A LOW COST APPROACH TO OSS&E ASSURANCE THROUGHOUT A SYSTEM'S LIFE

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ABSTRACT

In periods of declining budgets and downsizing, it becomes increasingly important to select the best possible design and development approaches that provide the desired life cycle cost benefits while sustaining system capability. Aging of the United States Air Force (USAF) systems, factored with efforts to extend their operational longevity, has an impact on the systems' safety and operational capabilities.

On 3 December 1997, the commander of the Air Force Materiel Command (AFMC) chartered an integrated product team (IPT) to develop a cost-effective Air Force policy for assurance of operational safety, suitability, and effectiveness (OSS&E) of USAF systems. The team developed this new policy based on proven commercial and U.S. Government practices, processes, and methodologies in place today. A key element of this policy is the certification process that ensures airworthiness is established and maintained throughout the life of the system. The highlights of the policy and the selected processes, best practices, and methodologies are presented.

1. INTRODUCTION

The commander of the Air Force Materiel Command (AFMC), General George T. Babbitt, has long been concerned about the configuration control of Air Force systems. In 1997, he saw an alarming trend in the mishap rates in fielded systems and end items, which led him to question his technical staff as to how airworthiness is managed within the USAF.

To address this question, Aeronautical Systems Center (ASC) provided a comprehensive briefing in December 1997. It pointed out that the USAF did not have clearly documented airworthiness policies similar to those that the Federal Aviation Administration (FAA) imposes on commercial aircraft. The briefing emphasized that, as a regulatory body, the FAA is empowered by the FAA Reauthorization Act of 1996, as amended. The Act very clearly applies to civil aircraft and air commerce, but it does not apply to purely military aircraft. If the FAA were to address military aircraft, legislation would be required. Further, the FAA would have to expand its capabilities to address military-unique equipment and operations.

The briefing also points out that airworthiness is only one element of overall flight safety. Airworthiness is concerned with system design, the quality of the parts and their integration, operational flight limits, and the maintenance and repair of the aircraft and its equipment throughout its service life. The second element is the capability of the aircrew, which necessitates proper qualification and training requirements.

The safety of aircrew members is extremely important to the USAF. Equally important is the successful conduct of USAF military operations. Thousands of military and civilian lives are at stake if the outcome of a military operation cannot be controlled. Recent experiences indicate that air dominance plays the major role in controlling outcomes. Therefore, the Air Force's ability to accomplish its missions at will and in a timely manner is of the utmost importance. Thus, the suitability of the aircraft and its effectiveness also become key considerations along with safety of flight. For this reason, it was only logical for General Babbitt to expand the USAF airworthiness effort to include the operational safety, suitability, & effectiveness (OSS&E) required for successful military operations.

The current high rate of mishaps, decreasing trends in the mission capability rates, and the effectiveness of USAF systems have a profound effect on the ability of the Air Force to fight wars safely and effectively. These factors, combined with the realities of a shrinking DoD budget and workforce, demand that our resource utilization be improved considerably to sustain our air dominance in the world. Furthermore, for the past decade, workforce downsizing has constantly eroded our technical foundation in both experience and corporate knowledge.

The USAF aircraft mishap rate per 100,000 flying hours continues to climb. Mishaps may be caused by a variety of factors, including human performance, weather, design, technical orders/ manuals, operation, training, maintenance, aging of systems, dwindling resources, and infrastructure. For many USAF systems, aircraft mishaps are largely caused by human error. Yet, some of these human error mishaps are attributable to inadequacy of technical orders or manuals, or training of pilots or maintenance personnel. The USAF has the ability to control the factors that contribute to aircraft mishaps, except purely human errors, by improving technical rigor and applying disciplined engineering design techniques governed by appropriate policies and priorities. Therefore, AFMC has set an objective by the year 2005 to reduce by half the mishap rate resulting from controllable factors.

Concerned about the mishap trends and their potential impact on national security, General Babbitt tasked the commander of the Aeronautical Systems Center in December 1997 to take the lead for the USAF in establishing a new policy to assure operational safety, suitability, and effectiveness. The IPT chartered to develop this policy faced several challenges that are discussed in this paper. The specific objectives of the IPT and the philosophy adopted to overcome those challenges are also briefly discussed. The highlights of the policy are summarized. The major portion of the discussion, however, is devoted to those technical aspects that create the bedrock for this proposed policy. This paper further describes how those technical aspects could contribute to reducing the mishap rate. Additionally, it explores the costs for applying the disciplined systems engineering rigor and supporting processes, best practices, and methodologies.

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2. DISCUSSION

IPT Effort and Challenges

A highly cohesive, cross "Center of Excellence" OSS&E Integrated Product Team (IPT) was formed to address operational safety, suitability, and effectiveness issues and develop options for resolution. This effort affects USAF Product Centers, Logistic Centers, the Air Force Research Laboratory, Air Force Major Commands, the Air Reserve component, and Defense Logistics Agency. Stakeholders in addition to the Air Force include the FAA, Army, and Navy. A tremendous amount of information was collected from the various services and the FAA. As a basis for developing the policy, the team conducted a comprehensive review of existing policies, mishaps, airworthiness certifications, best practices, and processes. From these, the team selected information that could support a disciplined systems engineering process for OSS&E. In order to avoid duplication on joint programs and commercial procurements, one of the team's major objectives was to harmonize with the other services and FAA the USAF's proposed approach.

Mishap rate is a serious challenge for the USAF. The number of fiscal year 1999 (FY99) mishaps has already exceeded the number of FY98 mishaps." As of February 18, the rate of major F-16 accidents for FY99 was 5.83 per 100,000 flying hours. The rate in FY98 was 3.89, which was a 30 percent increase over the FY97 rate of 3.0 and an 81 percent increase over the FY96 record-low rate of 2.14 [1]. Engine failures and human errors continue to be the primary causes. However, most of the aircraft are designed for a 20-year design life and are flying today beyond their service life [2]. To a varying degree, all these airplanes can be expected to experience such aging problems as cracking and corrosion [3].

Furthermore, the aging aircraft inventory impacts safety and creates economic burdens. "Corrosion and fatigue separately have led to serious safety as well as economic problems" [4]. These problems are common to both military and commercial aircraft and have resulted in several mutual efforts to resolve those issues. For example, in 1989, the failure of the maintenance program to detect the presence of fatigue damage was cited as the probable cause for the commercial airline accident [2] [5] that led to military and commercial aircraft policies and priorities that benefited both. The FAA and NASA are developing a host of advanced, highly accurate, nondestructive evaluation systems that will significantly improve the accuracy of inspections while reducing airframe disassembly and associated costs [6].

The aircraft aging problem has been well recognized by the USAF and is being tackled on several fronts, such as structural integrity and corrosion control programs. The USAF has the experience in inspection and repair techniques to extend airframe lives beyond the 20-year design life [7]. The USAF structural integrity program and other services' efforts, in combination with industry initiatives, have kept aging issues in check to date. However, continued focus is needed in this area. The Air Force expects to mitigate the adverse trend in mishap rate through the development and application of the OSS&E policy and an emphasis on the use of disciplined engineering and risk management processes.

Mishap investigation reports provide much insight on the prevention of mishaps and possible safety improvements. The analysis of the information received reveals a clear breakdown in the Air Force technical processes. The technical processes are inconsistently applied across systems during acquisition and are seldom applied during the sustainment phases of their life. Because unauthorized changes have been made to systems in the field without the application of a disciplined engineering process, it is not clear who is accountable or responsible for some mishaps. Thus, the second objective of the team was to require the application of a disciplined engineering process throughout the life of the system. And a third objective was to delineate clearly the roles and responsibilities of the organizations and individuals (that is, the chief engineer and the single manager) in the policy documents.

The IPT faced many challenges in creating the OSS&E policy. Two major challenges are especially difficult to overcome in today's austere environment. The first one is that policies are generally viewed as adding to the product's cost unnecessarily. The issuance of a policy requires coordination with a multitude of organizations with varying interests. Valid concerns of everyone should be carefully considered and appropriate adjustments made to accommodate those concerns.

The second major challenge is that the acquisition reform advocates view imposition of policy as contrary to their initiatives. Most of the acquisition reform initiatives enjoy high visibility within the DoD and are resulting in significant cost savings. Therefore, it is extremely important to ensure that the new OSS&E policy continues to embrace acquisition reform initiatives. Open communications and stakeholder involvement are key in facing both of these challenges and gaining support.

Weighing these factors, and recognizing our dwindling resources, the team adopted a philosophy to develop a policy that fosters the combined use of industry and Government resources as a single team in fielding and sustaining capabilities required for our national defense. The team was cautious to avoid any policy content that may result in duplication of effort (e.g., obtain FAA certification where possible) or that may be in conflict with other initiatives. For example, the policy should not restrict the use of the clear-accountability-in-design (CAID) approach. Under this approach, the contractor is given control of the design and technical documentation, while the Government retains the responsibility for defining the required performance capability. While this eliminates duplication of responsibilities, it also affords a contractor opportunities to cut the development cost of products and parts. Given this authority to control the detailed design, technical data, manufacturing, and quality assurance, in essence, contractors are provided the flexibility to take advantage of nondevelopmental items (NDI), commercial-off-the-shelf (COTS) products, and the best practices & processes they deem necessary.

The IPT developed a common technical management process and created a draft guidance document, a draft Air Force policy directive, and a draft Air Force instruction in the short period of one year for the Headquarters AFMC to sponsor at the Air Staff level. In December 1998, the USAF Chief of Staff directed the cognizant organizations to expedite formal coordination of this policy.

USAF Policy Highlights

This section provides the synopsis of the new USAF policy for OSS&E assurance that is delineated in several hierarchical policies and related documents. The policy applies to Air Force systems and end items. The main focus of the policy is on improving the technical disciplines for effectively fielding Air Force systems. It requires the Air Force to assure the OSS&E of systems currently in, or entering the operational inventory and to employ a disciplined engineering process and effective operational, training, supply, and maintenance procedures to preserve its OSS&E throughout the operational life.

This policy mandates:

1) Systems and end items must be delivered with a baseline that enables continuing assurance of OSS&E.
2) Preservation of baseline OSS&E characteristics of systems and end items over their operational life.

Certifications, such as airworthiness and nuclear surety, are referenced in this policy as important, supporting processes, central to baseline establishment and preservation. These focused activities remain stand-alone Air Force policies. A separate Air Force Airworthiness Certification policy has also been drafted and staffed. Airworthiness certification responsibility resides with the single manager (SM) for the program.

The single managers and chief engineers are responsible for preservation of operational baselines and are required to utilize a disciplined engineering process toward that end. AFMC further assigns technical responsibility to its four Product Centers. Each Product Center is responsible for providing supporting policy, guidelines, processes, and technical standards tailored to their unique product lines. These tools will assist the single managers and their chief engineers in accomplishing their responsibilities and provide AFMC with necessary insight into the health of the fielded systems and end-items. The Air Force Operating Command will coordinate any changes to configuration or usage with the single manager/chief engineer.

While the single managers have the ultimate responsibility for OSS&E, they are expected to delegate authority to competent technical entities, as appropriate. The new policy requires that a chief engineer or lead engineer be assigned to each program. It allows the single manager to delegate authority for OSS&E technical aspects of the SM responsibilities to the chief system engineer. As an example, the chief engineer is responsible and accountable to the SM for assessing the airworthiness and formulating certification recommendations throughout the system's operational life. He/she will be responsible for preserving the baseline for fielded systems. The chief engineer will continue to provide technical risk assessments so the single manager, in conjunction with the users, can make informed cost and performance tradeoffs.

Selected Processes

The OSS&E Process Overview

The OSS&E process consists of two parts: 1) establishing the OSS&E baseline and 2) preserving OSS&E baseline characteristics throughout the life of a system. To establish the baseline, air systems are assessed for operational safety, suitability, and effectiveness. To preserve the baseline, this OSS&E assessment is updated throughout the operational life as missions and system use change, or as modifications are incorporated. Correspondingly, the airworthiness certification process also consists of two parts: 1) certifying airworthiness and 2) maintaining airworthiness certification throughout the life of a system. Aerospace vehicles are initially certified for airworthiness. To maintain airworthiness, the certification is updated to account for configuration changes throughout the operational life of the system.

Disciplined Systems Engineering Process

A disciplined systems engineering process is a comprehensive, orderly, iterative, problem-solving process that transforms validated user needs into a cost effective product for the customer to use reliably throughout its defined life. Many supporting processes are involved in transforming customer's requirements into a description of a balanced life-cycle solution, including people, products, and subprocesses. The systems engineering process and its subprocesses apply to new system product and process upgrades and modifications, as well as to engineering efforts conducted to resolve problems in the field or on the manufacturing floor.

The following subsections address a few of the key systems engineering subprocesses. These are described at a very top level and are not meant to be all encompassing. Some of the generic subprocesses such as definition of requirements, incremental milestones (that is, design reviews, etc.), and test and integration are commonly applied across Air Force systems with varying degrees of success. They are necessary but are not addressed in this paper. Refer to MIL-HDBK-500, "Key Supplier Processes for Aeronautical Sector Acquisition and Sustainment Programs" [8] for further detailed information on those processes. The subprocesses discussed below, system integrity, risk management, and configuration management, occasionally lack discipline in their application during the development and sustainment of systems.

System Integrity Subprocess

The system-level integrity program is crucial to the engineering and management process used to ensure the design/modification, manufacture, quality, and maintenance of a system is consistent and compatible with both its intended and actual use. This is necessary to ensure the required levels of safety and reliability are achieved while meeting other performance requirements. When technological capabilities are incapable of maintaining sufficient safety margins while meeting required performance levels, safety margins shall be maintained via the modification of inspection, repair, and/or replacement intervals based on the life used and margin remaining. This necessitates a feedback or tracking mechanism to ensure adaptability to changes in usage. Additional feedback should also be provided to ensure the correctness and completeness of technical orders and training. Strong ties are required between configuration management and the system level integrity program to allow determination of the item's life remaining based upon how the system is used and maintained versus its expected usage at the beginning of the program.

Throughout the development (or modification) process, several integrity program functions should be performed. Figure 1 depicts key elements of the system integrity process. Each ele-

ment, and its function or related activity necessary for ensuring integrity of the system, is discussed briefly.

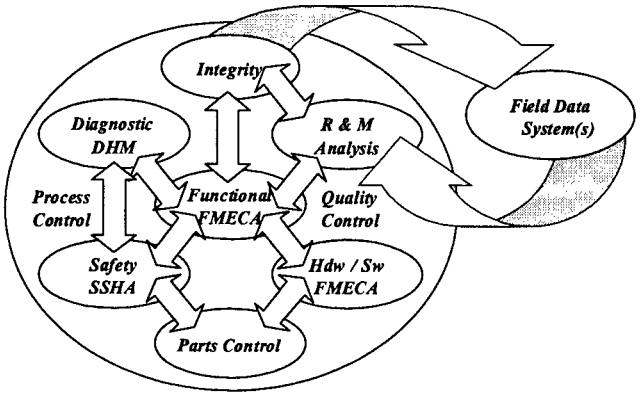

Figure 1
Key Elements

Field data system(s): Field data systems should provide serial number, part number, manufacturer number, tail number, accumulated stress, or hours as needed to be able to determine life used and indicate when maintenance, replacement, or inspections are called for to maintain appropriate design margins. Field data systems should accurately reflect the impact of functional failures and maintenance activities on meeting operational capabilities. Systems should minimize the need for input by maintainers and pilots. Notes from maintainers and pilots should be available for review. Databases containing maintenance information should provide direct links to manufacturing databases (failure reporting, analysis, and corrective action systems) and to warranty tracking systems to ensure manufacturers have the latest field information. Information should also be available for the chief engineer to review current fielded status and prioritization of fixes, etc.

Reliability & maintainability (R&M) analysis: Provides system level design considerations to ensure mission and hardware reliabilities are achievable and consistent with the user's needs. Integrity program tasks ensure a sound understanding of the environment and usage as well as the consistency and level of product quality to be accounted for in design.

Failure modes effects criticality analysis (functional): Functional failure modes effects criticality analysis (FMECA) is accomplished at the system level and should include functional failures of lower-level subsystems (both internal failures and loss of input). The functional FMECA describes, through the database, how functional failures propagate through the system as well as the eventual effects of said functional failures. These are expressed in terms of safety in addition to the diagnostic indicators that should appear and the actions the pilot or maintainer should take to mitigate the problem.

Subsystem safety hazard analysis: Safety draws initial information from FMECAs. Unlike FMECAs the subsystem safety hazard analysis (SSHA) evaluates multiple failure scenarios. The SSHA can result in designating items as safety critical and safety significant. A safety significant item or system is one that requires multiple failures to cause the loss of a function. For example, loss of flight controls on the new systems usually requires loss of three independent channels: in such a case each channel is considered safety significant.

Diagnostics & health management (DHM): DHM information is included in functional FMECA(s). Since both information pointing at the loss of a function and the cause of the problem are in the FMECA, it is a good source for DHM analysis. DHM can further use the FMECA(s) to develop fault-filtering algorithms to provide better isolation and to reduce false alarms. Where the loss of function is significant, it may also be presented to the pilot as an integrated caution and warning (ICAW). These, too, are usually part of FMECA(s).

FMECA (hardware or software): Hardware or software (Hdw/Sw) level FMECAs are generally done by subcontractors and are based on a piece-part (for software it means computer software unit) analysis of the subsystem in question. Hdw/Sw level FMECAs relate individual piece-part failure modes to losses of functions. The functional losses expressed in Hdw/Sw level FMECAs should be the same as those functional losses examined in the functional FMECA. Standardized database structures would help relate these level FMECAs to functional FMECAs and reduce the manpower needed to accomplish FMECAs in general. Hdw/Sw level FMECAs, when tied to functional FMECAs, reveal which part failures result in the loss of a safety critical and/or mission critical function.

Parts control: Parts control provides control for safety-critical parts through a serial number tracking system. Parts identified as safety critical through the FMECA, and those also identified as safety significant (needs multiple failures) via the subsystem safety hazard analysis (SSHA), may require special checks during manufacturing as well as in field usage. The parts control system should be capable of ensuring that the parts purchased are consistent with the intended usage and environment and have quality levels as good as or better than the parts they replace. Necessary part functional tolerances should be evaluated when considering a replacement part. Authority should reside under parts control engineering as opposed to being relinquished to a purchasing agent who is not under engineering control.

Quality control: The assurance of quality for production articles is critical to assurance and preservation of OSS&E. Quality, for the purpose of this discussion, refers to the engineering of the product to meet user's needs reliably (design quality) and the manufacturing of production units repeatedly in complete agreement with the design (production quality). To assure the quality of design, and to assure that the as-built configuration matches the as-designed configuration, an effective quality system should be in place.

Process control: In order to assure OSS&E of a product, the capability and stability of the manufacturing processes are extremely important. Therefore, the processes need to be qualified and controlled by the manufacturers throughout the life of a system. It would be possible to test fully each unit of product, including comprehensive testing necessary for the intrinsic manufacturing processes subsequent to the first production unit delivery. However, a more economical approach is to assure that follow-on units are functionally identical to the one that is tested. This should address the product characteristics that exert some influence over the product's OSS&E. Manufac-

turers should consider the minimum set of criteria listed below to assure OSS&E of a system (for noncomplex or COTS items, verification inspection and testing may be sufficient). A prime contractor for the system is responsible for the flow down of these criteria to appropriate suppliers.

1) Identify product's key characteristics (at the form, fit, and function level) that are related to OSS&E.
2) Identify appropriate product appraisal methods (inspection/test) for key characteristics and report results of those appraisals.
3) Identify key manufacturing process parameters that determine integrity of the product.
4) Identify the required key manufacturing process capabilities (e.g., process capability index, such as Cpk) and match them to the design requirements.
5) Implement controls over the key manufacturing processes.

Risk Management

Risk Management is a key element in the disciplined engineering process required to assure OSS&E and is an essential component in the Department of Defense's strategy for acquiring and sustaining mission-capable weapon systems in an environment of diminishing resources. A disciplined, comprehensive risk management structure involves the early and continuous identification of critical program risks, and the establishment and monitoring of risk handling plans. When properly implemented, an effective risk management program facilitates identification of areas that require special attention and supports setting realistic and executable technical, schedule, and cost objectives. Integrated Risk Management is the practice of controlling risks (those things that are in conflict with achieving program objectives). ASC uses the integrated risk management (IRM) process, which consists of four essential elements: planning, assessing, handling, and monitoring risk. It is implemented by IPTs, throughout the life of a program, to focus resources on the areas of the program that are most critical to delivering weapon systems that meet the user's mission needs. To be effective, risk management should be a continuous, daily activity employed from cradle to grave.

Configuration Management

An effective configuration management (CM) program is imperative in order to maintain operational safety, suitability, and effectiveness of Air Force weapon systems. CM provides the discipline, control, management of data, and access to accurate data that is necessary to implement the systems engineering process. CM principles are inherent in sound business practices to develop, integrate, test, acquire, operate, maintain, logistically support, and dispose of a weapon system. These practices apply across parts, assemblies, subsystems, hardware, software and firmware, and, indeed, all modifications to weapon systems.

Operational safety, suitability, and effectiveness are associated with a specific system or end-item configuration. The specific configuration and its characteristics should be defined by engineering data at all times. Therefore, a robust configuration management process should be used to establish and preserve operational safety, suitability, and effectiveness baselines. Permanent and temporary configuration changes, as well as the use of nonconforming material, will be reviewed and approved prior to implementation or installation. Delegation of specific configuration management authority between organizations should be formally documented. This authority includes configuration management responsibility for supply, maintenance, and user- and test-initiated changes.

Best Practices

In developing this policy, the IPT made a conscious effort not to limit any use of best practices currently reaping benefits in both the civil and the Government sectors. This approach lowers both acquisition and sustainment costs significantly and allows industry and Government to share benefits. Some of the best practices are briefly presented in this section.

Commercial Off the Shelf (COTS)/Nondevelopmental Items (NDI)

The DoD places enormous emphasis on the use of COTS and NDI for several reasons. COTS and NDI have many common attributes that reduce the total ownership cost of Government systems. All COTS are NDI, but not all NDI are COTS. The NDI could be a product or part that has been developed for another military application and may not have led to use in any commercial application. In contrast the COTS are products and items that are developed for the commercial market and are readily available for Government applications. In either case, there is no development effort involved. Both reduce acquisition cycle times for fielding a product, and the procurement costs are significantly reduced.

As a keynote speaker at a conference in 1998, Mr. Robert Spitzer, Vice President of Engineering at Boeing Commercial Airplane Group, remarked "Throughout years of air travel, safety has improved with the development of new technologies" [9]. He cited the development of jet engine technology as an example to support his point. Use of COTS items leverages the technology innovations of the commercial market that are outpacing DoD's ability to exploit them. This improves safety while increasing the availability of products from the commercial marketplace that satisfy military needs. The use of proven technologies further reduces another major portion of the cost; namely, that associated with an item's testing/qualification.

COTS items cover the entire spectrum ranging from systems down to piece parts. Where the Air Force mission is similar to the commercial sector, it affords a tremendous advantage to the Air Force to buy, in an expeditious manner, a commercial aircraft that has already been developed, tested, and certified by the FAA. Such acquisitions result in tremendous savings to the Air Force. The use of COTS at an equipment or part level improves the supply chain management posture for fielded systems. It increases the availability of equipment and systems for the war fighters. Additionally, utilizing commercial inventories provides the Air Force opportunities to reduce infrastructures that are required to support those weapon systems.

The use of COTS/NDI also allows our contractors to use their production, maintenance, and test facilities as well as associated staffs and processes for both commercial and Government use. Dual use of products, equipment, processes, and practices by the

civil and military sectors, where it makes sense, is a "win-win" situation for the industry and Government. It not only cuts down the cycle time, but it also eliminates duplication. Further, COTS/NDI has a potential for minimizing inefficiencies and avoiding the waste of valuable national resources if the appropriate level of technical assessments and analyses are accomplished prior to their use.

There are two key elements of OSS&E that should be considered when using COTS/NDI. The first element is an understanding of the inherent capability of the COTS/NDI so as to form an initial OSS&E baseline. The second element is a thorough understanding of the operational requirements associated with its intended use as an end item or as an integrated part of a larger platform. Lack of, or incomplete knowledge of the inherent capability of the COTS/NDI does not exempt the chief engineer from OSS&E responsibility. It is the responsibility of the chief engineer, as part of the overall acquisition strategy, to acquire or develop the key product characteristics, including COTS/NDI, necessary to form the basis for an initial OSS&E assurance baseline.

Performance Based Specifications

Military specifications and standards reform initiated in 1995 was a key aspect of DoD acquisition reform. Any military specification or military standard which contained detailed levels specifying "how to design" systems/items was considered inappropriate for new development efforts. Most were cancelled and others needed to be rewritten.

Back in the 1970s, the Air Force had embarked on a standardization effort called MIL-PRIME to ensure that the Government provided requirements for acquiring aircraft products in terms of operational performance. Having used this approach to acquire many systems, the industry and other services within the DoD endorsed this idea.

The MIL-PRIME concept was generally acceptable, but the documents needed restructuring and editing. MIL-PRIME documents were not consistent in content, and their level of detail varied.

Under the purview of the Joint Aeronautical Commander's Group (JACG), therefore, this initiative to specify performance requirements was revived with industry participation under the name "Joint Service Specification Guides (JSSG)" [10]. The JSSGs are being developed by the JACG Aviation Engineering Board (membership includes Industry, Army, Navy, and Air Force). These Guides contain the current best available guidance for identifying general performance requirements for aeronautical systems and subsystems. These guides are fundamental for preparing specifications for performance-based systems and major subsystems and airworthiness certification criteria. This JSSG approach provides the contractors clear accountability in designing safe, effective systems in a most economical way.

Form Fit & Function (F3)

The concept of form fit & function has been applied selectively to military systems for at least the past three decades [11]. Its application has brought mixed success for many reasons. One of those reasons has been that, until recently, commercial technologies lagged the technologies needed by the Government by several years. Another major obstacle has been that commercial parts and equipment were not suitable for military use mainly due to their lower standards for reliability.

This trend has now reversed. A large, competitive, commercial marketplace exists with expanding domains of application. Competition is driving technology innovations and variety in functions and performance. The technology innovations, in turn, have vastly improved reliability of electronics equipment and parts; and the trend continues. At present, the commercial technology is outpacing DoD technological needs. Parts and equipment that provide the desired functionality and performance at competitive prices are readily available commercially. In addition, system architectural schemes allow replacement of older equipment with new-technology equipment using the F3 approach. This is especially attractive for the military applications in which system life spans several decades.

The OSS&E policy takes these considerations into account and encourages the exploitation of the F3 concept. As long as the usage spectrum and the environments are conducive to the use of F3 parts or equipment, the original equipment manufacturers are given the flexibility to make that determination without being hindered by the Government. The F3 concept is an integral part of several cost-cutting initiatives being pursued jointly by the industry and the Government. A few of these initiatives are total system performance responsibility (TSPR), flexible sustainment, and diminishing manufacturing resources.

FAA Certifications

The FAA certification methodology has been developed over 40 years and is accepted world wide as the premier method of certifying aircraft. The new Air Force policy takes full advantage of the FAA methodology, when practical. For systems with unique Government missions, the Air Force has created a methodology that parallels the FAA policy construct. Current USAF commercial-derivative aircraft with missions similar to commercial operators (e.g., C-20, VC-25, C-32, C-37) will be FAA certified. The USAF hybrid commercial-derivative aircraft (e.g., E-3, E-4) should comply with FAA standards to the extent possible. Use of commercial-derivative aircraft in meeting Air Force missions is a special case and usually requires adaptation of the Air Force airworthiness methodology. Obtaining and maintaining FAA certification for the above cases is both cost effective and the preferred method of assuring airworthiness.

Methodologies

System Safety

System safety is a vital part of the OSS&E for the life of a system. The objective of system safety is to achieve an acceptable level of mishap risk through a systematic approach of hazard analysis, risk assessment, and risk management. Current Air Force policy details responsibilities for program managers with regard to the US Air Force Mishap Prevention Program. Specifically, program managers responsible for the development or modification of a system are to establish and maintain a tailored system safety program in accordance with MIL-STD-882D [12]. MIL-STD-882D has recently been revised with industry participation under the guidelines of acquisition reform. The resulting document requires judicious imposition of MIL-STD-882D. Only section 4 of the standard is contractually binding. This

section provides for (1) documentation of the system safety approach, (2) identification and tracking of hazards and (3) acceptance of residual risks by the appropriate authority.

In addition to establishing and maintaining a system safety program, the policy requires system safety groups (SSGs) to be established for aircraft programs unless waived by the appropriate Government office. The purpose of the SSG is to oversee the system safety program throughout the life cycle of the system and to document the mishap risk review process. The Chief Engineer is a key member of the SSG. The SSG is to be chaired by the program manager or the deputy program manager, and is to have a charter which includes representatives from the system user in the membership. The system safety policy also defines the appropriate levels of Government authority for acceptance of residual mishap risks. This methodology is extremely important for the Government to maintain the cost control by focusing on eliminating unacceptable risks.

Operational Clearances at Program Milestones

The operational clearance approach is an orderly, incremental, sequential activity that leads to aircraft certification. This incremental clearance approach establishes a framework of responsibility and accountability for establishing and maintaining the operational safety, suitability, and effectiveness of weapon systems throughout their life. The operational clearance approach can be applied to new acquisitions, to modifications to fielded systems, and to modified commercial items. This approach should be applied any time changes are made to the approved configuration of a system or end item. The configuration control board should not give approval for any temporary or permanent modification unless this approach has been followed. It is comprised of two parts. One part deals with clearance for individual equipment items, and the second part deals with the aircraft as a whole.

Equipment operational clearance (EOC): The EOC methodology described here (or one similar) is a disciplined engineering process for assuring OSS&E of aircraft. It should be recognized that products that are safe, suitable, and effective result from the disciplined application of multiple technical processes. Some of these key processes have been presented above. These processes embody a number of functional disciplines, each with its own unique, expert knowledge base. Criteria are extracted from the expert knowledge base of several functional disciplines that have a direct effect on the achievement of OSS&E. Adherence to these minimum criteria may not guarantee safety, suitability, and effectiveness; however, deviations from these criteria dramatically increase the likelihood of unfavorable results. Additionally, more detailed criteria may apply given particular programmatic details. A prime contractor may have a more detailed description of methodology to accomplish the equipment operational clearances. At the discretion of the prime contractor, suppliers and equipment developers may be required to follow that specific methodology.

The contractor accomplishes initial clearance of the equipment prior to approval for first flight by the Government's aircraft program manager. The update to the clearance is accomplished for the follow-on clearances throughout the development activities leading to the final airworthiness certification for operational use. Any modification to the equipment that received an EOC as part of original aircraft certification effort will require an EOC and, depending on the magnitude of the modification, most likely recertification of aircraft.

Figure 2 is a notional representation of the equipment operational clearance methodology. It depicts progressive levels of design maturity as equipment moves to higher levels of clearances. This methodology would be applied to hardware, software, and removable/replaceable items comprising the various component items of the total system.

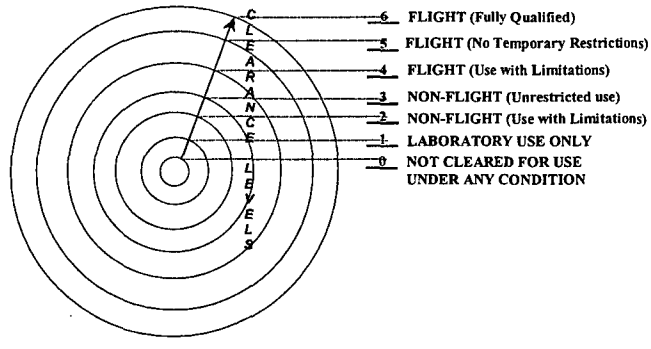

Figure 2.
Notional Equipment Operational Clearance Methodology

The exit criteria for each level should be established. Clearance to the next level should not be permitted unless the established minimum exit criteria for the current level has been met. To control the length of this paper, exit criteria for all levels are not presented. However, to illustrate how the graduation to next level of clearance takes place, level 0 exit criteria are provided below which show some top-level minimum criteria that should be satisfied to clear a particular item to the next level; that is, to level 1.

1) Functional requirements are properly defined and allocated
2) Integrity analyses are complete
3) FMECA is complete (functional, hardware/software)
4) Safety hazard analysis is complete
5) Interface requirements are documented
6) Detailed design criteria are documented
7) Conformity check is complete
8) Laboratory operating restrictions and limitations are documented
9) Laboratory test planning is complete

Air vehicle operational clearance: When we speak of the air vehicle as a whole, in contrast to the EOC discussed above, we are concerned only with establishing clearance levels 4 to 6, where flight operations are involved. As an example, minimum criteria to consider when clearing the air vehicle to level 4 are as follows:

1) All equipment operational flight clearances are at level 4 or higher
2) Flight test planning is complete
3) Aircrew and maintenance personnel are trained
4) Safety hazard analysis is complete

5) Flight and maintenance manuals are reviewed for adequacy
6) All aircraft operating restrictions or limitations are identified and documented
7) All problems from lower level testing are reviewed and dispositioned
8) All complaints from pilot simulations are reviewed and dispositioned
9) All problems from functional checks are reviewed and dispositioned
10) Independent review team review has been conducted (for air vehicle first flight)
11) All ground operation restrictions and limitations are identified and documented
12) Ground verification testing , flutter excitation, structural coupling, and electromagnetic interference tests are complete
13) Taxi runs are complete

Unless the minimum level 4 criteria are met, the air vehicle should not be cleared for first flight. In all cases, the individual hardware, software, or other removable/replaceable items of the air vehicle should have achieved an equivalent, or higher, level of clearance to that sought for the air vehicle. As mentioned above, the prime contractor, responsible for the development of the system, is also responsible for ensuring clearances. However, in addition to the contractor's clearances, the final approval authority for the conduct of first flight resides with the Government. With a large investment usually in billions of dollars and the fate of a program at stake, a comprehensive and complete review must be accomplished to determine airworthiness of the air vehicle. To conserve resources, it is only prudent to conduct a joint Government and industry review. Depending on the technical complexity of the program, a review conducted by a team of senior level experts from industry, Government and academia is highly recommended. Their recommendations to the appropriate Government official should form the basis for determination whether the air vehicle is safe and suitable for first flight. Again, more detailed criteria may be added given particular programmatic details.

Iterative application: Once level 6 clearance has been achieved for the air vehicle/equipment, any proposed change to the approved configuration baseline should enter the incremental clearance process at the lowest level and earn its way to the top. This iterative nature of the process application is what necessitates strict configuration control of the baseline configuration by the SM and the chief engineer. It is the linchpin in successful life cycle management of OSS&E.

Product Acceptance Criteria (PAC)

The methodology of product acceptance becomes of utmost importance in establishing and maintaining weapon system operational safety, suitability, and effectiveness. In the performance-based environment, it is almost certain that production products delivered to the customer will not be of the same physical configuration as the original qualified article. Proper documentation, an audit trail of qualifications, and a structured methodology for product development could avoid unnecessary expensive testing costs when accepting production products. Under the purview of the Joint Aeronautical Commanders, a "Performance Based Product Definition Guide" [13] has been developed which addresses PAC methodology in more detail.

A robust systems engineering process should go beyond simply providing a product design which has been verified through the qualification process to meet stated requirements. Design owners should also define and document "design intent," which captures the physical and functional aspects of the design solution that are key to its successful function. In addition, design owners should quantify the amount of variation of these "key characteristics" which is allowable in order for the product to function as intended. This information set is a subset of the total product definition that completely defines the product configuration and the processes used to produce it.

Once the key characteristics and limits of acceptable variation are defined, the design owner can develop product acceptance criteria (PAC) linked directly to these characteristics, which are traceable to the performance based requirements. Note that product acceptance criteria may take many forms: from physical measurement and inspection of hardware, to an acceptance test procedure, to statistical process control. The specifics will vary from case to case, but a common attribute is that any product that meets the criteria will possess the necessary functionality regardless of differences in physical configuration. This scheme also provides a baseline against which the design owner can evaluate the acceptability of future design and process changes.

The essential point is that the design owners should have the means to determine the adequacy of the products that they deliver to their customers. And the customers should, in turn, have assurance that the criteria that are to be used for product acceptance are based on sound engineering practices and are linked directly to the system performance requirements. This qualification process should be complete at the end of the development phase so that the PAC are available for use during the production program and the sustainment phase.

3. CONCLUSION

Mishaps in the aircraft business are inevitable. There are many factors that contribute to mishaps and most of those factors cannot be completely controlled. Therefore, complete prevention of mishaps is an impossible task. Safety hazards should be identified and eliminated or reduced to acceptable levels of risk over the operational life of the system. And those risks should be managed throughout the life of a system.

A reality that aggravates this challenge, today and for the foreseeable future, is managing risk within an environment of DoD downsizing and scarce budgets. OSS&E will continue to be a primary concern of the USAF. The process must continuously adapt to scarce resources in order to deal effectively with the changing situations in the world. Partnerships with industry, use of available proven processes and methodologies, and use of best practices are steps in the right direction to cost-effective improvement of OSS&E and mishap reduction.

Issuance of a high-level Air Force policy is only the first step toward this endeavor. The policy must be effectively promulgated throughout the Air Force for the entire product line. It is incumbent upon program managers, chief engineers and their

staffs, maintainers, and operators to maintain a diligent approach to this serious matter. Concerned parties must understand their specific roles and responsibilities and must work in partnership with industry as a cohesive team to meet this challenge. The chief engineer is the critical link between the contractor and the customers. His task is to ensure implementation of a disciplined engineering approach that establishes and preserves technical integrity throughout the life of Air Force systems. Yet, the degree of success depends on the level of cooperation that stakeholders give to the chief engineer. Collaboration potentially can assure OSS&E of USAF systems, which furthermore extends to reducing the DoD economic burden.

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