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RB211-H63 ADVANCEMENTS IN BEING ABLE TO MEET FUTURE DEMAND OF OIL & GAS REQUIREMENTS IN MIDSTREAM APPLICATIONS

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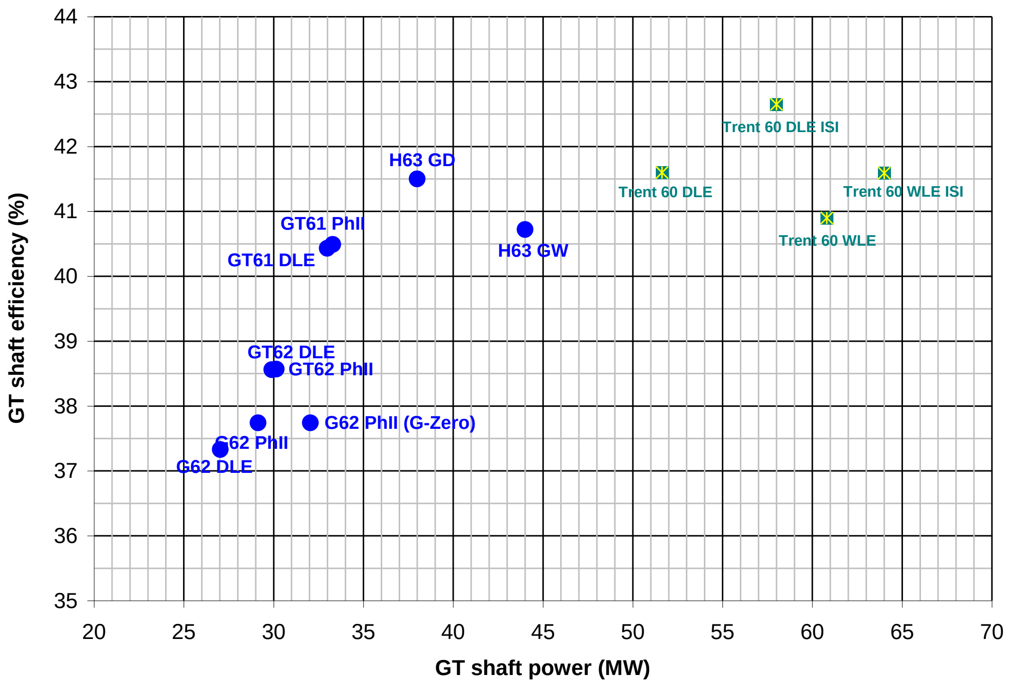
Abstract

Midstream natural gas assets, such as gathering systems, processing plants, transmission pipelines, storage fields, and liquefied natural gas (LNG) import terminals, will continue to play a role in an efficient natural gas market. Without continual investment, a lack of infrastructure can lead to price volatility, reduced economic growth, and reduced delivery of natural gas to consumers and industrial companies alike. The advent of shale gas both in Canada and in the United States will have an effect on natural gas supplies and create new opportunities for future investment. In order to meet future midstream requirements, Rolls-Royce has made a strategic investment in bringing the RB211-H63 gas turbine to market. The RB211-H63 is the latest new product that Rolls-Royce is introducing to its well established aero derivative gas turbine portfolio. It is aimed at both the Oil & Gas and Power Generation markets and fills the power gap between the RB211-GT and Trent products. This paper will detail some of the methodology used to help expand the power, efficiency and maintainability of a gas turbine package.

1. Introduction

The RB211-H63 is aimed at both the Oil & Gas and Power Generation markets and fills the power gap between the RB211-GT and Trent 60 products. With the current Rolls-Royce RB211 rated up to 33MW and the Rolls-Royce Trent 60 being aimed at the higher power aero-derivative market, the gap between the two products and the future needs of the oil & gas and power generation markets are a natural fit for the RB211-H63 product. See figure 1.

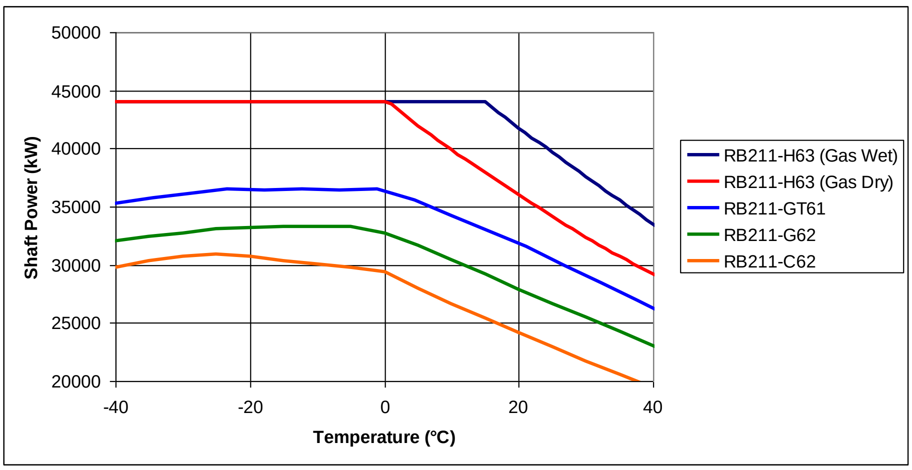
Figure 1 : RB211-H63 product placement



2. The need for the RB211-H63.

The first step in the design of a new gas generator is a clear understanding of requirements. These requirements come from a number of sources including market intelligence, trends in current and past sales, market and customer feedback, and published data. The key requirements for the RB211-H63 are power ratings of up to 44MW (wet or dry) with conventional combustion, which is shown graphically in figure 2, versus the current RB211 engine variants, on figure 1.

Figure 2: Predicted Ratings of the RB211-H63 and other current RB211 models



In addition, the product must have the potential for 15% future power growth and an efficiency improvement of 2%. The ability to operate with dual fuel, the use of water injection for emissions control, and a DLE combustor option are also demanded. From an engine ease of ownership perspective, the modular design of the current RB211 engine is required to be retained.

Once the customer and business requirements are determined and understood, the process of putting together the building blocks of the RB211-H63 sub-system designs begins.

3. The starting point

The success of the current Rolls-Royce portfolio led to the rationale behind the new RB211-H63. To combine the proven, high performance, highly reliable components and systems and integrate into them into a new product was the next challenge. Where necessary and appropriate, proven technologies from the existing Industrial Trent and RB211 product portfolios could be infused in order to provide the attributes required for our current and future customers. The use of many existing components and assemblies also enable the engine production build time to remain aggressive.

Armed with a vision of an update to today's RB211 2-spool engine, a rough layout was born. This was effectively an 'Engineer's cartoon' of what the product could look like. The next step is critical and can define a product entirely, and that is to add the detail.

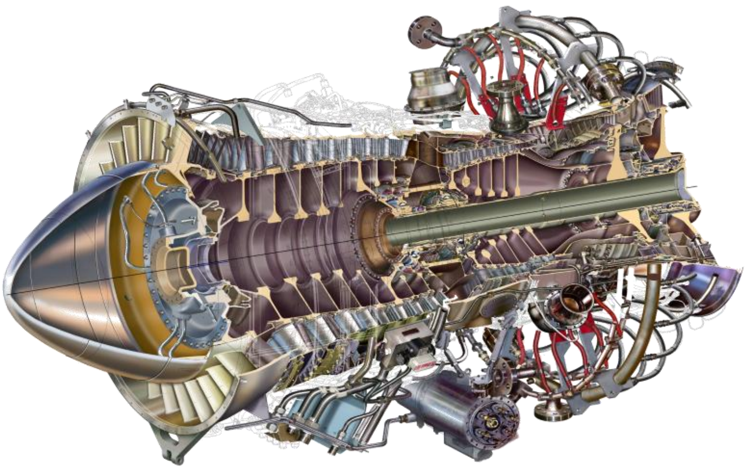
4. Systems Architecture

Among the hardest parts of the design of a new gas generator are the engine systems. By this we mean the non-hardware portion of the design such as fluid systems, whole engine thermal and mechanical models, performance deck, and bearing loads. These items are so finely balanced that change in any one of them can significantly change the others. Adding to the complexity of the system architecture is that each of these system parameters are dependant on the hardware designs which have in them selves not yet reached the detail design phase. In essence, we have a large number of systems and components that are all interdependent.

The starting point in this process is done by pulling together a number of assumptions for component efficiency, fluid systems, thermodynamics, bearing loads, and the like based on previous Rolls-Royce engine designs and components. This gives a degree of authenticity and confidence in the numbers used. Once all of these have been identified, each of the systems models is run with the generic inputs from the other systems. This provides a slightly more accurate slew of models and predictions than the initial inputs. How the models affect on each other becomes more visible, allowing further iterations knowing the attributes and interdependencies within the various models. Of course, at this stage, this is still based on component assumptions and not real component geometries. The systems iteration approach is continued throughout the component design phases in order to identify the required behaviours of each component. Component design will then be changed in order to satisfy the overall requirements of the product. Once a baseline systems design is available, the work of detail designing components to fit around the framework begins.

The component design approach taken for the RB211-H63 is that of the RB211 engine. This allows for the modular approach to be taken for simplicity of maintenance and build. Starting from the front of the engine and working rearwards, the following sections show the designs solutions for each of the modules. A schematic of the completed H63 gas generator is shown in Figure 3.

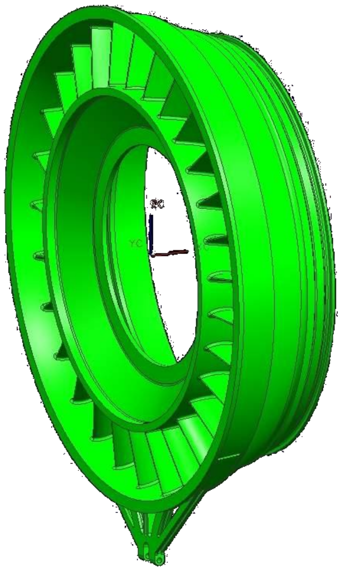
Figure 3: Diagram of the RB211-H63 gas generator



5. Air inlet casing

This is the front end of the gas generator, mating to the inlet duct of the package on the one side and to the IP Compressor casing on the other. This module provides location for the front bearing housing. All Rolls-Royce Industrial engines have this component, but is generally designed as light as possible as it is taken directly from the aero engine design. The RB211-H63 deviates from this commonality strategy in that it has an industrial specific inlet casing, manufactured from sand-cast stainless steel. The main considerations are to retain the aerodynamic attributes required to maintain engine performance and efficiency at the required level and to ensure that the front engine bearings are located correctly throughout the entire operating range. One additional change to this module was that of a new IP Compressor front stub shaft. This is the rotative part that locates the front of the rotor. The RB211-GT uses modulation to control its bearing loads to acceptable levels. Whilst this is a proven and robust design, the H63 design chose the option of an increased rotating seal diameter. The advantage of this design is that it provides a large diaphragm diameter to offset bearing loads, and thus eliminates the need for bearing load modulation, resulting in fewer parts and therefore higher reliability.

Figure 4: Air Inlet Casing Model



6. Compressors

It was clear early in the design phase that the 7-stage IP Compressor from the RB211-GT engine would not provide the power or efficiency requirements for the H63, especially with power growth in mind. Potential solutions were to add a zero-stage to this compressor, to use the current Trent compressor or to look within the newer aero Trent engines for a usable compressor. The last option was quickly ruled out on cost grounds. The option between the zero-staged and Trent compressors was not so clear cut. Both offered high reliability, a proven track record, high performance and efficiency to match the needs of the product. The decision was tough, but the Trent compressor was chosen on the basis of maintaining commonality with the Industrial Trent engine. This also eases the engine build logistics in that the same supply chain and parts would be used for two engine lines.

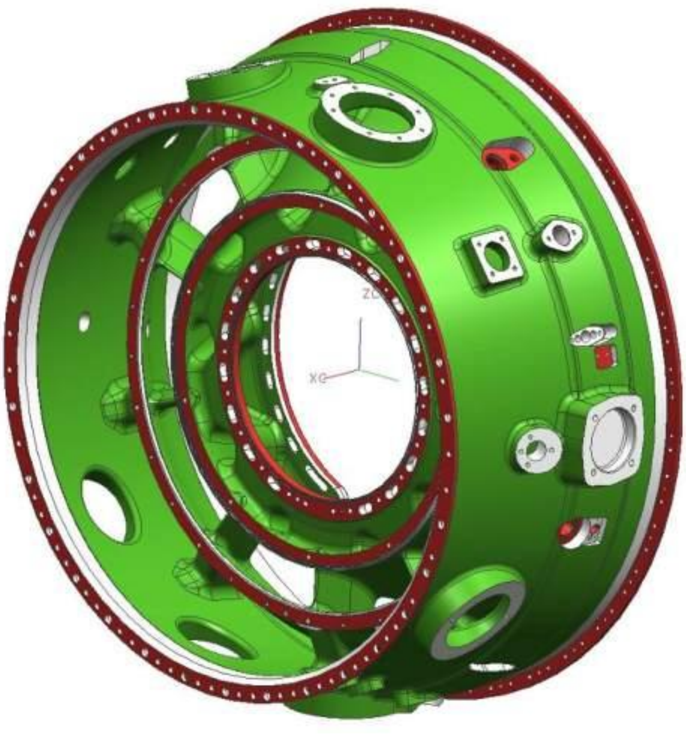
The Trent IP Compressor casing is taken from the aero Trent 800. It's a double skinned (in conjunction with the Trent intercase) 'A' frame design as this is what is required for holding an aero engine off the wing. This light weight design, whilst appropriate for aero applications, is overly complicated for industrial applications and gives no real benefit to an industrial engine. Presented therefore was a classic opportunity to make a design change to suit the needs of an Energy product. A simple centri-spun casting design was chosen. A horizontal split line was introduced to ease build, strip and maintenance. The benefits of this design are many: a reduced parts count, an easier build, and an easier, less fussy way of clipping external components to this casing which resulted in a more elegant solution overall.

7. Intercase and internal gearbox

The material of the intercase used for the RB211-GT is an aluminium casting. This was not an option for the H63 as the elevated temperature consistent with the higher power output meant that the material properties would be exceeded at the higher power growth requirements of the H63. The Industrial Trent intercase is an investment cast titanium unit taken directly from the aero Trent800 - exceptionally lightweight, complex and over designed for industrial applications.

The opportunity was available to design a new intercase that would meet the requirements of the H63 while offering an occasion to reduce the cost and complexity of this part. In many ways, this was one of the more challenging component designs for the H63; the choice of materials, the thermal and stress management, the effect on mating components all needed to be considered. A number of iterations ensued after the first design concept. The scope of this design was large, new materials testing was required, state-of-the-art stress and thermal analysis were performed, and novel design approaches were needed. Independent laboratories were used for extensive materials testing and Rolls-Royce corporate materials experts were enlisted at every stage of the design. A large portion of this work was to ensure that the material selected, a sand cast ductile iron, had the material properties required.

Figure 5: Intercase Model



Once an agreed design was available, suppliers were engaged in the concurrent engineering process. After both casting and machining houses had bought into the design, the manufacturing phase began. The process of pouring the casting, as anticipated, took a number of iterations, each one solving issues of the previous until the design intent was met and the quality was beyond question. It took six such iterations to get to a design that met the requirements.

The internal gearbox within the intercase has also been simplified compared to the RB211-GT. Bearings were taken from the aero Trent 800 and 900 engines. Both of these are capable of taking more load than will be exerted by the H63 and each have millions of hours of aero service behind them. Rather than the gearbox and clutch arrangement as per the RB211-GT, the H63 has a direct, permanently driven electric starter motor connected to the HP shaft via a clutchless external gearbox. This is very similar to an already standardised Industrial Trent system. In comparison to the RB211-GT design, the H63 has a significant reduction in moving parts which will equate to increased reliability.

8. HP and Combustion Systems

This HP compressor and Turbine module are in many ways the easiest of all the choices for the H63. Due to the power and efficiency requirements, the only real choice was to adopt those of the Trent engine. This uses aero common parts having proven reliability and high efficiency levels. Very importantly, it offers significant power growth potential to the H63 as the baseline turbine inlet temperatures of the H63 are less than that of the Trent.

The combustion system was a choice between 2 variants. The Phase II as per the RB211-GT or the Phase V as per the Industrial Trent (and aero Trent800). Whilst the Phase II offered a small cost advantage, the Phase V, being newer technology, offers lower emissions. The Phase V was chosen, along with all of the casings of the Industrial Trent. The only difference is that of the outer combustion casing which is an aero Trent 700 part for the H63. This was chosen as a 'plug and play' option compared to the aero Trent 800 casing of the Industrial Trent based purely on cost grounds.

The fuel burners for the H63 are identical to those of the Industrial Trent. They offer dual fuel operation and water injection for emissions control. Once the FMV (fuel metering valve) has been commanded to move, fuel change-overs from gas to liquid takes 60 seconds, and from liquid to gas 15 seconds, without a need for a power reduction, are possible. This functionality has been proven over and over again on the Industrial Trent to the tune of many hundreds of thousands of hours.

9. IP Turbine

The IP Turbine system deviates slightly from either the RB211-GT or the Industrial Trent designs. A key requirement was that the interface between the gas generator and the power turbine remain as per the RB211-GT. This precluded the use of the Industrial Trent IP turbine. The RB211-GT IP Turbine would not meet the life requirements of the H63 due to this engine's higher temperatures needed for product future ratings. In addition, the efficiency and capacity of the RB211-GT's parts would not meet the more stringent requirements of the H63. The answer was to use similar parts to the RB211-GT's but to introduce more modern materials and aerodynamic aerofoil designs.

The IP NGV was skewed in order to provide the correct capacity, and modern pedestal cooling provides an efficiency upgrade as did revised aerodynamics.

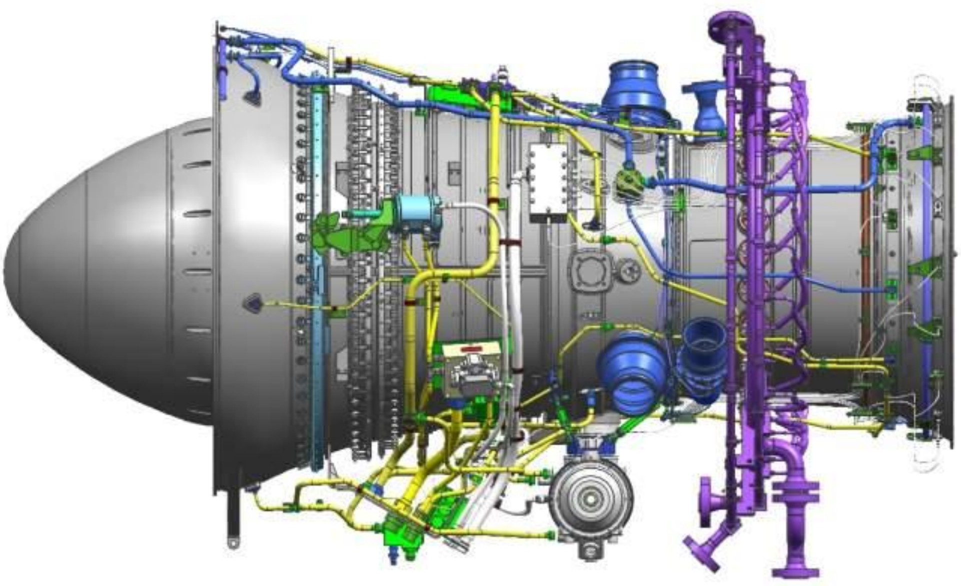
The IP Turbine blade was upgraded to a higher specification material, as used in the Trent engines. This increases both the temperature capability and life of the turbine. The aerodynamic features were also improved and profiled end walls were utilised to gain an efficiency advantage. The interaction of the air over the blade tip was also improved with the introduction of a new seal segment and blade shroud. All of these design changes equate to an improvement in turbine efficiency.

10. Project Governance

Rolls-Royce has strict processes and guidelines for New Product Introductions with a view of using the best brains and experience within Rolls-Royce to help, guide and review Projects. The challenge of this process is to instil quality and rational risk into the product.

Throughout the entire H63 design process there have been significant design reviews. These have varied in terms of involvement depending on the design and stage in the process. Regular 'internal' reviews are held on all designs and systems where gates have to be passed in order to progress forwards. These are chaired by the Chief Audit Engineer, the Chief Engineer and the local subject matter expert, and corporate experts are brought in where necessary. In addition to internal reviews, Corporate Audit reviews are held at regular stages of the Project. These are chaired by the Corporate Chief Audit Engineer, who assembles a team from various parts of Rolls-Royce where he needs to pull-in expertise and experience. The purpose of these reviews is to delve into the depths of the Technical and Business facets of the Project from the company's best and most experienced personnel. Strict pass/fail criteria are adhered to, and any actions that result from these reviews are monitored on a regular basis from the Office of the Chief Executive.

Figure 6: Side View of RB211-H63 Gas Generator



11. Engine Validation & Build

How to put a combination of new and existing componentry together, coupled with new power and efficiency requirements, then adding in new fluid system behaviours, new thermal and whole engine management, and produce an engine that meets all of its required attributes, results in a complex engine validation process.
Within this paper, the process of pulling all of the parts and systems together on paper was explained. The delivery of hardware, controls panels, software, and the like are obvious key deliverables, but these in isolation do not make a successful gas generator that meets its business and customer requirements.

The validation process starts as early as when models, either mechanical or systems are available. These are refined as the design matures and are subject to an iteration process as already discussed. This process generally stops once a Bill of Material (BoM) is defined. This indicates that the design is frozen at that point. This BoM is the standard of engine build for the initial development test.

The next step is to define how to instrument and test the engine in order to validate the models.

The instrumentation type, location, and above all the rationale for it, is key to the validation of the models and the process for identifying all of these has many facets. In simple terms, the question of which parameters and in which locations is required in order to validate the predicted capability & suitability of the components and systems. On top of this, the considerations of how to account for redundancy or circumferential differences need to be addressed. At this point, a rational decision has to be made on which parameters to include and which to leave out with respect to instrumentation. Options of applying additional instrumentation to later development engine vehicles are also considered. The bottom line is that sufficient information is required from the development engine tests to fully validate the models and the engine in a production environment, not just that of the development engine run on a test bed over a small range of ambient temperatures, humidity, and so on. This is key in determining the engine behaviour when run in the many conditions of the real world. As an indication of the development instrumentation count for the first H63 development engine test, there are in excess of 350 Pressure tapings, 650 thermocouples, 50 strain gauges, 70 accelerometers, and a host of rub pins, thermal indication paint, and so on.

The build of the new production engine is not anticipated to be complicated, after all, it uses many common parts with existing RR Energy products. The build processes are well known and are completed on a regular basis by the RR Canada Build Shop. However, what makes this considerably more complicated and time consuming on a development engine is the addition of the instrumentation provision, the rework of the parts to accept instrumentation, the parameter fitting, the lead-out routing and clipping, and then the build of components that may have significant instrumentation parameters and cables attached.

The test strategy is key in extracting sufficient information out of the engine and accessories in order to standardise the engine, and to consider all possible operational requirements that this engine could experience in the field. A validation program is not worth much if after standardisation, additional tests are required in order to understand and solve issues from in-service units. There are several distinct development tests planned for the H63. These include tests within the Montreal development test facility which are run into a jet-pipe configuration and additional tests within the Mount Vernon, Ohio, facility where the engine will be connected to the RT63 power turbine.

Conclusion

The RB211-H63 gas generator is predicted to meet its objectives. Models are completed and designs have been finalised for development. A Bill of Material is complete. The majority of components have been delivered and engine instrumentation and build has started. Validation plans are in place and the initial engine test program has been defined.

Figure 7: Diagram of the RB211-H63 on Power Generation Package