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MITIGATING DIMINISHING MANUFACTURING SOURCES/MATERIAL SHORTAGES
(DMS/MS) AND OBSOLESCENCE FOR THE T-6 CANOPY FRACTURING INITIATION
SYSTEM (CFIS)

THESIS

Richard P. Carrano, DP-5, USN

AFIT/GSE/ENV/12-M01DL

**DEPARTMENT OF THE AIR FORCE
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AIR FORCE INSTITUTE OF TECHNOLOGY

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THESIS

Presented to the Faculty

Department of Systems and Engineering Management

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the
Degree of Master of Science in Systems Engineering

Richard P. Carrano

March 2012

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FRACTURING INITIATION SYSTEM (CFIS)

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Richard P. Carrano
Dayton, Ohio
March 2012

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Abstract

The Joint Primary Aircraft Training System (JPATS) lost the supplier for its canopy fracturing initiation system (CFIS) with no prospect for a replacement. This forced a complete CFIS redesign to supply both an active production line and sustain fielded aircraft. Compounding the problem, the existing CFIS became obsolete, which forced an interim design to be produced until a final long term solution was fielded. This thesis developed a method to optimize the redesign by determining the lowest cost path for both fielding the interim design and phasing in the final retrofit. Using the Excel Solver® modeling program, an optimal rate was found to expedite interim design introduction and fleet changeover to the final design. The analysis concluded that using achievable stretch goals, existing production capacity could be adjusted to field the final configuration at the lowest cost.

MITIGATING DIMINISHING MANUFACTURING SOURCES/MATERIAL SHORTAGES (DMS/MS) AND OBSOLESCENCE FOR THE T-6 CANOPY FRACTURING INITIATION SYSTEM (CFIS)

I. Introduction

1.0 Background

This thesis describes the methodology for developing and fielding a replacement Canopy Fracturing Initiation System (CFIS) for the USAF/USN Joint Primary Aircraft Training System (JPATS), depicted in Figure 1 (JPATS PMR, 2010), in a manner that minimizes the cost of simultaneously maintaining the existing subsystem. JPATS is the primary student pilot training aircraft for both services and consists of a single engine, dual-seat turbo-prop aircraft shown in Figure 2 (JPATS PMR, 2010).

A generalized formula will be developed to model an optimal solution that minimizes the cost of developing, fielding and procurement of an interim short-term replacement subsystem needed to keep the JPATS fleet operational while expediting development of a long term system level solution which will render the subsystem obsolete immediately upon fielding.

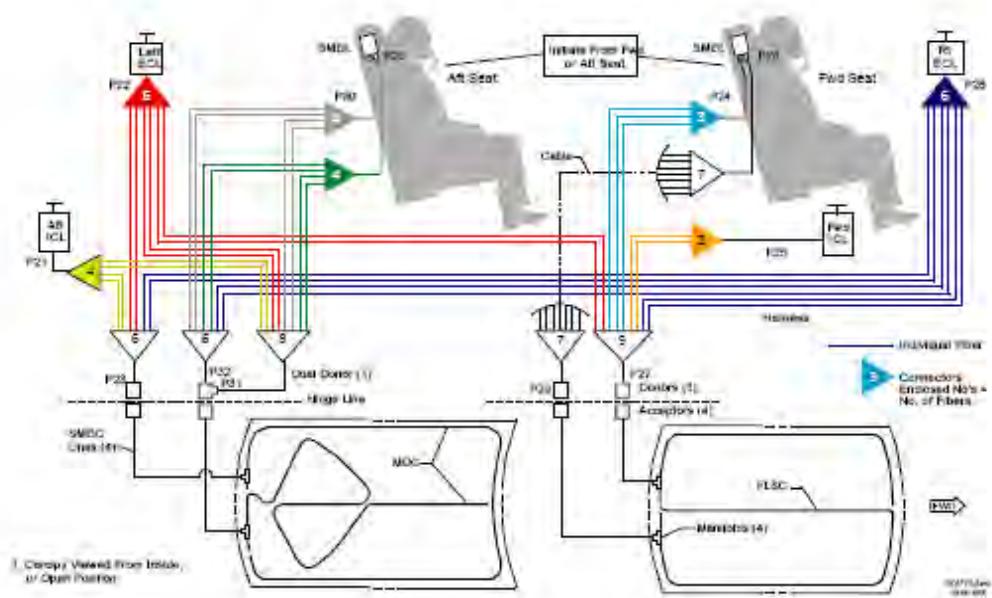


Figure 1. JPATS Canopy Fracturing Initiation System (CFIS) (JPATS PMR, 2010)



**Figure 2. Joint Primary Aircraft Training System Air Vehicle Platforms
USAF T-6A (above) USN T-6B (below) (JPATS PMR, 2010)**

The reason this is so important to the US Government versus commercial suppliers such as consumer electronics or auto manufacturers is the length of expected service life of the average military system. (Builder, 1997:120) Military hardware undergoes extensive and expensive qualification once developed and is typically updated/upgraded throughout a longer useful life versus the planned obsolescence common in the commercial sector. The item therefore needs to recover this higher development cost by remaining in service as long as possible, which drives the concept of periodic upgrades rather than complete replacement whenever possible to maximize the payback of the investment. But just as incremental upgrades extend the useful life of systems, the longer period of service also forces a need to manage operational costs; otherwise the overall benefit of the item will be lost under the burden of sustainment. This requires in constant monitoring of existing systems to ensure their reliability and maintainability are balanced to avoid runaway costs. At times this requires leadership to move decisively when a system's cost of operation proves unacceptable, despite every effort to make it viable. This can be painful, especially when huge costs were expended and a vested interest has been established. But allowing an untenable situation to persist will ultimately result in higher costs. The sooner a decision is made to change course and abandon a system, or sub-system, when necessary, the quicker the situation will right itself.

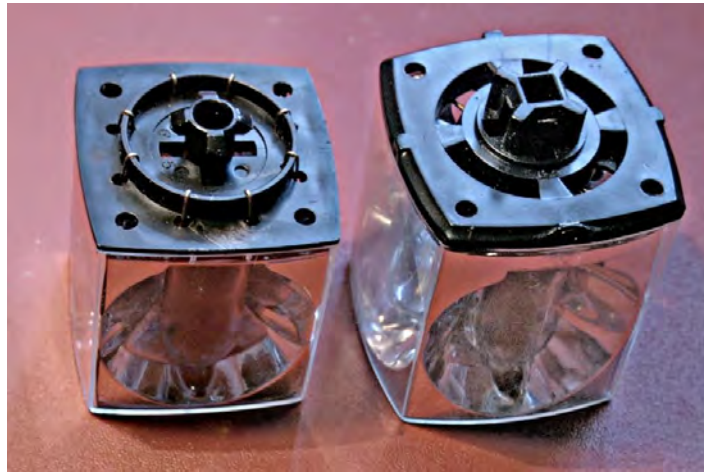
The joint USAF/USN Joint Primary Aircraft Training System (JPATS) currently faces a serious risk of production line interruption in 2013 due to inadequate supplies of a critical component that initiates the firing sequence in the canopy fracturing system,

which allows the seat to safely clear the aircraft during an emergency ejection. The existing Canopy Fracturing Initiation System uses a flash-bulb initiator and fiber optic circuit to start the firing sequence and ignite detonation cord embedded in the canopy, fracturing the canopy into pieces to allow unimpeded seat egress from the aircraft without injury, during either ground evacuation or ejection seat deployment.

The current flash bulb initiator in the JPATS aircraft Figure 3 was designed in the 1990s and was based on a system using a fiber optic energy transfer line to initiate the firing sequence. At the time, both JPATS and NASA (NASA, 2011) were considering the use of this leading edge technology. Optical flash bulb technology was considered the next technological leap and was expected to become the de facto standard based on its simplicity and predicted reliability. Once fielded, however, the system did not meet life cycle cost expectations for JPATS and NASA abandoned its plans to use a flash bulb initiator. The space agency switched paths and subsequently chose another system, leaving JPATS as the only crewed system operating with flash bulb technology. Mean Time Between Failure (MTBF) of the system never met original predictions and shrank steadily as JPATS fleet accumulated flight hours to the point where sustainability costs became intolerable. No other ejection seat equipped aircraft under development considered an optical system for their fracturing initiation system (NAVAIR, 2010) which meant the supplier had no incentive to make improvements in the system to satisfy other demand for the product. In 2007, JPATS started an initial design effort to replace the system which was expected to employ a fracturing method already deployed in other aircraft systems.

The JPATS CFIS is now an orphaned product (Builder, 1997:119), with no supplier able to provide replacement flash bulbs for the original design. Unlike true obsolescence, where the infrastructure no longer exists to allow use of an item, the current flash bulb does perform its intended function. The problem instead is one of Diminishing Manufacturing Sources and Material Supply (DMS/MS) (National Research Council, 2011), since there is no way to replenish bulbs consumed.

Compounding the existing problem, current supplies of flash bulbs for the initiator are limited and insufficient to meet demand based on the higher Mean Time Between Failure (MTBF) that the JPATS fleet is experiencing. The bulb elements in the original design employed a technology in common use throughout the consumer photography industry during 1970-1980s. The same flash bulbs were used in Kodak (Kodak, 2011) flashcubes® and Magicubes® (Kodak, 2011) for traditional film “Instamatic” cameras (Figure 4) and in flash bars used in instant photography (Figure 5). This technology is no longer produced as a result of the shift from film photography to digital image processing. The manufacturing community has not produced flash bulbs for over 14 years and a study seeking to locate and restart bulb manufacturing was deemed impractical. With supply no longer available and no vendors willing to attempt reviving production capacity, an alternative must be found since the existing flash bulb stockpile for making CFIS initiators will be exhausted by April 2013.



**Figure 3. Flashcube (Left) and Magicube (Right) for Kodak® Instamatic Cameras
Circa 1970-1980s (Kodak, 2011)**



**Figure 4. Flash bars used in instant photography (General Electric®)
(EBay, 2012)**

2.0 Problem Statement

Since there are other elements besides the flash bulbs in the existing CFIS contributing to excessive maintenance costs, a permanent CFIS replacement must be developed in parallel that will eventually eliminate the optical flash bulb design and use instead a simpler, more robust system, preferably based on existing technology already in service, to reduce life cycle costs to acceptable levels. Even if a complete CFIS redesign is developed, that effort is not anticipated to be developed, qualified and deployed by April 2013, so an interim solution must be found to sustain the JPATS fleet while the long-term CFIS replacement design is eventually fielded. Options to procure or produce the current flash bulbs must be considered and a make or buy cost-benefit analysis performed to determine the optimal path. If there is no viable option to restart dormant manufacturing capacity for the current flash bulb, then an alternate solution must be found to avoid production stoppage when the stockpile of all available existing flash bulbs is exhausted in April 2013.

Two simultaneous efforts are required to resolve the JPATS CFIS situation. First, a substitute flash bulb must be designed, qualified and fielded as a drop-in form-fit-function interim replacement. Second, a long-term solution must be started to fulfill the life-cycle demands of CFIS across the JPATS fleet.

3.0 Research Objectives/Focus

The goal of this thesis is to determine what is the optimal strategy to 1) design, develop, qualify and field an interim flash bulb while 2) simultaneously developing a complete CFIS redesign that eliminates the flash bulb entirely 3) to avoid overspending

on production of the replacement flash bulb since that design will become obsolete immediately upon fielding the redesigned CFIS system. The objectives will be the identification of the solution(s) to consider minimizing the development cycle for both the interim and replacement systems.

4.0 Investigative Question:

How should a DMS/MS optimality problem be structured and solved from a near, mid and long-term perspective?

This answer to this question supports many program office decisions. Is it economically feasible to restart the dormant manufacturing line to resume manufacturing flash bulbs that have not been produced for 25-30 years? (Camerapedia, 2012) If production is resumed, how much of the replacement bulb should be made as an interim solution until a newly designed CFIS can be fielded? What is the optimal cost-benefit break-even point between the substitute flash and the replacement CFIS development and procurement cost?

5.0 Methodology

This research effort focuses on exploring tools, methods, and metrics for evaluating and contrasting the source selection for a replacement flash bulb and the criteria for ensuring a cost-effective, robust CFIS replacement design that provides equivalent performance to the existing system while avoiding the high cost maintenance drivers that made the current design uneconomical.

The thesis will examine DMS/MS approaches through a literature search, and then engage in discussions with technical experts to collect data. This data will be fed into a constrained optimization problem and incorporate estimated design parameters to answer the question of how to structure the most economical for both short and long term solutions.

6.0 Assumptions/Limitations

Assumptions include a readily available technology, funding and technical expertise to successfully develop, qualify and field the interim and long term CFIS solution and that all current parties operating JPATS will pursue the same replacement strategy to optimize cost sharing. An additional assumption is subject matter experts have access to, and will share, realistic data. If not available, estimates will be used.

Since there has never been a design challenge of this magnitude facing the JPATS program to date, there are several ground rules and assumptions that will be used to mitigate the risk involved with retrofitting the current JPATS fleet of over 570 aircraft which is expected to grow to 747 by the end of production in 2016 (GPO, 2009). Since there are over 480 JPATS aircraft fielded with the current CFIS, including USAF, USN, and foreign military operators, and an unknown scheduled cut-in for fielding the replacement CFIS system, sufficient quantities of a qualified interim flash bulb must be procured, including spares, to satisfy the demand of all current JPATS operators. The goal is to only procure enough interim flash bulbs to cover retrofit and sustainment of the CFIS until the replacement non-flash bulb technology is in place.

The challenge will be to not overproduce the interim design, since it will become

obsolete once the replacement system is fielded and successfully passes operational test and evaluation. And since the development, qualification and ramp up schedule for the new system is still unknown, the challenge will be finding a conservative estimate for the quantity of interim flash bulbs to bridge the introduction of the new CFIS and provide a margin of safety to allow for unexpected startup delays.

The limitations are an inability to precisely predict the reliability and cost of either the interim solution or the integration challenge of the legacy replacement system. The break-even point for achieving cost savings over the current situation will contain estimation errors.

7.0 Implications

The implication is that similar design dilemmas such as the JPATS CFIS have a high probability of occurring with other crewed aircraft as their design useful lives are reached. Numerous aircraft in the current Department of Defense inventory face obsolescence challenges due to advances in technology and diminishing sources of supply and material shortages (DMS/MS) (National Research Council, 2011) as suppliers abandon support for product lines that no longer produce acceptable profit returns.

8.0 Preview

This thesis presents an analysis of how and why the JPATS CFIS was initially selected, fielded and operated based on the acquisition strategy in place at the time of contract award. The literature search will introduce similar optimization challenges from other programs, describe how they were resolved and apply any lessons learned

applicable to the JPATS CFIS. Further, interviews with technical experts will explain how the unexpected added cost of operation of the current CFIS design grew so burdensome as to force abandonment of the laser-based CFIS system in all manned flight vehicles except for JPATS. The general optimization mathematical solution developed provides a parametric framework for assessing what parameters and constraints are needed to build a model to derive a solution and develop a confidence level for program managers to assess the risks presented by alternative, specifically in optimizing return on investment by not overspending on interim measure when a long-term solution is the ultimate solution.

Finally, a specific solution will developed as a mathematical model as it pertains to the current JPATS case, using estimates for design, procurement, retrofit and sustainment which capture total cost of a developing and fielding an interim solution as well as designing and qualifying a new replacement system.

II. Literature Review

2.0 Chapter Overview

The purpose of this chapter is to introduce the concept of obsolescence as it pertains to aerospace applications, review previously documented research for similarity to this problem and, if relevant, examine how the solution was achieved; level of success, observed shortcomings and further research conducted using the approach or a modification.

2.1 Obsolescence & Diminishing Material Supply/Manufacturing Sources

2.1.1 Obsolescence

In the 32-year professional aerospace engineering experience of the author, obsolescence (National Research Council, 2011) can also be defined as the inevitable loss of usefulness of an item due to changes in its operating environment or introduction of alternatives that better perform the intended purpose, based on the opinion of the user. It occurs for various reasons, such as scientific advances, changes in consumer attitudes, or regulatory mandates.

Table 1. Simple Examples of Obsolescence

Product	Present state	Improvement	Rationale
Software	Existing version	New Release	Speed, Features
Hardware	Ethernet Card	Wireless	Portability, Speed
Hardware	Analog	Digital (Transistor)	Reliability, size, cost
Software	Version matched to OS hardware	DEC PDP 11/44	Obsolescence

The user is the critical factor in the definition of obsolescence. The mere fact that a new means may arise to perform a function is not sufficient to cause obsolescence. Only the inability to perform an existing function with available supplies will force an obsolescence response. Unless there is an obvious advantage to voluntarily change, users must perceive enough reason to abandon the sunk cost of their existing equipment to pursue a better alternative. Whether it's a lower cost, better performance or added features, enough justification must exist, otherwise the current means to fulfill a need remains satisfactory. This does not preclude the fact that users can be coerced to perceive a benefit over the status quo. This is what *marketing* does in a capitalistic society to boost sales of a new product. But the discussion of how a sales strategy can convince an operator to change equipment sooner than is absolutely necessary is beyond the scope of this thesis. See Figure 5 for a graphical representation of the obsolescence process.

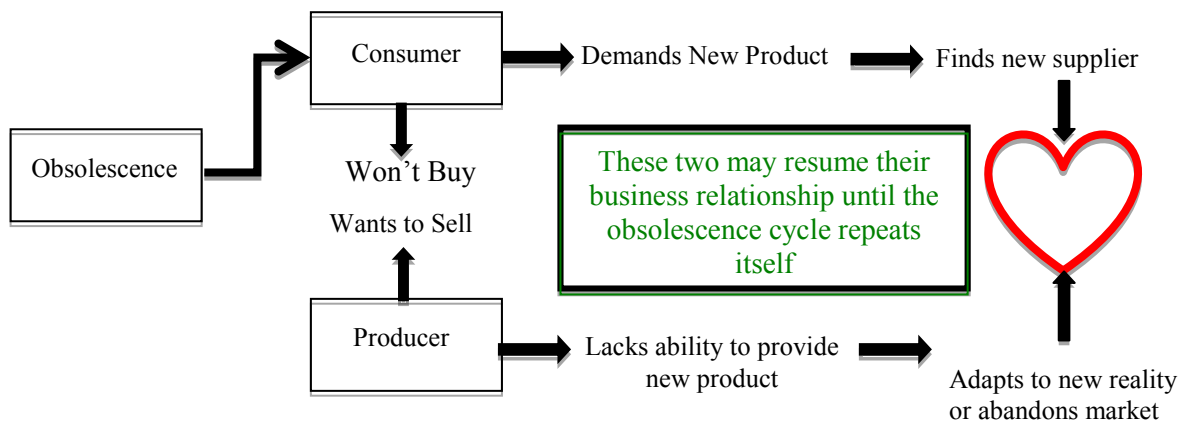


Figure 5. Obsolescence Process

2.1.2 Diminishing Material Supply/Manufacturing Sources (DMS/MS)

2.1.2.1 Diminishing material supply

This occurs when either the raw material to produce an item is no longer readily

available to the product's suppliers or the material has become so prohibitively expensive that it is not cost effective to maintain it as a product ingredient in the item's formulation. (Builder, 1997:119) In the commercial world, this means the item cannot achieve a reasonable profit margin. In the public sector, past pricing for similar items would determine acceptability. DMS/MS is independent of product utility or the technology behind its operation. Many perfectly viable parts that meet or exceed user's expectations simply cannot be produced in their present configuration if the availability of a key item in the manufacturing process is lost. See Figure 6 for a depiction of the DMS/MS process and how adjustments are made to accommodate the user's needs by finding either replacement suppliers or substitute products.

2.1.2.2 Diminishing manufacturing sources

This is a situation where the available source of suppliers is no longer willing to produce an item for economic reasons (Builder, 1997:119). The available supply dries up, making it difficult if not impossible to continue operations that rely on that item, jeopardizing a firm's ability to meet customer demands.

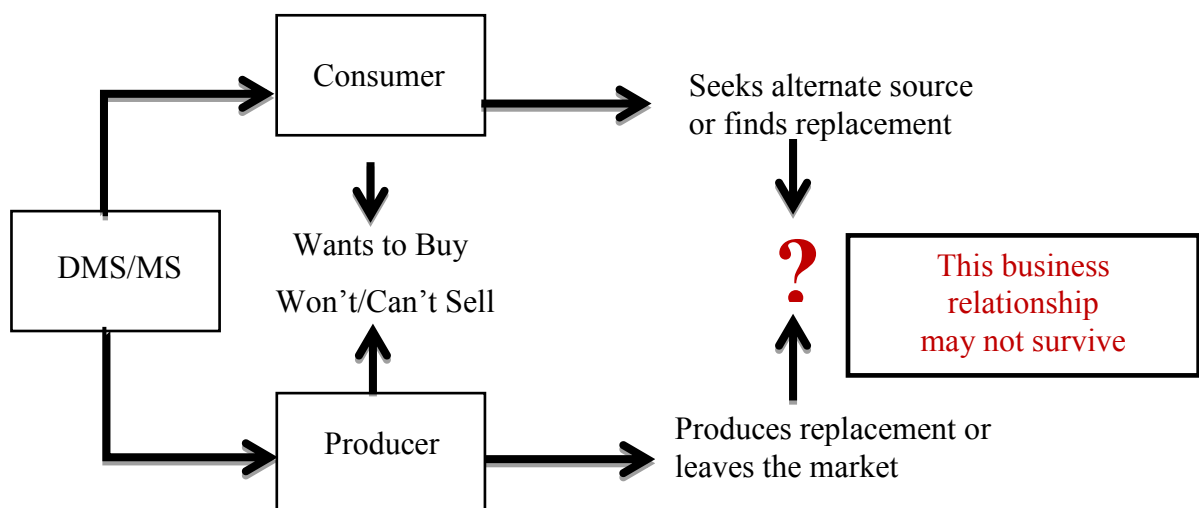


Figure 6. Diminishing Manufacturing Sources/Materiel Supply (DMS/MS) Process

2.1.3 Causes of DMS/MS

Market forces are the primary drivers affecting availability of any product, whether in the private or public sector, and, if these forces cannot be readily resolved by the infrastructure in place, the result is a DMS/MS situation (Cordero, 1991). This issue is even more troublesome in the public sector, because it's harder to increase the price paid for an item when it suddenly becomes scarce. The private sector is always more nimble and can move quickly to buy up remaining supplies to minimize DMS/MS effects, since they can simply pass on the higher price to their customers as a cost of doing business. The typical causes for DMS/MS fall into several broad categories:

2.1.3.1 Internal Competition for Resources

If there is strong enough internal competition for production resources that could be used by a firm elsewhere to increase profit or market share, then existing product lines are at risk of being either curtailed, reapportioned, or, if necessary abandoned (Builder, 1997:119).

2.1.3.2 Rebalancing a Product Mix

If a firm finds itself too heavily weighted in one product line, exposing it to unnecessary risk in the event its main income-producer falters in the marketplace or an interruption adversely impacts production, then a conscious decision could be made to change its mix of offerings to lessen an overdependence on a particular item. This may cause a short-term negative impact, but the assumption is that the firm would be healthier in the long run, much like pruning trees creates more growth in future seasons.

2.1.3.3 Responding to Outside Factors

If scarcity of a material drives the cost too high to provide profit justification, or some other outside factor such as newly enacted regulations that are costly to satisfy, then the cost-benefit to a firm could result in cessation of an item.

2.1.3.4 Coping with Marketplace Realities

If a technology change or breakthrough occurs in the marketplace that provides a different means of satisfying customer need for an existing product, and the new item achieves universal appeal, then the company would shift to the better prospect. In many cases, the DMS/MS information services are not available to many small businesses to stay ahead of an impending shortage situation, because they simply cannot afford to pay for such information which means they cannot perform the key element of obsolescence forecasting critical to effectively mitigate obsolescence before an issue occurs. (Sandborn and Singh, 2006:120)

All of these reasons may not immediately cause a mass exodus of producers, but a trend will begin which will slowly erode the previously reliable supply and the number of firms willing to carry or even provide quotes will diminish. If enough firms depart, then any infrastructure associated with the operation of the product also will shift away from supporting it, and the user would find it untenable to keep the item in its own systems, forcing a redesign or replacement effort. These forms of obsolescence occur daily across the DoD.

2.1.4 DMS/MS mitigation

DMS/MS can be mitigated through many ways, but the only method that avoids a reactionary mode of response is one that incorporates an active DMS/MS management

program as part of a basic acquisition contract. Unless this mitigation process is included as a contract deliverable, there can be no assurance that DMS/MS concerns will be discovered well in advance to allow an opportunity to address them proactively, preventing any manufacturing disruptions.

Mitigation requirements placed on contract can impose on the Original Equipment Manufacturer (OEM) periodic updates in areas such as monitoring and reporting on raw material price and availability (JPATS PMR, 2010), market trends for new products or techniques to satisfy existing need, health of sub vendor businesses, and status of regulatory compliance. A program of planned obsolescence can also be a basic part of a contract with an expectation that technology will be periodically refreshed at a certain interval, and, if not outright replaced, upgraded with the latest features of value to the user.

Other options to mitigate DMS/MS are incentivizing vendors to perform their own internal DMS/MS management program or subsidize suppliers by means of providing access to information resources (access to paid databases or subscription information services). At a minimum, whether or not part of a contractual obligation, a concerted effort should be undertaken within each OEM to at least periodically review market conditions that could affect their own supplier base so they can secure their relationship with their customers by ensuring an uninterrupted flow of existing product or equivalent substitutes to perform the mission. The entire field of Value Engineering (L. D. Miles 1961) started in the U.S. in the 1940s in response to the lack of critical hardware to satisfy the nearly insatiable demand for materiel during the peak of World War II production. The DMS/MS solution under Value Engineering was to find alternate solutions that

produce the same results without necessarily trying to duplicate the parts exactly. Instead, the focus was on what function the item was designed to perform and then find creative ways to achieve this faster and cheaper than the original design. However, not all DMS/MS resolution can result in lower per unit costs, as changes in operating environment since a product's introduction, as well as uncontrollable factors such as inflation, price of commodities, etc., may raise the price of any alternative chosen.

A final DMS/MS mitigation thought – it is far easier to plan for obsolescence by building modularity into products, especially high cost defense systems, than to preserve a supplier base, because, eventually, the extra effort to nurse dwindling industries to sustain them becomes a case of diminishing returns. The added cost would be better spent preparing for a transition to alternatives. Modularity also allows for a “remove and replace” sustainment strategy without needing to redesign or retool. The Office of Secretary of Defense (OSD) is currently sponsoring research into “flexibility of design” strategies through a Joint Task Force on Open Systems Design. (OUSD AT&L, 2011).

2.2 Sources of Obsolescence

2.2.1 Normal Life Cycle

Once a product or service capability is achieved and can be reliably maintained, the user community becomes convinced of its utility, and the producer's natural tendency is to improve on its performance through refinements to maintain the status quo and stave off obsolescence. Eventually, however, a different technique or solution appears that provides better capability, supplanting that status quo. Sometimes this happens through small, yet progressive design changes until the product or service reaches a plateau beyond which there is no available technical solution to advance the original concept

further from a cost-benefit standpoint. One of the most difficult points to grasp is when a product has reached its full capacity to deliver what was initially envisioned. A tendency to push for more features is valuable up to a point, but there is threshold beyond which added elements could significantly detract from the original intent. A good example is the Swiss Army knife, which, at its core, is a cutting tool. Over the years, designers have sought to enhance the item by adding more attachments until the higher-end model no longer resembles a basic tool. And with each added feature, the knife had to keep compromising its core mission to accommodate additional benefits (Zipkin, 2001:81). So, when trying to use the blade, it now must compete with other features, which makes the simple task of cutting cumbersome because the knife has grown to an unwieldy size. The bottom line, however, is that no single function performs its intended task as well as a tool devoted solely to that one particular task. Those tradeoffs are accepted to save the cost by enhancing an existing design rather than developing an entirely new unproven concept. On rare occasion, a novel approach to meet a need produces a simple, “elegant” solution, which, once implemented, seems so obvious in retrospect. The design of the safety pin is one such simple device designed in a moment of inspiration by twisting wire together. The lesson is that the simplest route is often the most elusive to achieve, even though that sounds counterintuitive at first thought.

2.2.2 Step Function Technology Shift

Another cause of obsolescence is a sudden shift in technology. Rare instances occur where something totally unexpected fundamentally breaks the normal cycle of incremental enhancements that immediately renders some current technologies obsolete, soon forcing many existing items into extinction, evaporating whatever loyal following

they may have enjoyed (Olleros, 1986:5-18). History is filled with examples of such tectonic technology shifts such as the inventions of telegraphy, radio, light bulb, and airplanes, to name a few.

2.2.3 False Starts and Abandoned Technology

There are other situations where, for example, competing technologies may show promise to perform a task equally as well, with the potential to cause a fundamental shift if developed for practical implementation. The expectation is that the marketplace will force the necessary refinements still needed to realize the full potential of the new product and that once matured, it will be fully accepted by users. However, if this does not occur, then the item becomes orphaned or abandoned, and either the existing method to meet the need remains the defacto standard, or a competing new technology emerges as the new preferred method.

2.2.3.1 Examples of False Starts

As shown in Figure 7, an experimental subway concept in New York City was developed by Alfred Ely Beach (Beach, 2011) in 1870 and operated as a demonstration project until 1873 and covered a distance of one city block, about 300 feet. Although it successfully demonstrated the ability to provide such a service, expanding this concept on a large scale was never pursued as the electric locomotive was viewed as a more practical alternative and the pneumatic transit project was abandoned, the tube walled off, and the only existing passenger car remains buried under the streets of the city to this day gathering dust while the Interborough Rapid Transit system, which broke ground in 1900, now transports an average of 5 million passengers every weekday, and over 1.6 billion people annually (MTA, 2010).

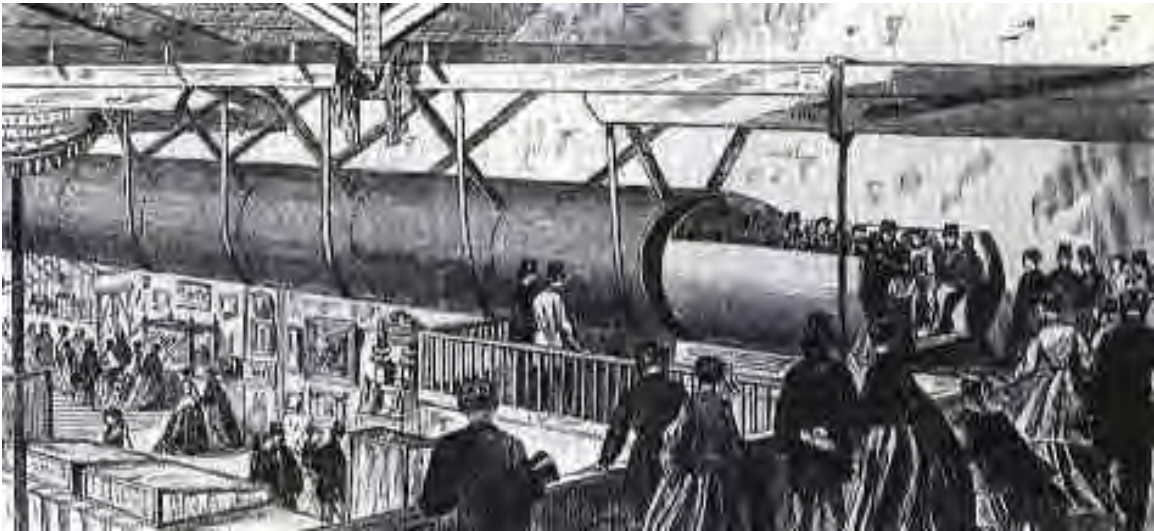


Figure 7. 1870 Beach Pneumatic Subway New York City, NY (Beach, 2011)



Figure 8. Edison public electrocution - Topsy the Elephant at Coney Island on January 4, 1903 using Alternating Current (Wired, 2011)

Another example is Thomas Edison's desire to electrify the US with Direct Current (DC) versus the competing method, which used alternative of Alternating Current (AC) proposed by George Westinghouse. This prompted the famous "current wars," with Edison holding macabre public demonstrations to warn of AC's dangers in which dogs, cats and even an elephant (Figure 8) (Wired, 2011) were electrocuted with alternating current. Edison at first failed to realize the huge cost of transmitting DC, requiring generating stations to be built every few miles to account for line losses. His idea lacked practicality. Eventually one of Edison's brilliant associates, Charles Steinmetz, convinced him that AC was the most practical means of long-range electrical transmission at a reasonable cost.

The lesson learned is that some ideas are either misguided from the start or are so far ahead of their time when first introduced that their risk of failure does not justify significant initial investment until their concept is both proven and universally accepted. For instance, after losing the current wars, Edison moved on and attempted designing a

battery powerful enough to operate an automobile. By 1900, 28% of automobiles produced in the U.S. are powered by electricity. But when Henry Ford introduced the Model T in 1908 (Figure 9), (Henry Ford Museum, 2011) the first affordable, mass produced gasoline-powered automobile, the electric car became impractical with the available state of battery technology in the early 1900s. More than a century would pass before the concept would again become practical, with the introduction of the Nissan Leaf, the world's first mass production all-electric vehicle (Figure 10) (Motor Trend, 2011). Whether the electric car succeeds this time on a massive scale remains to be seen.



**Figure 9. Henry Ford's Model T Automobile Production Line – 1908
(Henry Ford Museum, 2011)**

2.2.3.2 Abandoned Technology

The previous two examples provide the background for understanding the case of the JPATS canopy fracturing system. Existing technologies existed at the time of adoption but an emerging method that showed promise using a simple light transferring energy through a fiber optic cable instead of heavier, rigid ballistic-coated lines and explosives to initiate canopy fracturing. These lines required an explosive charge to

ignite them, and in turn required a burning fuse to flash inside a ballistic transfer line to a point where the actual canopy fracturing occurred. The optical initiation offered by CFIS would reduce the amount of aircraft explosives since it did not require either an initial charge or explosive coated transfer lines (JPATS PMR, 2010). Initiation for the optical CFIS used simple piezo-electric crystals that generated a small amount of electricity when pressure was applied during lever actuation, setting off the light bulbs, and generating photon energy sufficient to initiate the canopy fracturing sequence.



Figure 10. Nissan Leaf Production Line (2011)

(Motor Trend, 2011)

In reality, the simple optical initiation system was not robust enough to handle the rigors of the JPATS mission, and reliability suffered with failure rates rising to the point where the flash module system was not economical. In fact, in FY 2007, the annual maintenance cost for training aircraft cartridge actuated devices (CAD) used in the JPATS CFIS were higher than what the USAF paid for either its bomber or fighter aircraft fleets. The initial promise of lifetime installation and little or no maintenance proved false once the CFIS flash module was integrating into JPATS and fielded. The

higher-than-expected routine maintenance costs prompted a study to commence to replace the light energized CFIS with a legacy alternative that had a proven track record in other fielded aircraft. So the JPATS CFIS, although shown to be a viable option, never reached the level of universal acceptability within the aerospace community and therefore lost the backing of the major suppliers who would have to commit resources based on the assumption that a sufficient long term market existed that would justify their investment in equipment and materials to sustain production capability. As this was never realized, the technology was left unsupported and eventually no longer was produced, leaving JPATS without adequate supplies of spare parts and forced a design change to a legacy system in use by multiple existing platforms, thus securing a supply base for the remainder of the JPATS useful life.

The interesting element of this particular situation is that the flash bulb is not obsolete in the sense that if enough could be scrounged from warehoused sources, they would still perform acceptably in the current JPATS CFIS system. But there are no remaining sources to produce the current design flash bulb which means this situation is more serious than diminishing sources of supply in that there are *no* sources available – the sources are not disappearing, they are extinct. The very technology used to produce the bulbs has in fact become obsolete with respect to the need for such devices in the current electronic flash market that supplanted one-use flash bulbs. The original source of supply has sold off the equipment used to manufacture the current flash bulbs, the technical skills are no longer in place to resurrect this dormant process and business case analysis indicates it would be more prudent to develop a new replacement bulb based on

current technology despite the risk involved in development and integration into an existing system.

2.3 Obsolescence and DMS/MS Planning

Obsolescence is a situation where the external environment conspires to eliminate the value once placed on a mainstay product that held a commanding share of market and was generally considered indispensable. One example would be the overnight loss of the entire market share for buggy whips once the automobile became the commonly preferred method of transportation. Obsolescence and DMS/MS are related and one can result in the other but they are also mutually exclusive. When the environment in which a product must operate changes so drastically as to prevent the item from functioning, obsolescence erases the demand. Regardless of whether there are suppliers still willing or able to produce the item, the lack of demand forces supply base to switch to producing a new item that users want.

DMS/MS planning, when included as part of a management strategy, typically seeks to put a process in place to monitor and attempt to accurately anticipate when demand will wane and predict when replacement technologies will emerge to displace an existing product, creating a seamless transition to prevent potential production interruptions. That's the ideal theory. In practice, DMS/MS planning is not as simple to implement. It is not a simple phase curve that can be tracked so that the exact amount of resources is applied just when needed to head off any issues. If one primary source of supply decides to restrict output of a previously plentiful commodity, it can cause nearly instantaneous material supply shortages, if the supply chain lacks resilience. Some historical cases are Russia and Iran. Russia, the world's largest producer of titanium,

(SRAS, 2011 2011) raised fears in the aerospace industry when price hikes for titanium skyrocketed in 1996. (RAND Corp, 2009) Iran's mining of the Straits of Hormuz during the "Tanker Wars" with the US in 1987-1988 (Zatarain, 2009), threatened a cutoff of oil shipped through this strategic chokepoint during the Iran-Iraq conflict. Even if a source exists and is willing to produce an item, a natural impediment like a seaway bottleneck that blocks transportation can produce the material shortage.

2.4 Value Engineering and Risk Management

2.4.1 Value Engineering Definition

Value engineering is the technique of assigning value to all elements of a process stream to determine which factors contribute the most to total ownership costs. The ultimate goal is to reduce the cost as much as possible by developing alternative methods to achieve the same product performance at a lower price. Value Engineering (VE) was founded by Lawrence D. Miles who applied this technique, originally called Value Analysis, while working for General Electric around 1940. (Miles, 1961) He was attempting to solve critical parts shortages in the production of aircraft bombers during World War II. The basic premise of VE is to decide what functions an item has which gives it value and then evaluate how to achieve the same function by alternative, less costly means. Some of Larry Miles's more famous quotes are: "an item has value if it has proper function and the right cost," and "all cost is for function." Value Engineering grew out of a need to hire Value Analysts when GE had no internal job descriptions to hire analysts, but plenty of openings available for engineers. Value Methodology is described by the LD Miles Foundation as "a planned expenditure to analyze the functions of systems, design, criteria, etc. to satisfy needed quality and user requirements at optimal

cost of ownership” (Miles, 1961:34). In the United States, value engineering is specifically mandated for federal agencies in Public Law 104-106, which states that each executive agency shall establish and maintain cost-effective value engineering procedures and processes (OMB Circular A-131,1993). Value engineering can be considered both a “problem-solving discipline and incentive mechanism” for developing approaches to lower ownership cost (Mandelbaum et al, 2008:34).

2.4.2 Risk Management

In terms of supply chain management to avoid DMS/MS or obsolescence, risk management involves several approaches, all of which address the root causes of both issues. As with all risk management, all probable outcomes are considered and ranked according to their probability of occurrence and the severity of the outcome if they do happen. The current JPATS supplier has been tracking all available supplies of flash lamps from any source and has even resorted to open purchase on EBay[®] (EBay, 2011) of small quantities of stockpiled flash bulbs from various sources that are then harvested and made into CFIS flash modules. This results in a drop-out rate based on the yield of useable bulbs that have been stored for years under various conditions, mainly in uncontrolled environments regarding temperature, humidity, moisture and sunlight exposure. Nevertheless, this is the only available supply to sustain a capability in the short-term, there is no other choice but to follow the path of scrounging from every source that can be found. The only proactive move to exit the window of risk is to apply more resources to expedite development of a substitute as quickly as possible.

2.5 Supply Availability Monitoring

How do DMS/MS issues occur? While the useable lifespan of a product cannot

be accurately predicted, due diligence demands at least an effort to consider an alternative course of action in case a part or key component of a part could someday no longer be reliably obtained in the marketplace at an acceptable cost. In some cases, planning for this eventuality turns out not to be needed, since the product itself may become redundant before any of its subcomponents reach obsolescence. But planning for the possibility that it will occur during a product's useful lifetime is low cost insurance to avoid unpleasant lifecycle cost surprises and should never be ignored in acquisition planning and execution. It is extremely unlikely in the rapidly changing pace of today's technology that a product will remain in its original form for more than a few years or at most a decade. Although there are rare examples where this has occurred, it should never be considered the norm. It is doubtful we will ever see again an example similar like the ubiquitous light bulb that's still in worldwide use in virtually the same design form as Edison invented 130 years ago.

2.6 Technology Progression

If a requirement is so elemental to a system that it cannot be avoided through discovery of a new means that avoids it use, then the best that can be expected is that the technology matures to either simplify its design or to eliminate a rare ingredient, lowering the item's unit cost. One historical example is gold leaf, once used commonly aerospace applications as recently as 15 years ago, and is no longer a practical raw material.

Although it can be reduced in thickness for manufacturing purposes to between 0.1 and 0.125 μm , which is almost transparent, it is still costly in today's market of approximately \$1430 per troy ounce. Surprisingly, in some cases a technology is adapted to meet an alternate need for which it was not originally conceived and yet performs

remarkably well. An example from the pharmaceutical industry is Minoxidil®, (National Institutes of Health, 2011) the popular ointment used to treat male pattern baldness.

Marketed under the commercial name Rogaine, it was a drug originally developed to treat high blood pressure. It was discovered to have an interesting side effect – an ability to increase growth of body hairs. And since the patent expired in 1996 for the proprietary formulation, it is now available for mass cut-rate public consumption, to the delight of barbers concerned over dwindling numbers of baby-boomer clients.

2.7 Summary

Obsolescence is part of lifecycle logistics planning. It is a safe assumption that some, if not most, of the components in a system will undergo further refinements over time to enhance their performance, and their replacements sold to existing users. There is a risk of losing market share for users who choose not to upgrade to a higher value-added offering, since their competition will most likely do so. Obsolescence replacement may also include enhancements such as added features to satisfy spin-off demands that may have arisen after product introduction and, owing to advancements in technology or process development, the improved item may cost no more or even less than the original item. Diminishing Manufacturing Sources/Material Supply (DMS/MS) issues cannot always be planned or predicted effectively. They arise for financial reasons in the marketplace when there is either insufficient demand or profit to be gained from supplying a product on the open market and therefore no incentive for existing suppliers to continue producing the item. Moving to a producer using cheaper labor or overseas production are ways to stave off an eventual loss of supply from domestic sources, but beyond a certain point, even the lowest cost producer will find it unprofitable. Changes

to a product formulation or construction can preserve the source if the demand is sufficient, but this also has its limits and ultimately reaches a point of diminishing return. DMS/MS is best mitigated by accepting acceptable substitutes using methods such as Value Engineering to identify critical elements of performance needed from end items and then creatively developing solutions to achieve the result using multiple available resources to satisfy demand.

III. Method of Optimization

3.1 Chapter Overview

This chapter describes the approach to the general methodology used to setup a parametric model to conduct sensitivity analysis by varying overall cost and schedule to retrofit the USAF and USN fleets. The model is subject to the constraints of maximum production capacity and the operational user's ability to cycle a portion of their fleet through depot retrofit while still meeting mission requirements. The value of an optimization model is measured by how comprehensive the objective function is in capturing relevant parameters which can be adjusted by manipulating constraints to develop an array of available operating scenarios. This is especially useful in sensitivity analysis since parameter value weightings often shift in actual practice to correspond with real-time changes in the operating environment. For example, a program office may be constrained by funding at project inception only to later realize a windfall from fallout activity in competing programs which are unable to execute their funding. Therefore, the ability of the model to iterate easily over multiple courses of action provides the flexibility to quickly execute among alternatives and is key to capitalize on opportunities to maximize the efficient use of resources.

One measure of a model's utility is the amount of what can be adjusted by weighting parameters of most value to the user. This ability is important to all organizations, whether in the private or public sector, because of the constant demand for hypothetical analyses to adjust to unplanned effects on steady-state operating conditions. Responding to circumstances out of management's control is both the greatest challenge and opportunity to excel that faces leadership, because the competition is facing the same

situation, and only those applying the best response first will gain an advantage. Whether there is a critical shortage of material, a natural disaster, or changes to the spending plan, an ideal model is constructed to be nimble, so that it can mitigate unexpected events to minimize detrimental effects as well as capitalize on opportunities where and when they present themselves.

The proposed concept for the replacement flash module was reverse-engineered from the original design, and will use ceramic instead of gold as the reflective coating on the module's inner wall, with no appreciable degradation of transmitted light output. Unexpected benefits will also occur by replacing the five individual bulbs now used in the module with the proposed annular design (Figure 9), since the annular internal volume produces higher light output than the 5-bulb design with a smaller footprint, saving space and weight.



Figure 11. Design concept for the replacement flash bulb technology
(JPATS PMR, 2010)

This allows the module to have a higher wall thickness, which provides a better margin for error when welding the end caps to the flash module. And since weld burn-through is

the largest factor in yield loss for the current flash lamp, the annular design should be lower the manufacturing scrap rate.

3.2 Optimization Model

The model prepared in this thesis used was based on optimization modeling described in *Spreadsheet Modeling & Decision Analysis, 5th ed.* (Ragsdale, 2007). The methodology in this reference derives optimal solutions to problems containing multiple options to achieve objectives. For each case, the option was carried out to the point where it was determined that no additional value was added by continued iterations, forcing a best available final solution. The objective will seek to minimize total ownership cost. Three sets of decision variables are needed: L_i for the number of legacy configurations remaining in year i ; INT_i for the number of interim configurations; and LTS_i for the number of long term configurations, for year $i = 1, \dots, 20$. Each configuration corresponds to one aircraft. Legacy systems are a sunk cost and thus are not considered in the model's objective function, which is shown in equation 1:

$$\text{Minimize: } \sum_{i=1}^{20} (\$80,000 * INT_i + \$30,000 * LTS_i) \quad (1)$$

Equation 1 minimizes the total retrofit cost, considering both interim and long term configurations. The objective function solutions are subject to the following constraints:

1. INT_i, LTS_i, L_i are integer for all $i = 1, \dots, 20$
2. $0 \leq INT_i \leq 187$ for all $i = 1, \dots, 20$
3. $0 \leq LTS_i \leq 70$ for all $i = 5, \dots, 20$
4. $INT_i + LTS_i + L_i = 747$ for all $i = 1, \dots, 20$
5. $\sum_{i=1}^j (INT_i - LTS_i + L_i) = 747$ for all $j = 1, \dots, 20$

$$6. \quad \sum_{i=1}^{20} INT_i \leq 747$$

$$7. \quad LTS_i = 0 \quad \text{for all } i = 1, \dots, 4$$

$$8. \quad \sum_{i=5}^{20} (INT_i + LTS_i) = 747$$

$$9. \quad L_i - L_{i-1} + INT_i = 0 \quad \text{for all } i = 1, \dots, 20$$

$$10. \quad INT_j = INT_{j-1} - LTS_{j-1} - L_{j-1} \quad \text{for all } j = 5, \dots, 20$$

$$11. \quad LTS_j = LTS_{j-1} + INT_{j-1} + L_{j-1} \quad \text{for all } j = 5, \dots, 20$$

Constraint 1 limits the solution options to whole numbers since the replacement items cannot be procured in fractional units. Constraint 2 limits the interim production rate to a level which will retrofit at most 187 aircraft per year. This reflects an average of the production ramp up and the expected steady state rates which will maintain the required level of quality to satisfy performance requirements. Constraint 3 limits the long term production rate to 70 units per year from year 5, when it is first available, through year 20. This is based on the maximum aircraft the user can induct into depot level maintenance while still meeting mission readiness. The long term solution requires complete removal and replacement of the existing CFIS which will remove aircraft from service for 5-7 days. Constraint 4 defines the three canopy fracturing system options available, including multiple configurations fielded at the same time. Constraint 5 limits the total CFIS fielded to the summation of the legacy and interim units minus the long term solution, which all must equal 747. Constraint 6 limits the maximum number of interim solutions deployed to less than or equal to 747. Since the development time for the interim solution is shorter than for long term, there is a possibility that legacy units

will have reached their useable installed life before long term units are available, leaving the entire fleet deployed only with interim. Constraint 7 limits the first available fielding of a long term solution to year 5 to account for its development lead time. Constraint 8 specifies that the sum of the interim and long term solutions fielded from Year 5 to 20 must equal 747. This accounts for the retirement of the legacy units after their 4-year installed life expires. Constraint 9 specifies a one-for-one replacement of legacy units with interim units until all legacy units are removed from the fleet due to expired 4 year installed life. Constraint 10 limits the interim units in year j to the interim units from the previous year minus the contribution from the previous year's legacy or long-term units produced for years 5 through 20, since year 5 is the first year long-term units are available. Constraint 11 limits the long-term units in year j to the long-term units from the previous year plus the number of long-term units that replaced interim units in year j , plus the contribution from the previous year's legacy units for years 5 through 20.

Program management will be provided data that shows the cost benefit of attempting to expedite the retrofit of the JPATS fleet from the current CFIS system to a more reliable system currently in use on other USAF/USN aircraft. Since the unscheduled ongoing maintenance burden of the JPATS CFIS is excessive and growing daily, there is incentive to explore completing the complete retrofit as soon as practical. The model will assess the point of diminishing return for additional funds expended.

3.2.5 Solving for the Objective Function

The Excel Solver optimization tool calculates a total installed cost per aircraft for retrofitting INT_i and LTS_i into the fleet and will include the following:

- 1) Burn down of the existing Legacy units already fielded
- 2) Replacement of L_i units during required time change out using the remaining stores of L_i units
- 3) The introduction of the INT_i and subsequent replacement of L_i with INT_i units.
- 4) The introduction of the LTS_i at a point where all of the L_i units have been exhausted and the eventual burn down of the INT_i units until they are all replaced by LTS_i in the final fleet design configuration.
- 5) The total cost for implementation of the transition from L_i to INT_i to LTS_i is calculated for different production rates of the respective hardware and the retrofit of aircraft to the different configurations.
- 6) The model's projected INT_i and LTS_i initial production rates are based on historical rates for similar JPATS ejection system life support hardware. The best indicator of throughput constraint is the user's ability to provide aircraft to induct into the retrofit line to install the final LTS_i design solution while maintaining operational readiness at acceptable levels. Since the INT_i solution is installed at the organizational level as part of routine maintenance, there is no inconvenience burden to the user as there is with LTS_i . However, the longer INT_i remains in place, there is continued concern over the additional cost of maintenance the existing laser-based CFIS system. This cannot be classified as a risk since it is an undefined consequence. Multiple failure points in the CFIS have continued to fail prematurely at unpredictable rates and each has a different cost. In total, aside from the need to address obsolescence, the lack of robustness and system reliability is the main reason for replacing the entire CFIS with the LTS_i .



3.2.6 Sensitivity Analysis

To evaluate whether any benefit can be obtained by shifting constraints within reasonable limits of production capacity, two trials were run changing the following:

- (1) The annual number of field retrofits of the LTS_i accomplished per year.
- (2) The end date for completing LTS_i retrofit using the original retrofit schedule to assess whether extending the end date would derive any total cost savings.

The analysis will run iterations of the fleet retrofit rate per year per Table 2. Note:

Table 2 – Sensitivity Analysis

Configuration	L_i	INT_i	LTS_i
Retrofit Rate	N/A ¹	70	70
		80	80
		90	90
		100	100
		120	120

¹ L_i units are no longer in production. Entire fleet is currently fielded with L_i . L_i spares available until 2014 when INT_i becomes available. Last remaining L_i units installed in 2014 expire and removed from service by 2016.

IV. Analysis and Results

The approach taken to develop a mathematical model captured the major cost elements of the simultaneous development and acquisition of both the interim and long-term solutions. The cost elements were scaled according to their proportional representation in the fleet mix of total USN and USAF aircraft procured. An Excel network model was set up to solve the objective function, according to the coefficients and constraints needed to accurately bound the problem statement. This allowed Solver to run optimization trials and perform sensitivity analyses based on the trade-off between cost and time to implement. The results indicate the optimal mixture of interim solution parts to be purchased one development is concluded that will satisfy the demand for ongoing maintenance (sustainment) while the long-term solution is deployed and begins service.

4.1 Application of Methodology

A graph was generated within the model to represent the burn-down of the Interim units and the ramp-up of the Long Term units. The resulting graph generated of the interim versus long-term solution clearly depicts a period where the interim is phased out while the long-term solution is slowly integrated into the fleet. The best-case scenario is a seamless transition with no excess interim product remaining once the long-term solution is on place. This ideal situation will never occur in reality, which is why an optimization can only be a best solution based on contingencies.

4.2 Graphical Optimization Model Results

Figures 13-15 provide plots of data results from Excel Solver model iterations of the Objective Function using different constraints which varied production rates for the fleet retrofit to the INT_i and LTS_i configurations.

4.3 Contingencies Affecting Optimization

Occasionally, factors out of the control of program managers will impact the implementation of optimization efforts and may delay the realization of benefits or affect the overall cost benefit upon project completion. All models must be based on initial conditions and assumptions from which constraints are established. When reality intervenes, the model must be adjusted to accommodate for these uncontrollable elements. A robust model possesses the flexibility to make these adjustments without requiring a major overhaul of its logic and programming. Some examples of these factors impacting long-term solution retrofit are:

- 1) Quality or qualification issues that delay fielding LTS_i
- 2) Inability to predict accurately the reliability of the LTS_i once fielded
- 3) Difficulties with installing the LTS_i until several installations are completed, which cause reduction of required throughput to achieve optimization.
- 3) Startup issues with infant mortality of components that may have been qualified individually but not yet tested in an operational environment as an integrated system.
- 4) Retrofit funding constraints that affect timing of aircraft inductions into the modification line, delaying retrofit beyond the ideal timeline predicted by the model.

- 5) Operational needs of the users may require a smaller percentage of the fleet to receive the retrofit per year, even if excess retrofit capacity is available.
- 6) Delays in long-lead parts from various suppliers due to, for instance, raw material shortages or sub-vendor throughput constraints.

Because there was a sunk cost incurred in developing the interim solution, which has no value once the *LTS_i* is fully implemented, there could be a management bias to produce excess interim solution items to account for unanticipated startup or retrofit delays. Resisting this temptation is imperative if the optimization is to be realized. Although there will never be a perfect solution, minimizing the interim excess is the ultimate goal since the product becomes obsolete for the JPATS fleet once the *LTS_i* is fielded, because *LTS_i* eliminates the flash-module entirely in its basic configuration. And each interim flash module is expected to have a predicted unit cost in the five-figure range. With a total of 8 flash modules per aircraft, the estimated cost for each *INT_i* installation is approximately \$80K per aircraft, which is hardly a cost avoidance to be taken lightly. The downside of not procuring sufficient supplies of *INT_i* flash modules would be degraded mission capability, but if there is a quick-turnaround production lead time for *INT_i* this may allow the USG to keep minimum inventories and thus reduce holding costs while still maintaining levels of aircraft availability that may not be optimum, but are still acceptable to satisfy the mission. This would ultimately be resolved upon *LTS_i* retrofit.

The model helps support program office decisions on timing of funding needs, execution timetables and vendor expectations to ensure mission capability. The intent is to answer questions such as how quickly to procure and retrofit the *INT_i* and *LTS_i*, or

whether it is economically feasible to resurrect the dormant manufacturing line by reverse engineering and manufacturing flash bulbs that have not been produced for 25-30 years? If production of the L_i bulb is deemed too costly, then how much of the replacement bulb should be made as INT_i until a newly designed CFIS can be fielded? What is the optimal cost-benefit break-even point between interim bulb and the long term solution in terms of development and procurement costs? As there is always a margin of error when estimating cost-benefit, the program manager would also benefit if the analysis also provided a range of options, ranked from worst, most probable, to best case.

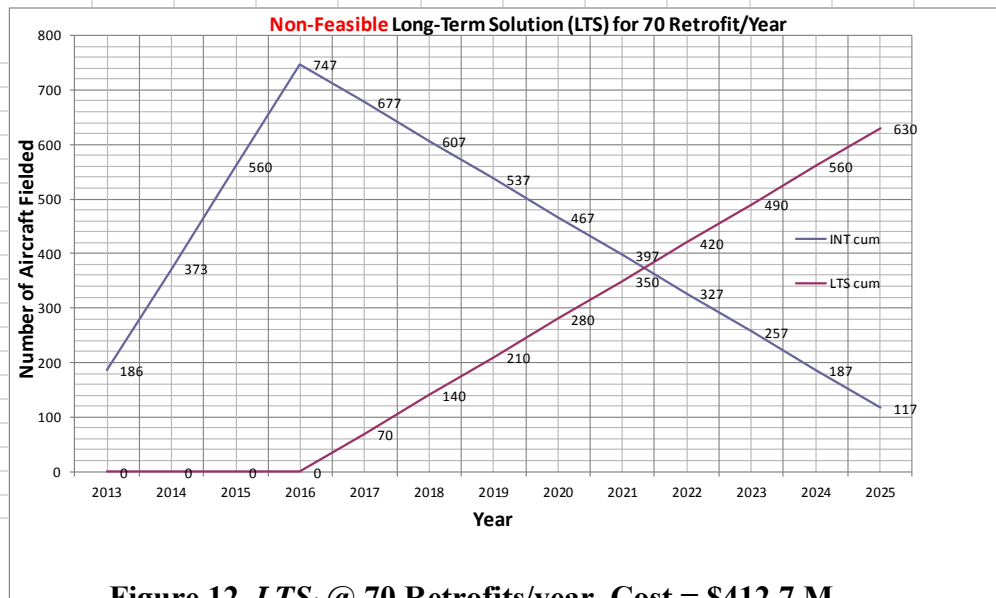


Figure 12. LTS_i @ 70 Retrofits/year, Cost = \$412.7 M

Shown in Figure 12, at 70 retrofits/year, there is insufficient time available to completely retrofit the fleet before the end of the aircraft service life of 24 years. This is a Non-feasible option.

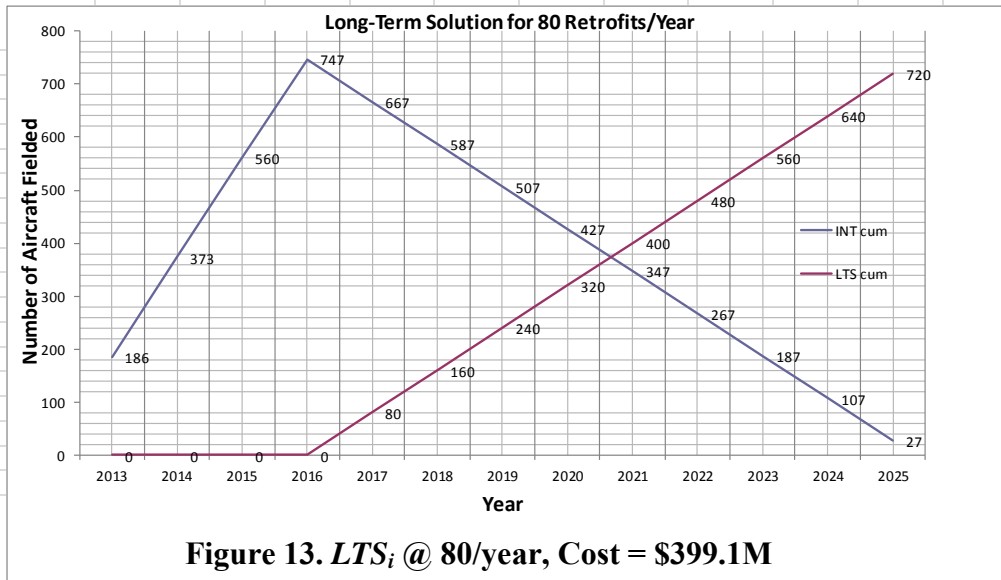
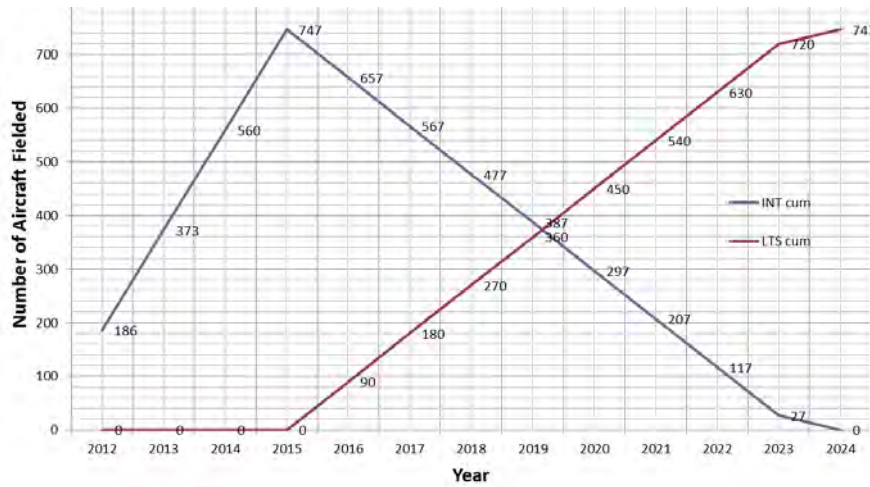


Figure 13 shows one option that will complete the entire fleet retrofit by 2025. The model constraints were then varied to calculate the lowest cost option. This option was not the lowest cost.



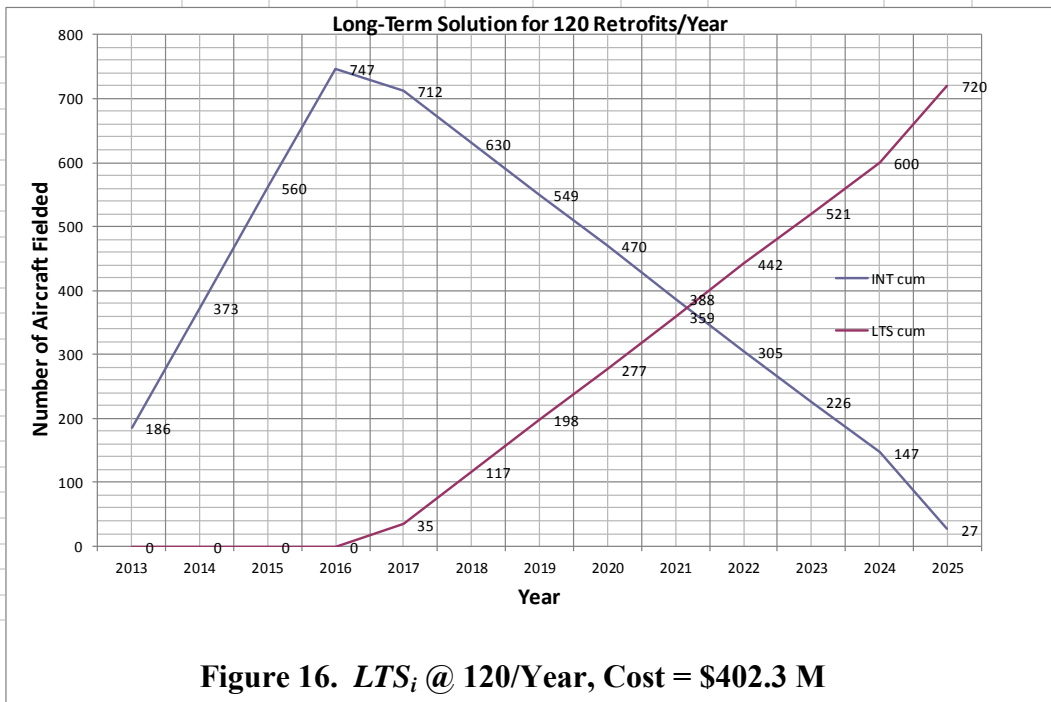
This is the lowest cost option which meets the criteria of retrofitting the entire fleet while maintaining a 747 aircraft operational inventory. This trial is the optimal solution for three reasons:

- 1) The current retrofit line operates at a rate of approximately 5-6 aircraft per month.
Increasing this to a rate of 7-8 per month is a reasonable increase to negotiate with the user to reduce the ongoing maintenance cost overrun and subsequent non-availability associated with the existing CFIS.
- 2) A 90 retrofits/year rate demonstrates the lowest total cost.
- 3) There is no cost benefit to increase the rate of retrofit to replace *LTS_i* faster than 90 per year. The cost calculated by the model is greater for both 100 and 120 retrofits per year. These increases would also incur additional infrastructure costs to add more retrofit line capacity that is not captured in the mode.



This option accelerates the retrofit without any corresponding reduction in total cost. Also, non-recurring costs not captured by the model incurred in this option involve increasing retrofit line capacity. This further increases the cost of this non-optimum

option. Additionally, the user would not be able to supply this number of aircraft to induct into retrofit without degrading their mission availability rate.



Similarly to Figure 16, there is no cost benefit to increasing the retrofit rate to 120 aircraft/year if the cost is higher and the user cannot accommodate that number of aircraft in not mission capable (NMC) status during the retrofit period.

4.4 Sensitivity Analysis

As shown in Table 3, the lowest cost is 90 LTS_i retrofit installations per year. There is no added value derived from increasing the retrofit throughput higher than 90/year because this would entail adding an additional retrofit line to the present OEM’s capacity and require paying overtime to meet the increased capacity surge, both of which would negate any added benefit from retrofitting sooner.

The JPATS users would also incur operational hardships if forced to induct more than 90 aircraft per year into the retrofit line. The model’s optimal rate of 90 per year is

coincidentally the OEM’s maximum rated JPATS production capacity. Although this value has never been sustained in practice since initial production began in 2001, it is within the capability of existing manufacturing planning and assembly processes. JPATS operators would have to adjust their training syllabus to accommodate this rate, but the cost benefit would justify this modification of their training curriculum, since the savings would be \$14.1 M when compared with to the next available alternative of 100 retrofits/year.

Table 3. Cost Versus Long-Term Solution Installation Rate

Production Rate (Installs/Year)	Cost (\$M)
70	412.7
80	399.1
90	385
100	403.9
120	402.3

Table 4 shows the relationship between varying the end date for installation of the long-term solution. Its purpose is to identify any benefit from surging the retrofit to assess if the total cost is lower by completing it sooner. The data in indicates the installation end date does not varying significantly when the *LTS_i* retrofit is increased from the optimal 90 per year to 100 or 120 per year. The end date remains 2025 in all cases because it is based on availability of *LTS_i* retrofit kits (there is a fixed rate of production) and this acceleration does not factor in the added cost of extra shifts or expanding the retrofit line’s capacity to accommodate the higher aircraft flow rate. The cost for 100 or 120 retrofits/year is higher than the optimal 90/year as expected due to the required additional resources to increase capacity. The user will endure operational

hardship if required to provide more than 90 aircraft/year for retrofit, and the modification line will incur additional costs to expand capacity,

Table 4. End Date Versus Long-Term Solution Installation Rate

LTS_i Installation Rate/Year	LTS_i Installation End Date
60	2027
80	2026
90	2025
100	2025
120	2025

Figure 17 is the notional schedule for the L_i replacement units showing the phase-in and overlap until the entire fleet is retrofitted to the LTS_i design solution in 2032.

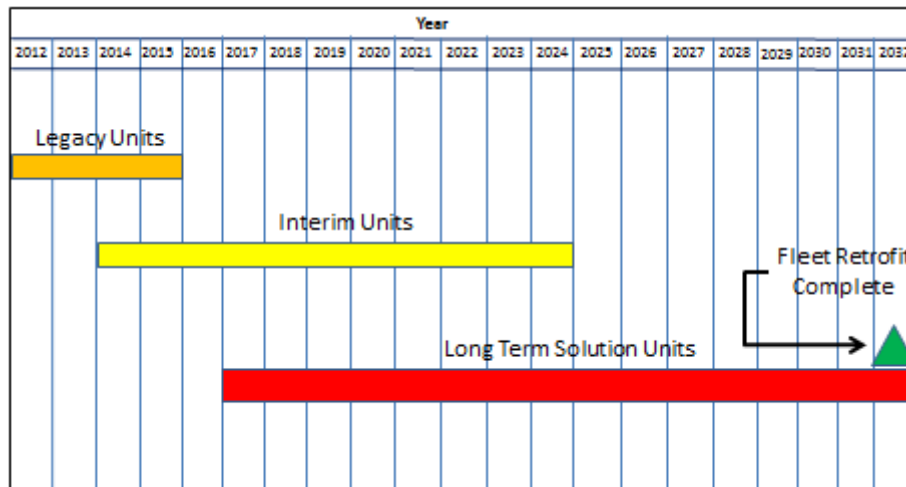


Figure 17. Notional Implementation Schedule

V. Conclusion and Recommendations

5.1 Summary/Conclusion

This thesis analyzed the three current design configurations for the JPATS CFIS and developed an optimization model to determine the lowest cost approach for retrofit the JPATS fleet to a more robust design that eliminates the maintenance drivers adversely affecting reliability. The model determined the lowest cost for the best retrofit rate of 90 aircraft per year. Coincidentally, the steady-state condition for the present modification line is between 6-7 aircraft per month (72-84/year), making the 90/year optimal rate a reasonable stretch goal to achieve. In addition, the user can be reasonably expected to support this retrofit throughput knowing that the maintenance drivers will be eliminated with the LTS introduction. The eventual cost-benefit to the user more than compensates for the short-term inconvenience to mission capable

5.1.1 Structuring an optimality problem

Optimality can only be achieved for a specific set of parameters of value to the user. For this reason, optimality is by nature subjective. Another aspect affecting optimality is the complexity of the solution model, driven mainly by the amount of simultaneous constraints that must weigh into the final answer. The more comprehensive the goal, the more constrained the model's mathematical formula will be, and consequently compromises must be made to accommodate all of the concurrent demands on the model. In simple terms, the more you are trying to accomplish at once, the harder it is to simultaneously satisfy all goals equally, forcing inevitable compromises.

Optimization is not a process that normally achieves immediate results, although if the initial conditions are so poor, even its short-term effects can be dramatic. Optimization is

designed to be a progressive exercise that requires patience, perseverance and flexibility to allow the necessary tweaking during implementation to achieve a best outcome.

5.1.1.1 Near-term optimization

A near term optimality solution, as in the case of a manufacturing line, must be simple enough to address the user's most pressing need and provide easily run sensitivity analysis to identify steps to be taken to keep the line operating without interruption, producing product on schedule at an acceptable cost. There is less optimization underway in the near term as it simply seeks to first achieve consistency and then form a baseline from which to make further improvements.

5.1.1.2 Midterm optimization

A midterm optimization tries to look several years into the future to assess the factors that will impact producibility, with a goal to structure the environment outside of the immediate area of control so that it sustains, complements and supports the operation. Mid-term goals also seek to instill optimization principles in the sub vendor network the producer relies on so that all parties in the supply network benefit from obtaining the highest value at the least cost.

5.1.1.3 Long Term optimization

Long term optimization looks at the current product, tries to envision where the demand will be in the out-years, whether the current production will be sustainable, and if not, what steps must be taken in the near or midterm to begin a transition. Long term optimization could result in a decision that producing an item is no longer in the best interest of a firm and that the product should be abandoned. The cost-benefit must be carefully reviewed so that an opportunity remains to still serve markets where a

technology may still be in demand, although infrequently, at a premium. This would, in some cases, justify keeping a product line in preservation state but still capable of startup and production on a small scale to meet demand. Examples are the specialty products produced for the nuclear power industry which carry a high premium, are produced by only a few select, certified manufacturers, and must be available immediately during periodic scheduled maintenance shutdowns. Another example is specialty steel manufactured for the defense industry. The Berry Amendment (U.S. Code Title 10 Section 2533a 2011, Title 10 Section 2533a), which, along with the Buy America Act (US Code Title 41 Section 116 1993, Sec 1638b), requires material used in manufacturing DoD hardware to be produced by U.S. suppliers. In these examples, maintaining a foothold presence in certain markets, which by mandate are restricted to domestic suppliers, is clearly not an example of a long term strategy, rather, they are examples of how an overall optimization model can include multiple aspects which, by themselves, are not necessarily optimal.

Long term optimization attempts to divine the lifespan of a product, predict future demand and assess when a replacement should be ready to satisfy the future demand. The purpose of long term optimization is to place the entity acquiring the item in the best position to meet demand at the lowest cost, with the most consistency, efficiency and effectiveness under the conditions at the time of future delivery. The best example in the aerospace industry is the legendary Southwest Airlines long-term fuel contract pricing optimization scheme. Southwest had the foresight and wherewithal to negotiate contracts with fuel suppliers which guaranteed future prices, similar to call options in the stock market. They had predicted a spike in future fuel cost and it turns out they were correct.

While many of their competitors were losing money and instituting numerous nuisance fees on their customer base to try to make up for lost profits, Southwest remained profitable and not only avoided imposing fees such as baggage check, they were able to incorporate this advantage over the competition into their advertisements.

5.2 Future Research Questions

1. Could the OEM have known about the flash bulb DMS/MS? JPATS reached its current DMS/MS state because there was no incentive for the OEM to be proactive with DMS/MS. The JPATS program was structured to require the US government to pay for all obsolescence mitigation above \$100K. This threshold was determined reasonable during source selection based on the premise that a commercially-derived system would not experience the type of obsolescence issues typical of the DoD's more advanced, state-of-the-art aircraft systems with no commercial equivalent. In retrospect, this proved not as valid an assumption as envisioned, and the \$100K OEM-responsibility threshold was found to be too low to be useful in cost-sharing mitigation of all but the most minor cases of obsolescence, since virtually all JPATS DMS/MS issues to date have exceeded \$100K in value with resolution paid for by the US government. The question remains whether a means to provide an equitable balance can be reached and incorporated into a production contract at a program's inception such that the OEM and the customer share a fair portion of the risk. The question that must be resolved in negotiation is that fair balance, so each party bears a portion of the risk.

2. If JPATS COTS procurement was mandated, then, in retrospect, is there an alternative to pure COTS that would provide better USG protection?

In a situation when COTS is the preferred alternative to satisfy a DoD mission need, there must be a rigorous review early on in the acquisition execution strategy of all unique military requirements that require additional analysis, testing or other validation in a realistic operating environment to ensure operational suitability and effectiveness will be met for the non-commercial user. By its nature, a COTS component is designed to appeal to a larger broader-based market, optimized to provide the greatest value in terms of initial cost and typically not designed to remain in service as long as the military user expects items to perform.

3. Perhaps a hybrid solution is necessary with cost sharing and incentivizing?

Use of an incentive system similar to an AFTO 22 Suggestion Program where a flat reward is earned for accepted suggestions. Or even more attractive to the OEM is the use of Value Engineering Change Proposals (VECP) where the manufacturer shares in the benefit achieved by receiving a cash payment for a portion of any savings realized.

4. Is it possible to incentivize constant DMS/MS monitoring to look for and recommendation proactive actions that eliminate DMS/MS before it occurs?

For instance, OEM IR&D savings ideas with USG paying OEM 60% of eventual savings realized, but payment would be in arrears to ensure that the actual savings occur. USG would be required to support the effort and follow through on the implementation. If it fails, USG would still own rights to data gathered and OM would be paid for Bid & Proposal costs incurred.

5. Who should be responsible for managing parts obsolescence? Effective obsolescence management is clearly in the best interest of both the prime and the customer receiving the product, but who should be responsible for paying for the effort?

Would cost sharing be a better alternative if subsequent savings are also shared? In DoD acquisition, is the US government primarily responsible since an OEM cannot be expected to anticipate future parts shortages from technology and market shifts that adversely impact their supply chain?

6. *Should the US government always pay the most in resolving JPATS DMS/MS since they derive the most benefit?* Is this really the case? If so, is the USG paying for what should be normal cost of doing business for their OEMs? If so, is the USG subsidizing the OEM's operational cost to maintain competitiveness? And if so, is this bad policy in light of current international competition where foreign nations routinely subsidize their domestic industries to ensure their competitiveness and lock-out foreign producers selling to their own local markets?

It is important to understand how obsolescence occurs in the normal course of acquisition and to recognize ways to avoid simply reacting to an adverse condition caused by obsolescence. Value engineering is used to identify required functionality so that consistent performance delivery criteria can be established, allowing each option to be fairly assessed so the best course of action is pursued at minimal cost. It is generally accepted that all acquisitions are unique in the sense that following every step in the overall procurement process is not necessary in every situation. Applying the best outcome solution to the JPATS CFIS will involve tailoring to achieve the immediate goal of ensuring an interim solution is in place before available supplies of spares are exhausted.

5.3 JPATS DMS/MS Situation

The CFIS DMS/MS problem facing JPATS arose as a result of several factors, which are discussed in the following subsections.

5.3.1 Introducing a known technology into an unproven application

During JPATS development, an attempt was made to anticipate the next technological shift in the method used to fracture aircraft canopies during ejection. An optical based system showed promise by employing a simple light source as and fiber optic signal transfer lines instead of the legacy ballistic method used in other fielded USAF and USN aircraft consisting of explosives encased in armored lines.

There was an element risk involved in this approach, but early innovation in principle should not be avoided entirely since many products began life with different unrealized potential but later thrived when alternative uses were discovered, often by accident. A good example is the removable “Post-it” removable notes from Minnesota Mining and manufacturing Corporation (3M). When a chemist failed to produce the desired results from an experimental adhesive formulation, the commercial research & development effort stalled. The chemist used some of the batch to glue page markers on his hymnal in the church choir. The reusable feature of his “failed” glue formula became a new product line and a ubiquitous stationery item.

In the JPATS case, the use of flash bulbs designed for disposable consumer applications, was an unknown that carried significant risk in terms of durability, since there was no reliability data to judge its utility from similar aircraft applications.

Unfortunately for JPATS, the gamble did not pay off since the operating cost for the

fiber-optic system became too costly to sustain over the life of the platform, far exceeded comparable costs for legacy systems.

Given that General Electric decided to stop producing the flash bulbs when the JPATS aircraft design was being developed, the flash module supplier placed what it considered to be a “lifetime buy” order for flash lamps before manufacturing ceased. This is a common practice in the defense industry as suppliers move in and out of various markets when profitability is no longer assured for a product line. The flash lamp lifetime buy placed was based on the predicted for the CFIS system which indicated that parts would last at least 12 years before requiring replacement. The JPATS aircraft has a planned service life of 24 years, through 2025. In reality, the CFIS initiators have been failing at a rate which will exhaust the entire “lifetime supply” of lamps in 2013, two years before final production ends for the JPATS Navy buy under current conditions. At a nominal production rate of 60 aircraft per year, that would create a deficit of up to 120 aircraft unable to be fielded due to a lack of flash modules for the production canopies. This would reduce the US Navy’s fleet by 40%, negatively impacting student pilot training rates; jeopardizing follow-on advanced training and degrading overall mission readiness. This would also introduce a logistics shortfall created by an insufficient supply to satisfy production line demands or sustainment of fielded aircraft undergoing scheduled maintenance.

Malcolm Baca (Baca, 2005:1) states that “one problem (in obsolescence) is the continuing decline of the purchasing power of U.S. Department of Defense (DOD) for components. Another problem related to DOD’s weakening purchasing power is that fewer components are needed.” Both of these factors contribute to a shrinking supplier

base, since the potential lower volume of parts to be produced no longer justifies the added administrative burden of dealing with the Department of Defense.

5.3.2 Lack of a DMS/MS mitigation strategy addressing all supply chain tiers

There was no attempt to contractually impose a DMS/MS management requirement on any of the JPATS sub-tier suppliers, which is why the looming flash bulb supply crisis was not detected until it became an issue. In fairness to the original developers, the speed at which the integral flash was introduced into modern photography could not be accurately predicted in the 1990 timeframe that the JPATS design was initially conceived. The actual JPATS flash module change out cycle has been 18-24 months since the inception of field operations, as compared to the initial 4 year prediction. This amounts to \$300M in additional unplanned life cycle cost that the program would have to absorb if no change was made to the existing CFIS design, equivalent to the cost of 50 additional JPATS aircraft.

5.3.3 Lack of reliability data to estimate accurate operational costs

This was also caused by no other similar fielded applications from which to draw lessons learned from operational experience. The resulting underestimation of what constituted a “lifetime buy” contributed to the current time urgency of an April 2013 deadline for exhausting all remaining flash modules in the inventory.

In particular, since a commercial Off-The-Shelf (OTS) purchasing strategy was used for the JPATS procurement, there was no effort to analyze the specific design elements for operational feasibility which may have uncovered some of the shortcomings of the CFIS design approach chosen. As such, the CFIS was not pursued as part of planned obsolescence since the expected installed lifetimes of the components did not

necessitate such scrutiny. In hindsight, insufficient “what-if” risk analysis was performed on a critical system. Lesson learned: New technology cannot accurately predict its utility until several years of operational usage are available. If flight safety critical, risk analysis must identify the risk early and mitigation plans put in place to avoid any possibility of operational stand down or production line interruption. Unproven technology should not be considered for large production run programs where a miscalculation will result in a large retrofit cost to correct any deficiencies. A smaller effort such as Advanced Concept Technology Demonstrator (ACTD) would be better suited for attempting to evaluate the value of a new technology. In the case of commercial-derivative procurement, the design elements must be reviewed to ensure that this risk is avoided.

Planning for obsolescence is a requirement of any well-managed program. Given the uncertainties of when a technology will lose its allure to be supplanted by an emerging method, it is virtually impossible to predict with any accuracy the exact moment when the effort should be started. Despite these doubts, it is still imperative that the best effort must be made to ward off any program interruptions caused by obsolescence, using the most efficient methods to avoid excessive cost. An important point to consider is what Singh and Sandborn describe as knowing the difference between “refresh and redesign.” Refresh comes short of a total redesign and if properly executed can extend the life of existing systems without incurring the high expense of a total redesign and integration.

In an October 2008 Government Accountability Office Report (GAO, 2008:09-05), “Obsolescence Driven Design Refresh Planning or Sustainment-Dominated Systems,” it

was noted that the Department of Defense was not monitoring the supplier base for obsolescence concerns in a standardized manner that could be applied throughout the department. Instead, the response was focused on supplier efforts on particular programs or sectors of the defense industry. In the case of JPATS, which began as a commercial derivative program, there was no contractual obligation placed on the Original Equipment Manufacturer (OEM) to monitor the supply base viability using any established methodology or to report trends and track technology development and market availability. And although JPATS does have an internal DMS/MS program that has actively sought to remain ahead of known pending obsolescence issues such as the rapid replacement of analog gauges by multi-function cockpit displays, the OEM was responsible for following their internal supply chain management policies to periodically monitor their suppliers and anticipate any obsolescence concerns to allow enough advance notice to take appropriate mitigation actions. In practice, this is an imprecise exercise, owing to the nature of initial logistics sustainment planning which relies on predictions using best available estimates at product introduction. In the case of JPATS CFIS, initial reliability predictions turned out to be grossly inaccurate, forcing a management decision to abandon the original system. But simultaneously, an unanticipated obsolescence issue arose due to higher than expected consumption of CFIS spares caused by the low reliability, which only actual field service data could provide. Despite program efforts to make CFIS flash components “lifetime buys” prior to lamp production line cessation, these lifetime predictions also underestimated the demand.

The primary purpose of this thesis is to attempt to develop a methodology for assisting program manager’s to decide what actions to take which will, as closely as

possible, satisfy both user demand for a system while expending only what is absolutely necessary to meet that demand. The luxury of estimating on the high side when calculating safety stock is not a prudent or tolerable in the current environment stressing increased efficiencies in defense procurement. Nor should this practice of avoiding potential loss of availability by carrying excess spares ever be viewed as a preferable business method. However, the nature of defense procurement necessitates an inherent inefficiency by design in the overall procurement process which must be acknowledged and included in acquisition planning. This inefficiency stems from two areas. First, there is no guarantee of complete accuracy in any prediction situation, so, for example, a foot soldier on patrol in a combat zone cannot accurately estimate how much ammunition is needed for every enemy encounter, nor can they always maintain a percent accuracy for every shot expended. This requires overestimation of ammo stockpiles to provide a cushion for these unknowns. Secondly, in the example of naval ship deployments, an aircraft carrier wing cannot estimate with complete accuracy the amount and type of maintenance needed on its air assets, and there is no Just-In-Time inventory replenishment available at sea as there would be, for example, in a commercial environment such as with Toyota's tight-knit supplier base that can custom produce and deliver parts within days based on the appropriate demand signal.

A Government Accountability Office (GAO) report in April 2007 (GAO, 2007:07-232) cited opportunities for the US Air Force to save billions in spare parts inventory by avoiding excessive inventory holding costs. The report state that "more than half of the Air Force's secondary inventory (spare parts), worth an average of \$31.4 billion, was not needed to support required on-hand and on-order inventory levels from

fiscal years 2002 through 2005, although increased demand due to ongoing military operations contributed to slight reductions in the percentage of inventory on hand and the number of years of supply it represents.” So even when factoring in the “foot soldier inefficiencies,” there were only slight reductions in inventory. In fact, “the value of Air Force on-order inventory not needed to support required inventory levels increased by about 7.8 percent, representing an average of 52 percent (\$1.3 billion) of its on-order inventory... GAO calculated that it costs the Air Force from \$15 million to \$30 million annually to store its unneeded items. Inventory not needed to support required inventory levels can be attributed to many long-standing problems, such as decreasing demands, retaining items used to support aging weapon systems that have diminishing sources of supply or are being phased out of service...” The report also points out an irony in all the excess: “although more than half of its secondary inventory was not needed to support required levels, the Air Force still had shortages of certain items. From fiscal years 2002 - 2005, the percentage and value of the Air Force’s inventory shortages remained the same at about 8 percent and \$1.2 billion.

5.4 Lessons Learned

5.4.1 How could this DMS/MS situation have worked better?

Incentivize the OEM with Value Engineering Change Proposal (VECP) option. Right now, it is economically more profitable for the OEM to not use VECP but instead bid on ECPs since they are always the sole source.

5.4.2 What is the real value of FAA certification after an aircraft is delivered?

There’s not much value after aircraft delivery. Military certification is commonly used to modify aircraft once fielded. JPATS used FAA certification to qualify the design

that was then modified to meet a military mission. The only value in using FAA certification is to take advantage of the FAA's existing codified process to approve airworthiness for commercial derivative aircraft. This saves the Department of Defense (DoD) the time and expense of preparing and executing their own airworthiness certification plan. DoD just accepts the FAA certification process in its entirety and only performs additional testing on those aspects of operation unique to the military mission. Once aircraft are delivered, they are no longer maintained to FAA standards. Instead, they use USAF Technical Orders and USN Technical Directives to perform all maintenance and repair actions. Unless the FAA certified aircraft delivered to the US military are ever planned to be resold into the commercial marketplace after their useful military life is expended, maintaining FAA airworthiness certification has no intrinsic value. JPATS aircraft were never planned to enter commercial service after their 24-year useful life. If anything, they would undergo Service Life Extension Programs (SLEP) to allow continued use of the airframe beyond its original design life, and, in that case, the aircraft would be totally under a military certification plan with no FAA involvement whatsoever.

Military certification may be the better way to proceed from an airworthiness standpoint it but does exonerate the OEM from liability for any non-standard configuration features of the aircraft that the US military deems necessary.

5.4.3 Could the JPATS CFIS interim solution been military certified?

Yes, but the time constraint of the interim solution forced a decision to remain with the OEM and its supplier who have the best understanding of the flash module.

For the long-term solution, there are still options to compete the effort among US military laboratories who could entirely manage the project to ensure military needs are met while completing the project faster and at lower cost than the OEM.

5.5 Alternative Approaches to Mitigate Risk & Avoid the JPATS CFIS Situation

During program development, flash module CFIS should have been treated as a Joint Capability Technology Demonstration (JCTD). “JCTDs typically have one of three outcomes: 1) enter into formal acquisition as a new program; 2) integrate with an existing program; 3) return to technology development. A JCTD becomes a candidate for transition following a successful military utility assessment.” (AFI-63, 2009:74) The flash module CFIS design should not have been fully developed further until all aspects of obsolescence were addressed. The most puzzling aspect is an unproven design concept was allowed to enter into the largest aircraft fleets for both services. This laser technology would have been better suited for introduction into a smaller fleet where it could have less logistical impact if it did not prove reliable. “JCTDs are intended to exploit mature and maturing technologies to solve important military problems and to concurrently develop the associated CONOPS to permit the technologies to be fully exploited. (AFI-63, 2009:74)” The only plausible explanation for incorporating flash module CFIS is the JPATS mandate for commerciality per FAR Part 12 commercial contract, which limited the normal level of technical scrutiny that would have occurred on more traditional FAR 15 type military procurements. As such, there was an acceptance of the Original Equipment Manufacturers (OEM) reliability predictions without a formal military assessment. These initial predictions have been shown to be inaccurate with parts change outs average 18-24 months versus a 4-year baseline standard

for similar ejection seat components, achieving only 38-50% of predicted life. In the case of the JPATS, the CFIS flash lamp technology should have been returned for future development.

Since JPATS CFIS flash-module design was pursued at project inception, then once the flash lamp DMS/MS concern was discovered, an incentivization program with the OEM & suppliers could expedite implementing a solution. The issue with the current incentives available with a typical Value Engineering Change Proposal (VECP) seen in Value Engineering examples is that the JPATS OEM lacks sufficient engineering staff to adequately prepare and execute a VECP even with the potential to share in any cost savings resulting from the effort. The OEM is better off from a profit view to respond to a Request for Proposal, charge the US government for the bid & preparations cost, and then execute the development plan and procurement all at either a firm fixed price or cost-plus basis. There is no risk involved in this scenario. In the VECP example, unless significant savings are realized, the OEM does not receive their 50% of the savings, despite their efforts to voluntarily propose the VECP. Under the VECP, the OEM expends their own time and funds under the expectation that the rewards will be shared. With an ECP, there is no risk that the rewards won't justify the effort to offer a VECP, since all expenditures are paid for by the US government.

5.6 Summary

As more and more commodity-type items are being produced by foreign suppliers whose lower labor costs create a market where they are the only viable producer who can supply the item and still make a profit, the US government will reach a point where there may be no US supply available for commodity items like the flash bulbs that formed the

basis for this thesis. Existing laws require that US defense acquisitions to be sourced from domestic sources or from nations whose domestic stability and amicable relationship with the US provide reasonable assurances of continued supply in the event of international political unrest. But with the prospect of a shrinking global supply base, other alternatives should be explored to ensure continue access to the technology required to maintain our level of national defense preparedness. These options include:

5.6.1 Relaxation of current statutory restrictions

This would allow a broader base of supply to produce scarce items, thereby reducing risk of interruption if one supplier fails to produce. The advantage is that no one source can produce a stranglehold on the supply chain. The disadvantage is that this approach does not address the potential pitfalls of trusting that foreign parts installed in mission critical US defense systems will perform as specified and not produce adverse secondary effects.

5.6.3 Stockpiling critical commodities to safeguard against shortages

Although this is an absolute assurance that shortages will not occur in the short term, providing the forecasted demand was estimated accurately, this mitigation method is not an ideal solution. Stockpiling does not address the underlying issue of a reliable source that can respond to a demand-pull signal and transfers the wasteful inventory holding costs to the end user.

5.6.4 Revitalizing domestic markets by providing economic stimulus

This approach would attempt to correct the negative return on investment that caused domestic sources to stop producing. This would require laws to be revised to ensure that US suppliers the same opportunity as foreign suppliers.

5.6.5 Invest in US industrial infrastructure

This would require the US government and industry to partner together to identify critical industries where there has been significant erosion of key industrial capabilities which threaten our ability to self-produce items and maintain vital capacity to field defense systems solely from domestic sources. The loss of capacity over the past 25 years has created a growing dependence upon foreign suppliers for key products and has relinquished our ability to be self-sustaining. While the world is and always will be an interconnected global marketplace with US inextricably woven into that fabric, a distinction still must be made to ensure that key vital production capacity to safeguard our national interests is not lost in the euphoria of globalization.

5.7 Recommendations for Implementation

5.7.1 JPATS Procurement Should Avoid Purely Commercial Derivative

JPATS was a commercial derivative aircraft based on the Pilatus PC-9, and was designed to take full advantage of existing technology to produce the lowest cost article and the greatest value for the US military. However, many of the expected benefits were not realized once JPATS was operationally deployed, when the strain of constant usage in a military training environment started degrading system availability and subsequently required significant upgrades to correct a lack of robustness in key systems. In retrospect, the JPATS mission was not as ideally suited for a commercial derivative application as originally thought. Although some durability and structural life testing was conducted during design development to model the expected military operating environment, either the assumptions used were not as accurate as needed or there were unexpected factors at play that were not modeled and only discovered after the system

was deployed, both of which drove a succession of design upgrades within a few years of system deployment. To be fair, design improvements are a natural fall-out of operational usage for any designed system, but in the case of a commercial-derivative platform, there is no ability to begin the design process with a clean slate of requirements and then build a system based around those needs. As such, much of the basic design must be accepted in its current form based on the estimation that it will meet specific requirements. This raises the chances that more frequent and extensive design modifications will be required sooner over the life of a commercially-derived aircraft than one designed from its original concept for a particular mission. An excellent example of this is the canopy fracturing initiation system. The CFIS was expected to never require replacement and only periodic removal of expendable life-limited components easily changed in the field. The CFIS's lack of reliability which is causing an unexpectedly high maintenance burden has now forced its entire replacement to avoid unacceptably high operational costs over the life of the platform.

5.7.2 Formalized DMS/MS Program

Although JPATS had a formal program to anticipate diminishing sources and obsolescence, it was not able to see the CFIS DMS/MS problem looming on the horizon. There was no periodic review of the OEM's vendors as part of the JPATS contract, which meant self-reporting by the sub-tier suppliers was the only mechanism to identify DMS/MS concerns. In addition, because obsolescence resolution was the US government's responsibility to fund, there was no incentive for the OEM to monitor its sub vendors closely or aggressively pursue obsolescence avoidance. In fact, supply chain management shortfalls have been documented within the JPATS program since the first

aircraft deliveries began.

5.7.3 Introduction of Leading Edge Technology

JPATS provides a vivid example of the risk of introducing new technology into a large aircraft production run (JPATS platform is largest single aircraft in both USAF and USN fleets). Consequences of failure in achieving reliability predictions are magnified due to the fleet size. Without a pedigree to vouch for its robustness under actual field conditions, new technology should be reserved for small scale experimental purposes until vetted properly through operational experience and solid reliability data.

5.7.4 Value Engineering

Value engineering is a valuable tool that should be employed whenever pursuing alternatives for replacing components when necessitated by either loss of supplier base or technological obsolescence. In the case of the JPATS long-term solution, VE provided the insight to decompose required functions and performance, which were then compared with canopy fracturing systems currently in use to assess applicability. That led to incorporation of those features into the long-term solution which increased CFIS reliability, reduced operating cost and recouped the investment within an acceptable timeframe. The end result was a more robust platform with a pedigree. Value Engineering was used in conjunction with the DMS/MS risk strategy to solve a potential production line stoppage and sustainment breakdown that would have ceased deliveries and grounded aircraft due to a lack of spares. The use of VE allows the DoD to spread non-recurring engineering costs over time, making them far easier to fund. (Mandelbaum et al, 2008:115-139). Original Equipment Manufacturers should be incentivized in their contracts to employ Value Engineering principles in their design strategy to reduce cost

and share in the rewards from savings realized.

5.7.5 Analytical Modeling to Assist in Decision Making

Although all modeling carries a level of uncertainty due to the assumptions and constraints that must be made to obtain a feasible solution, properly constructed models can provide program management with reasonable approximations of the probability of success and identify areas of risk that must either be considered before major decisions are made that commit significant funds. The model must also have the ability to conduct rudimentary sensitivity analysis, which accommodates shifting priorities in response to either unexpected operating environment changes or inaccuracies in the initial modeling assumptions. Linear modeling using commercially available software is sufficient for the level of accuracy required to advise on leadership on recommended courses of action.

5.7.6 Funding Allocation Revision

With the current severe fiscal constraints now gripping the nation and the need to maximum efficiency to deliver ever-greater returns on investment, action is needed to correct the toll that current funding poses in the Defense Department procurement process. If adequate supplies of resources and timely delivery of product to meet mission needs are the true goals, then the present politicizing of funding must be kept to a minimum. Once decisions are made to pursue the development of an effort such as the CFIS replacement, there should be no revision of that plan unless the results clearly indicate unacceptable execution. Otherwise, the OEMs that provide the hardware to fulfill the mission are left without assurances that their capital investment is worth the effort and the dwindling supply base will continue to decrease until a critical mass of capability cannot be maintained without drastic infusion of funds. That would be an

expensive reactionary action and one that can be avoided if proper due diligence is applied upon inception of programs, including an assurance that funding is protected from involuntary reallocation from the onset. Otherwise, the US government will be saddled with expensive legacy systems like the current JPATS CFIS that will be increasingly expensive to maintain as other components begin to degrade over time as the aircraft fleet ages.

5.8 Epilogue

As is the case with all real-time events, some of the initial conditions for this thesis have changed as a result of marketplace interventions unanticipated at the time of its conception. Although the validity of the investigative approach remains sound and the lessons learned can be universally applied to similar situations, it is worth noting the changes and how they would change some of the investigative approaches.

5.8.1 Windfall of legacy flash bulbs

In April 2011, a previously unknown source of supply was discovered and the OEM was able to procure an additional 28,000 legacy flash bulbs that had been collecting dust in a warehouse. The viability of these flash bulbs remains to be proven with lot sampling and testing, but it is expected that the yield of flight-worthy items from this cache will be approximately 60%, or 1,680 additional bulbs. Since there are 40 legacy bulbs per aircraft, the additional bulbs will service an additional 42 aircraft. And since 25% of the fleet of 747 aircraft, or 187, requires flash bulb change out each year, when the legacy bulbs reach the end of their useful life, the extra bulbs will only represent 42/187, or approximately three months' worth of bulb change out. This means the windfall will provide a relatively insignificant amount of additional capacity to the

maintainers and therefore will not affect the overall plan to replace the legacy bulbs with interim annular flash modules when they become available.

The original hope of the program office was to reduce the number of interim bulbs originally planned or perhaps eliminate the need to procure any interim bulbs if the additional bulbs could bridge the gap until the long-term solution was available to install in the fleet. But this was not the case with the stash discovered, and as a result the extra margin of safety stock provided by the cache proved insufficient to justify altering the original procurement plan.

Glossary

- ACTD** Advanced Concept Technology Demonstrator – A demonstration effort where a new technology is demonstrated in a real-time operation to assess whether a maturing advanced technology(s) is ready to deliver a significant new military capability. The results of an ACTD may lead to eventual full-scale development or may simply end at the conclusion of the demonstration if the technology if there is insufficient justification to continue further development.
- CAD** Cartridge Actuated Device – a small explosive device used to activate explosive systems and initiate aircrew escape devices.
- CFIS** Canopy Fracturing Initiation System – the subsystem which initiates aircraft canopy fracturing to provide a clear path for either ejection seat travel out of the cockpit during airborne ejection or aircrew egress in the event of a ground emergency.
- CONOPS** Concept of Operations – is a document which describes the characteristics of a system’s intended function or operation.
- DMS/MS** Diminishing Manufacturing Sources/Material Shortages – the progressively diminishing number of suppliers and/or materials to produce the defense systems deemed necessary to fulfill the missions of the DoD. DMS/MS is driven by forces in the marketplace that make it either unprofitable for a supplier to either produce an end item or procure the raw material to manufacture the item.

- GAO** Government Accountability Office - The office within the U.S. Congress which investigates the performance of the federal government by evaluating the use of public funds and providing analytical, investigative and legal services to support to Congress in its policy formulation and decision making. Prior to 2004, GAO was known as the General Accounting Office.
- INT_i* Interim Solution – the short-term solution that will provide continuing service for the T-6 aircraft canopy fracturing system until the long-term replacement system can be developed, qualified and deployed.
- IR&D** Internal Research & Development – an effort undertaken usually within a private sector organization using corporate funds with the intent to produce a marketable product that will be offered to existing or new customers. Often, IR&D is conducted within the military hardware industry by suppliers who recognize that their existing product line requires enhancements to remain viable with their competition’s offerings.
- JPATS** Joint Primary Aircraft Training System – consists of the aircraft, simulators (ground-based training devices), and information management system to record and maintain training records. JPATS is also referred to as the T-6 Texan II aircraft, currently procured by the USAF and USN in both T-6A (USAF) and T-6A& T-6B (USN) variants.
- L_i* The legacy T-6 aircraft production configuration flash lamp assembly currently installed in the JPATS fleet that initiates canopy fracturing. It

will be replaced in the short-term with the interim solution which in turn will be eventually replaced by the final Long-Term design solution.

- LTS_i* Long-Term Solution – the final design solution that will replace the current T-6 aircraft canopy fracturing system with a more robust design to eliminate the current DMS/MS situation impacting operational readiness.
- MTBF Mean Time Between Failure – the average service life of a part operating in its intended environment.
- NASA National Aeronautics and Space Administration – the agency created by the National Aeronautics and Space Act on July 29, 1958, replacing its predecessor, the National Advisory Committee for Aeronautics (NACA). NASA’s mission is to "pioneer the future in space exploration, scientific discovery and aeronautics research."
- OEM Original Equipment Manufacturer – the primary supplier for a hardware end item or product, also known as the prime contractor. The OEM has typically developed, tested and qualified an item and holds patents protecting the proprietary nature of its investment from infringement by its competitors.
- OTS Off-the Shelf – hardware produced from readily available technology that is typically not patent-protected and which has often been certified for use in its intended environment using universally accepted standards.
- SLEP Service Life Extension Program – a program which seeks to allow a system to remain in operation beyond its originally intended retirement date. As part of SLEP, an assessment of the current hardware is

conducted at the end of the initially planned service life to identify additional rework or modification that must be performed on a system to allow continued service.

VE Value Engineering - an organized approach to providing the necessary functions at the lowest cost by identifying and eliminating unnecessary elements that increase cost. It was conceived from the work of Lawrence D. Miles, a purchasing engineer for General Electric, during the 1940s.

VECP Value Engineering Change Proposal - a proposal submitted by a contractor that, through a change in the contract, would lower the project's life-cycle cost to DoD with a share in the attendant savings going to the contractor making the VECP proposal.

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