Thèse de doctorat

Pour obtenir le grade de Docteur de l'Université

POLYTECHNIQUE HAUTS-DE-FRANCE

Spécialité micro et nanotechnologies, acoustiques et télécommunications

Présentée et soutenue par Doan LE ANH.

Le 01/03/2019, à Valenciennes

Ecole doctorale :

Sciences Pour l'Ingénieur (SPI)

Equipe de recherche, Laboratoire :

Institut d'Electronique, de Micro-Electronique et de Nanotechnologie/Département d'Opto-Acousto-Electronique (IEMN/DOAE)

Du micro véhicule aérien au nano véhicule aérien : études théoriques et expérimentales sur un insecte artificiel à ailes battantes

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Abstract

In recent decades, the prospect of exploiting the exceptional flying capacities of insects has prompted much research on the elaboration of flapping-wing nano air vehicles (FWNAV). However, when designing such a prototype, designers have to wade through a vast array of design solutions that reflects the wide variety of flying insects to identify the correct combination of parameters to meet their requirements. To alleviate this burden, the purpose of this work is to develop a suitable tool to analyze the kinematic and power behavior of a resonant flexible-wing nano air vehicle. The key issue is evaluating its efficiency. However, this ultimate objective is extremely challenging as it is applied to the smallest flexible FWNAV. However, in this work, we worked first with a flapping-wing micro air vehicle (FWMAV) in order to have a tool for the simulation and experimentation of wing actuation, take-off and hovering. Some of the knowledge and experience acquired will then be transferred to better understand how our FWNAV works and identify the energy, power distribution.

Although both of the vehicles employ the insect wing kinematics, their wings actuation mechanisms are not the same due to their sizes difference. Since the FWNAV is smaller, their wings flap at a higher frequency than the FWMAV as inspired by nature. As a consequence, from MAV to NAV, the wing actuation mechanism must be changed. Throughout this work, it can be seen clearly that this difference affects the whole vehicles development including the design, the manufacturing method, the modeling approach and the optimizing process. It has been demonstrated that the simulations are in good correlation with the experimental tests. The main result of this work is the proper wing kinematics of both FWMAV and FWNAV which leads to a lift to the weight ratio bigger and equal to one respectively. The FWMAV is even success to take-off and vertically stable hover. Moreover, taking advantage of the Bond Graph-based models, the evolution power according to the wing dynamic and the efficiency of the subsystem can be evaluated. In conclusion, this study shows the key parameters for designing and optimizing efficiency and the lift generated for two flapping wing vehicles in different size regimes.

Keywords: nano air vehicles, micro air vehicle, flapping-wing, power, energy, Bond Graph

Résumé

Au cours des dernières décennies, la possibilité d'exploiter les capacités de vol exceptionnelles des insectes a été à l'origine de nombreuses recherches sur l'élaboration de nano-véhicules aériens (NAVs) à ailes battantes. Cependant, lors de la conception de tels prototypes, les chercheurs doivent analyser une vaste gamme de solutions liées à la grande diversité des insectes volants pour identifier les fonctionnalités et les paramètres adaptés à leurs besoins. Afin d'alléger cette tâche, le but de ce travail est de développer un outil permettant à la fois d'examiner le comportement cinématique et énergétique d'un nano-véhicule aérien à ailes flexibles résonantes, et donc d'évaluer son efficacité. Cet objectif reste néanmoins extrêmement difficile à atteindre car il concerne des objets de très petites tailles. Aussi, nous avons choisi tout d'abord de travailler sur un micro-véhicule aérien (MAV) à ailes battantes. Il s'agit avant tout de valider l'outil de modélisation à travers une comparaison systématique des simulations avec des résultats expérimentaux effectués lors de l'actionnement des ailes, puis au cours du décollage et du vol stationnaire du prototype. Une partie des connaissances et expériences acquises pourra ensuite être utilisée afin de mieux comprendre le fonctionnement et identifier la distribution d'énergie au sein du NAV.

Bien que les deux véhicules s'inspirent directement de la cinématique des ailes d'insectes, les mécanismes d'actionnement des ailes artificielles des deux prototypes ne sont pas les mêmes en raison de la différence de taille. Comme le NAV est plus petit, ces ailes ont un mouvement de battement à une fréquence plus élevée que celles du MAV, à l'instar de ce qui existe dans la nature. En conséquence, lorsque l'on passe du MAV au NAV, le mécanisme d'actionnement des ailes doit être adapté et cette différence nécessite d'une part, de revoir la conception, l'approche de modélisation et le processus d'optimisation, et d'autre part, de modifier le procédé de fabrication. Une fois ces améliorations apportées, nous avons obtenu des résultats de simulations en accord avec les tests expérimentaux. Le principal résultat de ce travail concerne l'obtention pour les deux prototypes, le MAV et le NAV, d'une cinématique appropriée des ailes, qui conduit à une force de portance équivalente au poids. Nous avons d'ailleurs démontré que le MAV était capable de décoller et d'avoir un vol stationnaire stable selon l'axe vertical. En tirant parti des modèles basés sur le langage Bond Graph, il est également possible d'évaluer les performances énergétiques de ces prototypes en fonction de la dynamique de l'aile. En conclusion, cette étude contribue à la définition des paramètres essentiels à prendre en compte lors de la conception et l'optimisation énergétique de micro et nano-véhicules à ailes battantes.

Mots clés: nano-véhicules aérien, micro-véhicule aérien, ailes battantes, puissance, énergie, Bond Graph

Preface

This dissertation is formatted in accordance with the regulations of the University of Polytechnique Haut-de-France and submitted in partial fulfillment of the requirements for a PhD degree awarded jointly by the University of Polytechnique Haut-de-France. Versions of this dissertation will exist in the institutional repositories of this university.

All aspects of the material appearing in this thesis have been originally written by the author unless otherwise stated.

This work has been done in the IEMN-DOAE laboratory under the supervision of Prof. Sébastien Grondel, and Prof. Eric Cattan.

A version of chapter 4 has been submitted. [A.L. DOAN], D. Faux, O. Thomas, S. Grondel, E. Cattan, Kinematic and power behavior analysis of a resonant flexible-wing nano air vehicle using a Bond Graph approach, January 2019. All the experiments and simulations were conducted by the author under the supervision of Prof. Sébastien Grondel, and Prof. Eric Cattan.

A version of chapter 3 was presented at the International Micro Air Vehicle conference and Flight Competition on the flapping wing MAV, 2017 (A.L. DOAN, C. Delebarre, S. Grondel, E. Cattan, Bond Graph based design tool for a passive rotation flapping wing IMAV2017, p. 242).

A version of chapter 4 was presented at the International Mechatronics conference on the flapping wing MAV, 2017 (A.L. DOAN, D. Faux, S. Dupont, S. Grondel, E. Cattan, Modeling and simulation of the vertical takeoff and energy consumption of a vibrating wing nano air vehicle REM2016, p. 123).

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Abbreviations

UAVs	Unmanned aerial vehicles
DC	Direct Current
MAV	Micro Air Vehicles
NAV	Nano Air Vehicles
FWMAV	Flapping Wing Micro Air Vehicles
FWNAV	Flapping Wing Nano Air Vehicles
SNCF	Society of French railways
Re	Reynold number
CDF	Computational Fluid Dynamics
LEV	Leading edge vortex
TEV	Trailling edge vortex
BEM	Blade Element Method
ASIC	Application Specific Integrated Circuit
IC	Integrated circuit

Acknowledgements

I wish to express my deepest gratitude to two Professors, **Sébastien Grondel** and **Eric Cattan**, my advisors, for his guidance, patience and careful supervision towards my academic program. My study in the laboratory IEMN-DOAE and this thesis would not be done and completed without his persistent support and encouragement. He showed me how to be an intelligent scholar who rigorously pursues the truth. He made me know that I can do things that I thought to be beyond my capacity.

I would like to express thanks to Associate Professor **Thi Muoi Le**. She was the first person who helped, encouraged me to come to Valenciennes to study.

I gratefully acknowledge and would like to express special thanks to my friend **Damien Faux**, who allowed me to use a part of his research for my work. He has given me also a lot of constructive comments and valuable suggestions all the way long.

I am especially indebted to the **Polytechnic University of Hauts-de-France** for granting me study leave and supporting me during my stay.

I would like to express thanks to my all friends in France who bring me so much fun!

Finally, I owe an immeasurable indebtedness to my family who has always stayed beside me. Their continuous support and encouragement have been my sources of confidence that my study and my work in France would eventually be completed!

Best regards, THANKS ALL!!!

Dedication

I dedicate this thesis

To the memory of my late grandparent