CFD-BASED STUDY OF DAMAGE LOCATION INFLUENCE ON AERODYNAMICS OF WINGS WITH SINGLE AND DOUBLE THROUGH HOLES

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Abstract

Aerodynamic influence of simulated gunfire damage location on wings is studied using CFD method. Lift and drag coefficient increments of wings after damage are calculated to measure the damage influence and flow visualization is used to describe interactions between different damage holes' jet flow. Four scenarios are set for single and double through damage holes with different locations.

For single hole damage, moving hole damage towards wing trailing edge decreases the magnitude of lift coefficient decrement and increases the lift-drag ratio. Meanwhile, with the movement, sizes of the outside pair of vortex within downstream of the jet flow decrease and the inside pair's size increases, two pairs merging into one gradually and disappearing finally.

For double damage holes located along wing chord, magnitude of dcl and dcd is bigger when one hole is near wing leading edge.The holes' span distance effects greatly on two holes' jet flow interactions and the force coefficient also changes accordingly. Flow field structures of double hole damage at different chord and span positions have the features of those only changing chord or span positions.

1 Introduction

Survivability is the capability of an aircraft to avoid and/or withstand a man-made hostile environment[1]. When suffering damage, it's of great significance for an aircraft to assess the degradation in flight capability, which helps pilots determine whether to continue completing the designated mission or not. Aerodynamic characteristic is one essential aspect to evaluate the extent of the degradation. Strength of aerodynamic influence of battle damage on wings is affected by factors such as damage location and so on.

Irwin researched damage location by placing single hole damage at four different chord locations(leading edge, 25%c, 50%c and trailing edge) and found the middle two locations' aerodynamic effects stronger[2]. P. M. Render studied simulated gunfire damage on finite-aspect-ratio wings and concluded that adding damage resulted in a lift-coefficient decrement and moving damage toward the wing tip reduced the magnitude of the effect[3]. Irwin set double through holes at different chord locations and analyzed the flow interactions between two holes' jet flow with visualisation as well as force coefficient changing trends[4].

Actual damage is possible to locate anywhere of the wing, so this paper chooses more locations along wing chord for single and double holes, trying to seek some other details. This paper also sets double holes along wing span and one other scenario combining chord and span locations.

Based on CFD, changes of lift and drag coefficient after damage are calculated and flow structures of damaged wing are shown and analyzed. Conclusions are given in the final section of this paper.

2 Computational Methodologies

Gunfire can attack wings in numerous directions and the petalling effect will affect damage shapes[4]. Then some assumption should be made first and CFD simulation methods are described as follows.

2.1 Assumptions

The following three assumptions are made to simulate the gunfire damage[4].

(1) Gunfire attack direction is 90° to wing chordline.

(2) Entry and exit holes of damage are of the same diameter.

(3) The internal wing space is solid and the hole' side wall surface is closed.

2.2 Modeling and Grid Generation

NACA64_1-412 is chosen as wing models' airfoil and the wing is infinite aspect ratio(2D) with zero taper and twist[2, 4]. Wings' chordlength is 200mm and the spanlength is 800mm[5]. Circular holes are reasonable representation of battle damage[6] and this paper uses circular holes to simulate gunfire damage. The numerical simulation domain is tetrahedral in shape and its geometry is shown in Fig. 1.

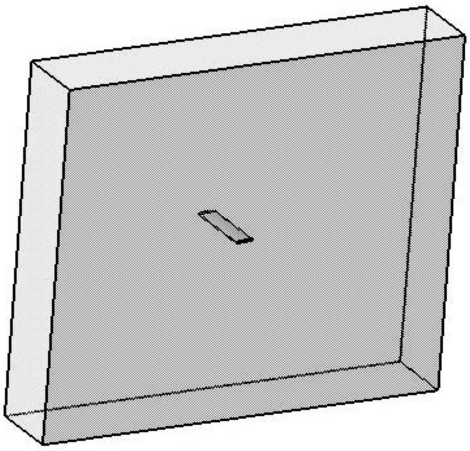


Fig.1 Geometry of numerical simulation domain

The solution domain is discretized by a structured grid of tetrahedral cells. The grid is generated by Icem software, with outer O-Block set around wing surface and inner O-Block within the damage hole. The final Block is shown in Fig.2 and the grid sectional drawing is in Fig. 3.The total number of cells for clean and damaged wings is 2400000 ~5020000 and all of the mesh quality is above 0.6.

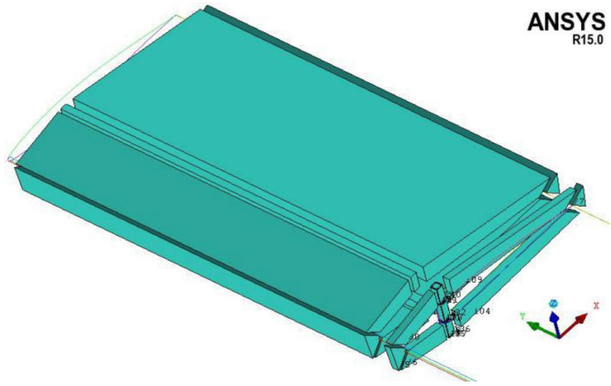


Fig.2 Block setting details of the damaged wing

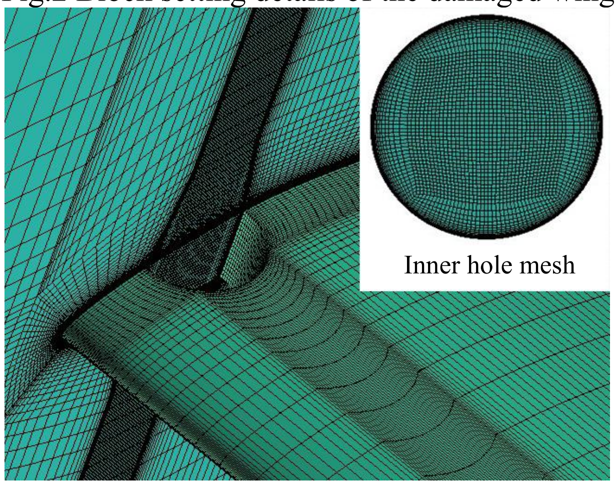


Fig.3 Grid sectional drawing of damaged wing

Fluent software is used to conduct the numerical calculation in this paper, with double precision to increase accuracy. The solver is pressure-based and turbulence model is k-ω SST. For the solution domain, the two side surfaces' boundary conditions are symmetry and the rest four surfaces pressure_far_field. The air pressure is 101325Pa， temperature 288.15k, wind velocity 40m/s and air density 1.225kg/m^3.

2.3 Qualitative

Strength of the gunfire damage's aerodynamic effect on wings is measured by changing values of wing's force coefficient after damage, which are calculated as follows.

$$dcl = cl_{damaged} - cl_{undamaged} \tag{1}$$

$$dcd = cd_{damaged} - cd_{undamaged} \tag{2}$$

The subscript damaged means values for wings with damage and undamaged for clean wings. For all calculation, reference area is the airfoil's projection area.

3 Simulation Results

Four scenarios are set to research the influence of damage locations. The first scenario is for single holes and the rest are for double holes.

3.1 Scenario 1

In scenario 1, damage is single hole and located at mid-span and 5%c, 10%c, 25%c, 35%c, 50%c, 65%c, 80%c, 95%c along chord respectively. The hole diameter is 5%c.

Lift and drag coefficient increments in scenario 1 at different incidences are shown in Fig.4 and Fig.5. Fig.4 shows that moving damage towards the trailing edge, values of dcl turns a tendency to decrease. Besides, dcl is more sensitive to location movement when damage location is near the leading edge, for dcl difference between 5%c and 25%c is bigger than that between 25%c and 95%c.

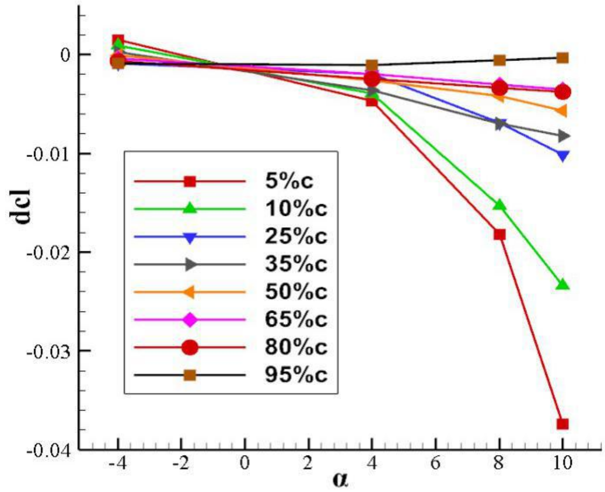


Fig.4 Lift coefficient increments in scenario 1

Values of dcd are negative for damages close to the trailing edge(Fig.5), which results from that jet flow through the relative small damage hole weakens the separation of upper surface flow and this benign influence is stronger than the damage's adverse effects. Moreover, absolute values of dcd keep decreasing trends with the hole moving to the trailing edge. Results of the 25%c and 35%c don't meet the trend, which may be explained by the complicated interaction between the hole jet and the separated flow on the upper wing surface.

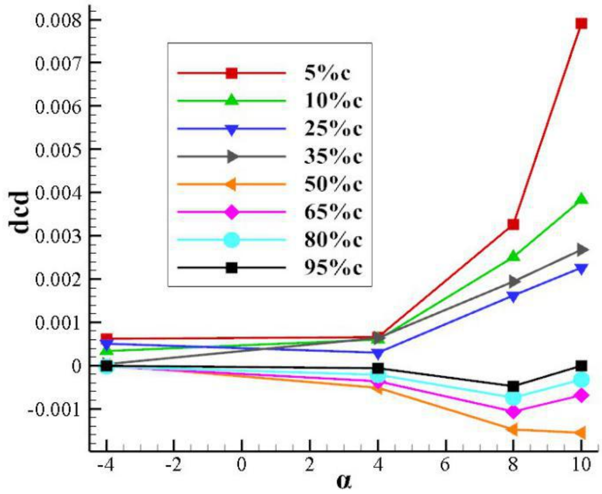


Fig.5 Drag coefficient increments in scenario 1

Values of lift-drag ratio in scenario 1 is shown in Fig.6. Damage decreases the magnitude of lift-drag ratio and also the angle of attack corresponding to the maximum lift-drag ratio. With damage moving to the trailing edge, values of lift-drag ratio decrease.

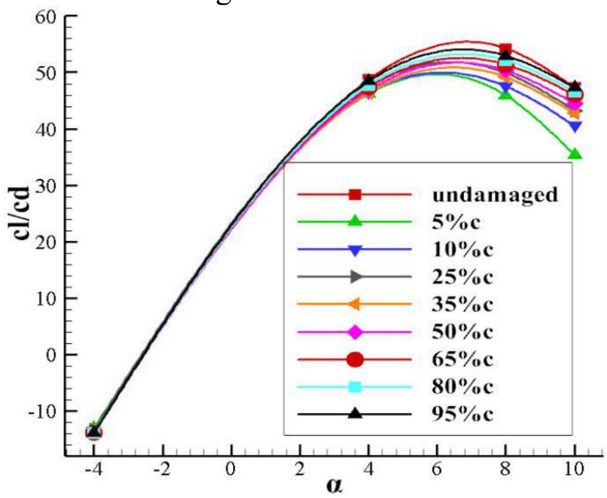
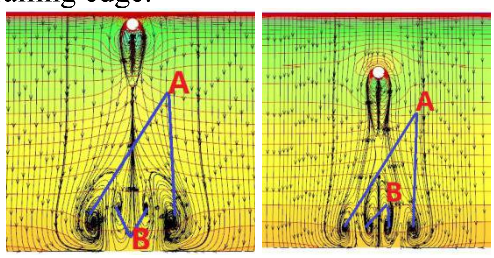


Fig.6 Lift-drag ratio in scenario 1

Fig.7 describes streamlines near damage hole in scenario 1 at 8° incidence. Sizes of the outside pair of vortex(A) decrease and the inside pair(B) size increases as damage moves backwards, then two pairs merge into one gradually and disappear when damage is near the trailing edge.



5%c 25%c

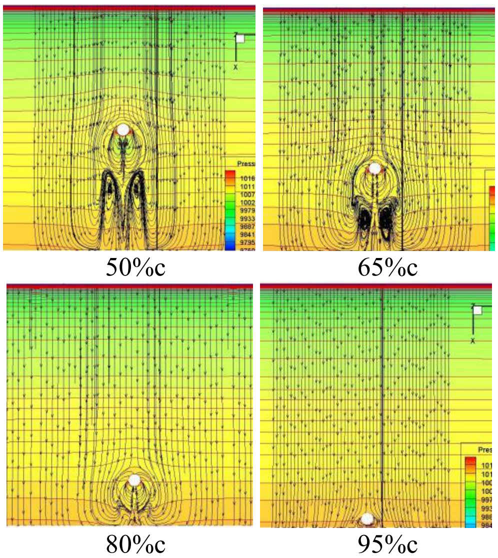


Fig.7 Streamline near damage hole in scenario 1

3.2 Scenario 2

In scenario 2, damage is double holes and located at mid-span and every two locations of 5%c, 25%c, 50%c, 80%c and 95%c along chord. The hole diameter is 5%c.

Lift and drag coefficient increments in scenario 2 at different incidences are shown in Fig.8 and Fig.9. Double holes whose locations contain 5%c will generate bigger values of dcl and dcd than others. While for holes including 95%c, values turns to be smaller. Comparing scenario 1 and 2, we can find that double holes have more effects than either single hole on the aerodynamic characteristics of wings, and the effects are not simple superposition of the two single holes.

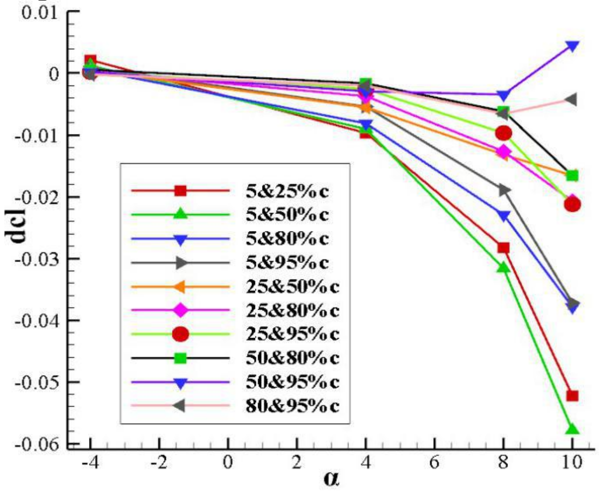


Fig.8 Lift coefficient increments in scenario 2

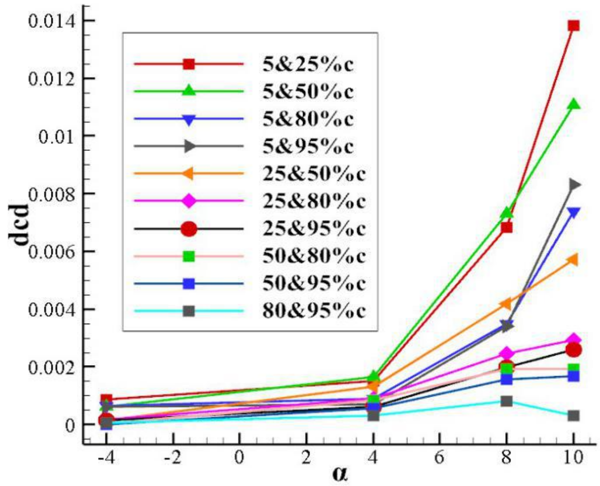


Fig.9 Drag coefficient increments in scenario 2

Flow structure of double hole damage is different from either single hole (Fig. 7 and 10). However, if one hole is close to the trailing edge, structure of the jet flow turns much similar to that of the other hole alone, which can be seen by comparing the streamline of 5%c in Fig.7 and 5%c&95%c in Fig. 10.

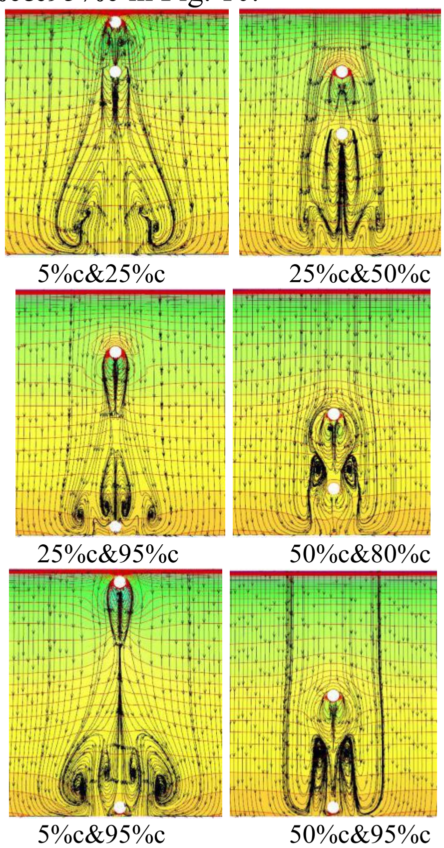


Fig.10 Streamline near damage in scenario 2

3.3 Scenario 3

In scenario 3, damage is double holes and located symmetrically on both sides of the mid-span and 25%c, with hole center distance 20mm, 50mm, 90mm, 120mm, 160mm, 200mm, 240mm respectively. The hole diameter is 5%c.

Lift and drag coefficient increments in scenario 3 at different incidences are shown in Fig.11 and Fig.12. With double holes' distance increasing along wing span direction, magnitude of dcl first decreases, then increases and keeps constant finally. Meanwhile, magnitude of dcd first decreases and keeps constant finally.

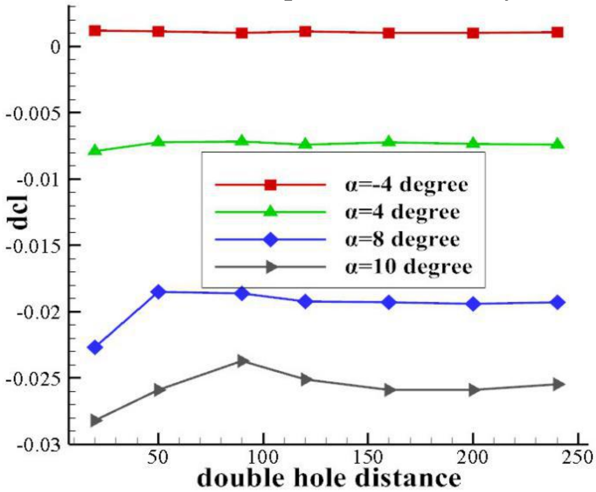


Fig.11 Lift coefficient increments in scenario 3

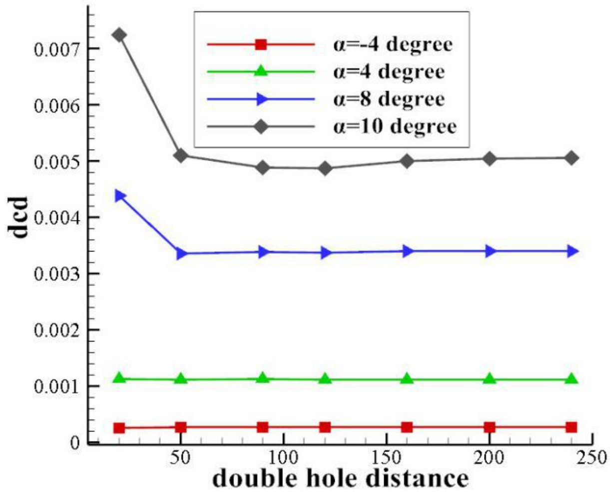
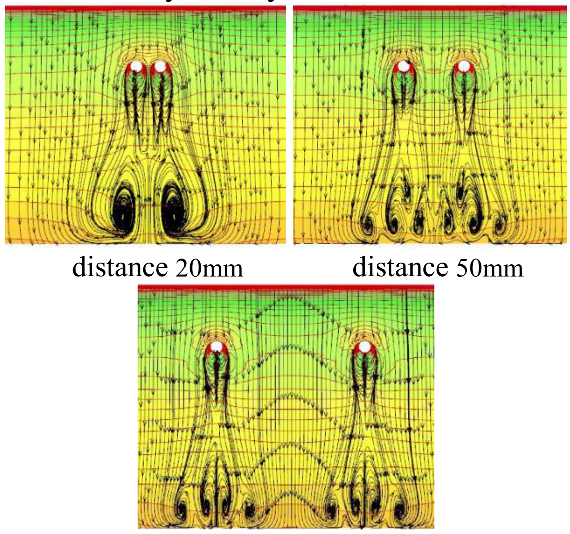


Fig.12 Drag coefficient increments in scenario 3

Force coefficient changing trend is greatly decided by flow structure of the wing. Fig.13 shows the streamline near damage holes in scnario 3. When holes' span distances are relatively small, downstream of the jet flow is much similar to that of one bigger single hole and there exists a pair of big vertex downstream, which results in the biggest magnitude of dcl and dcd. As the distance increases, interactions between two holes' jet flow become very prominent and the flow structure is so complicated, leading that the magnitude of dcl and dcd decreases and the magnitude of dcl begins increase at a certain span distance. When the distance is big enough, the interaction of the two holes is so weak that double holes become independent of each other. And magnitude of dcl and dcd stays steady as distance increases.



distance 20mm distance 50mm

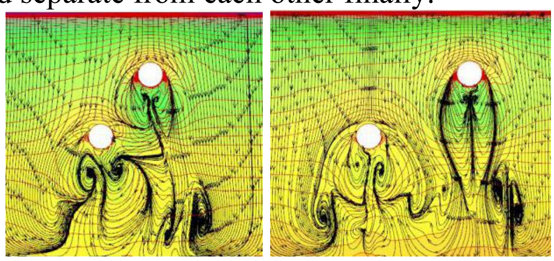
distance 120mm

Fig.13 Streamline near damage in scenario 3

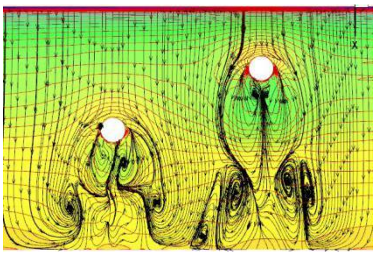
3.4 Scenario 4

In scenario 4, wing damage is double holes and located at different chord and span positions. The chord locations are 25%c and 50%c, and the span distance is 40mm, 80mm and 120mm separately. The hole diameter is 10%c.

Streamline near damage of this scenario is shown in Fig.14. It can be seen that streamlines are more complicated than those in scenario 2 and 3. Comparing the three calaulation results, when the double holes' span distance is relative small, the interaction of the two jet flow is so strong that the deformation of the streamline is rather severe. With the span distance increases, interactions of the two holes' jet become weak and separate from each other finally.



distance 40mm distance 80mm



distance 120mm

Fig.14 Streamline near damage in scenario 4

4 Conclusion

- Moving single hole damage towards wing trailing edge, magnitude of lift coefficient decrement decreases, while lift-drag ratio and the angle of attack corresponding to maximum lift-drag ratio increases.
- For single hole damage, values of dcd can be negative when damage hole is relative small and located near wing trailing edge.
- Moving single hole damage towards wing trailing edge, size of the outside pair of vortex within downstream of the jet flow decreases and the inside pair's size increases, two pair of vortex merging into one gradually and disappearing finally.
- For double holes located along wing chord, magnitude of dcl and dcd is bigger when one hole is near wing leading edge and the magnitude smaller when near trailing edge.
- With double holes' wing span distances increasing, magnitude of dcl first decreases, then increases and keeps constant, while magnitude of dcd first decreases and then keeps constant.
- With double holes' wing span distances increasing, interactions between two holes' jet flow weakens and the two holes' flow structures separate from each other finally.
- For double hole damage at different chord and span positions, flow structures have the features of those only changing chord or span location of damage.

5 Acknowledge

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References

[1] Robert E.Ball. *The fundamentals of aircraft combat survivability analysis and design*. Second edition, American Institute of Aeronautics and Astronautics, Inc., 2003.

[2] Irwin, A. J.,et a;. Investigation into the aerodynamic praperties of a battle damaged wing. *Applied Aerodynamics Conference* 2013.

[3] Render, P.M., Samad-Suhaeb, M., Yang, Z. and Mani, M. Aerodynamics of battle-damaged finite-aspect-ratio wings, *Journal of Aircraft*, Vol. 46, No. 3, pp. 997-1004, 2009.

[4] Irwin, A. J. Investigation into the aerodynamic effects of simulated battle damage to a wing. Ph.D. Thesis, Loughborough Univ.,Loughborough, England, U.K., May 1999.

[5] Soheila Abdolahipour, Mahmoud Mani, et al. Numerical & experimental study of the influence of damage on the aerodynamic characteristics of a finite wing. *Proceedings of the ASME-JSME-KSME Joint Fluids Engineering Conference.* Hamamatsu, Shizuoka, Japan, Vol. 1(D), pp. 1441-1447, 2011.

[6] Mahmoud Mani, et al. Experimental investigation into the aerodynamic characteristics of airfoils with triangular and star shaped through damage. *23rd AIAA Applied Aerodynamics Conference.* Toronto, Ontario, Canada, pp. 1-27, 2005.

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