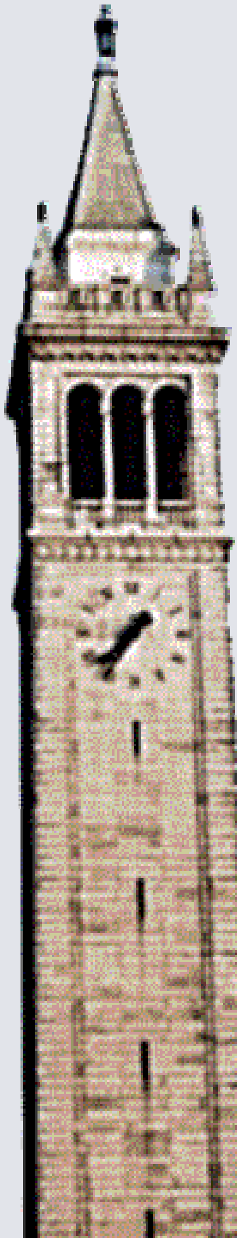
Critical Avionics Software

Edited and presented by
Claire J. Tomlin
UC Berkeley

Chess Review
November 21, 2005
Berkeley, CA



Outline

- A viewpoint from production military systems [David Sharp, Boeing Phantom Works]
- System development and certification
  - DO 178 B and C
- High level design examples:
  - Collision avoidance systems
  - Operating envelope protection
- Tools for modeling, design, and code generation
- NITRD HCSS National Workshop on Software for Critical Aviation Systems

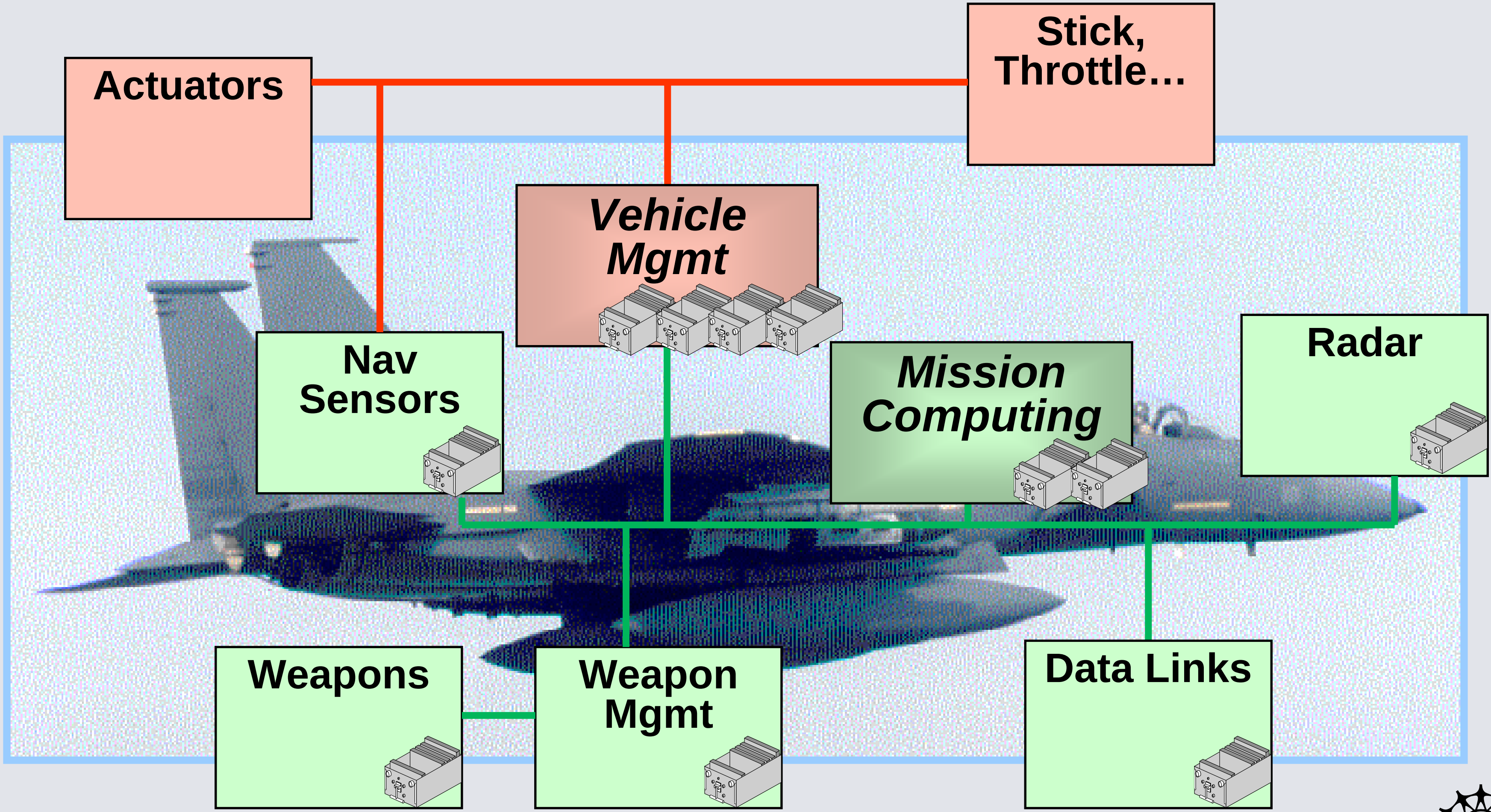
A Viewpoint from Production Military Aircraft

- Technology Trends in Avionics Systems Are Driving Exponential Growth in Software Complexity
  - Autonomous systems, adaptive systems…
- Traditional Approaches and Processes Are Already Stressed
  - Program-specific architectures, languages, tools
  - Unaligned with commercial practices

Current Technology, Practices and Culture of the Industry Cannot Meet Emerging System Needs

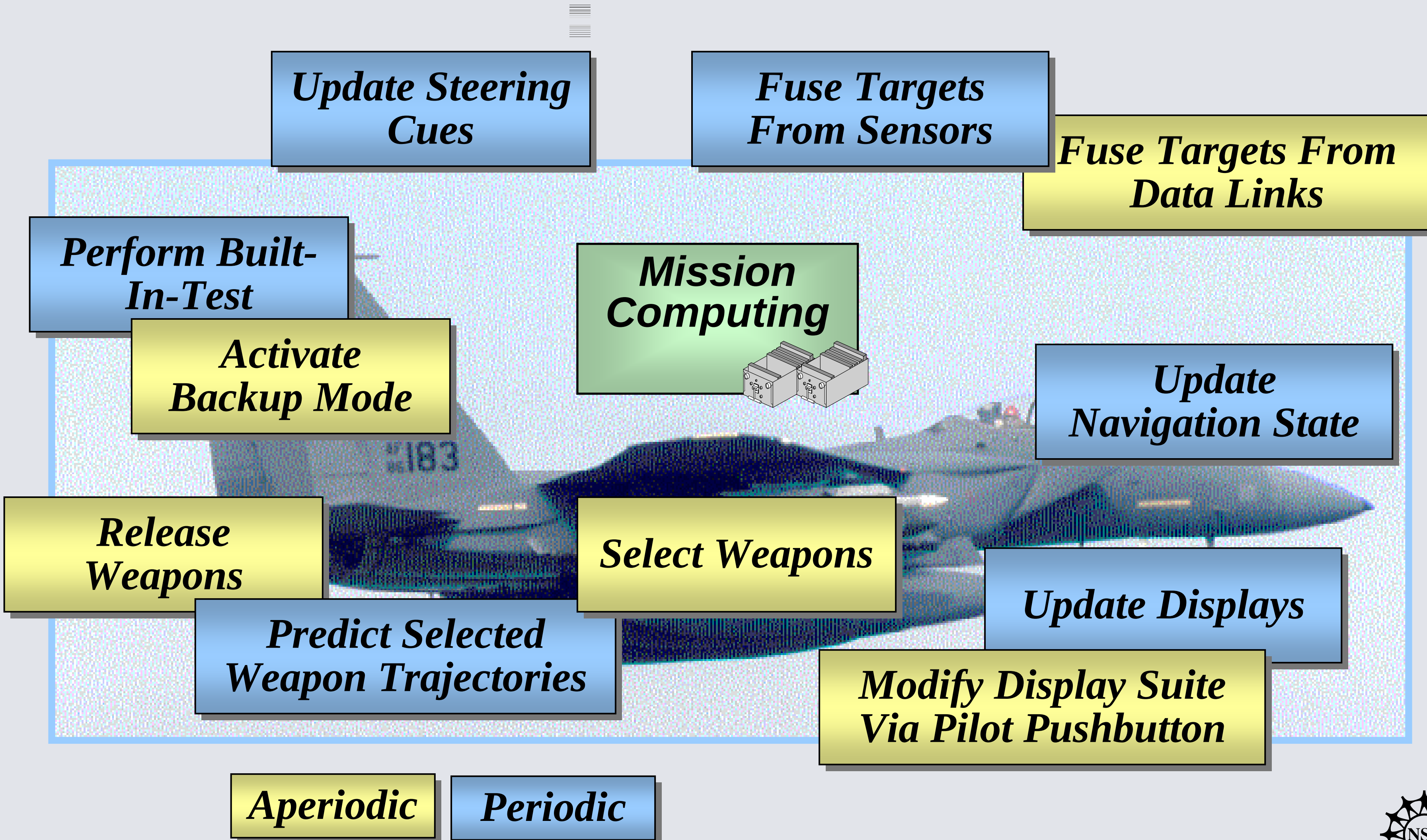
David Sharp, Boeing Phantom Works, HSCC Plenary Talk, Stanford, March 2002

Example: Fighter Avionics Domains



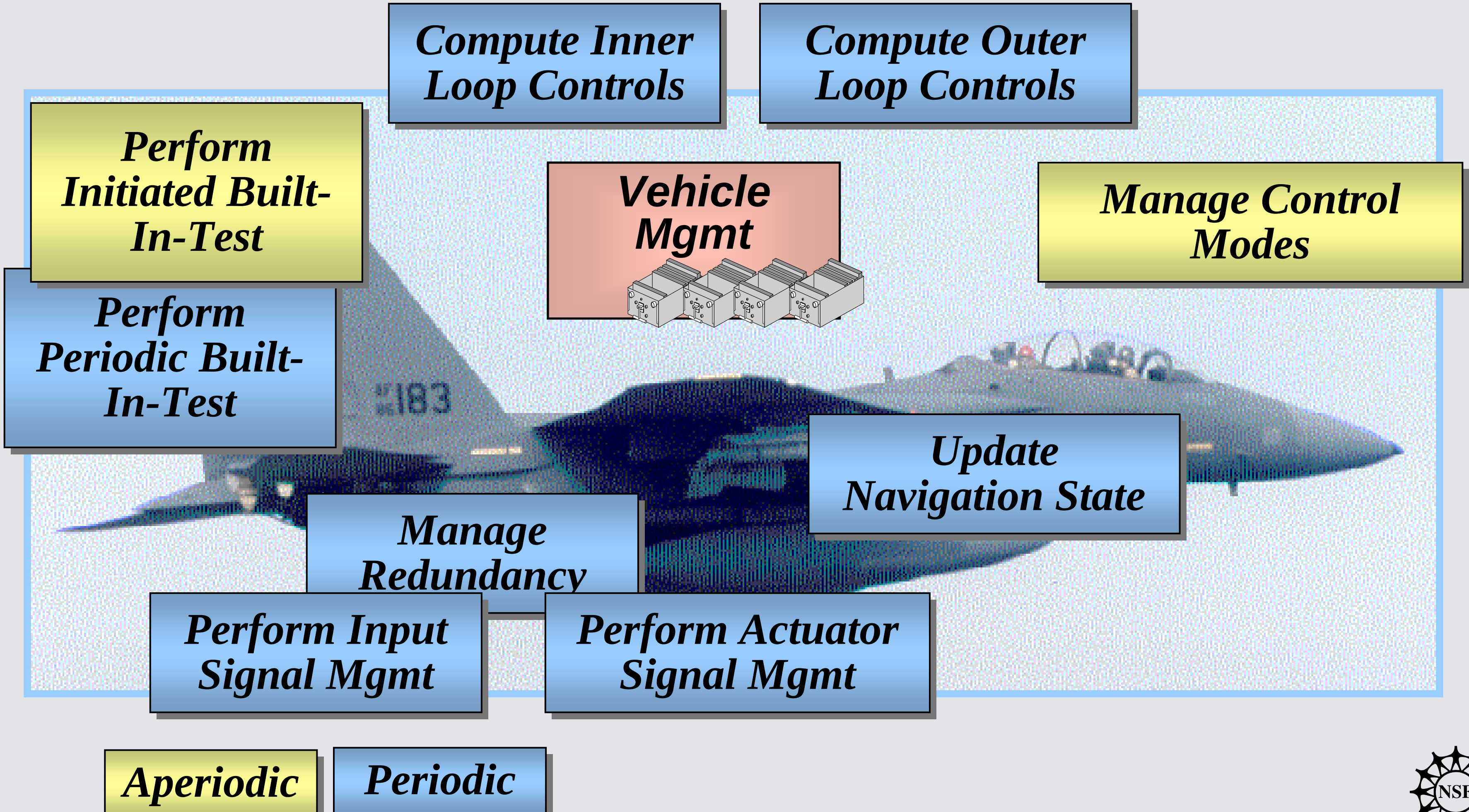
David Sharp, Boeing Phantom Works, HSCC Plenary Talk, Stanford, March 2002

Mission Computing: Example Functionality



David Sharp, Boeing Phantom Works, HSCC Plenary Talk, Stanford, March 2002

Vehicle Management: Example Functionality



David Sharp, Boeing Phantom Works, HSCC Plenary Talk, Stanford, March 2002

Typical Mission Computing Legacy Characteristics

- 10-100 Hz Update Rates
- Up To 10-100 Processors
- ~1M Lines of Code
  - $O(10^3)$ Components
- Proprietary Hardware
  - Slow CPU, small memory
  - Fast I/O
- Test-Based Verification
- Mil-Std Assembly Language
- Highly Optimized For Throughput and Memory
- Functional Architectures
  - Flowchart designs
- Frequently No Maintained Requirements or Design
  - Ad-hoc models used by algorithm developers
- Hardcoded Hardware Specific Single System Designs
- Isolated Use Of
  - Multi-processing
  - Schedulability analysis
    - Frequently overly pessimistic to be used

David Sharp, Boeing Phantom Works, HSCC Plenary Talk, Stanford, March 2002

Typical Vehicle Management Legacy Characteristics

Additional Characteristics

- 80/160 Hz Update Rates
- Single CPU System/ Quad Redundant
- Dual/Quad Redundant Sensors and Actuators
- <100K Lines of Code
- Extensive Built-In-Test
  - >50% of code
- Extensive Testing
  - Very conservative development culture
  - >50% of effort
- Control System Models Carefully Developed And Used
  - Home grown
  - Matlab/MatrixX with auto code generation

David Sharp, Boeing Phantom Works, HSCC Plenary Talk, Stanford, March 2002

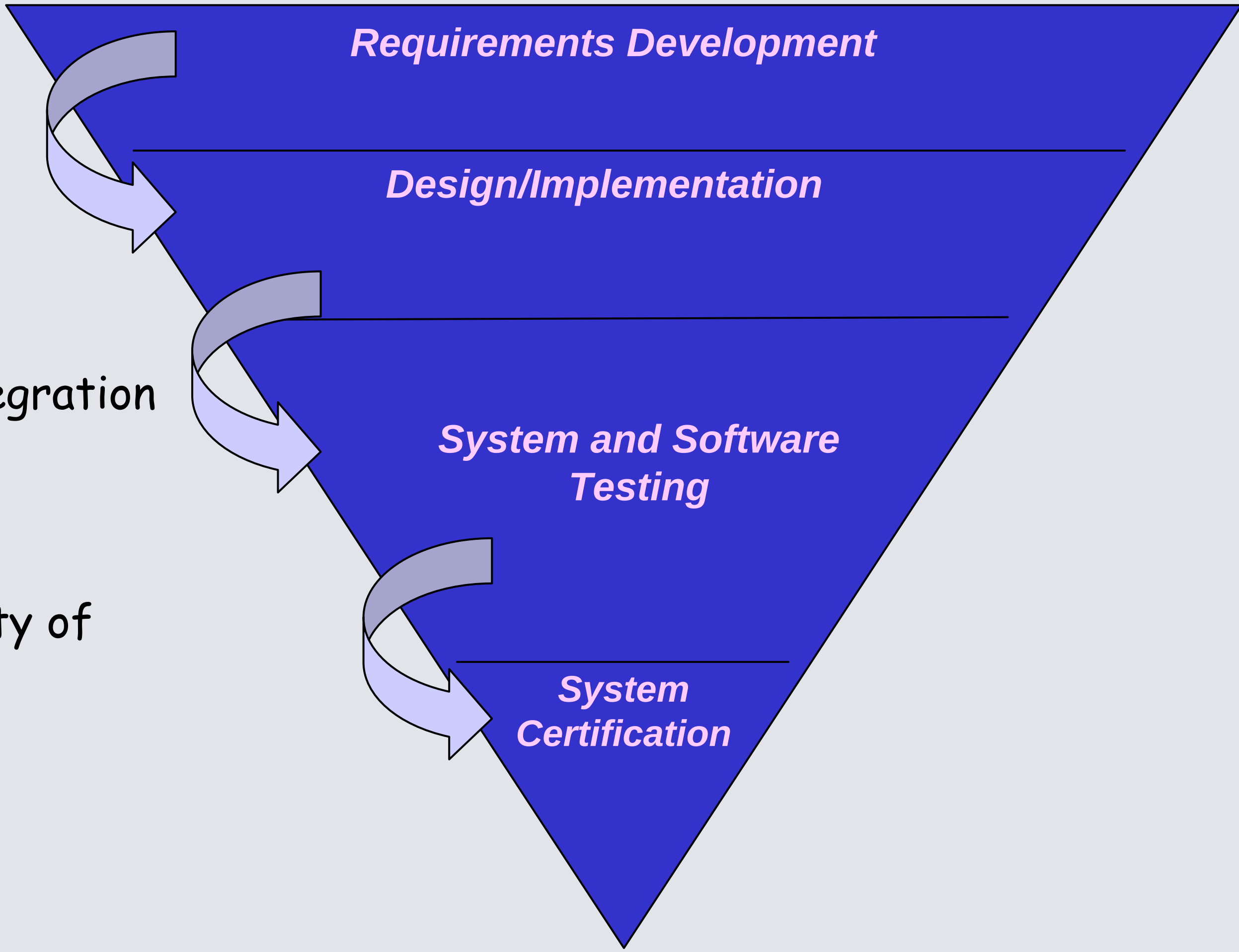
System Development and Certification

Model V&V
- Control Power V&V
- Control Law V&V
- Functional V&V

Software V&V
- Unit/Component Test
- Hardware/Software Integration (HSI)

Hardware V&V
- Qualification Test (Safety of Flight)
- Aircraft Integration

System V&V
- Standalone (Static)
- Integrated (Dynamic)
- Failure Modes and Effects Test (FMET)



[Source: Jim Buffington, LM Aero]

FAA regulatory standard: RTCA DO-178B

Project management, risk mitigation, design and testing activities for embedded software developed for the commercial avionics industry are based on the FAA standard:

RTCA (Radio Technical Commission for Aeronautics) DO-178B: "Software Considerations in Airborne Systems and Equipment Certification"

- "Process-based" certification
- Interesting points:
  - Certification applies to the end product (ie. airframe), encompassing all systems
  - It applies to a given application of a given product (other applications of the same product require further certification)
  - It requires that all code MUST be there as a direct result of a requirement
  - It requires full testing of the system and all component parts (including the software) on the target platform and in the target environment in which it is to be deployed

DO-178 History

- Timeline History
  - Nov. 1981- DO-178-SC145
  - Mar. 1985- DO-178A -SC152 (4 years)
    - Software Levels 1,2,3 – Crit, Essential, NonEss
    - Software Develop Steps D1-D5
    - Software Verification Steps V1-V7
  - Dec. 1992- DO-178B -SC167 (7 years)
    - Objectives Based Tables
      - What, not how
    - Criticality Categories (A,B,C,D) / Objectives Matrix
  - 12 years Since DO-178B ➔(15 years)

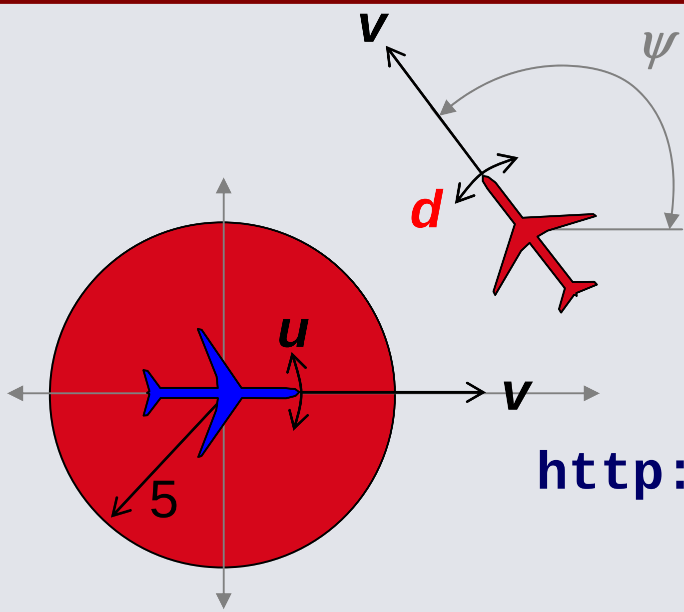
[source: Jim Krodel, Pratt & Whitney]

Issues Under Consideration for SC205 Sub-groups

- Technology/Domains Under Consideration
  - Formal Methods
  - Model Based Design & Verification
    - Model Verification and Level of Pedigree
    - Certification of Proof by Models
  - Software Tools
    - And our reliance on them from a certification perspective
  - Object Oriented Technology
  - Comms-Nav-Sur/Air-Traffic-Management

[source: Jim Krodel, Pratt & Whitney]

Example 1: Collision Avoidance Systems

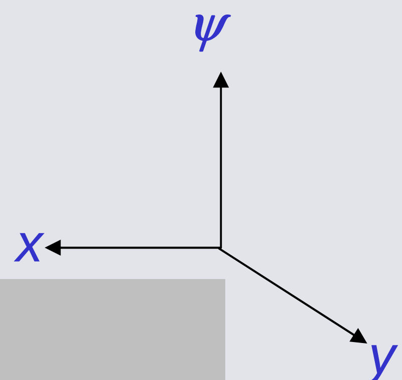


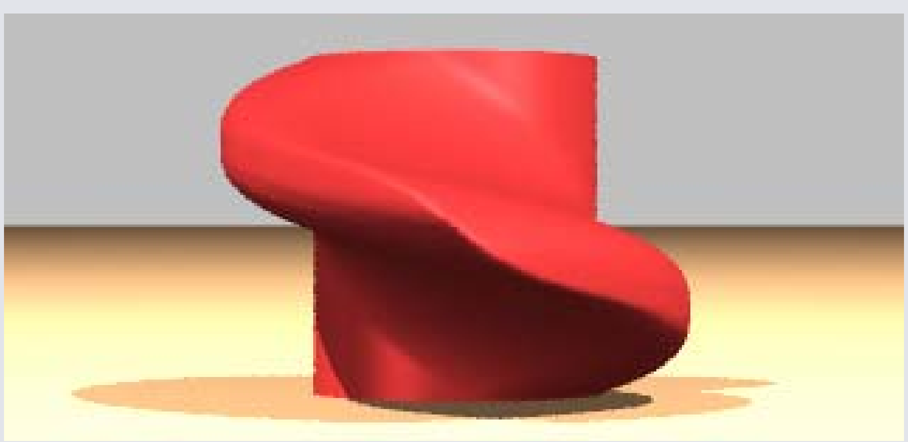
Differential game formulation:

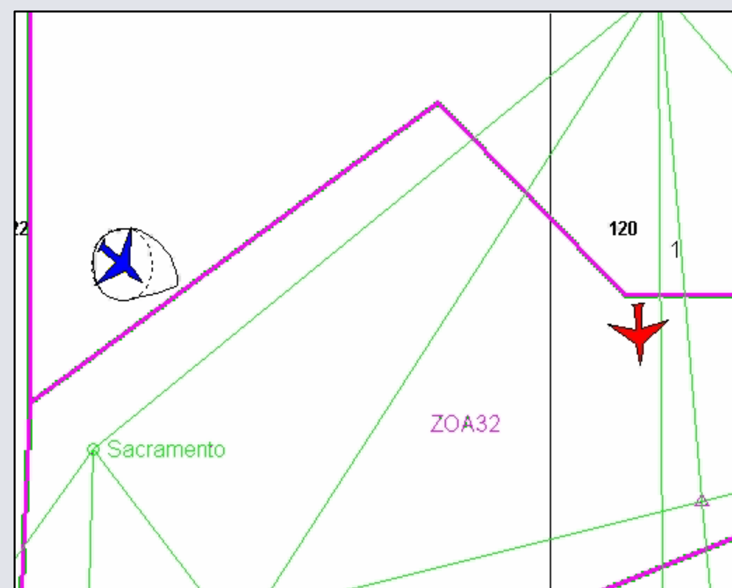
Compute the set of states for which, for all possible maneuvers (d) of the red aircraft, there is a control action (u) of the blue aircraft which keeps the two aircraft separated.

http://www.cs.ubc.ca/~mitchell/ToolboxLS/

[Tomlin lab, 2002]







Example 2: Operating Envelope Protection

User Interaction with Aerospace Systems:

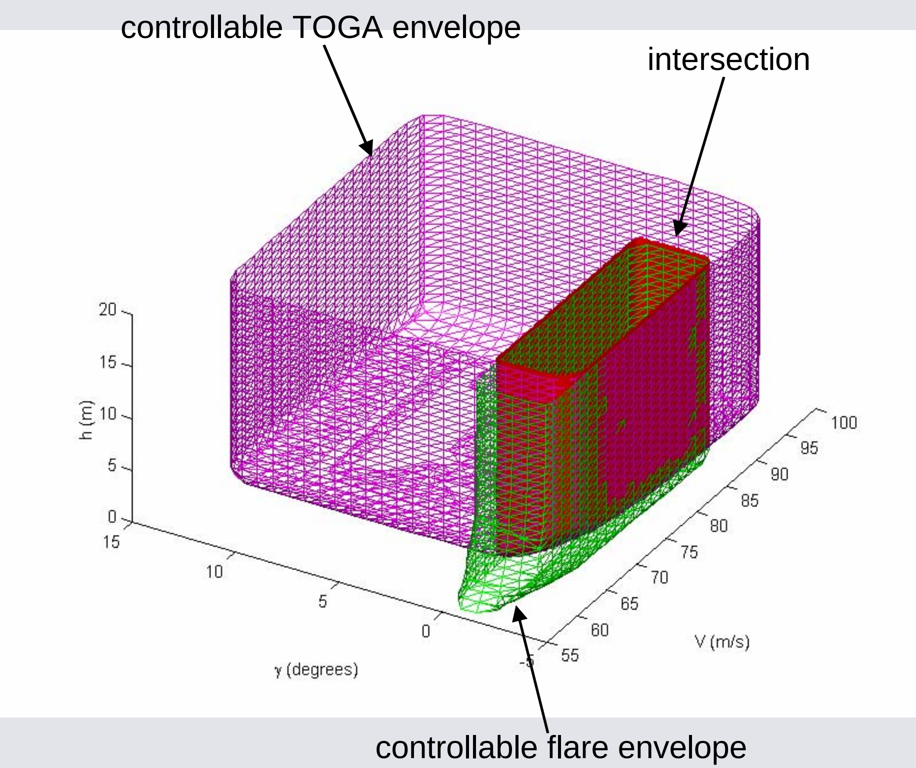
- Interaction between
  - System's dynamics
  - Mode logic
  - User's actions
- Interface is a reduced representation of a more complex system
- Too much information overwhelms the user
- Too little can cause confusion
  - Automation surprises
  - Nondeterminisim

For complex, highly automated, safety-critical systems, in which provably safe operation is paramount,

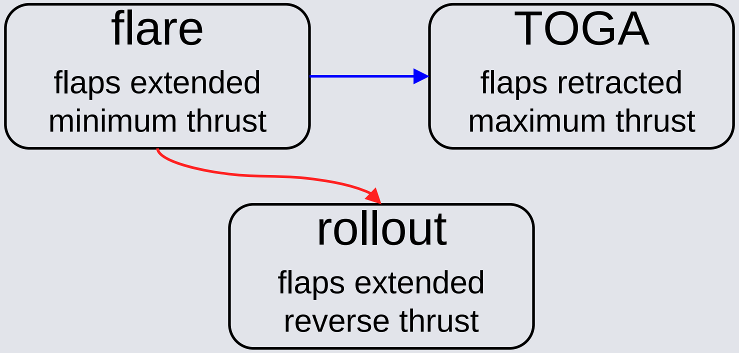
What information does the user need to safely interact with the automated system?

Example 2: Operating Envelope Protection

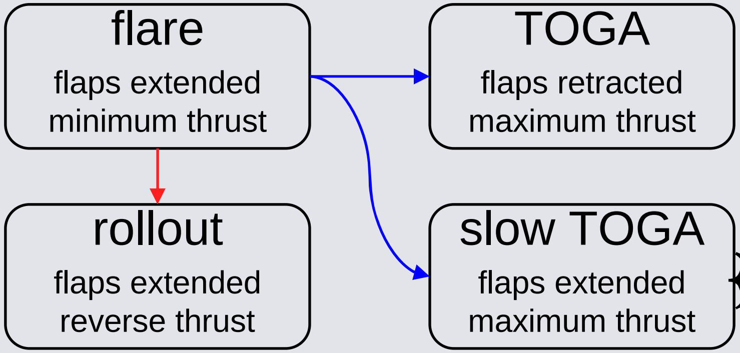
- Controllable flight envelopes for landing and Take Off / Go Around (TOGA) maneuvers may not be the same
- Pilot's cockpit display may not contain sufficient information to distinguish whether TOGA can be initiated [Tomlin lab, 2003]



existing interface



revised interface



http://www.cs.ubc.ca/~mitchell/ToolboxLS/

Tools for modeling, design, and code generation

Designing safety critical control systems requires a seamless cooperation of tools:

- Modeling and design at the control level
- Development tools at the software level
- Implementation tools at the platform level

- Corresponding research needed:
  - Development of algorithms and tools to verify and validate the high level design – currently tools such as reachability analysis tools for hybrid systems are limited to work in up to 4-5 continuous state dimensions
  - Development of code generation tools (ideally, verified to produce correct code)
  - Tools to check the correctness of the resulting code
  - Algorithms and tools to automatically generate test suites

Static Program Analysis Tools

Static program analysis

is used at compile time to automatically determine run-time information and properties which are extractable from the source code. These include:

- Ensuring that the allowable range of array indexes is not violated
- Ensuring simple correctness properties: functional (such as dependencies between aspects of variables or invariants on the shape of data structures) or nonfunctional (such as confidentiality or integrity for security-critical applications)
- Identifying potential errors in memory access
- Type checking
- Interval analysis
- Checking for illegal operations, like division by zero

Currently, properties such as absence of run time errors and worst case execution time have been tackled: more research is needed to address problems arising from a distributed, embedded setting, such as checking for safety conditions, and for the absence of deadlocks

NITRD HCSS National Workshop on Software for Critical Aviation Systems

- Workshop co-chairs: Tomlin and Hansman
- NITRD HCSS Co-Chair: Helen Gill
- Planning meeting: University of Washington, Nov 9-10 (~35 participants from Industry, DoD, Govt, and Academia)
- Workshop, June 2006, Washington DC
- Application domains:
  - Air traffic management, C&C
  - flight control, UAVs
  - CNS, aircraft and infrastructure integration
  - Satellite and space system control

NITRD = Federal Networking and Information Technology Research and Development

HCSS = High Confidence Software and Systems

NITRD HCSS National Workshop on Software for Critical Aviation Systems

Issues:

- Reduce software development time and costs for next generation avionics platforms
  - Distributed systems
  - Adaptive systems
  - Mixed criticality systems
  - Human in the loop
  - Security in the loop
- Design for certification
- Design for re-use
- Minimize re-test
- Open experimental platforms: high pedigree models for application of technologies