The Institute for Advanced Technology — Advancing the State-of-the-Art in Electromagnetic and Hypervelocity Research

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The use of electromagnetic energy to propel objects to extremely high speeds has broad and important consequences for many elements of our society, including transportation, communications, energy, national defense and space. Both the U.S. Army and the U.S. Navy (USN) have interest in electromagnetic launch to provide enhanced lethality at greatly extended ranges. The U.S. Air Force is examining the possibility of electromagnetically inserting satellites into low Earth orbit. These applications all require a base of fundamental research. The Institute for Advanced Technology (IAT) at the University of Texas-Austin (UTA) is providing these scientific underpinnings. IAT was founded in 1990 and in 1993 became the very first Army University Affiliated Research Center (UARC). The IAT is chartered to perform basic research in electromagnetic launch, pulsed power, hypervelocity physics and education.

The UTA IAT is at the forefront of hypervelocity projectile/ballistics research. Besides the Army, other federal agencies interested in the IAT's technological breakthroughs are the Department of Energy and NASA. Here, the "energy flash" is created by a projectile launched at extreme velocity during a ballistics test. (Photo courtesy of NASA.)

Electromagnetic launch research is primarily directed at the physics of rail guns. A rail gun consists of a pair of parallel rails between which a conducting projectile (armature) travels. The electrical current passing through the rails generates a magnetic field that acts on the conducting armature to produce the Lorentz force to accelerate the projectile. Rail guns have achieved velocities up to 6 kilometers per second (km/s). Present Army interest is in the range of 1.5-2.5 km/s. Given the high currents and magnetic fields associated with these launchers, the thermal, structural and electrodynamic behavior of the hypervelocity projectile and launcher cannot be defined with either conventional modeling or experimentation. IAT is developing the techniques necessary to attack these problems.

The Electromechanical Analysis Program in Three Dimensions, better known as EMAP-3D, code under development at IAT provides the best model of the environment during launch, as illustrated in the adjacent figure. This shows the magnitude of the magnetic field induced around the projectile and rails. The code couples electromagnetic, thermal and structural dynamics. The electromagnetic environment must be accurately described to predict the loads to which the projectile and launcher are exposed. Since the currents passing through rail guns can reach 5 million amperes or more, the thermal loadings associated with ohmic heating critically influence the survival of both the projectile and launcher. Typically, projectiles lose part of their mass as the armature ablates away.

In addition, a phenomenon called contact transition takes place when the rail/armature contact changes from a solid to a plasma contact. Damage to both the projectile and launcher may take place during and after transition. IAT is developing the theory to describe these high-velocity interface dynamics so that future Army electromagnetic launch systems can be effective. Important input to the model is detailed material properties. The UARC has developed a unique experimental capability to measure these properties under conditions of impulsive thermal, mechanical and electrodynamic loads. The data has proven that significant differences exist when compared to static or nearly static databases.

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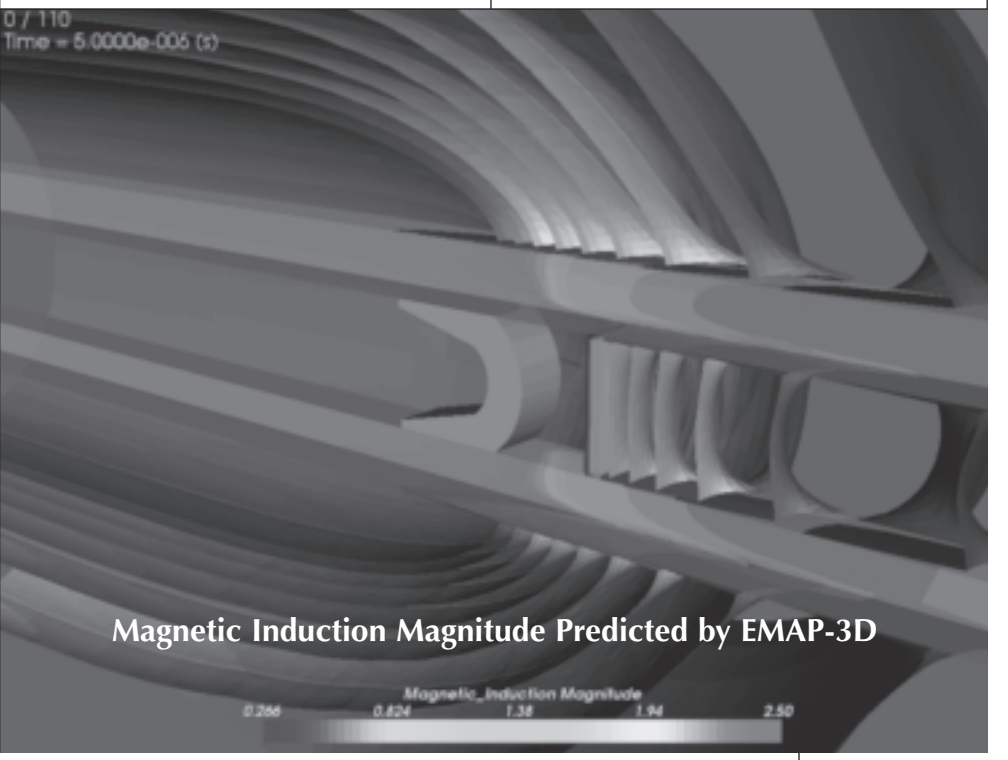
To provide validation of theory and to test advanced concepts, the IAT operates a premier electromagnetic rail gun research laboratory that contains multiple rail guns, extensive diagnostic instrumentation and is powered by a flexible capacitor-based pulse-forming network.

Experiments conducted in the Electromagnetic Research Facility have led to theoretical treatments for the control of hypervelocity gouging. This phenomenon occurs when two surfaces slide over each other at high speeds and is characterized by the production of gouges or divots in the softer surface. This theory is being applied by both the Army and USN in developing electromagnetic launchers and projectiles. This facility has provided the best fundamental description of contact transition and how it progresses across the armature during the launch process. It is presently being used to analyze the physical processes that lead to rail and insulator wear and erosion. If the rail gun is to be practical, it must be comparable to conventional propellant guns and survive thousands of shots. Typically, laboratory rail guns only operate for a few shots and then they are re-cored. IAT technology has provided insight to the



Magnetic Induction Magnitude Predicted by EMAP-3D

life problem and has demonstrated up to 100 shots. This work is continuing to prove that rail guns have even greater useful lives.

The most critical problem faced by the Army's electromagnetic program is to develop pulsed power that is compact, lightweight and efficient. These characteristics are requirements for mounting an electromagnetic system on a mobile ground-fighting platform. IAT research is making important, long-term contributions to solving this problem. Both analytic and numerical models are being developed to describe the physical and electromechanical characteristics of pulsed power. The primary Army electrical power system is the rotating machine or pulsed alternator. IAT has developed a model to describe machine performance and its interaction with the electromagnetic gun and projectile. IAT is also looking into longer-term solutions using alternative approaches that just might prove to be more effective. A wide range of techniques have been examined ranging from explosive flux compressors to advanced, high-energy density capacitors.

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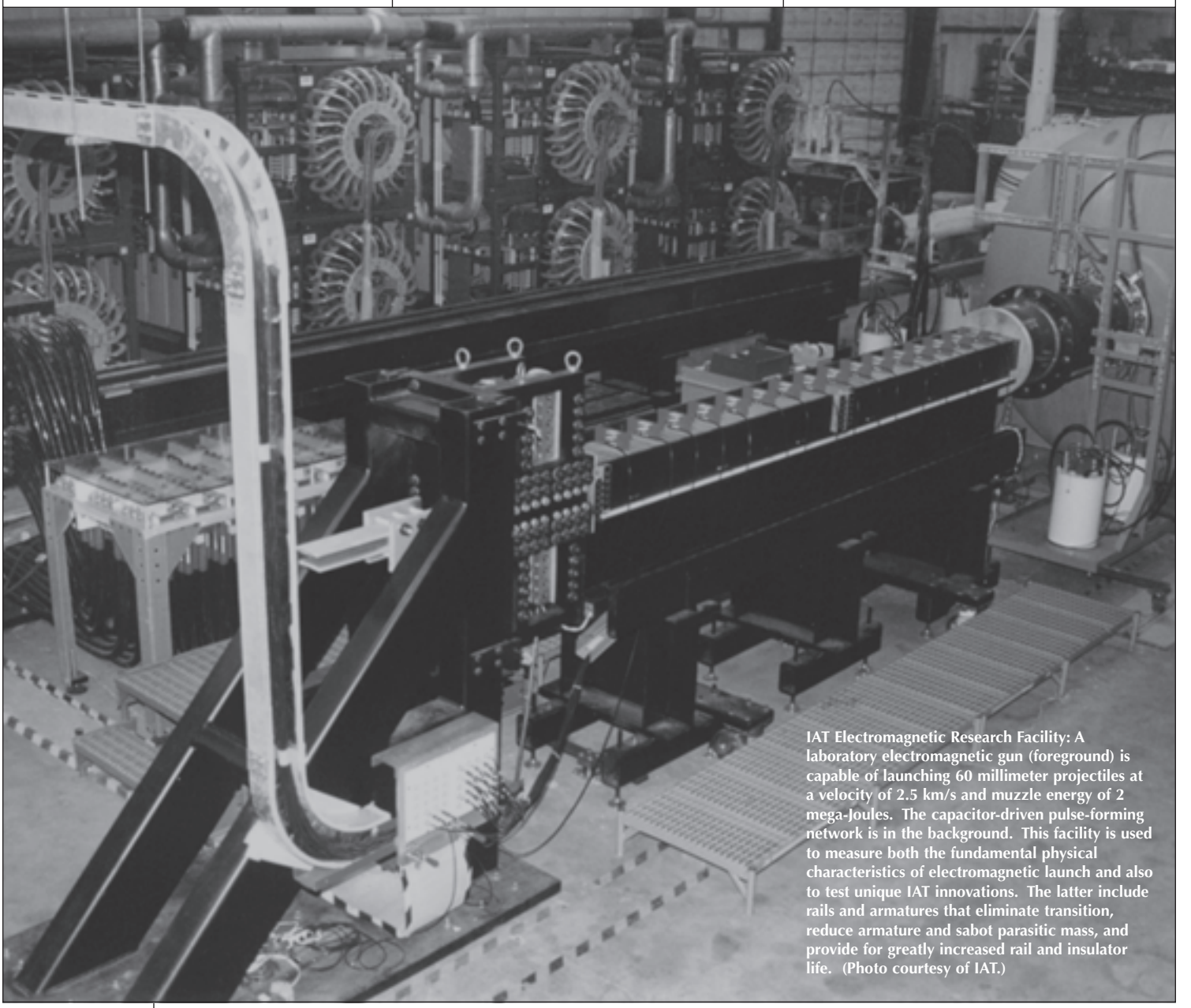
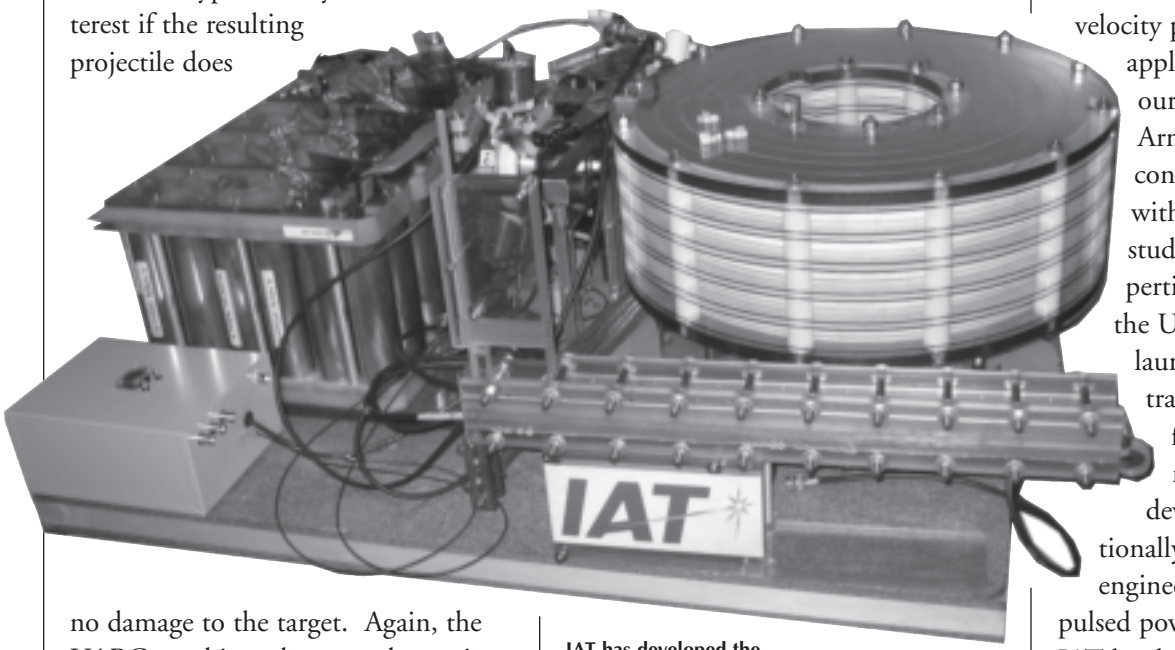
One approach that is receiving particular attention is the battery-inductor. This device uses lithium-ion batteries discharging through an inductor coil to fire a small caliber rail gun. The system has demonstrated the ability to rapidly recharge and has fired



IAT Electromagnetic Research Facility: A laboratory electromagnetic gun (foreground) is capable of launching 60 millimeter projectiles at a velocity of 2.5 km/s and muzzle energy of 2 mega-Joules. The capacitor-driven pulse-forming network is in the background. This facility is used to measure both the fundamental physical characteristics of electromagnetic launch and also to test unique IAT innovations. The latter include rails and armatures that eliminate transition, reduce armature and sabot parasitic mass, and provide for greatly increased rail and insulator life. (Photo courtesy of IAT.)

multiple-shot bursts. The technology is being scaled up to a size more compatible with actual Army needs.

Of course, having the capability to launch at hypervelocity is of little interest if the resulting projectile does no damage to the target. Again, the UARC combines theory and experiment to describe the processes associated with hypervelocity impact. It has long been known that monolithic rods achieve their greatest penetration (per unit impact energy) at a velocity of around 2.2 km/s. IAT has demonstrated that this process can be greatly enhanced through the use of novel kinetic energy penetrators having unique geometries to optimize their effectiveness. IAT uses and improves upon the latest state-of-the-art models developed by the Department of Energy. It has successfully modified the codes to treat novel kinetic energy penetrators. The process of performance optimization requires validation of the code predictions. IAT operates an impact physics laboratory containing the largest and most highly diagnosed hypervelocity light gas gun of any university worldwide. The facility is capable of detailed measurements of penetration into the complete range of targets of Army interest.



IAT has developed the battery-inductor driven rail gun, which has demonstrated that it can fire multiple-shot bursts. (Photo courtesy of IAT.)

The IAT also serves as a center for education in the disciplines associated with electromagnetic launch. It sponsors guest researchers who pursue advanced degrees at UTA. It has a strong outreach program to attract high school students and undergraduates, including cadets and midshipmen, to study science and engineering. IAT is also the lead biannual Electromagnetic Launch Symposium sponsor, bringing together people from around the world working in this technology. IAT conducts frequent short courses in support of Army and national needs. As a separate activity, it hosts the Army Senior Service Fellows. This group of field grade officers is pursuing War College-equivalent studies at UTA.

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The IAT continues to support the Army by executing world-class research in electrodynamics and hypervelocity physics pointing the way to applications with high payoff for our armed forces. As the Army's first UARC, the IAT continues to assist the Army with data generation, analytic studies and subject matter expertise. Recent commitment by the USN in electromagnetic launch for ships is being fast-tracked through lessons learned from Army-sponsored IAT research. By recruiting and developing the leading internationally recognized scientists and engineers in hypervelocity physics, pulsed power and electrodynamics, IAT has built a research team to conduct world-class, tightly coupled theoretical, computational and experimental research. Many science and technology challenges considered to be insurmountable have yielded to this focused research team. The IAT remains committed to providing pioneering research and development for the implementation of advanced electric weapons systems for the Future Force.

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