ROLLOVER-PLUS:

A GREAT WAY TO BUILD SECOND-RATE FIGHTERS

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ABSTRACT

The shrinking defense budget and the ill-defined threats of the post-cold war world, have given rise to alternative acquisition strategies. These strategies seek to maintain America's technological and qualitative fighter aircraft superiority, while simultaneously saving the cost of large-scale procurement. This paper compares two of these strategies. On the one hand, Rollover-plus purports to maintain US superiority by building technology-advancing prototypes. The technology would then roll over into a production fighter at some later date, as dictated by the threat or the current aircraft's obsolescence. On the other hand, Silver Bullet proposes building a small number of operational aircraft and integrating them into the existing fighter force structure. By examining the contributions operational F-15 flying made to developing the Advanced Tactical Fighter, this paper demonstrates that Silver Bullet should be the Air Force's future acquisition strategy. Rollover-plus is an inadequate strategy because it does not provide the critical feedback that DOD and industry need to define and produce successive generations of advanced aircraft. Without this feedback, the US can build new fighters but they will not be as good as they should be. Given that our National Military Strategy relies on a dominating fighter force, we cannot afford second-rate airplanes.

Lastly, Silver Bullet can maintain our technological edge and save procurement costs, but not without change. Both industry and DOD need to pursue specific initiatives that will enable aircraft manufacturers to achieve rate transparency, i.e. the production of small numbers of aircraft (less than 100) at unit costs comparable to those of large production runs. There are certain lean production methods that when combined with

better DOD requirements, open production lines, and reduced government oversight, will help make rate transparency a reality.

The F-15 program showed that operational flying contributes to advancing fighter aircraft design in a way that a prototype program cannot. If we allow ourselves to accept Rollover-plus as our new acquisition strategy, we are committing ourselves to an expensive, second-rate fighter force.

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Chapter 1

Introduction

"95 to 0 Air Combat Victories." According to McDonnell Douglas Aerospace, that is the current box score for the F-15 versus all comers.[1] Looking at such a performance record in light of the shrinking defense budget, one may easily question the need for a successor to the F-15.[2] In fact, Ronald Dellums, Chairman of the House Armed Services Committee, sees no reason to field the Advanced Tactical Fighter (ATF). According to Dellums, there is no anticipated threat to the F-15 and it will remain serviceable until 2010.[3] DOD, on the other hand, questions the F-15's ability to achieve air superiority in the near future and is concerned about the aircraft's obsolescence. Additionally, DOD feels the ATF is necessary to maintain America's fighter aircraft industrial base. While both positions merit analysis, this paper will address a broader, less obvious concern--continuity in fighter aircraft development. It will use the relationship between the F-15 and ATF programs to show that if the US Air Forces is still going to develop and deploy the world's best fighters, it must produce new operational aircraft even if the current jet seems to be "good enough" for now.

Justification for buying a new airplane like the ATF usually centers on a combination of three issues--the threat, aircraft supportability, and technological obsolescence. Looking at the F-15 in relation to these issues illustrates why questions arise when DOD proposes a new system. The Gulf War confirmed the F-15 as the world's premier air superiority fighter. Given its track record and the absence of a worthy foe, one could argue there is no need to procure the ATF to ensure continued US air superiority. Second, there is the question of maintenance. At some point an aircraft reaches the end of its service life. The airframe wears out and parts become too expensive, primarily because the airplane is out of production. The F-15 has not reached this point. The airframe is actually exceeding its original design specifications and F-15E production, as well as foreign sales of various F-15 models, still makes parts procurement financially reasonable. Finally, there is technological obsolescence. It occurs when an aircraft's level of technology is one that industry no longer supports. Such technology, for example, exists in several integrated circuit cards in the F-15. However, because of the modular design of F-15 avionics, it is possible to integrate state-of-the-art circuitry into the system and thus extend the aircraft's service life. Clearly, we experience difficulty in advocating a new aircraft program when there is no apparent military, logistical, or technological reason to replace the current fighter. The situation has generated alternative acquisition strategies.

Les Aspin, during his tenure as Chairman of the House Armed Services Committee, proposed the two acquisition strategies this paper will examine--Rollover-plus and Silver Bullet. Both concepts seek to advance defense technology while saving the cost of full system procurement.

In Rollover-plus the idea is to advance weapons-related technology through a prototype-only production strategy. DOD funds the development of a new system up to the point of producing operational prototypes. The prototypes would be as close as possible to an operational system, both in their final form as well as in their production methods. Once the contractor builds the prototypes, DOD could put them on the shelf and use them at a later date when the threat dictated it or the current system reached obsolescence. Alternatively, industry could roll the technology over into the next generation of aircraft.[4] This paper will argue that the Rollover strategy does not adequately maintain fighter development because it ignores the major role operationally deployed aircraft play in fielding their successor, and because it fails to maintain the design and engineering base needed to move from one generation of fighter to the next. Silver Bullet, however, addresses both problems.

The Silver Bullet strategy advocates producing a limited number of high-tech aircraft. These systems advance technology, maintain the defense industrial base, and serve as a force multiplier "when needed."[5] However, the Silver Bullet Strategy does have problems. Correctly predicting when a combat commander would need a system, as well as relying too much on quality over quantity, are two weaknesses of the strategy. Nevertheless, Silver Bullet is preferable to Rollover-plus because it keeps the engineering and industrial bases healthy, while providing operational systems to the field. This paper will address Rollover and Silver Bullet by examining them in the context of ATF development. By showing how the lessons learned from operational F-15s were critical to ATF development, the paper will show that only Silver Bullet assures continuity in fighter development.

In particular, Chapter 2 will show three ways ATF development would have suffered without the F-15. First, without having flown the F-15 operationally, the Air Force would not have had the feedback necessary to define the requirements for the ATF. Operational flying enabled pilots to take advantage of new technologies to develop new tactics. These tactics, in turn, produced requirements for new technology that appeared in the specifications for the ATF. Flying the F-15 identified maintenance and supportability issues that ATF engineers would not have addressed otherwise. Second, chapter 2 will also show how the F-15 was important to the ATF design. The design engineers received significant feedback from fielded F-15 forces that enabled them to address several key issues resulting in a better ATF. Finally, chapter 2 will address production. An open production line facilitates the development of new manufacturing techniques that allow designers to take advantage of technologies previously too expensive to produce. Production lines also provide feedback to the engineers by showing them that their designs do result in a cost-worthy airplane. In short, chapter 2 will show that defining, designing, and building an airplane is a process that depends on feedback from the operational world--feedback Rollover-plus cannot provide.

Chapter 3 will then provide a model that describes the feedback that fighter development requires. It will show how only full-scale production and operational deployment provide the robust feedback necessary to maintain America's future edge in fighter aircraft. This chapter will specifically address the reasons why a prototype-only strategy, such as Rollover-plus, cannot provide the feedback actually required, even when augmented by computer simulation.

Chapter 4, in turn, will examine the fiscal feasibility of Silver Bullet. Rate transparency--producing small numbers at the same unit cost as higher numbers--is the key. It requires industry to develop production techniques that reduce manufacturing costs and make the assembly process more responsive. Such initiatives will partially overcome the learning curve phenomenon, which expects increased production efficiency to make the last airplane built cheaper than the first. Chapter 4 will also describe DOD's role in helping industry achieve rate transparency. DOD must modify its current acquisition methods by changing the way it defines requirements and by reducing program oversight costs.

Finally, chapter 5 will review the above issues to reinforce the paper's two central conclusions--prototyping alone will not insure continuity in fighter development and, the Silver Bullet strategy is financially possible, but only if industry and DOD work together to achieve rate transparency and responsive production.

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[1]McDonnell Douglas advertisement, *Air Force Magazine*, 77, no. 4 (April 1994): back cover.

[2]Unless stated otherwise "F-15" in this paper always refers to the F-15 A-D models. These are the dedicated air superiority airplanes the ATF is to replace.

[3]Steven Watkins, "New report may assist Hill critics of F-22," *Air Force Times,* April 11, 1994.

[4]Senate, *Consideration of Hon. Les Aspin to be Secretary of Defense,* 103rd Cong., 1st sess., 20 January 1993, 22.

[5]Senate, 22. Pat Towell, "Panels Zero In On Combat Planes As Crux of Spending Debate," *Congressional Quarterly Weekly Report* 51, no. 24 (12 June 1993) 1497.

Chapter 2

Operational Contributions to Requirements, Design, and Production

One may think of fielding a fighter aircraft as a three-step process--define the requirements, design the airplane, and build it. The requirements are generally of two types. The first type defines what tasks the airplane must do. In the case of the ATF, all the tasks defined in DOD's Operational Requirements Document (ORD) focus on the air superiority mission. The second type of requirement focuses on aircraft maintenance and supportability. It defines things such as component reliability and reparability, the support equipment necessary for the airplane, and the complexity of various maintenance tasks. DOD, in conjunction with industry, defines both types of requirements and then engineers design the airplane. At this stage, designers balance DOD requirements against available technology, and then design an airplane that industry can produce at a reasonable cost. It is important that the engineers account for both systems integration issues and manufacturing limitations during the design phase, or they will not design a produceable aircraft. Finally, the contractor must build the airplane. The actual production relies on processes developed when building earlier aircraft. Some of the processes carry over directly to the new system because industry will produce some components in a similar way. Other processes carry over in a less direct fashion. In both cases, however, production line organization and management will have an effect on the next airplane. A production program that encourages innovation and efficiency, as well as quality, will provide a positive environment for building a new aircraft.

This chapter will show how the F-15 contributed to the ATF at each of the three developmental steps. It will show that having a predecessor in full-scale production contributed in critical ways to defining, designing, and potentially building a follow-on system[1]. In other words, operational F-15s provided continuous and necessary feedback to the process. Before starting, however, one caveat applies. The ATF design process obviously did not draw on just the F-15 program. Other aircraft programs enhanced the feedback process. However, for two reasons this study will limit itself to looking at just the F-15's contributions. First, looking at other aircraft programs would unnecessarily expand the scope of the paper without providing any more supporting evidence. Second, by assuming an environment with only one potential predecessor, the paper remains relevant for the future, since we should expect to see only one fighter in production at a time.

REQUIREMENTS

Defining requirements is a complex, iterative process. It requires a thorough knowledge of the military tasks required of the system as well as an understanding of current and near-term technologies. When done properly, the scientist and the operator talk to each other in the requirements phase. The operator-warfighter is responsible for defining Campaign and Operational Objectives based on National Security Objectives. He then defines specific tasks the system must accomplish to achieve his operational ends.[2] At this point, the operator must interface with the scientist, who is responsible for suggesting cost-effective technologies that will accomplish the airman's tasks. Unfortunately, DOD sometimes defines requirements either too narrowly or not broadly enough. In addition, the fact that there are two sets of customers, the operator and the acquisition professional, further complicates the process. These customers do not always coordinate with each other and they leave industry to figure out how to satisfy them both.[3] Despite these problems, the Air Force produced an Operational Requirements Document (ORD) which defined both tactical and logistical requirements for the ATF. The following discussion of these two types of requirements will show that they generally addressed F-15 shortfalls identified through operational flying and maintenance. For the most part, operators did not discover any of these problems prior to the F-15 reaching Initial Operational Capability (IOC).

TACTICAL REQUIREMENTS

Tactical requirements, at first glance, appear to be threat-based.[4] I contend, however, that so called threat-driven requirements result instead from deploying and training against our own aircraft. For example, a cursory look at fighter development since World War II reveals a general trend of threat countries <u>reacting</u> to US fighter development.[5] If threat nations historically react to what we field, logic dictates that <u>we</u> are the threat. What we field causes a potential enemy to develop comparable aircraft, which then forces us to develop a new system to maintain our tactical edge. Within this context, the F-15 spurred the development of the two most recent Soviet fighters and therefore defined the requirements for the ATF. In essence, the ATF had to be able to defeat the F-15.

However, defeating the F-15 requires you to identify its weaknesses. Aggressively training against it in simulated combat scenarios does just that. As "adversaries" gained experience against the F-15, they learned to exploit its shortfalls. Unfortunately, the real enemy observed and learned about these shortfalls also. While tactical doctrine evolved in an attempt to overcome the F-15's weaknesses, it was insufficient to overcome certain design and technological limitations. As a result, the

ATF ORD seeks to insure these limitations are not part of a successor aircraft, as the following five requirements illustrate.

1. High Fast Flyer

Aircraft that pose a threat by flying at both high altitude and high airspeed are commonly referred to as high fast flyers. The ORD specifies criteria for the ATF to counter high fast flyers, like the MiG-25. F-15 design engineers felt the aircraft was capable of handling this type of threat, but after a few years of operational flying it became necessary to detune the F-15's engines to increase their service life. As a result, the thrust-to-weight ratio of the operational F-15 became less than designers expected. By the mid-1980s, training experience against threat simulators like the SR-71 demonstrated that even perfectly executed F-15 tactics did not provide the desired probability of intercept against this type of threat. This limitations resulted in an ATF requirement to better counter a high fast flyer.[6]

2. Point and Shoot

Several requirements in the ORD improve on the F-15's capability to point and shoot. There is a need to quickly point an air superiority airplane at the target and employ a weapon, thus minimizing the time it occupies a particular area in the sky. ATF requirements that support this capability are high turn rates, rapid acceleration, and certain fire control system characteristics. Designers originally hoped the F-15 would provide its pilot with the situational awareness (SA) necessary to enter a fight with an advantage, and then outmaneuver any opponent. However, as "adversary" pilots gained experience against the F-15, F-15 pilots discovered that even low technology airplanes were potentially lethal in visual fights. In fact, one of the typical lessons learned, especially during large scale exercises, was that the life expectancy of an F-15 in a turning fight was inversely proportional to the time it was engaged. Due to the aircraft's large size, it became an easy target for smaller, less capable aircraft if it stayed in a maneuvering fight too long. This inherent weakness, validated after a few years of F-15 operations, dictated that the ATF quickly get into valid weapons parameters, fire, and then separate from the area.

3. Air-to-Air Gun

The fighter community first debated the value of an air-to-air (A/A) gun during Vietnam. Because the early (and gunless) F-4s found themselves vulnerable during close-in engagements, the A/A gun became an F-15 requirement. Operators debated the issue again with the ATF and, once more, operational flying determined the requirement. The US Navy did not originally require a gun on the F-4 because they felt air-to-air missiles alone could handle an opponent. Some requirements writers attempted to make a similar case for the ATF. However, had they looked at the F-15 ten years after IOC, they would have seen that the aircraft still needed an A/A gun. Despite the quantum leaps in missile and fire control system (FCS) technology, situations still arose that made the gun the weapon of choice. Given the ATF will further improve missile lethality, it was tempting to argue for no A/A gun on the ATF. Operational F-15 flying prevented us from repeating the same error we had made with the F-4.[7]

4. First Look/First Kill

Numerous improvements in both enemy and friendly FCS technologies have negated the F-15's first look, first kill advantage. The F-15 can no longer guarantee its pilot that he can detect and fire on an enemy aircraft before the adversary returns the favor. A number of key ATF requirements address this shortfall and they center on various low observable techniques. Due to the classification level of this paper, it is impossible to go into more detail, but the operational history of the F-15 played a major role in determining these requirements as well.[8]

However, just as operational training identified the chinks in the F-15's armor, it also highlighted its strengths, as illustrated by the case of F-15 beyond-visual-range (BVR) missile employment tactics. The F-15, with its APG-63 radar and AIM-7 radar guided missile, introduced the first credible BVR threat. However, it was not until 1984 that pilots began to seriously train using the BVR capability. Once integrated, BVR tactics training identified several key F-15 systems engineers needed to enhance on the ATF. These systems will contribute to regaining the first look/first kill advantage and include the following.

a. Automatic Identification Friend or Foe (IFF)

The IFF system on the F-15 and the ATF serves two purposes. It allows the aircraft to identify itself via electronic codes and it allows the pilot to interrogate radar targets for the same codes in order to identify friends or foes. Engineers designed the F-15 so that pilots had access to all the required IFF switches. This adjustment addressed F-4 pilot complaints and, based on subsequent F-4 tactics, seemingly solved the access problem. However, as F-15 pilots developed their BVR tactics, they realized that electronic identification was becoming more complex and more critical to mission execution than it had been with the F-4. This was due to the F-15's larger missile employment envelope and to more complex IFF codes designed to prevent enemy compromise. In short, pilots had to accomplish more tasks prior to shooting a missile

BVR. While these tasks were crucial to preventing fratricide, they demanded too much pilot attention to the IFF system.[9] As a result, alleviating the problem became an ATF design requirement.

b. Single-Point, Long-Term Cryptographic Coding

Airspace control plans dictate that pilots periodically change certain IFF codes, as well as secure UHF radio settings. Again, the F-15 design addressed the shortfalls of the F-4 but failed to foresee the importance of these codes as procedures became more complicated. Again, the tactics pilots developed in the early 1980s increased their cockpit workload and left them with less time for mundane chores such as changing and entering crypto information. These same tactics, however, significantly increased the importance of having the correct codes entered. The problem was significant enough in the F-15 to warrant a change for the ATF, whereby maintenance personnel can enter the codes and have them remain valid for a time period long enough to preclude the pilot from having to enter new codes in flight.

c. Training Mode Incorporation

The Air Force did not sufficiently consider training when it built the F-15. The gun camera was not much of an improvement over those used in World War II. Additionally, there were no systems dedicated to evaluating pilot effectiveness in the training environment. As BVR tactics came to dominate F-15 training programs, it became obvious there was a problem in evaluating simulated kills. Before this time, most kills occurred in visual range, thus allowing pilots to identify "enemy" aircraft and evaluate the effects of their evasive maneuvers on the F-15's shots. As weapons employment ranges increased, pilots had to do the same tasks based mostly on radar instead of visual information. Unfortunately, assessing radar-based kills is more difficult and introduces counterproductive artificialities to training scenarios. In addition, pilots sometimes employ tactics that allow them to "game" the system in order to claim valid kills. Sadly, these tactics may not be the most effective ones for combat. They teach pilots how to win the training war, but not necessarily the shooting war.

This issue came to a head in the mid and late 1980s, at Red Flag and other large-scale exercises, where other aircraft developed and employed their own BVR tactics. The kill evaluation problem led to numerous arguments over who shot whom and took away from meaningful discussions about mission execution. These training problems contributed to ATF requirements that facilitate more realistic shot and kill evaluation.[10] It is unlikely that pilots would have recognized the far-reaching effects of this problem had F-15 tactics development taken place using only a few prototypes.

d. Training Device Concurrency.

Training device concurrency refers to a problem that currently exists between the F-15 and its simulator. The simulator attempts to duplicate F-15 avionics and allow pilots to practice realistic tactics. Unfortunately, the components of the simulator only superficially represent the airplane. The displays look like the airplane, but the software driving the simulator's FCS is different. As a result, the simulator routinely lags behind the aircraft in terms of software generated displays, as well as in the actions different switches command. The obvious problem is that the pilot must use certain tactics and switchology for the simulator that may not be valid in the airplane. The Air Force routinely upgrades the F-15's computers in order to take advantage of emerging technologies. However, when developing the F-15, they did not foresee the simulator updates lagging behind the aircraft. Because BVR tactics drove changes to the FCS that made it more complicated, the value of the simulator as a training device only increased, thus making the difference between the simulator and the aircraft a significant problem. ATF requirements addressed this issue by requiring a simulator program that would be responsive to software changes concurrently with modifications to the airplane.[11]

Advanced BVR tactics were not the only influence on ATF requirements to come from long-term training. The F-15's significantly improved thrust-to-weight ratio also impacted tactics and, in turn, ATF requirements. The fifth tactical requirement resulted from pilots taking advantage of the increased thrust.

5. Close Combat Radar Modes

As the F-15 matured, dogfight tactics--known collectively as Basic Fighter Maneuvers (BFM)--matured also. The most effective tactics became those that de-emphasized vertical maneuvering while taking advantage of the F-15's turn capability, as well as its ability to fly at high angles of attack (AOA). One result of this trend was a mismatch between the original radar modes (designed for F-4 maneuvering) and the BFM the pilots actually began to fly. Although the improved tactics became widespread in 1985, the radar modes needed to take advantage of them were not identified and incorporated until 1989. These operational lessons also went directly into refining ATF requirements.[12]

While flying operational F-15s did not identify all the ATF's tactical requirements, the above examples show it did identify critical ones. With this point clarified, we now turn to maintenance and supportability requirements and look for similar F-15 to ATF links.

MAINTENANCE AND SUPPORTABILITY REQUIREMENTS

Defining the requirements for maintenance and supportability (M&S) becomes increasingly important as the aircraft fleet grows smaller. With fewer planes available, each one out of service for maintenance reduces force structure by a larger percentage than in the past. M&S considerations are also important because reduced maintenance requirements and less support equipment make the force less vulnerable. Unfortunately, the F-15 has reached the point where high failure rates on key components, such as the radar and the engines, are significantly increasing force vulnerability. Coupled with erroneous fault indicating systems and incompatible test equipment, the issue of M&S for the F-15 has become critical.[13]

The following ATF requirements for M&S all reflect operational F-15 experience. Like the tactical requirements, designers could have built the ATF without considering the F-15 logistical experience, but it would have been a less capable airplane. Many of the ATF requirements came about not just from having the F-15 in service for a long period of time, but more importantly because a full spectrum of pilots and maintainers flew and serviced the jet.

1. Fault Identification and Isolation

Engineers put several systems into the F-15 to identify faults and malfunctions. Warning lights and readouts notify the pilot of malfunctions, a panel in the nosewheel well identifies certain system faults to maintenance personnel, and a built-in-test (BIT) device on individual aircraft components "latches" if there is trouble. The problem with all of these systems is they are unreliable, complicated, and prone to deliver ambiguous indications.[14] As a result, maintainers cannot isolate malfunctions. They are forced to change out a component using a best guess estimate or, alternatively, they list the problem as a CND (could not duplicate). The fact that many faults only occur in flight complicates the issue.

Early operational tests revealed some of the above problems, but the maintenance community did not realize their full magnitude until the F-15 reached IOC. By the mid-1980s, individual units began to address the fault identification issue with local initiatives that sought to track “bad actor” components. (These were components that passed ground-based tests, yet continued to fail in flight). This situation led to ATF requirements that call for better fault isolation and identification. In addition, they specify on and off-airplane test coherency. In other words, if the aircraft system identifies a fault, the ground-based test equipment should see the same problem. These initiatives will reduce the maintenance load on the ATF.

2. Engine Monitoring and Failure Indications

The original F-15 engine turned out to be much less reliable than anticipated. The problem puts increased responsibility on test equipment to identify engine faults, but the fault isolation system is not as effective as it could be. Complicating the repair problem is the absence of information the technician requires. He needs specific engine indications present at the time the problem occurs. While the pilot has access to those readings, the malfunction typically diverts his attention elsewhere. By the time he handles the immediate inflight problem, the pilot has usually changed the engine settings and therefore cannot provide the specialist with the necessary information. Again, the severity of this problem was not readily apparent until the F-15 flew operationally, primarily because the actual engine operating envelope was much different from what the designers had anticipated. As a result, the ATF ORD specifically addresses this issue.[15]

3. Improved Vulnerability to Ice Damage

The F-15 engine is more susceptible to ice damage than designers anticipated because of certain intake airflow characteristics. This problem is understandable because it is impossible to model all the various environments in which an operational aircraft flies. Interestingly enough, most unexpected icing problems occurred in the relatively mild climates of Virginia and Germany. The combination of factors that caused this vulnerability was unpredictable and subsequently led to an ATF requirement for not only better ice detecting systems, but also for engines that withstood ice ingestion better.[16]

4. Less-than-Idle Engine Setting for Taxi

F-15 engineers did not anticipate the high brake wear eventually reported by field units. One of the culprits for this problem is relatively high thrust at idle throttle settings. Even at idle, the airplane taxies at too great a speed for some conditions, resulting in the pilots riding the brakes. This problem is worse on wet or icy runways and not only increases brake wear, but also creates a safety hazard. The Air Force instituted procedures for pilots to shut down an engine for taxiing, but even one engine at idle sometimes provides too much thrust. The problem resulted in an ATF requirement for a sub-idle engine setting.[17]

5. Idiot Proof Windshield Anti-Icing

The windshield anti-ice switch in the F-15 is a toggle switch that when activated gives the pilot no indication that the system is on. If the pilot leaves the switch on for too long, the hot anti-ice air damages the windscreen, which then requires replacement. Because of numerous F-15 windscreen replacements, the ATF ORD levies a requirement for a system that clears ice away while avoiding any possible windscreen damage.[18]

6. Intercom Access

For the crew chief to communicate with the pilot, he has to plug a communication cord into the airplane and talk with the pilot over a headset. Because designers located the intercom panel near the left engine intake, there have been numerous incidences of foreign object damage (FOD) to the left engine, as well as some cases of personal injury. As a result, ATF requirements specify safe access to the intercom while both engines are running.[19]

7. Break Rate/Fix Rate/Mission Capable Rate

The Air Force typically measures aircraft reliability against statistics that gauge how often an airplane breaks, how long it takes to fix, and what percentage of the aircraft are in service. The extensive F-15 and F-4 operational data bases gave the Air Force objective information on which to base realistic ATF requirements. Such requirements simply set them up for time and cost overruns later in the program. These same data bases provided industry a confidence level that assured them they could meet Air Force demands. A look at one of these statistics, break rate, will illustrate the concept.[20]

If an aircraft lands with a malfunction that requires more than normal servicing (fuel, oil, armament etc.) prior to taking off again, it is broken. The rate at which this occurs is the break rate and it is defined in terms of a percentage of sorties flown. (The lower the number, the better.) By looking at F-4 and F-15 break rates from 1977 to 1982, we can see why the current ATF requirement is logical.[21] The F-15 improved on the F-4 by 35 percent. Similarly, the ATF requirement is a 35 percent improvement over the F-15.[22] Since the more complex F-15 broke 35 percent less often than the F-4, both industry and DOD had the confidence they needed to commit to the ATF requirement. With an extensive F-4 data base, but only a small prototype F-15 data base, DOD would have been unwise to press for the very stringent ATF requirements. Similarly, industry needed the F-15 to prove its performance over the long haul and thus give them the necessary confidence to accept the ATF requirements. In short, the F-15 provided a necessary intermediate step.[23]

8. Airlift Requirements

A final key supportability requirement is an aircraft's associated airlift support. A 24-aircraft F-15 squadron requires approximately 24 C-141s to deploy into an operating base.[24] The ATF requirement reduces airlift support to only eight C-141s.[25] The 1st Tactical Fighter Wing's deployment to Saudi Arabia for Operation DESERT SHIELD highlights the importance of reducing airlift requirements. The wing deployed two squadrons, but the associated maintenance package for only one squadron arrived concurrently with the aircraft and pilots. While there were several reasons for this event, an airlift requirement two-thirds smaller would have alleviated the problem.

9. Miscellaneous

Because line personnel flew and maintained F-15s, the Air Force could better define several other M&S requirements. These requirements include computerized access to repair manuals, automated servicing data reporting, single panel monitoring of fluid levels, and reduction in the number of hand tools and specialized servicing stands.[26] Operational units helped identify all these areas of emphasis because they were irritations that made their day-to-day jobs more difficult and, therefore, adversely affected the mission. Without the broad base of F-15 experience, the Air Force would certainly have failed to address some, if not all, of the above problems. The result would have been a less capable ATF. Having examined the very real impact operational F-15 flying had on defining ATF requirements, we can now turn to its effects on the aircraft's design phase.

AIRCRAFT DESIGN

Engineers designing new airplanes need some kind of baseline from which to begin the process. Operations analysts provide the designers a starting point by looking at the way pilots flew the previous airplane. Two key areas they analyze are flight regimes and tactical doctrine. The analysts determine the typical flight regimes of the earlier aircraft and pass that information to the structure and propulsion engineers. Engineers will design an aircraft that needs to go low and fast without turning at high G-loads differently than one expected to dogfight at high angles of attack (AOA). The analysts consider tactical doctrine in order to predict which technologies will be most useful on the next aircraft. This tactical analysis gives the avionics engineers an idea of which technologies to pursue in helping the pilot execute the mission. This process is known as defining the usage envelope.[27]

The usage envelope is critical to design engineers. Without it they would have to design an airplane that could do everything well. Such a design would probably be impossible, not to mention cost prohibitive. An operational program provides a continually changing data base that modifies the current aircraft's usage envelope. Since this changing usage envelope is the starting point for designing the next airplane, the more complete the data defining that envelope, the better the starting point will be for the next design. Engineers have discovered that it is very difficult to predict the next usage envelope, even when building on an operational aircraft program. And while historical analysis is not the only determinant of the next aircraft's envelope, it is a critical factor in reducing the risk associated with new aircraft design. [28] What follows are examples of how design engineers relied on the F-15 usage envelope when they designed the ATF. Each of the examples comes from senior engineers at McDonnell Douglas, all of whom have experience with both the ATF and the F-15.

1. Flight Control Vibration at High AOA

F-15 design engineers did not completely anticipate the degree to which pilots would take advantage of the airplane's high AOA capability. The system's high thrust-to-weight ratio led to new maneuvers that frequently placed the airplane in high AOA regimes that resulted in significantly more vibration on control surfaces than engineers predicted. The results were cracked tails and wings as well as detached wing tips and horizontal stabilizer leading edges.[29] Had the Air Force not flown the F-15 long enough for these problems to surface, there is no reason to believe the engineers would have anticipated the same problems for the ATF. With the F-15 data in hand, however, the engineers were better able to design an aircraft to withstand the extensive high AOA maneuvering required of a high thrust-to-weight fighter.

2. Multi-Sensor Integration

As previously observed, the F-15 was the leader in developing BVR tactics. To successfully execute these tactics, the pilot had to assimilate information from several different sources. Primarily he needed radar-derived target information, IFF data, and threat information from the radar warning receiver (RWR). Attempting to correlate this information, and fly the airplane at the same time, resulted in more work for the pilot primarily because of the way tactics developed around BVR technology. The danger of pilots developing information overload highlighted a need in the ATF to automatically integrate sensors and then display the information to the pilot in a relatively simple format. Engineers thought they could address some of these problems on the F-15. As they looked for solutions however, they found that existing architecture and design tolerances were insufficient to provide the best solutions. In general, the sensors were not accurate enough in azimuth, and the computers, with their limited data buses, were incapable of processing the wide variety of inputs. These problems directly influenced the avionics designers working on the ATF. Once again, F-15 operations identified a problem, and in this case, it also showed engineers how to solve it on the ATF.[30]

3. Computer Processing Requirements

Although contractors routinely update the F-15's avionics (especially the radar) via software changes, the basic avionics architecture has insufficient computer capacity.[31] This problem limits the pilot's capabilities because each time the Air Force contracts for a software update, it must decide what to delete to make room for the new additions. The ATF requirements specify a capability to expand its computer processing capacity by 200 percent, and thus accommodate tomorrow's technology and doctrine.

4. Engine Durability

Engine durability is another problem that can be attributed, at least in part, to the way F-15 pilots fly BFM. Because of the F-15's high thrust, pilots frequently modulate the power setting and generate 16 times the number of engine cycles designers initially expected.[32] (Simply put, engine cycles are the number of times a pilot changes the power setting from idle to afterburner). The high number of cycles has contributed to Air Force dissatisfaction with the engines' durability and reliability. Engine Component Improvement Programs have resulted in numerous modifications, including improved life cores (4000 hour cores versus the original 2500 hours) and digital electronic engine controls. The engines' manufacturer, Pratt and Whitney, credits millions of F-15 engine hours with making these and other improvements possible. In turn, the Pratt and Whitney ATF engine may be completely new, but all the lessons learned from the F-15 were applied to its design.[33]

5. Avionics Component Reliability

The F-15 was the first airplane to make extensive use of modular avionics components. McDonnell Douglas intended for the fault isolation system to isolate a problem to one of the "black boxes." Maintenance people would then replace the unit on the flight line and send the failed component to a back-shop for repair. While I have already identified some fault isolation problems, there are other problems with the boxes "talking" to each other. A box may test perfectly, but when connected to the rest of the system it does not work. In other cases, a box is selective about which other boxes it will work with. Most experienced maintenance personnel trace the problems to the large number of components involved and their connecting architecture. As a result, ATF designers emphasized fewer components and thus less connecting architecture. These improvements should make the system more reliable and lighter. In addition, the ATF avionics will better handle the structural loads experienced in high-G maneuvering. Engineers found that they did not design the F-15 modules strong enough to hold up in that environment.[34]

6. Environmental Issues

In designing the F-15, McDonnell Douglas found it was impossible to predict all the environmental conditions in which the aircraft would operate. For example, field personnel discovered that honeycomb construction made some F-15 structures especially susceptible to moisture damage. Moisture weakened these structures increasing their vulnerability to high AOA vibration.[35] The impact of this issue on the ATF is somewhat indirect. The ATF will introduce many different construction techniques and materials based on stealth requirements. The F-15 experience suggests that testing will not reveal all of the potential environmentally induced problems, so the ATF engineers needed to design-in a larger margin of error for unknown environmental factors.[36]

Design engineers are quick to say past aircraft designs influence their work and that they rely heavily on seeing how their designs perform in the real world. It is difficult, however, to isolate specific examples of this process. While there are undoubtedly more examples than those I have described here, the evidence shows that, as with requirements, the ATF design would not be as advanced without the benefit of an operational F-15. With this point established, we will briefly examine the role of an open production line in advancing fighter aircraft design.

PRODUCTION

An active production line contributes to improved fighter development in two ways. First, it allows design engineers to integrate their ideas onto fighters in production. This opportunity is important because engineers must design with production in mind. There are many good designs that are unproduceable given current manufacturing limitations.[37] Second, an open production line provides an avenue for developing and validating new production techniques that integrate previously unusable technologies. Feedback from the production line goes back to the design engineers and directly affects their work. The following two examples show how F-15 production led to manufacturing improvements that influenced the way engineers designed ATF components. In each case, the improvements did not come from the early production phase of the aircraft. Instead, McDonnell Douglas developed and validated them over an extended production run.

1. High-Speed Machining

High speed machining techniques are appearing on the F-15 production line in order to reduce the aircraft's number of structural parts. This type of machining allows a worker to make a part from a single piece of material primarily because high speed tools cut the material to tighter tolerances than previous techniques. As a result, high speed machining makes components lighter, generally stronger, and more durable than the same part constructed from several pieces.[38] In addition, high-speed machining allows design engineers to save weight on structural components and devote the savings to other areas such as avionics.

2. Super-Plastic Formed/Diffusion Bonded Manufacturing (SPFBD)

SPFBD is a manufacturing method that forms titanium with super-plastic. This process led to the development of built-up low-cost advanced titanium structures (BLATS). McDonnell Douglas has used these structures to build late model F-15 engine bay panels, and thus use 20 percent of the parts originally required. They have also used BLATS stiffen F-15 gear doors. SPFBD and BLATS are significant in terms of the weight savings they provide, but more importantly they validate the one piece construction concept for very large aircraft parts. In addition, the use of titanium shows that engineers can design certain structures with previously unsuitable material.[39]

Because the ATF has not yet reached production, it is difficult to discuss in more detail, the effects of F-15 production on the ATF. The point of the above examples is that an open production line provided an opportunity for McDonnell Douglas to develop new manufacturing techniques. The new techniques, in turn, gave engineers options previously unavailable using old methods.

CHAPTER SUMMARY

Adding together the requirements, design, and production examples of the last 20 pages, makes it is obvious that the <u>operational</u> F-15 contributed in large measure to the ATF's development. While industry could certainly build an ATF without the F-15 experience to draw from, it would not be the same airplane. The latter ATF would have obvious weaknesses, primarily because the engineers would have unwittingly designed problems into the aircraft; problems that an active F-15 program did identify. Therefore, feedback from the F-15 was critical to designing an ATF that truly is on the cutting edge. With this point now established, chapter 3 will clarify the feedback process in fighter construction via a design model. It will also demonstrate the inability of a prototype-only strategy to provide the feedback needed to advance fighter aircraft design.

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[1]"Potentially" is used because the case study for this paper is the McDonnell Douglas design, the one that lost the fly-off competition.

[2]David A. Thaler, *Strategies to Tasks, A Framework for Linking Ends and Means*, RAND Report MR-300-AF (Santa Monica, Calif.: Rand Corporation, 1993), 4.

[3]David Hamilton, "Concept Selection: A Process for Aerospace Design Decisions" (St Louis Mo.: McDonnell Douglas Aerospace, 1993) 3-4.

[4]Ibid.

[5]While the reverse may be true in the case of the MiG-21 and the F-4, the Soviet Union certainly reacted to US technology, especially with their fourth generation fighters, the MiG-29 and SU-27.

[6]ATF SORD TAF 304-83-1/II-A (Revision 1) Annual Update, *System Operational Requirements Document (SORD) for an Advanced Tactical Fighter (ATF)* (U), 15 June 1990. (Secret-NoForn), 5. Information extracted is unclassified.

[7]Ibid.

[8]ATF SORD, 8.

[9]ATF SORD, 12.

[10]ATF SORD, 13.

[11]ATF SORD, 12.

[12]Robin DeTurk, interviewed by author during visit to McDonnell Douglas Aerospace, St. Louis Mo., 21 December 1993.

[13]ATF SORD, 7

[14]Ira Pope, Dave Kunz, Bob Lutter, Dan Gardner, interviewed by author during visit to McDonnell Douglas Aerospace, St. Louis Mo., 21 December 1993.

[15]ATF SORD, 28.

[16]ATF SORD, 28.

[17]ATF SORD, 30.

[18]ATF SORD, 33.

[19]ATF SORD, 30.

[20]Break rate serves as the example because it is the one least impacted by outside influences. Fix Rate and Mission Capable Rate are both significantly affected by funding levels and Air Force decisions regarding the number of spare parts maintained in stock. These outside factors make it difficult to compare data over any extended time period.

[21]This time period is the best one for illustrating the point. It is the most recent five year period where there were still significant numbers (11) of bases flying F-4s.

[22]Data provided by Rod Schultz, Field Data Analysis, McDonnell Douglas Aerospace, 12 May 1994.

[23]ATF SORD. Larry Niedling, interviewed by author during visit to McDonnell Douglas Aerospace, St. Louis Mo., 20 December 1993.

[24]Lt Col Edward Felker, interviewed by author at Maxwell AFB Al on 2 May 1994.

[25]ATF SORD, 18.

[26]ATF SORD, 8. Pope et al.

[27]DeTurk.

[28]DeTurk.

[29]Niedling.

[30]Larry Nanney, interviewed by author during visit to McDonnell Douglas Aerospace, St. Louis Mo., 20 December 1993.

[31]Ibid.

[32]Pope et al.

[33]Robert Shambaugh, St. Louis Office Manager, Pratt & Whitney, Memo, subject: P&W Engine Development, May 1994.

[34]Pope et al.

[35]Bill Richards, interviewed by author during visit to McDonnell Douglas Aerospace, St. Louis Mo., 21 December 1993.

[36]Gary Hakanson, interviewed by author during visit to McDonnell Douglas Aerospace, St. Louis Mo., 20 December 1993.

[37]Jeffrey A. Drezner et al., *Maintaining Future Military Aircraft Design Capability,* RAND Report (Santa Montica, Calif.: Rand Corporation, 1992), 58,62. William B. Vance, “Lean Production: A Focus for Defense Procurement Success,” *Program Manager* 22, no. 5 (September-October 1993): 42.

[38]Dee Gill, Dan Drapp, Fred Stahl, interviewed by author during visit to McDonnell Douglas Aerospace, St. Louis Mo., 21 December 1993.

[39]Frank Friet, interviewed by author during visit to McDonnell Douglas Aerospace, St. Louis Mo., 21 December 1993.

Chapter 3

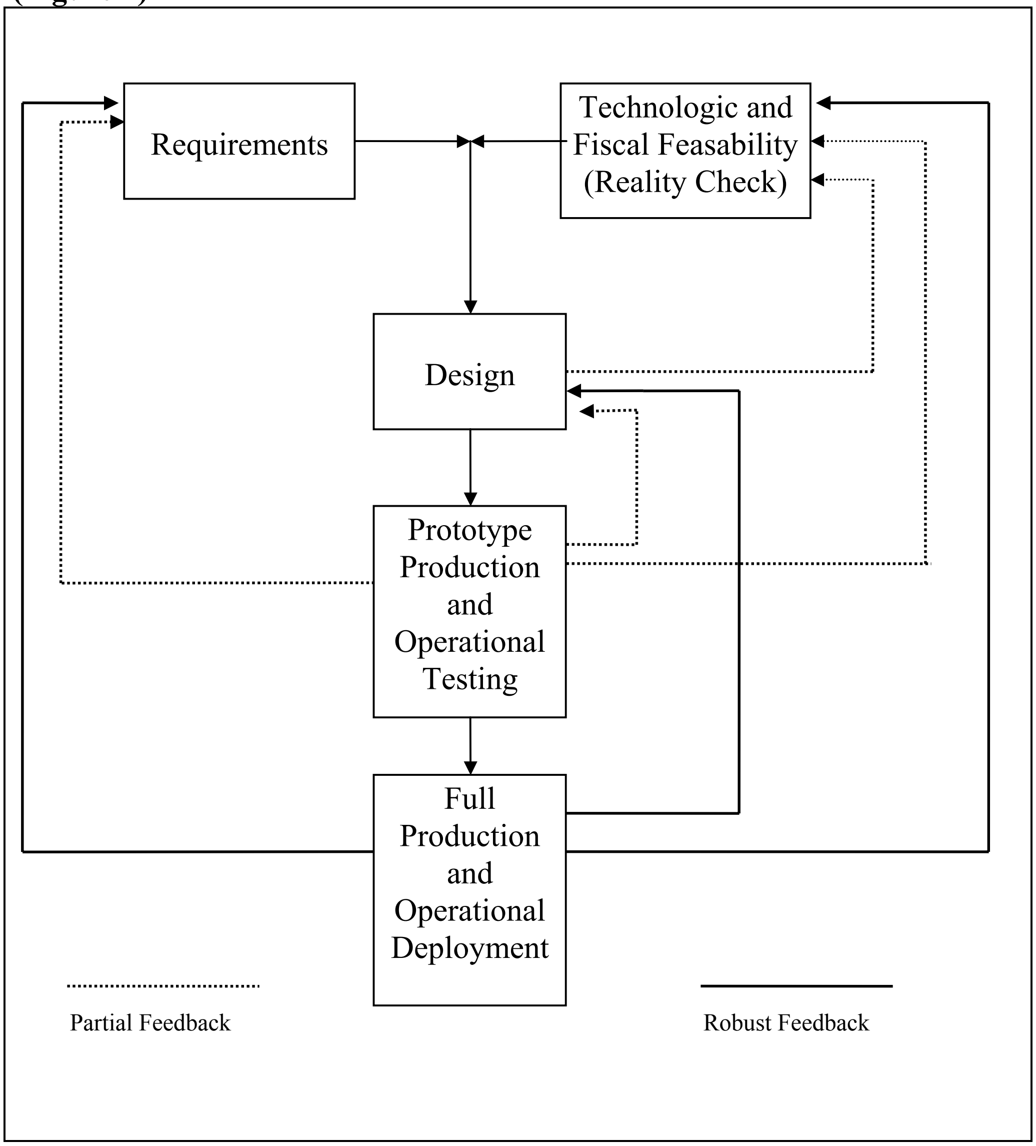
Feedback for Design Continuity

Chapter 2 gave numerous examples of how operational F-15 flying directly contributed to developing the ATF. Drawing from those specific examples, the first section of this chapter provides a model that shows how and why robust feedback loops are necessary to field cutting edge fighters. With the model acting as a foundation, the chapter will then explain why the Rollover-plus acquisition strategy is incapable of providing the critical feedback needed for fighter development, even considering the effects of advanced computer simulation. As a result, the Silver Bullet strategy is the only viable alternative to the current acquisition practices.

FEEDBACK MODEL

The fighter development model (Figure 1), visualizes the various feedback channels discussed in chapter 2. It also shows the relative importance of each channel to the overall process. The model begins with merging requirements and feasibility, both technical and fiscal. As discussed earlier, this is the phase where the warfighter consults with the scientist to insure that what the warfighter is asking for is both technologically possible and fiscally reasonable. Likewise, the warfighter must insure that the scientist understands each requirement and can satisfy them with available technology. Once they complete this step, the project enters the design phase.

Fighter Development Model
(Figure 1)



In the design phase, engineers attempt to design the aircraft within certain constraints. They must consider weight, cost, systems integration, production, and a myriad of other factors that if not considered would make a design useless. At this stage there is some partial feedback to the system. Technologies that engineers originally thought might work may prove to be impractical for one reason or another. This feedback goes back into the "reality check" stage and future consideration of that technology will have to address whatever made it impractical. An example of this might be a requirement for an Infrared Search and Track System (IRSTS). As the engineer designs the IRSTS, he may find the sensor is too large and would have an unacceptable aerodynamic effect on the airplane. Perhaps when it is time to build the next generation aircraft, the sensors will be smaller and make the IRSTS practical.

After the necessary design work is completed, the next step in the process is prototype production and operational testing. While prototyping is not always a prerequisite for production, it is included in this model because it incorporates the Rollover-plus alternative. Building and testing operational prototypes partially validates the design from a systems integration standpoint, thus providing more feedback than design work alone. Additionally, if the contractor builds prototypes using production techniques, the experience can help validate the manufacturing process. However, it is important to note that the typical prototype today is not built this way. Industry generally "hand-builds" prototypes that bear little more than a superficial resemblance to actual production aircraft. Not only do companies use one-time tooling and production methods, but they also fly the airplane without integrating the complete production avionics package. Such "hand-built" systems provide little useful feedback and they are not the systems Rollover-plus requires. Rollover-plus depends on operational prototypes that are as close to production aircraft as possible, both in performance and manufacturing technology.

Assuming the presence of an operational prototype, the testing phase provides designers with a partial validation of their design. This phase also relates back to the "reality check" step by highlighting problems that will not appear until a test pilot flies the airplane and tests the new technology. Finally, this phase provides partial feedback to the requirements stage because test pilots with operational backgrounds have an opportunity to superficially evaluate new technologies in relation to existing tactical doctrine. Yet as chapter 2 illustrated, the operational test phase feedback is incomplete because the Air Force and industry learn substantial lessons well after this phase. Therefore, the model shows robust feedback coming only from full-production and operational deployment.

Having shown how the feedback loops work, we will now look at why they are important. From the model, and from previous F-15 experience, we can conclude that operational flying is critical when radically new technology appears. This is true because it is impossible to predict all the effects that result from new technology integration. Three examples illustrate the point. First, the F-15's thrust-to-weight ratio of greater than one was a new technology that had far reaching effects. The main impact was how this innovation changed the aircraft's usage envelope. The thrust increase allowed pilots to fly the airplane at higher AOA and higher G-loads. Designers knew this; however, they could not predict the degree to which pilots would exploit this new capability. As we have seen, exploiting this flight regime unexpectedly stressed the aircraft and caused various cracks and component failures. Additionally, the increased capability led to new BFM tactics that later led to new requirements designed to increase the pilot's ability to point and shoot. Since the thrust-to-weight change from the F-4 to the F-15 was revolutionary it caused many unforeseen events.[1] The ATF will have an increased thrust-to-weight ratio over the F-15, but the change will be an evolutionary one. Because F-15 flying identified various characteristics associated with high thrust-to-weight ratios, engineers were better able to predict the ATF usage envelope.

Thanks to the F-15's operational experience, the maneuvering portion of the ATF usage envelope should hold few surprises; however, the introduction of low observable technology will be revolutionary and have unpredictable effects on maintainability and tactics development. Some lessons will carry over from the F-117, but they will be limited because the mission of the ATF is significantly different and so is its usage envelope. From a maintainability standpoint, for example, we cannot predict how well low observable materials will stand up to the stress of high-G maneuvers, nor is it clear how they will react to the environment.[2] (Remember that the F-117 flies relatively benign maneuvers and is well protected from the weather.)

Lastly and perhaps most importantly, we cannot predict how tactics will change based on low observable innovations. Being able to avoid both airborne and ground-based radar detection will certainly affect air-to-air tactics. In addition, new sensors which emphasize low emissions will radically alter current tactical doctrine as it applies to radar search and targeting. Some low emission sensors will be more useful than others based on their ability to provide useful information to the pilot. This technology will have a revolutionary impact on tactical employment and while we could assess some of the impact in the ATF test phase or by using simulators, our F-15 experience indicates that new tactics will not become self-evident until the airplane is deployed operationally. The "fog" and "friction" which hamper success will not appear until daily flight operations challenge the airplane's design. The fact that these effects will be unpredictable is exactly why the Air Force should field and fly the ATF operationally. Revolutionary change makes this a clear necessity.

Having demonstrated via specific examples, and a general model, that radically new technology affects an aircraft in unpredictable ways, we must now look at why a prototype program will not identify the most significant problems, nor the most promising technologies.

WHY ROLLOVER IS NOT THE ANSWER

This section will show why Rollover-plus is incapable of maintaining fighter development continuity. It will do so by showing that a prototype-only strategy fails to allow for tactics development, does not support the engineering design base, is financially unrealistic, cannot identify every critical design fault, and does not encourage improved production techniques.

Prototypes do not allow sufficient tactics development.

In the area of tactics development, we have seen that it takes time for pilots to learn how to best use new technology and subsequently determine its effects on doctrine and future requirements. This is evident when one looks at how tactical doctrine evolves, the way the Air Force identifies aircraft shortfalls, and finally by the results of an early operational F-15 test. In the first case, the Air Force publishes tactical doctrine in Multi-Command Manuals (MCM) 3-1. Significantly, the service did not publish the first F-15, F-16, or F-117 MCM 3-1 until about 18 months after the aircraft reached IOC. It took that long for pilots to develop some initial ideas on how to use the new airplanes.[3] It is also important to note that doctrine continues to evolve, especially at annual conferences where representatives from operational units present their ideas. The mere fact that doctrine is constantly changing indicates we need long-term flying to completely take advantage of a new aircraft. Rollover-plus will not provide that opportunity.

In the second case--identifying aircraft shortfalls--prototyping is also inadequate. One can support this assertion by analyzing the source of Form 37s and Tactics Improvement Proposals (TIPs). Form 37s are a formal way of recommending changes to an airplane. The changes generally address some software or switchology shortfall. Sometimes the Air Force cannot fix the problem, given a current aircraft's architecture, but it saves the idea for future consideration when building the next aircraft. TIPs recommend new tactical doctrine as well as equipment enhancements. 80 percent of the 200 TIPs submitted each year, as well as the majority of Form 37s, come from field units versus the test community. This indicates that operational flying is, by far, the richest source of information for identifying what the next airplane must be able to do.[4] Rollover-plus simply cannot provide the same rich source of ideas.

An early operational F-15 test is the final, and best example, of why a prototype program cannot adequately explore new technology and develop associated tactics. The 1979 Air Combat Evaluation (ACEVAL) tested this very concept. The Air Force flew six operational F-15s to determine the effectiveness of a high-quality, low-quantity force against a low-quality, high-quantity adversary. Pilots flew numerous scenarios with varying numbers of friendly and enemy aircraft. While it was not the test's primary goal, ACEVAL did lay the building blocks for F-15 employment. What is relevant here is that the test did a poor job of predicting changes in air-to-air tactics resulting from new technology in the F-15. The tactics that did emerge from the test were very different than the tactics F-15 units were flying five to six years later. For example, the ACEVAL lessons learned regarding BVR employment suggested vastly different radar employment techniques than what eventually emerged as tactical doctrine.[5] Additionally, the test pilots only superficially addressed the problems associated with electronic identification and instead emphasized using a rifle scope for visual identification. None of the findings emphasized the importance of sensor integration and pilot workload. ACEVAL, effectively an operational prototype test, failed to identify almost all the key factors driving ATF requirements.

Prototypes encourage design base atrophy.

As we have just seen, Rollover-plus does not allow the fighter community to fully explore the tactical applications of a new aircraft design. In this section and the one that follows, we will see that Rollover-plus also shortchanges industry. One goal of the strategy is to maintain the defense industrial base.[6] That view is too narrow, however, because advancing fighter design means more than simply preserving factories and equipment.

Arguably, the most important factor in advancing fighter design is the availability of skilled and experienced engineers. While a prototyping strategy may be sufficient to keep some corporations open, maintaining engineering expertise without at least low-rate production is going to be difficult.[7] According to Air Force Secretary Widnall, one aspect of the problem is a growing age gap developing among aircraft engineers. Today's entry-level engineers will build the next generation fighter. However, because of the current defense drawdown, the number of young engineers is growing disproportionately small. In fact, 40 percent of today's engineers are over 40, and the downsizing is forcing many into early retirement. This means that there are fewer engineers available to pass on their experience. The problem is compounded by the fact that there will probably be only one design in production between now and 2010. As

Secretary Widnall notes, "It's hard to keep the experience base for military aircraft design capability if you don't have designs to work on," and prototyping and technology demonstrators are only part of the solution.[8] An additional effect of failing to maintain the engineering base is higher costs due to reduced engineering proficiency.[9] This is because "[a]n aircraft design team, no matter how qualified and well supported, will inevitably lose its overall ability to produce new aircraft designs that incorporate new technology if it goes too long without actually designing, flying, and testing new aircraft."[10] The conclusion is obvious; in order to control costs and maintain the fighter aircraft engineering base, industry must sustain at least low-rate production.

Low-rate production, as called for by Silver Bullet, would also address another issue--the process engineers adopt. Engineers must design with production in mind because only designing prototypes puts an emphasis on performance at the expense of produceability.[11] Without production, engineers are not forced to deal with the realities of fitting technology into an operational airplane.[12] Additionally, without operational flying, the engineers operate in a vacuum because they are not incorporating inputs from various feedback loops. Silver Bullet addresses all of these aspects of design engineering.

A prototyping strategy is financially unrealistic.

In addition to a skilled engineering pool, a strong aircraft industry also needs enough organizations to maintain competition, a sustained program of technology advancement, and a business environment that supports all of the above. Organizations that satisfy all these criteria have a $100 million annual budget, employ 1000 engineers and technical managers, and maintain expensive support equipment like factories and large wind tunnels.[13] Because Rollover-plus is inherently R&D intensive, a major shift in budget philosophy is required in order to sustain such organizations. This is because industry R&D funding does not come just from the funds earmarked for R&D in the defense budget. Most of the funding comes from production, and without production industry will not have the money needed to develop new technology.

According to former Deputy Defense Secretary Atwood, the money for a prototype acquisition strategy will be available only if R&D is attractive in its own right.[14] An operational prototype program would cost about $100 billion a year, tripling the current R&D budget. Getting this type of funding from Congress would be impossible and even if you could, the profit margin in a prototype program is too small. There is only 7-10 percent profit in this type of program and because the total cash flow would be limited, there would be insufficient assets to support the organizations described earlier.[15] These facts lead to the conclusion that making Rollover work from a financial standpoint would be very difficult. Given its other shortfalls, the effort to sell the program to Congress is not worth it.

Prototypes do not identify all the problems.

Even if the Air Force could sell Rollover-plus funding to Congress, they should not because it fails to identify two types of aircraft problems: systems integration issues and safety concerns. Systems integration problems are tricky because some do not appear until there are large numbers of aircraft flying. This is especially true with electronic emissions interference. Industry usually develops and tests avionics on platforms other than the aircraft in development. This method fails to expose the components to dense and varied signal environments typical of fighter operations and, as a result, unforeseen problems develop. One example is the F-15E ground collision warning system. McDonnell Douglas tested it by flying two aircraft in formation and found no unexpected emissions interference. However, the first time the system flew in Red Flag, mutual interference problems appeared when four aircraft flew together in a dense signal environment. This was the engineer's first clue that a problem existed; an especially significant problem given the system affected. Without such a "test," the Air Force would not have discovered the problem and a Rollover-plus strategy would not allow many tests with the scope of a Red Flag.[16]

As the above systems integration example hints at, there are also safety concerns that a prototype program may not identify. The Air Force lost its first F-15 when a pilot activated the wrong switches after experiencing an engine malfunction. His actions aggravated the problem and cost him his life. The accident board determined that a contributing factor was the design of certain cockpit switches. Testing never identified a potential problem with the switchology; sadly, it took an accident to do so.[17] This problem, as well as the one with the ground collision warning system, highlight a primary concern of design engineers. They realize that it takes a certain amount of experience with an airplane before all the design flaws are discovered and as a result, they are very conservative when designing systems that directly affect flight safety. In fact, one engineer stated that when designing such systems, he uses conservative tolerances until he is confident of the system's reliability. That confidence comes, according to him, only after the system is field proven.[18]

Given that the above problems may not appear in the prototype phase, we must determine how much flight experience an aircraft needs before the Air Force can be assured it has identified its critical faults. Although engineers are sure that operational experience is necessary for complete fault identification, they are unsure of exactly how much flying time is required.[19] When pressed to come up with a number, one group felt that 60-70 airplanes fielded for four years, with about 1000 hours on each aircraft, would be sufficient to provide all the feedback necessary. A data base of that size insures "all the bugs are out." The figures are based primarily on the group's experiences with structural integrity and avionics reliability.[20]

Prototypes do not advance production methods.

The fourth major problem with the Rollover-plus strategy is its inability to advance production techniques. Aircraft production in World War II demonstrated the importance of this capability. By 1944, production improvements allowed the US to cut the labor cost for each pound of airplane by two-thirds. These improvements came from producing a lot of airplanes and making a conscious effort to do so more efficiently and effectively. Similarly, the major aircraft manufacturers today are concentrating on improving production efficiency, but they are limited by current production levels. Senior officials at both Lockheed and McDonnell Douglas have expressed concern over this issue. According to Sherm Mullin, President of Lockheed's "Skunkworks", " [A] handful of aircraft does nothing for manufacturing technology at the major subcontractor or prime levels."[21] In a similar vein, Jim Sinnet, Senior vice-president and General Manager of McDonnell Douglas' New Aircraft and Missile Programs (NAMP) division said that developing new manufacturing techniques requires open production lines.[22] These statements indicate that despite its stated goals, Rollover will not generate enough production to advance manufacturing technique.[23] If a company gears up to produce six aircraft for example, and comes up with a new production idea on the fourth one, there are not enough production airplanes remaining to recoup the financial costs associated with changing the process. This failure to advance manufacturing technique, like the previous four Rollover-plus shortfalls, is a critical problem that prevents prototyping from advancing fighter design.

COMPUTER SIMULATION WILL NOT MAKE ROLLOVER WORK

Recent advances in computer technology suggest that simulation can perhaps make up for some of Rollover-plus' shortfalls. Unfortunately, because computers only model the real world they are inherently inaccurate and cannot substitute for the experience one gains from actually building and flying new designs. Models are tools that rely on empirical data to be accurate. The smaller the empirical data base behind the model, the less complete its simulation of real life. When designers introduce a new technology, the data base for any model will necessarily be small and as such the engineers will have to make some assumptions that affect the model's underlying algorithms. The fact they are forced to make assumptions means the model will be inaccurate to some degree and the conclusions they draw will be inherently imprecise.[24] An earlier example from the F-15 highlights the possible ramifications of such assumptions. Propulsion engineers designed the F-15 engine for a certain number of cycles. As it turned out, the assumption designers made regarding cycles was off by a factor of more than 16. Because of this one assumption, the engine became a maintenance nightmare and the aircraft fell short in certain tactical scenarios, specifically countering the high fast flyer. Because they had no historical data on an airplane with a thrust-to-weight ratio greater than one, the engineers relied on the F-4 experience which proved to be a poor basis for prediction.

Compounding a model's inaccuracy (due to its underlying assumptions), is the sheer complexity of system interactions. This is especially true in the area of human interface with advanced technology. The fog and friction of war significantly affect this interface. Because those factors are so unpredictable, any model will have difficulty predicting operational effects. An example of this is the advanced avionics technology in the latest F-15 models. The aircraft is now capable of displaying more information to the pilot than he can practically use. Part of the reason for this is because the avionics are developed in the simulator. In the simulator the pilot can devote more time to the avionics and less time to actual flying, thus giving a skewed impression of how pilots will use the system in flight. In addition, the Air Force typically uses very experienced pilots to help contractors develop new displays. As a result, the effects of inexperience are subdued. Without advances in integration engineering, it will be impossible to draw accurate conclusions about human interactions using current modeling techniques.[25] Even if we could, there are other dangers in relying too much on computers.

While the computer is a useful tool, it cannot provide "intuition and inspiration."[26] These characteristics are symptoms of wisdom and judgment that come from the actual design experience. Although the younger generation of engineers has the computer know-how, the older engineers have the experience. If the drawdown exacerbates the age gap, industry may be in a position where they have a pool of engineers who are adept at designing things on a computer, but because they do not have the design experience to draw on they may find themselves searching for ways to integrate new technology. To avoid this problem, industry must have the opportunity to combine computer expertise with the experience older engineers have gained from the last 30 years of designing fighter aircraft.[27] Low-rate production will provide the forum to pass on that irreplaceable experience.

The last point on advanced computer simulation concerns aircraft simulators. As previously stated, feedback is most critical when a revolutionary technology appears. New technology starts a chain reaction that generates new tactics, which in turn require new technologies. The question is whether the fighter community can complete this loop in the simulator? The answer is no. Today's state of the art simulators provide visual cues to the pilots, reproduce all of the applicable cockpit displays, and even tie multiple simulators together allowing more realistic training. What the simulators cannot duplicate is the "feel" of the airplane, nor will they be able to do so in the foreseeable future. Until the pilot actually flies it, the engineer will never truly know how well his design works. That is because the pilot instinctively reacts to "seat-of-the-pants" inputs that cannot be simulated. For example, in high AOA flight the F-15 pilot feels the aircraft buffet which causes him to manipulate the controls in reaction to the buffeting. A simulator cannot accurately duplicate that buffet and therefore cannot show the engineer exactly how a pilot will fly his design. As alluded to earlier, an additional problem with simulators is the pilot is not worried about actually flying the airplane. Because there are no consequences for crashing, he can devote more time to fire control displays than is realistic, which means the simulator does not force the pilot to deal with the same time compression factors he faces when flying the airplane. The result is the designer does not get valid feedback on the quality of his design. The lack of feel and the inability to force the pilot to parcel out his attention realistically make the simulator inadequate for completely evaluating the effects of new technology. Pilots simply do not fly the simulator like they do the airplane. In the final analysis, the simulator and the other computer tools can help shape the problem and provide some feedback, but they will never be able to simulate the real world.

CHAPTER SUMMARY

Thus far, this paper has illustrated that there are feedback loops critical to maintaining continuity in fighter aircraft design. A prototyping strategy, even one augmented with computer simulation, cannot provide the feedback necessary for the requirements, design, and production phases of the fighter development process. What then is the solution? A Silver Bullet strategy, properly executed, will provide the operational experience necessary to satisfy the robust feedback described at the beginning of this chapter. The strategy will procure the aircraft needed to explore the tactical effects of new technology, and thus define the requirements for the next fighter. There will be enough airplanes to accumulate the flying experience necessary to validate engineering designs. And finally, there will be an open production line to not only improve manufacturing technology, but also generate funds for research and development. None of this is possible under Rollover-plus. As a result, the next chapter look at how to implement Silver Bullet, to include examining the technological and fiscal feasibility of the strategy.

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[12]Drezner et al., 58,62. Pete Von Minden, interviewed by author during visit to McDonnell Douglas Aerospace, St. Louis Mo., 21 December 1993.

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[27]Canan, 39.

Chapter 4

Making Silver Bullet Work

The previous two chapters concluded that the Silver Bullet strategy is capable of maintaining the US advantage in fighter design, while at the same time reducing procurement costs. This chapter will address how to implement Silver Bullet. It will suggest the size and frequency of Silver Bullet buys, describe the key industrial concepts that will make the strategy viable (lean production and rate transparency), and explore contractor and DOD initiatives necessary to make the strategy work. It is important to note that this chapter is not intended to stand alone as proof that Silver Bullet is financially or technically possible. Instead, its purpose is to provide some background on the issues most critical to making Silver Bullet work.

HOW MANY AIRPLANES AND HOW OFTEN

DOD must answer two key questions before pursuing a Silver Bullet strategy--how many airplanes do we buy and how often do we buy them? Determining the number of aircraft to buy requires DOD to look at the feedback process described in this paper. To get that type of feedback we need enough airplanes to develop tactics, provide the broad data base necessary for the engineers to validate their designs, and keep the production line open at a low rate of one or two aircraft per month. The Air Force can meet these requirements by buying 64 aircraft: 24 for an operational squadron, 12 for Operational Test and Evaluation, 10 for operational upgrade training, 10 for the USAF Weapons School, two for those in depot repair status, two for weapons load training, two for maintenance training, and two for aerial demonstration aircraft. In addition to providing necessary feedback, a 64 aircraft buy will ensure the weapon system does not become irreplaceable. The B-2 illustrates the point. If a CINC has 20 airplanes available, it only takes a loss of one or two aircraft to attrit a large percentage of the force, thus making him hesitant to use them. A larger buy provides the reserves necessary to avoid this problem. It is important to remember that the 64 aircraft buy is not intended to replace the current force structure. However, in order to serve their purpose of providing continuity in fighter development, the Air Force must fully integrate these planes into exercises and contingency planning. The aircraft should not be held in reserve and used only when "needed."

The second key question is how often should DOD execute Silver Bullet? While this question is difficult to answer, there are at least two possibilities. One is based on the ideas of Colonel John Warden, as expressed during several informal lectures at Air University. Warden believes we should not react to the threat; instead, we should be the threat. If we produced a new fighter aircraft every five to seven years, our adversaries would be hard pressed to counter our last aircraft before we fielded its follow-on. This is essentially a capabilities-based procurement strategy. The problems with it include frequently retraining a large number of pilots and maintenance personnel each time we field a new aircraft, and the issue of whether industry can build 64 aircraft at a unit cost acceptable to Congress.

Another possibility is DOD could execute Silver Bullet about halfway through the useful life of the current system. This would mean making a Silver Bullet buy and a "normal" buy about every 35 years. The F-15 and ATF programs can illustrate how this cycle might work. The F-15 entered operational service in 1975 with an expected service life of about 35 years. Halfway through the F-15 service life, about 1993, the Air Force would begin fielding 64 Silver Bullet ATFs. These airplanes would be completely integrated with the F-15 force in order to gather the data necessary to build the F-15 replacement. Then, in about 2010, the Air Force would begin replacing the F-15s with ATF follow-ons. The advantage of this strategy is that it avoids the retraining problem; however, the disadvantage is that the threat you present to potential enemies remains relatively constant. Also, like Warden's concept, you still must be able to execute Silver Bullet economically. The financial problems associated with the Silver Bullet strategy are sizable. To make it work, industry must overcome the belief that it is always cheaper to buy in bulk. This can only be done by achieving rate transparency.

RATE TRANSPARENCY AND LEAN PRODUCTION

Achieving rate transparency through lean production methods is the key to making the Silver Bullet strategy work financially. This section will discuss rate transparency and show that conventional wisdom works against its success. It will also describe the learning curve phenomenon and show why overcoming it is critical to Silver Bullet's success.

Rate transparency is the ability to defy economies of scale. You achieve it when you can build 10 of something at the same unit cost as if you were building 100 or 1,000 of the same item. Industry feels they can achieve rate transparency by instituting some lean production initiatives that I will describe later. These initiatives will allow manufacturers to produce items at a low rate and still maintain a reasonable profit margin. In addition, good lean production techniques are effective in larger production runs. This is a necessary capability, especially for the defense industry, because a national security crises may make it necessary to significantly increase production rates on short notice.[1]

Rate transparency and lean production face many hurdles, not the least of which is conventional wisdom. Several analysts doubt the approach's viability. According to Jeffrey Drezner of the RAND corporation, intuition says you simply cannot overcome economies of scale.[2] Mike Maltenfort, F-15 program business manager at McDonnell Douglas, believes achieving rate transparency will be difficult because you must work with existing factories that were designed to produce up to 100 aircraft per year. According to Maltenfort, they cannot operate efficiently at rates of 12 to 24 aircraft per year.[3] Finally, an unnamed Senior Air Force official is quoted as saying lean production "is a lot of words to pacify people in the industrial base." He points to the B-2 program as proof. After $42 billion, the manufacturing process is nonexistent and will not exist even after the Air Force builds 16 aircraft.[4] However, supporters of the concept argue that the U-2, SR-71, and F-117 programs all indicate lean production is possible.[5]

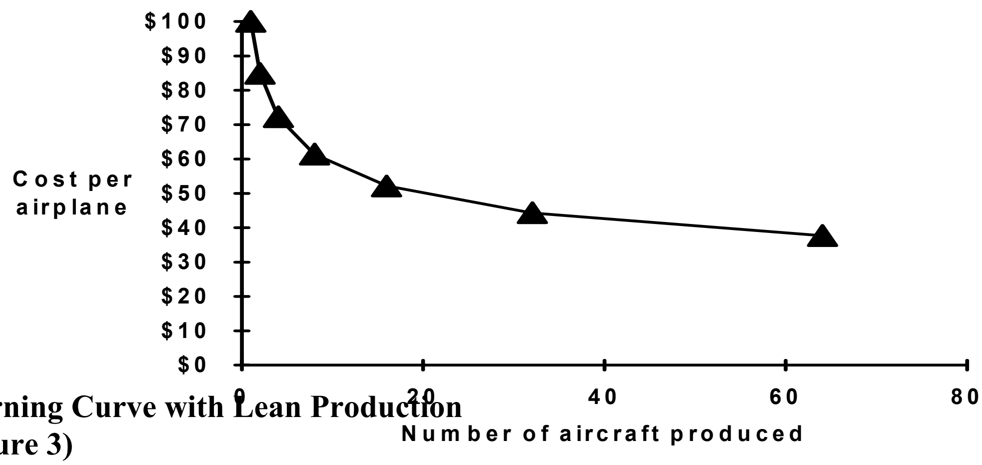
In fact, not only is lean production possible, but according to the only two remaining fighter aircraft builders, it is absolutely necessary. According to Lockheed's Sherm Mullin, "Companies are going to have to figure out how to do LRP [low-rate production] or they're not going to be in business."[6] McDonnell Douglas has similar feelings. Their NAMP division in St. Louis is working hard on developing lean production methods. They know that future defense budgets are not going to support production at historic rates. The rates may be one or two aircraft a month which is the same schedule for the Japanese F-15s they are now producing. Unfortunately, the

Japanese are spending about three times as much to purchase F-15s as the US Air Force did during its mass F-15 production run.[7] Clearly something will have to change.

There are several options to choose from if lean production is the goal. Some see simultaneous development as the key factor, where the product design and manufacturing phases occur at the same time. Others see the supplier base as being pivotal. Because there are such a large number of subcontractors involved in producing an airplane, they have to operate successfully at low rates to allow the large corporations to do the same. Others options include integrated design environments, flexible tooling, manufacturing cells, fast setup, small inventory lots, multi-skilled labor, short lead times, and designed-in quality.[8] All of these steps, and probably others, would be useful initiatives. There are however, four key lean production ideas that are especially promising because they help overcome the learning curve. Before discussing them in detail, it is important to understand what the learning curve is and why it is an inhibitor to Silver Bullet production.

The learning curve provides the basic data industry uses to set aircraft prices. This principle assumes that over the course of a production run, the manufacturing process will become more efficient and the cost per airplane will go down.[9] Lean production techniques will overcome this phenomenon in two ways. First, the techniques make airplanes cheaper to build in any quantity, thus making the first airplane's cost lower. Second, these improvements make the manufacturing process more responsive. It enables industry to quickly identify and incorporate better production methods in a cost effective manner. As a result, the learning curve shifts to the left, reducing the amount of production necessary to realize efficiency-driven savings. The following figures illustrate the point.

Learning Curve without Lean Production (Figure 2)



Learning Curve with Lean Production (Figure 3)

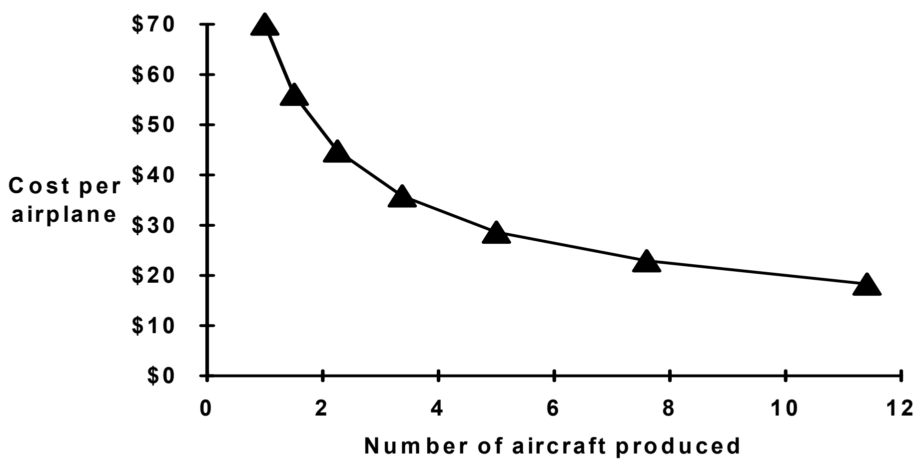


Figure 1 shows the typical learning curve today. In this example, the cost of the first airplane is $100 million and the cost decreases by 15 percent as the number of airplanes produced doubles. The company, in order to recoup the high costs of developing the airplane, would charge a cost equal to that of number 35, about $50 million. Figure 2 shows the potential advantages of using lean production. The cost of the first airplane drops because we are building airplanes cheaper and, because the manufacturing process is more responsive, we realize efficiency savings at the rate of 20 percent for every one and one-half airplanes built. The effect is a flatter learning curve shifted to the left that allows the contractor to base the unit cost on aircraft number six, in this case about $30 million. The effect is the contractor can operate at a profit over a much shorter production run than is typical today. While these examples are notional, they do illustrate the potential advantages to changing the learning curve. The next section describes the four primary initiatives industry should pursue in order to shift the learning curve. It also explains DOD's role in making rate transparency a reality.

INDUSTRY AND GOVERNMENT INITIATIVES

Both the aircraft industry and DOD have a vested interest in making rate transparency work. As stated above, the shrinking defense budget means that large production runs are a thing of the past. Therefore, if a contractor wants to stay in the fighter plane business, he is going to have to figure out how to produce airplanes at a low rate, and at a reasonable profit level. Of the several lean production initiatives mentioned earlier, four appear to be the most promising and achievable in the near future--improving the tooling process, increasing the level of cell manufacturing, integrating manufacturing data bases, and reducing the number of parts in an airplane.

1. Tooling

Tooling refers to the various jigs, molds, stands, and other structures an airplane manufacturer uses when building and assembling planes. Changing the current tooling process will facilitate the Silver Bullet strategy in two ways. It will reduce total program costs and make the manufacturing process more responsive to change. Tooling costs typically run upwards from 5 percent of total program costs. Using the F-22 program cost of $99 billion, we see that tooling improvements could save nearly $5 billion, a substantial sum in anyone's budget. Cost, however, is not the only incentive for improving tooling. Current tooling technology is not responsive. Today's techniques call for "hard tooling" (tools made of heavy gauge materials designed to produce a lot of parts from the same tool). Making tools this way is expensive and inflexible. If the contractor wants to change the manufacturing process to increase efficiency or because the customer requires a change, he must either wait until the tool is worn out or build a new tool, and accept the waste inherent in discarding the old, but still adequate tool. Current aircraft materials, particularly composites, are allowing industry to explore new tooling concepts. The trend is towards building cheap tools using materials such as plywood and foam. Such tools may only last long enough to build six aircraft, but because they are inexpensive you can build more tools with fewer sunk costs. Flexible, cheaper tooling thus allows changes during the production run because tooling costs are not an inhibitor.[10]

2. Cell Manufacturing

Transitioning to cell manufacturing from current assembly line methods will have direct and indirect effects that will contribute to making lean production possible. The assembly line technique segregates airplane production into numerous small tasks. The problem is that a part may be built in one building and then transferred to another building to install it on the airplane. This procedure incurs direct costs in transferring the part to the assembly building. It also incurs indirect costs in two other ways. First, parts become lost or delayed in the transfer process. This means money is spent chasing down lost parts, as well as maintaining excess inventory so the assembly line does not stop due to a lack of parts. Second, standard assembly line methods do not facilitate communication between parts makers and airplane assemblers. For example, if a parts maker is drilling a hole slightly out of position, causing the aircraft assembler to make some adjustments in order to install it, the assembly process is inefficient. By the time the assembler is able get the problem fixed, several more parts have probably been drilled incorrectly. One way to address these problems is by changing to a cell manufacturing process.[11]

In cell manufacturing the contractor groups several logical processes together in the same physical location. For example, say the part in the above scenario, plus three or four other major components, make up the nose section of an airplane. Using cell manufacturing, the workers that make and assemble the nose section parts would physically work in the same part of the factory--in a cell. The assembler would then have access to the parts builder, thus enabling him to work out the problem of the incorrectly drilled hole quicker. Another characteristic of cell manufacturing is that all members of the cell can do all the jobs in the cell. If someone is absent, or if one area of the cell is behind while another is ahead, workers can shift to other tasks to get the cell back on schedule. Lastly, cell manufacturing has the added benefit of giving the workers, as a group, ownership in the process. If given a new measurement of success, such as completed nose sections versus a certain inventory of parts on hand, the workers shift their attention toward an output goal instead of a less meaningful quantity goal.[12]

A primary barrier to transitioning to cell manufacturing is current labor relationships. Union rules restrict workers from training in numerous specialties and cell manufacturing eliminates some jobs, like moving parts from one area of the factory to another. While the exact cost savings due to cell manufacturing are still unknown, McDonnell Douglas has transferred one major manufacturing process over to this method and is pleased with the initial results.[13]

3. Data Base Integration

Improving computer data base integration will enable lean production in two ways. The first concerns the transition from design to production. Currently, an engineer designs an airplane part on a computer. Another engineer then manipulates the design in order to create the tooling software. However, the two processes are not directly connected. The production engineer cannot work with the design engineer's computer output as is. He must translate the data into a format usable for tooling and manufacturing. The translation process is not only costly in terms of man hours, but also because of the errors inherent in doing the translation. New techniques, however, tie the phases closer together. Instead of translating the design engineer's work, the production engineer can now use the designers data base for tooling and manufacturing. This will reduce labor costs as well as translation errors.[14]

The second way data integration will streamline the manufacturing process is by combining the myriad of control and performance reporting systems. Different people monitor different parts of the manufacturing process for different reasons, such as schedule, cost, and quality control. However, they all need similar basic data. By creating one automated data base, all users would have their information sooner. The sooner the data is available, the sooner the contractor can identify and fix problems. This helps shift the learning curve as described above. Early attempts at data integration have reduced the typical 30 day reporting cycle to only five days.[15]

4. Parts Reduction

Reducing the number of parts in an airplane contributes to lean production in several ways. One way to illustrate these advantages is by looking at how McDonnell Douglas makes the T-45 nose gear door. This door originally required 22 separate pieces, but through better manufacturing techniques (high-speed machining), this door now requires only five parts. It is a better door because with fewer parts it is stronger and lighter, but even more importantly, it is cheaper to build. Because there are 17 less parts, there is a corresponding reduction in the amount of tooling, and there are fewer hand tools required to assemble the door. Additional savings come from minimizing wastage. Airplane parts are made using irreversible processes like cutting and drilling. Therefore, the less you cut or drill, the less potential for wastage through mistakes. Finally, the builder saves the costs associated with transferring those extra parts around the factory. This in turn facilitates cell manufacturing, because a single, smaller cell can potentially build the gear door.[16]

Even if industry can successfully institute the four initiatives just described, they will not achieve rate transparency without some changes from DOD. The Air Force in particular needs industry to succeed in making low-rate production a reality. The funds are simply not going to be available for full-scale procurement as in the past, so if the Air Force is going to modernize the fighter fleet, it will have to be in small increments. According to General Loh, Commander, Air Combat Command, "High rate production targets are no longer realistic. Lean production requires [Air Force] contracting to reduce overhead and undergo a cultural change."[17] In short, the Air Force, just like industry, needs to change the way it does business. Two key areas that require attention are defining requirements and reducing oversight.

1. Defining Requirements

Changing the requirements process is difficult and has been a subject of debate for years. As discussed earlier, there needs to be interface between engineers and operators. The customer needs to define what the airplane must do so the engineer can put together technology to do it. However, there is a lot of gray area in that process. Industry feels they can work best with functional requirements. An example of a functional requirement might be "build an airplane that can outmaneuver a SU-27." While this requirement describes what the airplane needs to do, the Air Force would probably provide industry with something much more specific like, "build an airplane that can go Mach 1.3 in military power at 30,000 feet." The problem with such a specific requirement is that engineers are limited in their options. The first example permits the designer to look at a variety of systems to achieve the desired effect. The second example however, pretty much limits him to propulsion technology and airframe characteristics. DOD tends to argue for the more specific requirements in order to prevent technology from driving doctrine.[18] The argument is that if engineers are free to throw technology at the problem, they will determine doctrine because the operator's options will be limited by the engineer's solution. This paper will not resolve the issue because there is a proper balance between hard requirements, goals, and functional requirements that differs from project to project.[19] Determining the proper balance will come from a partnership between industry and DOD. The engineers must understand the requirements and where their expertise ends, while the operators need to trust the engineers enough to let them propose innovative solutions. Because the requirements documents are DOD products and because the contractor gets paid the same no matter which type of requirements he works with, the government should initiate an effort to resolve the issue.

2. Government Oversight

DOD needs to decrease the expense related to government oversight. The lucrative defense dollars available in the 1980s led to some unscrupulous business practices, which spurred a new round of regulation with its associated costs. Oversight cost estimates vary from three to 40 percent of total program costs.[20] Even splitting the difference involves enough money to make a new approach worthwhile. In order to lower these costs, DOD should look at better ways to integrate the customer into the production process and consider revising the antiquated military specifications (mil specs) that generate many of the oversight requirements.

Researchers, engineers, developers, testers, and operators need to work together to create a quality product. The current relationship among these groups is more adversarial than cooperative. Too often testers come across as inspectors who are looking to find problems, rather than fix them. Operators tend to view engineers and developers as technical specialists who do not understand the mission. Overlaid on this situation is a large cadre of inspectors who are measuring the output against specific requirements and mil specs that allow for little individual judgment in assessing the product. One way to fix this problem is to integrate the customer into the manufacturing process. DOD should empower inspectors and testers at various levels so they can make on the spot decisions when a problem occurs. As it stands now, inspectors inspect and report. If a product does not meet a certain specification, they have no leeway to change the requirement or waive mil spec compliance, no matter how insignificant. This results in increased costs due to the time and resources the contractor must expend to gain compliance. If, on the other hand, DOD empowered the on-site inspector, he could work with the contractor to resolve the problem when it occurs. Resolving the issue at the lowest possible level will result in a better solution that saves both time and money, while creating a more cooperative atmosphere among the participants. Such an approach will create an environment for insight versus oversight.[21]

Another way to bring the customer into the process is through data base integration. This expands on the idea proposed earlier regarding data base integration for the contractor management team. DOD and industry could expand this initiative to include the customer. Much of the information industry uses to track progress is the same data DOD needs to oversee a program. DOD could fund a program to automate dissemination of the information to government program managers. This adjustment would give DOD more timely information and it would reduce program costs by cutting down on the contractor's reporting workload.[22] McDonnell Douglas is experimenting with such a program on the F-18 E/F. While no specifics are available, they expect reporting cycle improvements such as those described earlier (30 days reduced to five), and they expect to see savings from the reduced reporting requirements.

Much of the oversight problem stems from the 45,000 largely outdated mil specs that cover almost everything. Adhering rigidly to them helps create an adversarial environment and measuring against them increases reporting requirements (i.e. costs).

DOD could potentially replace the current mil specs with about 1000 industry standards. This single act alone would significantly impact the oversight problem.[23] According to General Loh, "We over-regulate, over-manage, and over-audit our acquisition programs to death."[24] If DOD can resolve the requirements dilemma, better integrate itself into the manufacturing process, and move away from a World War II mind-set regarding mil specs, it will be well on its way to helping industry achieve rate transparency.

CHAPTER SUMMARY

Both industry and government must enact a number of new initiatives in order for the Silver Bullet strategy to work. Both groups have a vested interest in the program because, in the future, there will be fewer defense dollars available. Production runs will be shorter and force structures smaller. That means less room for error on both sides. Industry must build it right the first time; there will be no long production runs to recoup costs associated with learning curves and wasteful manufacturing and design practices. On the DOD side, there is less room for error because a smaller force structure necessarily puts more emphasis on high quality. Therefore, the government must clearly define requirements that will achieve military objectives and they must present those requirements in such a way that industry can provide effective and economical solutions.

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[1]Mike Maltenfort, interviewed by author during visit to McDonnell Douglas Aerospace, St. Louis, Mo., 20 December 1993.

[2]Jeffrey A. Drezner, RAND Corporation, telephone interview with author, 5 January 1994.

[3]Maltenfort.

[4]John D. Morrocco, "Dangers Cited in Implementing New Pentagon Acquisition Strategy," *Aviation Week and Space Technology,* 136, no. 10, March 9, 1992, 21.

[5]Auster, 53.

[6]Ibid., 54

[7]Will Shores, interviewed by author during visit to McDonnell Douglas Aerospace, St. Louis, Mo., 20 December 1993.

[8] Sinnett.

[9]Maltenfort.

[10]Sinnett.

[11]Gill et al.
[12] Ibid.
[13]Ibid.
[14]Ibid.
[15]Ibid.
[16]Ibid. Sinnett.
[17]Boatman, 10.
[18]Morrocco, 21.
[19]Sinnett.
[20]Drezner.
[21]Gill et al. O'Bryon, 30. Robert Trice, interviewed by author during visit to McDonnell Douglas Aerospace, St. Louis Mo., 21 December 1993.
[22]Sinnett.
[23]Donald J. Atwood, "Safeguarding Reconstitution, Industrial Capacities," *Defense Issues,* 7, no. 27 (28 April 1992): 7.
[24]Boatman, 10.

Chapter 5

Conclusion

If Mr. Dellums and the House Armed Services Committee succeed in delaying ATF production, now known as the F-22, until 2010, they will unwittingly execute the Rollover-plus strategy. With funds allocated, production is underway on the first six aircraft. Dellums would like to see production stop there, and then resume it again in 15 years when the F-15 is expected to reach the end of its service life. Congress would probably allocate the funds to resume production in about 2008, at which time the airplane's technology would be at least 15 years old. Under this plan, the fighter community would probably argue that producing the F-22 no longer makes sense. It would suggest rolling the F-22 technology over into a new generation aircraft, thus making the F-22 an operational prototype and turning the program into a Rollover-plus acquisition.

This paper has argued against Rollover-plus because it fails to maintain the US edge in fighter development. Since World War II, we have increasingly relied on technology and quality to overcome quantity shortfalls. Decreasing defense budgets will only increase that reliance. Unfortunately, Rollover-plus works against maintaining a qualitative advantage. If we only build and fly six F-22s, we will find ourselves in trouble in 2008, when we attempt to field the F-22 successor. The F-22 introduces revolutionary technology in the areas of low observable materials and operations with passive sensors. As seen with the F-15, we can expect unpredictable results when these technologies meet with the real world. However, with only F-22 prototype experience, we will not discover all the implications of the new technology. When it comes to fielding the next generation fighter, the Air Force will be less prepared to define requirements. Industry, in turn, will be at a disadvantage because the F-22 did not reach at least Silver Bullet status. As a result, the F-22 follow-on will not be the airplane it should be. Will it be sufficient to achieve the National Military Objectives?

Making the problem even more serious will be the aging and declining engineering base. Without an F-22 in at least low-rate production, American aircraft design expertise will continue to atrophy. As it is, there are only two active fighter production lines in the US now. Without the F-22, there will be only one, at McDonnell Douglas, and it is only open thanks to foreign military sales. Foreign sales alone will not generate the necessary funds to maintain fighter development on the cutting edge.

The real tragedy is that Congress will probably make its decision based on short-term political considerations. Budget pressures, coupled with employment concerns, will dictate the outcome. Unfortunately, the decision makers fail to realize the core issue: an operational F-22 is necessary to define, design, and build its successor. They may not understand how important it is to have an airplane in production in order to exercise and maintain the fighter plane industrial base, including the engineering expertise. And finally, they may not know how difficult it will be to make rate transparency a reality. Rate transparency requires an open production line so industry and DOD can develop viable lean production techniques. As we have seen, lean production is necessary to overcome the learning curve phenomenon, and until we overcome it, we will always view a new fighter program as being prohibitively expensive.

It may be true that the threat does not justify the F-22. It is definitely true that the F-15 is still a good airplane, and with relatively low cost upgrades has the potential for many more years of service. However, there is more to the issue. The US fighter community relies on its technological and qualitative superiority to succeed in war. Buying 64 F-22s is a prudent and necessary measure to insure it can continue to do so well into the next century.

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