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WENEMOR: Wind Tunnel Tests for the Evaluation of the Installation Effects of Noise Emissions of an Open Rotor Advanced Regional Aircraft

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This paper presents the key objectives from an European Union funded collaborative project investigating the noise installation effects for novel regional advanced aircraft concepts using Open Rotor (OR) propulsion systems. The consortium for the project:WENEMOR, will address the topic by carrying out aero-acoustic measurements in the open test section of a large low speed wind tunnel using a complete reduced scale modular model of different configurations of an aircraft with installed counter rotating open rotor systems operating in both pusher and tractor modes. The principal goal of the project is to assess experimentally the noise shielding effectiveness of classic airframe components for different Open Rotor aircraft configurations. A complete $1/7^{th}$ scale aircraft has been designed and built for installation in the Pininfarina Aerodynamic and Aeroacoustic Research Center Wind Tunnel. The model has two Open Rotors with a contra-rotating fan at the same scale as the airframe. Various positions of the ORs with respect to the airframe will be tested with noise measurements being performed both in the near and the far field. The test campaign will provide, for the first time in Europe, a comprehensive database on noise installation effects for novel regional advanced aircraft concepts using OR propulsion systems. Two accompanying conference papers present preliminary results.

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I. Introduction

There is a considerable emphasis at present in both the EU and the US on the implementation of new open rotor propulsion systems with the aim to achieve significant energy savings in respect of reduced fuel consumption. The Fundamental Aeronautics Program of NASAs Aeronautics Research Mission Directorate have begun to fund GE and Boeing for test programs on both isolated open rotor propulsion system and on scale models of aircraft equipped with these propulsion systems in low-speed wind tunnels to simulate low-altitude aircraft for acoustic evaluation. The Clean Sky Joint Technology Initiative is a Public-Private Partnership between the European Commission and Industry implementing the Level 3 project approach of FP7. Clean Sky issued a call for proposals under SP1-JTI-CLEAN SKY-2010-4 entitled Aero-acoustic noise emissions measure for advanced Regional Open Rotor A/C configuration. The WENEMOR project has been developed in response to the requirements described in the Clean Sky-Integrated Technology Demonstrators under the heading of Green Regional Aircraft of which AleniaAerMacchi, Italy and EADS CASA, Spain are the leaders. The project consortium consists of 7 partners including two universities (Trinity College Dublin and Universita Politecnica delle Marche), a large European wind tunnel facility (Pininfarina) and several SMEs (Eurotech, Teknosud, MicrodB and Paragon S.A.) with specific competencies in design and manufacture and noise measurements and data analysis, given in table 1.

Partner	Country	Type
Trinity College Dublin (Coordinator)	Ireland	HES
Universita Politecnica Delle Marche	Italy	HES
Paragon	Greece	SME
Eurotech SAS	Italy	SME
MICRO DB SA	France	SME
Teknosud S.R.L	Italy	SME
Pininfarina SPA	Italy	IND

Table 1. WENEMOR Partners

WENEMOR will address the topic by carrying out aero-acoustic measurements in the open test section of a large low speed wind tunnel using a complete reduced scale modular model of different configurations of an aircraft with installed open rotor systems operating in both pusher and tractor modes. The principal goal of the project is to assess experimentally the noise shielding effectiveness of classic airframe components for different Open Rotor aircraft configurations. A complete scaled aircraft has been designed and built for installation in the Pininfarina Aerodynamic and Aeroacoustic Research Center Wind Tunnel. The testing phase of the project was completed in May 2013 and with conclusion of the project planned for August 2013. The model features two Open Rotors with a contra-rotating fan in the same scale as the airframe. Various positions of the ORs with respect to the airframe were tested with noise measurements being performed both in the near and the far field. The test campaign provides, for the first time in Europe, a comprehensive database on noise installation effects for novel regional advanced aircraft concepts using OR propulsion systems.

To achieve the objectives of characterising the noise footprint of these systems, the project consisted of five work packages described briefly below.

- **WP1 Multi-Configuration Model Design**
  In this work package, test models together with the necessary wind tunnel installations were designed. Structural verification includes static and aero-elastic analysis. In parallel with this activity, the engine simulator assembly was designed and specified.
- **WP2 - Multi-Configuration Model Manufacturing**
  This part of the project manufactured both the test models and the engine simulator systems according to the specifications developed in WP1.
- **WP3 Wind Tunnel Test Campaign**
  The first part of this work package addressed and defined the experimental test program to be conducted

to achieve the objectives of the work: i.e. the characterization of the noise emitted by advanced open rotor configurations. The physical models built in WP2 were installed in the wind tunnel and preliminary tests to characterize the experimental set-up including the wind tunnel environment were performed. Following this, a test campaign was conducted in which measurements of both near and far-field noise were obtained for a series of operating conditions.

- **WP4 Aeroacoustic Measurement Analysis**
  In this work package, the data from the test campaign will be analysed and the characteristics of the various configurations tested established. The final part of the work will be a parametric study of the different engine positions to establish which configurations produce the least noise and are likely to lead to the most environmentally friendly systems.

- **WP5 Management and JTI GRA Interaction**
  This activity co-ordinates and manages the project to ensure that the progress of the work is run according to schedule. Dissemination aspects of the work and regular liaison with the JTI-GRA is also be an integral part.

II. Model Design

The wind tunnel test model used within WENEMOR was designed and built by Teknosud. This section outlines the model characteristics, model configurations, and the technical information related to the model construction. The manufactured model is a $\frac{1}{7}^{th}$ scale model of airplane equipped with two counter rotating open-rotor engines. A reference surface of the airplane and propulsion system was provided by AleniaAermacchi as an output from the Clean Sky Green Regional Aircraft program. The scaled model was chosen to balance the opposing needs of the required rotor dimension while still enabling adequate test conditions and limiting the engine simulator power requirement.

Figure 1 shows geometrical dimensions of the longest and shortest configurations. TR-D1 is a tractor configuration and PS-A is the baseline pusher configuration. In order to meet the requirement of multiple angles of attack settings in all test configurations, the aircraft model is installed on three pylons within the wind tunnel. The pylon configuration is as follows: the two under-wing pylons are the point of rotation for the model and the single rear pylon features the AoA control system. The AoA system is automated to allow precise positioning control of the model without the requirement for shutting off the wind tunnel. The model can be configured in either a take-off or approach setting through the mounting and dismounting of several fairings and details (e.g. kruger flaps and landing gear for approach configuration).

The aircraft model is modular in nature and features interchangeable tail pieces, engine pylon rotation and elongation and fuselage elongation. These features are summarised in table 2. A variety of materials were used for the model construction including carbon fiber, steel C40 and aluminium.

Table 2. Model geometry settings

Tail Types	Engine Pylon Angles	Engine Pylon Lengths	Fuselage Extension
T1	15^o	480mm	0mm (Pusher Baseline)
T2	42^o	522mm	133mm
U		589mm	200mm (Tractor Baseline)
L			333mm

The test program required surface noise measurements on the aircraft fuselage at axial planes around the front blade row. These were measured by means of 20 flush mounted pressure sensors. In order to accommodate the changes in configuration a variety of instrumented panels were manufactured to match each aircraft geometry. Therefore, over 100 pressure sensors were installed on various aircraft panels.

A total of 16 aircraft configurations were tested consisting of 9 pusher and 7 tractor configurations. Figure 2 provides a visual summary of the variety of model geometries tested and figure 3 shows the aircraft model during testing in the wind tunnel. Each aircraft configuration could in turn be modified to a take-off or approach setting. Using automated systems in the wind tunnel, each of these set-ups was then tested at a variety of angle of attack settings: $6°$, $8°$, $10°$, and flow speeds: $20m/s$, $24m/s$, $28m/s$. This led to a

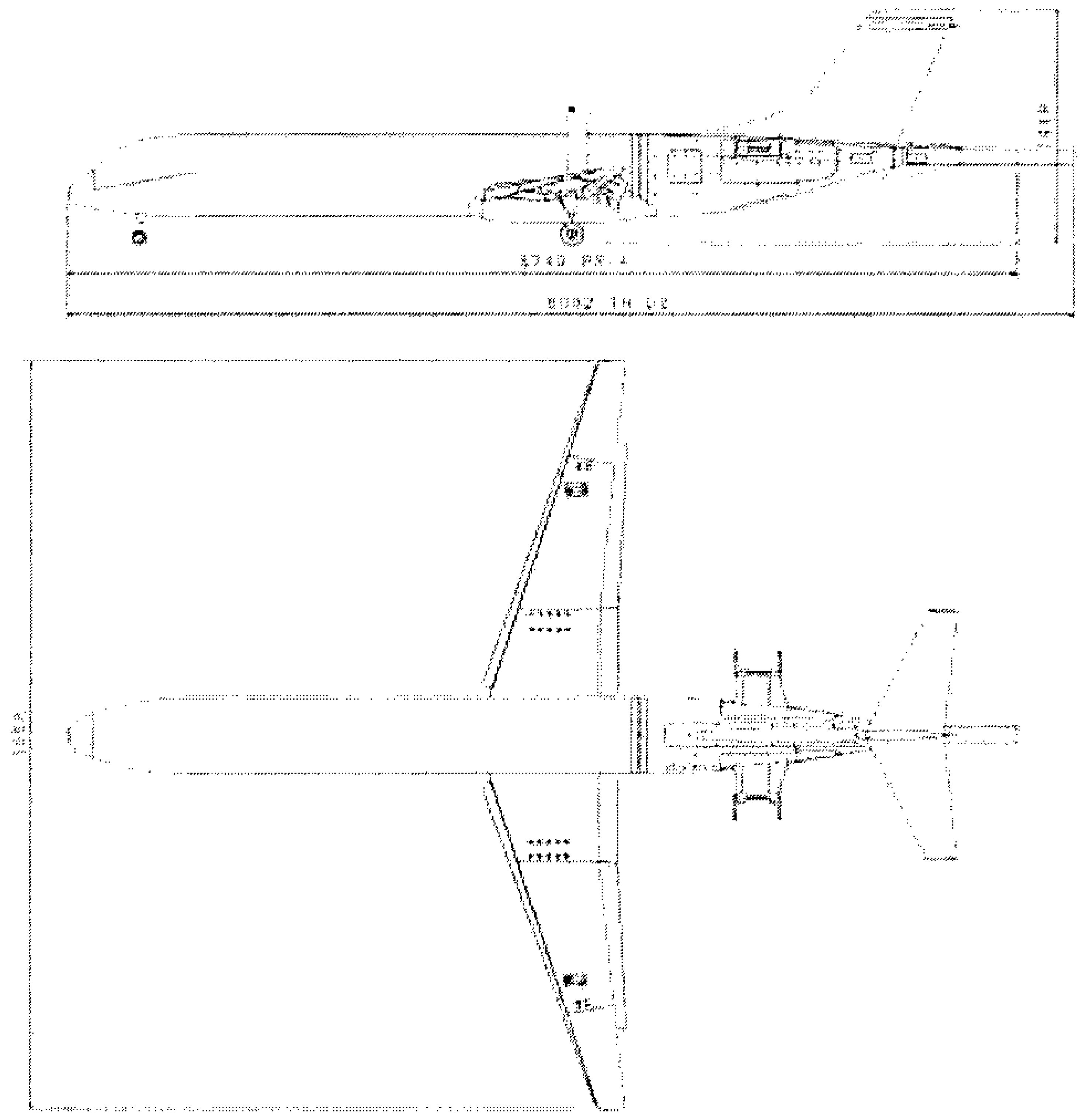

Figure 1. Aircraft configurations PS-A and TR-D1 (pusher and tractor)

total of 288 unique test set ups consisting of changes in model geometry, take off/approach setting, angle of attack and wind tunnel flow speed.

III. Propulsion system design

Eurotech designed and developed the CROR engines used in this project from specifications provided by Alenia Aermacchi. The design of the counter rotating open rotor used in this investigation features two planes of 12 blades. These are driven by a single electric motor and gear box which produced identical speed of rotation for both blade planes. One engine is instrumented with kulite pressure transducers on the front and rear blade planes: 12 on each row. The nacelle of this engine also houses slip ring connectors for instrumentation connections. Figures 4 and 5 show an internal schematic of the engine and a photograph of the engine installed in the wind tunnel in the pusher configurations.

The engine features variable blade pitch control which can be adjusted to either a take-off or approach setting. The blade pitch settings were identified experimentally during an engine calibration to match the required performance as specified by the designs developed within the Clean Sky Green Regional Aircraft program. The blade hub assembly was designed to feature blade pitch control over a range of 60^o. A simple rod and crank system allowed for adjustable blade pitch control without the need to disassemble the engine.

IV. Experimental facilities and instrumentation

The test program was largely conducted by Universita Politecnica delle Marche at the Pininfarina Aerodynamic and Aeroacoustic Research Center in Turin, Italy. This facility contains a test section of 8m x 9.6m x 4.2m which is shown in figure 6. Acoustic treatment of the wind tunnel has reduced background noise to 68.5 dBA at a flow velocity of 100 km/h and 77.7 dBA at 140 km/h. The tunnel produces a very uniform velocity flow which varies by only 0.5% over the area of the test section with a turbulence intensity which can be controlled between 0.26 - 8% as the tunnel also contains a controllable turbulence generation system.

A considerable array of instrumentation was deployed for each of these test set-ups. The aircraft model was instrumented with flush mounted pressure sensors in the engine blades and aircraft fuselage. Near field noise measurements were taken using a linear array of microphones mounted on a traversing arm used to take measurements at 7 planes centred about the front blade plane. Far field sound measurements were acquired by 3 microphone arrays, viz a top, lateral and front array and also on a far-field linear array of

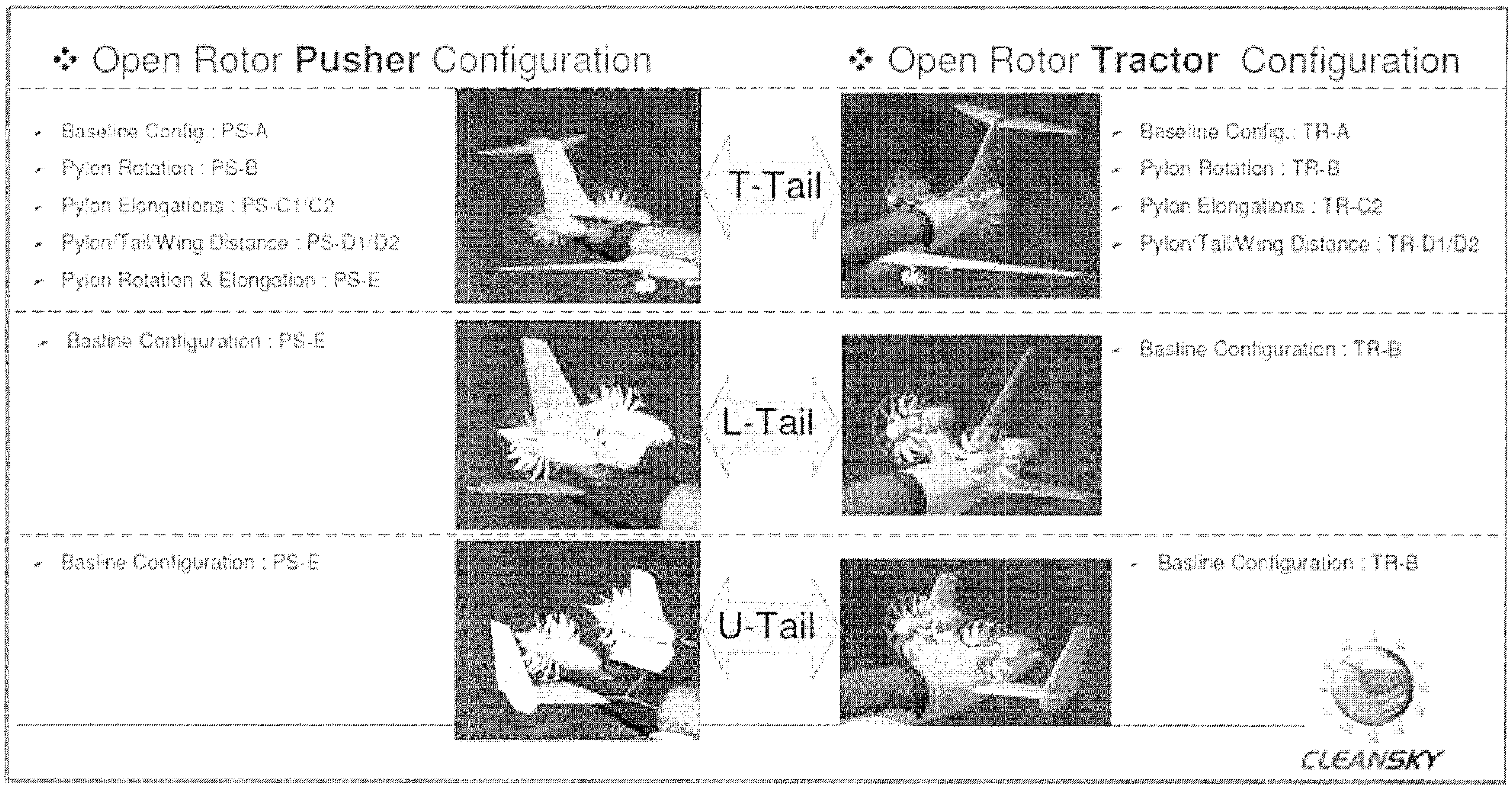

Figure 2. Model configurations

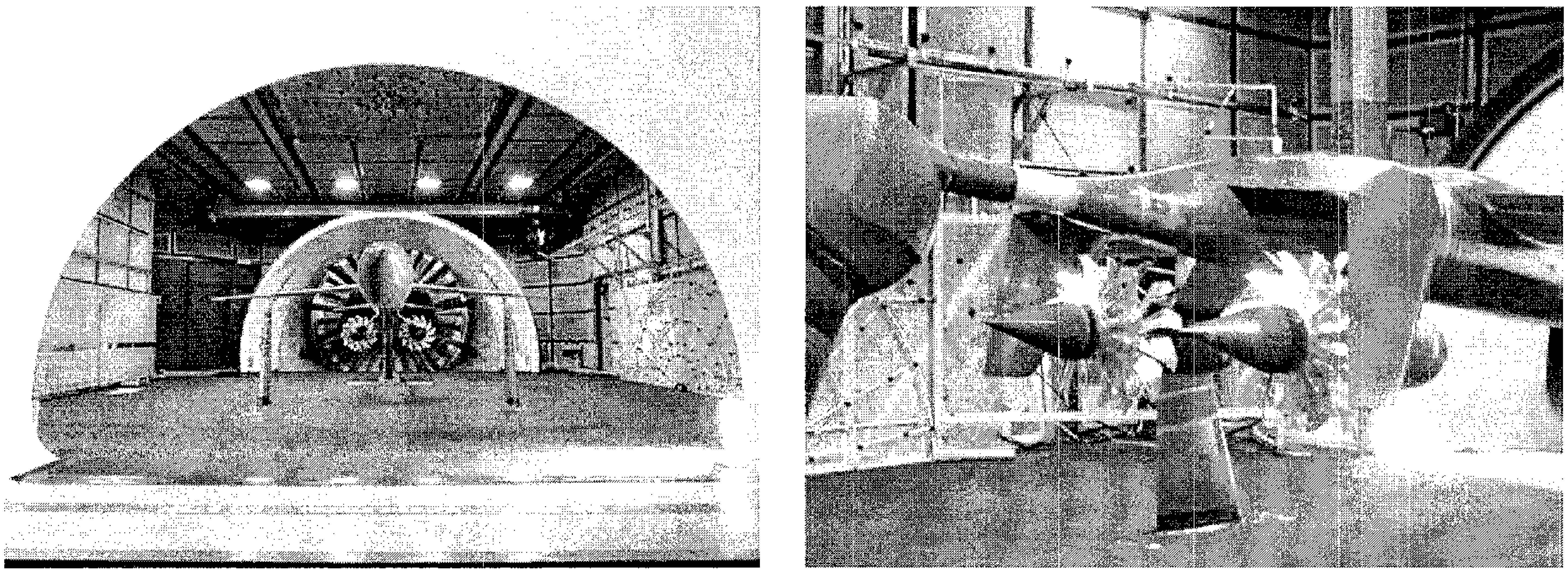

Figure 3. Model installed in the Pininfarina wind tunnel facility

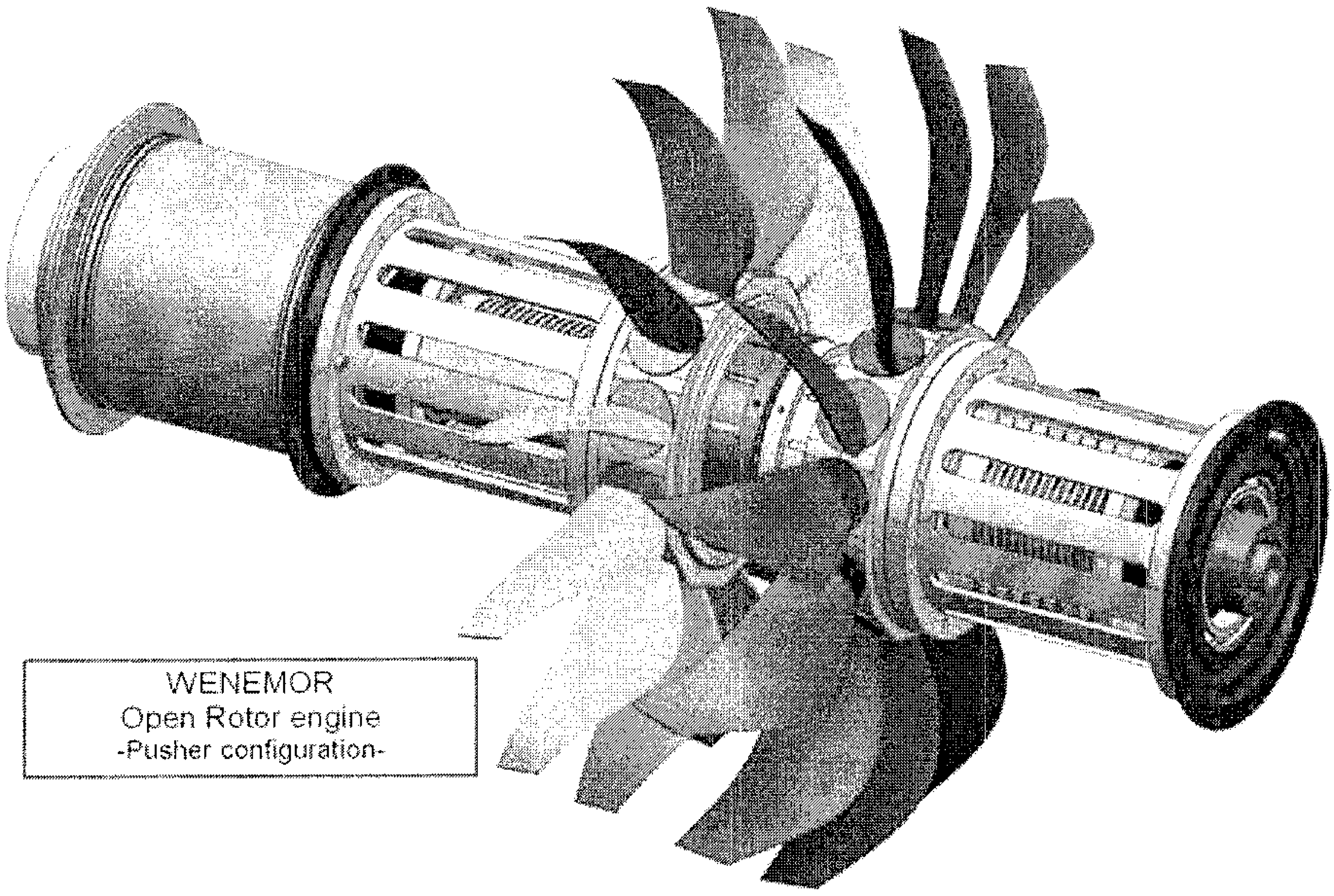

Figure 4. CROR Engine pusher configuration

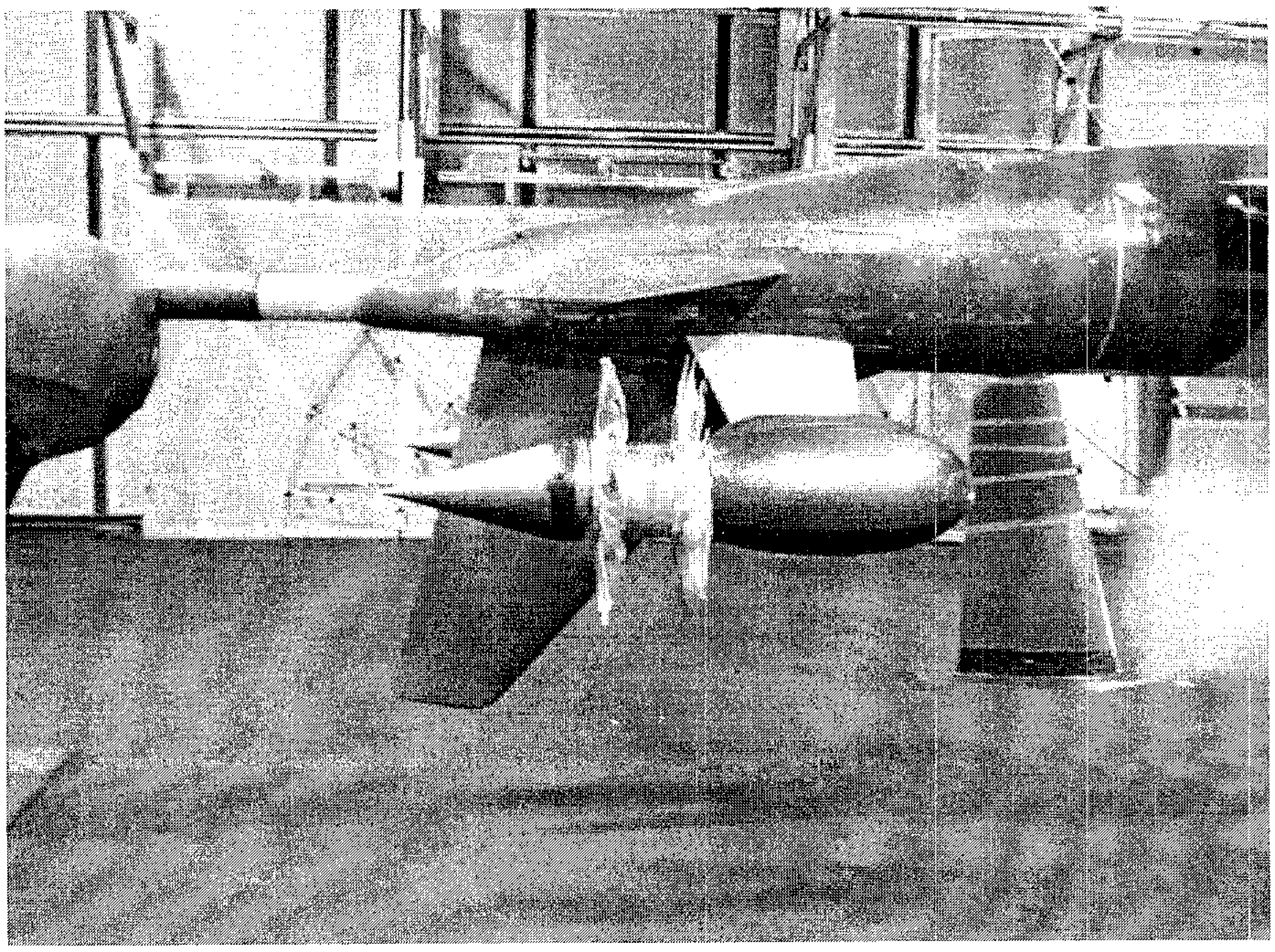

Figure 5. CROR engine installed in the wind tunnel in pusher configuration

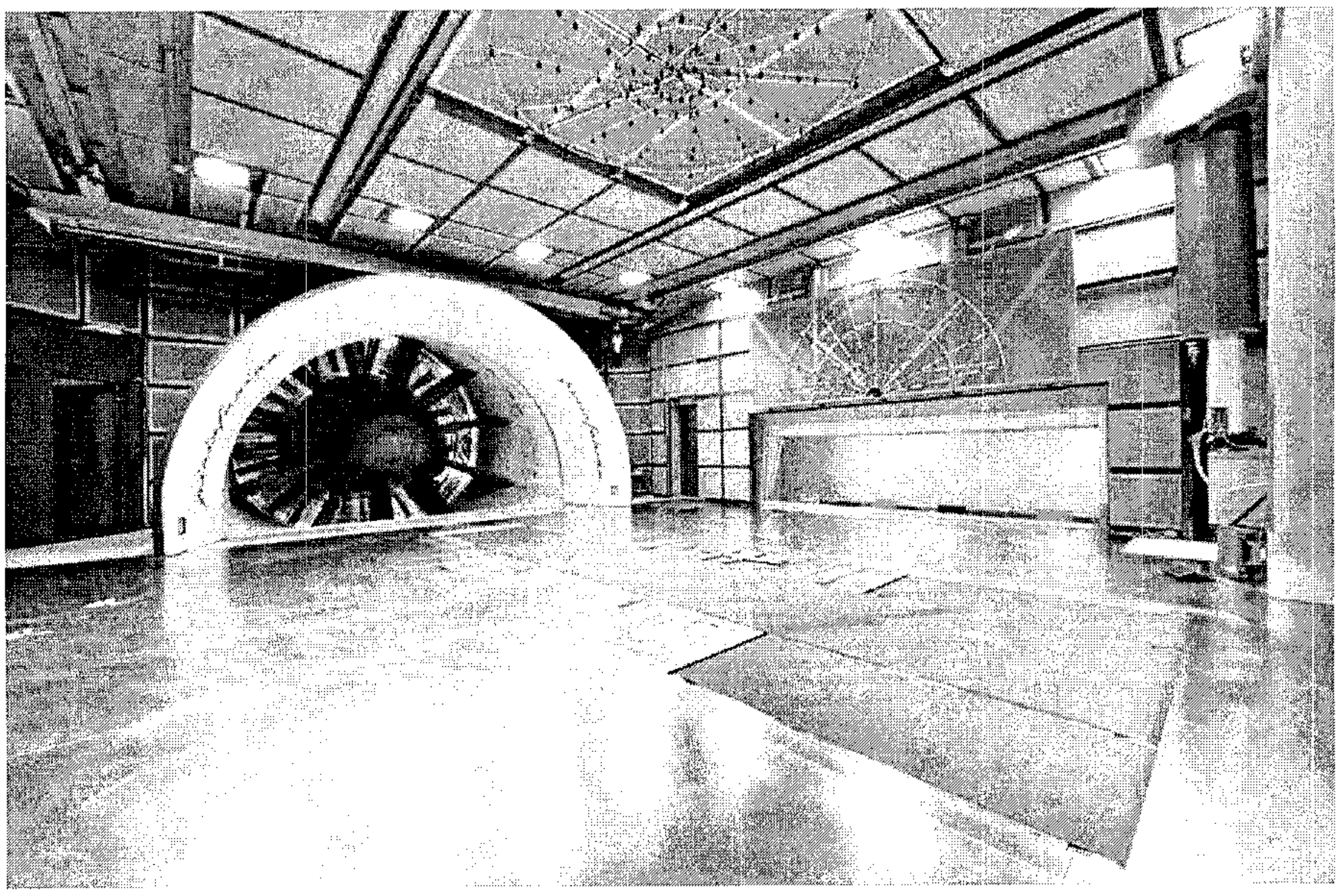

Figure 6. Pininfarina wind tunnel facility (including top and lateral microphone arrays)

microphones centred on the front blade plane covering angles from 30° to 150° about the blade side-line axis. Data were acquired simultaneously on all systems for the far field measurements at a data rate of 32,768Hz for 10s duration. Details of the number of sensors in each system are provided below:

- Blade Kulites (24 sensors)
- Fuselage Microphones (20 microphones)
- Near Field Traversing Array (5 microphones)
- Far Field Linear Array (13 microphones)
- Top array (78 microphones)
- Lateral array (66 microphones)
- Front array (30 microphones)

This produced a total of 174 sensors for the measurement of the noise emission of the installed CROR. In addition to these sensors the model was equipped with vibration monitoring sensors and the engine position and rpm were recorded using imbedded optical sensors and outputs of the engine control system.

The data from these systems were organized as a data-base for validation of other activities with the Clean Sky Green Regional Aircraft program. All sensors were analyzed to obtain:

- 1/3 OB SPL
- OASPL
- A-weighted-OASPL
- Auto-Spectra
- Cross-Spectra
- Coherence
- Turbulent boundary layer characterization
- Emitted noise maps on the model through beamforming measures

V. Integration with the Clean Sky GRA program

The regional market represents an important part of Air Transport System today. At present 45% of flights are operated by regional aircraft and it is estimated that in 2020 this share will rise to around 50%. The Clean Sky program has set a vision for the future of European air transport with challenging objectives namely:

- 50% reduction of perceived noise compared to aircraft in service in the years 2000
- 40% less CO2 and 60% less NOx compared to current years 2000 technology

It is therefore necessary that a substantial contribution to reach the Clean Sky objectives comes from the Regional Air Transport. In order to reach these objectives, the Green Regional Aircraft program is currently pursuing advances in:

- Weight reduction
- Low noise configuration
- Fuel consumption reduction (efficient Power Plant, all electric system)

The objectives of the work on counter-rotating open rotors are:

- The development of a software code simulating the noise generated by CROR propellers in free space and the main installation effects
- The validation of this code by means of a wind tunnel test program (WENEMOR)

The outputs of the WENEMOR project will form a database through which the other Green Regional Aircraft partners can validate the developed software codes. ONERA is currently pursuing the development of a source model of CRORs for aeroacoustic simulation of isolated and installed engine configurations. CIRA is undertaking CFD work to calculate the blade surface pressures experienced in a CROR design.

VI. Future work

The WENEMOR project will fully characterise the noise emission of installed counter rotating open rotors on an advanced regional aircraft design. The test campaign of the WENEMOR project was completed in May 2013. The data analysis phase of the project is currently on-going and the results will be reported in the literature over the coming months. The principle results currently under investigation include the following:

The results of a parametric study of the CROR noise emission including far field noise maps, CROR source spectra and directivity and the influence of the model geometry on interaction tones. The influence of aircraft geometry on the noise emission of the counter rotating open rotor will be investigated using a parametric study. The aircraft configurations will be grouped to investigate the effects of tail geometry, engine pylon length, engine pylon rotation and wing to engine distance. The effect of these parameters on third octave band spectra and overall sound pressure level will be reported using noise maps on the top and lateral microphone arrays. The effects of model geometry on interaction tones and directivity will be assessed using the linear far field array where results can be correlated with the blade and fuselage sensors.

The broadband CROR source will be characterized through the application of microphone array techniques. Information from both single microphones and microphone arrays is used for the characterization of the broadband open rotor noise emissions. In particular, the benefits of beamforming in the time domain[1,2] are fully exploited. The advantage of this approach is the ability to directly deal with broadband signals and short transients. However, the study is not limited to the broadband noise sources only. The tonal noise source emissions are presented and the relative importance of the tonal and broadband sources discussed. A robust narrowband beamforming method detailed in Sarradj's work[3] is adapted to identify the location of the tonal noise sources. The application of a partial coherence technique for source isolation on the blade surface, in conjunction with the beamforming output, will be investigated using Kulite pressure signals from the rotor blades.

The project consortium consists of several partners with a diverse set of competencies in terms of data analysis. In order to fulfil the objectives of the project a number of different approaches has been taken by the consortium in order to fully characterise the CROR noise source in the challenging environment presented by installation on the airframe.

Acknowledgments

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References

[1]Dougherty, R. P., "Advanced Time-Domain Beamforming Techniques," *10th AIAA/CEAS Aeroacoustics Conference*, No. AIAA-2004-2955, Manchester, UK, 2004.

[2]Dobler, D. and Schroder, R., "Contrast Improvement of Acoustic Maps by Successive Deletion of the Main Source," *13rd Berlin Beamforming Conference*, No. BeBeC-2010-19, Berlin, Germany, 2010.

[3]Sarradj, E., "A Fast Signal Subspace Approach for the Determination of Absolute Levels from Phased Microphone Array Measurements," *Journal of Sound and Vibration*, Vol. 329, 2010, pp. 1553–1569.