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Experimental and Numerical Investigation of Aerodynamic Performance of a Star-Shaped Damaged Wing

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ABSTRACT: In this paper, flow on a finite wing with star-shaped damage is numerically and experimentally investigated to understand effects of the damage on aerodynamic characteristics of the wing. To study effects of different span positions, the damage was considered in tip, middle and root position of the wing span. The Wing model is a section of NACA 64_1-412 asymmetric airfoil with 200 mm chord and 800 mm span. The aerodynamic coefficients and their increments due to the damage were extracted and the results were compared to the experimental data. Flow visualization over the damaged wing has been done with the paint technique to monitor the flow structure on the model and to understand the influences of the damage on the flow. To analyze ability of the numerical modeling in prediction of aerodynamic performance of a damaged wing, the results were validated with the experimental results. A star damage with area about 1% of the wing, can decrease the lift coefficient about 6% and increase the drag coefficient about 15.7% compared to an undamaged wing. The star damaged wing also experiences more pitching moment coefficient. The results of damage in different locations showed that the damage near to wing tip has less impact on reduction of aerodynamic efficiency.

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1- Introduction

One of the key aircraft design requirements is aircraft survivability. Survivability of the aircraft is dependent upon its vulnerability to damage caused by a variety of threat types [1]. Damage which results in physical removal of a portion of a wing or primary flight control surface undoubtedly leads to a reduction in aerodynamic performance and control degradation [2]. Irwin et al. [3] studied influence of a mid-chord damage on the aerodynamic characteristics of two-dimensional wings. The aerodynamics of wings with circular damage was experimentally investigated by Render et al. [4]. Analysis of partial wing damage on flying-wing unmanned air vehicle had been done by Ki-joon et al. [5].

As mentioned above, limited numerical and experimental researches have been conducted to study the aerodynamic effects of a damage to wings. The studies have mainly considered the effects of simple forms of damage, circular damage on infinitive airfoils, while realistic damage shapes have irregular edges and may occur in different positions of finite wing. Therefore, to achieve real shape of damages and to study the influence of sharp corners of damage, the flow on a wing with star-shaped damage in different span positions was numerically and experimentally investigated in this paper. The results of qualitative and quantitative investigations into aerodynamic characteristics of the damaged wing are presented and compared to the experimental results.

2- Computational and Experimental Methodologies

For the numerical and experimental studies, model of NACA 64_1-412 with 200 mm chord and 800 mm span was implemented. The damage is shaped as a star to study of the sharp corners effects. The geometric center of the damage was set at 150, 450 and 650 mm distances from the bottom of wing span which were named root, middle and tip positions of the span, respectively. The damages were chosen in least complication with location on mid chord only, entry and exit holes identical shape through the wing and normal to the chord. The study was done at velocity of 40 m/s and Reynolds number of 570000. Geometry of the damaged wing model and model installed in the wind tunnel test section are shown in Figures 1 and 2.

The experimental study was performed in wind tunnel at Aeronautical and Automotive Engineering Department of Loughborough University. This is an open circuit wind tunnel with a close test section dimensions 1.92×1.32×3.6 m, and a turbulence level of typically 0.15 %. A six component balance is located beneath the working section to measure forces and moments. The standard paint technique was also used for flow visualization on upper side of wing.

Numerical modeling is done by using Fluent software as a tool to predict the flow field around the wing which uses a finite volume method. The Navier-Stokes equations are solved by using pressure-based method. The flow is considered three-dimensional, steady state, viscous, and turbulent in which standard κ-ε model has been used for turbulence modeling. The entire domain is discretized by an unstructured grid of tetrahedral and wedge cells. The grid independency study has been done. Total number of cells is about 2,100,000 for clean wing and 2,350,000 for damaged wing. Three types of boundary conditions were used; wall, velocity inlet and, pressure outlet. In this study the length of width and height of numerical domain were considered the same size of the test

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section of the wind tunnel in experimental arrangement.

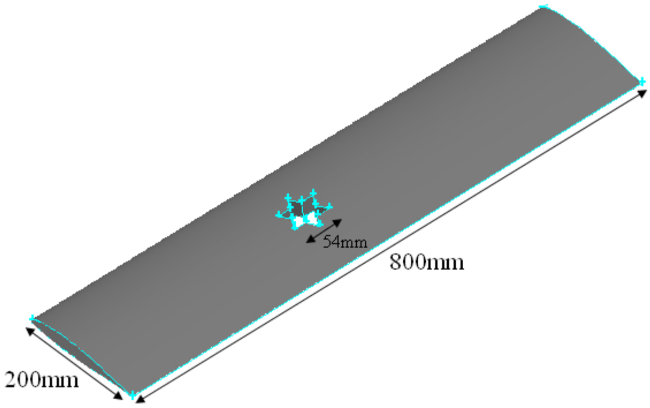

Figure 1. Geometry of damaged wing

Figure 2. Installed model in the wind tunnel test section

3- Results and Discussion

Flow visualization showed that there was the flow through the damage which was driven by the pressure difference between the upper and lower wing surfaces. The flow through the damage was formed in two types which was dependent on the incidence at all three positions of the damage. The first form was a weak-jet which formed an attached wake and resulted in small changes in free stream flow. The second form resulted from increased incidence. This was the strong-jet where through flow penetrated into the free stream flow with large separated wake and reverse flow (Figures 3 and 4). The aerodynamic coefficients of wing with damage in different span positions and their increments due to damage were extracted and the results were compared to each other and also to the experimental results. Fig. 5 shows the comparison between numerical and experimental results of lift coefficient for middle damage. Fig. 6 represents the lift-to-drag ratio of undamaged and damaged wing in different span positions against incidence.

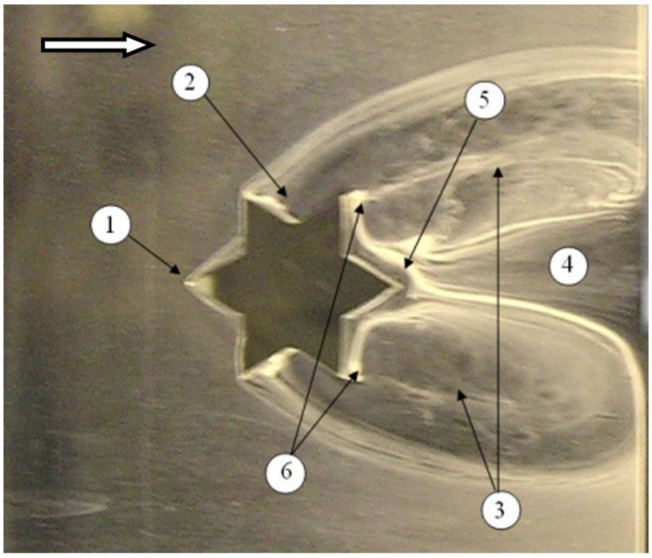

Figure 3. Flow visualization on upper side of wing

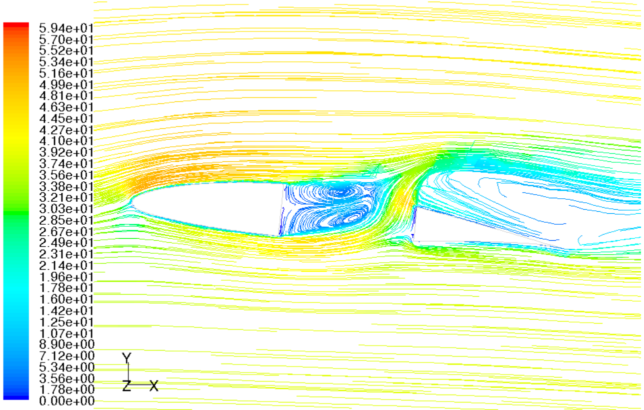

Figure 4. Numerical result, side view of path lines on hole center line, colored by velocity magnitude

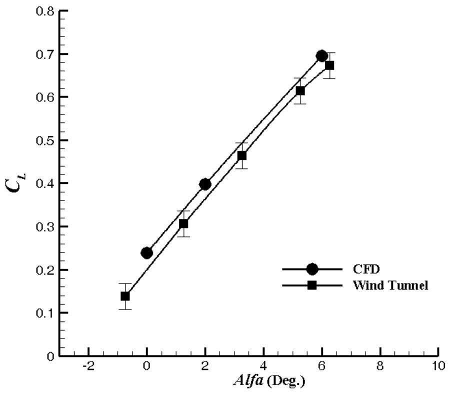

Figure 5. Comparison between numerical and experimental results of lift coefficient in middle position of span

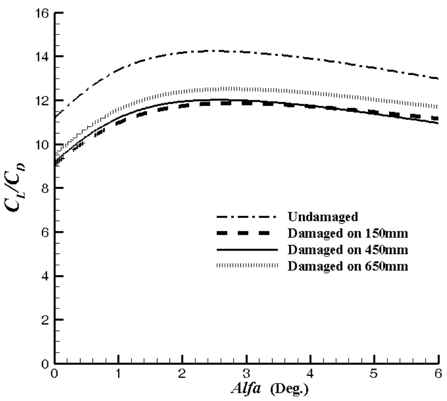

Figure 6. The lift-to-drag ratio in different span positions

4- Conclusion

Adding damage to wing resulted in a lift-coefficient decrement and drag-coefficient increment that increased in magnitude with incidence. Moving the damage toward the tip reduced the magnitude of these effects because of pressure distribution and wingtip vortices effect. A star damage with area about 1 % of the wing can decrease the lift-to-drag ratio about 19 % compared to the undamaged wing.

References

[1] U.K. military standard, "*Reduction of vulnerability to battle damage*", DEF STAN 00-970, 1, 1994.

[2] Irwin, A. J., "*Investigation into aerodynamic effects of simulated battle damage to a wing*", Ph.D. Dissertation, Loughborough University, loughborough, U.K., 1998.

[3] Irwin, A. J. and P. M. Render, ."The influence of mid-chord battle damage on the aerodynamic characteristics of two-dimensional wings". *The Aeronautical Journal, royal aeronautical society*, 104.1033 (2000): 153-161.

[4] Render, P. M., "Aerodynamics of battle damaged wings-the influence of flaps, camber and repair schemes". *23rd AIAA Applied Aerodynamics Conference*, AIAA-2005-4721, Toronto, Canada, 2005.

[5] Ki-joon, K., A. Jong-Min, K. Seungkeun, C. Jong-soo, S. Jinyoung, L. Heungsik and H. Gi-bong, "Analysis of partial wing damage on flying-wing unmanned air vehicle". *Journal of aerospace engineering*, Part G, 228.3 (2014): 355-374.

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