Singapore ATMRI Airborne Collision Research

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Outline

- Problem Statement
- Collision Probability Evaluation
- Collision Severity Evaluation
- Research Outcome and Significance

Problem Statement

UAS Presence within Aerodrome Airspace

At what point does the presence of a UAS within the operational airport airspace pose a threat that requiring the termination of airport operations?

What is the collision risk between UAS and manned aircraft within aerodrome environment?

Identification of UAS Collision Risk in Aerodrome Environment

1) Probability: Probability of collision between intruding UAS and CA

Collision Probability Evaluation

2) Severity: The potential damage severity from the possible collision

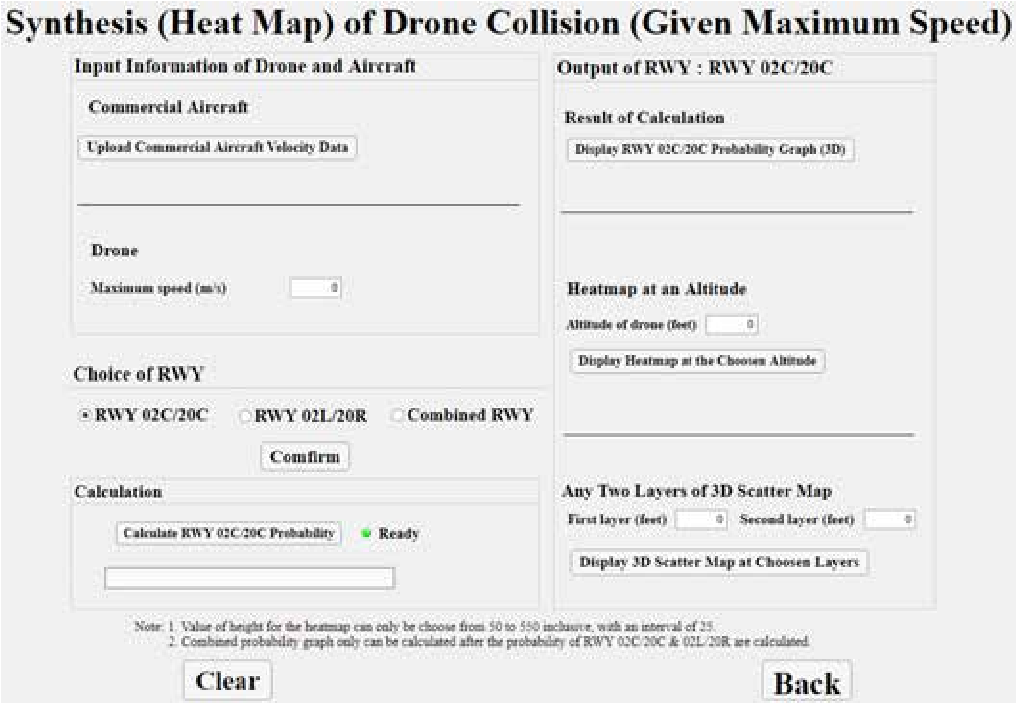
Collision Severity Evaluation

DRONE COLLISION PROBABILITY EVALUATION

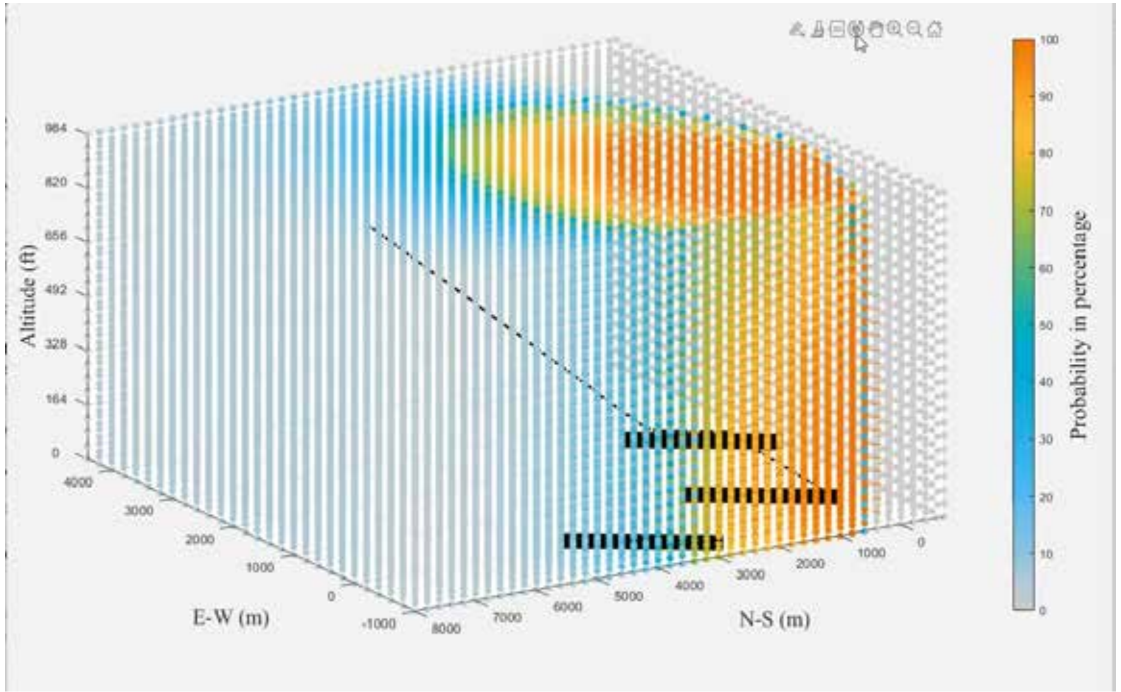
Collision Probability Evaluation

- To evaluate the probability of collision risk between a commercial aircraft (CA) with an intruding UAS in the airport airspace.
- The research team has developed the prototype of **Collision Probability Evaluation Platform.**

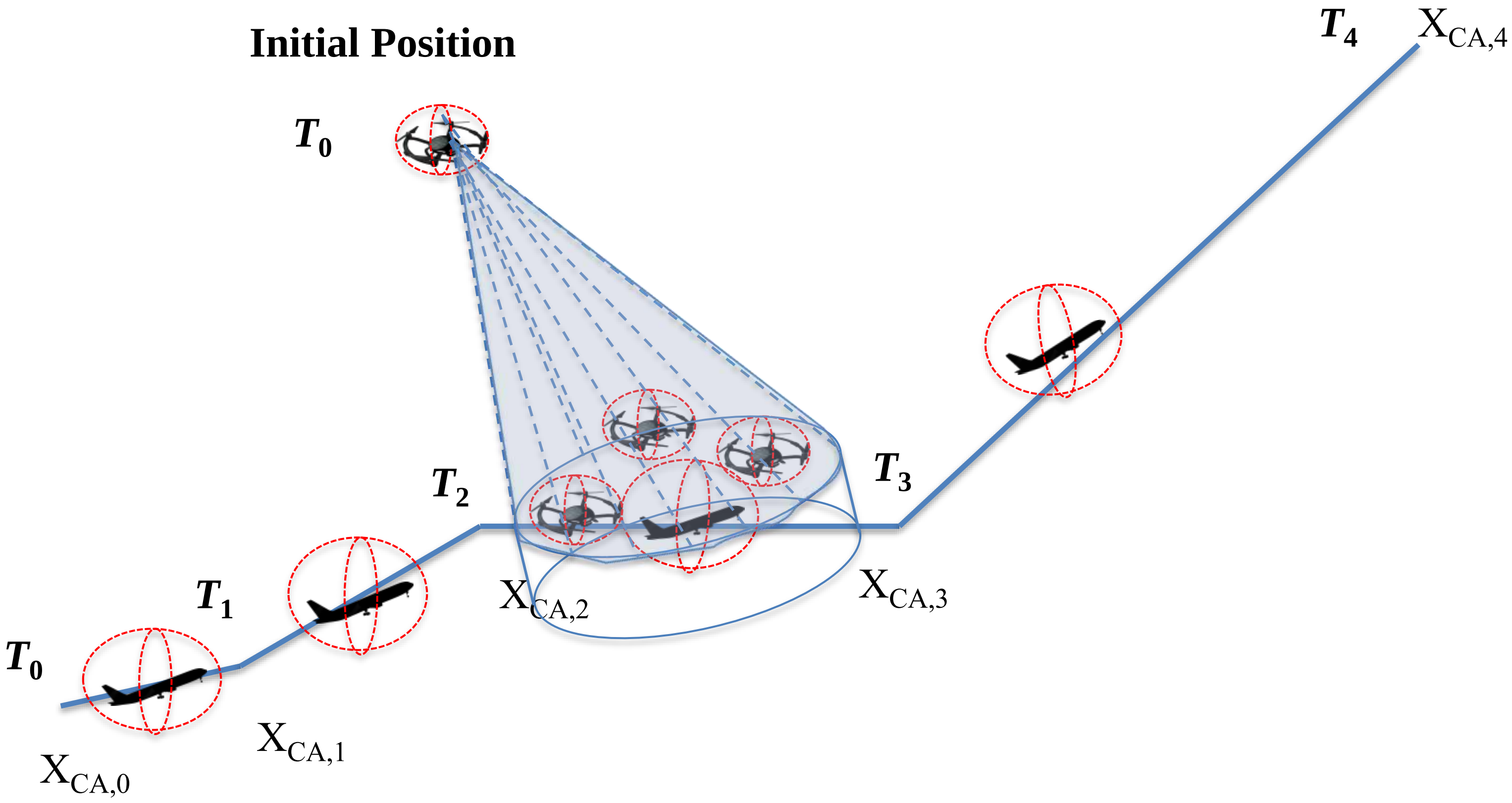
Platform interface to generate risk-mapping for intruding UAS into Changi Airport

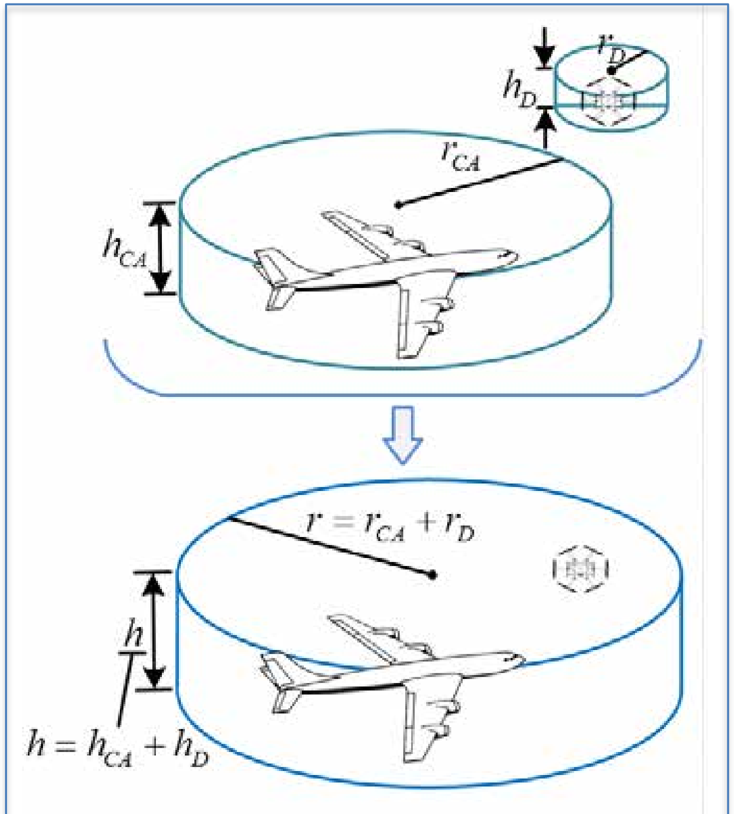


Heat-map showing collision risk posed by intruding UAS on departure aircraft from Changi Airport runway 02C



Collision Probability Modelling – Collision-course Trajectory Planning of Drone





Equivalent collision zone

Probability $P(t) = \frac{\sum_{N=1}^{N} P_n(t)}{N}$

Convergence condition $\frac{\left\| {}^{N+1}P(t) - {}^{N}P(t) \right\|}{{}^{N+1}P(t)} \le \varepsilon$

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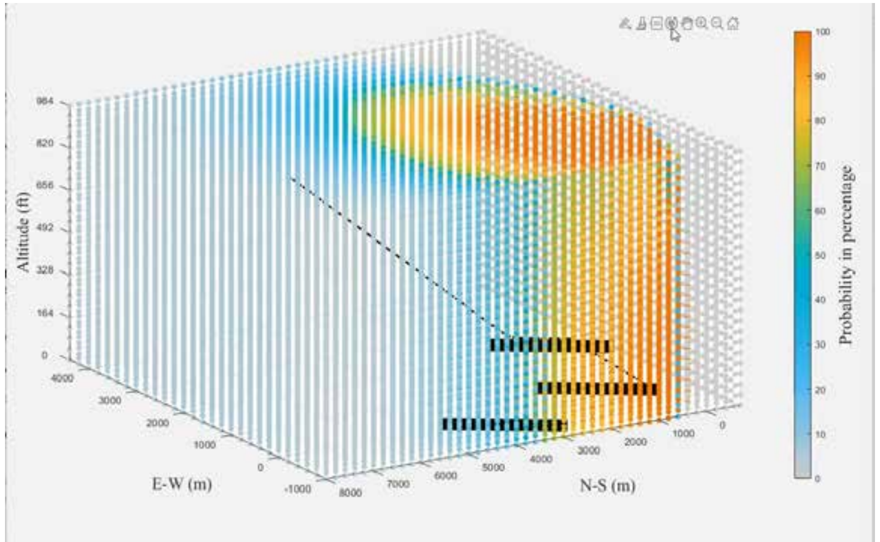
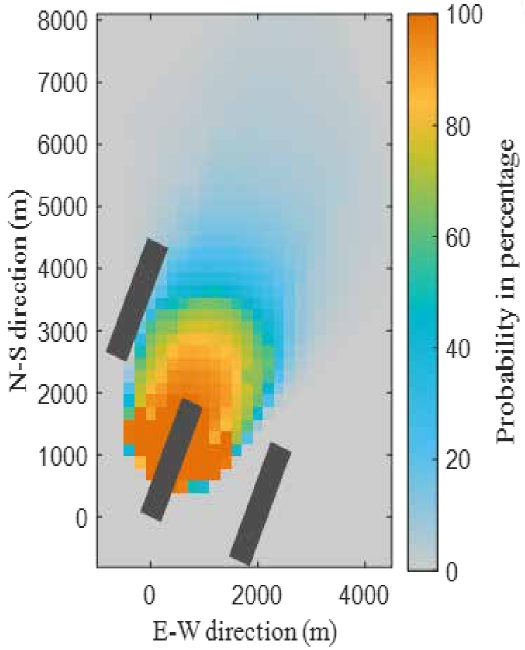
Collision Probability Evaluation Platform – Results

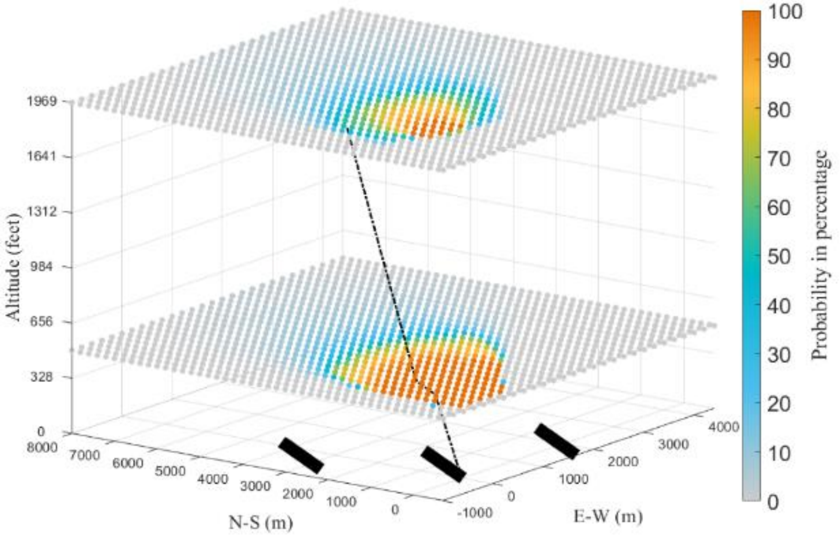
a) Heatmap for Single Runway (Runway 02C)



c) Heatmap at Altitude, *h*=250m (Runway 02C)

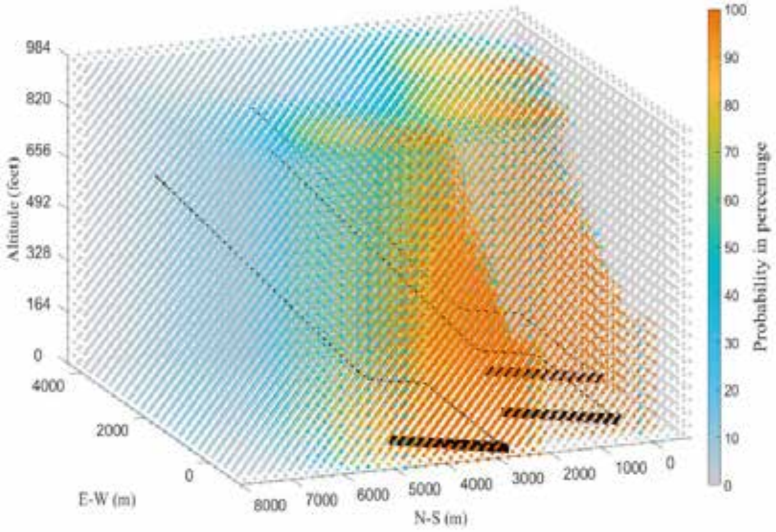


b) 3D Scatter Map at Two Arbitrary Altitudes (Runway 02C)



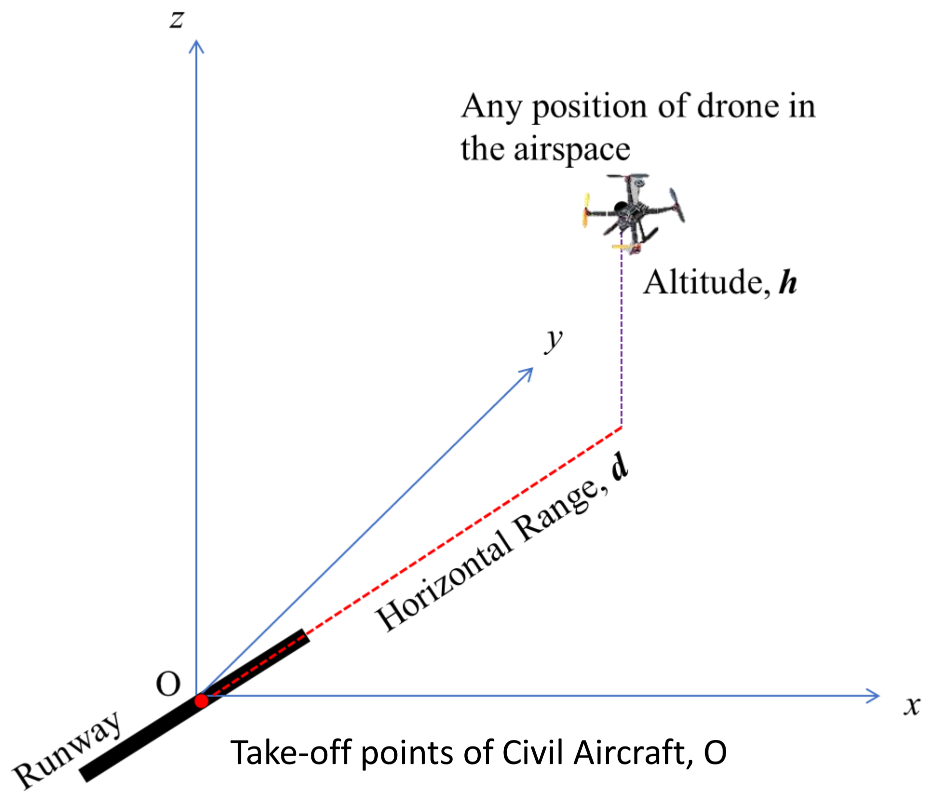
Two altitudes:
h_1=150m
h_2=500m

d) Synthetic Heatmap Considering Three Runways



Collision Probability Evaluation Matrix

Collision Probability Matrix based on drone positions (altitude & horizontal range)



Horizontal Range: The horizontal distance to the take-off points of Civil Aircraft.
Altitude: The vertical height over the airport.

Drone Speed 10 m/s

Altitude, *h* (m)	Horizontal Range, *d* (km)										
	<0.5	0.5-1.1	1.1-1.5	1.5-2	2-2.6	2.6-3	3-3.5	3.5-4.2	4.2-4.6	4.6-5.2	5.2-5.7
600	5	5	5	4	3	3	4	5	5	5	5
500	5	5	5	1	2	3	4	5	5	5	5
450	5	5	1	1	2	3	4	5	5	5	5
300	5	1	1	1	2	3	4	5	5	5	5
275	5	1	1	1	2	3	4	5	5	5	5
250	5	1	1	1	2	3	4	5	5	5	5
150	1	1	1	1	2	3	4	5	5	5	5
75	1	1	1	1	2	3	4	5	5	5	5
0	1	1	1	1	2	3	4	5	5	5	5

Level	1	2	3	4	5
Probability of MAC*	100%-90%	90%-75%	75%-50%	50%-30%	30%-0%

***MAC**: Mid Air Collision

DRONE COLLISION SEVERITY EVALUATION

Drone Collision Severity Evaluation – Overview

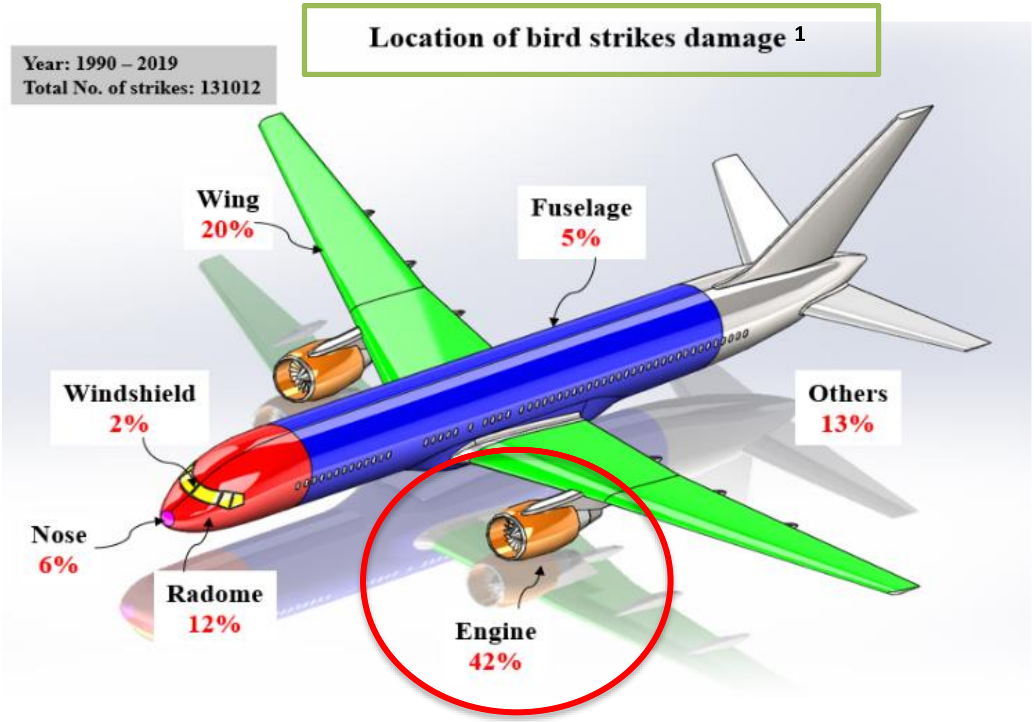
- To address the **Collision Severity Evaluation** between intruding UAS with commercial aircraft.

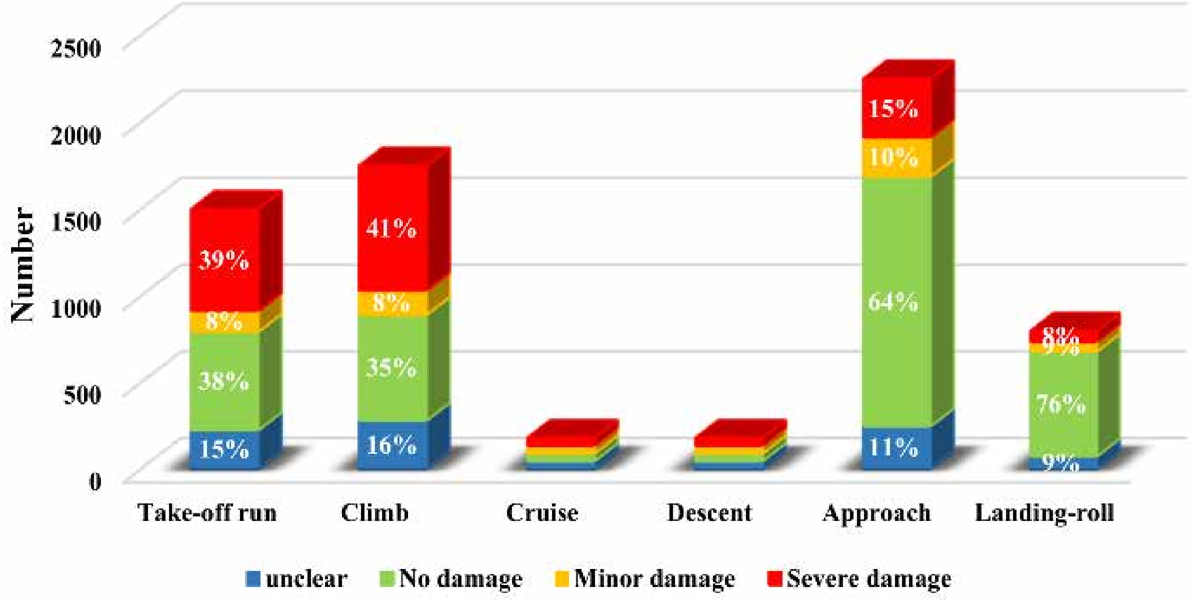
- The research team utilised computer-based simulations to establish an initial understanding, by include study on engine damage and thrust loss - further validation activities are required.

- The **Collision Severity Simulation** involved three main steps:

Modelling Physical Damage to the Engine → Modelling Thrust Loss due to the damage → Referenced damage to existing Severity Criteria

Collision Severity Evaluation: Assumptions





Location Bird Strike Damage: Engine[1]

- ➢ Referenced to the information from FAA bird strike database[1], the bird strike has caused highest percentage damage to aircraft engine.

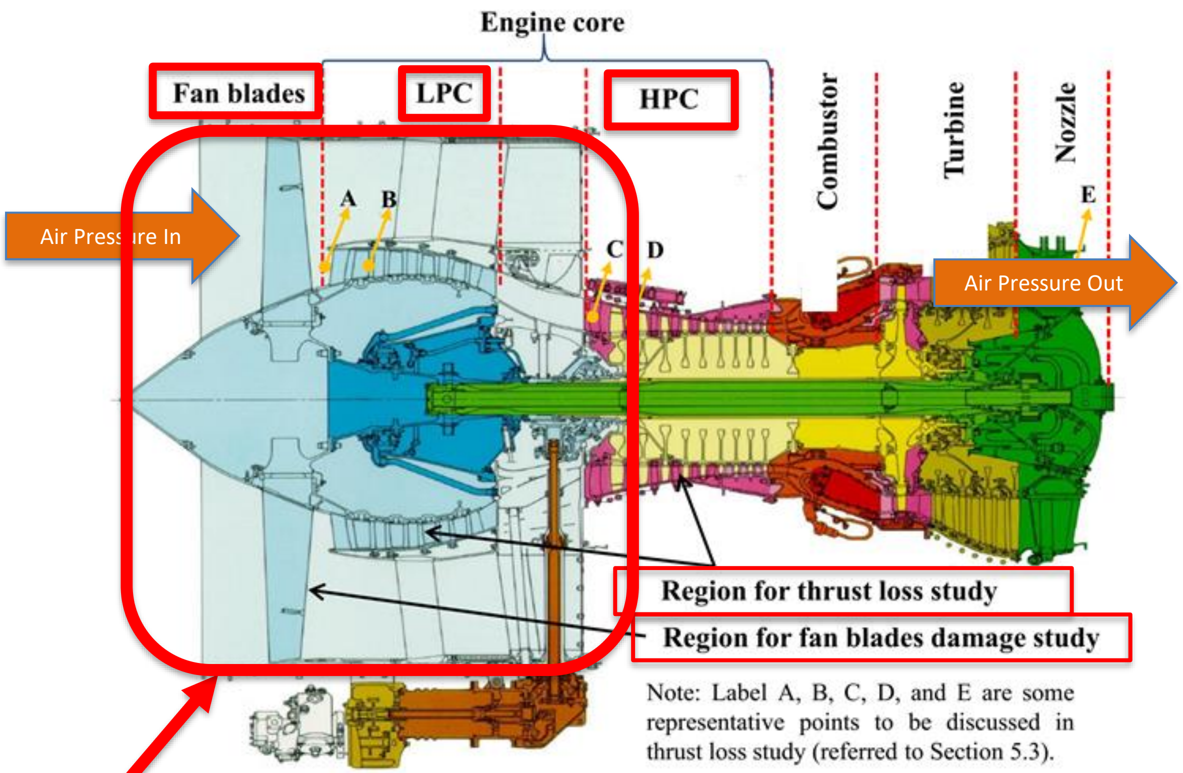
Flight Phase[1]

- ➢ Assessed that the Engine was most likely surface to suffer damage from a collision and this was most likely during the **take-off run, climb** and **approach**

[1]Source: https://wildlife.faa.gov/search

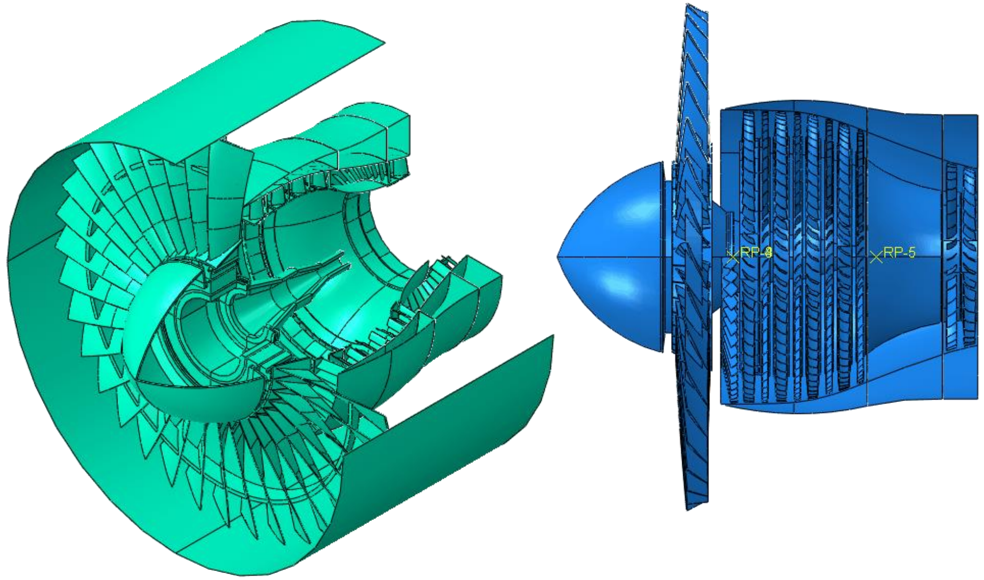
Model Setup - Development of Aircraft Engine Models

The CFM56 engine's fan blades, and compressor blades (*LPC and HPC) are developed to assess the engine thrust loss due to the drone ingestion.



Part of Engine Modelled

Part of Engine Modelled



***LPC**: Low Pressure Compressor
HPC: High Pressure Compressor

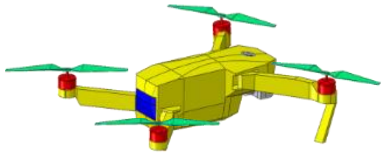
Model Setup - Development of UAS Models

- Drone geometries were obtained from 3D scanner data (open-source) and verified with manual measurements.

- Materials properties information obtained from studies by ASSURE[1].

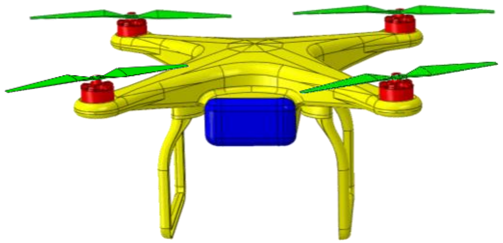
Small

(a) Mavic Mini (249-gm)



Medium

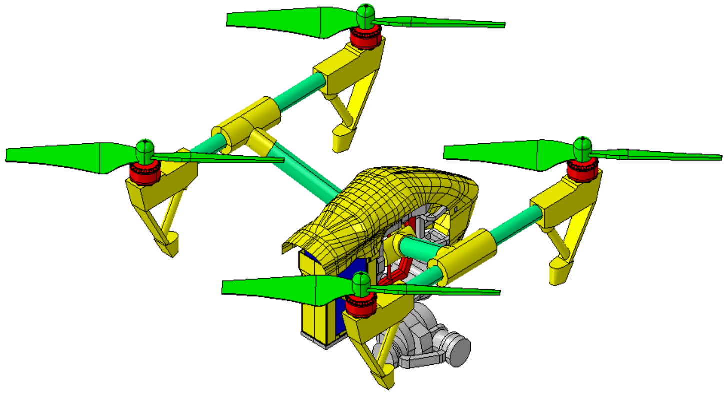
(b) Phantom 3 (1280-gm)



Code	Materials
	Polycarbonate Polymer
	Lithium-Polymer (Li-Po) Battery
	Cast Aluminum 520.0
	Steel Alloy AISI 4030
	Nylon
	Carbon Fibre

Large

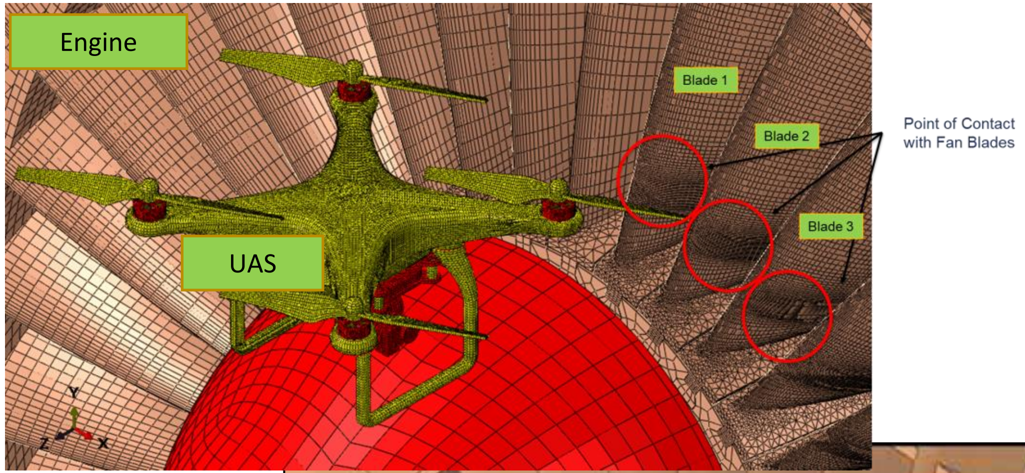
(c) Inspire 1 (3500-gm)

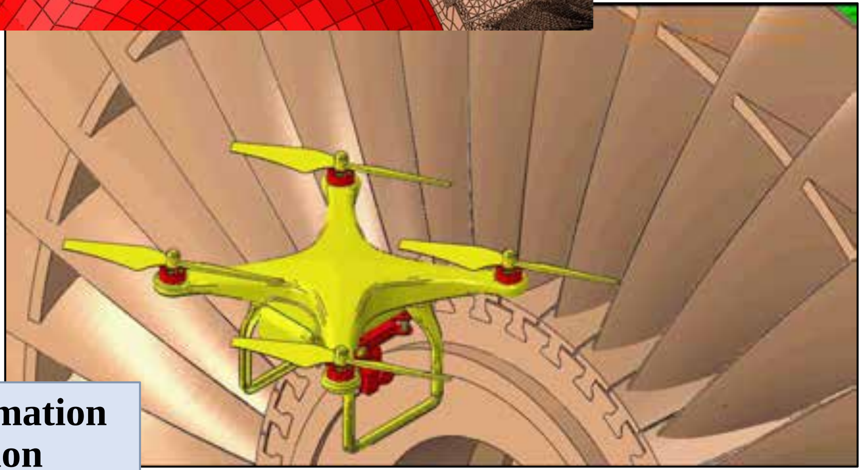


[1]Olivares G, Gomez L, Espinosa de los Monteros J, Baldridge RJ, Zinzuwadia C, Aldag T. Volume II–UAS Airborne Collision Severity Evaluation–Quadcopter. 2017.

Model Setup – Collision Severity Simulation

- Collision Severity Simulation is developed from combination of the developed Aircraft Engine and UAS model.





Example of Animation UAV Ingestion

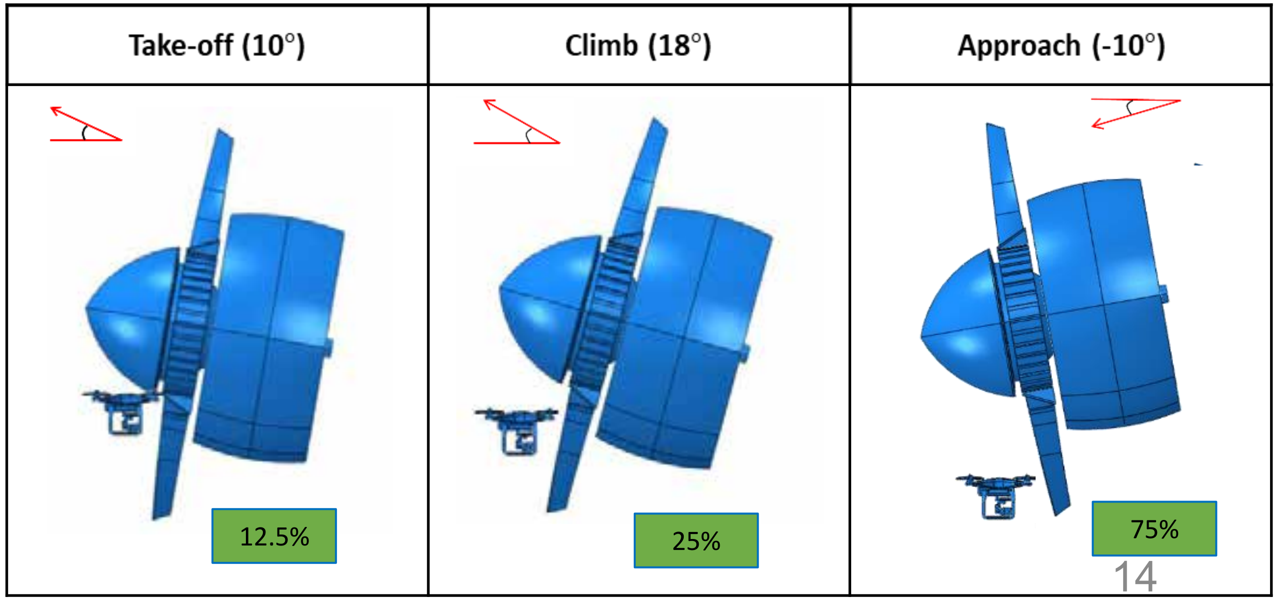
#FAA: AC No. 120-108

##http://www.aviationchief.com/cdfa.html

*https://www.bangaloreaviation.com/2009/05/typical-takeoff-and-climb-angles-of-all.html

- Parameters considered in the collision severity simulation.

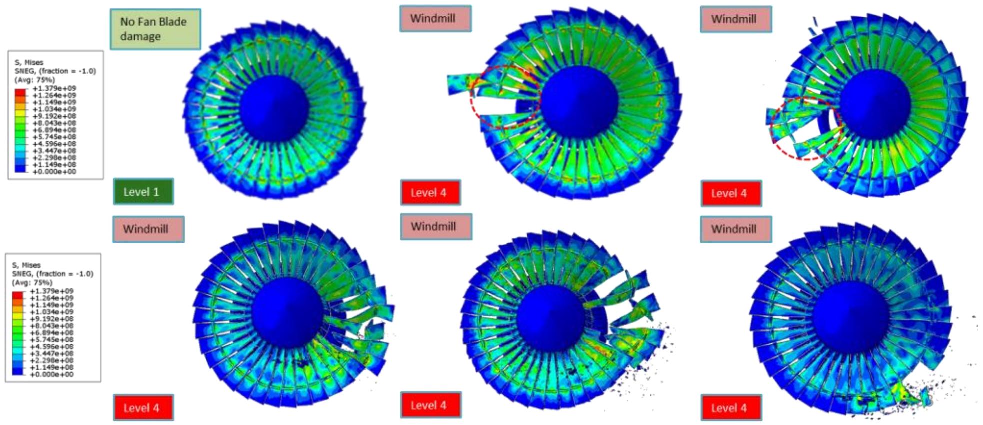
Parameters	Flight Phases		
	Take-Off	Climb	Approach
Aircraft Speed	145kts	175kts	250kts
Engine Rotation (RPM)	5000	3000	3000
Aircraft Angle	10°##	18°#	-10°*



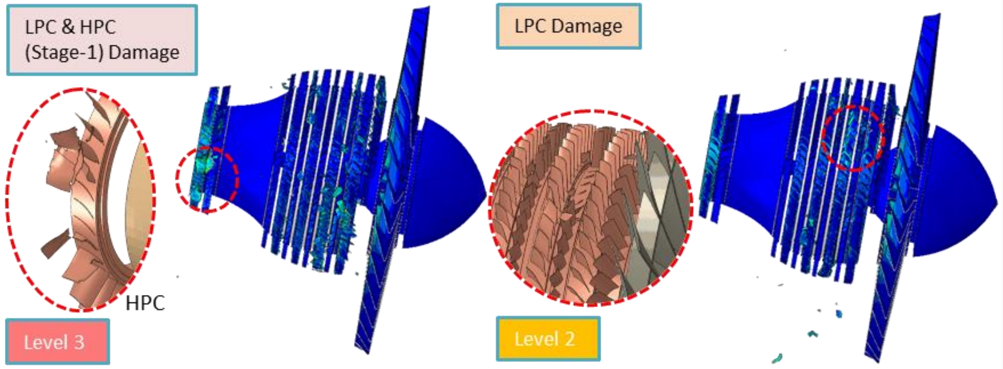
Collision Severity Simulation: Results – Physical Damage

- Two type of aircraft engine damage are found from different scenarios.

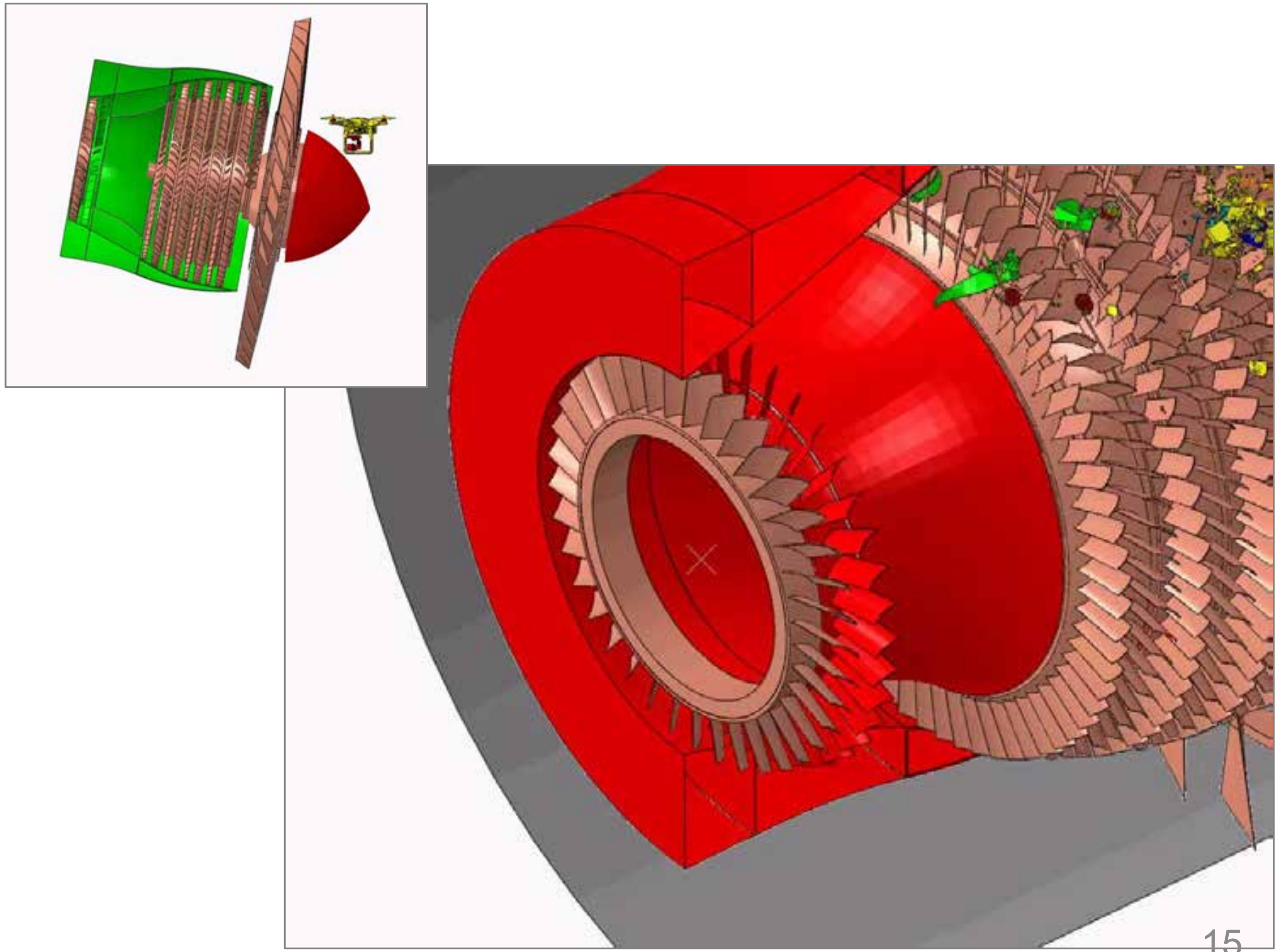
1. Fan Blades Damage



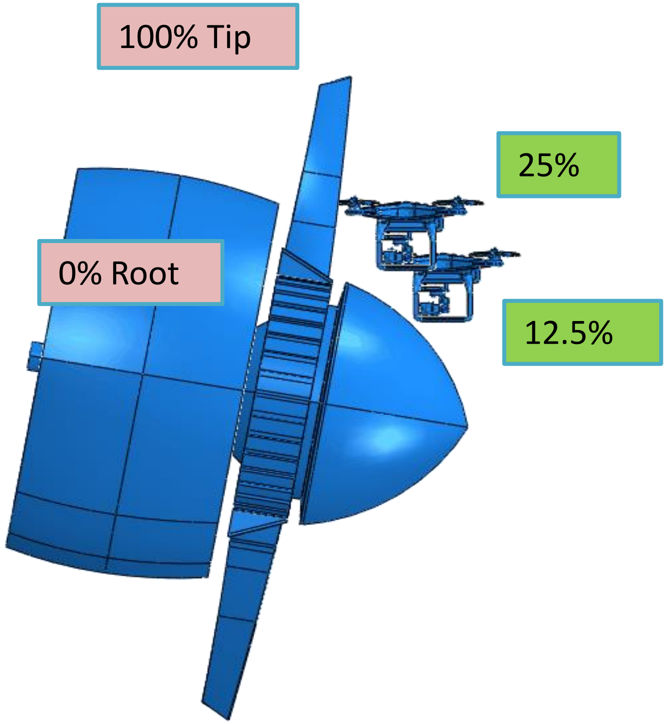
2. LPC and HPC Blades Damage



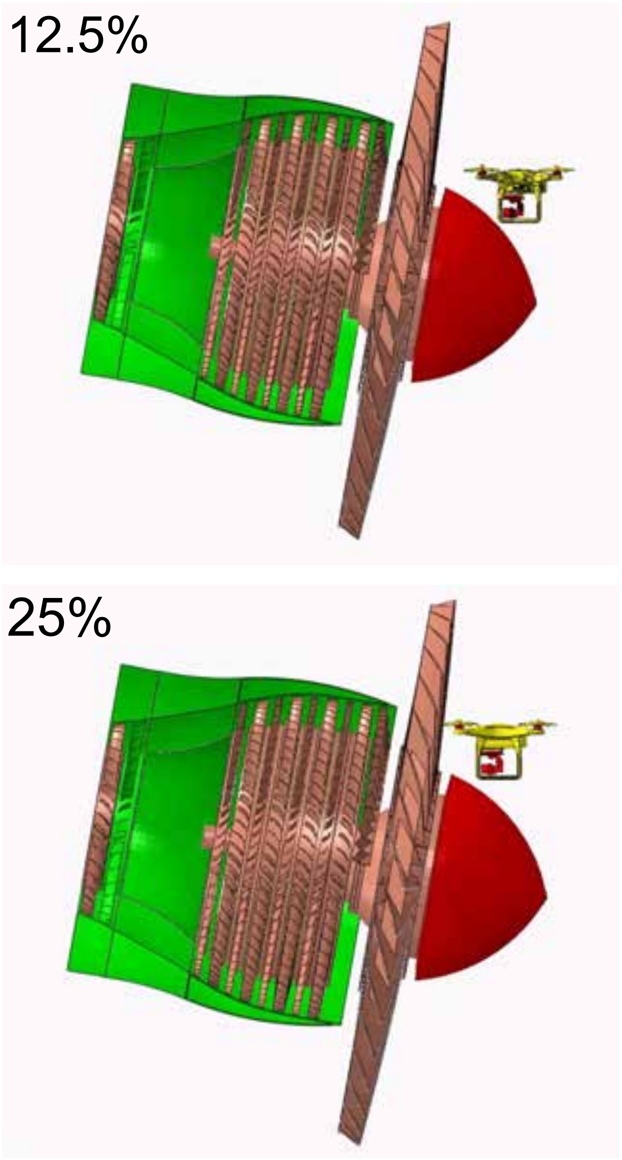
- The UAS debris ingested into engine core can cause damage to engine compressor blades (LPC and HPC).



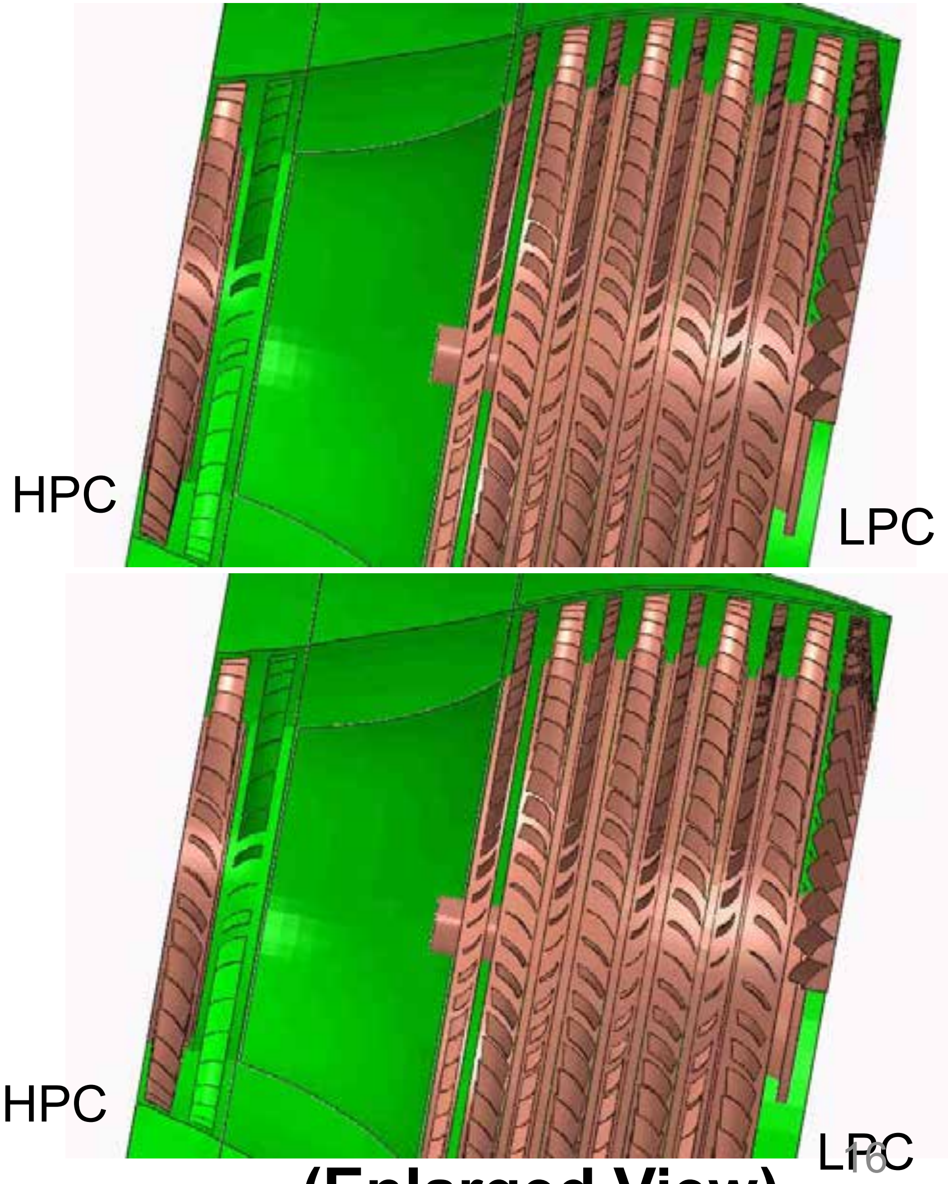
Collision Severity Simulation: Results – Physical Damage (Approach)



Simulation considering
Approach angle



(Full View)

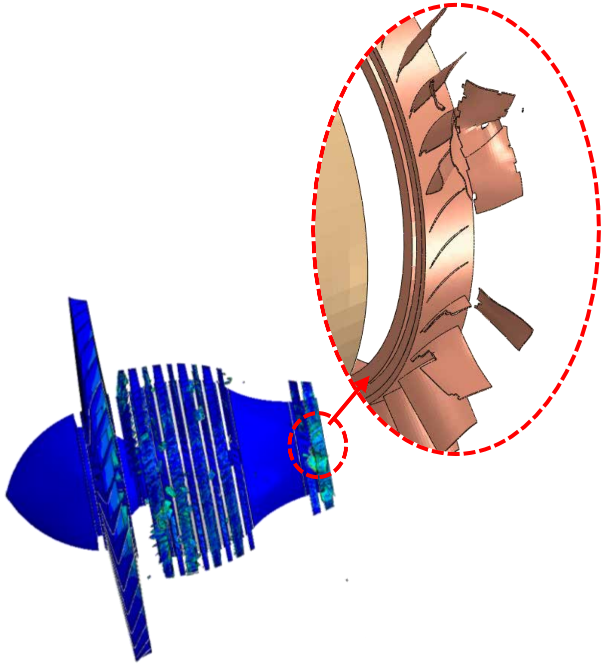


(Enlarged View)

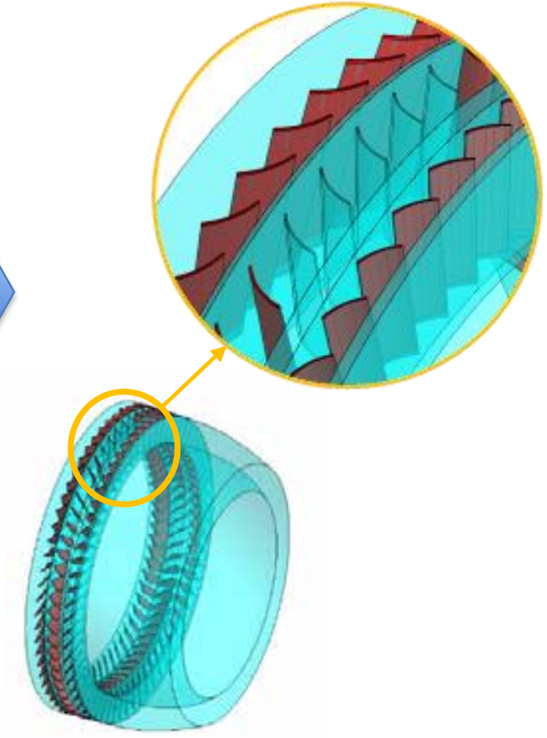
Damage to the Engine – Estimated Engine Thrust Loss

- The engine compressor blades damage (LPC and HPC) then transferred into Computational Fluid Dynamics (CFD) Software to estimate the engine thrust loss.

(FEM Software):
Physical Damage to HPC



(CFD Software):
Model of HPC Damage



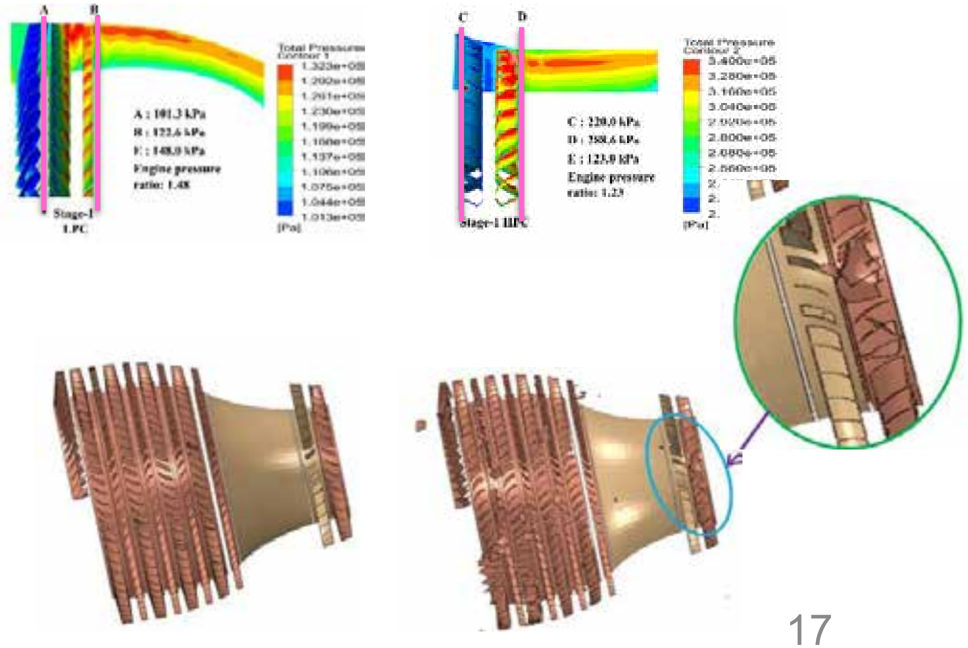
(CFD Results):
Thrust loss can be estimated from the Engine Air Pressure

No Damage

Damage to HPC

Pressure of Air Flow

Engine Model



Collision Severity Simulation: Results – Damage Severity

Damage Severity Summary

UAS Size Type	Location of Collision on Fan Blade (% of distance from root of blade)	Flight Phase		
		Climb (180kts, 3000 RPM)	Approach (250kts, 3000 RPM)	Take-off (145kts, 5000 RPM)
Small (< 250 g)	75%			
	25%			
	12.5%			
Medium (0.25 kg – 1.5 kg)	75%			
	25%			
	12.5%			
Large (>1.5 kg)	75%			
	25%			
	12.5%			

Damage Levels Criteria Based on Engine Certification Requirements

Damage Level	Description
Level 1	• No damage to the fan blade (e.g. no bending or material loss) and no thrust loss • No damage to LPC and HPC blades.
Level 2	• Minor damage to the fan blade (e.g. small banding or material loss) but Thrust Loss < 25% • Damage to LPC Blades only.
Level 3	• Major damage to the fan blade (e.g. large bending or material loss) but Thrust Loss 25% - 50% • Damage to LPC and HPC Blades.
Level 4	• Severe damage to the fan blade (e.g. Fan blade broken, windmilling) or Thrust Loss > 50% • Damage to LPC and HPC Blades only.

- **Initial Findings [Need validation and further study]:**
  - ➢ Damage from Small and Medium size UAS (during an aircraft climb) was not severe enough that require engine shutdown.
  - ➢ Damage from Large size UAS can cause enough damage require engine shutdown.

Research Outcome and Significance

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Outcome:

- Risk analysis software for UAS intruding into aerodrome.
- Severity analysis on CFM-56 ingestion of small UAS.

Significance:

- Understand potential collision risk with UAS operation within the aerodrome.
- Understand severity of engine (CFM-56) damage due to UAS ingestion.

Thanks for your attention!

Questions & Suggestions?

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