SCOTT D. ROBINSON & RICHARD S. MATLOCK

Leap Technology Upgrades to Tactical Missiles Provide Near-Term Options for Theater Missile Defense

THE AUTHOR

Scott D. Robinson *received a BS degree in engineering science (physics concentration) from the University of Virginia in 1985. After graduation, he served five years in a variety of assignments as an officer in the U.S. Army Signal Corps. He is a distinguished military graduate, an honor graduate of the signal officers' basic and advanced courses, and holder of the Kilbourne Leadership Award and Meritorious Service Medal, among other commendations. Since arriving at ANSER in 1990, Robinson has provided scientific, engineering, and technical assistance to the Ballistic Missile Defense Organization (formerly SDIO). He has played a pivotal role in the formulation and implementation of plans to effectively ground and flight test BMDO's lightweight exo-atmospheric projectile (LEAP) miniature, kinetic energy interceptor technologies. Recently, he has been instrumental in the development and conduct of plans to integrate the LEAP technologies with the Navy's STANDARD Missile systems. Robinson is an ANSER project manager, a tri-chairman of the Navy LEAP system safety working group, and a key member of the Navy LEAP test and evaluation steering committee.*

ABSTRACT

Over the past several years, BMDO's Lightweight Exoatmospheric Projectile (LEAP) program has achieved dramatic success in the development of advanced kinetic energy kill vehicle (KKV) technologies. Proof of principle ground and flight testing of these miniaturized interceptor technologies has been ongoing since 1989 with encouraging results. Recent testing successes have provided an excellent opportunity to investigate the incorporation of LEAP technologies into existing tactical missile systems for applications in Theater Ballistic Missile Defense (TBMD). Current tests and planning activities are building on lessons learned from previous LEAP tests to retrofit Navy, Air Force, and possibly Army missile systems with LEAP interceptors and kickstages in the interest of performing early technology demonstrations. These low-cost, integrated technology flight tests will take advantage of available missile systems, existing test activities, and established service infrastructures to evaluate LEAP technologies in a realistic tactical environment. They will also help determine the feasibility of performing long-range ballistic missile defense with KKVs from tactical platforms before commitment to the acquisition of new major weapon systems. Successful LEAP technology demonstrations could provide valuable contingency options for limited theater or national missile defense in the near term, prior to the fielding of proposed advanced systems.

INTRODUCTION

The Persian Gulf War and other recent developments such as ballistic missile flight testing of modified Soviet missiles by the North Koreans have shed new light on the U.S. need for improved ballistic missile defenses (BMD). With the breakup of the Soviet Union and the proliferation of increased-range tactical and intermediate-class missile threats throughout the Third World, renewed emphasis has been placed on the development of improved BMD to counter these threats. The U.S. Congress and Department of Defense, with legislation such as the Missile Defense Act of 1991 and the FY 93 National Defense Authorization Bill, have refocused U.S. BMD development efforts from a primary emphasis on defense of the U.S. from strategic, long-range missile attacks, to development of rapidly deployable, relocatable Theater Missile Defenses (TMD) by the mid 1990s. This task, though critically important, may prove to be extremely difficult.

As dramatized by the Gulf War, there is currently only one system in the U.S. inventory or scheduled for near-term deployment with any type of BMD capability, the Patriot missile system. This system, when used alone (although proven politically and militarily valuable during the Gulf War and currently undergoing improvements), has its drawbacks: it provides only limited area, terminal defense; offers questionable effectiveness and lethality; and requires a substantial logistics system to deploy and relocate. Ironically, during the war, several of the Navy's advanced Aegis ships sat off the coast of Iraq and watched helplessly as Scuds fell on Israel and Saudi Arabia. Iraq launched nearly 90 conventionally armed extended-range Scud missiles against U.S. and allied forces, civilians, and facilities. The AEGIS combat systems actively detected and tracked many of the Scuds from just after launch to near impact. Had these ships had a capable long-range interceptor, with only a few software modifications to the combat system to improve long-range tracking, they could have engaged the Scuds and provided an additional layer of protection for U.S. troops and allies.

Most air defense systems currently in the U.S. inventory, including the Army's Patriot and the Navy's STANDARD Missile, use an exploding fragmentation warhead to destroy airborne threats. As witnessed during the Gulf War, this ap proach, when used against ballistic missiles, often may not provide the desired reliability or lethality to completely destroy the threat and fully protect friendly assets. Even when the Patriot seemed effective in detonating the incoming Scud warhead, friendly territories were still at risk from falling missile fragments and debris. An ideal missile defense system would provide effective wide area coverage by intercepting incoming threats well beyond the range of their intended targets and completely destroying the warheads, including enough of their delivery systems (missile bodies) to ensure that friendly assets are not affected by falling debris. This concept is particularly important for defense against weapons of mass destruction such as nuclear, biological, or chemical munitions.

Kinetic energy weapons (KEWs), which destroy their targets by direct impact with the incoming warhead, can provide a more effective method of defense over the exploding, proximity-fused interceptor approach. The KEW method requires, of course, very precise, high-energy impact of the interceptor with the incoming warhead. This, in turn, requires highly accurate, long-range target detection and tracking coupled with highly responsive and maneuverable interceptors using long-range boosters and very precise guidance methods. In the early 1980s, BMDO, formerly the Strategic Defense Initiative Organization (SDIO), began development of several of the advanced technologies required to address the critical issues associated with performing BMD with hit-to-kill interceptors.

Initial SDIO development efforts led to significant advances in KEW technologies, particularly in the area of integrated KKV technologies. Through programs like LEAP, these early KKV technologies have evolved to a point where they have shown tremendous potential for application in BMD systems. What is more exciting is that the nature of their evolution has made these technologies inherently compatible with existing and developing tactical weapon systems. The LEAP technology development program had an initial objective of improving KKV performance, reproducibility, deployability, and cost-effectiveness by driving down size and weight. The size and weight of the LEAP projectiles and kick stages are now of a magnitude where they can be easily integrated into the front end of several existing tactical missiles without major redesign. The advanced, miniaturized LEAP technologies have also reached a state of maturity where comprehensive flight testing to determine their effectiveness has begun.

As a technology development effort, the LEAP technologies have maintained a synergistic relationship with proposed and developing BMD systems such as the Army's Theater High Altitude Area Defense (THAAD) and Ground Based Interceptor (GBI) systems, the Air Force's Brilliant Pebbles, and others. Experience gained from LEAP development efforts, including lessons learned from early LEAP ground and flight testing, has contributed significantly to the design of these proposed systems. In return, the mission requirements being evolved and established in the system development efforts are being fed back into the technology programs for technology development, enhancement, and evaluation.

LEAP technologies have been undergoing extensive ground testing at the contractor facilities and BMDO's National Hover Test Facility (NHTF) for the past several years. They are currently in the last phase of a space flight testing program aboard research rockets at the White Sands Missile Range (WSMR). Based on the encouraging test results to date, test plans have been expanded to investigate the incorporation of LEAP technologies into existing tactical weapon systems. These aggressive tactical tests will be used to evaluate the transition of LEAP technologies into existing Navy, Air Force, and Army missile systems. Initial tactical demonstrations verifying the ability of the Navy's STANDARD missile and the Air Force's Short Range Attack Missile (SRAM) to support the high-altitude, long-range LEAP tests are already in progress. These advanced technology demonstrations (ATDs) will gradually incorporate more elements of LEAP technology and culminate in intercepts of ballistic missile targets by LEAP KKVs in a variety of scenarios.

The LEAP technology demonstrations leverage BMDO's prior technology investment to investigate the feasibility of long-range, hit-to-kill TBMD with tactical systems. They will maximize the use of existing tactical systems and established service infrastructures to help reduce the cost, schedule, and technical risks normally associated with weapon system development. This "build a little, test a little" approach will not only reduce the risk and enhance the development of proposed BMD systems; if successful, it could provide one of the few realistic options for a deployable TMD capability in the near-term as directed by the Missile Defense Act of 1991.

LEAP TECHNOLOGY DEVELOPMENT

Background

The goal of the LEAP technology program, as originally conceived and begun in 1986, was to develop and integrate the world's first advanced, miniature kinetic energy interceptors and associated technologies; then to demonstrate these technologies through extensive ground testing. The technologies were intended to enable development of ground- and space-based systems in support of the then-proposed Strategic Defense System (SDS) architecture. Although aggressive design objectives were established, the original design goals did not necessarily evolve from stringent system requirements. Instead, near-term vehicles were developed to demonstrate the validity of fully integrated miniature interceptors and to represent a step on the path towards an operational KKV system. Because of this flexible development approach, even though the missile defense architecture has changed often in response to the changing global environment, the LEAP program has been able to

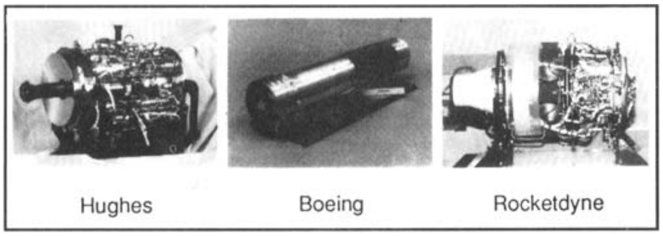


Figure 1. Evolved Projectile Designs-Hughes, Boeing, Rockwell.

maintain a robust, supporting technology focus.

The development of LEAP technology began with the realization that in order to improve overall KKV system performance, deployability, reproducibility, and cost effectiveness, the mass of the projectile must be driven down to something on the order of about 10 kg (22 lbm). This objective required a significant downsizing from existing designs. New designs were chosen to push the state-of-the-art in reduction of size and weight while maintaining or improving vehicle performance. As mentioned above, the LEAP projectiles were developed as technology pathfinders originally scheduled for ground testing only. As development progressed successfully, however, the test program was expanded to include extensive ground and flight testing. World events, such as the Gulf War, have continued to amplify the importance of hit-to-kill technology and the need for comprehensive LEAP flight testing.

Approaches

BMDO's Interceptor Technology Directorate (DTC) currently has two executing agents and three prime contractors developing similar yet unique designs for its LEAP interceptors. The U.S. Army Space and Strategic Defense Command (USASSDC) manages a contract with Hughes Missile Systems Company. This effort evolved from the DARPA/Gremlin program and was originally geared toward supporting ground-based interceptor applications. The U.S. Air Force Phillips Laboratory (PL) manages a contract with Boeing Defense and Space Group, which had its origins in the Have Sting hypervelocity gun study as well as the SAGITTAR and space-based interceptor (SBI) programs. PL also manages a contract with the Rocketdyne Division of Rockwell International Corporation that is a follow-on from previous kinetic hover integration test (KHIT), SBI propulsion, and antisatellite (ASAT) technology contracts. All three contractors are now developing projectiles that are intended to provide robust, advanced technologies for either ground-, sea-, or space-based applications (Figure 1).

Achievements

The LEAP interceptors range in mass from 6 to 18 kg (13 to 40 lbm). They have contributed significantly to both military and commercial applications from the development of their advanced infrared sensing technologies, to their fast-response, miniature propulsion systems, to their highly integrated, wafer-scale electronics. For reference, during the Homing Overlay Experiment (HOE) in 1983, a 1,000 kg (2,200 lbm) interceptor about the size of a Volkswagen destroyed an incoming reentry vehicle (RV). In 1991, the Exoatmospheric Reentry Vehicle Interceptor System (ERIS), a 150 kg (330 lbm) interceptor roughly the size of a freezer accomplished the same feat. The LEAP interceptor, which weighs about 6 kg (13.2 lbm), is approximately the size of a loaf of bread and recently demonstrated exceptional performance in a space flight mission. For further comparison, the reaction control propulsion thrusters used on the lunar module were about the size of a large coffee can. The LEAP thrusters are about the size of a roll of Lifesavers yet provide similar function and performance. Thus, over the past ten years, BMDO and the LEAP program have achieved dramatic success in the development of advanced interceptor technologies and in the reduction of interceptor size and weight.

As previously mentioned, intercepting high-speed ballistic missiles in flight with a KKV requires accurate, long-range target detection; a very responsive, high-performance maneuvering system; and an extremely precise navigation and guidance capability on-board the KKV. To meet these requirements, the projectiles use similar designs composed of essentially five major subsystems: a passive infrared (IR) body-fixed seeker; a guidance unit consisting of an inertial measurement unit (IMU) and an on-board avionics/electronics microprocessor; a divert propulsion system*; an attitude control system (ACS) propulsion assembly; and a communications/telemetry unit (Figure 2).

Over the past several years, numerous technology challenges have arisen in the LEAP program, particularly in the miniaturization of integrated electronics and propulsion systems. In response, many new manufacturing techniques have been developed. Tremendous advances have been made in the processes of welding small, high-pressure-tolerant tubing and tanks; the precise fabrication and machining of 3-D carbon-carbon thrust chambers and complex metallic/composite components; the creation of fast-response, miniature valves and nozzles; and the manufacturing of compact, high-density electronics. Critical technology hardware development achievements include:

- Demonstrated avionics/electronics units composed of eight daughter boards on one mother board with throughputs greater than 5 million instructions per second (MIPS) that fit on a disc about the size of a CD and weigh less than 150 g (0.33 lbm).
- Demonstrated Interferometric Fiber-Optic Gyroscope (IFOG) IMUs that operate at data rates up to 200 Hz, have less than 1 deg/hr single-axis drift, and fit in the palm of your hand.
- Proven miniature, liquid hypergolic divert propulsion

* Used to perform lateral maneuvers in order to remove delivery errors and target uncertainties during end-game terminal homing. The divert thrusters are arranged in a cruciform pattern at the center of the vehicle and provide thrust through the vehicle center of gravity (cg). The ACS thrusters are clusters of small nozzles located at the aft end of the vehicle providing pitch, yaw, and roll control. The divert and ACS propulsion systems are sometimes integrated as one subsystem.

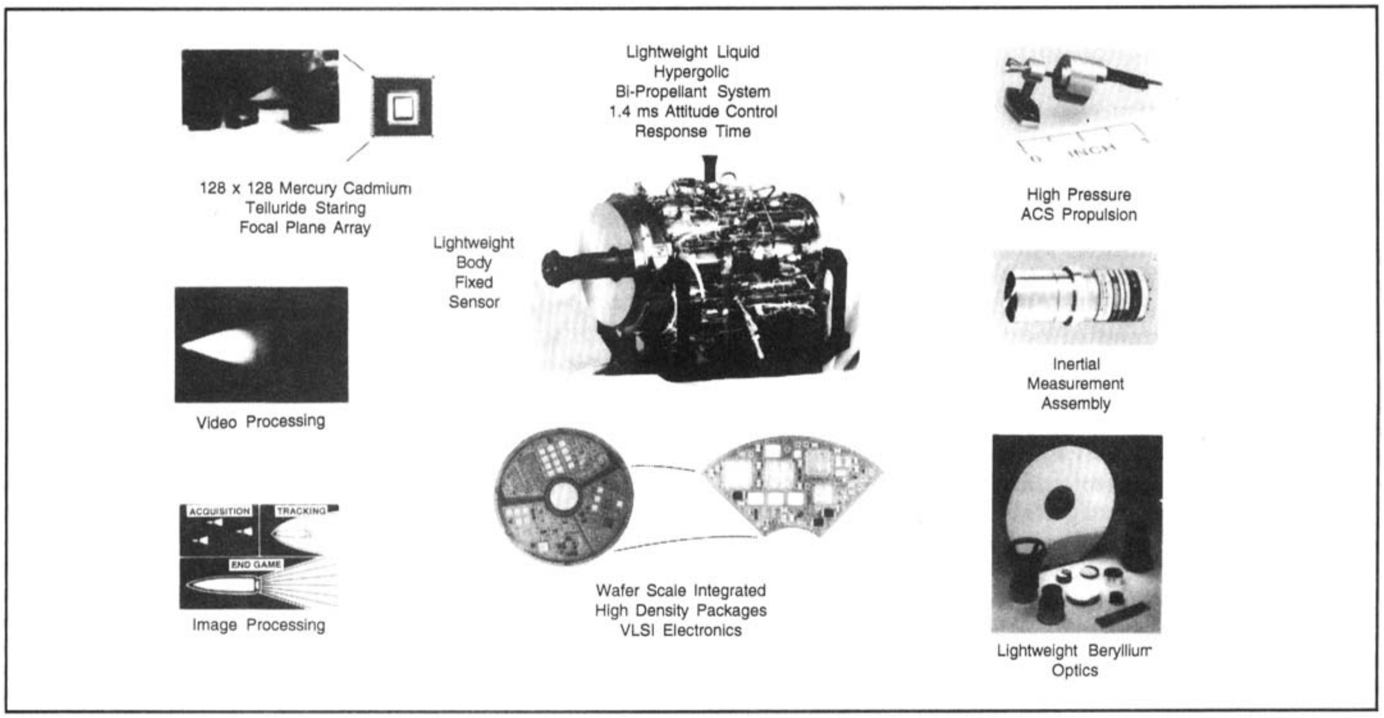


Figure 2. Example Projectile Subsystem Layout.

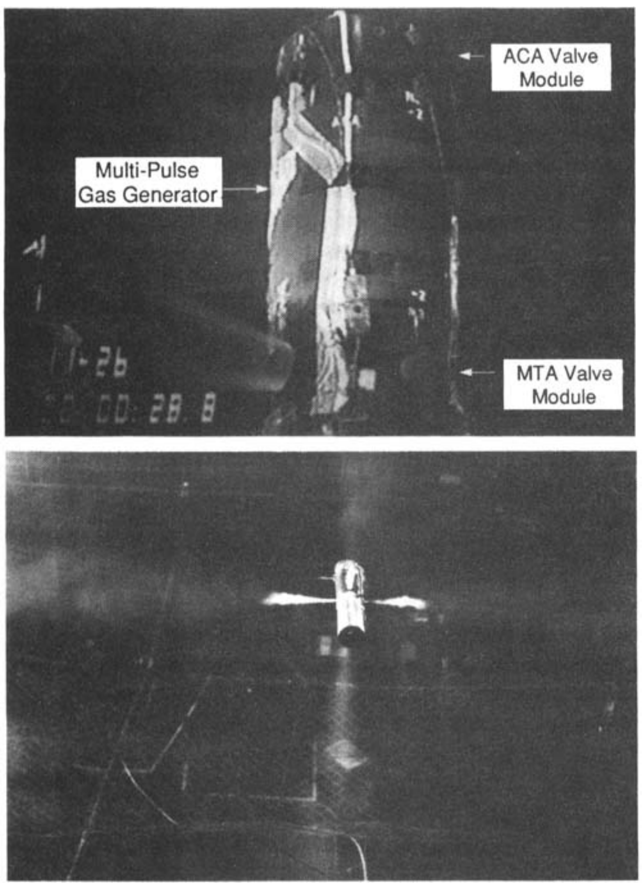


Figure 3. Static and Hover tests of the Boeing/Thiokol integrated solid propellant Dviert/ACS system.

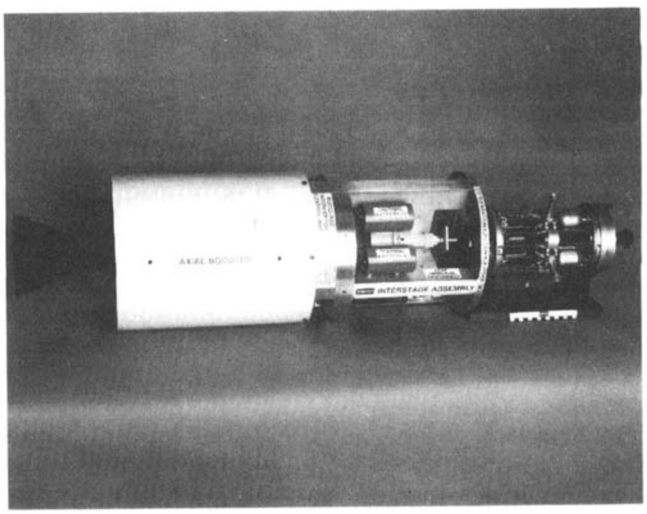


Figure 4. Midcourse interceptor concept.

systems with cg drifts less than 2 mm (0.08 in), divert valve response times below 5 msec, and thrust-to-weight ratios greater than 1,200:1 (30-110 lbf).

- Validated cold and warm gas ACS systems with nozzles that fit on a dime and provide 1-2 lbf thrust with less than 2 msec response.

- Proven mid- and longwave HgCdTe IR focal plane arrays (FPAs) in multiple sizes (64x64, 128x128, and 256x256 detectors) covering the complete mid- to long-wave spectrum (3-11 μm). Seeker noise equivalent intensity (NEI) values below 15 femtowatts/cm2 have been achieved with signal-to-noise ratios (SNRs) greater than 25 against typical TBM targets at acquisition ranges beyond 200 km (125 mi).

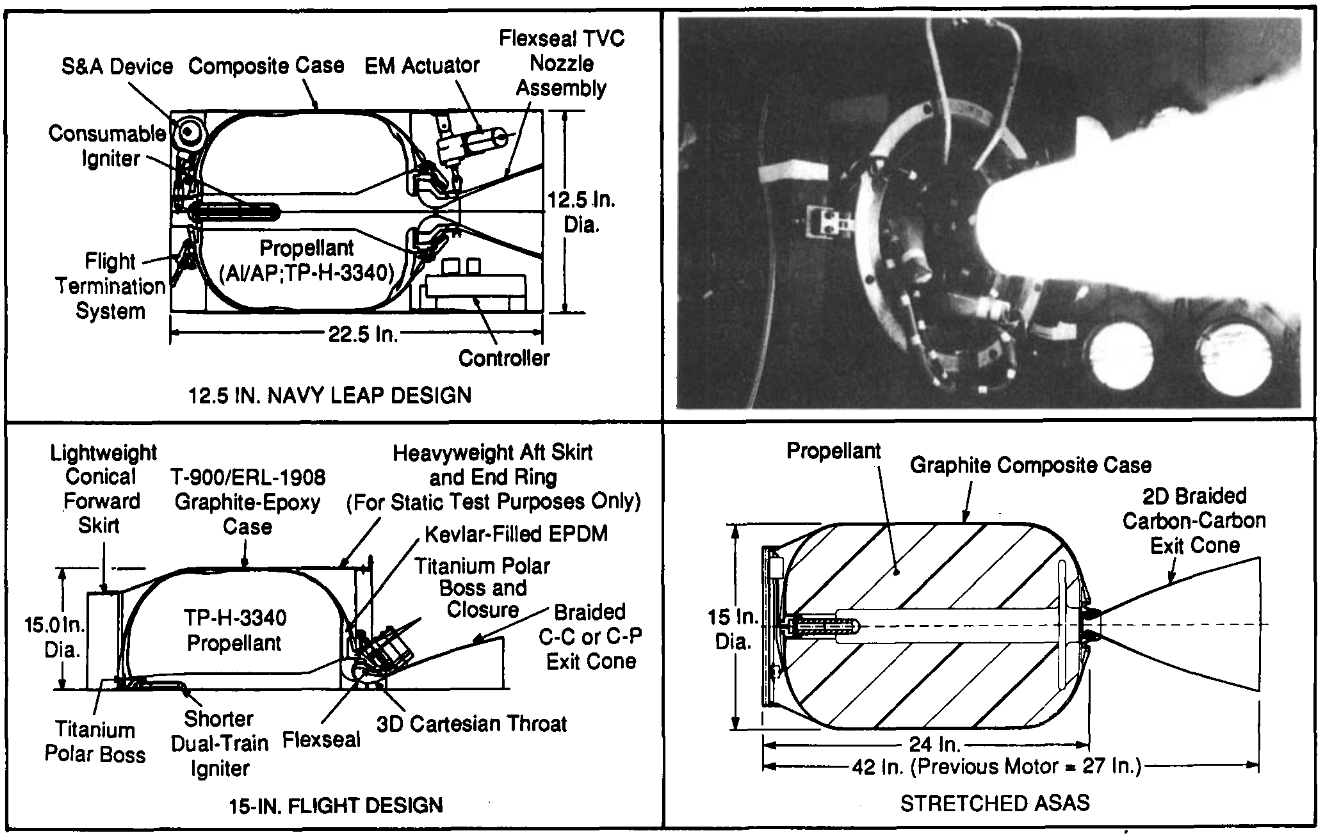


Figure 5a. Evolving ASAS designs.

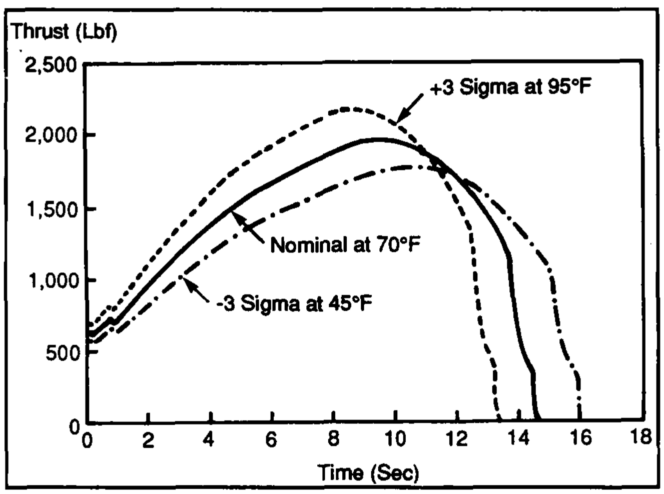


Figure 5b. ASAS predicted thrust vs. time.

Qualified, miniature Cassegrain optics weighing less than 250 g (0.55 lbm) using reflective and refractive components with 1 to 3 deg fields-of-view, apertures up to 15 cm (6 in), and less than 15% obscuration.

Extensive, incremental ground testing at both contractor and government facilities has been used to validate the performance of developed hardware and software. Components and subsystems are subjected to a comprehensive sequence of tests including hardware-in-the-loop, air-bearing, and integrated strap-down tests. Guidance algorithms and control software are verified through digital emulation and simulation prior to testing. Test results are then fed back into the simulations and software to improve their performance. Hover testing at BMDO's National Hover Testing Facility (NHTF) serves as the final proof of concept prior to space flight testing. Hover tests are performed by allowing the completely integrated LEAP vehicle to lift itself off of a test stand and hover autonomously in free flight using its divert and ACS propulsion systems. While in unencumbered free flight, the LEAP acquires and tracks a scaled infrared target located approximately 100 meters (330 ft) outside of the facility and performs a series of maneuvers as dictated by the particular objectives of the test. Hover tests are used to validate all of the primary functions required of the projectiles except the ability to perform terminal homing and intercept of the target. Over twenty hover tests have been performed to date. As a result, all three contractors have demonstrated the readiness of their designs for flight testing. Should significant design modifications be made, the vehicles again must "pass" a hover test. This stringent verification process helps ensure that vehicle designs are sound and minor "glitches" have not been overlooked.

One of the remaining challenges, the final ground validation of the world's smallest (<5 kg or 11 lbm), fully integrated solid divert/ACS propulsion system (Figure 3), recently passed a critical milestone by performing successfully in a hover test. This system uses a multigrain hot gas generator and clean burning Al/HTPB fuel with fluidic valves modulat-

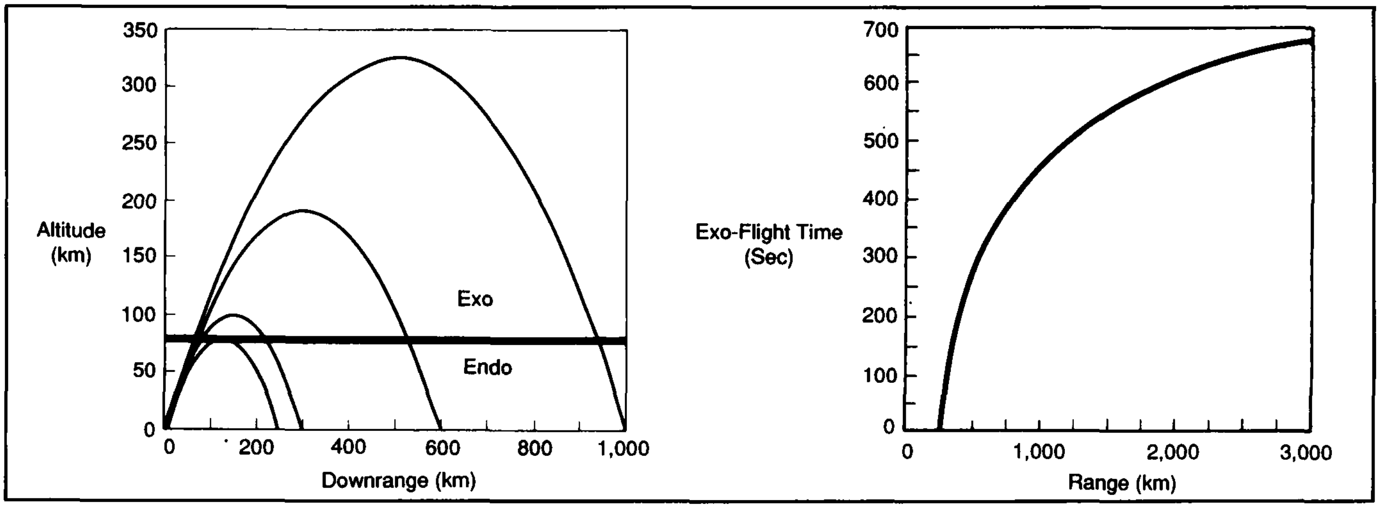


Figure 6. Minimum energy trajectories for typical ballistic missile threats.

ed at up to 200 Hz (1.2-2.0 msec response). The hot gas generator operates at temperatures over 3,700 deg F (2,040 C) requiring the use of new, high- temperature-tolerant materials. [1] During development of this system, Boeing, along with the propulsion contractor Thiokol, developed a number of manufacturing process innovations. Four processes of particular note are rhenium diffusion bonding, rhenium tube bending, electron-beam welding, and extremely precise 12-axis optical/digital tooling, integration, and alignment processes. An additional hover test of the Thiokol solid system integrated with the Hughes projectile is scheduled for the fourth quarter of FY 93. To provide an additional option for future solid systems, PL's Rocket Propulsion Laboratory (the LEAP solid propulsion government executing agency) has recently begun development of an enhanced solid divert system through a cooperative contract with Aerojet and its subcontractor, SEP of France. This system is scheduled for hover testing in mid FY 94. Once fully validated through successful ground testing, this new technology should provide an extremely attractive projectile divert/ACS propulsion option, especially for operations on-board Navy ships where there are concerns about the use of liquid fuels.

Additional Essential Enabling Technologies

In addition to technologies described above, the LEAP program has been evolving other critical technologies that will be essential to performing tactical or strategic missile defense with lightweight KKVs. One of these is the advanced solid axial stage (ASAS) rocket motor. PL and its prime ASAS contractor, Thiokol, have made substantial progress over the past several years in developing a small, high-performance (high mass fraction) kickstage to be used as axial propulsion for the KKV. The current ASAS has its heritage in Thiokol's STAR series of space motors. It uses a similar, high-performance propellant but a new, lightweight, graphite/epoxy overwrapped casing and advanced carbon composite materials in several of the inert components. It will provide the final axial boost to the KKV to increase the interceptor's closing velocity relative to the target and steer out a significant portion of the end-game errors prior to final LEAP ejection and divert maneuvering. The ASAS or "kickstage" will serve as one of three fundamental technology components of the modular "midcourse interceptor" (KKV/Interstage/ASAS) front end to be adapted to tactical systems (Figure 4). [2] The stage itself will include the following major subsystems: the ASAS motor, a dual-redundant flight termination system composed of two explosive transfer assemblies (ETAs), two safe-and-arm (S&A) switches, and a flexible linear shaped charge (FLSC); a 5-deg omniaxis thrust vector control (TVC) system consisting of two thrust vector actuators (TVAs), a controller, and batteries; and a consumable igniter. The stage will also include an attitude and roll control system in the aft end for additional controllability during either powered or unpowered flight of the midcourse interceptor.

The current ASAS design is 32 cm (12.5 in) in diameter and 57 cm (22.5 in) in length (Figure 5a). This design allows it to fit inside the Navy STANDARD Missile 2 Block II or III (SM2 Blk II/III) warhead section as well as in the Air Force's SRAM and the Army's Patriot Missile. A ground test program is under way to qualify this stage for use in technology demonstrations aboard a Navy ship. A system safety qualification plan for the technology demonstration flights has recently received concurrence from the Naval Sea Systems Command's (NavSea) Weapon Systems Explosives Safety Review Board (WSESRB). Three successful static firings of the current ASAS design have been performed. This relatively low-risk design uses approximately 33.6 kg (74 lbm) of aluminized ammonium perchlorate propellant (Al/AP). It has a motor mass fraction of approximately 0.75 and burns for about 14 seconds. It provides up to 2,000 lbf (8,896 N) of thrust and over 21,000 lbf-sec (93,408 N-sec) of total impulse with a specific impulse of approximately 286 lbf-sec/lbm (2,800 N-sec/kg). This stage will impart between 800 and 1,000 m/sec (2,625-3,281 ft/sec) of additional axial velocity to the midcourse interceptor. Figure 5b displays predicted thrust versus time for the current motor. [3]

The current kickstage design will be used in the

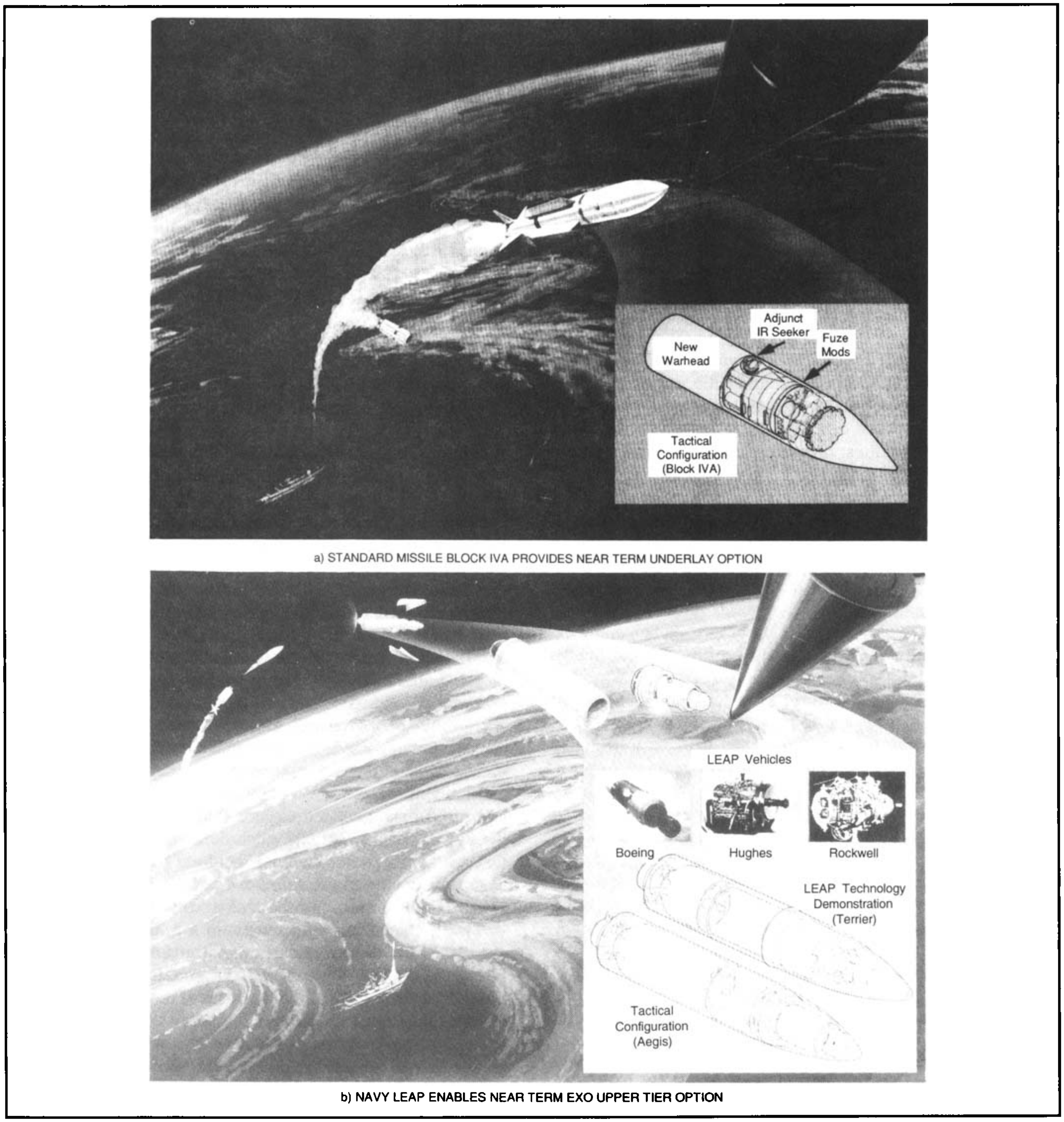


Figure 7. Navy Sea Based Multilayered TMD.

Terrier/LEAP portion of the Navy LEAP Technology Demonstration series and then lengthened and further optimized for later use in Aegis/LEAP. In addition to the single-pulse design, Thiokol has performed successful static firings of multipulse (up to three pulses) versions of the ASAS. These versions may prove valuable to future tactical tests where coast periods and in-flight target updates (IFTUs) are required between pulses to take full advantage of the relationship between the ASAS's maneuvering capability and the fire control system's tracking updates to remove large target state uncertainties. Larger versions of this motor [38 cm (15 in) in diameter by 61 cm (24 in) in length] containing up to 86 kg (190 lbm) of propellant have also been successfully static tested.

In addition to the ASAS and solid divert technologies, developed LEAP components and subsystems are continuously being enhanced to improve performance in evolving theater and national missile defense scenarios. Existing IR seekers are being fine-tuned to provide maximum effectiveness against anticipated threats. Modifications include optimization of the seeker passbands, widening of the fields of regard (FOR)**, reduction in system noise, and improvements in FPA sensitivity. Also, IMU performance is being improved to provide the extremely accurate position and attitude knowledge required for the tactical missions. Use of GPS receivers on-board the missile to update the IMU with a precise position and velocity reference is one method being pursued to minimize system bias (initialization and alignment errors) and IMU drifts. Additionally, LEAP on-board processing capabilities are being increased by upgrading and adding microprocessor chips to the avionics. These improvements will enable incorporation of advanced guidance and image processing algorithms, including the use of celestial tables and target object maps (TOMs) as necessary. And finally, propulsion system capabilities are being enhanced by increasing tank capacities, pressures, and duty cycle performance to allow additional fire control system margins by performing faster flyouts and longer engagements.

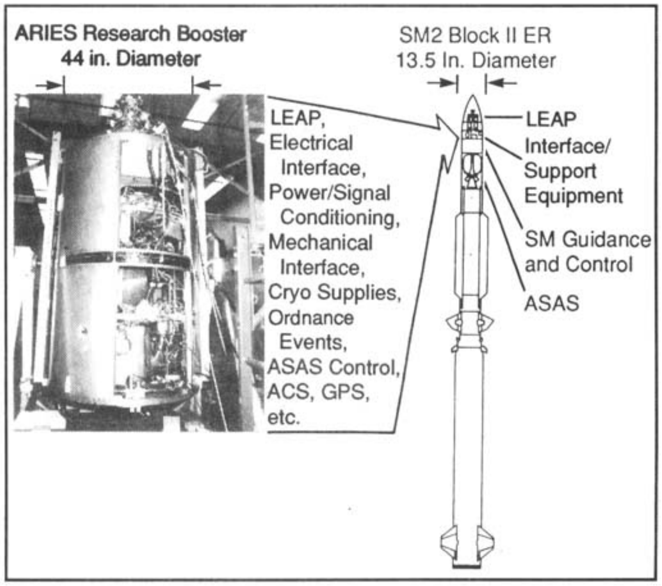


Figure 8. Tech demos address critical technology integration issues.

VALUE OF LEAP TECHNOLOGY FOR TACTICAL APPLICATIONS

An estimated 50 percent of the near-term (1995-96 timeframe) ballistic missile threat inventories around the world will have ranges greater than 250 km (156 mi). This number includes the Scud-B (~300 km or 188 mi range) and Scud-variant Al-Hussein (~600 km or 376 mi range) class missiles. Fifty percent of the world's far-term (beyond 2000) threat inventory is projected to have ranges beyond 450 km (281 mi). [4] Therefore, during a typical ballistic trajectory, a large number of both near- and far-term threats will spend a significant portion of their flight outside of the atmosphere and are potentially engageable with exoatmospheric interceptors (Figure 6).

Exoatmospheric interceptors have the advantage of not having to consider the aerodynamic controllability, aero-optical distortion, aerothermal heating, thrust amplification, and other effects on the interceptor caused by the atmosphere. Engagement outside the atmosphere also makes interceptor and target performance significantly more predictable. Target performance is particularly predictable after motor burnout, and most theater threats generally burn out before or just after exiting the atmosphere. Postboost, exoatmospheric targets are usually ballistic and not maneuvering, so the line-of-sight (LOS) ranges from the interceptor to the target do not fluctuate rapidly during engagement. Therefore, standard proportional navigation (ProNav) type guidance algorithms are sufficient to engage and intercept them. Thus, performing hit-to-kill is generally easier in the exoatmospheric regime.

Current LEAP interceptors are designed to operate at altitudes above the appreciable atmosphere [generally agreed to be above about 80 km (50 mi)] without experiencing significant effects from residual gas molecules. System effectiveness studies have determined that a tactical system taking advantage of LEAP technology could engage a large number of existing threats given a capable fire control/delivery system. A LEAP-based system would also afford the advantage of being able to engage targets at long ranges, perform a kill assessment, and reengage with additional interceptor(s) in a shoot-look-shoot-type scenario, if necessary. Moreover, intercepting threats outside the atmosphere reduces the chance that undetonated warheads, submunitions or debris (including nuclear, chemical, and biological agents) will survive reentry and reach their intended targets. Further, engaging many of the current theater threats, such as modified Scuds, before they reenter the atmosphere and begin to break up reduces the chance of having to discriminate between multiple target objects, thereby improving the ability to correctly engage the warhead. Using exo-interceptors in a multilayered defense composed of both exo- and endoatmospheric interceptors [such as the Navy's improved, dual-mode (IR/RF) homing SM2 Blk IVA and the Army's Patriot or developing Extended Range Interceptor (ERINT)] could provide extended area coverage, improved mission flexibility, and effective insurance against leakers (missed targets) and countermeasures (Figure 7). Developed LEAP hardware is available, and proven radars (such as the Navy's Aegis SPY-1), launchers, personnel, logistics, and training are already in place to begin early testing and potentially support such a system.

TESTING EVOLUTION TO TACTICAL SYSTEMS

As stated above, current LEAP flight testing activities are being performed at White Sands Missile Range (WSMR), New Mexico. These tests are geared toward providing proof of concept for LEAP exo-intercepts. As the first step in the space flight validation process, they are being performed

** The size of the area that the KKV seeker can cover in time to acquire the target and still perform the mission. The FOR is determined by the seeker field of view (FOV) and the projectile's ability to scan the target area.

with fairly large research boosters (Aries I - Minuteman 1 Stage 2 motors) in relatively cooperative scenarios using surrogate fire control solutions. The WSMR tests will validate the projectiles' ability to acquire, track, engage, and intercept postboost reentry body targets in space. Although extremely valuable as the first phase of LEAP spaceflight testing, these single launch tests do not provide a fully realistic testing environment or the ability to evaluate LEAP technology performance in a weapon system. Planned tests involving the STANDARD Missile, the SRAM, and potentially the Patriot will provide a natural extension of current testing activities to further stress the technology and evaluate its performance in more challenging and realistic scenarios (Figure 8).

Navy Test Plans

The Missile Defense Act of 1991 directed development of a TMD system that is both "relocatable and deployable" to protect friendly troops, embarkation ports, and facilities abroad. Use of modified Navy ship-based air defense assets, which are easily relocated and rapidly deployed, would provide an extremely attractive, cost-effective TMD option for most areas of the world. To begin investigating this option, BMDO and the Navy have established the Navy LEAP Technology Demonstration Program. [5] The Navy LEAP Tech Demo will investigate modifications to both the STANDARD Missile and its associated fire control systems [radars, weapons direction system (WDS), command display systems (CDS), telemetry systems, etc.] that will be necessary to perform ballistic missile intercepts.

The Navy LEAP Technology Demonstration Program is currently divided into two phases. To perform early demonstrations at sea, Phase I or Terrier/LEAP (which presently consists of five flights) uses systems that are currently available and deployed in the Fleet: the Terrier combat system and SM2 Blk II Extended Range (ER) missile. These systems are now scheduled for decommissioning by FY 95 but are providing an excellent opportunity for the resolution of technology integration issues and early testing while serving as a springboard for the transition to more advanced systems. Phase II or Aegis/LEAP, a series of six to ten experiments, will build on lessons learned from the Terrier tests to transition the technology to the Navy's advanced Aegis fire control system and improved long-range SM2 Blk IV missile as they become available (Figure 9). The SM2 Blk IV is scheduled to complete development and operational testing by the end of 1994, while the Aegis combat system is undergoing software modifications for TBMD applications under a baseline upgrade. The Aegis mods, which include enhanced energy management to provide longer-range, improved-accuracy detection and tracking, should be available by mid-1995, just in time for the follow-on Aegis/LEAP tests.

Additionally, BMDO and the Navy are currently investigating advanced methods of target cueing and handover to the Aegis system to improve the probability of long- range detection and acquisition. One of the methods being investigated is cueing from space assets such as surveillance satellites. The LEAP program has a sister technology development effort called the Miniature Sensor Technology Integration (MSTI) program that is developing low-cost, rapidly deployable satellites to be used as test-beds for developing sensor technologies. The MSTI satellites and an associated mobile ground station will, among other things, be designed to perform surveillance and cueing. The Terrier and Aegis/LEAP programs will provide the perfect opportunity to integrate the MSTI technologies and demonstrate the space cueing concept.

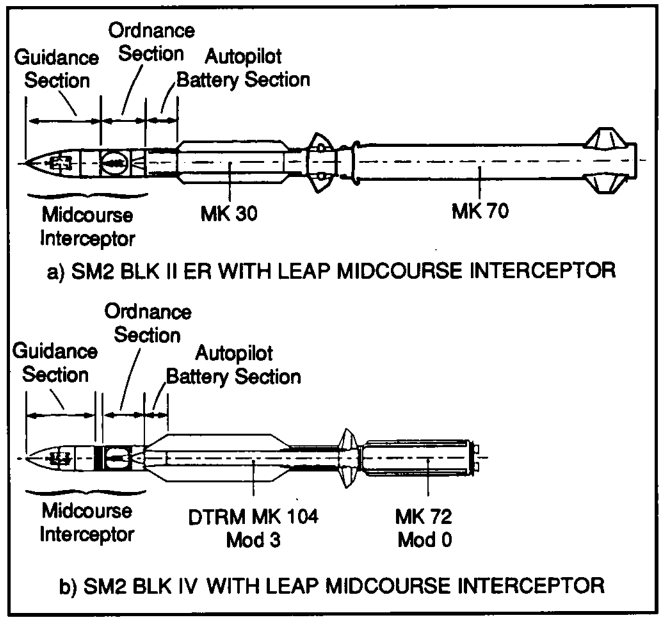


Figure 9. Standard missiles modified with LEAP technology.

Further, the Navy is also investigating the capability to perform multisensor fusion of land-, sea-, air-, and potentially space-based surveillance and tracking sensors. This program, called the Cooperative Engagement Capability program, will allow a great number of combat systems to "see" a consolidated picture of the battlespace that is better than any one system could provide for itself. It will also enable flexibility in the engagement doctrine to allow selection of the appropriate system(s) to engage the target based on this consolidated picture. The CEC concept will be particularly appropriate for long-range TBMD where over-the-horizon detection and cueing can dramatically improve system performance. Preliminary CEC development efforts are in progress, and the Navy LEAP program may serve as an excellent test-bed for this concept.

Phase I (Terrier/LEAP)

Terrier/LEAP makes use of the current New Threat Upgrade (NTU) Terrier weapons control system and the SM2 Block II ER missile to demonstrate the potential of LEAP technology for TMD applications. The first two flight tests validate the ability of the missile and fire control system to deliver a payload within the required error volume. Flights three through five gradually incorporate more system elements with a corresponding increase in mission complexity. During FTV-3, the SM2 warhead and semiactive homing radar are removed and replaced with the LEAP midcourse interceptor. A main objective of this flight is to ensure safe sep-

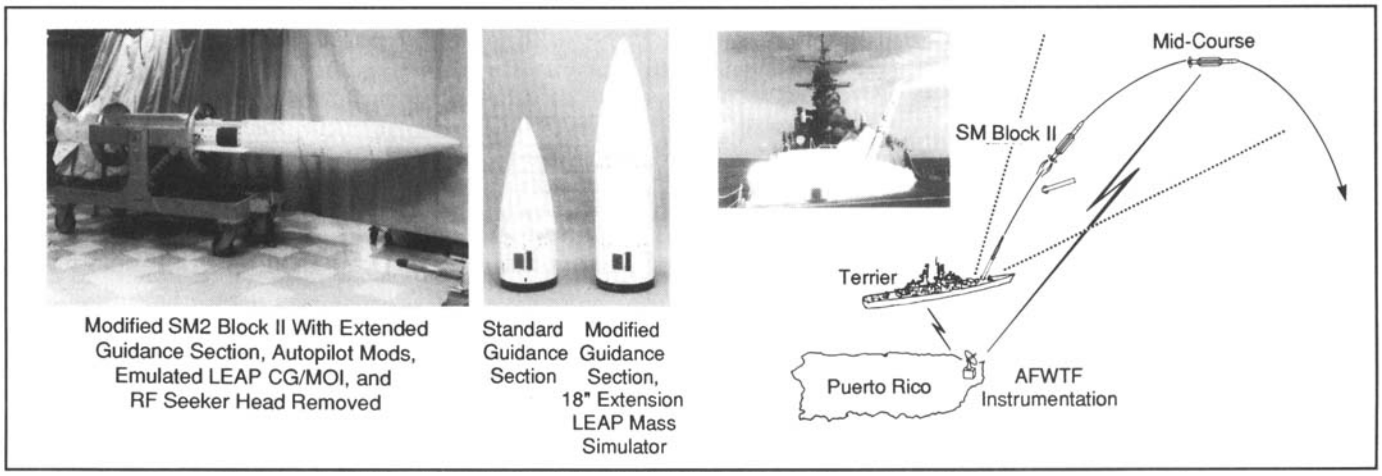
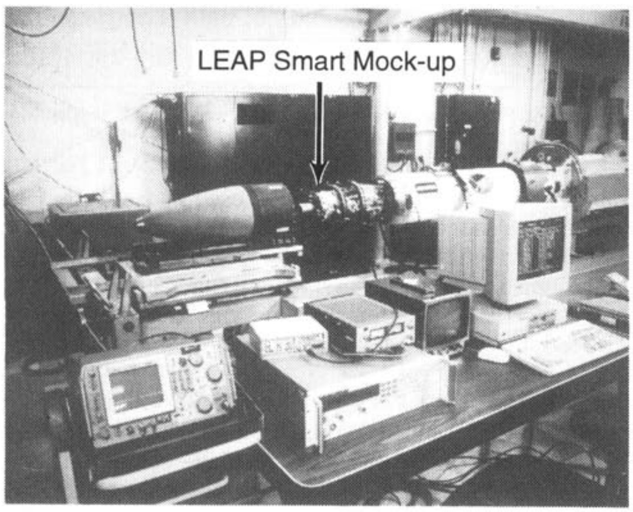


Figure 10. FTV-1 missile mods and mission scenario.



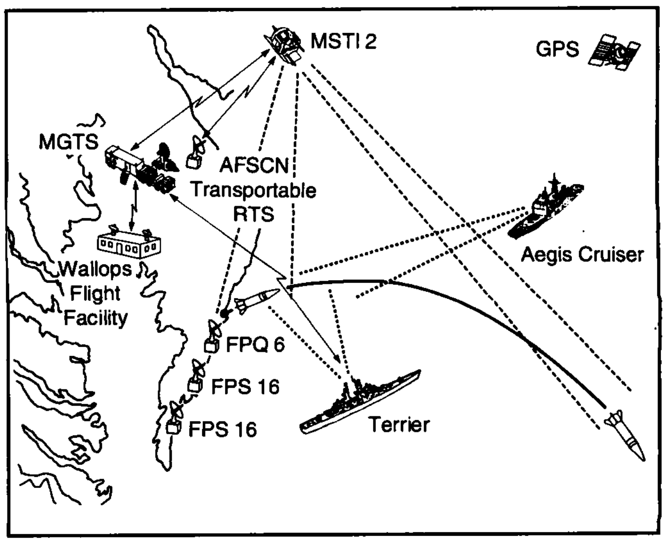


Figure 12. FTV-TD (Target Demo) mission scenario.

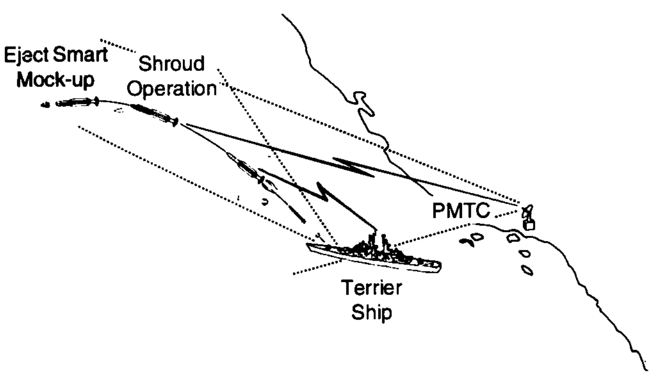


Figure 11. FTV-2 missile configuration and mission scenario.

aration of the midcourse interceptor from the SM2 sustainer. After separation, the kickstage ignites and flies the LEAP to a point in inertial space. After ASAS burnout, the LEAP is ejected and attempts to acquire a dynamic target. Instrumentation is used to evaluate the success of the mission. During FTV-4, the fire control targeting system should be validated and in place. This will allow closer engagement by the midcourse interceptor and will culminate in a LEAP/target flyby. Evaluation of all shipboard fire control system and missile modifications is the primary objective. FTV-5 is the final validation of the ship-based, upper-tier interceptor where intercept of the TMD-type target is performed.

FTV-1 was successfully completed at the Atlantic Fleet Weapons Training Facility (AFWTF) near Puerto Rico on 24 September 1992. The major test objective of this experiment was to "demonstrate the STANDARD missile and Terrier NTU ship system modifications required to launch and fly a weighted SM2 Block II ER (replicating LEAP physical attributes) into a predicted flight envelope." It was the first controlled exoatmospheric flight of a STANDARD Missile. The flight scenario and some of the missile modifications are reflected in Figure 10. The missile flew a semiballistic trajectory at a climb-out quadrant elevation angle representative of what would be expected for a ballistic missile target engagement (65 deg). Modifications to the fire control system included software mods to track a high-speed, high-altitude outbound target. Tracking was done with both the AN/SPS-48E phased array, air search radar

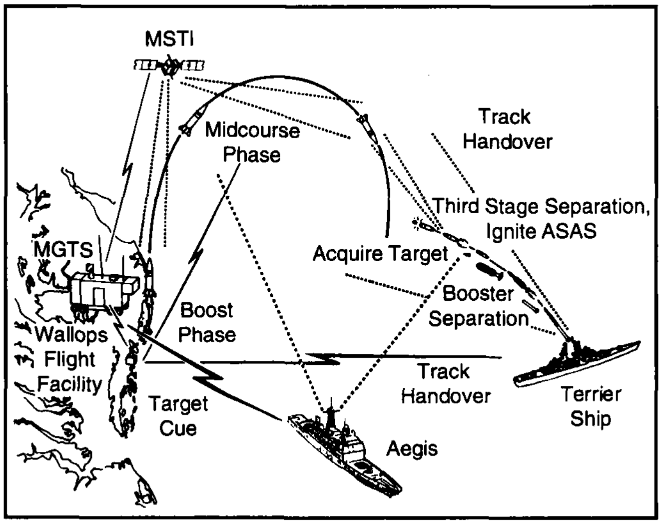


Figure 13. FTV-3 Mission scenario.

and AN/SPG-55B targeting radars. The vehicle obtained an exoatmospheric altitude of approximately 110 km (360,000 ft). It was destroyed on command after reentry, just before passing below the radar horizon. All flight objectives were successfully met, and the flight trajectory was a near overlay of preflight predictions.

FTV-2, scheduled for the end of September 1993, will involve the ejection of the missile nosecone and a LEAP mockup (Figure 11). The missile will fly a trajectory similar to FTV-1 but will test a new shroud and shroud removal mechanism. It will also demonstrate the incorporation and operation of a LEAP 'smart' mockup (includes camera, electronics, and an IMU) and its ejection system. FTV-2 is currently scheduled for the Pacific Missile Test Center (PMTC) aboard the USS *Jouett* off the coast of Pt. Mugu, California. Extensive on-board instrumentation, range radars, telemetry (TM) receiving equipment, and passive optical sensors will collect performance data on the mission.

Prior to FTV-3, a dedicated Navy LEAP target demonstration flight (FTV-TD) will be performed at NASA/GSFC's Wallops Flight Facility (WFF), Virginia (Figure 12). FTV-TD will be used to prove out the target and associated target launch procedures prior to involvement in an interceptor test where timelines are critical. Since NTU radars cannot currently detect theater ballistic missile (TBM) targets at long ranges, FTV-TD will characterize the accuracy of real-time target tracking solutions generated from range radar data. Radar tracking accuracies will be validated against data obtained from a GPS receiver and processor on-board the target. This mission may be used as a target of opportunity for tracking by multiple land-, air-, and sea-based tactical radars and for testing of available CEC mods.

FTV-3 will be the first Navy LEAP flight test to eject a full-up LEAP midcourse interceptor from a tactical STANDARD missile (Figure 13). It will also be the first dual launch mission involving launch of a "TBM-like" target. The objectives of the test will be to demonstrate third-stage separation, ignition, and controllability, as well as integration with the LEAP kickstage. Third-stage telemetry links

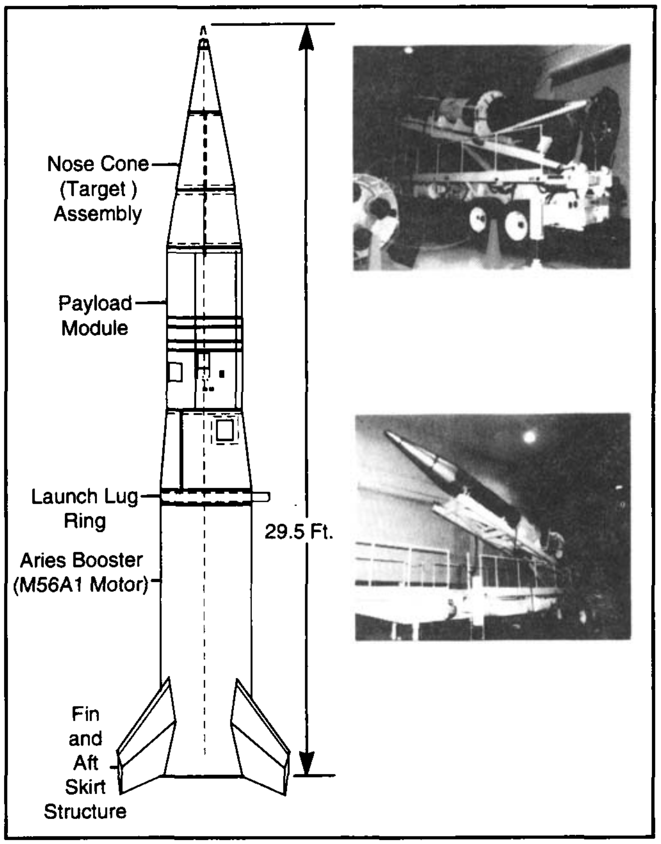


Figure 14. Aries target radiant intensity.

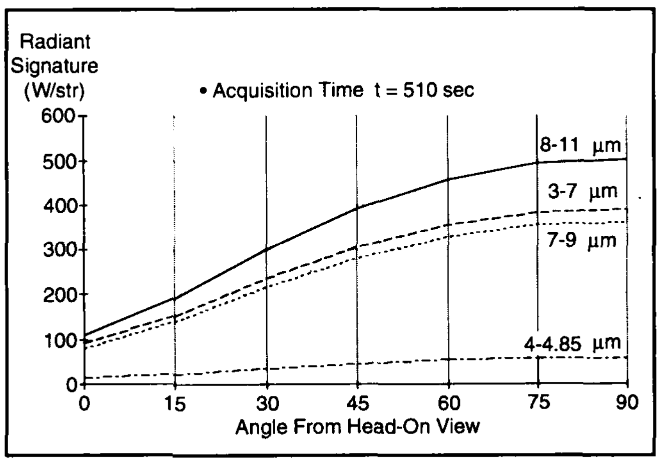


Figure 15. Aries target vehicle and transporter erector.

and LEAP IMU alignment with the third-stage inertial navigation system (INS) will be demonstrated. For FTV-3 and subsequent missions, an integrated Global Positioning System (GPS/INS) navigation system will be incorporated to provide the required accurate position and velocity reference for guiding the third stage to the intercept basket. After ejection, the LEAP will attempt to acquire and track the dynamic target. A preliminary targeting solution based on range radar tracking information will be used for guidance of the STANDARD Missile. The trajectory profile and timeline will be designed to provide critical risk reduction for the

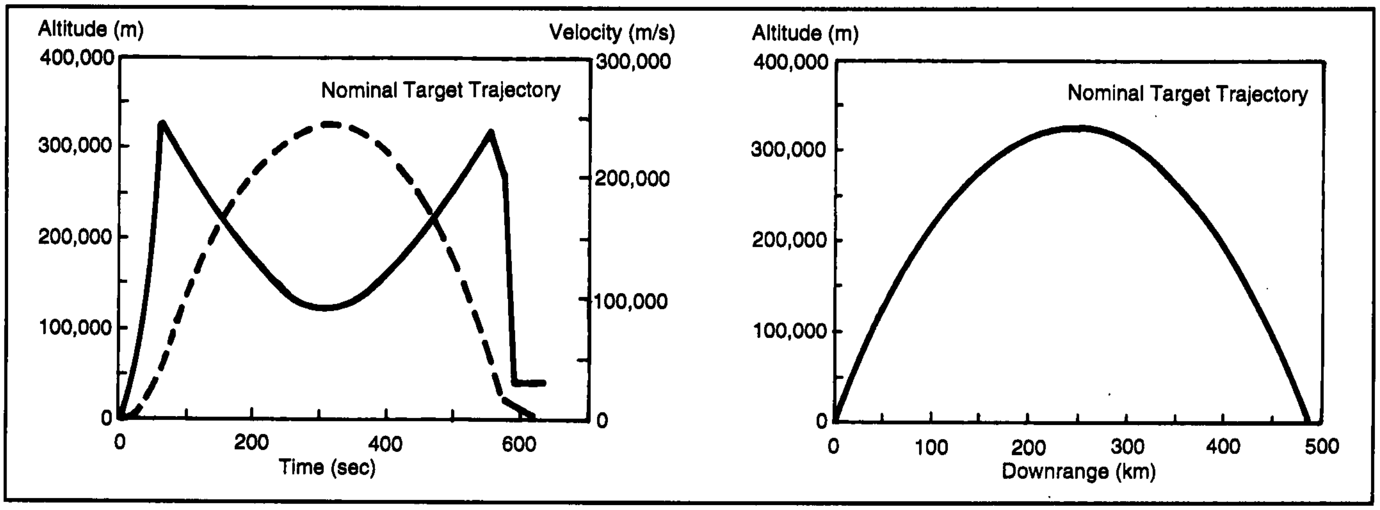


Figure 16. Typical target trajectory.

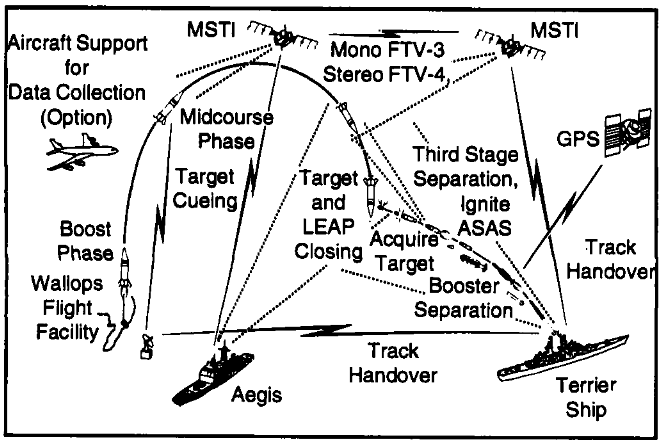


Figure 17. FTV-4 and -5 mission scenario.

FTV-4 and FTV-5 mission scenarios.

The Aries vehicle (Figure 14) was selected as the target for the Navy LEAP missions based on its demonstrated performance on numerous missions, including the LEAP WSMR flights, and on its ability to simulate the kinematics and RF/IR signature characteristics of representative tactical ballistic missile threats. Figure 15 indicates the expected target signatures for various aspect angles during engagement with LEAP IR sensors. The target signatures drive seeker acquisition range and subsequent LEAP free flight time to be defined in the mission requirements. All three LEAP contractors can acquire these targets at sufficient acquisition ranges to perform the mission. The typical target trajectory will achieve an apogee of about 328 km (1,075,000 ft) and ground range of about 490 km (311 mi) (Figure 16). Because of potential issues involving compliance with the 1972 Anti-Ballistic Missile (ABM) Treaty, the target will be designed so as not to be confused with an intermediate or strategic threat. Maximum velocities will be kept below 3 km/sec (9,900 ft/sec) so that engagements will be tactically representative but will not endanger the deployability of current STANDARD Missile systems (e.g., radars, launchers, missiles, etc.). Also, the target will use a fixed launching system that cannot to be misconstrued as a mobile launcher.

The fourth interceptor flight test, scheduled for the fourth quarter of FY 94, will demonstrate the capability of the SM2/LEAP to acquire, track, and guide towards a dynamic ballistic missile target (Figure 17). The Aries target will be launched from WFF in a southeasterly direction on approximately a 145 deg azimuth. After successful launch confirmation and reception of initial target state information, the SM2/LEAP interceptor will be launched in a northeasterly direction from a Terrier ship approximately 300 km (188 mi) off the North Carolina coast. SM2/LEAP launch will occur approximately 8 min after target launch. A nominal timeline of mission events for the SM2/LEAP is shown in Figure 18.[6]

FTV-5, planned for fall 1994, will incorporate all of the lessons learned from FTV-1 through FTV-4 to perform the intercept of the Aries (Figure 19). Mission timelines and engagement parameters will replicate those on FTV-4 as much as possible.

PHASE II (Aegis/LEAP)

Aegis/LEAP tests will transition experiences from the Terrier tests to the advanced Aegis Combat System and improved SM2 Blk IV missile. Test plans are in development and will involve increasingly challenging intercepts in a variety of realistic scenarios. Incorporation of improved missile fire control system modifications and LEAP interceptor enhancements is envisioned. Developing technologies such as solid divert propulsion systems and improved IR seekers, kickstages, and IMUs will be incorporated. Additionally, advanced methods of external cueing and target handover to the defending ship (e.g., satellite detection, track, and handover) will be investigated.

Some miniaturization of the STANDARD Missile guidance section components and LEAP support equipment hardware will be required since the SM2 Blk IV is fired from the fixed-length vertical launch system (VLS). The LEAP program plans to lengthen the kickstage to improve motor performance and maximize use of the available Block IV internal volume. Use of two-pulse kickstages is also

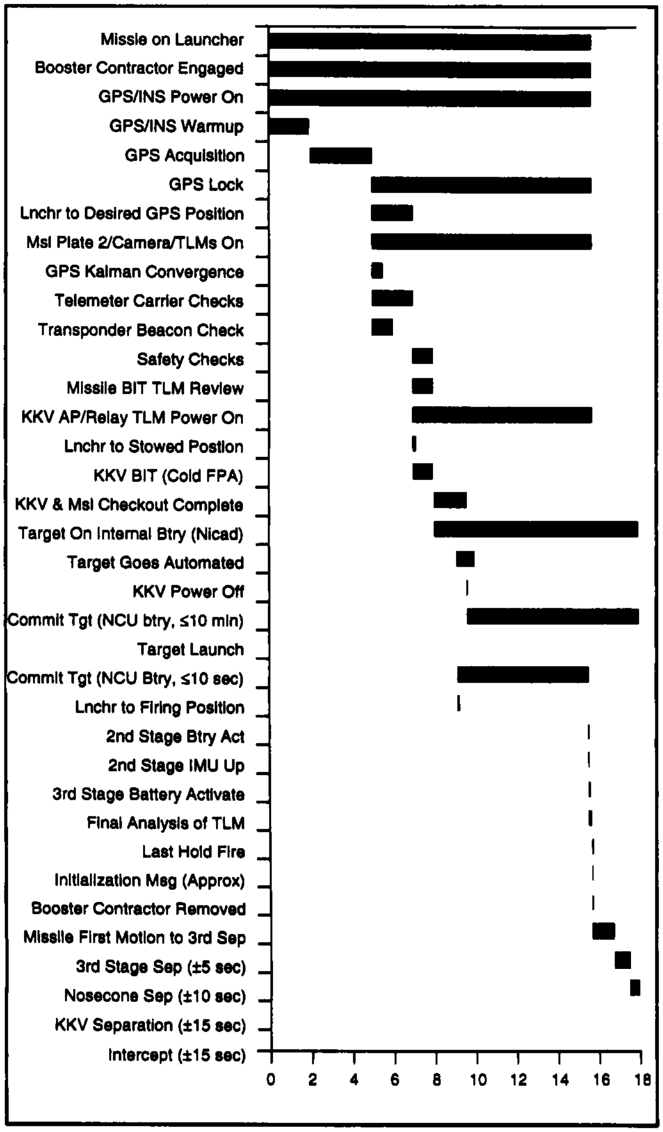


Figure 18. FTV-4 and -5 representative mission timeline.

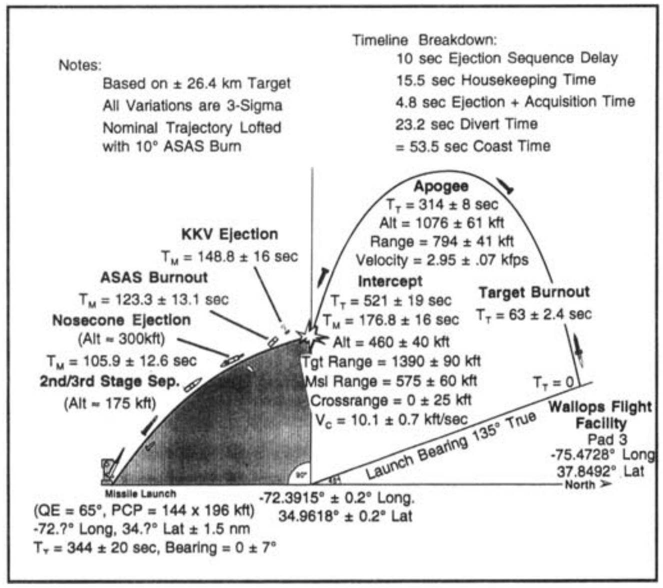


Figure 19.FTV-4 and -5 mission geometrics.

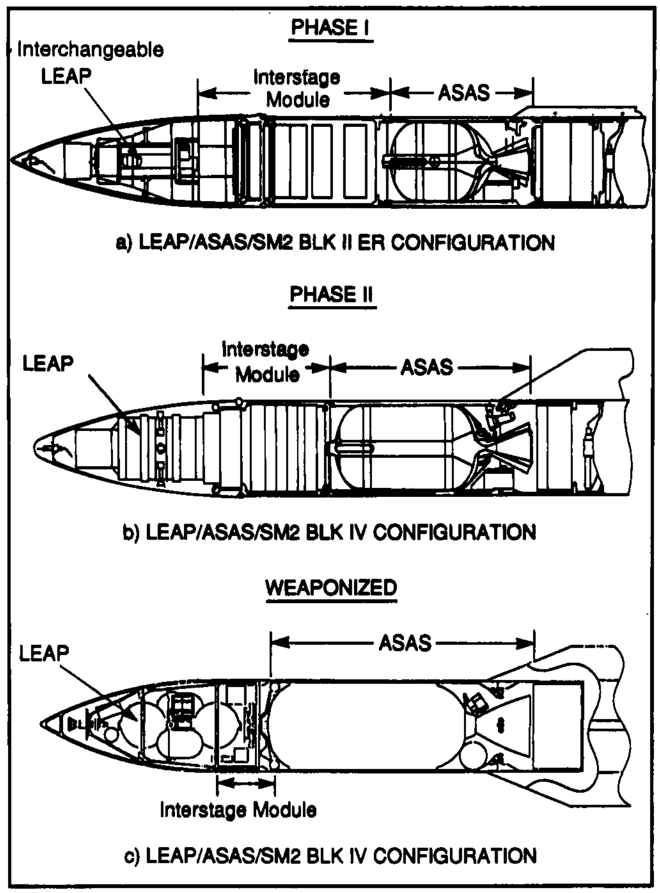


Figure 20. Proposed Navy LEAP wapon development.

being investigated. Increased performance will allow for a greater range of realistic tactical engagements and will significantly improve the system capability. At the end of the Phase II ATD, significant modifications to the Aegis weapon system will be complete. If successful, a national contingency capability for emergency deployment to the theater will exist. Future plans may call for engineering, manufacturing, and development (EMD) of a LEAP-based, upper-tier, wide-area defense capability (Figure 20).

SRAM/LEAP Tests

In addition to the Navy LEAP tests, BMDO and the Air Force have been investigating retrofitting SRAM missile systems with LEAP interceptors to perform boost phase and midcourse intercepts from a forward-deployed, manned aircraft. As with the Navy surface-launched systems, an air-launched TMD system could provide the desired rapid relocatability and deployability. As an air-launched missile that can be fired at altitudes above 9 km (30,000 ft), the SRAM also affords the advantage of not having to fly through a significant portion of the lower atmosphere. A large number of decommissioned SRAM Missiles, that were originally intended for precise air-to-ground delivery of nuclear munitions, are available. The SRAM provides both the

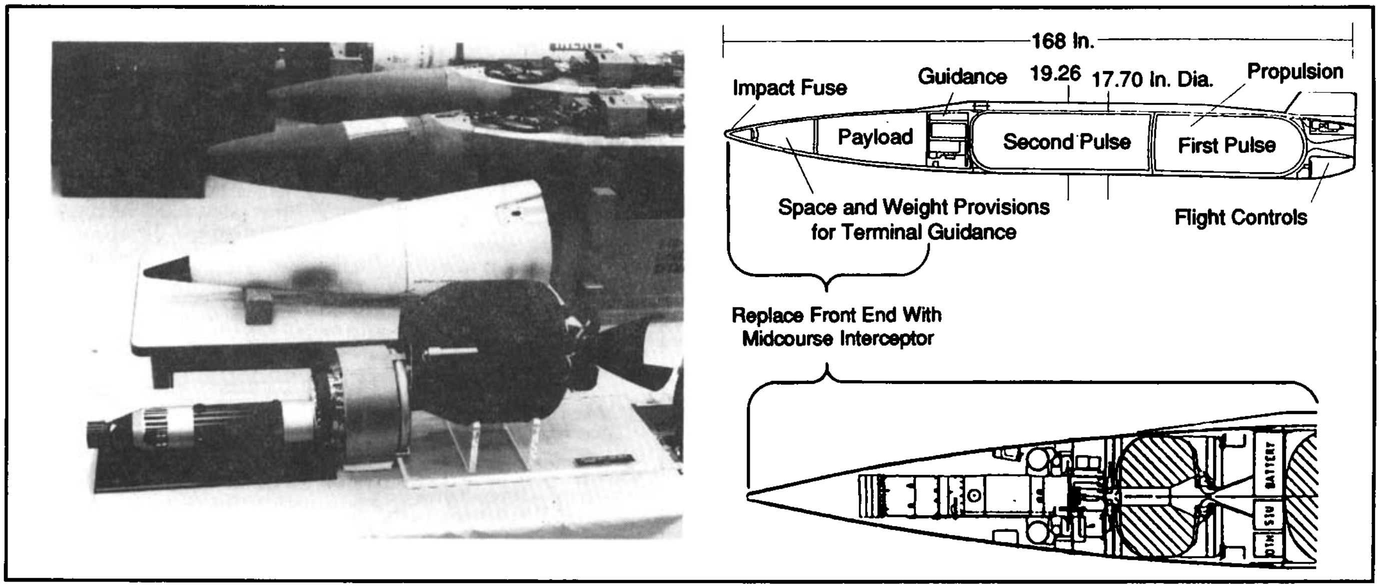


Figure 21. SRAM-A with LEAP technology modifications.

required kinematics needed to perform exo-intercepts and the available payload volume without major modifications. Proposed tests incorporate the LEAP and its kickstage with a newly developed interstage module (IM) into the warhead section of the SRAM-A and SRAM II (Figure 21). [8] This design will also require a removable shroud that may be very similar to the Navy design. Again, an incremental approach will be used to perform these low-cost tests. Test plans and objectives will be very similar to those of the Navy LEAP Tech Demo. As with Navy LEAP, early target launch detection, tracking, and handoff to the interceptor are critical to a tactical air-launched system and are carefully being investigated by the Air Force and the missile contractor, Boeing. Proposed netting of ground-, air-, and space-based sensors [such as Patriot, GBR-T and AEGIS radars, the AWACS, and BMDO's Brilliant Eyes or Miniature Sensor Technology Integration (MSTI) satellites] and use of advanced communications architectures (such as JTIDS) will help to resolve battle management, command, control and communications (BMC3) issues.

The first SRAM/LEAP feasibility test took place at the Pacific Missile Test Center (PMTC), Pt. Mugu, California on October 19, 1992. This test, called FT-0, was similar to the Navy LEAP FTV-1 experiment. FT-0 involved modifications to the missile flight software and aircraft mission tapes of an unmodified SRAM to allow it to fly out from under the launch platform (a B-1 Bomber) and upward in a TMD-type flyout (Figure 22). The mission was performed as an operational test launch from an operational platform. All experiment objectives were met. The missile achieved an altitude of greater than 60 km (200,000 ft) with better than expected stability and control. The two-pulse SRAM-A motor also experienced greater than expected ballistic performance and demonstrated its feasibility as a LEAP booster. The current test plan integrates the LEAP midcourse interceptor with the SRAM and performs an intercept of a TMD representative target by the end of FY 94. A second successful test of a SRAM-A (FT-1) similar to FT-0 was performed in April 1993 using a B-52 as the launch platform. Future tests will most likely use the B-52 since it is a long endurance, stand-off aircraft and would be better suited for this mission.

Patriot/LEAP Tests

As with the Navy and Air Force efforts, LEAP technology integration with existing Army systems is also feasible and being investigated. Patriot LEAP plans are not as far along as Navy and SRAM/LEAP tests but will most likely involve the integration of the LEAP technologies with the PAC II missile. With the current ASAS and LEAP designs incorporated, Patriot provides performance similar to the SM2 Blk II ER (Figure 23). [9] Since the Patriot has a larger interior diameter than both the SM2 and SRAM, however, a larger diameter kickstage with increased performance similar to the original 38 cm (15 in) ASAS design will most likely be used.

Potential Future BMDO LEAP Technology Upgrades

As follow-ons to current LEAP technologies, BMDO is developing additional lightweight interceptors to meet other system requirements. Endo-LEAP technologies and advanced discriminating interceptor (ADI) technologies may provide an improved capability against developing threats and countermeasures and can be integrated into future tests. In addition, the LEAP program is investigating the lower altitude limits of the LEAP operating envelope. Studies are under way to determine the minimum altitudes and conditions at which the current LEAP interceptors can operate in the very high atmosphere. These studies are also investigating minimum modifications that could be made to existing designs to allow them to operate more effectively in the high endoatmospheric environment. High endo operation

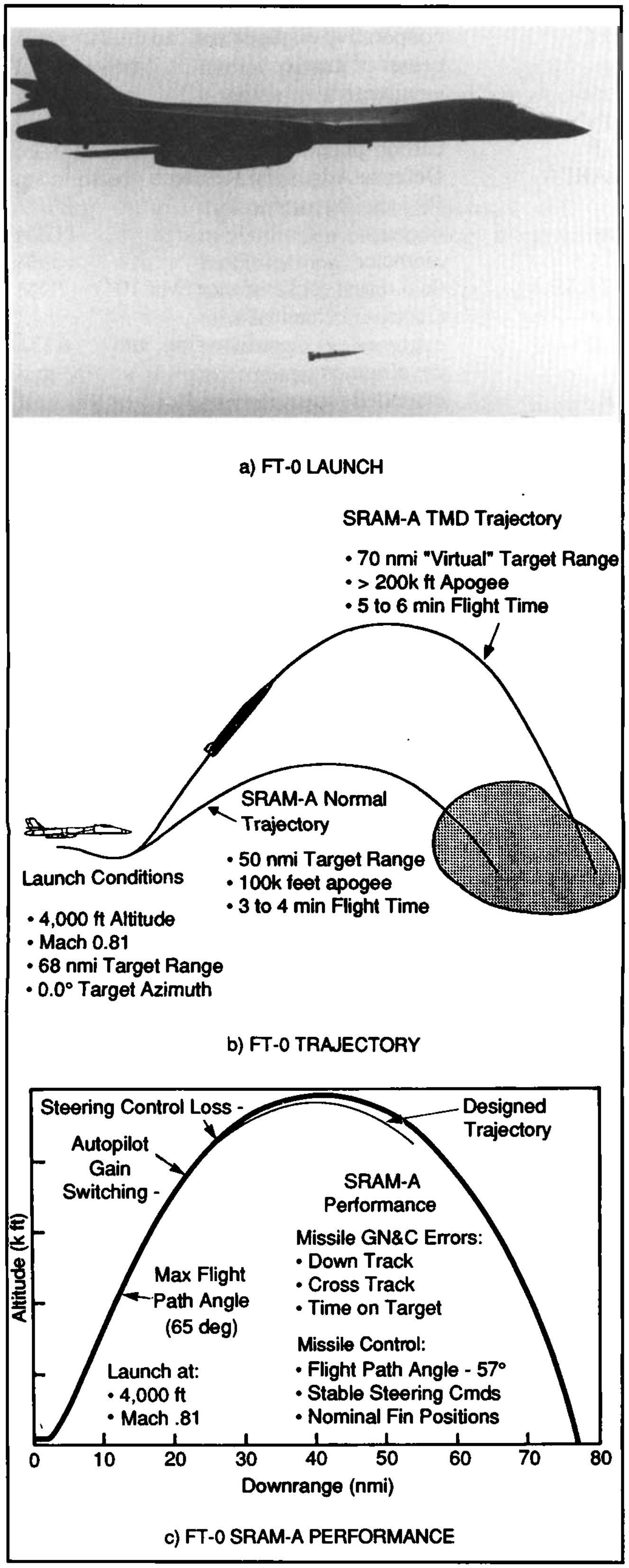


Figure 22. SRAM/LEAP flight test 0.

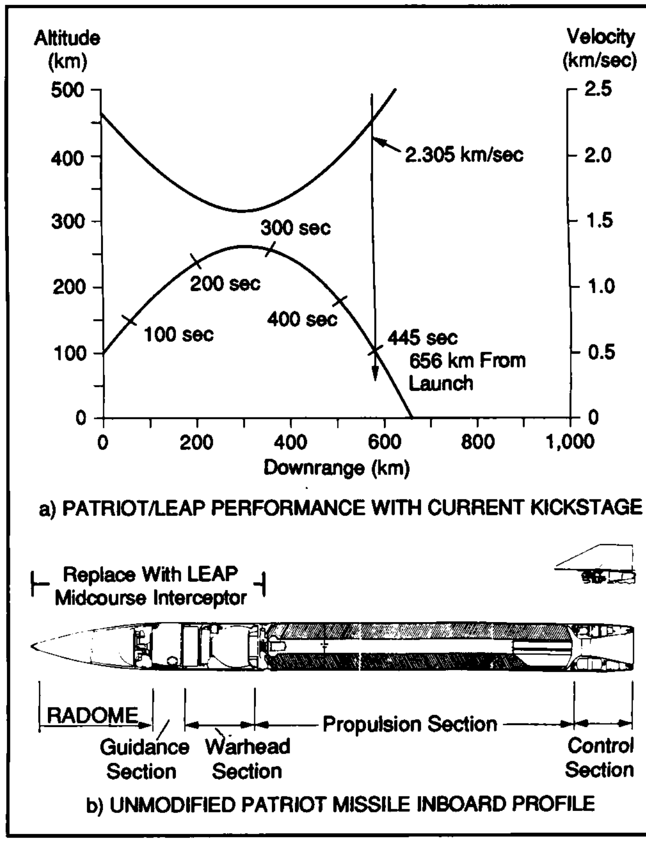


Figure 23. Modified Patriot provides performance similar to SM2 Blk II ER.

could allow some timeline relief for exo-intercepts and a greater capability against shorter range threats. Finally, should KEW lethality be determined to be an issue at tactical closing velocities using lightweight interceptors, simple modifications such as the addition of kinetic energy penetrators (KEPs) or small explosive charges can be easily integrated with minimal effect on performance. Since these very high dynamic reactions are extremely difficult to replicate on the ground, the LEAP tests will provide the first real insight into this issue.

SUMMARY

The Ballistic Missile Defense Organization has resolved the critical technology integration issues associated with the first generation of lightweight KEW interceptors. Developed LEAP interceptors have passed early ground and flight testing requirements and are just beginning advanced testing to determine their effectiveness in a more realistic, tactical environment. The Missile Defense Act of 1991 mandated the development of robust Theater Missile Defenses that are both relocatable and deployable by the mid 1990s. However, in the current fiscal environment, proposed system development efforts will have an extremely difficult time meeting these requirements. In contrast, the current state of LEAP interceptor technology coupled with the availability of existing, capable tactical missile systems and service infrastructures has made upgrading of tactical systems with LEAP technologies an attractive option. LEAP technology upgrades can provide significant reduction in both cost and deployment times over completely new systems.

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LIST OF ACRONYMS/ABBREVIATIONS

ABM	antiballistic missile
ACA	attitude control assembly
ACS	attitude control system
ADI	advanced discriminating interceptor
AFWTF	Atlantic Fleet Weapons Training Facility
AI/AP	aluminized ammonium perchlorate propellant
Al/HTPB	aluminum hydroxyterminated polybutadiene
ANSER	Analytic Services, Inc.
AP	autopilot
ASAS	advanced solid axial stage
ASAT	antisatellite
AWACS	Airborne Warning and Control System
BIT	built-in test
BLK	block
BMC3	Battle Management, Command, Control And Communications
BMD	ballistic missile defense
BMDO	Ballistic Missile Defense Organization
Btry	battery
C	centigrade
C-C	carbon-carbon
CD	compact disc
CDS	command display systems
CEC	cooperative engagement capability
cg	center of gravity
cm	centimeters
Cmds	commands
C-P	carbon-phenolic
DARPA	Defense Advanced Research Projects Agency
deg	degrees
Dia.	diameter
DTRM	dual thrust rocket motor (Mk 104)
EM	electro-mechanical
EMD	engineering, manufacturing, and development
ER	extended range
ERINT	extended range interceptor
ERIS	Exo-atmospheric Reentry Vehicle Interceptor System
ETA	explosive transfer assembly
ETP	environmental telepack
F	fahrenheit
FLSC	flexible linear shaped charge
FOR	field of regard
FOV	field of view
FPA	focal plane array
FT	flight test
ft	feet
FTV	flight test vehicle
FTV-TD	flight test vehicle - target demonstration
FY	fiscal year
g	grams
GBI	ground-based interceptor
GBR-T	ground-based radar theater missile defense
GN&C	guidance, navigation, and control
GPS	Global Positioning System
HgCdTe	mercury-cadmium-telluride
HOE	homing overlay experiment
hr	Hour
Hz	Hertz
IFOG	interferometric fiber-optic gyroscope
IMU	inertial measurement unit
IFTU	in-flight target update
IM	interstage module
in	inches
INS	inertial navigation system
ISI	Integrated Systems Incorporated
IR	infrared
IR/RF	infrared/radio frequency
JTIDS	joint tactical information distribution system
KEPs	kinetic energy penetrators
KEW	kinetic energy weapon
kg	kilograms
KHIT	kinetic hover integration test
KKV	kinetic kill vehicle
km	kilometers
Lat	latitude
lbm	pounds mass
lbf	pounds force
LEAP	lightweight exo-atmospheric projectile

Lncher	launcher
Long	longitude
LOS	line-of-sight
LVDTs	laser variable displacement transducers
m	meters
mi	miles
ms or msec	milliseconds
MIPS	million instructions per second
MSTI	miniature sensor technology integration
Mods	modifications
MOI	moment of inertia
Msl	missile
MTA	main thruster assembly
mm	micrometer
N	newtons
NASA/GSFC	National Aeronautics and Space Administration/ Goddard Space Flight Center
NAVSEA	Naval Sea Systems Command
NCU	nozzle control unit
NEI	noise equivalent intensity
NHTF	National Hover Test Facility
NiCad	nickel-cadmium
nmi	nautical mile
NTU	new threat upgrade
PL	Phillips Laboratory
PMTC	Pacific Missile Test Center
PRONAV	proportional navigation
RF	radio frequency
RV	reentry vehicle
S&A	safe-and-arm
SBI	space-based interceptor
SDIO	Strategic Defense Initiative Organization
SDS	strategic defense system
s or sec	seconds
sep	separation
SEP	Societe Europeenne de Propulsion
SM2 Blk II, III, or IV	standard missile block II, III, or IV
SNR	signal-to-noise ratio
SRAM	short range attack missile
TBM	theater or tactical ballistic missile
TBMD	theater ballistic missile defense
Tgt	target
THAAD	theater high altitude area defense
TLM or TM	telemetry
TMD	theater missile defense
TOMs	target object maps
TVA	thrust vector actuators
TVC	thrust vector control
USASSDC	U.S. Army Space and Strategic Defense Command
U.S.	United States
VLS	vertical launch system
VLSI	very large scale integrated
W/Sr or W/Str	watts per steradian
WCT	warhead compatible telemeter
WDS	weapons direction system
WFF	Wallops Fight Facility
WSESRB	Weapon Systems Explosive Safety Review Board
WSMR	White Sands Missile Range