U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND – AVIATION & MISSILE CENTER

Pioneering Disruptive, Real-Time, Software/System Engineering Capability for Army Aviation

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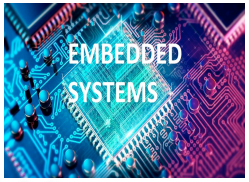
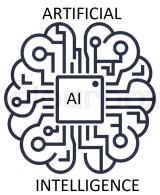
US Army Futures Command

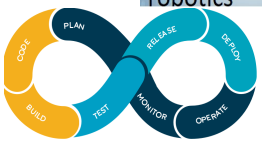
23 October 2019

BLUF

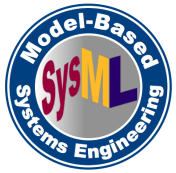




Autonomous vehicles



Agile / DevOps



- **Disruptive cost on Comanche, B787, A380, F22, and F35. Where is the Gap? Growth in complexity and late error discovery is the primary factor driving affordability in complex embedded systems. The Architecture Centric Virtual Integration Process (ACVIP) leveraging the Architecture Analysis & Design Language (AADL) provides a direct approach to resolving this issue.**

- **Technology demonstrations have proven the effectiveness of the ACVIP. These include DARPA and Army S&T demos maturing for production use. S&T now to be carried into early production use on FVL.**

ACVIP analysis and virtual integration needs to be added to embedded computing system developments in complex Aviation systems then applicable to other Cyber Physical Systems

RAH-66 COMANCHE – SOFTWARE REWORK & INTEGRATION COSTS

Photo Credit: Boeing-Sikorsky

Two major software (SW) rebuilds occurred during development indicating significant integration issues

- **1st increment: 75% of SW replaced**
- **2nd increment: 50% of SW replaced**

- ***In 1983, the Army planned to buy 5,023 vehicles at $12.1 million/copy.***
- ***Test schedule delays and increasing development costs scaled down the planned buy to 650 aircraft at $58.9 million/copy.***
- ***Most testing involved integration of the complete Mission Equipment Package, which incorporated a radar, infrared, and image-intensified television sensors for night flying and target acquisition.***
- ***Technical challenges remained in software development, integration of mission equipment, radar and infrared signatures, and radar perf.***
- ***The first flight had been originally planned to take place during August 1995, but was delayed by a number of structural and software problems that had been encountered.***
- ***Key program elements, including development and integration of certain software capabilities, failed to foster confidence with Army overseers; several capabilities were viewed as having been unproven and risky.***
- ***The anticipated consumption of up to 40% of the aviation budget by the Comanche alone for a number of years was considered to be extreme.***

References:

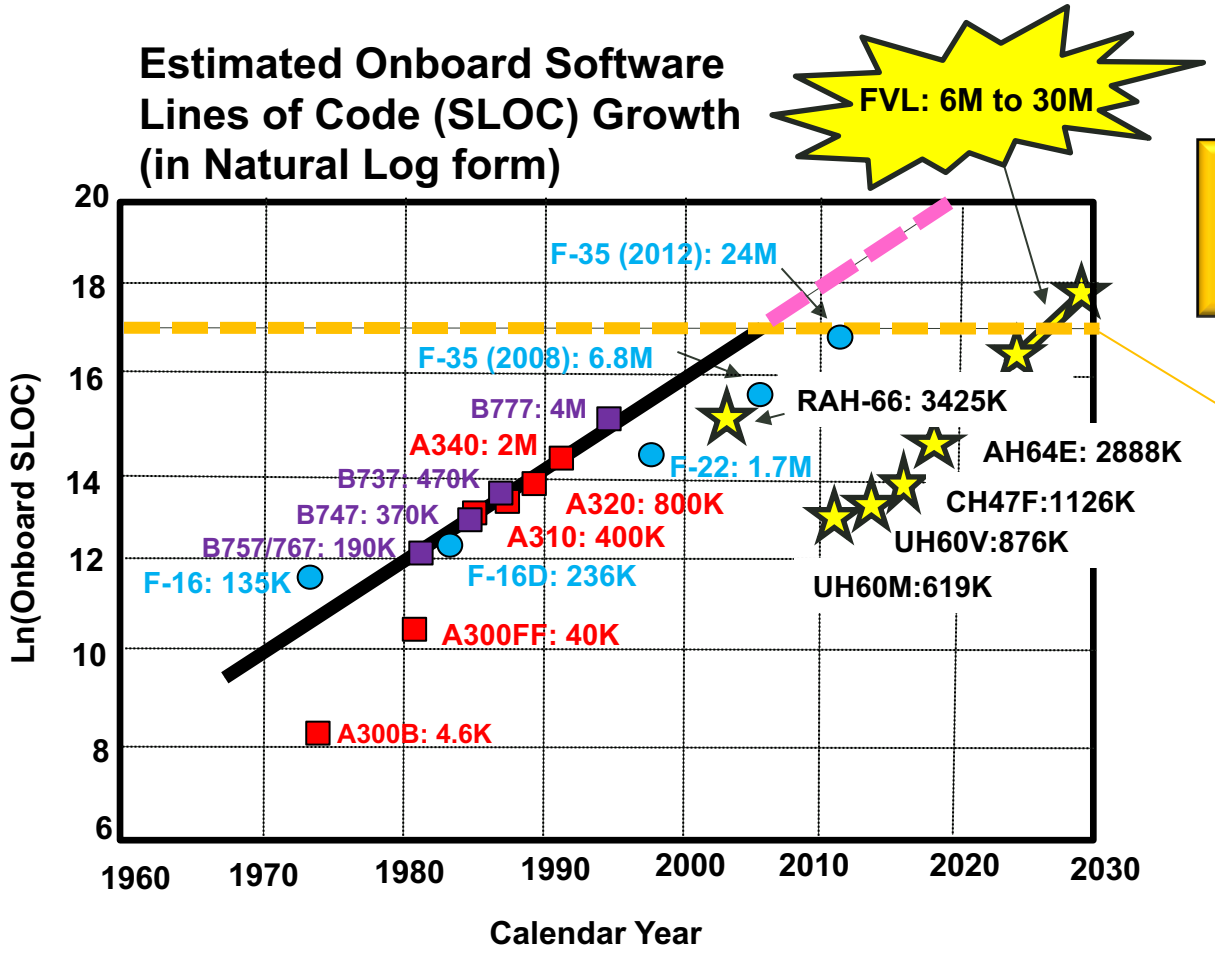
- *http://www.defense-aerospace.com/articles-view/release/3/32273/pentagon-hit-over-comanche-failings-(jan.-23).html*
- *https://en.wikipedia.org/wiki/Boeing%E2%80%93Sikorsky_RAH-66_Comanche#cite_note-26*
- *https://en.wikipedia.org/wiki/Boeing%E2%80%93Sikorsky_RAH-66_Comanche#cite_note-Eden_p139-9)*

Comanche costs were expected to consume up to 40% of US Army Aviation budget resulting in cancellation. Integration and software rework were significant cost contributors.

AVIATION SOFTWARE HAS ALREADY REACHED AFFORDABILITY BARRIER LIMITING CAPABILITY

A Commercial Aviation Industry Consortium

Estimated Onboard Software Lines of Code (SLOC) Growth (in Natural Log form)



Per SAVI, software as % of total system development cost
1997: 45%, 2010: 70%, 2024: 88%

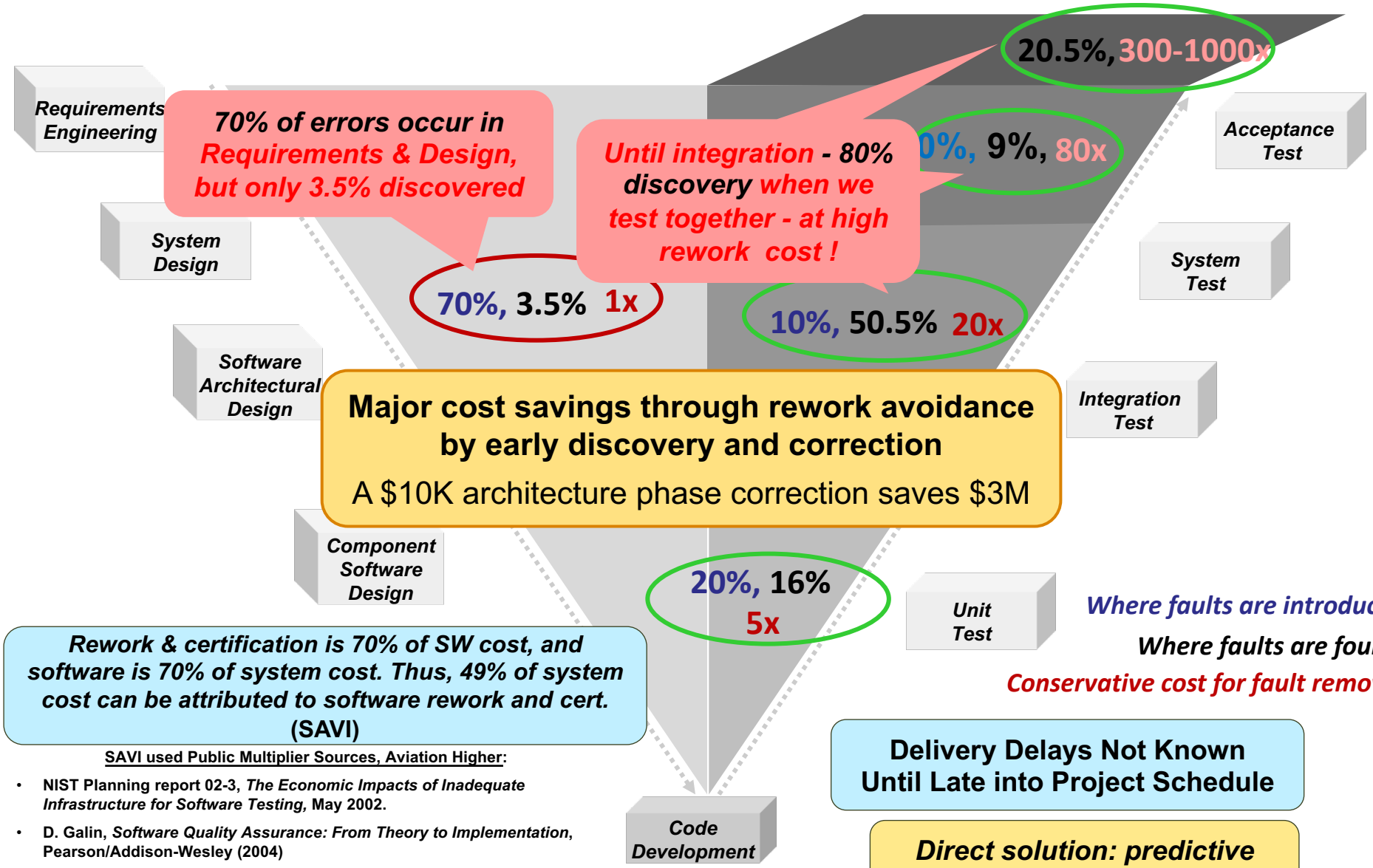
SAVI projects a limit of affordability at 27.5MSLOC or $10B in software costs

LEGEND

- Airbus
- Boeing
- Air Force Fighter
- Army Rotorcraft
- Affordability limit
- Unaffordable projection
- Straight line curve fit

Limiting SW capability directly impact strategic capabilities on weapon systems. Problem is getting worse. Leadership is key.

UNDERLYING CAUSE – INTERACTION REVEALED
LATE LARGE SOFTWARE REWORK



Rework & certification is 70% of SW cost, and software is 70% of system cost. Thus, 49% of system cost can be attributed to software rework and cert. (SAVI)

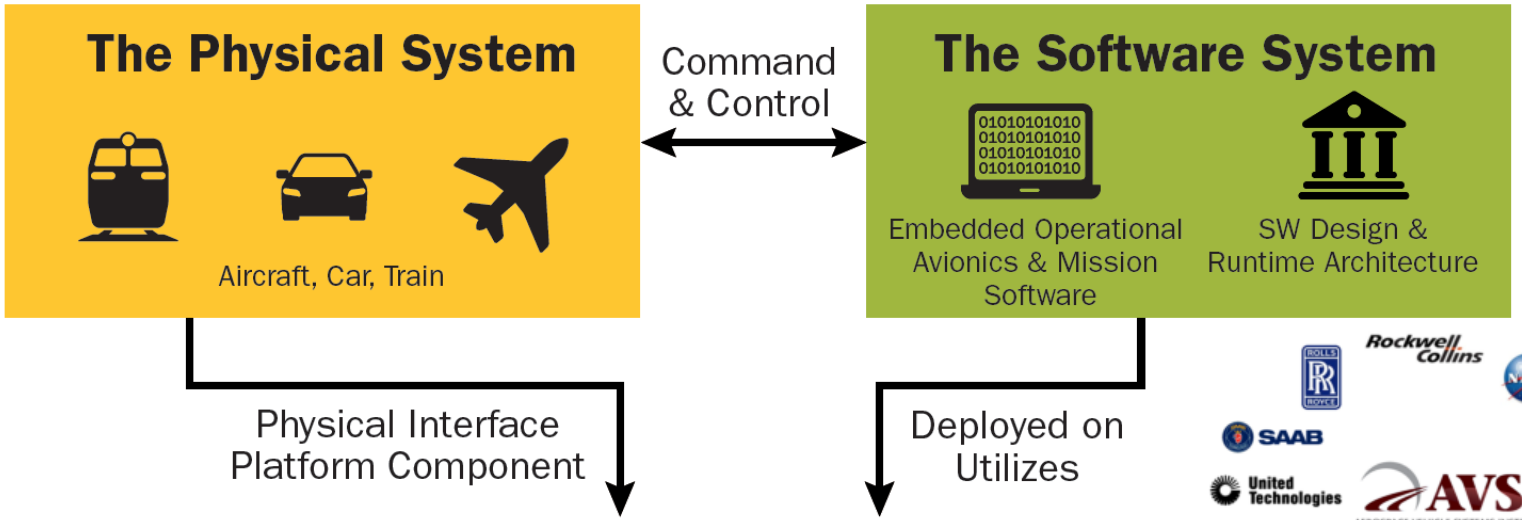
Delivery Delays Not Known Until Late into Project Schedule

Direct solution: predictive system virtual integration!

SAVI used Public Multiplier Sources, Aviation Higher:

- 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)

AADL ANALYTICALLY DESCRIBES THE REAL-TIME SYSTEM ENABLING VIRTUAL INTEGRATION



SAE International
AS 5506 Standard Suite

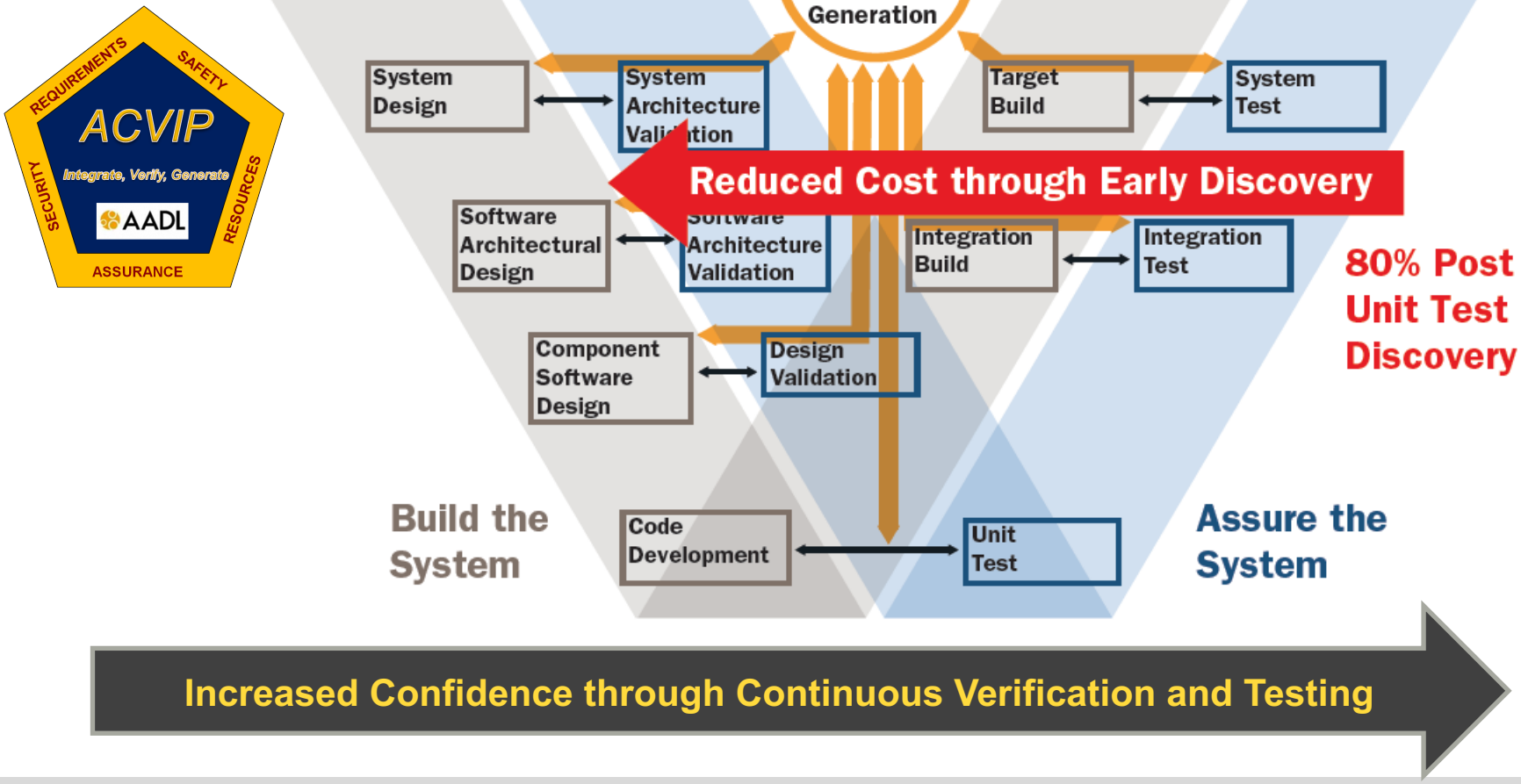
Standards provide long-term industry-wide solutions to support multi-organization model-based engineering

Rockwell Collins · NASA · SAAB · Honeywell · United Technologies · AVSI · AEROSPACE VEHICLE SYSTEMS INSTITUTE · aerospace valley · SAVI · System Architecture Virtual Integration · AIRBUS · EMBRAER · BOEING · AIRBUS GROUP

In 2008 Aerospace industry initiative chose AADL over SysML and other notations as it specifically addresses embedded software systems

Standardized AADL captures mission and safety critical embedded software system architectures in virtually integrated analyzable models

ACVIP PROCESS APPLIES AADL INCREMENTALLY TO CATCH INTEGRATION ISSUES EARLY



NEED FOR INTEGRATED ENGINEERING ANALYSIS OF EMBEDDED SOFTWARE SYSTEMS SIMILAR TO PHYSICAL

Virtual Integrated Physical System
Analysis Uses Computer Models (e.g. CAD)

- Aerodynamics
  - Aero elastics
  - Stall and Compressibility
  - Acoustics
- Structures
  - Static and Dynamic
  - Flutter and Vibration
  - Fatigue
- Drive Systems
  - Power Transmission
  - Wear and Fatigue
- Engine
  - Power Available
  - Fuel Required
- Mission Performance
  - Payload
  - Range
  - Speed

Change in # Rotor Blades from 2 to 4

↓

Increased Wt & Change in Vibrations

↓

Increased Power Transmission

↓

Increase in Fuel Flow

↓

Potential Loss of Capability

Virtual Integrated Software System
Analysis Uses AADL Model

- Security
  - Intrusion
  - Integrity
  - Confidentiality
- Resource Consumption
  - Bandwidth
  - CPU Time
  - Power Consumption
- Real-Time Performance
  - Execution Time / Deadline
  - Deadlock / Starvation
  - Latency
- Data Quality
  - Data Precision / Accuracy
  - Temporal Correctness
  - Confidence
- Safety and Reliability
  - MTBF
  - FMEA
  - Hazard Analysis

Change of Encryption From 128 bit to 256 bit

↓

Higher CPU demand

↓

Increased latency

↓

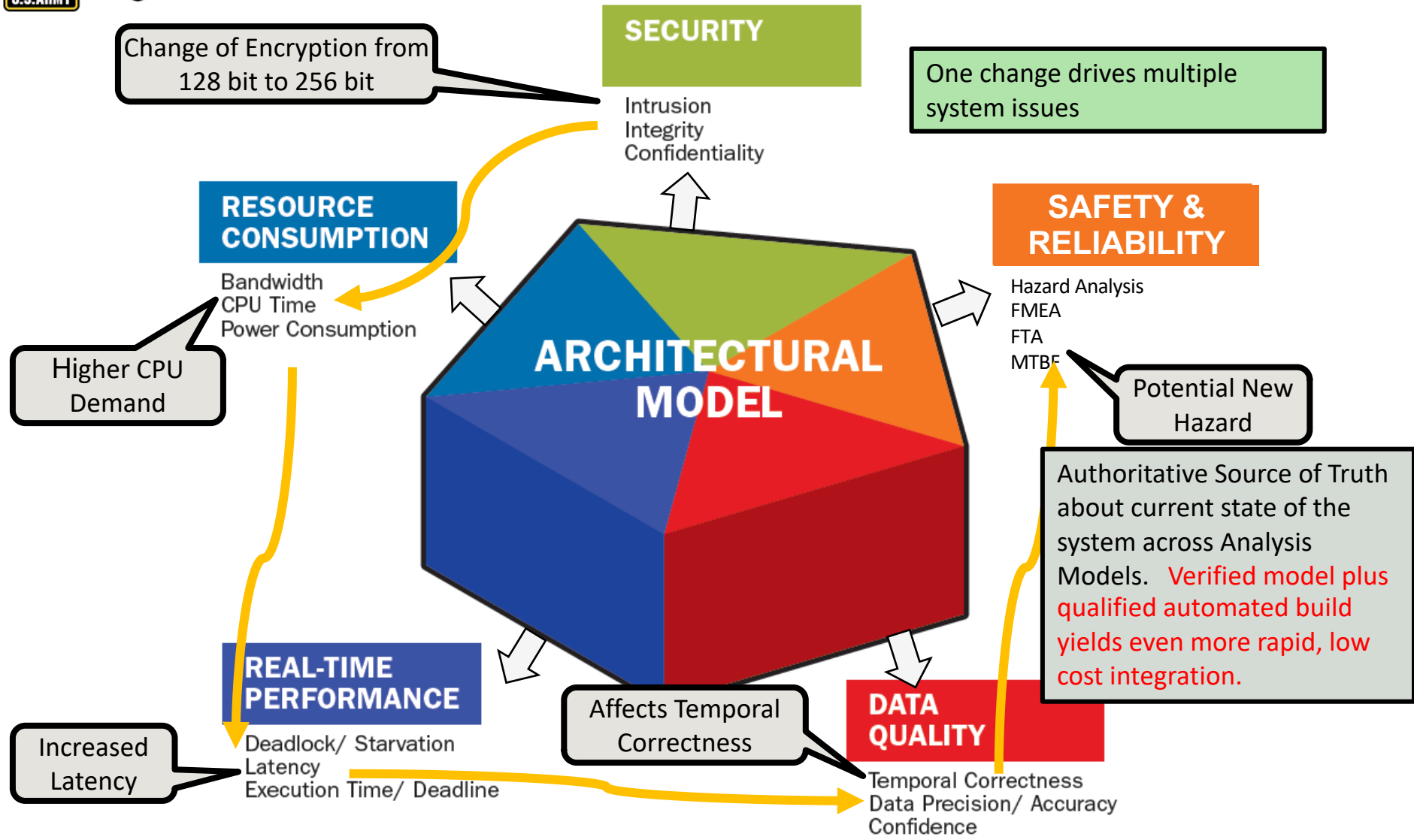
Affects temporal correctness

↓

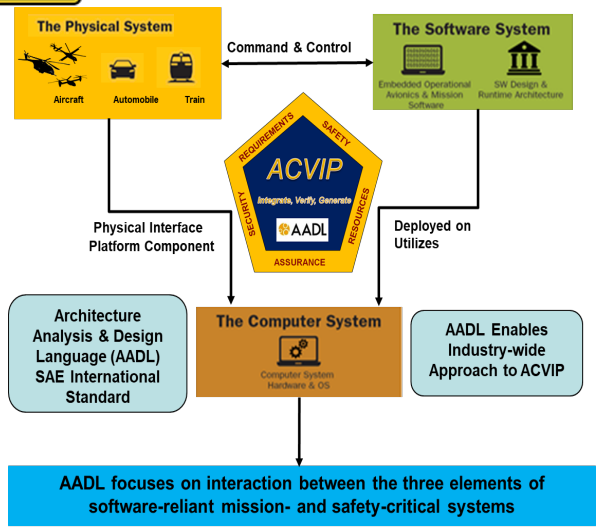
Potential new hazard

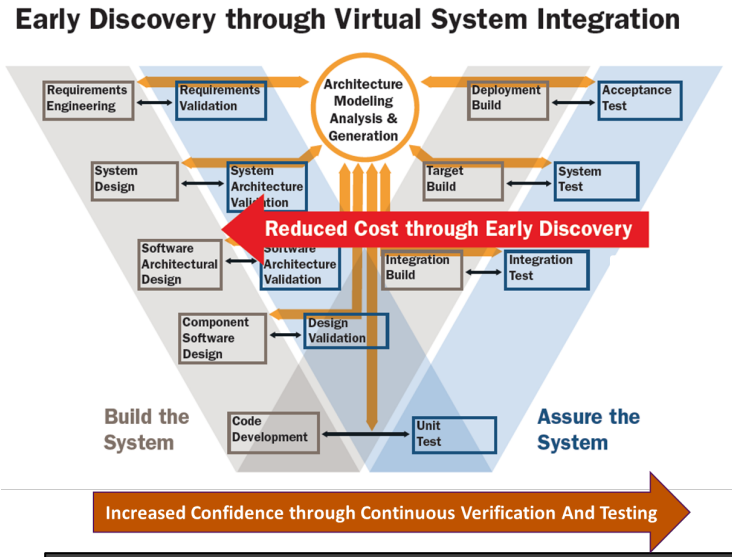
Auto code generation from AADL Virtual Model is similar to Automated fabrication from CAD Virtual Model

ACVIP INCLUDES MULTIPLE DOMAINS OF ANALYSIS AGAINST AN INTEGRATED ARCHITECTURAL MODEL TO REVEAL EMERGENT EFFECTS AND PROVIDE AN UP-TO-DATE SOURCE OF TRUTH



ARCHITECTURE CENTRIC VIRTUAL INTEGRATION PROCESS (ACVIP)

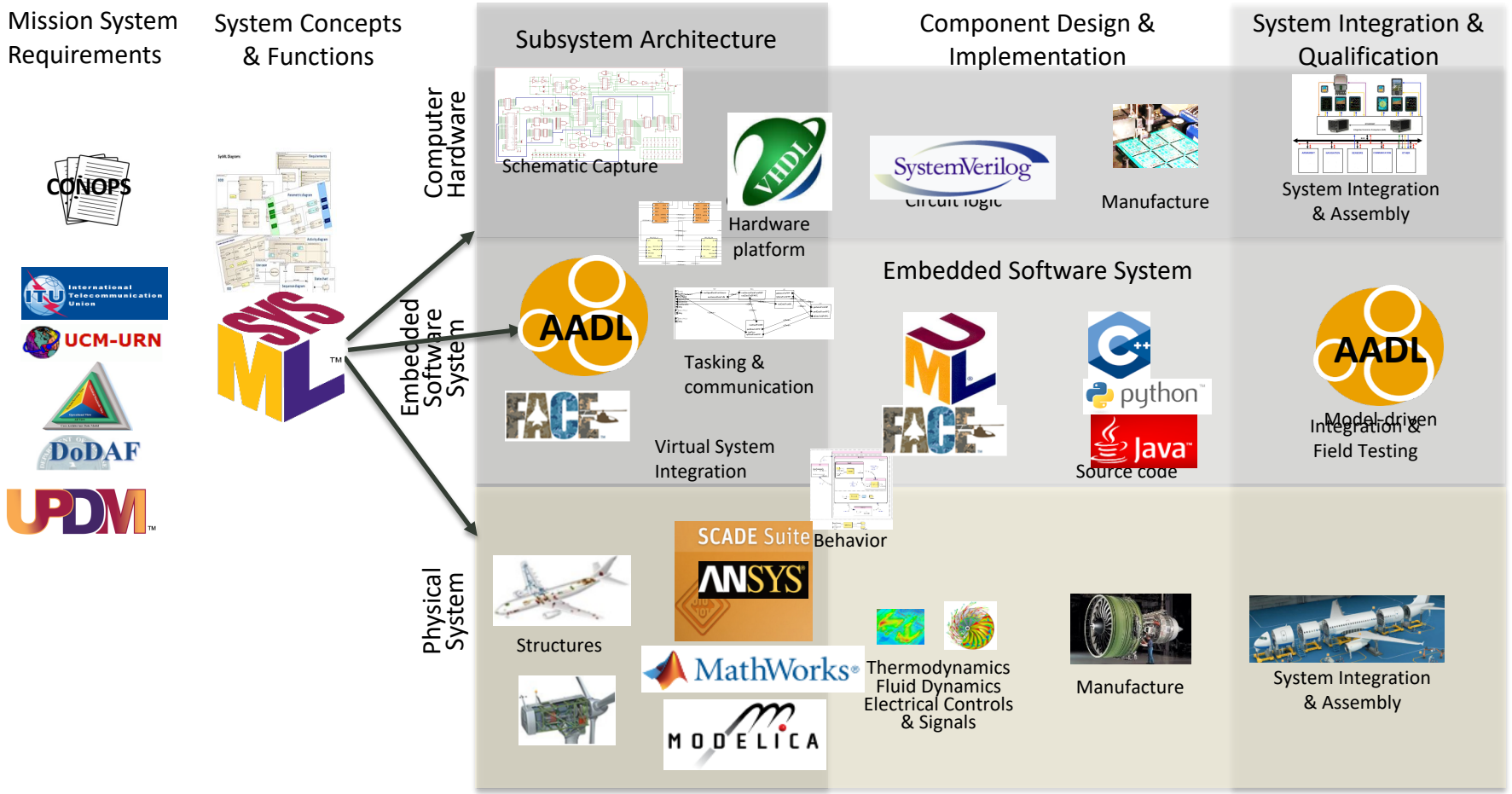




- **Leverages** research from the AVSI **SAVI** consortium which used virtual integration to draw down costs in commercial aviation systems
- **Utilizes architecture models** to perform **virtual integration focusing on** software-intensive parts of real-time safety- and security-critical **computing systems** to **identify issues early before integration**
- **Process** (from ACVIP Modeling & Analysis Handbook)
  1) **Develop ACVIP Management Plan**
  2) **Establish Model Structure**
  3) **Define Model Content Needed for Analysis**
  4) **Incrementally Execute Analyses, Resolve**
  5) **Build System in Conformance to Models**
  6) **Support Certification and Readiness Reviews**
- **Supports architecture-based compositional modeling and analysis** of computing system properties
- Analytical results support **increasing assurance confidence** and compliments testing
- Provides an **"Authoritative Source of Truth"** embedded systems architectural model

Virtual Integration of Software, Hardware, and System incrementally supporting verification, airworthiness, safety and cyber security certification

AADL COMPLEMENTS RATHER THAN REPLACES LANGUAGES AND TOOLS



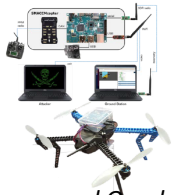
Filling the Modeling and Analysis Gap for Embedded Software System

DEMONSTRATIONS OF EFFECTIVENESS IN USE OF ACVIP WITH AADL

Finding Problems Early (AMRDEC/SEI)

- Summary: 6 Week Virtual Integration of health monitoring system on CH47F using AADL
- Result: Identified 20 major integration issues early
- Benefit: Avoided 12-month delay on 24-month program

CH47 Chinook



Unmanned Quadcopter

High Assurance Cyber Military Systems (HACMS)

TARDEC Autonomous Truck

Unmanned Little Bird

Improving System Security (DARPA / AFRL) 2017

AADL applied to Unmanned Aerial Vehicles & Autonomous Truck

Result: AADL models enforced security policies and were used to auto build the system

Benefit: Combined with formal methods verification, prevented security intrusion by a red team

Transforming procurement (Joint Multi-Role) 2017

- Summary: Industry/DoD mission system architecture demonstrations using ACVIP
- Result: Pre-integration fault identification
- Benefit: 10X reduction integration test cost

Makes complex capabilities possible through Agile analytic and virtual integration of real-time safety and security critical cyber physical embedded systems

ACVIP MODELING & ANALYSIS MATURED ON JMR MSAD DEMONSTRATIONS

FY14 | FY15 | FY16 | FY17 | FY18 | FY19 | FY20

1Q 2Q 3Q 4Q | 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 Demo / ACVIP Shadow

ACVIP Related Tasks

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

Boeing Sikorsky · Honeywell

ACVIP Shadow on JCA Demo: *>85 Issues found via requirements, safety and timing analysis*

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 provided "evidence" of ability to meet USG business and process goals and are relevant to industry and Army aviation PM plans
- Model exchange and analysis and tools exercised
- Generated several lessons learned

Boeing Sikorsky · Lockheed Martin · GE Aviation · Northrop Grumman · Honeywell · Rockwell Collins

AIPD Lessons Learned wrt ACVIP:

- *Modeling Plan is crucial for success else modeling for sake of modeling*
- *Continue Tool maturation and addition of tools*
- *Authoritative Source of Truth needed*
- *Upfront modeling and analysis appears to* ***add significant value: ~3x increase to requirements and design activities, resulted in ~10x reduction on test and integration activities***

Mission Systems Architecture Capstone Demonstration

△ RFI △ BAA △ Award △ Award △ Award △ Award

Approach

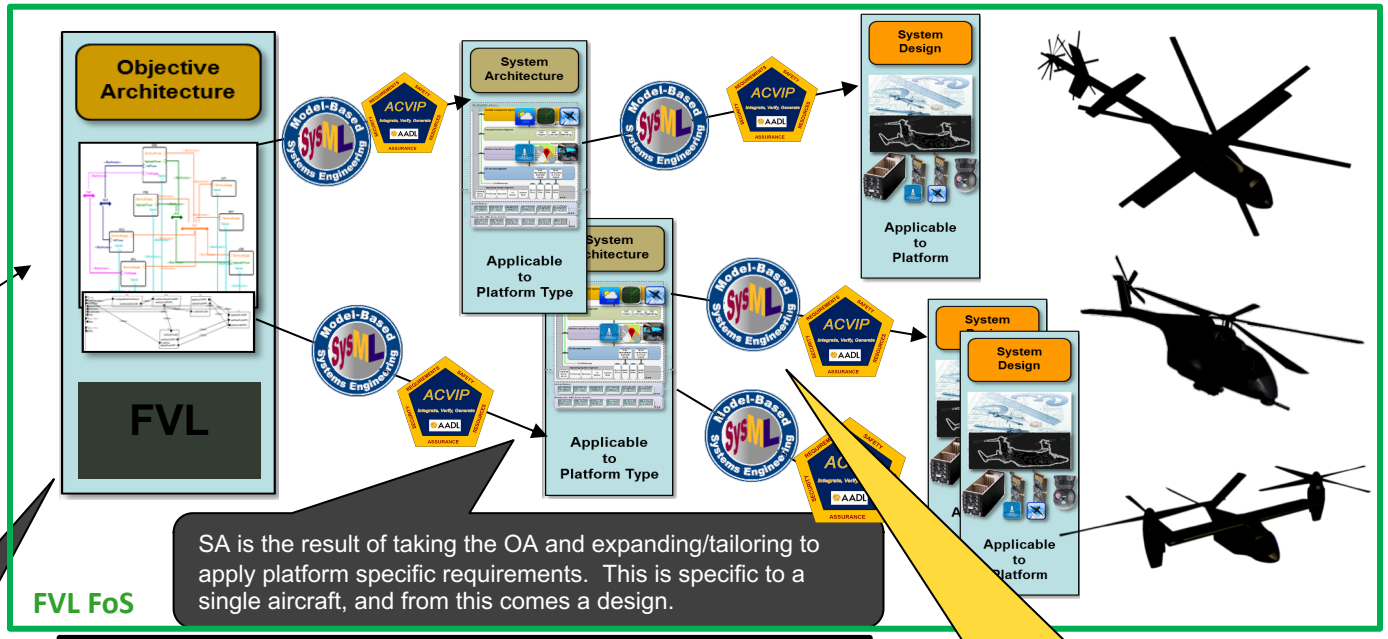
- Implementation of a partial, notional mission systems architecture
- Multiple vendors
- Model Based Acquisition
- ACVIP Modeling / Analysis
- JCA / FACE Validation
- Scope of implementation limited by available resources (i.e. design only, limited lab implementation / test, etc.)

ACVIP is being applied across JMR MSAD Demonstrations

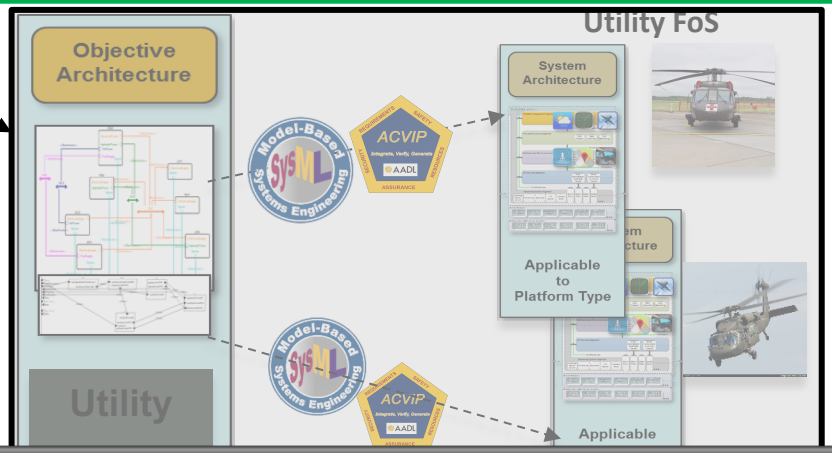
AADL/ACVIP TO BE APPLIED TO FUTURE VERTICAL LIFT & ENDURING FLEET

RA is a consolidated list of architectural resources such as FACE, JCA, HOST, reusable assets (e.g. IDM, 231, etc), domain specific data models, AV/MSA interface, use cases/CONOPs, policies and directives, and applicable standards, tools, practices such as MBSE, ACVIP, STPA etc.

OA is a selection of applicable RA content and applying it to a set of AVs that we intend to share a common set of attributes (could think of this as all sharing a "CAAS" or "MCAP" architecture, displays, etc). It is beginning to look like a system architecture, but it still is not specific to a single aircraft



SA is the result of taking the OA and expanding/tailoring to apply platform specific requirements. This is specific to a single aircraft, and from this comes a design.



MBSE leveraging SysML is applied to wide system level requirements modeling & analysis

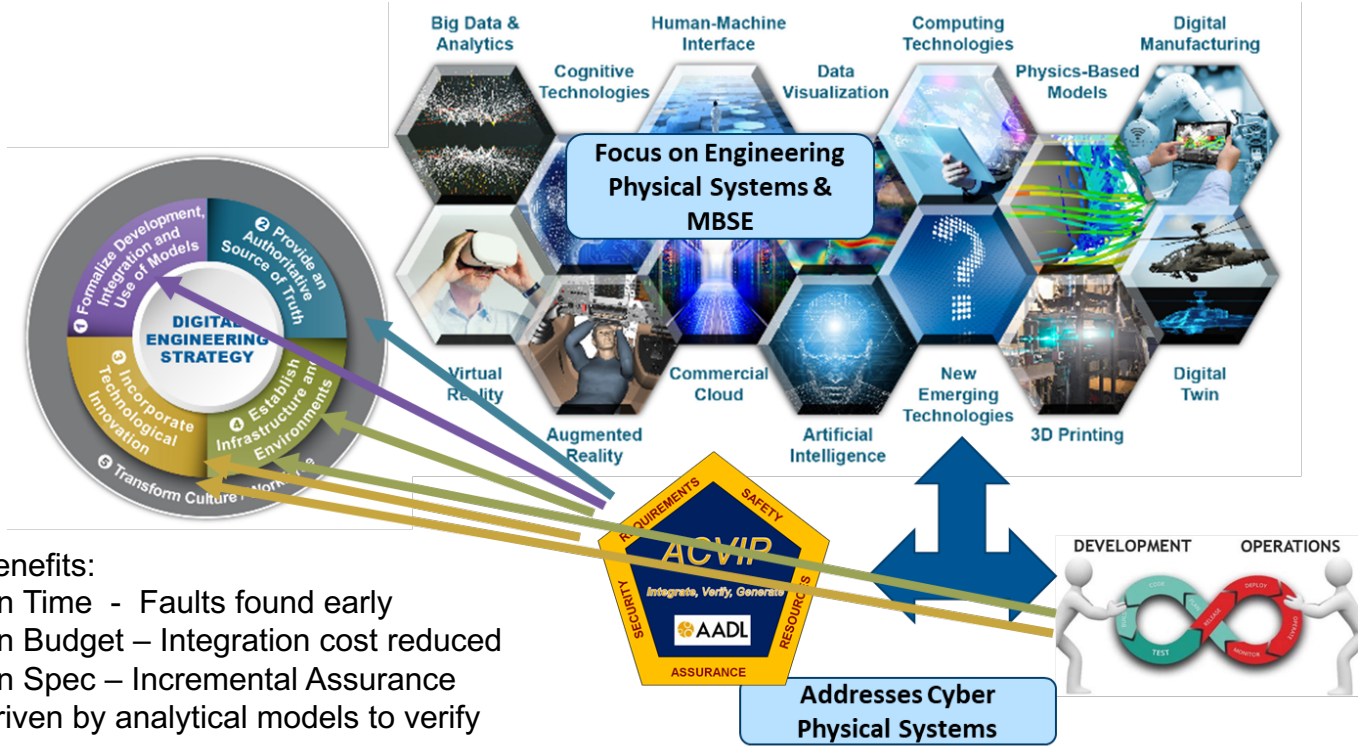
+

MBE with ACVIP leveraging AADL is applied to embedded computing system level modeling & analysis to mitigate integration issues

Controlling and reducing software/system integration is a key objective for Army Aviation. AADL/ACVIP will be used to directly address this issue.

DOD DIGITAL ENGINEERING STRATEGY: ACVIP & AADL FOCUSES ON CYBER PHYSICAL SYSTEMS

"A Cyber Physical System (CPS) is a system that is controlled or monitored by computer-based algorithms, tightly integrated networks and its users. In cyber-physical systems, *physical and software components are deeply intertwined, each operating on different spatial and temporal scales, exhibiting multiple and distinct behavioral modalities, and interacting with each other in a lot of ways that change with context*."



Source: "US National Science Foundation, Cyber-Physical Systems (CPS)"

https://www.nsf.gov/pubs/2010/nsf10515/nsf10515.htm

Benefits:
On Time - Faults found early
On Budget – Integration cost reduced
On Spec – Incremental Assurance
Driven by analytical models to verify

ACVIP with AADL is key for the modeling, analysis and generation of software intensive embedded and cyber physical systems

QUESTIONS?

MISSION


Deliver collaborative and innovative aviation and missile capabilities for responsive and cost-effective research, development and life cycle engineering solutions.

BY THE NUMBERS

12,054 FY19 Strength

3,036 Civilian

23 Military

~8,995 Contractor

FY19 Funding

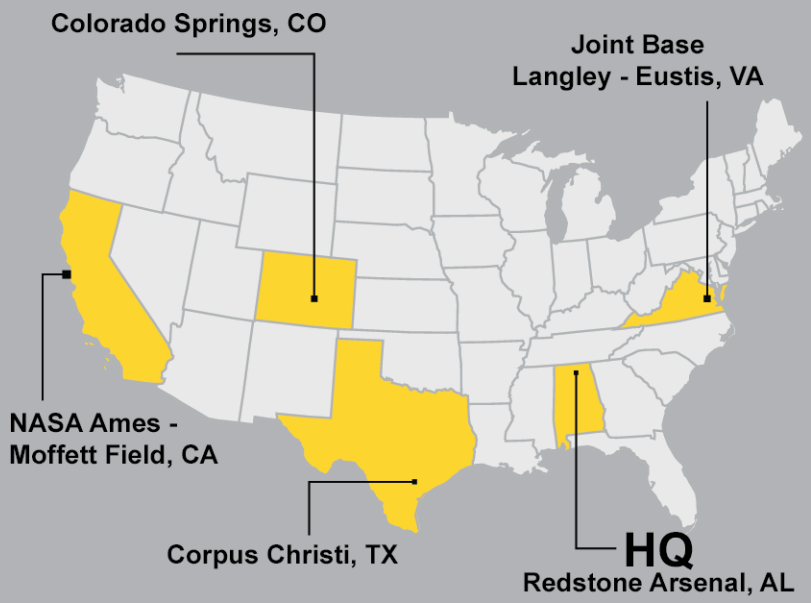
$3.8B

6% Aviation S&T

7% Missile S&T

59% Army

28% Other



Core Competencies

Technical Domain:

- Active and Passive Air Defense Sensor Technology (S&T)
- Aerial Autonomy
- Aerospace and Aerodynamics
- Capabilities Engineering
- Materials and Structures
- Fuzing, Guidance, Controls and Seekers
- Propulsion, Explosives, Energetics, Warheads

Capabilities Engineering:

- Software Engineering
- Weapons Assurance
- Modeling and Sim Design, Dev, VV&A
- Configuration Management
- Engineering Prototype Design and Dev
- Maintenance, Life Cycle Cost Reduction, and Logistics Engineering
- Manufacturing Tech and Production Support
- Multidiscipline Acquisition and Project Engineering
- Quality Engineering and Management
- Reliability, Availability, and Maintainability
- Sustainment, Industrial Base, and Obsolescence
- Systems Engineering, Integration, and Interoperability
- Test and Evaluation
- Air Defense Radar (Reimbursable)
- Airworthiness

PRIORITIES

#1: People

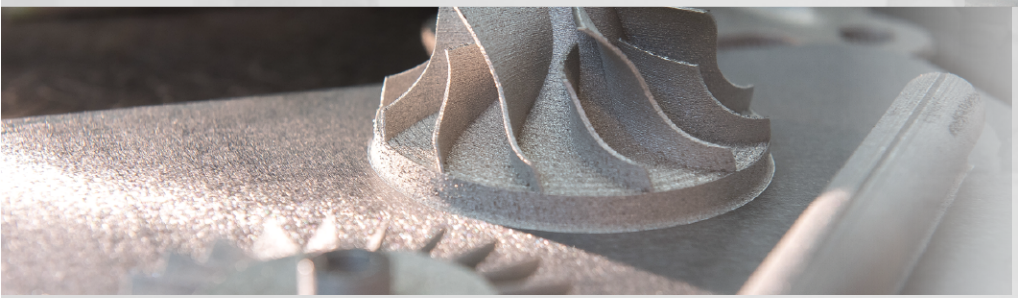
People are the Army's greatest strength and its most important weapon system.

#2: Readiness

The Army must be ready to defeat any adversary, anywhere, whenever called upon, under any condition.

#3: Modernization

The Army must modernize to remain lethal and ready to fight tomorrow, against increasingly capable adversaries and near-peer competitors.



#4: Reform

The Army will improve the way we do business, including how we implement our top priorities, to make the Army more lethal, capable, and efficient.

S&T PRIORITIES ALIGNED WITH THE ARMY MODERNIZATION STRATEGY

Supporting Army and Joint Readiness now and in the Future MDO Environment

RESEARCH ISO FUTURE FORCE

Driving the discoveries and innovations which will be critical to realizing new capabilities for the Army of 2030 and beyond.

ANALYSIS

Conducting objective experimentation and systems analysis to support the equipping and sustaining of our Warfighters.

ENGINEERING

Providing lifecycle engineering expertise to support fleet development and readiness across warfighting battlefield operating systems.

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