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Hybrid Micro Air Vehicle for Complex Environment Missions[†]

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Introduction

Modern urban reconnaissance missions dictate the need for a Micro Air Vehicle (MAV) platform capable of performing a complex mission : rapid and efficient ingress to a target location followed by slow loiter for quality image capture. This may be achieved using a tilt-body fixed-wing vehicle which combines the speed, range, and gust-hardiness of a fixed wing with the loiter and precision capability of a rotorcraft vehicle.

The MAVion, shown in Fig. 1, has been created for this purpose. It combines a fixed-wing airframe with tandem counter-rotating rotors. The direction of motor rotation has been chosen to counter wing tip vortices. Also, a tandem-rotor configuration has the advantage of providing an extra degree of freedom to control the vehicle along the yaw axis. From an aerodynamic perspective, it also allows for a larger wing area within the propeller slipstream, yielding higher aerodynamic flap efficiency and a better aerodynamic performance due to a higher aspect ratio.

(a) MAVion **(b) Roll & Fly**

Figure 1: The MAVion, a tandem-rotor tilt-body

Experimental Apparatus

Experimental studies on MAVs necessitate a low Reynolds number wind tunnel with the capability of supplying a stable and uniform flow at wind speeds ranging from 2 to 25m.s^{-1}. The SabRe wind tunnel located at ISAE has been designed for this purpose. As shown in Fig. 2, SabRe is a closed-loop wind tunnel.

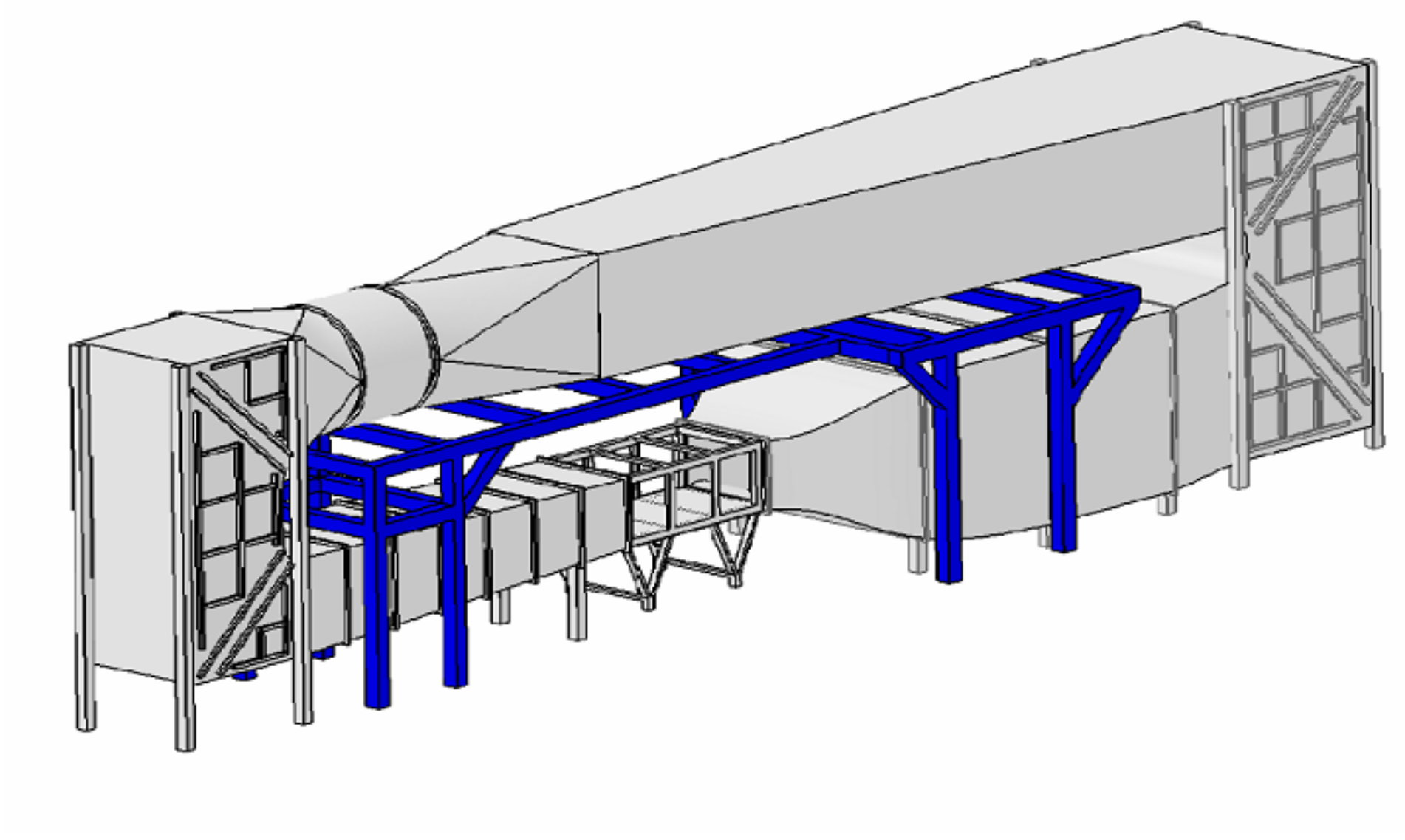


Figure 2: SabRe Wind Tunnel

The test section is 2400mm long with a square cross-sectional area of 1200 x 800 mm with a contraction ratio of 9. In order to produce a stable and uniform flow a pitch controlled fan was implemented along with a series of honeycomb grids and screens to split and damp vertical structure. By changing the fan speed and the pitch angle, turbulence intensity can be optimized and was found to be lower than 0.1 %.

A new 3-component aerodynamic balance devoted to MAV studies was used to measure lift, drag and pitching moment. The balance was designed to enable measurements at angles of attack between 0 and 90°. Two identical load cells were mounted on the parallelogram balance, giving uncoupled measurements of lift and drag while a final force sensor is mounted to the rear strut enabling a calculation of the moment about the center of gravity.

Equilibrium Transition

There are many ways to transition between horizontal and vertical flight modes. The intent of the current study is to explore equilibrium transition, defined here as maintaining the steady state forces and moments near to zero. This results in an energy efficient change between flight modes with no gain or loss of altitude.

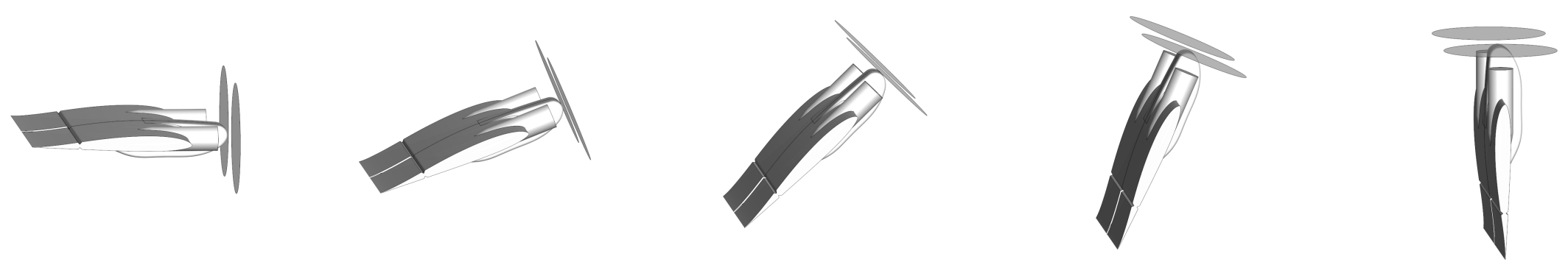


Figure 3: Equilibrium Transition

Wind tunnel tests were performed to determine the throttle setting, the elevator deflection and the upstream velocity for a given angle of attack during an equilibrium transition.

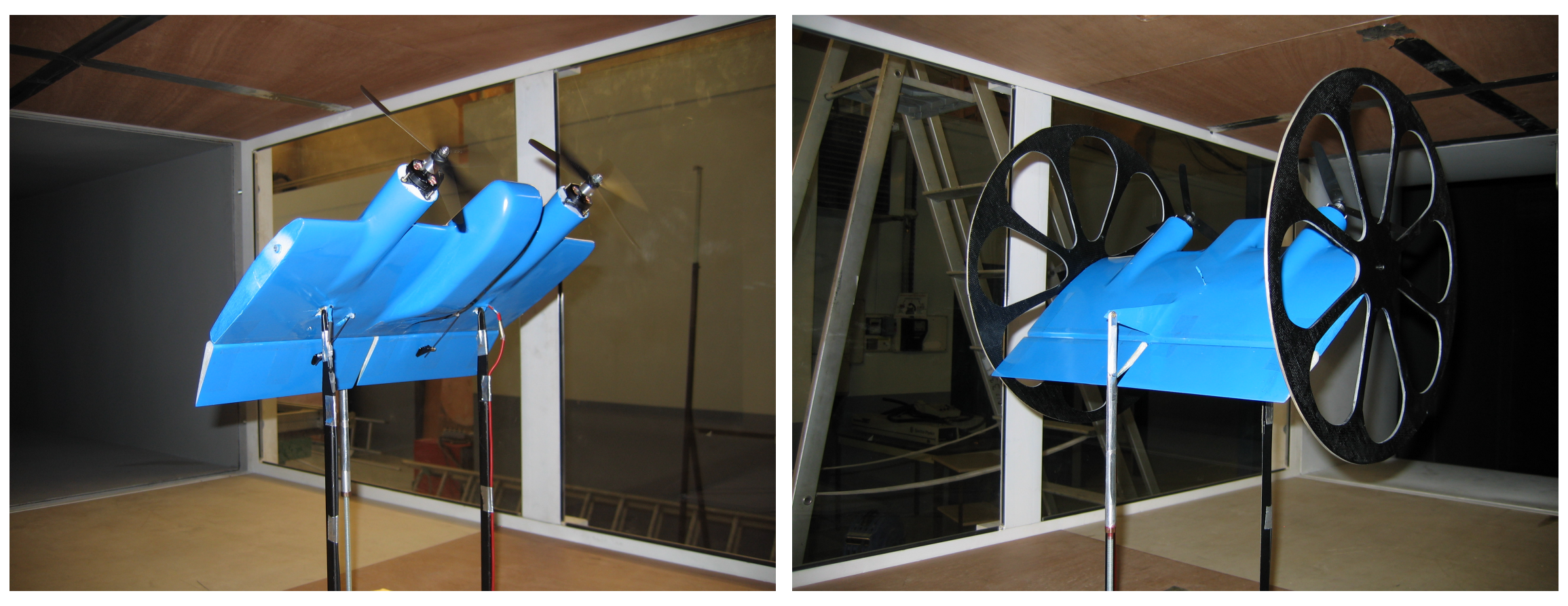


Figure 4: Wind Tunnel Model

The model, Fig.4, contains a core of expanded polypropylene surrounded by a shell of fibreglass. An onboard control and telemetry system was developed to reduce the need for physical cables which might affect the forces and torques measurements because of their intrinsic stiffness. The speed controllers have been programmed to return the rotation period of each motor. This information is used in a proportional-integrator (PI) loop to precisely control rotational velocity. This enables the operator to maintain a motor rotation speed despite changes in wind velocity or angle of attack.

The equilibrium curves are displayed in Figure 5 - 6.

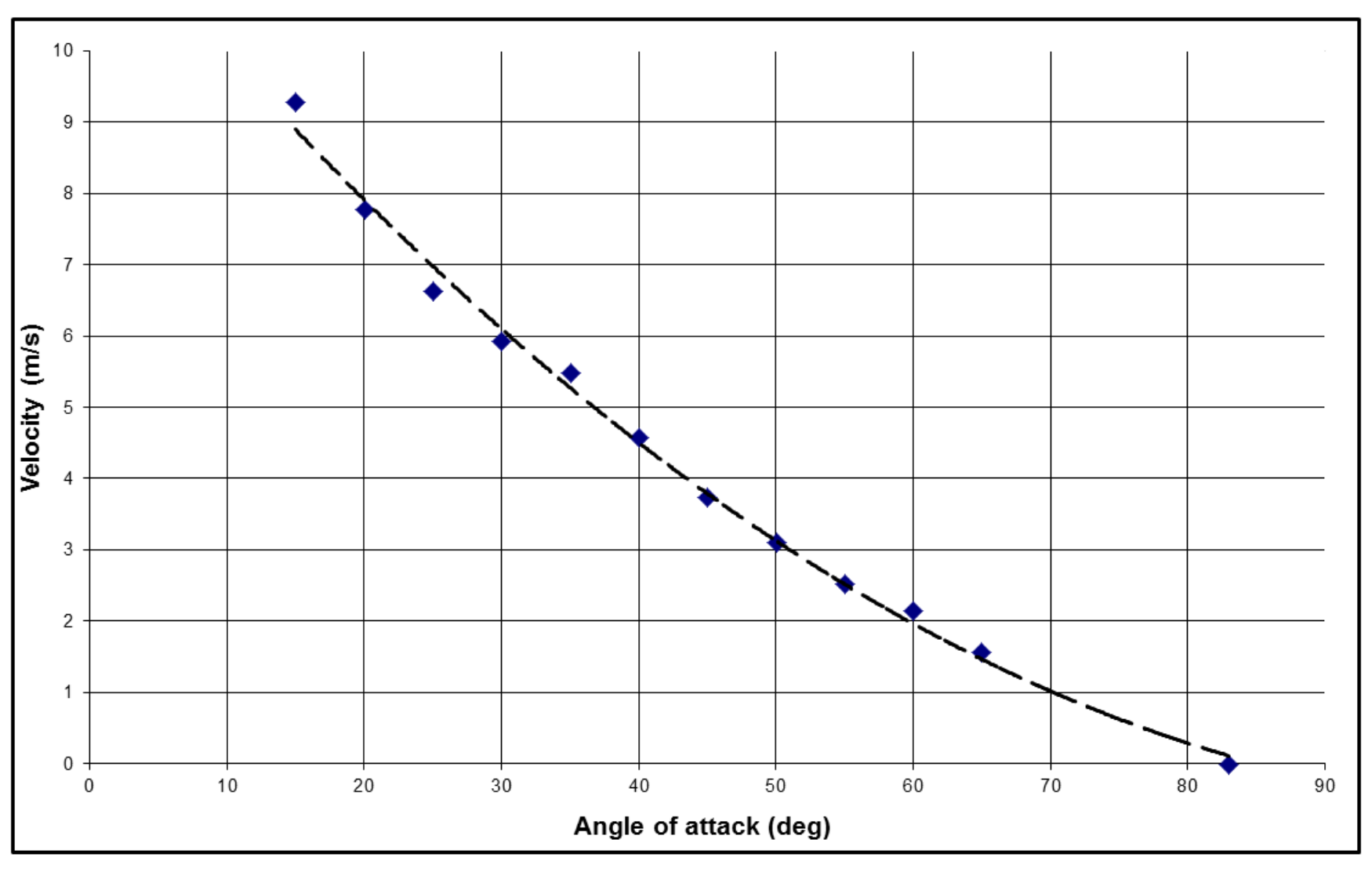


Figure 5: Wind-Tunnel Velocity for a specified Angle of Attack

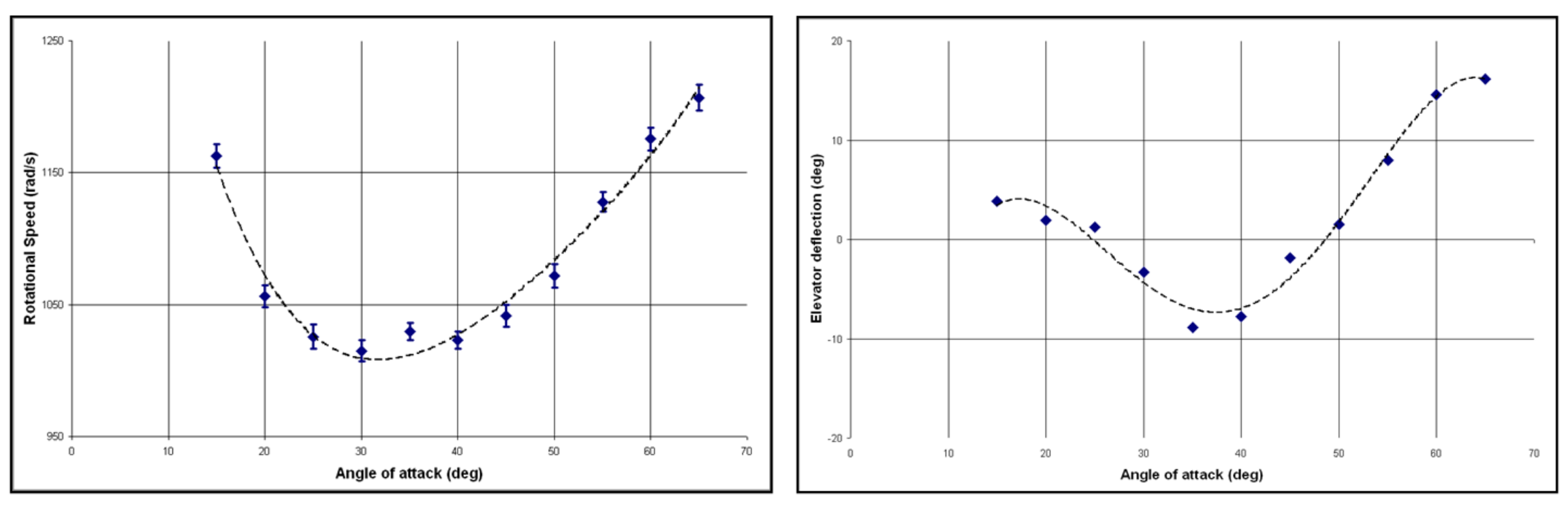


Figure 6: Motor speed and Elevator deflection for a specified Angle of Attack

Without motors the aircraft would normally stall at 20 degrees angle of attack. However, due to the momentum injected into the flow by the propwash, stall is never encountered. An additional conclusion can be drawn from investigation of Fig. 5 and 6. Between 20 - 40 degrees angle of attack, the required propeller rotation speed reaches a minimum. This the point at which the least power is required of the motors to maintain equilibrium flight. The cruise speed of the aircraft should be set between 5 - 8 m.s^{-1} to increase endurance for long flights.

Numerical Correlation

Numerical simulations are also in progress to validate the trim model and evaluate the specific nature of the flow. A structured C-grid of 5.10^{6} cells with an actuator disk is used to model the aircraft and the propellers as shown Fig.7.

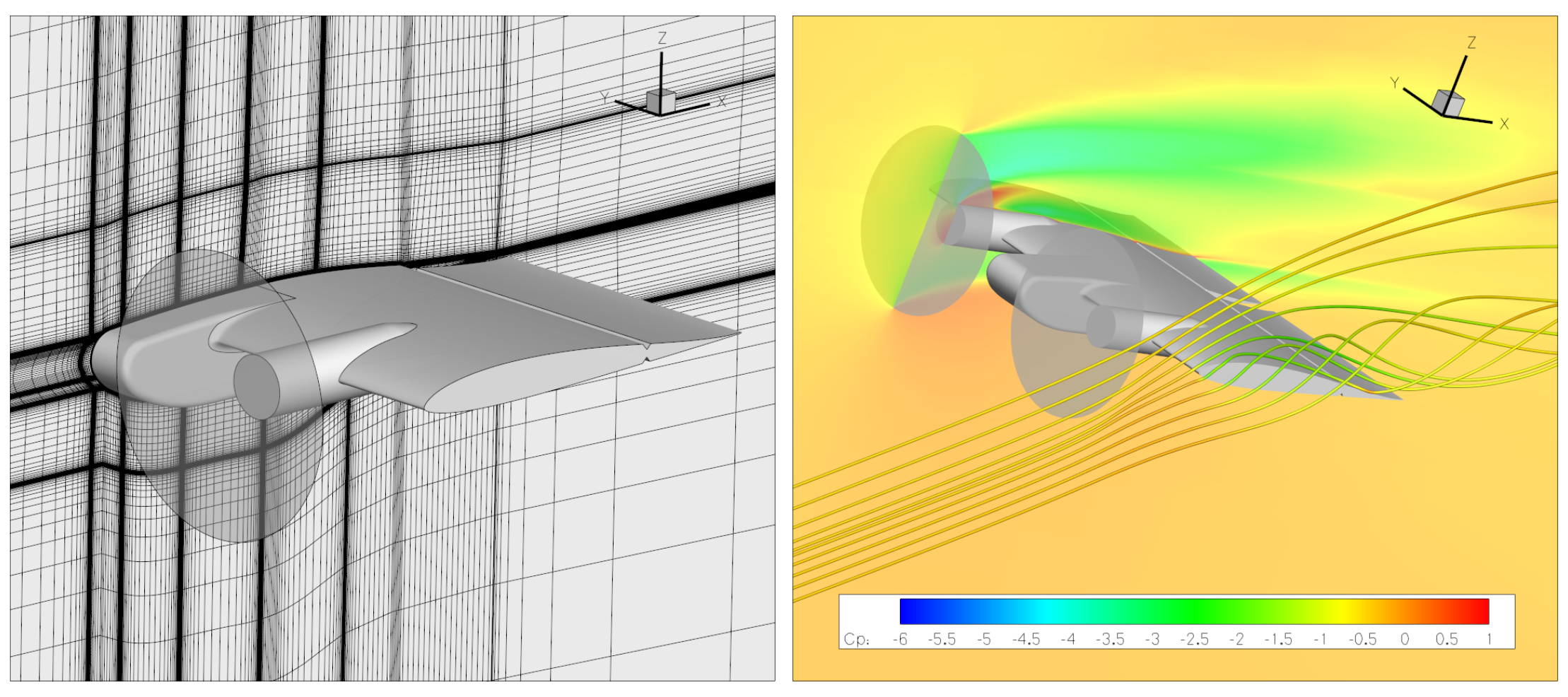
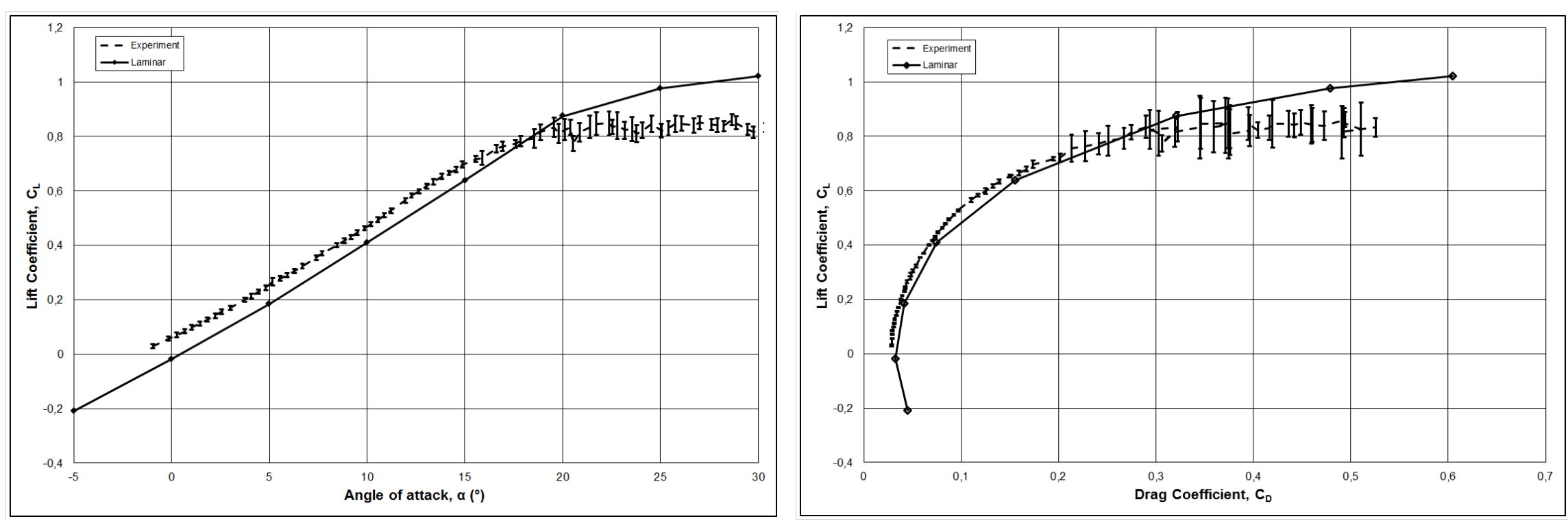


Figure 7: Meshing and Flow Analysis

First of all, a comparison between numerical and experimental data is done without propellers effect at *Re*=160 000. To provide accuracy close to the walls, a $y^+ < 5$ is implemented along with a viscous full Navier-Stokes computations with laminar approximation. Results are presented Fig. 8.

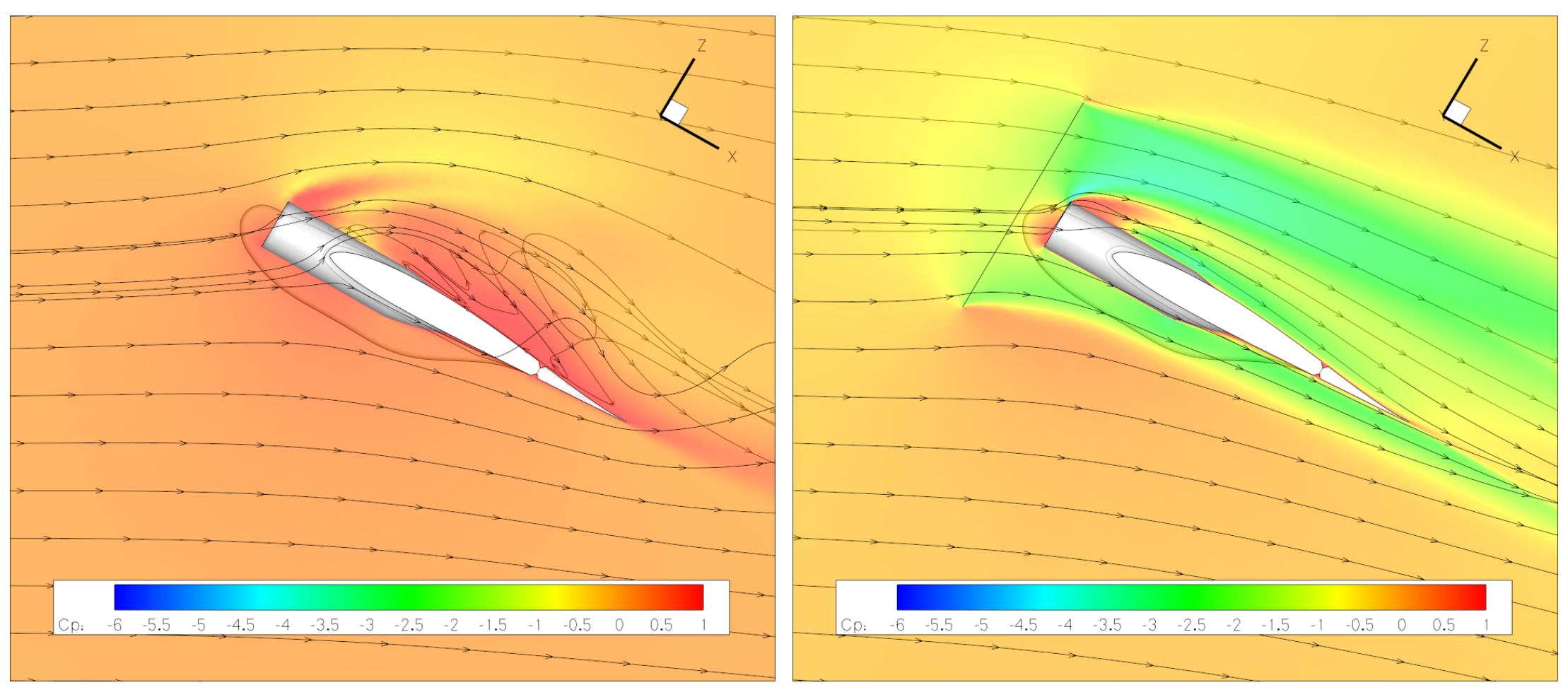


(a) $C_L = f(\alpha)$ **(b)** $C_L = f(C_D)$

Figure 8: Experimental & Numerical investigation

At angle of attack lower than 20°, numerical calculations fit with the experiment while higher angle is less accurate due to stall.

Then, based on experimental data, propwash effect is visualized Fig. 9, using a Y-plane on the motor mount with iso-pressure coefficient overlay to streamtraces.



(a) Without propeller **(b) Actuator disk approximation**

Figure 9: Iso-pressure coefficient & Streamtraces

Those computations confirm that due to the momentum injected into the flow by the propwash, stall is not encountered while transitioning.

Summary and Prospects

The end goal of the aerodynamic testing is to produce aircraft uniquely capable of vertical and horizontal flight modes. Two prototypes have already been constructed and developed at ISAE. The first, equipped with GPS, has demonstrated fully autonomous outdoor transitions. The second version, destined for mostly indoor flight, has carbon fibre wheels attached which are used to roll along the ground, walls, and ceilings guided by an attached camera using First Person Vision.

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