NIAR UAS Collision Simulation
Report No. NTSB002

NIAR Simulated Airborne Collision Report - Eurocopter AS350 B2 vs. DJI Phantom 3

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		1			4
		2			5
		3			6

Executive Summary

This report describes the possible outcomes of a horizontal stabilizer leading edge impact on a Eurocopter AS350 B2 with a DJI Phantom 3 quadcopter sUAS. The impact velocity range for this study was 150 kts to 222.6 kts, representing low velocity flare speeds through maximum velocity cruise speed of both rotorcraft and sUAS. Eurocopter AS350 B2 horizontal stabilizer FE model was derived from reverse engineered components from the actual aircraft under investigation. Material specifications were assumed to be typical for this type of aircraft; 2024-T3. Boundary conditions were idealized as rigid constraints at the interface of the horizontal stabilizer adjoining airframe components. Impact simulations were conducted at velocities of 150 kts through 222.6 kts for a variety of sUAS impact orientations and horizontal stabilizer leading edge (HSLE) skin mesh sizes. The simulation results indicate that the damage seen on the actual aircraft components is within the range of possible damage patterns for a quadcopter sUAS under the studied conditions.

Table of Contents

Table of Tables

Table of Figures

Nomenclature

CAD	Computer Aided Design
FE	Finite Element
HSLE	Horizontal Stabilizer Leading Edge
kts	Knots (airspeed)
NIAR	National Institute for Aviation Research
NTSB	National Transportation Safety Board
SPC	Single Point Constraint
sUAS	Small Unmanned Aerial System
UAS	Unmanned Aerial System

1 Introduction

This research effort was conducted by the National Institute for Aviation Research (NIAR) in support of ongoing accident investigation by the National Transportation Safety Board (NTSB). The horizontal stabilizer leading edge (HSLE) skin of a Eurocopter AS350 B2 (Figure 1.1 and Figure 1.2) was inspected, meshed, and applied to a finite element (FE) simulation of an impact event with a small Unmanned Aerial System (sUAS) model. The sUAS model chosen for this study was NIAR's FE quadcopter model representing a DJI Phantom 3, which has extensive documentation in the NIAR Airborne Collision Severity Evaluation report [1] and updated validation testing in NIAR's Ground Collision report [2]. The simulated impact conditions were based on data given by NTSB. These conditions were iterated in a parametric analysis of the velocities, sUAS orientations, and HSLE mesh sensitivity to demonstrate a range of feasible outcomes.

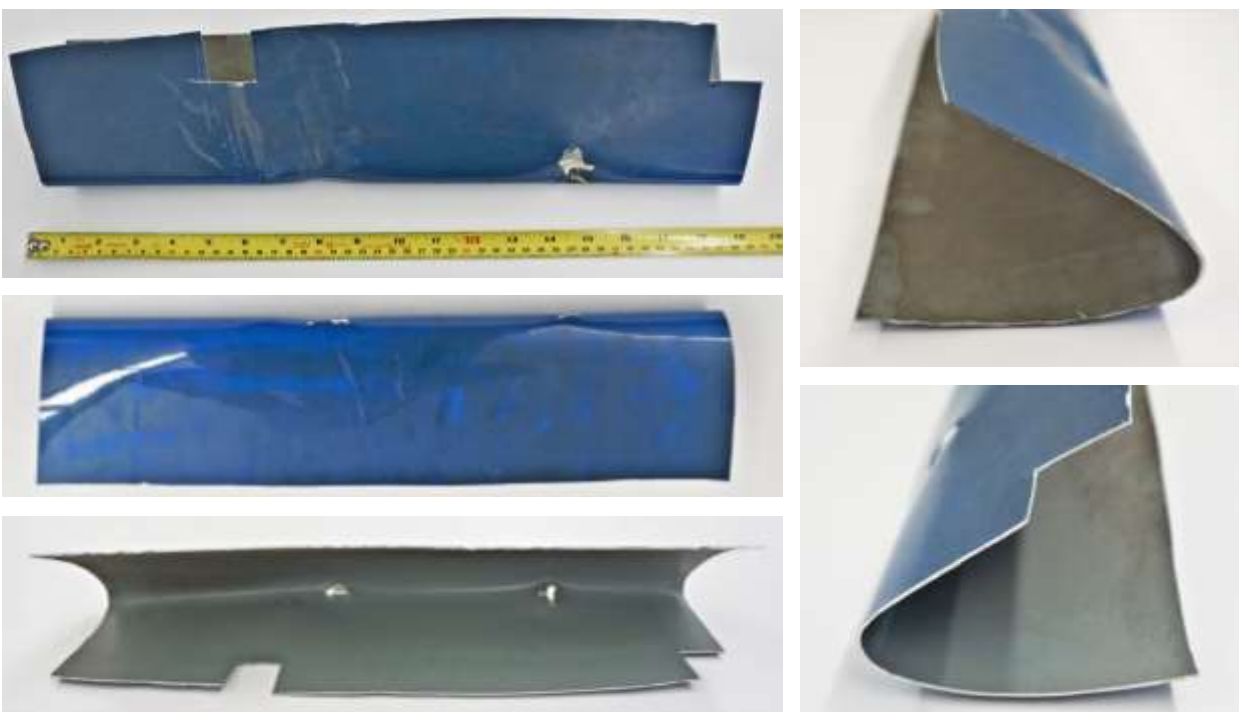


Figure 1.1 Horizontal Stabilizer Leading Edge (HSLE) Skin as Received by NIAR

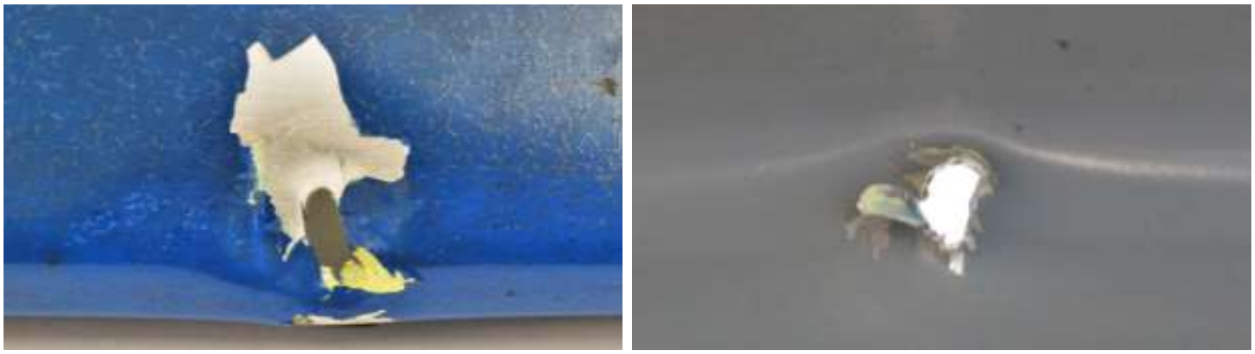


Figure 1.2 Detail Views of External Surface (Left) and Internal Surface (Right) HSLE Skin Puncture Damage

The general dimension of the AS350 B2 are shown in Figure 1.3. The HSLE was reverse engineered through different information sources, such as technical manuals and pictures of the actual part.

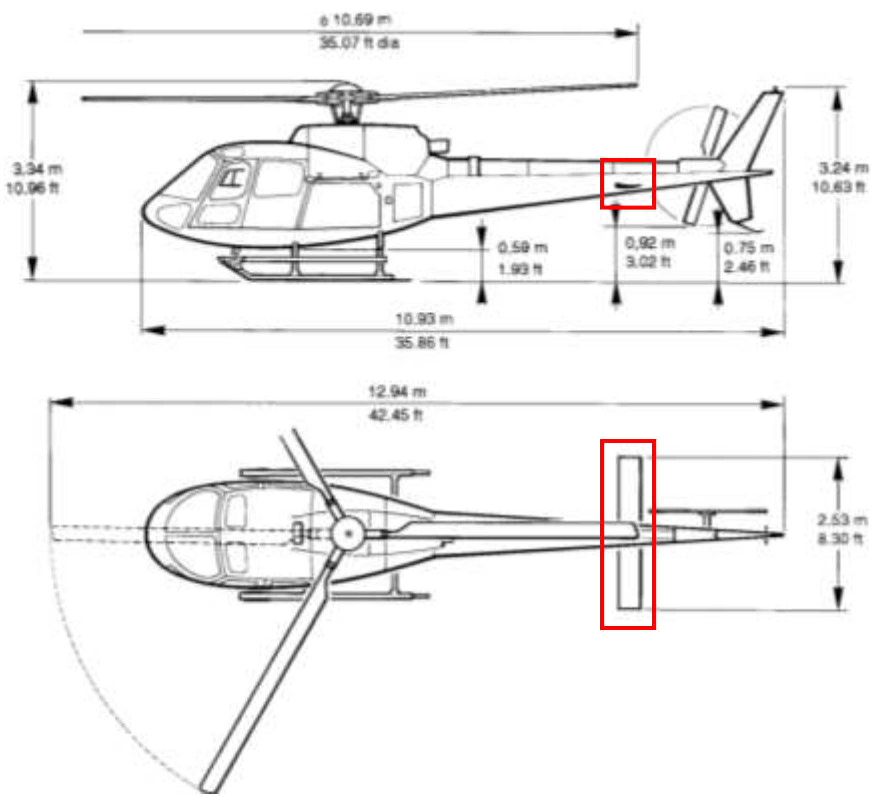


Figure 1.3 Eurocopter AS350 B2 Dimensions [4]

Through the reverse engineering process, it was possible to develop a CAD representation of the HSLE skin in the undamaged condition as shown in Figure 1.4.

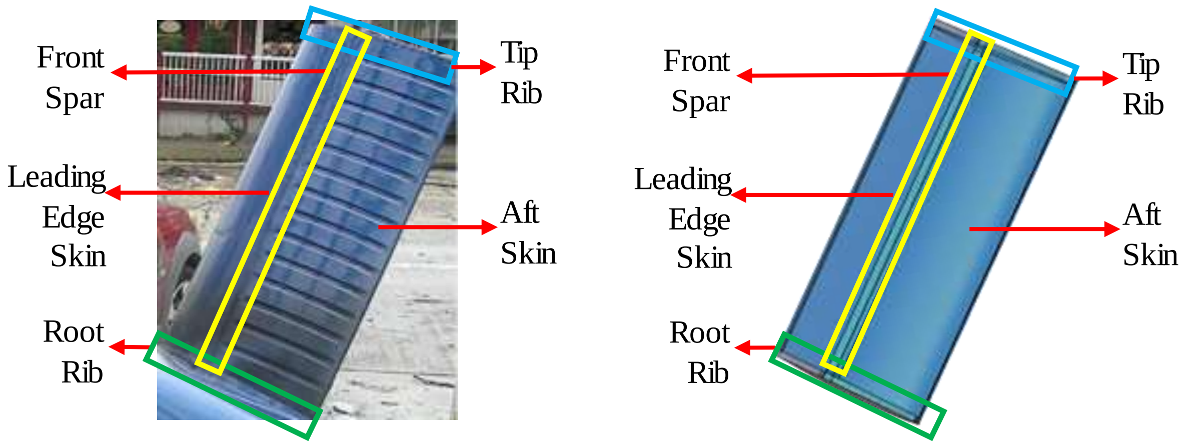


Figure 1.4 Eurocopter AS350 B2 Horizontal Stabilizer Actual Part (Right) and CAD Representation (Left)

The CAD representation was subsequently meshed as shown in Figure 1.5, and the boundary conditions, assumptions and the overall simulation setup were implemented.

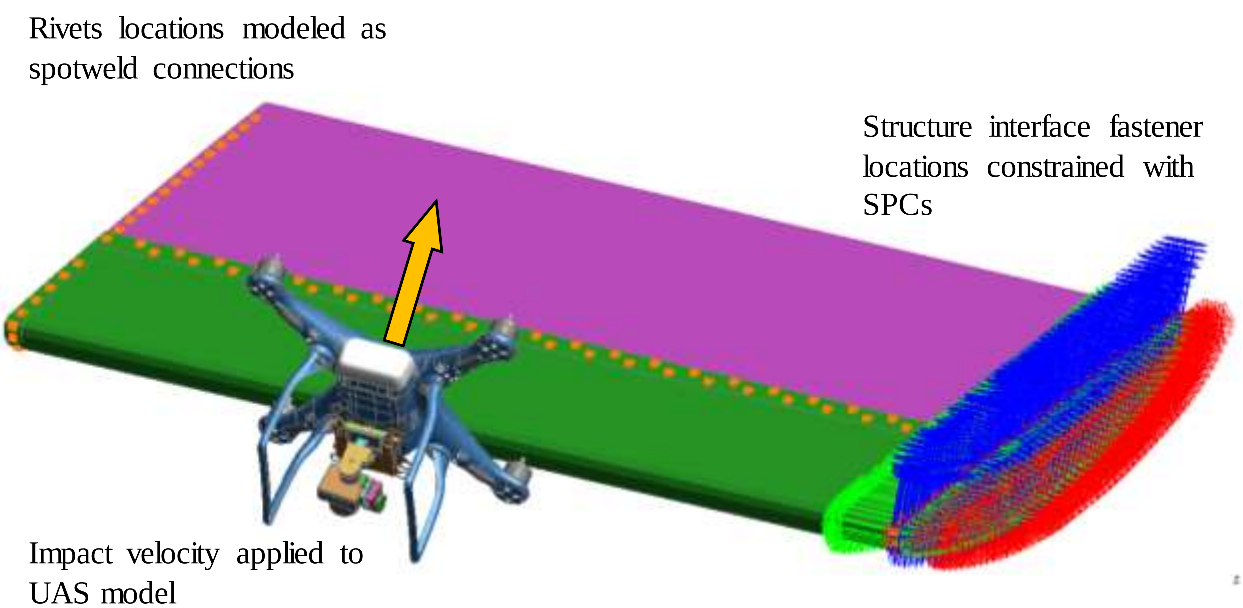


Figure 1.5 FE Simulation Setup – Undamaged Horizontal Stabilizer Showing Boundary Conditions at the Structure Interfaces

The material of the horizontal stabilizer skin panel was assumed to be 2024-T3 aluminum sheet, and modeled through *MAT_015* (Johnson-Cook material model) in LS-Dyna. These material properties are consistent with that of the aircraft models used in NIAR's airborne collision research [1], supported by test and simulation data found in DOT/FAA/AR-03/57 [3].

2 Impact Conditions

Various impact orientations were attempted based on the damage that was visible on the HSLE skin and the features of the sUAS that appeared to be capable of contributing the puncture damage and surface markings. It was identified that the puncture site was approximately the same distance from the shallow dented region as the motors of the sUAS were from the central body and battery case. Therefore, it was assumed that those features needed to make a glancing contact with the leading edge in order to produce the damage observed.

The impact conditions used for this study are documented in Table 2.1. The selected conditions reflect the realistic flight speed range of the aircraft and the performance potential of the sUAS. Note that the sUAS article involved in the collision is not confirmed to be the DJI Phantom3, so the flight conditions of the UAS are an approximation due to this assumption. For the conditions listed below, the aircraft and sUAS flight speeds were combined to from the "Closing Velocity" parameter. This denotes the speed at which the aircraft would be impacted by the sUAS, from the perspective of the HSLE. Two different sUAS orientations as shown in Figure 2.1 were evaluated. Finally, two different mesh sizes (see Figure 2.2) on the HSLE skin were employed to study its influence on the obtained damage results.

Table 2.1 Simulation Impact Conditions

Simulation Case #	Closing Velocity (kts)	Velocity Components			sUAS Orientation	HSLE Mesh Size (mm)
		X (kts)	Y (kts)	Z (kts)		
T1	214.9	180.4	77.6	87.3	Position 1	8.62
T2	222.6	186.8	96.2	100.7	Position 2	8.62
T3	222.6	186.8	96.2	100.7	Position 2	0.96
T4	150.0	125.9	56.3	58.9	Position 2	0.96
T5	180.0	151.1	67.6	70.7	Position 2	0.96

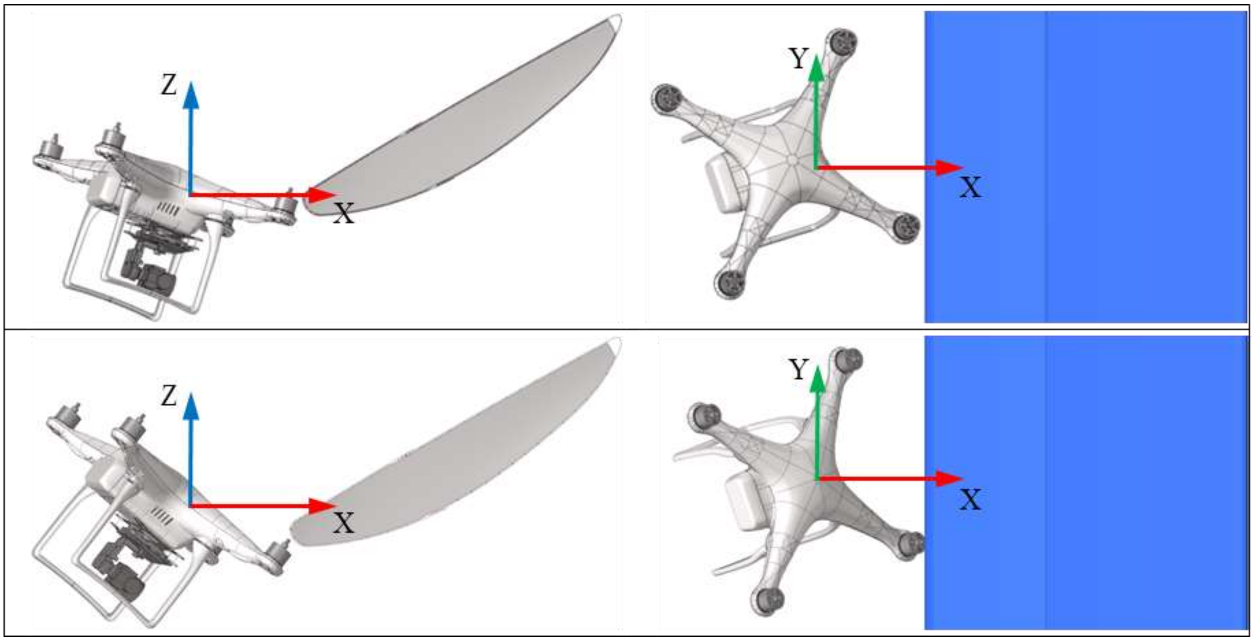


Figure 2.1 sUAS Side and Top View Impact Orientation for Position 1 (Top) and Position 2 (Bottom)

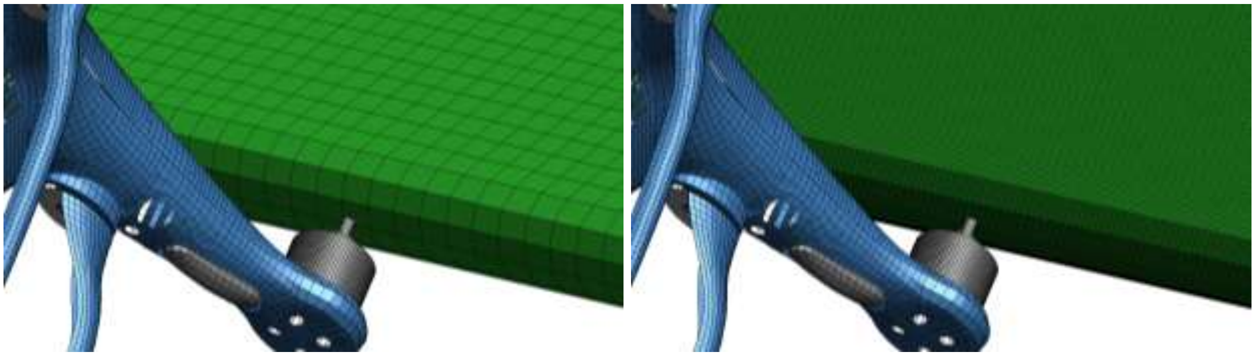
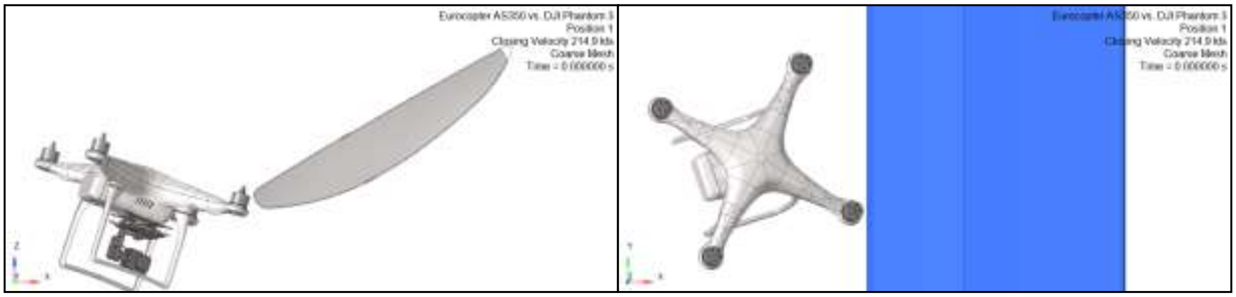


Figure 2.2 HSLE skin Coarse (Right) and Fine (Left) Mesh

2.1 Simulation T1 – 214.9 kts in Position 1; sUAS Body Impact Against a HSLE with Coarse Skin Mesh

In this condition several interactions between the sUAS and the HSLE skin were obtained as shown in Figure 2.3 and Figure 2.4, which could lead to the scratches on the surface and local damage on the HSLE skin observed on the studied article. However, as the sUAS body impacts and slides over the surface in this case, it is required to evaluate a direct contact on the HSLE with a sharp-edged feature of the UAS, such as the motor casing, to obtain the puncture damage on the article.

Initial Conditions



Damage Prediction

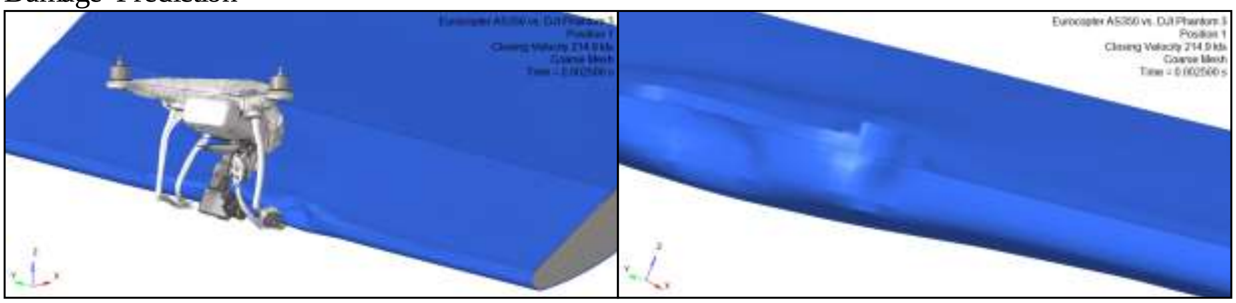


Figure 2.3 T1 Impact Simulation Initial Conditions (Top) and Damage Prediction Results (Bottom) – 214.9 kts in Position 1 with Coarse HSLE Skin Mesh

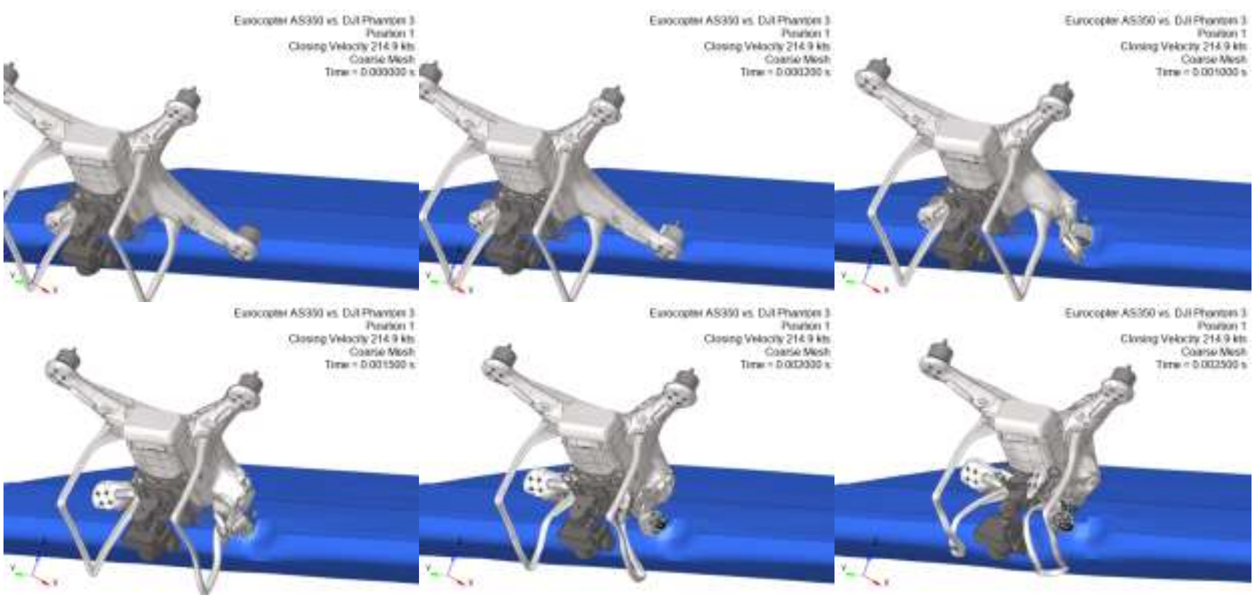


Figure 2.4 Impact Kinematics Progression – 214.6 kts in Position 1 With Coarse HSLE Skin Mesh

2.2 Simulation T2 – 220 kts in Position 2; sUAS Body Impact Against a HSLE with Coarse Skin Mesh

The damage predicted for the impact scenario shown in Figure 2.5 and Figure 2.6 exhibit high deformation on the impacted zone of the HSLE skin, which is representative to the impact observed on the article. However, no fracture on the HSLE skin was obtained in this case.

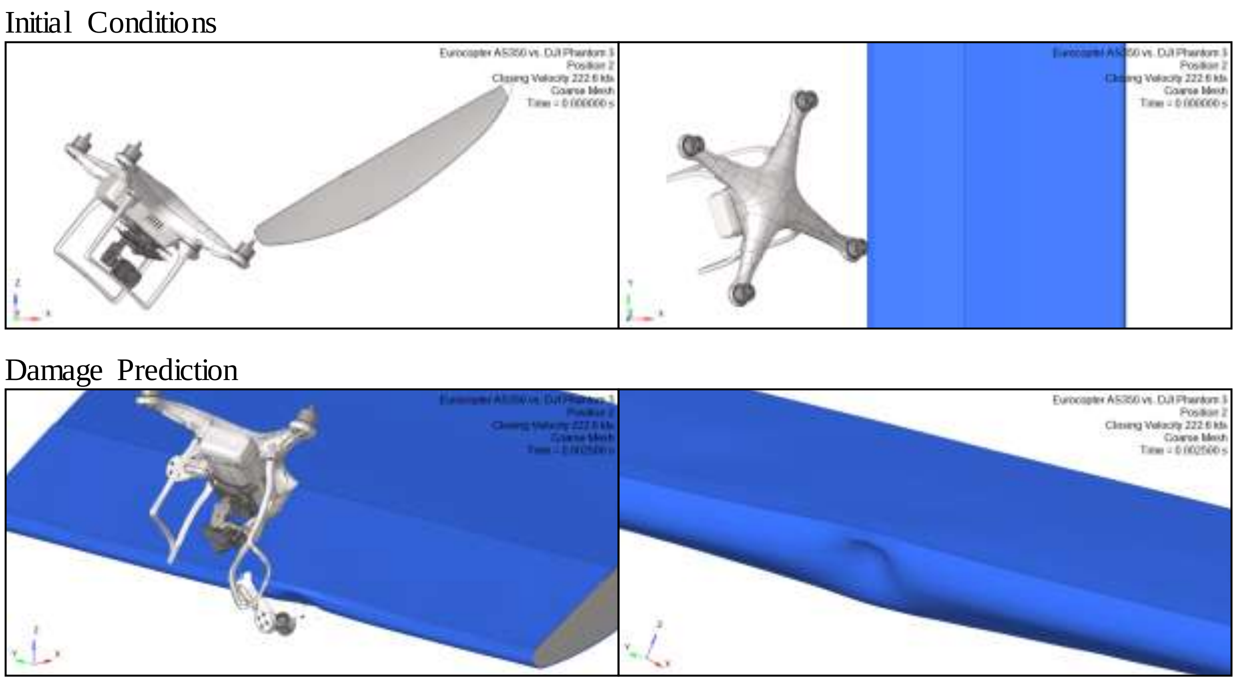


Figure 2.5 T2 Impact Simulation Initial Conditions (Top) and Damage Prediction Results (Bottom) - 222.6 kts in Position 2 with Coarse HSLE Skin Mesh

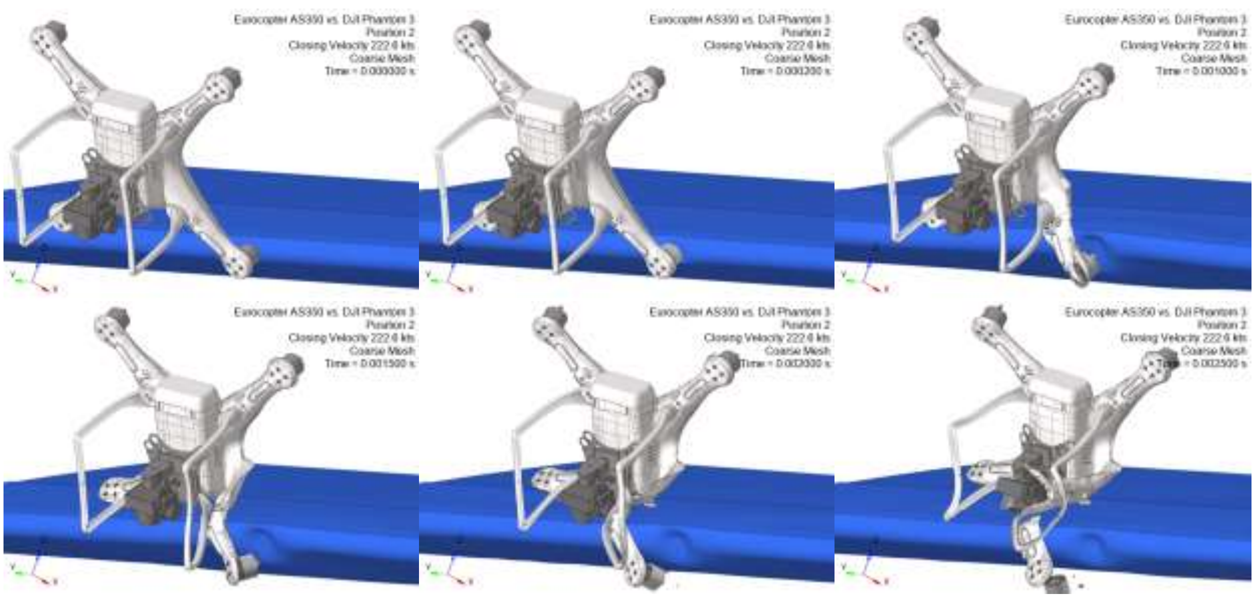


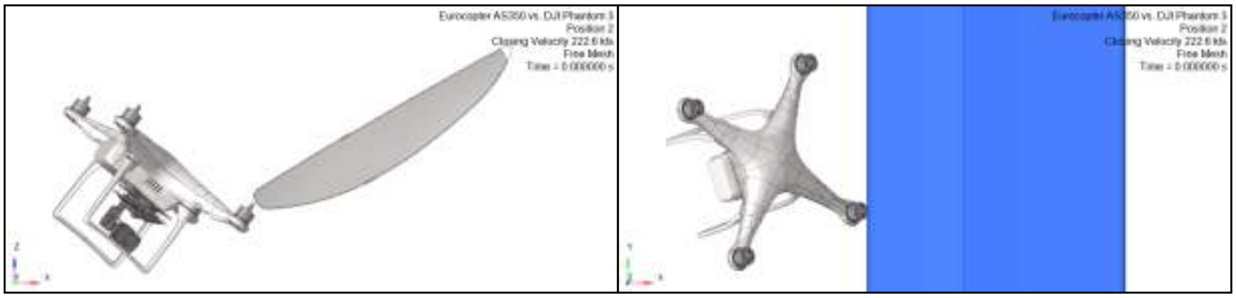
Figure 2.6 Impact Kinematics Progression – 222.6 kts in Position 2 With Coarse HSLE Skin Mesh

2.3 Simulation T3 – 220 kts in Position 2; sUAS Body Impact Against a HSLE with Fine Skin Mesh

The impact simulation setup and damage results are shown in Figure 2.7while the kinematics progression is illustrated in Figure 2.8. Note that by refining the HSLE skin mesh under the same impact conditions used on the T2 simulation, a failure on the skin was obtained. This brief mesh refinement study indicates that subsequent iterations and detailed refinements could produce a model with a stronger correlation between the physical event and the simulation. A full mesh refinement study would continue to reduce the element sizes until the element stress and strain outputs stabilize with subsequent iterations. This is not considered necessary for the purpose of this assessment.

It is noted that the velocity used in this case was greater than the likely closing velocity between the AS350 B2 and the DJI Phantom 3 at the time of the collision, so additional simulations were conducted to study a range of velocities closer to the AS350 B2 cruise speed in the following iterations.

Initial Conditions



Damage Prediction

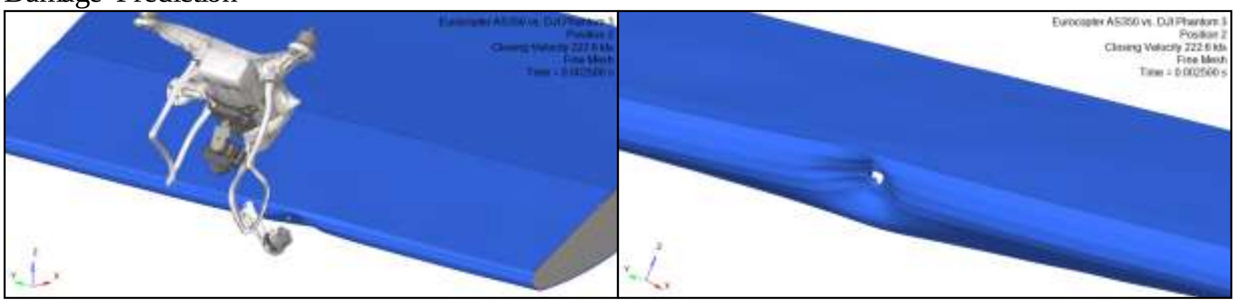


Figure 2.7 T3 Impact Simulation Initial Conditions (Top) and Damage Prediction Results (Bottom) - 222.6 kts in Position 2 with Fine HSLE Skin Mesh

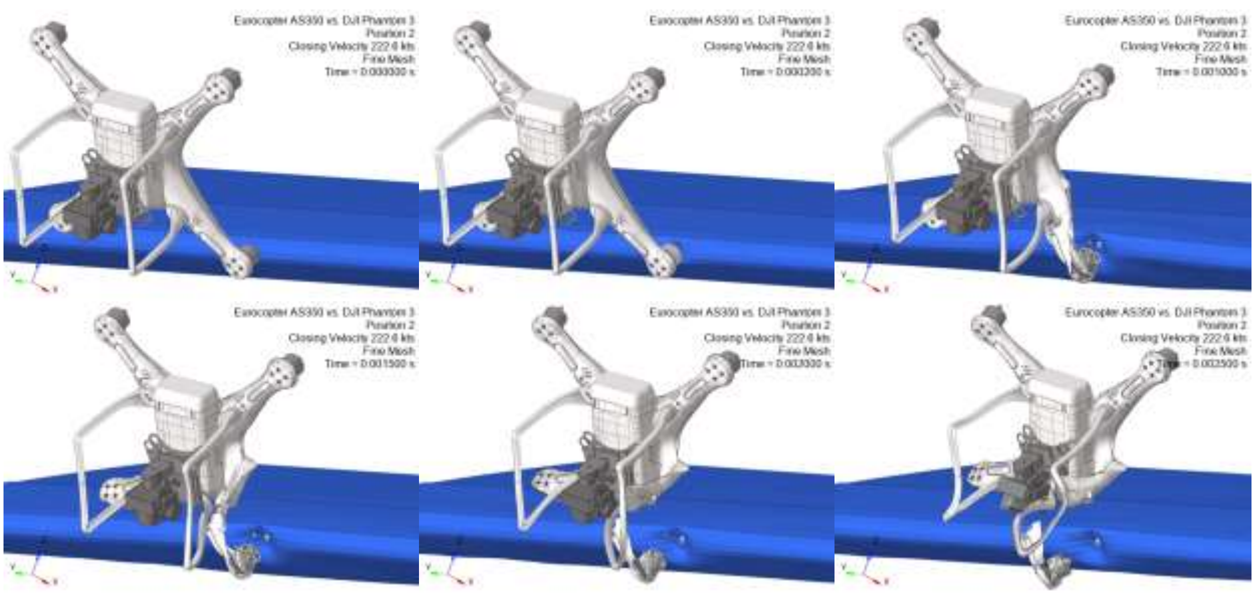


Figure 2.8 T3 Impact Kinematics Progression – 222.6 kts in Position 2 With Fine HSLE Skin Mesh

2.4 Simulation T4 – 150 kts in Position 2; sUAS Body Impact Against a HSLE with Fine Skin Mesh

In this case the closing velocity was set to 150 kts while the direction of impact was kept constant. Also, the fine HSLE skin mesh used on the T3 simulation was implemented. Note from Figure 2.9 and Figure 2.10 that the obtained deformation from the HSLE skin was reduced and no evidence of fracture was obtained.

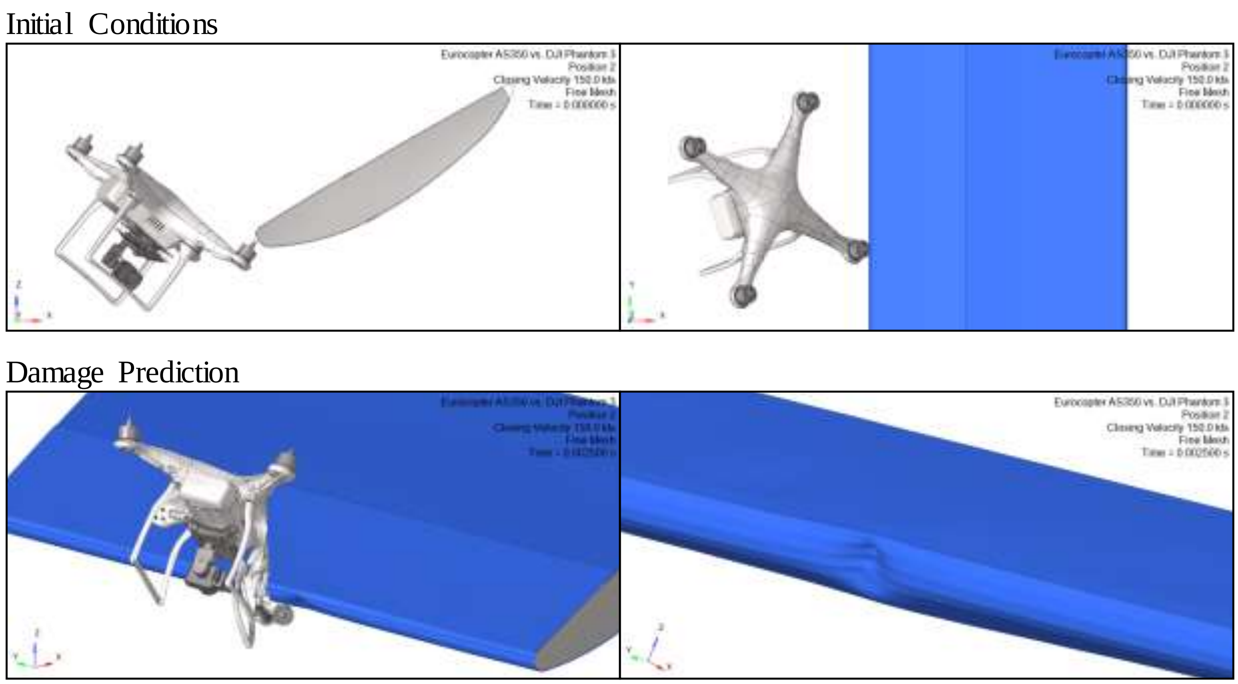


Figure 2.9 T4 Impact Simulation Initial Conditions (Top) and Damage Prediction Results (Bottom) - 150 kts in Position 2 with Fine HSLE Skin Mesh

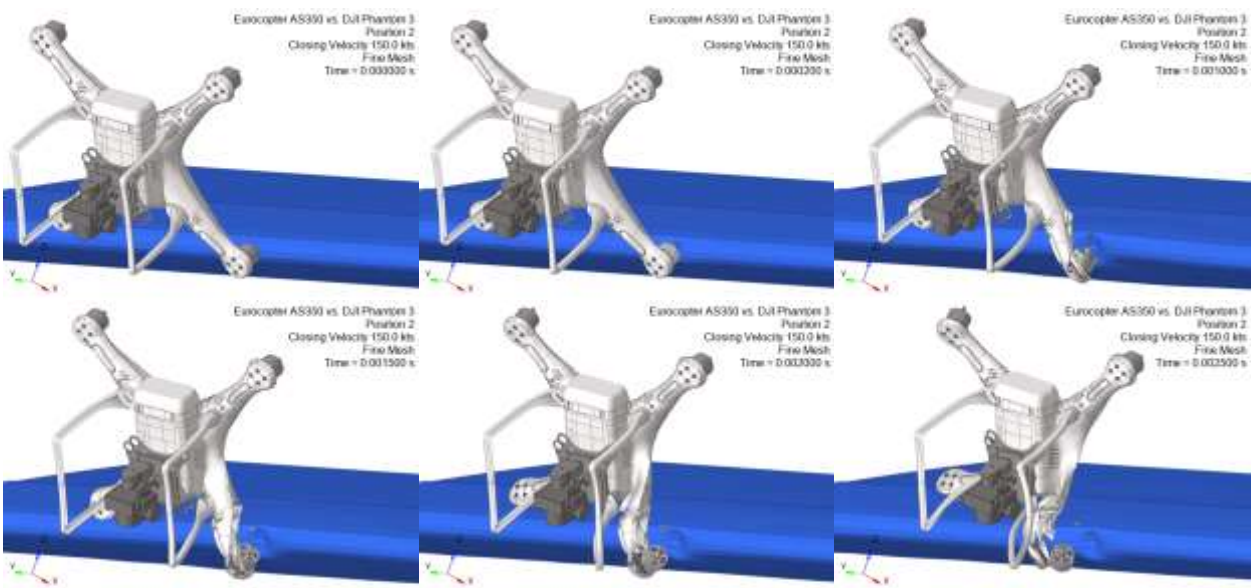
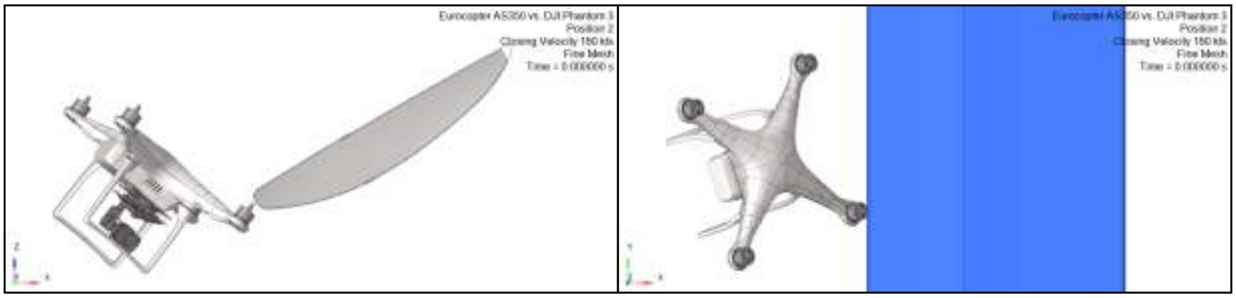


Figure 2.10 T4 Impact Kinematics Progression – 150 kts in Position 2 With Fine HSLE Skin Mesh

2.5 Simulation T5 – 180 kts in Position 2; sUAS Body Impact Against a HSLE with Fine Skin Mesh

In this case the closing velocity was set to 180 kts while the direction of impact was kept constant. Also, the fine HSLE skin mesh used on the T3 simulation was implemented. Note from Figure 2.11 and Figure 2.12 that under these conditions of velocity direction and sUAS mass, a fracture on the HSLE skin can be obtained.

Initial Conditions



Damage Prediction

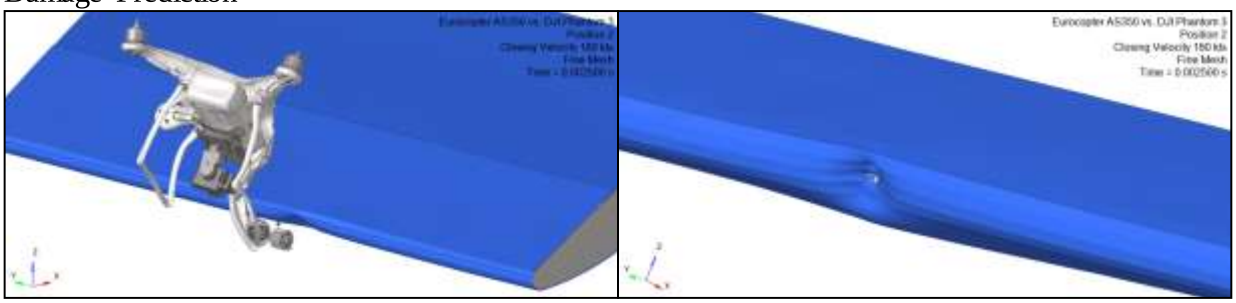


Figure 2.11 T5 Impact Simulation Initial Conditions (Top) and Damage Prediction Results (Bottom) - 180 kts in Position 2 with Fine HSLE Skin Mesh

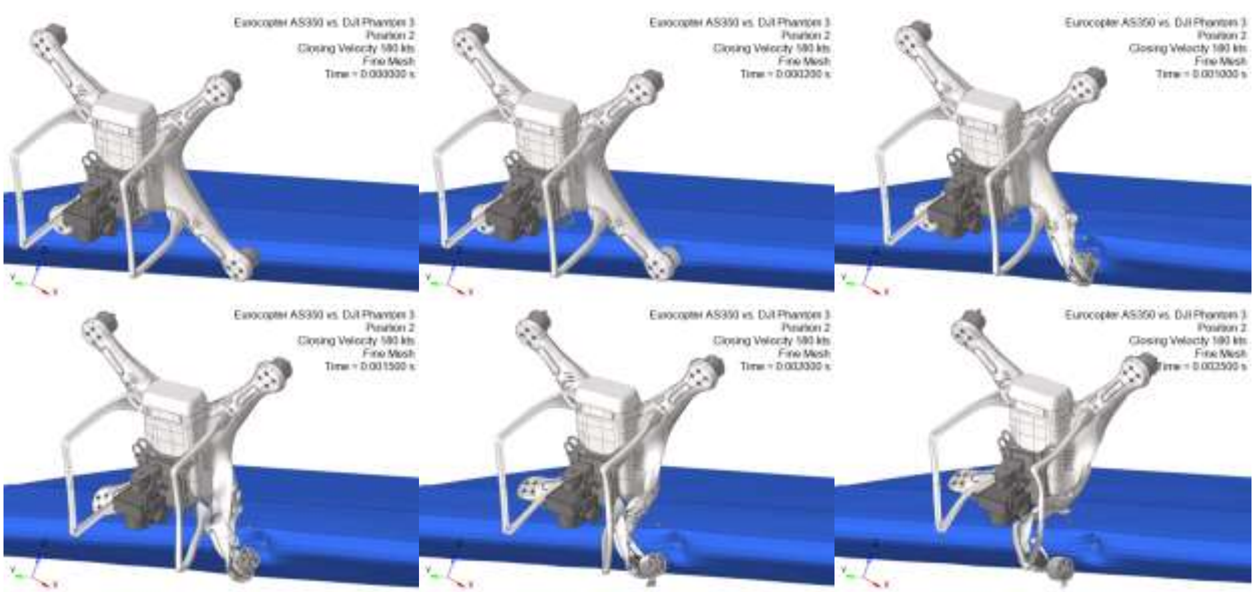


Figure 2.12 T5 Impact Kinematics Progression – 180 kts in Position 2 With Fine HSLE Skin Mesh

3 Conclusions and Discussion

The parametric study documented in this report considered simulations of a Eurocopter AS350 B2 horizontal stabilizer leading edge skin panel being impacted by a DJI Phantom 3 quadcopter sUAS. Due to the uncertain specific impact conditions and sUAS article details, the FE models were analyzed for impact conditions ranging from 150 kts through 222.6 kts, for a selected UAS impact orientation. The damage predicted on each simulation was compared to the condition of the actual aircraft article provided.

It has been shown in preceding sections that the overall damage pattern seen on the Eurocopter AS350 B2 are represented in the T1, T3, and T5 simulations. This indicates that a consumer type sUAS like the Phantom 3 could produce the damage seen on the HSLE skin. If a different quadcopter type sUAS (architecture, construction materials, larger mass, faster, etc.) were used in the preceding simulations, the damage could have been more severe. Due to the uncertainty of the specific sUAS model that was involved in the collision, further investigation into the mass distribution of the sUAS is recommended to understand the range of damage that could be possible from a glancing impact with a sUAS motor.

4 References

[1] Olivares, G., Gomez, L., Espinosa de los Monteros, J., Baldridge, R. J., Zinzuwadia, C., and Aldag, T., "Volume II–UAS Airborne Collision Severity Evaluation–Quadcopter.", 2017, Draft Report DOT/FAA/AR-XX/XX.

[2] Olivares, G., Gomez, L., Espinosa de los Monteros, J., Baldridge, R. J., Marco Carrillo, R., and Aldag, T., "Annex B. NIAR Final Report. Task A14: UAS Ground Collision Severity Evaluation 2017-2018", Draft Report DOT/FAA/AR-XX/XX.

[3] Kay, G., "Failure Modeling of Titanium 6Al-4V and Aluminum 2024-T3 With the Johnson-Cook Material Model", Report DOT/FAA/AR-03/57, Federal Aviation Administration, 2003.

[4] EUROCOPTER, "AS350 B2 Technical Data"

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