Design and Analysis of Cyber-Physical Systems: AADL and Avionics Systems

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Outline

Software-induced Challenges in Cyber-Physical Systems

SAE AADL: an Architecture Modeling and Analysis Framework

Virtual Integration of an Avionics System

Architectural Fault Modeling of Safety-critical Systems

Conclusions

We Rely on Software for Safe Aircraft Operation

Quantas Landing

Written by htbw

From: soyawan

Even with the autopilot off, flight control computers still ``command control surfaces to protect the aircraft from unsafe conditions such as a stall,'' the investigators said.

The unit continued to send false stall and speed warnings to the aircraft's primary computer and about 2 minutes after the initial fault ``generated very high, random and incorrect values for the aircraft's angle of attack.''

mayday call when it suddenly changed altitude during a flight from Singapore to Perth, Qantas said.

Embedded software systems introduce a new class of problems not addressed by traditional system modeling & analysis

lunge

lwide

irways

causing the jet to nosedive.

was cruising at 37,000 feet (11,277 meters) when the computer fed incorrect information to the flight control system, the Australian Transport Safety Bureau said yesterday. The aircraft dropped 650 feet within seconds, slamming passengers and crew into the cabin ceiling, before the pilots regained control.

``This appears to be a unique event,'' the bureau said, adding that

fitted with the same air-data computer. The advisory is ``aimed at minimizing the risk in the unlikely event of a similar occurrence.''

Autopilot Off

A ``preliminary analysis'' of the Qantas plunge showed the error occurred in one of the jet's three air data inertial reference units, which caused the autopilot to disconnect, the ATSB said in a statement on its Web site.

The crew flew the aircraft manually to the end of the flight, except for a period of a few seconds, the bureau said.

Even with the autopilot off, flight control computers still ``command control surfaces to protect the aircraft from unsafe conditions such as a stall,'' the investigators said.

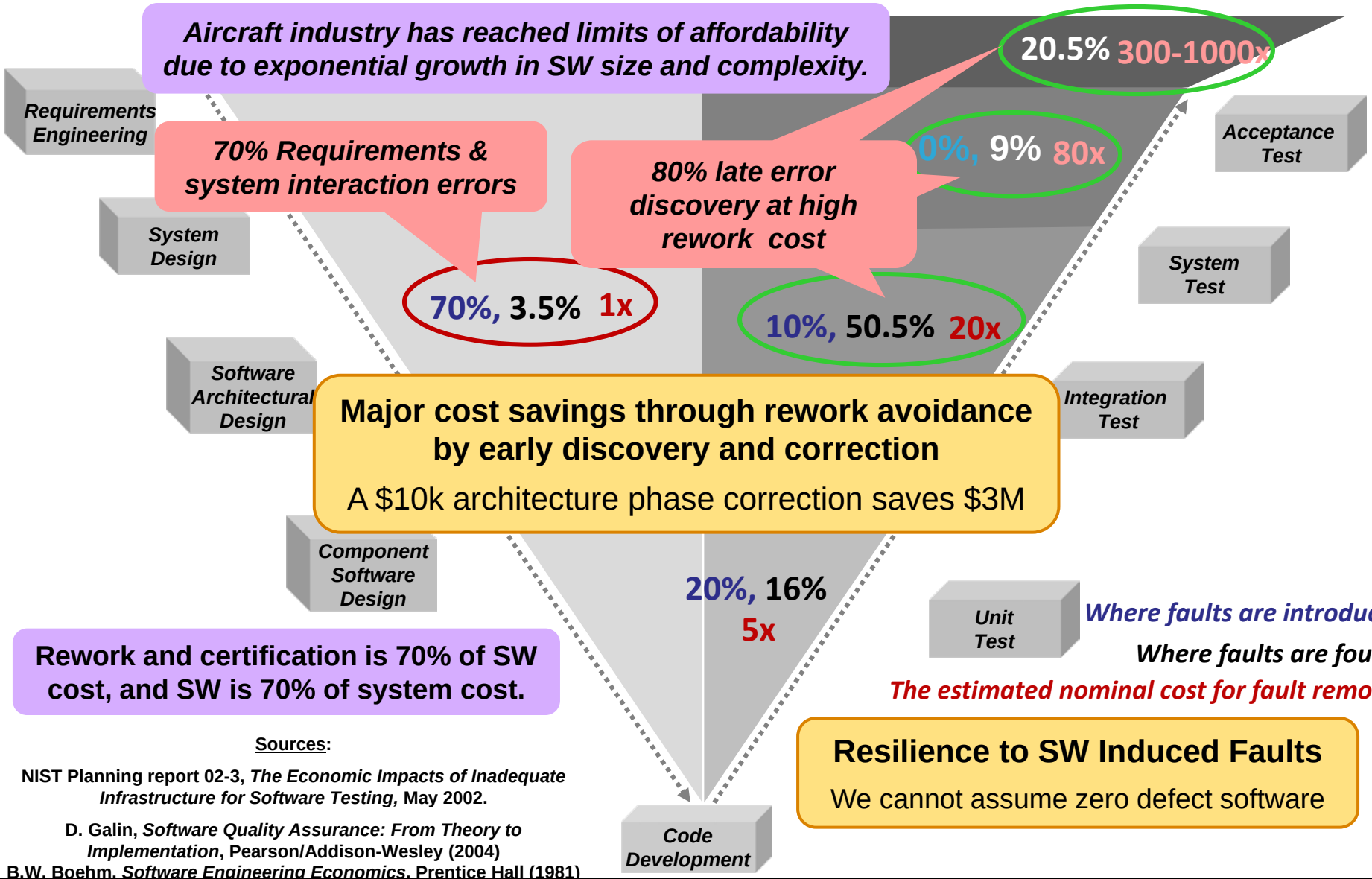
The unit continued to send false stall and speed warnings to the aircraft's primary computer and about 2 minutes after the initial fault ``generated very high, random and incorrect values for the aircraft's angle of attack.''

The flight control computer then commanded a ``nose-down aircraft movement, which resulted in the aircraft pitching down to a maximum of about 8.5 degrees,'' it said.

No `Similar Event'

``Airbus has advised that it is not aware of any similar event over the many years of operation of the Airbus,'' the bureau added, saying it will continue investigating.

High Fault Leakage Drives Major Increase in Rework Cost



Rework and certification is 70% of SW cost, and SW is 70% of system cost.

Resilience to SW Induced Faults

We cannot assume zero defect software

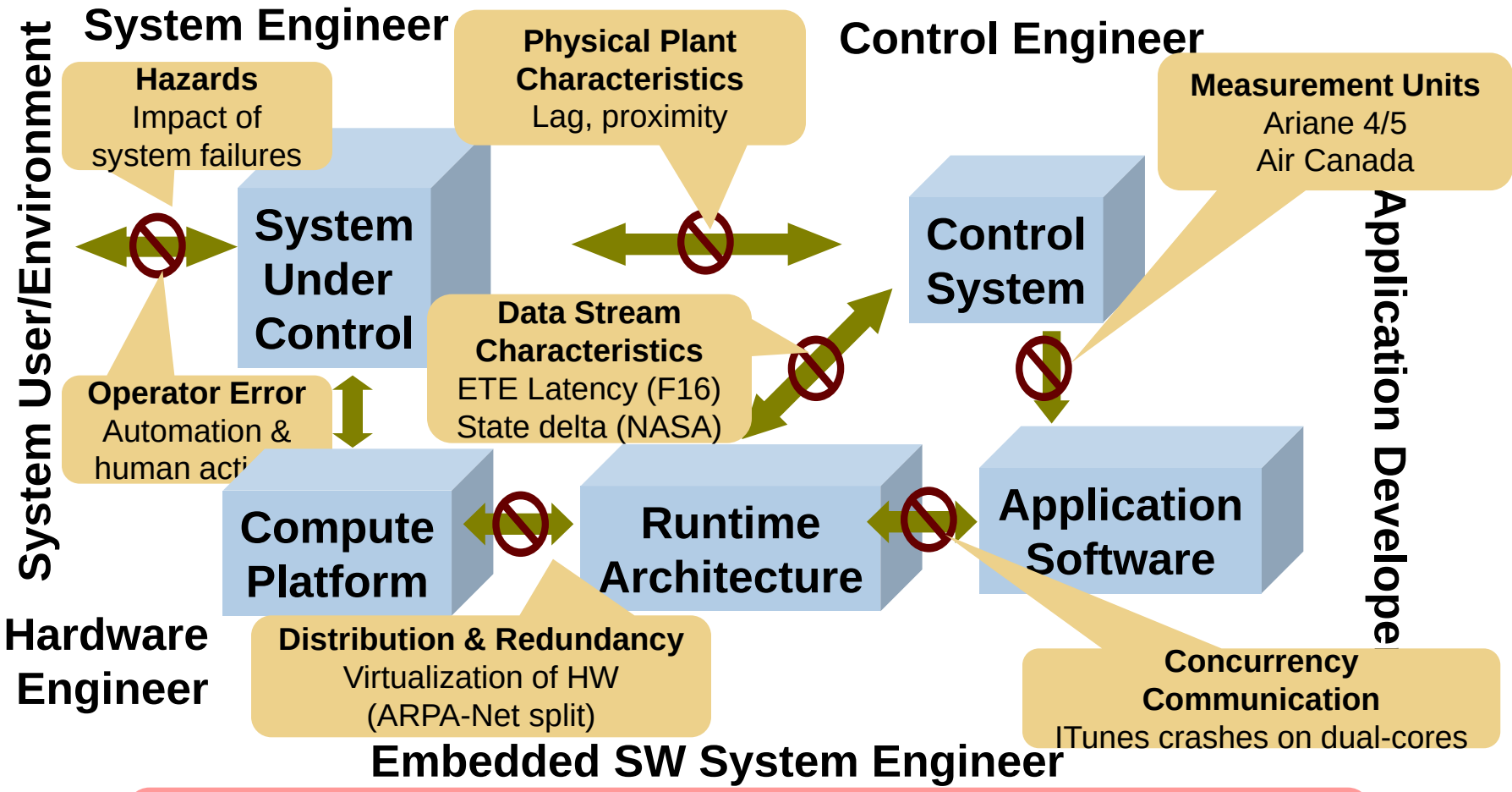
Sources:

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)

Mismatched Assumptions in Embedded SW



Why do system level failures still occur despite fault tolerance techniques being deployed in systems?

SysML does not address Embedded Software System Architecture Issues

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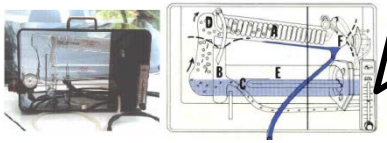
SAE Architecture Analysis & Design Language (AADL) Standard for Software-reliant Systems

The System

Physical platform
Aircraft

Continuous Distiller

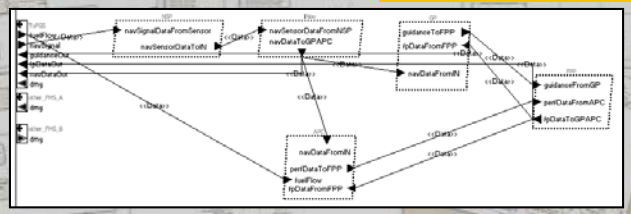


Control
Guidance

Embedded Application Software
Flight control & Mission

Focus on software runtime architecture

The Software



Deployed on
Utilizes

Physical interface
Platform component

Computer System
Hardware & OS

The Computer System

AADL focuses on interaction between the three elements of a software-intensive system based on architectural abstractions of each.

System Level Fault Root Causes

Violation of data stream assumptions
- Stream miss rates, Mismatched data representation, Latency jitter & age

End-to-end latency analysis
Port connection consistency

Partitions as Isolation Regions
- Space, time, and bandwidth partitioning
- Isolation not guaranteed due to undocumented resource sharing
- fault containment, security levels, safety levels, distribution

Process and virtual processor to model partitioned architectures

Virtualization of time & resources
- Logical vs. physical redundancy
- Time stamping of data & asynchronous systems

Virtual processors & buses
Multiple time domains

Inconsistent System States & Interactions
- Modal systems with modal components
- Concurrency & redundancy management
- Application level interaction protocols

Operational and failure modes
Interaction behavior specification
Dynamic reconfiguration
Fault detection, isolation, recovery

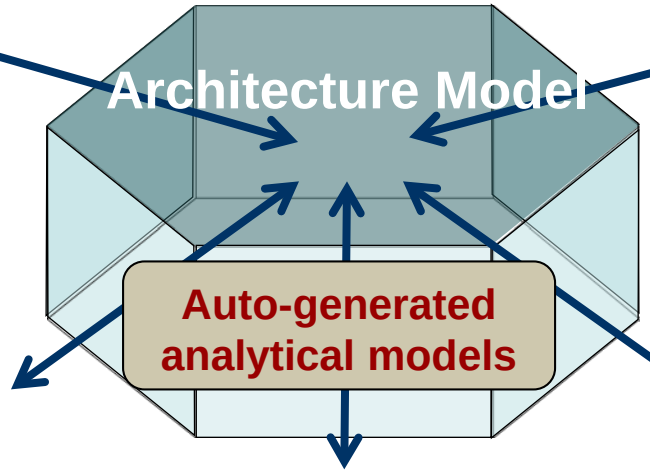
Performance impedance mismatches
- Processor, memory & network resources
- Compositional & replacement performance mismatches
- Unmanaged computer system resources

Resource allocation & deployment configurations
Resource budget analysis & scheduling analysis

Codified in Virtual Upgrade Validation method

Architecture-Centric Modeling Approach

Single-source Annotated Architecture Model Addresses Change Impact Across Analytical Models and Non-Functional Properties



Safety & Reliability
- MTBF
- FMEA
- Hazard analysis

Security
- Intrusion
- Integrity
- Confidentiality

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

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

Resource Consumption
- Bandwidth
- CPU time
- Power consumption

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Early Discovery and Incremental V&V through Virtual Integration (SAVI)

Aircraft: (Tier 0)

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

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

System & SW Engineering:
Mechatronics: Actuator & Wings
Safety Analysis (FHA, FMEA)
Reliability Analysis (MTTF)

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

OEM & Subcontractor:
Subsystem proposal validation
Functional integration consistency
Data bus protocol mappings

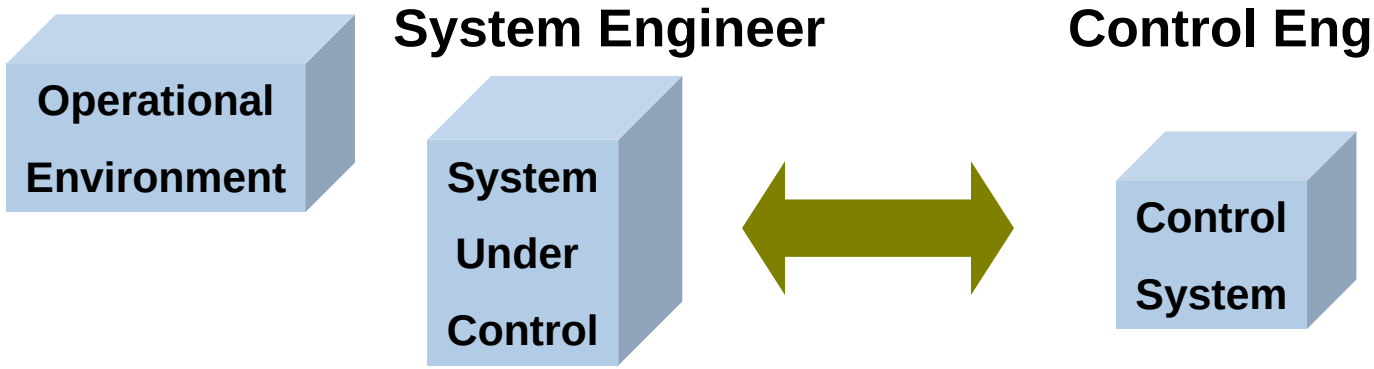
Repeated Virtual Integration Analyses:
Power/weight
MIPS/RAM, Scheduling
End-to-end latency
Network bandwidth

Proof of Concept Demonstration and Transition by Aerospace industry initiative

- **Propagate requirements and constraints**
- **Higher level model down to suppliers' lower level models**
- **Verification of lower level models satisfies higher level requirements and constraints**

- Multi-tier system & software architecture (in AADL)
- Incremental end-to-end validation of system properties

End-to-end Latency in Control Systems

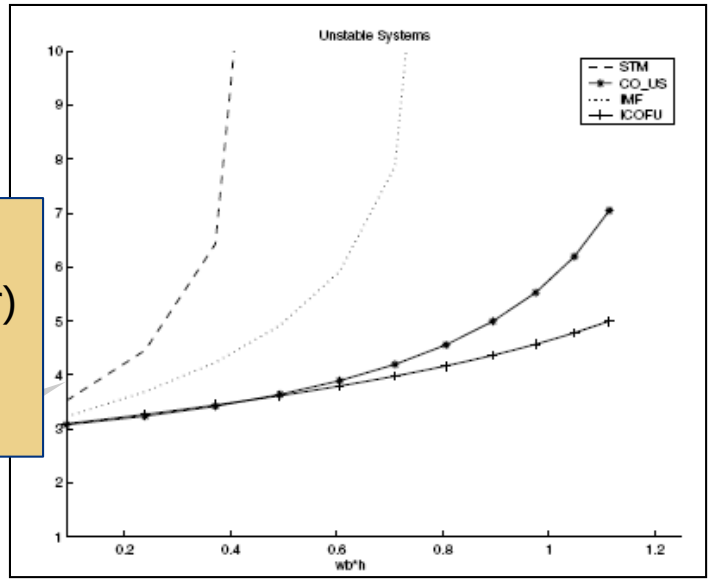


- Processing latency
- Sampling latency
- Physical signal latency

Impact of Software Implemented Tasks

Jitter affects stability of control behavior (subtle value error)

AADL immediate & delayed connections specify deterministic sampling

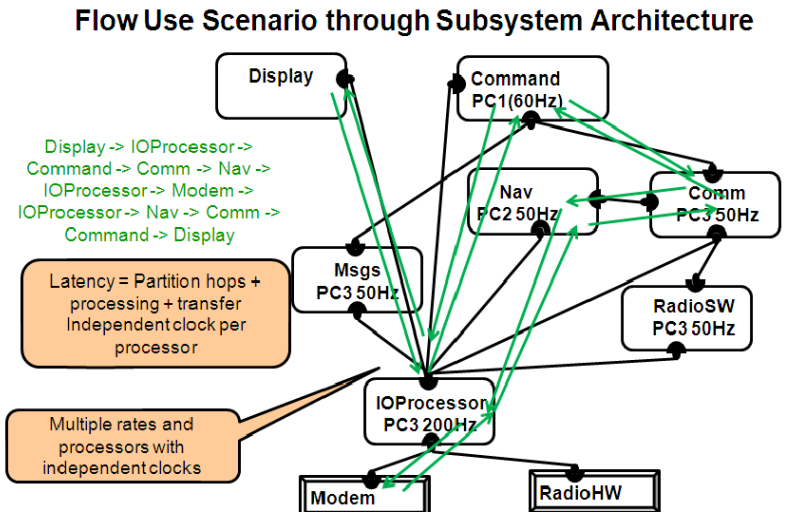


Impact of Scheduler Choice on Controller Stability

A. Cervin, Lund U., CCACSD 2006

Software-Based Latency Contributors

- Execution time variation: algorithm, use of cache
- Processor speed
- Resource contention
- Preemption
- Legacy & shared variable communication
- Rate group optimization
- Protocol specific communication delay
- Partitioned architecture
- Migration of functionality
- Fault tolerance strategy



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Error Model and the Architecture

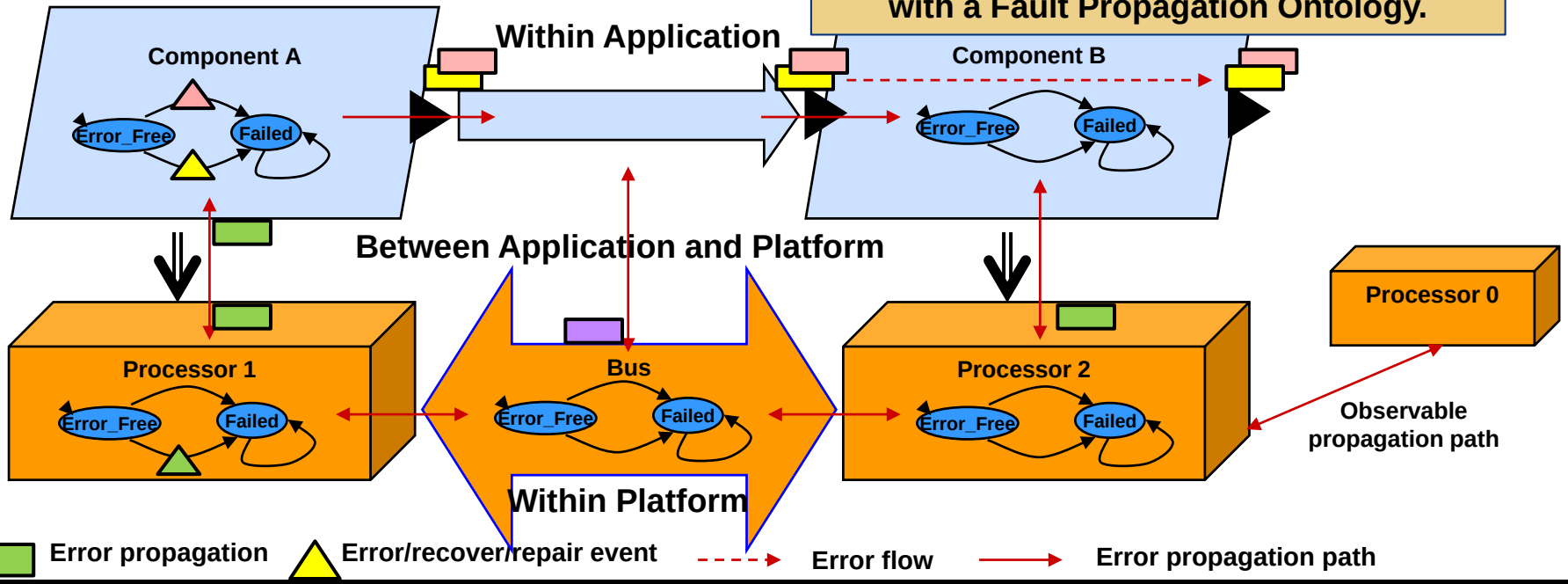
Propagation of *errors* of different *types* from *error sources* along *propagation paths* between architecture components.

Error flows as abstractions of propagation through components.

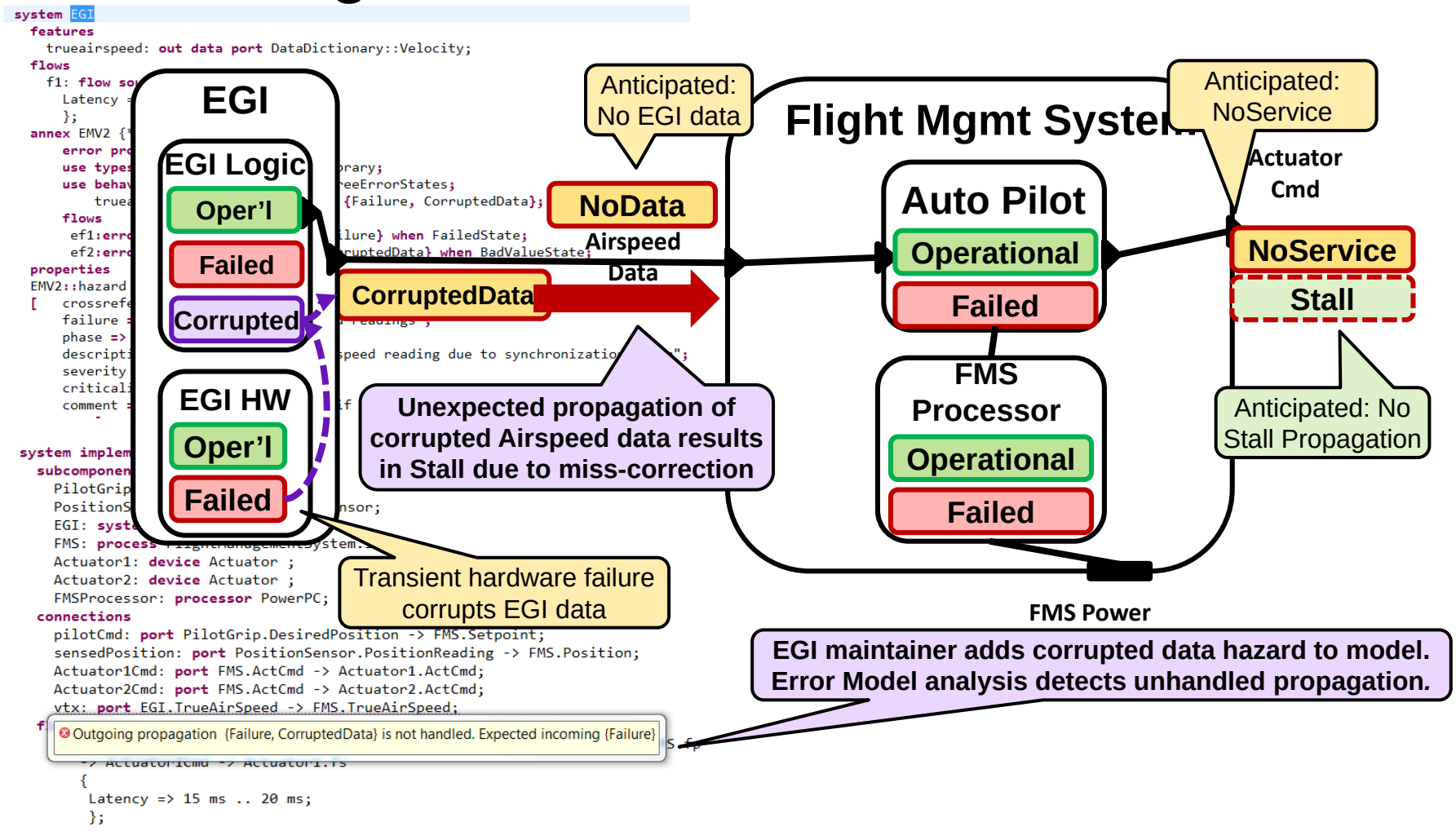
Component *error behavior* as *transitions, out propagations, and detection* based on *event, state* and *incoming propagation conditions.*

Composite error behavior in terms of component error behavior states in support of compositional abstraction.

AADL Error Model Annex Standard comes with a Fault Propagation Ontology.



Discovery of Unexpected PSSA Hazard through Virtual Integration



Recent Automated FMEA Experience

Failure Modes and Effects Analyses are rigorous and comprehensive reliability and safety design evaluations

- Required by industry standards and Government policies
- When performed manually are usually done once due to cost and schedule
- If automated allows for
  - multiple iterations from conceptual to detailed design
  - Tradeoff studies and evaluation of alternatives
  - Early identification of potential problems

ID	Item	Initial State	Initial Failure Mode	1st Level Effect	Transition	2nd Level Effect	Transition	3rd Level Effect	Severity	M
1	Sat_Bus	Working	Failure	Failed		Failed	Recovery	Working		Workir
1	Sat_Payload	Working		Working	Bus failure causes payload transition	Standby		Standby	Bus Recovery Causes Payload Transition	Workir
2	Sat_Bus	Working		Working		Working	5			
2	Sat_Payload	Working	Failure	Failed	Recovery	Working	5			

Largest analysis of satellite to date consists of 26,000 failure modes

- Includes detailed model of satellite bus
- 20 states perform failure mode
- Longest failure mode sequences have 25 transitions (i.e., 25 effects)

Myron Hecht, Aerospace Corp.
Safety Analysis for JPL, member of DO-178C committee

Impact of Deployment Configuration Changes on Availability

FMS Failure on 2 or 3 processor configuration (CPU failure rate = 10^{-5})

FMS Failure Rate	0	$5*10^{-6}$	$5*10^{-5}$
MTTF – One CPU operational	112,000	67,000	14,000
MTTF – Two CPU operational	48,000	31,000	7,000

Side effects of design and deployment decisions on availability predictions

Workload balancing of partitions later in development affects reliability

3 processor configuration can be less reliable than 2 processor configuration

Example: Replicated AP and FG channel (re)distributed across two processors

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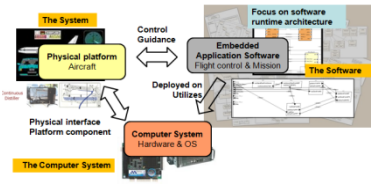
Virtual Upgrade Validation Method

Early discovery of technical risks

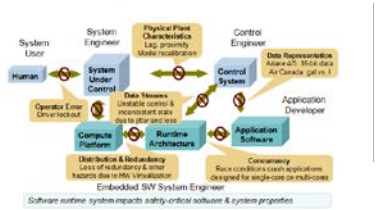
Capture Embedded Software System Architecture

Software runtime, computer hardware, mechanical system architecture in same SAE AADL model



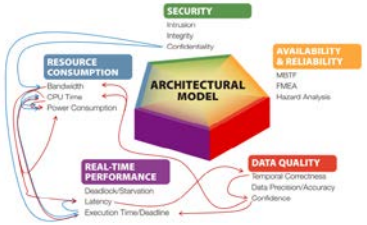
Utilize knowledge of potential mismatched assumptions

Codified in Virtual Upgrade Validation method



Analyze multiple operational quality attributes

Utilize SAE AADL single model truth approach and well defined semantics

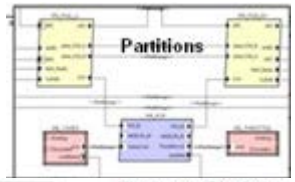


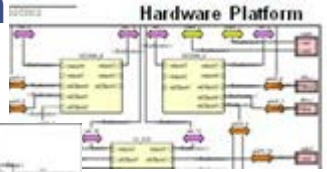
Sample Findings

Potential inconsistency and lack of integrity of recorded aircraft health data

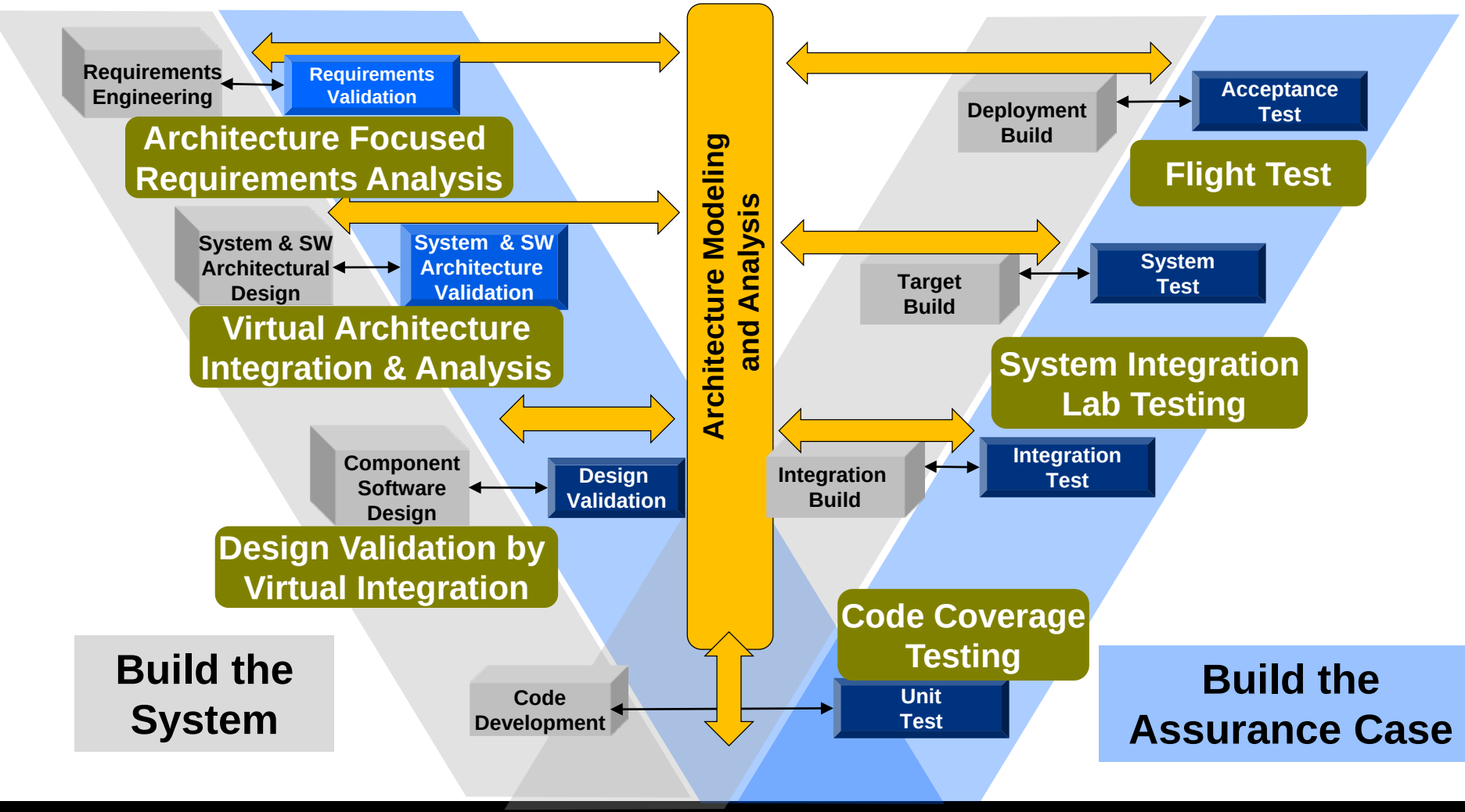
Ambiguous task and communication architecture has priority inversion potential under fault conditions

Corrupted airspeed data not considered as hazard





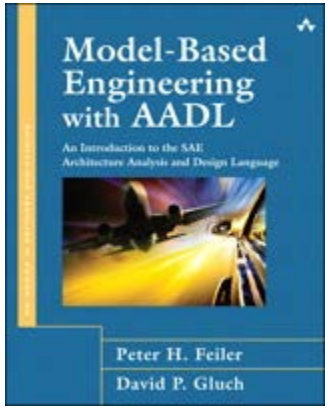
Increased Confidence through End-to-end Virtual Integration and Testing Evidence



Resources

Website www.aadl.info

Public Wiki https://wiki.sei.cmu.edu/aadl



AADL Book in SEI Series of Addison-Wesley
http://www.informit.com/store/product.aspx?isbn=0321888944