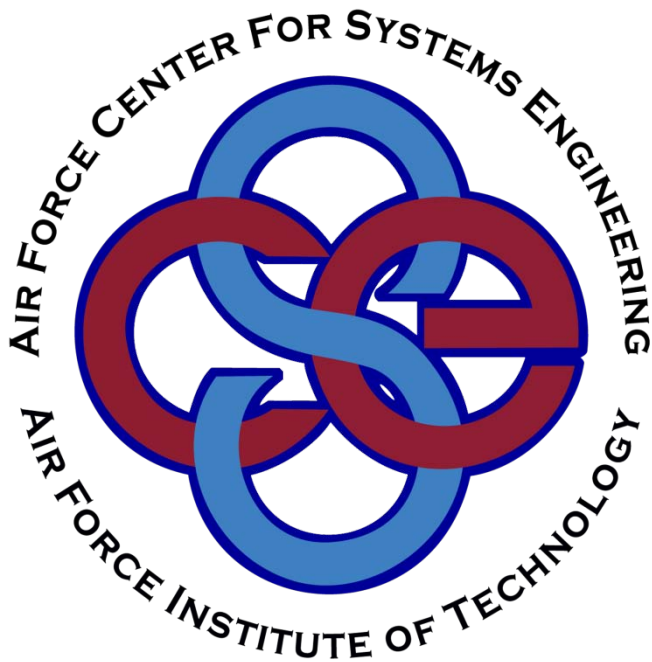


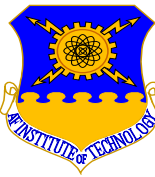
AFCS

Systems Engineering Research



David Jacques, Ph.D.
Chair, Systems Eng Programs
Department of Systems and
Engineering Management
20 Oct 08

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
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a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			



SE “Research”

Statements on SE Research by INCOSE



- Systems engineering is an integrative discipline which, like other engineering specialties, needs vibrant research
- INCOSE advocates the articulation of programs in basic and applied research in Systems Engineering
- INCOSE supports strongly doctoral level research in Systems Engineering

System Science Working Group

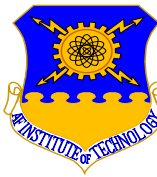
System Science is the enabling theoretical foundations and scientific underpinnings of systems engineering that contribute to better understanding of systems engineering practice, particularly of complex systems and large-scale enterprises

Conference on Systems Engineering Research (CSER)

	5th Annual Conference on Systems Engineering Research
	MARCH 14-16, 2007
	Stevens Institute of Technology Campus Hoboken, New Jersey



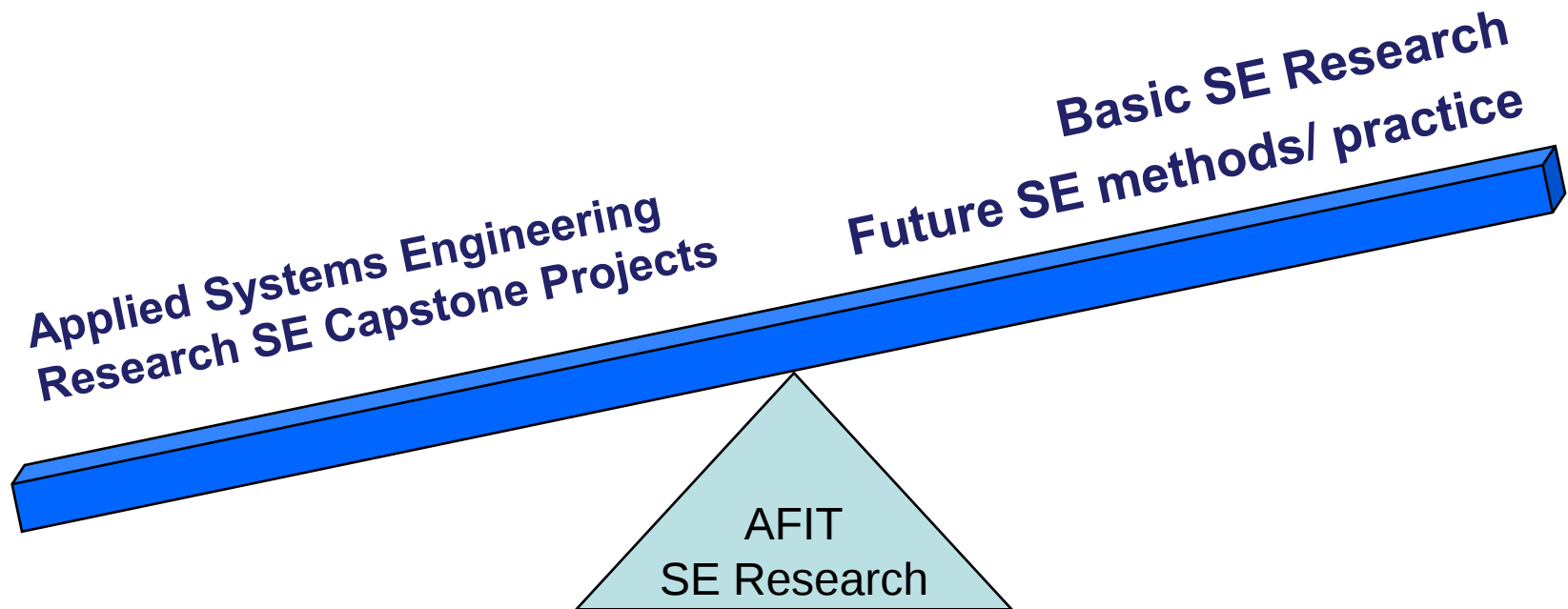
AFIT SE Research



- **All SE graduate programs require a capstone project**
 - Group projects provide integrated design team experience
 - Thesis for Masters (12 credits, 3 qtrs)
 - Capstone Design Project for IDE (9 credits, 3 qtrs)
 - Capstone for Certificate (4 credits, 1 qtr)
 - Individual Dissertation for Ph.D. students
- **AFIT solicits research grants just like civilian institutions**
 - Resident military student tuition is paid for, but ...
 - Civilian faculty are on academic year appointments (10 months), and ...
 - AFIT is not budgeted for research related travel, supplies, and equipment
 - We are cheap, but we are not free!
- **Funding for the SE group has been growing**
 - Over \$600K in 2008
 - Has allowed us to bring faculty from other programs onto SE projects



Balance Application of SE Practice with Basic SE Research



Last year, the balance clearly tipped towards the applied research side

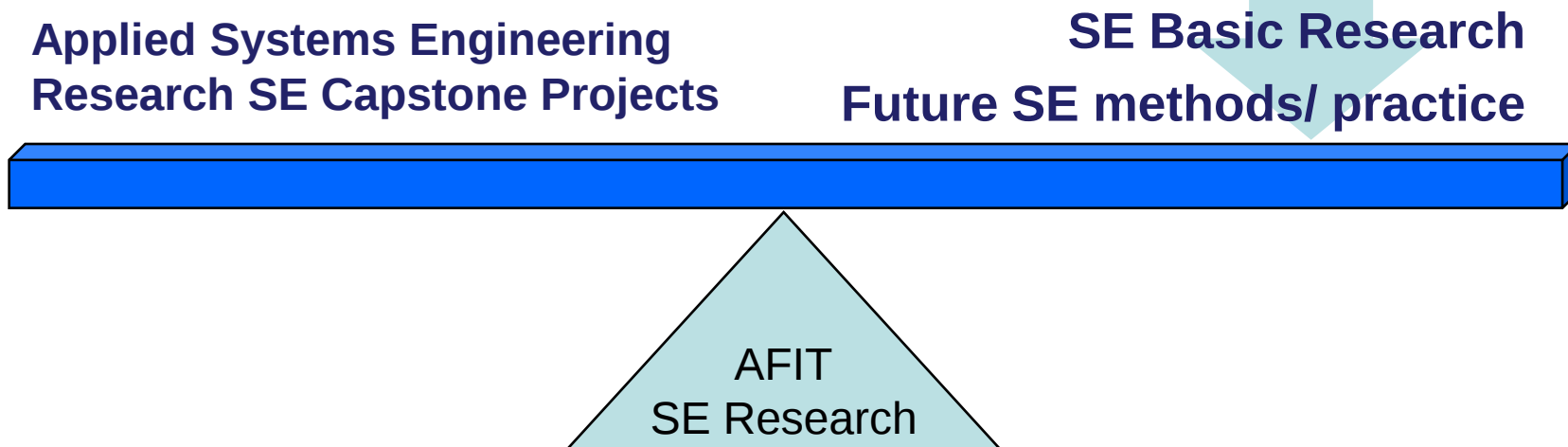
- Only one PhD student (our first) in dissertation research
- Sponsors of MS student research tend to focus more on application



Balance Application of SE Practice with Basic SE Research

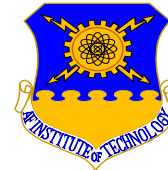


AFIT

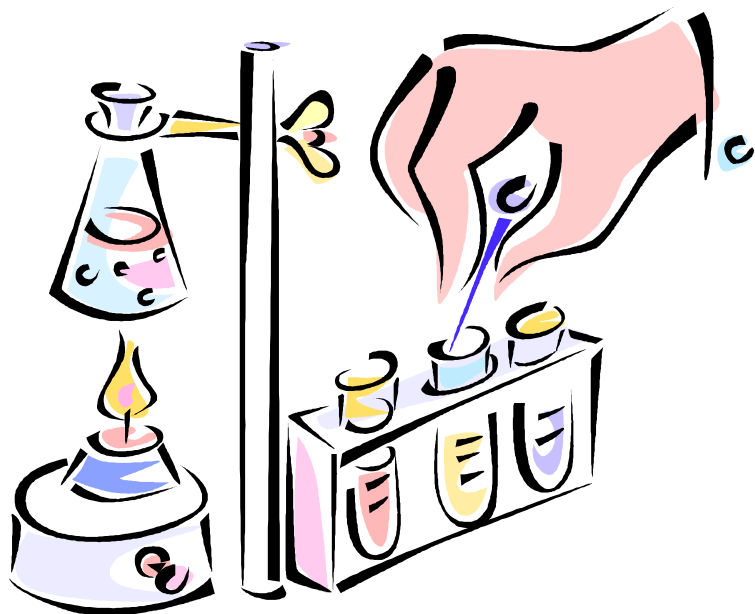


This year, the balance has been tipped towards more basic research

- More PhD students in dissertation research
- Greater effort to “shape” MS topics to address more fundamental questions



AFCS

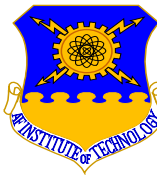


BASIC RESEARCH

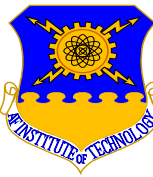


Challenge

Who funds Basic SE Research?



- **National Science Foundation**
 - Funds System Science, but typically not Systems Engineering
- **AFOSR**
 - Responsible for oversight and management of the Air Force program in basic research (6.1)
 - Orchestrates the research program with universities, industry, other government organizations, and the AF Research Lab (AFRL) technical directorates
 - AFOSR funding – traditional science areas
 - Aerospace and Materials Sciences
 - Physics and Electronics
 - Mathematics, Information and Life Sciences
- **SE University Affiliated Research Center (UARC)**
 - New initiative, funded by OSD, NSA
 - Award will be announced Oct 08 - Stevens Institute leading a large multi-university team
 - AFIT will participate in the UARC with the Stevens-led team
- We invite the AF CSE advisory council to help identify SE basic research funding sources



- **SE process improvements**
 - Modeling and evaluation of architectures
 - Modeling cognitive processes within the DoD Architecture Framework
- **System of Systems/ Network Centric Systems Analysis**
 - Graph Theory of Network Centric Operations
 - Interoperability Measurement
- **Integrated Health Monitoring**
 - Reliability models to support life cycle system design
- **Human Systems Integration (HSI) Design**
 - Graph theoretic analysis for HSI evaluation and design
- **Modularity in design vs. performance**





AIR FORCE CENTER FOR SYSTEMS ENGINEERING

Architecting Cognition within the Department of Defense Architecture Framework (DoDAF)

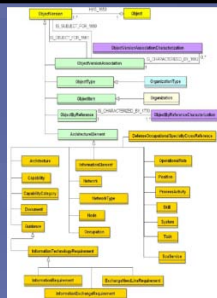
Research Sponsor: AFRL/RH, Wright-Patterson AFB
Maj David O'Malley Major Jonathan Zall



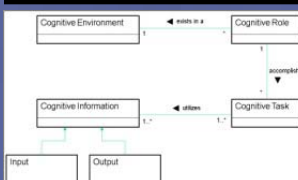
Problem: The design of complex, socio-technical systems requires that critical aspects of the whole integrated system be specifically defined upfront so that the implemented solution addresses human system integration (HSI) facets as well as technical system integration facets. HSI factors and constraints are not incorporated in the US Military acquisitions process until late in the process resulting in unnecessary risk incurred, cost overruns, and mission shortfalls.

Method: Define the cognitive aspect of Human Factors and develop a model of cognitive and pseudo-cognitive (CPC) elements for inclusion in DoDAF via the Core Architecture Data Model (CADM). Demonstrate the efficacy of DoDAF extended with CPC model during the Joint Capabilities Integration Development System (JCIDS) process.

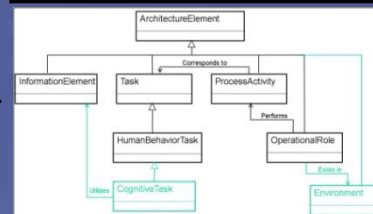
DoDAF version 1.5



Cognitive Elements



CADM with CPC Extension



DoDAF version 1.5 Operational View-5



Fundamental Cognitive Tasks

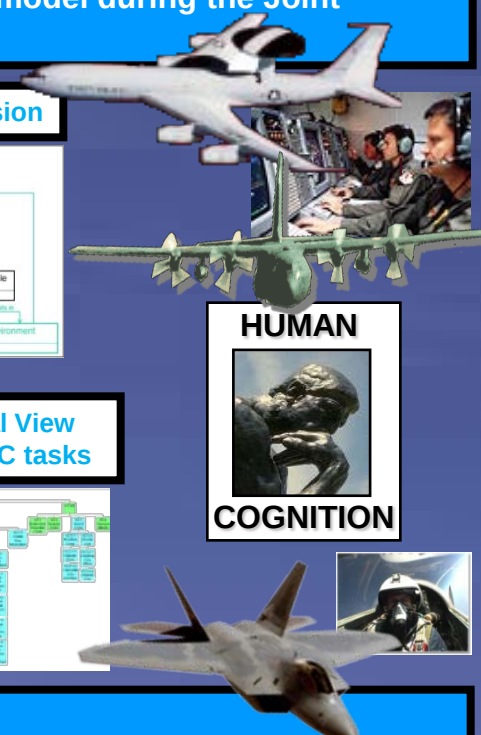
Cognitive Task Type Label	Description	Priority	Inputs	Outputs	Task ID
Identify (IC)	To identify a set of information through question flow, map spatial and/or temporal relationships and/or relationships to information.	P_1	R_1, A_1, B_1	P_2	1
Classify (CL)	To group objects within a given set of information according to a given set of attributes with value ranges.	P_1	R_1, A_1, B_1	P_2	2
Classify (CL)	To determine a set of attributes with value ranges from a given set of attributes with value ranges or a given set of information.	P_1	R_1, A_1, B_1	P_2	3
Classify (CL)	To identify a set of information based on a given set of attributes with value ranges or a given set of information.	P_1	R_1, A_1, B_1	P_2	4
Classify (CL)	To identify a set of information based on a given set of attributes with value ranges or a given set of information.	P_1	R_1, A_1, B_1	P_2	5
Classify (CL)	To identify a set of information based on a given set of attributes with value ranges or a given set of information.	P_1	R_1, A_1, B_1	P_2	6
Classify (CL)	To identify a set of information based on a given set of attributes with value ranges or a given set of information.	P_1	R_1, A_1, B_1	P_2	7
Classify (CL)	To identify a set of information based on a given set of attributes with value ranges or a given set of information.	P_1	R_1, A_1, B_1	P_2	8
Classify (CL)	To identify a set of information based on a given set of attributes with value ranges or a given set of information.	P_1	R_1, A_1, B_1	P_2	9
Classify (CL)	To identify a set of information based on a given set of attributes with value ranges or a given set of information.	P_1	R_1, A_1, B_1	P_2	10
Classify (CL)	To identify a set of information based on a given set of attributes with value ranges or a given set of information.	P_1	R_1, A_1, B_1	P_2	11
Classify (CL)	To identify a set of information based on a given set of attributes with value ranges or a given set of information.	P_1	R_1, A_1, B_1	P_2	12
Classify (CL)	To identify a set of information based on a given set of attributes with value ranges or a given set of information.	P_1	R_1, A_1, B_1	P_2	13
Classify (CL)	To identify a set of information based on a given set of attributes with value ranges or a given set of information.	P_1	R_1, A_1, B_1	P_2	14
Classify (CL)	To identify a set of information based on a given set of attributes with value ranges or a given set of information.	P_1	R_1, A_1, B_1	P_2	15
Classify (CL)	To identify a set of information based on a given set of attributes with value ranges or a given set of information.	P_1	R_1, A_1, B_1	P_2	16
Classify (CL)	To identify a set of information based on a given set of attributes with value ranges or a given set of information.	P_1	R_1, A_1, B_1	P_2	17
Classify (CL)	To identify a set of information based on a given set of attributes with value ranges or a given set of information.	P_1	R_1, A_1, B_1	P_2	18
Classify (CL)	To identify a set of information based on a given set of attributes with value ranges or a given set of information.	P_1	R_1, A_1, B_1	P_2	19
Classify (CL)	To identify a set of information based on a given set of attributes with value ranges or a given set of information.	P_1	R_1, A_1, B_1	P_2	20

New Operational View incorporating CPC tasks



Results:

- Standardized means for incorporating elements of human cognitions (Environments, Roles, Tasks, Inputs and Outputs)
- Accurate solution trade space constraints with traceable manpower, personnel, and training requirements
- Decreased cost, risk, and mission shortfalls of final solution
- Provide foothold for all other elements of HSI within the JCIDS process



UNIQUE & SUBSTANTIAL CONTRIBUTION

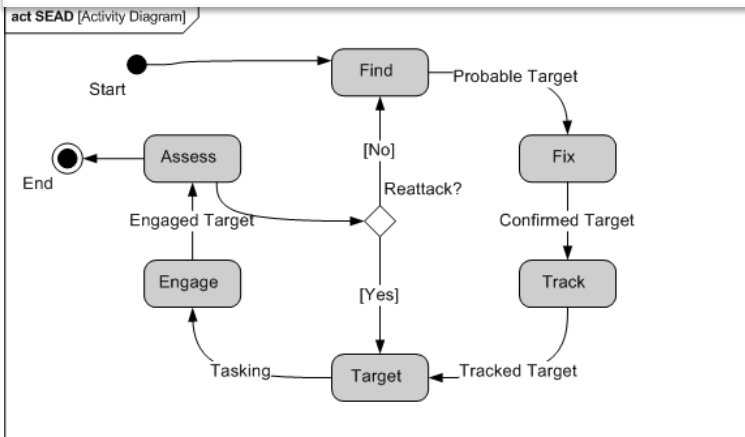
This research presents an inaugural general method of quantitatively measuring the collaborative and confrontational interoperability of a heterogeneous set of systems

The method:

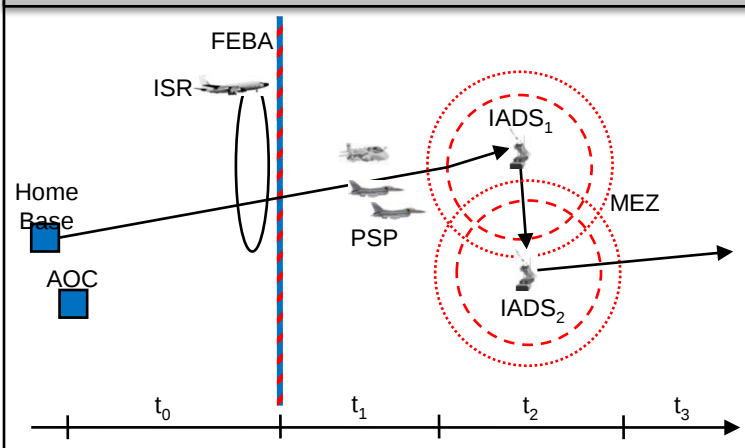
1. Accepts all system types (e.g., coalitions, technology, organizations, cultures, etc.)
2. Accepts all interoperability types (e.g., enterprise, joint, semantic, technical, etc.)
3. Describes interoperability in the context of an operational process
4. Provides for higher precision of measurement
5. Introduces confrontational interoperability and relates it to operational effectiveness
6. Accommodates all types of interoperability characteristics
7. Capitalizes upon existing architecture data

Suppression of Enemy Air Defenses

Operational Process



Operational View



Interoperability Model*

$$S = \{S_B, S_R\} = \{\{HB, ISR, AOC, PSP\}, \{IADS_1, IADS_2\}\}$$

$$X = \left\{ \begin{array}{l} 27 \text{ characters representing} \\ \text{joint operational function hierarchy} \end{array} \right\}$$

$$C = \{0, 1\}$$

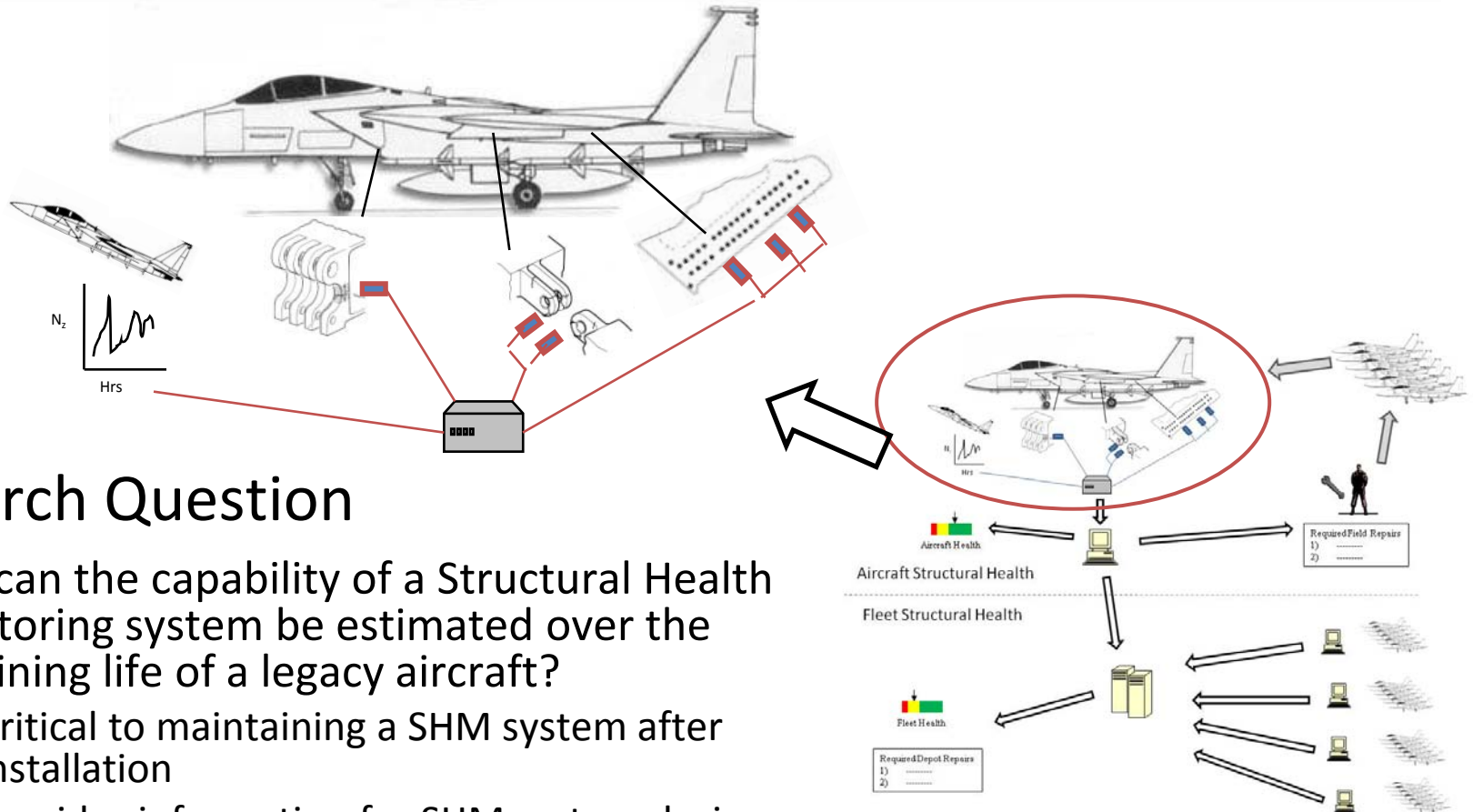
$$O = \{O_B, O_R\} = \left\{ \begin{array}{l} \text{Percent of enemy air defenses destroyed,} \\ \text{Percent of enemy air defenses protected} \end{array} \right\}$$

$$I = Sim_{Bin}$$

* System instantiation not pictured due to large size

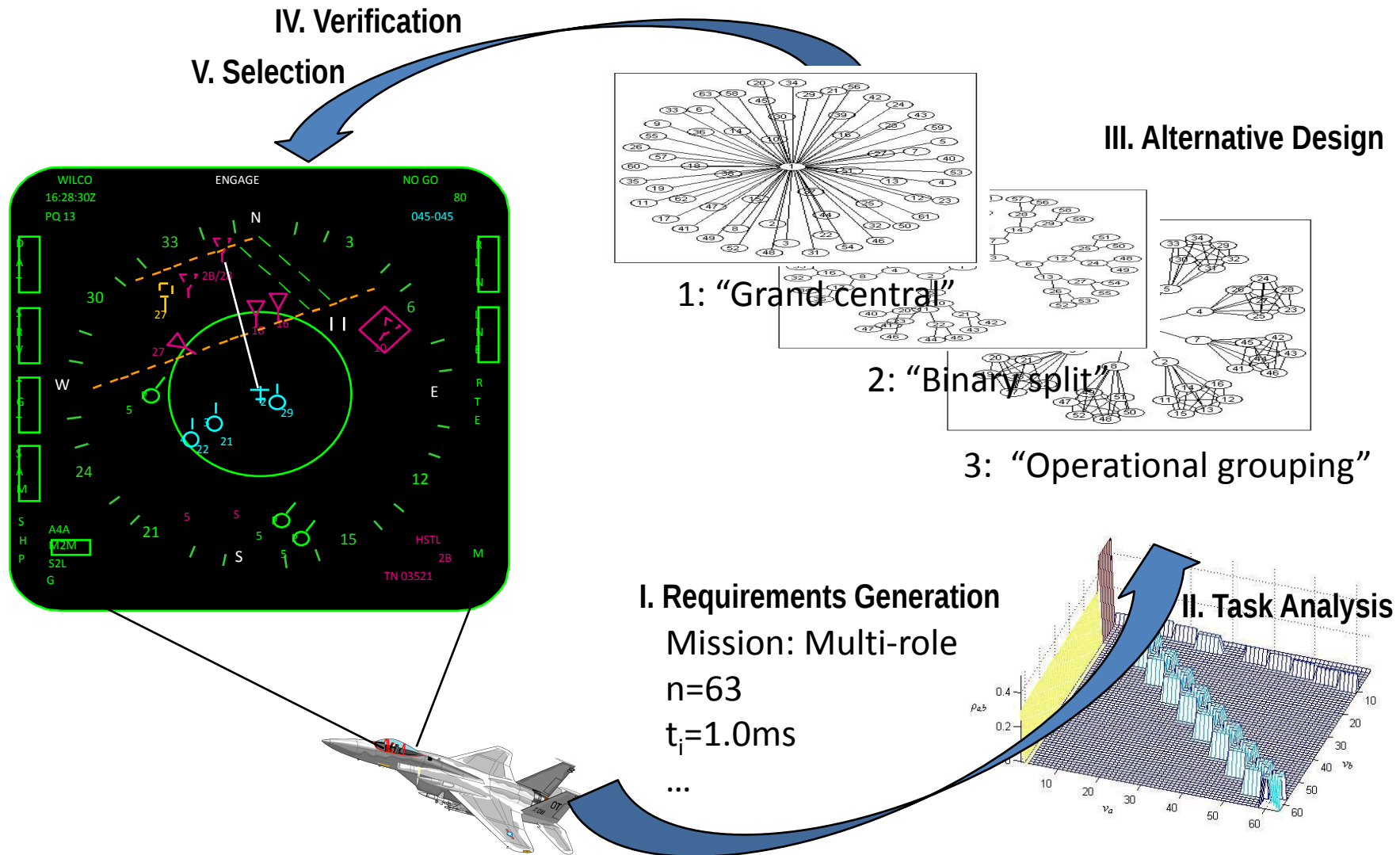
Interoperability Measurement

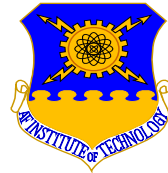
$$M = \begin{bmatrix} & HB & ISR & AOC & PSP & IADS_1 & IADS_2 \\ HB & 0 & \frac{1}{9} & \frac{1}{9} & \frac{1}{9} & \frac{2}{27} & \frac{2}{27} \\ ISR & \frac{1}{9} & 0 & \frac{5}{27} & \frac{8}{27} & \frac{2}{9} & \frac{2}{9} \\ AOC & \frac{1}{9} & \frac{1}{9} & 0 & \frac{4}{27} & \frac{2}{27} & \frac{2}{27} \\ PSP & \frac{1}{9} & \frac{1}{9} & \frac{1}{9} & 0 & \frac{7}{27} & \frac{7}{27} \\ IADS_1 & \frac{2}{27} & \frac{5}{27} & \frac{5}{27} & \frac{10}{27} & 0 & \frac{1}{3} \\ IADS_2 & \frac{2}{27} & \frac{5}{27} & \frac{5}{27} & \frac{10}{27} & \frac{1}{3} & 0 \end{bmatrix}$$



Research Question

- How can the capability of a Structural Health Monitoring system be estimated over the remaining life of a legacy aircraft?
 - Critical to maintaining a SHM system after installation
 - Provides information for SHM system design trade-offs
 - Provides information for Cost-benefit analysis
 - More SHM maintenance = Less cost savings
 - Method must relate to current practice for practical acceptance





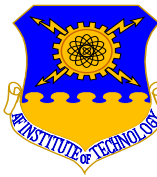
ATCSE



APPLIED RESEARCH



AFIT Applied Research Threads



A Sample of Applied SE Research at AFIT

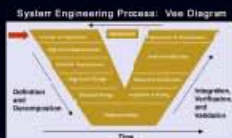
- **Rapid Response to Urgent Warfighter Needs**
- **Interdisciplinary/Interdepartmental Projects**
 - Cooperative small air vehicle surveillance concepts
- **Early SE Application for Technology and Capability Planning**
 - Analysis of functional autonomy
 - Process modeling and risk analysis for decision making
- **Architecture Modeling for Concept Evaluation**
 - Evaluating military worth using architecture based discrete event simulations
- **Spacecraft Dynamics and Control Testbed**



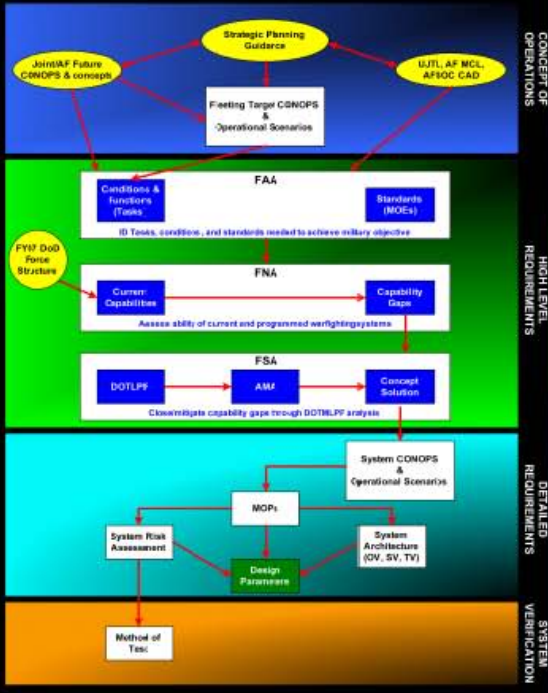
AIR FORCE CENTER FOR SYSTEMS ENGINEERING

Systems Engineering Analysis For Transition of Fleeting Target Demonstrator

Maj Laird Abbott, Maj Craig Phillips, Mr. Christian Stillings, Capt Garrett Knowlan



Fleeting Target Systems Engineering Process



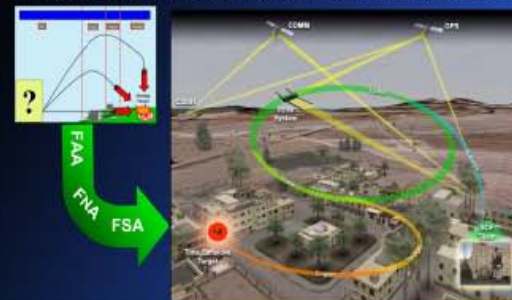
Test

Provide description of system under test, test objectives and procedures



Operations Concept

Identify system's purpose, major players, operating context, and mechanisms for accomplishing the mission



Functional Area Analysis

Identify tasks, conditions, and standards needed to achieve military objectives



Functional Needs Analysis

Assess ability of current and programmed warfighting systems



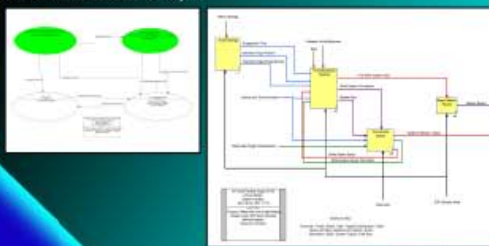
Functional Solutions Analysis

Assess all DOTLPE approaches to solve capability gaps identified in FNA



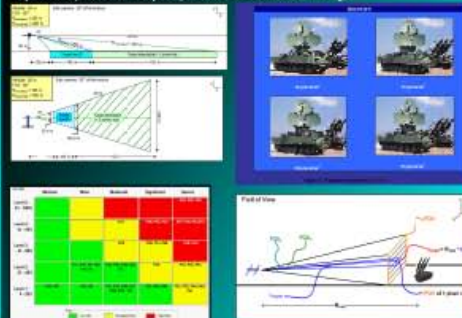
Architecture

Map out operational, system, and technical architecture to better describe and understand the system



Risk Analysis

Identify and assess uncertainties of schedule & performance through objective & quantitative analysis—provide recommendations to mitigate



A Focused Systems Engineering Approach to Rapidly Transition Technology to the Warfighter

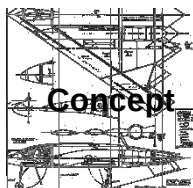


AIR FORCE CENTER FOR SYSTEMS ENGINEERING

An Analysis of Functional Autonomy

Sponsored by AFRL/RBAA

LCDR Scott Rivera Captain Anil Hariharan Captain Alan Louie



Concept

Establish 2035 Vision

Planners
Operators
Doctrine
Guidance

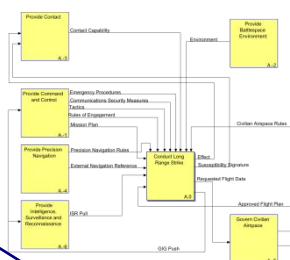


Operational
Concept

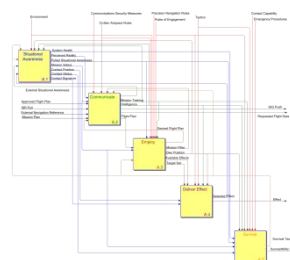


Global Strike
Persistent Attack
Time Sensitive Attack
Nuclear Strike
Show of Force

Describe System

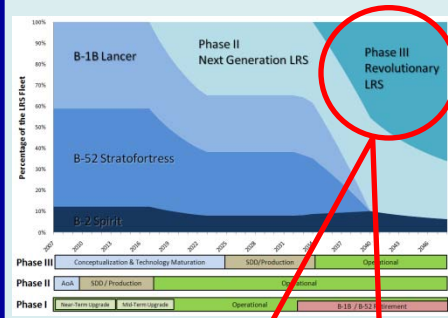


External Systems
Diagram



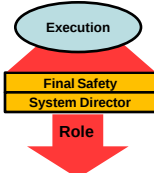
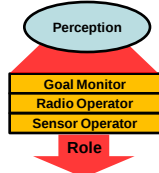
LRS Activity
Diagram

Problem



Can the 2035 LRS System
be Automated?

Identify Human Roles



High Level Activity

Low Level Activity

Sub-System	System Function	Perceive	Interpret	Plan	Execute	Survive
Performs	Provide High Capability					
Proposition	Provide Measure Capability					
Communication	Provide Target					
Navigation	Provide Guidance					
Command and Control	Coordinate Direct Mission Systems					
Subsystem	Coordinate Systems					
Fire Control	Provide System Readiness					
Survivability	Monitor Threats Environment					
Automatic Flight Control	Provide Data					
Weapons Delivery	Provide Interface to Payload					
Crew Station	Mitigate Susceptibility					
	Provide Effects Delivery Mechanism					
	Provide Human Operator					
	Provide Human Operator					

Planning

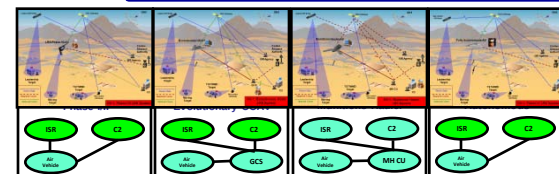
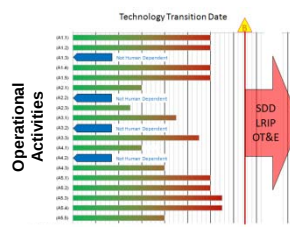
Navigator
Weaponner

Interpretation

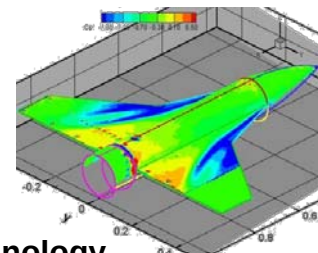
Data Analyst
Data Fuser
Data Sorter
Decision Maker
System Health Analyst

Methodology

Forecast Technology



Increasing Autonomy
Illustrative Variants



Technology

Results

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



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 Sprengle

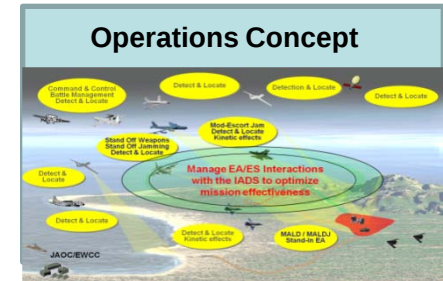


Results

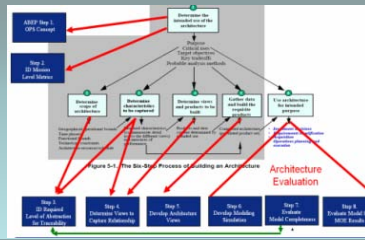
Measures of Effectiveness	No EWBM	EWBM		
	Baseline	No Decision Authority	Limited Decision Authority	Full Decision Authority
M1 Minutes to reassign AEA Assets		●	●	●
M2 Percent reduction in of SAM detection rate due to jamming		●	●	●
M3 Percent of strike aircraft Pd by Pop-up SAMs on route		●	●	●
M4 Percent 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 ● No statistically significant improvement or degradation ● Statistically significant degradation				

Problem Statement

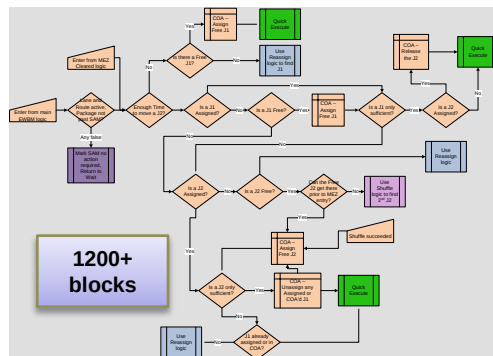
How can the AEA SoS architecture be used to evaluate the military worth of an Electronic Warfare Battle Management (EWBM)?



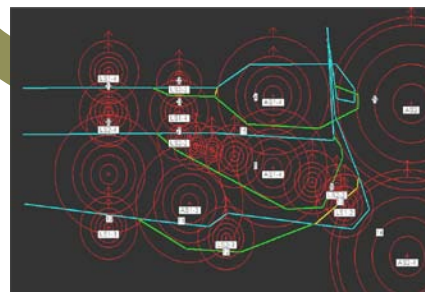
Architecture Based Evaluation Process



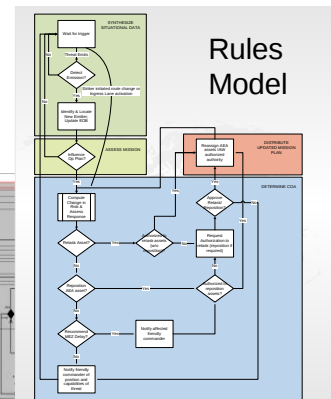
ARENA Simulation



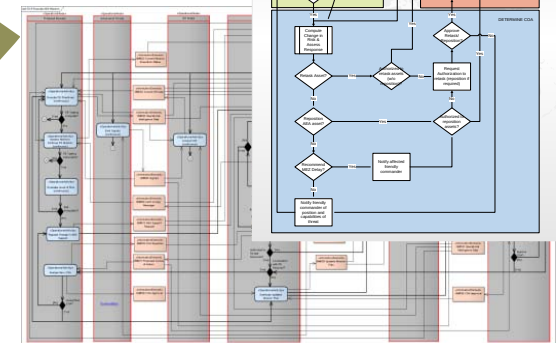
Falcon View Mission Plan



AEA SoS Architecture

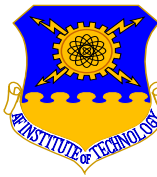


OV-5



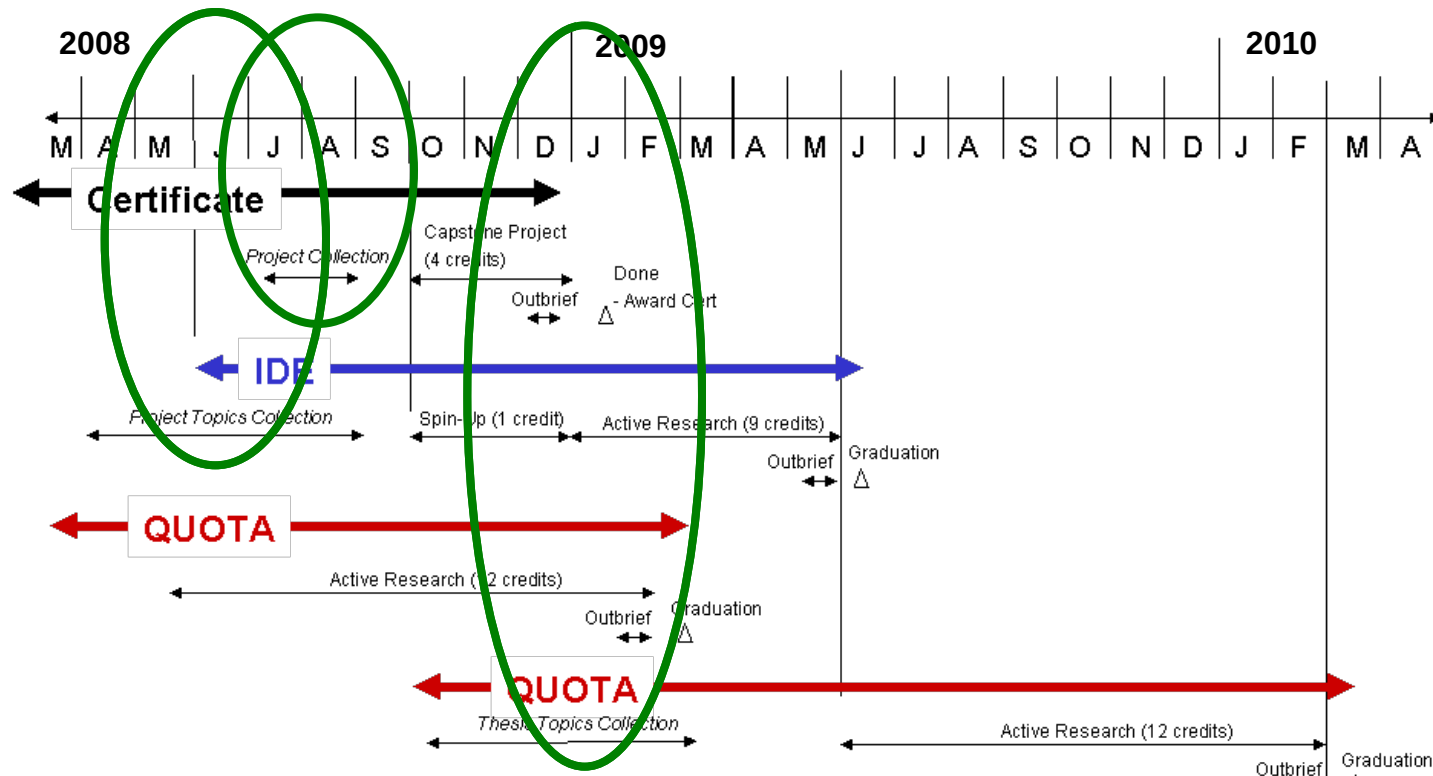


Challenge: Finding the best projects



AFCSF

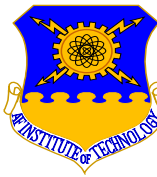
- We invite the committee to sponsor relevant projects for our SE students



Target Times for new projects: May-August (Certificate and IDE), Nov-Feb (Quota)



Conclusion



- **AFIT is focusing more effort on Basic SE Research**
 - Interoperability
 - Reliability and Integrated Health Monitoring
 - Design for Human Systems Integration
- **SE Research should include applied research activities in SE process improvement**
 - Early Enterprise and System Architecture and evaluation
 - Executable Architectures
 - Network Centric Operations modeling (graph theory, CPNs)



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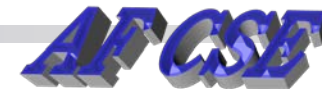
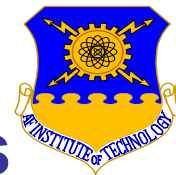


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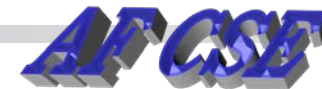
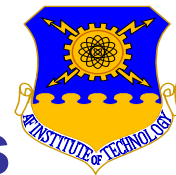


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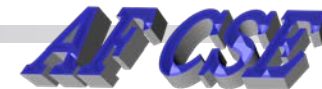
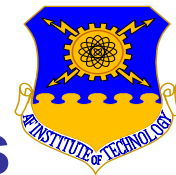


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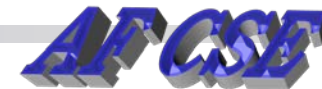
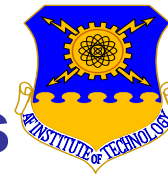


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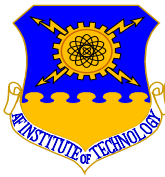


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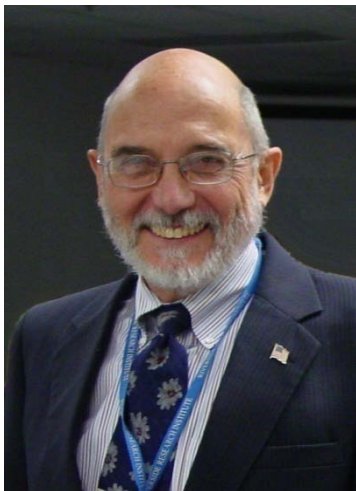


Contact Us –

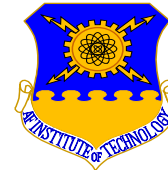
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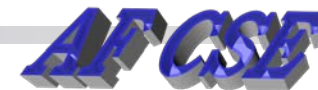
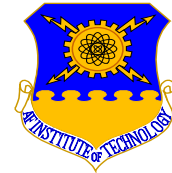


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ATCST

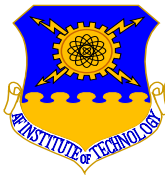
QUESTIONS ?



- Backups

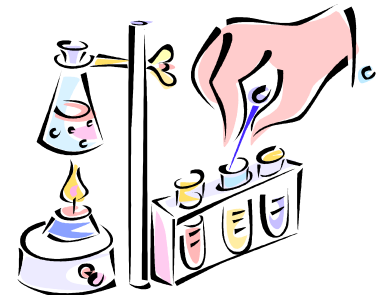


Research Definitions



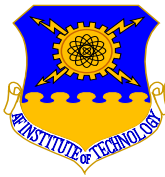
Basic Research Basic research is systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind. It includes all scientific study and experimentation directed toward increasing fundamental knowledge and understanding in those fields of the physical, engineering, environmental, and life sciences related to long-term national security needs. It is farsighted high payoff research that provides the basis for technological progress. ...

Refs: Office of Management and Budget Circular A-11 on budget regulations, Federal Acquisition Regulations, DOD's *Financial Management Regulation* (DOD 7000.14-R)





Research Definitions



Applied Research Applied research is systematic study to understand the means to meet a recognized and specific need. It is a systematic expansion and application of knowledge to develop useful materials, devices, and systems or methods. It may be oriented, ultimately, toward the design, development, and improvement of prototypes and new processes to meet general mission area requirements. Applied research may translate promising basic research into solutions for broadly defined military needs, short of system development. ...

Refs: Office of Management and Budget Circular A-11 on budget regulations, Federal Acquisition Regulations, DOD's *Financial Management Regulation* (DOD 7000.14-R)

