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Case Studies on Upgradable Engineering Design as a Powerful Tool for Air Force Industry

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Abstract

This essay demonstrates several case studies of Corporation Alpha's maintainability engineering group, which in turn offers evidence on the pivotal impact of upgradable engineering in air force. The application of these cases are used to collect both quantitative and qualitative data on the policies and processes involved in an aerospace system manufacturer's efforts to develop US Air Force fighter engines. Besides, further analysis has been proposed to emphasize efforts that the manufacturer implemented to design systems for maintainability and upgradability. In the future, research of the collected information is required for more detailed investigation.

Keywords: Upgradable; engineering; design; air force; maintainability.

1. Introduction

During fiscal year 1999, the United States Air Force was authorized to use over 24 billion dollars toward the operation and maintenance of its equipment [1]. These funds represent almost double the amount that the Air Force spends on procuring new hardware, and represents over 30% of the total Air Force budget. This fact has led the Air Force to launch investigations into what policies and practices allow them to most efficiently utilize these massive operations and maintenance funds.

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Given the Air Force's tremendous operations and maintenance budget, heavy competition exists to provide support services for Air Force aircraft. Moreover, Air Force officials want to minimize the funds used to operate their systems. One characteristic that determines how much effort and money aerospace system owners utilize to operate and maintain their systems is the system's sustainability. When a system is sustainable, the logistics, maintenance, and operations needs for that system have been optimized in order to minimize costs incurred by the owner of that system. Recently, the importance of system sustainability has increased because of pressure to reduce military spending while lengthening operational lives of aerospace systems.

Large Air Force operations and maintenance budgets and the heavy competition between civilian companies to support these operations have influenced the Air Force to gain greater understanding of aerospace system sustainability. This thesis examines how an American aerospace company designs sustainability into its products and what the results of those design efforts have meant to the users and maintainers of those systems.

2. Background

Corporation Alpha defines maintainability as "... the quantitative and qualitative system design influence employed to ensure ease and economy of maintenance and to reduce out-of-service time required for scheduled and unscheduled maintenance. 4" [2]. During my evaluation of Corporation Alpha, the company's maintainability and human factors engineering group expanded on their company’s efforts to design maintainability into its aerospace products. Unfortunately, due to proprietary considerations, the maintainability and human factors group could not fully reveal their reliability and maintainability (R&M) design techniques or how much usage of these techniques costs. I compensated for this omission through investigations of Air Force practices and examination of relevant literature.

2.1 EG10 and EG15 Maintainability Design Group

Between May 17, 1999 and May 18, 1999 I conducted a case study of the policies, technology, processes, and results related to Corporation Alpha's efforts to incorporate R&M into their systems. Corporation Alpha's maintainability and human factors group, composed of engineers specializing in the maintainability issues of the EG10 engine family and the EG15, hosted the interview process and provided the bulk of the research data [3].

In order to insure accurate recording of the statements and opinions of Corporation Alpha's maintainability group, my thesis advisor and I were both present during all interview sessions. After each session, we compared and contrasted our observations and made special note of issues we thought to be of particular importance. To add to the collected information, the maintainability group at times provided documentation to support their statements.

2.2 Engine Systems

The first engines of the EG10 family, the EGl0-1 and EGl0-2, were the engines that originally powered two of the Air Force's front line fighter aircraft, the F-15 Eagle and F-16 Fighting Falcon, during the 1970s and 1980s. The Air Force experienced a number of difficulties with these early EG10 variants including in flight

difficulties, which created especially dangerous situations for the single engine F-16 aircraft [4].

In response to Air Force complaints about the EG10-1 and EG10-2 engines, Corporation Alpha developed the EG 10-5 engine that entered service in 1986 and later the EGl0-9 engine that entered service in 1990. While also being designed to provide increased thrust, these engine systems were designed with maintainability as a major feature. According to Corporation Alpha's maintainability group, this focus on maintainability created an engine that was superior in flight and R&M performance to any other fighter engine system available [5].

Making systems capable of fulfilling customer desires and mission parameters has been the overarching goal of all the EG10 projects. To satisfy these obligations, each engine system has undergone a variety of changes, such as changes to the turbine stage, the exhaust generator, and other technical modifications. While some of these modifications have simply been to improve overall performance, many have been the result of efforts to improve the system's sustainability. Unfortunately, the exact development costs for the EG10 variants were proprietary information and could not be revealed.

The predecessor of the EG10 engine family, the EG15, will serve as the power plant for the Air Force's F-22 Raptor which is expected to enter service in 2001. During the EG15 development program, the engine's reliability, maintainability, and cost to operate were considered as vital to the engine's success as its operational performance and its stealth characteristics. The fact that the EG15 has fewer moving parts to make the engine more serviceable in the field and requires 40% less maintenance man-hours than the EG10 engines illustrates Corporation Alpha's efforts to improve the sustainability of their engines.

The EG 15 design process differed greatly from the process used to design the EG10 engine variants in that the EG15 was designed under Integrated Product Teams (IPT) teams consisting of the Air Force and Corporation Alpha personnel, and there was more analysis and testing of components and systems under the Propulsion and Power System Integrity Program (PPSIP). The use of IPTs in the EG15 program was a strict requirement put forward by the Air Force.

2.3 Policy

The Corporation Alpha maintainability group stated that during the design phases of the EGl0-1 and EG10-2 the Air Force did not emphasize engine R&M performance. The Air Force was only concerned with the pure performance of the engine and its procurement cost. However, once the EG10-1 and EG10-2 engines entered operation, the Air Force began to realize that the engine's unique modular construction would allow for different maintenance techniques and policies. The Air Force liked the new maintenance options, but they were unable to implement the ideas because the infrastructure did not exist within the Air Force to support them.

During the late 1970s and early 1980s, Air Force personnel decided to obtain an engine system that reduced the tremendous cost of ownership and relatively low reliability of the EGl0-1 and EGl0-2 engines in the Air Force's front line fighter aircraft. To promote the innovations needed to provide an improved engine system, the Air Force maneuvered both Corporations Alpha and Beta into creating new engine systems. The threat of competition motivated both companies, especially Corporation Alpha, to create new products that better

addressed Air Force needs. By fostering a policy of competition, the Air Force was able to leverage both manufactures into creating superior products thus creating an extremely positive situation for the Air Force.

During the late 1980s and early to mid-1990s American aerospace engineering corporations, including Corporation Alpha, had to adapt to a dramatically different world environment in order to survive. In addition to significant military spending reductions, foreign aerospace manufacturers were taking away market share from the American aerospace companies. In 1990, American aerospace companies provided systems for 90% of the worldwide commercial aerospace market, but by 1995, this percentage had decreased to less than 70% Aerospace customers were seeking alternatives to the traditionally long and expensive development timelines of the past, and the American aerospace companies had to change in order to survive [6]. As a result, many aerospace corporations began to investigate how to streamline their processes utilizing tools such as concurrent engineering, IPTs, and improved risk assessment.

There exists a debate about incorporating maintainability into aerospace systems. Some believe that making the engine less maintainable can reduce the cost and weight of the engine system. However, the people in the Corporation Alpha maintainability group countered this belief by stating that the money saved will be overshadowed by the huge amount of money lost by not making the system maintainable. One of the engineers in the maintainability group stated that they could build an engine for less now without maintainability included, but it will cost more in the long term."

Corporation Alpha believes that if they effectively design their systems for sustainability they will see savings in overall cost and manpower plus a more efficient sustainment pipeline. However, the. maintainability group clearly stated that the logistics pipeline providing replacement materials and parts to support the engine system must be pull driven in order for benefits of a truly sustainable engine to be realized. Contractor companies must be able to quickly respond to the military needs, and the military's infrastructure must be capable of quickly delivering necessary equipment and materials to operational squadrons. The Corporation Alpha maintainability group believes the only disadvantage in designing for sustainability may be the risk of lowered engine part availability. If the entire enterprise does not learn lean practices, this negative situation may occur.

3. Case studies of Corporation Alpha Organizational Structure

During the EG10-1 and EG10 -2 development phase, Corporation Alpha engineers worked in one of two teams, the project engineering team and the design and analysis team. The teams were composed of approximately 1500 engineers, each responsible for portions of Corporation Alpha's many projects. While this arrangement aided earlier sequential engineering processes where designs were moved from one engineer to another as work progressed, it hindered cross-discipline communication and prevented engineers from combining their skills.

Corporation Alpha design teams are currently organized into IPTs, Component Centers, and Module Centers. Through these different organizational structures, each Corporation Alpha project becomes the responsibility of an engineering team. The project's engineering team would be composed of engineers from different disciplines, such as maintainability, manufacturability, and performance characteristics, thus allowing each

engineer to work within their specialty while also allowing him or her to contribute to the work of other team members. IPT teams and other new organizational structures began to be implemented during the design of the EG10-5 to better address maintainability and performance issues, and the usage of IPTs has continued to mature throughout both the EGl0-9 and EG15 design programs [7].

In order to aid the design process, Corporation Alpha engineers receive formal IPT training. Their training includes conflict resolution methodology and methods of using disagreements as opportunities for design innovation. Another notable characteristic of Corporation Alpha IPTs is that the organization of the team itself is relatively flat, whereas one or two senior engineers dominated past teams. When presented with a task, first IPT members examine design requirements and parameters individually. Then, as a team, they write a formal contract for the task being examined and begin working out design details. Throughout the process, team members work to insure that the final product will adequately meet all customer requirements.

Participation of others, such as the Air Force or Corporation Alpha subcontractors inside Corporation Alpha IPTs very depending on the issue being discussed. However, the Corporation Alpha maintainability group mentioned that personnel from the Air Force or subcontractors are more than welcome to participate within the company's IPTs when necessary.

3.1 Maintainability/Human Factors Engineering Group

Corporation Alpha established its maintainability and human factors group during its efforts to design the EG 10-5 engines for the Air Force. Each Corporation Alpha engineering project effort includes a maintainability and human engineering discipline group that functions as part of that system's engineering integrity team7• They, with contributions from other engineering IPT groups, work to insure effective, timely, and economical accomplishment of identified program requirements.

A project's maintainability and human factors engineering group is charged with ensuring that new engine systems comply with customer and government maintainability regulations. Additionally, the maintainability and human factors group is charged with duties, such as improving product maintainability by implementing lessons learned and knowledge from field research. They also ensure that tools and other support equipment are designed properly from a maintainability and human factors perspective.

The Design Manual for Maintainability/Human Factors Engineering suggests implementing a number of major engineering design reviews early in the system's design stage and a critical design review performed just prior to freezing the design. These reviews insure that the new engine system will fulfill all customer requirements, including requirements for maintainability. If the system fails to satisfy any element of a review, the project is returned to the previous stage of its development. Because of the heavy competition and tight budgets affecting Corporation Alpha, it is likely that the continuation of the project is called into question if it fails a review stage [8].

3.2 Engine Metrics and Characteristics

According to the maintainability group, sustainable engines demonstrate the characteristics of durability, survivability (surviving handling by maintenance technicians and the rigors warfighting), maintainability, reliability, reparability, and affordability. Different military services and manufacturers have different metrics for measuring R&M [9].

However, even with the multitude of metrics used to gauge system maintainability, neither Corporation Alpha nor any other organization produces standardized definitions for sustainment terminology. It is conceivable that two individuals or corporations utilize the same word to refer to different characteristics.

Both intermediate level and depot level maintenance involves usage of civilian and military labor. Aerospace industry and government leaders have been debating the merits of two-level maintenance, maintenance using only the organic and depot levels, versus three-level maintenance for over a decade. The EG15 engine was originally designed to have three levels of maintenance, but the Air Force executed a policy change that altered the requirements for the EG15 to utilize two-level maintenance, and Corporation Alpha adapted accordingly to fulfill Air Force requirements.

Corporation Alpha maintains the capability of designing their engines to be compatible with whatever maintenance scheme their customers wish to use. When the Air Force implemented a two-level maintenance scheme with the EGl0-5, they were unable to support the weapon system because of an insufficient infrastructure. Cost benefit analysis studies are presently being done at Dulles AFB to determine which maintenance scheme is most effective. In the meantime, Corporation Alpha is looking into engine designs that incorporate even greater modularity allowing the engine to be separated into various modules for maintenance with even less difficulty.

According to the maintainability group, Corporation Alpha has been taking steps to incorporate R&M characteristics into the designs of its engines since the beginning of the EG10 series. By this group's estimations, while the R&M characteristics and overall R&M effectiveness of the EGl0-1 and EGI 0-2 engines were good, the engines developed afterward demonstrated tremendously improved R&M performance, as illustrated by the EG10's UER and MTBM metrics. However, the maintainability group emphasized that there was always room for improvement [10].

3.3 Technology

These first EG10 engines represented a tremendous technical advancement in fighter engine technology. First, they provided dramatically more thrust than previous fighter engines from Corporation Alpha or any of its competitors. Secondly, these engines were designed to allow its different subsections (e.g. turbine, compressor, combustor, afterburner, and etc.) to be removed and maintained separately. Before these EG10 engines, entire engine systems would be removed from operation and repaired. With the EG10 only one section needed to be removed. However, this new flexibility in engine maintenance led to logistical problems as personnel attempted to take advantage of engine modularity while the Air Force possessed an insufficient infrastructure to support the new practices.

3.4 Maintainability Technology

Designing maintainability into complex systems such as gas turbine engines is a very challenging task, but for the EG10 engines and the EG15, the process has an added degree of difficulty. These engines serve as power plants for high performance fighter aircraft, and on these aircraft, all characteristics, to a point, are optimized to maximize the aircraft's flight performance. Corporation Alpha designers must balance weight, performance, cost, and other characteristics with maintainability to achieve a balanced engine design. Among other practices, Corporation Alpha engineers combine their efforts and experiences in IPTs to achieve a design that satisfies all customer requirements. Additionally, Air Force personnel participate in these teams to insure that Air Force needs are satisfied.

Corporation Alpha's efforts can be illustrated by examining the placement of Line Replaceable Units (LRUs), engine components that can be removed and replaced by flight line technicians, on their engine systems. Removing and replacing LRUs account for many of the MMHs accumulated by fighter engine systems. The Air Force expects LRUs to require a minimum amount of effort to remove and replace while also having low MTTR characteristics. Each new generation of the EG10 engine has illustrated improvements in LRU design ranging from less cumbersome connections to error proofing LRU replacement tasks. The EG15's LRU features are particularly interesting because they can be serviced without removing the engine from the aircraft and have been specially designed to reduce technician workload in diagnosing and removing the parts [11].

4. Methodology of Design Processes and Tools

Corporation Alpha personnel believe the company's overarching goal is to provide its customer with a quality product in a timely fashion and always at a value added cost.

Corporation Alpha's efforts to incorporate sustainability into their engine designs have been guided by military directives such as Designing and Developing Maintainable Products and Systems - MIL-HND-470A which describes the processes that should be utilized to make new military systems maintainable. Moreover, Corporation Alpha also utilizes an internally published Design Manual for Maintainability/Human Engineering to aid its R&M design efforts. According to the manual, the amount of maintenance a system requires is a function of its use, environment, durability, maintenance procedures, and engine design.

Corporation Alpha engineers utilize computer based tools such as Transom- Jack/Jane, Stereo-Lithography, and CATIA to help them design their systems for maintainability. They also use older methods, such as building wooden system mock-ups, but such methods are being replaced with advanced software packages. Corporation Alpha st1ppliers have some access to these tools and the results that they produce, with larger suppliers having greater access than smaller suppliers.

4.1 Transom Jack/Jane

Transom Jack/Jane is a software suite that supplements and in many cases replaces creation of full wooden mockups to test the maintainability performance of engine designs. Through the Transom Jack/Jane program,

Corporation Alpha personnel conduct human factors analyses to measure the degree of difficulty that technicians of various sizes, shapes, and strengths have in performing a given maintenance task.

To facilitate their human factors analyses, Transom Jack/Jane creates a storyboard layout of male or female technicians, with physical characteristics predestinated by the design engineer, performing needed maintenance tasks on the engine. Transom Jack/Jane provides estimates on the difficulty of the maintenance task by analyzing the simulated technician's position and what percentage of his or her strength is required to complete the task. Transom Jack/Jane also shows the design engineers the simulated technician's field of view while performing the task.

4.2 Upgrade Process

Corporation Alpha often creates upgraded engines that incorporate improved performance to entice a customer into buying more of the product. Because of this policy, Corporation Alpha engineers must consider upgradability when they first begin to design the product. A maintenance group engineer stated "upgradability is a function of pure capitalism" while describing Corporation Alpha's policy toward incorporating upgradability into its systems. 1n the past it has been difficult to execute technical upgrades since everything in the engines are closely linked, making it difficult to just upgrade the system [12].

In order for an upgrade to be effective, it must be transparent to those maintaining the aircraft. When an engine upgrade is transparent, maintenance technicians do not have extreme difficulty when transferring from servicing the older version to servicing the upgraded version. Factors affecting system transparency include whether the upgraded model uses many of the same parts, particularly LRUs, as the older version, and if technicians need to learn many new maintenance procedures. In the case of a completely transparent upgrade, the flight-line technician would be able to use the same tools and procedures on the upgraded system as on the previous model.

Processes used to decide which upgrades to implement include risk assessment, cost benefit analysis, and trade studies. In some ways, these processes are similar to the ones originally used to design the system. Corporation Alpha utilizes a number of methods to survey its customers as to what upgrades to incorporate into the next generation of engine system. These survey tools include lessons learned databases, the Propulsion and Power System Integrity Program (PPSIP), program reviews, Air Force IPTs, Corporation Alpha IPT trade studies, and Failure Reporting and Corrective Action System studies [13].

4.3 Suppliers

Corporation Alpha contracts many smaller corporations to provide the individual components needed for their complex engine systems, such as, turbine blades and individual LRUs. Problems experienced by these suppliers can have a great impact on Corporation Alpha's ability to fulfill its obligations to the Air Force. In fact, a series of labor strikes affecting Corporation Alpha suppliers in the late 1970s crippled the company's ability to produce EGl0-1 and EGl0-2 engines and eventually resulted in large amounts of ill will between Corporation Alpha and the Air Force12 [14].

Because of the great effect that suppliers can have on Corporation Alpha's business, the company chooses its associates very carefully and attempts to monitor their performance. Corporation Alpha mainly relies on suppliers with whom it has a long history and that have good performance records. Prior relationships with Corporation Alpha also help to determine how much information sharing occurs between Corporation Alpha and its suppliers. Corporation Alpha gives its suppliers access to its huge databases of project related knowledge. This depends, however, on the niche that they fulfill in the current operation, given that these suppliers often operate on a need to know basis.

5. Conclusion

Corporation Alpha maintains an extensive non-government funded lessons learned database incorporating information and experiences from all of the company's past projects to aid its IPT teams in negating and mitigating problems. Checking the lessons learned database is specifically marked on the designer's formal checklist of things to do when designing a system. The database is completely online, meaning that company personnel at any Corporation Alpha facility can look at the same lessons learned database. Because of proprietary considerations, I was unable to examine the database.

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