The System Architecture Virtual Integration (SAVI) Project

An Integrated Modeling Environment for Improved Design of Complex Systems

David Redman, Aerospace Vehicle System Institute (AVSI)
Safe & Secure Systems & Software Symposium
10:30-11:00 June 17, 2010
Outline

• The Situation
• The AVSI Approach
• Proof of Concept Project I
• Proof of Concept Project II
• The SAVI Program
The Situation

High-level Design RFP Response
- High-level Req’s in RFP
- Trades
- Req’s Defined
- Sys Design
- Detailed Design
- Sys Re-Design
- Sys Development
- Sys Integration
- V&V
- Target Completion

System Integration Checks
- Req’s Changes
- PDR
- CDR

Aero Avionics Systems

Suppliers

COST GROWTH
SCHEDULE DELAY

6/17/10
Systems Are Becoming More Complex

Estimated Onboard SLOC Growth

Slope = 0.17718
Intercept = -338.5
Curve implies SLOC doubles about every 4 years

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 are in excess of $10B.

...with complex Development Ecosystems
... and constrained by dated SE methods

Silo’ed Organizations

“pi”

3.14

3.1415926

53589793

Written Requirements

Mismatched Assumptions
Current means of managing complexity have issues

Operational Models

Indeterminate Change Impact

Incompatible Abstractions

Multiple Truths

Modeling Domains
- Ops/Mission Analysis
- System Design
- Algorithm Design
- Hardware Design
- Manufacturing
- Logistics Support
- Performance Simulation
- Testing Analysis
- Human System Integration

System Architecture Model
(Integration Framework)
- Analysis Models
- Hardware Models
- Software Models
- Verification Models

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)
Common issues create common goals

• Minimize system requirements errors so we know system will integrate and work before we build it
• Know the full impact of changes
• Design flexibility
• Catch integration issues early when costs are lowest
• Improve systems
... suggesting a cooperative solution

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

A coordinated, industry-wide effort is needed to solve this issue.
AVSI is a global cooperative of aerospace companies, government organizations, and academic institutions. Past AVSI projects have covered the breadth of aerospace systems and current research includes projects in the areas of reliability, certification, and virtual integration.

The System Architecture Virtual Integration program is an AVSI program addressing virtual integration of systems.
Boeing brought these issues to AVSI

<table>
<thead>
<tr>
<th>Year</th>
<th>AFE 32 &amp; 32S1</th>
<th>AFE 57</th>
<th>AFE 58</th>
<th>AFE 59 Plan</th>
<th>AFE 59</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>BCA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>AFE 58</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td></td>
<td>AFE 59</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Boeing**
- **Goodrich**
- **Honeywell**
- **Rockwell Collins**

**BCA**

**BR&T**

- **Airbus**
- **BAE Systems**
- **Boeing**
- **GE Aerospace**
- **Honeywell**
- **Lockheed Martin**
- **Rockwell Collins**
- **FAA**
- **DoD Army**
- **DoD Navy**

- **Airbus**
- **BAE Systems**
- **Boeing**
- **GE Aerospace**
- **Lockheed Martin**
- **Rockwell Collins**
- **FAA**
- **DoD Army**

- **Dassault**
- **Goodrich**
- **Honeywell**
- **NASA**

**CMU/SEI**

- **6 L-Yrs (1.5)**
- **9+ L-Yrs (1)**
- **16+ L-Yrs (2)**
- **? L-Yrs (?)**
AFE 32 - ADL’s

• There existed no Architecture Description Language that could capture a complete system definition

• There existed several candidate languages developed for various analytical domains:
  – UML
  – SysML
  – AADL
  – Modelica
  – ...
Two Approaches to MBSE

Linked Models

Reference Model
The System Architecture Virtual Integration Program

“Integrate, Then Build”

• SAVI is
  – A research effort to define the standards and technologies needed to effect virtual integration
  – A global collaboration
  – Integration of three emerging technologies
    • Model-based,
    • Proof-Based, and
    • Component-Based engineering
  – Structured/transformable data interfaces
  – A changed acquisition paradigm to facilitate systems integration

• SAVI is not
  – A software tool or a design tool
  – A continuation of current system development practices
# AFE 57 – SAVI High-Level Planning

- Identify the early (virtual) integration analyses we wish to perform
  - Includes gap analysis (on everything)

- Identify the information needed to support the analyses
- Identify the tools necessary to produce and analyze the information
- Define the data structure needed for information storage & analysis (Model Repository)
- Define the data transforms needed for information interchange (Data Exchange/Translation)
  - Working with tool vendors
- Build PoCs & perform pilots
- Coordinate with Airworthiness Authorities
- Participate on Standards Committees

Subset of these performed during PoC I
AFE 58 – Proof of Concept I

Objectives

Investigate Changes to Acquisition Model

Perform Proof-Of-Concept Experiment

Estimate ROI

Create SAVI Roadmap

Results

Documented “as-is” and “to-be” acquisition models

Created representative models and acq. use case in AADL

Analysis shows favorable ROI using conservative assumptions

Created a more detailed roadmap for SAVI development/implementation
Architecture-Centric Engineering

Availability and Reliability
- MTBF
- FMEA
- Hazard analysis

Data Quality
- Data precision/accuracy
- Temporal correctness
- Confidence

Virtual Integration & Validation of System Architecture

Annotated Architecture Model

Cyber Security
- Availability
- Authentication
- Integrity
- Confidentiality
- No repudiation

Resource Consumption
- Bandwidth
- CPU time
- Power consumption

Auto-generated analytical models

Real-time Performance
- Execution time/Deadline
- Deadlock/starvation
- Latency

source: SEI
How Will SAVI Work?

Requirements
- Suppliers
- Descriptions
- Models
- Data
- Analysis Results

Verification/Validation
- Regulators
- Require/Specify Tools
- Design/Build Tools
- Integrate/V&V Tools
- Other Tools

Design and Build
- Airframers

Integration/Deployment
- Users
- Information: Virtual Integration Data
- Model Bus
- Define the data structure needed for information storage and analysis (Model Repository)
- Define the data transforms needed for information interchange (Model Bus)
Proof-of-Concept (PoC) Demonstration

• Three Models (Tiers 1, 2, and 3) Analyzed
  – Tier 1 (Aircraft level)
  – Tier 2 (Aircraft system level)
  – Tier 3 (Sub-system/LRU level)

• Analysis and Demonstration
  – Propagated requirements and constraints from higher-level model down to suppliers' lower-level models
  – Verified lower-level models satisfy higher-level requirements and constraints

• Evaluation Based on Quality Factors
  – Started with 19 (Criticality, Frequency, Difficulty, Cost,...)
  – Video demonstrations available
Global Team Implemented PoC Demo

A distributed, multi-party development team implemented the PoC demo, reflecting current real-world development environments.
A Multi-Tiered Model Was Produced

Incremental Multi-Fidelity Multi-dimensional Multi-Layered Architecture Modeling & Analysis

Aircraft system: (Tier 1)
- Engine, Landing Gear, Cockpit, ...
- Weight, Electrical, Fuel, Hydraulics, ...

IMA System: (Tier 2)
- Hardware platform, software partitions
- Power, MIPS, RAM capacity & budgets
- End-to-end flow latency

Subcontracted software subsystem: (Tier 3)
- Tasks, periods, execution time
- Software allocation, schedulability
- Generated executables

OEM & Subcontractor:
- Subsystem proposal validation
- Functional integration consistency
- ARINC 429 protocol mappings

Additional Opportunities:
- Safety & security analysis
- Fault modeling & impact analysis
- What-if trade studies

- System & software system
- Integrator & subcontractor virtual integration
Virtual Integration Throughout Life Cycle

Sensitivity analysis for uncertainty

Confidence in implementation

From Prediction to Validation

Model-driven artifact generation
Conformance of models and systems

→ generation of test cases
← updating models with actual data
### SAVI Development Roadmap

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td></td>
<td></td>
<td>SAVI Process description v1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Model Bus &amp; Model Repository Specs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ADL Selected</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td></td>
<td></td>
<td>SAVI Tools pre-implementation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Encapsulation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ADL based &amp; Multi-level</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Functional</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Functional &amp; types</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Full data</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td></td>
<td></td>
<td>Full SAVI systems scope</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Aircraft signature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2014</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Key Milestones
- **TRL 5**: DEC 2011
- **TRL 7**: JUN 2013
- **TRL 9**: DEC 2014

**SAVI Tools & Process**
- Full data
- Full SAVI systems scope
- Aircraft signature

**SAVI Deployment**
- Partial Supply Chain integration (SAVI partners)
- Full supply chain integration

**Tools Vendors (partners)**
- Tools Vendors Integration

**AIRCRAFT APPLICATIONS**
- Airframer
- Suppliers

**Architecture design**
- Prelim. system design
- SAVI partners
- All suppliers
Data Exchange and Repository Development

• Collect and prioritize early integration use cases to form an initial requirements set for SAVI 1.0.
• Expand the Proof of Concept demonstration to implement a specific subset of the collected use cases. This expansion will include subsystems without software content.

Address Questions With Current SAVI Approach

• Survey existing Architecture Description Languages (ADLs) / Interface Description Languages (IDLs) against the collected early integration use cases.
• Investigate multi-language-model approaches to the Model Repository

Improved ROI

• Refine and Expand Return on Investment (ROI) Analysis Framework developed during AFE 58.

Develop SAVI 1.0 Program Plan

Outreach
Mechatronics Architecture

- **Interface**
  - Displays
  - User Controls
  - Haptics
  - Remote Links
  - ...

- **Electronic Control Unit (ECU)**
- **Sensors**
- **Actuators**
- **Communications Bus**

- **Software**
  - Functions
  - States
  - Modes
  - ...
  - Libraries
  - Modules
  - Messages
  - Protocols
  - Code
  - ...

- **Mechanical Systems**
  - Kinematics
  - Dynamics
  - Powertrain
  - Thermal
  - Fluids
  - Electric Power
  - ...

- **Electronics**
- **PoC I**
- **PoC II**

- **Mechatronics Architecture**

---

6/17/10
2010 Safe & Secure Systems & Software Symposium / © Texas Engineering Experiment Station 26
Define SAVI Use Cases

- Use cases reflect modes of interaction in SAVI framework
- Identify initial high-level requirements
- Will help identify technology gaps
- Use cases will be used to exercise PoC models
A coordinated, industry-wide effort is needed to solve this issue.
Conclusion

• Standard data storage and exchange constructs enable early virtual integration of models distributed across the supply chain. A monolithic solution is not practicable.

• The AVSI SAVI Program represents an industry-based effort to address the common issue of cost and schedule growth due to the growth of system complexity.

• SAVI is just one of several efforts in this problem space. We cannot afford to solve this problem multiple times.
Questions?

Contacts:
Dr. Don Ward
Phone: (254) 842-5021
Mobile: (903) 818-3381
dward@avsi.aero

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