ОРИНОКО

ORINOCO

Publishable summary

In the domain of civilian aeronautics, the increasing noise restrictions around airports are a challenging problem for aircraft and engine manufacturers. By 2020, the ACARE agenda has stated a reduction of the external noise by 10 EPNdB per operation of fixed-wing aircraft. The efforts in research and development for many years have resulted in significant reduction in the sound pressure level radiated by aircrafts engines currently in service, especially for jet noise which remains the main source of noise at take-off.

After the introduction of the high by-pass ratio engine, which contributed to both an improved aerodynamic efficiency and a substantial noise reduction, jet noise reduction has been treated by the implementation of passive devices such as chevrons or mixers, which enhance the mixing in the shear layers to reduce jet noise, but unfortunately decrease the engine performance during cruise. Therefore, to reach ambitious noise reduction goals without thrust penalty, it is necessary to implement new ideas, based on active devices that can be switched off during cruise. Micro-jet actuator was one of the first implemented solutions, with reduction comparable with chevrons. However, air supply for theses devices has to be taken from the engine, when the maximum thrust is needed. Another solution is to use plasma actuators system that can be easily configured in any spatial form near nozzle orifice.

ORINOCO is the cooperation between Europe and Russia for advanced engine noise control based on plasma actuators. Plasma technologies have initially been developed for flow control and their first applications for jet noise reduction were confronted with technical aspects far from acoustics. This use of plasma actuators is a novel concept that requires fundamental approaches to understand the interaction mechanisms with the main jet and the resulting radiated sound.

Toward the final goal of the evaluation of plasma actuators concepts for jet noise reduction, several points have been identified, including theoretical, numerical and experimental investigations:

- To develop and enhance plasma actuators technologies dedicated to jet noise reduction;
- To investigate instability waves concepts for jet noise;
- To formulate noise control strategy;
- To implement jet noise control based on plasma actuators.

Jet noise reduction is a major goal for aeronautical industry, and plasma technology presents a promising solution. However, the concept needs to prove its potential. Thanks to the fundamental works performed during the first stages of the project, aeroacoustics tests will be carried out in wind tunnel facilities. The experimental results will be analysed to evaluate the potential of plasma actuators concepts for jet noise reduction.

The project is divided into four technical work packages (WP).

The plasma actuators will be developed and improved in WP1 with the support of theoretical considerations, numerical simulations and experimental tests in laboratory. Control strategies will be investigated to define the best mean of acting on the flow in order to reduce the jet noise. Finally, linear and non-linear feedback control laws will be developed in preparation of the assessment.

Instability wave is the physical mechanism exploited by some plasma actuators concepts in ORINOCO. WP2 deals with the instability waves concept physics to define its parameters in the vicinity of the nozzle and the characteristics of actuators to generate anti-phase waves.

The objective of WP3 is to assess the various control concepts developed in ORINOCO Project. The tests campaigns will be carried out on isothermal single jet at small scale, with aerodynamic (hot wire anemometry, LDV, PIV) and acoustic measurements (near and far field). With the support of the conclusions of WP2 about instability waves concept physics, the actuators developed in WP1 will be tested and different configurations of implementations will be investigated.

In WP4, a synthesis of the acoustic performance of each plasma actuator concept for jet noise reduction will be achieved. Specifications for the extension of these concepts to full scale will be done.

For the development and the improvement of plasma actuators (WP1), the definition of control strategies (WP1) and the investigation on instability wave concept (WP2), the second period was clearly the continuation of the first one.

As a reminder, several plasma techniques were investigated during the first period in WP1: the Dielectric Barrier Discharge, the slipping surface multipoint discharge, the barrier corona discharge, the magneto-plasma actuators and the Plasma Synthetic Jet.

All these plasma actuators were tested in laboratory facilities what gave the opportunity to assess their ability to have an effect on the jet flow, and also to see their limitation or implementation difficulties. In that way, several techniques were improved:

- The original Dielectric Barrier Discharge (DBD) was able to generate instability wave, but the level was weak. To increase this level, TsAGI and JIHT-RAS decided to use High Frequency DBD; specific high voltage generator was designed and manufactured. The resulting actuator was proved to generate higher levels of perturbations in the jet.
- The combination of DBD and corona discharge was investigated as Barrier Corona Discharge and can generate pulsed ionic wind parallel to the jet flow. The first design was poor to generate noticeable disturbances. After identifying the cause of this weak behaviour (gap between the nozzle edge and the actuator orifice), a new actuator was designed: the disk barrier discharge actuator.
- The actuator based on magnetically driven arc discharge deigned by JIHT-RAS was also modified. After the design and manufacturing of dedicated power supply providing a better control of the pulse shape, a multi electrode system was created, providing six discharges around the nozzle edge.

After these improvements, all the actuators were implemented on nozzles and their ability to generate coherent structures in the turbulent shear layer of the jet was proved.

Concerning the Plasma Synthetic Jet (PSJ) of Onera, it is not the actuator that was modified, but the way to implement it on the nozzle. The classical one corresponds to the PSJ located around the exhaust of the nozzle; in the new concept, the actuators are implemented in the inner surface of the nozzle in order to be used as Vortex Generator. As for the other techniques, the two concepts were investigated in laboratory, with acoustic and PIV measurement in order to characterise the impact on the jet and on the radiated sound. Generation of strong coherent structures was also highlighted.

In order to effectively reduce jet noise, a large part of ORINOCO activities is dedicated to the understanding of jet noise mechanisms. Unsteady numerical simulations were performed in NLR and Onera and compared with aerodynamic measurements performed in the ECL-LMFA and in the Delft University of Technology. In this last facility, an innovative tomographic PIV technique was used, giving access to the velocity field in the completed volume of the jet. NLR's numerical simulation was done on two nozzle geometries (without actuators) and their numerical data were provided to the University of Roma3 to analyse the pressure in near field: with a method based on wavelet transform, they succeed in separating hydrodynamic and acoustic components of the pressure. On the other hand, in Onera, the Large Eddy Simulations were done without and with 12 Plasma Synthetic Jets. Similar results were obtained between numerical simulations and measurement, giving the opportunity to go further in the analysis of the impact of the actuators on the jet.

Still on the jet noise mechanisms, CNRS has completed his analysis of the near field pressure. Thanks to synchronised measurements, it was confirmed that the instability wave were strongly correlated with the noise radiated in the far field. However, this component of the pressure field appears to be insufficient to capture the essential sound producing dynamics. This difference may be attributable to the jittering wave-packet behavior, corresponding to non linear dynamics present in the jet. This near field analysis was completed with the separation of hydrodynamic and acoustic component performed by the University of Roma 3 on the basis of the measurement of CNRS.

Experimental investigations on instability waves concepts were also carried on and the results were used for the assessment tests of WP3. On the basis of the fundamental studies performed during the first period, three approaches have been chosen for the implementation of the jet noise reduction.

In the first approach, the Suppression of Artificial Instability Wave (SAIW) focussed on instability wave excited by a loudspeaker located inside the nozzle, upstream. The presence of instability wave in the mixing layer was verified thanks to PIV measurements. Other loudspeakers were installed around the nozzle, given the possibility to excite the instability wave. It was proved that it was possible to suppress the Artificial Instability Wave with the generation of another wave, with a different phase. After this first step, the plasma actuator concepts developed in WP1 were implemented to test their ability to generate instability wave too. Again, the presence of instability wave was confirmed thanks to the Time-resolved PIV system implemented in TsAGI’s anechoic chamber AC-2. As for the sound-sound control, the phase of the signal sent to the plasma actuator was tuned in order to suppress the instability wave generated by the loudspeaker (see Figure 1). This was successfully realized and as a result, jet noise reduction was measured in the far field.

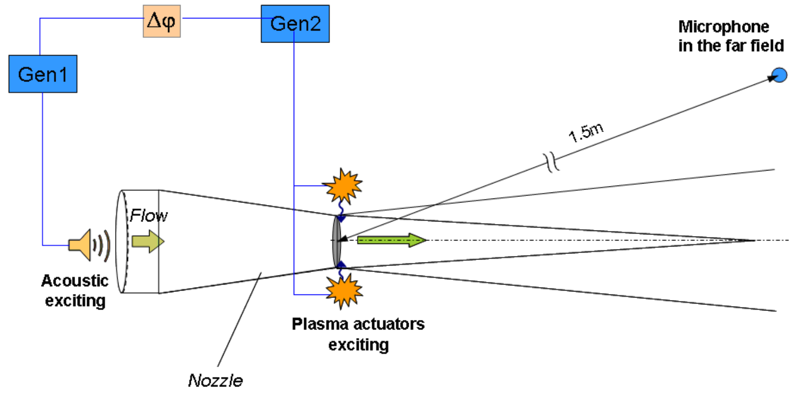

Figure 1. Sketch of plasma actuator instability wave control experiments

As a first step toward the Suppression of Natural Instability Wave (SNIW), 12 Plasma Synthetic Jets of Onera were implemented on a 50 mm diameter nozzle in the test facility of ECL/LMFA. The plasma actuators were used with different excitation frequencies, at different locations and with several modes of actions. In this case, as no particular one is excited, all the instability waves are present contributing to a broadband noise in the far field. Despite strong effect on the jet, no acoustic reduction was observed. According to literature, higher frequencies of excitation are necessary to reach this result.

The second approach is based on the Azimuthal Mode Coupling Technique: Theoretical analysis pointed out that excitation of high azimuthal mode can result in the reduction of the first azimuthal mode thanks to coupling mechanisms; the first mode is known to be the main contributor in the far field noise. Corrugated nozzle was designed and manufactured by TsAGI in order to favour the excitation of the 6^{th} mode (Figure 2). Their acoustic efficiency was tested in anechoic chamber and a reduction of more than 2 dB was effectively measured in the far field. The second stage of this approach consisted in replacing the corrugated nozzle by a circular nozzle equipped with 6 plasma actuators. During the evaluation test with plasma actuators, broadband noise reduction was measured in the far field, validating the concept of mode coupling.

Figure 2. Corrugated nozzle family with equivalent area of the output cross section

Finally, the feedback control approach was investigated. Based on measurement performed on near field microphones azimuthal array in "Bruit & Vent" facility, CNRS developed a reduce order model thanks to the method ARMAX (Auto-Regressive Moving-Average eXogenous identification). This approach, based on azimuthal modes decomposition, does not imply any physical aspect, what allows fast processing and robustness. The results were found to be very encouraging: using sensors located in the near-nozzle region, it was possible to perform real-time prediction of the instability-wave characteristics for distances of about 3 jet diameters in the downstream direction.

The end of the project is scheduled for the end of year 2013. Until then, the remaining activities are connected to the synthesis of the results obtained with the plasma actuators during the assessment tests of WP3 and the recommendations for full-scale implementations of these actuators. The Industrial Expert Panel will be involved in this last task to give their point of view and constraints for future evolution of plasma actuators. As a conclusion of technical activities of ORINOCO, a Dissemination workshop, open to public, is planned on 25th October in Onera with 12 presentations on the work performed in the project.

Altogether, the results obtained by ORINOCO are on line to reach the objectives fixed at the beginning of the project. New plasma actuators were developed, when others were improved. They have been implemented on single stream nozzle and succeeded in generating strong coherent structure convected by the jet. In some cases, noise reduction was obtained on the far field. On the subject of jet noise mechanisms based on instability wave concepts, great progresses were achieved: experimentally, the existence of instability waves was demonstrated and the possibility to suppress its presence too. Fundamentally, it was found that instability wave mechanisms are strongly connected with the noise radiated in the far field, and non linear behaviours were highlighted. Thereby, ORINOCO project has increased knowledge on jet noise and plasma actuators mechanisms, and draw recommendations on the future research to be performed in the field of jet noise by aeronautical industries to reduce external noise and conform to ACARE agenda. Thus, The ORINOCO project will support European competitiveness in aeronautical domain as well as benefiting to citizens by promoting noise reduction.

http://www.orinoco-project.org/