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Air-to-Air collisions: Quadcopter Drones VS. Part 25 Category Aircraft

Dr. Azzedine Dadouche

Senior Research Officer

Aerospace Research Centre

Gas Turbine Laboratory

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NRC AEROSPACE

Objective

- To assess damage severity resulting from drone impact on aircraft structure
- To support regulators (Transport Canada - TC) and defence (Defence Research and Development Canada - DRDC) with experimental data and damage analysis to create evidence-based rules for drone airspace usage and procedures for aircraft operation (civilian and military).
- To validate/fine-tune advanced FEM modeling & simulation

NRC Expertise

- The National Research Council of Canada is one of multiple agencies in the world that support aircraft and engine manufacturers to certify their products against bird strikes.

- The first windshield and aircraft structure bird impact tests conducted by NRC were reported in 1965.

- Multiple cannons with different barrel bore diameters: 0.9 cm (3.5 in), 1.3 cm (5 in), 15.2 cm (6 in), 43.8 cm (17.25 in)

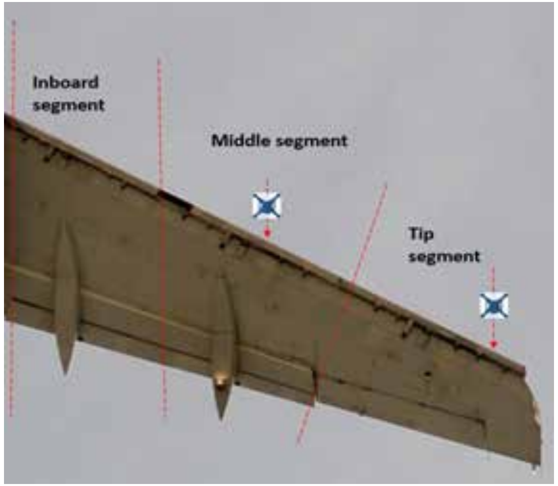
Drone Cannon

- Called the “Super Cannon”
- Developed at NRC in close collaboration and partnership with TC & DRDC.
- Pilot testing has been conducted on flat plates and selected aircraft segments (Part 23 and Part 25).

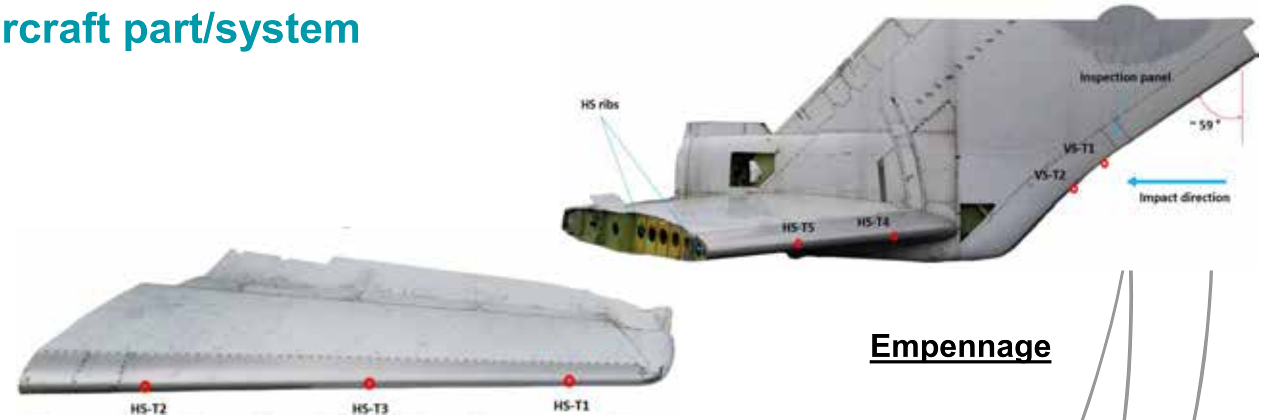
Drone/Aircraft Impact Testing

Speed [knot, m/s]	Leading Edge
140 (±5), 72 (±2.5)	Deployed slat
250 (±5), 129 (±2.5)	Retracted slat

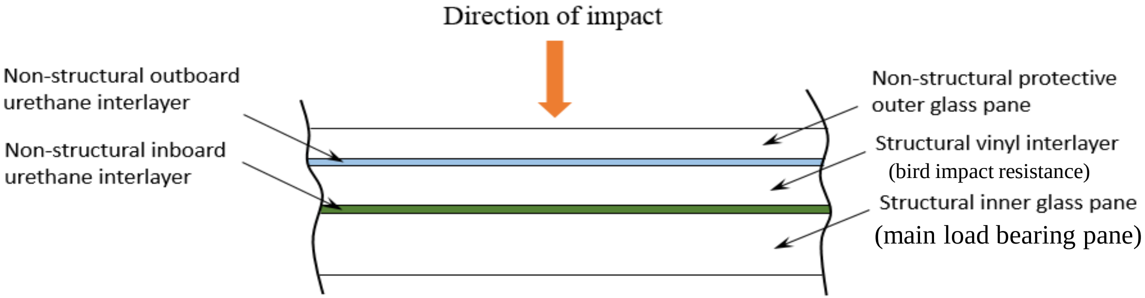
- Damage assessment for aircraft part/system
- Risk of collateral damage
- Risk of fire



Wing leading edge

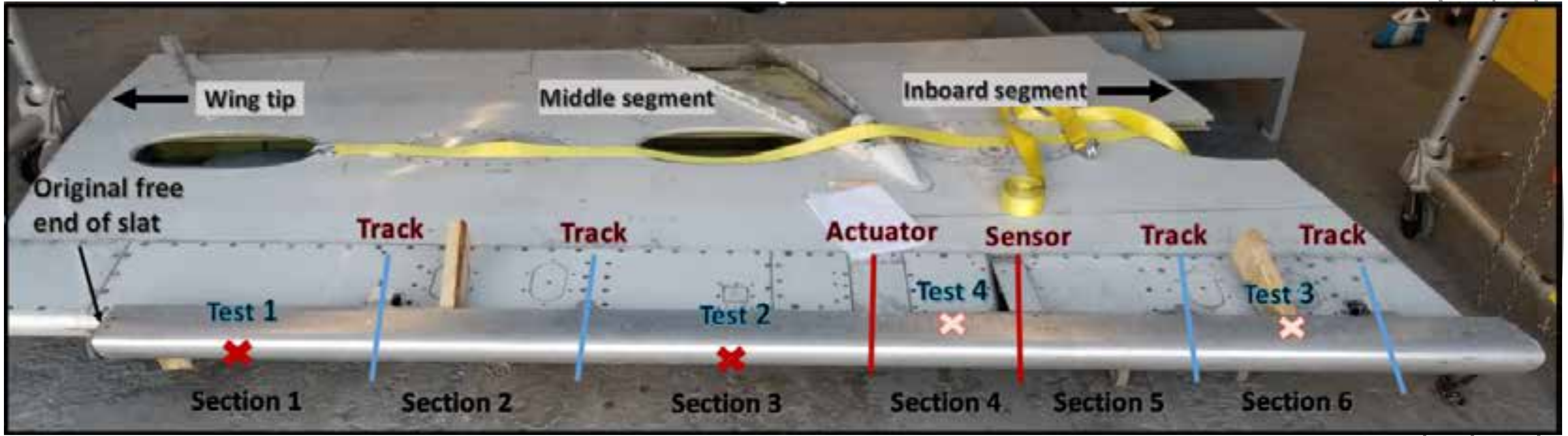


Empennage



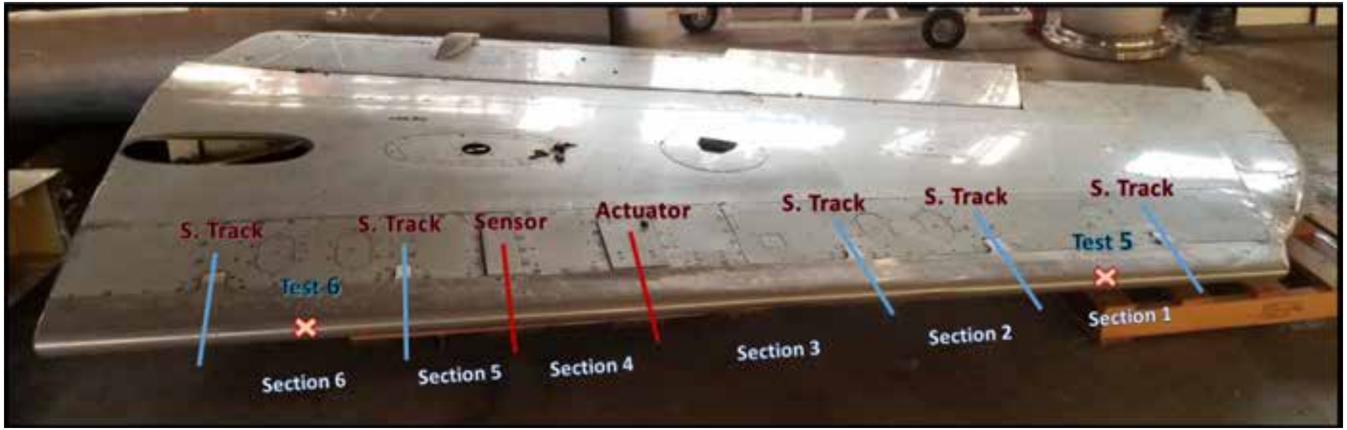
Windshield

Wing Leading Edge Testing



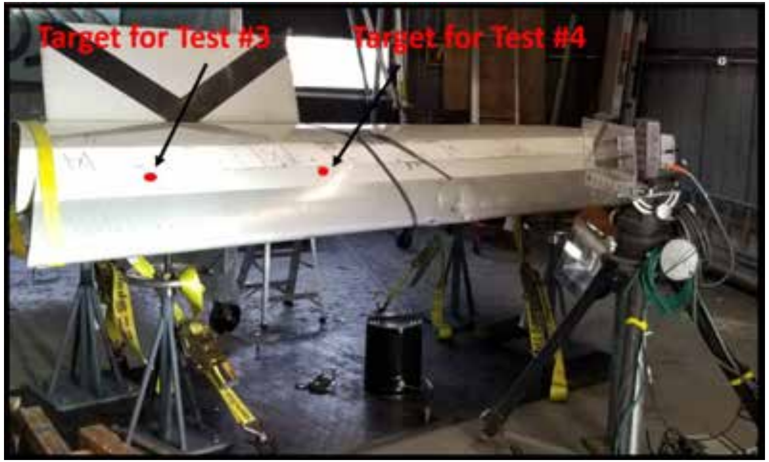
Test #	Velocity [knot, m/s]	Location	Battery
1	140 (±5), 72 (±2.5)	Leading edge of slat, free end	Discharged
2	140 (±5), 72 (±2.5)	Leading edge of slat, between tracks	Charged
3	140 (±5), 72 (±2.5)	Upper side of slat, between tracks	Discharged
4	140 (±5), 72 (±2.5)	Upper side of slat, between actuator and sensor	Charged

Wing Leading Edge Testing



Test #	Velocity [knot, m/s]	Location	Battery
5	250 (±5), 128.6 (±2.5)	Leading edge of slat, between tracks	Discharged
6	250 (±5), 128.6 (±2.5)	Leading edge of slat, between tracks	Charged

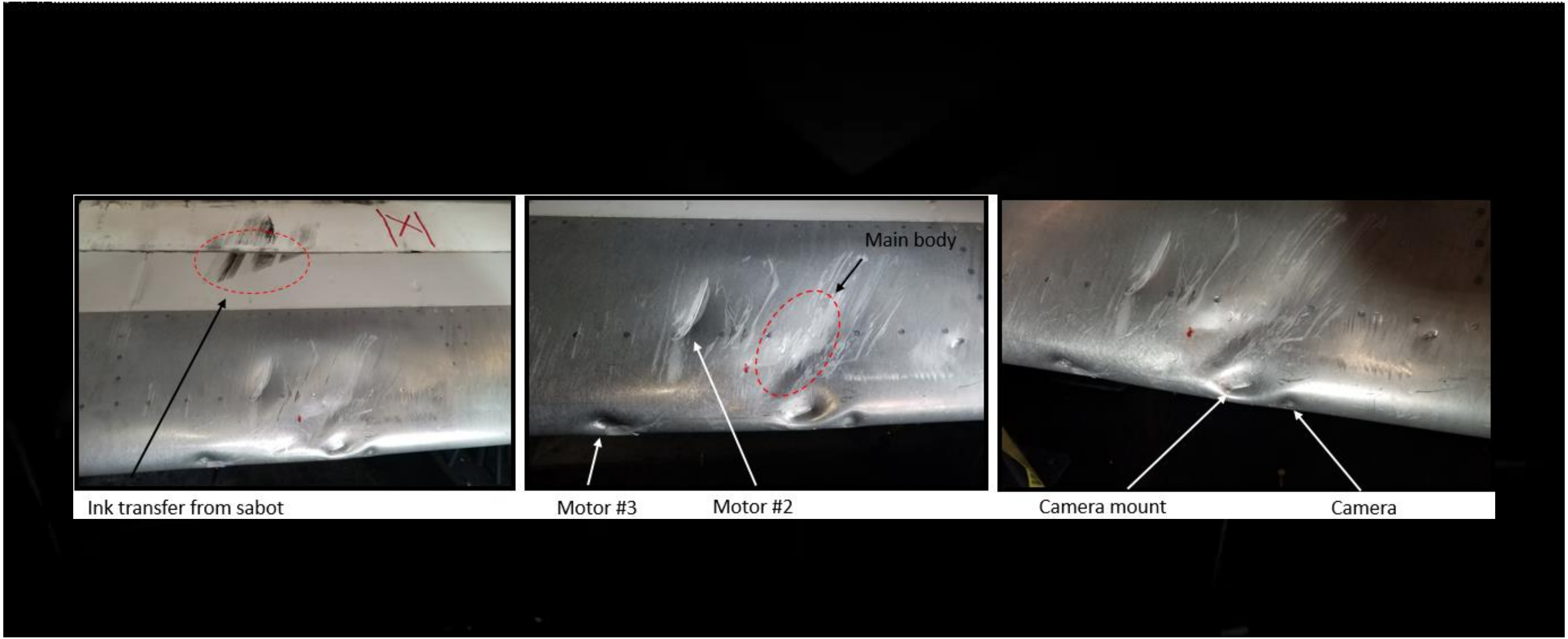
Wing Leading Edge Testing



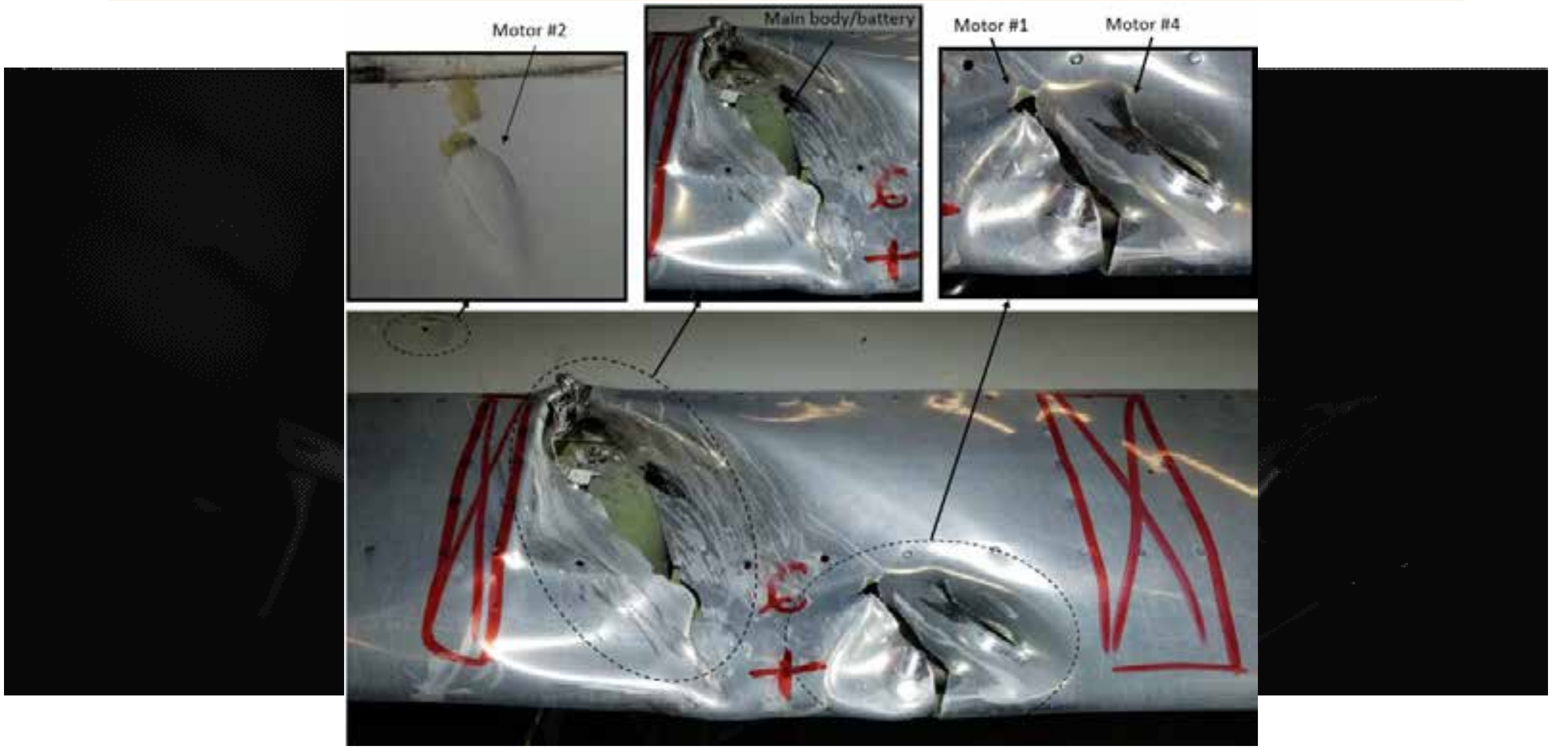
Setup for low and high speed impact testing

Speed [knot, m/s]	Leading Edge
140 (±5), 72 (±2.5)	Deployed slat
250 (±5), 129 (±2.5)	Retracted slat

Drone/slat impact at 140 knots (Test#2, deployed slat, charged battery)



Drone/slat impact at 250 knots (Test#6, Retracted slat, charged battery)



Empennage Testing

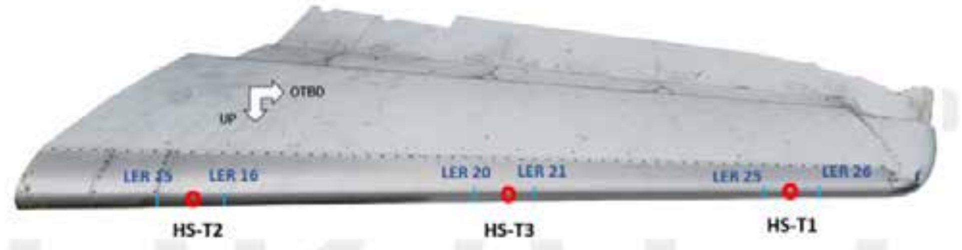
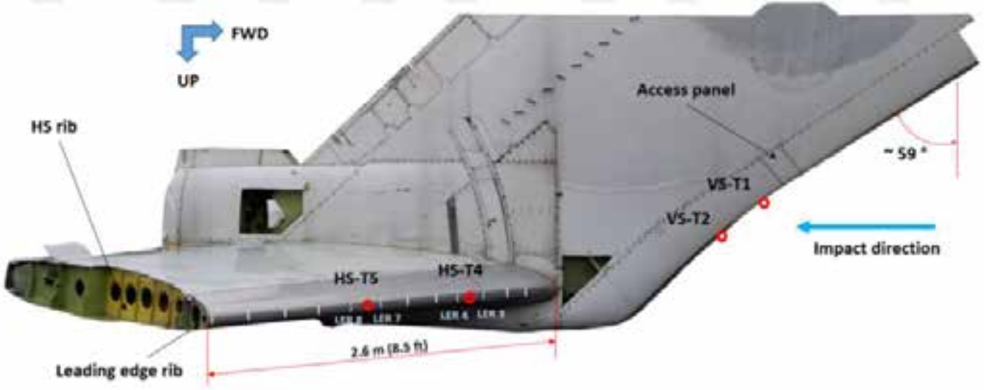


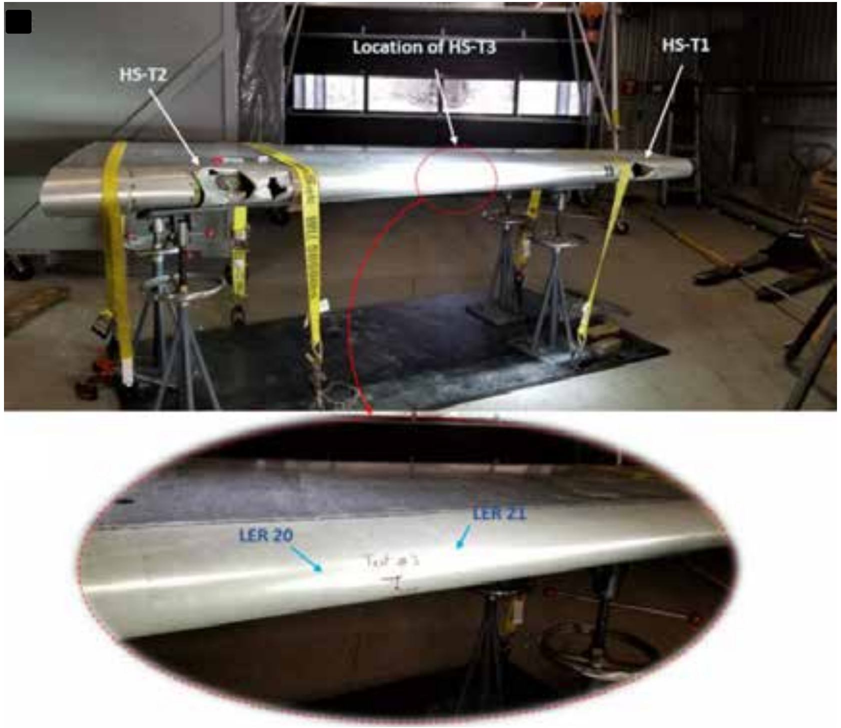
Figure 6: Tip segment of RHS HS (shown upside-down)



Test #	Projectile	Weight, kg (lb)	Velocity		Target	Sweep angle, °	Battery condition
			m/s	knots			
1	Quadcopter	1.2 (2.6)	128.6 (±2.5)	250 (±5)	LHS HS, tip (HS-T1)	32	Discharged
2	Quadcopter	1.2 (2.6)	128.6 (±2.5)	250 (±5)	LHS HS, (HS-T2)	32	Discharged
3	Quadcopter	1.2 (2.6)	128.6 (±2.5)	250 (±5)	LHS HS, middle (HS-T3)	32	Charged
4	Quadcopter	1.2 (2.6)	128.6 (±2.5)	250 (±5)	LHS HS, root (HS-T4)	40	Discharged
5	Quadcopter	1.2 (2.6)	128.6 (±2.5)	250 (±5)	LHS HS, middle (HS-T5)	40	Discharged
6	Quadcopter	1.2 (2.6)	128.6 (±2.5)	250 (±5)	VS (VS-T1)	59	Discharged
7	Quadcopter	1.2 (2.6)	128.6 (±2.5)	250 (±5)	VS (VS-T2)	59	Discharged
8	Bird carcass	1.2 (2.6)	128.6 (±2.5)	250 (±5)	RHS HS, middle (HS-T6)	32	N/A

Empennage Testing

Horizontal stabilizer setup (HS-T3)



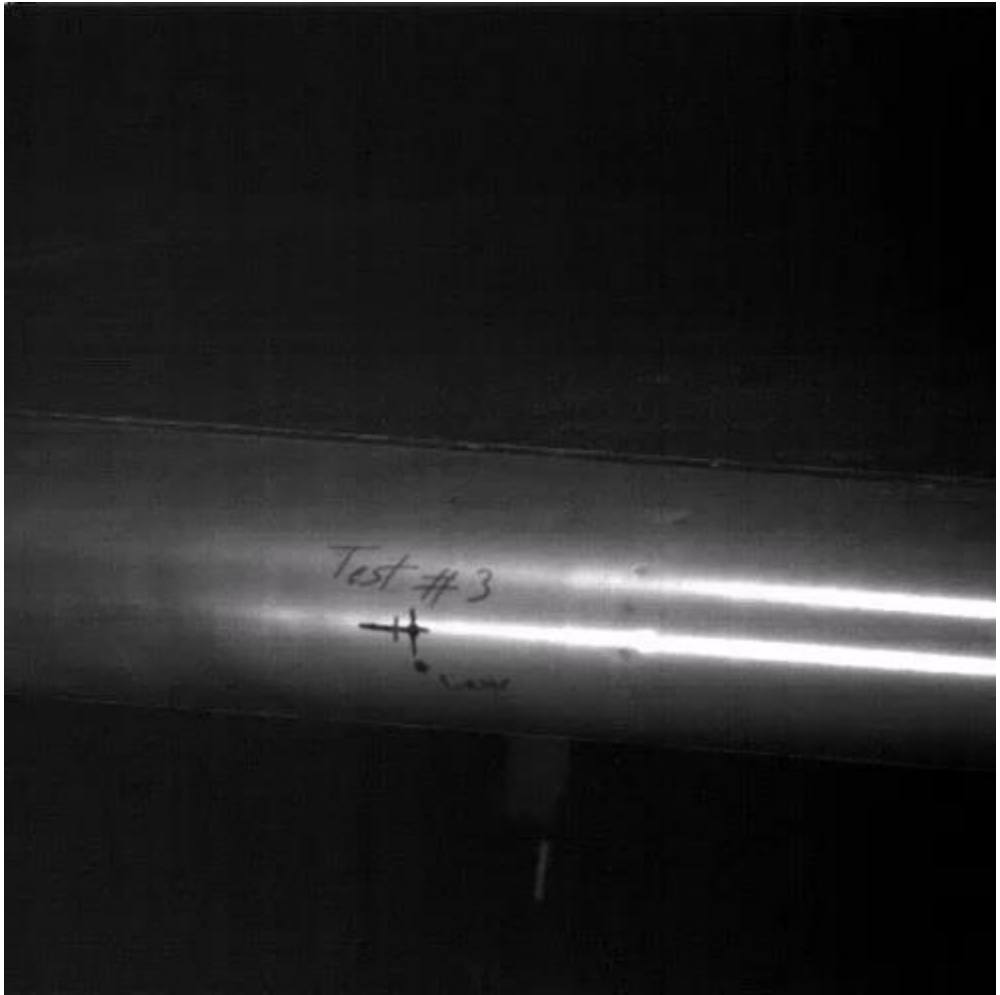
Vertical stabilizer setup (VS-T2)

Empennage Testing

Bird gun

Horizontal stabilizer setup (Bird impact)

Drone impact on HS (charged battery)

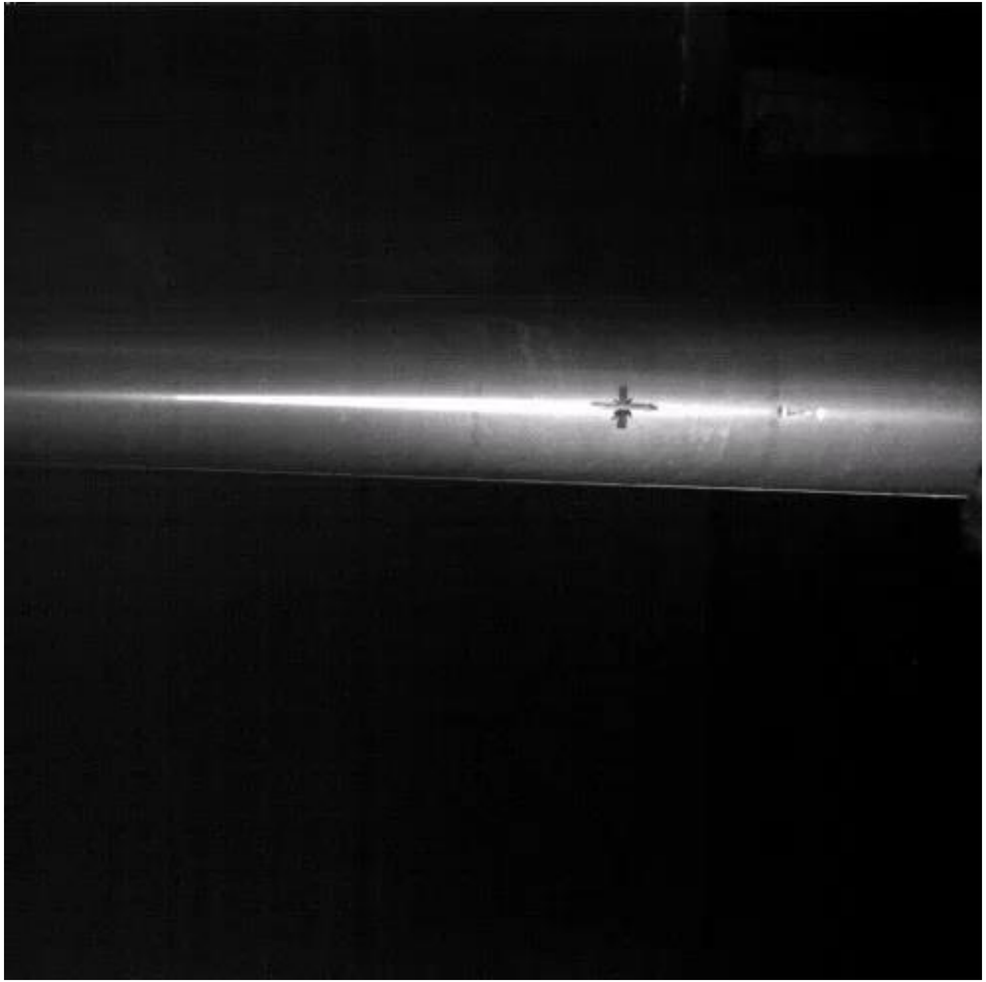


Post-test video

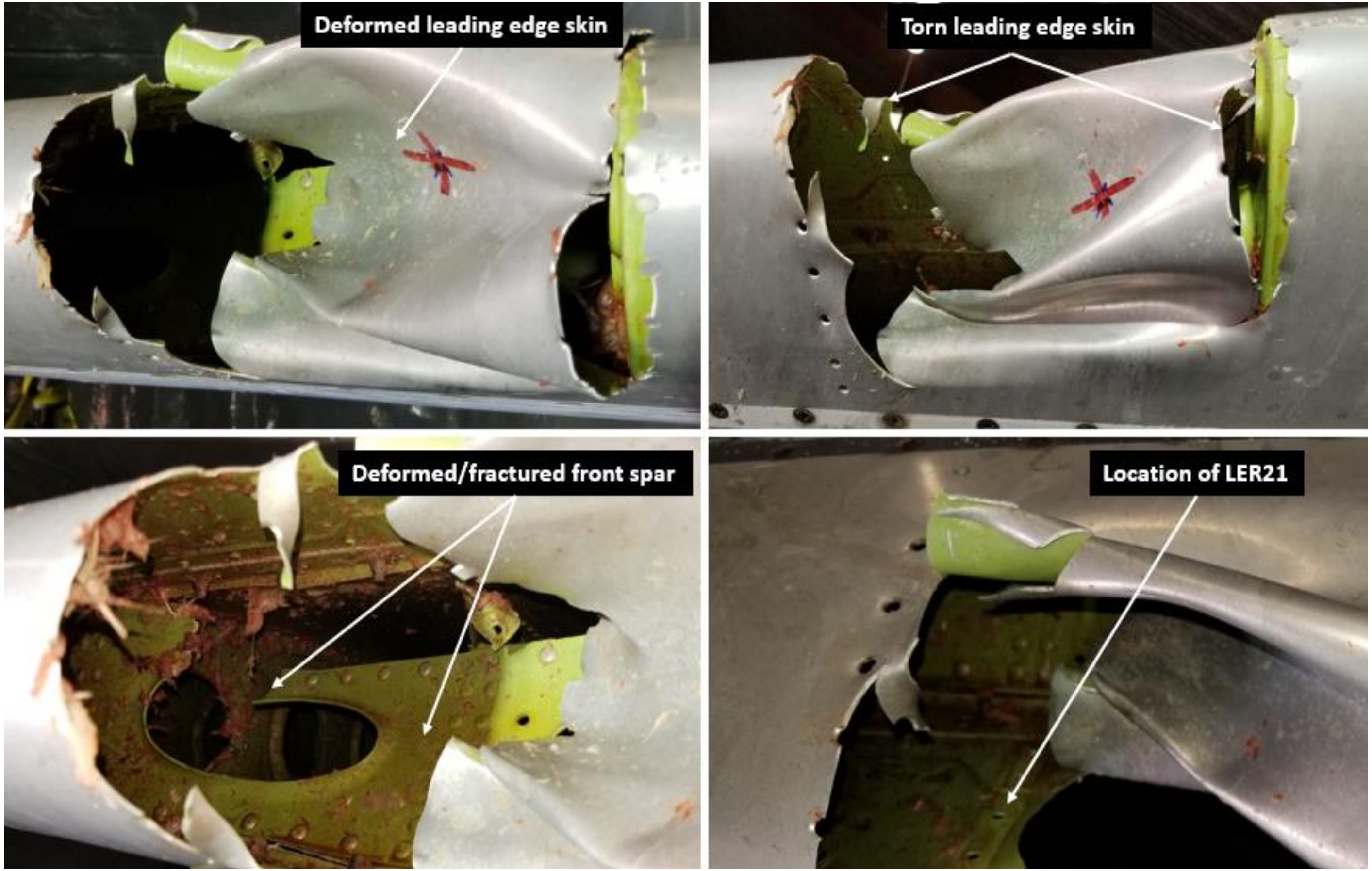
~ 4 minutes after the impact


Fumes

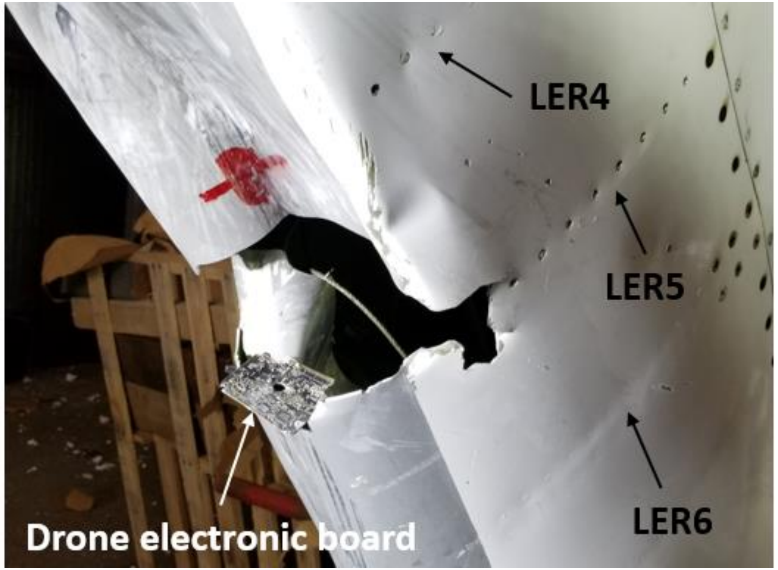
Bird impact on HS

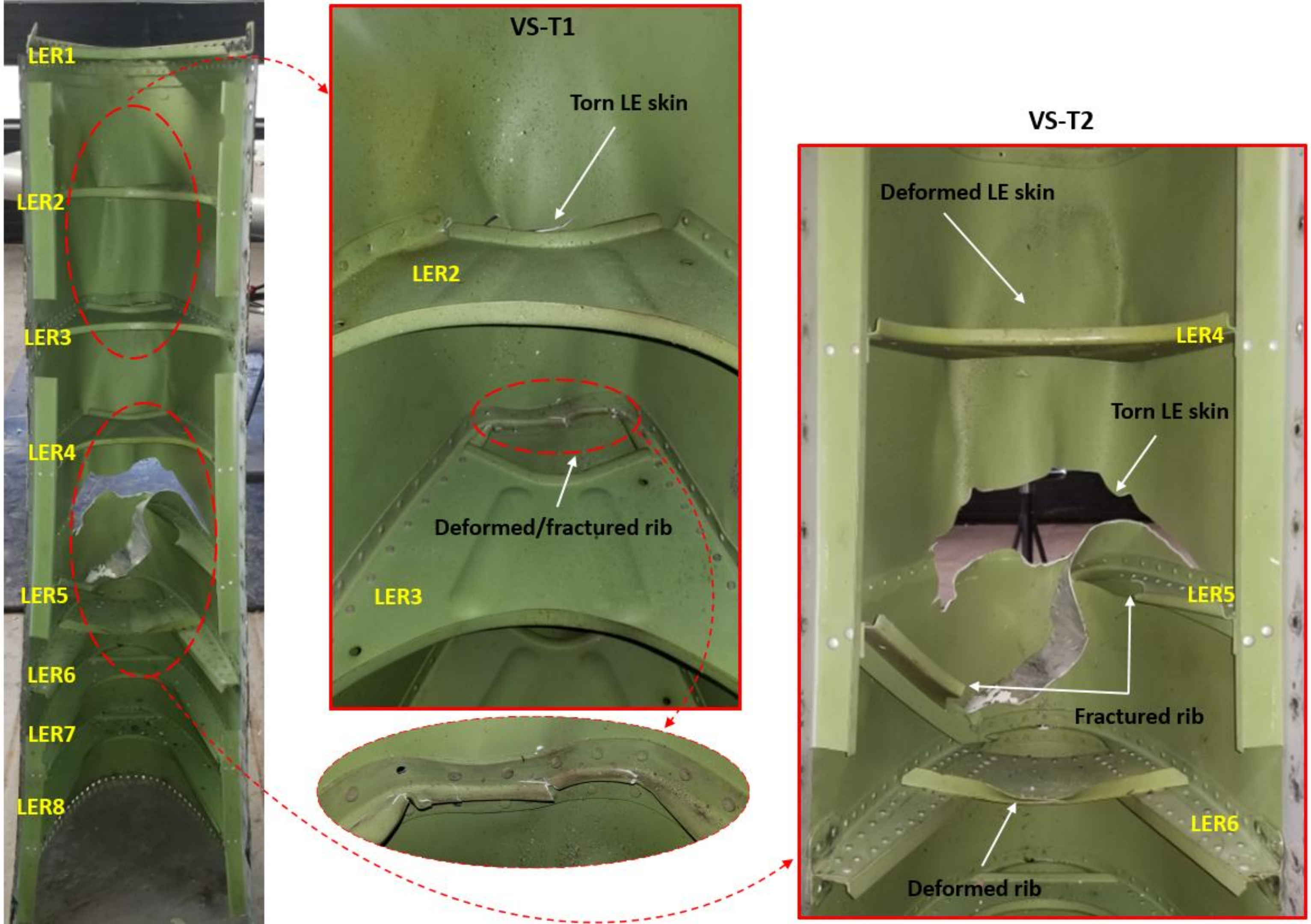


Damage caused by the bird impact



Drone impact on VS (discharged battery)



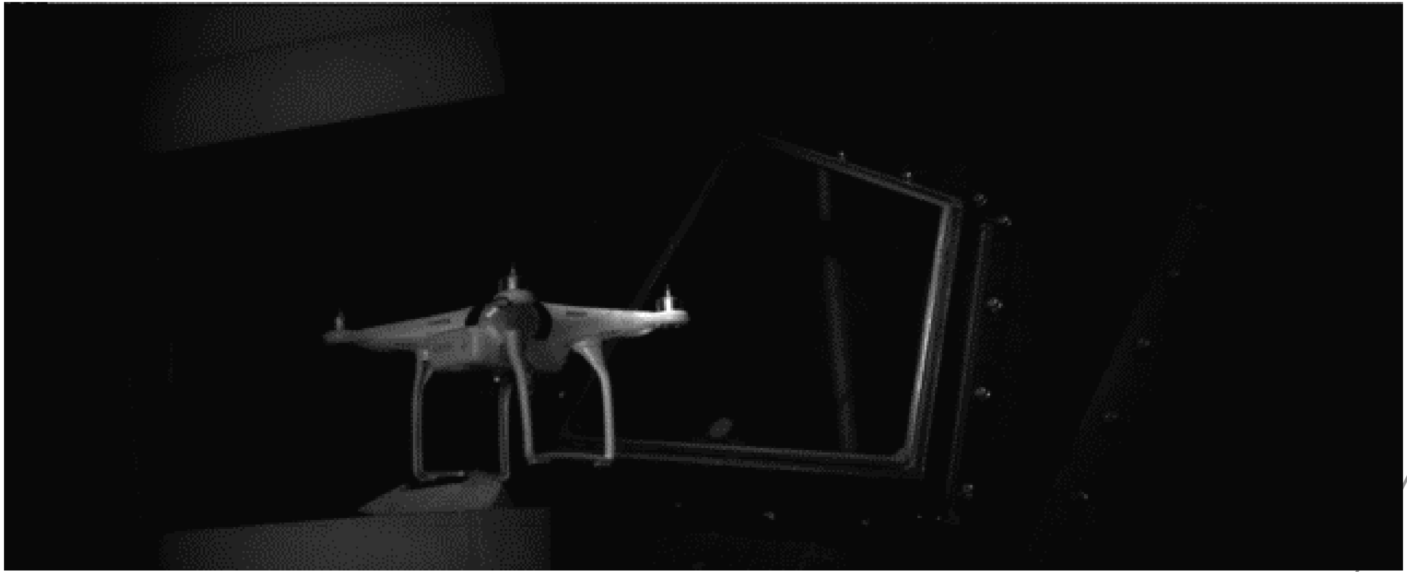


LER1
LER2
LER3
LER4
LER5
LER6
LER7
LER8
VS-T1
Torn LE skin
LER2
Deformed/fractured rib
LER3
VS-T2
Deformed LE skin
LER4
Torn LE skin
LER5
Fractured rib
LER6
Deformed rib

Windshield Testing

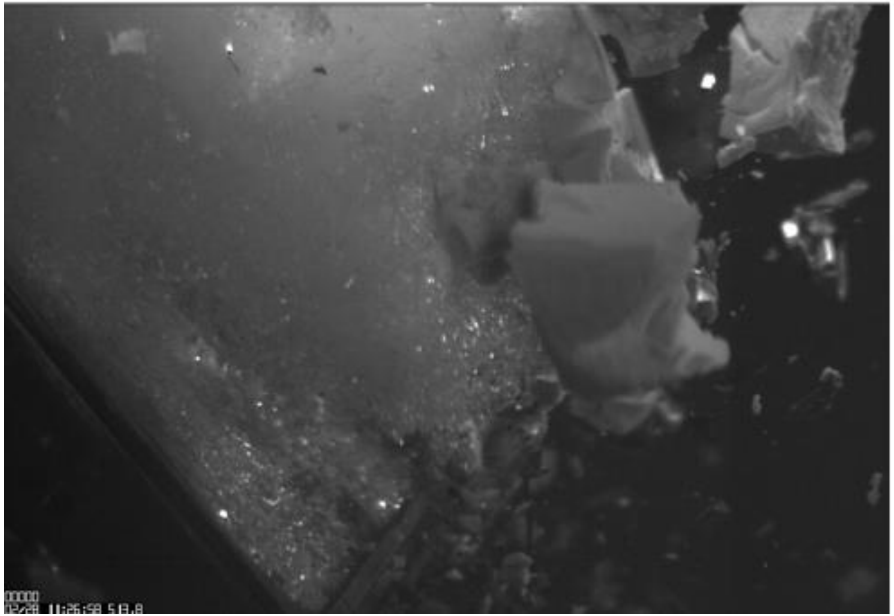
Test	Speed [knot, m/s]	Windshield	Battery status
1	140 (±5), 72 (±2.5)	LHS	charge ≤ 25%
2	250 (±5), 129 (±2.5)	RHS	charge ≤ 25%

Selected windshield results



Selected windshield results

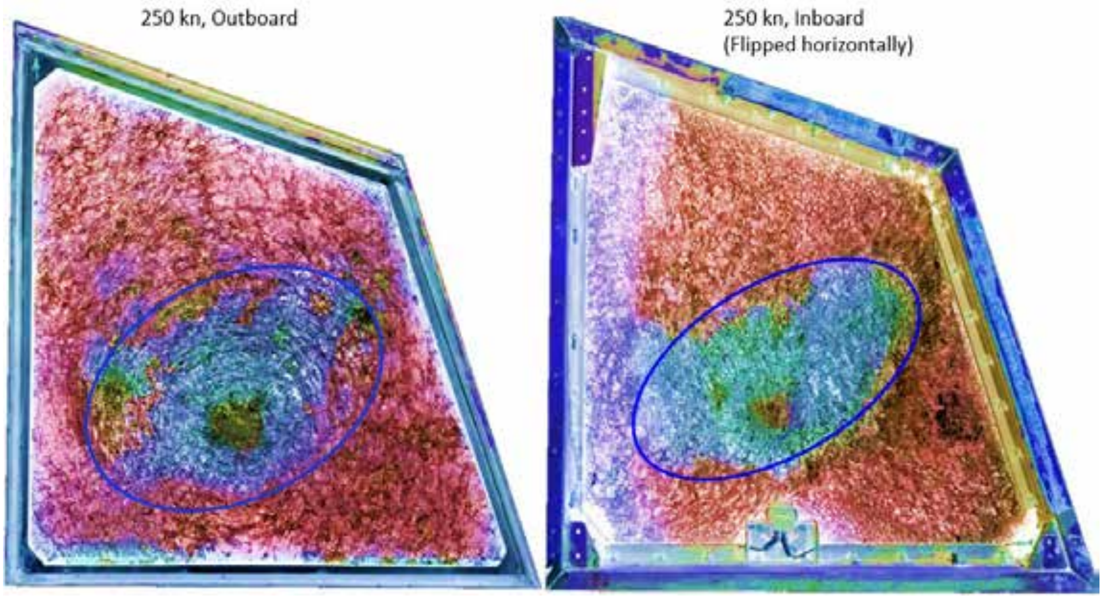
Side view (C2)



Isometric view (C4)

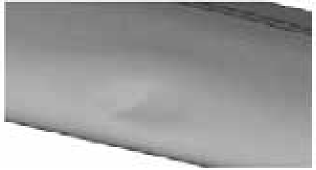
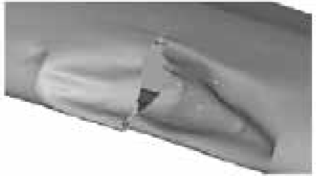
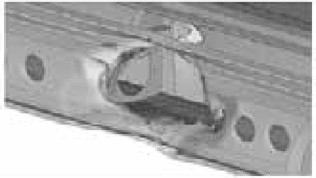
Generation of cloud of glass fragments during impact
(Test #2 @ 250 knots)

Selected windshield results



~ 25% of the inner structural ply glass was spalled off down to the inboard surface of the structural vinyl interlayer (Test #2 @ 250 knots)

Damage severity level (ASSURE)

Severity	Description	Example
Level 1	• Airframe undamaged. • Small deformations.	
Level 2	• Extensive permanent deformation on external surfaces. • Some deformation in internal structure. • No failure of skin.	
Level 3	• Skin fracture. • Penetration of at least one component into the airframe.	
Level 4	• Penetration of UAS into airframe. • Failure of parts of the primary structure.	

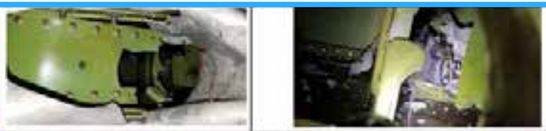
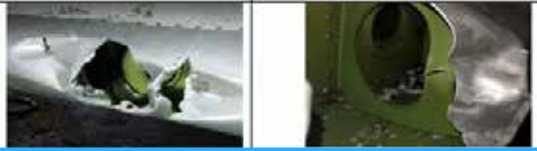
Damage severity – Wing leading edge

Test #, speed (kn)	Severity	Description	Damage picture
1, 140	Level 1	Small plastic deformation Battery missed target	
2, 140	Level 2	Extensive plastic deformation on external skin. Distortion of secondary parts No failure of skin	
3, 140	Level 2	Extensive plastic deformation on external skin. Partial failure of skin Partial damage to underlying structure	
4, 140	Level 2	Extensive plastic deformation on external skin. Localised failure of skin Partial damage to underlying structure Battery missed target	
5, 250	Level 2	Skin fracture Extensive plastic deformation of skin Secondary damage (tracks) Battery missed target point	
6, 250	Level 3	Extensive failure of the skin Penetration of drone debris inside the fractured area Secondary damage (tracks) Slat jammed in place	

Deployed slat @ 140 kt

Retracted slat @ 250 kt

Damage severity – Empennage (250 kt)

Test ID, speed (kt)	Severity	Selected damage pictures
HS-T1, 250	Level 4	
HS-T2, 250	Level 4	
HS-T3, 250	Level 4	
HS-T4, 250	Level 4	
HS-T5, 250	Level 4	
HS-T6, 250	Level 4	

HS - Drone impact

HS – Bird impact

VS-T1, 250	Level 3	
VS-T2, 250	Level 4	

VS – Drone impact

Note: Final report is currently under review by TC and DRDC

Results Summary

AWM 525 (Part 25) Aircraft								
	Leading edge slat						Windshield	
	Deployed, 72 m/s				Retracted, 129 m/s		72 m/s	129 m/s
Case	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 1	Test 2
Severity	Level 1	Level 2	Level 2	Level 2	Level 2	Level 3	Fail	Fail
Fire risk	Low	Low	Low	Low	Low	Low	Low	Low

AWM 525 (Part 25) Aircraft								
	Horizontal stabilizer						Vertical stabilizer	
	Quadcopter					Bird	Quadcopter	
Test ID	HS-T1	HS-T2	HS-T3	HS-T4	HS-T5	HS-T6	VS-T1	VS-T2
Severity	Level 4	Level 4	Level 4	Level 4	Level 4	Level 4	Level 3	Level 4
Battery charge level	<25%	<25%	%	<25%	<25%	N/A	<25%	<25%
Fire risk	Low	Low	High	Low	Low	N/A	Low	Low

Conclusion

- Damage severity level resulting from a drone impact on wing LE slat depends on speed, drone rotation angles and impact location on the slat.
- Drone impact on HS and VS result in a penetration and cause significant damage to the leading edge structure regardless of the sweep angle (layback for VS).
- Bird carcass impact on a segment of HS caused damage to the leading edge and internal structure of the HS equivalent to that inflicted by a drone of the same weight.
- The impact test using charged batteries (LiPo) resulted in severe failure of the batteries cells (generation of toxic fumes, ignition, open flame and elevated temperature).
- Drone impact on windshields results in a considerable damage especially at the speed of 250 knots. All the glass plies were fractured and a significant amount of glass fragments were released into the cabin (~25% of the structural inner glass pane).
  → Such an impact results in completely impaired vision through the windshield.
  → The cloud of fragments released into the cabin would have posed a penetration and inhalation hazard to the operator located directly behind
- Damages caused by quadcopters or bird carcasses need to be evaluated to ensure aircrafts can withstand 70% flight loads and 40% gust velocities as required by regulators for bird impact certification. This can be verified through analysis and/or testing.

References

- **Drone impact assessment on aircraft structure: flat plate testing and analysis**
  Dadouche, Azzedine; Galeote, Brian; Breithaupt, Timothy; Greer, Allan; Backman, David; Li, Gary (Linxi); Vidal, Charles; Gould, Ron

- **Drone impact assessment on aircraft structure: windshield and leading edge testing and analysis**
  Dadouche, Azzedine; Greer, Allan; Galeote, Brian; Breithaupt, Timothy; Vidal, Charles; Gould, Ron

- **Drone Impact Damage Assessment on AWM 525 (Part 25) Aircraft Structure: Empennage Testing …** *coming soon ☺*

Brian Galeote Allan Greer

Tim Breithaupt

Ron Gould

Transport Canada

Carlos Ruella
RPAS Task Force Engineering

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Mark Espennant
Centre for Security Science

QUESTIONS ?

Azzedine Dadouche, Research officer • Azzedine.Dadouche@nrc-cnrc.gc.ca