Ecole doctorale SMAER
Sciences **M**écaniques, **A**coustique, **E**lectronique, **R**obotique

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Laboratory : ISIR

University: UPMC

Title of the thesis: **Modelling and model identification for convertible mini aerial vehicles**

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Collaborations within the thesis:

Program affiliation:

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This subject can be published on the doctoral school's web site: Yes

Thesis's summary (abstract):

Mini Aerial Vehicles (MAVs) have become an essential tool to address surveillance and inspection applications. Depending on the mission, different types of MAVs can be preferred. This thesis concerns so-called "Convertible MAVs" that combine the characteristics of rotary-wing systems (e.g., multirotors) and fixed-wing systems (airplanes). Thanks to a combination of propellers and wings, these vehicles can perform both stationary flight and efficient cruising flight. However, this versatility also comes with specific challenges. The main one concerns the transition from stationary flight to cruising flight, which is associated with strong and fast variations of aerodynamic forces. This issue is all the more critical that precise aerodynamic modelling of these systems is very difficult. The objective of this thesis is to develop dynamic models of convertible MAVs that can be used for the design of flight controllers, and model identification methods in order to estimate the model parameters from flight data, either online or offline. The thesis will involve both methodological developments and experimental developments based on a new convertible MAV developed at ISIR.

Modelling and model identification for convertible mini aerial vehicles

Context: In the last decade, Mini Aerial Vehicles (MAVs) have emerged as an efficient and low-cost solution to address lots of inspection and surveillance missions. Like more traditional full-scale aircraft, most MAVs belong to one of the following categories: fixed-wing, rotary-wing, or convertible aerial vehicles.

- Except for their size, fixed-wing MAVs do not fundamentally differ from full-scale airplanes. Thanks to their wings, they constitute an energy efficient solution for long-term/long-range missions.
- Contrary to most fixed-wing MAVs that cannot perform stationary flight, the main advantage of rotary-wing MAVs is their ability to hover. Helicopter-like MAVs belong to this class but, from the beginning of this century, multirotors (quadrotors, hexarotors, etc.) have been used increasingly. Compared to helicopters, their lower energy efficiency is compensated by a much simpler mechanical design synonymous of reduced cost and maintenance, and increased robustness.
- Convertible MAVs combine stationary flight capacities (like rotary-wing aircraft) with improved efficiency in cruising flight (like airplanes), thanks to a combination of wing(s) and propellers. Different configurations have been proposed and research on this topic is still very active. These systems are useful for long-range missions that require to take-off and land in a narrow area, or that require performing stationary inspection along the mission. Examples include inspection of off-shore wind turbines or maritime surveillance with take-off/landing from a small ship.

This thesis concerns convertible MAVs and more specifically the problem of constructing dynamic models of these systems and identifying the model parameters from flight data. It is related to the recent development at ISIR of a new convertible MAV structure (shown below), which has given rise to the patent [1].

Objectives: The long term objective of our research on convertible MAVs is the development of autopilots in order to ensure efficient and safe autonomous flight. To design such autopilots, it is necessary to develop a dynamic model of the MAV, from which the control design can be performed. The main issue encountered today is the lack of existing models in the literature, especially as concerns the aerodynamics of these systems. This aerodynamics is known to be complex due to a variety of reasons:

- Due to their small size, MAVs are sensitive to external wind conditions and large variations of the angle of attack can occur. Linearized aerodynamic models, as classically used in aeronautics of full-scale aircraft, are no longer sufficient to cover all flight phases.
- Transitions from stationary flight to cruising flight go with strong and fast variations of aerodynamic forces. Dynamic aerodynamic effects can then become important.
- Aerodynamic interactions between propellers and wings can be important due to their close proximity and due to the relatively large size of propellers compared to full-scale aircraft.

The development of autopilots relies on dynamic models of the system. Aerodynamic modelling has to be representative of the physics, but it also has to be simple enough to allow for control design and implementation. In this respect, infinite-dimensional models based on Navier-Stokes equations are not suited for feedback control design. What we need are explicit finite-dimensional models involving a reduced set of parameters that can be identified from simple measurements and/or flight tests. In this respect, this thesis is inspired by a control/robotics approach. A first objective of the thesis is to propose such models, knowing that they should be representative of the flight dynamics in a large flight envelope. The rich aeronautics literature is obviously a good starting point for such models but as far as convertible MAVs are concerned, this literature is limited. Specific models need to be developed. Another objective is to develop the identification methods that will permit to identify the parameters involved in these models from flight data. Both offline and online methods will be considered. Finally, the last objective of the thesis is to validate these models and model identification methods on our convertible MAV and possibly on other types of convertible MAVs.

Expected results: The thesis is part of a research program which aims at making a leap forward in the control of convertible MAVs. Existing studies have been based on classical aeronautics methods, which rely on linear aerodynamic models. The impact of these methods has been limited so far. There is no genericity in the way the control of these systems is addressed and the literature only shows case by case approaches with limited practical impact. We believe that modelling/model identification is a key to the control of these systems. By proposing simple but generic flight models easily identifiable through flight tests, the thesis can highly contribute to a better understanding of convertible MAVs and to a new generation of drones.

[1] P. Morin, O. Gasté, D.-K. Phung, Light unmanned vertical takeoff aerial vehicle, Patent N° WO/2016/092102, 2016.