DESIGN STRATEGIES FOR A COST EFFECTIVE F-22 TRAINING SYSTEM

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Abstract

The development of the F-22 Training System is perhaps the largest such effort for a new weapon system in the post Cold War era of reduced military spending. As a result of increased customer emphasis on development and production costs, the F-22 Engineering & Manufacturing Development (EMD) Program has implemented a number of innovative strategies to make cost effectiveness a systemic feature of the F-22 Training System, rather than a reductive process. This budgetary challenge is accompanied by customer and user requirements for a state-of-the-art training system without the shortfalls in training effectiveness experienced by past fighter aircraft training programs. For example, a foundational requirement of the F-22 Training System, and a key factor in training effectiveness, is referred to as concurrency. Concurrency means that the functional and physical configuration of the fielded training equipment (simulators and other instructional materials) matches that of the fielded aircraft at all times during the weapon system's life cycle. The lack of concurrency has been a notable problem in some other major military aircraft training programs. Although requirements for cost effectiveness and training effectiveness appear to be conflicting, the F-22 development effort has been structured to achieve both goals with common means. These include both business and technical strategies such as end-to-end weapon system procurement, best commercial practices, federated system design, selective aircraft equipment reuse, and use of computer-based training and commercial equipment. This paper describes the implementation of these strategies in the development of the F-22 Training System, their effectiveness, challenges encountered, and lessons learned to date.

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F-22 TRAINING SYSTEM OVERVIEW

The mission of the F-22 training system is to provide Air Force pilots and maintainers with the knowledge and skills needed to operate and support the F-22 air dominance fighter aircraft throughout its life cycle. The F-22 training system includes its own management and logistical support functions as well.

The F-22 aircraft, support, and training systems have been in the Engineering and Manufacturing Development (EMD) phase of DoD's weapon system acquisition process since 1991. The Air Force currently plans to acquire 339 F-22 aircraft through the year 2013 and the means to train all required pilots and maintainers. This places the development of F-22 training among the largest weapon system training programs in the post Cold War era of reduced military expenditure rates. The emphasis on cost control and the increasing commercial availability of powerful multimedia information systems have converged to create end user expectations for high performance at low cost. The training system portion of the F-22 EMD contract provides unprecedented opportunities for the use of innovative system management and design strategies to realize these expectations.

Training System Elements

The F-22 training system consists of four major functional elements: Pilot Training System (PTS), Maintenance Training System (MTS), Training Management System (TMS), and Training System Support Center (TSSC). The EMD contract involves the design, development, and delivery of all these elements, to include all PTS and MTS courseware and one set of associated training devices. At present, the training system development has completed the requirements analysis phase and is in the preliminary design phase. The Preliminary Design Review (PDR) is scheduled for March 1998.

Pilot Training System. The F-22 PTS includes all the courseware and air vehicle simulators required to produce mission capable F-22 pilots at the Air Force's Formal Training Unit (FTU) schoolhouse and mission ready pilots at operational locations. Formal PTS training includes Basic (B), Transition (TX), and Instructor Pilot (IP) courses. These courses provide instruction using the simulator, computer based training (CBT), classroom lecture, and in-flight environments. Three different PTS simulators are under development: Full Mission Trainer (FMT), Weapons & Tactics Trainer (WTT), and Egress Procedures Trainer (EPT).

Maintenance Training System. The F-22 MTS includes all the courseware and air vehicle simulators required to train and certify Air Force maintenance personnel at the 3, 5, and 7-levels in the fifteen Air Force Specialty Codes (AFSCs) required to maintain the F-22 weapon system. MTS courses are divided by AFSC, skill level, and prior student experience. All 3-level courses are taught at the Air Force's Resident Training Center (RTC) schoolhouse. Higher level courses are taught at F-22 maintenance bases. These courses provide instruction using the simulator, computer based training, classroom lecture, and on-aircraft environments. Nine separate MTS simulators are under development representing distinct air vehicle systems: Armament, Landing Gear, Cockpit & Forward Fuselage, Seat & Canopy, Aft Fuselage, Engine, Fuel System, On-Equipment Structures, and a hybrid Base-Level Forward Fuselage Trainer.

Training Management System. The F-22 TMS is an information collection and distribution system designed to perform training scheduling, record keeping, trend analysis, and system evaluation functions. The TMS interfaces with other Air Force administrative systems to share appropriate personnel management data.

Training System Support Center. The F-22 TSSC provides the technical functions necessary to support, maintain, provide configuration management, and update all simulator and courseware components throughout the training system's life cycle. Performing these functions requires an effective communications and distribution infrastructure linking TSSC to all F-22 training sites as well as to sites responsible for F-22 aircraft engineering modifications.

Principal Customer Requirements

The F-22 EMD contract does not include a detailed specification for the training system. Rather, the F-22 Training System Segment Specification functionally specifies the above described major system elements and ascribes several principal requirements to the entire training system. Most of these requirements originate from lessons learned on past Air Force training programs. Many of them, not coincidentally, are intended to be cost control measures. Indeed, affordability has become the preeminent concern throughout the F-22 weapon system program. These principal requirements are described below.

Concurrency. Concurrency refers to the capability of the training system to adapt to aircraft configuration changes. The lack of concurrency in past aircraft training programs has sometimes resulted in negative training because simulators and course materials do not accurately represent operational equipment and procedures. Upon completing formal training, many military pilots and maintainers have had to unlearn those outdated, trainer-unique items and expend valuable operational time, in flight or on-aircraft, to learn items and capabilities not present on the training equipment.

Availability. The availability requirement levied on F-22 training devices is 95%. This means that they must be ready to support training exercises for 95% of scheduled training time which is specified at 16 hours per day, five days per week. Availability is calculated and achieved as a composite of reliability and maintainability factors (e.g., mean time between failure and mean time to repair).

Instructional System Development. The F-22 Training System Segment Specification mandates that the contractor use an instructional system development (ISD) process in all phases of training development. As described by MIL-STD-1379D, an ISD process involves a logical sequence of learning objectives analysis, training media type assignment, media and courseware development, training integration, and formative evaluation. One of the precepts of the ISD process in use within the F-22 program is that training devices will be designed to the minimum fidelity required to meet their assigned learning objectives. This requirement is intended to avoid the unnecessary expense of developing training devices having excessive technological sophistication by setting training effectiveness, rather than exacting aircraft simulation, as the design goal.

Contractor Logistics Support. Another principal customer requirement, primarily intended to reduce system operating costs is that the F-22 training system be designed for operation and maintenance under a contractor logistics support (CLS) concept throughout its life cycle. This is a significant departure from the interim contractor support procurement strategy. Typically, new weapon systems procurements include an interim contractor support period of a few years following initial delivery to permit the procuring service to build up an organic maintenance, operational, and support capability specific to the new weapon system. In the case of a new training system, this build up would involve purchasing simulator spare parts and stocking the government's supply inventory, training uniformed instructors and technicians, building and outfitting schoolhouses, and establishing or modifying administrative support offices and procedures. F-22 training will be a CLS operation throughout its life cycle.

STRATEGIES FOR COST EFFECTIVE PROCUREMENT

Various strategies contribute to the cost effectiveness of the F-22 training system development, production, operation, and support. These strategies are not unique to the F-22 training program; in fact, many of them are increasingly employed by other programs in conjunction with the DoD's acquisition reform policy promulgated by the Secretary of Defense in a June 1994 memorandum entitled "Specifications & Standards -- A New Way of Doing Business."

Even within the F-22 weapon system program, the air vehicle development effort and production planning is adopting or studying streamlining initiatives such as best commercial practices and contractor support, to name only two. However, the specific implementation and interaction of these strategies is unique to the F-22 training program. Their successes and shortfalls can serve as a useful model for validating these strategies and provide a baseline on which to improve for future procurements.

Cost Performance. Although detailed cost savings data is not available since alternative cost strategies or hypotheses cannot be fully investigated (as they might be in an academic exercise), the overall cost performance of the F-22 training development program illustrates the effectiveness of the strategies discussed herein (see Figure 1). Despite an aggregate budget reduction of 26% since program start, coupled with a two year extension of the period of performance, the F-22 training development effort is on schedule and within budget. The following strategies have contributed to this success to date and must continue to be applied and renewed as the training system design matures.

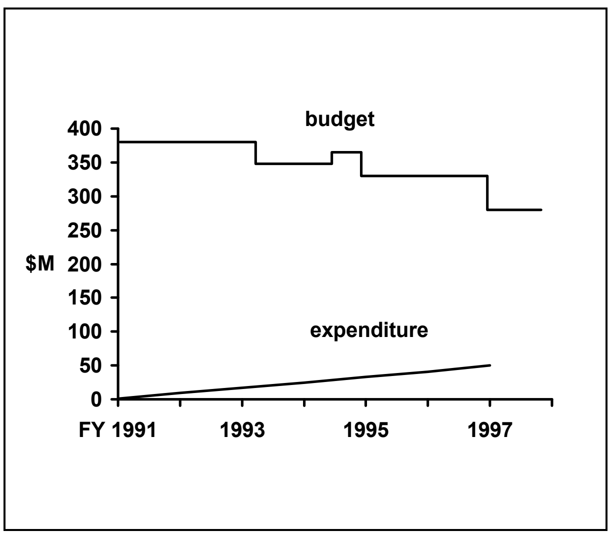

Figure 1. F-22 training system cost performance

Whole Weapon System Procurement

The Air Force is procuring the entire F-22 weapon system development under a single contract. The F-22 weapon system consists of the air vehicle, its support system, and the training system. This is a significant departure from the norm in which aircraft and training systems are developed under separate contracts, usually procured by different Air Force agencies from different contractors.

Administrative Savings. Aside from avoiding the obvious and substantial overhead costs incurred by administering independent contracts of this magnitude, there are also savings associated with the more efficient flow of aircraft design data, hardware, and software targeted for reuse to the training system development team. As members of the same contractor team, aircraft designers have an incentive to provide needed information to the training designers--an uncommon situation in traditional separate contracting arrangements. Furthermore, there is no need to involve the sponsoring government organizations as middlemen in the data request and transfer process, saving valuable time and administrative overhead. The security restrictions inherent in the transfer of classified or special access design data are also less onerous and time consuming when both organizations are operating under the same contract and security procedures.

More Efficient Change Processing. Engineering changes are numerous and nearly continuous in any large, multi-year weapon system development effort. Integrated aircraft and training system development permits the concurrent assessment of the impact of design changes on both the aircraft and training system, again saving time and duplication of administrative functions across multiple contracts. Cost estimates associated with proposed requirements changes more accurately reflect the total impact to the weapon system and enable more cost effective choices to be made when multiple design solutions are available. Traditionally, changes to aircraft capabilities, via post development engineering contract change action, have induced hidden training costs as simulators needed to be updated to regain concurrency. Just as whole weapon system procurement enables comprehensive change assessment, it enhances coordination of change incorporation into both air vehicle and training systems to ensure concurrency is maintained throughout the weapon system life cycle. This unified team approach will enable the Air Force to avoid training costs caused by the lack of concurrency. For example, the F-15C/D training program suffered from a lack of simulator-to-aircraft radar concurrency, which had to be compensated for by additional costly flight training hours.

Integrated Product Teams. Managing the development of a large and complex weapon system through an Integrated Product Team (IPT) approach is another F-22 innovation. F-22 IPTs are arranged by tiers according to product line (see Figure 2). The Training System IPT is a second tier IPT having management oversight at the same level as the air vehicle and support system. This is critical to ensuring that training issues are proactively identified, considered, and resolved in a timely manner, avoiding costly downstream concurrency problems. For example, in 1996, plans to build a two-seat F-22B model were scrapped to cut overall program costs. Because the training of several pilot learning objectives depended on the two-seat model, the cost of modifying the simulator design and courseware to compensate for its absence was assessed and included in the engineering change proposal from the start.

F-22 Weapon System	*tier 1*
Air Vehicle	*2*
Airframe	*3*
Aft Fuselage	*4*
Engine Installation	*5*
...	
...	
...	
Support System	*tier 2*
...	
Training System	*tier 2*
Analysis & Integration	*3*
TMS/TSSC	*4*
CBT	*4*
Pilot Training System	*3*
Pilot Simulators	*4*
Maintenance Training System	*3*
Maintenance Simulators	*4*

Figure 2. F-22 Integrated Product Team structure

Proper Simulator Fidelity

The most costly single component of an aircraft training system is the simulator. Simulators are generally complex, high maintenance systems. For example, flight simulators usually contain high fidelity cockpit representations, simulation software processors, image generators, and visual projection systems. Due to their complexity, the operational and support costs of aircraft simulators are relatively high, in addition to the initial purchase price. The F-22 SPO and user community have constantly emphasized the need to minimize simulator cost, making it a major design driver. At the same time, the Air Force is striving to shift many ground maintenance and flight training exercises traditionally performed in or on operational aircraft to simulators; actual aircraft are, of course, even more expensive to procure, operate, and maintain than simulators. The ISD analysts consider these factors as well as training effectiveness in allocating learning objectives to training media and in assigning component fidelity levels. Once the initial analysis is complete and entered in a relational database, contractor and Air Force subject matter experts (SME) review the data to ensure that the analysis is complete, consistent, and feasible. On occasion, learning objectives are reassigned or fidelity levels are modified based on SME experience or lessons learned.

Simulator Suite Definition. For example, the F-22 ISD process resulted in the definition of a third pilot training device, the Weapons & Tactics Trainer (WTT), to which many learning objectives are assigned that do not require the 360^{o} out-the-window field of view of the Full Mission Trainer (FMT). In this way, the considerable procurement costs associated with high end simulator visual systems can be avoided at many F-22 training locations. Over the planned production run from FY2001 to FY2013 in then-year dollars, comparing the currently estimated WTT's $850K average unit production price (AUPP) for 38 units with the FMT's $5M AUPP for 33 units makes the cost savings gained by designing to proper fidelity levels evident.

Maintenance training media analysis included an engineering review that resulted in a logical grouping of learning objectives, collapsing the number of different trainers required from 15 to 9, based on aircraft location and student throughput projections.

Fault Isolation Training on CBT. Recent advances in computer based training (CBT) have helped lower the required complexity and cost of traditional aircraft maintenance simulators. For example, CBT is the training medium to which most F-22 fault isolation learning objectives have been allocated in lieu of traditional aircraft simulators. This eliminates the need for and cost of rehosting or creating simulations of the diagnostic and health management software for each aircraft subsystem on its respective training device. CBT lessons are used which guide the student through selected fault isolation scenarios using full color visual animation, audio instruction, examples of different possible equipment responses, and provide prompting when responses indicate the student needs assistance.

Reuse of Aircraft Components

The direct incorporation of selected aircraft components into training device design can reduce simulator costs. Indeed, all F-22 aircraft hardware, support equipment, and software components are being considered for reuse in the F-22 training devices. Reuse of hardware components includes both the production of extra units for training use as well as opportunistic reuse of non-flight qualified hardware and tooling. Also, both operational flight program (OFP) and simulation software produced as a byproduct in OFP development are considered for reuse in the simulators being developed for F-22 training.

Hardware Reuse Issues. Trade studies on the direct reuse of flight qualified F-22 hardware for training have found that this approach has limited utility within F-22 for several reasons. In many cases, the requirement to limit simulator fidelity to that required to meet assigned learning objectives enables the use of lower cost simulations or facsimiles. For example, cockpit control panels whose functions are not employed by the Egress Procedures Trainer are represented pictorially showing the proper look, scale, and placement of the actual controls. Direct reuse of aircraft hardware is also generally not done for components made of exotic materials, like titanium, when their special properties are not needed by the training hardware.

Another argument against direct reuse, often cited by experienced Air Force operational personnel, is the risk of cannibalization of simulator parts by operational units as spares for hard-to-obtain aircraft parts, leaving the simulator unavailable for training use.

It sometimes makes economic sense to recycle aircraft parts or tooling for training application. For example, blemished cockpit canopies and ejection seats spent in testing have been earmarked for use in the first set of F-22 training devices. Of course, prior to full scale production, alternate sources will have to be identified due to the uncertain supply of recyclable parts. An instance of tooling reuse is the fabrication of training device outer skin panels using the same molds originally built for full scale aircraft models to support radar cross section testing and other purposes. Opportunistic reuse is greatly facilitated by the whole weapon system and IPT concepts. The IPT environment and close links to the Air Vehicle and Support System IPTs provides the Training System IPT with timely knowledge of scrapped parts available for training use.

Aircraft Design Data Reuse. Weapon system design requires the generation of large quantities of technical manuals, drawings, and other graphical data, usually in electronic format. Although produced mainly for design engineers' visualization of the aircraft and its systems, much of the same graphical and textual information is also needed in the training environment. Here again, the Training IPT's courseware developers are taking advantage of the existing aircraft data by direct electronic transfer to training products. F-22 courseware developers have already successfully demonstrated the capability to electronically transfer technical manual pages and CATIA® images and models for display within CBT lessons. This process saves many hours of graphical artist labor.

Best Commercial Practices

Even from the time of contract award in 1991, the F-22 Training System Segment Specification differed from the F-22 air vehicle specifications in that it stated the Air Force's requirement for the contractor's use of best commercial practices (BCP) in lieu of the plethora of government and military standards invoked by the air vehicle specifications, as was the norm for defense contracts. Following the 1994 debut of DoD's above referenced acquisition streamlining policy, the F-22 air vehicle specifications have indeed been revised to significantly reduce the number of government and military standards ("milspecs") on contract. The use of commercial standards is particularly beneficial in the design and construction of simulators and information management systems such as TMS and TSSC.

Replacement of milspec "how to" requirements with performance oriented requirements such as availability, service lifetime, and concurrency, enables a simulator contractor to apply familiar processes and materials proven in the competitive commercial training systems industry. F-22 training system requirements call for the use of BCP for transportability, storage, parts control, corrosion prevention, electromagnetic compatibility, product marking, workmanship, interchangeability, and human engineering. One notable exception is the use of the Ada programming language (formerly MIL-STD-1815A) for newly developed simulation software. This does not, however, preclude the use of commercial software in its native format. The currently planned design strategy for TMS and TSSC is the use of commercial software hosted on commercial processors with appropriate security provisions.

In addition, the use of BCP is also being applied to F-22 computer based training (CBT) development. The CBT IPT has adopted the formatting standards of the Aviation Industry Computer Based Training Committee (AICC). Primarily developed for commercial aviation training, the use of AICC standards facilitates the rapid and flexible redeployment of commercial courseware production staff to F-22 work without retraining.

Another cost effective practice being borrowed from the commercial aviation training industry is the use of the electronic classroom for delivery of CBT and lecture-style instruction. The electronic classroom is an integrated multimedia environment incorporating CBT workstations for both self-paced and instructor-led training, large screen projection, and other audio/visual systems. An instructor workstation provides productivity enhancing software applications for automating lesson plans, monitoring student progress, transitioning between media types, etc.

Various CBT efficiency studies have concluded that the multimedia approach reduces training time (including military training) anywhere from 25 to 50+% (ref. Rex J. Allen's article in *CBT Solutions*, March/April 1997).

Looking beyond the EMD program, application of BCP to the fielded F-22 training system is also being studied. Under the current contractor logistics support (CLS) concept, the Air Force would own all training equipment and provide all facilities and much of the instructional staff. The contractor provides simulator maintenance and some instructors and administrative personnel. The F-22 training team is building on recent trends toward privatization of traditionally government operated functions such as military training. The team is studying a new CLS approach called comprehensive contractor training in which the contractor owns and provides most or all training equipment and instructors. The contractor sells turn-key training services to the Air Force. It is currrently estimated that this approach would save the government at least $200M over the baseline CLS approach.

Commercial Equipment Use

The F-22 Training System IPT is planning to maximize the incorporation of commercial-off-the-shelf equipment (COTS) in all major system elements. This is expected to be a major contributor to cost effectiveness both in reduced development (i.e., EMD) cost and in downstream maintenance and technology upgrade costs.

A prime example of the use of COTS as a cost savings mechanism for F-22 training, is the design decision to host simulation software on commercial processors in lieu of the Common Integrated Processor (CIP) designed specifically for the F-22 avionics suite. In addition to avoiding the militarized CIP's estimated average production unit cost of $4.9M in then-year dollars, a COTS-based design permits the insertion of upgrades to the simulation processing hardware as the market evolves. By contrast, the CIP is already undergoing a costly redesign effort due to projected component obsolescence well prior to the end of the F-22's design service life. COTS solutions are also planned for F-22 CBT workstation design and the associated lesson authoring software. In the latter case, Macromedia's Authorware® toolset has been selected and is now being used in prototype lesson development. CBT COTS selections are being made for common application to both pilot and maintenance training. This further enhances cost effectiveness both in terms of economy of scale by enabling larger quantity purchases and in lower operating costs.

CHALLENGES

While many of the strategies for cost effective training discussed above seem to be a matter of common sense, the customer/contractor/user team faces significant challenges in implementing and enforcing them even in today's reform-minded military systems acquisition environment. Many of these challenges are related to having a lengthy system development cycle compared to the timescale of associated technological changes and the average job rotation of both civilian and military team members. The F-22 training system development program duration, as currently planned, exceeds a decade. This is driven largely by the air vehicle development schedule and program extensions caused by the government's near term budgetary constraints. Because the training system development is dependent on aircraft design data and year-to-year funding issues are not completely predictable, there is no effective way to insulate the training effort without sacrificing the benefits of whole weapon system procurement. In fact, unspent training system budget often presents an irresistable target for offsetting shortfalls on the air vehicle side of the ledger (see Figure 1 budget reductions), making these cost saving strategies even more critical.

Technical Baseline Management

In any system engineering effort, the ultimate success and efficient operation of the system design depends on the methodical progression from a functional requirements baseline through a design baseline to a product baseline. The ISD process provides a similarly logical progression for the development of training products. During its many years in a multilateral IPT environment, the F-22 training system has amassed a large body of training requirements in the form of ISD analysis. This analysis has provided the basis for training media definition, including a functional requirements baseline for each simulator. The periodic replacement of key team members with new decision makers, each having unique training preferences and often lacking a sense of ownership in predecessors' effort, sometimes results in time consuming revisitation of prior decisions. This process usually delays planned work such as ISD analysis of newly available aircraft data, course design, and other preliminary design activities. While the capability of a training system design to adopt beneficial elements of technological change is desirable and achievable, system design decisions must be made in synch with the established baselines and schedules if the program is to succeed. Program success is defined by a product which meets its specified requirements on time and within budget. Understandably, this fundamental business fact is not widely understood within the military training user community, which tends to be focused on tangible product characteristics rather than arcane contractual matters such as specifications and baselines. At the same time, the contractor must seek and be responsive to user input to ensure customer satisfaction with the product. A critical element in achieving a mutually successful system design effort is the procuring agency, or SPO. Having expertise in both acquisition matters and areas of concern to the user community, the SPO must provide the means to reconcile evolving user expectations with the technical baselines which drive the business realities of budget and schedule. This challenging role is essential to the IPT process and a successful system design.

Of course, these customer/contractor relationship challenges are not unique to the F-22 program. The transition from the traditional buyer-seller relationship to a team environment of common objectives, within the required contractual constraints, is a major challenge being faced by both sides across many industries.

Integration with Air Force Infrastructure

Designing a system for smooth integration with future (ca. 2004 and beyond) Air Force training, personnel management, and facilities infrastructures presents a formidable systems engineering challenge. While the adverse effect on user friendliness and operating cost of not providing these interfaces is clear, the design criteria for these interfaces is unclear or nonexistent. Examples of such future infrastructure include training management systems like the Advanced Training System (ATS) and similar functions of the Joint Primary Aircraft Training System (JPATS). Although the F-22 customer has expressed a desire to interface with these systems, the immaturity of their design, relative to the F-22 program schedule, means that these interfaces cannot be designed and incorporated within the current system design schedule. As a means to mitigate this schedule disconnect, development work on the F-22 TMS has been delayed by approximately a year and a half. It is hoped that this will enable the other systems to develop at least enough design information so that the F-22 TMS design does not inadvertantly preclude an efficient training data sharing interface.

Another example that could be categorized as a future Air Force infrastructure interface is the joint operation of different military simulators now under discussion in terms of the High Level Architecture (HLA) simulation protocol. Similar to the aforementioned training management systems, the genesis of the Air Force's desire to incorporate HLA came midstream in the development of the F-22 training system and has not been formally added to the F-22 requirements baseline. This a difficult task to specify, as HLA development is in a relatively early evolutionary phase. Pending the receipt of requirements for an HLA implementation, F-22 simulation design is proceeding so as not to knowlingly preclude HLA compatibility.

These examples represent risk to the cost performance of the training system design process, as does the likelihood of the emergence of other new design enhancements, add-ons, or interfaces during the years remaining in the F-22 training system development program. Careful management and coordination amongst the customer/contractor/user team is vital to overcoming these risks and ensuring a successful program, from all points of view.

OUTLOOK

The system design strategies adopted by the F-22 training program are working together to produce a training system which meets its requirements within budget and on schedule. These strategies can be traced to costly lessons learned from past aircraft training programs. Already, significant savings are apparent as a result of their application to F-22. However, the continued effectiveness of these strategies through the detailed design, fabrication, and evaluation phases of the EMD effort depends on the support that all members of the customer/contractor/user team provide. Given today's environment of military spending reduction, this support is expected to grow and spread to other programs as well.