Compositional Reasoning for Architectural Models

Software Certification Consortium
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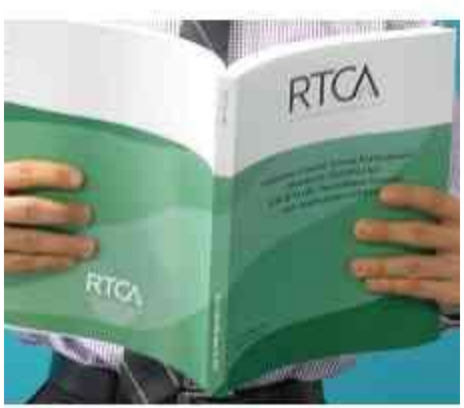
Verification of Safety-Critical Embedded Software

- **Problem**
  - As complexity increases, verification has become the most costly part of development
  - Integration can be especially challenging and expensive
- **Approach**
  - Model system architecture with standard notation with clear semantics
  - Divide verification task into manageable, reusable pieces
  - Translate these models to a form that can be interpreted by powerful general-purpose engines (SMT-based model checkers)

Certification

- We also care about certification
  - Compliance with current practice and certification guidance



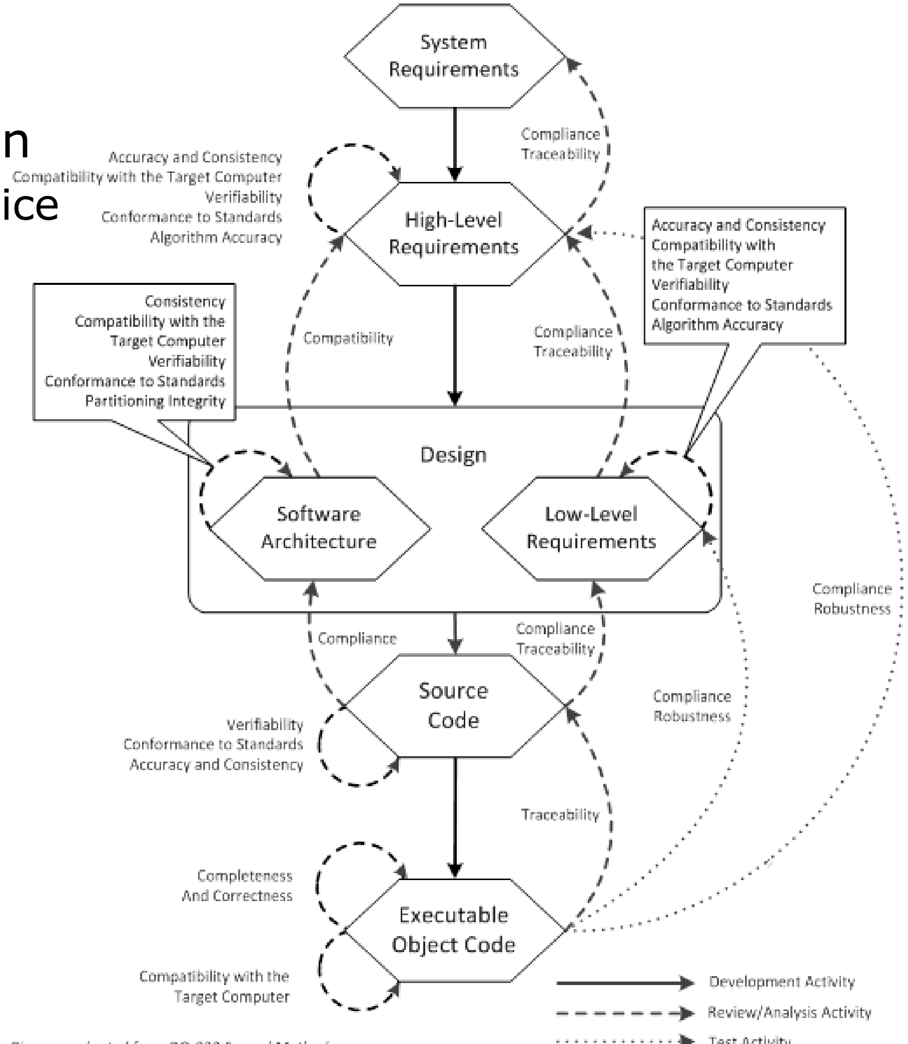
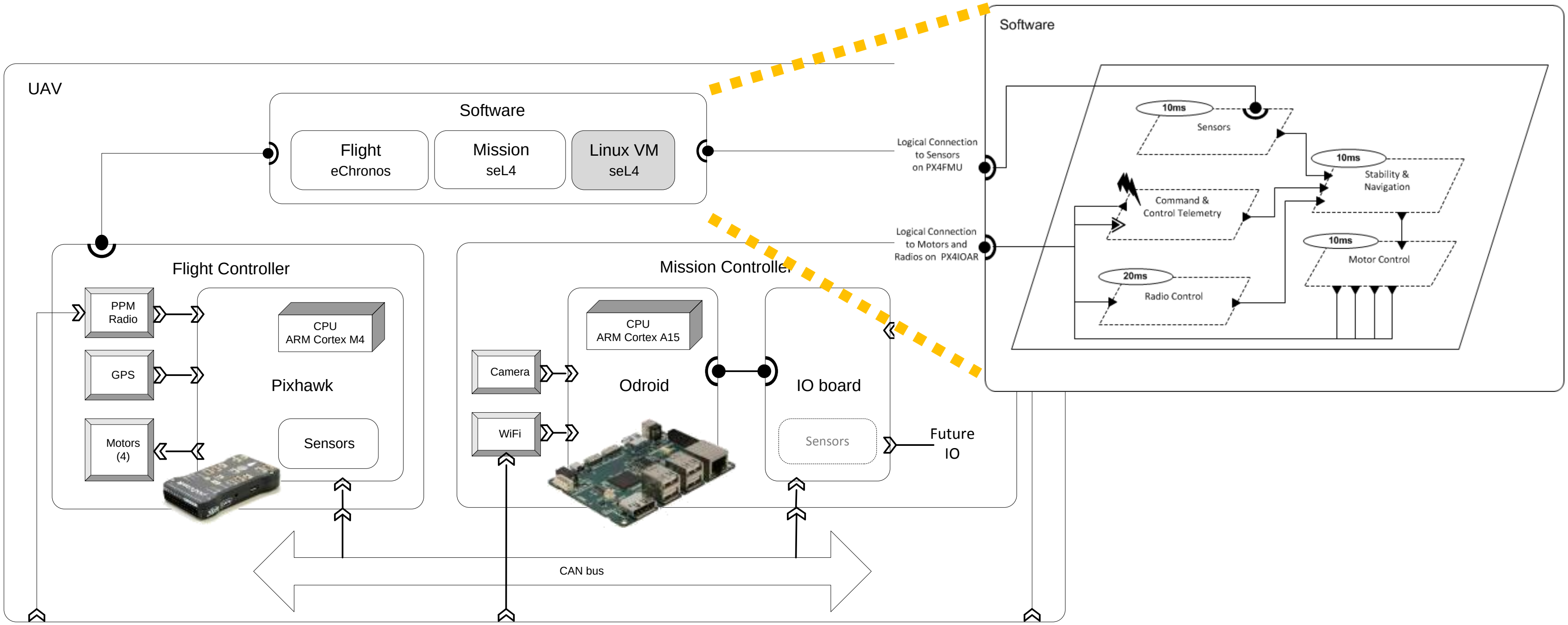


Diagram adapted from DO-333 Formal Methods Supplement to DO-178C and DO-278A

Note: Requirements include Derived Requirements

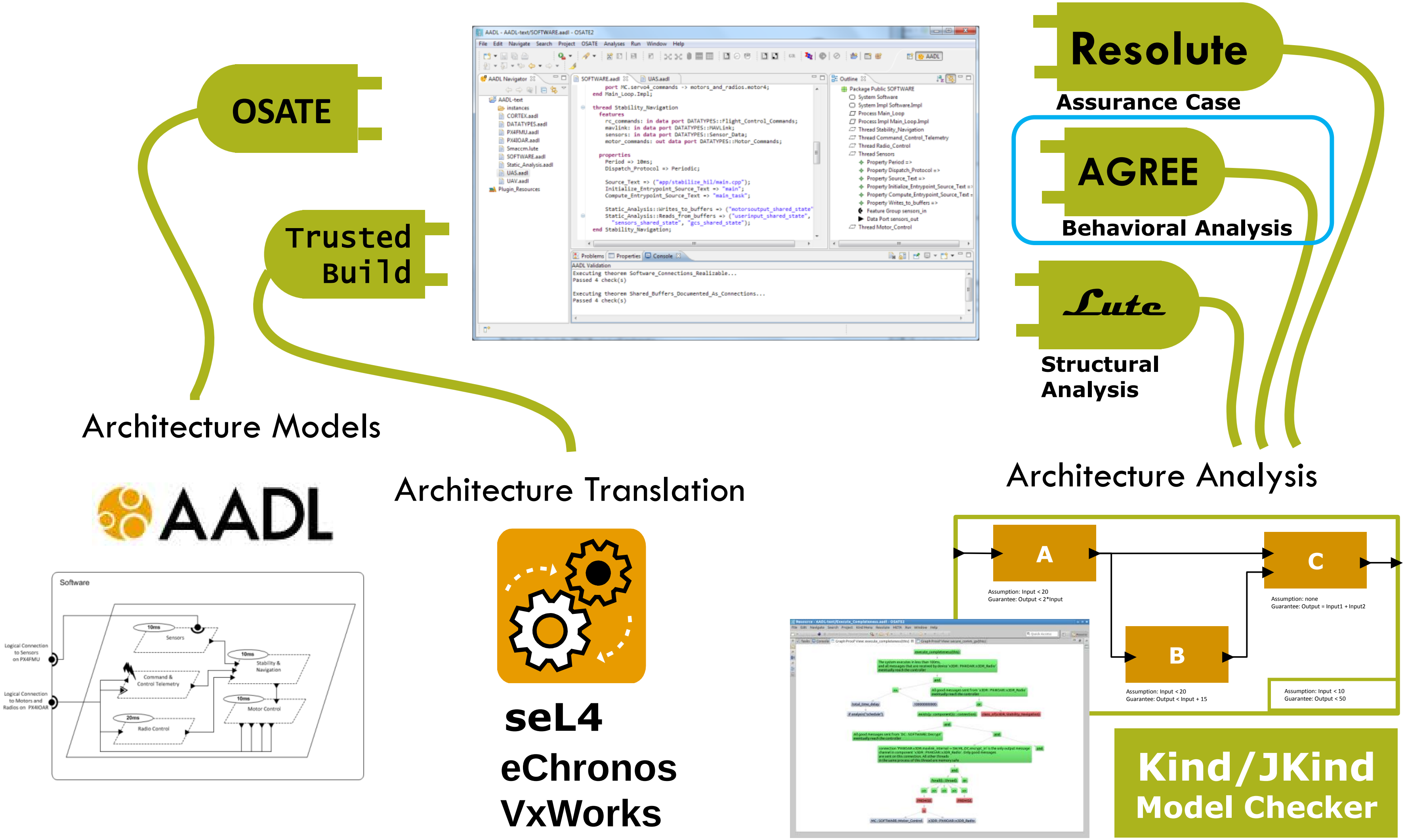
Architecture Analysis and Design Language (AADL)



AADL = SAE AS5506 standard

- Target: Embedded, real-time, distributed systems
- Describes both hardware and software
- Extensible syntax (annex)
- Open source tools, supported by SEI

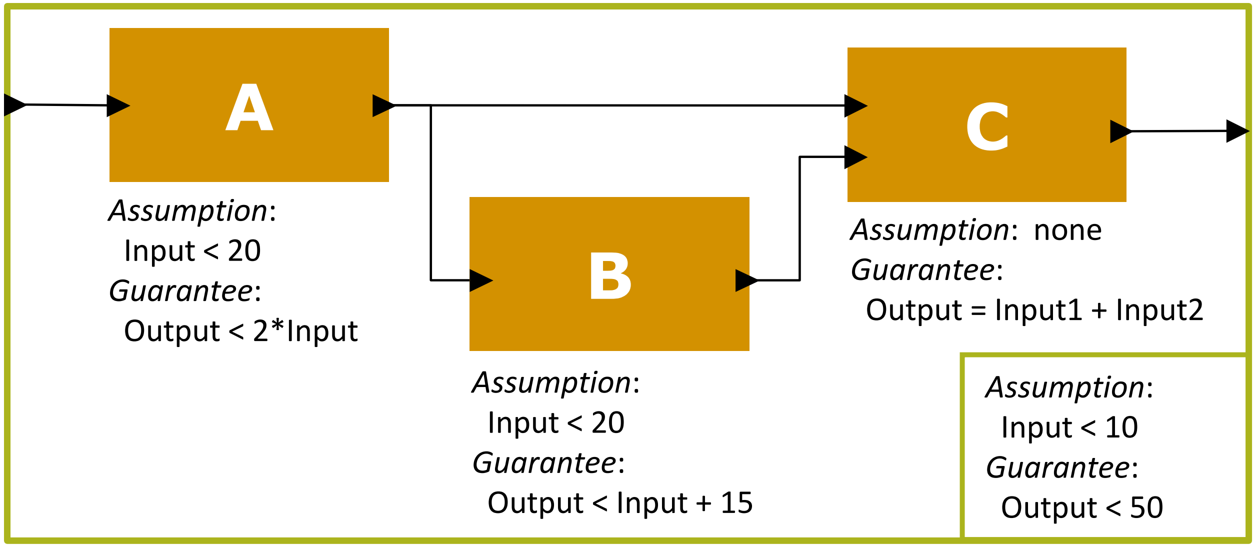
Architecture Modeling and Analysis Tools



AGREE: Assume-Guarantee Reasoning Environment

- Each AADL component contains a **assumptions** about its inputs and **guarantees** about its outputs in a **contract**.
- AGREE uses a k-induction model checker to determine whether a component implementation (its subcomponents) satisfies its contract.
- Analysis proceeds hierarchically on the model:
  - Evidence that a component’s guarantees hold only relies on evidence from its subcomponents.
  - This allows analysis to scale to larger designs.

Simple Example



Assuming the **input** to the system <10, is the **output** <50?

- Given
  - System assumptions
  - Subcomponent contracts
  - Architecture model
- Prove
  - System guarantees

Proof Obligations

$A_S \rightarrow A_A$

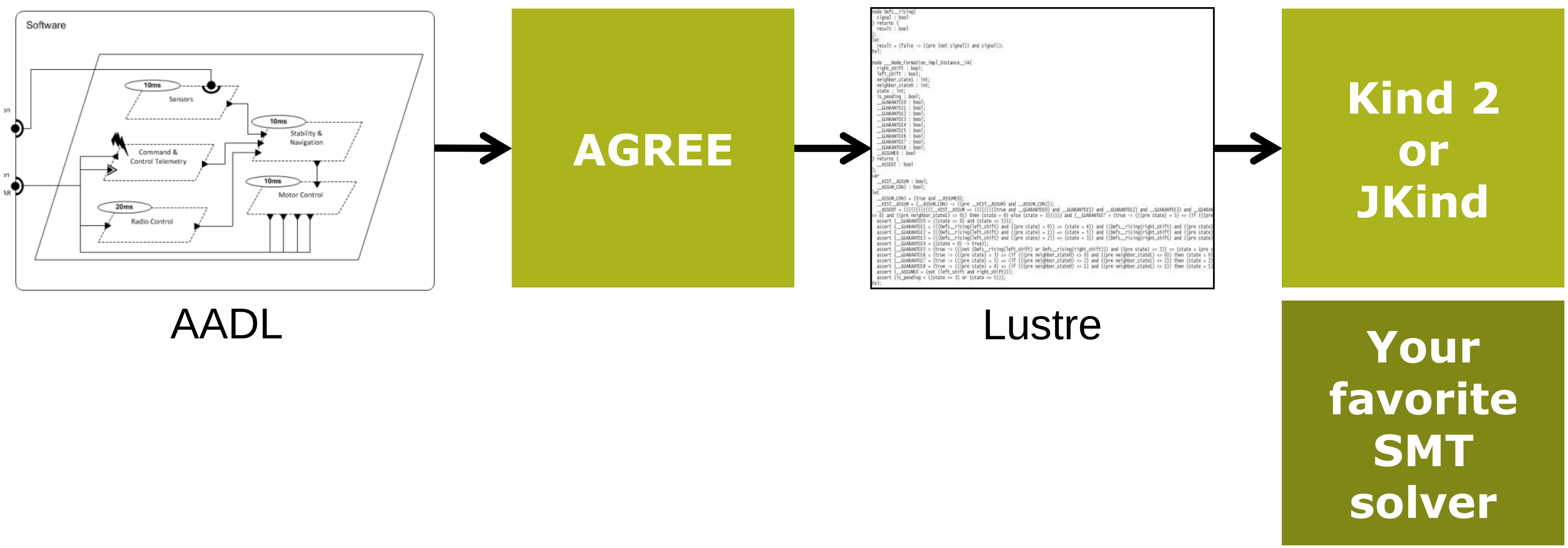
$A_S \wedge G_A \rightarrow A_B$

$A_S \wedge G_A \wedge G_B \rightarrow A_C$

$A_S \wedge G_A \wedge G_B \wedge G_C \rightarrow G_S$

AGREE Translation

- Translates AADL models with AGREE annotations into Lustre for analysis by k-induction model checkers
  - Kind 2 (University of Iowa)
  - JKind (Rockwell Collins)



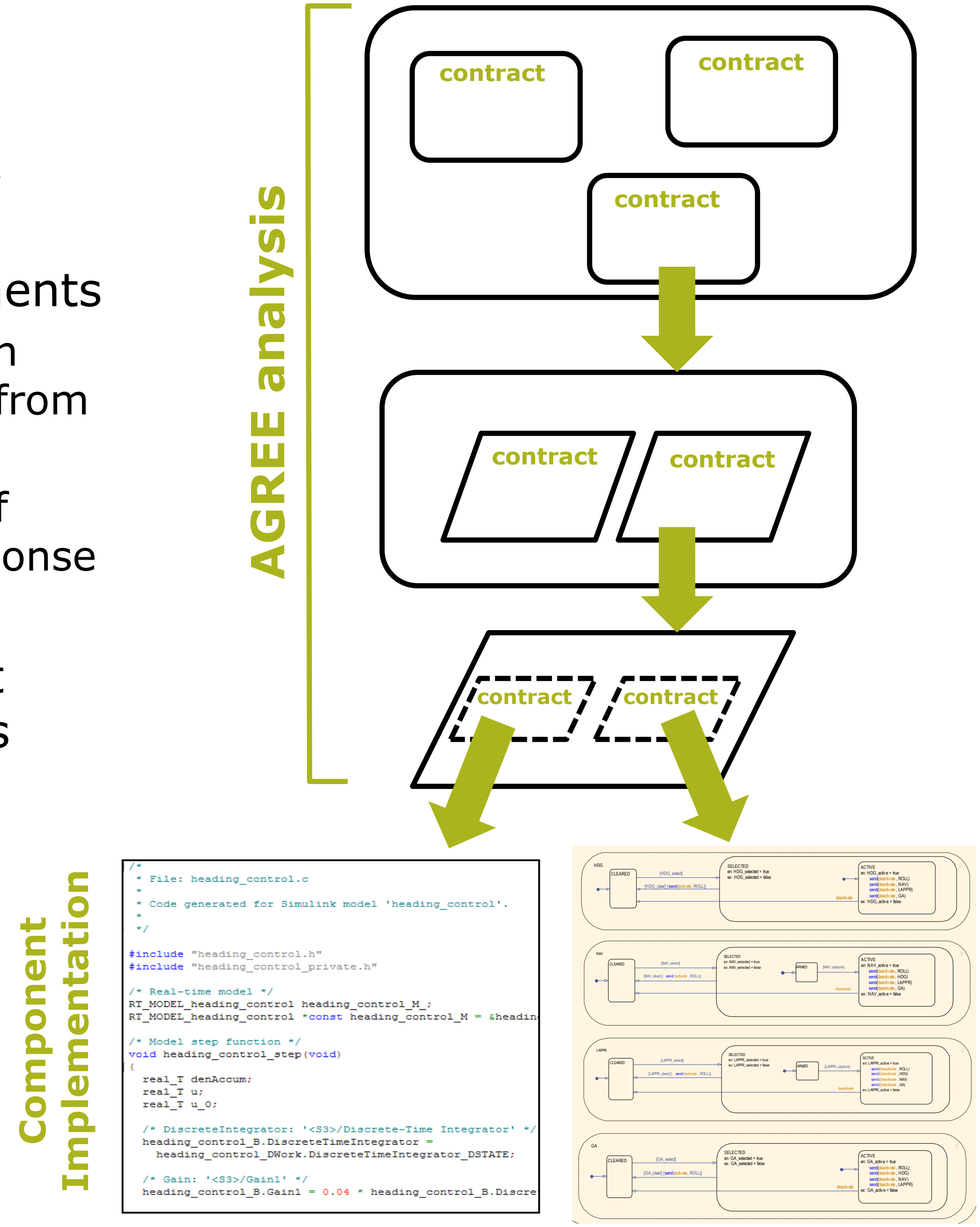
AGREE Annex to AADL

- Annotate AADL model with assume-guarantee contracts

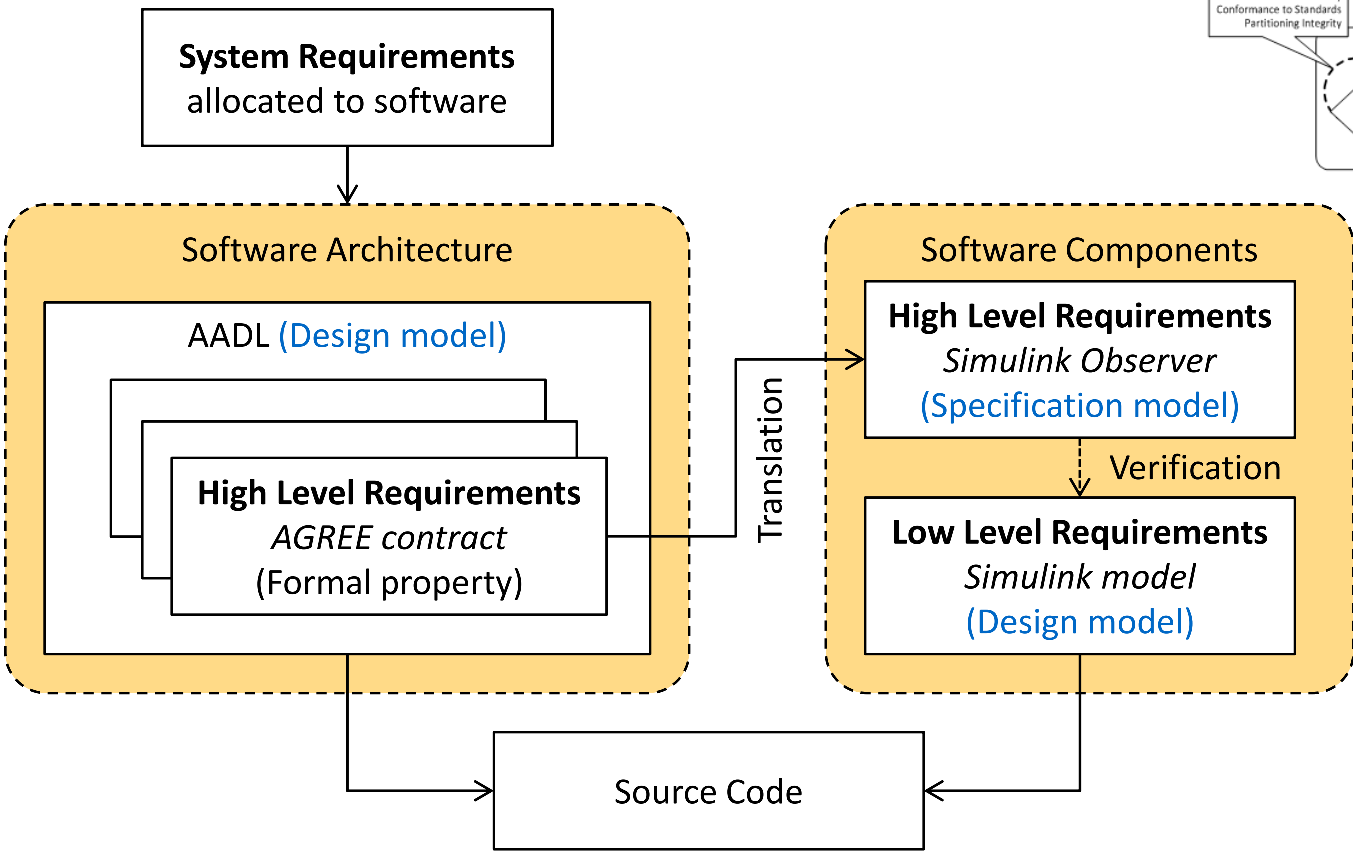
```
system Car
  features
    Target_Speed: in data port Types::speed.speed_impl;
    Actual_Speed: out data port Types::speed.speed_impl;

  annex agree {**

    const MAX_ACCEL : real = 2.0;

    assume "target speed is positive" : Target_Speed.val >= 0.0;
    assume "reasonable target speed" : Target_Speed.val < 150.0;

    eq const_tar_speed : bool =
      Agree_Nodes.H(Target_Speed.val = prev(Target_Speed.val,0.0));

    guarantee "actual speed is less than constant target speed" :
      const_tar_speed => (Actual_Speed.val <= Target_Speed.val);

    guarantee "acceleration is limited" :
      Agree_Nodes.abs(Actual_Speed.val - prev(Actual_Speed.val, 0.0)) < MAX_ACCEL;

  **};

end Car;
```

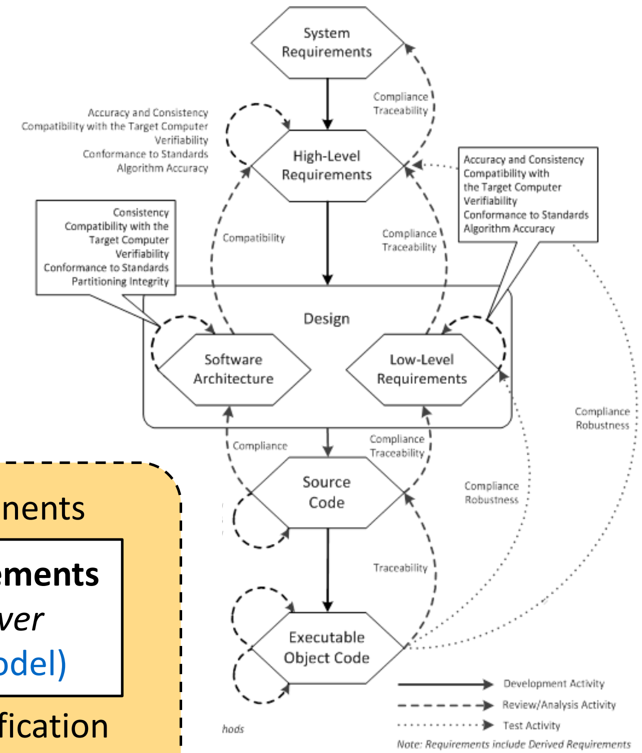
Export component contracts to Simulink

- Formal contracts on components
  - Assumptions: Constraints on what a component expects from its environment
  - Guarantees: Specification of component behavior in response to its environment
- The contract of a component specifies requirements for its *implementation*
- Tools link system development environment to component development environment

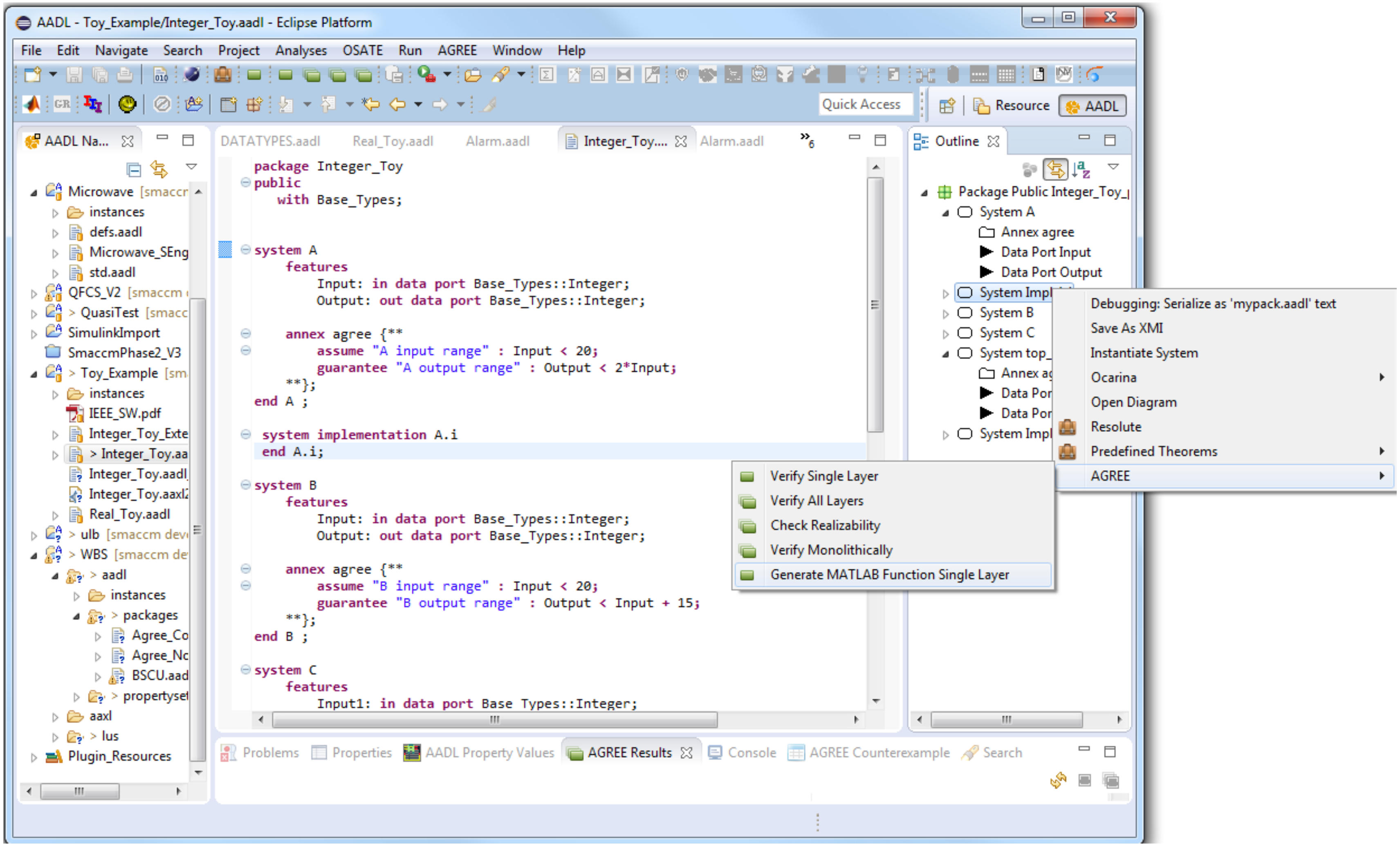


DO-178C Process

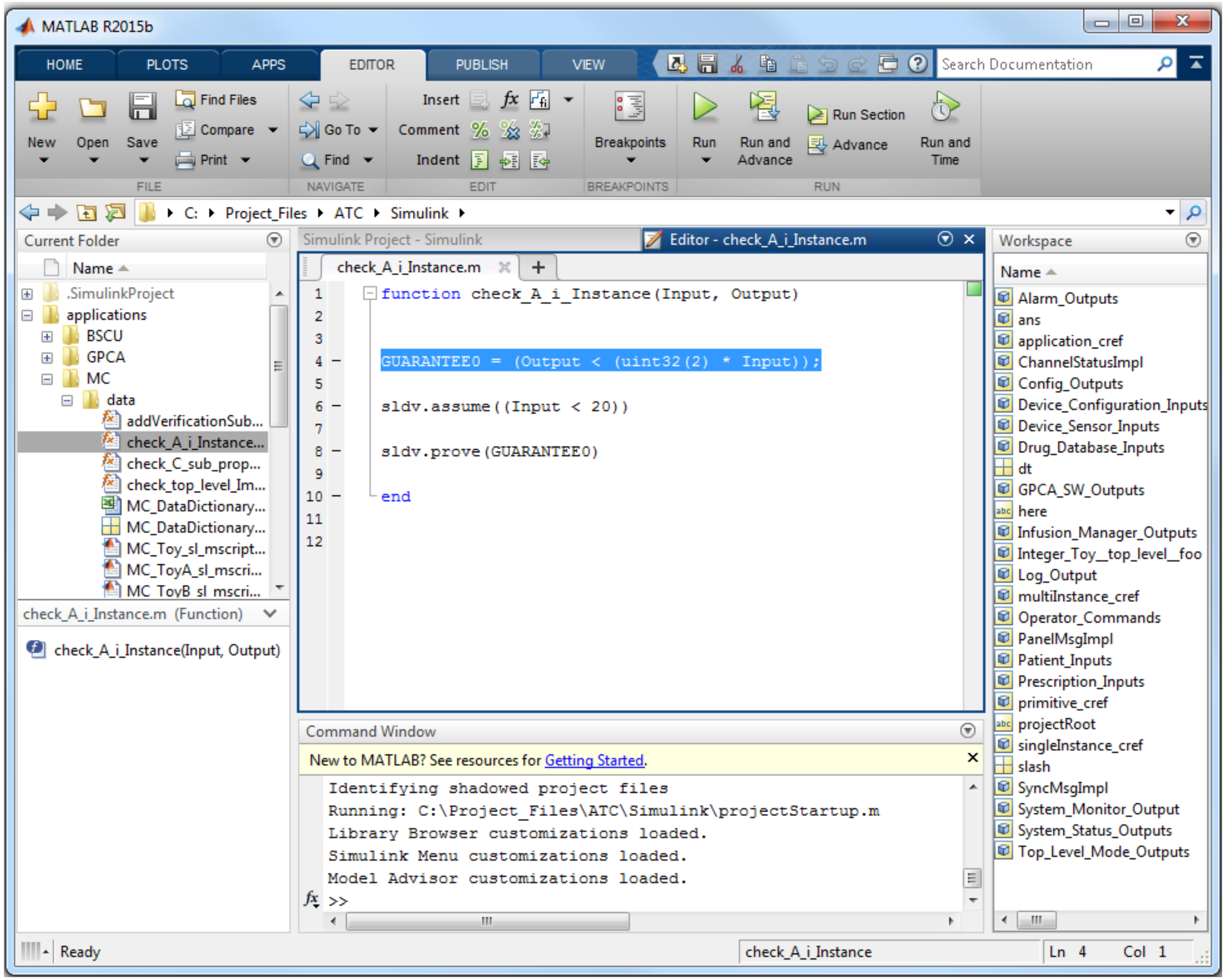




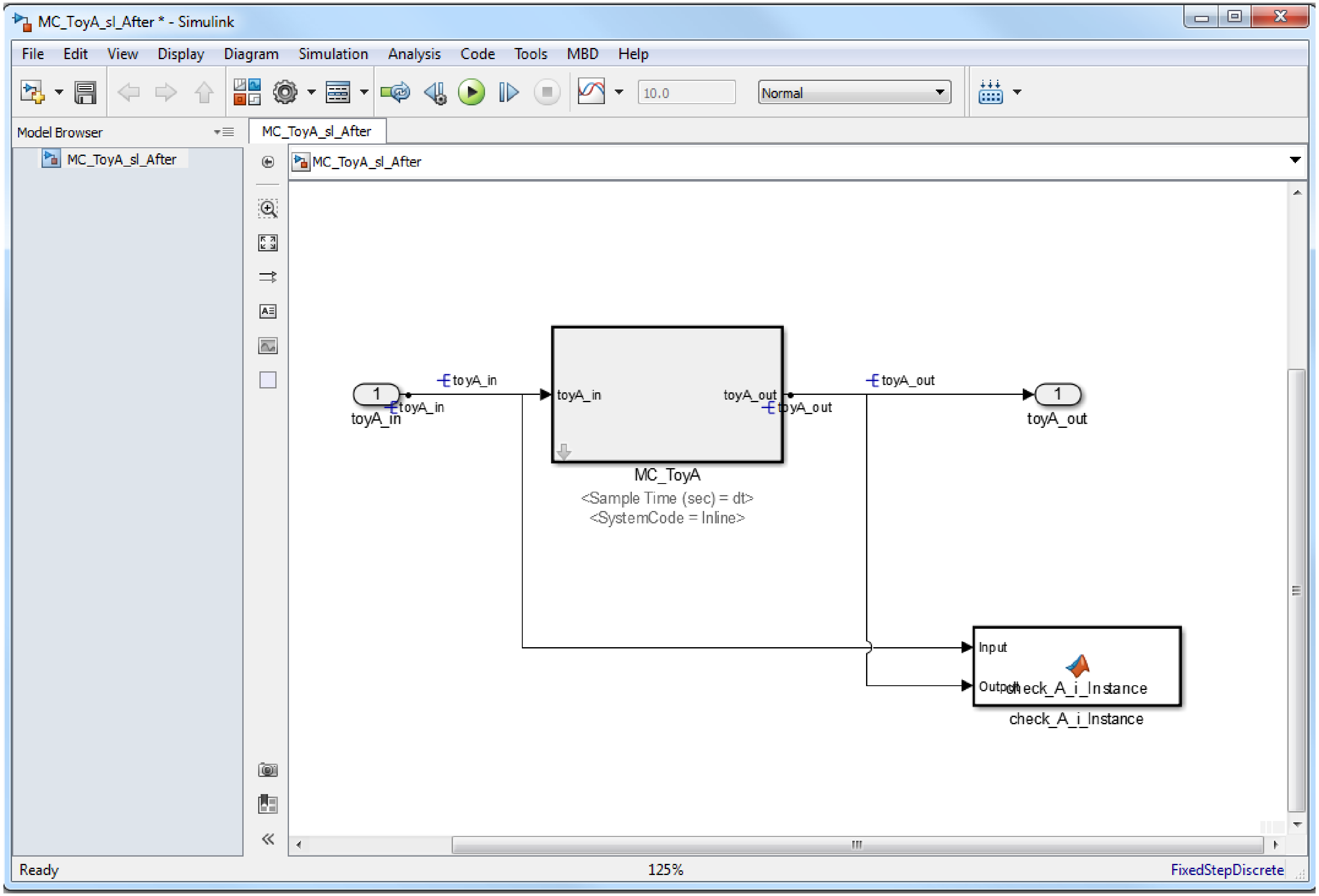
Export Design Contracts



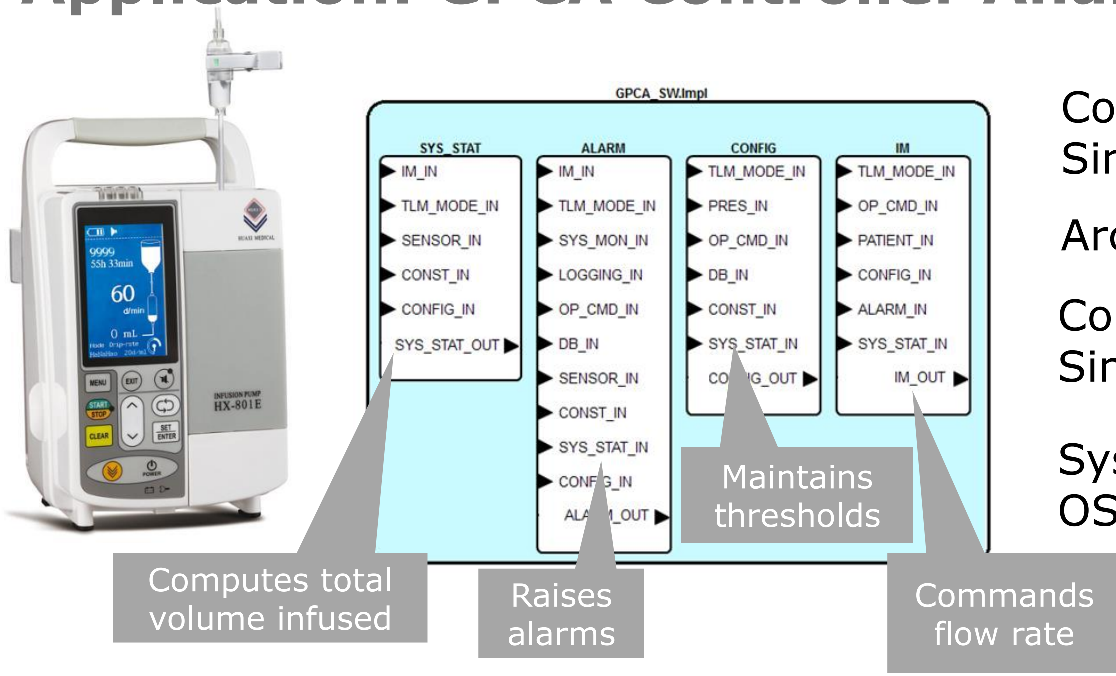
Translate to MATLAB Function



Insert Property Observer in Simulink Model



Application: GPCA Controller Analysis



Components modeled in Simulink

Architecture modeled in AADL

Component verification using Simulink Design Verifier

System verification using OSATE/AGREE

Example Requirement:

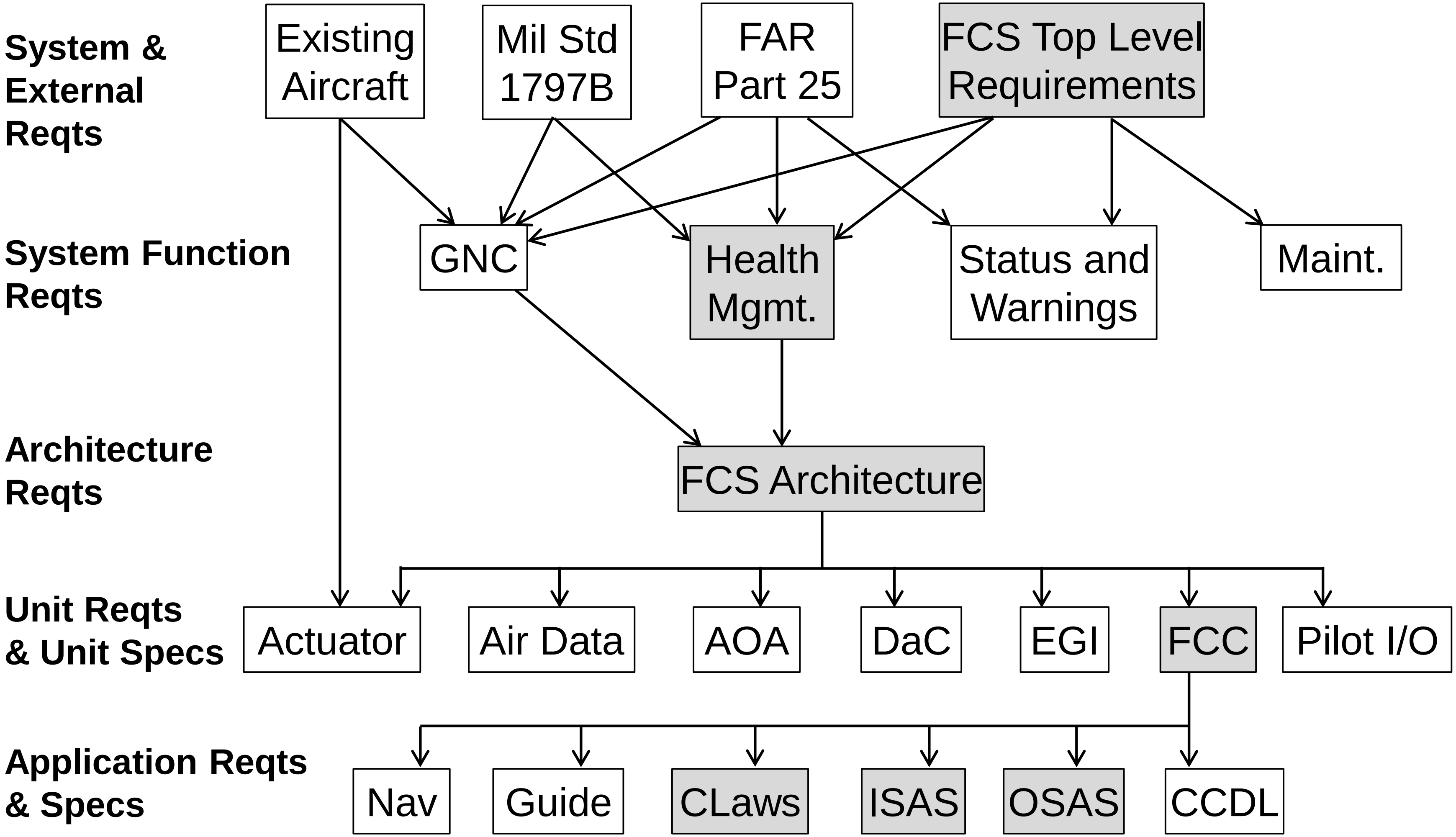
If the drug reservoir is empty, the infusion flow rate shall be zero.

Counterexample found in <1 second

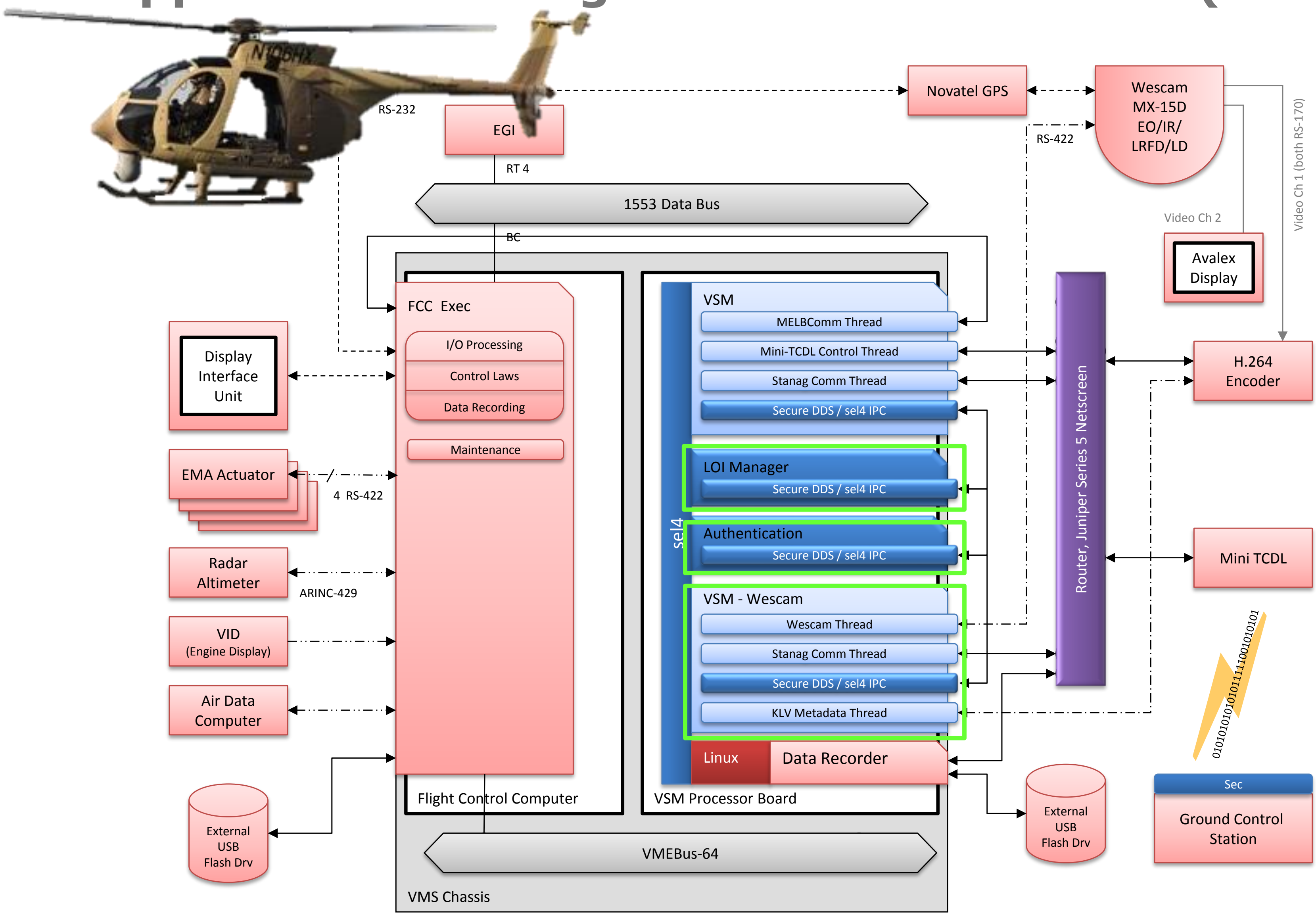
Analysis Time:

Monolithic Model	Composed Model
> 1 hour (12/19 proved)	4m 33s

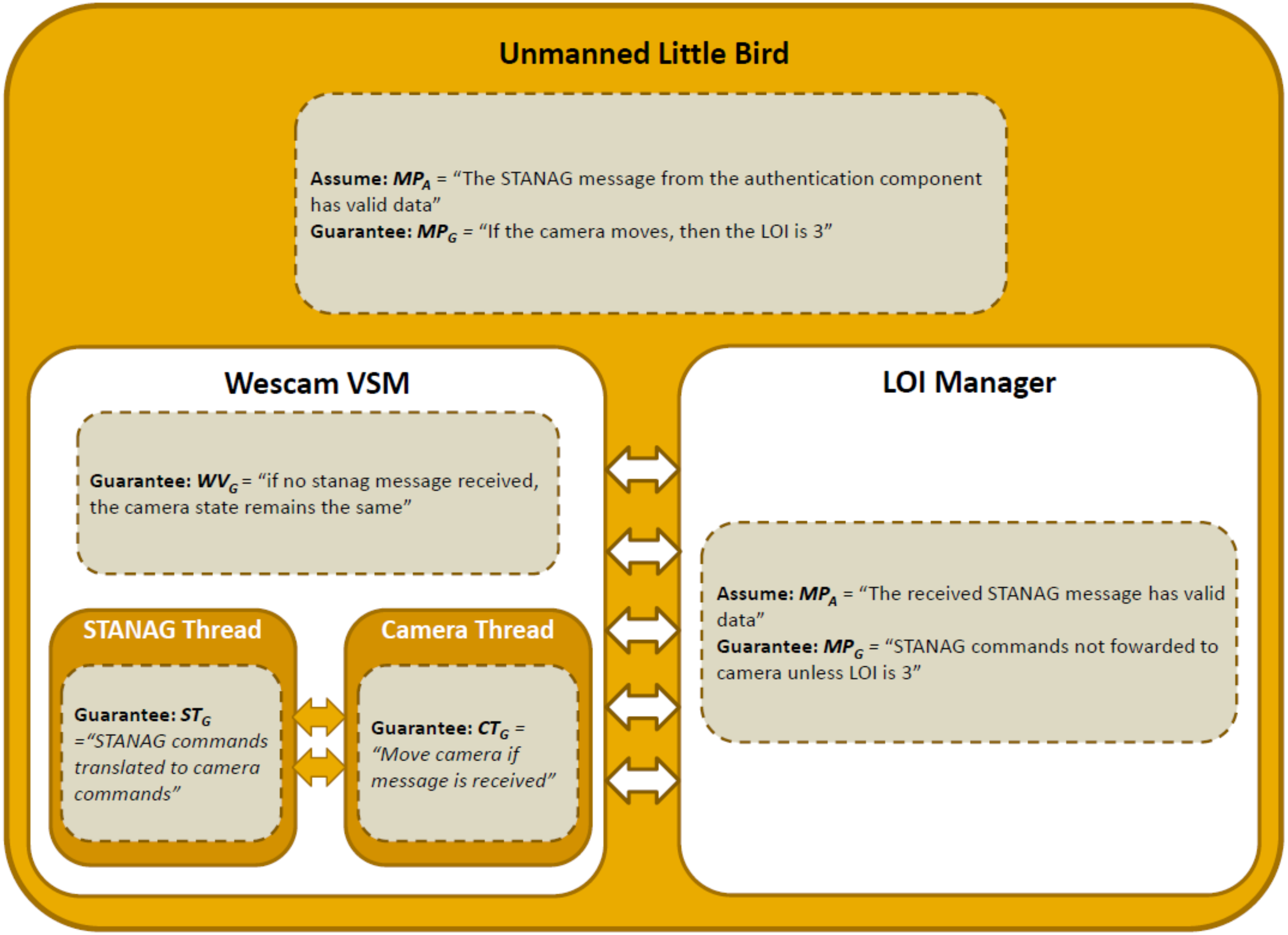
Application: NASA Quad-Redundant Flight Control System



Application: Boeing Unmanned Little Bird (HACMS)



Example: ULB Contracts



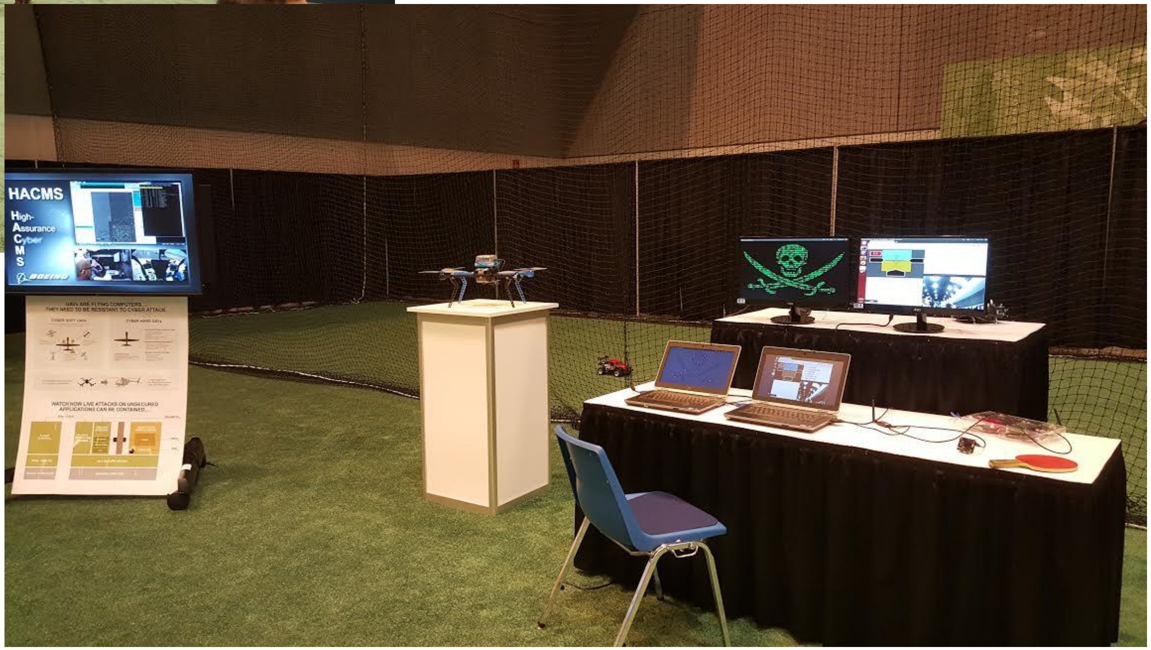
ULB Phase 2 Flight Demo – 24 July, Mesa AZ

Rockwell Collins

DARPA "Wait, What?"
St. Louis, 9-11 Sept 2015

WAIT WHAT
A FUTURE TECHNOLOGY FORUM

Formal Methods



Observations

- Some requirements are not compositional
  - High level requirements contain details of low level specifications
- Errors found during formalization
  - Problems became evident when translating the English requirements to AGREE syntax
- Errors found during model checking
  - Counterexample provided by Kind 2/JKind
- Errors found by realizability analysis
  - No possible implementation existed for a component with the given requirements

Current Work

- Support for more AADL constructs
  - Shared Data
  - Remote Procedure Calls
- Exporting component contracts to other environments
  - C/C++
- Changes to specification language
  - More expressive, more user-friendly
- Richer timing semantics
  - Real-time

More information, code, and papers available at:

Loonwerks.com