LAc-LoRR OTS

Low speed AeroaCoustic test of a Large Open Rotor Rig in an Open Test Section

State of the art – Background

Since 1980s with the GE36 flying test bed, significant efforts have been done until the 90s on Contra Rotating Open Rotor (CROR) development due to rising oil price. Key issues at this time were noise, vibration and structural integration.
At Clean Sky start, CROR has been considered as the best disruptive powerplant candidate thanks to its best propulsive efficiency but with a relatively low maturity level.
Risks and opportunities had to be understood before implementation onto Aircraft and first aero-acoustic, safety and certificability studies as well as physical integration trade-offs within SFWA-ITD

The CROR gate held in July 2013 concluded that Airbus is confident a CROR pusher aircraft (A/C) is feasible, including for noise certification, but its economic viability needs to be improved to become a serious alternative to conventional turbofan A/C. As a result, an "economic viability phase" ending mid-2017 was introduced to the long term CROR strategy, with potential large changes on A/C and engine definitions, including blade design. Several "techno bricks" aiming at reducing the A/C Cash Operating Cost (COC) were launched for example the alternative design of a Rear-puller A/C configuration.

In the framework of engine architecture optimization towards light weight, Safran proposed the Unducted Single Fan (USF) concept in puller configuration: it is like a CROR puller with stopped rear rotor acting as Outlet Guide Vanes (OGV) of a turbofan, i.e. as a stator. Its block fuel and COC potential was judged more attractive compared to CROR pending blade installed performance assessment and noise de-risk.

LAc-LoRR OTS & LAAME-CROW two projects combined in a complementary approach

The test program LAc-LoRR OTS was realized in combination with its partner project LAAME-CROW. Both projects were making use of the same 1:7 scale, open rotor driven single aisle large passenger aircraft model, the so-called Z08 model, which was provided by the Topic Manager (Airbus). The Z08 model is basically the same as used in the CleanSky project L-CROR-CTS (JTI-CS-2012-01-SFWA-02-028) at DNW-LLF in 2012.

Low-speed aerodynamic and aeroacoustic tests were carried out in the 8 m x 6 m open test section (OTS) of the DNW-LLF low-speed wind tunnel in the Netherlands. The Z08 model was equipped with two powered (compressed air) engine simulators, provided by the Topic Manager, to simulate and investigate the aerodynamic and aeroacoustic effects of an installed USF propulsion system. The Z08 model was mounted on a dorsal sting, located at tunnel centre line. Both tests were conducted at DNW-LLF in September/October 2016. The total test duration for both tests was 20 testing days, with 10 days for the LAc-LoRR OTS test program and the other 10 testing days for LAAME-CROW, which also included 5 days for commissioning of the Z08 model and the new USF engines.

Within the activities for the LAc-LoRR OTS test at DNW-LLF the Z08 model assembly and the overall preparations of the test setup were coordinated and realized by DNW. This included also the breakdown of the test setup in the open test section and dissembles of the Z08 model after the test.

The main objective of the LAc-LoRR OTS test was the investigation of the aerodynamic behaviour and performance of the new USF propulsion system, when installed onto a full aircraft model with realistic high-lift wing configurations. These aerodynamic and performance data were also used by the LAAME-CROW test to select the most promising conditions for the propeller and wind tunnel settings for the optimum application of the advanced measurements techniques used in the LAAME-CROW program.

In the complementary direction online results from the PIV measurements in the USF propeller inflow area, as realized in the LAAME-CROW program, were used for the LAc-LoRR OTS program to optimize the selection of model components and their placement to optimize the aerodynamic performance of the USF propulsion system.

Inflow near-field and semi near-field data and out-of-flow far-field acoustic data were measured within the LAc-LoRR OTS test program. The acoustic out-of-flow data were also used to verify

the acoustic results from the enhanced phased microphone array technique, which was applied within the LAAME-CROW test program.

Objectives

LAc-LoRR OTS specific objectives and activities

One main objective of the LAc-LoRR OTS program was generating high quality aerodynamic performance data of the installed USF propulsion system. The other was generating of high quality aeroacoustic data, measured in the near-field, semi near-field and far-field of the USF engine and the Z08 airframe.

The aerodynamic performance data of the Z08 aircraft model was measured by means of DNW's high quality six components internal main balance and DNW's multi-channel steady pressure measurement system (about 400 pressures were measured by this system for this test).

The performance of the USF propeller was measured by a six components rotating shaft balance (RSB) system, provided and operated by the Topic Manager. Dynamic and steady data from the highly instrumented USF rotor blades were continuously observed, measured and processed by data acquisition systems provided by the Topic Manager.

Near-field acoustic data were measured by a large amount of 'Kulite-type' pressure sensors, which were installed into the surface of the USF rotor blades and by microphones, which were installed into the surface of the fuselage of the Z08 model. Semi near-field acoustic data were measured by means of a traversable inflow wing, which was instrumented with 48 inflow microphones and were provided by the Topic Manager. The near-field and semi near-field signals were measured and processed by the Topic Manager and were only used by the LAc-LoRR OTS test program.

Out-of-flow far-field acoustic data were measured by means of four axial microphone lines, which were installed outside of the open jet flow on the floor of the of the open test section. Each line was instrumented with 13 microphones. Two lines were installed on the star-board side and two lines were installed at the port-side of the Z08 model. With these four lines the polar and lateral acoustic directivity of the starboard or port-side installed USF propulsion system could be investigated including the assessment of shielding effects of the Z08 fuselage. Also the far-field noise caused by the Z08 airframe was investigated by these four microphone lines. Furthermore the out-of-flow data were used to verify the results from the phased microphone array, which was applied in the LAAME-CROW project.

Description of work

Based on all relevant model information and the proposed test matrices as delivered by Topic Manager, a wind tunnel test campaign description was written.

All model parts and related systems from the partners were delivered to DNW in Q3 of 2016. The Z08 aircraft model inclusive the powered USF engine simulators was built up in one of the DNW model preparation halls where all necessary pre-checks were performed within a period of several weeks (see Figure 1).

The assembled Z08 model was mounted onto the model support (sting) in the open test section of the wind tunnel (see Figure 2). The open test section was prepared for the acoustic configuration. For this purpose four lines with microphones were installed onto the floor of the test section, the traverse mechanism for the inflow microphones and the phased microphone array was placed below the Z08 model and the floor of the test section was covered with acoustic lining material (see Figures 3 and 4).

After successful completion of the commissioning phase, which was covered by the LAAME-CROW project for a period of total 5 test days, the LAc-LoRR OTS test program for the aerodynamic performance and aeroacoustic investigations of the installed USF engine were performed for a total duration of 10 testing days. During the first part of the LAc-LoRR OTS test program a single USF engine was installed at the starboard side of the Z08 fuselage. High-lift configurations of the aircraft wing for approach and take-off were investigated in combination with and without the powered USF. During the second part of the LAc-LoRR OTS test program a single USF engine was installed and operated at the port side of the Z08 fuselage.

The test program (test matrix) was followed as agreed with the Topic Manager. Changes in this test matrix were mutually agreed upon and accordingly documented. During the test preliminary on-line data were provided and simultaneously all raw data were stored on local data acquisition storage disks. At the end of the test a complete set of preliminary data was provided to the Topic Manager.

At the end of the LAc-LoRR OTS test the Z08 model was unmounted from the test section and dissembled in a model preparation hall (see Figure 5). Finally the model was prepared for shipping back to the Topic Manager.

After the test the aerodynamic and acoustic data were corrected for several typical wind tunnel testing related phenomena in close consultation with the Topic Manager. The final deliverables consisted of corrected final data and final test reports of the various stages of the project.

Results

Technological results

For the successful execution of the test with the current wind tunnel model two high performance air powered engines were developed to drive the new developed high performance USF propellers. The USF propellers were highly instrumented and provided detailed performance data.

A new designed system of four acoustic observer lines was successfully applied for the first time at DNW.

Scientific results

Generation of data about the aerodynamic and aero-acoustic characteristics of a newly developed USF rotor and stator blade design in combination with installation effects onto a full aircraft model inclusive high-lift wing configurations. Acoustic measurements and propulsion simulations were successfully combined.

Extensive databases of aerodynamic and performance data of the USF system were measured in combination of the complex flow field caused by a full aircraft model in high-lift wing configuration. These data are highly representative for a realistic full scale propeller installed on an aircraft. The aerodynamic and performance data are of high value for validation of CFD model simulations for reliable prediction of new enhanced USF propeller systems.

Extensive databases of acoustic inflow near-field and out-of-flow far-field microphone data were generated for the assessment of the feasibility of the USF propeller technology for an energy efficient engine system with acceptable noise impact to the environment.

Impact

The test has been a substantial (and critical) intermediate step in the development of a new European of future large passenger aircraft and the design rules of USF engines installed as puller configuration at the aircraft fuselage behind the wing section. In that respect the test cleared grounds for the preparation of a first flight of a test aircraft.

In particular, the test aims to:

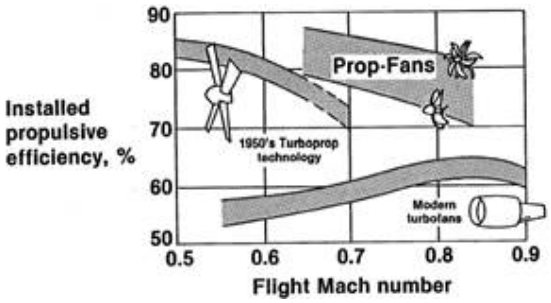
- de-risk noise certification for rear puller USF
- understand noise mechanisms and installation effects associated to rear puller USF A/C configuration

a) Timeline & main milestones

MS1 week 30 2016 receipt of model at the wind tunnel for setup activities (see Figure 1).
MS2 week 36 2016 model ready for transport to test section (see Figure 2).
MS3 week 36 2016 model and acoustic test set-up ready for testing (see Figures 3a, 3b and 4).
MS4 week 40 2016 model removal from test section after finalizing of test program (see Figure 5).

b) Environmental benefits

The Topic Manager (Airbus) is now in a position to assess the efficiency of this new engine concept based on the USF operating conditions investigation and the environmental noise impact in particular the compliance to noise certification.
The CROR has the potential for a uniquely large reduction in the specific fuel burn compared to classical turbofan (see scheme below)



According to the Topic Manager, the USF option of the CROR family is currently more attractive in terms of -aircraft block fuel and COC reduction potential than the conventional CROR studied so far in SFWA, pending installed USF noise de-risking and performance confirmation. These tests enable to know the low speed noise and performance of an USF powered aircraft and to investigate finely the noise generation mechanisms. They contribute significantly to assess the feasibility of a USF powered aircraft, which represents a potential of significant fuel consumption and pollution reduction compared to turbofan engines.

c) Dissemination / exploitation of results

Type: Organization of Workshops
Main leader: STICHTING DUITS-NEDERLANDSE WINDTUNNELS
Date: 03/10/2016
Place: DNW-LLF, The Netherlands

Countries addressed: Europe
Title: Z08 Project information meeting and workshop at DNW - LAc-LoRR & LAAME-CROW at DNW-LLF USF – first results for performance, acoustic & PIV

The test results will be analysed by Airbus and Safran and constitute a crucial input to the orientation of future Open Rotor studies and to the strategy concerning Open Rotor powered aircrafts. The results will be disseminated in the frame of Clean Sky 2 if conclusive.

Pictures reference:

Figures 1 to 5 are made by DNW for the LAc-LoRR OTS test at DNW-LLF in 2016.

Figure 1: MS1 - Z08 model setup in DNW-LLF preparation hall

Figure 2: MS2 - Z08 model installation in DNW-LLF open test section

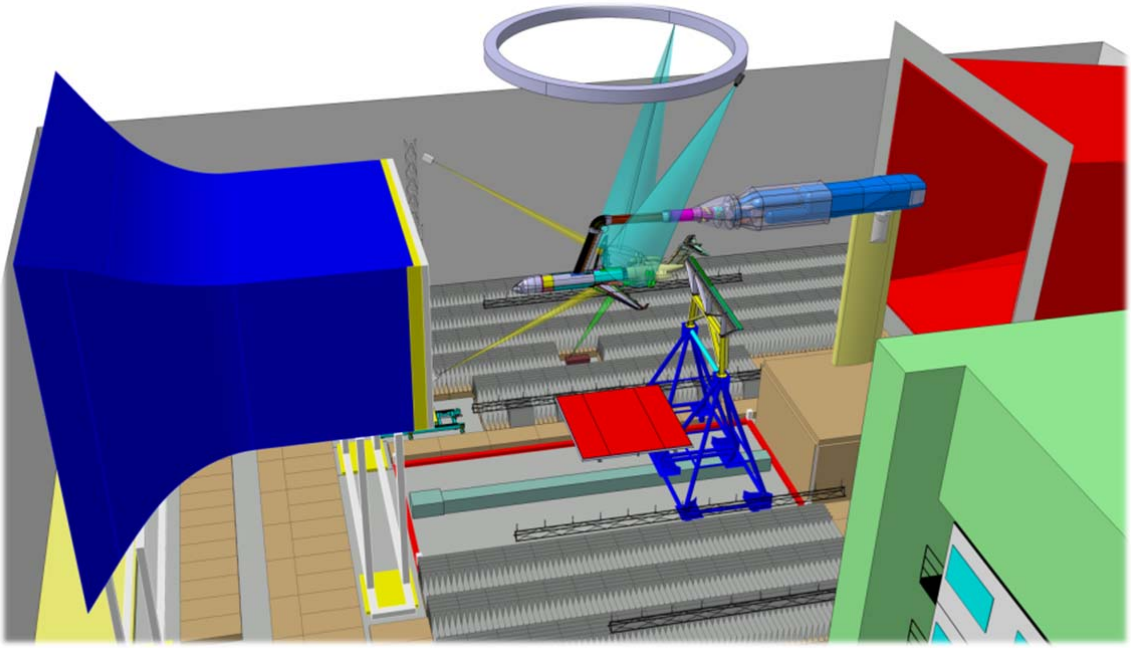


Figure 3a: MS3 - CAD design of test setup with inflow microphone wing, phased microphone array and out-of-flow side-line microphones on the floor

Figure 3b: MS3 - Z08 model in DNW-LLF open test section during aerodynamic and acoustic test

Figure 4: MS3 - Details of two starboard floor side line microphone lines and PIV laser unit setup

Figure 5: MS4 - Z08 model removal from test setup back to model hall for break down after the test

Project Summary

Acronym:	LAc-LoRR OTS
Name of proposal:	Low speed aeroacoustic test of an open rotor powered complete model
Involved ITD	Smart Fixed Wing Aircraft ITD
Grant Agreement:	326005
Instrument:	Clean Sky Joint Undertaking
Total Cost:	1,347,631.16 Euro
Clean Sky contribution:	974,250.00 Euro
Call:	SP1-JTI-CS-2012-02
Starting date:	1 August 2015
Ending date:	30 October 2016
Duration:	15 months
Coordinator contact details:	Oliver Fries STICHTING DUITS-NEDERLANDSE WINDTUNNELS Voorsterweg 31 8316 PR Marknesse The Netherlands Phone +31 527 248561 oliver.fries@dnw.aero
Project Officer:	Sebastien DUBOIS (CSJU) sebastien.dubois@cleansky.eu
Participating members:	STICHTING DUITS-NEDERLANDSE WINDTUNNELS

Clean Sky