PATRIOT ADVANCED CAPABILITY-THREE (PAC-3)
The First Deployable Hit-to-Kill Technology

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Abstract

The U. S. Army is upgrading its PATRIOT Air Defense Missile System with hit-to-kill technology. The improvements of the launching station, engagement control station and the addition of a hit-to-kill guided missile interceptor are managed under the PATRIOT Advanced Capability-3 (PAC-3) Missile Segment Program, now three years into it's development contract. PAC-3 uses an extremely accurate on-board seeker and guidance system and an agile attitude control system to achieve a direct hit by the interceptor on the target. The hit-to-kill concept utilizes kinetic energy as its primary kill mechanism to disintegrate incoming tactical ballistic missiles and their warheads. PAC-3 is being executed within the most advanced defense acquisition reform policies. It uses the Integrated Product and Process Development (IPPD) concept with government/ contractor Integrated Product Teams (IPT). Streamlining of the establishment of the product baseline has been achieved by mutual agreement on design review scheduling and content. Extensive use of state-of-the-art modeling and simulation as well as exhaustive component testing are in combination the mechanism which is building confidence that the hit-to-kill technology is ready for production and deployment. This will provide substantial advancement in Army Theater Missile Defense (TMD) Active Defense force dominance.

Introduction

The U. S. Army PATRIOT PAC-3 Program, a block upgrade to the PATRIOT Air Defense Missile System, is developing a new hit-to-kill missile and upgrades to the PATRIOT ground equipment which integrate the new missile into the deployed system. The prime contractor for the PAC-3 missile and its command and launch system is Lockheed Martin Vought Systems in Grand Prairie, TX. Raytheon, Inc., in Bedford, MA, is the PAC-3 missile segment integration contractor. Both participate with each other through an associate contractor agreement. The program is well into its Engineering and Manufacturing Development (EMD) Phase.

The PAC-3 program was selected by the Army to be the first of three major acquisitions designated by the Under Secretary of the Army, with the approval of the Deputy Secretary of Defense, as *Army Lead Programs for Streamlining and Reform.* When it was approved in May 1994, the PAC-3 EMD Program was seen as an ambitious, accelerated undertaking. At that time there was a fortunate convergence of proven missile technology, the emerging acquisition management "technologies", and the confirmation of the tactical need for TMD.

What follows is a discussion of the applied missile design principles which had matured and were ready for development into a deployable enhancement to the PATRIOT role in force dominance. Also, in the missile technology area, the importance of the hit-to-kill lethality mechanism will be covered. Further, the contribution of available computer modeling technologies will be covered within the context of how to establish confidence in design maturity and its readiness for actual flight testing. The management environment within which the PAC-3 missile program is being executed must also be addressed. This environment is critical to the rapid application of the PAC-3 science and engineering in a manner that will lead to its earliest possible production and deployment. This meets the need established by the Army Air Defense Artillery to provide an effective active defense against theater of war level ballistic missiles with mass destruction warheads.

Technology Exploitation

Figure 1, represents the convergence of the need for TMD, the emerging technologies for hit-to-kill, and the principles of acquisition and application of this technology to defense needs. Hit-to-kill technology uses the combined kinetic energy of an incoming target missile or warhead and an interceptor kill vehicle. This combination of effects creates high enough impact forces and heat to disintegrate the target. Early work was done on the need to have the kill vehicle hit the target in the Strategic Defense System (SDS). The Small Radar Homing Intercept Technology (SR-HIT) Program and the Flexible Lightweight Agile Guided Experiment (FLAGE) were among the early successful tests of technologies that were directed against the terminal phase of

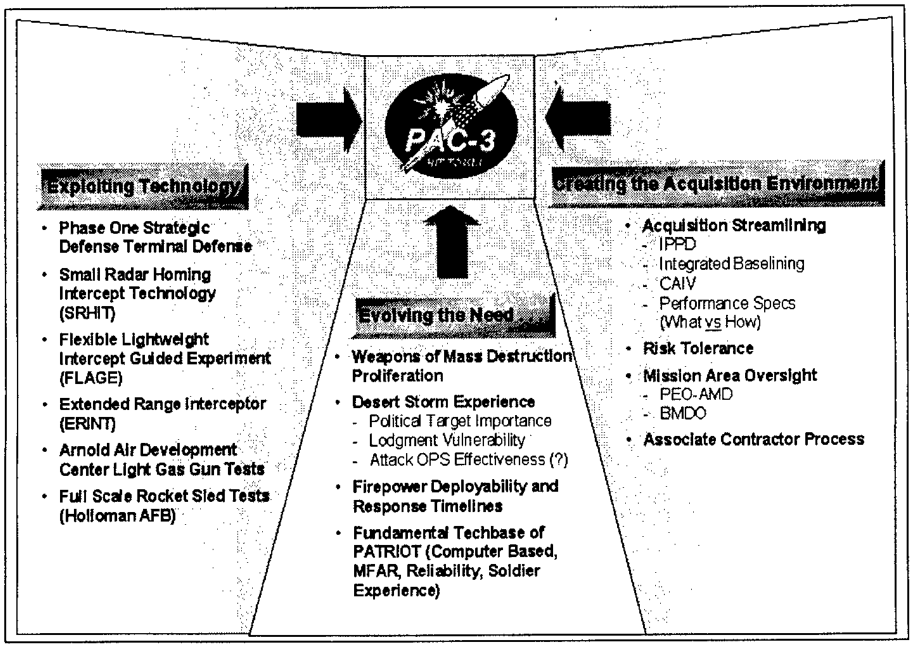

FIGURE 1. THE PAC-3 CONVERGENCE OF TECHNOLOGY, NEED, AND ENVIRONMENT

defense. Key goals were to create a guidance and control technology that would be accurate and agile enough to ensure the interceptor achieved a direct hit on the target ballistic missile warhead. One aspect of this was the use of many small attitude control rocket motors to provide end-game lateral control of the interceptor. This allowed much more responsive control than could be achieved with fins alone. The development of the Extended Range Interceptor (ERINT) missile by LTV Corporation with Rockwell International as the seeker developer was the proof of principle for a practical approach to the combination of end-game seeker accuracy and interceptor maneuverability. The last three test flights of the ERINT program achieved interceptor hits on the targets and total destruction of the targets.

While SR-HIT, FLAGE, and ERINT were applying guidance, control, and propulsion technologies to show that direct hits were possible, other tests were demonstrating the hit-to-kill would achieve the results needed; that is, the complete destruction of weapons of mass destruction warheads. Sub-scale tests of typical interceptors and targets were done at the Arnold Air Engineering and Development Center in Tennessee. Full scale rocket sled testing was done at Holloman Air Force Base in New Mexico. These tests, done against a variety of projected threat warheads, proved that if high velocity metal-on-metal impacts were achieved, then kinetic energy was always sufficient to completely destroy the target.

Need Evolution

Thus, the technologies were being proven which could, if applied to theater level air defense, provide a method to protect deployed forces. Before the Desert Storm experience, however, there was a growing perception that such a defense might not be necessary. There was evidence that ballistic missile delivery systems and the associated weapons of mass destruction warheads were proliferating. There was some thought, however, that the threat of retaliation would prevent their use. Desert Storm showed that theater ballistic missiles, even with only large high explosive warheads, were a threat to both military and political targets. There was also the problem of finding and destroying TBM Transporter-Erector Launchers (TEL). By the end of hostilities it was apparent that a highly effective active defense was needed. Because the threat TBM launchers would likely be available, it became clear that one of the first defense deployments in the future needed to be a high firepower TMD to protect the build-up lodgments of ground and air forces. The shortcomings of the PATRIOT Air Defense System in the defense against TBM were rectified through a series of incremental upgrades termed PATRIOT Advanced Capabilities. With the need clarified and documented, the ERINT concept was chosen as the needed PATRIOT TMD improvement and collectively with changes to the radar and ground equipment was called PAC-3.

Acquisition Environment Creation

So, there was a convergence of the available technology with an agreed upon need. What developed was a very fortunate creation of major top-down policy changes in defense acquisition. The reforms and streamlining which were being mandated were applied from the start of PAC-3 EMD. This means for PAC-3 that it could be planned and executed in such a fashion to begin to fill the need for a much more effective air defense force enhancements in a very short time. In PAC-3 this will be shortening a seven to ten year cycle to something more near five years.

PATRIOT and apply advanced technologies for future lower tier defenses. Threats for these systems when deployed together include TBM, aircraft, and cruise missiles.

PAC-3 modifies the current PATRIOT Air Defense Missile System. Radar improvements are managed separately and are not part of the PAC-3 missile segment which is being addressed here. The major element of the PAC-3 segment is the completely new missile. It uses a highly accurate on-board seeker and end-game maneuver system to achieve hit-to-kill lethality. Unlike the passive electro-optical seekers used on other hit-to-kill systems which require infrared target signatures, PAC-3 uses an active radar seeker. This allows it to

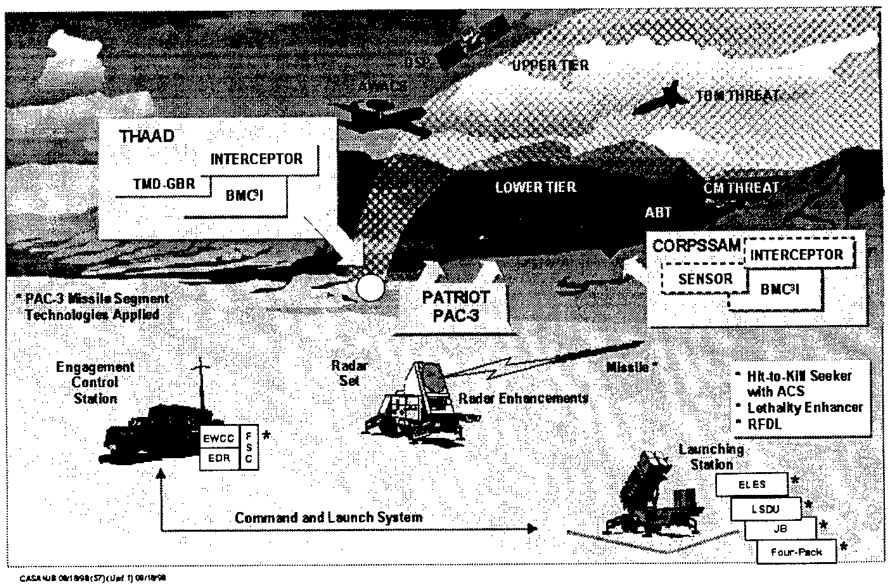

FIGURE 2. FORCE DOMINANCE ENHANCEMENT THROUGH ARMY TMD

Figure 2 portrays the place PAC-3 holds in the broader PATRIOT and active defense elements of army TMD. PATRIOT is the currently deployed force which provides High and Medium Altitude Air Defense (HIMAD) to the Army Corps and Divisions and the Air Force and other defended assets under PATRIOT's umbrella. Since PATRIOT provides lower tier asset defense within Army TMD, Theater High Altitude Area Defense (THAAD) will reach to much higher altitudes and cover wide areas as opposed to specific assets, forming the upper tier of Army TMD. Army Active Defense is complimented by the Navy Area Defense System which provides off-shore TBM defense. The Corps Surface to Air Missile (Corps SAM) or Medium Extended Air Defense System (MEADS) will be more mobile than engage the full spectrum air supported threats to include fixed wing aircraft, helicopters, UAV, RPV, and cruise missiles. Being smaller than the current PATRIOT missile, PAC-3 replaces the four now on a PATRIOT Launching Station (LS) with four four-packs of PAC-3 missiles. This increases the firepower of the PATRIOT LS to sixteen missiles versus the current four. The LS has several modifications to aid in the selection and launch of the PAC-3 missiles. These are packaged in the Enhanced Launcher Electronics System (ELES), a new diagnostic unit, and a modified junction box and cables. The Engagement Control Station (ECS) Enhanced Weapons Control Computer (EWCC) which provides the battle and engagement command element of the PATRIOT Fire Unit has a PAC-3 improvement embodied in three printed circuit boards called the Fire Solution Computer (FSC). Thus, PAC-3 missile segment technologies impact the ECS and LS to provide the hit-to-kill effectiveness against target TBM. All PATRIOT fire units will retain the current generation of PATRIOT missiles, which remain fully effective against all aircraft in the HIMAD zone of coverage.

There are many valuable features of IPPD. Two have been especially visible and valuable to PAC-3. First, we have all the technical and functional expertise represented on each IPT. This means that issues are surfaced as early as possible and integrated solutions are developed quickly, often virtually instantaneously. Issues are identified in process well before good solutions become impractical or infeasible because of adverse impact

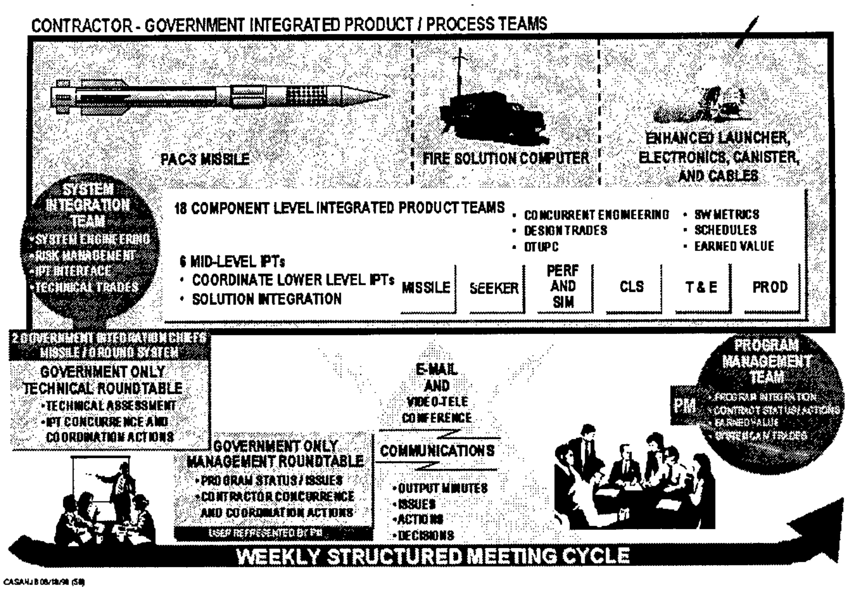

FIGURE 3. PAC-3 INTEGRATED PRODUCT DEVELOPMENT

PAC-3 Management Strategies

Early in the PAC-3 EMD program, the prime contractor agreed to implement IPPD. While there have been some evolutionary changes, the structure as shown in Figure 3 has been used through most of EMD. Essential to this stability has been the selection of the six mid-level IPTs. Three of these are responsible for configuration item products: Missile, Seeker, and the Command and Launch System. The other three are responsible for key development processes; Performance and Simulation (P&S), Test and Evaluation (T&E) and Production. The leaders of these IPTs participate in the System Integration Team (SIT) where technical expertise focuses to resolve multi-product/discipline issues. The SIT provides a comprehensive perspective on program status as the basis for technical guidance to mid-level IPTs. The SIT provides technical input to the Program Management Team (PMT) where prime and major subcontractor program managers and the government PM meet to assess progress and to give guidance and advice to the SIT and mid-level IPTs.

on work accomplished. By dealing with technical problems in real-time, there is a broad base of alternative solutions to choose from.

An example was the early detection of a static margin problem with the missile. If this problem could be solved, an improvement in performance was expected. The missile IPT took the lead on this question with input from the P&S and Seeker IPTs. There were many small shifts in component locations and there were impacts on missile weight and the center of gravity, all of which were accounted for in the entire missile design. There were trade studies and verifications that had to be completed, and when all was said and done a comprehensive integrated solution was found in a few weeks. Had the IPPD processes not been operating, there would have been several uncoordinated solutions accomplished separately within several days, but by the time all of the interfaces and interactions had been worked out, after the fact, the time consumed would have been months.

A key to the effectiveness of IPTs is the decentralized empowerment to make decisions. For the government side, there were sixteen Product Integration Leaders chartered by the PATRIOT Project Manager and the PAC-3 Product Manager. These covered the SIT, the six mid-level CI and Key Process Teams, and thirteen component level teams. MRT deal with total program (cost, schedule, performance, and risk) issues and status. Top level trades and related integrated decisions are made by these teams as long as they are within contract scope of work and total program resources.

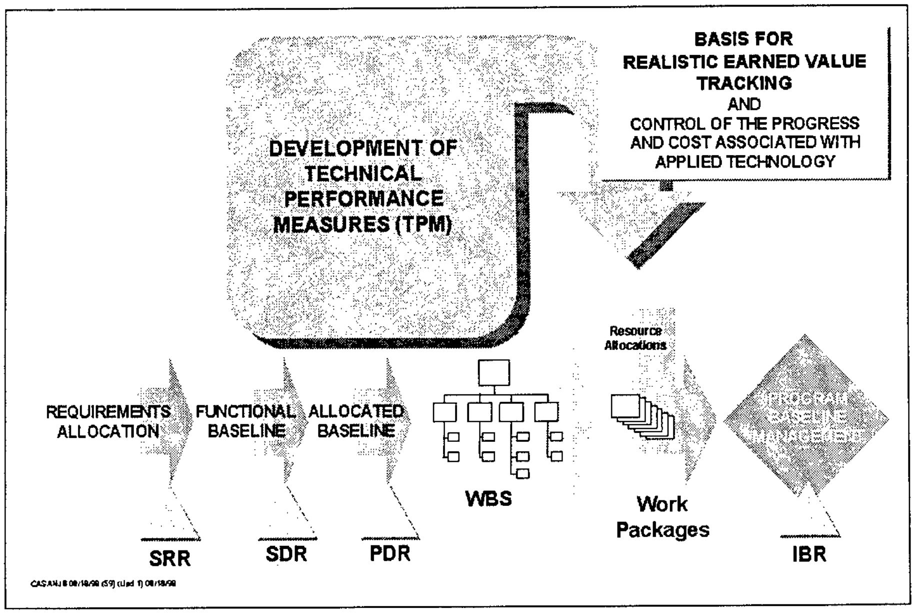

FIGURE 4. PAC-3 INTEGRATED BASELINE DEVELOPMENT

In addition, two Integration Chiefs are chartered to be responsible for the entire missile and ground system for PAC-3.

Electronic communications has proven a key element of IPT operations. PAC-3 government and contractor team members use electronic mail (e-mail) and video teleconferencing (VTC) to pass information and to participate in weekly meetings. The government team representatives also come together once a week for two roundtables, always held on Monday to kick-off the workweek. One is the PAC-3 government Technical Roundtable (TRT) which receives a brief status update for Missile Integration and Ground System Integration. Then each IPT and functional representative discuss their issues that are in process or have recently surfaced. This forum provides for the total technical view from the government perspective. Minutes of the TRT as well as a list of actions assigned are published and distributed to all government team members, to functional support staffs, and to the prime contractor.

Weekly meetings of the SIT which is a contractor led IPT, are held and its results are provided to the TRT, the Program Management Team (PMT), and the Government PAC-3 Management Roundtable (MRT). The PMT and the

PAC-3 Integrated Baseline

Figure 4 represents the process, which has been accomplished for requirements and design reviews within the PAC-3 program through its first Integrated Baseline Review (IBR). The set of reviews is typical of system engineering for weapons systems. Under the concept of streamlining and IPPD, it was argued that some or all of these reviews could be eliminated and replaced with program status briefings to oversight agencies. The evolution and establishment of a product design through the system engineering baselining program with requirements and design reviews is a time-honored technique. Conventional wisdom and sound system engineering dictate that a stable and effective design be established. A compromise was implemented which retained the basic three reviews: System Requirements Review (SRR), System Design Review (SDR) and Preliminary Design Review (PDR) followed by an IBR. To gain some advantage of the streamling license associated with acquisition reform, it was agreed to tailor the criteria in MILITARY STANDARD 1521B and to hold reviews when sufficient data was available to attain tailored objectives.

It became evident that the contractor and government teams had different ideas on what would constitute a successful SDR. It was through the cooperation and arduous work of top government and contractor management that necessary and sufficient criteria were agreed upon, and met, to allow approval of the functional baseline. A clear outcome for future reference in PAC-3 was that mutual understanding of expectations was going to be key to attaining the objectives of the PDR. Extensive training was conducted for all participants for the IBR. It was emphasized that integral to controlling costs is the establishment of a comprehensive and stable program management baseline. The process shown was used for verification that the technical baseline was accurately built in a logical sequence with necessary resources allocated. The development and the subsequent monitoring by Technical Performance Measurement, Earned Value Management, and critical path analysis provided the PAC-3 team insight into controlling costs and creating full confidence in out year estimates. Furthermore, if there was to be a true team effort between the government managers and the EMD Contractor, there had to be a mutual understanding of exactly what was expected to be developed and how the development was to be executed.

For the PDR and the Critical Design Review (CDR), which was conducted after the IBR, executive level exit criteria were agreed to by the Product Manager and the Contractor Program Manager. For the CDR, which initiated the product baseline, entrance conditions were also agreed upon to improve the preparation and to ensure readiness for this final design review. During PDR and the CDR the increasing maturity of the IPTs was evident as each took the executive level criteria and developed lower level entrance conditions and exit criteria.

The team approach had created the foundation of the baselining effort by developing a complete and mutual definition of the PAC-3 technical approach and its implementation. The validation of the implementation plan requires government understanding of the planned utilization of contractor resources which was gained through an IBR. Using the Army guidance and principles, PAC-3 conducted an IBR immediately after the PDR and after the cost elements of the EMD contract were definitized. PDR provides the allocated technical baseline and creates confidence that the Work Breakdown Structure (WBS) can meet the needs of allocated functional requirements. Configuration Items are defined and are coordinated and integrated. We capitalized on the product technical knowledge gained by government IPT participants during the PDR process and utilized these government IPT members to review contractor allocation and scheduling of resources for work packages in the contractor program baseline. This IBR process allowed government assessment of the adequacy of the contractor work package resources and the logic of task sequencing. It provided PAC-3 government lead representatives a comprehensive understanding of cost, schedules, and technical objectives and thresholds.

The combined impact of the streamlined, yet disciplined process for maturing the technical baseline and the integrated cost and schedule allocations of the IBR was the basis for realistic earned value tracking by the IPT. This process has provided the control needed to assess on a regular monthly basis the affordability of the applied technology associated with hit-to-kill improvements for PATRIOT.

PAC-3 Technology Assessments

Figure 5 shows the extensive and comprehensive application of design evaluation science and technology used in PAC-3. The goal is to establish sufficient high confidence to make the decision to proceed with Low Rate Initial Production (LRIP) in the first half of the federal fiscal year 99.

Prime contractor managed and executed validations of the PAC-3 hit-to-kill product baseline form a major part of the test and evaluation process. Design verification tests to prove functionality are conducted at various levels from component to major assemblies. Flight worthiness and flight acceptance tests, as well as flight and ground environmental qualification testing, are done for components and assemblies. A Software Integration Laboratory (SIL) has been established to integrate software with hardware for the evaluation of performance and functional integrity. The missile electronics and software which includes all the guidance and control functions are tested for each test flight in a Hardware-in-the-Loop (HWIL) anachoic chamber to ensure that actual flight systems will meet mission requirements. In order to comprehensively test performance boundaries, a set of off-nominal test runs of HWIL are also made. Because there are multitudes of first and higher order effects of the firing of the Attitude Control Motors (ACM) a series of ACM compatibility tests are conducted. These ensure that no adverse interactions are possible. To ensure that the seeker and the Radio Frequency Data Links

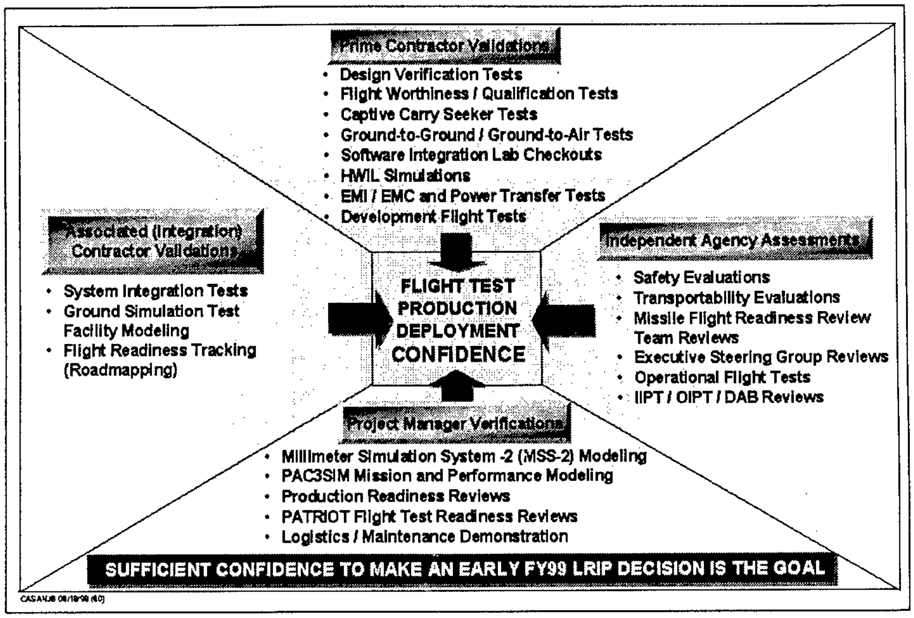

FIGURE 5. PAC-3 APPLICATION OF STATE-OF-THE-ART EVALUATION PROCESSES

(RFDL) are meeting their requirements, a separate series of ground-to-ground and ground-to-air tests are planned. Also, the seeker will be tested in the free space flight environment of a series of captive carry flight tests where the seeker will be mounted on an aircraft and fly against another target aircraft. All of the tests, plus other special tests, such as electro-magnetic interference and power transfer tests, culminate in the development flight tests. These fly the full-up PAC-3 missile against a series of representative threat targets.

To ensure the PAC-3 is fully evaluated in a total system environment, the integration contractor (Raytheon) is responsible for testing of the PAC-3 in the PATRIOT system. The principle test set up for this is the Guidance Test Simulation Facility (GTSF) which tests hardware in the loop with flight and ground software. Each flight performance envelope will be tested prior to movement of the missile to the launch site. Finally, the integration contractor tracks all the activities and their status needed for a successful mission.

The PATRIOT Project Manager conducts several evaluations in government facilities. The guidance and seeker systems are tested in the Millimeter Wave Simulation System-2 (MSS-2) at Redstone Arsenal. A government owned model called PAC3SIM has been developed and is being used to evaluate the performance of any iteration of the PAC-3 design. To prepare for the production decision and to move toward consistency and repeatability of the design, Production Readiness Reviews (PRR) are held by the government at each contractor facility. A special series of flight readiness reviews are jointly conducted before the missile forebody is shipped to the test range, then before the system is assembled, and finally just prior of movement to the launch pad. To check readiness for deployment and human interfaces, logistics and maintenance demonstrations are held in conjunction with representative soldiers and combat organizations.

As a triple check set of measures several independent agencies assess PAC-3. The Army Safety Board oversees safety tests such as insensitive munitions testing. Transportability is separately evaluated for safety and for the capability of the system to meet all deployability requirements. The Program Executive Office for Air and Missile Defense (PEO-AMD) has established a group of senior scientists called the Missile Flight Readiness Review Team (MFRRT) to carry out a continuous review of the PAC-3 design and flight readiness. At the Department of Defense level a panel of general officers called the Executive Steering Group (ESG) review the progress of EMD and flight test readiness and results. Also, the higher level IPTs, constituted to oversee the PAC-3 decision process, are in place and are currently operating. Perhaps the most significant independent assessment will be the operational flight tests that are conducted by soldiers at the end of EMD.

All of this evaluation, testing, modeling, simulation, and assessment is expected to come together for one purpose. That objective is the necessary and sufficient confidence for the PAC-3 program to proceed to each flight test, then to production, and finally to deployment of the hit-to-kill technology within the PATRIOT system.

Conclusion and Lessons

Bringing PAC-3 hit-to-kill science and technology to practical fruition is still underway. Since the EMD contract for EMD was definitized in November 1995 almost three years have passed and approximately two years remain until the first unit is equipped. There are many lessons being learned about applying a new technology very rapidly to a time-critical need. The reality that risks will exist and are acceptable is a first principle of getting innovative science and technology quickly applied for force enhancement. Prior to the implementation of current Acquisition Reform (AR) policies, risk was in most cases controlled by the dictating of proven military standards with the government bearing an associated cost. PAC-3 used performance specifications to eliminate much of this specific "how to do it", allowing more flexibility on the part of the contractors. Quality and acceptance testing of higher level assemblies without component testing was a method selected by the contractor to accelerate flight qualification. Higher risk was accepted, because there was potential for cost and schedule savings. What has turned out to be true in many cases is that component failures have occurred which might have been found and corrected earlier with less rework and retest if lower level testing had been done. Cost growth and schedule slippage are occurring. Our lesson-learned is that a careful examination of the potential result of risk acceptance with an eye on design maturity is needed.

A principle of AR was used in the scope of work for the PAC-3 Segment EMD contract was that the contract is told WHAT to do, but not HOW to do it. Performance requirements were enumerated without use of specific processes, military standards, military specifications and data item descriptions. This has been an important factor in the control of cost, because the contractor has the ability to use what is judged to be the most cost-effective methods. Although no specific records are kept of cost savings (that would, after all, have been itself a government driven added cost), both the contractor and government agree that the cost avoidance is substantial.

PAC-3 has begun to observe that AR or at least some of its principles may be foreshortening the view of the contractor management. This seems to be occurring, because to meet cost goals the principles of innovation and risk acceptability for cost savings are too quickly applied. This innovation as opposed to known good practice breeds near term problems which must be solved. This requires more time and attention and that comes at the expense of looking ahead. Lower level engineers and managers must increase the breadth of their viewpoints, because the IPPD requires the integration of all disciplines. Often this means much more attention on the present at the expense of the future. None of this is to suggest that AR, with proper innovation and wise choices about where there is a good risk, is not a good thing. What is important is that a new generation of designers and managers has to be trained to give attention to the future impacts of near term actions so that we do not have to say that, "It seemed like a good idea at the time." Also, care must be taken not to be over confident in technology, especially when it is not mature. It seems vitally important that the vision of programs be broad and deep and to expand the field of view as much as possible.

With these lessons in the background, PAC-3 can expect success in the fielding of the hit-to-kill capability. The technology which has been developed and the EMD program execution, which in itself represents advanced management science, are creating the needed confidence for production and deployment decisions. When these decisions are made PAC-3 will provide a major force enhancement for TMD and soldier protection, meeting the Army Air Defense Artillery motto of being ready to be *"First to Fire!"*

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