PATRIOT ADVANCED CAPABILITY-3 (PAC-3)

DoD ACAT ID Program

Total Number of Systems:	36 Tactical Fire Units
Total Program Cost (TY$):	$6093M
Average Unit Cost (TY$):	$169M
Full-rate production:	1QFY02

Prime Contractor

Raytheon
Lockheed Martin Vought Systems

SYSTEM DESCRIPTION & CONTRIBUTION TO JOINT VISION 2020

The PATRIOT is an air-defense, guided-missile system originally designed to counter the air-breathing threat of the 1990s and beyond. Two modifications, PATRIOT Advanced Capability 1 and 2, were added to provide a limited capability for defense against tactical ballistic missiles. The key features of the PATRIOT system are the multifunctional phased-array radar, track-via-missile guidance, and extensive modern software and automated operations, with the capability for human override.

The PATRIOT Advanced Capability-3 (PAC-3) growth program is being implemented through a series of three stand-alone fielding configurations. Configurations 1 and 2 have been fielded. Each configuration consists of a grouping of materiel-change packages and a software upgrade called a post-deployment build, which includes a collection of software product upgrades.

Configuration 1 consists of: (1) an expanded weapons control computer; (2) optical disk drives; (3) an embedded data recorder; and (4) implementing software. These upgrades provide four times greater computer throughput and a more efficient data recording and retrieval capability. Configuration 1 also includes the hardware associated with Radar Enhancement-Phase II, which incorporates a dedicated pulse-Doppler processor.

Configuration 2 includes the Communication Enhancements Phase I, which is a materiel-change package that provides improved external communications (to the PATRIOT battalion), and includes linkage into the Theater Missile Defense (TMD) architecture. Configuration 2 software improvements include: (1) a counter anti-radiation missile capability to minimize vulnerability to those missiles; (2) Classification, Discrimination and Identification-Phase I to improve the Tactical Information Broadcast System interface; and (3) a software implementation of Radar Enhancement Phase II.

Configuration 3 consists of: (1) three materiel change packages, (2) three significant software improvements, and (3) the PAC-3 missile. These improvements were required by the user to significantly improve PATRIOT performance. They also incorporated the DoD mandated conversion of the Information Coordination Central software from JOVIAL to Ada.

The three materiel-change packages are: (1) Radar Enhancements-Phase III, which provides significant improvements in system performance; (2) Classification, Discrimination and Identification-Phase III, which provides a high-range resolution radar capability; and (3) a Remote Launch/Communication Enhancement Upgrade to provide the capability to deploy missiles launchers at remote launcher farms, and improve intra-battalion voice and data communications.

The three software improvements provide: (1) PATRIOT and THAAD interoperability, which optimize the warfighting capability of PATRIOT and THAAD; (2) Joint TMD interoperability, which allows the capability to receive and transmit tactical ballistic missile-related data in a joint-Services environment; and (3) Launch Point Determination, to calculate tactical ballistic missile launch points.

The PAC-3 missile is designed to provide hit-to-kill lethality against high-speed tactical ballistic missiles; maneuvering tactical missiles; low-radar cross-section, 1000 km-range targets in operational environments; cruise missiles; and other air-breathing aircraft.

PAC-3 embodies the ***Joint Vision 2020*** operational concept of ***precision engagement***. It supports ***dominant maneuver*** by our forces and provides ***full-dimensional protection*** for friendly forces and facilities. It incorporates ***focused logistics*** to facilitate rapid deployment in times of crisis. PAC-3 uses ***technological innovation*** and relies on ***information superiority*** to fully support the lower-tier theater air and missile defense mission.

BACKGROUND INFORMATION

Subsequent to Desert Storm, the PAC-3 Operational Requirements Document (ORD) was developed to provide focus for several already planned improvements, plus additional improvements to include a new missile capability. The ORD identifies additional performance requirements needed to counter advanced stealth technology, advanced electronic countermeasure techniques by air-breathing targets, unmanned remotely piloted vehicles, anti-radiation missiles, tactical air-to-surface missiles, and tactical ballistic missiles. The ORD requires that the PAC-3 system be rapidly deployable, robust in

firepower, tactically mobile, survivable, low-in-force-structure demands, and able to interoperate with other TMD systems.

Each materiel change package is tested individually and then re-tested as part of a fielding configuration during integrated system testing. Operational testing prior to FY00 included Configuration-2 FOT&E (FOT&E-2), successfully conducted at White Sands Missile Range, NM, and Ft. Bliss, TX, during May-June 1996. The FOT&E-2 consisted of tests using the hardware-in-the-loop Flight Mission Simulator, battalion-level field exercises, and a multiple simultaneous engagement live missile-firing exercise. The live fire test involved a simultaneous engagement by two PAC-2 missiles against a simulated ballistic missile target (a PATRIOT missile) and an air-breathing target (an MQM-107). The MQM-107 was successfully intercepted. The PATRIOT target self destructed before the PAC-2 missile could intercept it. FOT&E-2 evaluated the Configuration 2 (and Configuration 1) materiel-change packages and software improvements. An Operational Assessment based on FOT&E-2 was completed in August 1996. Operational testing for Configuration 3 will not start until the fall of 2001.

Phase 2 of Configuration 3 Developmental Test and Evaluation (CDTE-3) was conducted from May-August 1999, and focused on evaluating enhancements to the ground portion of the system—the Post Deployment Build-5 software; Radar Enhancement Phase-3; Classification, Discrimination, and Identification-3; and Remote Launch/Communication Enhancement upgrades.

CDTE-3 included four flight tests of PAC-2 missiles. The first, on July 16, 1999, tested a Configuration-2 (plus) fire unit against an MQM-107 drone. The other three tests used Configuration-3 fire units. On December 1, 1999, a Guidance-Enhanced Missile (GEM; improved PAC-2) engaged a drone emulating a low altitude low-RCS cruise missile in clutter. This test was not completely successful; problems were revealed with ground radar tracking and PAC-2 fuzing. On December 15, 1999, a PAC-2 missile from a remote launcher intercepted a Lance TBM target. On March 15, 2000, a PAC-2 missile intercepted a POTA-Tow (PATRIOT Omni-directional Training Aerial-Tow) target being towed by an MQM-107 drone.

The PATRIOT ground equipment tested in CDTE-3 had serious reliability shortfalls. The following Configuration-3 major items failed to meet the required mean time between critical mission failure rates for the operational system:

- Engagement Control Station (mission critical failure rate was 5 times greater than allocated).
- Communications Relay Group/Launch Control Station (9.6 times greater).
- Radar Set (2.4 times greater).
- PAC-3 Launching Station (1.3 times greater).
- PAC-2 Launching Station (1.1 times greater).

The total fire unit MTBCMF rate was 2.3 times greater than allocated. As discussed below, the MTBCMF rate was generally better in the LUT, but was still 1.7 times larger than allocated.

Flight-testing of the new PAC-3 missile was completed through DT-3 prior to FY00. In September and December 1997, controlled non-intercept flights of the PAC-3 missile, DT-1 and DT-2,

were successfully conducted. Flight-testing of the PAC-3 missile continued with the successful intercept of a Hera TBM target during the Seeker Characterization Flight on March 15, 1999. DT-3 was successfully conducted on September 16, 1999. The target for the Seeker Characterization Flight contained simulated chemical submunitions; the DT-3 reentry vehicle was a simulated bulk chemical warhead. Both the Seeker Characterization Flight and DT-3 missions were conducted with prototype PAC-3 hardware and software configurations and non-tactical seeker software.

TEST & EVALUATION ACTIVITY

Flight Testing

To help clarify the following discussion, it is noted that flight-testing has not necessarily been conducted in numerical order. For example, DT-7 was conducted prior to DT-6. Also, DT-4 was postponed; however, some of the DT-4 test objectives were addresses in other flight tests.

Flight-testing of the PAC-3 missile continued in FY00 with the successful intercept of a unitary Hera TBM target (MBRV-3) during the DT-5 mission on February 5, 2000. DT-5 was the first developmental flight test to use tactical seeker profiling algorithms to determine the aimpoint. Other test objectives included demonstration of remote launch (8 kilometers) capability and intercept of a full-body TBM target performing a low-magnitude helix maneuver. Problems during the test included a 40-second period five minutes before launch when the system reported that it had zero missiles in the launcher, low radio frequency data link signal strength and downlink power during the PAC-3 missile flyout, and unexpected detections in the PAC-3 seeker profiling spectrum. These problems did not affect the test, but could have an impact on PATRIOT system performance in other engagements.

DT-7, the first PAC-3 missile intercept of a cruise missile target occurred on July 22, 2000. In addition to demonstrating missile performance and lethality against a low-altitude cruise missile, DT-7 also demonstrated remote launch and the performance of a cold conditioned launcher, canister, and missile.

Engage on Remote-A (EOR-A) successfully demonstrated PAC-3 capability to engage over-the-horizon targets using data from remote sensors on July 28, 2000. It was the second PAC-3 intercept of a cruise missile target.

The DT-6 flight test was performed on 14 October 2000. This flight test was the simultaneous engagement of a Storm TBM by a PAC-3 missile and an MQM-107 drone by a PAC-2 missile. The PAC-3 missile, canister, and launcher were cold conditioned. The Storm target carried 28 simulated chemical submunitions (filled with water) and released a second object shortly before intercept to test PAC-3 missile discrimination. The PAC-2 target was a MQM-107 drone. Both missiles were launched near simultaneously; the PAC-3 missile intercepted the Storm target just before the PAC-2 warhead detonated past the tail of the MQM-107. While the PAC-2 is designed to destroy targets through use of a warhead and not body-to-body impact, the timing of the warhead detonation was anomalous with only a few fragments impacting the tail of the drone. Post mission analysis clearly shows that this anomaly was the result of a PAC-2 missile hardware failure in a roll rate gyro and not related to the simultaneous engagement. The objective of demonstrating the ability to simultaneously engage targets with both PAC-3 and PAC-2 missile was met.

A summary of all PAC-3 flight tests conducted to date is shown in the following table.

PAC-3 Flight Tests To Date

Flight Test ***(Date)***	**Primary Objective(s)**	**Successful Intercept?**
DT-1 *(29 Sep 97)*	First Control Test Missile (CTM) (no seeker or target)	N/A
DT-2 *(15 Dec 97)*	Second CTM; extended range	N/A
Seeker Characterization Flight *(15 Mar 99)*	Risk mitigation flight; intercept of short-range TBM with submunition payload	Yes
DT-3 *(16 Sep 99)*	Intercept of short-range TBM with bulk chemical warhead	Yes
DT-5 *(5 Feb 00)*	Intercept of short-range TBM with low-magnitude helix maneuver using 8 km remote launch	Yes
DT-7 *(22 Jul 00)*	Intercept of low-altitude cruise missile	Yes
EOR-A (*28 Jul 00*)	Intercept of low-altitude cruise missile	Yes
DT-6 *(14 Oct 00)*	Multiple simultaneous engagement: PAC-3 versus short-range TBM (with submunition payload) and PAC-2 versus ABT threat	PAC-3: Yes PAC-2: *

**** Target successfully engaged but not killed due to hardware anomaly not related to the multiple simultaneous engagement test objective.***

Limited User Test (LUT)

The PAC-3 system LUT was conducted during March-June 2000 at Ft. Bliss, TX, and consisted of a combination of sustained operations field exercises and Mobile Flight Mission Simulator (MFMS) exercises. No missile firings were conducted during the LUT. The LUT was designed to provide data to support the Army's decision to equip the first unit with the PAC-3, Configuration-3 ground system. A LUT regression test was conducted in October 2000 to assess progress in addressing issues identified in the LUT; the data are being analyzed.

Sustained Operations Field Exercises

The LUT sustained operations field exercises were conducted during March 27-April 10, 2000, at Ft. Bliss. Live aircraft flight operations were also conducted in the airspace over McGregor Range, NM. During this test phase the PAC-3 system was employed in the field as a PATRIOT Battalion (Bn) defending against non-TBM targets in a realistic combat environment.

These exercises used a PAC-3 Configuration-3 Bn minus (-) configuration operating with post-deployment build 5 (PDB-5) software. The LUT Bn(-) consisted of one Information Control Central and three fire units, with one Engagement Control Station, one radar set, and eight launcher stations (LS) for each fire unit. These eight launcher stations consisted of a combination of two to four PAC-3 launchers plus four to six PAC-2 launchers, using simulated pre-PAC-3 missiles. These sustained field exercises were broken into two separate events: a 72-hour (3-day) exercise and a 144-hour (6 day) exercise.

The PATRIOT Live Air Trainer (LAT) was used during live air missions. Operations were initiated by tester-generated situational message traffic in accordance with a time-ordered event list. Test controllers in the Air Defense Tactical Operation Center, Tactical Air Operations Module, Tactical Control System, and Information Control Central then passed these messages based on approved campaign scenarios containing non-TBM threats. The threats included live fixed-wing aircraft, unmanned aerial vehicles, cruise missile surrogates, and rotary-wing aircraft flying in accordance with approved threat profiles. The threat fixed wing aircraft also employed Self-Screening Jamming and Stand-Off Jamming. Friendly aircraft flew through friendly corridors and employed IFF (Identification Friend or Foe).

The PAC-3 system was deployed in accordance with its wartime operational mode summary/mission profile, and operated and maintained by representative soldiers using the procedures in the TRADOC test support package. During this test phase the PATRIOT nodes were evaluated on their capability to march order, emplace, initialize, communicate, interoperate, and fight an air battle. Reliability, availability, and maintainability (RAM) test incident reports were collected. These field exercises were conducted during both day and night, and in simulated Nuclear, Biological, and Chemical environments.

Mobile Flight Mission Simulator (MFMS) Exercises

The MFMS test phase of the LUT was conducted from May 1-June 2, 2000 at Fort Bliss. The MFMS is a hardware-in-the-loop (HWIL) real-time PATRIOT system exerciser used to evaluate PATRIOT system performance at the fire unit level against both TBM and non-TBM threats. The MFMS simulates threat targets by injecting RF (radio frequency) target response waveforms into the radar. Scripted multi-target MFMS scenarios permit PATRIOT crews to use tactical hardware and software to participate in simulated engagements.

The primary test elements consisted of the MFMS, PAC-3 radar, Engagement Control Station, and the Communication Relay Group. Other elements included non-tactical Data Transfer Units, acting as simulated launchers. The simulated launchers contained only PAC-2 and Guidance Enhanced Missiles; no PAC-3 missiles were included in the simulated missile inventory.

Nine PATRIOT soldier crews (three persons each) participated in the MFMS tests, which addressed 20 threat scenario vignettes. These vignettes were smaller portions of two larger Northeast Asia and Southwest Asia scenarios. The air defense artillery battalion performed the placement of the launchers in each vignette two weeks prior to the start of the MFMS test phase. Five replications were conducted for each vignette, for a total of 100 trials.

Data collection was primarily automated. The system Embedded Data Recorders collected most of the performance data. Other data that was collected during these trials included RAM test incident reports, and manpower and personnel integration surveys at the end of the trials.

Live Fire Test & Evaluation

The LFT&E program planned in the TEMP uses data from a combination of sled tests, light gas gun tests (LGG), and simulations to determine the lethality of the PAC-3 hit-to-kill missile. The High-Speed Test Track (HSTT) at Holloman AFB, NM, was used to test the full-scale PAC-3 missile forebody against a full-scale target. The maximum achievable velocity on the full-scale track is at the lower end of the range of expected intercept velocities, necessitating the use of scaled testing via the LGG. The LGG G-Range at Arnold Engineering Development Center, Tullahoma, TN, was used to test 40-percent subscale PAC-3 missile forebodies intercepting scaled targets at higher velocities more representative of the expected intercept conditions. Physics-based hydrocode simulations and use of the PEELS model complemented testing.

All sub-scale light gas gun testing was completed by 2QFY99. Fourteen of 15 full-scale sled tests against unitary and submunition chemical, high-explosive submunition, nuclear, and biological submunition targets have also been completed. The remaining full-scale test, replication of the DT-6 flight test on the HSTT to correlate ground test results with flight test results, is planned for 3QFY01. The LFT&E program for lethality against tactical missiles should be complete by the end of FY01.

The LFT&E program also includes the lethality contribution of the steel cylindrical projectiles (lethality enhancers) that are released by the PAC-3 missile in its terminal phase to damage air breathing threat targets such as cruise missiles, fixed-wing and rotary-wing aircraft in case of a near miss. The first test series of 15 shots against plate targets was conducted in February 2000. Test data are being applied to the lethality model used for attack of air breathing targets. The second series of 15 shots against target components is currently unfunded by the project office.

Other T&E Activity

The Force Developmental Test and Experimentation (FDT&E) was conducted White Sands Missile Range in September-November 1999. The FDT&E focused on ensuring that the PAC-3 doctrine, tactics, training, and logistics were appropriate prior to the start of the LUT. The test concept was similar to that used during the LUT, namely, a combination of live-air search and track (twelve missions) plus MFMS exercises (11 scenarios). The results of the FDT&E indicated that there were no significant issues concerning doctrine, tactics, training, or logistics, the main focus of the tests. Demonstration of system reliability was not a primary objective of the FDT&E; however, it was noted that a number of subsystems did not meet the required mean time between critical mission failure rates (although the system did perform somewhat better than in the preceding CDTE-3). For example, the failure rate for the: Engagement Control Station was 2.7 times greater than allocated, and the failure rate for the PAC-3 Launching Station was 1.3 times greater. The Radar Set did exhibit good reliability during FDT&E, with a failure rate 3.8 times smaller than allocated.

A PATRIOT "live-over-simulation" flight test was conducted at White Sands Missile Range on June 1, 2000. A PATRIOT standard production missile successfully engaged an unaugmented MQM-107 drone. The flight test used Configuration-3 hardware and PDB-5 software. The primary objective of this firing was to evaluate system operation during an engagement while the HWIL Fixed Flight Mission Simulator (FFMS) presented a large number of targets for the radar to process, evaluate, and track. Other objectives included demonstration of the ability to launch a standard PATRIOT missile in the presence of other potential targets, and collection of reliability data. This "live-over-simulation" test marked the first time that a PATRIOT missile was fired against a target while the FMS was loading the system with simulated targets.

TEST & EVALUATION ASSESSMENT

ATEC's evaluation of the LUT concluded that notwithstanding the demonstrated improvements in capability, the system, as tested, has problems with target classification, discrimination (major), identification, and track management that limit effectiveness. Additionally ATEC assessed the PAC-3 Configuration-3 Ground Equipment as not operationally suitable. The reliability and maintainability characteristics of the Configuration-3 equipment do not meet the PAC-3 ORD requirement for the mean time between critical mission failure and operational availability. However, the ground equipment is assessed as operationally survivable and as capable of executing its operational missions in a tactical environment. DOT&E has independently evaluated data from the LUT and fully supports the ATEC evaluation.

The LUT revealed a number of PAC-3 system reliability problems. Although the reliability improved between CDTE-3 and the LUT, the Communications Relay Group mean time between critical mission failure (MTBCMF) rate was seven times greater than allocated, and the Engagement Control Station MTBCMF rate was twice as large as allocated. The Radar Set and PAC-3 Launch Station met their MTBCMF rate requirements in the LUT. The Routing Logic Radio Interface Units "hangs" were the primary reasons that the fire unit MTBCMF rate was 1.7 times greater than the requirement. The Routing Logic Radio Interface Units and Data Link Terminals continue to be major contributors to poor system reliability. While some of these reliability problems may have been caused by hardware, most of them are attributed to software. The PM and contractor have prepared a "get well" plan to correct and verify through testing that these problems have been fixed, prior to starting the IOTE on the full-up ground system and new PAC-3 missile.

The LUT FMS trials on the PAC-3 ground system revealed approximately 38 instances of high priority problems with the PDB-5 software. Most notable were instances where the system dropped target tracks, misidentified objects, engaged debris, or did not engage threatening TBMs. Many of these instances involved system boundary issues that occurred in some of the threat scenarios. These problems are being evaluated since these were not software errors that could be fixed. A new PDB-5 software drop occurred at the end of FY00, and a series of FMS "regression tests" of this software began in October 2000 to prove out the changes. The regression tests demonstrated that all priority one and two software problems have been corrected, although lower priority problems still exist. The PM plans a "limited material release" of the ground systems to the field, which would allow the Army to begin upgrading older PAC-3, Configuration-2 systems to the newer PAC-3, Configuration 3 capability at the rate of about three or four systems per year. The ATEC recommendation, which DOT&E supports, is to hold up material release on the PAC-3, Configuration-3, ground system until the problems found in the LUT have been demonstrated corrected. The PAC-3 ground system reliability will be tested during the IOTE.

With the completion of the DT-6 intercept test, the PAC-3 missile has completed five successful intercepts against limited threat representative targets. Of all the PAC-3 missiles flown in tests to date, the PAC-3 interceptor flown in the Engage-On-Remote-A (EOR-A) test was the only missile that is considered "production representative." The current TEMP requires production representative missiles throughout the DT and OT flight test program. Slower than expected software development and unexpected hardware problems have resulted in the need to use non-production representative hardware and software in much of the flight test program to date. This, coupled with relocation of the seeker assembly facility from Georgia to Alabama and the need for temporary "white wire" fixes in the seeker circuitry, resulted in testing a missile that is not considered production representative. Using these non-production prototype missiles in testing does not adequately address the suitability and effectiveness

issues for the final production missile configuration. At the encouragement of DOTE, BMDO and the Army are restructuring the program to address the production representative issues, among other programmatic concerns.

CONCLUSIONS, RECOMMENDATIONS AND LESSONS LEARNED

The PAC-3 system has achieved six intercepts in six attempts (against four TBM targets and two cruise missile targets). A large part of this success derives from the program office's commitment to mitigate flight test risks by conducting extensive ground testing. For example, DT-6 was originally scheduled to occur at the very end of FY00, but pre-test hardware-in-the-loop testing revealed a potential problem with the tactical PAC-3 missile discrimination software. This problem could have led to the PAC-3 missile engaging the wrong target. The current PAC-3 FY01 schedule includes eight flight tests, each of which is significantly more complex than any previous flight test. Given the success-oriented nature of the PAC-3 flight test matrix, the contractor and project office must strive to ensure that the risk is mitigated through continued maximum use of hardware-in-the-loop, digital models and simulations, and other ground-based tests.

A serious potential problem with the PAC-3 ground system is the reliability shortfalls demonstrated in the CDTE and LUT tests. These reliability problems must be corrected before the ground system is fielded or enters IOT&E. Other PDB-5 software deficiencies revealed in the LUT must be corrected before the system can enter IOT&E.