THE OPEN ROTOR SPECIAL ISSUE – AN INTRODUCTION

Progress towards open rotor propulsion technology

It is 40 years since the 1970s oil crisis which prompted the first major look at a drastically different civil aero-engine propulsion concept to the conventional and highly successful turbofan configuration. Work by NASA, Hamilton Standard, Allison and GE led to flight tests of two different 'pusher' (blades aft of engine) contra-rotating propeller engines in the 1980s. The Pratt & Whitney/Allison/NASA 578-DX was a geared concept, with two stages of propeller blades driven through a reduction gearbox. The General Electric GE36 'UnDucted Fan' (UDF), or PropFan, was a direct drive concept, with contra-rotating rotor blades, again aft of the engine, directly driven by different turbines. In the UK, similar studies were being undertaken by Rolls-Royce, Dowty Rotol, British Aerospace, and the Aircraft Research Association, although these studies were restricted to model-scale rigs in a high-speed wind tunnel. Reductions in the oil price along with concerns over higher noise emissions from these unshielded rotors meant that, in the end, industry preferred to concentrate on improving turbofan fuel efficiency, leading to the ultra-high-bypass designs recently proposed. Nevertheless, continued growth in air traffic, the attraction of lower SFC (reductions of 20-30% are often quoted), and environmental pressures associated with the search for greener, sustainable aviation, has meant that in the last few years propeller, or 'Open Rotor', concepts have been revisited, with renewed interest in applying the technology advances of the last three decades to explore improvements in Open Rotor performance/noise emissions characteristics.

In 2012 a one-day conference was held at the Royal Aeronautical Society (for the Combined Propulsion Technical Activity Committee of RAeS and IMechE – organised by Professor Jim McGuirk (Loughborough University) and Dr Simon Weeks (Rolls-Royce)) to review progress. Presentations were made by Airbus and Rolls-Royce, Universities and Research Establishments active in Open Rotor research, and from NASA summarising US work. The objectives of the conference were to indicate the advantages of Open Rotors, highlight the technical challenges from both an aircraft and an engine perspective, and present evidence of progress in areas such as aerodynamics, noise, and systems integration.

Five of the 2012 RAeS Open Rotor conference presentations were expanded into written papers and have been combined to form this Special Issue of *The Aeronautical Journal*. The first from Cambridge University outlines an approach to design of the contra-rotating fan blades of an Open Rotor to optimise aerodynamics at both take-off and cruise. The strategy to use blade re-pitch and speed-up at take-off to maximise efficiency and minimise noise sources is illustrated using 3D CFD. A preliminary design methodology based on a combination of 2D CFD and a Blade Element method is also demonstrated. The second paper by Southampton University describes the current status of Open Rotor prediction methods for both tonal and broadband noise, as well as their validation using acoustic data from high-speed wind-tunnel testing of a model-scale advanced Open Rotor rig. The importance of considering the extra noise sources associated with installation effects (e.g. pylon wake/rotor interaction noise) is also underlined. These two papers were intentionally focussed on aerodynamics and noise in isolation; they are followed by two

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papers from DLR(Braunschweig) and DLR(Berlin)/DLR(Cologne), which combine CFD and CAA (Computational Aero-Acoustics) to study coupled aerodynamics and acoustics performance. Both papers consider a 'pusher' configuration; this has advantages for cabin noise, certification issues for blade loss, and avoids potentially large installation drag increases compared with the 'puller' configuration (blades at front). The DLR(Braunschweig) paper discusses aerodynamic and acoustic effects caused by the engine-pylon wake interacting with the rotors, as well as important installation issues due to the same sense of rotation of the front rotor inevitably introducing asymmetric effects (port/starboard engines experiencing down-behind-pylon and up-behind-pylon angle of attack differences); this is shown to play a significant role in both aerodynamic and acoustic performance. The 2nd DLR paper also adopts a combined CFD/CAA approach, validated against wind-tunnel data and then used as part of a multi-disciplinary multi-objective optimisation loop, allowing for many variable parameters (aft rotor crop, hub contour changes, variable pitch etc.). The final paper presents joint work by NASA/FAA/GE involving model-scale testing of advanced Open Rotor concepts. The results demonstrate that contemporary CFD/CAA design methods can produce blade designs that maintain efficiency with acceptable acoustic signatures. NASA and GE independent system studies are described that indicate the best configuration was predicted to achieve 26% better fuel burn (relative to a baseline CFM56-7B) and 15-17EPNdB cumulative noise margin (relative to CAEP Chapter 4).

The overall impression gained from these papers is of considerable progress made towards Open Rotor propulsion, with significant improvements over the 1980s standard. Many of these improvements, particularly lower noise, can be attributed to the availability and application of new computer modelling tools, accompanied by extensive low and high speed rig tests (of both isolated and installed Open Rotors), incorporating advanced test and measurement techniques. Of course there is much work still to be done (even the choice of pusher or puller configuration is still open), including important certification issues. This will require close collaboration between airframer and engine manufacturer, since, for Open Rotor propulsion, these papers have clearly demonstrated that the link between engine design and new aircraft configuration is extremely strong.

Professor J. J. McGuirk
Department of Aeronautical and Automotive Engineering
Loughborough University, UK

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