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# Application of product lines in industrial gas turbine control systems

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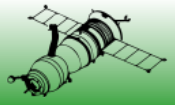
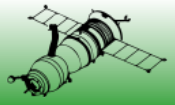



# Contents



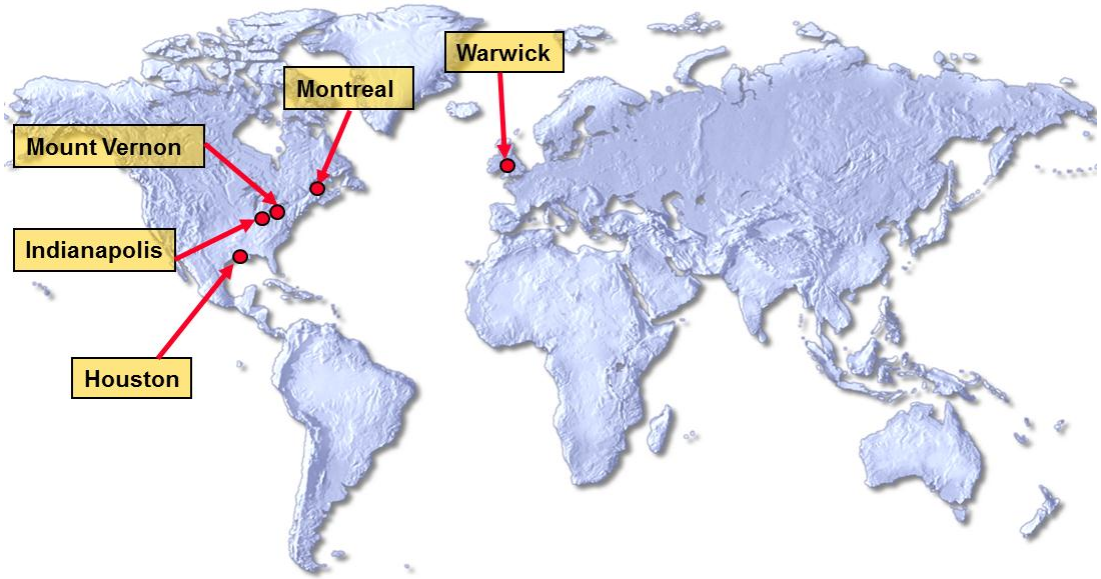
- Overview of Rolls-Royce Energy
- Systems Engineering challenges in aero-derivative gas turbine control systems
  - Functional architecture
  - Product lines
  - Safety
- Conclusions and questions


# RR Energy Business



- 2,400 employees across the globe
- RR installed fleet in 32 countries:
  - 2,500 aero-derivative GTs
  - 1,700 compressors
- RR is selling its Energy gas turbine and compressor business to Siemens



# RR Energy Business

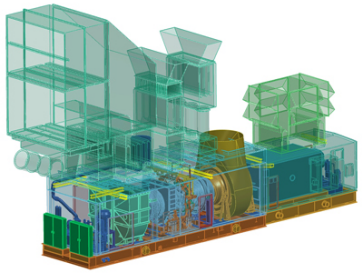



Oil & Gas

Power Generation

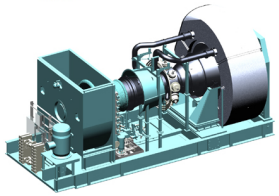
# RR Energy Products





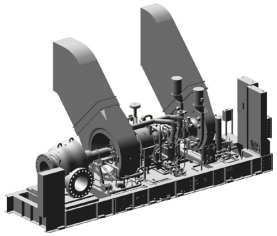
Trent - 64MW

**Aero-derivative from Trent 800**



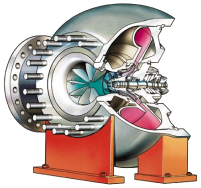
RB211 - 32-44 MW

- **RB211-G(T)**
- **RB211-H**



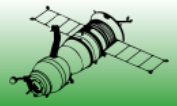
501/Avon - 4-14MW

**Mature products; few new equipment sales**
**Continuing aftermarket**



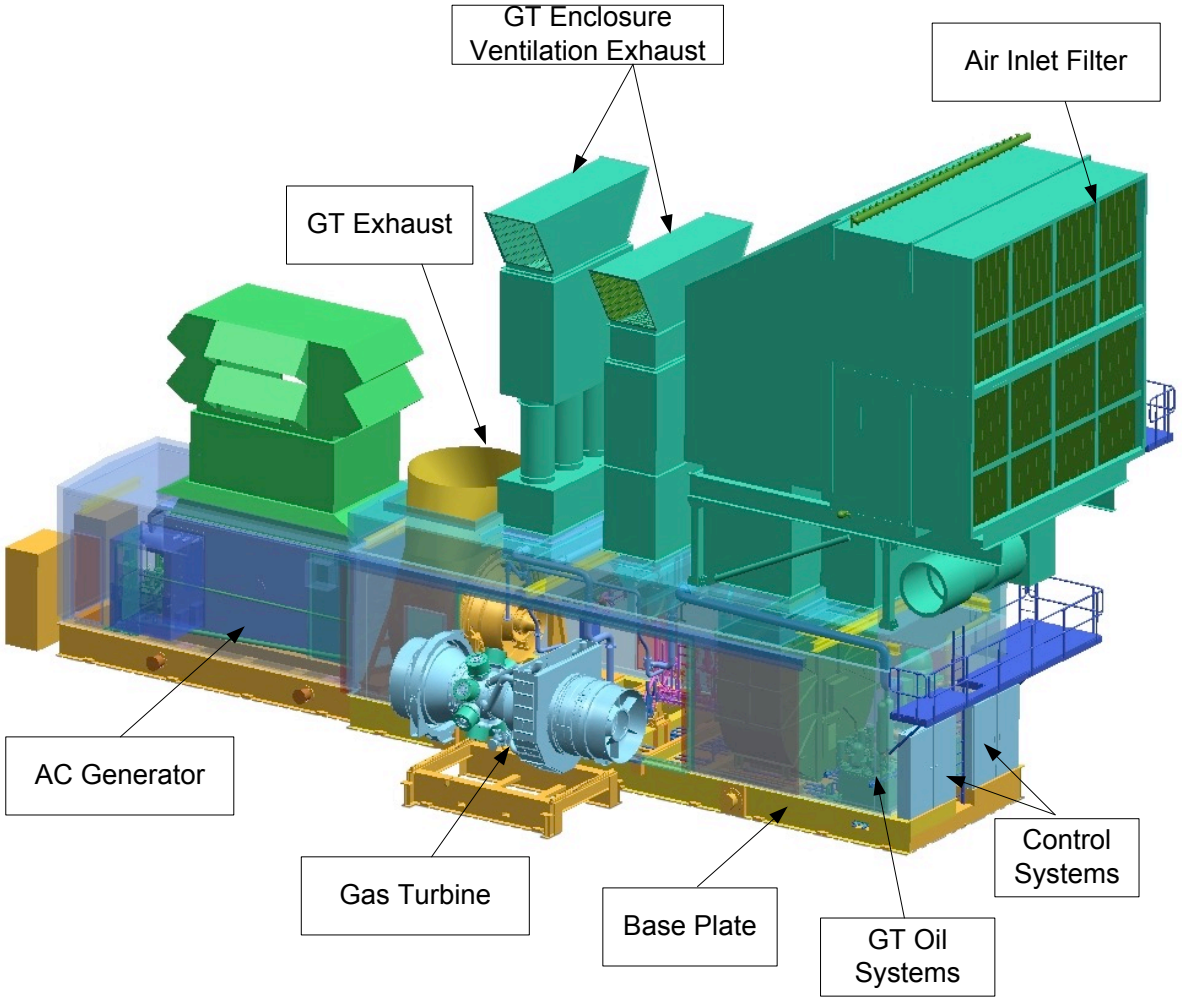
RFA - 50,000 HP

**Pipeline compressor**


# Context

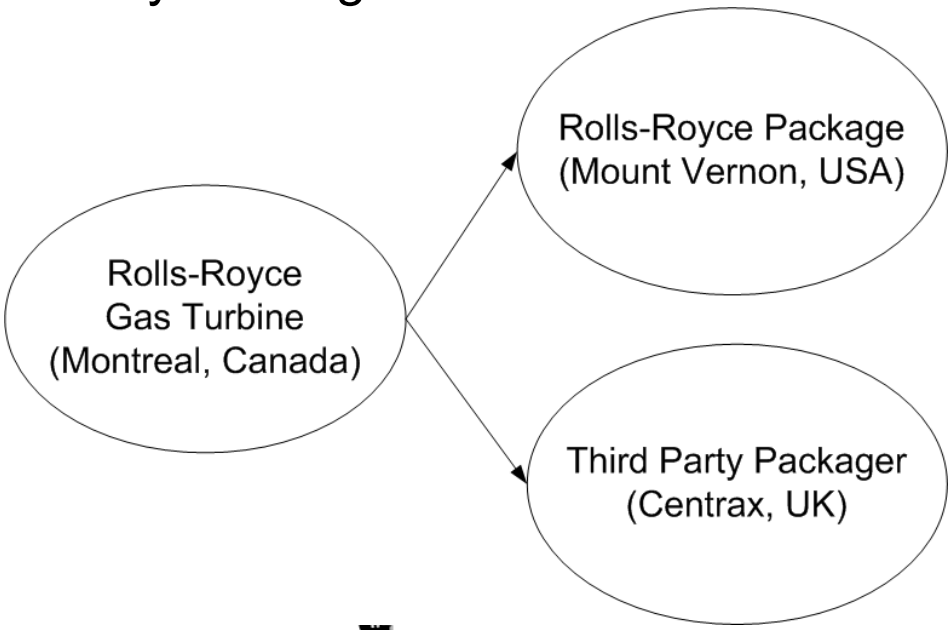



GT Enclosure Ventilation Exhaust
Air Inlet Filter
GT Exhaust
AC Generator
Gas Turbine
Base Plate
GT Oil Systems
Control Systems

# Problem

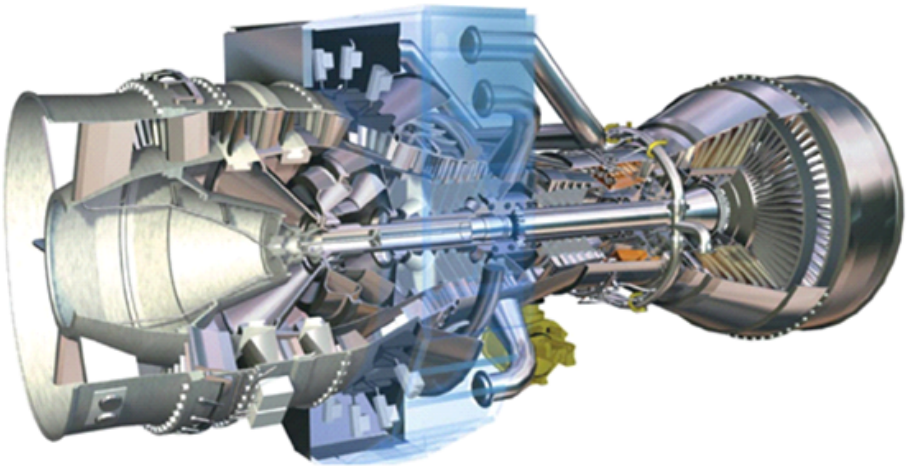


- The current Engine Control System (ECS) and the Safety Instrumented System (SIS) includes software logics for off-engine sub-systems.
- Hardware ownership of off-engine sub-systems is with the packager
- Maintenance of these logics within ECS has become increasingly difficult.
- It was required to review the current architecture (and interface)
- The justification for this architectural change becomes more apparent when considering Third Party Packager.



# Functional architecture

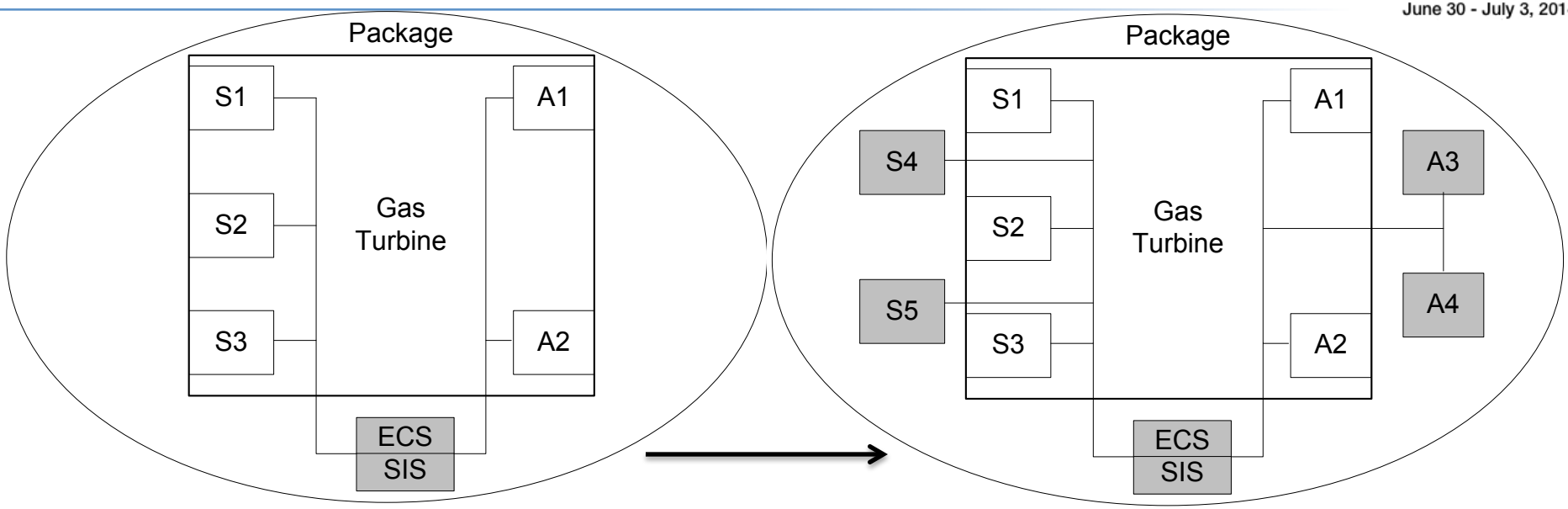




- DELIVER AIR
  - Inlet Spray Injection
  - Fog
- DELIVER WATER
  - Water Injection
- DELIVER IGNITION
  - Ignition Box
- DELIVER FUEL
  - Gas Fuel
  - Liquid Fuel
- DELIVER LUBE OIL
  - Oil Supply
- COMPRESS AIR
  - Starter
  - Variable Geometry
- Maintain engine within operational limits
  - Bleed Off Valve
- EXPAND HOT GASES
  - TURBINE
- Control Gas Turbine
  - Engine Control System
- Weather Station
- Emission
- DELIVER TORQUE
- DELIVER HOT GASES
- DELIVER HYDRAULIC
  - Hydraulic Supply
- REMOVE FUEL/WATER FROM SKIDS
  - Shop Air | Air Purge
  - Water Flush
- COOL BEARINGS
  - Bearing Purge
- Protect Gas Turbine
  - Safety Instrumented System

# GT Control System Architecture






- In order to improve functional interface between the GT and the Package, the architecture of GT Control System has been revised.
- This new architecture aims to split the controls hardware not only to its *physical location* (i.e. off-engine, on-engine), but also to its *functionality* (control, protection, safety)
- The shaded sensors and actuators shaded are off-engine, but design authority will jointly belong to GT & Package Engineering due to their criticality for safe GT operation.

# Controls H/W Requirements



| Sensor Technology | On-engine | Off-engine | Function |
|---|---|---|---|
| Pressure transducer | 4 | 16 | Control, protection |
| Thermocouples | 27 | 0 | Control, protection, safety |
| Resistive Temperature Device (RTD) | 2 | 7 | Protection, safety |
| Magnetic PickUp (MPU) | 9 | 0 | Control, protection, safety |
| Linear Variable Differential Transducer (LVDT) | 10 | 0 | Control, protection |
| Accelerometer | 3 | 0 | Protection |
| Proximity switch | 0 | 5 | Safety, protection |
| Resolver | 0 | 2 | Protection |
| Humidity sensor | 0 | 1 | Protection |

| Actuator Technology | On-engine | Off-engine | Function |
|---|---|---|---|
| Hydraulic | 11 | 0 | Control |
| Pneumatic | 8 | 0 | Control |
| Electric | 3 | 5 | Safety, control, protection |

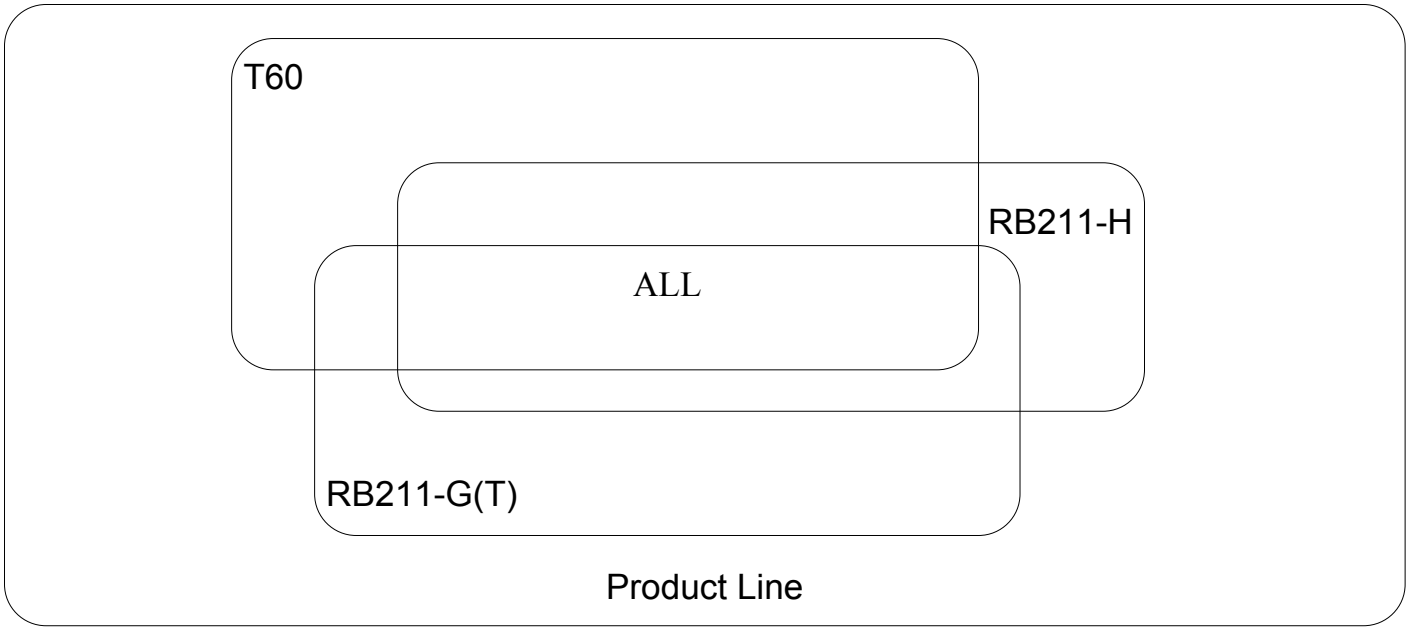
- Many off-engine sensors and actuators are safety related
- It was agreed to extend GT Control System across our products.
- To produce a generic GT control system architecture, there was an opportunity to apply a product line approach.

# Features Coverage



The product line covers three engines in the 32-64 MW range:

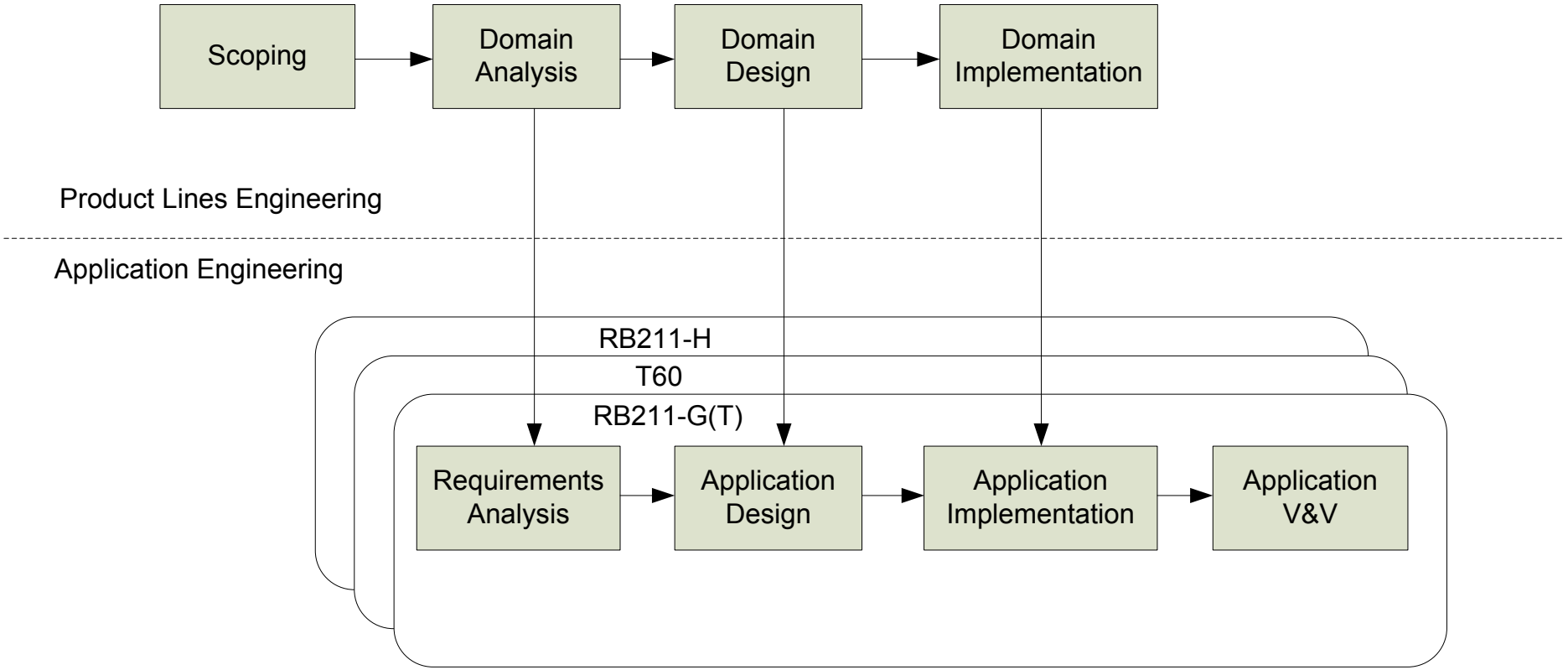
- RB211-GT rated up 32 MW
- T60 rated up to 64 MW
- RB211-H rated up to 44 MW




The RB211-H is drawn from T60 and RB211-GT products

# Development Process



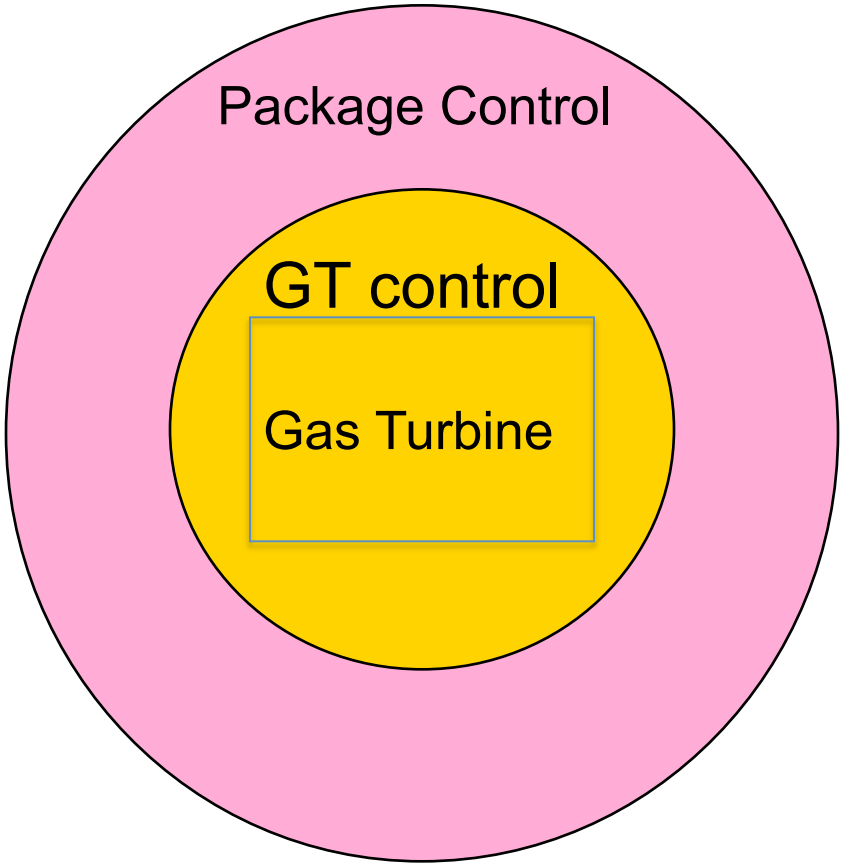


# Scoping – Who is in charge?



## GT Control (in scope)

- GT operation functions integral to GT
- Time critical fuel control
- Auxiliary demands critical to engine operation
- Engine protection functions
- Pre/Post operation and Maintenance functions

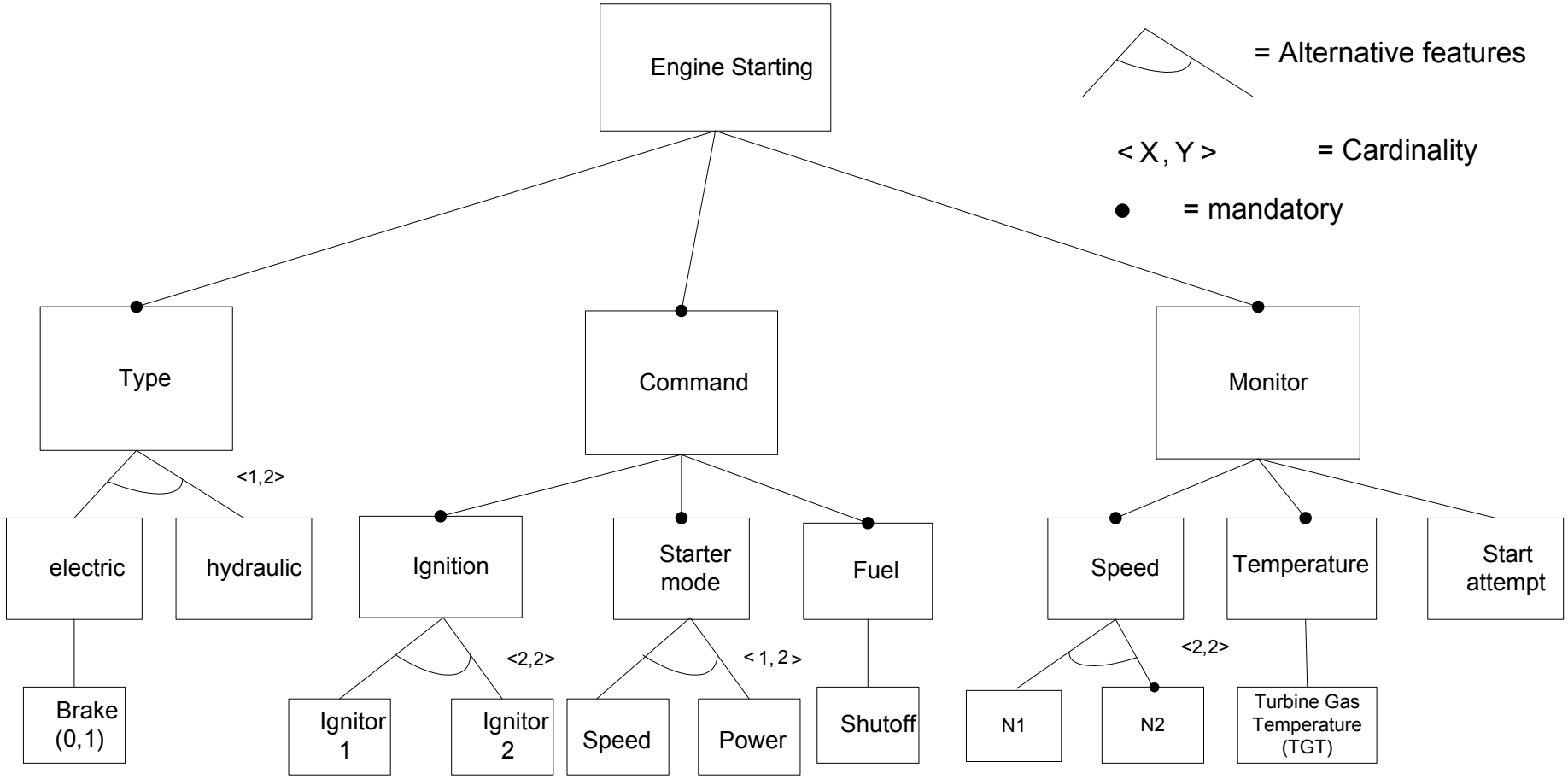



## Package Control

- Delivery of non-time critical substances
- Protection functions related to delivery of non-time substances
- GT protection functions related to drain and vent services
- Pre/Post operation and Maintenance functions related to all of the above

# Domain analysis: feature diagram






- Engine starting is a sub-system of GT Control System domain.
- Feature Diagram aims to identify the common and varying points

# Domain design & implementation



- Design guidance documented as patterns
  - repeatable solutions for commonly-occurring problems.
- A standard tabular template has been produced to address the questions below:
  - What does the solution do?
  - Where is it applicable?
  - What impact does it have on the design?
- Patterns link into one another

# Pattern template

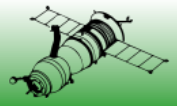


**Relevancy/Discovery**

- Name
- Intent
- Concerns
- Example Problem
- Example Solution
- Applicability

**Application/Effects**

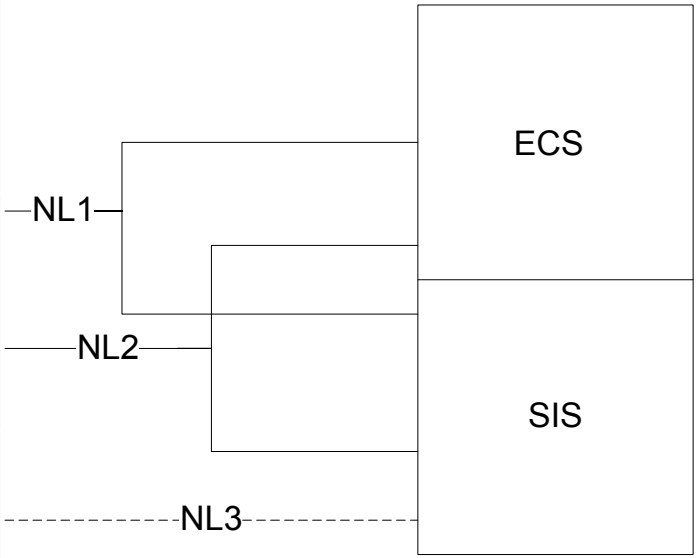
- Template Problem
- Template Solution
- System Interaction
- Sources of Change
- Variation
- Collaborating Patterns


# Pattern template - Example



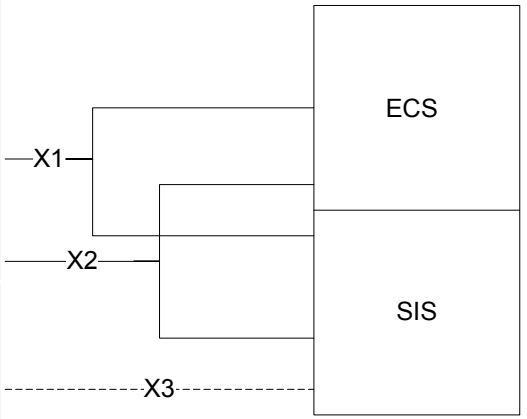
| Relevancy/Discovery | |
|---|---|
| Name | Overspeed |
| Intent | Provide selection of independent input values to mitigate sensor, network or wire failures |
| Concerns | Fault-tolerance |
| Example Problem | The ECS/SIS shall accommodate failures of Low Pressure Spool Speed (NL) signals |
| Example Solution | This solution splits the NL1 and NL2 signals into the ECS and SIS. NL is a critical parameter for GT control, protection, and safety. |
| Applicability | This pattern is applicable if:<br>Input signal is critical to effective power control<br>Input signal arrives from two or three independent sources<br>Input signals have similar characteristic curves |



# Pattern template - Example

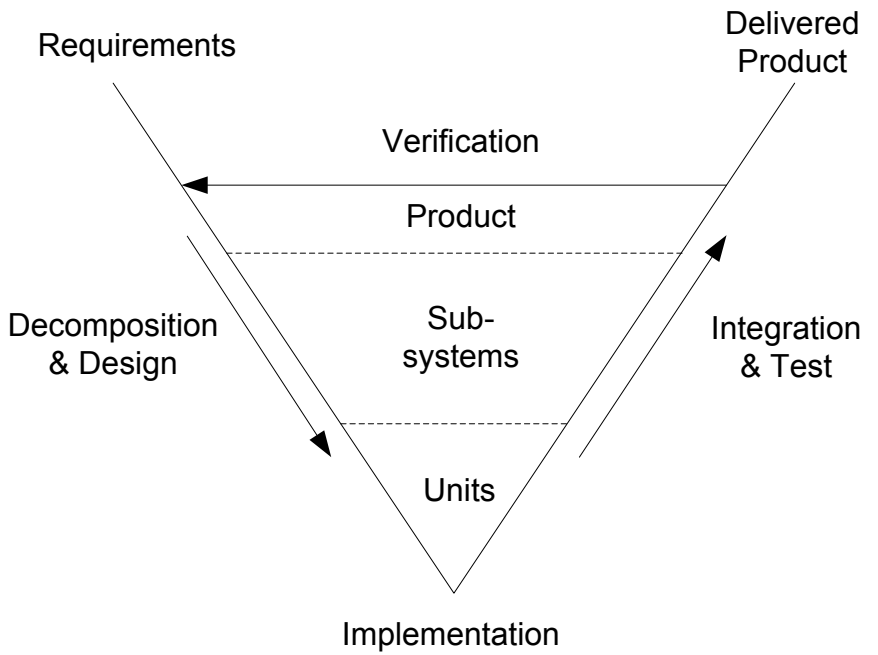


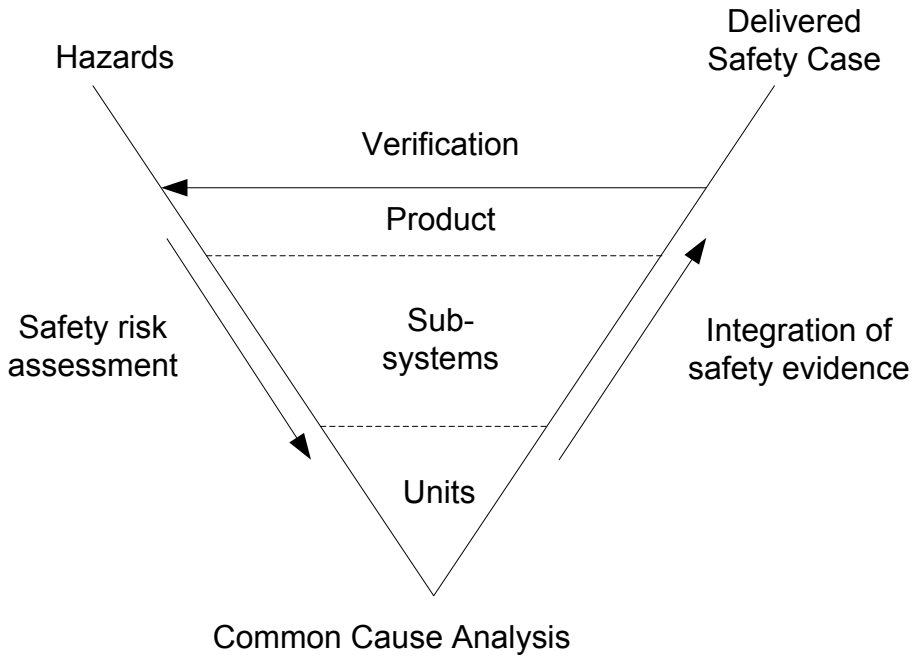
| Application/Effects | |
|---|---|
| Template Problem | The ECS/SIS shall accommodate failures of {X} speed signals |
| Template Solution | |
| System Interaction | The speed signal will be used in the control and safety loops.<br><br>A faulty speed signal may need to be masked to prevent nuisance messages when multiple faults occur. |
| Sources of Change | The use of the pattern may need to be revised if independent overspeed system is provided from SIS. |
| Variation | A third speed signal can be added |
| Collaborating Patterns | *Completing*: Fault tolerance, collect inputs (speed, temperature, vibration, pressure)<br><br>*Alongside*: Fault mask, control laws<br><br>*Using*: route multiple sources |



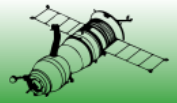
# Development and Safety Processes






Our current safety process follows IEC61511 is thought of as cyclic and is for a single product approach rather than a product line approach.

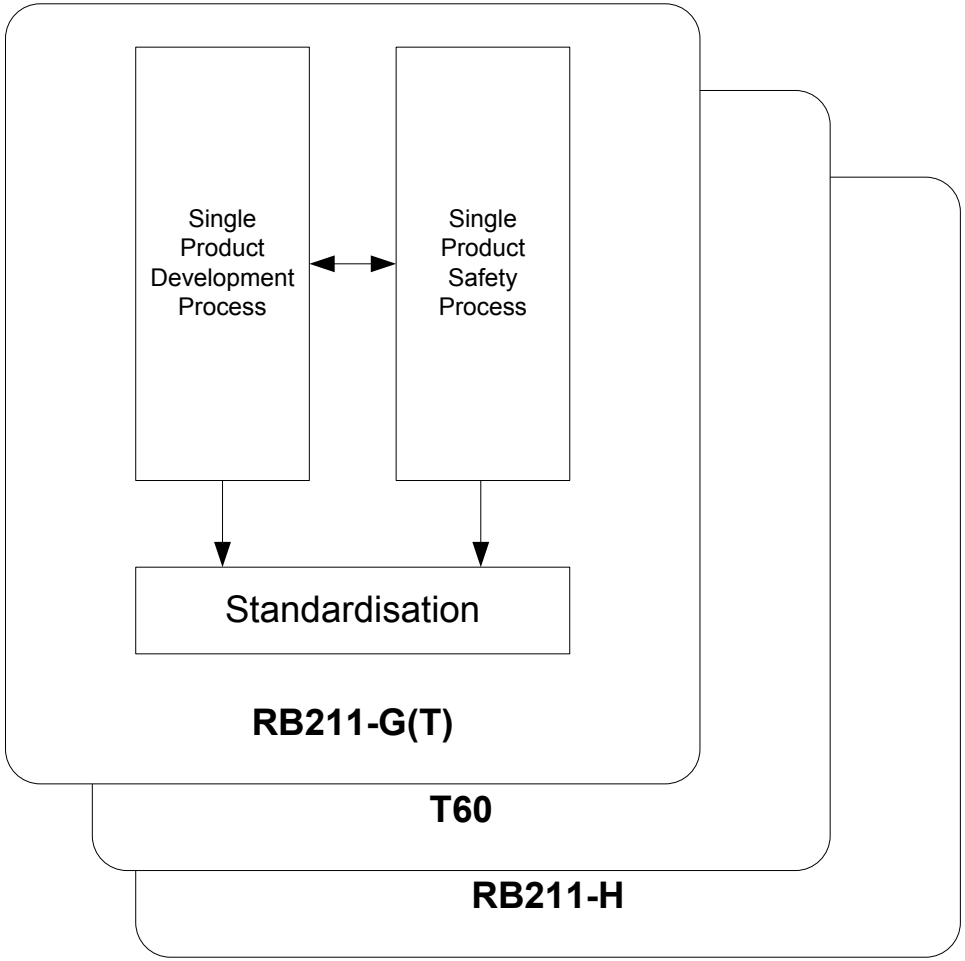

# Single Product versus Product Line

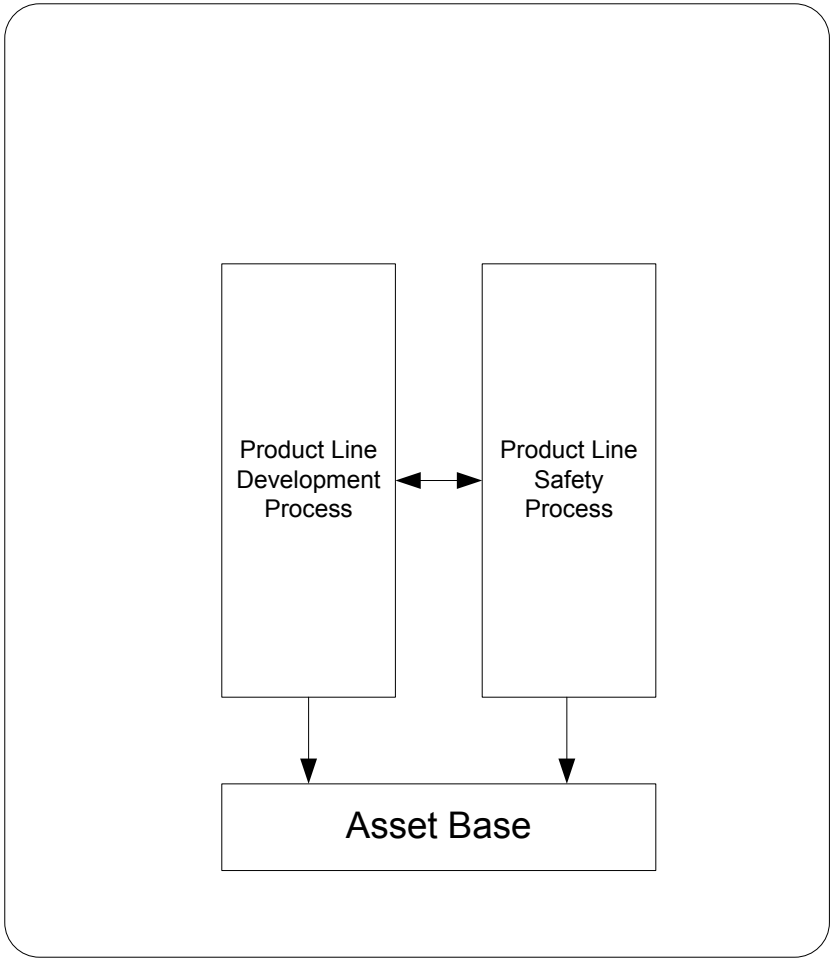


- The safety risk assessment has to change to consider hazards for the whole product line rather than a particular system.
- Safety of each system is not a property of its individual features, but as a whole.
- The introduction of product line safety process would provide clearer mapping of activities with the product line development process
- The aim of the product line safety process will be to provide the safety information for an asset base (not for a single product)

# Single Product versus Product Line





# Conclusions



- The application of product lines in industrial GT control systems has enabled the development of common controls architecture.
- Reuse of architecture (product line) perhaps greatest benefit
- Safety cases and V&V activities are still done for each project
- Systems engineering, especially architecture needs to be documented
  - But there are no prizes for making paper walls!

# Questions