Aerospace Vehicle Systems Institute

SAVI Support of DoD Architecture Centric Virtual Integration

System Architecture Virtual Integration Program

Dr. David Redman, Dr. Don Ward  AVSI
Mr. Martin Walsh  ADD/AMRDEC, RDECOM
Mr. Bruce Lewis  SED/AMRDEC, RDECOM

NDIA Systems Engineering Conference  30 October 2014

“DISTRIBUTION STATEMENT A. Approved for public release.”
Agenda

• Motivation for Virtual Integration
• AVSI and the SAVI Program
• DoD Participation in SAVI
• The JMR TD/MSAD Program
• Conclusion / Q&A
MOTIVATION FOR VIRTUAL INTEGRATION
Systems Are Becoming More Complex

Estimated Onboard SLOC Growth

Slope: 0.1778 Intercept: -338.5
(commercial airliners only)
Curve implies SLOC doubles about every 4 years

This line fit is pegged at 27.5 M SLOC because the SLOC sizes for 2010-2020 are not affordable. The COCOMO II estimated costs to develop that much software is in excess of $10B

Airbus data source: J. P. Potocki De Montalk, “Computer Software in Civil Aircraft,” Sixth Annual Conference on Software Assurance (Compass ‘91), Gaithersburg, MD, June 24-27, 1991
Boeing data source: J. J. Chilenski, 2009
The impact is documented

High-level Design
RFP Response

PDR

Req’s Changes

CDR

System Integration Checks

Target Completion

High-level Req’s in RFP

 Trades

 Req’s Defined

 Sys Design

 Detailed Design

 Sys Re-Design

 Sys Development

 Sys Integration

 V&V

70% errors
3.5% detect
1x cost

10% errors
80% detected
16-100x cost

500-1000x (INCOSE 2011)
Current means of managing complexity have issues

- Operational Models
- System Models
- Component Models
- Functional/Behavior Model
- Performance Model
- Structural/Component Model
- Cost Model
- Safety Model
- Security Model
- Reliability Model
- Maintainability Model
- Structural Model
- Mass Production Model
- Manufacturing (Assembly) Models

Indeterminate Change Impact

Incompatible Abstractions

Multiple Truths

Modeling Domains
- Ops/Mission Analysis
- System Design
- Algorithm Development
- Hardware Design
- Software Design
- Logistics Support
- Manufacturing Integration & Test
- Performance Simulation Engineering Analysis
- Human System Integration

System Architecture Model (Integration Framework)
- Analysis Models
- Hardware Models
- Software Models
- Verification Models
The Problem Affects Everyone

• Integration complexity will continue to increase
• Current solutions are insufficient
• Individual companies cannot solve it alone
• Industry cannot afford to solve it multiple times
• We can’t afford not to solve it

A coordinated, industry-wide effort is needed to solve this issue.
THE SYSTEM ARCHITECTURE
VIRTUAL INTEGRATION PROGRAM
# The Aerospace Vehicle Systems Institute

## Full Members
- Airbus
- Boeing
- DoD
- Airbus Group
- Embraer
- GE Aviation
- Honeywell
- Rockwell Collins
- Rolls Royce
- Saab
- United Technologies

## Liaison Members
- FAA
- NASA
- Aerospace Valley
- SEI

## Associate Members
- ATI Wah-Chang
- BAE Systems
- Lockheed Martin
- Rafael D. S.
- SAES-Getters

## Motivation
- AVSI & SAVI
- DoD & SAVI
- JMR

<table>
<thead>
<tr>
<th>Status</th>
<th>Member</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current SAVI member</td>
<td>ActiveForm Systems</td>
</tr>
<tr>
<td>Joining SAVI now</td>
<td>Boeing</td>
</tr>
<tr>
<td>Discussing joining SAVI</td>
<td>Embraer</td>
</tr>
<tr>
<td>Participated earlier in SAVI</td>
<td>United Technologies</td>
</tr>
</tbody>
</table>
SAVI Goals and Approach

• SAVI target/goals (summary)
  – Reduce costs/development time through early and continuous model-based virtual integration
    • Distributed inter-domain/inter-model consistency checks throughout development - (start integrated, stay integrated)
    • Protect intellectual property (IP)
    • Capture incremental evidence for safety analysis and for certification Approach
  – Capture Requirements and Use Cases that define the following:
    • SAVI Data Exchange Layer
    • SAVI Model Repository
    • SAVI Virtual Integration Process (VIP)
    • SAVI distributed inter-domain/inter-model dependencies and consistency checks
SAVI Objective and Themes

• Reduce costs/development time through early and continuous model-based virtual integration
  - **Shift** to new paradigm – integrated models rather than documents
    • Systems engineering in cross-domain context
    • Models provide basis for improvements
    • Models promote consistency – “absence of contradictions”
  - **Architecture-centric approach** – start with models, but more
    • Meld with requirements for traceability
    • Facilitate trade studies
  - **Virtual Integration** – early and continuous integrated analysis
    • Proof-based (consistency checked – but not all with formal models)
    • Component-based (hierarchical models)
    • Model-based (annotated models)

*Integrate, analyze ... then build*
Inter-Model Consistency

Dependencies Are Key

The SAVI Repository stores the links

When an element is changed, links and relationships are traced to find affected elements

Industry wide, 50% of requirements will change between CDR & delivery into service

The SAVI Repository stores the links
SAVI Virtual Integration “Vee”

Sensitivity analysis for uncertainty

Confidence in implementation

Keeping the system continuously integrated!

Top-Level Verification Items

Requirements Engineering

High-level ADL Model

System Design

Detailed ADL Model

Hardware Architectural Design

Specify Model-Code Interfaces

Software Architectural Design

Hardware Development

Component Hardware Design

Software Development

Component Software Design

Flowchart is inside each of these triangles

Model-driven artifact generation

Compliance of models and systems

Integration Test

SW Int. Test

HW Int. Test

Validation

Confidence in implementation

Acceptance Test


generation of test cases

updating models with actual data


detailed model - SPECIFIC IMPLEMENTATION

Specifications & Code Interfaces
AVSI
INITIAL VIP CAPABILITY
VERSION 1.0A - 2013
WBS Safety Analysis

• Selected as a pathfinder/demonstration for SAVI analysis
  – Existing “S-18 Aircraft” wheel braking system (WBS) in Aerospace Information Report (AIR) 6110
  – Example of 4754A development process and supporting 4761 safety analysis
  – Specific focus on WBS PSSA within process flow

• Highlight the iterative design process
  – First safety evaluation
  – Refinement through system development

• Enable trade-studies incorporating safety

• Use of commercial and open-source tools
  – Industry standard or low/no cost tools and capabilities in SAVI infrastructure
AFE 61 Model Overview

• The model set for the AFE 61 WBS PSSA consists of five models for the simplified WBS
  – A set of requirements from AIR 6110 (Spreadsheet)
  – A Publisher/Subscriber model forming the basis for an ICD later in the project (Spreadsheet)
  – A SysML model documenting the architecture at the beginning of the project (Enterprise Architect, SCADE System)
  – An AADL model documenting the refined (final) architecture model at the end of the project (OSATE)
    • Along with the associated Error Model supporting the automated safety analyses
  – A solid geometry model documenting the location of components in 3-space (Solidworks, NX)
Inter-Model Consistency Checks

Solid models

- BSCU
- Hyd power supply
- Accumulator

Functional Models
(AADL – SysML)

Motivation
AVSI & SAVI
DoD & SAVI
JMR
Automation of Safety Analysis Practice

• Use of Error Model EMV2 and ARINC653 annexes
  – Relevance for the avionics community

• Comparative architecture trade study
  – Federated vs. Integrated Modular Avionics (IMA) architecture

• Support of SAE ARP 4761 System Safety Assessment Practice
  – Hazards (FHA), Fault Trees (FTA), Fault Impact (FMEA)
  – Reliability/Availability Markov Analysis (MA)/Dependence Diagram (DD)
AFE 61S1 (2014) Use Cases

• Printed Circuit Board Interconnect
  – Prove physical implementation matches (is consistent with) the logical design (schematic)
  – Demonstrate use of PLCS data model for cross-domain consistency

• Future: expand use case to include wiring harnesses
**AFE 61S1 (2014) Use Cases**

- **Autobrake/antiskid enabled**
  - Multiple communicating state machines
  - Multiple communicating control laws

- **Electro-mechanical braking system**
  - Adds multi-physics simulation models to the mix

- **Develop behavioral modeling capability**
Collaboration is Central to SAVI

A coordinated, industry-wide effort is needed to solve this issue.

Motivation AVSI & SAVI

DoD & SAVI

JMR
Sustained Efforts Toward Architecture Centric System Development

DoD / SAE Development

- MetaH
- DARPA DSSA program
- DoDAF V1.0
- SAE AS5506 – AADL V1.0
- DoDAF V1.5
- DoDAF V2.0
- SAE AS5506A
- SAE AS5506B AADL V2.0

Other Efforts

- European, Consortia, Tools, Standards
- ASSET
- TOPCASED
- SysML V1.0a
- PLCS/ISO 10303-239 V1.0
- OMG V1.0
- OMG V1.0
- OMG V1.3
- CRYSTAL
- JMR
- ERS
- System 2020

SAVI PROJECTS

- Proof of Concept
- SAVI 1.0
- DoD Joins SAVI

Just these European Programs represent an investment of > $220M
JMR TD Mission Systems
Architecture Demonstration (MSAD)

- Background: It is too early to design a mission equipment package (MEP) or mission systems architecture for FVL
- Objective: Provide FVL development with the tools, information and processes necessary to design and implement a mission system suite that is effective and affordable
- Approach: Develop and validate new approaches through:
  - Analysis
  - Modeling and Simulation
  - Laboratory instantiation and test
- Products for transition to FVL
  - Standards
  - Processes
  - Tools

Focuses on concepts, tools and processes, not an objective design for an FVL MEP or architecture
The Mission Systems Architecture Demonstration (MSAD) consists of a series of increasing complex demonstrations directly relevant to FVL implementation.

Investigate the challenges related to implementing a mission systems architecture for FVL:
- Safety & Airworthiness Certification
- Security Certification
- Reliability
- Commonality
- Resiliency

Determine the best ways of overcoming the challenges using existing and emerging technologies and methodologies.
- Open Systems Architecture (OSA)
- Model Based Systems Engineering (MBSE)
- Architecture Centric Virtual Integration Process (ACVIP)

Demonstrate the utility of the technologies and methodologies and invest in enhancements / maturation.

Define processes for implementing the technologies and methodologies across development community (fleet manager, PM, requirements generator, certifier, systems integrator, component developers, etc.).

Provide FVL with the guidance and infrastructure to succeed.
### MSAD Schedule

####FY14 - FY19

<table>
<thead>
<tr>
<th>Year</th>
<th>1Q</th>
<th>2Q</th>
<th>3Q</th>
<th>4Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY14</td>
<td>1Q</td>
<td>2Q</td>
<td>3Q</td>
<td>4Q</td>
</tr>
<tr>
<td>FY15</td>
<td>1Q</td>
<td>2Q</td>
<td>3Q</td>
<td>4Q</td>
</tr>
<tr>
<td>FY16</td>
<td>1Q</td>
<td>2Q</td>
<td>3Q</td>
<td>4Q</td>
</tr>
<tr>
<td>FY17</td>
<td>1Q</td>
<td>2Q</td>
<td>3Q</td>
<td>4Q</td>
</tr>
<tr>
<td>FY18</td>
<td>1Q</td>
<td>2Q</td>
<td>3Q</td>
<td>4Q</td>
</tr>
<tr>
<td>FY19</td>
<td>1Q</td>
<td>2Q</td>
<td>3Q</td>
<td>4Q</td>
</tr>
</tbody>
</table>

####JCA V1.0 Development

**Products**
- Behavior Model
- Data Model
- Guidance Documents
- JCA Revs to FACE Tools

**Tasks**
- Assimilate MS ETA Results
- Coordinate with Community
- SME Support
- Update MPS
- Compile Supporting Docs
- Semi-annual Updates

####Baseline Objective MEP Def.

**Tasks**
- Assimilate MS ETA Results
- Coordinate with Community
- SME Support
- Update MPS
- Compile Supporting Docs
- Semi-annual Updates

####JCA Demo / ACVIP Shadow

**Tasks**
- Source Selection
- AADL Modeling
- JCA Model Refinement
- Lab Integration / Testing
- Report Generation
- Process Refinement

####JCA Sustainment

**Products**
- Analysis Tools
- Demo Models
- Model Translators / Interfaces
- Notional FVL Requirements Model

**Focus Areas**
- JCA / ACVIP Maturation
- Model Based Approaches
  - Single Truth Model
  - Model Based Systems Eng (MBSE)
  - Model Based Acquisition
- Infrastructure Technologies
  - Multi-core processors
  - High speed databuses (e.g., Fiber, Wireless)
  - Deterministic protocols (e.g., TTP)
  - VPI/VPX
- Focus Areas
- Safety & Airworthiness Certification
- Security Certification
- Reliability
- Commonality
- Resiliency, Fault Tolerance, FDIR
- Availability

####Architecture Centric Virtual Integration Process (ACVIP)

**Products**
- Analysis Tools
- Demo Models
- Model Translators / Interfaces
- Notional FVL Requirements Model

####Architecture Integration Process Demonstrations

**Focus Areas**
- JCA / ACVIP Maturation
- Model Based Approaches
  - Single Truth Model
  - Model Based Systems Eng (MBSE)
  - Model Based Acquisition
- Infrastructure Technologies
  - Multi-core processors
  - High speed databuses (e.g., Fiber, Wireless)
  - Deterministic protocols (e.g., TTP)
  - VPI/VPX
FVL DOD Organization

FVL Executive Steering Group

FVL Joint Council of Colonels

S&T IPT
(Led by Army AMRDEC)

Commonality IPT
(Led by Navy PEO-A)

Joint Service Participation

Requirements IPT
(Led by USAACE CEAD)

Acquisition IPT
(Led by Army PEO AVN)

Vertical Lift Consortium
(formerly Center for Rotorcraft Innovation)
Non-Profit
Vertical Lift Consortium Mission/Membership

**Mission:** Work collaboratively...to develop and transition innovative vertical lift technologies to rapidly and affordably meet warfighter needs.

**Large Contractor**
- EADS North America
- Northrop Grumman Corporation
- Raytheon

**Large OEMs**
- Bell Helicopter
- Lockheed Martin Corporation
- Sikorsky Aircraft Corporation
- The Boeing Company

**Supplier**
- D-Strut
- Dynetics, Inc.
- Galorath
- Honeywell
- Howell Instrument
- Lord Corporation
- Precision Gear, Inc.
- PRICE Systems LLC
- SELEX Galileo
- United Technologies Aerospace Systems
- United Technologies Research Center (UTRC)

**Non-Traditional Contractor**
- Altair Engineering
- Blue Force Technologies
- Clausewitz Technology
- duPont Aerospace Company, Inc.
- EMTEQ
- Groen Brothers Aviation Global
- MD Helicopters
- Modus Aircraft
- Parker Ostovich & Associates
- Peduzzi Associates, Ltd.
- RMCI

**Small VTOL R&D**
- Acellent Technologies
- Advanced Optical Systems
- Advanced Rotorcraft Technology
- AVID LLC
- AVX Aircraft Company
- Clockwork Solutions LLC
- Continuum Dynamics, Inc.
- Karem Aircraft, Inc.
- Mide Technology Corp.
- Piasecki Aircraft Corp.
- Saddle Butte Systems, LLC
- Sentinent Corporation
- Texas Research Institute Austin, Inc.

**Engine**
- Advanced Turbine Engine Company
- GE Aviation
- Pratt & Whitney
- Rolls-Royce Corporation

**Academic/Non-Profit**
- Georgia Institute of Technology
- The Ohio State University
- The Pennsylvania State University
- University of Alabama in Huntsville
- University of Illinois at Chicago
- University of Maryland
- University of Michigan
- University of Notre Dame
- University of South Carolina
- University of Tennessee
- University of Texas - Arlington

**AHS**
- AHS International

[www.verticalliftconsortium.org]
SAVI Aligns with DoD Objectives

**Systems 2020**
- DEVELOP FAST: 3x reduction in time to acquisition
- FLEXIBLE: 4x reduction in time to update
- ADAPTABLE: intrinsic mission adaptability

**Engineered Resilient Systems**
- Informed Decision Making
- Trustworthy and Adaptable Design
- Affordable and Timely

**FACE**
- Standard COE to support portable applications across DoD avionics systems
- Reduce life cycle costs and time to field
- Facilitate conformance with standards to maximize interoperability

**JMR TD / MSAD**
- Provide FVL development with the tools, information and processes necessary to design and implement a mission system suite that is effective and affordable

- Reduce rework through virtual integration
- Architecture-centric enables patterns and reuse
- Enhanced trade space for analysis of potential architectures for metrics such as adaptability

- Manage dependencies for consistency and change impact
- Reduce time and schedule by reducing rework

- Leverage best practices and existing standards
- Standards-based Virtual Integration Process
- Architecture-centric, semantically precise models to enable quantitative systems analyses

- Tool agnostic to leverage domain-specific expertise and sunk investment in tools
- Standards-based Virtual Integration Process to promote broad adoption and interoperability throughout the supply chain
Questions?

Contacts:

Dr. Don Ward
Office: (979) 862-2316
Mobile: (979) 218-2272
dredman@avsi.aero

Dr. Dave Redman
Office: (979) 862-2316
Mobile: (979) 218-2272
dredman@avsi.aero

http://www.avsi.aero
http://savi.avsi.aero
References

**System 2020:**


**FACE**


**ERS**

# List of Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AADL</td>
<td>Architecture Analysis and Design Language</td>
</tr>
<tr>
<td>ACVIP</td>
<td>Architecture-Centric Virtual Integration Process</td>
</tr>
<tr>
<td>ADL</td>
<td>Architecture Description Language</td>
</tr>
<tr>
<td>AFE</td>
<td>Authority for Expenditure</td>
</tr>
<tr>
<td>AIR</td>
<td>Aerospace Information Report</td>
</tr>
<tr>
<td>AMRDEC</td>
<td>Aviation and Missile Research Development and Engineering Center</td>
</tr>
<tr>
<td>ARINC</td>
<td>Aeronautical Radio, Incorporated</td>
</tr>
<tr>
<td>ARP</td>
<td>Aerospace Recommended Practice</td>
</tr>
<tr>
<td>ASSERT</td>
<td>Automated proof-based System and Software Engineering for Real-Time applications</td>
</tr>
<tr>
<td>AutoSAR</td>
<td>AUTomotive Open System ARchitecture</td>
</tr>
<tr>
<td>AVSI</td>
<td>Aerospace Vehicle Systems Institute</td>
</tr>
<tr>
<td>BSCU</td>
<td>Brake System Control Unit</td>
</tr>
<tr>
<td>CDR</td>
<td>Critical Design review</td>
</tr>
<tr>
<td>COE</td>
<td>Common Operating Environment</td>
</tr>
<tr>
<td>CRESCENDO</td>
<td>Collaborative and Robust Engineering using Simulation Capability Enabling Next Design Optimisation</td>
</tr>
<tr>
<td>CRYSTAL</td>
<td>CRitical sYSTem engineering AcceLeration</td>
</tr>
<tr>
<td>DARPA</td>
<td>Defense Advanced Research Projects Agency</td>
</tr>
<tr>
<td>DoD</td>
<td>Department of Defense</td>
</tr>
<tr>
<td>DoDAF</td>
<td>Department of Defense Architecture Framework</td>
</tr>
<tr>
<td>DSSA</td>
<td>Domain-Specific Software Architecture</td>
</tr>
<tr>
<td>EMV2</td>
<td>Error Model annex Version 2</td>
</tr>
<tr>
<td>ERS</td>
<td>Engineered Resilient Systems</td>
</tr>
<tr>
<td>ESA</td>
<td>European Space Agency</td>
</tr>
<tr>
<td>FAA</td>
<td>Federal Aviation Administration</td>
</tr>
<tr>
<td>FACE</td>
<td>Future Airborne Capability Environment</td>
</tr>
<tr>
<td>FHA</td>
<td>Functional Hazard Assessment</td>
</tr>
<tr>
<td>FMEA</td>
<td>Failure Modes and Effects Analysis</td>
</tr>
<tr>
<td>FTA</td>
<td>Fault Tree Analysis</td>
</tr>
<tr>
<td>FVL</td>
<td>Future Vertical Lift</td>
</tr>
<tr>
<td>HW</td>
<td>Hardware</td>
</tr>
<tr>
<td>ICD</td>
<td>Interface Control Document</td>
</tr>
<tr>
<td>IMA</td>
<td>Integrated Modular Avionics</td>
</tr>
<tr>
<td>INCOSE</td>
<td>International Council on Systems Engineering</td>
</tr>
<tr>
<td>IP</td>
<td>Intellectual Property</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>JCA</td>
<td>Joint Capability Area</td>
</tr>
<tr>
<td>JMR TD</td>
<td>Joint Multi Role Technology Demonstrator</td>
</tr>
<tr>
<td>MBSE</td>
<td>Model Based Systems Engineering</td>
</tr>
<tr>
<td>MEP</td>
<td>Mission Equipment Package</td>
</tr>
<tr>
<td>MoSSEC</td>
<td>Modelling and Simulation in Collaborative Systems Engineering Context</td>
</tr>
<tr>
<td>MSAD</td>
<td>Mission Systems Architecture Demonstration</td>
</tr>
<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
</tr>
<tr>
<td>NDIA</td>
<td>National Defense Industrial Association</td>
</tr>
<tr>
<td>OMG</td>
<td>Object Management Group</td>
</tr>
<tr>
<td>OSA</td>
<td>Open System Architecture</td>
</tr>
<tr>
<td>PCB</td>
<td>Printed Circuit Board</td>
</tr>
<tr>
<td>PDR</td>
<td>Preliminary Design Review</td>
</tr>
<tr>
<td>PEAVN</td>
<td>Program Executive Office Aviation</td>
</tr>
<tr>
<td>PLCS</td>
<td>Product Life Cycle Support</td>
</tr>
<tr>
<td>PM</td>
<td>Program Manager</td>
</tr>
<tr>
<td>PSSA</td>
<td>Preliminary System Safety Assessment</td>
</tr>
<tr>
<td>RFP</td>
<td>Request for Proposal</td>
</tr>
<tr>
<td>S&amp;IPT</td>
<td>Science and Technology Integrated Product Team</td>
</tr>
<tr>
<td>SAE</td>
<td>Society of Automotive Engineers (SAE, Inc.)</td>
</tr>
<tr>
<td>SAVI</td>
<td>System Architecture Virtual Integration</td>
</tr>
<tr>
<td>SCADE</td>
<td>Safety-Critical Application Development Environment (Esterel)</td>
</tr>
<tr>
<td>SEI</td>
<td>Software Engineering Institute at Carnegie Mellon University</td>
</tr>
<tr>
<td>SLOC</td>
<td>Source Lines of Code</td>
</tr>
<tr>
<td>SME</td>
<td>Subject Matter Expert</td>
</tr>
<tr>
<td>SW</td>
<td>Software</td>
</tr>
<tr>
<td>SysML</td>
<td>Systems Modeling Language</td>
</tr>
<tr>
<td>TOICA</td>
<td>Thermal Overall Integrated Conception of Aircraft</td>
</tr>
<tr>
<td>TOPCASED</td>
<td>Toolkit in OPen source for Critical Applications and SystEm Development</td>
</tr>
<tr>
<td>TTTP</td>
<td>Time-Triggered Protocol</td>
</tr>
<tr>
<td>USAACE CEAD</td>
<td>U.S. Army Aviation Center of Excellence / Concepts, Experimentation, and Analysis Directorate</td>
</tr>
<tr>
<td>VIP</td>
<td>Virtual Integration Process</td>
</tr>
<tr>
<td>WBS</td>
<td>Wheel Braking System</td>
</tr>
</tbody>
</table>

30 October 2014 | NDIA Systems Engineering Conference 2014 © AVSI