THE MORE ELECTRIC AERO-ENGINE: A GENERAL OVERVIEW FROM AN ENGINE MANUFACTURER

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SUMMARY

This paper discusses the reasons for industry interest in More Electric Aircraft and More Electric Engines, describes the basic technologies that could be incorporated into a More Electric Engine and compares and contrasts a More Electric Engine with today's style of aircraft engine. Some ideas on how a More Electric Aircraft could be configured to make best use of the capabilities of such an engine are introduced.

INTRODUCTION

Despite explosive growth in telecommunication technologies (such as mobile phones, satellite TV and the Internet), the long-term outlook for world air travel continues to be very positive:-

- Passenger traffic has grown by an average of 5.9% per year between 1988 and 1997, despite a dip in 1991 caused by the Gulf War and subsequent terrorism threats. Rolls-Royce forecasts that it will continue to grow by an average of 5.1% over the period from 1998 to 2017 (1);

- Cargo traffic has grown even faster, by an average of 8.3% per annum between 1988 and 1997. Rolls-Royce forecasts that it will continue to grow by an average of 6.5% over the period from 1998 to 2017 (1).

These growth rates are occurring in a highly competitive environment for all the participants in the industry. The suppliers of the smallest components, the manufacturers of complete engines and airframes, the aircraft operators and the travelling public all expect continuous improvements in capability and services offered and continuous reductions in costs and environmental impact. Such expectations are becoming increasingly difficult to fulfil by incremental changes to existing products, as both fundamental physical barriers and conflicts between requirements begin to emerge. In order to meet expectations, the whole industry is going to have to radically re-think its approach to the whole aircraft system. It is now no longer sufficient to optimise each component and subsystem of an aircraft individually; global optimisation of the entire aircraft is the only way to produce meaningful improvements in the total aircraft package.

The More Electric Aircraft (MEA), and its companion concept the More Electric Engine (MEE) , are seen as ways of optimising the total aircraft package, by:-

- replacing three individually optimised but collectively sub-optimised secondary power systems (electric, hydraulic and pneumatic) with one globally-optimised electrical system. There is widespread agreement that electricity should be chosen as the common power transfer medium, because, unlike the other two power transfer media mentioned, all aircraft systems (from low-power avionics to high power galleys, jacks and actuators) can be configured to use it;

- using emerging electrical machine and power electronic technologies to enable proper integration of propulsion and secondary power into the airframe.

Figure 1 compares current conventional aircraft systems with equivalent More Electric Engine/Aircraft systems; note the elimination of some items of equipment and the simplification of the engine/airframe interfaces.

A study done by NASA (2) demonstrated that use of such technologies could, for a typical 200-seater aircraft, result in a 10% reduction in aircraft empty weight, a 13% reduction in required engine thrust and a 9% reduction in aircraft fuel burn; these are significant improvements, both economically and environmentally.

MORE ELECTRIC ENGINE TECHNOLOGIES

The technologies behind the More Electric Engine can be summarised as follows:-

- High-power, high-efficiency, lightweight motor/generators connected to each of the main shafts of an engine, which would be used to:-
  - provide electric power to the airframe;

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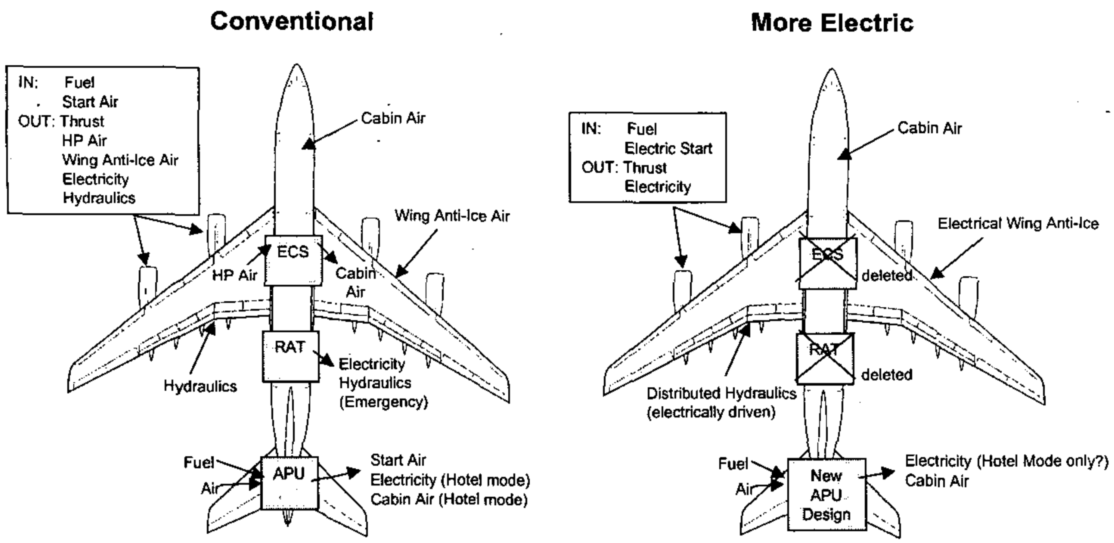

Figure 1: Comparison of Conventional and More Electric Engine/Aircraft Systems

- enable the removal of hydraulic pumps from the engine, thus simplifying the engine/airframe interface;
- enable power extraction from windmilling engines, making the provision of Ram Air Turbine(s) (RATs) for emergency power generation unnecessary;
- transfer power between shafts, thus improving engine starting and relighting and potentially enabling control of engine compressor working points during transient operation without the usual aerodynamic 'crutches' of variable stator vanes and handling bleed valves;
- replace current pneumatic starting with electrical starting, thus further simplifying the engine/airframe interface.

Such motors could either be mounted on the outside of the engine carcass and connected to the main shafts via gearboxes (the 'external' option), or mounted co-axially with the shafts and connected directly to them in the more demanding thermal environment inside the engine (the 'internal' option).

- Active Magnetic Bearings (AMBs), which would replace the current ball- and roller-bearing systems used to locate the shafts with electro-magnetic levitation. Such bearings offer:-

  - the possibility of removing the oil system(s) from the engine, which would dramatically reduce both scheduled and unscheduled maintenance;
  - better control of engine vibration, since the shafts would rotate about their centres of mass rather than their centres of geometry;
  - better engine diagnostics, since changes in the feedback signals in the bearings used to control levitation would provide positive indications about the changes in shaft dynamic performance.

- Electrically-driven compressors and heater/cooler units to pressurise and condition the air in the aircraft cabin, removing the requirement for the engines to provide such air. These units could be powered by electricity generated by the engines, but the need to provide conditioned cabin air when the main propulsion engines are not running would mean that one or more Auxiliary Power Units (APUs) would need to be provided to guarantee power availability to the aircraft under all conditions for cabin air conditioning, pressurisation and other vital services. As indicated in (3) and (4), such an arrangement could provide a much better cabin environment for the passengers and crew than current systems, as well as reducing aircraft fuel burn. It would also enable the elimination of many components, such as bleed ducting, pre-coolers, and current Environmental Control Systems (ECS), needed to cool and depressurise engine offtake air;

- Lightweight, high-power power electronics modules, to control power flows within the engine, between engine and airframe and within the airframe;

- Electrically-driven accessories, such as fuel pumps, fuel flow governors (or combined pump/governor units), oil pumps and breathers (if needed), etc.

THE MORE ELECTRIC ENGINE

Figure 2 shows, in diagrammatic form, a Rolls-Royce Trent engine and its airframe interfaces. It is seen that electric power, hydraulic fluid, high-pressure air, fuel and control signals all cross the engine/airframe interface.

Figure 3 shows the More Electric Engine. The More Electric Engine would differ from the current Trent engine in the following ways:-

- A Fan Shaft Generator would allow the hydraulics to be removed from the engine carcass: electric power from this generator would be used to power an electric motor/hydraulic pump assembly situated in a convenient part of the airframe. Electric power could also be taken from the Fan Shaft Generator if desired for airframe use;

- Oil-lubricated ball and roller bearings would be replaced with Active Magnetic Bearings (AMBs);

- IP and HP motor/generators would be embedded into the core of the engine. These electrical machines would be combined with the AMBs in the cold end of the engine. The HP motor/generator would be used to start the engine electrically. The inter-shaft power transfer system would improve the operability of the engine, enabling a reduction in the number of compressor stages and/or the removal of some or all of the handling bleed valves and/or variable guide vanes; such changes would make the engine lighter and less costly. Power generated from these machines could be exported to the airframe when not required by the engine;

- Engine controls and core-mounted electrically-driven accessories could be removed from the fancase and distributed around the engine core. The Power Transfer and AMB Controllers could be airframe-, pylon- or core-mounted depending upon installation needs. A separate small generator incorporated into the Fan Shaft Generator could provide power to these units;

- The above changes would eliminate the need for the radial drive shaft, internal and external gearboxes, and lubrication systems, leaving fuel as the only fluid on the engine;

- All air offtakes would be removed from the engine. Cabin air would be provided from a Continuously-Running APU or other equivalent electrically-driven ECS system. An alternative electrical nacelle/wing/tail anti-ice system would also be required.

To summarise, the More Electric Engine, incorporating all the technologies discussed in this paper, would eliminate the following systems (the maintenance of which forms a large proportion of the total engine maintenance burden) from the engine:-

- Gearbox(es) and associated drive shaft(s);
- Lubrication system(s);
- Hydraulic system(s);
- Pneumatic engine starting system;
- Bleed air offtake system(s).

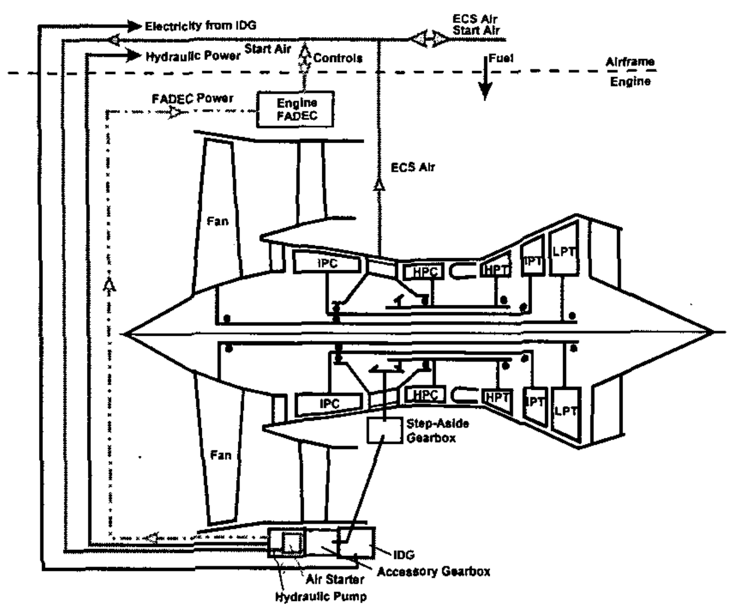

Figure 2: Current Trent Engine, showing Engine/Airframe Interfaces

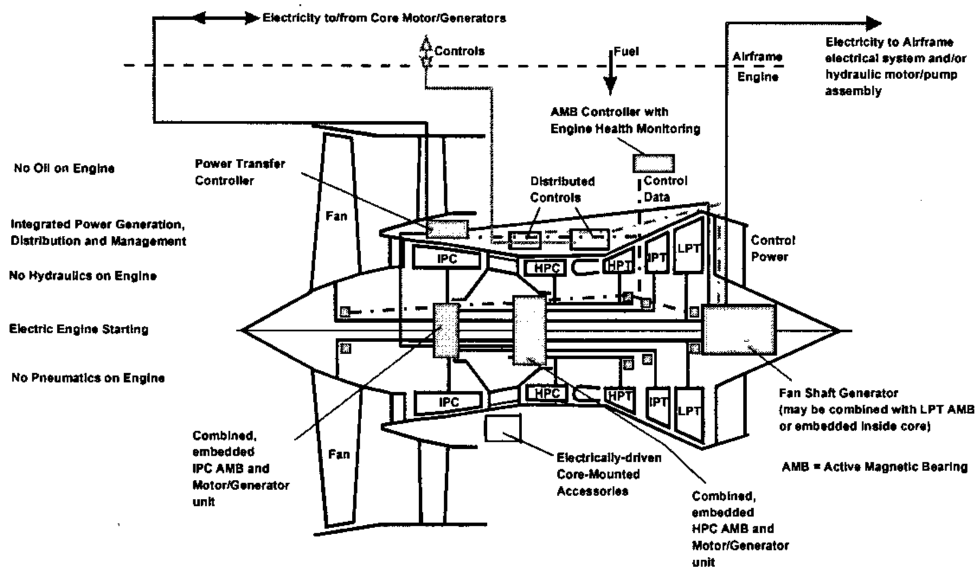

Figure 3: More Electric Engine, showing Engine/Airframe Interfaces

The interface between the engine and aircraft would obviously be considerably simplified, having been reduced to electric power, fuel and control signals only. These changes (and their associated 'knock-on' effects, such as a simplified nacelle structure that does not need fan cowl doors because access to the fan cowl is no longer required, as well as a simplified pylon structure) would result in lighter, less costly, cheaper to operate and more effective powerplants for the aircraft.

It should be pointed out that, because there are many possible combinations of the More Electric Engine technologies, it would be possible to 'mix and match' them in order to produce an incremental family of engines to meet market needs as the technologies develop, without having to wait for all the technologies to be available before producing products.

THE MORE ELECTRIC AIRCRAFT

As indicated earlier in the paper, the More Electric Aircraft would replace three individually optimised but collectively sub-optimised secondary power systems (electric, hydraulic and pneumatic) with one globally-optimised electrical system. The More Electric Engine would clearly be ideally suited to such an aircraft, because of its ability to supply electric power to (and receive electric power from) such an all-electric system. However, in order to fully optimise the whole aircraft, the electrical system architecture would need to be chosen carefully.

Most current civil aircraft electric power systems use a combination of 115V 400Hz AC for large loads and 28V DC for avionics and battery-driven vital services. Variable frequency AC systems are now being considered by the industry, in order to replace the Integrated Drive Generators (IDGs) on current engines (which need complex hydraulic systems to generate constant frequency AC voltages from variable speed engine shaft power inputs) with simpler, lighter generators. Given that the More Electric Engine would generate electricity at a range of frequencies (because the various engine shafts to which the motor/generators are connected will all rotate at different speeds), it would make sense to use power electronics to convert all the motor/generator outputs to a single high-voltage DC output (the voltage level of which would be possibly determined by the capabilities of DC switchgear) for export to and transmission around the airframe. The rationale for such a choice can be summarised as follows:-

- In order to reduce weight, power should be transmitted at high voltage (resulting in low current);
- Higher voltages also reduce the power losses in the transmission of the electric power because, for a given cable, the losses are proportional to the square of the current;
- Using the same voltages for generation and transmission would avoid the need for one set of voltage converters;
- AC systems require larger cables than DC systems, because of reactive power flows and, at high frequencies, skin effect;

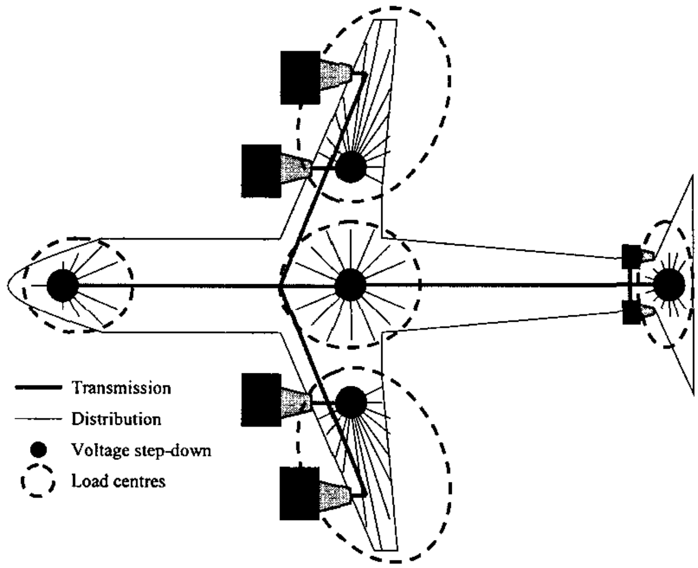

Figure 4: Conceptual Electrical System Layout for a More Electric Aircraft

- Historically, AC systems were preferred because changes in voltage level could be achieved through transformers. Today, power electronics can now be used to make these changes in voltage level irrespective of frequency;

- Safety levels can be maintained or improved relative to current systems by using earth fault detection to trip any faulted conductor.

More Electric Aircraft Electrical Layout

Figure 4 shows a conceptual electrical system layout for a four-engine, two-APU More Electric Aircraft:-

The use of a high-voltage DC transmission system would mean that voltage step-down equipment is required between the transmission system and the loads. The system proposed here splits the loads into a number of regions, called load centres, and transmits power between the load centres via the high-voltage DC 'skeleton'. Power would be distributed from the voltage step-down equipment within the load centres to each of the actual loads. The voltage required at the distribution system would be determined by the load requirements; inverters could be used as the voltage step-down devices to provide AC power at the various voltage levels and frequencies acceptable to equipment presently fitted to the aircraft by the airframe manufacturer and end user.

CONCLUSIONS

- Incremental changes to current engines and airframes will not produce the improvements in aircraft cost and capability that the market demands.

- The More Electric Engine, incorporating new advances in motor/generators, active magnetic bearings, power electronics and other electrical technologies, promises to be lighter, more efficient, more reliable and less costly than current designs; it can also be more easily integrated into airframe systems.

- The More Electric Aircraft offers similar benefits, by replacing three individually optimised but collectively sub-optimised secondary power systems (electric, hydraulic and pneumatic) with one globally-optimised electrical system, more easily integrated with the More Electric Engine.

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