Rolls-Royce

INCOSE International Symposium
Philadelphia, PA
June 24-27, 2013

Developing Product Lines in Engine Control Systems: Systems Engineering Challenges

Malvern Atherton
Shawn Collins
Rolls-Royce
Indianapolis, Indiana, USA

Agenda

1. Overview of Rolls-Royce
2. Context challenge
   - Market Demand
   - Product Line Definition and Scope
   - Regulatory Environment
3. What we did
   - Reuse Goals (Product Lines “through the V”)
   - Product Line Development (down the left side)
   - The Enabling Organization
4. Lessons Learned and Conclusions

Rolls-Royce

INCOSE International Symposium
Philadelphia, PA
June 24-27, 2013

Overview of Rolls-Royce

Rolls-Royce

Civil aerospace

Unprecedented volumes

Defence aerospace

Well placed in product terms and new markets to exploit

Marine

Huge potential to increase service revenues

Energy

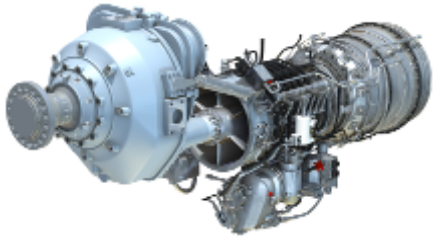
A£30 billion market

Indianapolis Site Products

- Small to medium engine sizes for commercial and military customers
- Industrial and marine engines (e.g. 501K)

AE3007 Turbofan

AE2100 Turboprop



CTS800 Turboshaft

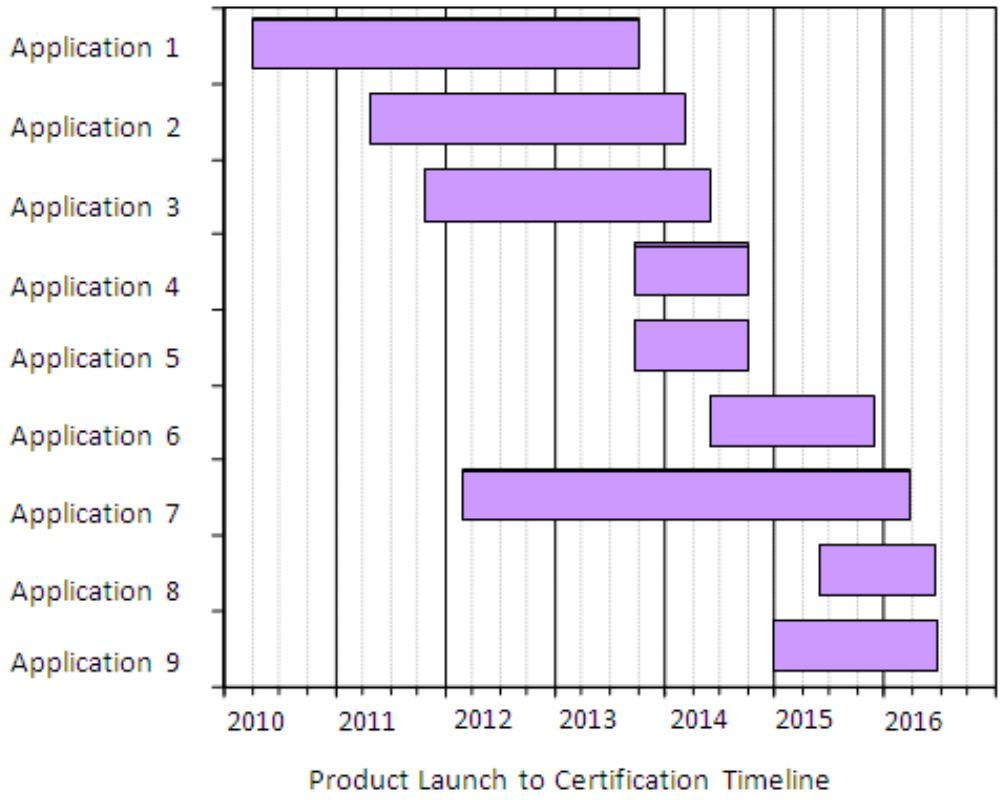
Rolls-Royce

INCOSE International Symposium
Philadelphia, PA
June 24-27, 2013

The Context Challenge: Engine Control Systems

The Market Demand

- Development cost and timeline preclude bespoke designs
- Effective control system 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
  - Military market emphasizes capability
  - Commercial market emphasizes cost

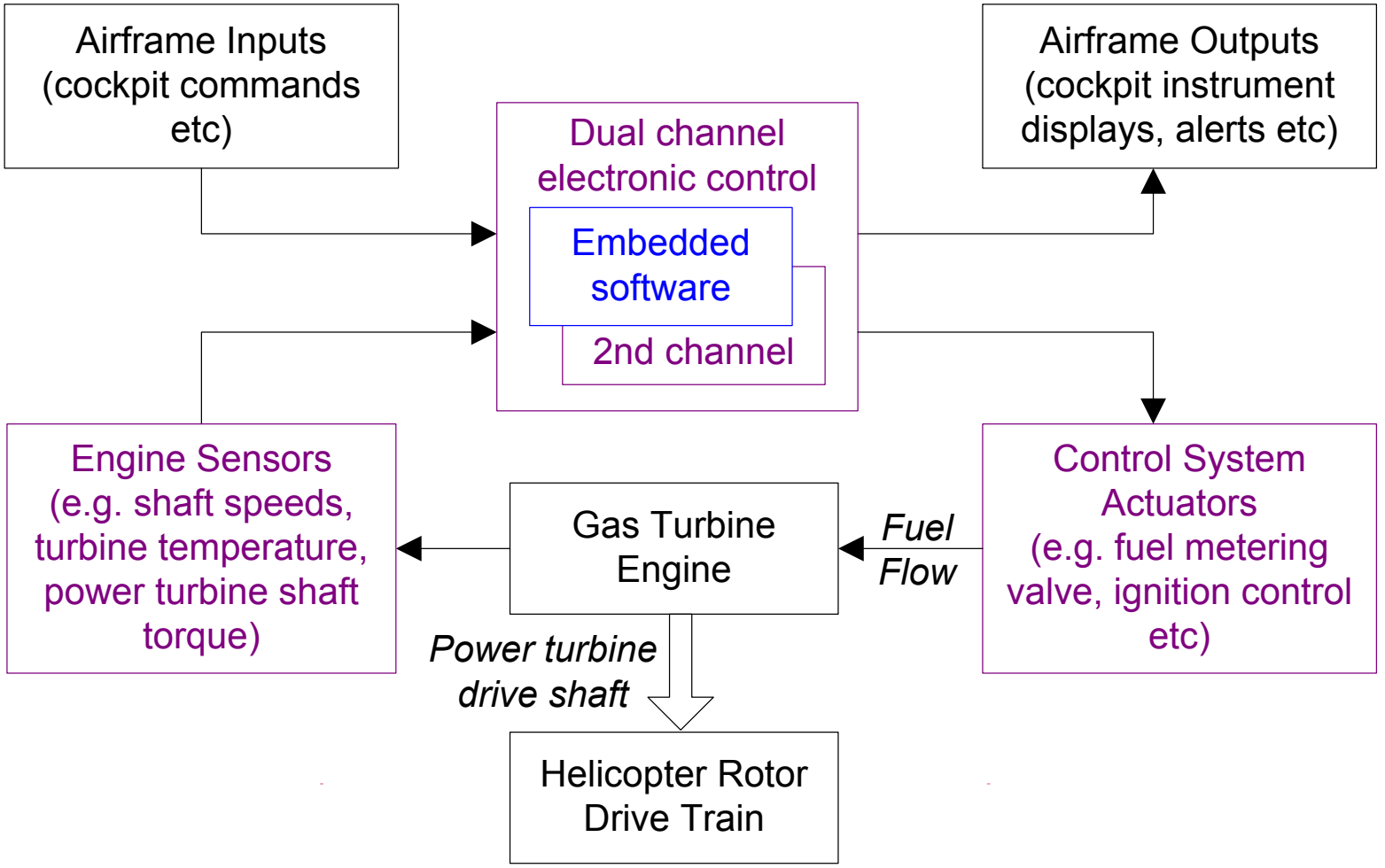


Product Line (PL) Definition

Software Product Line, as defined by SEI: ‘ 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.’

Rolls-Royce uses principles defined for Software Product Lines, but extends them to include the full control system

Product Line Architecture



- Software PL concepts are understood
- Rolls-Royce's goal is a full control system PL

Product Line Market Scope

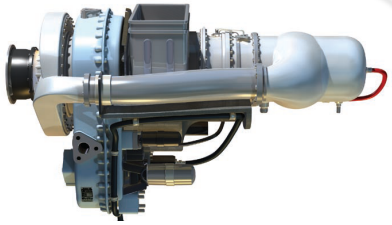
- Must clearly define the Market Scope
- Small Gas Turbine FADEC (SGTF) product line covers:
  - M250 engine product range
    - 300 – 700hp turboshafts and turboprops
  - CTS800 engine product range
    - 1300 – 1600hp turboshafts
  - Military and commercial applications
- Product line boundary defines reasonable variability
  - E.g., fuel pump for a small helicopter engine won't work on a B787
  - E.g., does not include applications that Rolls-Royce does not approve

Regulatory Environment

- Whole engines are certified, not just control systems
  - The certification evidence must address the full system context

Aircraft are certified

Engines are also certified



But components are not certified individually

Regulatory Environment: – Export Control

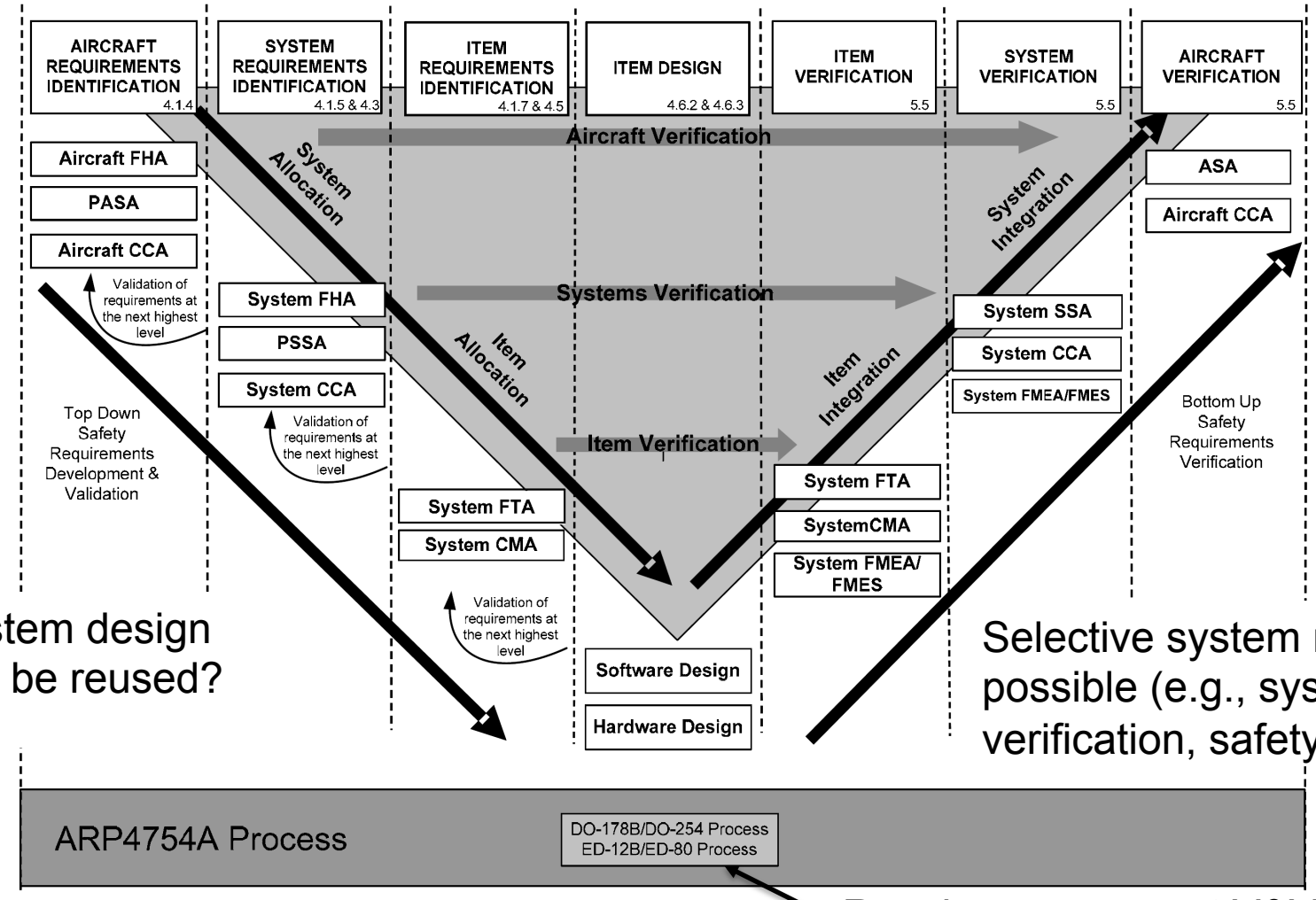
- US Export Control covered by:
  - Commerce Dept for commercial applications
    - EAR – Export Administration Regulations
  - State Dept for military applications
    - ITAR – International Traffic in Arms Regulations
- SGTF Product Line aims for Commerce Dept jurisdiction to support international sales
- US Military applications do have unique requirements
  - Product line architecture must manage the separation
  - Allows ITAR controlled applications to be instantiated from the product line without affecting the EAR status of the product line

Rolls-Royce

INCOSE International Symposium
Philadelphia, PA
June 24-27, 2013

What we Did: Tackling the Product Line Challenge

Product Lines through the "V"



Can system design artifacts be reused?

Selective system reuse is possible (e.g., system verification, safety)

Reusing component V&V evidence is straightforward

System Requirements Flowdown

- Be clear about the functions required from the system
  - For shared functions within the Product Line
  - For unique functions on each application
- Define a clear system boundary
- Define the interfaces at the boundary
  - Common naming conventions for signals
- Ensure requirements only address functionality which can be provided within the system boundary
  - Resist demands to take responsibility for functionality outside the boundary
- None of these concepts are new to SE. Applying them to manage variability and improve reusability is new.

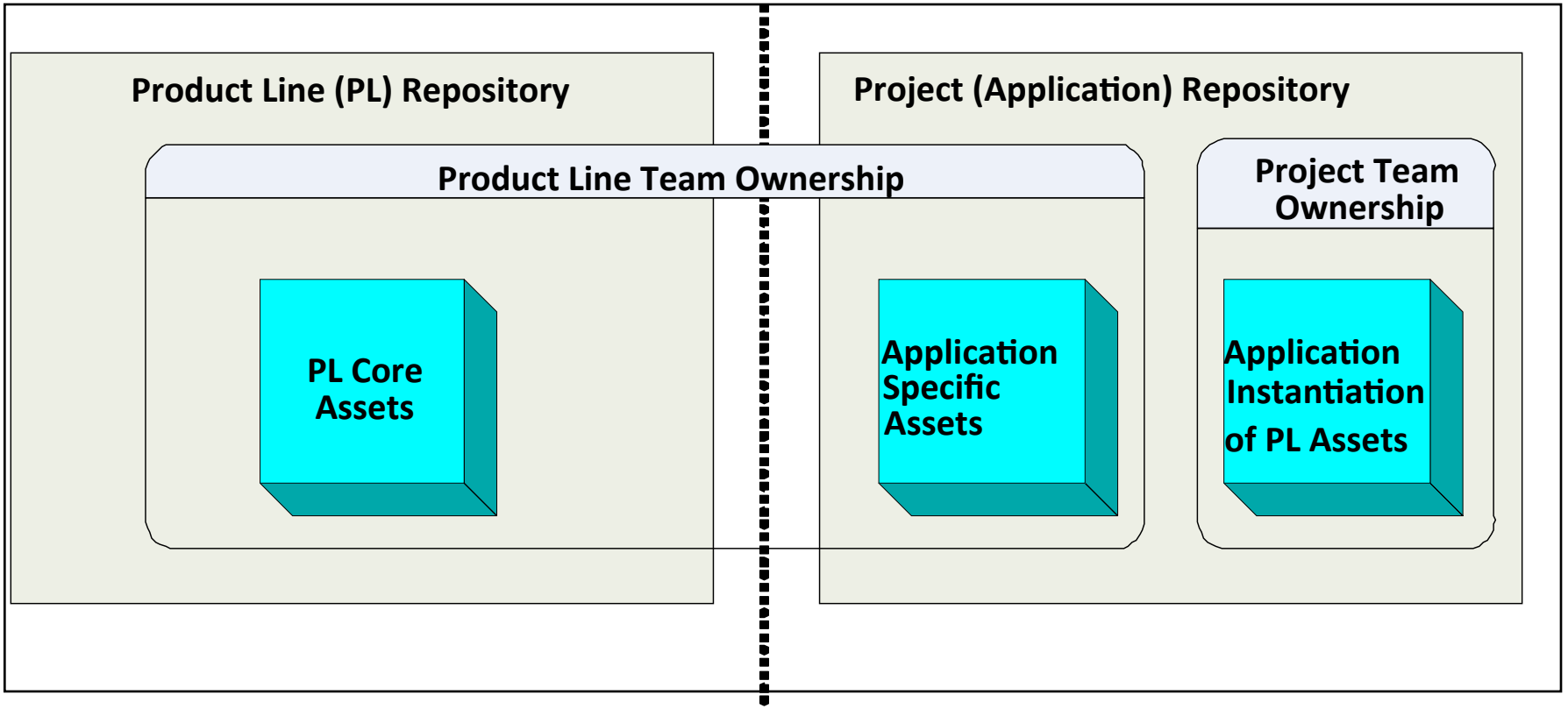
System Architecture Trade Studies

- Product Line Architectures requires greater emphasis on flexibility and adaptability to unknown future application requirements
- Traditional design delivers to a customer's tailored needs

Trade Matrix / Success Criteria		Additional Detail	Alternatives					
			Option 1 Direct Connection		Option 2 Serial to Interface Box		Option 3 A/C Avionics	
Mandatory	Safety			0		0		-1
	Certifiability	Other reg (e.g. Military or EASA)		0		0		0
Critical	Certifiability	FAA Cert - ease of certification		1		0		-1
	Exportability	No ITAR restrictions and compliant with compartmentalization strategy		0		0		0
	Product Cost (BOM)			-1		-3		1
	Schedule	TTM (both PL and reuse)		0		-1		0
Necessary	Agility	Developability - Upgrade / Modular / Low Risk		0		0		-1
	Maintainability / Serviceability	HW Upgrade / Obsolesce		0		0		0
	Product Line NRE			0		-3		0
	Reliability			0		0		1
	Ease of retrofit			3		3		-3
	Schedule	Predictability		0		-1		0
	Technology Readiness			3		0		0
	Variability			0		0		0
Important	Extensibility	Unplanned Variability		0		1		0
	Performance	Engine or Control System		1		0		0
	Size and Shape			0		-1		1
	Weight			-1		0		1

The Enabling Organization

- One team designs the Product Line Core
- Another team deploys the Product Line Core on unique applications
- Do this at both the control system and software level
- Increase complexity by including the supply chain



Some Lessons Learned

- We evaluated SE "state of the art" concepts (it's in the paper)
  - MBSE, green versus brown field design, lean
- The FAA certifies engines, not control systems
  - Cannot obtain approval for a product line system architecture
  - Regulations assume bespoke planning, verification, config mgmt
- Certification and product line processes and tools have proven to be the most challenging aspect
  - These show some characteristics of *wicked problems*
    - You don't understand the problem until you have a solution
    - Solutions to wicked problems are not right or wrong, simply "better," "worse," "good enough," or "not good enough"
    - Every solution to a wicked problem is a "one-shot operation"

Conclusions

- The market won't allow bespoke design timescales or costs
- Demand is increasingly to rapidly modify fielded applications
- A system level product line has been developed to address this
  - Regulatory processes do not support product line development for a system
  - The processes and tools have proven to be very challenging
- This is both a significant challenge and tremendous opportunity
- How do we demonstrate SE value for Rolls-Royce?
  - Silver bullets (MBSE, lean, product lines)?
  - Put existing concepts together in ways that enable our internal customer to meet a business demand
- Did it really work? Stay tuned (we're in the middle of flight test)

Questions?

INCOSE International Symposium
Philadelphia, PA
June 24-27, 2013

Please take the time to rate this presentation by submitting the web survey found at: www.incose.org/symp2013/survey

Survey

INCOSE International Symposium
Philadelphia, PA
June 24-27, 2013

Please take the time to rate this presentation by submitting the web survey found at:

www.incose.org/symp2013/survey