livermore, and tests are expected to start early this year.

The model will have a 60-foot track and the vehicle cradle, including magnets, will weigh about 22 lbs. Ray Smith, deputy associate director for applied energy technologies at Livermore, said that if the lab gets its third year of funding for the project from NASA, it will build a larger model, with a 350-foot track, which is expected to reach Mach 0.5.

Proponents of maglev say the potential for savings over time is substantial, not only because of the difference in weight, but also because a magnetic levitation leaves the first stage of propulsion intact on the ground, waiting for the next flight. Buschmann at the Marshall Center has come up with an informal estimate that accelerating a 120,000-lb. launch vehicle from a maglev track could use an equivalent of as little as $75 worth of electricity, at current, local market rates.

A scale model of the linear induction track at Foster-Miller. Preliminary tests of its maglev launch system were conducted with a 40-foot-long synchronous motor.

The size of vehicle that NASA has envisioned for its maglev tests is of a different order from the current Space Shuttle. The liftoff weight of Discovery in the latest mission to rendezvous with the Hubble Space Telescope was 4.5 million lbs.

The goal of using magnetic levitation is to help reach a target of reducing the cost of launching payload from the present $10,000 a pound to less than $1,000, and perhaps eventually to $200 a pound or so.

A maglifter would bring some changes to a space launch. There would be no countdown for a maglev lifter launch, for instance. A launch vehicle could leave just like a jet airliner, one every hour. The launch using the maglev track would start by accelerating in a horizontal direction, rather than vertical, and when it disengaged from the levitating shuttle, the launch vehicle would have to pull up, like an airplane. The familiar launch towers at Cape Canaveral would become a thing of the past. In their place would be a couple of kilometers or so of track.

Buschmann said that NASA's plan is to ignite the booster engines while the launch vehicle is still on the ground. Then, if there is a problem, the launch can be aborted.

Scelzo expects that the launch speed will require extra distance on the track, just as insurance against emergencies. The magnetic system is expected to accelerate a craft to launch speed in about nine seconds.

"In nine seconds of propulsion, a pilot could not even breathe," Scelzo said, "and there is no way anyone can react in nine seconds to the need to abort."

Scelzo recommends a track with extra length built in for the possibility of an abort.

The Father of Linear

Scelzo was associated for 30 years with Eric Lathwaite, a man who is often called the father of the linear induction motor.

Lathwaite conducted many of the original experiments in electrical levitation at Imperial College in London, where he taught, and then later at the University of Sussex in Brighton, England.

Lathwaite tried to spark interest in magnetic propulsion and levitation for years.

Lathwaite built a model of his linear induction, or transflux, motor that could be taken apart to explain the idea. He likened it to a rotary motor split in half, with the rotor removed from the vehicle. In Lathwaite's model, the track becomes the rotor.

According to Scelzo, "A maglev system generally guides a vehicle just like the riverbanks guide a river. That's why the transflux motor is sometimes referred to as a magnetic river."

Because electricity powers a maglev launch, the source can be fossil, solar, geo, or any other electrical generating technology, as long as there is plenty of juice available in the few seconds the shuttle requires to get its load up to speed. Post of the Livermore lab estimates that the launch of a 220,000-lb. spacecraft accelerating at 3 gs to Mach 0.8 could require as much as a gigawatt of power.

The question, then, is where that kind of power will come from. "Nobody's going to let you draw down a gigawatt from the grid," Post said.

Smith pointed out that grid power is not right for the job, even if it were available in sufficient quantity. The system relies on shaped, pulse power. The electric pulses have to reach successive sections of track at ever briefer intervals as the vehicle accelerates.

Smith sees the power question coming up against economics. "The pulse power system is going to drive the cost of the whole system," he said.

According to Smith and others, the likely solution is to be found in energy-storing flywheels, which can be charged before a launch and then provide the necessary bursts of power.

Lathwaite and Scelzo worked together on the problem of energy storage, and developed the concept of a compulsator, a combination of capacitor and alternator. According to Scelzo, this device, which has been reduced to a size that can fit into a car trunk, can store as much as 1.48 MW of power.

The U.S. Maglev Technology Assessment, written jointly by the Corps of Engineers and the Department of Transportation, points out that since "magnetic drag is small at high speeds, only aerodynamic drag consumes appreciable energy. Limiting the top speeds of maglev is a cost tradeoff decision, not a physical or engineering limit."

The more optimistic supporters of maglev predict that as early as 2007 a launch assist system could be used to send up small satellites for thousands of dollars per pound. Within 20 years, they say, this technology could help send much larger payloads into orbit for only hundreds of dollars a pound.

NASA has suggested that, if the cost of space flight can be brought down that far, it could become practical to begin selling tickets — only for well-heeled tourists, certainly. But then after all, the trip is out of this world.