Overview

- Establishing the SE Case Study Process
  - Background
  - Applying the Friedman-Sage Framework
- First four SE case studies
  - C-5 Galaxy
  - F-111
  - Theater Battle Management Core System
  - Hubble Space Telescope
- Analysis and Application of Results
**Report Documentation Page**

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Background

- Special Systems Engineering Subcommittee
  - Chaired by Dr. Alexander Levis, AF Chief Scientist
  - Membership included:
    - BG Tom Sheridan, USAF
    - Dr. Dennis Bueda
    - Dr. George Friedman
    - Dr. Elliot Axelband
    - Dr. Andy Sage
    - Dr. Dave Evans
    - Dr. Daniel Steward
- Selection of Four Cases in May 03
  - Not currently-politically charged
  - Original development completed, historical
  - Diverse domains

Initial SE Case Studies

- C-5 Galaxy
- F-111
- Hubble Space Telescope
- Theater Battle Management Core Systems (TBMCS)
Purpose for Developing Case Studies

- Support teaching of Systems Engineering principles
  - Systems engineering/programmatic decisions
  - Operational effectiveness
  - Processes, principles, tools
  - Decision material
  - Highlight the importance of skills from multiple functional areas, including multiple engineering disciplines
- Develop a new set of Teaching tools

SE Case Study Format

- General Systems Engineering Process
- Case Study Learning Principles
  - Organized by key program technical/program management vignettes
  - Each learning principle developed chronologically
- Systems Engineering trade data included
- Summary discussion
Overview

- Establishing the SE Case Study Process
  - Background
  - Applying the Friedman-Sage Framework

- First four SE case studies
  - C-5 Galaxy
  - F-111
  - Theater Battle Management Core System
  - Hubble Space Telescope

- Analysis and Application of Results

Establishing the Case Study Process

- Need to understand scope as key controlling factor
  - Time/ Schedule
  - Total Resources
  - Outline/ Page Allocation

- Apply a framework
  - Assessment
  - Reference
Process Described

- Initial Draft Outline
  “Baseline”

- Iterate/ Refine/ Corroborate/ Change

Friedman-Sage Framework

U.S. AIR FORCE

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<th>CONCEPT AREA</th>
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<td>E. Risk Management</td>
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<td>F. Systems Integration &amp; Interfaces</td>
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<td>G. Life Cycle Support</td>
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<td>H. Deployment and, Post Deployment</td>
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<td>I. System and Program Management</td>
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Integrity - Service - Excellence
C-5 System Description

- Heavy-lift aircraft capable of carrying multiple tanks and related equipment
  - Maximum take-off Gross Weight over 764,000 pounds!
  - Unique front and aft ramps facilitate easy drive-on, drive-off loading of military vehicles and equipment
  - Accomplishes tasks that no other military aircraft can perform, such as the new C-17, or any derivative of commercial aircraft

C-5 Successful System

- Over 34 years of successful operational performance in support of the Nation’s cargo/transport needs
  - USAF inventory of 126 C-5 aircraft: 74 C-5A, 50 C-5B, 2 C-5C
- During Operation Desert Storm, C-5 fleet carried 46% of the total inter-theater cargo, flying only 29% of the cargo missions
- In Operation Iraqi Freedom, the C-5 fleet carried 48% of total cargo flying only 23% of the cargo missions
C-5 Synopsis

- LP #1. Systems requirements need to integrate the User (warfighter), planners, developers, and technologists into a well-balanced, well-understood set of requirements.

- LP #2. Total Package Procurement Concept (TPPC) was a fixed-price, incentive fee contract strategy for the design, development, and production of 58 aircraft. Invented to control cost growth, it was the underlying cause for the overrun.

- LP #3. A Weight Empty Guarantee was included in the specification and in the contract as a cost penalty for each delivered overweight aircraft. This measure dominated the traditionally balanced requirements resulting in a major shortfalls in wing and pylon fatigue life.

- LP #4. Independent Review Teams (IRTs) were to assemble national experts to examine the program and provide the best advice and recommendations to the government in structures design, technology and service life.

C-5 Trade Studies
C-5 Learning Principle

Highlight

- Weight Empty Guarantee
  - Performance Specification limited Tradespace
  - Contract Penalty: $10,000 per pound per delivered aircraft
  - Goal: Manage cost growth as aircraft cost related to weight

- Consequence
  - Negative effects of forcing (out-of-balance) one aspect of the system
  - Realize a trend in forcing an aircraft from "nominal" weight

Weight Report

- Expected weight trend
F-111 System Description

- In 1950s, USAF needed a replacement for F-100, F-101, and F-105 fighter-bombers
  - Mach 2+, 60,000 foot altitude
  - All-weather fighter, originally specified as capable of vertical and short takeoff and landing (V/STOL)
- Many firsts
  - 1st terrain-following radar, allowing it to fly at high speeds and low altitudes
  - 1st production aircraft with variable swing wings
  - 1st crew escape module

F-111 Successful System

- One of the most effective all-weather interdiction aircraft in the world
- Established the best safety record of any aircraft in the Century Series of fighters --- only 77 aircraft being lost in a million flying hours’
- First used in 1968 during Combat Lancer program, flying 55 night missions against targets in North Vietnam
  - Ability to deliver precision-guided ordinance in all-weather conditions, they played a key role in the destruction of Iraqi key targets in the Kuwait theatre of operations.
  - Flew 2500 sorties,
  - Destroyed 2203 targets
F-111 Synopsis

- LP #1: Ill-conceived, difficult-to-achieve requirements and attendant specifications made the F-111 system development extremely costly, risky and difficult to manage.
- LP #2: Systems Engineering managers (both Gov't and contractor) were not allowed to make the important tradeoffs that needed to be made in order to achieve an F-111 design that was balanced for performance, cost and mission effectiveness (including survivability) and the attendant risk and schedule impacts.
- LP #3: The F-111 suffered from poor communications between the Service technical staffs, and from over-management by the Secretary of Defense and his staff, which restricted the System Program Office (SPO) Director from applying sound systems engineering principles.
- LP #4: The F-111, like any complex weapon system development program which provides new war-fighting capability, had areas of risk that came to light during RDT&E even though there was perceived low risk in the design.
- LP #5: Cancellation of the Navy F-111B in 1968, after the bi-service design was frozen, and production of the Air Force F-111A was well underway, had a lasting impact on the United States Air Force F-111 performance and cost.

TBMCS System Description

- Theater Battle Management Core System (TBMCS) is an integrated air command and control (C2) system
- Performs secure, automated air battle planning and execution management for Air Force, multi-service, and allied commanders
- Provides the means to plan, direct, and control all theater air ops and to coordinate with land, maritime, and special ops elements
- Modular and scalable for air, land, or sea transport and the deployed configurations can be tailored to meet a particular contingency
TBMCS Successful System

- Deployed worldwide as the mandated joint system that the JFACC uses to plan, manage, and execute the air battle
- Demonstrated very rich functionality: it can produce a very complicated integrated air battle plan
- During Operation Iraqi Freedom (OIF), the size of the Air Tasking Orders, which planned all sorties, well exceeded system performance parameters

<table>
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TBMCS Synopsis

- LP #1: The government did not produce a Concept of Operations, key operational performance parameters, or a system specification for the contractor
- LP #2: The high-level system architecture and the government’s mandates for software reuse and use of commercial software (COTS) products were contradictory and problematic for the system development
- LP #3: The system and subsystem design was severely hampered by the complexity of legacy applications and misunderstanding of the maturity and complexity of commercial and third party software
- LP #4: Systems and interface integration was highly complex - integrating third party software was an arduous process and required extensive oversight.
- LP #5: The lack of a firm requirements baseline made validation and verification very difficult. The scheduled-driven program often ran parallel tests without clear measures of success. Not being able to replicate the operational environment prior to acceptance test created severe problems.
Hubble System Description

- Launched in 1990, scheduled operation through 2010
- Permanent space-based observatory - planned regular servicing missions
- 2.4-meter reflecting telescope deployed in low-Earth orbit (600 kilometers) by the Space Shuttle Discovery
- Complement of science instruments, spectrographs cameras and fine guidance sensors operating near-infrared into ultraviolet spectrums providing resolution of 0.1 arc-seconds

HST Successful System

- Over 100,000 observations of more than 20,000 targets have been captured for retrieval
Hubble Synopsis

- LP #1. Early and full participation by the customer/user throughout the program is essential to program success.
- LP #2. The use of pre-program “Phased Studies” to broadly explore technical concepts and alternatives is essential and provides for a healthy variety of inputs from a variety of contractors and government (NASA) centers.
- LP #3. Provision for a high degree of systems integration to assemble, test, deploy and operate the system is essential to success and must be identified as a fundamental program resource.
- LP #4. Life Cycle Support Planning and Execution must be integral to design. Programs structured with real life cycle performance as a design driver will be capable performing in-service better, and will be capable of dealing with unplanned, unforeseen events (even usage in unanticipated missions).
- LP #5. For complex programs, the number of players (government and contractor) demands that the program be structured to cope with high risk factors in many management and technical areas simultaneously.

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Analysis and Application of Results

- Analysis of Case Study Findings
  - Historical systems were simpler, more controllable
  - Today's SE process evolved/matured from those systems
    - Dimensions are more complex
    - Lesser percentage of skills within a single company
    - Broad scope of operational connectivity
  - Documentation/Training needs are greater
    - More players/more companies on a program
    - Less experienced

- System of Systems Implications
  - Evolving to an Architecture-Driven Systems Engineering process
  - Interfaces between/among elements vital

Analysis and Application of Results

- Systems Engineering and Program Management
  - Director of Engineering (DOE) Responsible for SE Process
    - Process operates for the entire program
      - Program Manager
      - Functional
    - IPT Chiefs are direct reports to Program Manager and Functionals for certain items
    - Interface Management needs IPT/DOE/PM visibility

- Supplier relationships
  - Must be integrated on the program team at all levels
  - Equivalent to past Branch chiefs or Division Chiefs
Continuing Efforts

- B-2
- Joint Air-to-Surface Standoff Missile (JASSM)
- Information on obtaining Case Studies will be posted on http://cse.afit.edu/
  - Teaching Material also forthcoming

Summary

- Case Studies are a new Tool
  - Brings Systems Engineering practice to the classroom
  - Valuable source of lessons
  - Base to evolve/mature the process to a more complex world
  - Underscore the effect of decisions
  - Emphasize the vital role of SE to bring proper decision material forward
- Teaching tool for the Program Management Field
  - Underscores responsibility of SE to the Program
  - Shows ways for all disciplines to operate in the SE process
- Starting point to further evolve Architecture Driven SE
  - Assist in Systems of Systems Development
  - Provide guidance for developing procedures and tools