More Electric Aircraft Forum

Engine Powerplant Electrical Systems

Adam McLoughlin
Rolls-Royce plc

Copyright © 2009 MOET Project Consortium – ALL RIGHTS RESERVED

ABSTRACT

As the aerospace industry is moving towards the More Electric Aircraft, there is a growing demand for electrical power to feed the increasing electrical loads in the aircraft. More Electric Aircraft (MEA) and More Electric Engine (MEE) are terms that are sometimes mistakenly being used interchangeably, but that are actually very different. This paper outlines some of the issues that have been considered in the MOET program that relate to the effects of increased electrical power provision on design of the aircraft engines and the differences between MEE and MEA from the authors perspective.

INTRODUCTION

More Electric Aircraft is a term that is now widely used and well understood in the aerospace community. ‘More Electric Engine’ is also a term that is becoming more widely used, but perhaps is less well understood. A More Electric Engine takes the engine control elements of the engine, such as fuel pumping, oil pumping and engine actuation that are conventionally powered through mechanical means and converts them to electrically powered operation. The idea that a More Electric Aircraft necessitates the use of a more electric engine to power it is not true. However, both MEE and MEA have significant, but different effects on the engine. Once the differences between and dependencies upon each other have been discussed briefly, the paper goes on to discuss the effect of the MEA on the engine that have been studied within the MOET program, and then considers some of the issues that must be taken forward to develop the more electric engine.

MEA VS MEE

The aerospace industry is pushing ahead with More Electric Aircraft. Recently, both Airbus’ A380 and Boeing’s 787 have taken advantage of more electric technologies – in different ways. In A380, the hydraulically powered flight control actuation system has been partially replaced by electrically powered actuator units. The Boeing 787 has
embraced electric power for the Environmental Control System (ECS) and Wing Ice Protection System (WIPS), replacing their pneumatically powered predecessors. By moving to electrification of these functions, the 787 has eliminated the requirement for bleed air to be extracted from the engine, hence engine starting is also facilitated by using the same electric machine as generates the aircraft electrical power. In comparing the A380 and 787 implementations of more electric aircraft, it is the 787 that has provided the biggest challenge for the engine since replacement of the bleed air driven functions with electric alternatives has a dual impact on the engine:

- removal of the bleed air, currently used to provide “handling” benefits to the engine;
- increase in the electrical power required from the engine powerplant, requiring a significant increase in the mechanical torque offtake from the engine via the accessory gearbox.

While both A380 and 787 are More Electric Aircraft, neither is fitted with a More Electric Engine. More Electric Engine considers electrification of the control functions of the engine and is implemented through replacement of hydraulic, fuel/air of pneumatic functions of the engine. These can include fuel system, oil system and engine actuation functions, many of which are being considered in ongoing research programs. However, the benefits and issues related to the implementation of these functions are still under investigation; consequently there is not currently a more electric engine in-service, or close to being in-service today.

ROLLS-ROYCE STUDIES UNDER MOET

Within the MOET program, Rolls-Royce has explored a number of research topics including:

- Embedded generation
- Electrical power offtake
- Effects of electrical offtake on engine speed control
- Electric actuation for engine applications

Each of these areas will now be considered in more detail.

EMBEDDED GENERATION

Under the Power Optimised Aircraft (POA) program, Rolls-Royce, in partnership with other consortium members, developed an electrical machine and associated control that provided part of the electrical generation capability via an embedded electrical machine. The machine in question was a permanent magnet machine fitted to the high pressure shaft of the engine, located between the HP and IP (Intermediate pressure) compressors in the engine core. This is an extremely harsh environment in which to operate such a machine. In addition, the same machine and controller provided the engine start function via electrical means.

Within the remit of the MOET program, this concept was explored further, taking the concept developed under POA and making consideration of the effects to be addressed in a ‘real’ engine environment, using the MOET reference aircraft as a basis for this work.

Taking the requirements of the MOET reference architecture and mapping these into a parametric model based on the POA engine starter/generator system gave the opportunity to assess the impact on whole engine weight and drag. The possibilities of installed location were also considered. Lessons learned from recent engine design experience were also considered alongside the POA experience.

Recent engine design experience has proved that it is possible to start the engine by driving the IP shaft rather than the HP shaft as previously. This offers overall benefit to the engine installation since there is no need to provide any mechanical interconnection between the IP and HP shafts that would
facilitate HP starting with IP power offtake. This configuration offers the possibility of installation of the embedded machine in front of the IP shaft, hence providing simplified access for maintenance by removal of the fan. Access to the machine in the POA engine would require significant engine strip due to it's location in front of the HP compressor drum. Figure 1 indicates the potential location of an embedded electrical machine in a turbofan engine. However, even taking into account the benefits of this revised installation, the increase in engine length and consequential increase in drag due to nacelle length increase, would be detrimental to the overall efficiency. Installation in front of the IP compressor also requires an increase in engine weight when taking into account the additional bearing requirements to support the electrical machine.

Figure 1 - Embedded machine location

The POA concept was successfully tested, for both starting and generating, in a series of engine tests conducted in 2008. However, in order to provide an attractive solution for future configurations, it is clear that the provision of an electrical machine embedded into the core of the engine still needs significant development to ensure a viable, whole engine solution.

EFFECTS OF ELECTRICAL POWER OFFTAKE ON ENGINE SPEED CONTROL

The effect of electrical power offtake can have a significant effect on the engine. Figure 2 shows two operational scenarios that can have significantly different effects on the engine operation.

Consider the first scenario shown, which is typical during the taxi, hold and descent phases of flight. During these phases, the aircraft does not require large amounts of thrust and hence the power setting of the engine is low. However, the on-board systems still require electrical power. This is indicated proportionately in Figure 3. It is clear that the effect of the electrically powered systems during this phase is significant since they require a high proportion of engine power during that phase. Hence the electrically powered systems can have a significant impact on the control of the engine during that phase of operation.

Figure 2 - Operational scenarios
Considering the second operational scenario shown, it is clear that the major requirement during the take-off / climb phase is for thrust power – the effect of the electrically powered systems during this phase is small because of the relative proportion of thrust power to electrical offtake power.

During the first scenario considered, the engine is operating at a low power setting, often close to idle. Electrical load steps present themselves to the engine as an increase in mechanical torque required. From Figure 3 it is clear that the electrical load induced effects are significant and hence the effect on engine speed due to increasing mechanical torque to provide the additional electrical power to accommodate the electrical load steps is significant.

These load changes cause torque transients on the engine that result in changes in engine speed. The idle speed of the engine is set such that these electrical load changes do not cause the idle speed of the engine to drop below its ‘surge line’; the point at which the engine core can stall. It follows that the electrical loads drive the idle speed setting to be higher than required in order to accommodate the electrical transients. Hence if the engine receives prior knowledge of impending load changes, the operating speed at that time can be adjusted to take account of electrically induced transients.

If the engine speed can be controlled in this more dynamic manner, then it is possible for the normal idle speed of the engine to be reduced, leading to reductions in fuel burn. The engine speed is then raised prior to electrical loads being applied and hence the potential for engine surge is avoided.

**ELECTRICAL POWER OFFTAKE FOR FUTURE ENGINE CONFIGURATIONS**

The move towards more efficient and greener engine types has prompted significant investment in the Open Rotor style of engine. Initially developed in the mid 1980’s, recent advances in technology have made the open rotor concept potentially more viable – using advanced FE modeling techniques the engine’s noise footprint is now more fully understood – hence can be engineered to produce an acceptable product.

Advances in the engine technology that support the open rotor concept necessitated investigation on the techniques of obtaining electrical power for the airframe. Hence the electrical power offtake studies under MOET have focused on the open rotor engine style. Since the open rotor engine is housed in a relatively small nacelle as shown in Figure 4, efficient use of space within the nacelle is important. Consideration of possible locations for the electrical generators is one part of that study and will be described here.
Figure 5 - Open Rotor Schematic

Figure 5 shows the baseline open rotor configuration used for these studies. It comprises a gas turbine core, similar to today’s turbofan engine that drives a free power turbine that in turn drives the open rotor blades. The starter/generator is shown connected to the LP/HP boundary where it connects to the LP shaft via a conventional radial drive shaft to provide start and generation capability. This configuration provides the closest match to today’s turbofan engines and hence a good baseline from which to draw comparison.

Figure 6 - Different Offtake Configurations

Figure 6 shows four configurations that provide alternatives for starting and generating from the open rotor engine.

Configuration (a) is attractive since the power is extracted from the free power shaft of the engine. This provides power offtake from the most efficient engine shaft, and hence should provide the most efficient electrical power source for the engine. However, it is not possible to start the engine by driving the free power shaft and so a second electrical machine is included to provide engine start functionality by driving the LP shaft. Both machines are mechanically connected via radial drive shafts, so this configuration requires the addition of a second radial drive shaft. The addition of either a a second electrical machine or a second radial drive shaft is not attractive from an overall engine concept.

Configuration (b) removes the need for a second radial drive shaft by mounting the starter on the engine shaftline in the nose area of the engine. The starter acts on the LP shaft to provide the start function. Drive for the main generator is still facilitated via a radial drive from the free power shaft. This
configuration provides some benefit over (a) but still required a radial drive shaft.

Configuration (c) combines the start and generation functions into a single electrical machine, hence simplifying the overall installation by removing one electrical machine and its’ associated drive components. However, in this configuration overall efficiency may be compromised since the electrical power is extracted from the LP shaft – the overall efficiency of this shaft is lower than the free power turbine.

Configuration (d) takes the best features of the previous configurations by fitting the electrical machine to the engine shaftline, but including an extension to the free power shaft such that the electrical machine can connect to the LP shaft for starting and to the free power shaft for generating. Installation of this concept is more complex, but overall efficiency should be improved. In this configuration a clutch element would be required to allow switching between the LP and FP shafts as required.

Taking these basic observations into account, more detailed installations for the baseline and configuration (d) have been produced.

Figure 7 - Radial shaft driven starter/generator
The baseline configuration is shown in Figure 7. Here the details of the engine are omitted, but the relative sizes of the electrical machine and the nacelle are correct. This indicates that the baseline configuration is viable within the installation envelope as currently defined. However, in order to make this configuration totally viable, the clutching mechanism necessary to allow connection to both LP and FP shaft needs further development.

Figure 8 - Nose mounted starter/generator
The nose mounted configuration offers benefit by enclosing the generator within the nose structure, hence providing good access for maintenance whilst removing the radial drive shaft. However, it is clear from Figure 8 that the limited space envelope within the nose cone does not allow adequate space in which to install the electrical machine – it currently protrudes into the air flow path around the nose cone. Consequently, this configuration does not appear to offer a viable solution at this time.

It is clear that the methods of free power turbine offtake considered in this study could be made to work effectively. However, the nose cone mounted machine looks impractical due to lack of space. Modification is necessary to optimize any configuration with current estimates indicating that a slight increase in engine length (~25mm) is likely and there is likely to be an increase in structural weight. However this would have to be traded against aerodynamic effects to assess potential benefits.

ELECTRIC ACTUATION FOR ENGINE APPLICATIONS

A key application for electrification around the engine appears to be actuation – various vane and valve mechanisms are fitted around the engine to provide control functions. These are traditionally carried out either by fueldraulic or pneumatic means since both sources of power are readily available in the engine frame.
Moving from turbofan engines to the open rotor configuration provides a different opportunity for electric actuation to be considered – the thrust variation of the open rotor engine is largely controlled by changing the pitch angle of the rotor blades and hence changing the volume of air that they act upon. Unlike the turbofan where thrust variation is largely implemented through changing the engine shaft speed, the shaft speed of the open rotor remains fairly constant under the majority of its operating cycle. Providing actuation for these blades can be done hydraulically as indicated in Figure 9.

However, even in the simplified schematic presented here, it is clear that the mechanism required to actuate the blades is complex. In order to preserve the integrity of hydraulic connections, the actuating elements are located on the static engine structure. The arrangement of the actuator motion through the static to rotary interface is provided via motion transfer bearings, which are shown at three places. It is also clear that the actuation motion must translate through the epicyclic power gearbox to reach the rear rotating hub. Hence complex, and potentially unreliable mechanisms are necessary to fully realise this scheme.

Under the MOET program, Rolls-Royce has undertaken a preliminary study to consider the potential for providing blade pitch actuation via an electrically powered system. The basic blade component layout from the hydraulic baseline has been preserved and electrically powered alternatives considered using a linear ball screw actuator as shown in Figure 10, and a rotary drive using a harmonic drive principle as shown in Figure 11.

A major constraint posed by electric actuation is to find a suitable location for the electric motor and drive elements of the system. Due to the relative novelty of electric actuation in aerospace applications, the failure rates and failure mechanisms of such actuators is still not fully documented. Consequently access to these components for maintenance was considered to be a key requirement and hence they are located in the tail cone region of the engine. Consequently this leads to a complex mechanical installation; the rotating drive from the front hub drive motor is...
required to pass through the epicyclic gearbox, leading to a drive train that incorporates several gear meshes and gear shafts. This presents issues related to system inertia and control system resolution that must be addressed. The compromised system response time and additional weight required to address these issues makes an unattractive system solution.

Further complication is added by locating the motor drive in the rear rotating hub. This leads to control and monitoring signals having to pass from the static engine frame into the rotating frame – again adding complexity to the communication system – and requiring development of wireless or alternative non-contacting signal transfer method. The effects of providing electric actuation of the blade pitch still needs significant development to address cost, weight, system complexity and safety case challenges that exist with the designs as indicated in this paper.

CONCLUSION

It is clear that the effect of the More Electric Aircraft on engine operation is significant. Engine characteristics including cost, weight, installation and operation are all affected. However, the issues that must be addressed to ensure cost effective and safe solutions are well understood – as has been shown with the engines developed for the Boeing 787. Inevitably operational service will uncover issues that were not identified during the engine design phase and will need rectification.

The More Electric Engine provides significant challenges. It is clear from the work completed under the POA program that the technologies for MEE systems are largely viable and available. However, the architecture to support such systems still require further development as does embedded generator technology to facilitate elimination of the accessory gearbox. It is also clear that in considering the application of electric drives to actuation functions, such as the blade pitch mechanism, on the engine that the installation constraints for such components are key, and that the supporting architecture, both system level and mechanical needs significant further development.

ACKNOWLEDGMENTS

The MOET project is a European Project, co-funded by the European Commission within the Sixth Framework Program.

CONTACT

Adam McLoughlin is work package leader for WP2 – Power Providers within the MOET program. e-mail: adam.mcloughlin@rolls-royce.com. Since graduating from Nottingham Trent University in 1991 after gaining a first class MEng/BEng Computer Aided Engineering degree, Adam has always worked in the aerospace industry. Initially working as a Research & Development Engineer for Lucas Aerospace, now Goodrich Actuation Systems, he has worked with electrically powered systems for actuation and now engine related applications. He has held a number of Engineering Management positions within Research and Development and Systems Engineering functions. Adam is currently working as Lead Engineer, Electrical Systems with Rolls-Royce plc, where he is taking a major role in developing the Rolls-Royce position in considering the application of electrical systems to a civil aerospace engine platform.

DEFINITIONS, ACRONYMS, ABBREVIATIONS

- ECS : Environmental Conditioning System
- FE : Finite Element
- FP : Free Power
- FPT : Free Power Turbine
- HP : High Pressure
- IP : Intermediate Pressure
- LP : Low Pressure
- MEA: More Electric Aircraft
- MEE: More Electric Engine
- MOET: More Open Electric Technologies
- POA: Power Optimised Aircraft
- SG: Starter/Generator
- WIPS: Wing Ice Protection System