Virtual Engine Design Systems

Rolls-Royce (lead), University of Leeds, University of Southampton, Imperial College London, University of Cambridge, Loughborough University, University of Oxford

Project details:

Rolls-Royce is developing Virtual Engine Design Systems (VEDS) for deployment in the Civil and Defence sectors. The primary aim of the VEDS is to deal with process integration, and automation from preliminary design, up to fully detailed whole engine modelling; and to support the engineering community by providing faster and better solutions to the engine design process.

Environmental and competitive pressures are constantly pushing design and analysis capability to, and beyond its limit, and recent experience has shown New Product Introduction (NPI) programmes entering the development phase with a performance shortfall. This results in additional programme activities and associated higher costs to recover.

The project addressed innovations required to improve the NPI process and its ability to produce products that reliably meet challenging performance and business requirements by addressing four high-level objectives:

- Accurate prediction of whole system behaviour
- Faster delivery of results with appropriate fidelity
- Faster, more agile exploitation of design knowledge
- Development and embed low cost compliant solutions
- Improve knowledge, information and data management throughout the business

Table 1: Summary of the project grant details

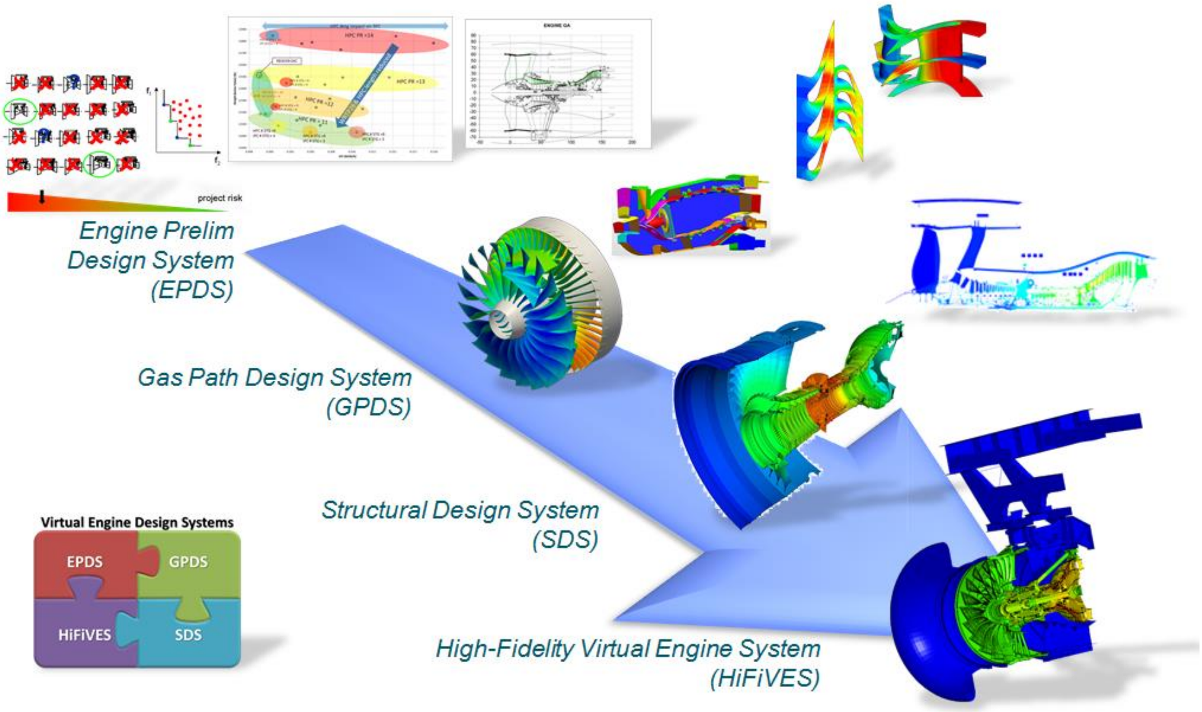
Project	Funding	Lead Partner	No. of Partners	Partner Composition	Duration
110123 SILOET II P10	Total: £9m Grant: £4.5m	Rolls-Royce	7	1 Large company, 6 Academic	May 2013 to Sep 2016

Table 2: Summary of the project focus areas

ATI Value Streams		ATI Enablers		ATI Attributes		Strategic Horizon	
Whole Aircraft		Aerodynamics	X	Safety		Secure	
Structures		Manufacturing		Cost	X	Exploit	X
Propulsion	X	Materials		Environment	X	Position	
Systems		Infrastructure		Fuel Burn	X		
		Process and Tools		Operational Needs			
				Passenger Experience			

Technology Achievements:

As part of SILOT II project 10, improvements have been made to the individual design systems in VEDS and the underlying building blocks such as geometry, aerodynamic simulation, mechanical integrity (lifing), whole engine and unit cost modelling.



Virtual Engine Design Systems (VEDS) to enable faster engineering simulation from conceptual to detailed product design

The project delivered several technology achievements across six work packages:

Design System Integration

A new automated workflow for preliminary component sizing and predicting service life has been developed and implemented into the EPDS tool for faster feasibility assessment of High Pressure Turbine Disc (HPTD) designs. This result in a more comprehensive design study across different engine architectures to find best trade-offs between high-level engine attributes such as efficiency, life, cost, weight and emissions.

To produce high quality and parametric geometry that can be analysed quickly in any of the VEDS systems, an automated geometry modelling technique called User Defined Features (UDF) has been developed and implemented into the Rolls-Royce Computer Aided Design system. This new development enables an engineer to design a full set of turbine or compressor aerofoils in minutes rather than weeks.

A key enabler for automated design is the expert knowledge that needs to be captured and implemented in the design systems. To improve knowledge capture, a new Knowledge Acquisition Modelling Process (KAMP) has been developed, and the knowhow of high profile individuals across the business captured. The benefit of this approach ensures that the most appropriate and experienced personnel can be utilised in the system design process, saving time and cost.

Aerodynamic Simulation

Value stream analysis in previous studies has shown that the meshing part of a simulation process chain is one of the most time-consuming steps and can become the bottleneck when conducting many large simulations. In order to address this issue, the high-quality meshing capability used in aerodynamic simulation modelling has been enhanced. The new capability developed in this work package allows the meshing of complex geometries and the automation of multiple manual engineering steps, resulting in 50-60 times increase in process speed. This leads to an overall time and cost reduction for large simulations.

Mechanical & Lifing Simulation

Lifing is the calculation of maximum declared component service life at all stages in the design life cycle of the component. Lifing simulations and calculations are typically time-consuming for the analyst. As part of this work package, a significant reduction in lead time has been achieved by automating key stages of the lifing prediction process. Software has been developed that provides better signal processing and data handling methods to extract the principal features of measured data from development engines. Another software tool has been developed as a plug-in (SK18 for contact) for the Rolls-Royce in-house Finite Element Solver SC03. The new plug-in reduces analysis times with the same accuracy as the previous method, resulting in an approximately 50% reduction in computational time compared to existing commercial codes. These improvements have contributed to a 10-fold reduction in the component lifing prediction process time compared to the conventional manual process.

Whole Engine Dynamics

Early design Fan Blade Off (FBO) assessments have been successfully demonstrated for novel engine architectures. Post FBO analysis time has been reduced by 75% through use of a frequency domain analysis method rather than the conventional time domain approach. A full epicyclic gearbox has been modelled successfully in the LS-Dyna simulation software package. This is a company first for Rolls-Royce, and provides the ability to explore different failure scenarios and influence the design process at an early stage. A Squeeze Film Bearing rig has been successfully designed and built. A Squeeze Film Bearing is an oil-filled thin film space, surrounding conventional rolling element bearings. The rig has been run for several configurations to enable development of a representative model. A validated model will ultimately reduce the amount of testing required during the development of future systems.

Product Cost Engineering – Capability Improvement

The costing analysis tools within the VEDS have been improved. These have been integrated with cost analysis tools for the Engine Preliminary Design System (EPDS). This has delivered a more accurate analytical tool for determining whole engine cost. The result has been a predicted 2.5% reduction in unit cost.

Robust Simulation

The project has delivered the capability to use measurement data to assess the geometry of as-manufactured and used components, giving cost savings on concessions of approximately £5m per year, and facilitating faster and more accurate Robust Design of products (TRL6). Traditional optimisation methods are very complex to use and special expert knowledge is required. As part of this work package, better numerical optimisation methods have been developed to help the engineering community achieve faster and better solution finding.

An increase of analysis accuracy has been achieved through a new mesh smoothing method (TRL4), which has the benefit of being able to be used in any robust design study.

Predicting the outcome of uncertainties in the design process requires that the impact of every output variation needs to be assessed against any input changes. This would traditionally require large Monte-Carlo Simulations (MSC) which consume large amounts of time and computational resource. To make uncertainty assessment in an engineering environment feasible, a faster and more efficient process for estimating the effects of uncertainty in computer simulation-based product design has been developed (TRL4). A significant reduction in simulation effort has been achieved, with the magnitude of the benefit dependant on the number of inputs and outputs in the design process.

Table 3: Summary of the technology achievements

Project	Performance Improvements	TRL Progression
110123 SILOET II P10	Component sizing and lifing workflow for HPTD WP1	TRL 6
	Automated design process for aerodynamic simulation WP2	TRL 6
	Improved mechanical and lifing simulation WP3	TRL 6
	Fan Blade Off analysis run time reduced for high fidelity simulation by 75%	TRL 6
	Epicyclic gearbox run in LS-Dyna simulation software (ongoing development in the UltraFan® Project	TRL 4
	Squeeze Film Bearing rig designed and run (methods have been developed to TRL 6 in follow up project and deployed for use on live projects)	TRL 4
	Capability improvement of 2.5% avoidance in unit cost	TRL 7
	Cost savings of ~£5m per year on concessions and performance (WP6)	TRL 6
	Component sizing and lifing workflow for HPTD WP1	TRL 6

Economic Impact:

Rolls-Royce employed around 50 full time equivalent staff during this project. These worked on a range of disciplines including manufacturing engineering, operations, automation, inspection, materials science and process modelling. This level of effort is expected to continue in future years as the technology continues to mature. The capability of Rolls-Royce staff in the domain of engine design systems has grown significantly as a result of this project.

A total of 8 students completed their PhDs through this project, and have the potential to secure employment in the aerospace sector.

The availability of improved VEDS and Component Design Systems, which are achieving faster, more accurate results will enable Rolls-Royce to move the focus from sub-system to whole engine design and optimisation. New capability and knowledge-capture processes enables delivery of the most competitive solutions first time, improving Rolls-Royce's performance in existing markets, and protecting the Rolls-Royce UK workforce and its UK supply chain. The capability gained in this project will directly benefit the Trent 7000 and Trent XWB-97.

The VEDS programme should deliver environmental benefits of 1% SFC improvement from whole system optimisation, 50% increase in raw material utilisation from forging optimisation and 50% increase in rate of fuel burn improvement; set to be achieved after the ATI-funded GEMinIDS and APROCONE follow-on projects. These efficiency gains will result in reduced CO2 emissions thereby assisting Rolls-Royce to meet engine and aircraft efficiency targets for 2050, set out by the Advisory Council for Aviation Research and Innovation in Europe (ACARE).

Table 4: Summary of the economic impact

Project	Value created	Employment
110123 SILOET II P10	More competitive products through improved designs	50 jobs safeguarded

"The Virtual Engine Design Systems (VEDS) deal with process integration and automation in order to support the engineering community in faster and better solution finding. By applying VEDS on our Trent XWB-97 program has allowed us to develop a more competitive product, faster. Design iterations that took weeks now take less than an hour. By freeing up our engineering time, we can produce better solutions."

Tiffany White – Head of DaVinci, Rolls-Royce

Next Steps:

Improvements to all new engine projects will be made due to the improved simulation tools and Integrated Decision Support Systems developed in this project. This will result in faster and more accurate Virtual Engine Design Systems.

The projects benefitting directly are the large civil engine models using User Defined Features (UDFs) including UltraFan® and Advance3. Analysis techniques developed in this project are being applied to the UltraFan® demonstrator to investigate structural behaviour under transient loading of the front engine architecture.

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