Verification and Validation of Flight Critical Systems (VVFCS)

Area 2 (SSAT 4.1.3) – Integrated Distributed Systems
Area 4 (SSAT 4.1.4) – Software Intensive Systems

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Areas 2 and 4

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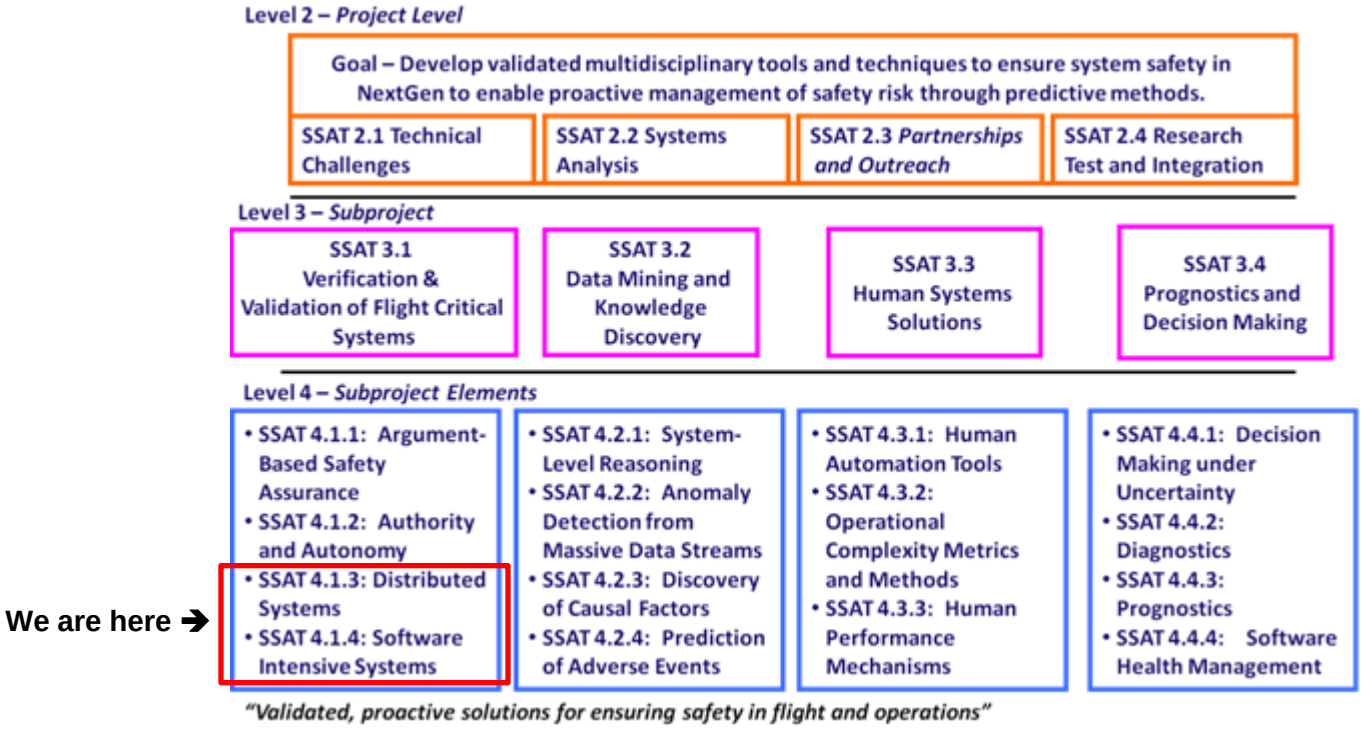
- **NASA is sponsoring a multiple-area multi-year program for verification and validation of flight critical systems.**
- **Objective**
  - **Provide advanced analytical, architectural, and testing capabilities to enable sound assurance of safety-critical properties**



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Area 2 – Integrated Distributed Systems - Overview

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- **Program to mature processes and tools, by creating:**
  - **Advanced analytical, architectural, and testing capabilities**
  - **Comprehensive collection of re-usable models**
  - **Approaches enabling objective engineering trade-offs to resolve debates about "best" approach**
- **Motivation**
  - **Integrated systems are becoming more complex**
  - **Next Gen systems will be even harder**
  - **Often a gap between formal theory and real-world systems**
    - E.g., Byzantine fault tolerance is often over-looked
    - On other hand, systems designed for worst-case theoretical modes of failure can be overly brittle
    - Need better modeling technology to focus attention on what really matters
- **Team**
  - **Prime: Honeywell**
  - **Subs: SRI and WW Technology Group**
- **Phases**
  - **Phase I: One Year – September 2010 to September 2011**
  - **Phase II: Two Years – September 2011 to September 2013**

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Area 2 – Phase I Focus and Key Results Overview

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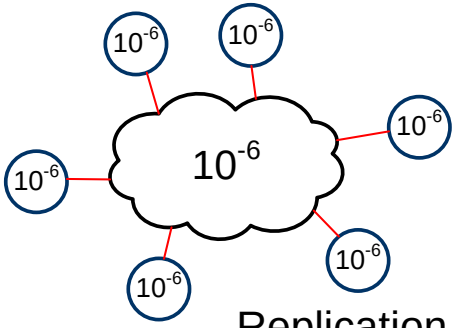
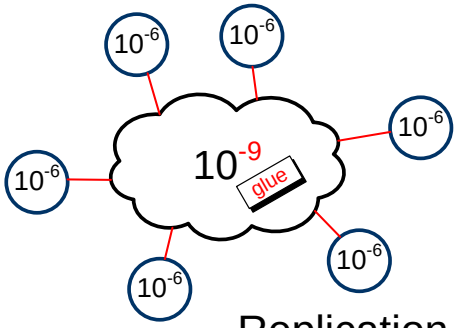
- **Main focus on communication networks**
  - **Why are data networks so important?**
    - Network(s) form the backbone of a system
    - The design of the network(s) becomes an approximation for the system architecture
    - In the absence of system architects, the network designers become the architects
  - **As "glue" for a fault tolerant system, the network must be more dependable than any component**



Replication useless



Replication useful

- **Some Key Results**
  - **Maturation of Architecture Analysis and Design Language (AADL)**
  - **Discovered an edge-case in TTEthernet**
    - Able to fix the SAE 6802 standard before its ratification
    - Able to fix NASA Orion CEV ASIC design before "cast in silicon"
  - **System-level test generation for distributed architecture**
    - Full MC/DC protocol coverage

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Area 2 – Phase I Work

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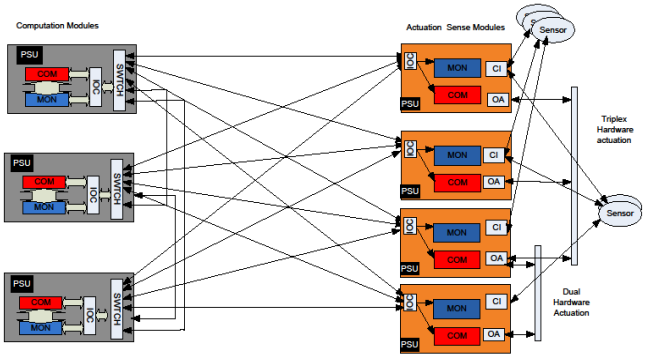
- Initial AADL modeling of diverse set of networks
  - SAFEbus (a backplane bus based on self-checking pairs)
  - TTP/C (a time-triggered bus protocol using simplex nodes)
  - SPIDER (a voter-based Byzantine-tolerance broadcast network)
  - BRAIN (a braided ring using high integrity message forwarding)
- PRISM probabilistic modeling of the SPIDER broadcast protocol
- Model-driven distributed test generation
- EDICT modeling derived from some of the AADL models and explored "out-of-band" error propagation
- A framework for relating properties in architectural models to control software models to support an end-to-end assurance case

- **Year 2 – Extending models to applications**
  - **Triplex high-integrity control case-studies**
    - Asynchronous / Time Triggered Architectures
    - Homogeneous / Heterogeneous Networks
    - Voted / Masked fault tolerance strategies
  - **Technologies**
    - Formal analysis of architecture behavior and key safety properties
    - Integrated formal analysis of continuous and discrete systems
    - Integration of AADL error and behavioral modeling



- **Year 3 – Extending models for system-of-systems**
  - **Looking for some good system-of-systems examples**

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Area 2 – General Influence of Phase II Studies

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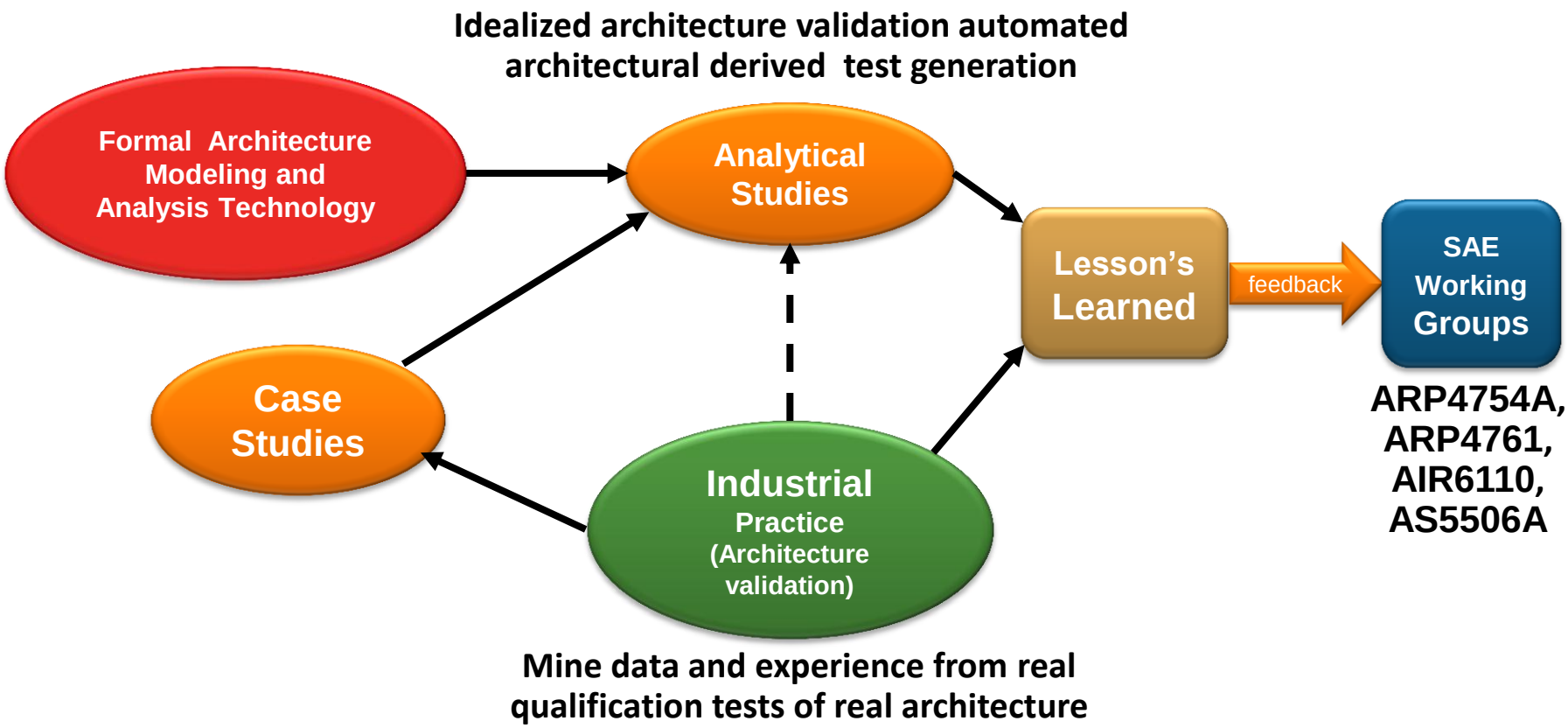

ARP4754A: Guidelines for Development of Civil Aircraft and Systems
ARP4761: Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment
AIR6110: Contiguous Aircraft/System Development Process Example
AS5506A: Architecture Analysis & Design Language (AADL)

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Area 2 – Phase II Async Case Study Influence Flow

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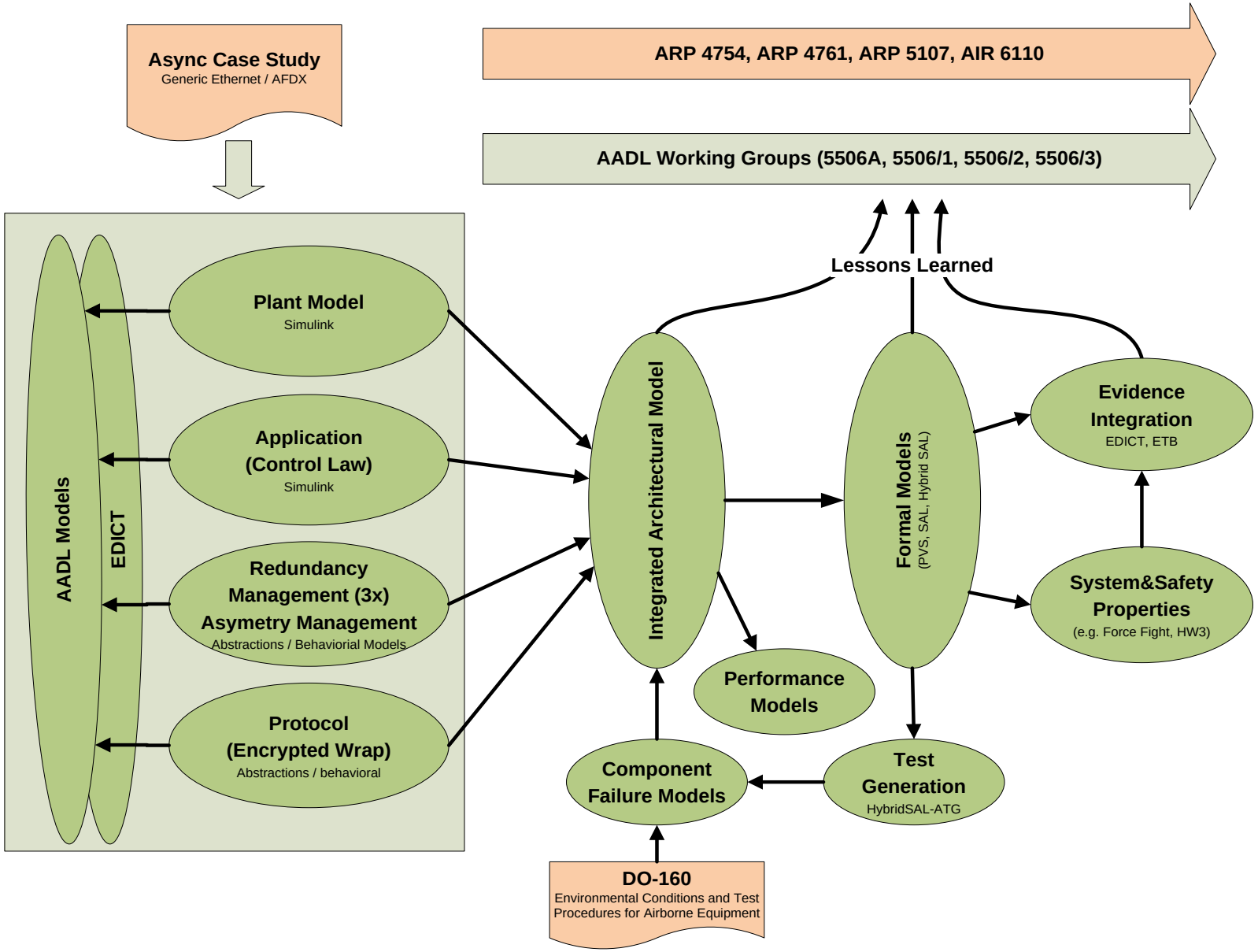

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Area 2 – Phase II Sync Case Study Influence Flow

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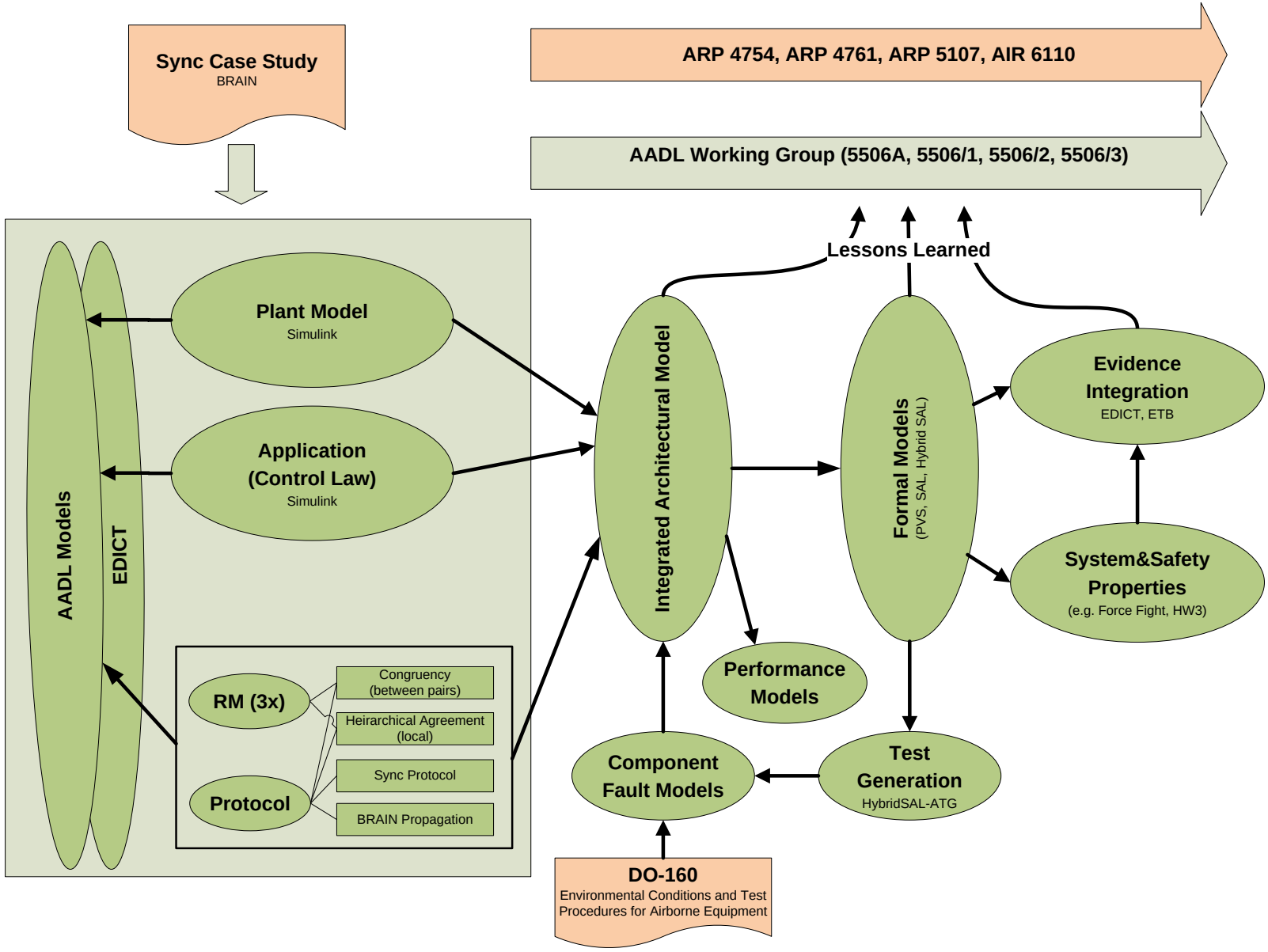

An Evidential Tool Bus for Flight-Critical Software Systems

- **We are developing a semantic framework for the end-to-end assurance of flight-critical software, specifically**
  - **Model-based design methodologies**
  - **Analysis capabilities based on powerful deductive tools**
  - **Formalized mathematical libraries for engineering complex systems**
  - **Compositional analysis of software-intensive systems**
- **The Evidential Tool Bus (ETB) is a platform for integrating multiple analysis capabilities into a unified assurance case**
- **Team**
  - **Prime Contractor SRI International: Shankar Natarajan and Sam Owre**
    - shankar@csl.sri.com
  - **Sub Contractor Honeywell: Devesh Bhatt, David Oglesby, Gabor Madl**
    - devesh.bhatt@honeywell.com

Note: The remainder of this presentation contains Honeywell's examples for model-based analysis tools interacting over ETB.

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Area 4 – The Evidential Tool Bus (ETB)

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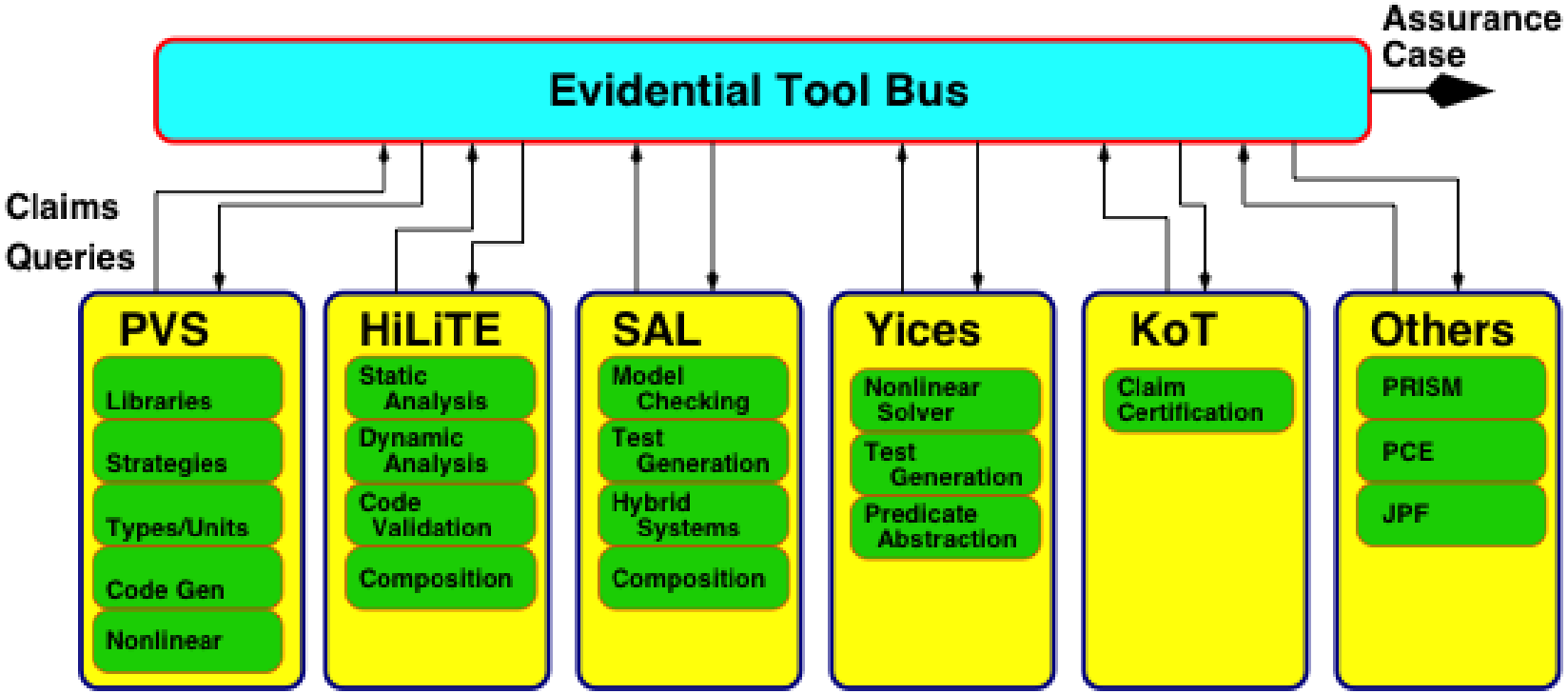

- Each tool registers a set of *claims rules* with ETB that the tool can invoke to satisfy the claim: e.g., Yices_satisfiable, HiLiTE_range_bounds_check
  - Data inputs and outputs associated with a claim: values, files (hash), JSON objects (e.g., range bounds)
- A tool can make a *query* (proof obligation) that can be satisfied by another.
- The assurance case gets dynamically constructed: ETB invokes tools to satisfy claims – and new claim queries that get generated. (*Claims Table*)

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Area 4 – HiLiTE *

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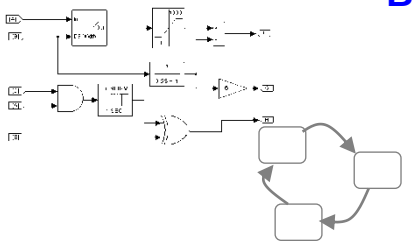
MATLAB Simulink and StateFlow Models



Multiple Block Library sets

General

Engine Control

Flight Control

System Dictionaries

I/0, Symbols ranges, type, code arch.

HiLiTE

Test Generator

Code Generator

Model Analysis

Test Cases

Test Driver

Model Object Code

Reuse Libraries

Target Processor

Detection of Design Problems
- Logic/relational conflicts
- Un-testable conditions / paths
- divide by zero, overflow
- numerical error: ambiguity/stability
- Control function level analysis

Design review automation

* HiLiTE = Honeywell Integrated Lifecycle Tools and Environment

Benefit: Reduced certification cost & cycle time; detect design problems early

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Area 4 – Approach for Tool Integration into ETB

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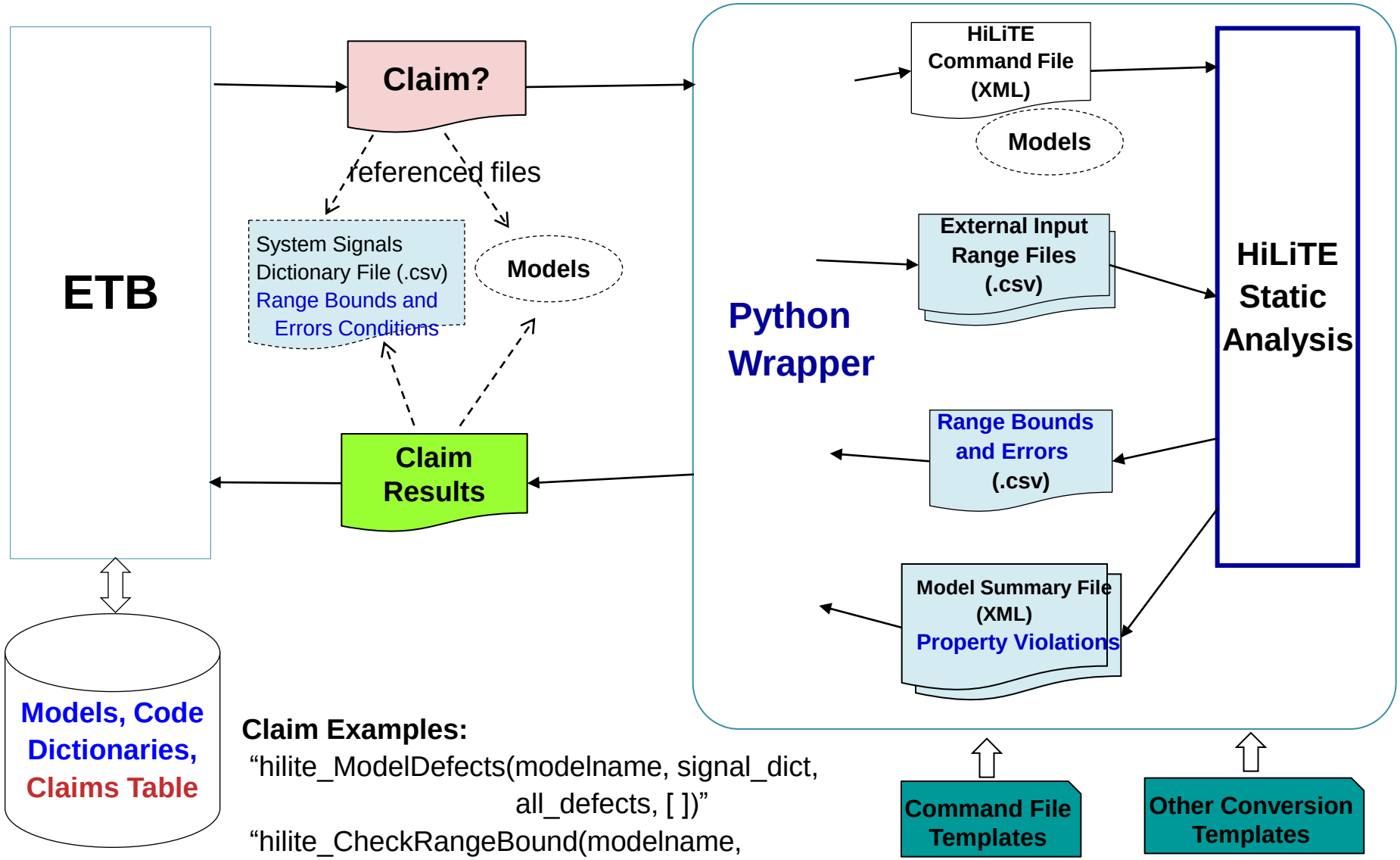

Claim Examples:

"hilite_ModelDefects(modelname, signal_dict, all_defects, [ ])"

"hilite_CheckRangeBound(modelname, {signal_name, bound}, signal_dict, [ ])"

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Area 4 – Example Claims Satisfaction Across Multiple Tools

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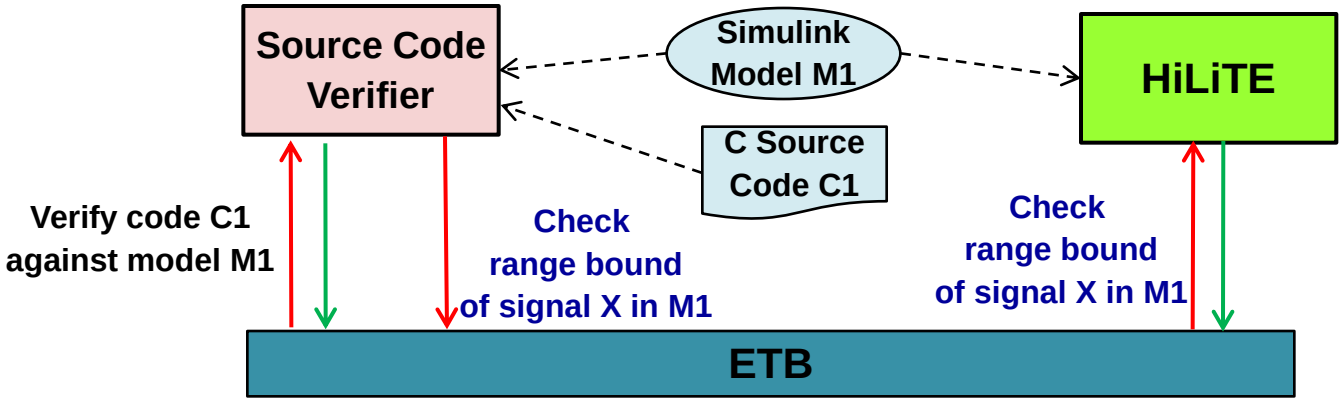

- **Claims are uniquely identified with the specific version of files (hash) and value arguments**
  - **Development artifacts: requirements, models, source code, object code**
  - **Verification artifacts: verification properties, range bounds, model defects, tests, test results**
- **Versions of files are identified with hash and maintained in distributed repositories (e.g., git) at multiple ETB nodes.**
  - **E.g., presence of a new object code file can trigger a chain of claims and tool invocations to create tests from the corresponding version of model, static analysis, checking of model, etc.**
    - Claims related to previous versions of these artifacts are irrelevant

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Area 4 – ETB Usage/Benefits in Certification Process

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- **Keeping track of changes, dependencies, and incremental verification**
  - **Many artifacts go into a verification task (activity)**
    - Input artifacts to the activity must have claims associated with specific versions of those artifacts
    - Info in files' headers needs to be matched/verified to claim an artifact's veracity
  - **Current process: detailed manual work instructions that trace artifacts and changes**
  - **ETB process: claims and goals automatically generated and chained – change impact analysis can be automated by reverse chaining**
    - E.g., presence of new object code can set off chain of claims related to source code, model, compiler
- **Composing a DO-178B/C verification objective from multiple claims**
  - **A typical DO-178B/C verification objective has many sub parts which require different types of analyses and verification methods**
  - **Current process: each objective (including all sub parts) is assigned to a specific team or tool; sometimes requires manual work/interaction to complete sub parts**
  - **ETB process: goals for each sub part of the objective are automatically generated and can be assigned to different teams/tools that can produce claims for those goals.**

- **Dispositions of problems/observations found as a result of a verification activity**
  - **E.g., in model analysis and test generation, sometimes design defects and test coverage holes are observed**
    - Each of these observations needs to be "disposed" in a combination of several ways: analysis of existing verification artifacts, supplemental analysis, design change.
    - Often, "dispositions" require manual analysis and generation of related artifacts
  - **Current process: issue/problems reports exchanged among multiple design/verification teams, manual analysis work – delays and informal/undocumented assumptions**
  - **ETB process: queries can be automatically generated from "dispositions" returned by a tool's analysis, analyses can generate claims to satisfy the queries, assumptions are formally documented and justified and can be extracted automatically by wrappers from artifacts**
    - E.g., if a variable is not explicitly initialized in the model/code then a model analyzer tool generates a query that can be satisfied by a claim (made from HW model) that all variables are implicitly initialized to 0 in flash memory.