LAAME-CROW

Low speed Aeroacoustic Advanced MEasurement for CROR Wind tunnel test

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 LAAME-CROW was realized in combination with its partner project LAc-LoRR OTS. 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 data and performance data were also used by the LAAME-CROW test to select the most interesting 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 program to optimize the selection of model components and their placement to optimize the aerodynamic performance of the USF propulsion system.

Near field acoustic data were measured by means of a traversable inflow wing, which was instrumented with 48 inflow microphones. These microphone signals were measured and processed by the Topic Manager and only used by the LAc-LoRR OTS test.

Within the LAc-LoRR-OTS program DNW's far-field acoustic system was applied to measure on four axial lines of the test section floor, with 13 microphones per line, the far-field noise field outside of the open jet flow. Two lines were installed on the star-board side and two lines were installed at the port-side of the Z08 model. By means of 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 model was investigated by these microphone lines. The data from the LAc-LoRR program were also used by the LAAME-CROW program to verify the results measured with the phased microphone array system.

Objectives

LAAME-CROW specific objectives and activities

The first main objective of the LAAME-CROW program was generating high quality aerodynamic data in the inflow area of the USF propeller and high quality aeroacoustic noise location data of the Z08 model and the USF propeller. The flow field data should be measured by means of DNW's three components Particle Image Velocimetry (PIV) system. And the noise source localization data should be measured by DNW's large aperture phased microphone array system.

Another important objective of the LAAME-CROW program was the realization of a dedicated commissioning program for the new engine and propeller hardware, which should be applied in the LAc-LoRR-OTS test for the first time.
Furthermore the parameters for the optimum application of the PIV measurement system and the phased microphone array system should be identified during this commissioning program.
The importance of this commissioning part is shown in the fact, that the Topic Manager had reserved about half of the total duration for LAAME-CROW the test time for the commissioning. This was about 5 days of the total 10 testing days.

Description of work

The first main activity was the preparation of test specific hardware and software necessary for two requested advanced measurement techniques. DNW's three components PIV system was applied for flow field measurements in the USF propeller inflow area. And DNW's phased microphone array system was applied for localization of airframe noise sources at the Z08 aircraft model and at the USF propeller engine. This work package included the design of an optimized test setup (see Figure 1), based on feasibility evaluation test setups, calibration of all systems and the realization of the final test setup.

The second main activity was the realization of a dedicated commissioning and optimization program of the realized test setup (see Figure 2). This work package was requested by the Topic Manager due to the application of his new developed hardware for the two air engines and USF propellers, which hasn't been tested at such conditions in a wind tunnel before.

The third main activity was the execution and data processing of the PIV aerodynamic measurements and the phased microphone array acoustic measurements. This work included also the documentation of the test and reporting of the data processing.

Results

Technological results

By means of PIV and phased microphone array techniques combined complex aerodynamic and aero-acoustic measurements in a large low speed environment performed on an open rotor (USF) powered large passenger aircraft model were successfully realized.
High resolution 3 components PIV measurements were realized in the inflow of the propeller engine, which was installed on an aircraft model downstream of a high-lift configuration wing (typical result shown in Figure 6).

A high resolution phased microphone array with a large aperture of 4m was applied for detailed noise source localization of airframe noise and propeller related noise sources (see Figures 7a to 7c). By applying of state of the art deconvolution processing a superior signal to noise ratio could be realized, which surpasses the dynamic range of classical beamforming processing by more than 20 dB. By means of a traversing system also the directivity of these noise sources could be investigated.

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.

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

Extensive databases of aerodynamic flow-field PIV data at the USF propeller and acoustic microphone array data for the assessment of the feasibility of the USF propeller technology for an energy efficient engine system with acceptable noise impact to the environment.

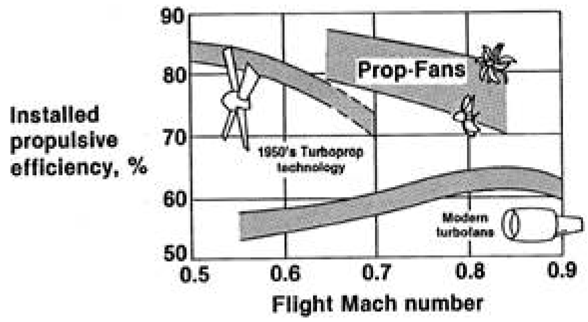
Impact
The test has been a substantial (and critical) intermediate step in the development of a new European future large passenger aircraft and the design rules of USF engines installed as puller configuration at the aircraft fuselage behind the wing section. In that respect the test cleared grounds towards the preparation of a flight 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 35 2016, 'Z08 model to wind tunnel preparation ready and advanced measurement techniques ready for testing', (see test setup in Figure 1).
MS2 week 36 2016, 'Z08 model and test setup commissioning ready', (see Figures 2 and 3).
MS3 week 36 2016, preliminary data delivery
MS4 week 47 2016, 'Final data delivery', (examples shown in Figures 6 to 8).

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 7 are made by DNW for the LAc-LoRR OTS and LAAME-CROW tests at DNW-LLF in 2016.

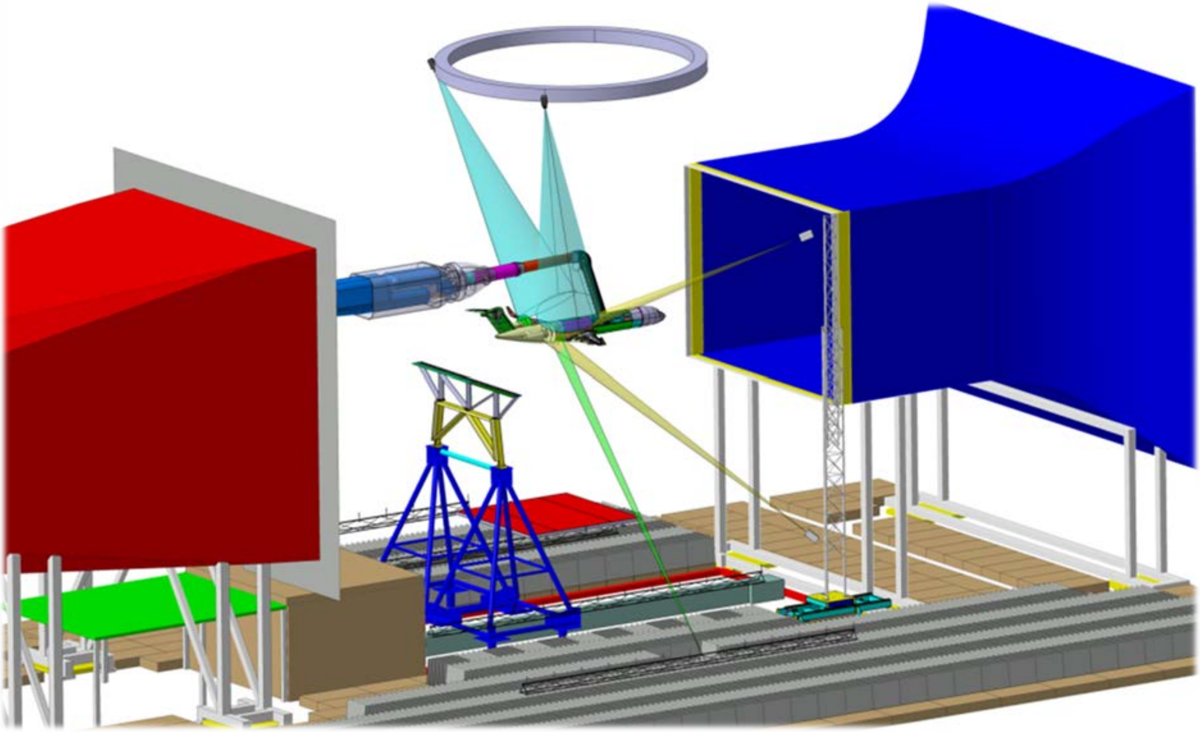
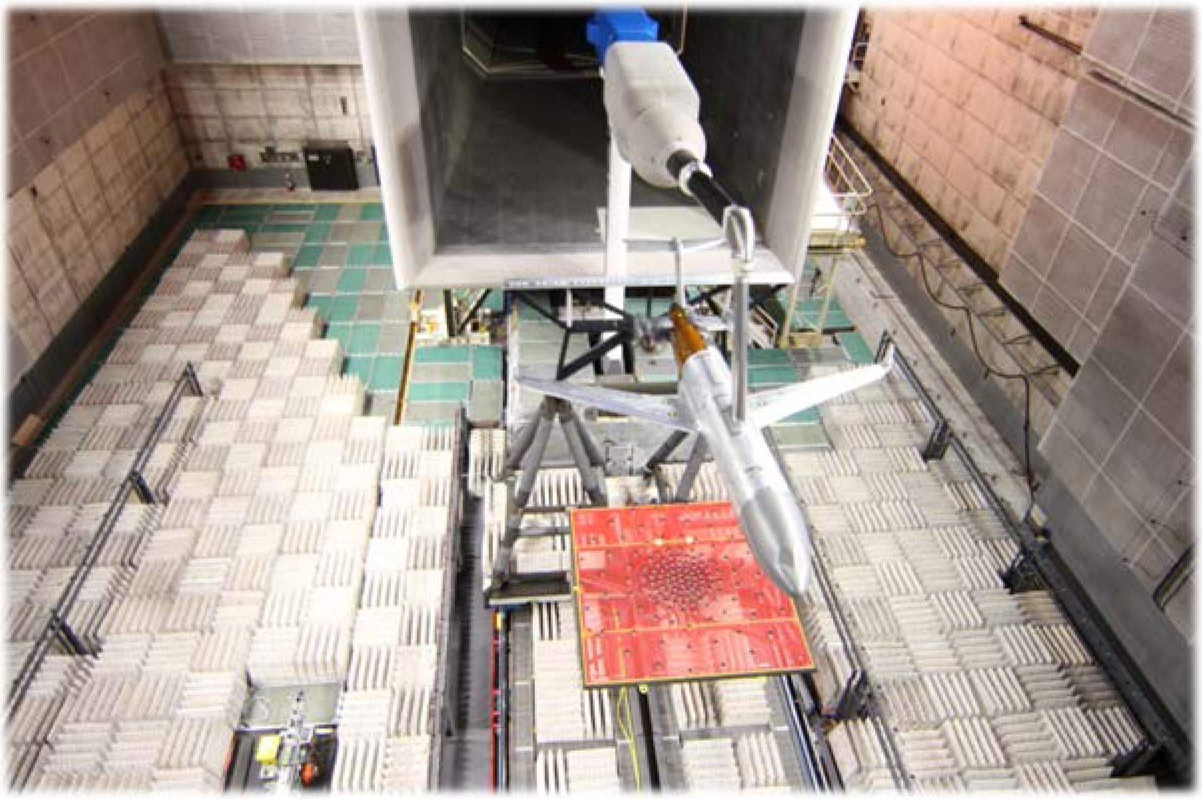


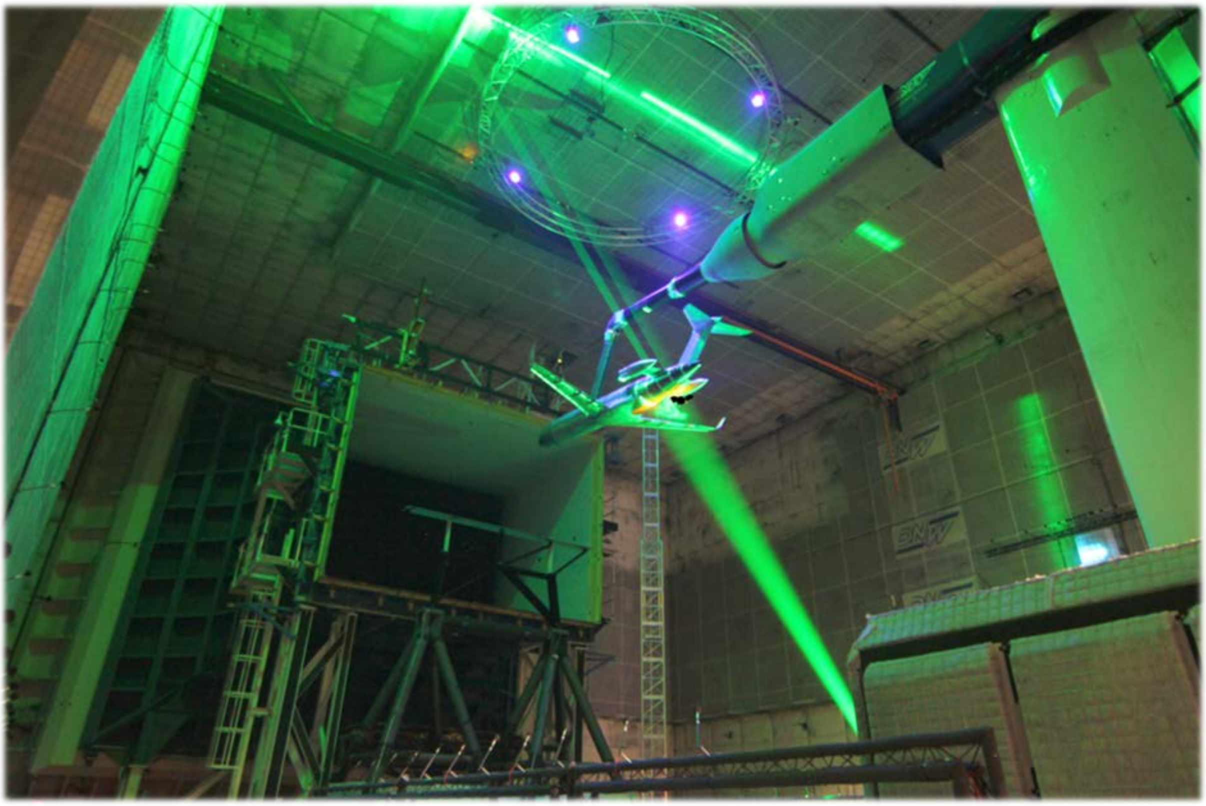
Figure 1: CAD design of test setup with inflow microphone wing, phased microphone array and PIV

Figurer 2: Z08 model in DNW-LLF open test section during commissioning phase, wind-off

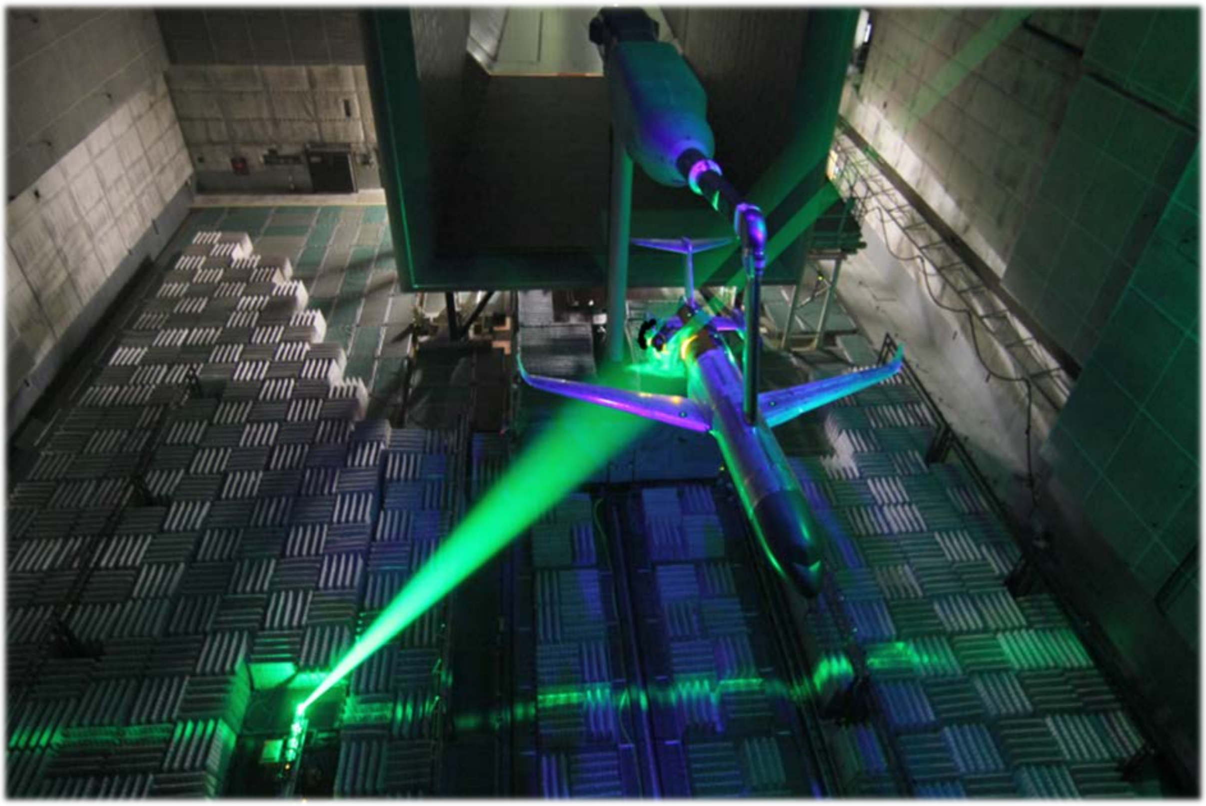


Figurer 3: Z08 model in DNW-LLF during acoustic commissioning phase, wind-on

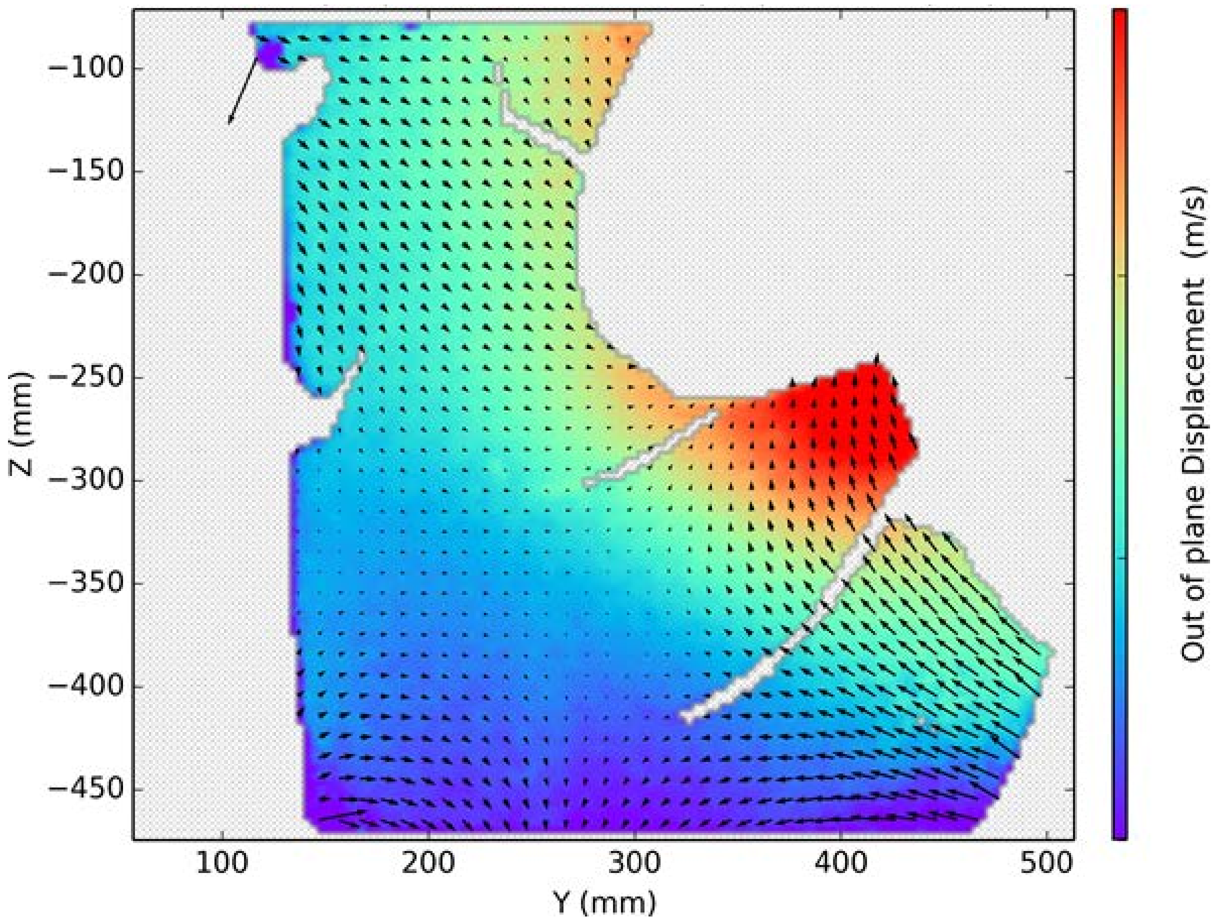
Figurer 4: Z08 model in DNW-LLF open test section during acoustic test phase



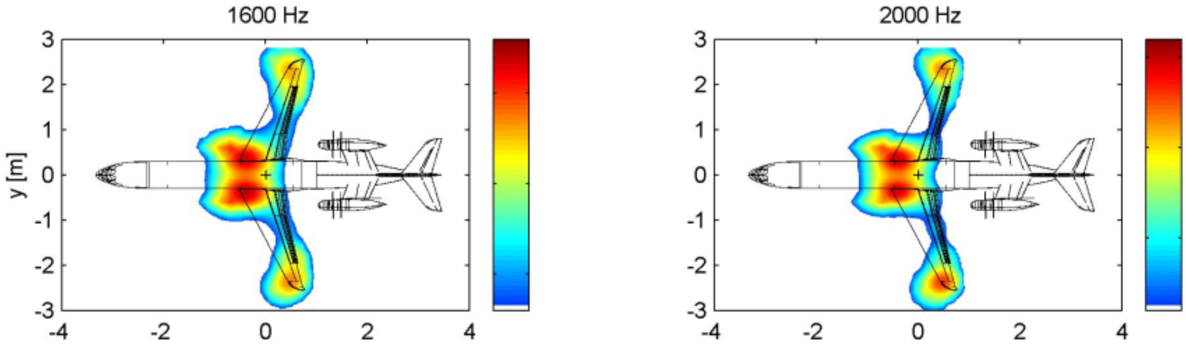
Figurer 5a: Z08 model in DNW-LLF open test section during PIV test phase (bottom view)



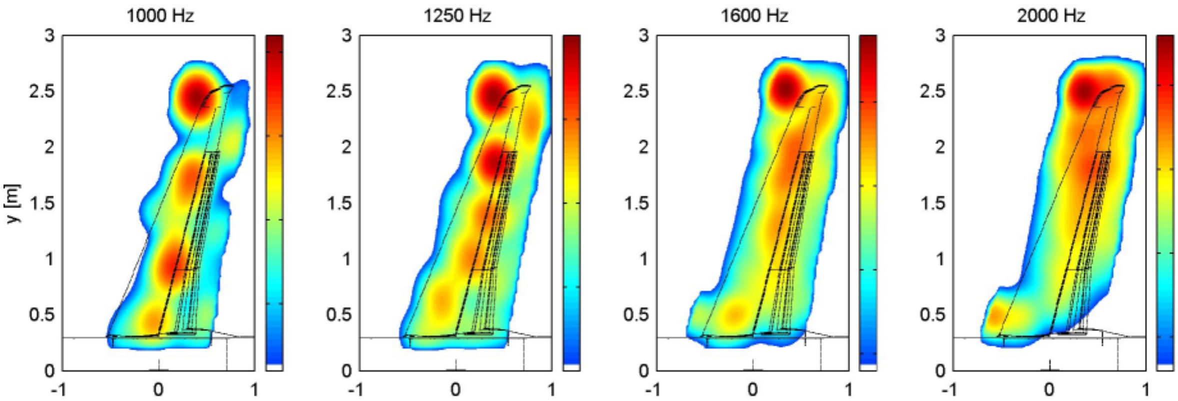
Figurer 5b: Z08 model in DNW-LLF open test section during PIV test phase (top view)



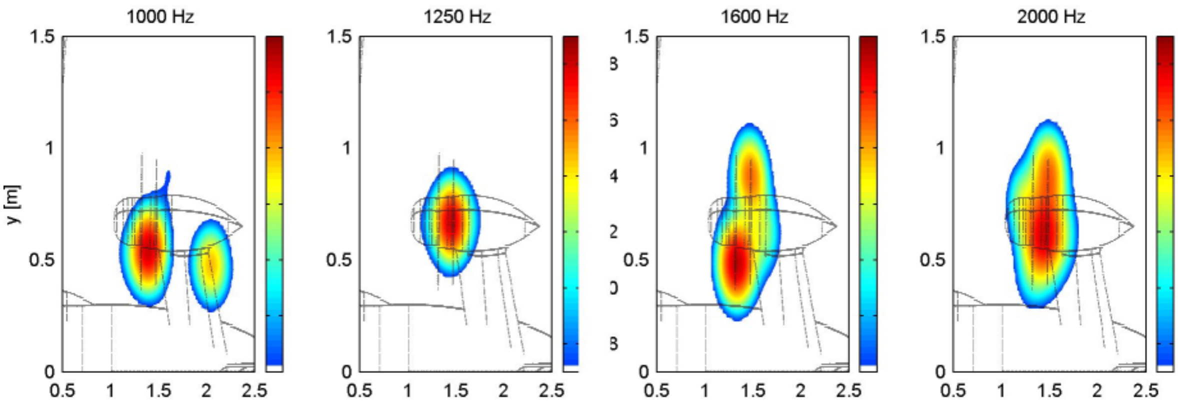
Figurer 6: Typical PIV visualization result in the propeller inflow area



Figurer 7a: typical array noise source plots for the full model (power-off)



Figurer 7b: typical array noise source plots for the starboard wing area



Figurer 7c: Typical array noise source plots for the starboard propeller engine area (power-on)

Project Summary

Acronym:	LAAME-CROW
Name of proposal:	Advanced Measurement Techniques in a Low Speed CROR Wind Tunnel Test
Involved ITD	Smart Fixed Wing Aircraft ITD
Grant Agreement:	632601
Instrument:	Clean Sky Joint Undertaking
Total Cost:	1,234,235.26 Euro
Clean Sky contribution:	710,790.00 Euro
Call:	SP1-JTI-CS-2013-02
Starting date:	1 August 2015
Ending date:	30 October 2016
Duration:	15 months
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