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Doctoral Dissertation  
Doctoral Program in Aerospace Engineering (37<sup>th</sup> cycle)

# Experimental evaluation and modeling of ground, ceiling and wall effects for small-scale quadcopters

By

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Politecnico di Torino

2025

## Abstract

Multicopters hold great potential for indoor applications. However, their performance is strongly influenced by aerodynamic interactions with nearby surfaces such as walls, ceilings, and the ground. Anticipating these effects in advance can be leveraged for more accurate trajectory planning and, ultimately, for improving the autonomy and safety of rotorcraft operations. While previous studies have addressed these phenomena, the influence of air density has remained largely unexplored.

Among these interactions, the ground effect—well established in helicopter aerodynamics since the 1950s—is the most widely studied. Yet, the increasing use of multirotors has highlighted the need for accurate models that also capture the aerodynamic disturbances induced by proximity to ceilings and walls. Such models can contribute to more efficient and reliable flight in constrained environments.

In this work, experimental campaigns were carried out with a quadrotor inside the terraXcube climatic chamber at EURAC Research, where both pressure and temperature could be controlled. A force–torque sensor was used to record the aerodynamic forces and moments during hovering conditions as the UAV approached different surfaces. This climate-controlled setting made it possible to simulate high-altitude environments, particularly relevant for search-and-rescue operations in mountainous terrain. Complementary experiments were also performed at the University of Denver with a different test setup, enabling valuable cross-validation of results.

Following the experiments, two modeling approaches were developed: exponential regression and Gaussian Process regression. The final campaign results were accompanied by a detailed uncertainty assessment. In addition, a CFD validation of the experimental setup was performed for ground and ceiling effects, showing strong agreement with the measurements within a 10% error margin.