Air Force Institute of Technology

Integrity - Service - Excellence

AFIT SE Research

Dr Dave Jacques

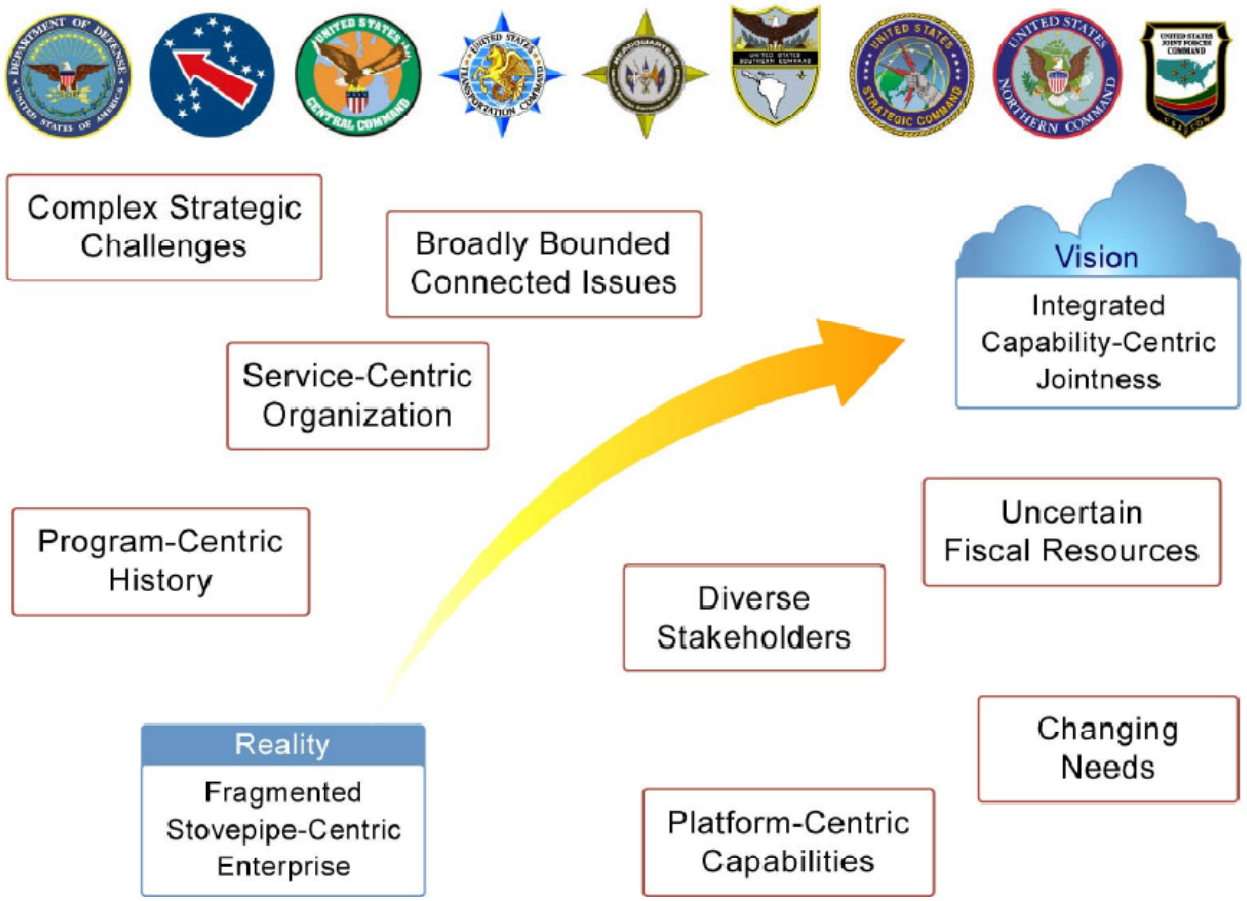
Dr John Colombi

Dept of Systems and Engineering Mgt

AFIT/ENV

U.S. AIR FORCE

DoD Transformation Drives Research



Dr. William J. Reckmeyer, Plenary Address, 1st Annual SoS Engineering Conference, 13 June 2005

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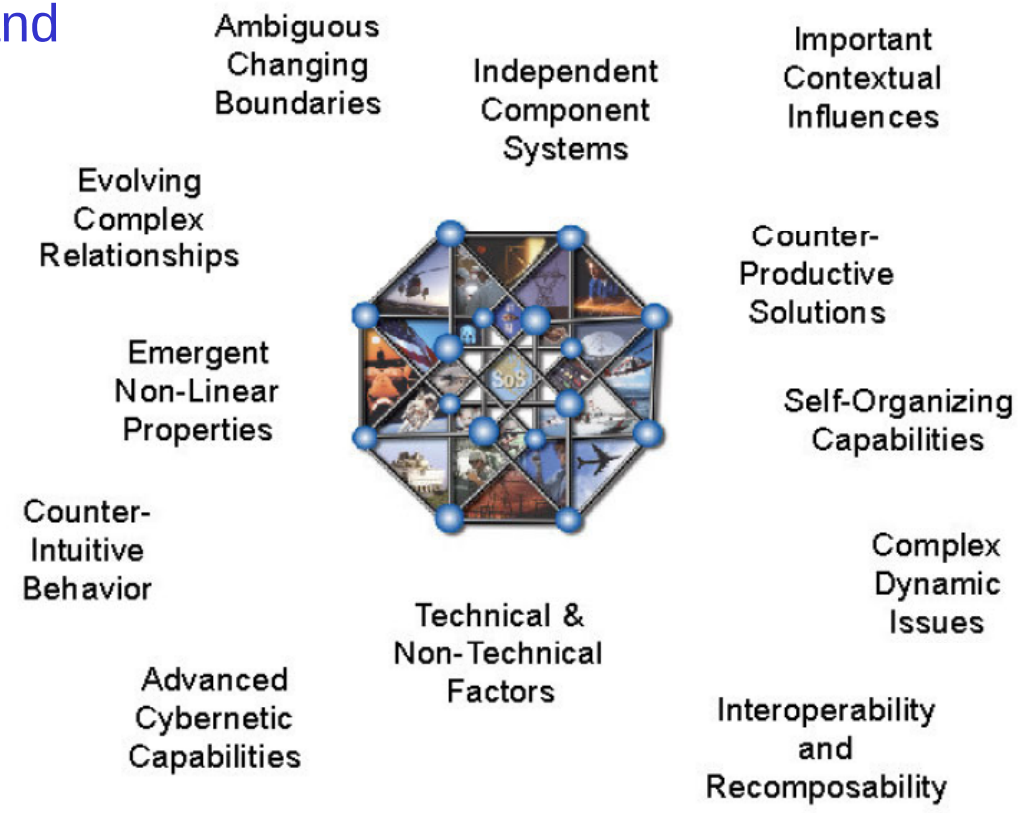
System Characteristics

Each system/subsystems and component is
more complex,
intelligent,
software-controlled,
Internetworked
with quickening release



Dr. William J. Reckmeyer, Plenary Address, 1st Annual SoS Engineering Conference, 13 June 2005

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AFIT Research Thrusts

- **Early application of SE**
  - **SoS architecture analysis and evaluation**
  - **DoDAF support for decision making**
  - **Interoperability measurement**
- **Human System Integration**
  - **Allocation of human functions in conceptual design**
  - **Human centered design**
  - **Trust in automation**
- **Applied design for mission effectiveness**
  - **Multi-UAS concepts**
  - **Theater ISR**
  - **Integrated Health Monitoring**

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AFIT Students …

…mature, motivated, and experienced!

- **AFIT students are typically DoD employees**
  - **Most are commissioned officers**
  - **Almost all hold SECRET level clearance or above**
- **AFIT students have experience in acquiring, testing, sustaining or operating DoD systems**
  - **Almost all of our students have at least 1-2 military assignments under their belt**
  - **They often have direct knowledge of sponsoring organization**
- **AFIT students understand the importance of their research**
  - **Their lives (or their friend's lives) depend on DoD weapon systems**

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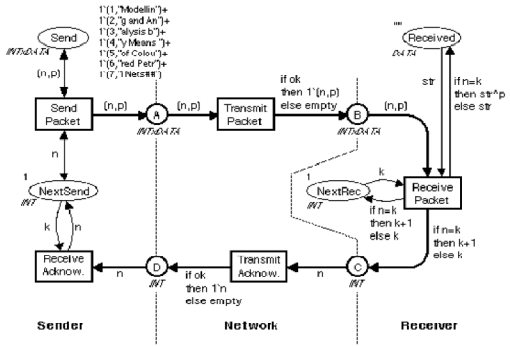
Sample of Methods/ Tools

- **Operational Research**
  - **Discrete event or Agent based simulations**
  - **Monte Carlo analysis, sensitivity analysis**
  - **Optimization methods**



- **Graph Theory**
  - **PetriNets/ Coloured PetriNets (bipartite directed multigraphs)**
    - **Many extensions: Stochastic, Hierarchical, Timed, etc**
    - **Used in Manufacturing, Communications, Protocol development**
    - **CPNTools, MATLAB PetriNet toolbox**
- **Complexity Theory**
  - **Biologically inspired Models**
  - **Local collaboration dynamics, Clustering, Self-Organization**

AIR FORCE CENTER FOR SYSTEMS ENGINEERING

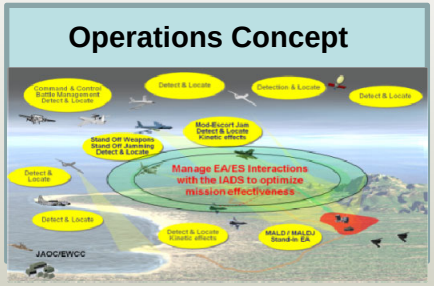
Creating a Discrete Event Simulation to Determine the Military Worth of Developing an Electronic Warfare Battle Manager Function within an Airborne Electronic Attack System of Systems Architecture

Research Sponsor: Capability Planning Office ASC/XRS, Wright-Patterson AFB, OH
Mrs. Trina Bornejko, Maj Charles Glasscock, Maj Dennis Sprenkle

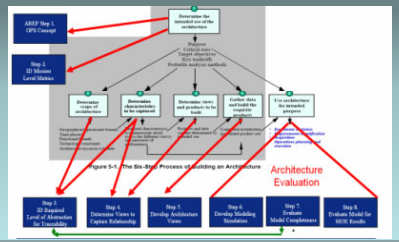
Problem Statement

How can the AEA SoS architecture be used to evaluated the military worth of an Electronic Warfare Battle Management (EWBM)?

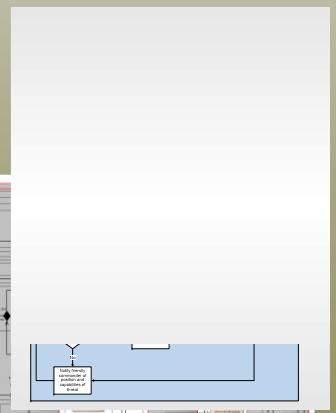
Operations Concept



Architecture Based Evaluation Process

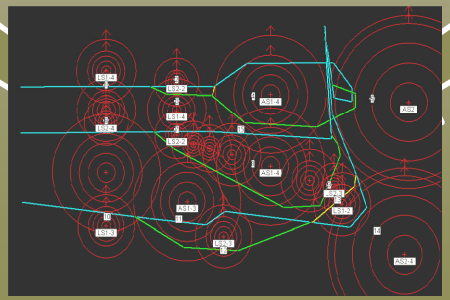


AEA SoS Architecture

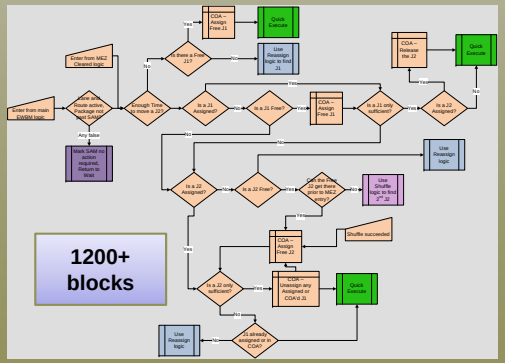


OV-5

Falcon View Mission Plan



ARENA Simulation



MESSURES of EFFECTIVNESS	NO EWBM	EWBM		
		No Decision Authority	Partial Decision Authority	Full Decision Authority
M1 Minutes to reassign AEA Assets	Baseline			
M2 Percent reduction in of SAM detection rate due to Jamming				
M3 Percent of strike aircraft Pd by Pop-up SAMs on route				
M4 Percent of strike aircraft Pd by known SAMs on route				
M5 Percent of strike package attritions due to enemy air defenses				
M6 Percent of strike packages whose mission is degraded by enemy air defenses				

Statistically significant improvement at 99% C.I.
No statistically significant improvement or degradation at 99% C.I.
Statistically significant degradation at 99% C.I.

Air Force Institute of Technology
Department of Systems and Engineering Management

INTEROPERABILITY MEASUREMENT AND APPLICATION

Sponsor: Air Force Research Laboratory (AFRL)/Layered Sensing

Problem/ Opportunity

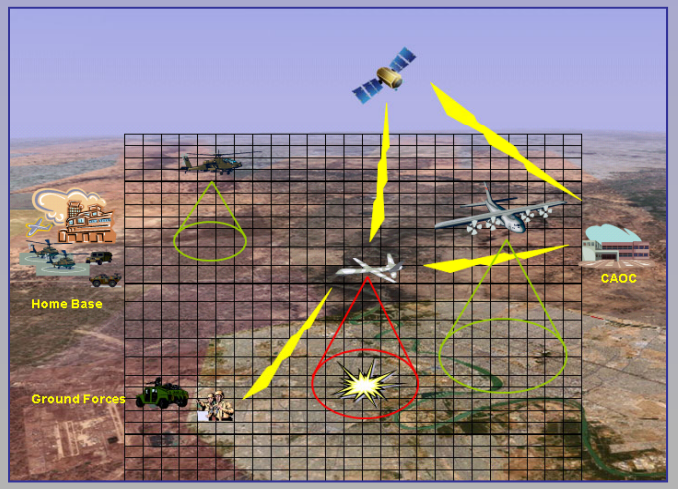
A general method of measuring collaborative and confrontational interoperability does not exist

There is no analytical means of relating the interoperability of a heterogeneous set of systems implementing an operational process to a measure of effectiveness for the process

Classes of Systems	
•Technical	Organizational
Biological	Environmental
Conceptual	Physical
Philosophical	Virtual
Etc…	

Phylogenetics

$$S = \{s_1, s_2, \ldots, s_n\}$$



Method Application

•Simulate layered sensing architecture observing urban operations mission thread scenario to obtain Measures of Effectiveness (MOE)
•Link interoperability measurements to MOE

DEFINITION (System Instantiation)

Given a specific $s \in S$ and a set $x \subseteq X$ of system characters descriptive of s, then $\sigma = x(s)$ is a sequence of system character states, called the instantiation of s, which models s.

Interoperability measurement becomes a similarity measure… using systems characters

$$Sim(\sigma', \sigma'') = wf(\sigma' \cap \sigma'') - \alpha f(\sigma' - \sigma'') - \beta f(\sigma'' - \sigma')$$

$$I = Sim_{Bin}(\sigma', \sigma'') = \left(\frac{1}{n}\right)\sum_{i=1}^{n}\left(\sigma'(i) \wedge \sigma''(i)\right)$$

$$I = Sim_{Real}(\sigma', \sigma'') = \left[\frac{\sum_{i=1}^{n}\sigma'(i) + \sum_{i=1}^{n}\sigma''(i)}{2nc_{\max}}\right]\left[1 - \left(\frac{1}{\sqrt[r]{n}}\right)\left(\sum_{i=1}^{n} b_i \left(\frac{\sigma'(i) - \sigma''(i)}{c_{\max}}\right)^r\right)^{1/r}\right]$$

INTEROPERABILITY: The ability of systems, units, or forces to provide services to and accept services from other systems, units, or forces and to the use the services so exchanged to enable them to operate effectively together.

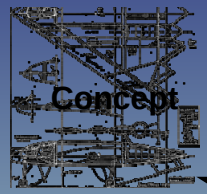
AIR FORCE CENTER FOR SYSTEMS ENGINEERING

Long Range Strike 2035:

An Analysis of Functional Autonomy

Sponsored by AFRL/RBAA

LCDR Scott Rivera Captain Anil Hariharan Captain Alan Louie



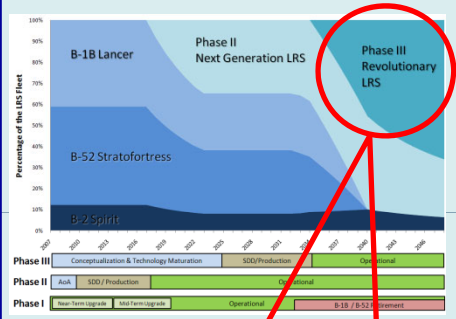
Establish 2035 Vision

Planners
Operators
Doctrine
Guidance

→ Operational Concept →

Global Strike
Persistent Attack
Time Sensitive Attack
Nuclear Strike
Show of Force

Problem



Can the 2035 LRS System be Automated?

Describe System

External Systems Diagram

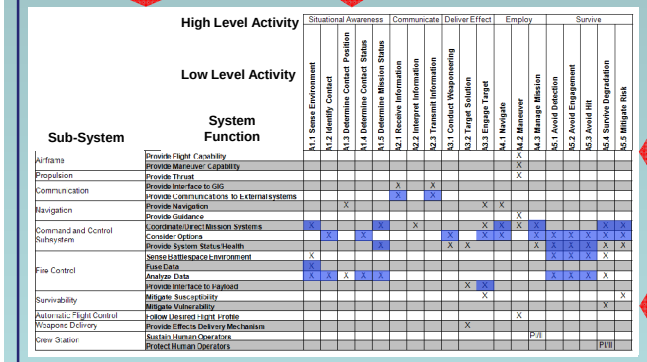
LRS Activity Diagram

Methodology

Identify Human Roles

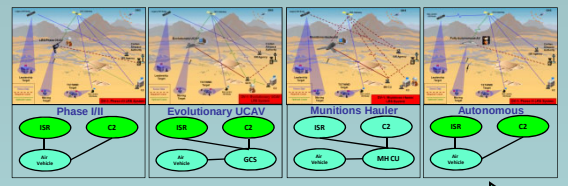
Perception
Goal Monitor
Radio Operator
Sensor Operator
Role

Execution
Final Safety
System Director
Role



Planning
Navigator
Weaponeer
Role

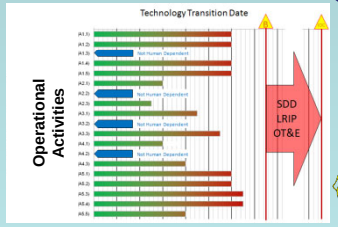
Interpretation
Data Analyst
Data Fuser
Data Sorter
Decision Maker
System Health Analyst
Role

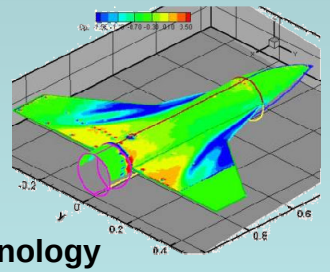


Increasing Autonomy

Illustrative Variants

Forecast Technology





Technology

Results

- The 2035 LRS system can be Automated
- Concept can be linked to enabling Technologies

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Department of Systems and Engineering Management

EMPIRICAL METHODS FOR HUMAN SYSTEMS INTEGRATION

Research Sponsor: 711th Human Performance Wing (711th HPW/RH)

Problem/ Opportunity:

Many projects and systems still fall short of effectively integrating humans in the systems engineering processes. Improve quantitative methodology to integrate human considerations into early system design

Method Summary

- **Improves display layout design and evaluation by transforming the problem into graph-theoretic models and performing subsequent analysis**

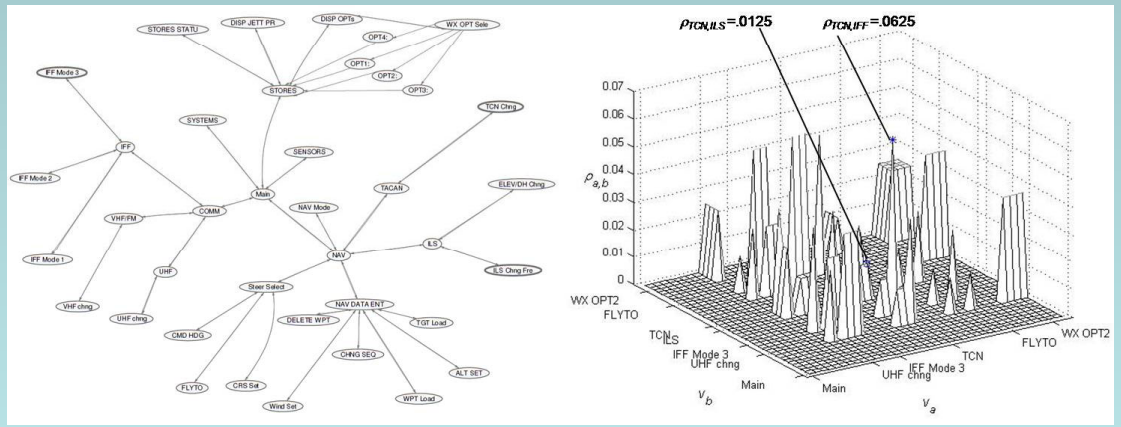
Compared to F-15 and A-7 test data from AFRL cockpit design research, Reising and Curry, 1987

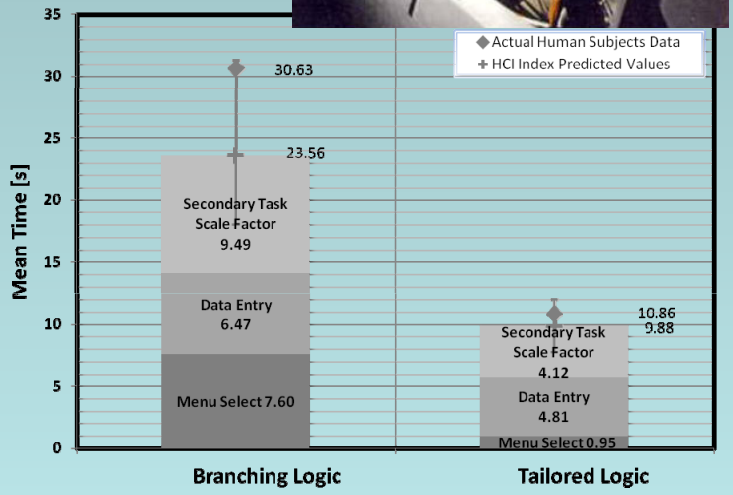
Time to move through a submenu

$$d_w(v_0, v_k) = \sum_{i=1}^{k} \left(t_i + \left(0.212 + (0.152) \log_2 \left(d^+(v_{i-1}) + 1 \right) \right) \right)$$

Avg control time, HCI Index

$$D_{w.\rho}(G) = \sum_{v_a, v_b \in V(G)} d_w(v_a, v_b) \cdot \rho_{a,b}$$





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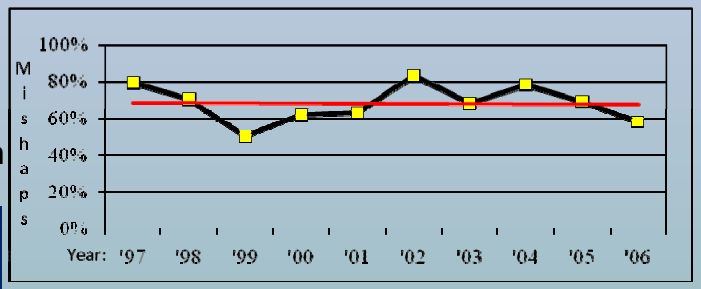
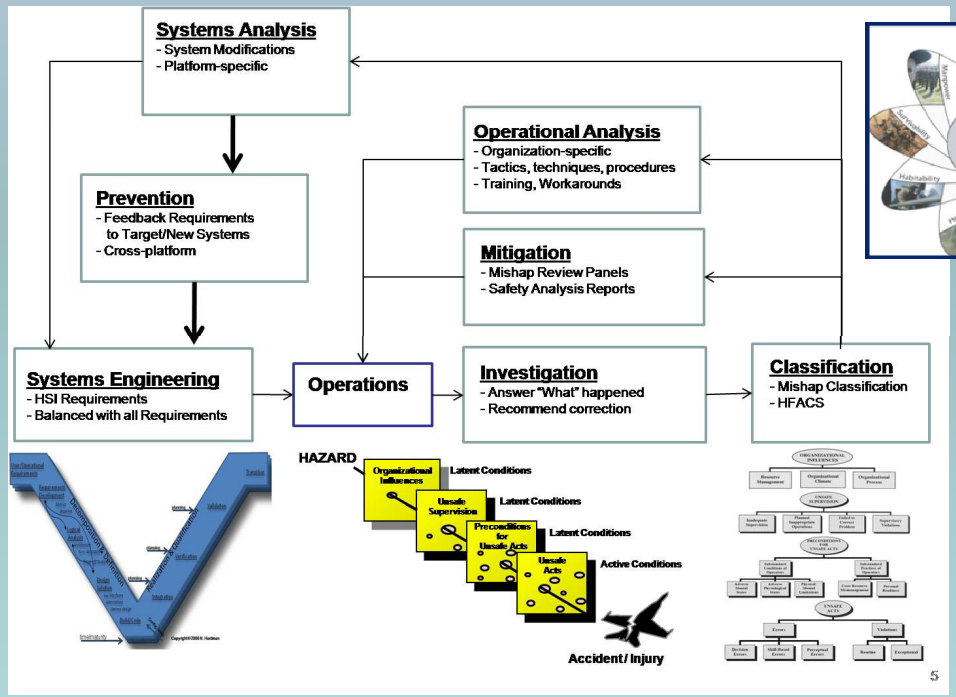
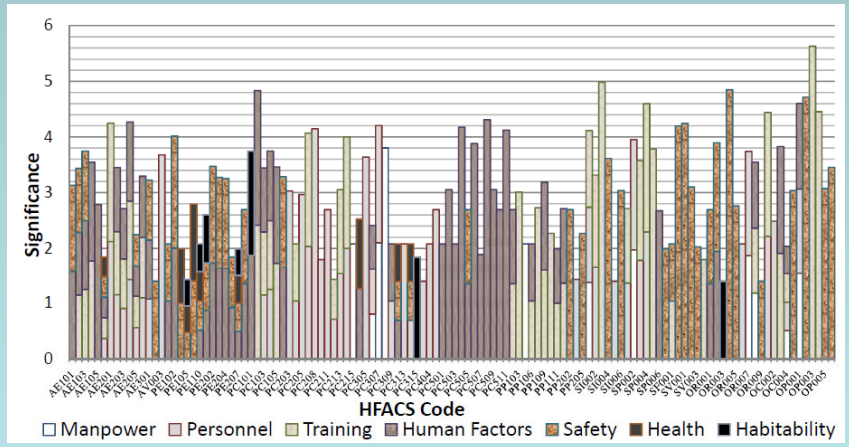




HFACS	Description	Related Domain(s)
OP003	Procedural Guidance/Publications	Training
SI003	Local Training Issues/Programs	Training
OR004	Acquisition Polies/Design Processes	Safety
PC102	Channelized Attention	Training, Human Factors
OP002	Program and Policy Risk Assessment	Safety
OP001	Ops Tempo/Workload	Human Factors, Manpower, Personnel
SP004	Limited Total Experience	Training, Personnel
OP004	Organizational Training Issues/Programs	Training



Method Summary

- Study mishaps in legacy systems where human error was identified as a causal factor
- Quantify the effect of human-machine interaction
- Use that empirical data to predict, and justify, requirements for new system design

AIR FORCE CENTER FOR SYSTEMS ENGINEERING

COOPERATIVE UNMANNED AERIAL SURVEILLANCE CONTROL SYSTEM

Sponsored by AFRL/RY, AFRL/RBC, and AFRL/RW

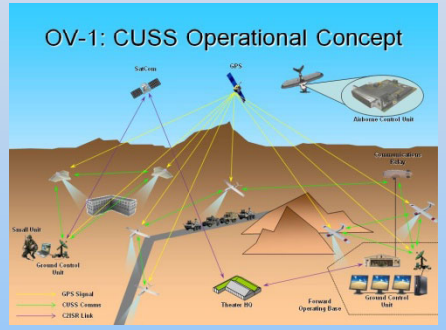
LCDR Ted Diamond — **Maj Adam Rutherford** — **Maj Brett Taylor**
Capt Chris Booth — **Capt Shannon Farrell** — **Mr. Austin Smith**

OVERALL OBJECTIVES

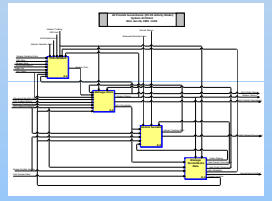
- Develop a CONOPs and conceptual architecture for cooperative UAV control
- Create a test bed for cooperative control research
- Evaluate concurrently developed UAV algorithms

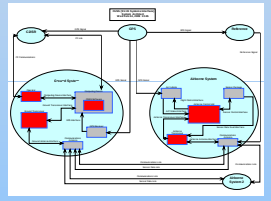
Adaptable Sensor Coverage | **Increased Sensor Coverage**

Reduced Revisit Time | **Persistent Surveillance**



Conceptual Architecture





Test Bed

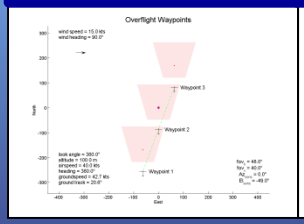
Flight Test Results

- Auto Pilot Tuning
- Navigation Accuracy
- UAV Performance
- Communication Challenges
- Sensor Feed Constraints
- Human Factors Considerations

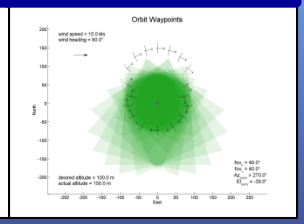
Control Algorithm Development

Sensor Aimpoint Flight Plan Algorithms

Overflight



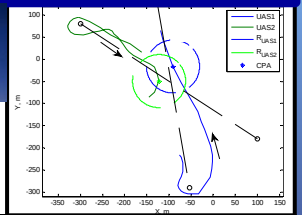
Orbit

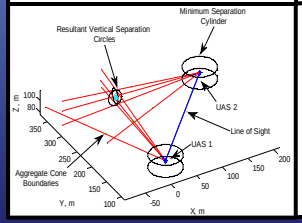


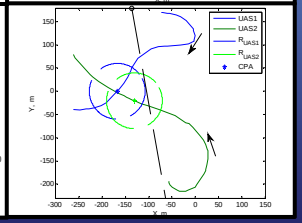
UAS Collision Avoidance Algorithm

Theory and Control

Results

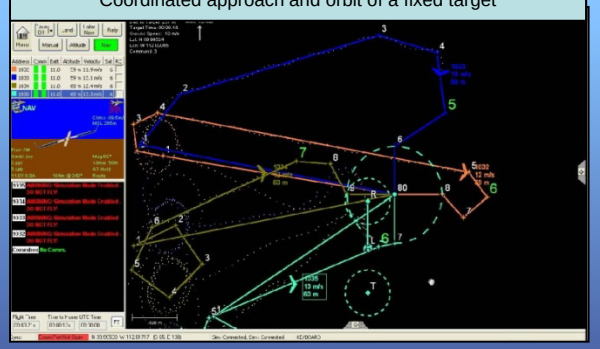






Cooperative Control Algorithm

Coordinated approach and orbit of a fixed target



OVERALL RESULTS

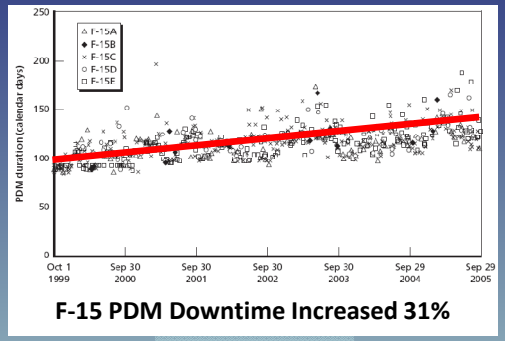
- Created conceptual architecture
- Flew 4 UAVs simultaneously
- Identified UAV cooperative control risks & challenges
- Demonstrated UAV algorithms

AIR FORCE CENTER FOR SYSTEMS ENGINEERING

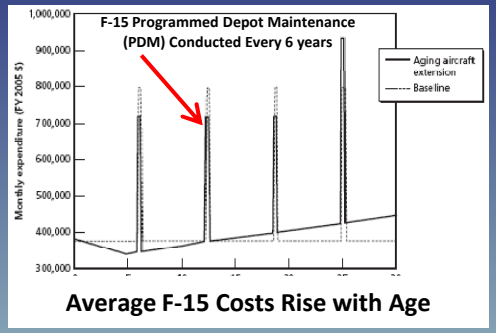
Integrated Structural Health Monitoring for Aging Aircraft III

Research Sponsor: AFRL/RXLP
Captain Jason Brown 1Lt Travis Hanson

The Problem



F-15 PDM Downtime Increased 31%



Average F-15 Costs Rise with Age

Methodology:

- Used Strategic Guidance
- Functional Area Analysis
- Functional Needs Analysis
- Functional Solution Analysis

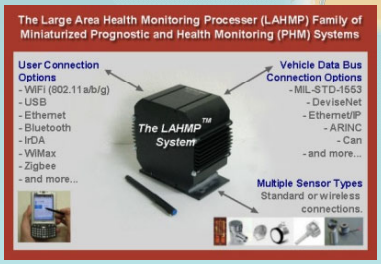
→ Developed CONOPS
→ Identified Capability Needs
→ Identified Current Capabilities
→ Conducted Analysis of Alternative Solutions

UJTL, AFTL, ASIP, JOCs, JICs, JFCs

Necessary Capabilities:

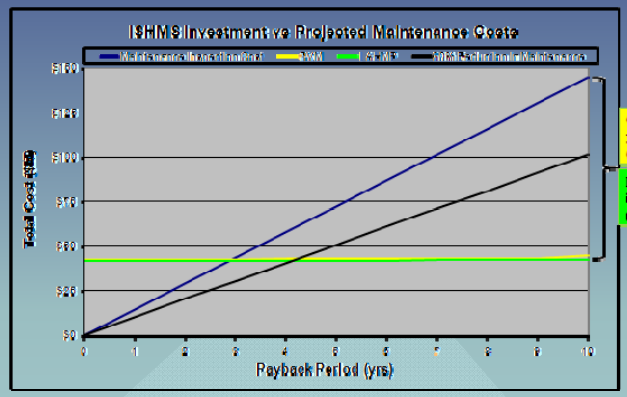
- Reduce Sustainment
- Maintain Situational Awareness
- Facilitate Informative Decision Making
- Assess Performance and Implementation Improvements

Analysis of Solutions:

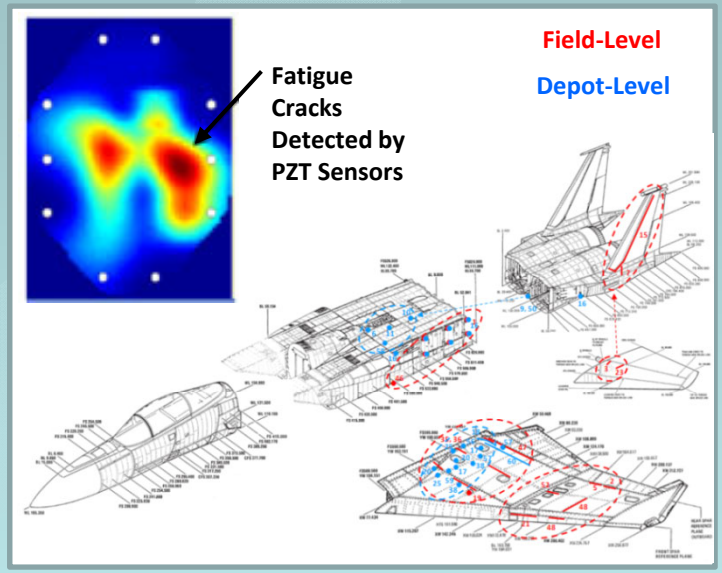


The Results

Significant Cost Savings Over Current Inspection Methods with Increased Visibility of Structural Deficiencies and Safety of Flight



Provides Near Real-Time Monitoring of Crack Initiation and Propagation



U.S. AIR FORCE

Summary

- AFIT SE research program is growing
  - Good balance of basic and applied research
  - DoD sponsored work supporting acquisition, sustainment and operational communities
- AFIT faculty and students provide perspective unmatched in civilian universities
  - Students know DoD challenges because they live them
  - Military/civilian faculty mix provides balance between new initiatives and sustained research in depth
- AFIT research strengths
  - Architecture, early application of SE
  - Human System Integration
  - Applied design for mission effectiveness