inter.noise 2014
MELBOURNE AUSTRALIA
16-19 NOVEMBER

Aeroacoustic source localization on open rotor aircraft model in wind tunnel tests

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ABSTRACT

Phased Array aeroacoustic measurements are gaining an increasing interest in automotive and aeronautic design.

This paper describes the beamforming approaches used for characterizing acoustic sources on an counter rotating open rotor (CROR) installed on a 1/7th scale model of an advanced regional air-craft design. The tests were conducted in a large Low Speed Wind Tunnel (WT) at The Pininfarina Aerodynamic and Aeroacoustic Research Center in Turin, Italy, within the framework of the FP7 EU Clean-Sky WENEMOR (Wind tunnel tests for the Evaluation of the installation effects of Noise EMissions of an Open Rotor advanced regional aircraft) project. Three planar microphone arrays were installed in Pininfarina WT: a wheel array (3m diameter) placed at the ceiling of the WT (Top), a half-wheel array positioned broadside and parallel to the axis of the open rotor (Lateral) and a spiral array (2.5m aperture) placed upstream the blade plane and at an angle of 10 degrees to the blade plane (Upstream). Measurements were performed for a variety of aircraft geometries (involving different fuselage and rotor configurations), angles of attack and wind speeds. Preliminary beamforming results obtained processing the Top and Lateral arrays are presented and discussed.

Keywords: Aeroacoustic, Beamforming I-INCE Classification of Subjects Number(s): 21.6.2, 74.7

1. INTRODUCTION

The need for lowering fuel consumption in modern aircrafts has re-given Open Rotor (OR) propulsion systems high attention during the last years. This is mainly due to their inherent fuel burn efficiency compared to the current generation high bypass ratio turbofan engines. However, with respect to turbofan engines, OR systems are less efficient in terms of acoustic emission, therefore to make this solution feasible on next generation aircrafts, OR inherent acoustic issues has to be faced. Acoustic Beamforming can be considered a good candidate for tackling these aspects, since a noise problem, on a first attempt, can be faced by locating the strongest noise sources.

Nowadays beamforming methods can be considered standard noise mapping approaches in the aeronautic field. Interesting examples can be found, for instance, in (1) for inlet/aft duct fan noise, in (2) for full scale engine testing and in (3) for scaled jets. However, apart from technique inherent uncertainty (4), difficulties may arise when using beamforming for locating sources on Counter Rotating Open Rotor (CROR) propulsion systems, since no definitive studies exist on OR noise emission and therefore the assumption of spherical/pane emission that characterizes beamforming algorithms might not be valid anymore. Moreover, if the CROR propulsion system is installed on an aircraft model, OR noise itself might be significantly louder than aeroacoustic noise associated with aircraft frame components (slat, flap, landing gear).

This paper aims at discussing preliminary results obtained from beamforming tests performed on a 1/7th scale model aircraft with installed open rotors within the framework of the FP7 EU Clean-Sky WENEMOR project (5). This represents a breakthrough, since a model of such scale has never been

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tested previously. Measurements were performed for a variety of aircraft geometries (which involve different fuselage and rotor configurations), Angles of Attack (AoA) and Flow Speeds (FSs) in order to understand influence of these parameters to the noise emitted. Some other preliminary results related to these tests can be found in (6).

2. EXPERIMENTAL SET-UP

The test program was conducted at the Pininfarina Aerodynamic and Aeroacoustic Research Center in Turin, Italy. This facility contains a test section of 8m x 9.6mx 4.2m which is shown in Figure 1. The wind tunnel was specifically acoustically treated in order to reduce background noise. This intervention made it possible to reduce background noise to 68.5 dBA at a velocity of 100 km/h and to 77.7 dBA at 140 km/h. The tunnel produces a very uniform velocity flow: an overall variation of 0.5% over the area of the test section is estimated. Moreover, the turbulence intensity can be controlled between 0.26 - 8% as the tunnel also contains a controllable turbulence generation system.

Three planar microphone arrays were installed in Pininfarina WT: a 78 microphone wheel array (3m diameter) placed at the ceiling of the WT at a distance of 2.5m from the model axis, a 66 microphone half-wheel (3m diameter) array positioned broadside, parallel to the axis of the open rotor and at a distance of 4.2m from the model axis and a 39 microphone spiral array (2.5m aperture) placed upstream the blade plane and at an angle of 10 degrees to the blade plane. Figure 1 shows the test section with installed model and microphone arrays, while positions of arrays with respect to the model are presented in Figure 2.

Fig. 1: Test set-up in Pininfarina WT (rear view of the aircraft model)

All sensors were acquired synchronizing two DAQ systems with a common reference signal. Signals were sampled at a sample rate of 32768 Hz for 10 seconds duration.

The CROR tested features two planes of 12 blades. Both left and right engines of the aircraft model were driven from a single power supply and controlled by dedicated control systems (one per motor). The speed was set at 2359 RPM, since this represent the estimated flight conditions of the full scale aircraft (approximately 880 RPM at a height of 250 m) when Strouhal number scaling is performed.

Table 1 – Test configurations for the T-Tailed model in Take-Off condition

Angle of Attack (AoA) [deg]	Flow Speed (FS) [m/s]
6	20
8	24
10	28

Different design configurations of the model were tested during the whole test campaign (different tails, CROR in pusher and tractor configuration, different distance of the CRORs with respect to the model fuselage, etc…) at different Flow Speeds and Angles of Attack. Angle of Attacks differed also with respect to the Take-off or Approach model configuration. Results discussed in this paper refer to a T-Tailed model tested in Take-off condition with CRORs in pusher configuration. Angles of Attack (AoA) and Flow Speed (FS) variability is reported in Table 1.

Data discussed in Section 3 refer to beamforming results obtained processing the wheel array placed on the ceiling (Top array) and from the half-wheel array on the side (Lateral array) of the WT. Data collected from the upstream array are still under processing.

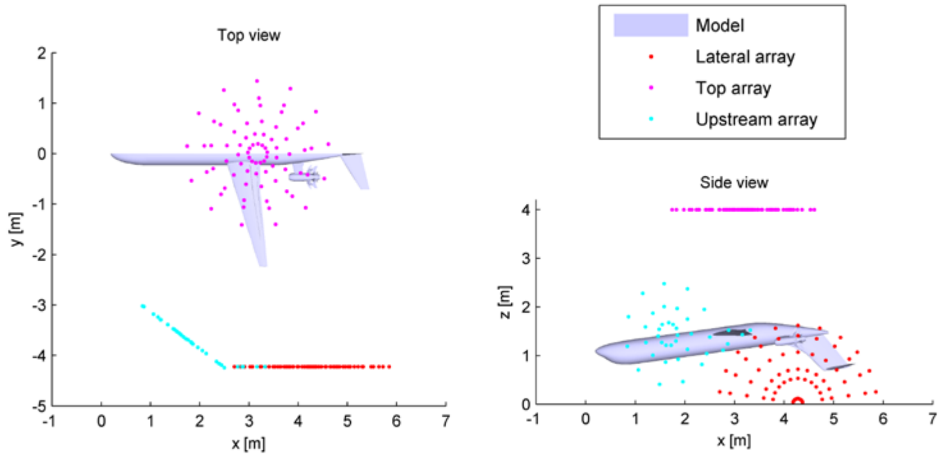


Fig. 2: Beamforming array positions with respect to CROR model (half model reproduced in the picture)

3. RESULTS

Some preliminary results achieved by processing data from the Lateral and Top Arrays are reported hereafter. Figure 3 shows the 1/3 Octave Band (OB) Spectra obtained from the spatial average of pressure data collected by the microphones on the Lateral *(a)* and Top *(b)* array. Absolute values of such spectra are omitted for confidentiality issues. Spectra refer to the test performed at AoA 10° for a Flow Speed of 28m/s, which represents the most extreme condition. Spectra are presented only up to 5Hz, since a loss of coherence over microphones of the arrays have been detected at higher frequencies. This can easily happen in open jet wind tunnels when microphones are placed outside the flow (7).

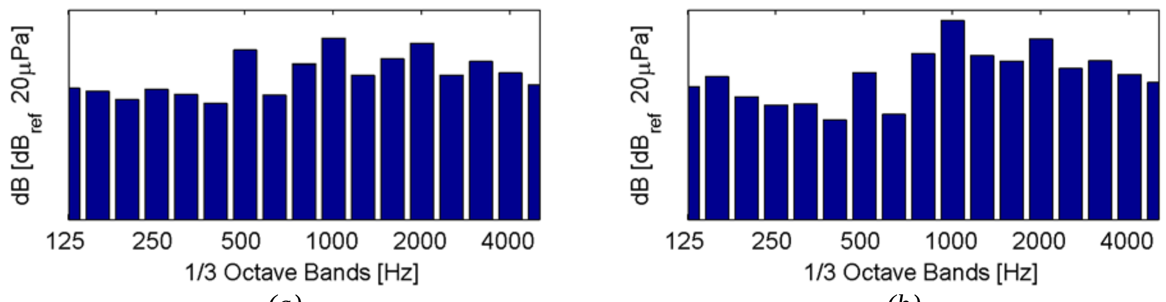


Fig. 3: 1/3 Octave Band Spectra from Lateral Array *(a)* and Top Array *(b)*: AoA 10°; FS 28m/s

The main noise sources are identifiable at the 500Hz, 1kHz and 2kHz central frequencies. The related bands also contain the tonal components characterizing the CROR noise, therefore beamforming results are presented on these bands. Beamforming calculation planes ranges from the front wing to the rear wing in the *x* direction, comprising only the negative *y* direction. Calculation planes were created parallel to the related microphone array and containing the CROR axis. Only half model is presented in the following figures for sake of clearness. In each plot the highest displayed level is normalized to 0 dB for confidentiality issues. Corrections for microphones self-noise, amplitude and phase variations due the presence of shear layers and mean flow have been also performed in the conventional beamforming processing. These compensations are needed, in wind tunnel testing, because the presence of shear layers and mean flow strongly modifies the noise propagation, as widely discussed in (7).

3.1 Dependence on Angle of Attack (AoA)

Figures from 4 to 6 show beamforming maps, calculated on the 1/3 OBs related to the central frequencies 500Hz, 1kHz and 2kHz, for tests performed at different Angles of Attack at a Flow Speed of 28m/s. The simultaneous view of results related to Lateral and Top arrays gives the possibility of better understanding the source distribution with respect to the CROR and to the aircraft fuselage.

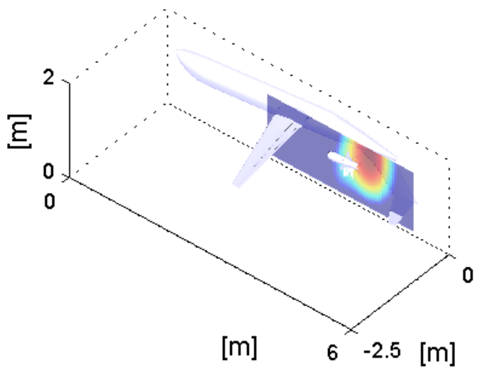
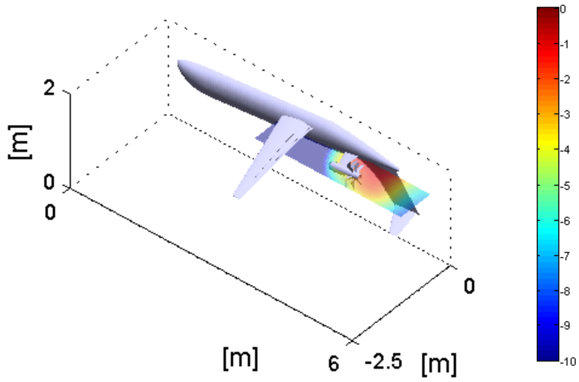
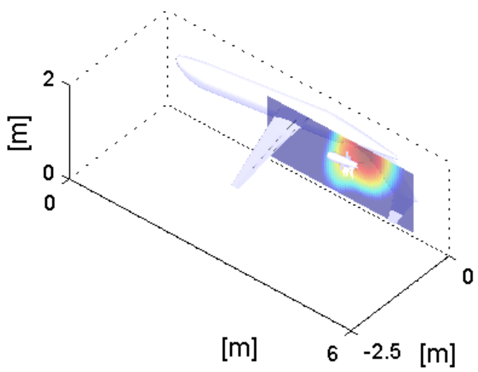
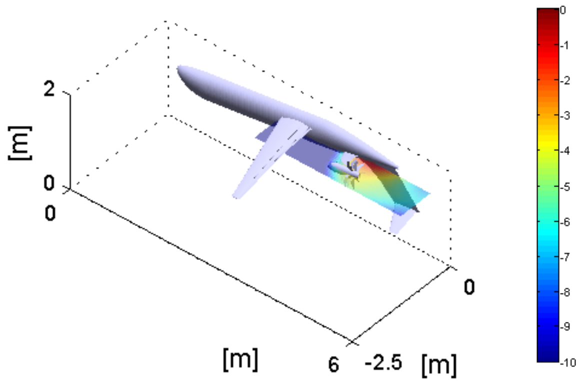
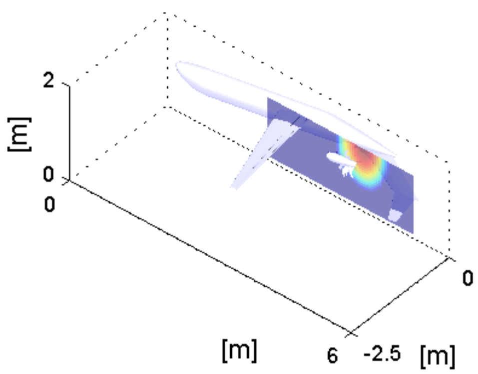
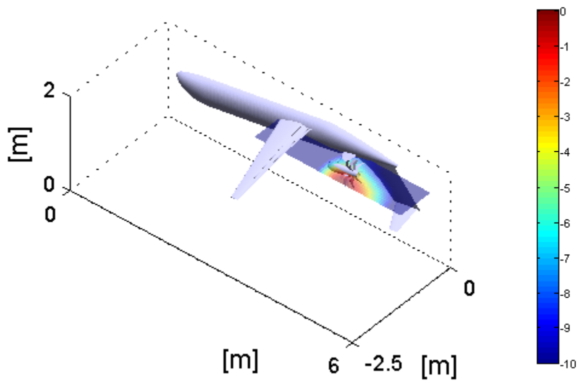
AoA [deg]	Lateral Array	Top Array
6		
8		
10		

Fig. 4: Noise map at 500Hz 1/3 OB (normalized dB level – dB_{ref} 20μPa) vs AoA (FS 28 m/s)

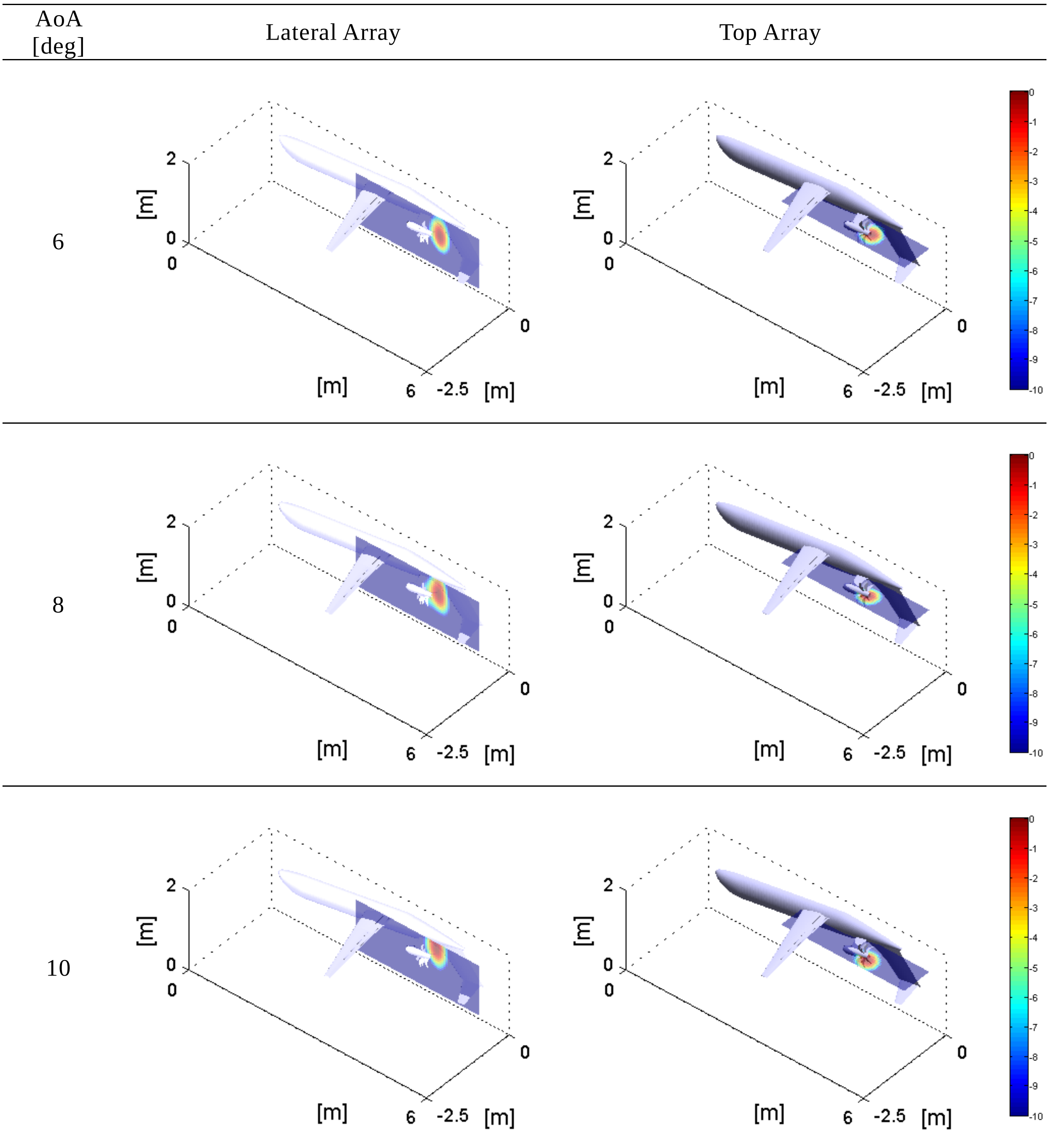


Fig. 5: Noise map at 1kHz 1/3 OB (normalized dB level – dB_{ref} 20μPa) vs AoA (FS 28 m/s)

The CROR is located as the strongest noise source at all frequencies and independently from the AoA. The interaction between the CROR and the fuselage is evident only at low frequency (Figure 4). Multiple reflections that can occur on the fuselage are seen as single source at low frequency also because the reduced performance of the arrays in terms of resolution.

It is possible to notice the tendency to locate the strongest sources progressively farther from the fuselage with the increase in AoA. This is evident on results from both the Lateral and Top arrays, especially at higher frequencies (Figure 6) because of the improved resolution.

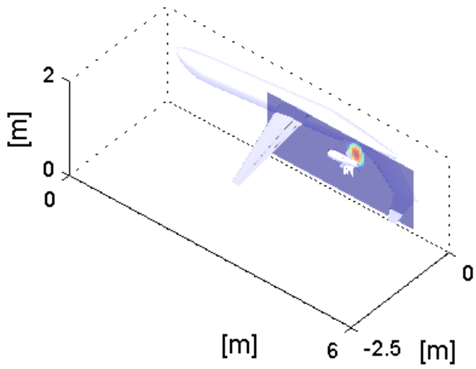
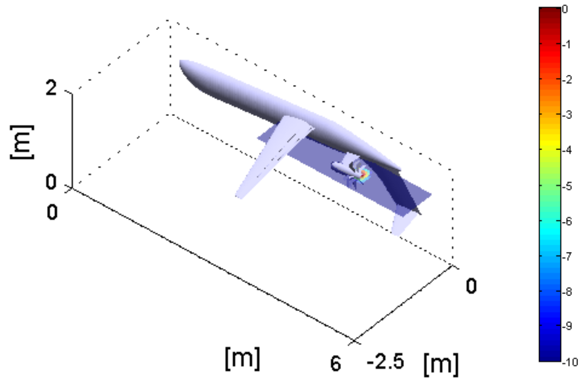
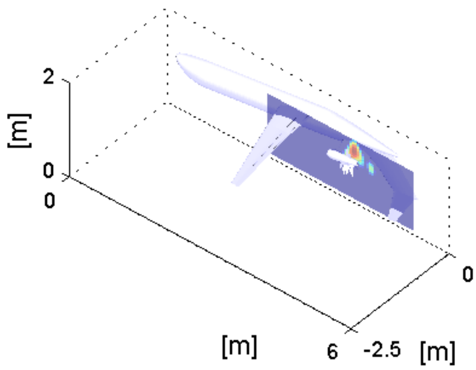
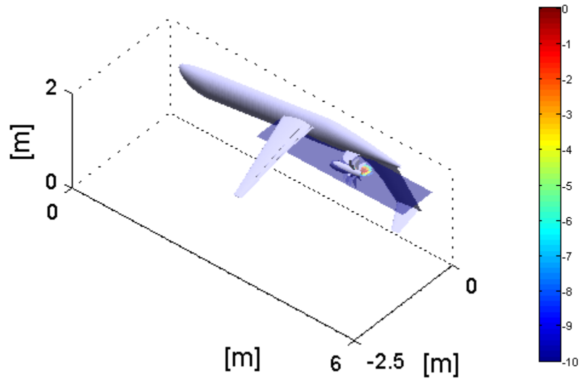
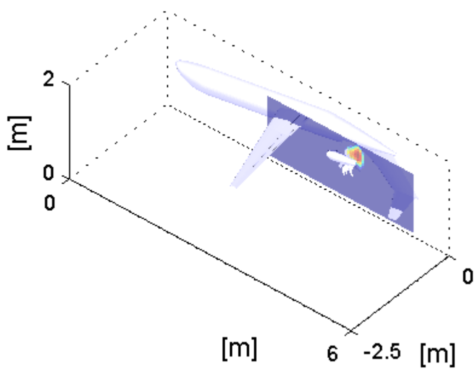
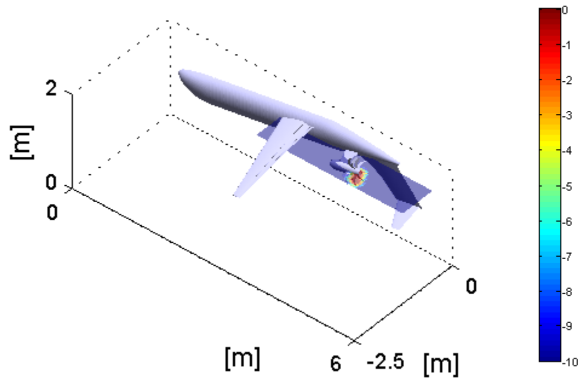
AoA [deg]	Lateral Array	Top Array
6		
8		
10		

Fig. 6: Noise map at 2kHz 1/3 OB (normalized dB level – dB_{ref} 20µPa) vs AoA (FS 28 m/s)

3.2 Dependence on Flow Speed (FS)

Figures from 7 to 9 compare beamforming maps (1/3 OBs related to the central frequencies 500Hz, 1kHz and 2kHz) calculated for different Flow Speeds with the model at 8° of Angle of Attack.

The strongest noise source is again identified at the CROR position at frequencies 1kHz and 2kHz. A noise source located between the CROR and the fuselage is evident at 500Hz. Again, this is due to a combination of longer wavelength that might give rise to reflections on the aircraft model and to poor beamforming resolution at lower frequencies.

No evident phenomena, apart from a spatial narrowing of the source with respect to its dynamic range can be recognized with the increase in Flow Speed.

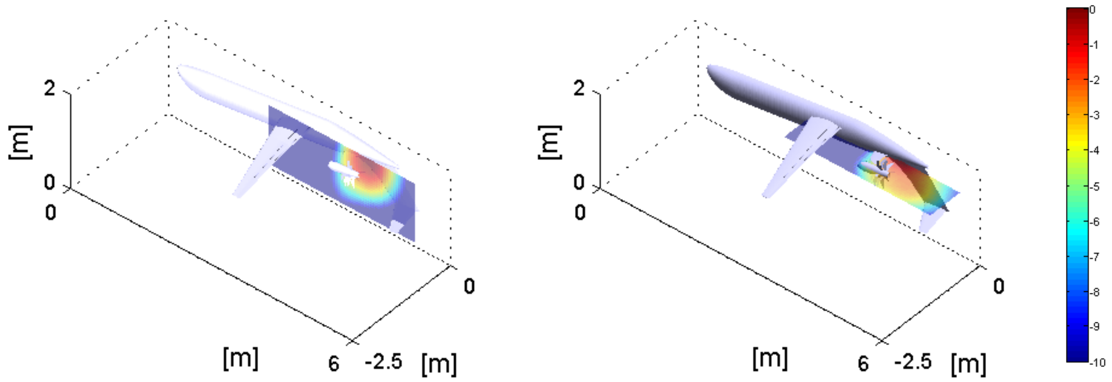
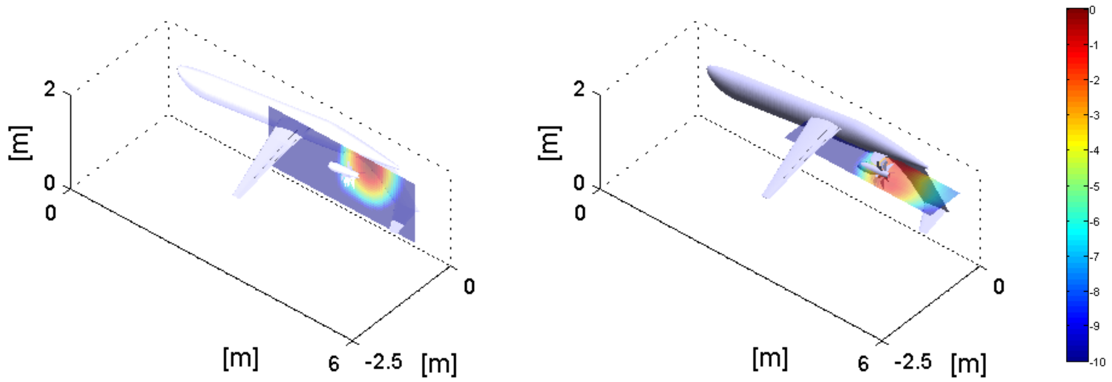
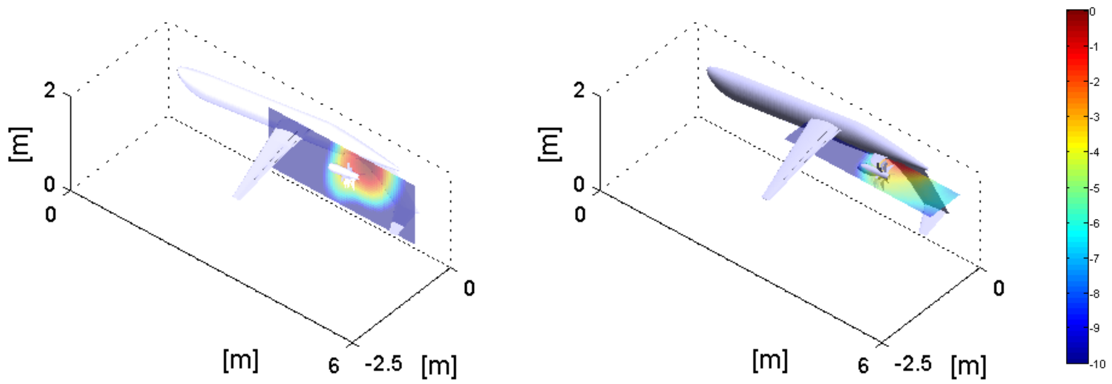
FS [m/s]	Lateral Array	Top Array
20		
24		
28		

Fig. 7: Noise map at 500Hz 1/3 OB (normalized dB level – dB_{ref} 20μPa) vs Flow Speed (AoA 8°)

FS [m/s]	Lateral Array	Top Array
20		
24		
28		

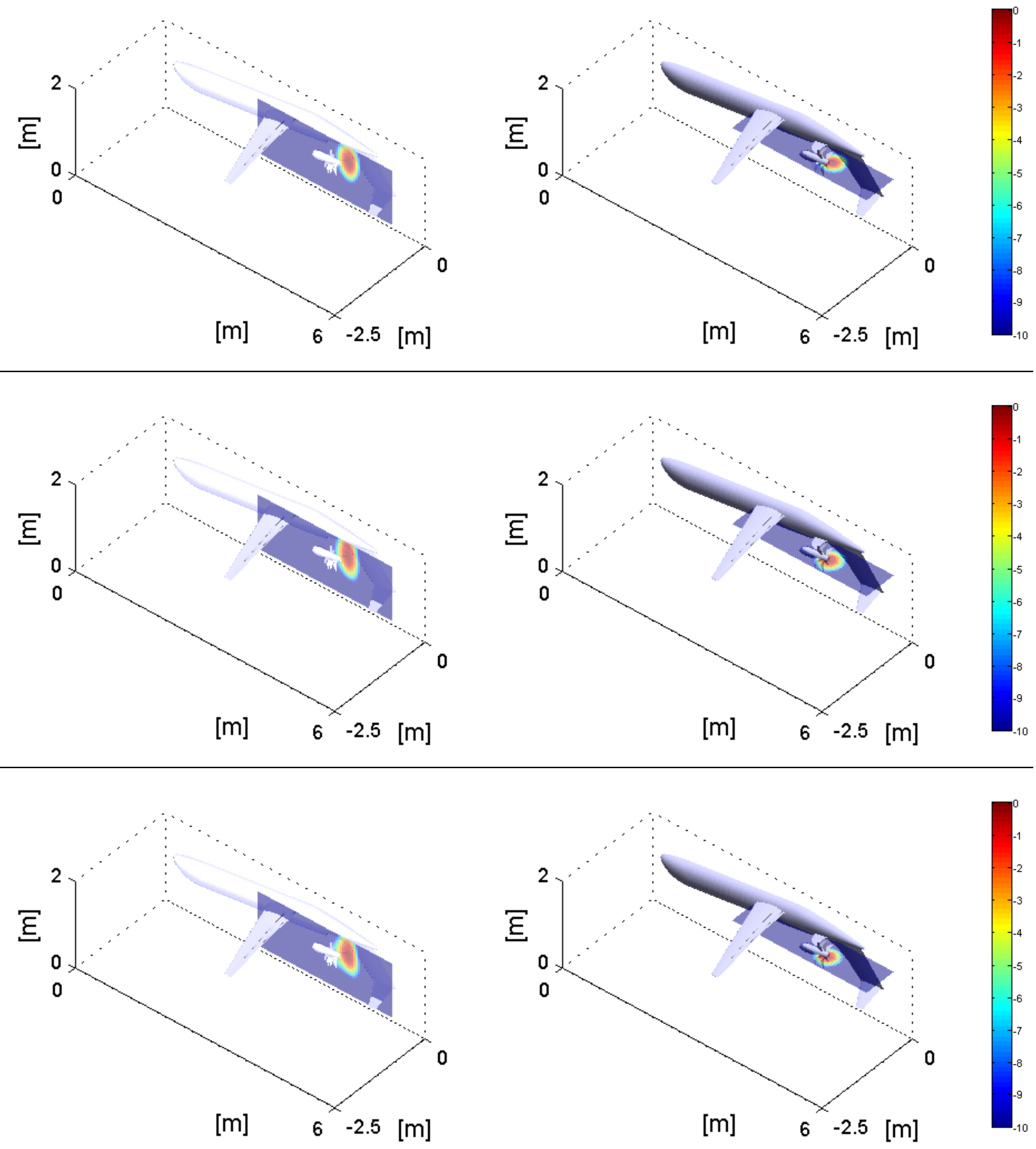


Fig. 8: Noise map at 1kHz 1/3 OB (normalized dB level – dB_{ref} 20μPa) vs Flow Speed (AoA 8°)

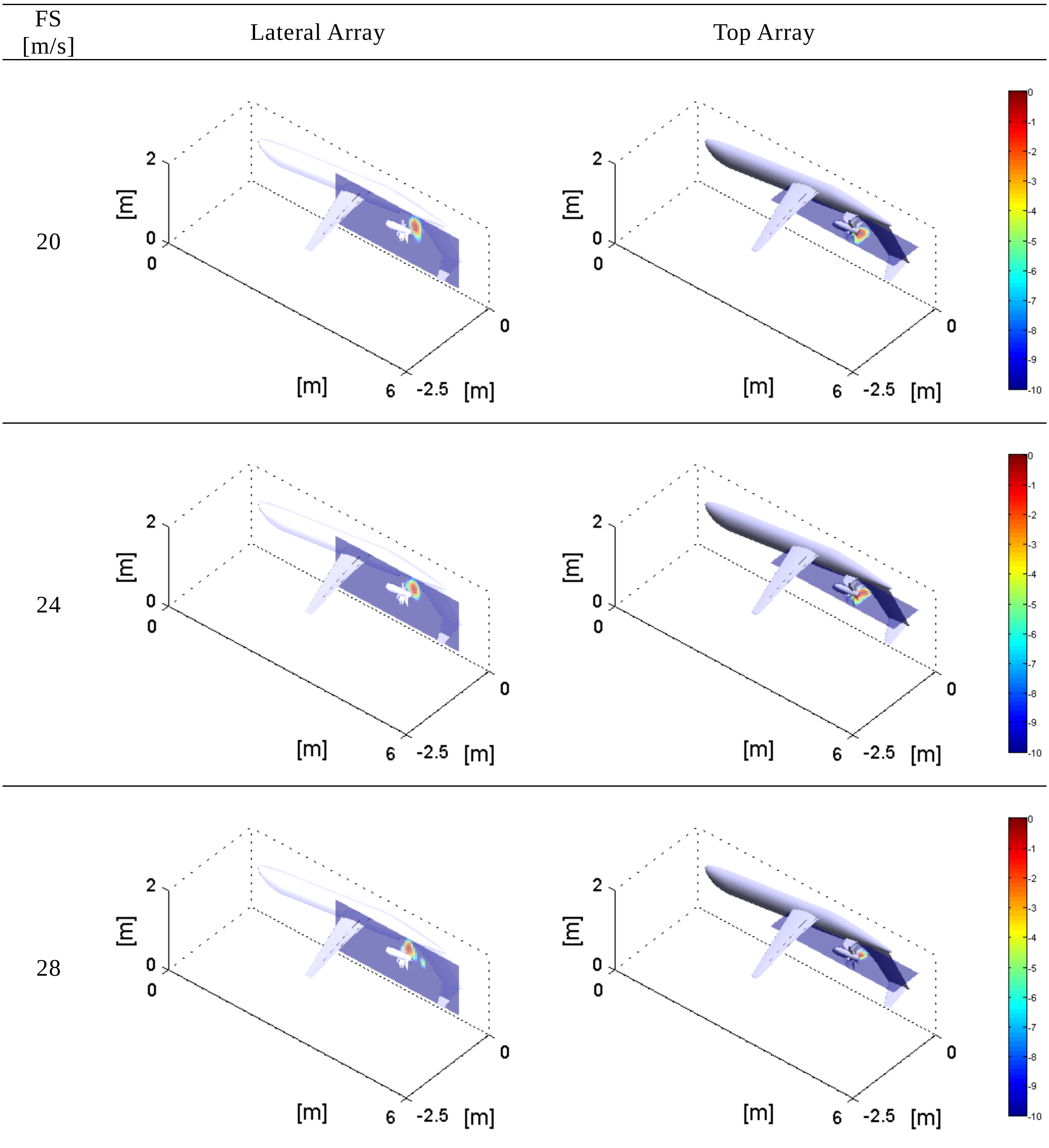


Fig. 9: Noise map at 2kHz 1/3 OB (normalized dB level – dB_{ref} 20μPa) vs Flow Speed (AoA 8°)

4. CONCLUSIONS

A preliminary study of noise source localization of the installed CRORs on regional aircraft model has been reported and discussed throughout the paper. A parametric approach has been adopted in order to understand possible modifications to the positioning of the noise sources with respect to variations in terms of Angles of Attack and Flow Speeds. No particular phenomena can be highlighted apart from a tendency to locate the strongest sources progressively farther from the fuselage with the increase in AoA (enhanced by both the Lateral and Top arrays) and the spatial narrowing of the source with respect to its dynamic range at increased Flow Speed and constant AoA.

The lack of a full understanding of the OR noise propagation and the large level difference which exists between the CROR sources and rest of the airframe noise components (e.g. wings, landing gears, etc.) makes difficult a comprehensive explanation of the aero-acoustic phenomena that characterize the CROR when installed on an aircraft. However, this is out of the scope of the paper, whose final aim was to present further results, with respect to those already presented in (6), of a beamforming analysis performed for the first time on a 1/7th scale model aircraft with installed open rotors with arrays not specifically developed for the purpose.

Data from the test campaign are still under processing. Different algorithms (e.g. deconvolution approaches) are going to be tested and reported in future works, as well as results obtained by combining the different arrays in the beamforming processing, since preliminary analyses have given promising results.

ACKNOWLEDGEMENTS

Authors may acknowledge financial support by EU FP7 CleanSky Joint Technology Initiative Grant Agreement no.278419.

REFERENCES

1 Dougherty RP, Walker BE, Sutliff DL, Locating and Quantifying Broadband Fan Sources using In-duct Microphones, 2010, Proceedings of the 16th AIAA/CEAS Aeroacoustic Conference, AIAA 2010-3736.
2 Podboy GG, Horvath C, Phased Array Noise Source Localization Measurement Made on a Williams International FJ44 Engine, 2009, Proceedings of the 15th AIAA/CEAS Aeroacoustic Conference, AIAA 2009-3183.
3 Dougherty RP, Podboy GG, Improved Phased Array Imaging of a Model Jet, 2009, Proceedings of the 15th AIAA/CEAS Aeroacoustic Conference, AIAA 2009-3186.
4 Castellini P, Martarelli M, Acoustic beamforming: Analysis of uncertainty and metrological performances, Mechanical Systems and Signal Processing, Volume 22, Issue 3, April 2008, Pages 672-692
5 Bennett GJ et al., WENEMOR: Wind Tunnel Tests for the Evaluation of the Installation Effects of Noise Emissions of an Open Rotor Advanced Regional Aircraft, 2013, Proceedings of the 19th AIAA/CEAS Aeroacoustics Conference AIA 2013-2092
6 Kennedy J et al., The application of advanced beamforming techniques for the noise characterization of installed counter rotating open rotors, 2013, Proceedings of the 19th AIAA/CEAS Aeroacoustics Conference, AIAA 2013-2093
7 Mueller T, Aeroacoustic Measurements, Springer; 2002