The Aerodynamics of a Damaged Wing

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Background

Because Unmanned Aerial Vehicles (UAVs) provide surveillance and reconnaissance in a discrete, low-risk way, militaries utilize them to gather data from unauthorized territories. This often results in the enemy attempting to shoot down the aerial vehicle. Since 2018, the number of UAVs crashing in conflict zones rose by 322%. This significant increase of crashes prompted us to investigate how the aerodynamic forces of a UAV change when its wings have sustained battle damage. The goal is to provide results that can help improve the UAV's resiliency so that its flight time can be extended. By extending the flight time, the UAV has a better chance at escaping retrieval by the adversary. Keeping the UAV out of the enemy's hands is crucial, as they can extract recorded data from the UAV and can improve their arsenal of aerial vehicles by analyzing the technology that built it.

Approach

The testing of two 3D printed NACA 4409 aerofoils in a wind tunnel at a low Reynolds number was carried out to determine the aerodynamic characteristics of battle damaged holes. The first wing had a span of 48 inches and the second had a span of 24 inches. The chord length for both wings was 8 inches. The damage to the wings was simulated as cylinders. The small holes were 16.67% of the chord, and the large holes were 25% of the chord. These wings were tested at a wind speed of 10 m/s and force measurements were recorded. With the force data, the lift and drag coefficients as well as the lift to drag ratios were recorded for both damaged and undamaged cases. The two wings used for this study are pictured in Figures 1 and 2.

Figure 1: Wing 1

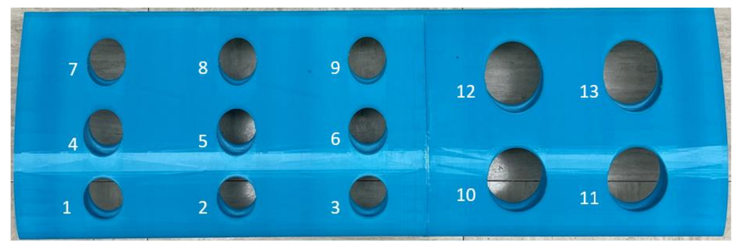

Figure 2: Wing 2

Figure 3: The wind tunnel in the Fluid Mechanics Research Laboratory at Tennessee Tech University

Figure 4: Wing 1 mounted inside the test section of the wind tunnel

Results

WING 1

	Lift Coefficient of Damaged Cases	Lift Coefficient of Undamaged Cases	% Change Between Damaged & Undamaged Cases	L/D Ratio of Damaged Cases	L/D Ratio of Undamaged Cases	% Change Between Damaged & Undamaged Cases
H1	0.4610	0.5270	-12.5	0.3827	0.4548	-15.9
H2	0.4448	0.5290	-15.9	0.3727	0.4615	-19.3
H3	0.4098	0.5311	-22.8	0.3524	0.4682	-24.7
H4	0.4815	0.5331	-9.7	0.4157	0.4749	-12.5
H5	0.4847	0.5351	-9.4	0.4408	0.4816	-8.5
H6	0.4890	0.5372	-9.0	0.4357	0.4884	-10.8
H7	0.4788	0.5392	-11.2	0.4615	0.4951	-6.8
H8	0.5038	0.5325	-5.4	0.4292	0.4873	-11.9
H9	0.4683	0.5238	-10.6	0.4003	0.4729	-15.4
H10	0.4816	0.5151	-6.5	0.3943	0.4584	-14.0
H11	0.4909	0.5065	-3.1	0.4045	0.4440	-8.9
H12	0.4843	0.4978	-2.7	0.4127	0.4296	-3.9

Table 1: The summary of the averages of the lift coefficients and L/D ratios recorded for wing 1

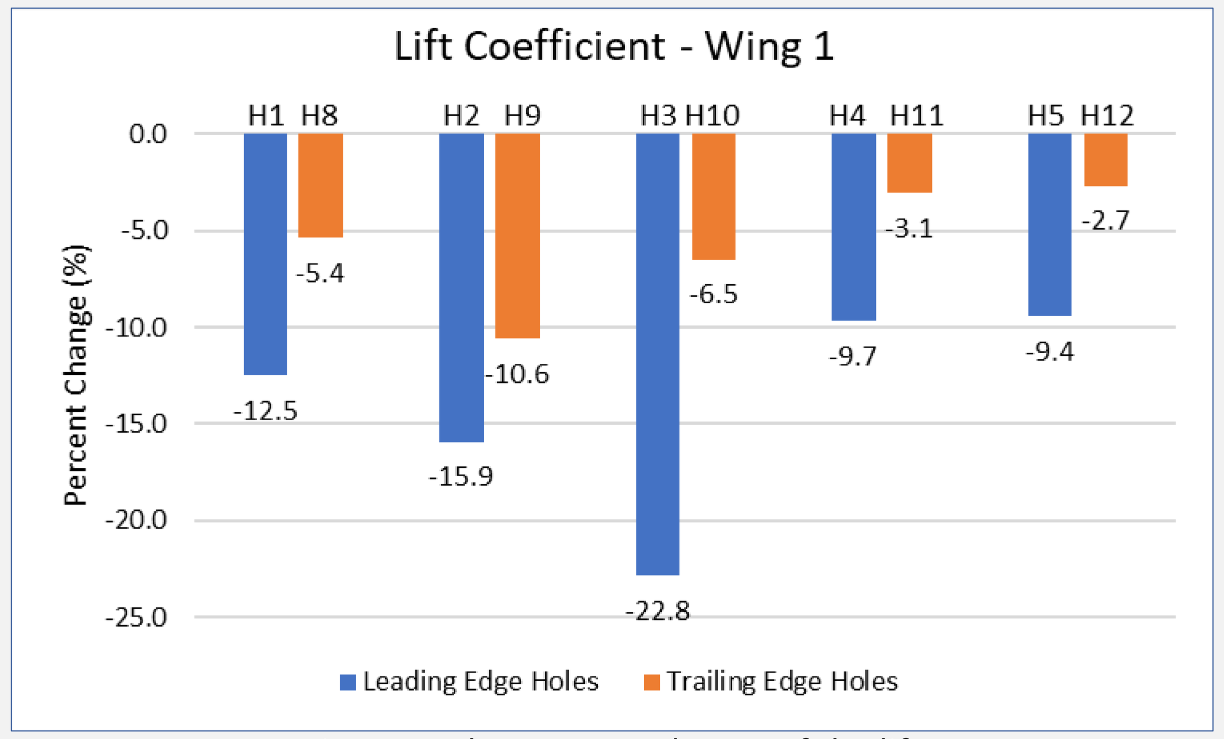

Figure 5: The percent change of the lift coefficients found for wing 1

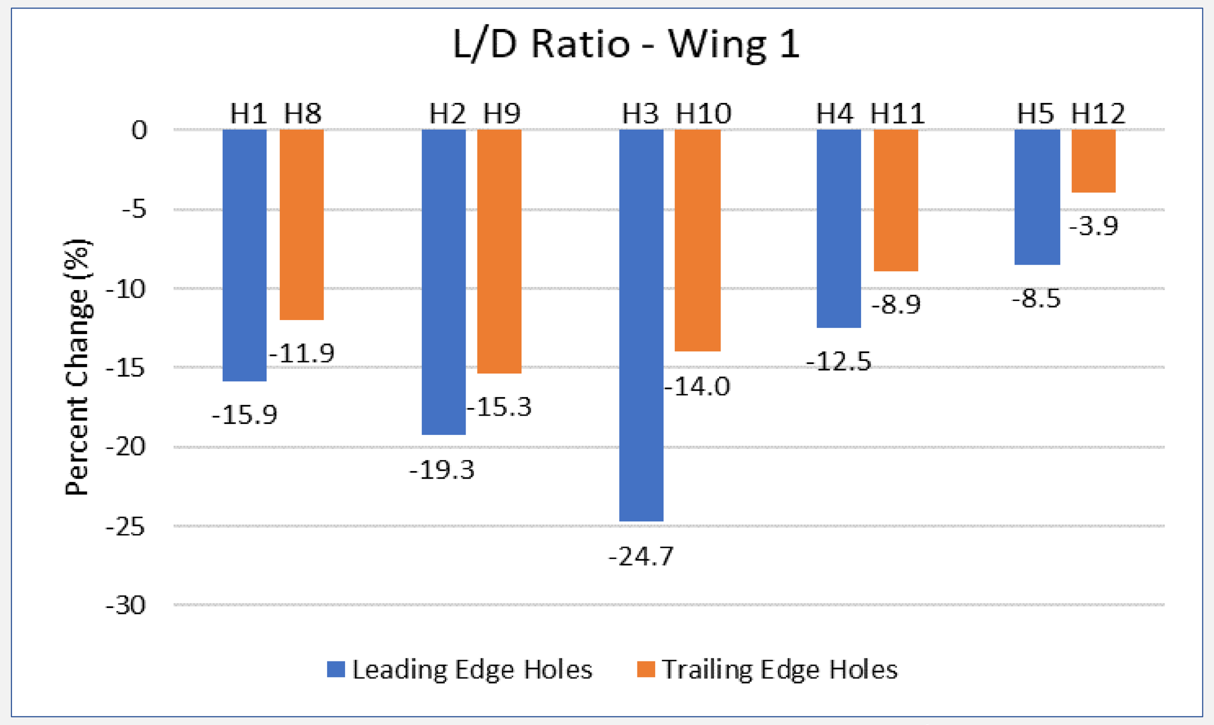

Figure 6: The percent change of the L/D ratios found for wing 1

WING 2

	Lift Coefficient of Damaged Cases	Lift Coefficient of Undamaged Cases	% Change Between Damaged & Undamaged Cases	L/D Ratio of Damaged Cases	L/D Ratio of Undamaged Cases	% Change Between Damaged & Undamaged Cases
H1	0.1621	0.1913	-15.3	0.1283	0.1613	-20.5
H2	0.1545	0.1907	-19.0	0.1243	0.1604	-22.5
H3	0.1472	0.1902	-22.6	0.1208	0.1594	-24.3
H4	0.1697	0.1897	-10.5	0.1405	0.1585	-11.4
H5	0.1641	0.1891	-13.2	0.1311	0.1575	-16.8
H6	0.1574	0.1886	-16.6	0.1253	0.1566	-20.0
H7	0.1660	0.1881	-11.7	0.1342	0.1557	-13.8
H8	0.1674	0.1876	-10.8	0.1374	0.1547	-11.2
H9	0.1647	0.1870	-11.9	0.1352	0.1538	-12.1
H10	0.1434	0.1861	-22.9	0.1192	0.1553	-23.2
H11	0.1577	0.1858	-15.1	0.1266	0.1585	-20.1
H12	0.1640	0.1854	-11.5	0.1430	0.1566	-8.7
H13	0.1654	0.1851	-10.6	0.1291	0.1547	-16.5

Table 2: The summary of the averages of the lift coefficients and L/D ratios recorded for wing 2

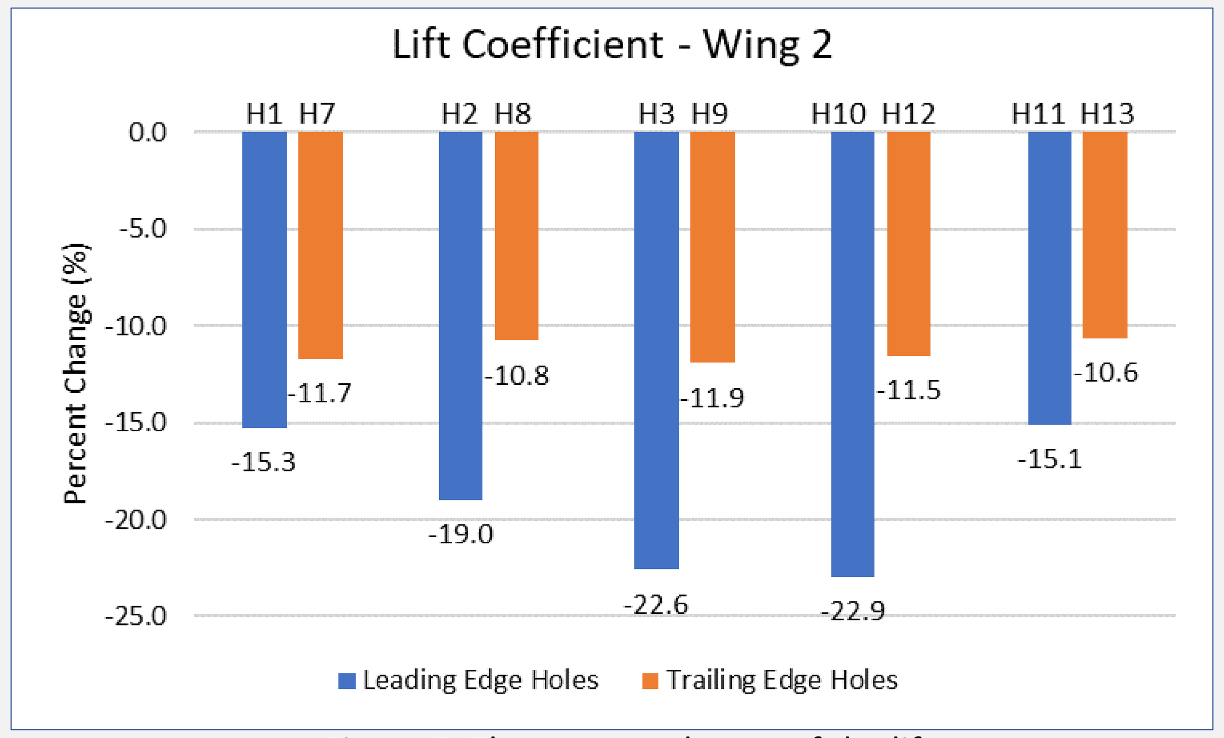

Figure 7: The percent change of the lift coefficients found for wing 2

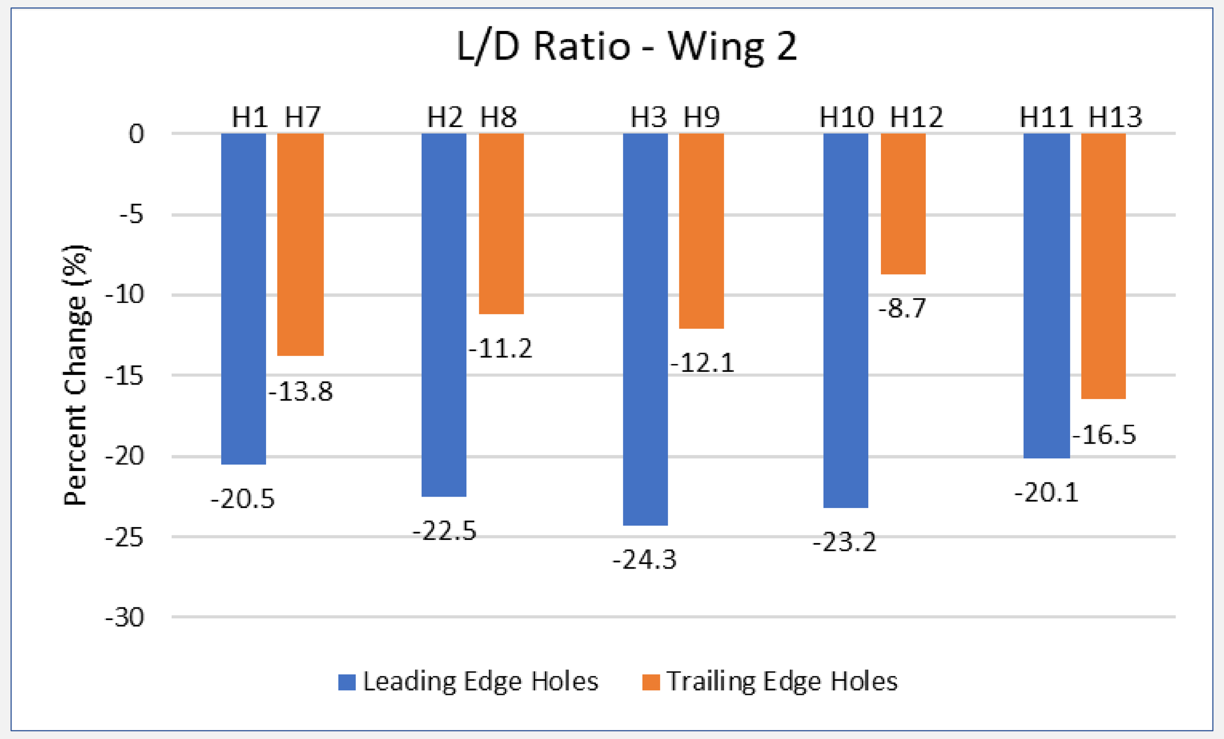

Figure 8: The percent change of the L/D ratios found for wing 2

Conclusion

- **The Leading Edge is Most Sensitive to Damage:** Damages occurring to the leading edge of the wing are more significant than damages to the wing's trailing edge. This is evident by Figures 5 – 8, which show the percent difference in the lift coefficients and L/D ratios of the holes compared to the undamaged cases. In all figures, the percent difference of the holes located on the leading edge are greater, indicating that the leading edge is more sensitive to damage than the trailing edge.
- **Damage is Most Significant at the Center of the Wing for Leading Edge Damages:** Figures 5 - 8 show that damage increases in significance as you approach the center of the wing for holes located on the leading edge. All figures show a greater percent difference for such cases. The drop in lift is greater for the holes at the center of the wing than for the holes at the tips of the wing.
- **The Greater the Damage Size is, the Greater Impact on the Lift:** Figures 5 and 6 show that the greatest change in lift coefficient and L/D ratio occurs for the larger holes. This is true for both the leading edge and trailing edge of the wing. On wing 1, holes 1 and 5 are both located closest to each end of the wing. The hole location and flow is the same for both holes, but the impact of the damage is greater for hole 1 due to its hole diameter being larger. This is true for holes 2 and 4 also.