(1) CONTRA-ROTATING OPEN ROTOR INTEGRATION OVERVIEW
In the context of increasing economic and environmental pressure, there is a renewed interest in the CROR (Contra-Rotating Open Rotor) propulsion system as the most fuel efficient and low CO2 emission commercial aircraft propulsion system. Airbus is actively building a technical dossier on such propulsion systems for future application. Key problematics resulting from CROR integration are investigated to reduce uncertainties and develop enabling technologies on those specific fields. After presenting what are the key problematics for CROR integration on an Aircraft, the author will detail for each of them some illustrations of recent activities. An overall picture of the feasibility dossier will be given as well as maturation plan envisaged.

(2) CHALLENGES OF OPEN ROTOR PROPULSION FROM AN ENGINE PERSPECTIVE
The Open Rotor engine concept offers to provide a step change for future powerplant solutions. The isolated engine SFC improvement presents the potential for reduced fuel burn future applications. Whilst offering great potential, the Open Rotor engine architecture and installation required to deliver these improvements presents the whole engine designer with a number of engineering challenges and highlights the task of moving from concept to product. This presentation will discuss and provide an overview of these engineering challenges, at both engine and integrated power plant level, which have to be addressed in order to deliver a robust engine solution.

(3) PERFORMANCE AND MULTI-DISCIPLINARY DESIGN OF CONTRA-ROTATING OPEN ROTORS
The prediction capabilities developed at the DLR’s Institute of Propulsion Technology in order to assess and improve the performance of open rotor propulsion systems are reviewed. One of the objectives is to combine engine cycle, aerodynamics and acoustics calculations into an optimisation framework in order to improve performance. The following results will be presented. 1) The benefit of CROR in terms of fuel burn saving, with respect to some other engine concepts. 2) An example of blade shape optimisation using steady-state RANS calculations and a basic acoustic cost function, in order to mitigate interaction tones. 3) An attempt to reduce interaction tones by means of trailing-edge serrations on the front rotor. 4) The prediction of open rotor noise with a RANS informed analytical method. 5) The problematics of properly extrapolating URANS data to the acoustic far field. Note that most of the points relate to the acoustic performance.

(4) HOW TO IMPROVE OPEN ROTOR AERODYNAMICS AT BOTH CRUISE AND TAKEOFF
A key challenge in open rotor design is getting the optimum aerodynamics at both the cruise and takeoff conditions. This is a particularly tough challenge because the operation and the requirements of an open rotor are very different at cruise compared to takeoff. This presentation reviews the main features of the open rotor flow-field at these conditions. It then explores the impact of various design changes on the cruise and takeoff flow-fields. The presentation also considers how a given open rotor design is best operated at takeoff to minimise noise whilst maintaining high thrust.

(5) THEORETICAL PREDICTION OF OPEN ROTOR NOISE
This presentation will describe the work which has and is currently being undertaken at the ISVR on the prediction of open rotor noise. Topics which will be covered are tone noise prediction, scattering/shielding of open rotor noise, centrebody scattering, broadband noise prediction and installation effects (pylon + angle of attack).

(6) A QUIET OPEN ROTOR
The presentation discusses Rolls-Royce’s efforts to predict open rotor acoustics/aerodynamics and the resultant open rotor designs. It starts with the first test of a contra-rotating device in 1989 and shows how subsequent designs have evolved. For each test, Rolls-Royce has improved its
understanding of open rotor aerodynamics/acoustics, and the prediction/design methods, and applied those methods to subsequent designs. The benefits of those design iterations have been demonstrated through low speed rig tests in 2008 and 2010 and through high speed rig tests in 2009 and 2011. The presentation will show how those programmes have led to significant reductions in open rotor noise compared to the designs of the 1980s. The presentation will also discuss the remaining challenges that lie ahead.

(7) ERA’S OPEN ROTOR STUDIES INCLUDING SHIELDING FOR NOISE REDUCTION

The Open Rotor is a modern version of the UnDucted Fan (UDF) that was flight tested in the late 1980’s through a partnership between NASA and General Electric (GE). Tests were conducted in the 9’x15’ Low Speed Wind Tunnel and the 8’x6’ Supersonic Wind Tunnel starting in late 2009 and completed in early 2012. Aerodynamic and acoustic data were obtained for takeoff, approach and cruise simulations. GE was the primary partner, but other organisations were involved such as Boeing and Airbus who provided additional hardware for fuselage simulations. This test campaign provided the acoustic and performance characteristics for modern open rotor blades designs.

NASA and GE conducted joint systems analysis to evaluate how well new blade designs would perform on a B737 class aircraft, and compared the results to an advanced higher bypass ratio turbofan.

Acoustic shielding experiments were performed at NASA GRC and Boeing LSAF facilities to provide data for noise estimates of unconventional aircraft configurations with Open Rotor propulsion systems.

(8) PROGRESS IN AERODYNAMICS AND AEROACOUSTIC INTEGRATION OF CROR PROPULSION CONCEPTS

Contra Rotating Open Rotor (CROR) propulsion systems have seen renewed interest as a possible economic and environmentally friendly power plant for future transport aircraft. Installation effects, i.e. the mutual interactions between airframe components and the rotors, have a pronounced impact on the aerodynamic and aeroacoustic performance for this type of engine.

In this presentation, a focus will be placed on highlighting some important aspects of the engine-airframe integration and their impact on the aerodynamic performance and the noise emissions of the CROR propulsion system. In particular, the mutual interaction between the rotors and the pylon for a pusher-configuration installation of the engine as well as the importance of the sense of rotation will be addressed. Both aspects have a notable influence on blade loadings, rotor performance and the CROR noise emissions as well as on the handling quality relevant in-plane rotor forces. The feasibility and efficacy of some novel technology applications aimed at ameliorating the adverse impact of installation effects on the open rotors’ performance will be discussed as will some aspects of the numerical simulation approaches to enable reliable predictions to guide design and analysis of installed CROR propulsion systems.