# Integrating Operational Simulation with Executable Designs in SysML

**…by developing executable SysML avionics models and integrating them with operational air vehicle models for requirements analysis and design solution assurance**

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# M&S is not yet at the core of product development processes

- Simulations of air vehicle and subsystem are in common use, but
- Without integration of detailed avionics models with operational simulation,
- Simulation results are not available in time to affect the design process

# The Pilot Leveraged An Existing Design Evaluation Trade Study

- To evaluate designs for adding terrain following and avoidance (TF/TA) capability
  - To an existing aircraft production model
  - That used the 1553 avionics architecture
  - With planned use of specific radar & other equipment
- The pilot had access to the trade study
  - Operational Requirements Documents
  - Trade study candidate solutions
  - Subject Matter Experts

# This Pilot Demonstrated Integrated M&S Can Be Used For Design Analysis By:

- Building detailed executable design models cost effectively
- Obtaining quantitative analysis results
- Incorporating the results into the design process

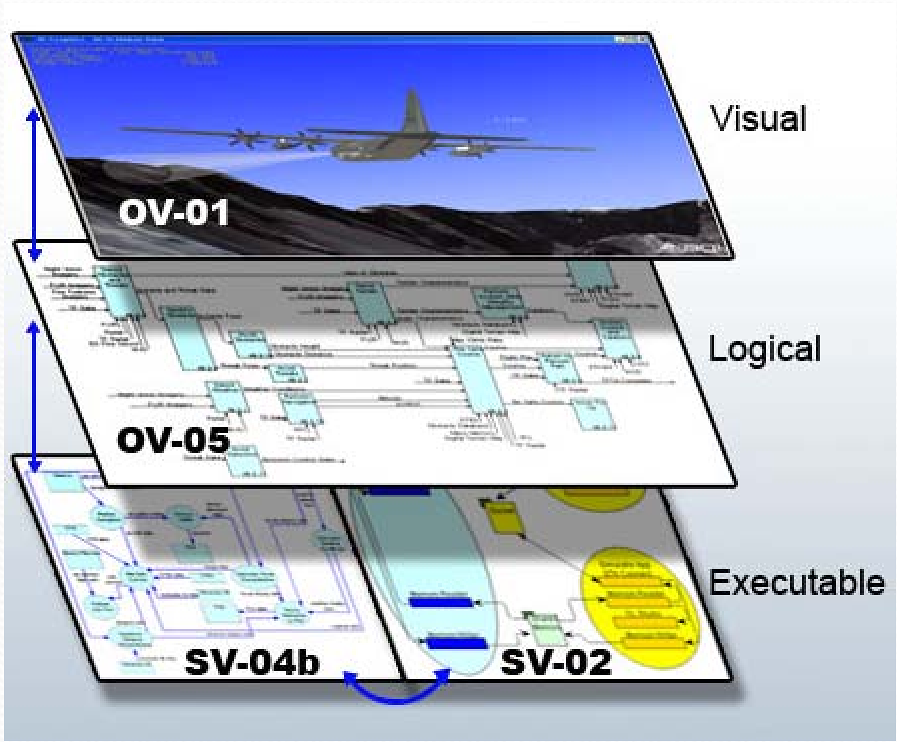
***… through a real design problem***

# The System Engineering Process For The Pilot Followed These Steps:

1. Analyzed customer level capability requirements
2. Established As-Is baseline system design
3. Determined performance budgets of the system design
4. Refined top level requirements to address verifiability
5. Produced allocated requirements for the modified design with performance budgets
6. Analyzed design modifications against allocated requirements

# Execution Of The Engineering Process Had Simulation At Its Core

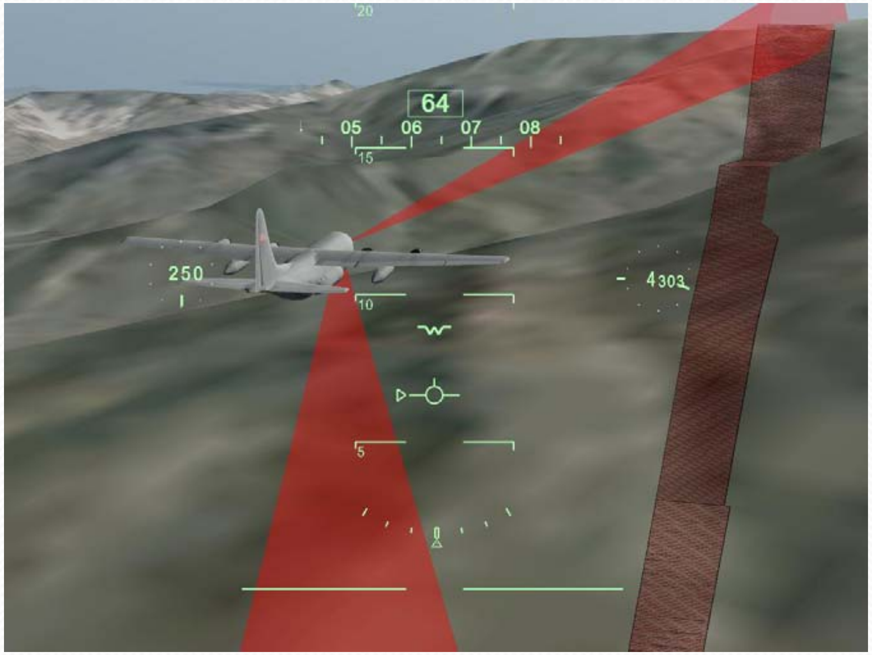
- Reviewed trade study info
- Put together a team with specific skills in operational simulation, SysML, etc.
- Identified requirements for a simulation execution environment
- Assembled the simulation environment and
- Began developing and integrating design models
- Ran simulations and collected results for statistical analysis




**Simulation Execution Architecture**

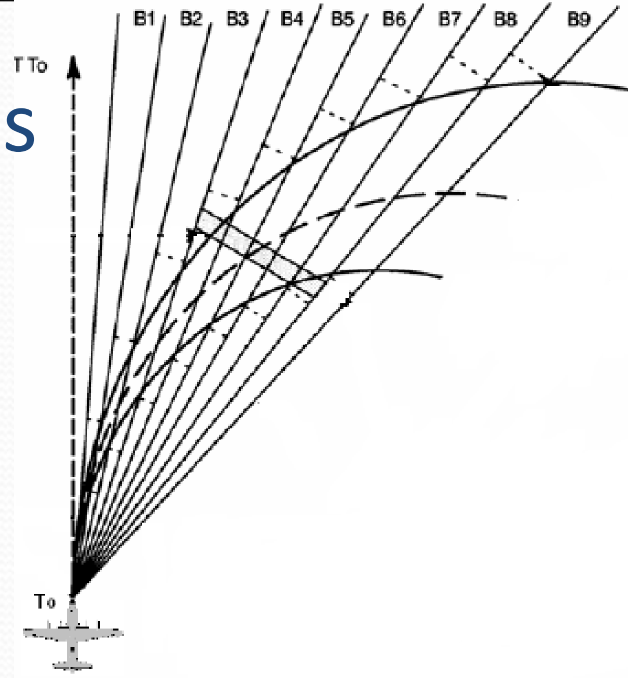
# The Initial Task Was Analysis of The TF/TA Capability

- By using the simulation environment configured with
  - Performance model of aircraft
  - Sensor models
  - Mountains, obstacles, weather, …
- To understand and refine the requirements
- To understand design constraints
  - Aircraft performance
  - Radar performance
  - In specific operational scenarios

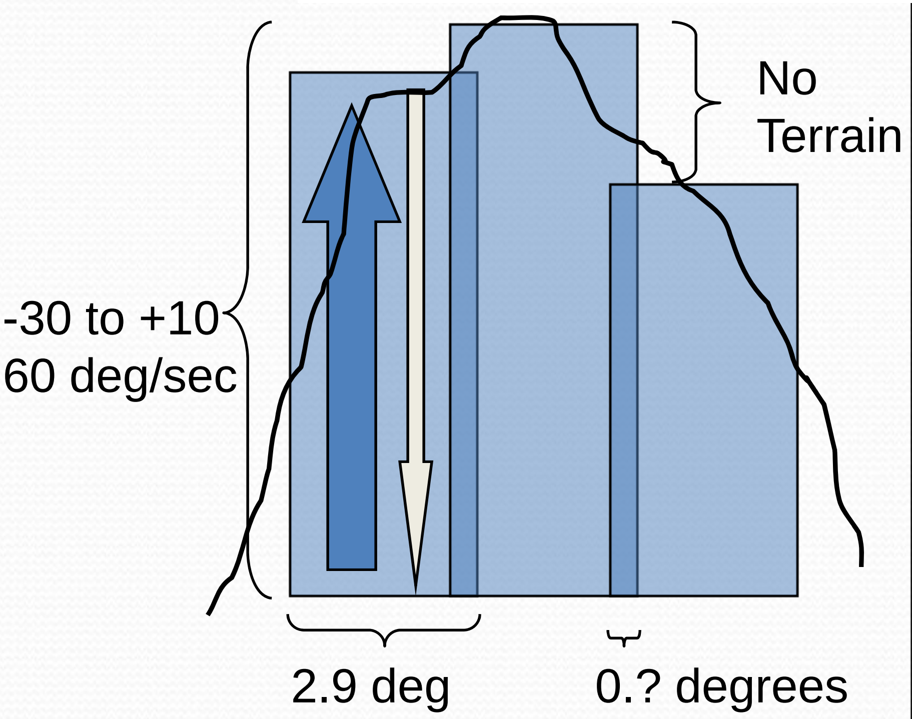



**Aircraft with radar altimeter and terrain detection radar**

# Critical Latency Timing Constraints Follow From Terrain Detection

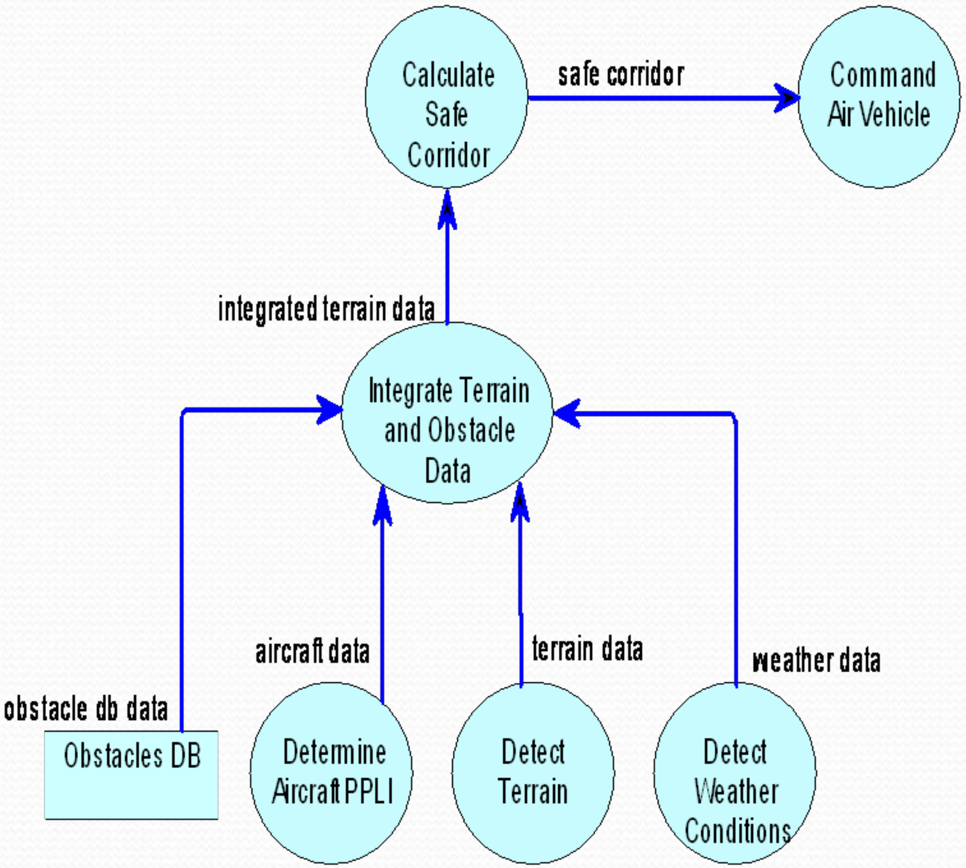



- We produced an operational simulation that capture radar performance characteristics
- The radar scans in an upward direction, stops when it detects horizon, turns around and moves back down to the bottom of the vertical scan, then scans upwards again.  It does not scan while moving downward.
- When the aircraft is turning it can scan up to 30 degrees in the direction of the turn.

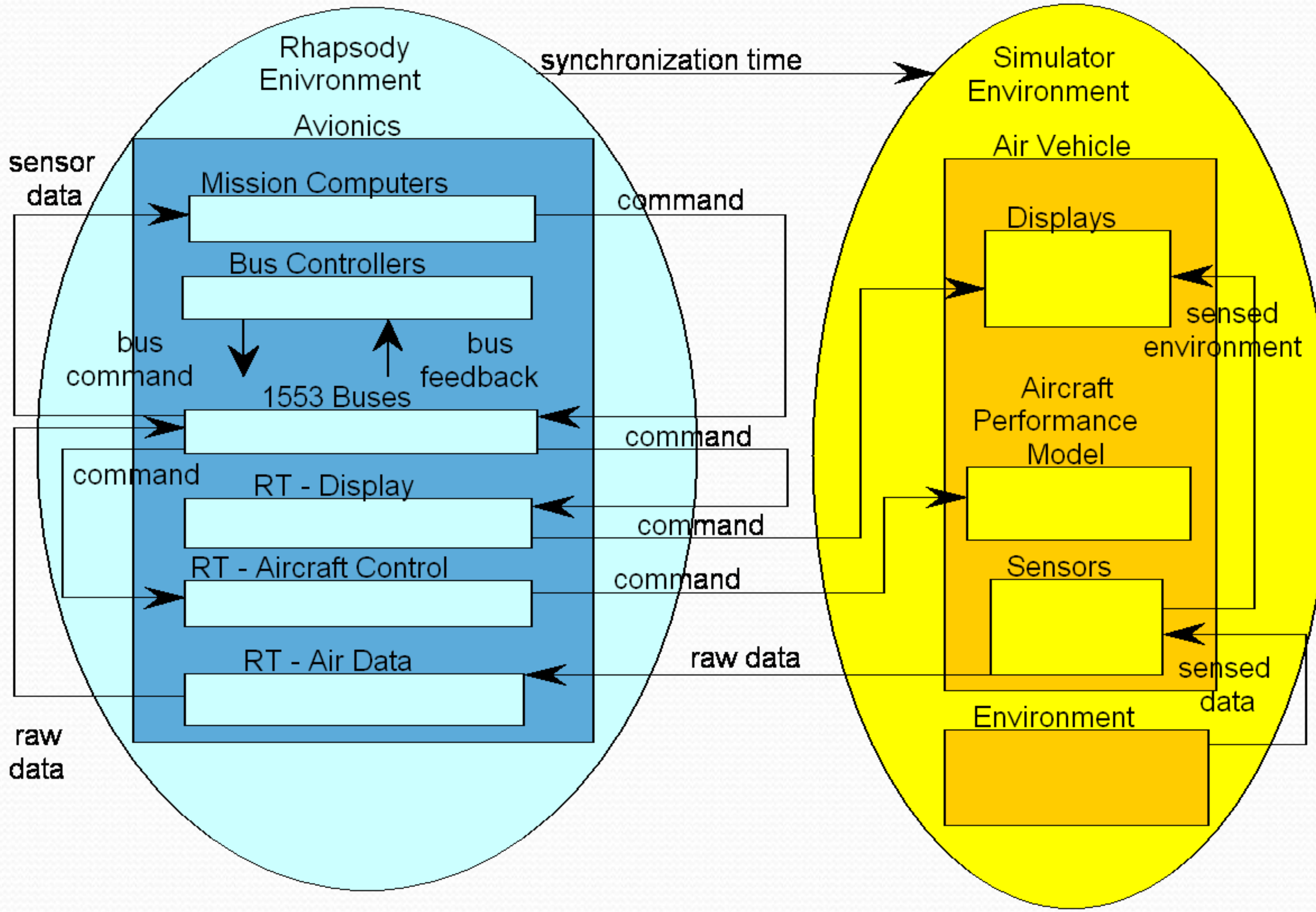


# We Constructed a Functional Flow Diagram To Help Isolate Design Issues

- Simulation allowed us to determine constraints of aircraft performance, radar obstacle detection, …
- Used existing algorithms for calculating a safe corridor based on aircraft performance data
- Bottom Line: basic design problem is timing latency to integrate data once aircraft detects obstacle

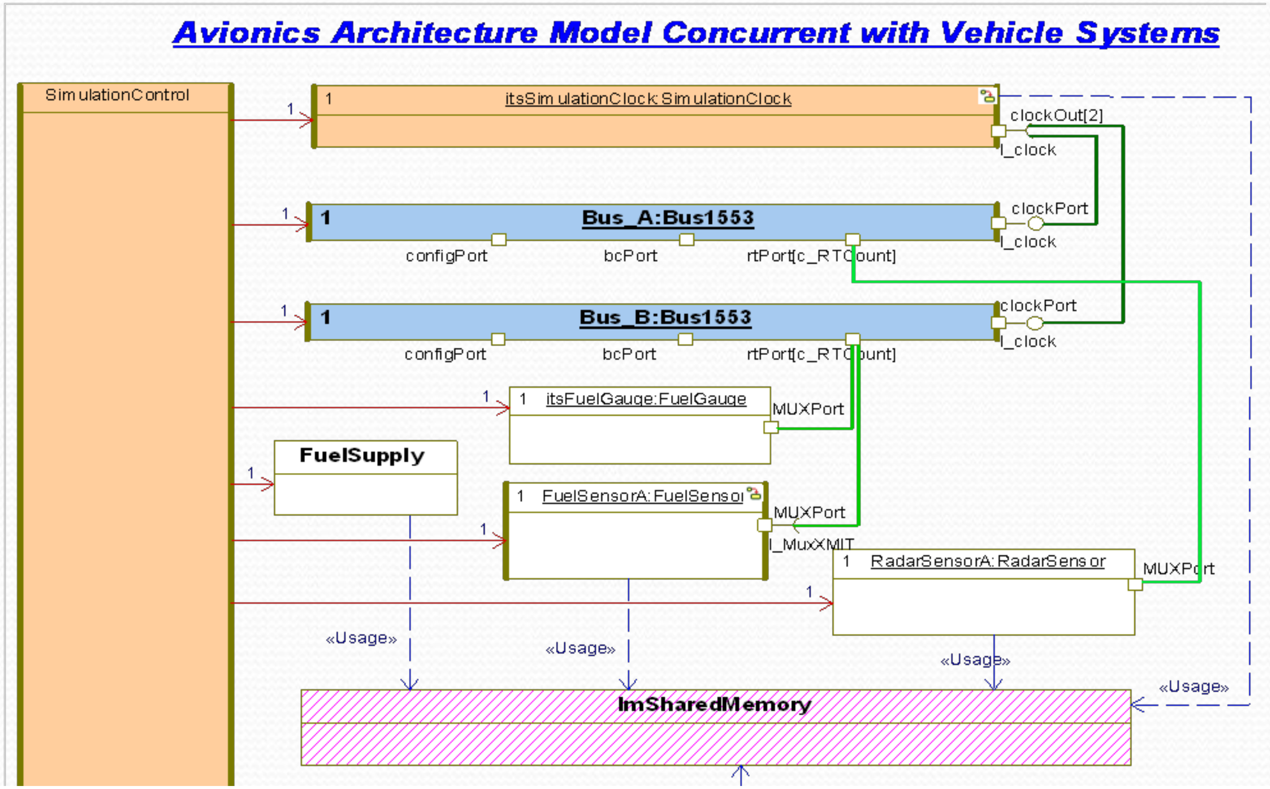


# The Avionics Design and Operational Air Vehicle Models Operate in an Integrated Environment



# We Built An Executable SysML Model Of The 1553b Avionics Architecture

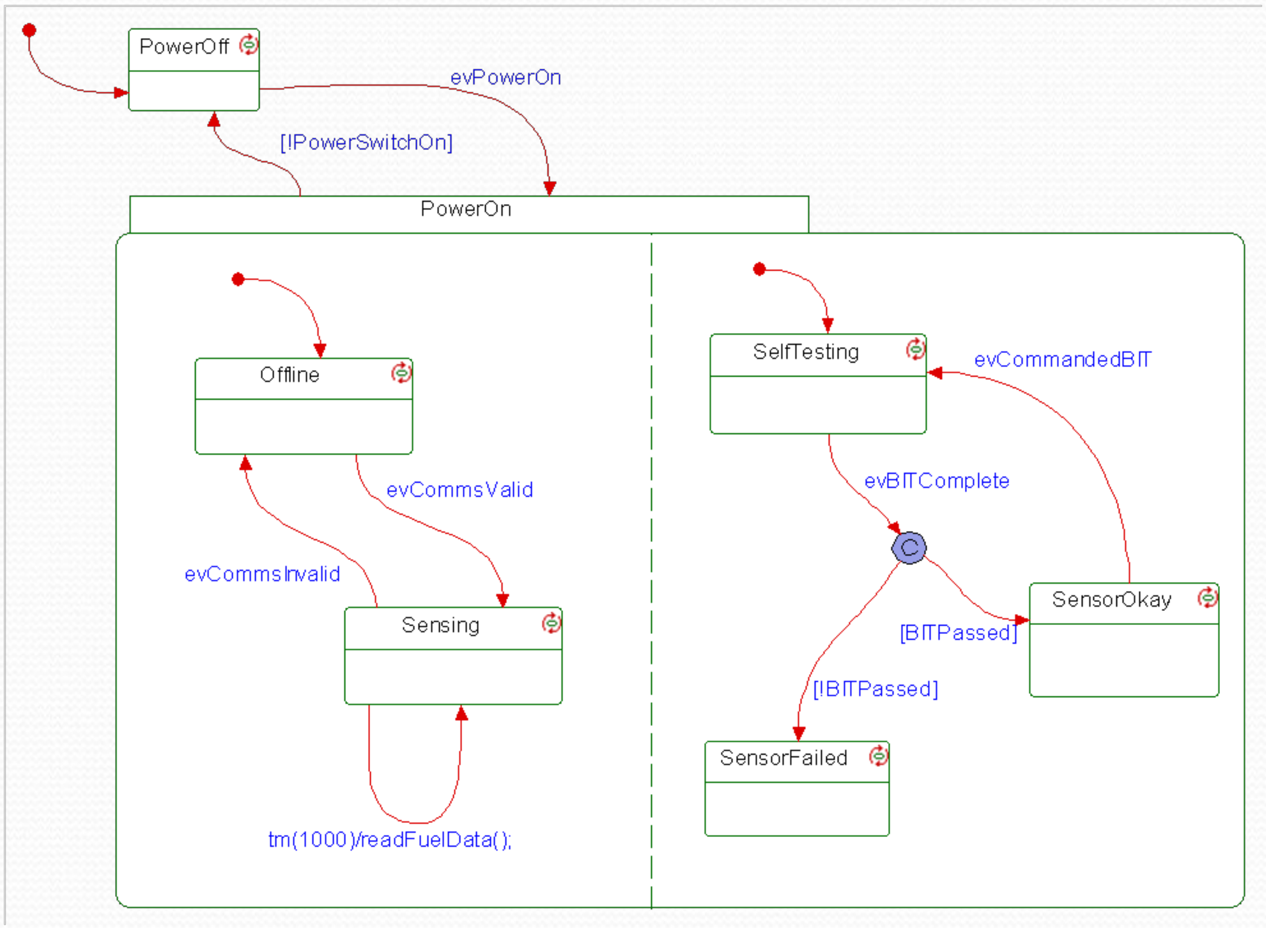
***…, and integrated with Simulation***




***… behavior defined by state charts, uses message table, with statistical assumptions about performance***

# The Behavior Of The SysML Models Are Represented Using State Transition Diagrams

***… fuel consumption is simulated with operational models***

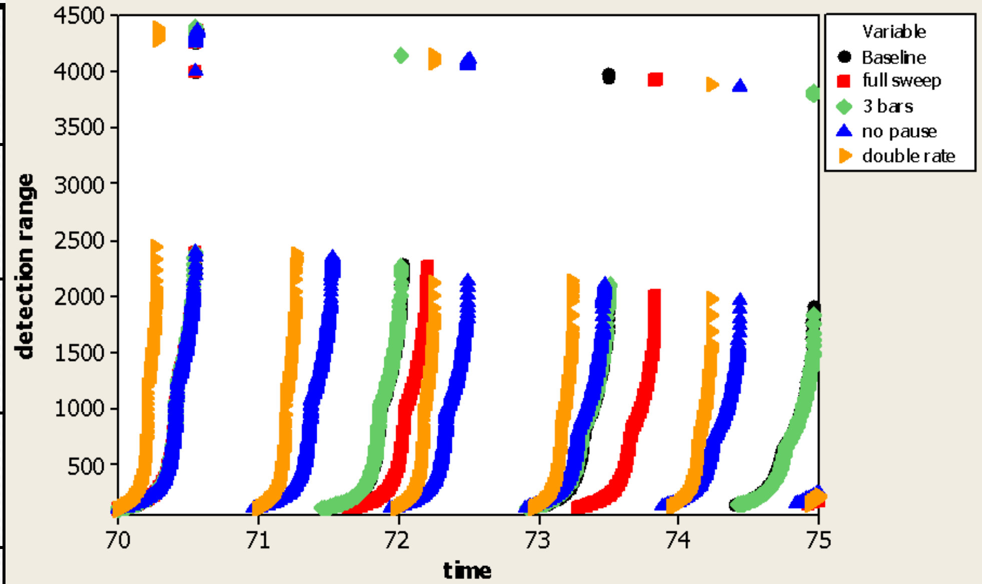



Fuel Sensor

# We Collected Extensive Data From Simulations For Statistical Analysis

***… to provide evidence for analysis results***

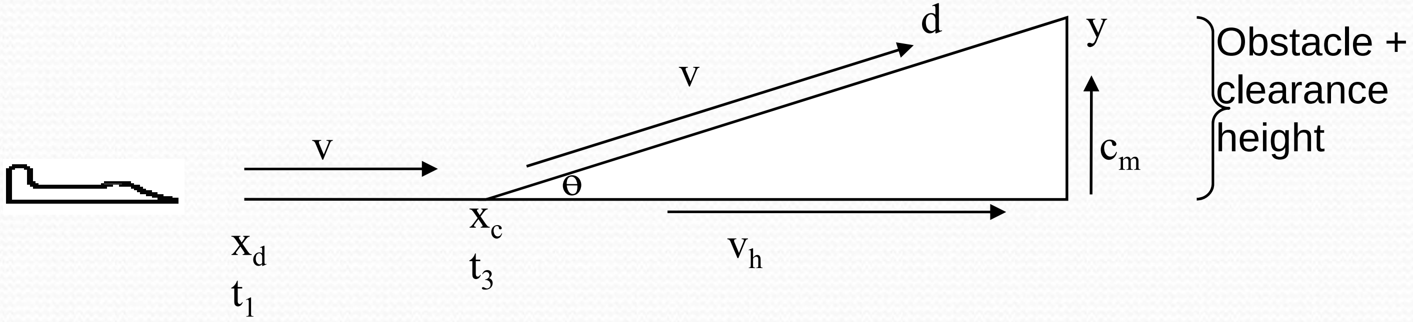
| Run | Speed | Radar |
|---|---|---|
| 1 | 250 knots | 2 bars, normal sweep pattern, normal sweep rates |
| 2 | 250 knots | 3 bars, normal sweep pattern, normal sweep rates |
| 3 | 250 knots | 2 bars, normal sweep pattern, double sweep rates |
| 4 | 250 knots | 2 bars, full sweep pattern, normal sweep rates |
| 5 | 250 knots | 2 bars, no pauses for the sensor to turn around, normal sweep rates |
| 6 | 200 knots | 2 bars, normal sweep pattern, normal sweep rates |




- Double rate sweep detects terrain faster
- 3 scan bars made no difference
- Full scan past horizon slowed down detection time
    - Increases probability of being detected

# We Refined The Requirements & Have Started The Design Solution Verification

***…crux of viability of different design solutions is time to integrate sensor data using the avionics bus***

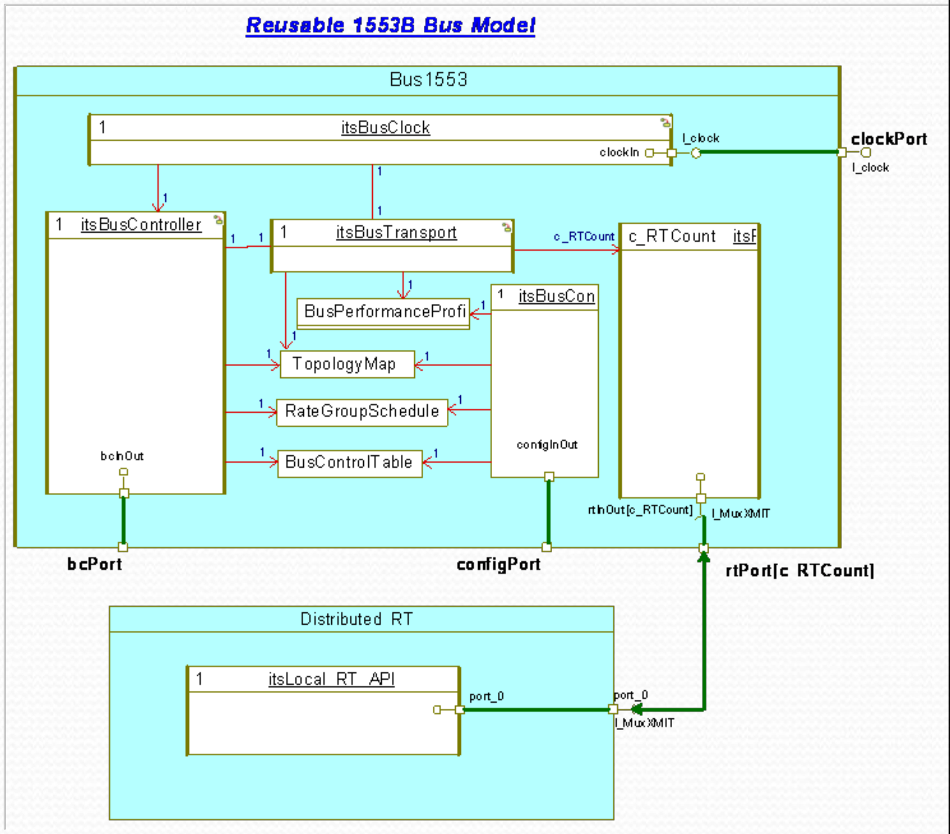



At a given distance, air speed, & obstacle height

- $t_1$ – time to detect obstacle
- $t_2$ – time to integrate sensor data & compute course $t_1 - t_3$
- $t_3$ – time to fly a safe course

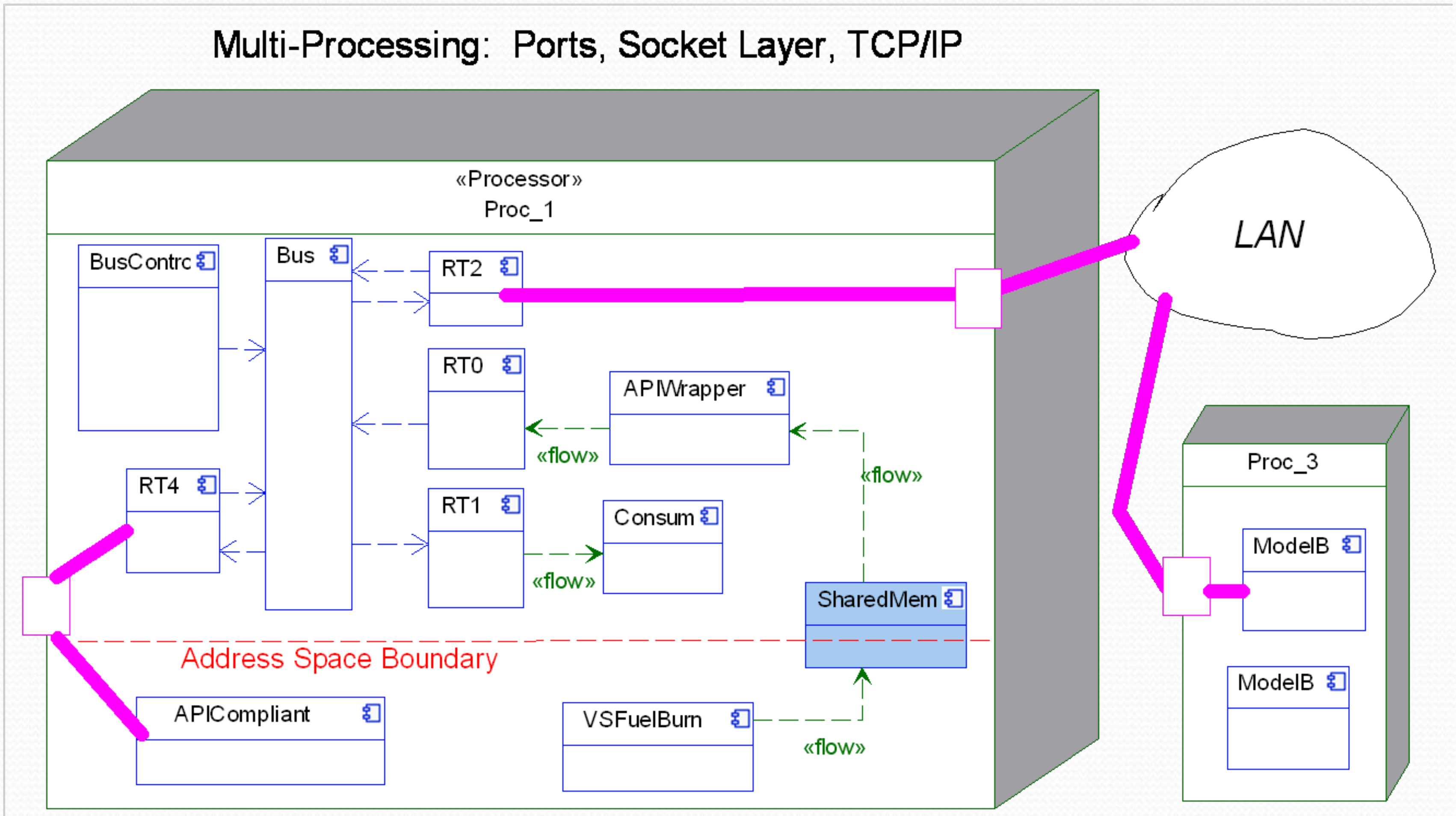
# Conclusions

- Building and assembling models, collecting simulation data, and performing analysis is relatively inexpensive
- Simulation framework is reusable
- Avionics architecture is reusable via specialization
- Execution architecture is scalable




**Reusable avionics architecture**

# Scalability Is Achieved Through Distribution While Maintaining Time Synchronization



# Next Steps

- Finish Pilot design analysis
- Do other 1553 avionics analysis
- Model other avionics architectures
- Integrate hardware-in-the-loop
- Use sensor analysis to verify design feasibility