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Ten years of aero-servo-elastic tests at large POLIMI's wind tunnel for active flutter control and loads alleviation

Sergio Ricci

Politecnico di Milano, Department of Aerospace Science and Engineering, Via La Masa 34, Milano, Italy

sergio.ricci@polimi.it

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Abstract. Born in the autumn of 2001, but fully operational since 2023, the large wind tunnel of Politecnico di Mlano turns 20 this year and today it is one of the 4 large research infrastructures of the University. Designed, from the point of view of fluid dynamics, entirely within Politecnico, it is close circuit wind tunnel characterized by a particular design that includes two test sections. The boundary layer section (14m x 4m x 38m), located in the return circuit, is particularly suitable for testing objects subjected to the action of the wind such as bridges, skyscrapers, stadiums and large roofing systems; this section is widely used for research in the wind energy sector. The low turbulence section (4m x 4m x 6m), located as usual between the convergent and divergent parts of the tunnel, is mainly used for aeronautical tests, such as airplanes and helicopters, but not only. Suffice it to recall the numerous tests carried out in the field of sport aerodynamics, because the dimensions allow the equipment to be tested directly with the athletes. The paper briefly describes the most relevant aero-servo-elastic tests carried out during the last 10 years of activity.

Introduction

In the late 1990s Politecnico di Milano decided to organize itself over a network of different campus, two in Milano, and other outside Milano in other cities such as Lecco, Como, Mantova and Piacenza. The new Bovisa campus, north side of the city, allowed to create large new laboratories for the Departments that decided to move there, at first Aerospace Department, followed by Mechanical and Energy. The design of the new spaces and new buildings has made it possible to create the large new wind tunnel, I would say unique in the university context.

The new wind tunnel, designed by taking advantage of the internal competences, is a traditional close circuit plant, but with unusual space organization. Indeed, the return circuit is used as a large chamber for wind engineering applications, with a maximum speed of 16 m/s, while two interchangeable test rooms of 4x4x6 m and a maximum speed of 55 m/s are used for typical aeronautical applications. Two characteristics make this wind tunnel especially useful for aeroelastic testing. At first, the large test rooms allow for testing large scale models, in some cases components at full scale. Second, the flow generation system based on 14 fans for a total of 1.5 MW power is fully protected by a steel grid, so that it cannot be damaged by possible brake of aeroelastic models. During years of activity the wind tunnel has been equipped with dedicated equipment for aeroelastic tests that will be presented in the following. Due to the limited space, mainly two kinds of aeroelastic tests will be briefly described: gust loads alleviation, and active flutter suppression tests.

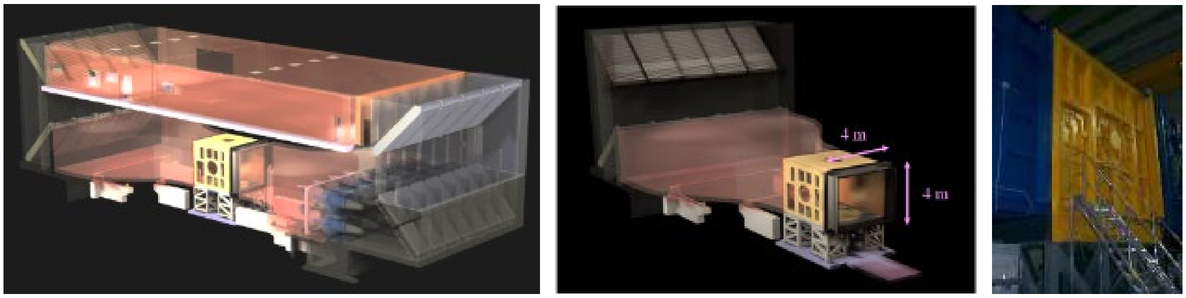

Figure 1: The POLIMI's large wind tunnel

Gust Load Alleviation Tests

During recent years a lot of studies have been dedicated to the implementation of maneuver and gust load alleviation techniques (MLA and GLA), as part of a more general strategy to decrease the environmental impact of future transport aircraft. Indeed, these techniques are believed capable for a further structural weight reduction of about 20%. Two are typically the challenges in testing in wind tunnel GLA control systems. The biggest part of the gust response is due to rigid body motion, so at least plunge and pitch motions must be reproduced. Second, due to the scale factor the bandwidth of actuators requested demands for sufficient space to install inside the model the actuators. These challenges have been addressed at POLIMI by means of the following strategies.

At first, a half model is usually adopted, and due to installation and accessibility problem, the half model is vertically mounted, the connection between the half fuselage and the wind tunnel floor is realized with a pivot, that preserves the pitch free body motion, mounted on a sledge that preserves the plunge free body motion. Since the gravity acts perpendicularly to the lift, a dedicated Weight Augmentation System (WAS) is used to artificially generate the weight force. The WAS consists in a linear electric actuator that acts on the moving sledge in correspondence of the center of gravity of the aircraft, reproducing the weight force indeed. An important ratio which cannot be preserved is the one between the inertial and gravity forces, represented by the Froude number. Thanks to the WAS, it is possible to impose the force that counteracts the lift force, and in the case of unit load factor n=1 it is the weight force. In this way the Froude scaling is preserved only for the plunge motion. For what concerns the model scaling, an iso-frequency approach is adopted, so that the control system designed for the full-scale aircraft can be plugged and played for the wind tunnel test. The different control surfaces are driven by Harmonic drive electric motors that guarantee large bandwidth, typically 15 Hz, and zero free play due to a patented gear box. A dedicated six vanes gust generator has been designed and manufactured able to produce typical 1-cos discrete gust as well as continuous gust excitation with prescribed PSD.

The equipment described above has been successfully tested during different European projects, such as GLAMOUR "*Gust Load Alleviation techniques assessment on wind tUnnel MOdel of advanced Regional aircraft*" (JTI-CS-2013-1-GRA-02-022), as well as the Clean Sky 2 AIRGREEN2 project. Figure 2, left shows the WTT3 1:8 scaled aeroelastic model representative of the future twin prop regional aircraft designed, manufactured, and tested by POLIMI in AIRGREEN project while in the same figure, on the right, a summary of results comparing the root bending moment reduction capabilities for different flight envelope velocities as well different control laws.

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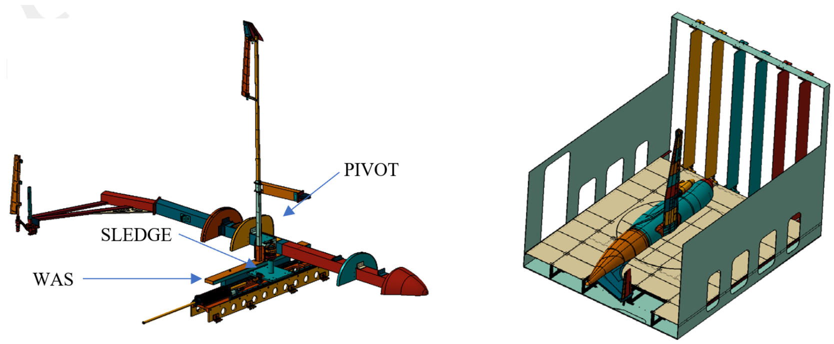

Figure 2: Photo of the aeroelastic half model installed on the WAS system (left) and the gust generator (right)

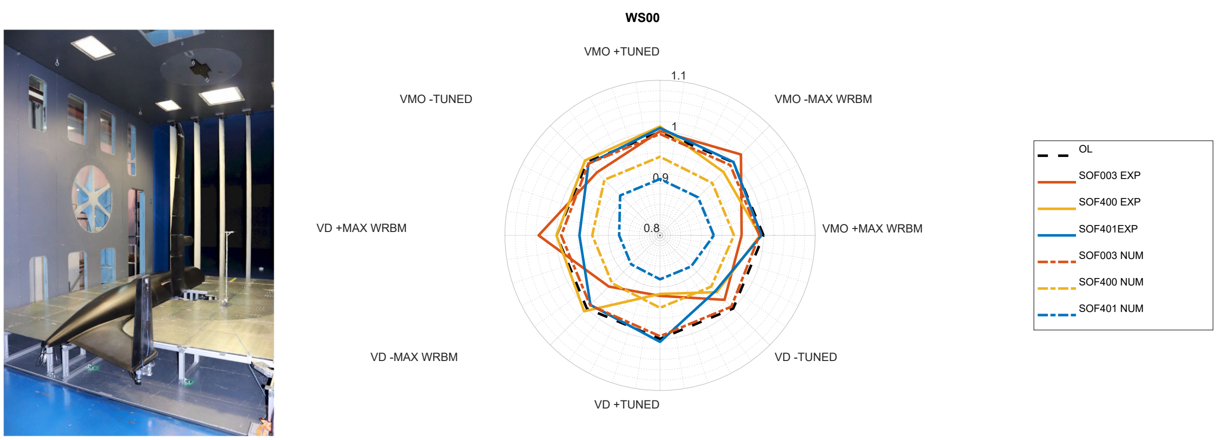

Figure 3: The WTT3 model (left) and the typical test results (right)

Active Flutter Suppression Tests

During the last 10 years POLIMI also acquired a deep knowledge in the design and manufacturing of aeroelastic scaled wind tunnel models used for validation of new active control strategies. One of them is for sure the so-called X-DIA model, three surfaces fully dynamically aircraft 1:10 scaled with respect the reference aircraft developed originally in the 3AS EU project and since then used for many wind tunnel test campaigns for multi surface aeroelastic control. The model has been updated in 2017 to a new, conventional configuration in the framework of the Active Flutter Suppression project in cooperation with the University of Washington in Seattle, USA, and FAA to investigate the robustness of active flutter suppression technologies. Different control laws have been developed and successfully tested, from the simple ones such as Static Output Feedback and ILAF, up to the more sophisticated and robust, such as H infinity. The ailerons, driven by Harmonic drive motors have been used for control. Dedicated safety devices installed on the tip based on a small moving mass from the rear to the forward position were adopted to stop the flutter in an automatic way in case of failure of the control system. The tests have been conducted with the model installed in the testing room by means of cable so to simulate the free-free conditions. During this study, more than 50 flutter conditions have been tested without any damage to the model, showing a very high reliability for the entire system.

During last two year the project focused on the effect of LCOs due to the free play in the control surfaces. Special devices have been designed and manufactured so to be able to apply accurate and small enough gaps to the elevators of X-DIA model. They have been tested separately and last February 2023 the new tailplanes have been installed on the X-DIA model to repeat the active flutter suppression tests in presence of LCOs. Due to the need to accurately set the angle of attack and side du to their strong effect on the preload in presence of gap on control surfaces, the model has been installed on a pylon, equipped with accurate alfa and beta positioning system. Due to the presence of the flexible pylon, the model shows now two flutter mechanisms: the original one, i.e. a symmetric bending torsion at 41.5 m/s, and a new one, an antisymmetric bending torsion at 47.5 m/s. This situation creates a challenging goal since, to identify the second flutter, it is necessary to control the first one. This has been done successfully, then also the second flutter has been actively controlled.

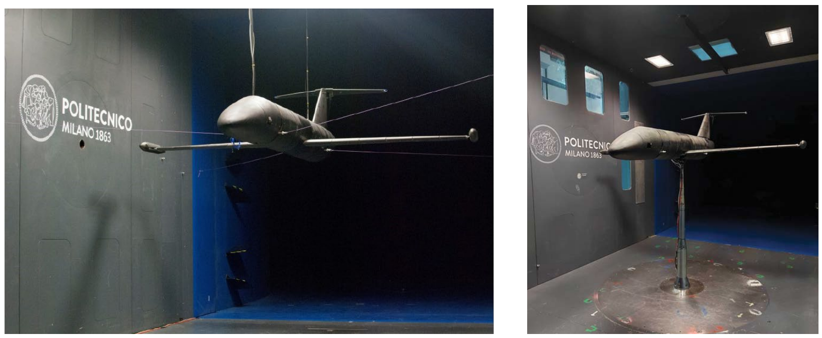

Figure 4: The XDIA model in free-free condition (left) and installed on the pylon (right)

Summary

In this paper a summary of the aeroelastic wind tunnel testing performed at POLIMI's large wind tunnel has been reported.

Acknowledgement

The large set of aeroelastic activities in the framework of different international projects has been possible thanks to the passion, dedication, and competence of many colleagues and students at different level involved. I would like to thank first Prof. Paolo Mantegazza that about 35 years ago founded the aeroelasticity branch at DAER-POLIMI. Then, the contribution of L. Riccobene, A. De Gaspari, F. Fonte, F. Toffol, L. Marchetti, N. Fonzi, V. Cavalieri and G. Bindolino is kindly acknowledged.

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