NUMERICAL MODELLING OF ULTRA-THIN STRUCTURES IN A FLUID DOMAIN

Varakini Sanmugadas

178083H

Degree of Master of Science

Department of Civil Engineering

University of Moratuwa

Sri Lanka

September 2018

NUMERICAL MODELLING OF ULTRA-THIN STRUCTURES IN A FLUID DOMAIN

Varakini Sanmugadas

178083H

Thesis submitted in partial fulfilment of the requirements for the degree
Master of Science in Civil Engineering

Department of Civil Engineering

University of Moratuwa

Sri Lanka

September 2018

DECLARATION

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books)

……………………………………… Date:

S.Varakini

The above candidate has carried out research for the Masters under my supervision.

……………………………………… Date:

Dr. H.M.Y.C. Mallikarachchi

ABSTRACT

Folding structures with a large surface area into a compact configuration and deploying them only when required can be achieved by employing origami based folding patterns. This technique is widely seen in nature and mimicking such mechanisms for folding and deployment purposes can lead to highly efficient systems. This study focuses on the biomimicry of insect wings in the design of wings for insect-sized micro air vehicles (MAVs). In order to achieve the required aerodynamic lift and forward propulsion, the wings have to be sufficiently large. At the same time, for manoeuvrability while on ground and also to protect the wings while not in use, the size can be a limiting factor. The wing-folding technique used by certain class of insects is an attractive design solution, which however leads to the need for rigorous numerical analysis, as the fold lines introduced for folding purposes can alter the aerodynamic behaviour of the structure. For a comprehensive analysis a fluid structure interaction (FSI) framework will be required.

This thesis presents a detailed study of how the capabilities of commercially available computational structural dynamics (CSD) and computational fluid dynamics (CFD) codes can be exploited in conducting a FSI study of a system involving thin, creased, membranous structures immersed in flowing fluid. For this purpose, initially the suitability of two widely used software environments, ABAQUS and ANSYS Workbench, was investigated. Based on requirements and resource availability ABAQUS CAE and CFD solvers were chosen for the current work and a rigorous study of the theoretical concepts employed by these codes was conducted to ensure that it was in line with the objective at hand.

The FSI framework was implemented in three stages. First, the structural domain was developed. A Mooney-Rivlin material model with a membrane formulation was found to be suitable for modelling thin biological membranes. However, for simplicity a linear elastic material with plastic properties was initially assumed and was used in combination with a shell formulation.

Next, the fluid domain was developed using a Spalart-Allmaras turbulence model and was verified qualitatively based on the variation in flow around a rigid cylinder with Reynolds Number. Finally, both aforementioned domains were coupled using an explicit Gauss-Seidal scheme through the Abaqus Co-simulation Engine. This was verified against a standard benchmark study conducted by Turek and Hron (2006), which involves a cylinder immersed in a laminar flow with a thin, flexible flap attached to its downstream side. The sinusoidal oscillation of the flexible flap was captured and features such as vortices and streamlines were reproduced to an acceptable extent. However, the numerical accuracy of the solutions needs further improvement.

As the next stage, the behaviour of a creased membrane immersed in the above fluid domain was studied. To introduce the crease effect, the crease geometry was pre-defined on the structural component and this was then coupled with a fluid domain set up following the same procedure as in the previous case. This method, while presenting a simpler modelling path, has the disadvantage that the exact hinge-effect introduced by an actual crease-line is not captured. However, the alteration to the flow path from a geometric perspective was captured.

In the developed model a main concern was the processing time. To address this issue a two-dimensional shell formulation was used in this work. The presence of the shell was indicated by a seam crack in the fluid domain. Despite that, the model still suffered from the severe disadvantage of processing time. Thus in future works, other techniques should be incorporated to overcome this constraint. Also, the actual behaviour of the crease-line and the region close to it should be captured. A technique that could be used in future works was presented in the final section of the thesis.

Key words: Fluid structure interactions; Origami; Biomimicry; Deployable wings; Abaqus co-simulation engine

DEDICATION

To my parents and sister for being with me at each step of my life and my supervisor, Dr.H.M.Y.C. Mallikarachchi, for his infectious enthusiasm and indelible mentorship.

ACKNOWLEDGEMENT

I would first like to thank my supervisor, Dr. Chinthaka Mallikarachchi, for encouraging my interest in the biomimetic area, though relatively new to the department, and supporting me in every step of this work. His technical guidance, motivational words and patience have been invaluable in overcoming the hurdles along the way.

Next, I extend my sincere gratitude to Prof. Priyan Dias and Dr. Chathura Ranasinghe for the valuable comments and suggestions given during progress reviews. Their well-informed insights have never failed to be thought provoking. Also, I would like to take this opportunity to thank all the academic staff of the Department of Civil Engineering, University of Moratuwa, for laying a strong technical foundation.

Also, I thank my research colleagues Mierunalan, Chamith, Milinda, Hasitha and Sahangi for the numerous discussions at and outside group meetings, which have often led to opening new lines of thought in my present work.

Finally I would like to thank the National Research Council, Sri Lanka and Senate Research Committee of University of Moratuwa for the financial assistance provided.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

MAV	Micro Air Vehicle
UAV	Un-aided Air Vehicle
PIV	Particle Image Velocimetry
CFD	Computational Fluid Dynamics
CSD	Computational Structural Dynamics
FSI	Fluid Structure Interaction

LEV	Leading Edge Vortex
DOF	Degree of Freedom
FEM	Finite Element Method
FVM	Finite Volume Method
ALE	Arbitrary Lagrangian Eulerian4
CSE	Co-simulation Engine
NSE	Navier Stokes Equation
VIV	Vortex Induced Vibrations

LIST OF APPENDICES