Center for Systems Engineering at the Air Force Institute of Technology

Application and Analysis of the Friedman-Sage Framework for Case Studies of Systems Engineering and Management

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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**

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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 Buede
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

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Initial SE Case Studies

C-5 Galaxy

F-111

Hubble Space Telescope

Theater Battle Management Core Systems (TBMCS)

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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

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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

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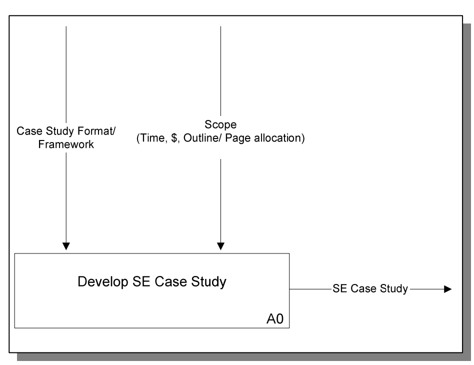
  - C-5 Galaxy
  - F-111
  - Theater Battle Management Core System
  - Hubble Space Telescope
- Analysis and Application of Results

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



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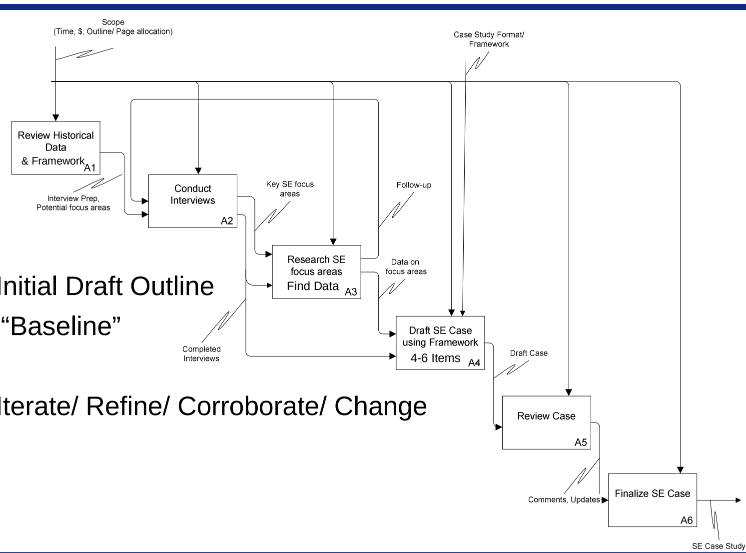
Process Described



- Initial Draft Outline
  "Baseline"
- Iterate/ Refine/ Corroborate/ Change

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Friedman-Sage Framework

CONCEPT AREA	RESPONSIBILITY DOMAIN 1 Contractor	 2 Shared	 3 Government
A. Requirements Def. and Management			
B. Systems Architecture Development			
C. System, Subsystem Design			
D. Validation/ Verification			
E. Risk Management			
F. Systems Integration & Interfaces			
G. Life Cycle Support			
H. Deployment and, Post Deployment			
I. System and Program Management			

C-5 System Description

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- 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

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- 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

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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

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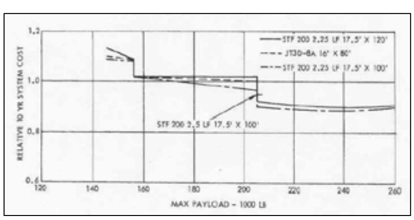
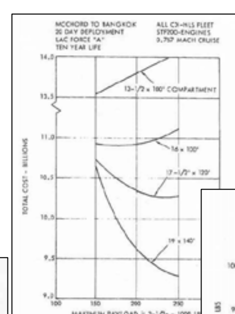
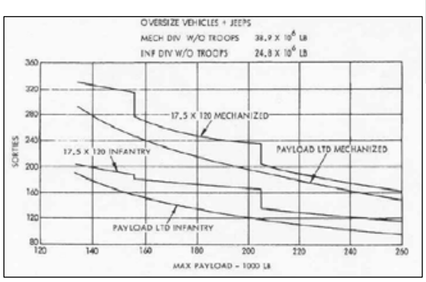
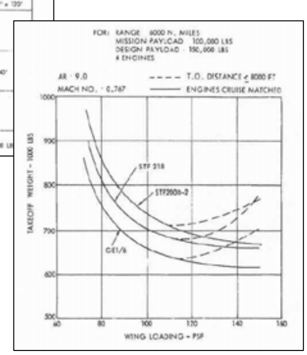
C-5 Trade Studies









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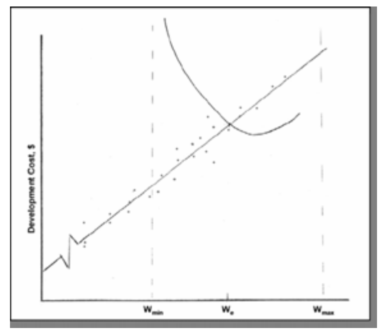
C-5 Learning Principle Highlight

- 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



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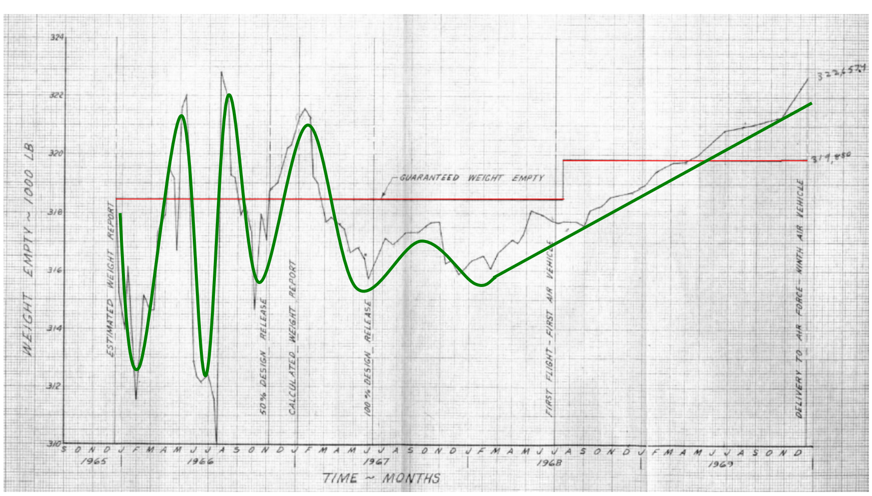
Weight Report



Expected weight trend

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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

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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
- During Desert Storm in 1991, 67 F-111Fs operated from air bases in Saudi Arabia.
  - 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

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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.

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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

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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

Total Sorties Flown	41,404
USAF	24,196
USMC	4,948
USN	8,945
USA	269
United Kingdom	2,481
Australian	565


TBMCS in the Air Operations Center, Al-Udeid, Qatar

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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.**

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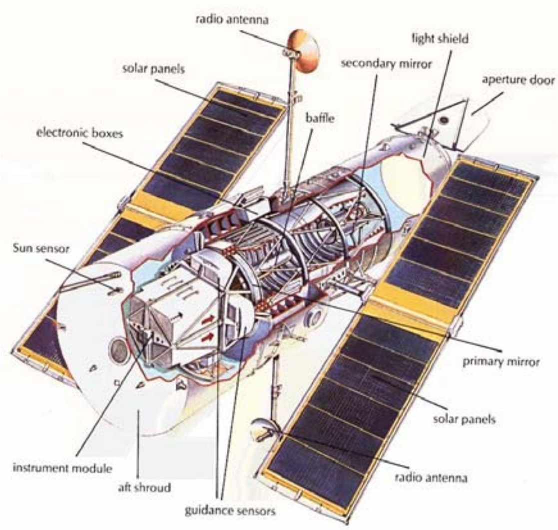
Hubble System Description



- 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

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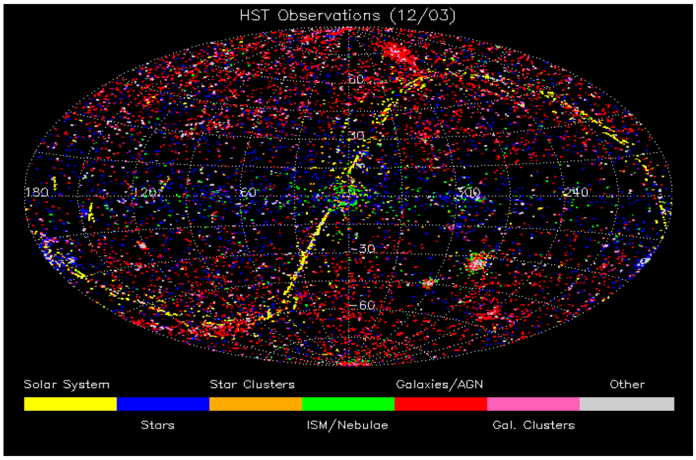
HST Successful System

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



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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**

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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

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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

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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

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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

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