~~A~~The Advanced Extremely High Frequency Ground Segment – ~~Should~~ Will its ~~L~~legacy ~~D~~dictate ~~the~~its ~~F~~future?

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Overview

The development of the Advanced Extremely High Frequency (AEHF) program ~~development has~~ spans~~ned~~ over ten years and it is nearly complete. The ~~final increment of the ground segment was completed August 2011, the~~ first satellite ~~was~~ launched in August 2010, the final increment of the ground segment completed in August 2011, and the second satellite launched in May 2012.

The~~re~~ ground segment development had~~were many~~ successes and challenges. ~~with the ground segment development, and this paper will describe the~~ The team learned lessons ~~learned and~~ that provide recommendations for future improvements~~s~~, especially when ~~. The paper will focus mainly on the ramifications of~~ building on an existing architecture ~~and how~~ . ~~d~~ Designing with testing in mind can ~~help~~ prevent technologically limiting legacies.

Introduction

Designing and engineering software with over 1 million lines of code is a ~~one~~ challenge, ~~but~~ but it becomes an entirely different endeavor ~~engineering software~~ when it's under a U~~.~~S~~.~~ government contract ~~is an entirely different endeavor~~. The AEHF Satellite Mission Control System (MCS) took ten years to develop. ~~and had~~ The early decisions ~~that~~ cemented a course wrought with challenges. Government acquisition of this magnitude involves many ~~many~~ stakeholders. ~~, and s~~Sometimes, the wrong decisions are made for the right reasons. ~~Certain p~~Pitfalls can be anticipated but not predicted, like funding instabilities, spacecraft anomalies, launch delays, and requirements creep. These are all part of the greater risk that is faced when procuring a large, complex, "one of a kind," satellite communication system. The massive numbers of intersegment dependencies (for example, space vehicles, terminals, and ground system) that must integrate and function seamlessly magnify the risk.

~~So how to mitigate the risk?~~ One ~~answer~~ way to mitigate the risk is to construct a robust acquisition and development strategy that can withstand the inevitable fluctuations in funding, schedule, and requirements, yet succeed in producing a high quality and highly sustainable system. Sometimes, hindsight is the only way to understand why large programs struggle to achieve their lofty goals. We can learn from the past to make better decisions in the future.

Background

The AEHF sSystem Description

The AEHF system provides satellite voice and data communications for the U.S. National Command Authority (NCA), military tactical and strategic forces, and users in the Netherlands, U.K., and Canada. The AEHF system consists of the Space Segment, Terminal Segment, and Mission Control Segment as as shown depicted in Figure 1.

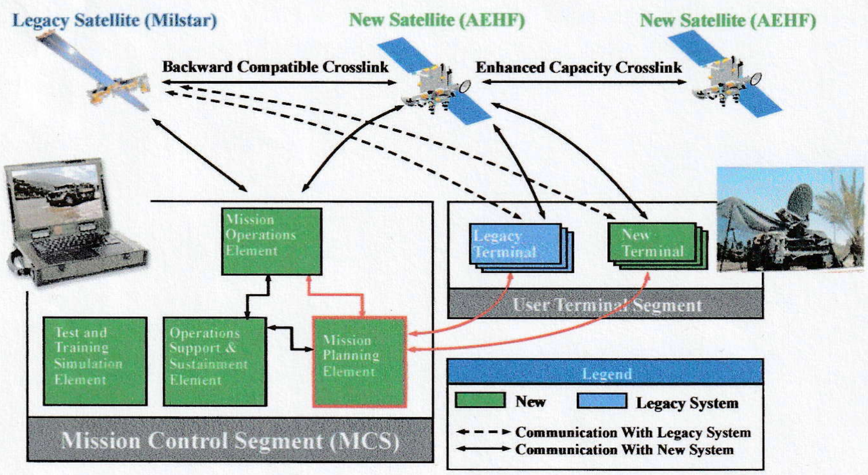

Figure 1:, Diagram of AEHF Satellite, Ground and Terminal System

AEHF Space Segment

The AEHF Space Segment consists ofis a constellation of four or more AEHF satellites in near-circular geosynchronous orbit. The AEHF satellites are capable ofcan interoperateion with legacy (Milstar) satellites and legacy Milstar Terminals. The transitional constellation will beis composed of AEHF as well aands Milstar satellites that are cross-linked as a single constellation.

AEHF Terminal Segment

The Terminal Segment of the AEHF system is comprised ocontainsf terminals located on aircraft, ships, and submarines, and on terrestrial platforms that are ground-transportable, mobile, and fixed terrestrial platforms. Terminals will provide AEHF communications capability and the associated communications resource control functions. The Terminal Segment includes AEHF terminals and upgraded legacy Milstar

An interesting ~~and~~ challenge~~ ing~~ ~~aspect of the system~~ was managing the user hierarchy and ~~how~~ the flow of resources ~~were flowed down~~ through the ranks (See Figure 2:~~.~~ User Hierarchy and Data Distribution). ~~At first glance~~Initially, ~~it would seem that~~ viewing this as an enterprise ~~would make a lot of~~made sense. However, this implementation~~ing~~ ~~as such~~ was ~~vastly~~ constrained vastly by the technology and the operational concepts practiced by the United States Department of Defense.

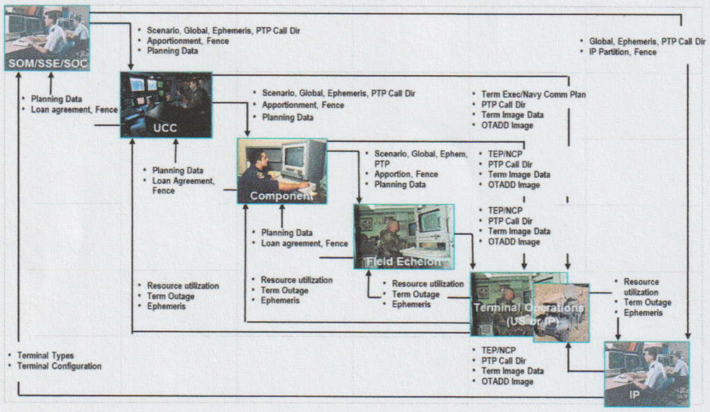

Figure 2:~~.~~ MPE Hierarchy and Data Distribution

Built in the early ~~nineties~~1990s, MCPTi relied on the technology of ~~the~~ its time.~~day. At the time,~~

- A~~a~~ Windows~~©~~ based system that used the~~ ing the~~ Microsoft Foundation Classes (MFC) application framework ~~was a good choice. It~~ provided a powerful and rapid way to develop applications with sophisticated user interfaces and was in broad use across many industries.
- ~~The~~ A data repository ~~selected~~ that was a simple file-based database that was easy~~ily~~ to copy~~ied~~ and move~~d~~ ~~from system to system. This~~ supported the distributed nature of ~~the~~ a system that~~where organizations~~ required autonomy ~~when~~ to plan~~ning their apportioned~~ resources between organizations.

At its core, the AEHF planning system is ~~nothing more than~~ a large database application, although ~~.~~ ~~There are~~it contains~~ many~~ many complex algorithms ~~required~~ that~~o~~ process the data and generate the products necessary to establish communications, such as~~ i.e.~~ payload tables and terminal images~~, but essentially this is a database application~~.

W~~So w~~hat makes this ~~particular~~ database application more challenging is the ~~than others? The answer is~~ breadth of its data and the operational concept of its use. The actual volume of data ~~has never been~~is not an issue~~. It is~~, but rather, the variety and unyielding combinations of data required to configure networks. ~~that make this hard. In order to better understand the operational concept of use, we will need to take a closer look at who uses the system and how MCPT-i evolved to become the AEHF planning tool.~~

terminals. The AEHF satellites and the Mission Control Segment ~~will be~~are interoperable with Milstar Terminals.

Mission Planning Element (MPE)

Communications management is a complex task that involves~~ing~~:

- ~~the~~ analysis of apportionments and allocations~~,~~
- development of communications plans~~,~~
- execution of ~~these~~ communications plans~~,~~
- monitoring of system performance~~, and~~
- management of assets in accordance with changing user requirements and operational environments~~.~~

The complexity of AEHF communications management dictates the use of a Mission Planning Element (MPE). The MPE supports the communications planner~~, defined as one who~~ that analyzes, plans, manages, and controls assigned AEHF and Milstar assets in support of ~~J~~joint and s~~S~~ervice-unique operations. The MPE ~~provides the capability for~~gives the communications planner the ability to support ~~both j~~Joint and s~~S~~ervice-unique missions at all levels of the communications management hierarchy, from the Joint Chiefs of Staff (JCS) to the terminal operator. The MPE is ~~comprised~~ composed of Mission Planning Subsystems (MPSS) deployed from the JCS level down to the field levels.

History and t/~~T~~imeline

The ~~advanced~~ AEHF system belongs to a family of military satellite communications systems known as ~~"~~Protected MILSATCOM~~"~~. The first real Protected MILSATCOM s~~S~~ystem was the Milstar system. ~~and Advanced EHF is an evolution of that system and is backwards compatible.~~ Milstar was developed in the 1980~~'~~s. ~~and 5~~ Five satellites were successfully launched, with the last launch in 2003. AEHF is an evolution of the Milstar system and is backwards compatible with it. A~~dvanced~~ EHF was developed in the 2000~~'~~s, with ~~and~~ the first launch ~~was~~ in 2010.

~~Prior to~~Before Milstar and ~~Advanced~~ AEHF, ~~SATCOM~~ satellite communication planning was ~~relatively~~ straight~~-~~forward and not ~~very~~ data intensive. ~~With~~ Milstar and Advanced EHF ~~and~~ required ~~their associated~~ planning and data complexity. ~~, s~~Satellite network and mission planning then emerged as a critical element in ~~the~~ overall system design and implementation.

Milstar communications planning was provided by a tool called the Milstar Communications Planning Tool, or ~~(~~MCPT-i~~)~~. The MCPT-i is a software application ~~which~~ that runs on a ~~Windows~~ PC~~. It~~ and consists of roughly 750,000~~k~~ lines of code. ~~and was i~~Intended ~~to be~~as an interim solution, ~~. i~~It ultimately became the operational software system for Milstar, and later ~~was chosen to~~ beca~~o~~me the reuse baseline for the development of the AEHF MPE. ~~As~~ When ~~MPE~~ development ~~has~~ completed and began transitioning to operations, ~~it's become~~it became clear that the strategy to reuse MCPT-i ~~has~~ was causinged difficulties in producing an operationally suitable MPE. The decision to reuse legacy software placed constraintsed on the development of MPE a modern program and caused serious usability concerns. This paper will explore the implications of reuse and along with the constraints it places on a modern program by using a legacy software system.

A sSoftware aArchitecture dDriven by lLegacy tTechnology

The development of the MCS ground architecture was largely driven largely by thea decision to reuse the software architecture of the previous planning system. One of the mostAn important aspects of the design was that it mustthe need to support massive data distribution, whileand, at the same time maintaining database consistency for all users. This included a broad collection of users, including types ranging from US strategic and tactical planners, to and international partners and their respective planners. If you look at tThe heritage of the AEHF planning system, you will find shows software that evolved over time to support the requirements of its users. This early system, referred to as MCPTi, replaced spreadsheets and other manual techniques that initially that were initially used to managed and configured satellite communication resources.

The developers worked closely hand in hand with the users to tailor functionality and deliver a product that was a large significant improvement over the traditional waysystem of doing business. Theis move to customized planning software took placehappened in the early nineties and was extremely well received. Use of t

***********The tool not only saved time by (**********Greg**********), i It also provided an accounting system for that maintaineding resource apportionments and configurations for all users.********* Consequently, The new product needed a sophisticated database consistency management system was required to minimize rework and maintain data integrity.

Evolution of the AEHF Mission Planning Element (MPE)

~~In the beginning,~~ MCPT-i was initially built ~~for planners~~ to apportion Milstar resources and to configure directed ~~LDR (~~Low Data Rate~~)~~ (LDR) services (between 75 and ~~-~~2,400 b~~its~~ p~~er~~ s~~econd~~) ~~in~~ to support ~~of~~ strategic nuclear warfighting.

The program ~~then~~ later experienced a major reorientation toward conventional forces that us~~ed~~~~ing~~ ~~MDR (~~Medium Data Rate (MDR) services (between 4.8 Kbps and ~~-~~1.544 Mbps). ~~Subsequently,~~ The functionality of MCPT-i ~~functionality~~ was extended to meet ~~this~~ the new focus on tactical operations.

Today, ~~with~~ AEHF and the introduction of ~~XDR (~~Extreme Data Rate (XDR) communications services (~~data rates~~ up to 8.192 Mbps)~~,~~ extended MCPT-i ~~has once~~ again ~~been extended~~ to support the new capabilities. ~~One thing becomes clear as we review t~~

The evolution of AEHF MPE~~, a piece of~~ shows that software that began as an engineering tool to ~~aid planners in~~ set~~ting~~ up strategic LDR services (MCPT-i)~~,~~ later became the foundation for ~~planning~~ strategic and tactical EHF communications across two distinct cross-linked constellations that support~~ing~~ LDR, MDR, and XDR protected waveforms. ~~Furthermore, t~~The tool must also now support ~~i~~International ~~p~~Partners in their planning activities, and deal with ~~the much~~ the more involved frequency planning aspects of an AEHF payload.

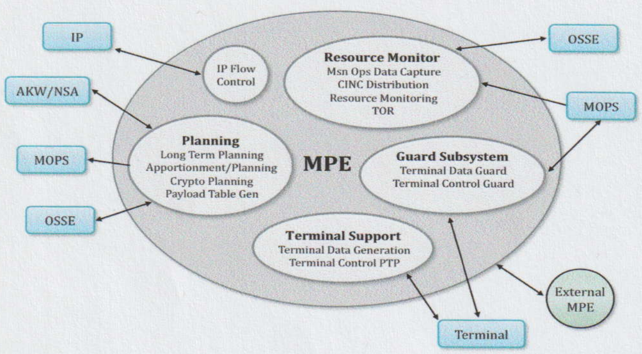

Figure 3:~~.~~ MPE Mission Executables

~~An i~~Interesting~~ly~~ ~~thing to note is that even with all of this added functionality~~, the architecture ~~has~~ remained fundamentally unchanged even with all this added functionality. The code size ~~has~~ is increased dramatically and the application now serves many new roles. ~~, yet~~ But the legacy design still dictates and constrains how the product ~~was~~ is built, how it ~~will be~~is used in operations, and how it ~~will be~~is maintained.

Designing with User Roles in Mind

As the scope of the original Milstar planning tool was extended to satisfy AEHF requirements, it ~~and~~ beca~~o~~me the planning tool that is in use today, or MPE. ~~, t~~The number and types of users also increased ~~as well; ranging from~~ to include national command authorities~~,~~ through all echelons, ~~to~~ field users, and international partners.

User Roles	
Initial Milstar Tool	**AEHF Mission Planning Element**

• Strategic Planner (LDR)
• Frequency Planning (Milstar)
	• Strategic Planner (LDR, XDR)
	• Frequency Planner (Milstar, AEHF)
	• Army Tactical (MDR, XDR)
	• Navy Tactical (MDR, XDR)
	• Air Force Tactical (MDR, XDR)
	• Marines Tactical (MDR, XDR)
	• International Partner Annex (XDR)
	• International Partners (XDR)
	  ▪ U.K.
	  ▪ Netherlands
	  ▪ Canada

Figure 4~~.~~: User Roles

(******************Many assumptions can be made when designing for a role... problems with one size fits all...***********************)

Designing with ~~T~~testing in m~~M~~ind

~~Taking a closer look at t~~The underlying architecture~~, we see~~ has a straightforward design (See Figure 5:~~.~~ MPE Software Architecture). Nothing ~~in particular~~ stands out as trouble~~some here~~ until ~~we begin to~~ testing at the unit level begins. Unit testing is manageable ~~F~~for an application with a limited number of screens and a small data footprint. ~~, this might be manageable, however, w~~The test may be impacted, however, when the screen count moves into the hundreds and the number of database tables surpasses three hundred.~~, the impact on test needs to be considered. In the case of MPE, there is a strong coupling between t~~ The ~~HMI (~~Human Machine Interface (HMI) component is strongly coupled with the ~~and the so called~~ business logic ~~i.e. (~~planning), scheduling, execution, and monitoring of satellite and terminal resources. Figure 5 illustrates how the business rules span both the HMI and the ~~DBCM (~~Database

Consistency Manager (DBCM). ~~-~~The DBCM component ~~is relied upon to~~ maintains the overall integrity of the database~~. In addition, it~~ and contains many of the ~~critical~~ algorithms ~~used~~ critical to process ~~-~~data and generat~~ee~~ products necessary for communication~~r comm~~. ~~-~~The strong data interdependencies ~~that exist~~ between the HMI and the DBCM ~~are what~~ make this system ~~very hard~~ difficult to test. ~~This problem is again magnified by~~ A~~a~~ strong coupling to the database magnifies this problem.

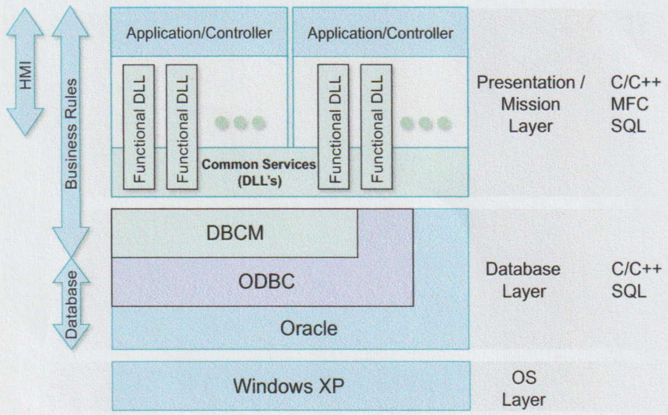

Figure 5~~:~~. MPE Software Architecture

~~Imagine trying to c~~Covering unit behaviors in ~~some form of~~ a test harness~~; it~~ is virtually impossible, or impractical at best. ~~-~~The HMI ~~is unable to~~can't function without the DBCM and the DBCM ~~is unable~~can't ~~to~~ function without the HMI. ~~-~~Both components expect a specific database state at every point of execution, and both interface directly with the underlying physical table structures and their associated relational constraints. ~~In the end, t~~The only feasible way to test ~~this~~ the product is directly through the HMI, ~~. This is~~ a time consuming endeavor ~~that is hard~~difficult to reproduce and verify.

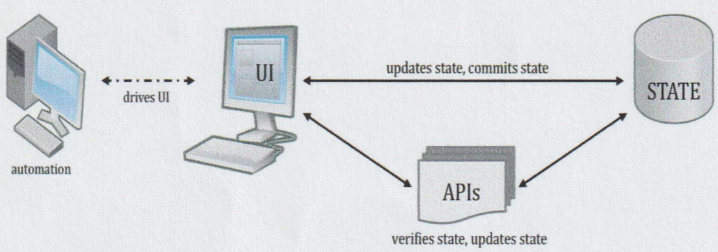

Figure 6.~~:~~ ~~-~~Strong Coupling

Designing with testing in mind is different than Test-Driven Design (TDD). In TDD, a module of software is considered "guilty until proven innocent." ~~-~~The test scripts are written and then the code is developed to make those test scripts execute successfully. ~~-~~This approach has merit but ~~would be~~is ~~completely~~ impractical in a situation that involves a large amount of reuse ~~such as is the case with MPE~~. ~~Instead, a~~A more practical methodology ~~would be~~is to ~~better~~ understand code dependencies and ~~then~~ to investigate how those dependencies might ~~might be broken~~ break with refactoring (See Figure 7~~:~~. Weaker

Coupling). Michael C. Feathers wrote a book dedicated to this, ~~topic titled "~~*Working Effectively with Legacy Code*~~".~~ ~~The book~~ that stresses the value of getting your code into a test harness, or ~~i.e.~~ covering behavior. Sometimes we focus too much on systems engineering and not enough ~~attention is given to~~on software engineering.

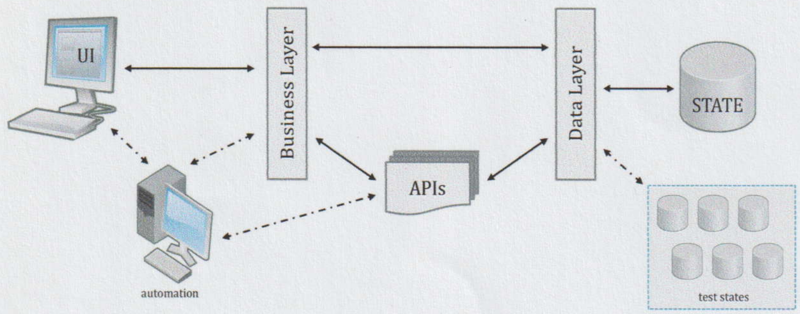

Figure 7:~~,~~ Weaker Coupling

Improving Ground Systems

Software development is different today than it was twenty, ten, or even five years ago; complexity has risen dramatically. The rise of open source, networking, and computing resources ~~allow~~ give us the power to do much more than was previously feasible. Increased capability provides increased complexity. ~~As a result, i~~It is no longer sufficient to rely solely on requirements-based testing to gauge quality and capability. The architecture and the design of the software must enable its testing downstream.

The AEHF ground segment inherited an architecture that was initially built as engineering software. ~~Consequently, it was c~~Its design constraints~~ed by the design and~~ rendered it unable to institute ~~some~~ useful concepts that would ~~have~~ produce~~d~~ a more robust model. It became a system that ~~proved~~ was difficult to design, build, test, and maintain. Furthermore, a lengthy incremental development plan coupled with unforeseen schedule delays resulted in the delivery of a system based on technology from two decades past. ~~The paper will discuss how some~~ K~~k~~ey design patterns and modern development strategies ~~might~~ must~~have been~~ be employed for positive effect. ~~With t~~The goal ~~being~~ is to avoid delivering a new "legacy" system that inherits ~~the~~ its predecessor's limitations ~~of its predecessor~~.