CHAPTER 5: CONCLUSION

5.1 Conclusions

The overall objective of this study was to produce a working simplified wing model based on a dragonfly wing. In order to achieve our objective, various methods were employed which resulted in our final product. Firstly, a methodology for producing accurate but simplified dragonfly wing models was described. The first step was to create a detailed model, using the Canny edge detection method on digital images of dragonfly fore and hind wings. The spatial network analysis method was then used to create simplified models from this detailed model. Both sets of models were used to calculate the natural flapping frequency, deformation, and displacement using Autodesk. It was shown that the simplified models produced very similar results (less than 13% difference for all calculations). Therefore, this shows that the spatial network analysis is a suitable approach to simplify a complicated insect wing structure (like a dragonfly). It is possible to fabricate this simplified model, because it is within available micro laser cutting and 3D printing allowances which enable its fabrication.

Secondly, a study that compares the mechanical properties of fourteen wing structures and analyzes the effect of adhering a chitosan nano-composite film membrane. Both FEA simulations and experiments were performed and all of the results showed good agreement (less than 10% difference). Each of the seven materials considered for the wing frame exhibited different characteristics. These seven materials were chosen because of their potential suitability for use as wing frames on a BMAV. Stainless steel (Type 321) has a high load bearing capacity, but experimental tests with steel wing frames showed that the addition of the film reduces its tensile resistance and causes aggressive oxidation. Steel is also relatively heavy making it a poor choice for this application. In contrast, film adhered
to a balsa wood wing frame increased its tensile strength by 125% to 200%, while the peak bending strength was improved by about 200%. However, both steel and balsa wood is relatively inflexible compared to the other two materials. The black graphite carbon fiber shows a remarkable load bearing capacity and its lightweight property makes it suitable for BMAV applications. Its primary disadvantage is the practical difficulties involved in carving it into the simplified wing frame structure. Wing frames fabricated from the red pre-impregnated fiberglass mimics the elasticity and flexibility of an actual dragonfly wing structure, making it the most suitable material to be used. Results show an increase in

Use of PLA materials, fabricated using a 3D printer were also examined. The PLA wings showed a remarkable load bearing capacity. The peak tensile strength for the forewings, with and without membranes, is 200.07 MPa and 175.46 MPa, respectively. The results for the hindwings, with and without membranes, are 197.33 MPa and 162.06 MPa, respectively. This shows that the addition of film increases the ultimate strength by 14% to 22%. This shows that the adhesion of the film to these PLA models moderately increases addition of the film reduces its tensile resistance and causes aggressive oxidation. Steel is also relatively heavy making it a poor choice for this application. In contrast, film adhered to a balsa wood wing frame increased its tensile strength by 125% to 200%, while the peak bending strength was improved by about 200%. However, both steel and balsa wood are relatively inflexible compared to the other two materials. The black graphite carbon fiber shows a remarkable load bearing capacity and its lightweight property makes it suitable for BMAV applications. Its primary disadvantage is the practical difficulties involved in carving it into the simplified wing frame structure. Wing frames fabricated from the red pre-impregnated fiberglass mimics the elasticity and flexibility of an actual dragonfly wing structure, making it the most suitable material to be used. Results show an increase in
ultimate strength after adhesion of the chitosan nano-composite film. The primary drawbacks in using red pre-impregnated fiberglass is that it undergoes warping and rapid shrinkage. The load bearing capacity is also low compared to the other materials. The PLA wings showed a remarkable load bearing capacity. The acrylic wings, exhibited similar results to PLA wings with the adhesion of chitosan nano-composite film significantly increased the strength. The adhesion of chitosan nano-composite film to ABS wing models yields noticeable amount of increase in strength. It shows that the adhesion of the film to these acrylic models slightly increases its ultimate strength. The percentage differences between the simulation and experiments are approximately 1.73% and 1.56%, with and without membranes, respectively.

One of the many challenges faced in constructing a working BMAV, involves the need to fabricate a highly deformable and flexible wing that has a large load bearing capacity. The third phase of the research was to conduct an experimental study to assess aero-elastic properties of flapping wings fabricated from the three chosen materials (PLA, acrylic, and ABS). These materials were chosen due to a number of criteria; the thickness of the material was much thinner compared to steel, balsa, carbon fiber and red prepreg (less than 2mm). This matches the criteria of a dragonfly wing whereby the wings are supposed to be thin. These materials were much more flexible than the first four materials mentioned above (steel, balsa, carbon fiber and red prepreg). The simulation and experimental shows a better agreement of mechanical strength when compared to an actual dragonfly wing compared to the first four materials. The percentage difference between the actual dragonfly wing (based on previous literature) and the three materials (PLA, acrylic and ABS) ranged about 2%-5% which further strengthens the decision of selecting these materials. The structural design of each of these wings is identical and based on biomimicry of an actual dragonfly wing. The experimental results were compared to the
actual dragonfly wing, on which they are based, in order to assess their potential application to a BMAV design. A flapping mechanism that uses an electromagnetic actuator is used. This mechanism was used to flap the wings at various frequencies from 10 to 250 Hz. A high frame rate imaging system, that uses two cameras, was used to capture the three dimensional motion of the flapping wing. Several different aero-elastic parameters were measured: bending angle, wing tip deflection, wing tip twisting angle, and wing tip twisting speed. Analysis of wing bending angle and wing tip deflection indicates flexibility of the wing in the chordwise direction, while the wing tip twist angle and speed shows the flexibility of the wing in the spanwise direction. The ABS wing exhibited the highest chordwise flexibility (indicated by their large bending angles and wing tip deflections). Although the PLA and acrylic fabricated wings exhibited a much lower chordwise flexibility than the ABS fabricated wing and the dragonfly wing, their spanwise flexibility (indicated by their wing tip twist angles and speeds) closely matched the dragonfly wing.

These experimental results show that an actual dragonfly wing has a highly deformable structure despite its rigidity. Our materials, though possess a certain amount of flexibility, they were unable to match the twisting motions exhibited by an actual dragonfly wing. The materials examined in this study (PLA, acrylic and ABS) were selected due to their high flexibility, low density, and low fabrication costs. The ABS wing design gave better results in matching the chordwise flexibility of the actual dragonfly wing, while limiting the spanwise flexibility to much greater degree than the other two designs.
5.2 Future Work

The choice of materials available to model a wing frame is limitless. There are many other new emerging materials such as ultra-PLA, and nano-ceramics which can be explored to fabricate these wing frames. The basic idea of creating a simplified model has been given in this research. This model can be used for future studies. Despite its corrugated structure and brittle nature, an actual dragonfly wing can exhibit a high degree of flexibility. It is hoped that by exploring different wing frame materials, this degree of flexibility can be achieved. The idea of the simplified model can further be expanded to create a 3D model which encloses the tubules (hollow structures in the frame) if possible. It is hoped that this optimization (simplification) method will be further explored and will open up new possibilities to mimic various insect wings (for BMAV) application purposes.
REFERENCES


Ngoc San Ha and Nam Seo Goo. (2013 January). Flapping frequency and resonant frequency of insect wings. Paper presented at the 10th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI), Konkuk University.


Kinematics of Flapping Flights. Journal of Experimental Biology. 200, (3) 557-582.


Young J WS, Bomphrey RJ, Taylor GK, Thomas ALR. (2009). Details of insect wing design and deformation enhance aerodynamic function and flight efficiency.

LIST OF PUBLICATIONS

Journal articles


Conferences


APPENDICES

Appendix A: High speed camera images of PLA wing frame models

(a) Side view of PLA wing frame

(b) Front view of PLA wing frame
Appendix B: High speed camera images of acrylic wing frame models

(a) Side view of acrylic wing frame

(b) Front view of acrylic wing frame
Appendix C: High speed camera images of ABS wing frame models

(a) Side view of ABS wing frame

(b) Front view of ABS wing frame