Presented at:

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Architecture Centric Virtual Integration Process (ACVIP) Shadow Effort

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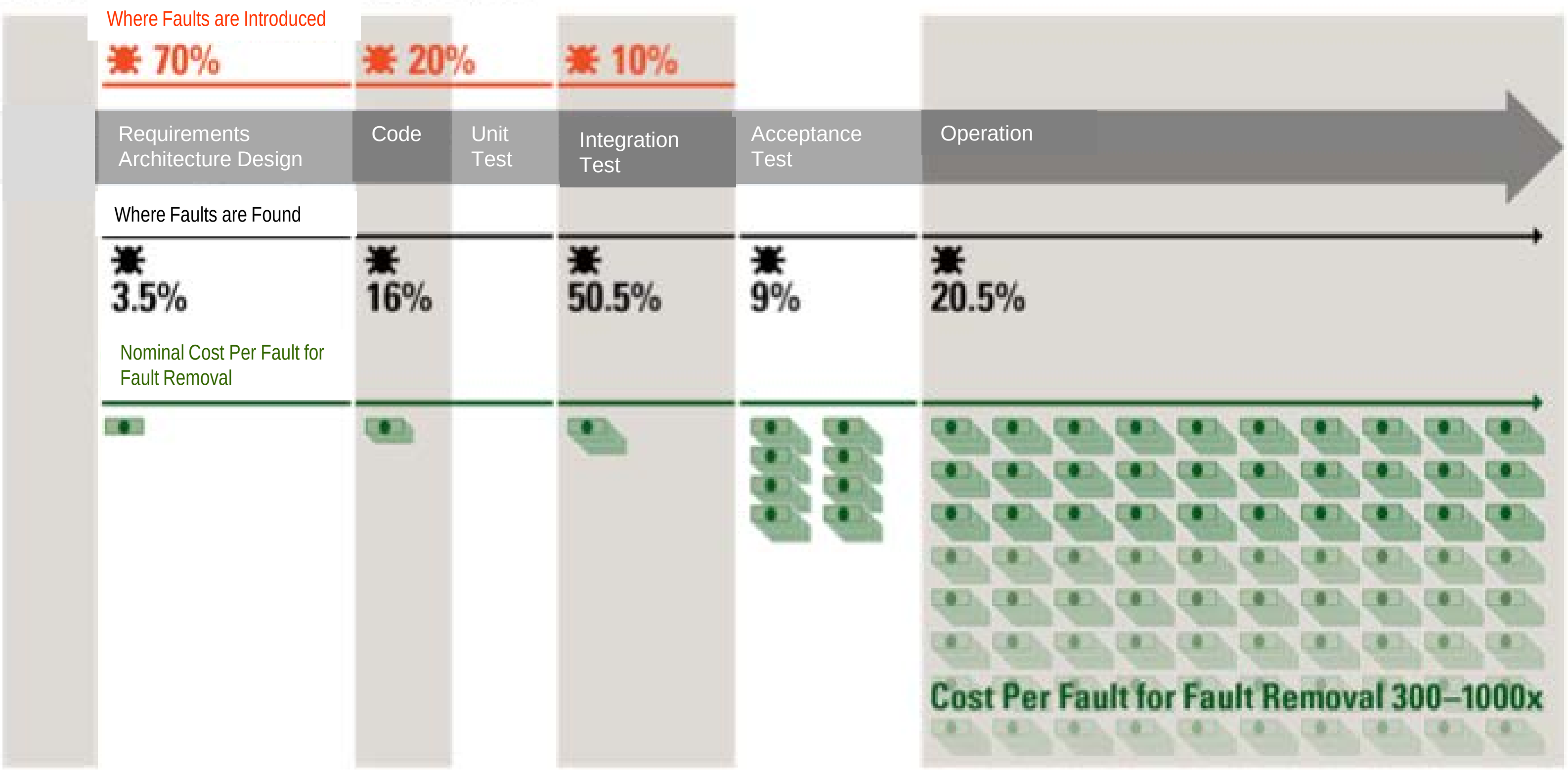
Opportunity for Rework Cost Reduction

Software Interaction Complexity Drives System Cost

Software Development Life Cycle

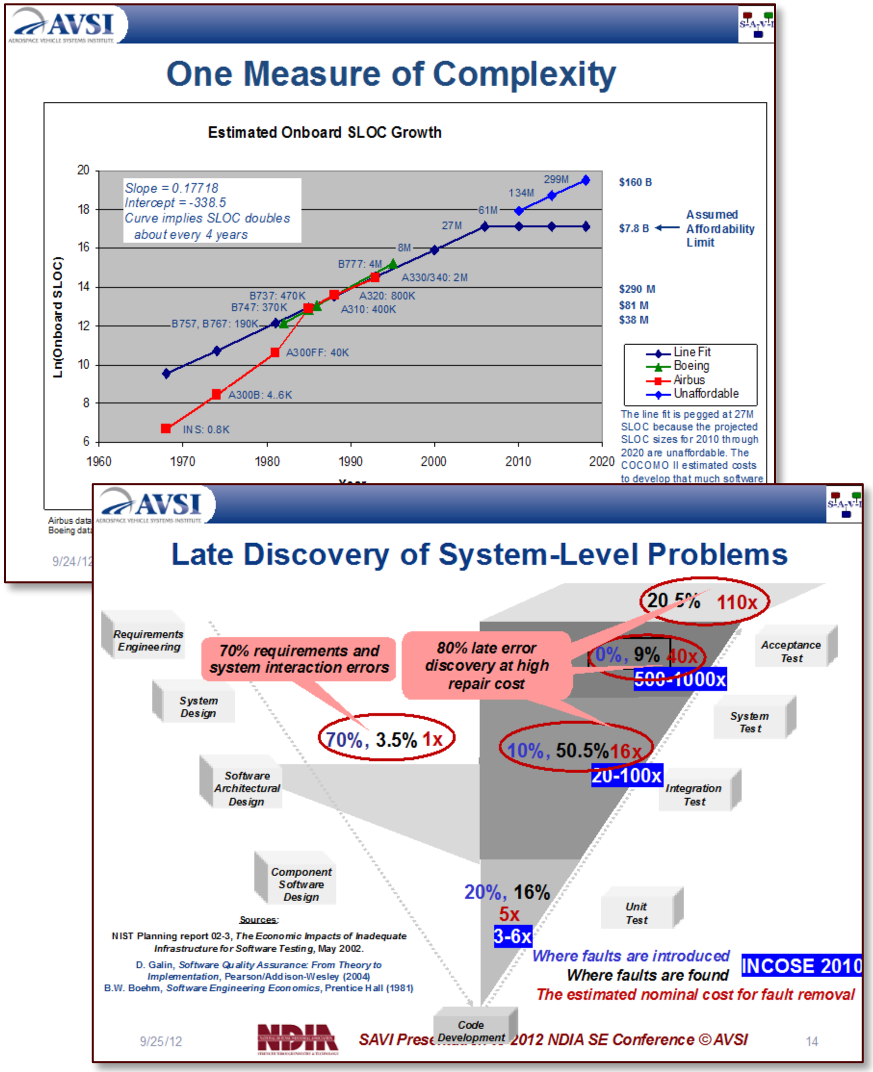


Sources: *Critical Code*; NIST, NASA, INCOSE, and Aircraft Industry Studies

Post-unit test software rework cost 50% of total system cost and growing

Software as % of total system cost 1997: 45% → 2010: 66% → 2024: 88%

System Architecture Virtual Integration (SAVI)



One Measure of Complexity

The line fit is pegged at 27M SLOC because the projected SLOC sizes for 2010 through 2020 are unaffordable. The COCOMO II estimated costs to develop that much software

Airbus data
Boeing data

9/24/12

Late Discovery of System-Level Problems

Sources:

NIST Planning report 02-3, *The Economic Impacts of Inadequate Infrastructure for Software Testing*, May 2002.

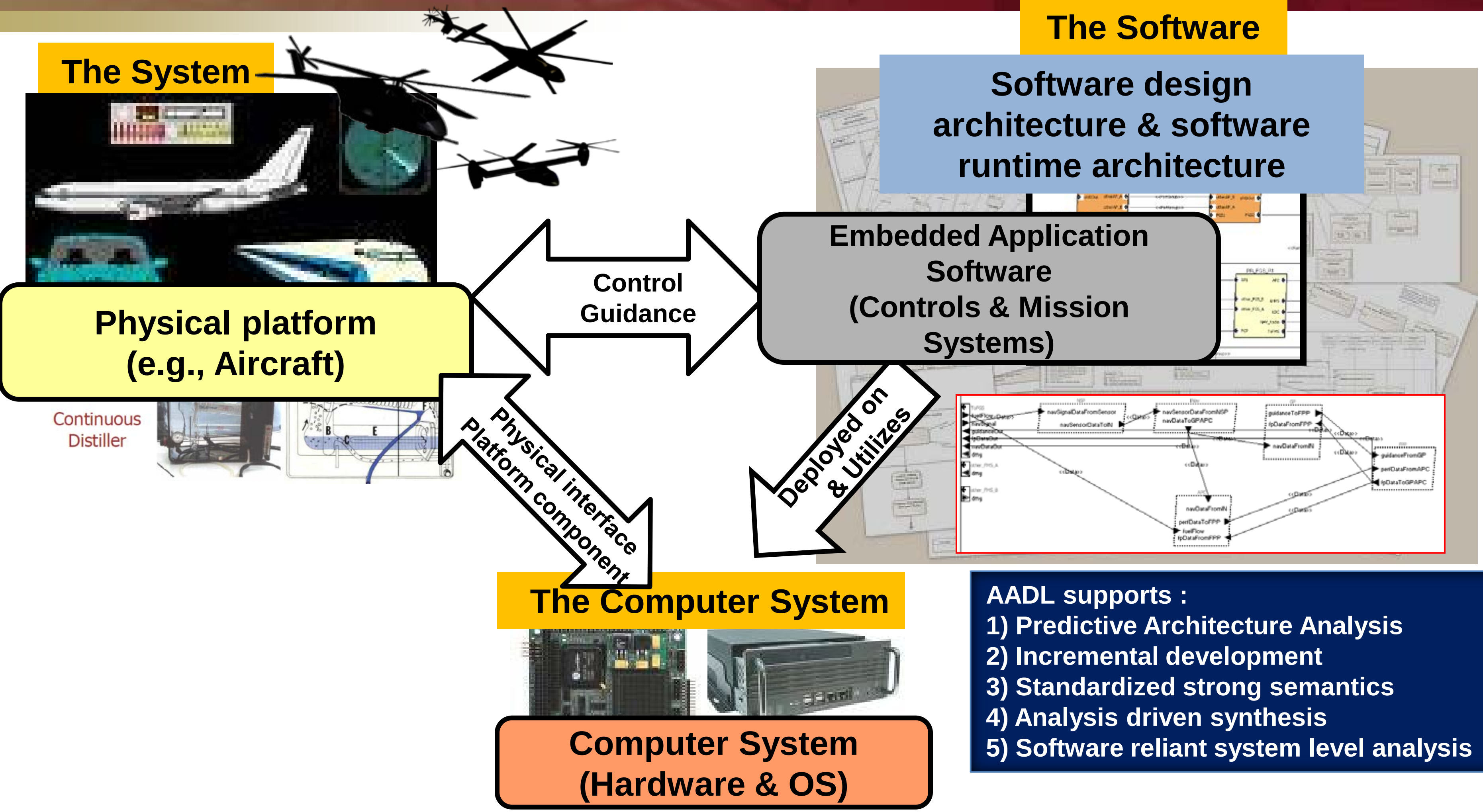
D. Galin, *Software Quality Assurance: From Theory to Implementation*, Pearson/Addison-Wesley (2004)

B.W. Boehm, *Software Engineering Economics*, Prentice Hall (1981)

9/25/12 NDIA SAVI Presentation 2012 NDIA SE Conference © AVSI 14

- Aerospace Vehicle Systems Institute (AVSI) is a consortium of commercial aerospace companies and gov't agencies
- AVSI Launched SAVI in 2008 to address the problem of growth in complexity of systems leading to cost and schedule overruns
- The objective is to develop a standards-based Virtual Integration Process (VIP) that allows multiple parties to virtually integrate and analyze systems throughout development life cycle
- The result is earlier detection and correction of errors leading to cost savings
- **Highly focused on integration – defining the state of the art in system integration consistency checking**

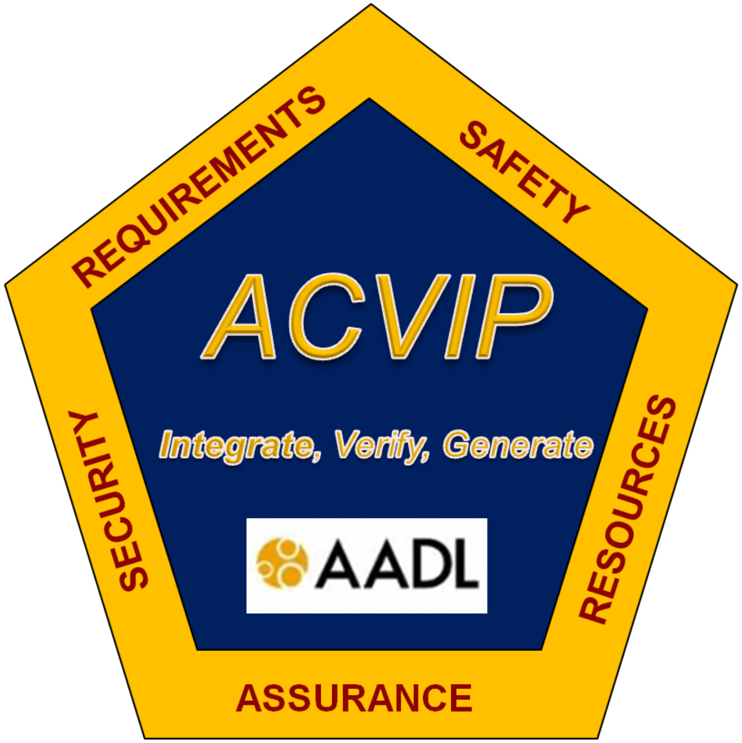
SAE AS5506 Architecture Analysis & Design Language (AADL) Standard


The Software
Software design architecture & software runtime architecture
The System
Physical platform (e.g., Aircraft)
Continuous Distiller
Control Guidance
Embedded Application Software (Controls & Mission Systems)
Physical interface Platform component
Deployed on & Utilizes
The Computer System
Computer System (Hardware & OS)

AADL supports :
1) Predictive Architecture Analysis
2) Incremental development
3) Standardized strong semantics
4) Analysis driven synthesis
5) Software reliant system level analysis

AADL focuses on interaction between the three major elements of a software-intensive system based on architectural abstractions of each

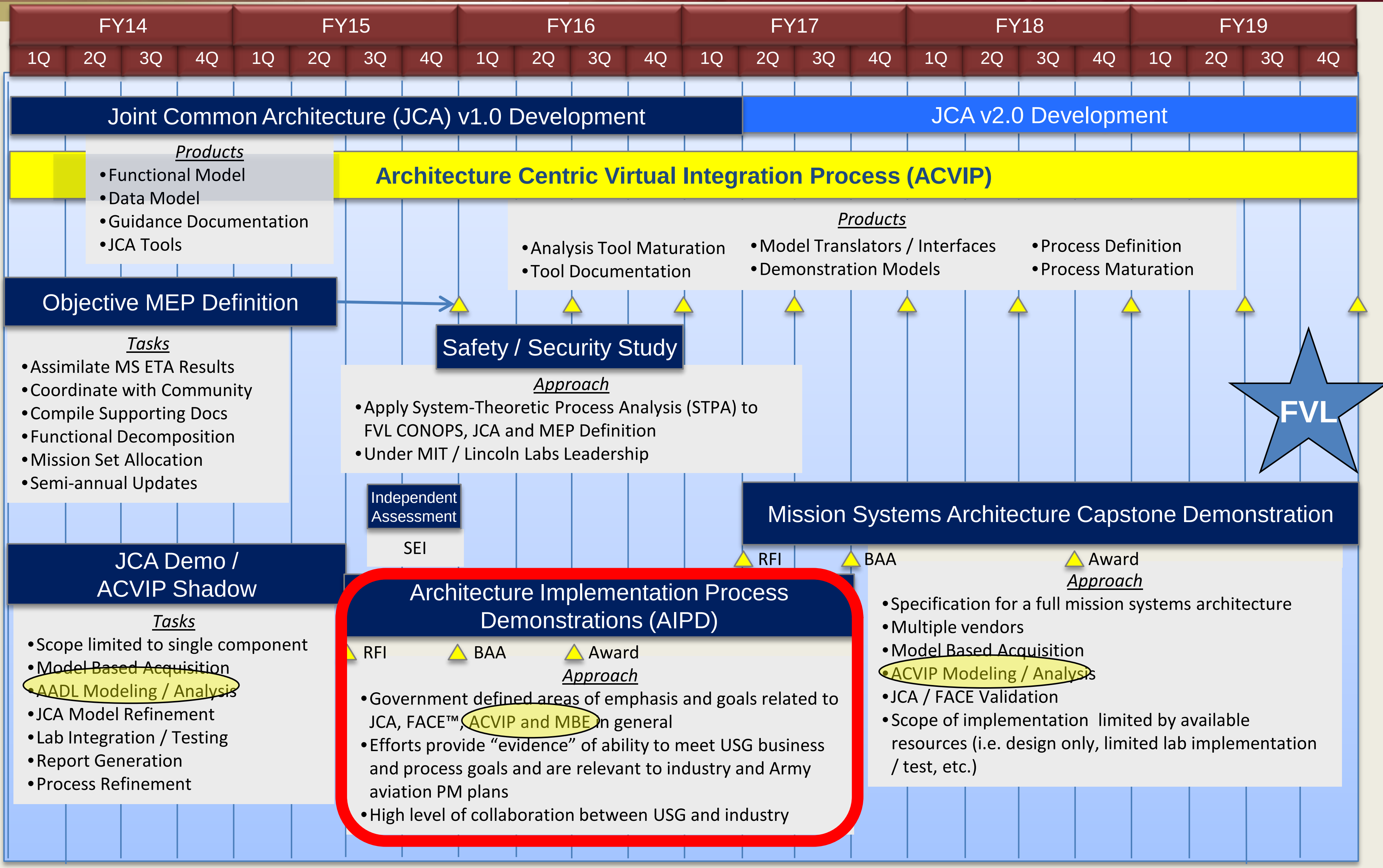
Architecture Centric Virtual Integration Process (ACVIP)



- Requires standardized architecture modeling language with well-defined semantics integrating hardware, software and systems
- Includes virtual, incremental, hierarchical, compositional analysis of a software-reliant system to evaluate integration effects
- Avoids the perpetuation of requirements defects into later phases of the development process enabling major rework cost reduction
- Increases assurance confidence by augmenting testing
- Enables rapid generative integration of the verified system
- Includes a “Single Source of Truth”
- Leverages the AVSI SAVI Project

Virtual Analysis & Integration of Software, Hardware, and Systems

Joint Multi Role (JMR) Mission Systems Architecture Demonstration (MSAD) Schedule



FY14 FY15 FY16 FY17 FY18 FY19

1Q 2Q 3Q 4Q 1Q 2Q 3Q 4Q 1Q 2Q 3Q 4Q 1Q 2Q 3Q 4Q 1Q 2Q 3Q 4Q 1Q 2Q 3Q 4Q

Joint Common Architecture (JCA) v1.0 Development

JCA v2.0 Development

Products

- Functional Model
- Data Model
- Guidance Documentation
- JCA Tools

Architecture Centric Virtual Integration Process (ACVIP)

Products

- Analysis Tool Maturation
- Tool Documentation
- Model Translators / Interfaces
- Demonstration Models
- Process Definition
- Process Maturation

Objective MEP Definition

Tasks

- Assimilate MS ETA Results
- Coordinate with Community
- Compile Supporting Docs
- Functional Decomposition
- Mission Set Allocation
- Semi-annual Updates

Safety / Security Study

Approach

- Apply System-Theoretic Process Analysis (STPA) to FVL CONOPS, JCA and MEP Definition
- Under MIT / Lincoln Labs Leadership

FVL

Independent Assessment

SEI

Mission Systems Architecture Capstone Demonstration

RFI BAA Award

Approach

- Specification for a full mission systems architecture
- Multiple vendors
- Model Based Acquisition
- ACVIP Modeling / Analysis
- JCA / FACE Validation
- Scope of implementation limited by available resources (i.e. design only, limited lab implementation / test, etc.)

JCA Demo / ACVIP Shadow

Tasks

- Scope limited to single component
- Model Based Acquisition
- AADL Modeling / Analysis
- JCA Model Refinement
- Lab Integration / Testing
- Report Generation
- Process Refinement

Architecture Implementation Process Demonstrations (AIPD)

RFI BAA Award

Approach

- Government defined areas of emphasis and goals related to JCA, FACE™, ACVIP and MBE in general
- Efforts provide "evidence" of ability to meet USG business and process goals and are relevant to industry and Army aviation PM plans
- High level of collaboration between USG and industry

JMR MSAD Role in ACVIP

- **ACVIP requires the processes and tools to be established and matured for effective use on Future Vertical Lift (FVL)**
- **ACVIP will be exercised, documented, applied and enhanced throughout the Mission System Architecture Demonstrations**
  - Definition, development and exercise of the ACVIP tools is initially performed by the tool developers
  - Application and evaluation is conducted during MSAD demos supporting maturation and technology transition

ACVIP Process &Tool Maturation

1. Define …2.Develop…3. Exercise …4. Document …5. Apply….6. Evaluate

|← JMR MSAD Demonstrations →|

Near Term MSAD Tasks related to ACVIP

- Develop First Edition ACVIP Handbooks
- AADL/ACVIP Training
- Provide tools for use during AIPD

ACVIP Implementation Vision

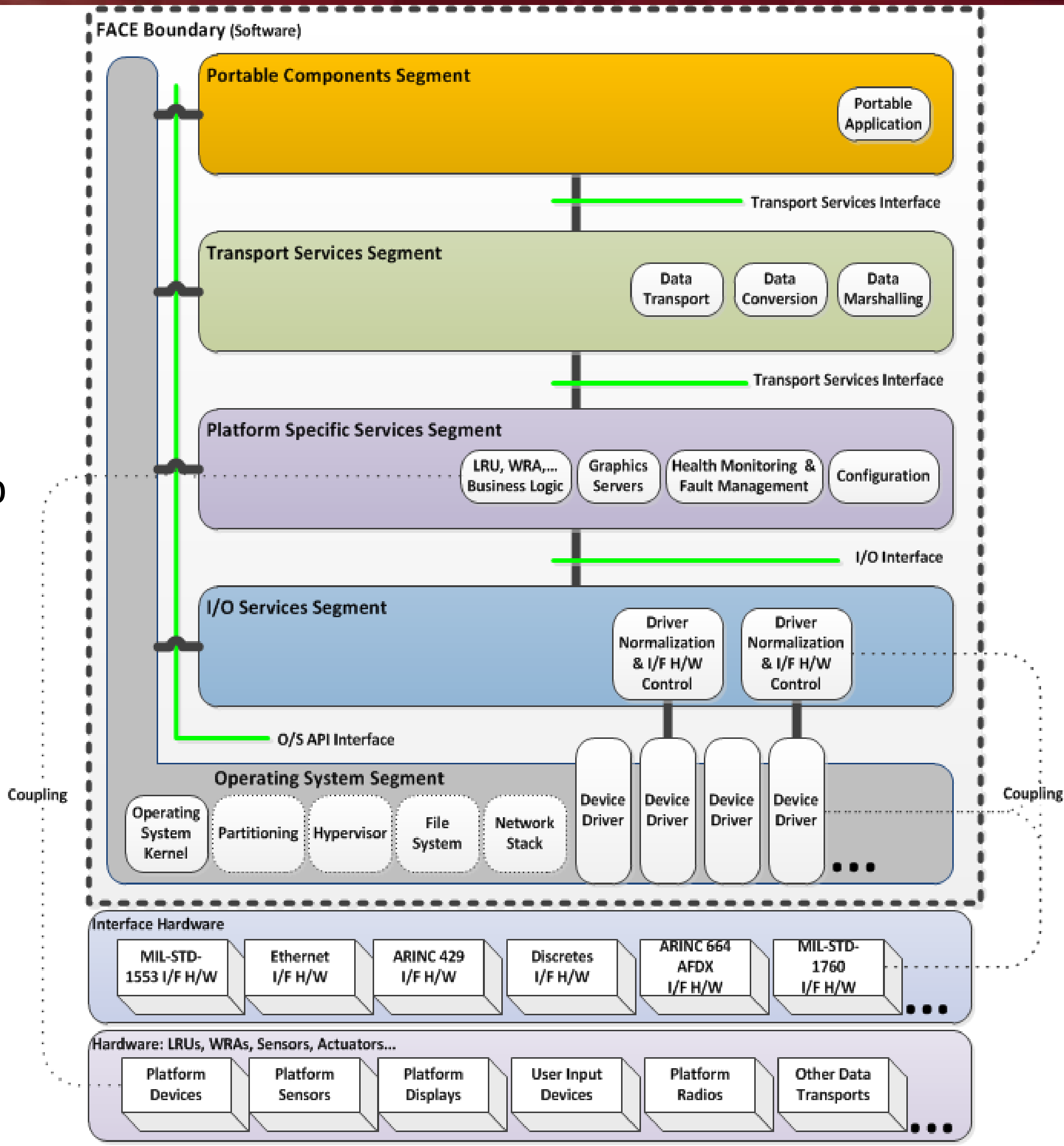
- **ACVIP as part of a Model Based Acquisition approach**
  - Model requirements in AADL and perform ACVIP analyses prior to solicitation for initial system architecture.
  - Systems architecture requirements specification model in solicitation and response.
  - Systems integrator communicates with component vendors via models.
- **Government's role in the development and analysis process**
  - Government sponsors independent analyses using architecture models.
  - Government requires receipt of architectural models in AADL and model ownership.
  - ACVIP analyses performed by contractor and Government during each architectural phase (functional, conceptual, design, integration).
- **Single source of truth**
  - Models will be used throughout the life-cycle and updated over time.
  - Will be used by multiple technical domains when performing analyses.
  - Models must be accurate, up-to-date, phase appropriate and integrated.
  - Distributed model repository for Government/integrator/supplier collaboration.
  - AADL used as the standard method of communication between tools and across organizations.

Communication of accurate information and virtual analysis is key

What is FACE ?

Future Airborne Capability Environment

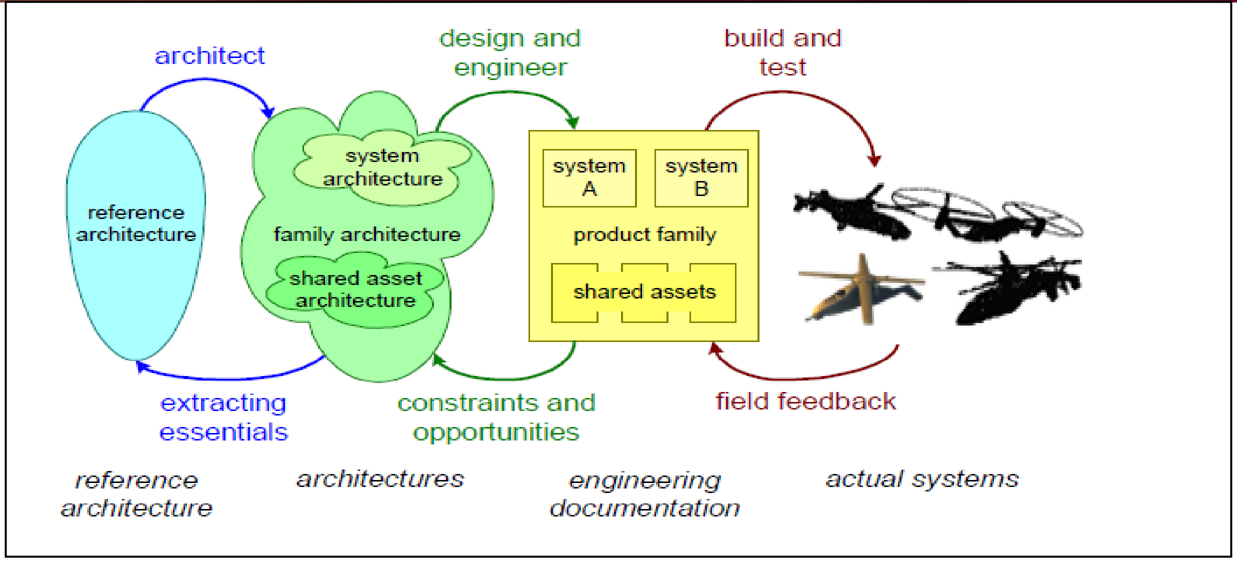
- Future Airborne Capability Environment (FACE™)
- Open standard established by DoD and Industry via The OpenGroup©
- The FACE™ architecture comprises points where variance occurs (i.e., layered architectural segments)
- A <u>SOFTWARE</u> computing environment to enable product lines for military aviation
- Eliminates barriers to software portability, prevents lock-in and improves competition
- Not only a technical standard but also includes a business strategy
- Includes:
  - Development Ecosystem
  - Conformance Test Suite
  - Verification & Certification
  - Repository



Learn more @ http://www.opengroup.org/face/face101

What is Joint Common Architecture (JCA)?

- **JCA is a Reference Architecture (not a system architecture) for FVL Family of Systems**
- ***JCA Guides and constrains* architecture implementations by providing:**
  - a common lexicon and taxonomy
  - a common (architectural) vision
  - modularization and the complementary context



- **JCA v1.0 describes conceptual avionics capabilities with specific focus on the Mission Computer (MC) subsystem**
- **JCA includes:** **Functional Model**
  - **Decomposed Mission Level Capabilities allocated to the MC subsystem and their top level organization and interactions**

  Semantic Model
  - **Conceptual level**
  - **Linked to Functional Model**

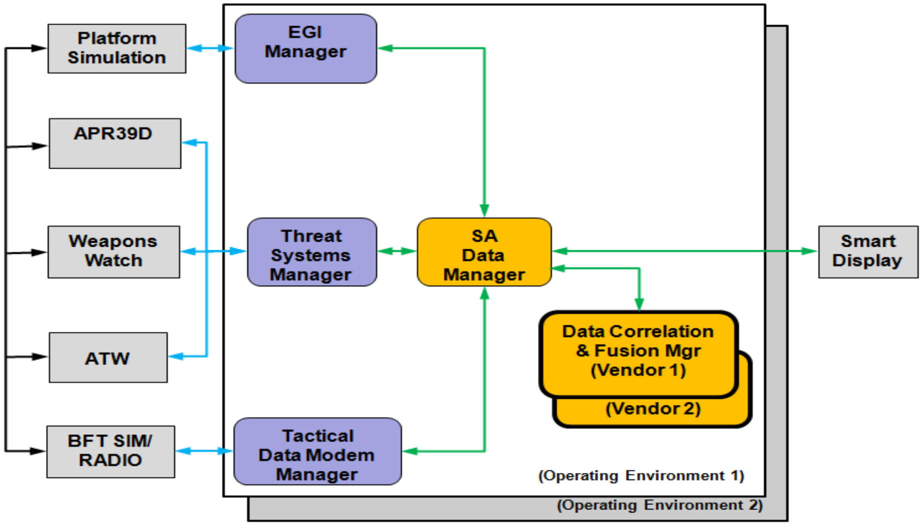
  Model Analysis
  - **Model representation in AADL allowing ACVIP type analysis**

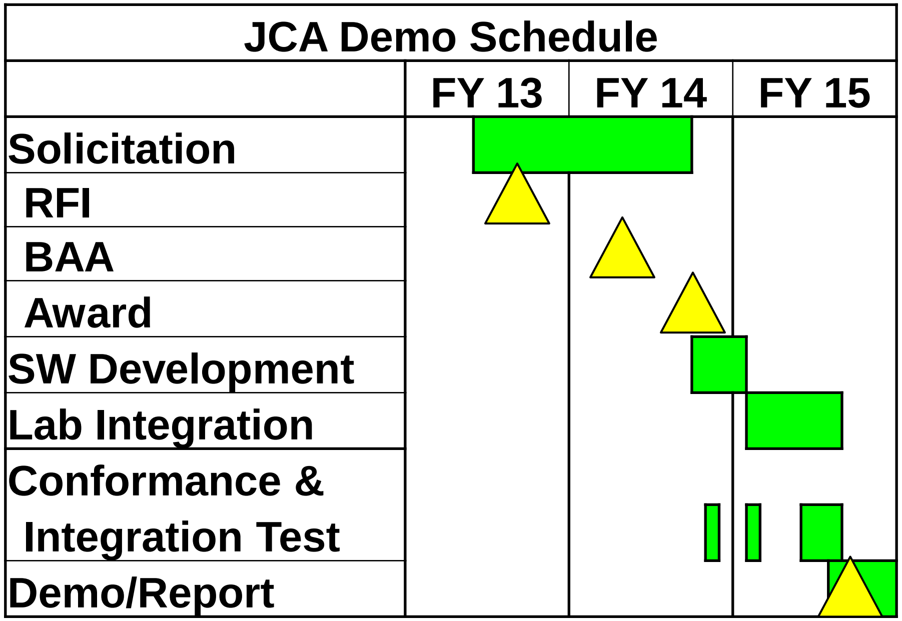
  Documentation
  - **Development Plan**
  - **Implementation Plan**

  Tools/Ecosystem
  - **Translation of the JCA v1.0 conceptual model into FACE v3.x conformant conceptual and logical models**
  - **JCA conformance**

JCA Demonstration Overview

Modular Integrated Survivability (MIS) System





Goals/Objectives

- Validate the JCA & FACE approaches
- Mature JCA, FACE Standard & Ecosystem tools, and business practices
- Gain experience implementing a model based approach (learn by doing)

Approach – Controlled Experiment

- Procure single software component from multiple vendors built to same specification
- Integrate component on two undisclosed Operating Environments (OEs)
- Execute a representative model-based acquisition approach
- Limit developers and integrator interactions
- Use FACE Ecosystem tools
- Exercise FACE Verification Authority process
- Procure a Reusable Verification Component
- Conduct a partial ACVIP as a Shadow Effort

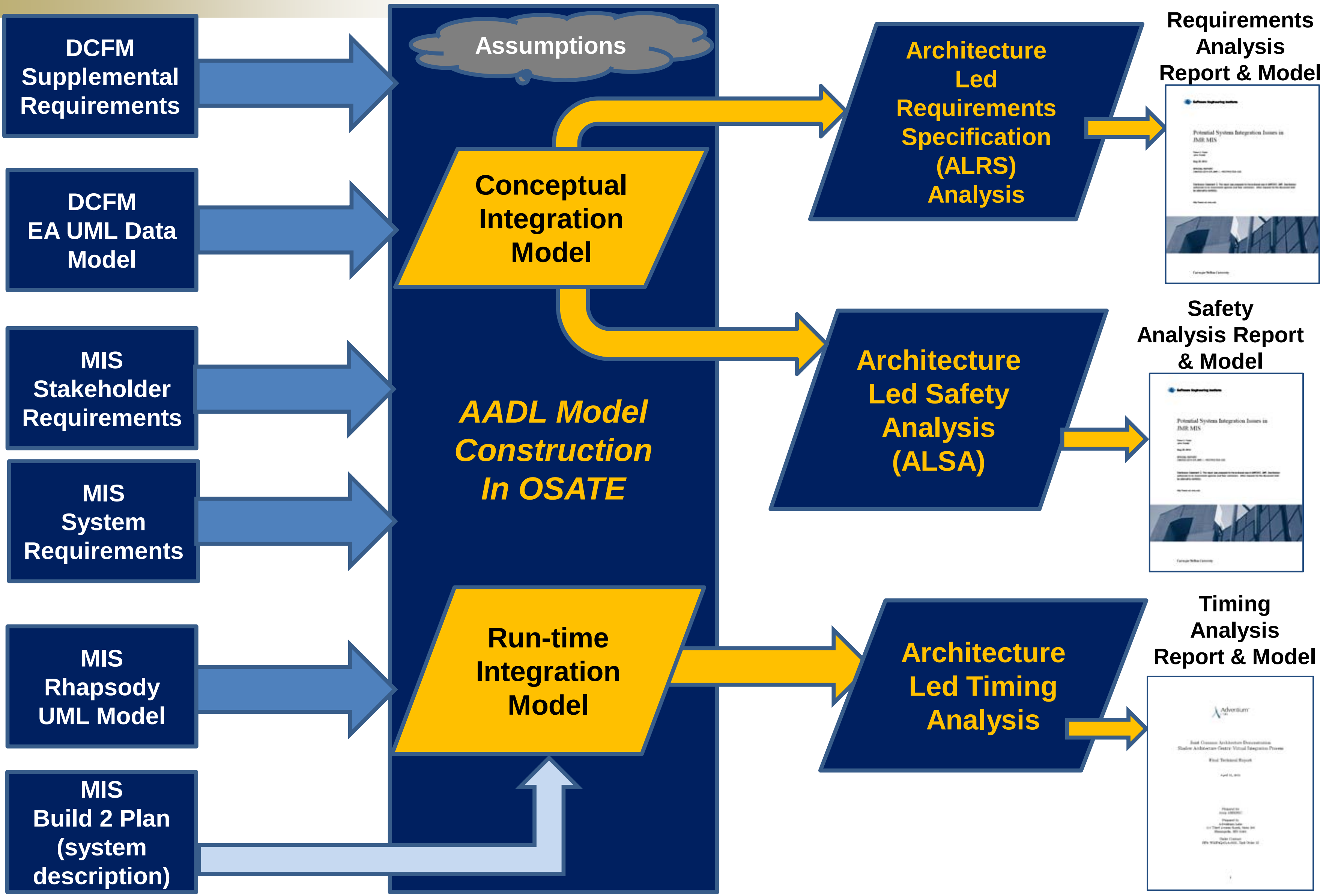
Payoff

- Reduces risk for future implementations
- Provide Government greater insight than from a typical acquisition

ACVIP Shadow Effort on JCA Demonstration

- **ACVIP Shadow Effort was performed by independent analysts from the Software Engineering Institute (SEI) of Carnegie Mellon University and Adventium Labs with information obtained from the component specification, component developers and system integrator. The purpose of the Shadow Effort was to:**
  - Gain experience with ACVIP
  - Demonstrate potential of ACVIP
  - Maturate Government-sponsored AADL tools
- **ACVIP was effective in the conduct of post-award analysis for:**
  - Requirements – checked for consistency, accuracy, completeness
  - Safety – identified potential safety hazards and safety assessment
  - Timing – analyzed adequacy of resource scheduling and partitioning
- **ACVIP Shadow effort did not demonstrate a representative ACVIP process; however, significant experience and results were obtained.**
  - Pre-solicitation requirements analysis would have reduced errors.
  - Models were not reused or integrated in a repository.
  - Analytical tools and processes were very immature.
  - Lack of accurate and/or complete information from DCFM developers and system integrator. Many assumptions had to be made.

ACVIP Process on JCA Demo



DCFM Supplemental Requirements

DCFM EA UML Data Model

MIS Stakeholder Requirements

MIS System Requirements

MIS Rhapsody UML Model

MIS Build 2 Plan (system description)

Assumptions

Conceptual Integration Model

AADL Model Construction In OSATE

Run-time Integration Model

Architecture Led Requirements Specification (ALRS) Analysis

Architecture Led Safety Analysis (ALSA)

Architecture Led Timing Analysis

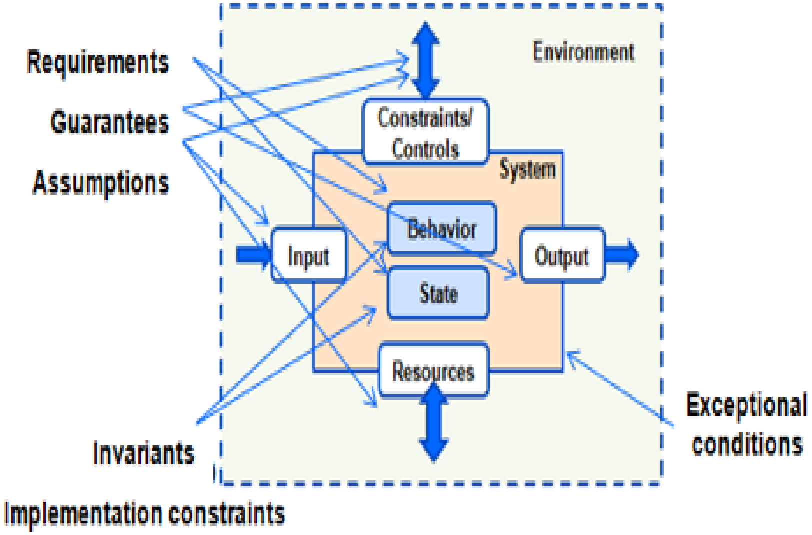
Requirements Analysis Report & Model

Safety Analysis Report & Model

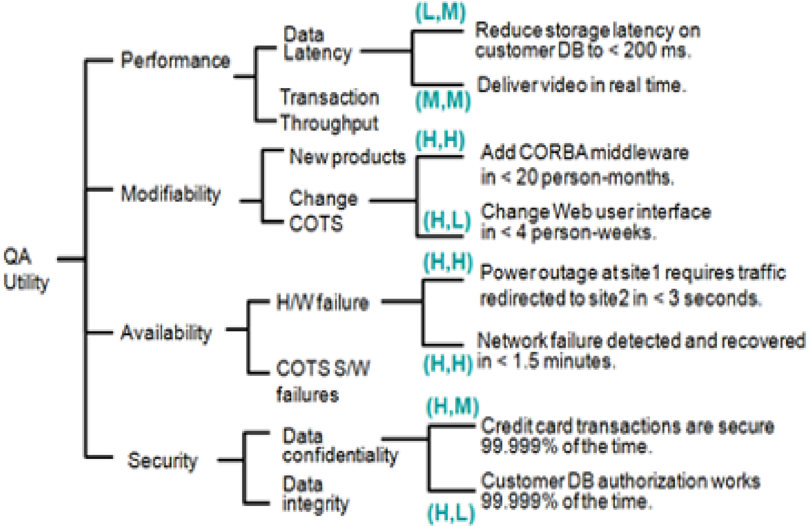
Timing Analysis Report & Model

Architecture Led Requirements Specification (ALRS) Analysis

- **Textual requirements results in:**
  - Ambiguous, missing, incomplete and inconsistent requirements.
  - Cost and schedule impacts due to error injected in the design
- **Solution:**
  - Represent verifiable requirements in an architecture model (based on AADL RDAL* Annex)
- **ALRS Analysis Process:**
  - Every element of a system specification must be addressed by requirements
  - Non-functional requirements are driven by utility trees as output of an ATAM**
  - Resulting annotated model is basis for Architecture-led Safety Analysis (ALSA)



EXAMPLE UTILITY TREE

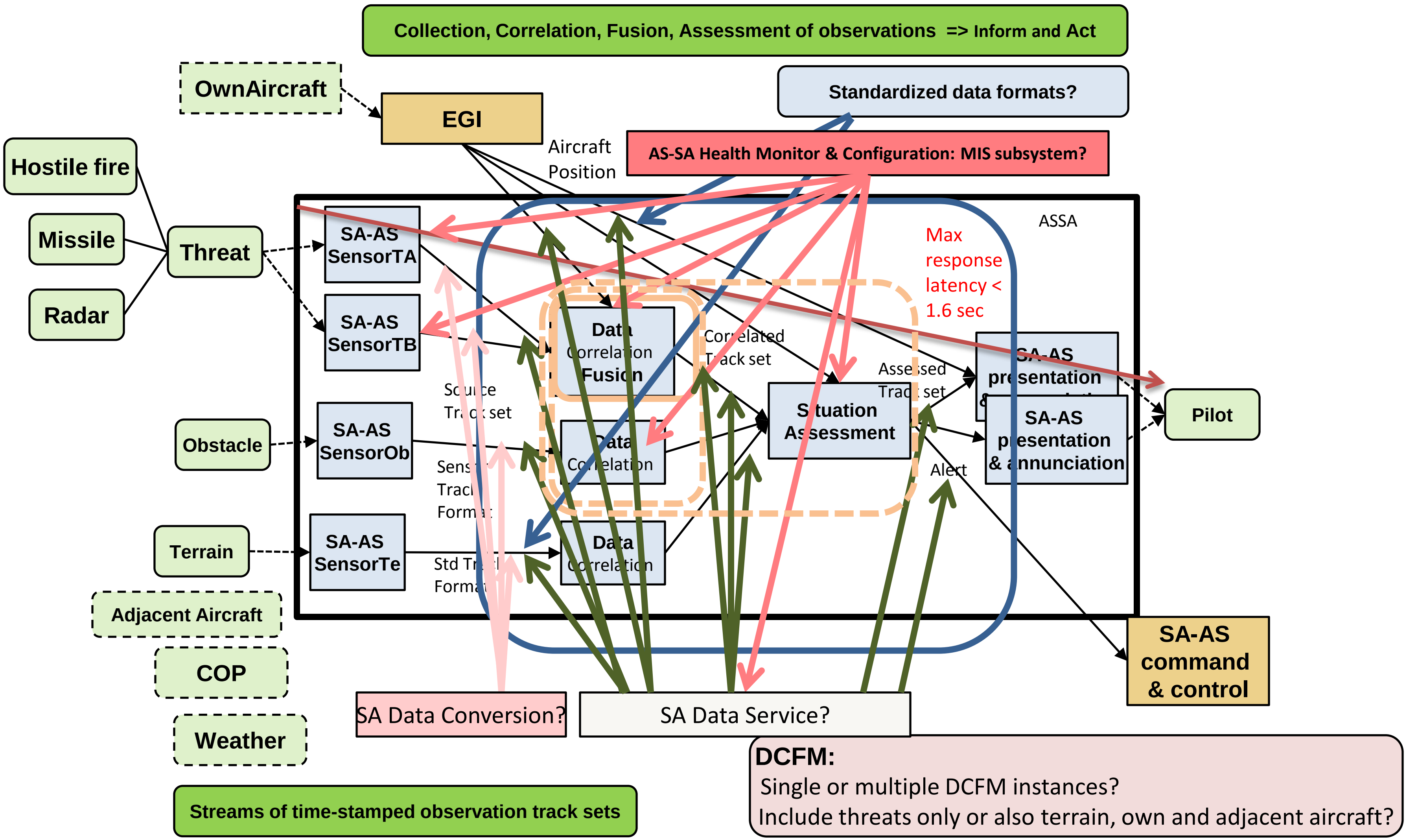

QA Utility
Performance
Data Latency
Transaction Throughput
(L,M)
Reduce storage latency on customer DB to < 200 ms.
(M,M)
Deliver video in real time.
Modifiability
New products
Change COTS
(H,H)
Add CORBA middleware in < 20 person-months.
(H,L)
Change Web user interface in < 4 person-weeks.
Availability
H/W failure
COTS S/W failures
(H,H)
Power outage at site1 requires traffic redirected to site2 in < 3 seconds.
(H,H)
Network failure detected and recovered in < 1.5 minutes.
Security
Data confidentiality
Data integrity
(H,M)
Credit card transactions are secure 99.999% of the time.
(H,L)
Customer DB authorization works 99.999% of the time.

* RDAL = Requirements Definition & Analysis Language

** ATAM = Architecture Tradeoff Analysis Method™

Architecture Led Requirement Specification (ALRS) on JCA Demo

Aircraft Survivability Situational Awareness System (ASSA) = DCFM Integrated with the MIS



Collection, Correlation, Fusion, Assessment of observations => Inform and Act

OwnAircraft

EGI

Standardized data formats?

Aircraft Position

AS-SA Health Monitor & Configuration: MIS subsystem?

Hostile fire

Missile

Radar

Threat

SA-AS SensorTA

SA-AS SensorTB

ASSA

Max response latency < 1.6 sec

Data Correlation Fusion

Correlated Track set

Assessed Track set

SA-AS presentation & annunciation

Pilot

Situation Assessment

Source Track set

Obstacle

SA-AS SensorOb

Sensor Track Format

Data Correlation

SA-AS presentation & annunciation

Alert

Terrain

SA-AS SensorTe

Std Track Format

Data Correlation

SA-AS command & control

Adjacent Aircraft

COP

SA Data Conversion?

SA Data Service?

Weather

DCFM:

Single or multiple DCFM instances?

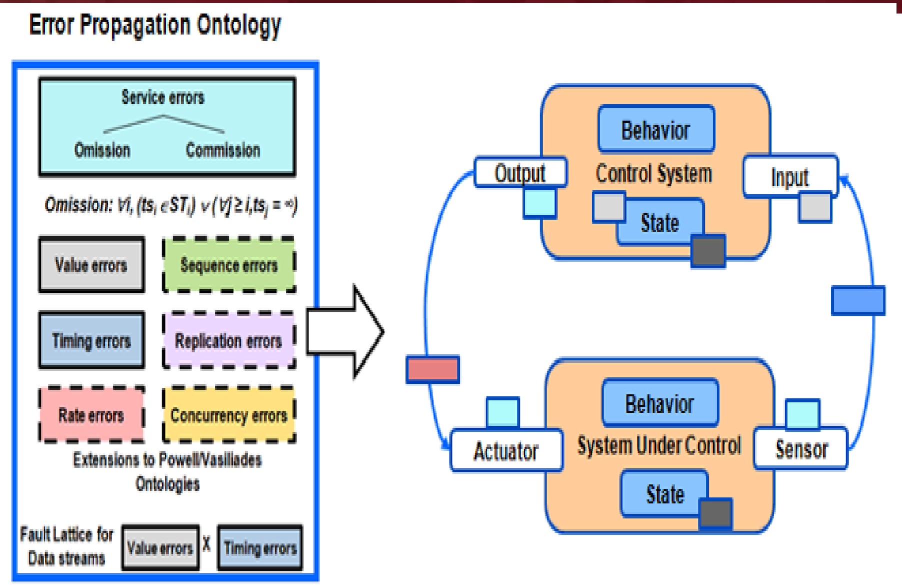
Include threats only or also terrain, own and adjacent aircraft?

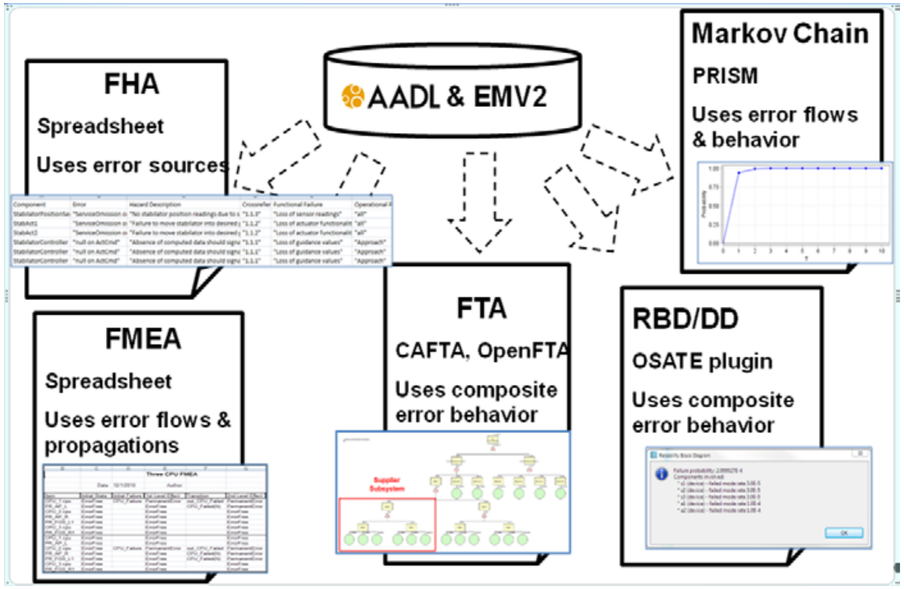
Streams of time-stamped observation track sets

SA Data Conversion & SA Data Service as two MIS subsystems

Architecture Led Safety Analysis (ALSA)

- SEI conducted a safety analysis of the JCA Demo system using ALSA
- ALSA based on the AADL Standard Error Model Ver 2 (EMV2) Annex
- EMV2 supports SAE ARP 4761
- An error propagation ontology guides identification of hazards
- Hazard annotations of AADL model lead to automated fault impact analysis and report generation
- ALSA extendible to security

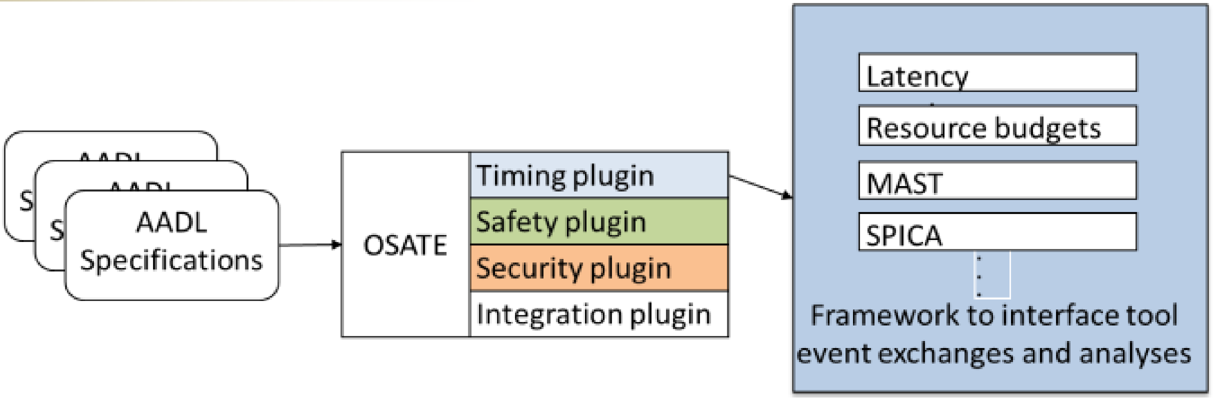



FHA
Spreadsheet
Uses error sources
AADL & EMV2
Markov Chain
PRISM
Uses error flows & behavior
FMEA
Spreadsheet
Uses error flows & propagations
FTA
CAFTA, OpenFTA
Uses composite error behavior
RBD/DD
OSATE plugin
Uses composite error behavior

Architecture Led Safety Analysis (ALSA) on JCA Demo

- **JCA Demo BAA assigned Design Assurance Level (DAL) E to DCFM, but:**
  - Aircraft are lost to operational threats, obstacles, and terrain.
  - Multiple minor hazard contributors can have catastrophic consequences.
  - Embedded software as major hazard source: unexpected interaction behavior.
- **SEI demonstrated the use of ALSA to assist in identifying the appropriate DAL for the system**
  - Identified critical areas related to the reporting of false positives, false negatives, untimely information.
  - Derived Health Monitoring System (HMS) requirements, clarifying expected functionality of the HMS.
  - Safety hazards introduced by health monitor.

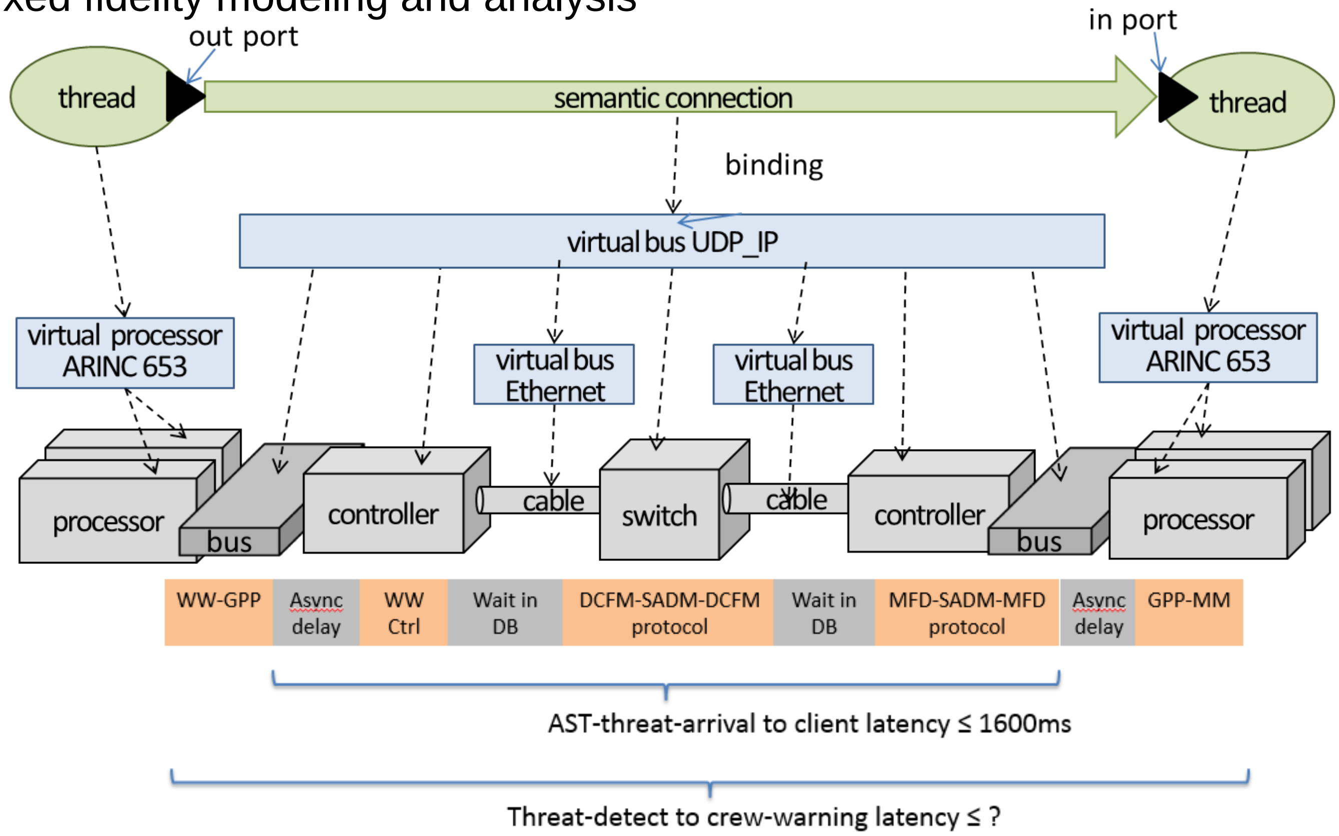
Architecture Led Timing Analysis (ALTA) Approach for JCA Demo



- **Challenge: analysis of end-to-end timing for distributed, multidisciplinary, heterogeneous computer systems**
  - Different scheduling on different network and processing nodes
  - Co-existence of sampled and event-driven processing of time sensitive information
- **Two approaches: simulation and schedulability analysis**
  - ACVIP Shadow focused on schedulability analysis
  - Survey identified 16 schedulability analysis tools
- **Adventium developed Framework of Schedulability, Timing and Resources (FASTAR)**
  - Integration of variable scheduled subsystems and end-to-end analysis
- **For JCA Demo FASTAR integrated the following two timing analysis tools:**
  - MAST: Modeling & Analysis Suite for Real-Time Systems for Switched Networks analysis
  - SPICA: Separation Platform for Integrating Complex Avionics for Partitioning analysis

Architecture Led Timing Analysis (ALTA) on JCA Demo

- **Functional Architecture Mapped to Hardware Architecture**
  - Identified system timing issues in layered hardware architecture
  - Hardware with different clock domains (e.g., Switched Ethernet & ARINC 653)
  - Unsynchronized compute module and the remote sensors
  - Mixed fidelity modeling and analysis



WW-GPP	Async delay	WW Ctrl	Wait in DB	DCFM-SADM-DCFM protocol	Wait in DB	MFD-SADM-MFD protocol	Async delay	GPP-MM

Significant ACVIP Analysis Findings on JCA Demo

- Unclear requirements between component states and MIS system state
- Missing specification of currency/staleness for the data and end-to-end timing requirement for hazard data
- Partition schedule did not meet ARINC 653 scheduling rules
- Non-clarity in protocol from MIS to support single or multiple DCFM instantiations
- Absence of data storage requirements between the DCFM and MIS
- Ambiguity of MIS system Operational State when a clock timer expires
- Missing source track quantity requirements for the aircraft survivability sensor
- Potential for track jitter
- Multiple sensor stream rates could create potential issues and requires further analysis
- Disagreement in threat thresholds between the DCFM and MIS
- Lack of memory requirements in MIS that could lead to memory leaks
- Ambiguity in the requirement to correlate 50 source tracks within 1 second

86 potential issues were elicited by ACVIP

ACVIP Lessons Learned on JCA Demo

- Process of modeling the architecture alone can uncover requirement issues
- Value in performing Architecture Led Requirement Specification analysis
- Accurate system information is required for valid analysis
- Translation between AADL and other modeling languages would reduce ambiguity and improve communication
- Metrics for measuring ACVIP effectiveness are lacking
- Additional timing analysis tools need to be added to FASTAR to address a broader range of timing issues.
- AADL training proved beneficial
  - Provided government personnel with insight into AADL modeling
  - Created interest with industry

Conclusions from JCA Demo ACVIP Shadow Effort

- Performing ACVIP analysis prior to the release of BAA would have been beneficial to overall program execution.
- ACVIP analyses could reduce error perpetuation from requirements phase to system integration & test.
- Many of the ACVIP tools are currently immature.
- Demonstrations can identify, validate, mature and transition methods and tools to support ACVIP.
- ACVIP must transition from execution by tool developers to Government and industry personnel.
- A full ACVIP needs to be exercised in a demonstration in order to understand the complete value of ACVIP.

JCA Demo ACVIP Shadow was successful in providing the Government with experience and validating the ACVIP concept.

Author Biographical Sketch

- **Alex Boydston is an electronics engineer working mission systems and architecture demonstrations for the US Army Aviation Development Directorate at Redstone Arsenal for the Joint Multi Role science and technology program to support the joint services Future Vertical Lift initiative. Alex has a Bachelor of Science and a Master of Science degrees in electrical engineering from the University of Alabama in Huntsville. Alex has over 25 years of engineering experience working for organizations such as Teledyne Brown Engineering as an communications systems engineer on the National Missile Defense program, payload systems integrator for NASA shuttle and station programs, AdTran Corporation as a embedded systems product design and test engineer, and Draper Laboratory and the U.S. Army as an avionics engineer.**

JMR
JOINT MULTI-ROLE
TECH DEMO