

**NUMERICAL MODELLING OF ULTRA-THIN  
STRUCTURES IN A FLUID DOMAIN**

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Degree of Master of Science

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Sri Lanka

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Thesis submitted in partial fulfilment of the requirements for the degree  
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## **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.

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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.

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# CONTENTS

Declaration .....	i
Abstract .....	ii
Dedication .....	iv
Acknowledgement.....	v
List of Figures .....	viii
List of Tables.....	ix
1. Background .....	1
1.1. Bio-inspired Deployable Structures .....	1
1.2. Problem Statement .....	3
1.3. Objective .....	5
1.4. Outline.....	5
2. Literature Review .....	7
2.1. Insect-scale Flight Mechanisms .....	7
2.1.1. Macro vs Micro Flight Mechanisms .....	7
2.1.2. Insect-scale Flight Concepts .....	9
2.2. Wing Structure of Insects.....	10
2.2.1. Material Model.....	10
2.2.2. Deployable Wings.....	10
2.2.3. Origami Concepts.....	11
2.3. Numerical Simulation techniques .....	16
2.3.1. Basic Concepts related to FSI Simulation.....	16
2.3.2. State of the Art in FSI Analysis .....	17
2.3.3. ABAQUS vs ANSYS Workbench .....	20
2.3.4. FSI Analysis Capabilities in ABAQUS .....	21



3. FSI Simulation of Thin Flexible Structures .....	24
3.1. Numerical Implementation Concepts.....	24
3.1.1. Structural Domain .....	24
3.1.2. Fluid Domain .....	26
3.1.3. Mesh.....	28
3.1.4. Coupling Scheme .....	30
3.2. Model Specifications.....	31
3.2.1. Verification Model .....	31
3.2.2. Structural Domain .....	33
3.2.3. Fluid Domain .....	35
3.2.4. Verification of Fluid Domain.....	36
4. Results and Discussion.....	40
4.1. Uncreased Membrane.....	40
4.2. Creased Membrane.....	44
5. Conclusion and Future Works.....	47
5.1. Conclusion.....	47
5.2. Future Work .....	48
5.2.1. Crease Modelling through Plastic Damage.....	48
REFERENCES.....	51
APPENDIX .....	56

## LIST OF FIGURES

Figure 1.1: Weight to span relationship of different natural and man-made fliers.....	1
Figure 1.2: Bio-inspired MAVs with flapping flight mechanism .....	2
Figure 1.3: Robobee developed at Wyss Institute, Harvard .....	4
Figure 2.1: Wingtip paths relative to the body for a variety of flyers.....	8
Figure 2.2: Flapping mechanisms in insects .....	8
Figure 2.3: (a) Path of the vortex on the upper surface of the wing (b) Suction zone created at the core of the vortex. ....	9
Figure 2.4: (a) Valley fold (b) Mountain fold .....	11
Figure 2.5: Folding sequence of thin membranes with “waterbomb” origami .....	12
Figure 2.6: (a) Paper model of the diamond-shaped crease pattern seen in the hind wings of ladybirds (b) Origami folding pattern in ladybird hind wings .....	13
Figure 2.7: (a) Folding mechanism in insect wing (b) Schematic representation ....	14
Figure 2.8: (a) Creased surface (b) 3-D truss representation .....	14
Figure 2.9: Partially elastic origami model. ....	15
Figure 2.10: Complexity level of an FSI analysis.....	16
Figure 2.11: Conceptual description of Lagrangian, Eulerian and ALE mesh .....	22
Figure 2.12: (a) Initial mesh (b) Distorted ALE mesh (c) Lagrangian .....	22
Figure 3.1: Boundary conditions imposed on the fluid domain.....	29
Figure 3.2: Seam crack definition .....	29
Figure 3.3: Coupling procedure for the co-execution of CSD and CFD modules.....	30
Figure 3.4: Schematic of benchmark study used by Turek and Hron (2006) .....	31
Figure 3.5: FSI set-up implemented in ABAQUS environment .....	32
Figure 3.6: Structural model set up in Abaqus/Standard.....	33
Figure 3.7: General-purpose element in Abaqus/Standard (a) S4 (b) S4R .....	33
Figure 3.8: FC3D8 element in Abaqus/CFD.....	35
Figure 3.9: Three-dimensional cut in fluid domain demarcating the fluid-structure interface.....	36
Figure 3.10: Flow patterns at different Reynolds numbers.....	36
Figure 3.11: Results from verification of fluid domain based on the simulation of “flow around a rigid cylinder” .....	38

Figure 3.12: Displacement of the free end of the flap in the y-direction .....	39
Figure 4.1: Velocity plot for inlet velocity (a) 10 m/s (b) 20 m/s .....	42
Figure 4.2: Displacement results in X and Y direction for: (a) Model 2 (b) Model 3 (c) Model 4 (d) Model 5. ....	43
Figure 4.3: Crease geometry used in the study .....	44
Figure 4.4: Comparison of flow over creased and uncreased membrane .....	45
Figure 4.5: Vorticity plot for a (a) uncreased membrane (b) creased membrane .....	46
Figure 4.6: Vorticity plot along the length of (a) Uncreased plate (b) Creased plate .....	46
Figure 6.1: Residual stress distribution in the through thickness direction of a folded sheet which has undergone plastic yielding. ....	49
Figure 6.2: Localizing a plastic deformation by pressing between two rigid plates..	50
Figure 6.3: Procedure to introduce crease as a plastic deformation.....	50

## **LIST OF TABLES**

Table 3.1: Spalart-Allmaras model coefficients.....	28
Table 3.2: Properties of structural and fluid components .....	32
Table 3.3: Different cases considered for FSI analysis.....	34
Table 3.4: Cases considered for verification of fluid domain set-up .....	37
Table 3.5: Comparison of period of oscillation from calculation and simulation .....	39
Table 4.1: Comparison of FSI simulation with benchmark test.....	42

## **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 Eulerian <sup>4</sup>
CSE	Co-simulation Engine
NSE	Navier Stokes Equation
VIV	Vortex Induced Vibrations

## **LIST OF APPENDICES**

APPENDIX A: Mesh details

APPENDIX B: Input files