Aerospace Vehicle Systems Institute

SAVI Support of DoD Architecture Centric Virtual Integration

System Architecture Virtual Integration Program

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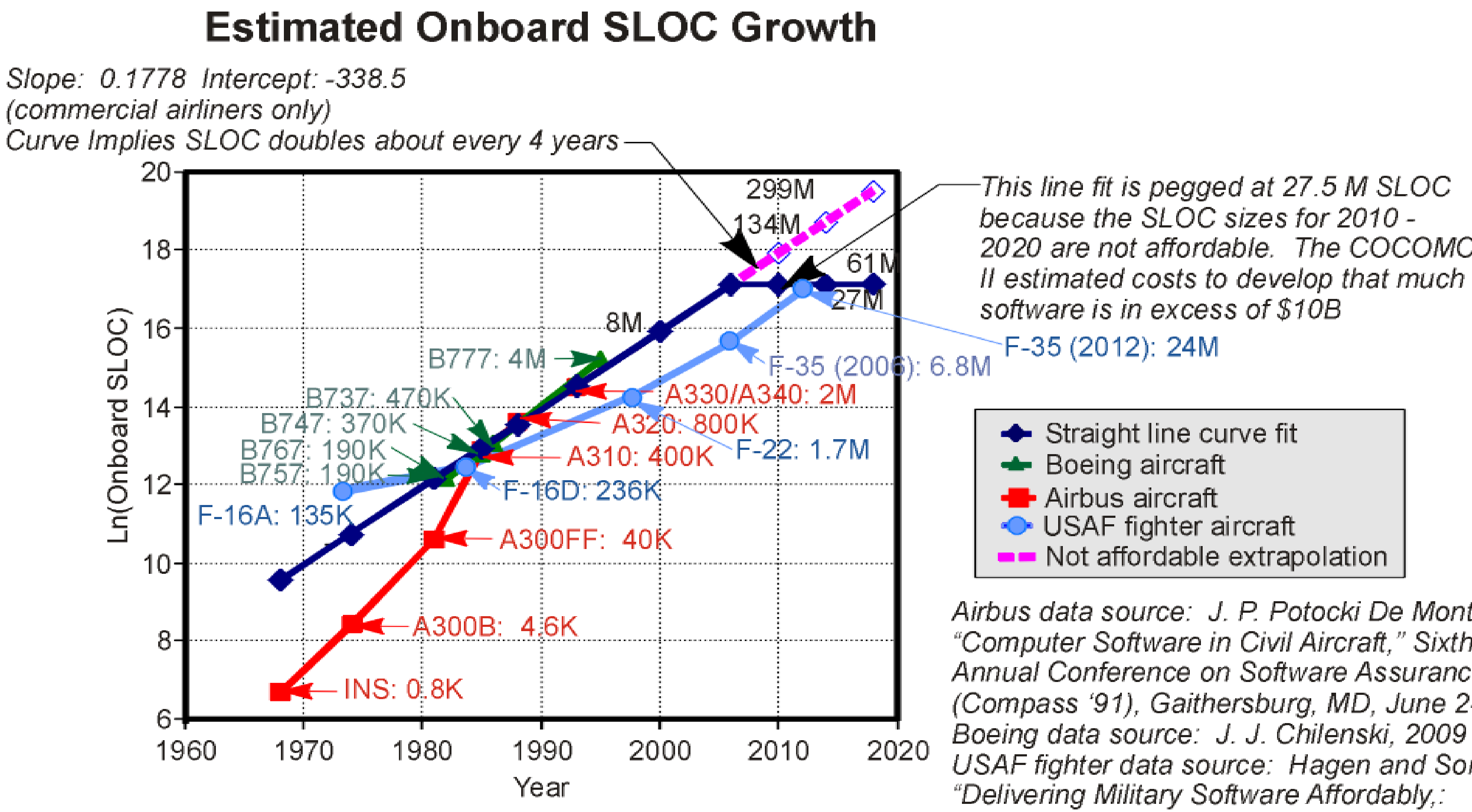
Agenda

- Motivation for Virtual Integration
- AVSI and the SAVI Program
- DoD Participation in SAVI
- The JMR TD/MSAD Program
- Conclusion / Q&A

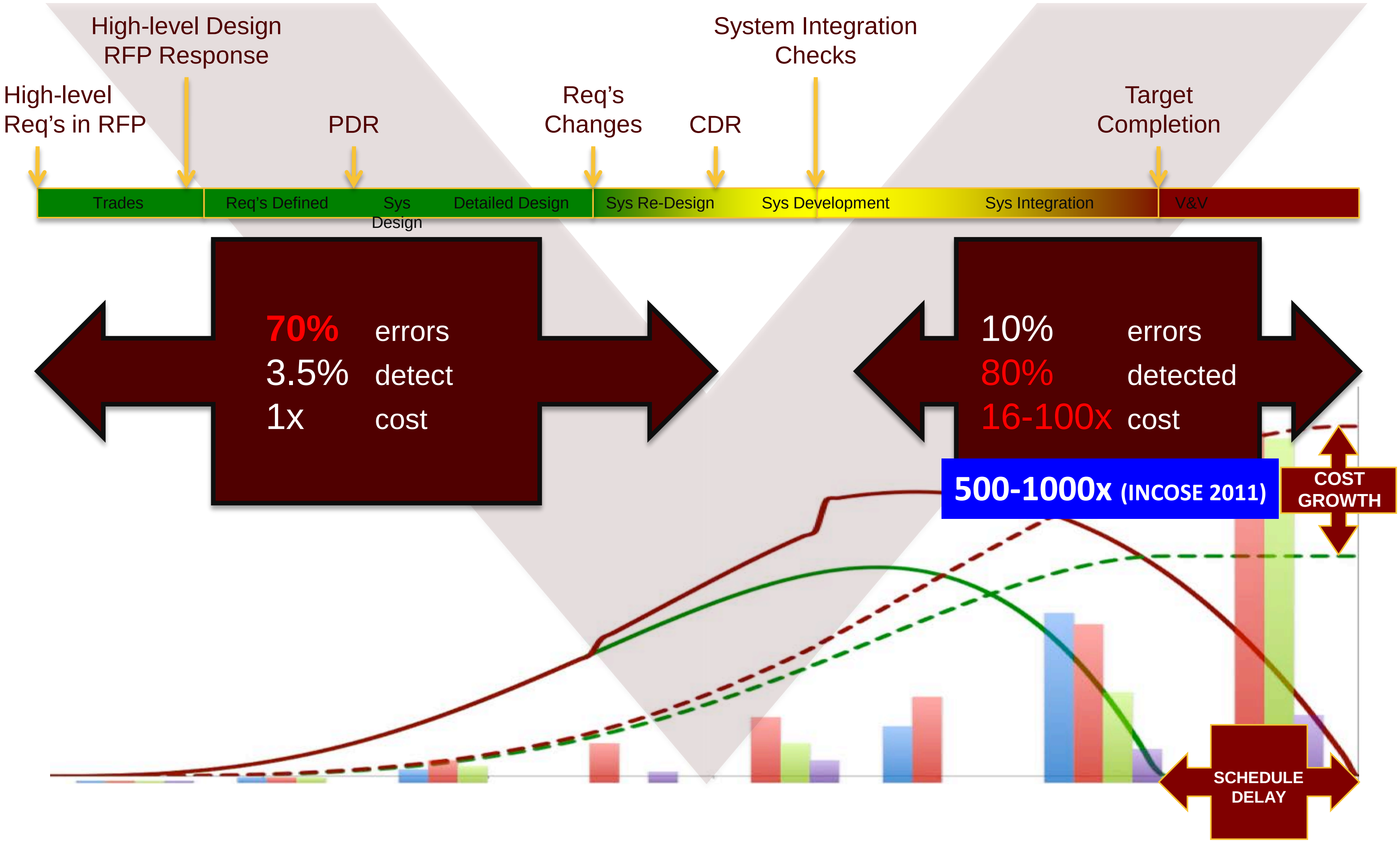
MOTIVATION FOR VIRTUAL INTEGRATION

Systems Are Becoming More Complex



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
USAF fighter data source: Hagen and Sorenson, "Delivering Military Software Affordably,: Defense AT&L, March-April 2013

The impact is documented



Current means of managing complexity have issues

- Ope tion Models
- ls
- avior Mo
- Perf ma e Model
- Stru tural/Compo ent M
- Cost Model
- Safety Model
- Security Model
- Reliability Model
- Mainta nabil y Model
- S
- odel
- sembly) Models

Indeterminate Change Impact

MODEL EXPLOSION

Multiple Truths

Incompatible Abstractions

- Modeling Domains
  - Ops/Mission Ana sis
  - Syste
  - Alg
  - Hardw
  - Sof
  - Logistics Su or
  - Manufacturi g
  - egration & Test
  - Performance Simulation
  - gineering 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

Current SAVI member
Joining SAVI now
Discussing joining SAVI
Participated earlier in SAVI

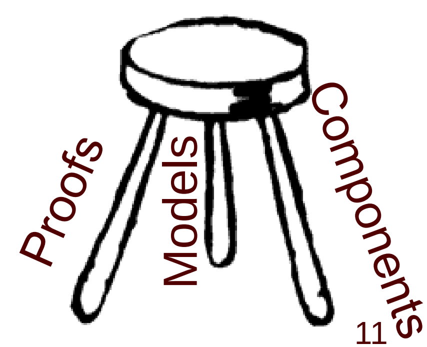
SAVI Goals and Approach

- 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

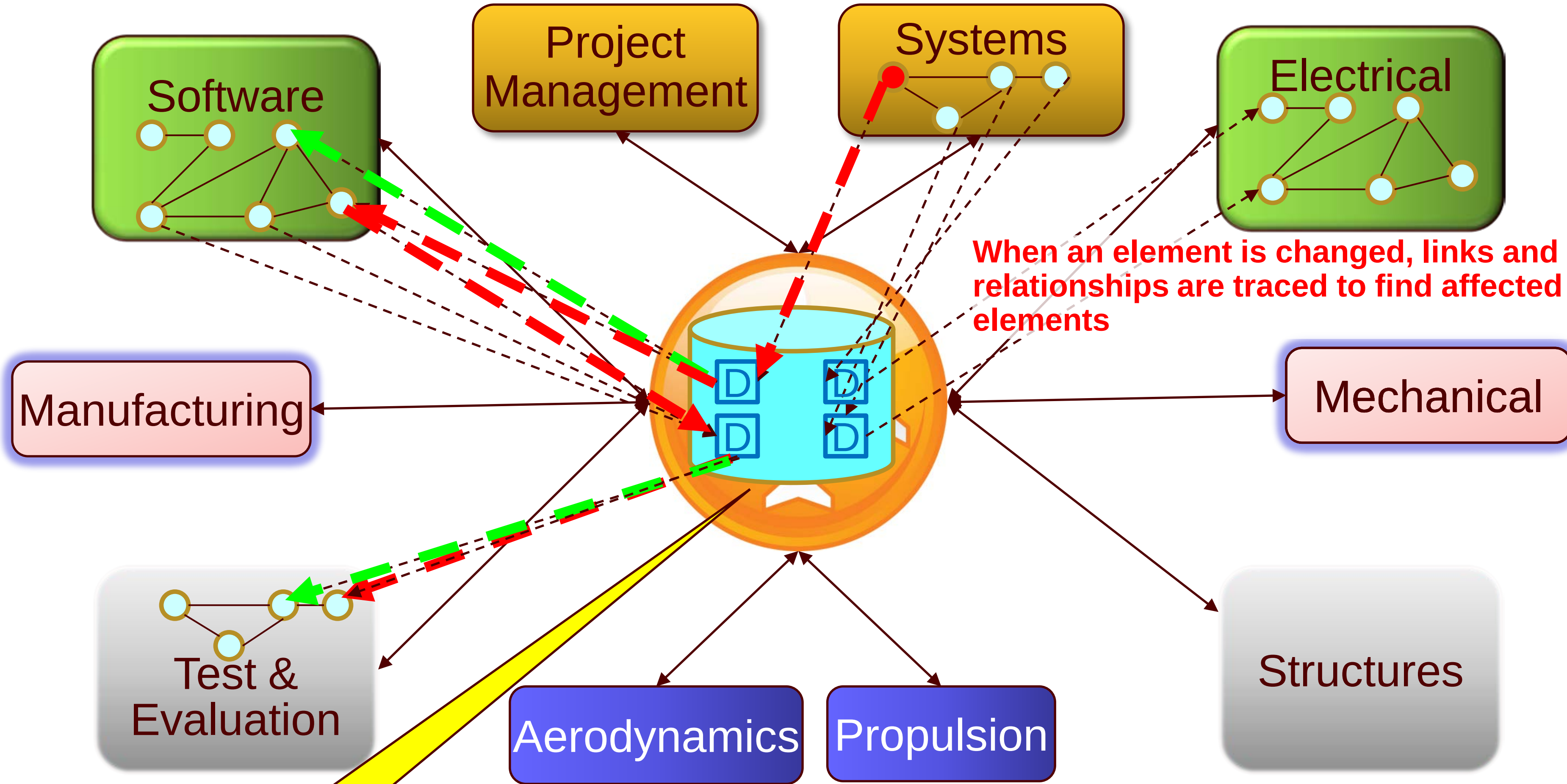
- Reduce costs/development time through early and continuous model-based virtual integration
  - **S**hift to new paradigm – integrated models rather than documents
    - Systems engineering in cross-domain context
    - Models provide basis for improvements
    - Models promote consistency – "absence of contradictions"
  - **A**rchitecture-centric approach – start with models, but more
    - Meld with requirements for traceability
    - Facilitate trade studies
  - **V**irtual **I**ntegration – 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

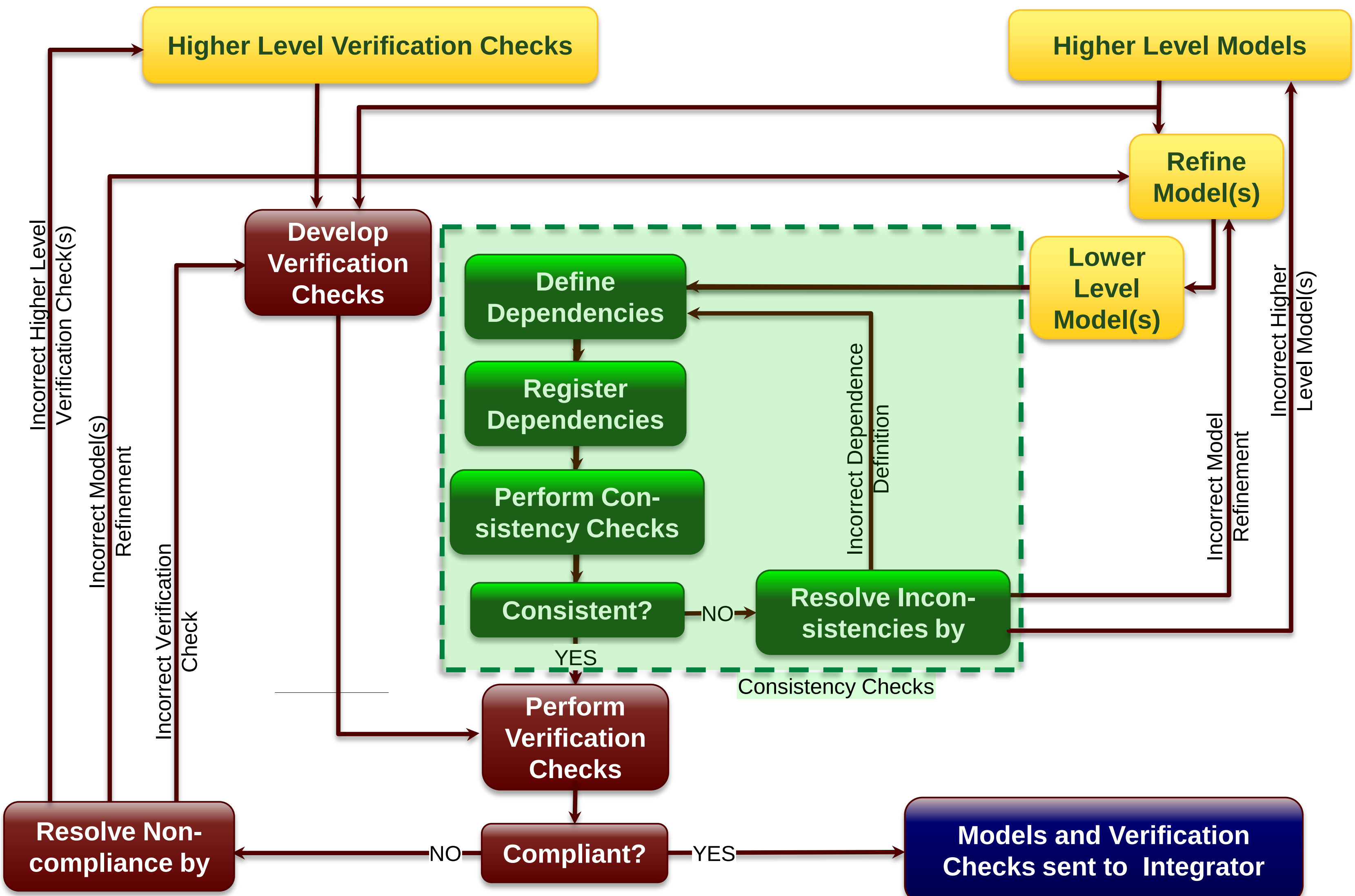
Dependencies Are Key



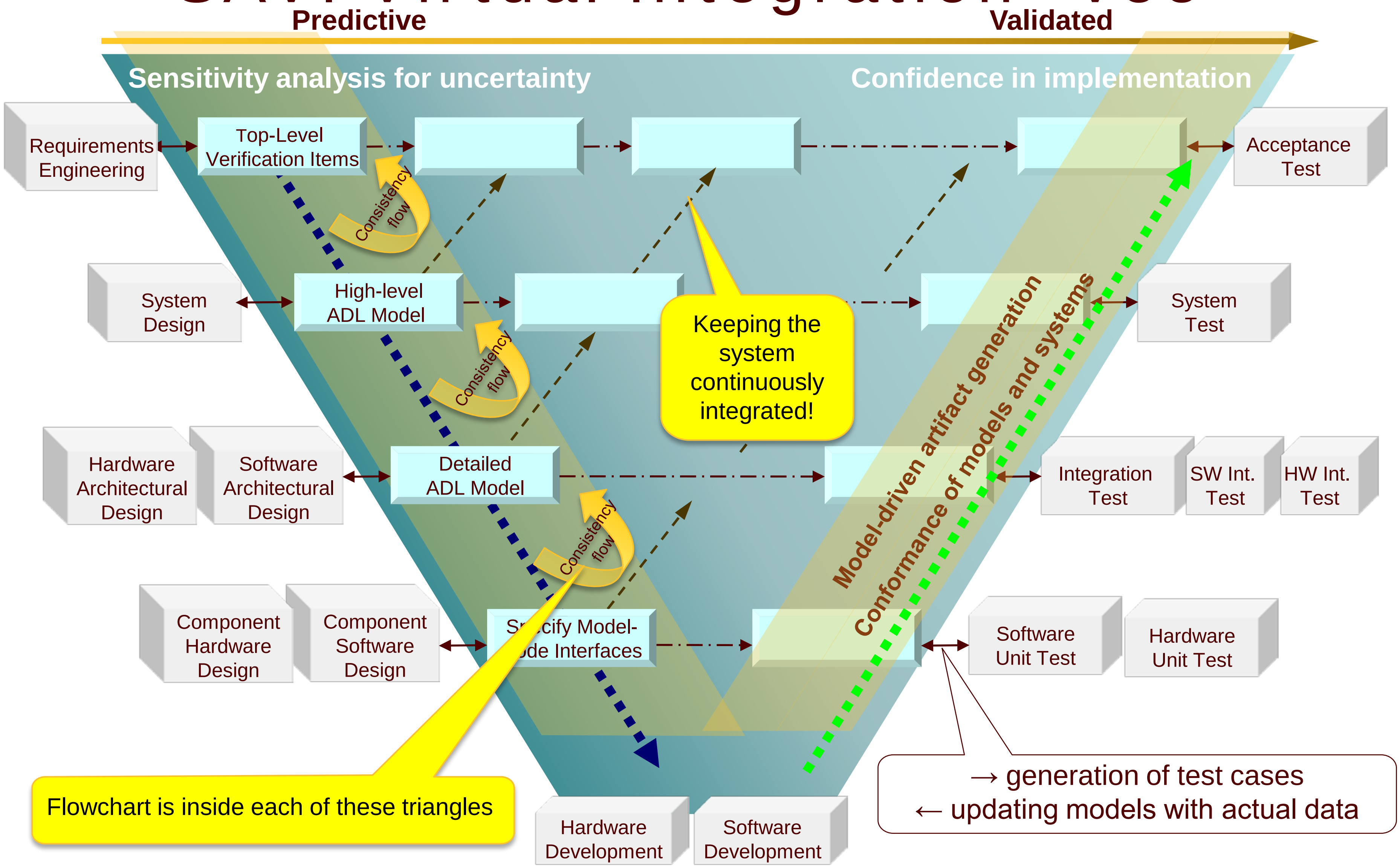
Industry wide, 50% of requirements will change between CDR & delivery into service

The SAVI Repository stores the links

SAVI VIP


Higher Level Verification Checks
Higher Level Models
Refine Model(s)
Develop Verification Checks
Lower Level Model(s)
Define Dependencies
Register Dependencies
Perform Con-sistency Checks
Consistent?
NO
YES
Resolve Incon-sistencies by
Incorrect Dependence Definition
Incorrect Model Refinement
Incorrect Higher Level Model(s)
Consistency Checks
Incorrect Higher Level Verification Check(s)
Incorrect Model(s) Refinement
Incorrect Verification Check
Perform Verification Checks
Compliant?
NO
YES
Resolve Non-compliance by
Models and Verification Checks sent to Integrator

SAVI Virtual Integration "Vee"



AVSI

INITIAL VIP CAPABILITY

VERSION 1.0A - 2013

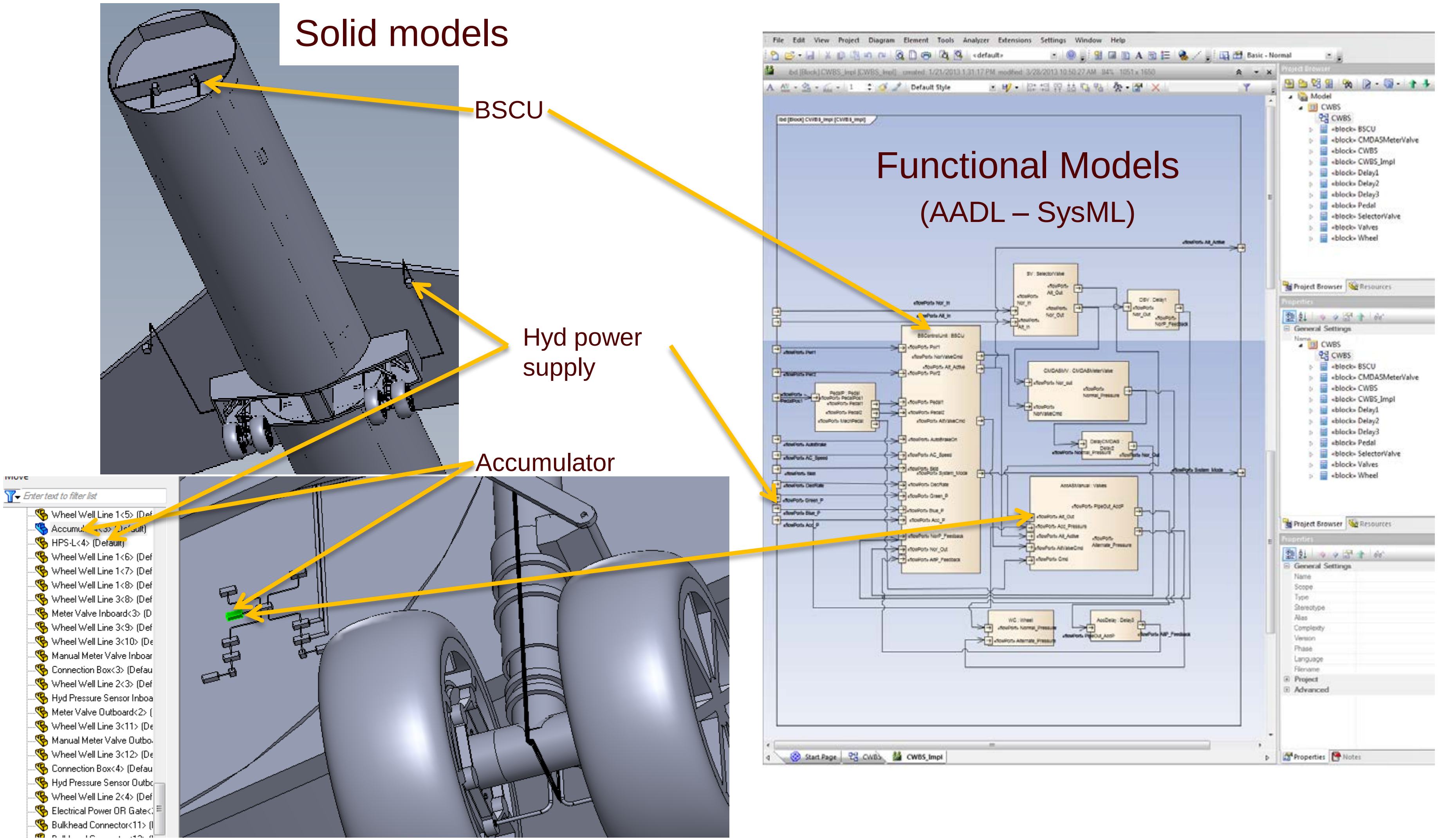
WBS Safety Analysis

- 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

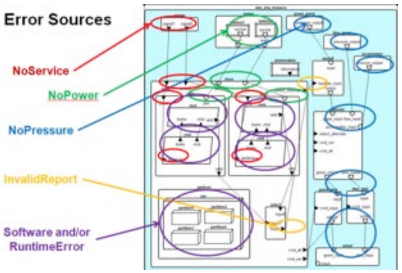
- The model set for the AFE 61 WBS PSSA consists of five models for the simplified WBS
  - A set of requirements from AIR 6110 (Spreadsheet)
  - A Publisher/Subscriber model forming the basis for an ICD later in the project (Spreadsheet)
  - A SysML model documenting the architecture at the beginning 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

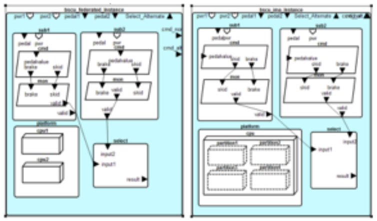


Automation of Safety Analysis Practice

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

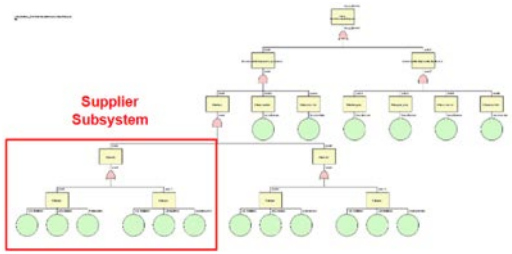


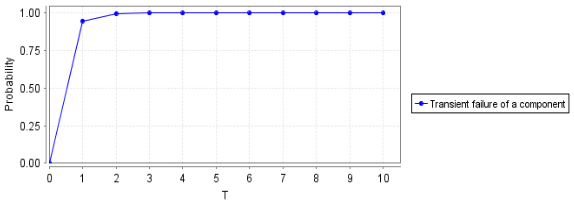
- Comparative architecture trade study
  - Federated vs. Integrated Modular Avionics (IMA) architecture



- 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)

Function Name	Failure Mode	Failure Rate (E-6)	Flight Phase	Failure Effect	Detection Method	Comments
+5 Volt	+5V out of spec.	0.2143	All	Possible P/S shutdown	Power Supply Monitor trips, shuts down supply and passes "invalid power supply (P/S)" to other BSCU system	BSCU channel fails
	+5V short to ground	0.2857	All	P/S shutdown	Power supply monitor passes invalid P/S to other BSCU system	BSCU channel fails
	Loss of / reduced filtering	0.3571	All	Increase Ripple	May pass out of spec voltage to rest of BSCU if ripple is such that it is not detected by the P/S monitor	May cause spurious P/S monitor trip
	+5V open	0.5714	All	P/S shutdown	Power supply monitor passes invalid P/S to other BSCU system	BSCU channel fails
	No Effect	0.1429	All	No Effect	None/No Effect	No Effect
Total Failure Rate of +5V Supply		1.5714				



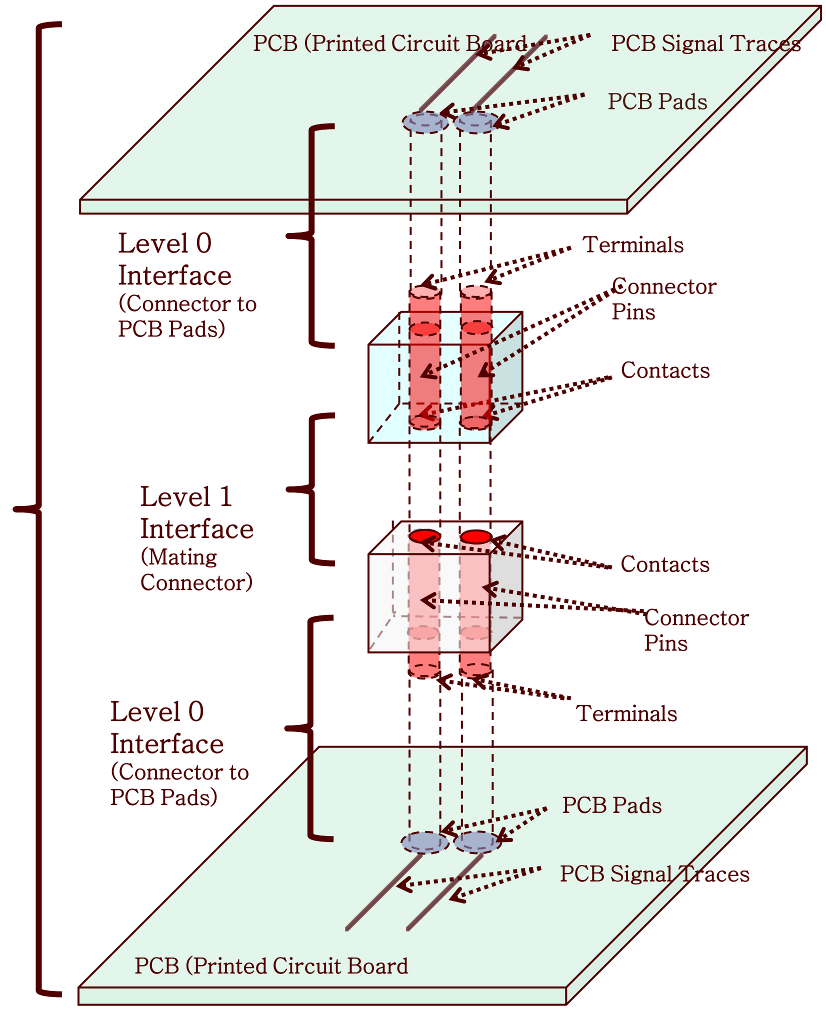


CAPABILITIES BEING ADDED

VERSION 1.0B - 2014

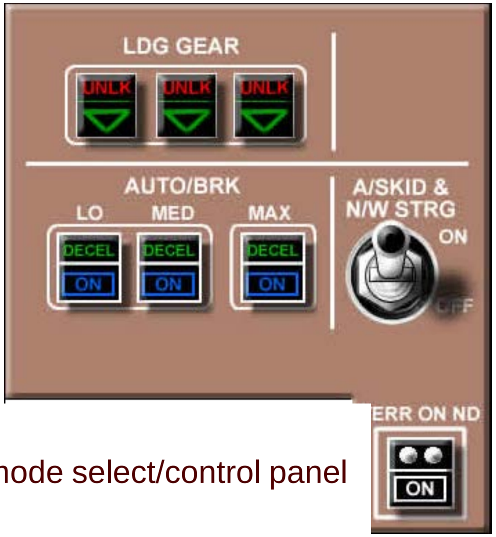
AFE 61S1 (2014) Use Cases

- 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



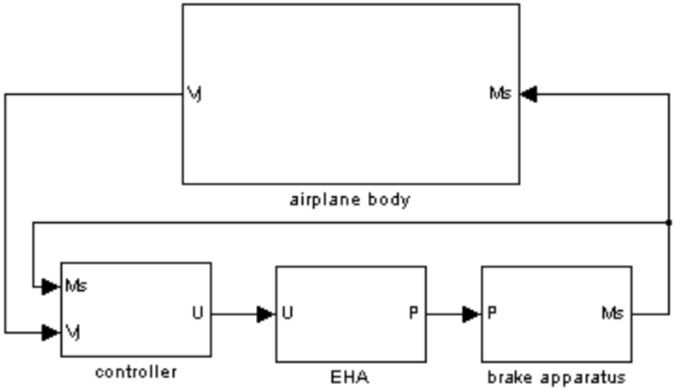
AFE 61S1 (2014) Use Cases

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



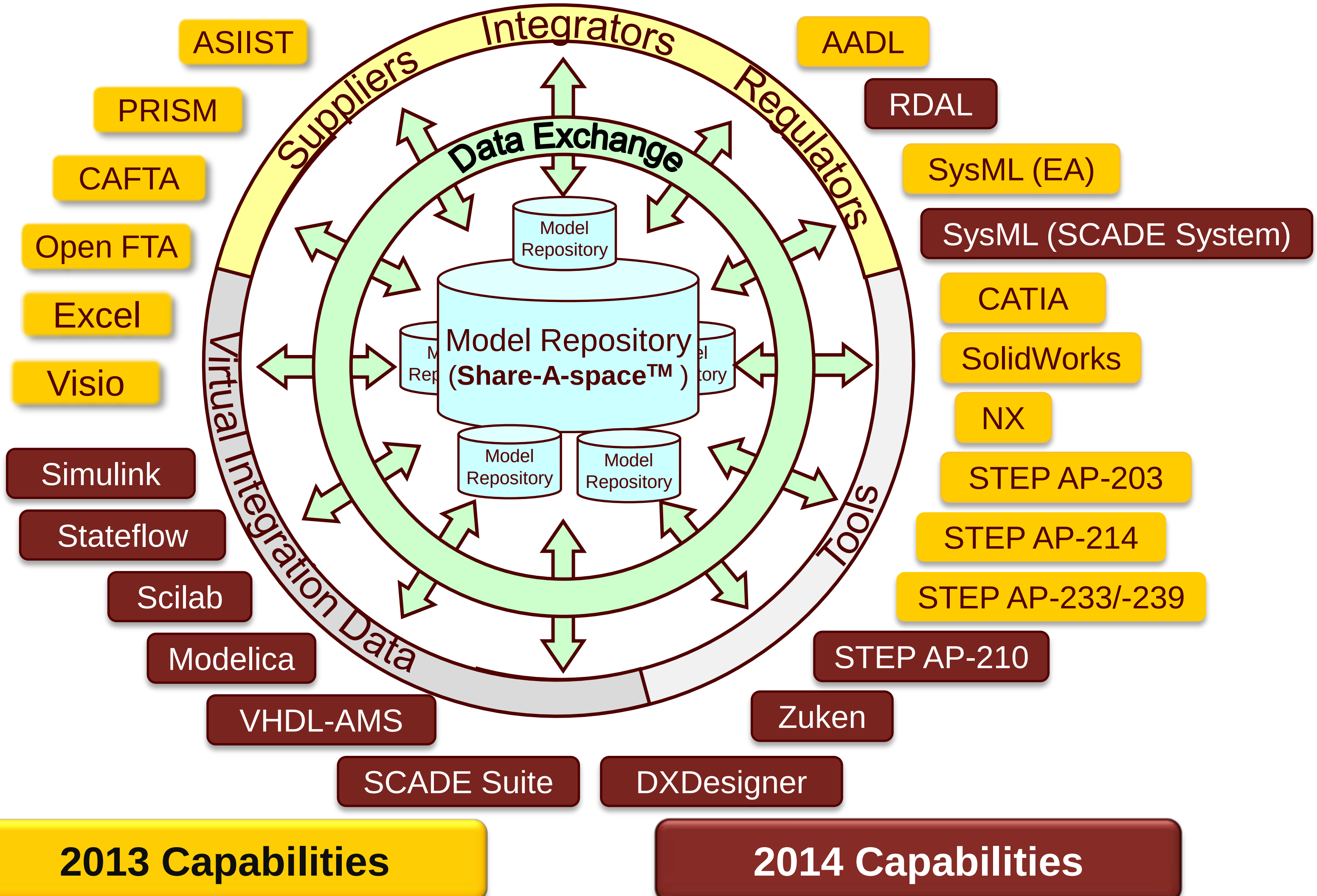
Typical mode select/control panel

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



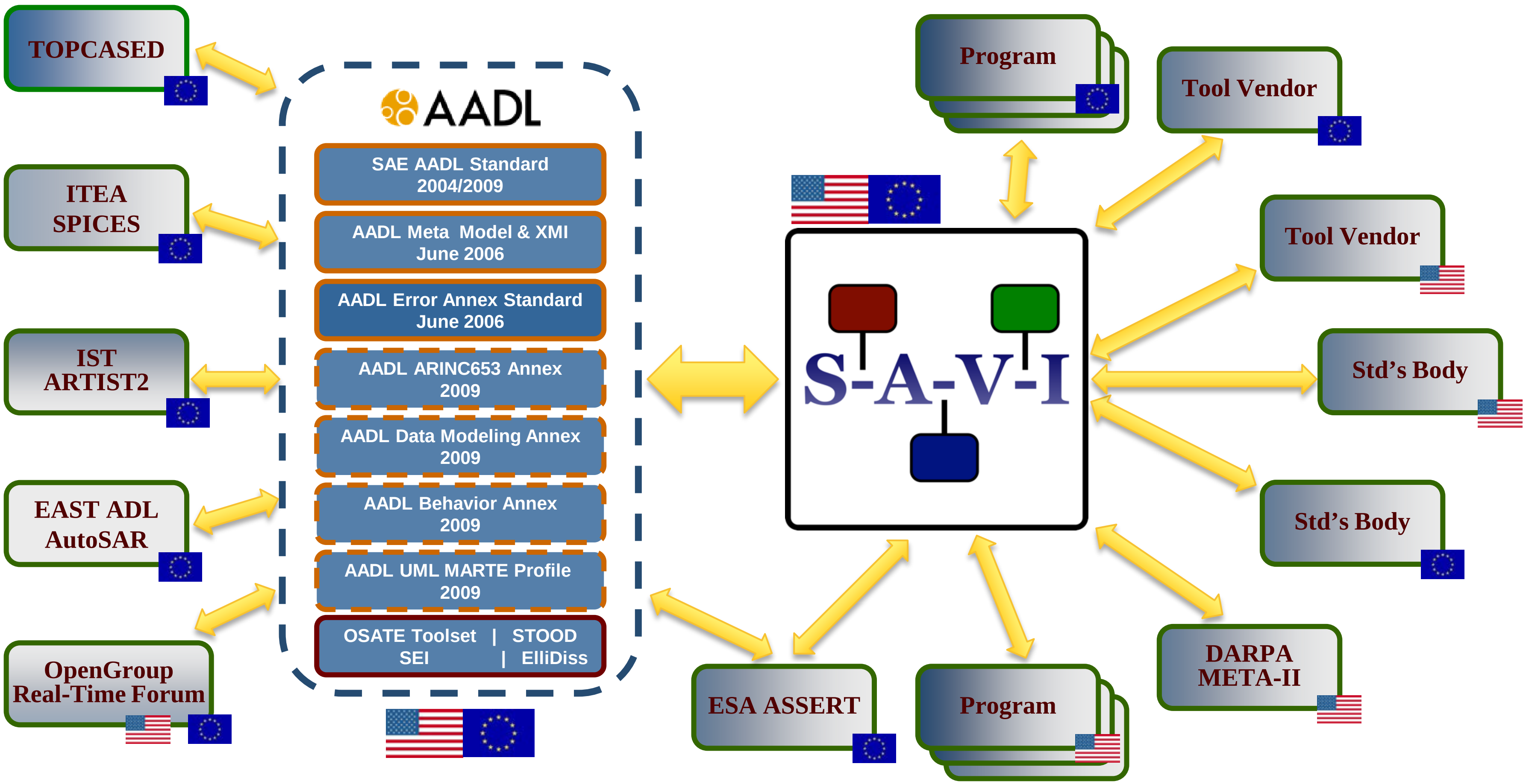
- Develop behavioral modeling capability

AFE 61S1 Model Map

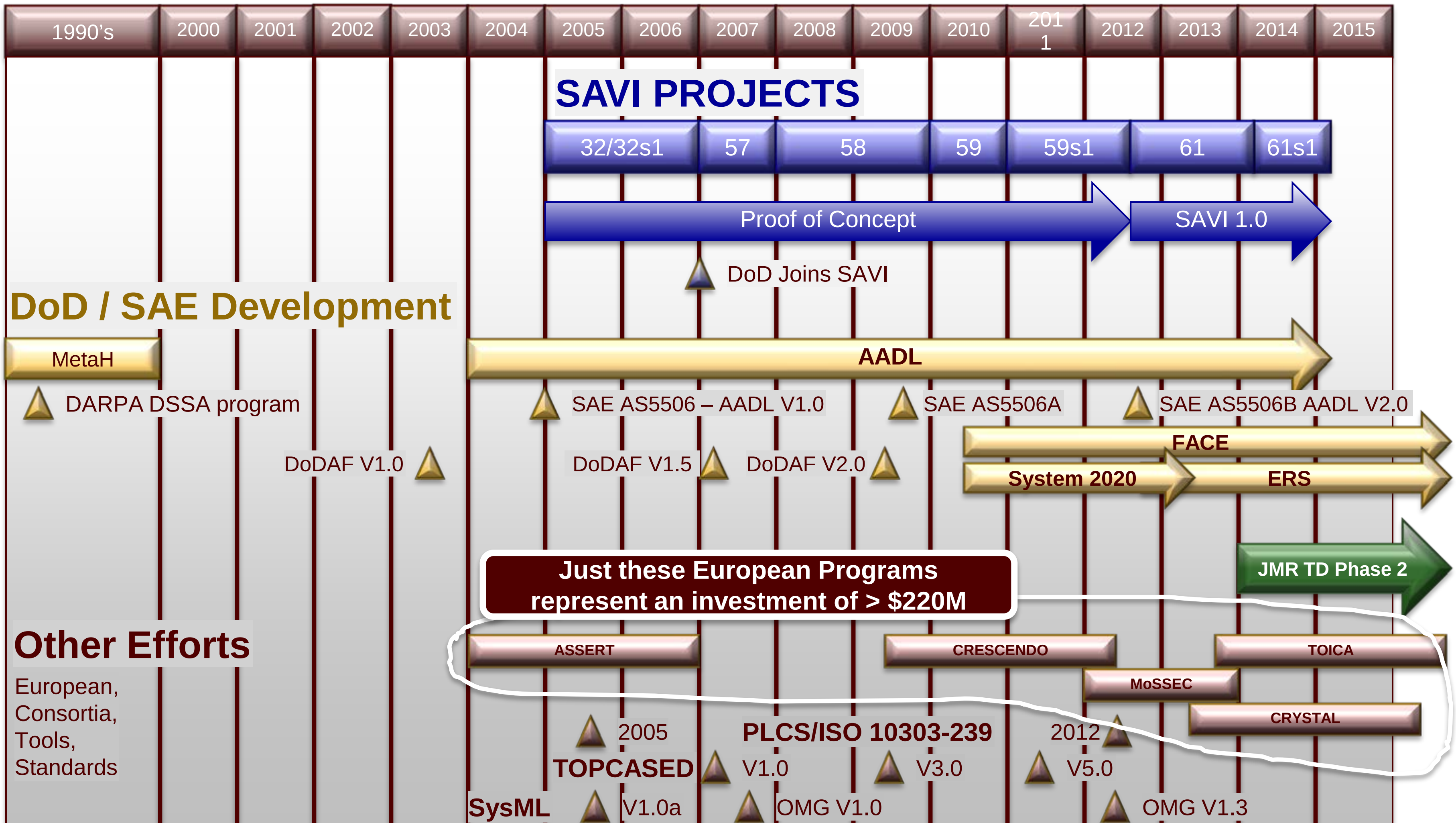


Collaboration is Central to SAVI

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



Sustained Efforts Toward Architecture Centric System Development



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

MSAD Approach

- **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				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

JCA V1.0 Development

JCA Sustainment

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

Architecture Centric Virtual Integration Process (ACVIP)

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

Baseline Objective MEP Def.

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

Architecture Integration Process Demonstrations

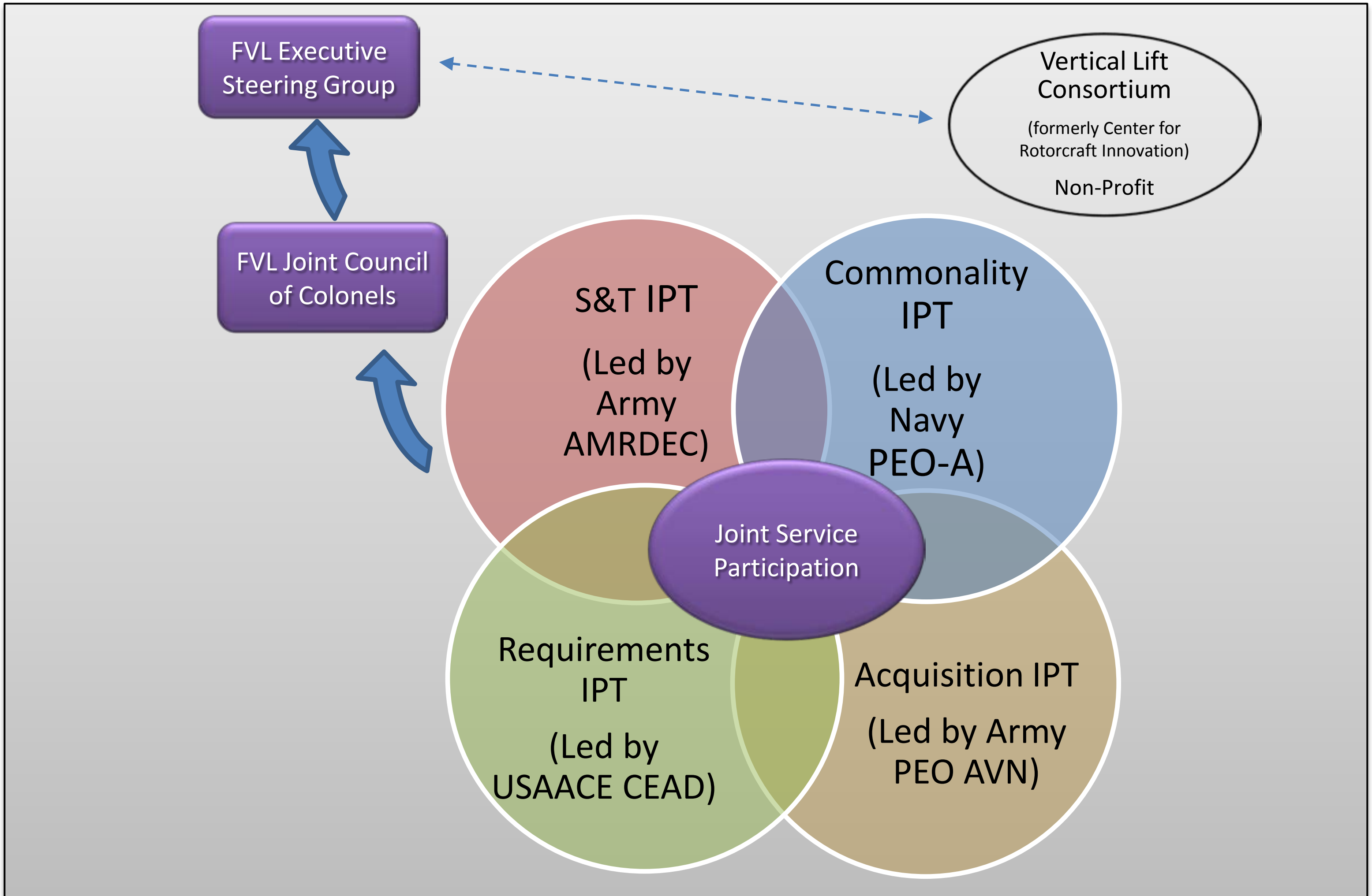
Focus Areas
- JCA / ACVIP Maturation
- Model Based Approaches
  - Single Truth Model
  - Model Based Systems Eng (MBSE)
  - Model Based Acquisition
- Infrastructure Technologies
  - Multi-core processors
  - High speed databases (e.g., Fiber, Wireless)
  - Deterministic protocols (e.g. TTP)
  - VPI/VPX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

JCA Demo / ACVIP Shadow

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

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

FVL DOD Organization



Vertical Lift Consortium Mission/Membership

www.verticalliftconsortium.org

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

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

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

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

Engineered Resilient Systems

- Informed Decision Making
- Trustworthy and Adaptable Design
- Affordable and Timely

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

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

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

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

- 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?

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http://savi.avsi.aero

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FACE

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ERS

- Dr. Randy Avent and Dr. Robert Neches, Presentation to NDIA/DoD Annual S&T Conference 20-23 June 2011, obtained from http://www.dtic.mil/ndia/2011SET/Avent3.pdf on 10/1/2014.

List of Acronyms

AADL	Architecture Analysis and Design Language
ACVIP	Architecture-Centric Virtual Integration Process
ADL	Architecture Description Language
AFE	Authority for Expenditure
AIR	Aerospace Information Report
AMRDEC	Aviation and Missile Research Development and Engineering Center
ARINC	Aeronautical Radio, Incorporated
ARP	Aerospace Recommended Practice
ASSERT	Automated proof-based System and Software Engineering for Real-Time applications
AutoSAR	AUTomotive Open System ARchitecture
AVSI	Aerospace Vehicle Systems Institute
BSCU	Brake System Control Unit
CDR	Critical Design review
COE	Common Operating Environment
CRESCENDO	Collaborative and Robust Engineering using Simulation Capability Enabling Next Design Optimisation
CRYSTAL	CRitical sYSTem engineering AcceLeration
DARPA	Defense Advanced Research Projects Agency
DoD	Department of Defense
DoDAF	Department of Defense Architecture Framework
DSSA	Domain-Specific Software Architecture
EMV2	Error Model annex Version 2
ERS	Engineered Resilient Systems
ESA	European Space Agency
FAA	Federal Aviation Administration
FACE	Future Airborne Capability Environment
FHA	Functional Hazard Assessment
FMEA	Failure Modes and Effects Analysis
FTA	Fault Tree Analysis
FVL	Future Vertical Lift
HW	Hardware
ICD	Interface Control Document
IMA	Integrated Modular Avionics
INCOSE	International Council on Systems Engineering
IP	Intellectual Property

ISO	International Organization for Standardization
JCA	Joint Capability Area
JMR TD	Joint Multi Role Technology Demonstrator
MBSE	Model Based Systems Engineering
MEP	Mission Equipment Package
MoSSEC	Modelling and Simulation in Collaborative Systems Engineering Context
MSAD	Mission Systems Architecture Demonstration
NASA	National Aeronautics and Space Administration
NDIA	National Defense Industrial Association
OMG	Object Management Group
OSA	Open System Architecture
PCB	Printed Circuit Board
PDR	Preliminary Design Review
PEO AVN	Program Executive Office Aviation
PLCS	Product Life Cycle Support
PM	Program Manager
PSSA	Preliminary System Safety Assessment
RDECOM	Research, Development and Engineering Command
RFP	Request for Proposal
S&T IPT	Science and Technology Integrated Product Team
SAE	Society of Automotive Engineers (SAE, Inc.)
SAVI	System Architecture Virtual Integration
SCADE	Safety-Critical Application Development Environment (Esterel)
SEI	Software Engineering Institute at Carnegie Mellon Univeristy
SLOC	Source Lines of Code
SME	Subject Matter Expert
SW	Software
SysML	Systems Modeling Language
TOICA	Thermal Overall Integrated Conception of Aircraft
TOPCASED	Toolkit in OPen source for Critical Applications and SystEm Development
TTP	Time-Triggered Protocol
USAACE CEAD	U.S. Army Aviation Center of Excellence / Concepts, Experimentation, and Analysis Directorate
VIP	Virtual Integration Process
WBS	Wheel Braking System