International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-9 Issue-3, January 2020

Design Fabrication of Adaptive Wing Structure

Nuramirah Azid, Dalia Abdul Manan, Ng Wi Tet, Ermira Junita Abdullah, Dayang Laila Abdul Majid

Abstract*: *This paper presents the design and fabrication work of adaptive wing using hybrid composite based on their structural response to shape memory alloy (SMA) actuation. The objectives of this study include designing a smart morphing wing, validating its structural response through computational and experimental analysis, and studying actuator placement in the adaptive wing. The computational analysis on the structural and aerodynamic performance is done with MSc Patran/Nasran and ANSYS Fluent respectively. The structural response observed is quite similar with computational analysis. From the obtained results, it can be taken that different actuator placement will produce a different profile of camber due to material stiffness and deflection. The actuator placement for the adaptive wing in this study has been found to produce positive camber and improve lift and drag aerodynamic performance.

Keywords*: *Adaptive wing, morphing wing, actuator placement, shape memory alloy, SMA actuation.

I. INTRODUCTION

By definition, the adaptive wing structures are intelligent, flexible systems that respond to ever changing environments. The analysis and design of adaptive structures require a highly multi-disciplinary approach, which will include the elements of structures, materials, dynamics, control, design and also a few inspirations from the existing biological systems. To date, the industrial applications, particularly in aerospace and space technology sector, have made progress towards advancement in adaptive structures including morphing wings, deployable space structure especially in using piezoelectric devices, and also vibration damping of tall buildings [1]. Furthermore, the adaptive composite structure sector already has a wide range of commercial applications, for instances vibration damping, precision positioning, noise actuation, and also surface shape control [2]. Rapid developments in design and manufacturing technologies have allowed further studies on adaptive system mechanism through the utilization of hybrid composites using smart structure.

In general, an aircraft with a morphing wing will be able to optimize its flying performance in the various flight regimes by changing its span-wise wing configurations or chord-wise airfoil cross-sections [3]. In retrospect, numerous morphing concepts have been proven as successful, including first flyer from the Wright brothers in 1903 and also unmanned combat aerial vehicle by the Northrop Grumman Corporation. Many of the early aircraft, which also include the Wright Brothers', are designed with a mechanism to twist the wing structure (i.e. wing warping) by using a series of pulleys and cables in order to achieve lateral control [4]. More recently, many engineers are trying to develop smart mechanism or using smart material to be located inside the wing that will enable the changing of its shape [5]. The concept of wing morphing greatly reduces the design complexity by eliminating the needs for a separate control surface, hinges and also control linkages. Hinge-less design can be made, which can significantly reduce drag and thus increase the aerodynamic efficiency. These qualities are making wing morphing a viable solution to the control system requirements. To achieve wing morphing, an active or 'smart material' can be utilized.

Currently, there are many different types of smart materials and some of them are already common. By definition, smart materials are solid-state devices that can change their shape in response to ever-changing condition from surrounding, hence they have no moving part and this makes them highly reliable. An exemplary class of smart materials with high reliability is the micro fibre composite, which shows no degradation in its performance for 100 million electrical cycles [6]. In addition, for aerospace applications, two types of smart materials that have been widely used to replace conventional actuators are the shape memory alloys (SMA) and the piezoelectric devices [7]. SMA operates on basic principle of shape memory effects with changes in temperature. After deformation, the materials will remember and return to their original shape. The change in its shape is the result from molecular re-arrangement due to the change in atomic crystal structure that is related to specific temperature.

Shape memory hybrid composites have been shown to have superiority in many areas with their unique properties such as good damage and fatigue resistance, and vibration damping, plus their proven capability to control and self-healing that is principally beneficial for shape control applications [8]. Kang et al. have designed a high-lifting device on a wing with shape memory alloy as actuator to improve aerodynamic efficiency [9]. Actuation of the shape memory alloy will cause the flap to deflect downwards and this subsequently increases the active camber of the structure, resulting in increased effective angle of attack and leads to increment of the lift force for the same angle of attack and wind velocity. Furthermore, SMA micro-springs are also proposed for the morphing wing prototype,

Revised Manuscript Received on January 30, 2020.

* Correspondence Author

Nuramirah Azid, Department of Aerospace Engineering, Faculty of Engineering, Universiti Putra Malaysia, Malaysia.

Dalia Abdul Manan, Department of Aerospace Engineering, Faculty of Engineering, Universiti Putra Malaysia, Malaysia.

Ng Wi Tet, Department of Aerospace Engineering, Faculty of Engineering, Universiti Putra Malaysia, Malaysia.

Ermira Junita Abdullah*, Department of Aerospace Engineering, Faculty of Engineering, Universiti Putra Malaysia, Malaysia.

Dayang Laila Abdul Majid, Department of Aerospace Engineering, Faculty of Engineering, Universiti Putra Malaysia, Malaysia.

which is to be fabricated using 3D-printing. Testing under the wind tunnel conditions have been conducted to understand the behaviors of the spring actuator when it is subjected to force and also strain [10].

This paper presents the development of an adaptive wing structure, which is a part of the conducted project on adaptive wing in Universiti Putra Malaysia. The general design process of the wing structure is highlighted, along with its fabrication process.

II. METHODOLOGY

Once the design requirements are established, the first step in designing the adaptive wing is to develop the structure. In this study, the computational fluid dynamics (CFD) method is used to determine the aerodynamics changes of the adaptive structure. In the meantime, the finite element analysis (FEA) method is applied to determine the force required to produce the actuation and also placement of actuator for the adaptive wing to achieve the aerodynamic shape that has been designed using CFD. For this initial design, the selected material for the structure is the hybrid composite using Carbon Kevlar.

GAMBIT software is used to model the 2D airfoil profile and also meshes for the symmetry wing and the adaptive wing. The dynamics simulation of the model flow is done using the ANSYS Fluent software for a total of four simulations of lift and drag coefficients at different angles of attack for both the symmetry and cambered airfoil profiles, and of the lift-to-drag coefficient for different velocities at zero angle of attack for both symmetry and cambered airfoil profiles. Meanwhile, the MSC Patran/Nastran 2010 software has been used for FEA to observe the behavior of the three layers of hybrid Kevlar that have been actuated using SMA. For this simulation, there are 12 samples of model with different orientations of the force applied (i.e. different location of actuator placement) that will be tested.

Once the design has been finalized, the fabrication process of the adaptive wing structure is conducted.

III. RESULTS AND DISCUSSION

Fig. 1 shows the grid display of boundary condition around the airfoil. In this diagram, the blue line represents inlet, white line is for the airfoil and red line for the outlet. The boundary condition of inlet is set at 20 m/s for x-velocity to calculate for lift and drag coefficient as in Fig. 2. This boundary condition is repeated at several different angles of attack and speeds for the cambered airfoil profile cases.

From Fig. 3, the geometry of NACA 0012 is developed by using CATIA and the drawing is then imported by Patran. The edge for the mesh with element length of 7 by 20 is developed based on convergence result. For the surface, three layers of hybrid Kevlar, each having a thickness of 0.3175 mm with 0° orientation, are constructed for input laminated parameters. In the meantime, the location of the nodes as indicated in Fig. 4 represents the placement of the forces that are being studied. Nevertheless, there is a limitation in accessing all nodes for applying the force, which is fixed by the prototype because of very small space inside the airfoil to work with. Therefore, the only regions of nodes that are analyzed are nodes 3 to 13 and nodes 33 to 43.

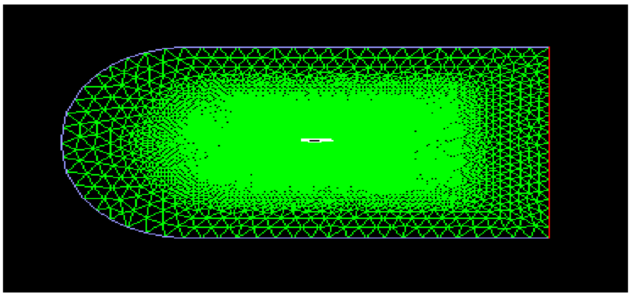


Fig. 1. Grid display with specified boundary condition

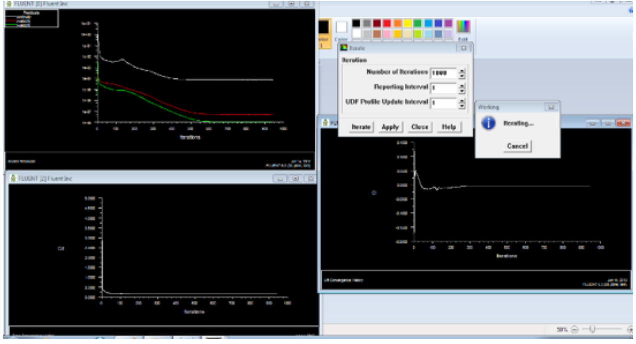
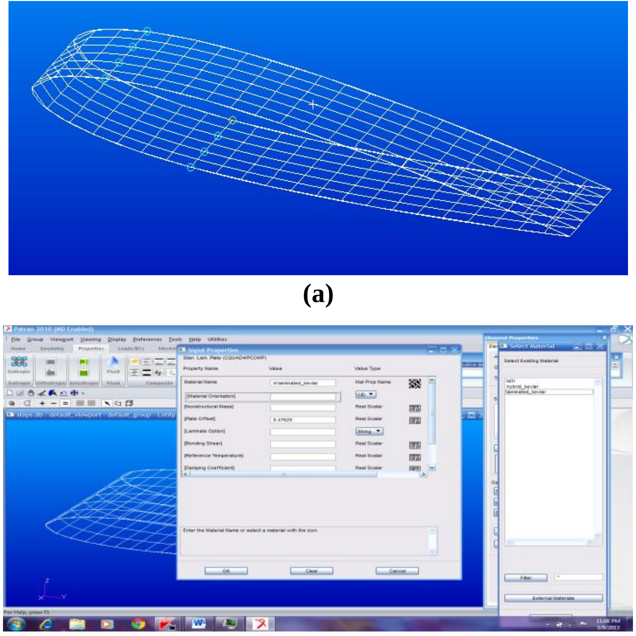


Fig. 2. Output of lift and drag coefficients



(a)

(b)

Fig. 3. Model with equivalence nodes and input Kevlar layer parameter

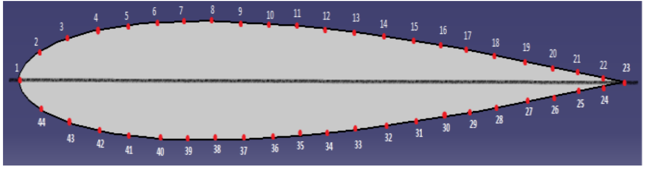


Fig. 4. Indicated nodes on airfoil profile

For force applied by SMA, the curve is created to represent the actuator wire. Then, the SMA properties are input to curve list. The analysis of the wing performance is made at different coordinates of the actuator in order to get different deflection of the wing trailing edge as illustrated in Fig. 5. The maximum camber produced for FEA is fixed at nodes 36-39 (37) and the force at node 3 produces trailing edge deflection of 6.51 mm.

The NACA 0012 mold has been produced using CNC 3-axis machine, which is then used to fabricate the NACA 0012 by using vacuum bagging process with three layers of Kevlar, and followed by Teflon for protecting the hybrid Kevlar and also for ensuring that the shape will not be distorted. Plastic is used to allow for the excess resin to be sucked out as depicted in Fig. 6.

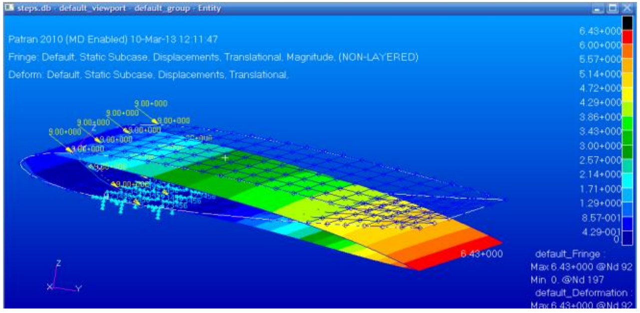
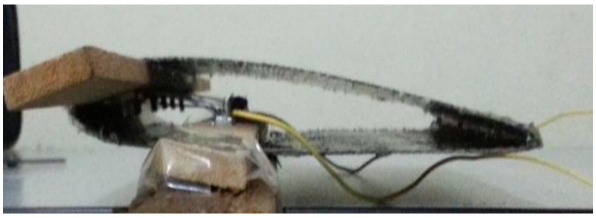


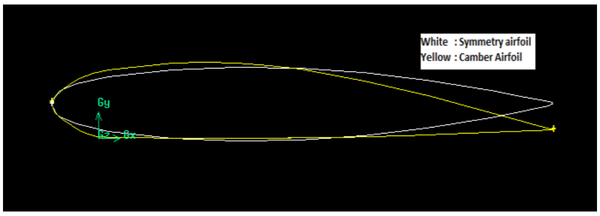
Fig. 5. Wing modelling performance

Fig. 6. Vacuum bagging process

From experimental analysis done on the hybrid composite adaptive wing structure, the obtained trailing edge deflection has been found to be about 5 mm as shown in Fig. 7. It should be noted that the trailing edge deflection in the testing is 23% less than the anticipated simulation results. This may be due to the quality of the hybrid composite Kevlar composite strength that might be higher than that specified in the simulation. The reduced trailing edge deflection subsequently also affects the camber change of the wing. In view of this, a new material is selected to ensure that the camber required for the design can be achieved. This new adaptive wing design is fabricated with ABS as the main material using 3D printing. Moreover, due to difficulty in assembling the SMA inside the wing of hybrid Kevlar composite, the wing design is then further improved by adding slot in-out for SMA actuators and standing slot for the six-component balance testing as illustrated in Fig. 8. This feature allows for easier maintenance of the SMA actuators.

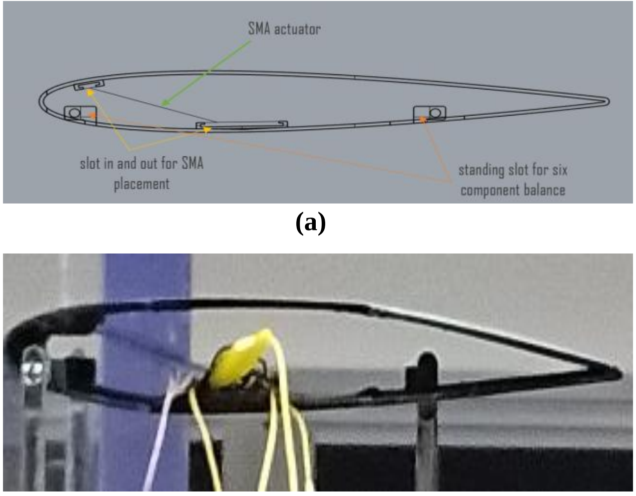


(a)



(b)

Fig. 7. Cambering effect on hybrid Kevlar airfoil



(a)

(b)

Fig. 8. 2D and full assembly of NACA 0012 with SMA actuator

IV. CONCLUSION

For the design of adaptive wing structure, the aerodynamics analysis has to be performed in order to determine the camber change for improved aerodynamic performance. Moreover, to optimize the design of adaptive wing structure, the analysis results for the different actuator placement in the wing can be used to produce the desired structural change of the adaptive wing. In this paper, the process of developing adaptive wing structure using hybrid Kevlar composite has been presented and the issues with the structure during fabrication and testing are also highlighted. New material and assembly design have been proposed to improve the adaptive wing structure. Future work will be to integrate the adaptive wing structure with the SMA actuation control system and experimental testing using wind tunnel to validate the aerodynamic performance of the adaptive wing.

ACKNOWLEDGMENT

The authors would like to acknowledge that the research findings presented in this paper are funded by the Research University Grant Scheme (RUGS) GP-IPS/2016/9513400 and UPM/700-2/1/GP/2017/9552700 from Universiti Putra Malaysia.

REFERENCES

1. D. Wagg, Adaptive Structures: Engineering Applications. Hoboken, NJ: Wiley, 2007
2. V. M. F. Correia, M. A. A. Gomes, A. Suleman, C. M. M. Soares, and C. A. M. Soares, “Modelling and design of adaptive composite structures,” Computer Methods in Applied Mechanics and Engineering, vol. 185, 2000, pp. 325-346

3. O. Bilgen, K. Kochersberger, E. C. Diggs, A. J. Kurdila, and D. J. Inman, "Morphing wing aerodynamic control via macro-fiber-composite actuators in an unmanned aircraft," AIAA Infotech@Aerospace 2007 Conference and Exhibit, California, USA, 2007
4. Wing Warping [Online]. Available: http://www.centennialofflight.gov/essay/Dictionary/wing_warping/DI56.htm
5. J. B. Cole, Variable Camber Airfoil. US Patent No. 3,994,452, 1974
6. W. Wilkie, J. High, and J. Bockman, "Reliability testing of NASA piezocomposite actuators," 8th International Conference on New Actuators, Bremen, Germany, 2002
7. Aircraft Maneuverability [Online]. Available: http://webdocs.cs.ualberta.ca/~database/MEMS/sma_mems/flap.html
8. Z. G. Wei, R. Sandstrom, and S. Miyazaki "Shape memory materials and hybrid composites for smart systems: Part II Shape-memory hybrid composites," Journal of Materials Science, vol. 33, 1998, pp. 3763-3783
9. W. R. Kang, E. H. Kim, M. S. Jeong, and S. M. Ahn, "Morphing wing mechanism using an SMA wire actuator," International Journal of Aeronautical and Space Sciences, vol. 13, 2012, pp. 58-63
10. A. Emiliavaca, C. de Araújo, C. Souto, and A. Ries, "Characterization of shape memory alloy micro-springs for application in morphing wings," Smart Materials and Structures, vol. 28, 2018, 015010

AUTHORS PROFILE

Nuramirah Azid is currently pursuing MSc degree at the Department of Aerospace Engineering, Universiti Putra Malaysia. She also holds a Bachelor degree in Aerospace Engineering from Universiti Putra Malaysia.

Dalia Abdul Manan has received a Bachelor degree in Aerospace Engineering from Universiti Putra Malaysia.

Ng Wi Tet has received a Bachelor Degree in Aerospace Engineering from Universiti Putra Malaysia.

Ermira Junita Abdullah is a senior lecturer at Department of Aerospace Engineering, Universiti Putra Malaysia. She received her PhD degree in Aerospace Engineering from RMIT, Australia. Her research interest is in control systems, flight dynamics, morphing wing design and shape memory alloy actuator.

Dayang Laila Abang Abdul Majid is associate professor at Department of Aerospace Engineering, Universiti Putra Malaysia. She received her PhD in Aerospace Engineering from Universiti Putra Malaysia. Her research interest is in composite structures.

Retrieval Number: C8802019320/2020©BEIESP
DOI: 10.35940/ijitee.C8802.019320
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication