Systems Thinking in Aero Engine Control System Development

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Overview of Rolls-Royce
Rolls-Royce

All require high-quality products, at right cost, delivered on time
2010 - £11.1 billion turnover, £955m profit before tax
Organization Challenge

Multiple sectors
Multiple layers in the organization
Multiple geographies

11,000 engineers worldwide growing to 12,000
Purpose of the Organization is to Add High Value

High value activity involves deep knowledge:

- It has a high research and technology content
- It requires a profound understanding of the customer
- It exploits both scientific and experiential intellectual property
- It involves the definition of solutions that meet complex requirements
- It requires well-developed systems integration skills
- It involves managing data to inform responses to complex events
- It is difficult to do well

Sir John Rose, “Creating a high-value economy” Address to the Royal Society for the Encouragement of Arts, Manufactures and Commerce, 10 November 2009
400,000 people fly with us every day

30,000 Vessels have Rolls-Royce equipment installed

5.5 million flights powered by us every year

130 Million Hours operating experience with Industrial Gas Turbines
Indianapolis Site Products

- Small to medium engine sizes for commercial and military customers
- Industrial and marine engines (e.g. 501K)
- Site was previously the Allison Engine Company
  - Founded pre war
  - Purchased by RR in 1995

AE3007 Turbofan

AE2100 Turboprop

CTS800 Turboshift
Control System Design and Development Engineers at Multiple Sites

Control Systems Engineers spread over the following sites

- **Aerospace Programs**
  - Derby, UK
  - Bristol, UK
  - Dahlewitz (near Berlin), Germany
  - Indianapolis, Indiana

- **Industrial Programs (Marine and Energy)**
  - Montreal, Canada
  - Mt Vernon, Ohio
  - Indianapolis, Indiana
Example of a Design Challenge – Fan Blade Containment
Systems Engineering Challenges in Engine Control Systems
Modern engines typically controlled using a Full Authority Digital Engine Control (FADEC) system
- Electronic Engine Controller (EEC) typically provides dual redundancy using two electrically isolated channels
- Various sensors and actuators interfaces to the EEC using a mixture of analog, discrete and digital interfaces
- Embedded software in the EEC provides control schedules responding to pilot commands and sends data to the cockpit

Hydromechanical components provide fuel pumping and metering and various other actuation systems are also used including compressor air bleed valves
SE Challenges in Control Systems

● Control system development provides a classic environment for the use of Systems Engineering and Systems Thinking
  • SE principles used in Control System development before other engineering functions within RR

● Complexity
  • Whenever safety critical software is involved, managing complexity is a major challenge!

● System Architecture
  • Trend towards greater integration of control systems with the aircraft

● Industry guidance and recommended practices have been developed in close conjunction with the FAA and EASA
  • SAE ARP 4754 for systems development processes
  • DO178B for software development

● Regulatory environment favors staying close to established design pedigree which can constrain innovation
Product Lines and Reuse

- High development costs of control systems drives towards reuse of system and software designs between applications
- Certifying authorities expect new data for each application
- Effective Product Line development requires achieving cost savings by avoiding redoing everything for each application
  - Traditional “clone and own” development does not support reuse of test evidence, design reviews etc
- Move towards greater use of model based design rather than the traditional docu-centric development approach
- Leveraging global experience also valuable to gain experience across sites
  - RR is working towards standardizing processes, tools and supply chain strategies
- However, differing markets at each site lead to differing priorities between customization and generalization
New Engine Control Systems for the Helicopter Market

Business Challenges
Product Line (PL) Definition

‘A set of systems sharing a common, managed set of features that satisfy the specific needs of a particular market segment or mission and that are developed from a common set of core assets in a pre-described way.’

Based on definition of Software Product Lines, from SEI
Product Line Objectives

- Traditional “clone and own” development reuse does not provide the real cost savings needed
  - V&amp;V costs are replicated for each application
  - New product line approach aims to use systems thinking to achieve cost savings from a holistic view
    - Need to align the architecture, organization, processes and tools to support PL objectives

- Product Line development is focused on reduction of Non Recurring Cost (NRC):
  - Design for future reuse
  - Reduced time to market for new products and product updates
  - However, up front costs are higher in a product line development environment, and for initial applications
Range of Customer Needs

● Military customers focus on
  • Capability
  • System Availability (during a mission)

● Commercial customers focus on
  • Minimizing life cycle cost
  • Requires a balance between availability, maintainability, unit cost, product line development flexibility

● Not all customer’s interests are aligned, so compromises are required
Product Line Challenges

- System features to support all customers in agreed scope
  - Provide key functionality needed by customers
  - But avoid unnecessary customization
    - Challenge customers to demonstrate why variation is needed
- The FAA certifies engines, not control systems
  - Cannot obtain approval for a product line system architecture
  - Test data or strong similarity arguments needed for applications
  - Model based design approach needed to support product line reuse objectives
- Product Line thinking is new to the organization so a set of Strategy Documents were written
  - Define product line application scope and business case
  - Documents trade studies which had been conducted
  - Ensures consistency of approach between teams
Product Line Market Scope

- Market choice needs to be chosen carefully to ensure reuse objectives are realizable
  - Would not expect a fuel pump for an engine needing 500lb/hr flowrate would work on an engine needing 40,000lb/hr

- Small Gas Turbine FADEC (SGTF) product line covers:
  - M250 engine product range
    - 300 – 700hp turboshafts and turboprops
  - CTS800 engine product range
    - 1300 – 1600hp turboshafts
  - Military and commercial
Product Line Market Scope

- How much flexibility should we allow for?
- Consider this application for the M250 engine
  - Uses time-expired helicopter engines on a motorbike!
- SGTF restricts the PL scope to aero engines only at this point
  - Not economic for wider applications
New Engine Control Systems for the Helicopter Market

Design Challenges
System Requirements Flowdown

- Must define a clear system boundary
- Must define the interfaces at the boundary
  - Common naming conventions for signals
- Ensure your requirements only address functionality which can be provided within the system boundary
  - Resist demands to take responsibility for functionality outside your boundary
- Be clear about the functions required from your system
System Requirements Flowdown

- Specifications provided to component suppliers are developed by extracting requirements allocated to the component across all functions.
System Architecture for Product Lines

- Trade studies to identify component reuse opportunities
  - E.g. common sensors, cockpit interfaces, reusable hydromechanical and electronic components

- ATAM (Architecture tradeoff analysis methodology)
  - Agreed set of assessment criteria and definitions across all trade studies
  - Aligned to product line business and technical objectives
  - Addresses customer required variability where appropriate
Software Requirements Management

- Develop the organization to support Product Lines
  - Team Structure
  - Tools – towards Model Based Design
  - Configuration Management Processes
  - Change Management Processes

- Development of a reference software architecture and gold standard requirements to gain agreement and buy-in
Verification and Validation Processes

- Reuse of component V&V evidence is straightforward
- System level reuse is more challenging
  - Selective reuse possible in system verification, system safety
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Regulatory Environment
Regulatory Environment

- US Export Control covered by:
  - Commerce Dept for commercial applications
    - EAR – Export Administration Regulations
  - State Dept for military
    - ITAR – International Traffic in Arms Regulations

- SGTF Product Line aims for Commerce Dept jurisdiction to support international sales

- US Military applications do have unique requirements
  - Product line architecture used to manage the separation
  - Allows ITAR controlled applications to be instantiated from the product line without affecting the EAR status of the PL
New Engine Control Systems for the Helicopter Market

Organizational Challenges
Organizational Challenges

- Global processes and tools
  - To support product line reuse across multiple sites, need a coordinated strategy for processes and tools
  - However, different market segments do require different priorities for cost, schedule, and performance
  - Effective global process alignment requires that key stakeholders have a deep understanding of each other’s site needs

- Supply Chain Strategy
  - Some suppliers have been changed to leverage better global supply chain strategies
  - New opportunities but also new relationships to be built
Organizational Challenges

- Cultural differences cannot be ignored in working globally
  - UK, US and Germany are the main RR sites for Aerospace market
  - Subtle language differences even between the UK and US can cause misunderstandings
  - Tension between adherence to locally optimized versus globally optimized processes

- Lessons learned
  - Don’t ignore the cultural aspects
  - Recognize that market differences require different priorities
  - Global alignment can be very difficult, but very rewarding, so expect it to be a challenge and do not give up!
Conclusions
Conclusions

● What has gone well?
  • Architecture and product line strategy
  • Process development at component level
  • Realignment of the organization to support product lines
  • Certification liaison

● What could be better?
  • Maturity of the new processes, particularly at System level
  • Readiness of the organization
    o Pilot studies are always preferred, but not always feasible

● Implications
  • More progress needed on Product Lines at System level
  • Processes will be matured on initial Product Line applications
  • Organization will not learn “product line thinking” until they’ve worked on the initial applications
Thank You.
Questions?

Reliability, integrity, innovation