Presented by

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Model Based Design for Fuel System Development

Use of Stateflow and Mathworks Toolsets

Airbus 40 years of innovation

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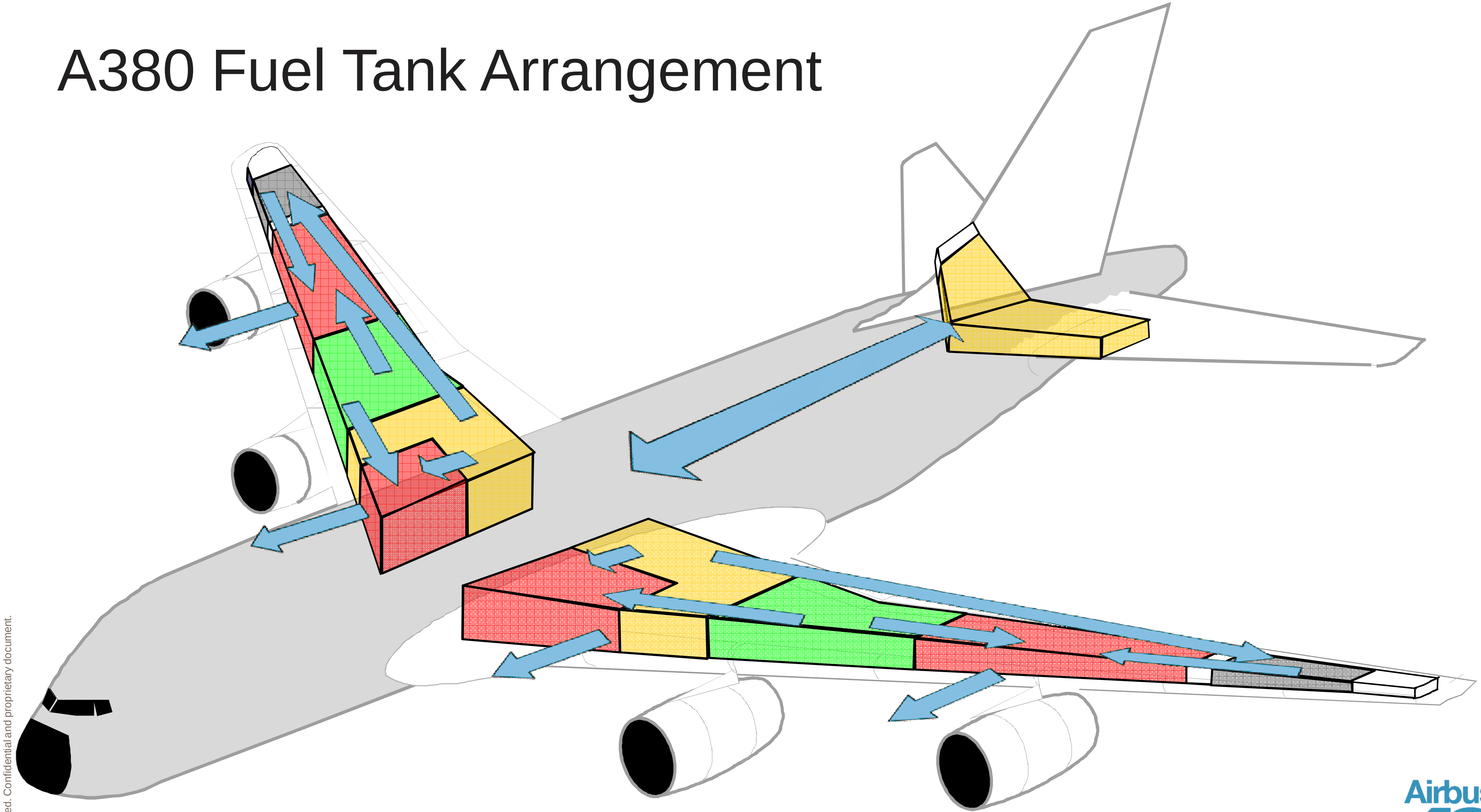
Why is it so complicated?

A380 Fuel Tank Arrangement



A/C Maximum Weight : 560 Tonnes.
Max Fuel Capacity : 250 Tonnes (320,000 Litres)
Payload : 550 Passengers + 35 Tonnes Cargo

Why is it so complicated?

Multiple engines & tanks

Numerous functions to manage (some of which are safety critical)

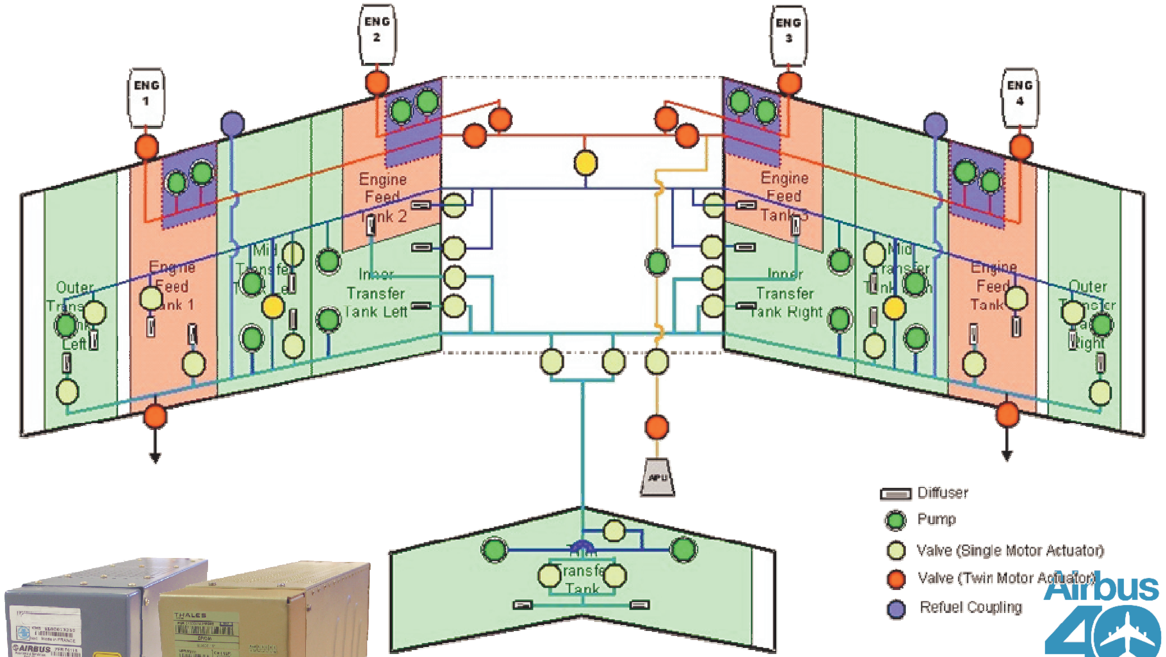
- Fuel Measurement
- Fuel Management
- CG control
- Refuel/Defuel
- Wing bending relief
- Communications to/from more than 20 other systems
- Hot/Cold Fuel Workarounds
- Self-test/Built in Test Equipment
- Failure Workarounds etc. etc.

Hundreds of individual pieces of equipment to manage

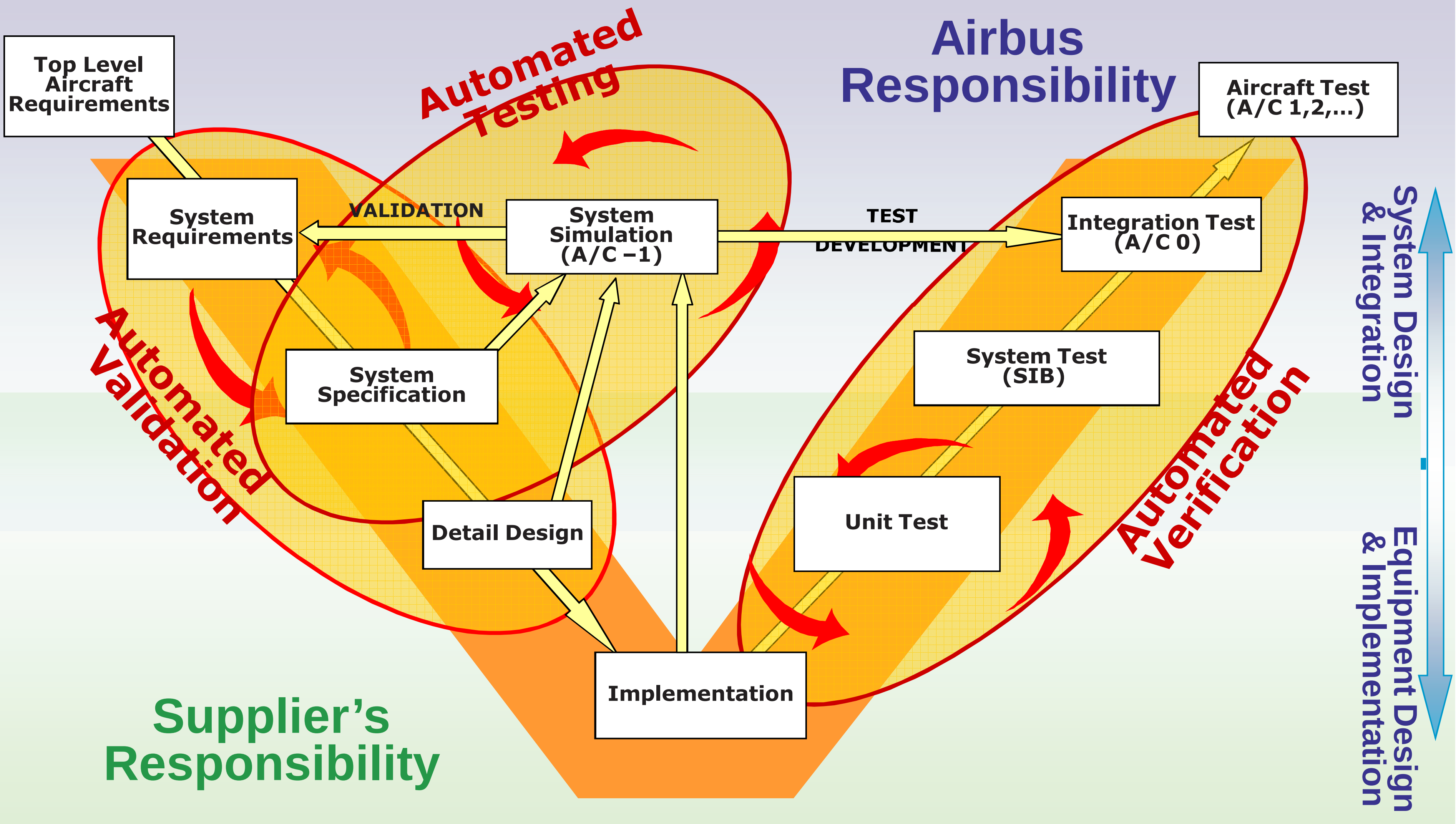
- A380; 13 tanks, 21 pumps and 43 valves

Safe Operation with Multiple Equipment Failures

- No turn-back/diversion
- No increased crew workload
- 2800 cases of "MMEL" + Single Failure

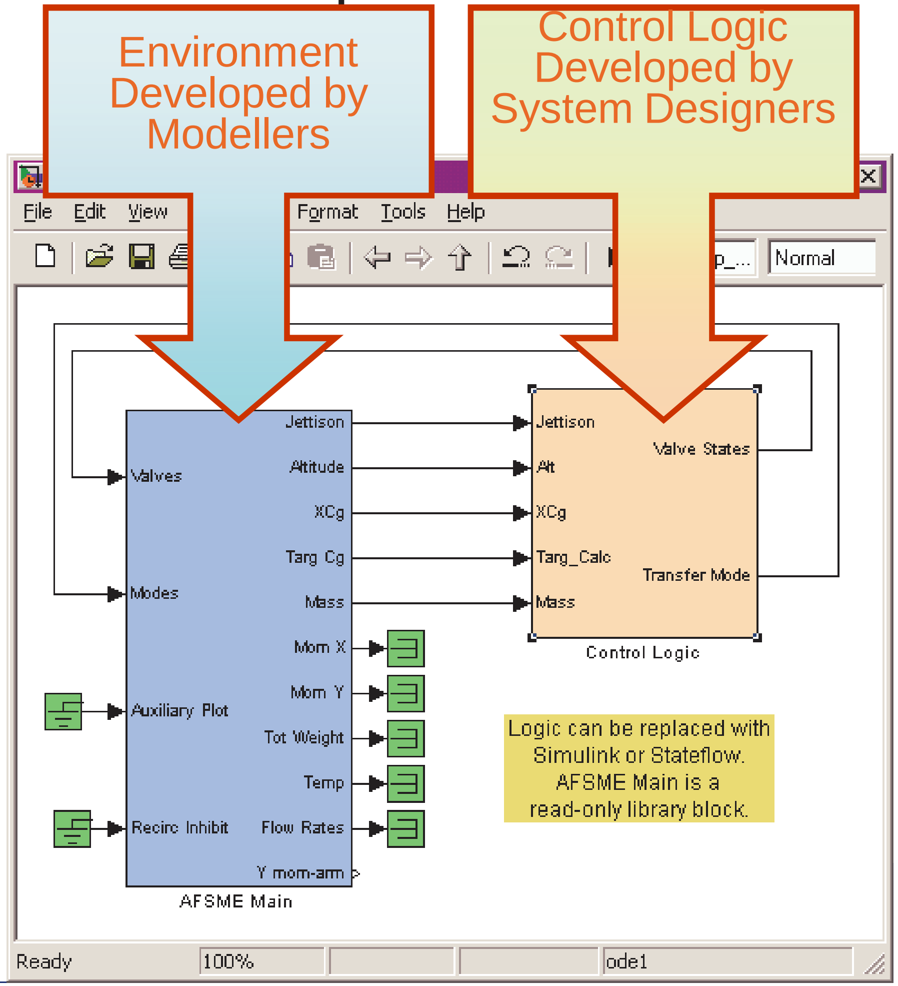


Systems Engineering V-Cycle



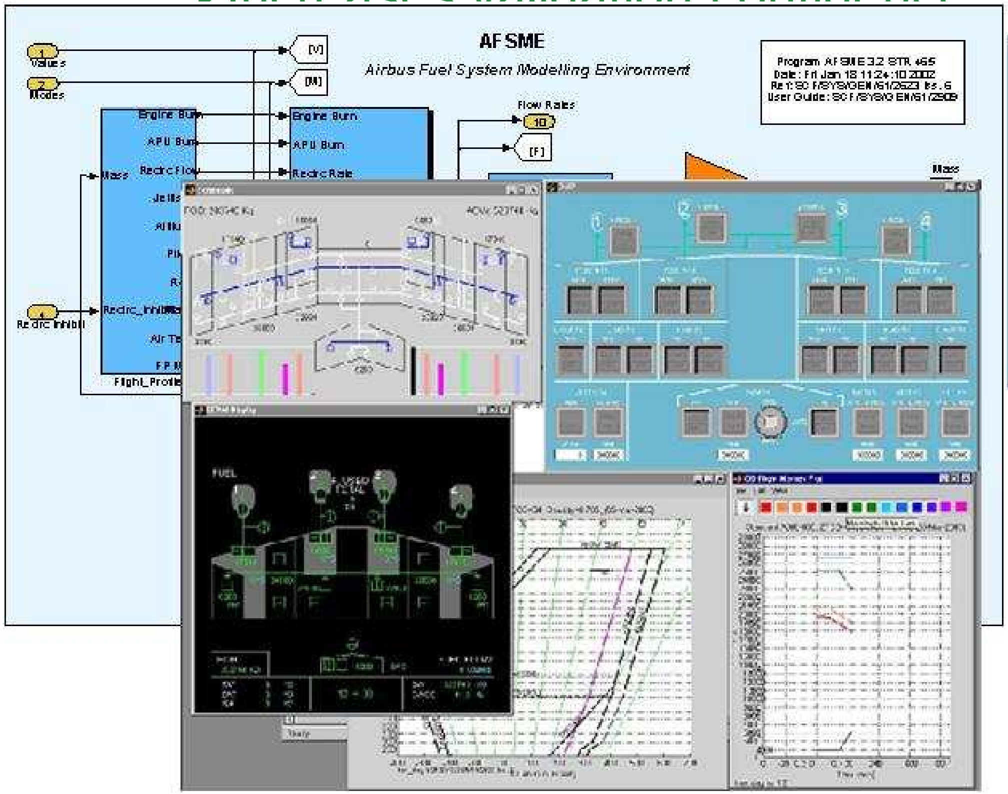
Model Based Development

- Development of Basic Operating Sequence.
  - Normal and Failure Operating Modes
- Rapid Prototyping of Transfer & Refuel Requirements.
- Simulink/Stateflow Application
  - Platform Independent
- Control Logic separated from Aircraft Environment
  - Engineers concentrate on System Design
  - Specialist Modellers concentrate on Environment Fidelity
- Statecharts control behaviour
  - Easier to use than “Enabled Subsystems”

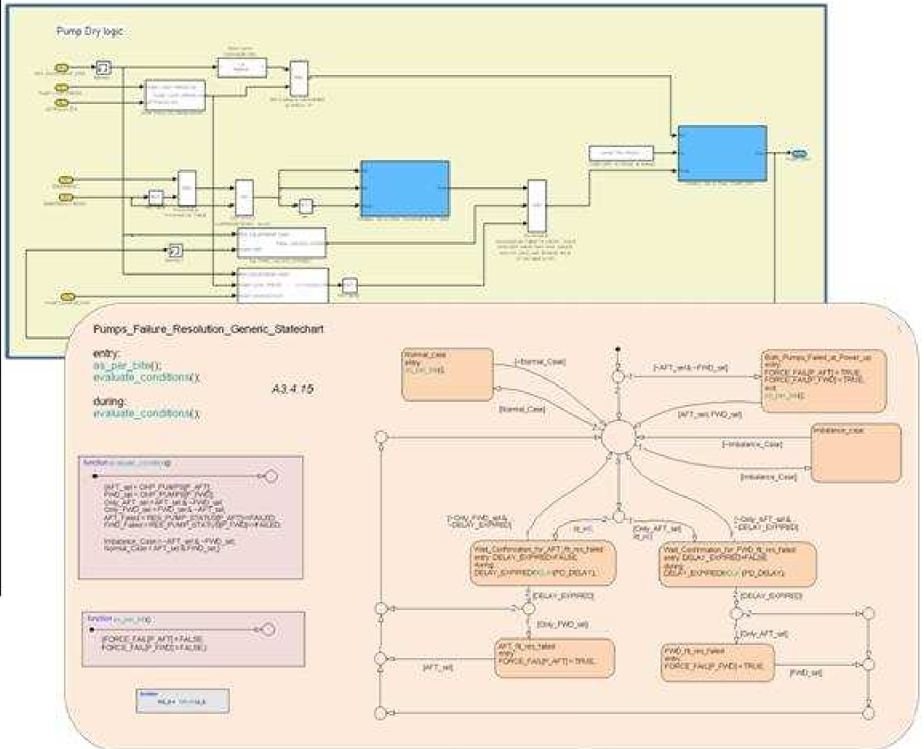


Model Based Design - In Practice

- Statecharts control behaviour
  - Easier than Enabled/Triggered Subsystems
- Enhanced Validation
  - Statechart representation can be clearer and less ambiguous
  - Increases validation confidence



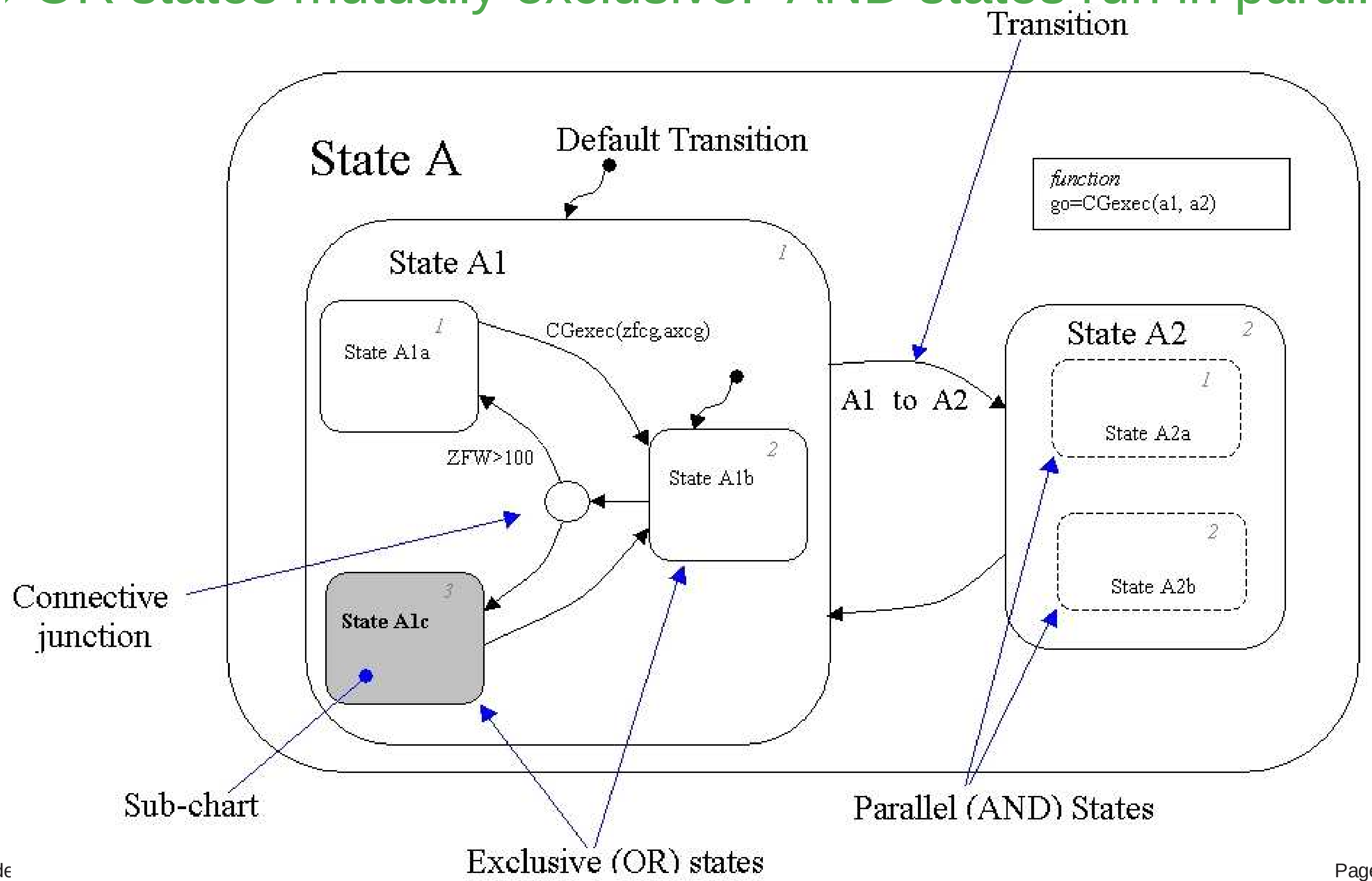
Fuel System Modelling Environment



Control Function Design

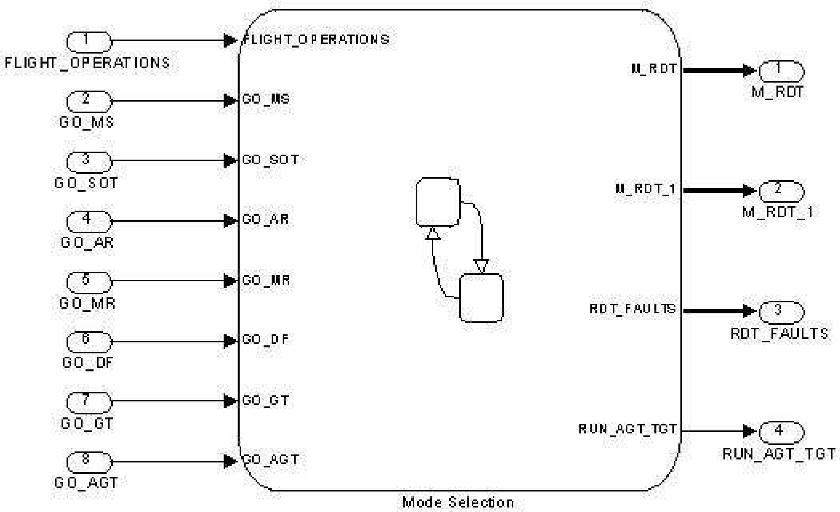
How Stateflow is Used

- Definition of Statechart
  - Describes the system states, rather than the functionality
  - Arrows show transitions between states, not data flow paths
  - OR states mutually exclusive. AND states run in parallel

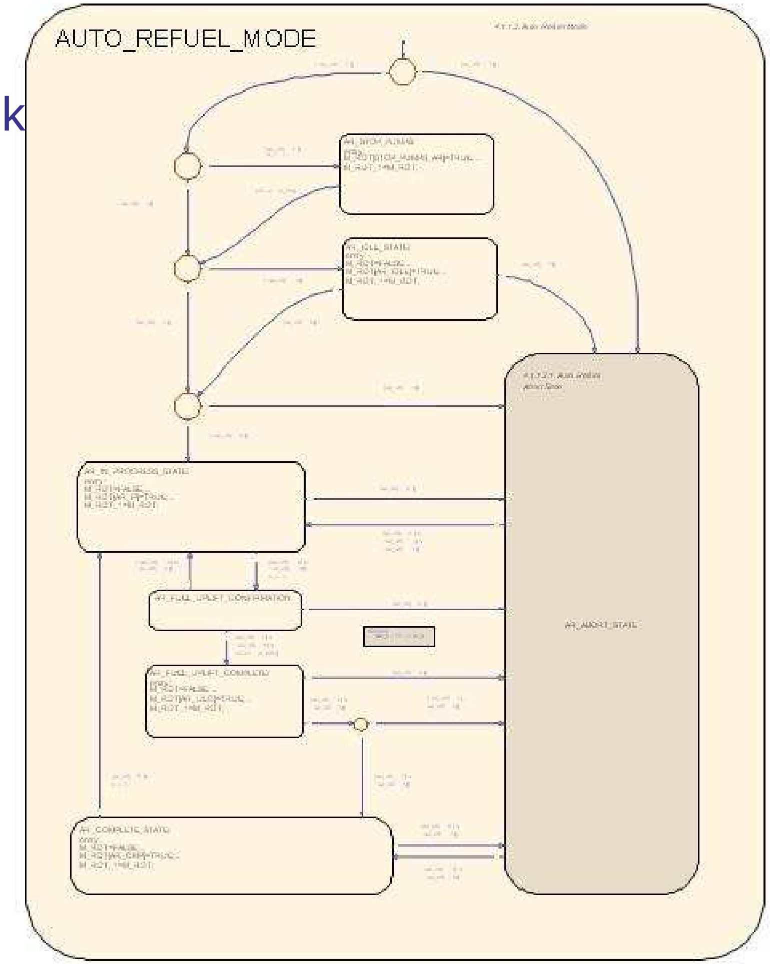


How Stateflow is Used

- Aircraft Fuel System Statecharts:
  - Linked to Requirements Database (DOORS)
  - Separate Chart for each Major A/C Function
  - Transition booleans calculated within Simulink
  - Input into Stateflow Chart
    - Driven behaviour of stateflow logic separated from driving conditions
    - Allows easier readability and testing



Top Level Chart



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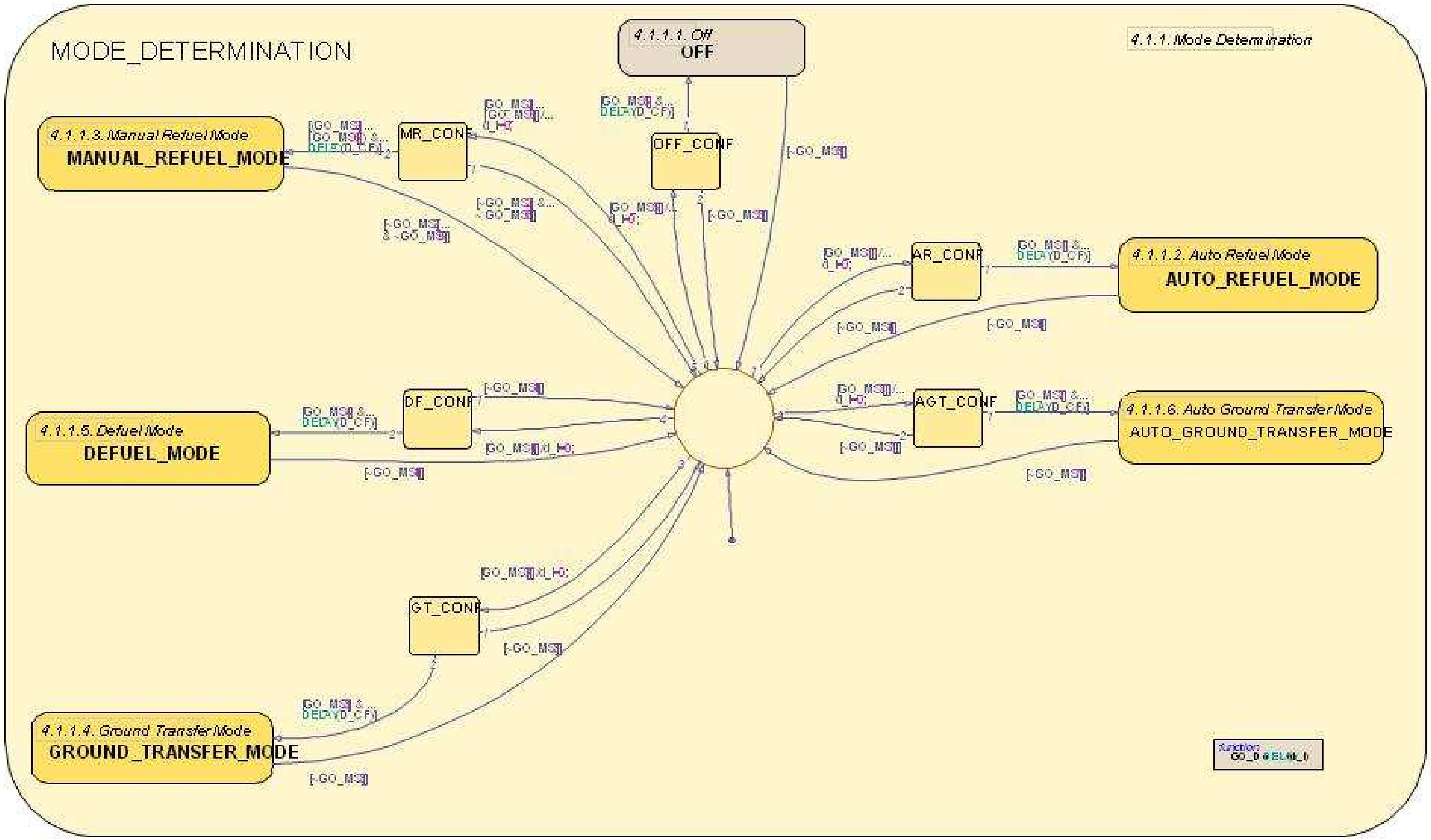
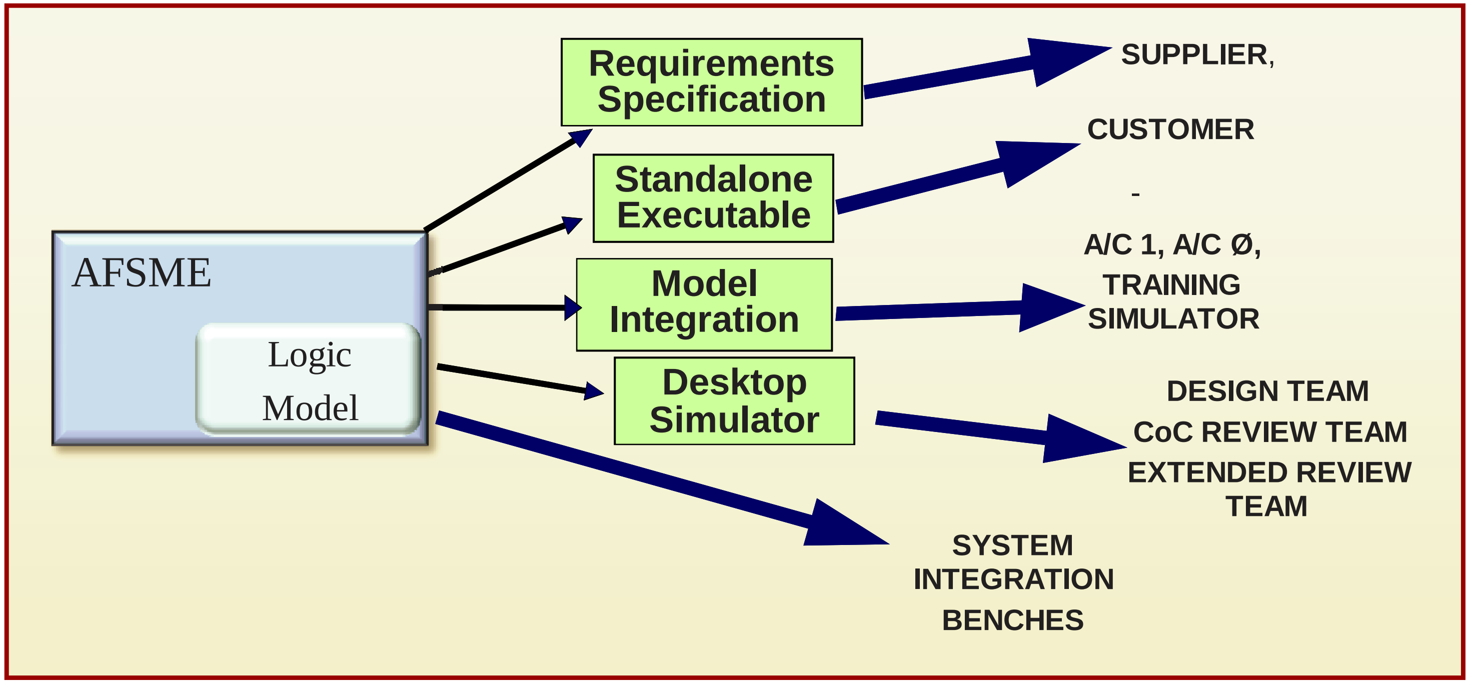
How Stateflow is Used

- Aircraft Fuel System Statecharts: On Ground Operations
  - Clean Layout – Sub-System dependencies unambiguous
  - System behaviour defined as mutually exclusive (OR) states.
  - System cannot be in (e.g.) “Refuel” and “Defuel” modes simultaneously



Where & When is Stateflow Used

- Model Re-Use
  - The model represents functional requirements
    - Can be used directly in a number of simulators:



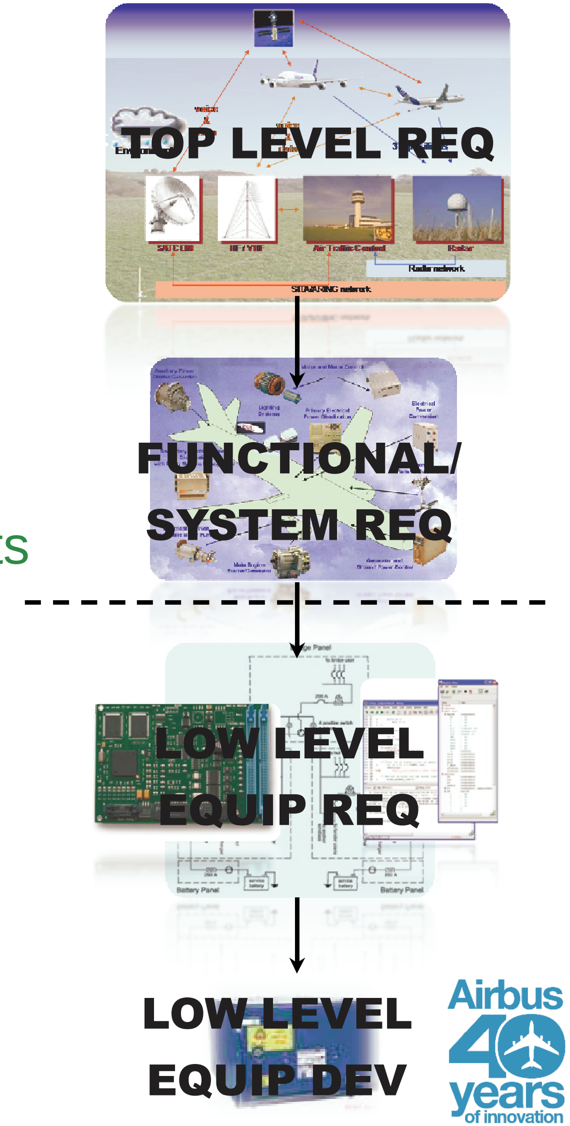
- Model is a "Write Once - Use Many" entity
- Changes to base model propagated down to each instance of use

Where & When is Stateflow Used

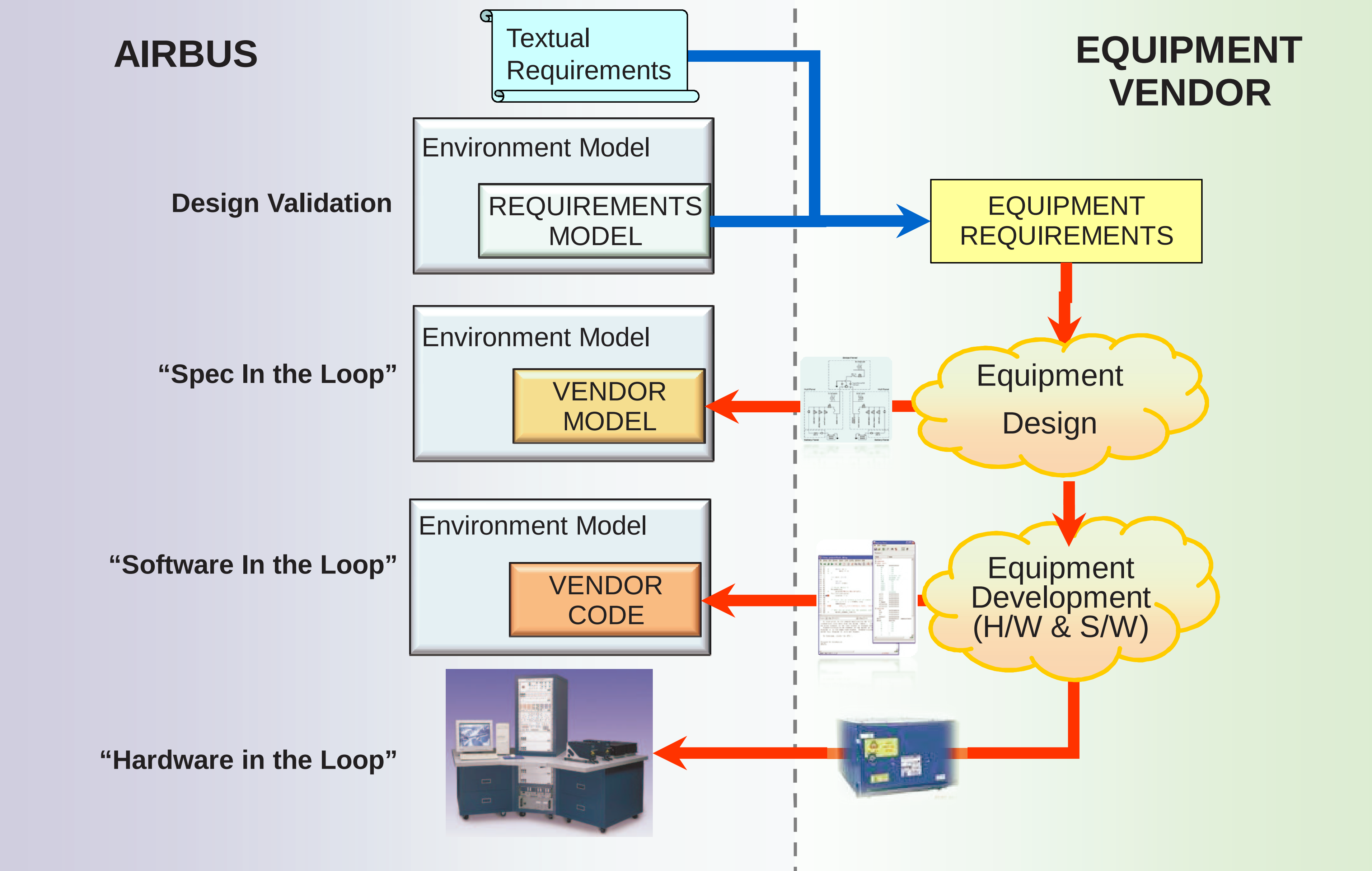
- Integrated Desktop Simulator
  - Requirements & Environment Model
  - Add Interfaces and other functionality
  - AutoCode using Real-Time Workshop
- Aircraft -1
  - Entire Software Simulation
  - Interfaces Identical to Aircraft
- Fuel System Test Benches
  - Verification of single equipment
- Aircraft-0 (Iron Bird)
  - Cockpit Avionics & Displays
  - All Systems Integrated (real & simulated)
- Full Flight Simulator
  - Single model for all platforms

Where & When is Stateflow Used

- Model Based Design Approach (Ideal)
  - Develop models to specify system functionality
    - Describes behavioural & functional aspects
  - Details become the System (and Sub-System) Requirements
    - Exercise the model to Validate Requirements
  - Delivered to Fuel System Supplier
    - Model contains Requirements *and* intent
    - Model execution provides system understanding
    - Minimal Work to turn into Code
    - Separate layer for independent validation

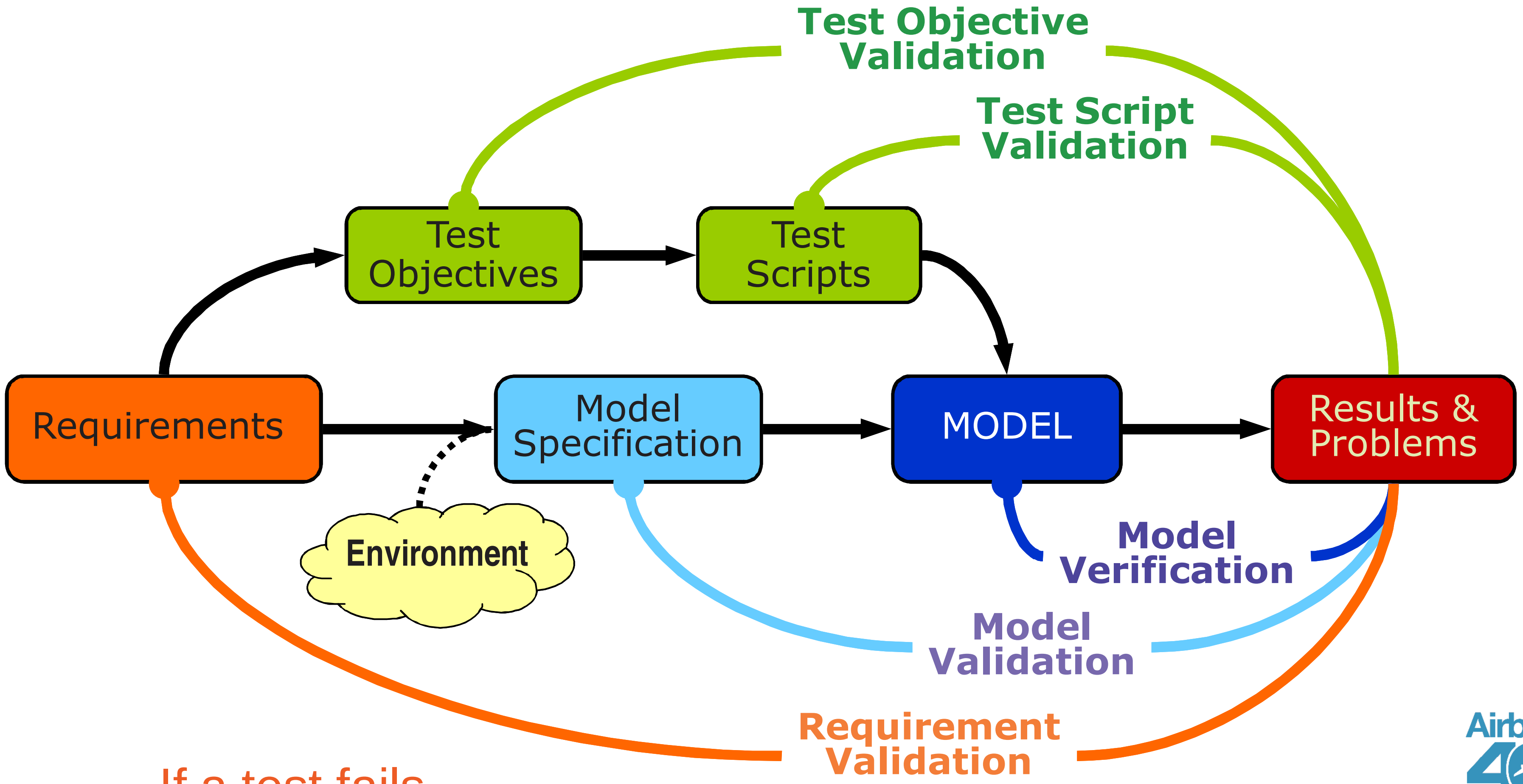


Early Supplier Involvement



Model Development Process

When the model is the requirements, the distinction between "Model Verification" and "Requirements Validation" is somewhat blurred



If a test fails –
is the requirement, the model or the test at fault?

Aviation Authorities View of MBD

- Certification Review Item : F17/ F22

"The complexity of specification written with formalised language raises the need for higher level specification description containing all the requirements implemented in the formalised specification"

- Effectively states that a model is only an implementation of unwritten requirements.
  - We need a model *and* textual requirements in order to sufficiently validate a system in terms of ARP4754/DO178B
    - E.g. Non-functional requirements difficult to model.
  - Affects our strategy for MBD

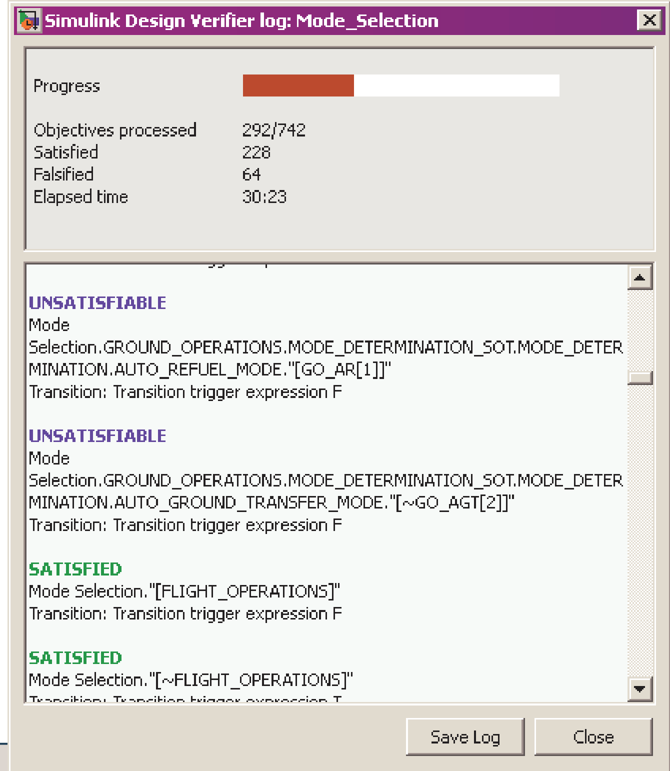
- This CRI specifically targets Software Specifications using SAO/SCADE/LDS
- But applied to SSRD developments using Stateflow.

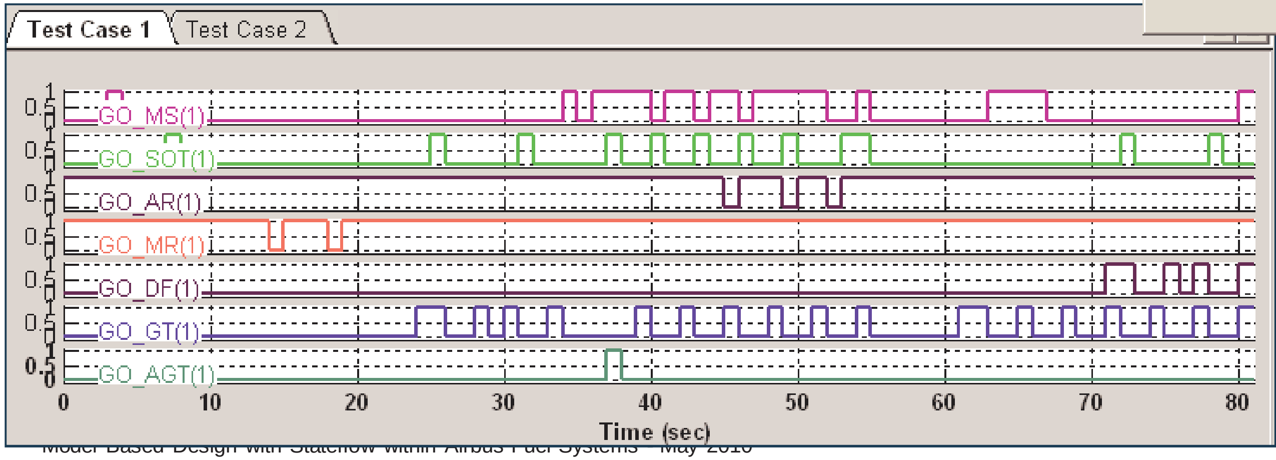
Advancements; Model Verification

- Recent use of “Simulink Design Verifier” (SLDV)
  - “Prover” Technology previously used with Esterel SCADE
  - Experimentations first with R2007b
    - Proof of concept, but unable to handle “large” models
  - Enhancements made in each release; R2008a, R2008b, R2009a, R2009b...
    - Now considered mature enough for industrial applications
- Two modes of Operation:
  - Test Generation
    - Tries to generate a minimal set of tests that provide maximal coverage.
      - Uses Modified Condition/Decision Coverage (MC/DC)
      - Conditional Transitions, Substate executed, Substate exited
  - Formal Proof
    - User specifies a property
    - SLDV tries to find a combination of inputs that falsifies that property

Model Verification – Test Generation

- Produces report showing:
  - "Objectives Satisfied"
    - – A test has been found that exercises a particular state or transition
  - "Objectives Proven Unsatisfiable"
    - Untestable/unreachable state or transition
  - "Objectives Undecided"
    - Could not determine an outcome in the time available
- Test harness Creation



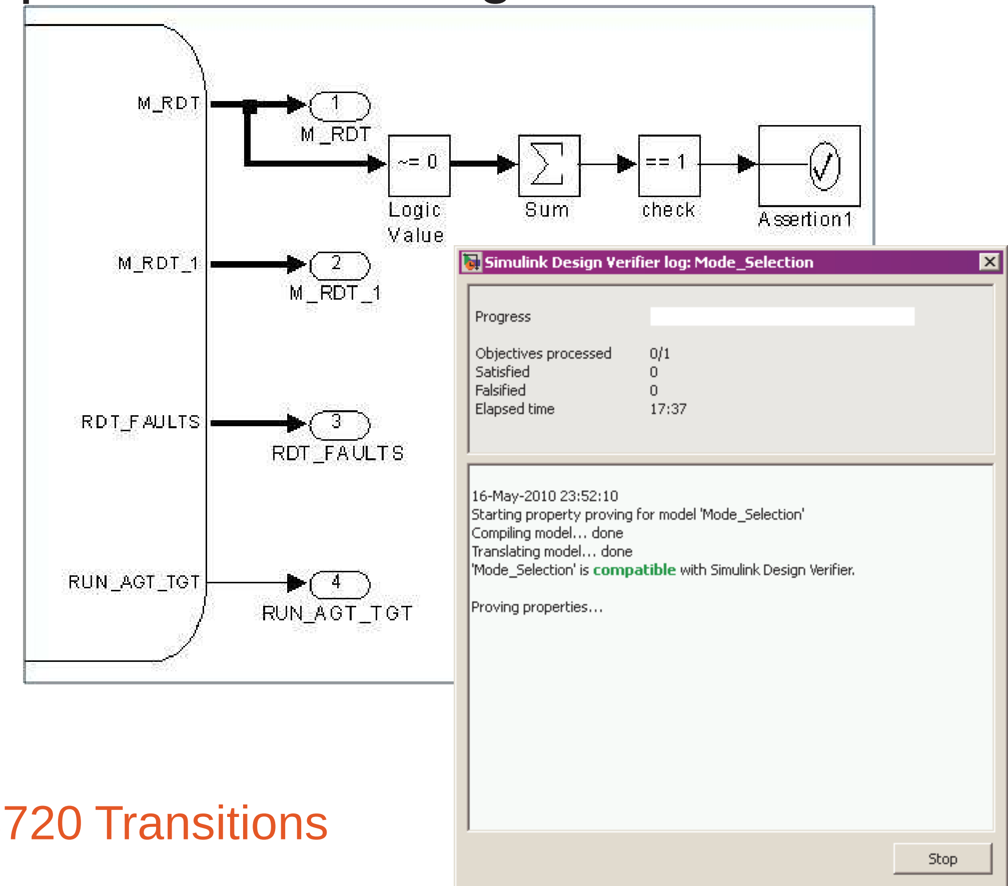


Subsystem comprising
1 Chart
102 States
186 Transitions

Model Verification - Model Proof

- Define Proof Objectives and Assertions
  - Using Simulink/Stateflow/Matlab
  - Based on higher level (inc. safety) requirements
- Proof Objective allows multiple values & ranges
- Example:
  - Output Array of booleans mutually exclusive
- If counterexample found, creates test harness
  - Can take a very long time...

"Simple" subchart of 102 States 186 Transitions – no counterexample found after 30 minutes.



Full A380 Fuel Model :

45 Charts, 5945 States and 8720 Transitions

Problems Encountered

- Process Problems
  - Model Style Guidelines need to be defined and rigidly enforced
    - Matlab code and “test” blocks find their way in to the model
  - Pure design requirements model unable to be exercised
    - “Extra” elements added to get it to operate. Need to clearly identify what are requirements and what are the “extras”.
  - Use of global (workspace) data
    - Obfuscates the system interfaces
  - Need to ensure that valves/pumps return to default values on exit of states
    - Multiple Exit Paths need to be considered
    - Implied Requirements
  - Keeping track of model updates with multiple designers
    - Potentially a configuration nightmare
    - Eased with the use of Model Reference

Problems Encountered

- Technical Problems
  - Fuel System Vendor uses SCADE for Qualified Code Gen.
    - No easy "auto" translator from Simulink/Stateflow into SCADE/SSM.
    - Hand conversion could introduce errors.
    - Vendors can develop "clever" tools for auto-conversion of charts
    - Aircraft Program "tied in" to a particular release of Matlab

      A380 Fuel still uses Matlab R12
  - Model Proof consumes lots of resources...
    - Memory
    - CPU Time
    - Large models need 64bit + lots of RAM
  - Extracting stateflow sub-charts quite a manual process
    - Improvements to toolset is making life easier

Lessons Learnt - Model Based Design

- Model build process can reveal anomalies/ambiguities
  - Validation for free
    - Identify Assumptions separately from requirements
    - Identify Executable Implementation from Requirements
- Model Architecture
  - Separate Requirements Model from Environment Model
  - Separate real interfaces from simulation/test interfaces
- Validation Testing
  - A test that is more complex than that being tested is probably wrong
  - Easy to be caught in the trap of “Test for Success”
    - Testing for intentional, but not unintentional behaviour
    - Project managers demand simple progress metrics

Lessons Learnt – System Design

- System Designers focus on Designing the System
  - The System Model is the System Requirements
    - – But extra functionality required to exercise model are not requirements
    - – Non-Requirements need clear labelling
- Discontinuity between Design and Implementation
  - Detailed Models required for Integration Simulators
    - – Required before availability of equipment
    - – Need to create models of *potential* implementation
- Easy for Designers can be Difficult for Simulators
  - Matlab Function Blocks
  - M-File S-Functions
  - Test Harnesses
    - – Can break the automatic code generators
- Model Size Increases Monotonically
    - – Can break toolsets e.g. SLDV

Summary – Model Based Design

- It's as bad to talk about "M&S" as it is to say "V&V"
  - Two distinct parts of an end-to-end process.
  - Two distinct methods of implementation, results and consequences
  - Modelling is a Means to an End – not an End in itself

- Difficult to distinguish between Verification and Validation
  - Each requirement has a validation statement
    - I.e. A "test"
  - If a test fails, have you performed:
    - Validation of the requirement?
    - Verification of the model?
    - Validation of the test?

Thankyou

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