Aerospace Europe Conference 2023
Joint 10th EUCASS – 9th CEAS Conference

Abstract #XXX *(to be filled by the organizers)*
Preferred Topics: UAVFUT / AEROFLIPHY / FDGNCAV
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Wind Tunnel Characterization of a Delta-Wing UAV for Model-Based Navigation

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Abstract
Model based navigation represents an attractive alternative to enhance the performance of autonomous (i.e. interoceptive) navigation through aerodynamic constraints on small UAVs where the quality of IMU is mediocre. It does so through mathematical modeling, i.e. without an implementation of an additional sensor. Simulations [1] and empirical testing [2][3] on small drone of a conventional aircraft with 5 (4-independent) control surfaces have shown considerable improvements of localization (an order of magnitude or more) compared to inertial coasting. The objective of this research is to obtain similar result in a real case scenario for a delta-wing UAV. However, contrary to a kinematic approach, the dynamic navigation requires identification of model structure and determination of its parameters. In this paper, we detail the experimental procedure to obtain the data needed for aerodynamic characterization of a delta-wing UAV using wind tunnel experiments. The experimental set-up is discussed first, then the adopted methodology to isolate the aerodynamic force and moment data. The experiments are divided in static and dynamic parts, with the former providing less noisy estimates (of some coefficients) while the latter supplying a more truthful representation of real flight condition. In particular, the design of dynamic experiments is motivated as it aims to define a trajectory that maximizes the flight parameters observability. We report the aerodynamic characterization of the propulsion system and analyze the mutual influences of UAV body and a spinning propeller blade, known as downwash and propwash effects. Then we briefly discuss the secondary aerodynamic influences such as the Reynold's number effect. Eventually, we discuss the model selection procedure, based on stepwise regression. Two models are presented, one minimalistic with only 16 coefficients, the other fitting the experimental data at a higher level of complexity. Finally, we establish a performance metric to assess which model is to be preferred while balancing the simplicity and accuracy trade-offs. We practically show the consequences of overfitting the experimental data with an overly complex model. Ultimately, we evaluate the performance of each selected model empirically in-flight with an (offline-implemented) navigation solution during GNSS-signal outages. We use an open-source PixHawk autopilot (FMUv5) with one of its IMU, data of which are recorded together with control-command and GNSS positions. Although implemented in replay, the filter provided solution is such as would be obtained in real time. The GNSS outages are reproduced by withholding GNSS observations within the filter. The results show that, during GNSS outage the model-based navigation solution manages to reproduce accurately the desired planned trajectory with a positioning error several times smaller than in the INS-GNSS navigation case.

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