Intro

Getting on a plane…
A passenger complained that £75 was too much. He was farmer. He had a top-line tractor.....

<table>
<thead>
<tr>
<th>Jet Engine</th>
<th>Tractor</th>
</tr>
</thead>
<tbody>
<tr>
<td>~$5 million</td>
<td>~$0.5 million</td>
</tr>
<tr>
<td>Pulls - 300 tonnes</td>
<td>Pulls 30 tonnes. Perhaps.</td>
</tr>
<tr>
<td>0-175mph - 21 secs</td>
<td>0-175 mph - No</td>
</tr>
<tr>
<td>0-2000ft - 40 secs</td>
<td>0-2000 ft - an afternoon up a windy road</td>
</tr>
<tr>
<td>0-10000ft - 5 mins</td>
<td>0-10000 ft N/A in Somerset</td>
</tr>
<tr>
<td>Climb to - 30,000ft+</td>
<td>Climb to – top of the hill.</td>
</tr>
<tr>
<td>Top speed - 500 mph +</td>
<td>Accelerate to - 40 mph?</td>
</tr>
<tr>
<td>Temperature from +50 to -60 °c</td>
<td>Temperature from +50 to -60 °c (but not in the same day!)</td>
</tr>
<tr>
<td>18 hrs/day</td>
<td>18 hrs/day</td>
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</table>
Complex environment

Complex system – Bill Gates said there is probably no development as complex as the development of a civil jet engine.

Much of the control and safety is handled by software

Safety is #1 priority

How does the testing help to achieve this?
Total control

Control of design, implementation and testing

Testing needs to be:

• Thorough (all software tested)
• Effective (all functionality tested)
• Affordable (cannot have team of millions)
• Achievable (needs to finish before first flight)

Also - we have total responsibility for suppliers and supplied components.
Electronic Engine Controller (EEC)
Design Structure (ideal)

Airframe reqts

Engine reqts

EEC reqts

EEC HW

EEC SW

HW Functions

SW Functions
Design Structure (reality)

EEC – Electronic Engine Controller
Constraints

- Aircraft first flight date is committed
- Fuel consumption must be >5% better than previous generations, therefore tolerances probably tighter and more functions than before
- Cost is committed
Testing

Software testing crosses several boundaries:

• Hardware testing
• System testing
• Engine testing
• Flight testing
Validation V – testing at various levels
Divide and conquer:

- Test requirements at suitable level, but also have ability to pass up or down
- Testing at higher levels costs more, and occurs later in the programme, so emphasis on testing early and low, (and repeating with lower risk at higher level)
- Need to track results passed up or down
- Need to track results tested across multiple vehicles
- Do requirements need to be tested at every level?
Structured testing

Tags

Tests

Vehicles

IP

Reqs

Multiple requirements

<table>
<thead>
<tr>
<th>Tag</th>
<th>Description</th>
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<tbody>
<tr>
<td>TG01</td>
<td>Description</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TG01</td>
<td>Description</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Description</th>
</tr>
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<tr>
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Example:

When temperature exceeds a limit - generate a message in the cockpit.
Hardware, firmware, OS level testing

- Tests box I/O and fault detection
- Tests under arduous conditions, such as:
  - Bake and Shake (high temp and vibration)
  - Hot, Cold
  - EMC
  - Internal faults, e.g. unstable reference voltages etc
- Provides the underpinning for the software layers above.
Software code level testing

• Functional block testing
  • Software Requirements tracing
  • Coverage of higher functional requirements where possible
• Formal methods
  • Code coverage / MCDC etc
  • Requirements traceability
AS/OS integration

- Representative hardware
- Often single lane
- Limited realism, e.g. pressures, temperatures etc run to crude model.
- Ability to perform deep inspection of software / force values etc.
Software / Hardware integration

- Real hardware
- OS/AS
- Real-time rigs
  - Run real-time engine model
  - Aircraft interfaces
- Run as white box testing
System Testing

- Tests end-to-end signals, e.g. temperature in to message out. Therefore tests hardware, firmware, OS and AS.
- Same real-time rigs
- Run as black box testing
- Realistic scenarios
- Can test areas of the envelope that engine test cannot e.g. extreme speeds or temperatures
- Tests system responses, e.g. signal short-circuits through validation, fault detection, limiters, governors, signal selection, control loop selection, message generation.
Engine test

• Real hardware on real engine
• Limited scenarios (engines are expensive!)
• 95% realistic (no variation in airspeed, temperature, pressures etc)
• Expensive (£5,000-10,000 /hr)
• Test engines heavily used for engine development
• Test stands heavily used for production passoff
Flight test

- Ultimate reality
- Limited time - airframers don’t want to spend their time testing our engines – they expect us to do that
- Even more limited range of tests (aircraft are even more expensive, and we’re sitting in them!)
Collate results

Vehicles

Tests

Tags

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IP

Results

Multiple results
Collate results

• Multiple vehicles and tests
• Multiple levels of requirement
• Some requirements tested at many levels, e.g. cockpit message generation, tested ‘everywhere’
• Easy to get 99 “passes” and assume success. Was there a 100\textsuperscript{th} test which failed?
Certification

• Engine is certified independently of airframe
• Need to prove:
  • Requirement traceability up and down
  • Code traceability – code ↔ requirements
  • Test coverage
  • Results
Summary

For a highly complex system:

- Intelligence is not so much in the nature of the tests
  - Each individual function is generally simple
- Intelligence is in the management of the process
  - Thorough (all software tested)
  - Effective (all functionality tested)
  - Affordable (cannot have team of millions)
  - Achievable (needs to finish before first flight)
  - Ensure everything covered adequately, nothing missed
- **Commitment to complete the process**
Arriving on holiday…