Rolls-Royce Group 2016

Trusted to deliver excellence

Rolls-Royce

Aktuelles Geschäftsergebnis (2015)

Auftrags-bestand	Operativer Umsatz	Operativer Gewinn	Mitarbeiter weltweit	Präsenz in Ländern weltweit
£76,4Mrd.	£13,4Mrd.	£1,4Mrd.	50.500	46

Rolls-Royce

Rolls-Royce in Deutschland

- **Rolls-Royce International**

- **Rolls-Royce Power Systems**
  Die Rolls-Royce Power Systems AG mit Sitz in Friedrichshafen ist mit den Produkten der Marken MTU, MTU Onsite Energy, L'Orange und der norwegischen Bergen Engines ein Spezialist für Großmotoren, Antriebssysteme und dezentrale Energieanlagen.
- **MTU/MTU Onsite Energy**
- **L'Orange**
- **Rolls-Royce Marine Deutschland**

- **Rolls-Royce Deutschland**
  Einziger behördlich genehmigter Triebwerkshersteller Deutschlands mit voller Systemfähigkeit
- **N3 Engine Overhaul Services**
  Joint Venture zur Triebwerkswartung mit der Lufthansa Technik AG

Über 6.000 Rolls-Royce Triebwerke
„Made in Germany" ausgeliefert

14 Rolls-Royce Standorte
in Deutschland*

Mehr als 24.000 MTU-Dieselmotoren
für kleine und große Schiffe ausgeliefert

Rund 12.000 Mitarbeiter
in Deutschland

*inkl. Rolls-Royce International und Rolls-Royce Power Systems Repräsentanz in Berlin

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Rolls-Royce Deutschland 2015

Auf einen Blick

Umsatz	Investitionen	Mitarbeiter	Produktionszahlen
€2,1 Mrd.	**€2,9 Mrd.**	**~3.500**	**609** Triebwerke

Programme

BR710

BR715

BR725

Tay

V2500

Spey

Dart

Gnome

TP400

T56

Tornado SPS

RTM322

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Triebwerksauslieferungen Rolls-Royce Deutschland

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FOD – Forgeign Object Damage

M.Wirth

21-02-2017

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It is foremost a safety issue!

Hudson River Accident – Duel Engine failure after multiple Bird Strike

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It is a cost issue!

Wildlife Strikes to Civil Aircraft in the United States, 1990–2013

Table 17. Continued (Page 17 of 21)

Wildlife group or species	24-year totals (1990–2013): Number of reported strikes: Total	With damage	With neg. EOF	With multiple animals[2]	Reported economic losses[1]: Aircraft down time (hrs)	Reported costs ($)
Total known birds	**69,777**	**6,319**	**4,983**	**12,584**	**439,424**	**464,008,815**
Total unknown birds	**68,480**	**6,138**	**3,887**	**7,029**	**150,918**	**132,729,045**
Unknown bird - ? size	3,601	310	265	197	8,305	2,687,676
Unknown bird - large	2,549	1,008	485	274	45,292	48,558,389
Unknown bird - medium	33,709	3,962	2,069	2,644	84,535	64,139,510
Unknown bird - small	28,621	858	1,068	3,914	12,786	17,343,470
Total birds[3]	**138,257**	**12,457**	**8,870**	**19,613**	**590,342**	**596,737,860**

Source: FEDERAL AVIATION ADMINISTRATION NATIONAL WILDLIFE STRIKE DATABASE SERIAL REPORT NUMBER 20

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A400M – Unprepared Runway Trials

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A400M – Thrust Reverse

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Airbus A350-900 XWB

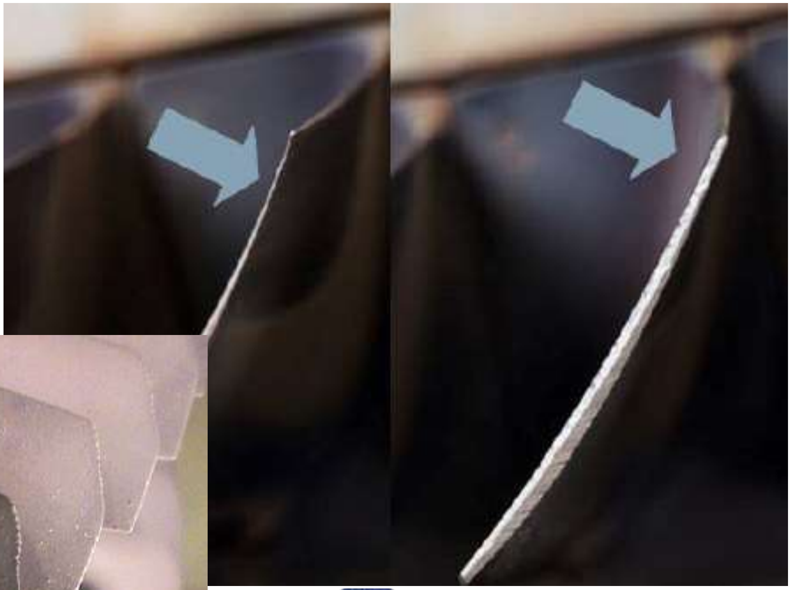
Content

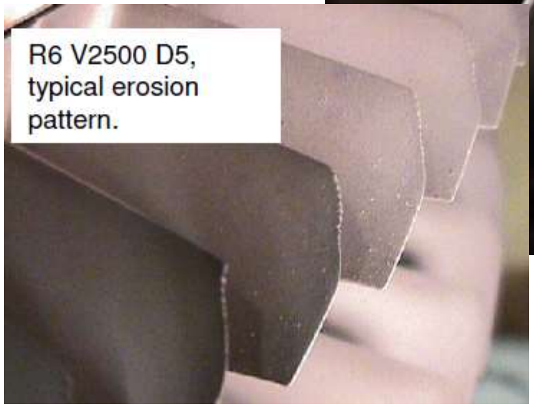
1. Types of FOD
2. Affected Components
3. Typical Damages
4. Engine Design for FOD
5. Engine Installation and Operation
6. Certification Requirements
7. Drones – a new challenge

Types of FOD

Soft particle FOD	Hard particle FOD	DOD – Domestic Object Damage
Bird (rarely common cause)	e.g. Gravel	
Ice – Slab (common cause)	Bolts / Nuts / Rivets / ….	
Hail (common cause)	Acoustic Liners (rare) / Intake Pieces / ….	
	Drones	

- There is a grey area between FOD and Erosion
- Erosion: Particles are too low energy to leave nicks but due to their number and speed, they will eventually cause severe damage
  - Sand / Dust Erosion
  - Water Erosion
  - Volcanic Ash Erosion





R6 V2500 D5, typical erosion pattern.

Components that are affected most by FOD

Fan Blades

Nose Cone

Fan-OGV

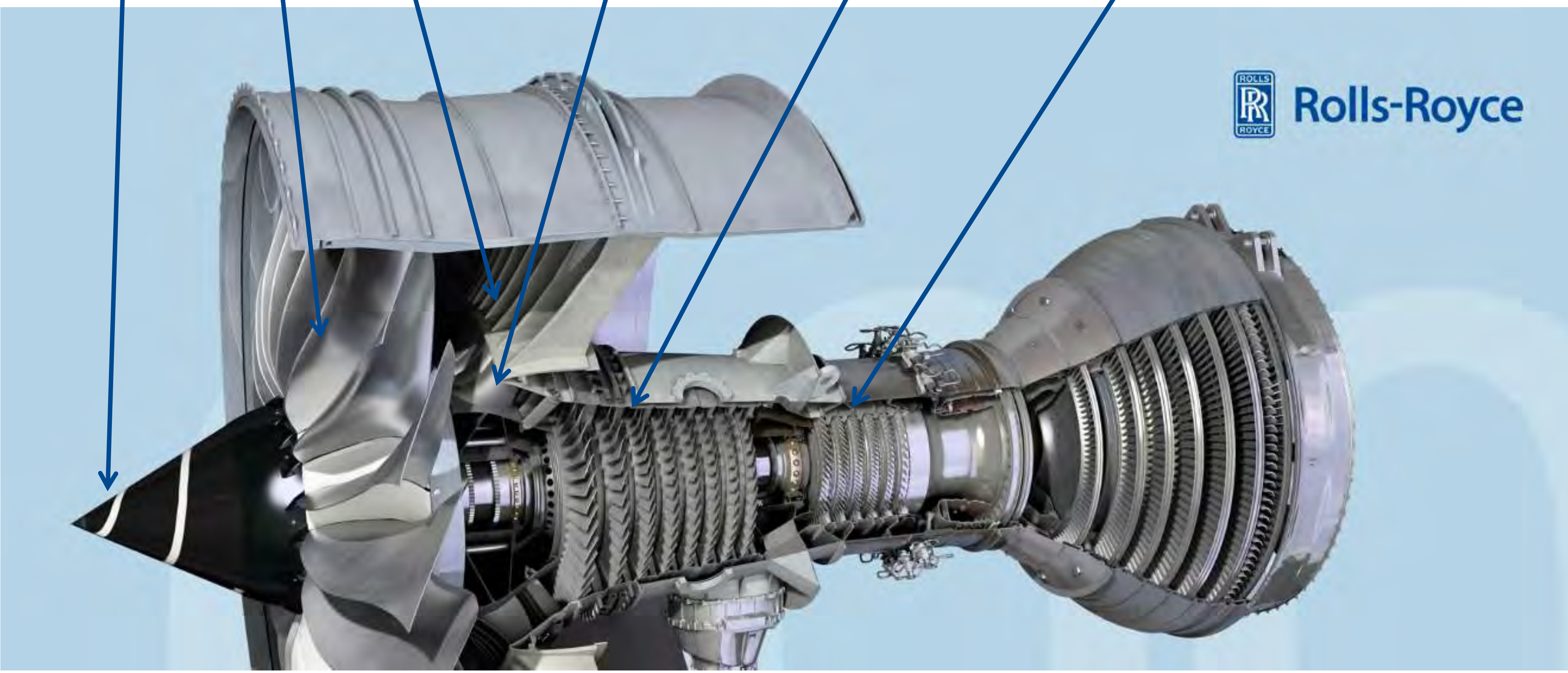
Fan-ESS

IPC Blades

IPC Vanes

HPC Blades

HPC Vanes



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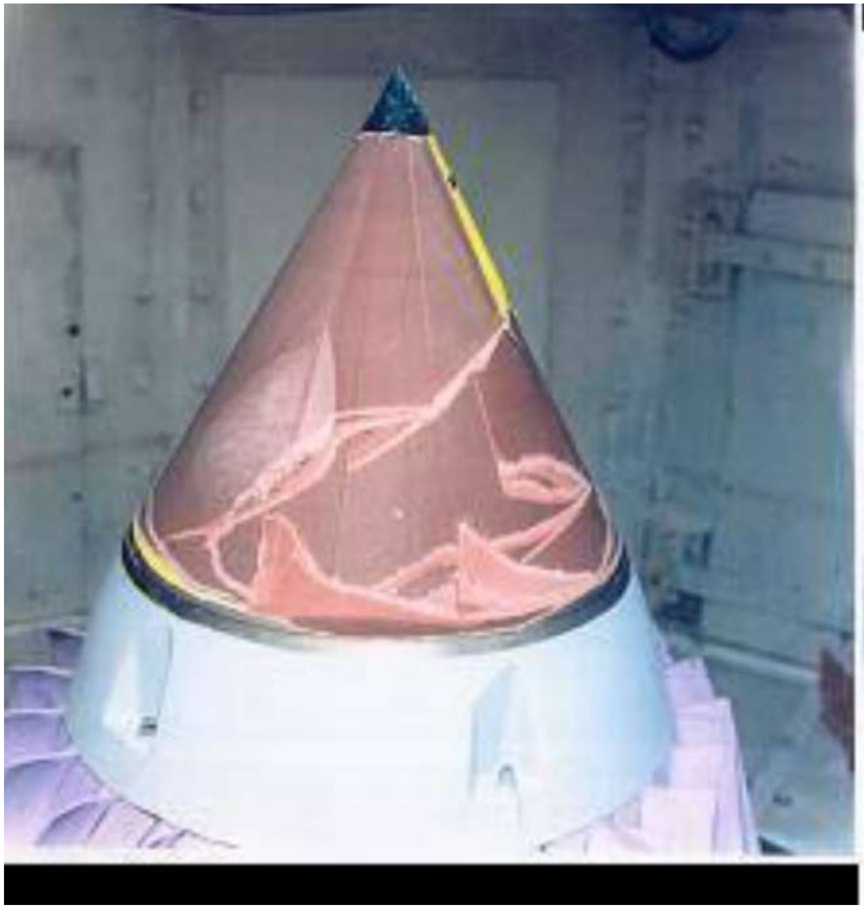
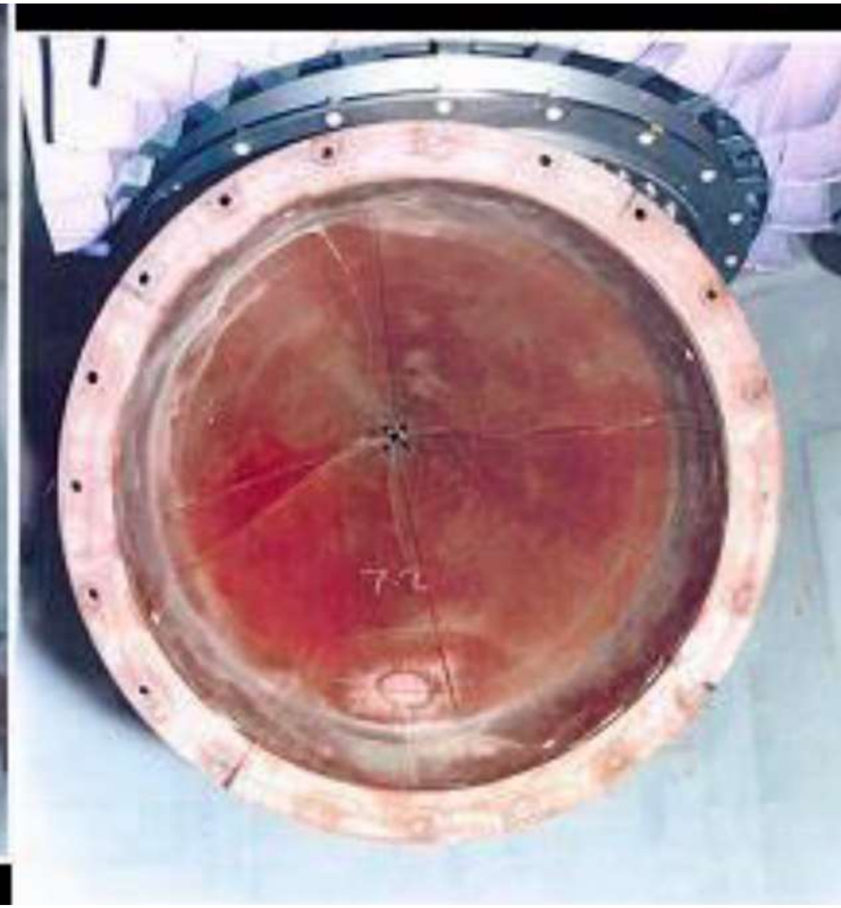
Hard Particle FOD (HPC Blades / Vanes)

Soft Particle FOD (Nose Cone - Bird)

Figure 13. The spinner cone immediately after impact with the 6.0lb bird.

Soft Particle FOD (Nose Cone - Bird)





Soft Particle FOD (Fan Blade - Bird)

<u>Canada Geese</u>

High Power

Low Power

Both events caused IFSD, uneventful landing.

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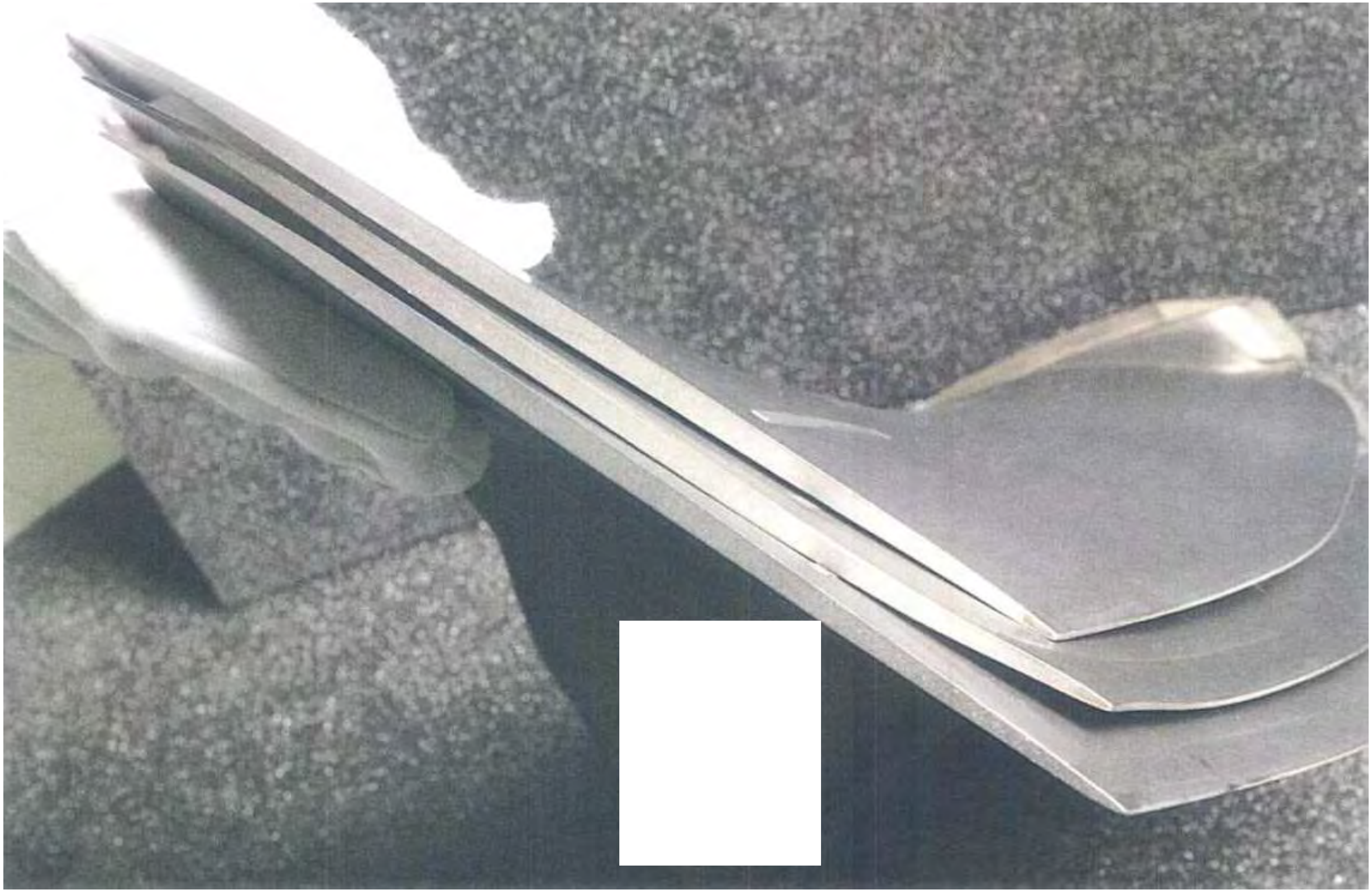
Soft Particle FOD (Fan Blade – Ice Slab)



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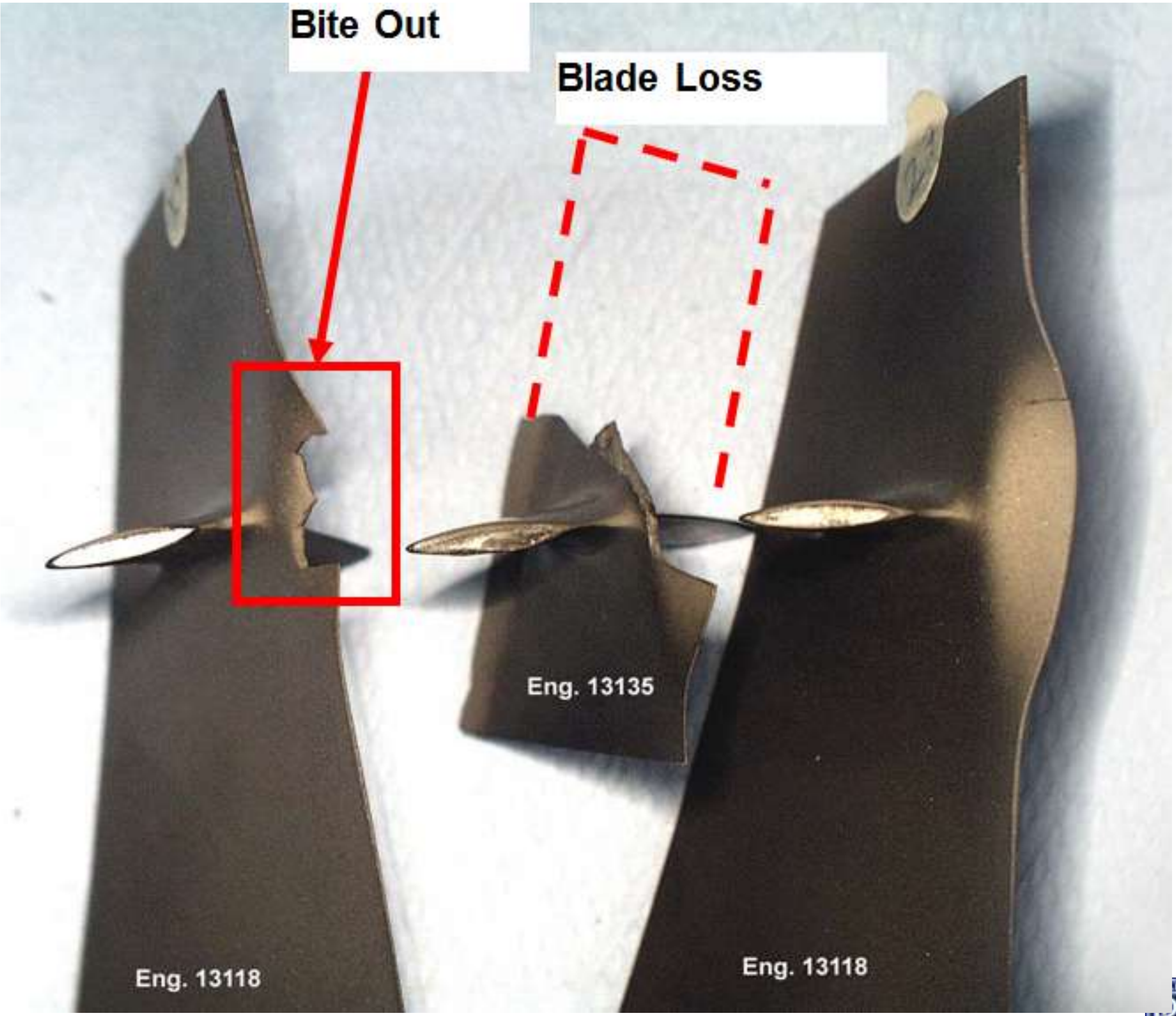
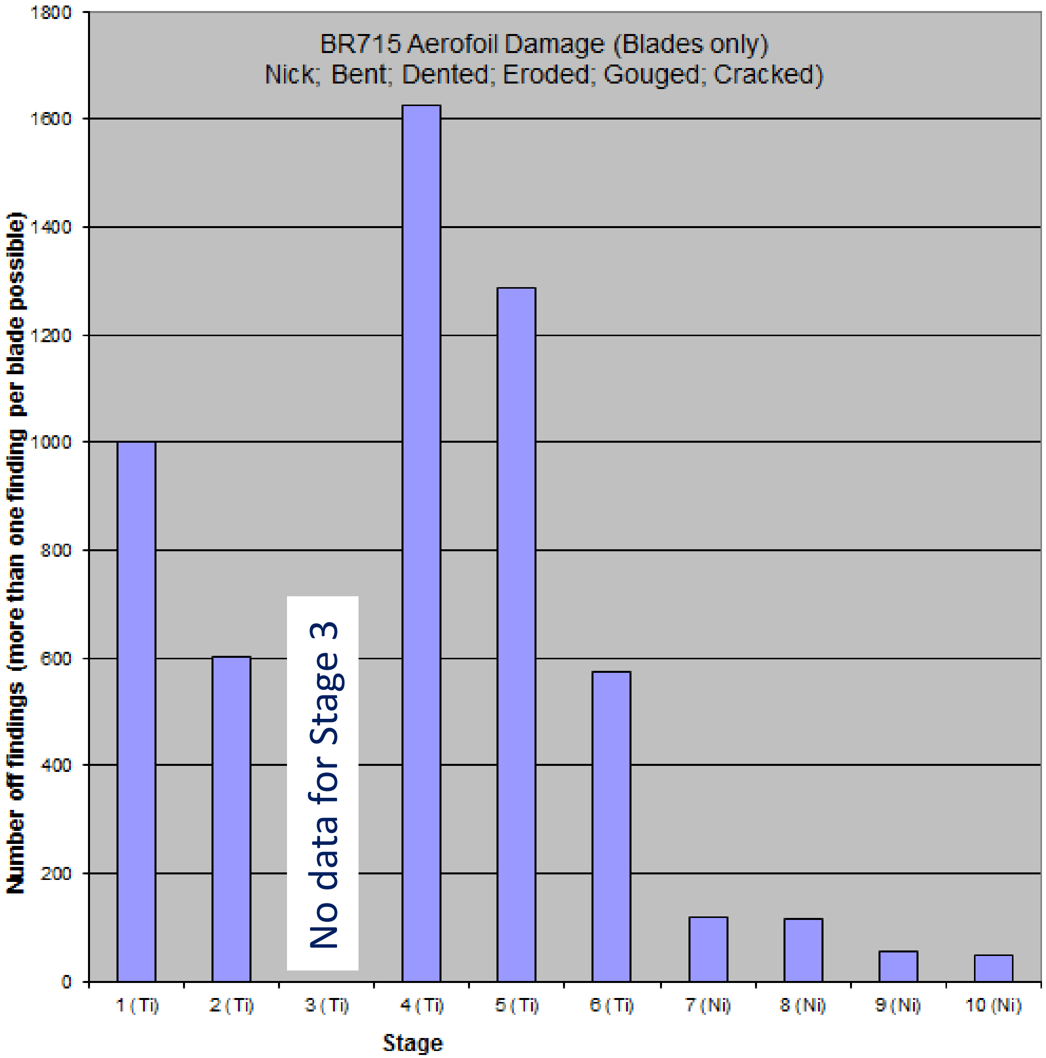
Soft Particle FOD (HPC R1)



Design: Materials – make a big difference!



- ➔ Compressor Blade Material will strongly affect number of FOD-findings.
- ➔ Typical for Blades are Titanium-Alloys up to about 450°C, then Nickel-Alloys (IN718).

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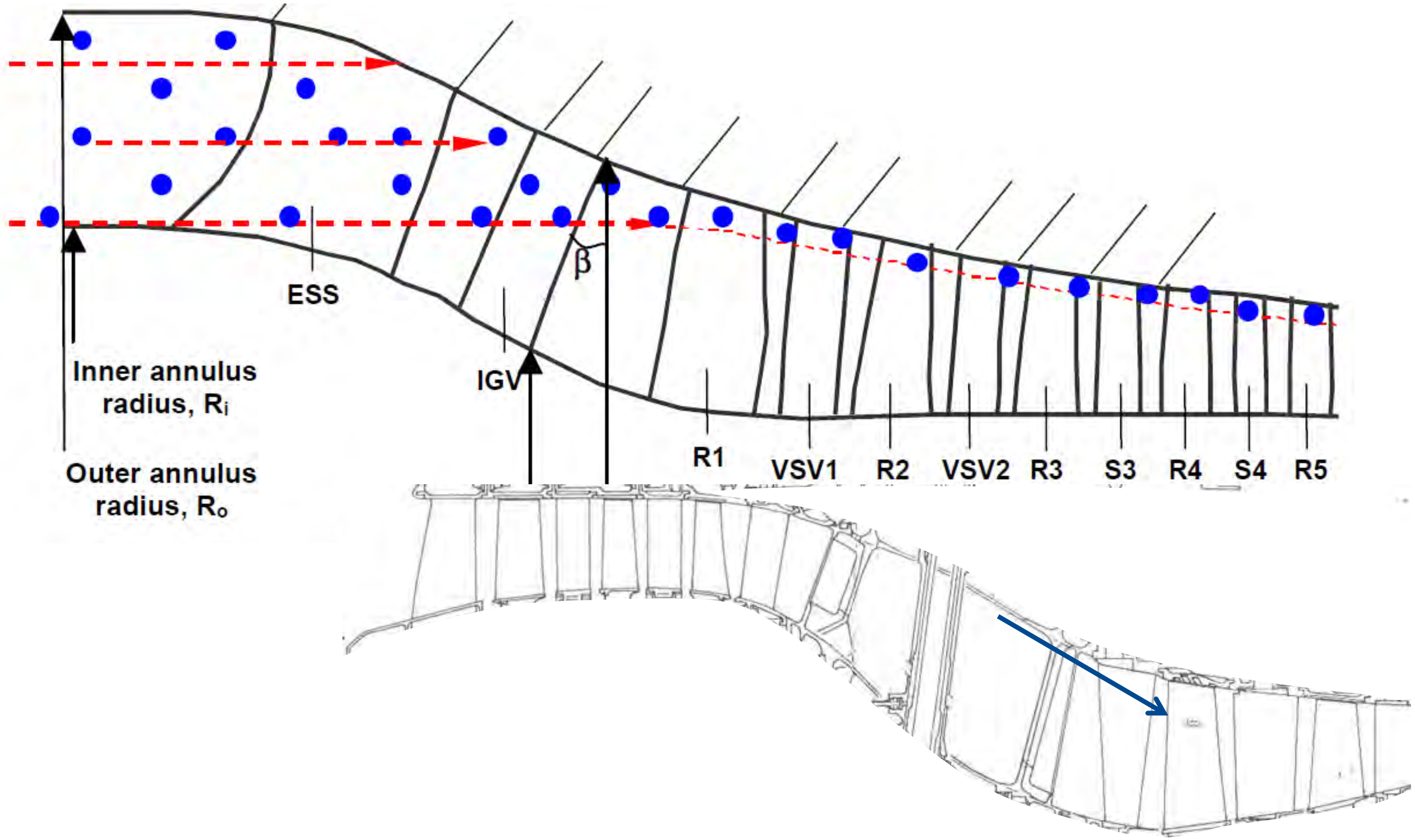
Design: Particle Trajectories



➔ The annulus shape can influence the blade height where FOD occurs most.

➔ Most Particles will be centrifuged outwards quickly.

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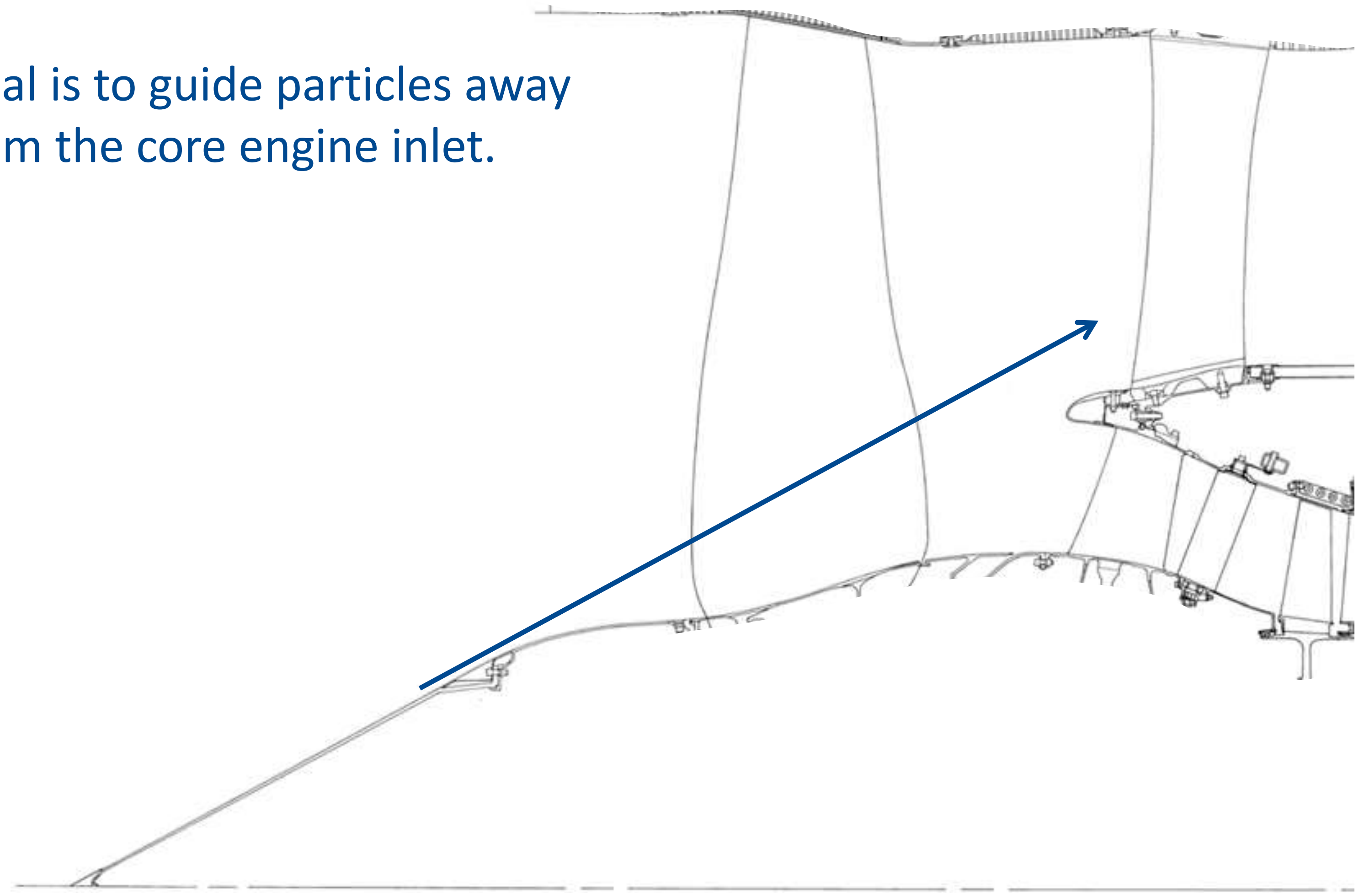
Design: Particle Trajectories

- Goal is to guide particles away from the core engine inlet.



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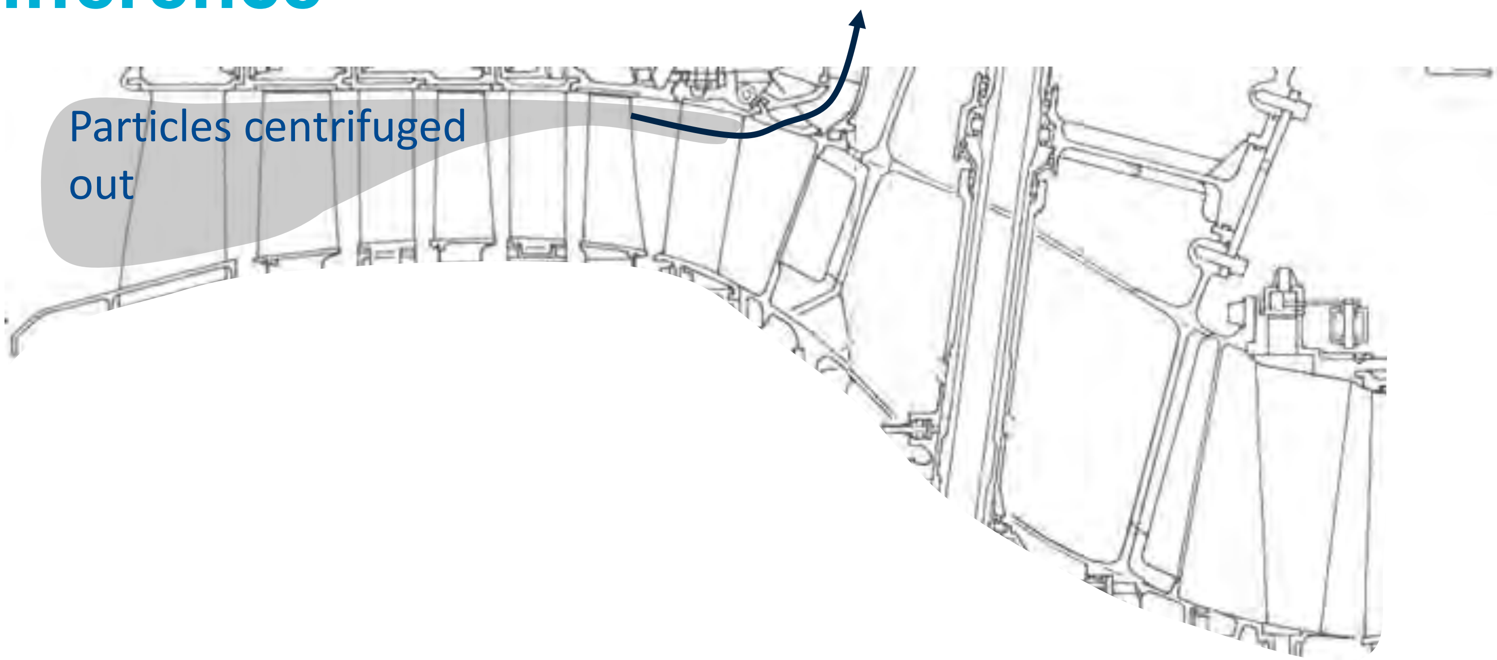
Design: Bleed Offtakes can make a difference



➔ Bleed Offtakes can help reduce the threat for subsequent stages.

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Engine Installation

- → Engine Ground Clearance
- → Engine relative Position to Wings and Undercarriage

Engine Operation

- ➔ Condition of Airfields / Environment
- ➔ Operating Practice (backing off the terminal with the Thrust reverser)

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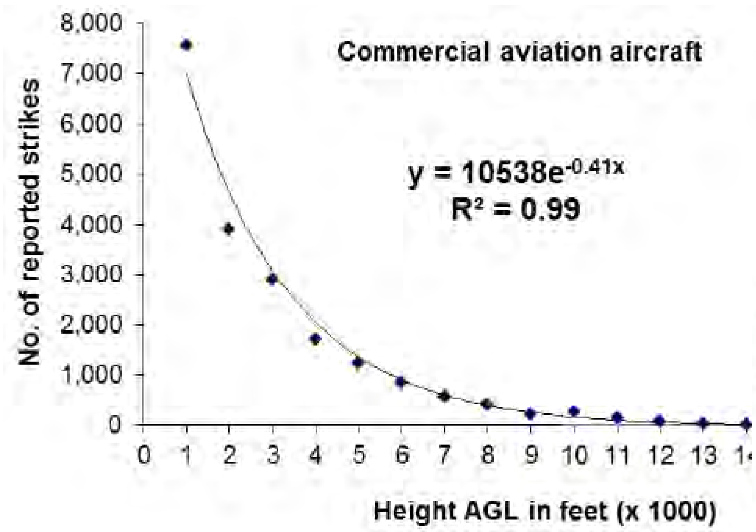
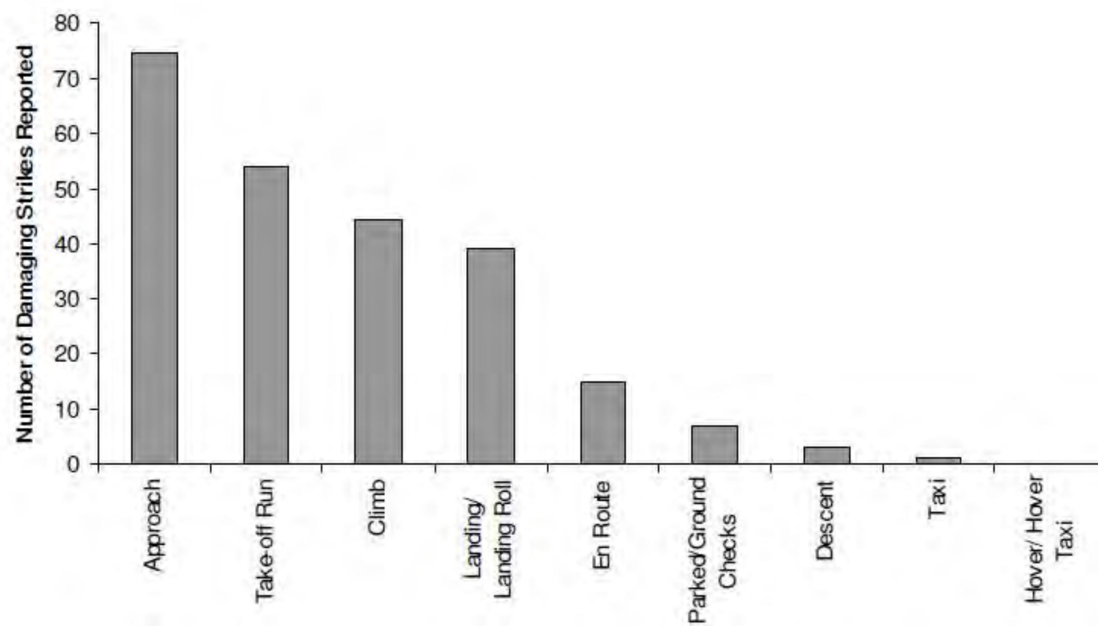
Bird Strikes





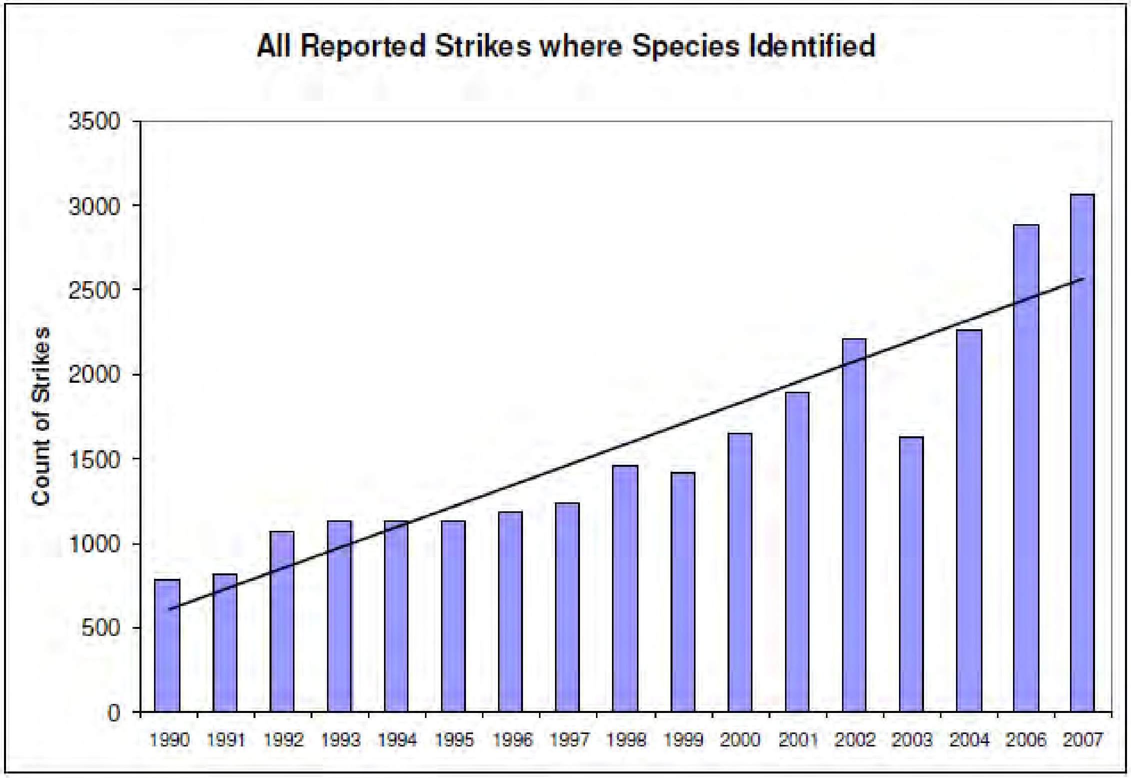
Source:

1. *FEDERAL AVIATION ADMINISTRATION NATIONAL WILDLIFE STRIKE DATABASE SERIAL REPORT NUMBER 20*
2. *EASA Bird Strike Damage & Windshield Bird Strike Final Report*

Bird Strikes

A significantly greater trend can be seen for all species, indicating that the above may simply be part of the general trend in bird strike reporting driven by the increased attention to reporting all strikes (mandatory in the UK since 2004). This is likely to affect mainly the low mass, non-damaging strikes that would previously have gone unreported.

Figure 5-4 Strike Trends for All Species



Source: EASA Bird Strike Damage & Windshield Bird Strike Final Report

Bird Strikes – Bird Management @ Airports

At the 2013 meeting of Bird Strike Committee-USA in Milwaukee, demonstrations were provided on various wildlife management techniques (e.g., pyrotechnics, left; live traps, right) during a field trip to General Mitchell International Airport. BSC-USA (www.birdstrike.org) is an organization of government and aviation industry members. Photo, R. A. Dolbeer.

Source: FEDERAL AVIATION ADMINISTRATION NATIONAL WILDLIFE STRIKE DATABASE SERIAL REPORT NUMBER 20

Certification Requirements (EASA / FAA)

Chapter	Title	FOD	Requirement
CS-E540	Ingestion of foreign matter	Anything "likely" to hit both engines	Continue safe operation, no unacceptable effect on operability or performance
CS-E800	Bird Ingestion	Depends on inlet size, 1,85kg…. 3,65kg.	Depends on Bird size. 1. Large: No Hazardous effect 2. Large Flocking: <50% thrust loss 3. Medium: <25% thrust loss
CS-E790	Rain and Hail	25-50mm Hailstone	No unacceptable thrust loss or mechanical damage
CS-E780	Icing	Ice Slab, depends on inlet area 88….1435cm³	No unacceptable damage or thrust loss.
CS-P360 (Propeller)	Bird Impact	1,8kg bird	No major or hazardous effect.

Drones – What is different ?

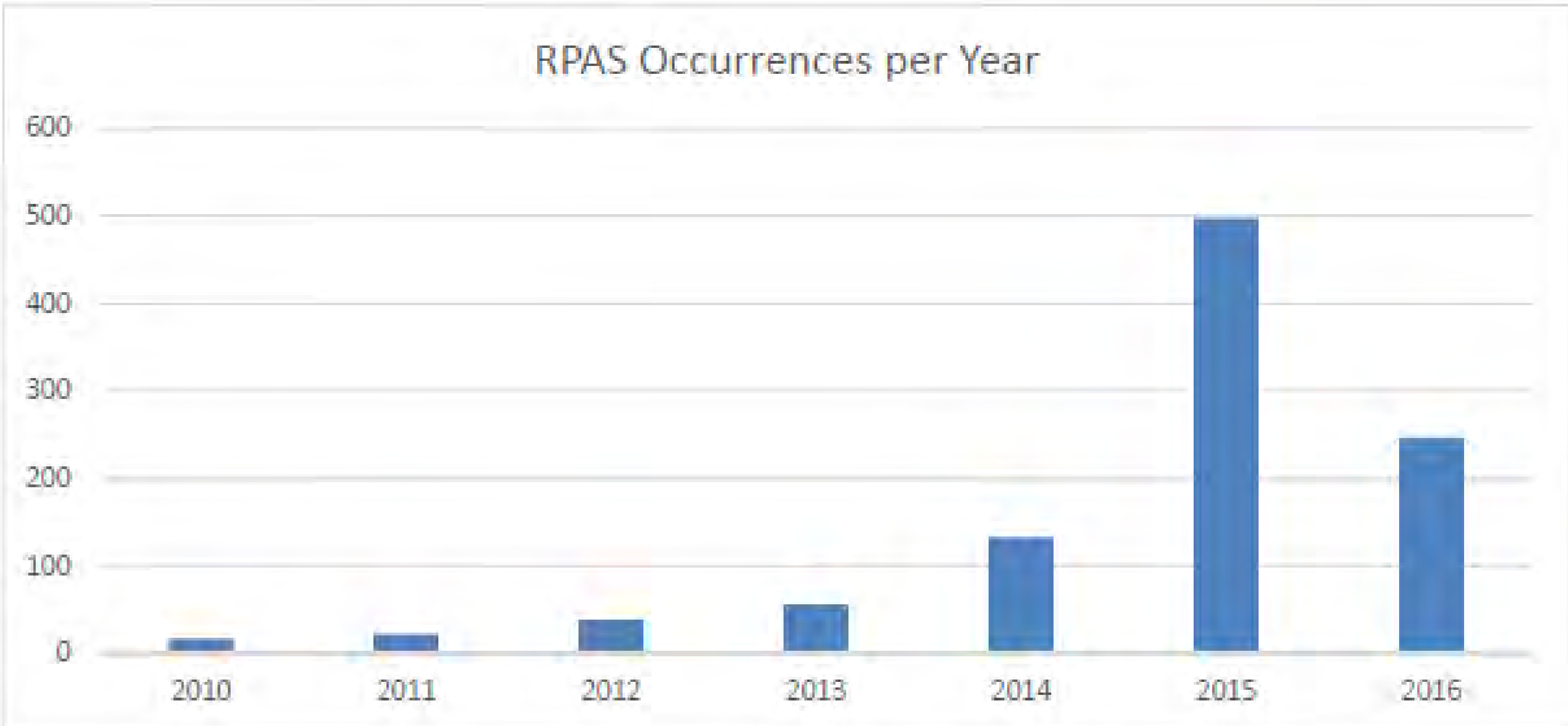


Figure 1 RPAS occurrences per year – 2010 to 31 May 2016.

Source: EASA Drone Collision Task Force; Oct. 2016

Drones – What is different ?

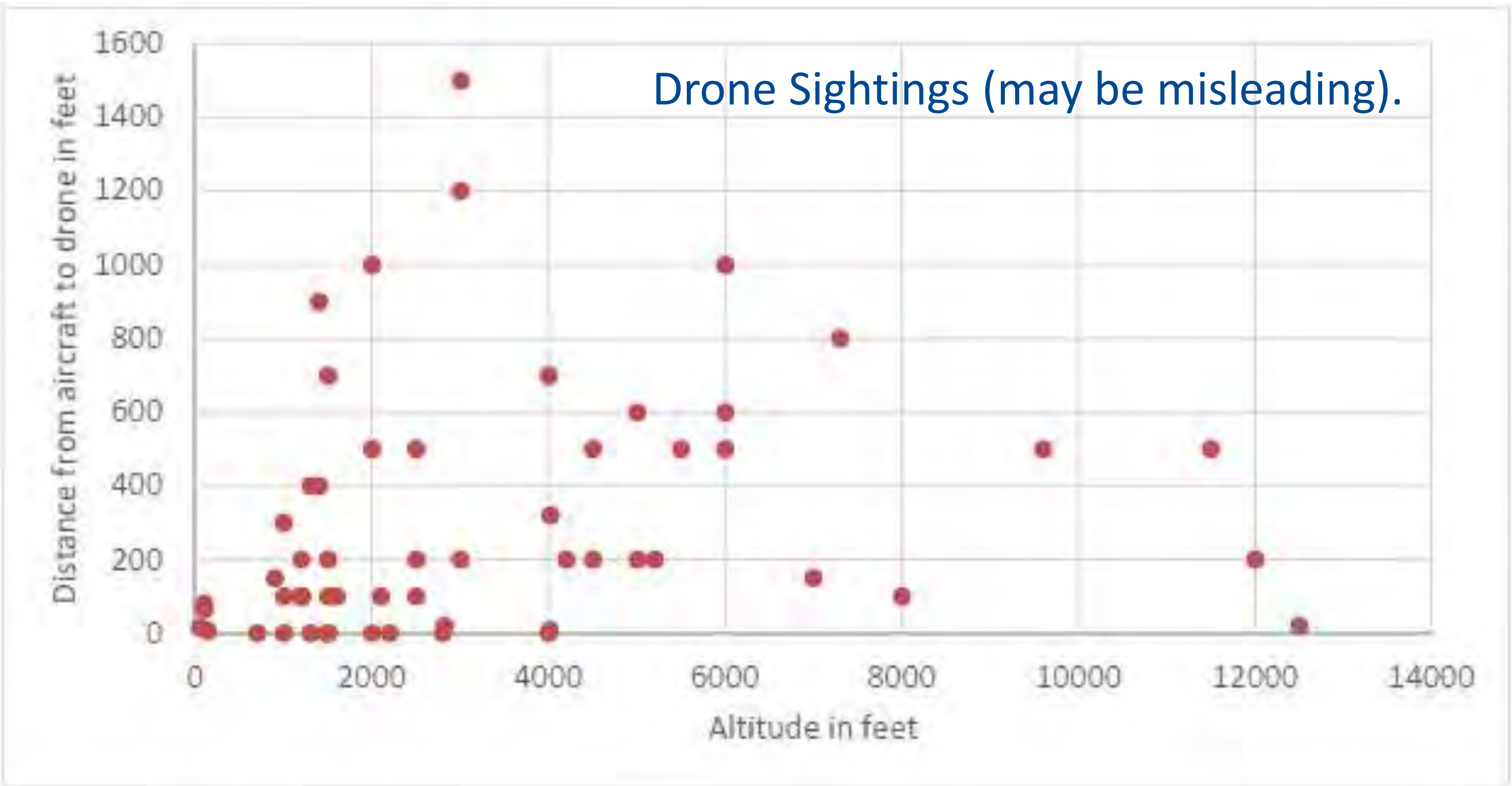


Figure 2 Distribution of RPAS Occurrences - Actual Aircraft Altitude vs Distance to Drone.

Source: EASA Drone Collision Task Force; Oct. 2016

Drones – What is different ?

"However, occurrences above 6 000 ft of altitude should not be disregarded, as aircraft groundspeeds increase with altitude, which could make an impact with a drone or even a weather balloon a very serious event."

"Lithium batteries contain hazardous materials such as lithium metal and flammable solvents, which can lead to exothermic activity and runaway reactions in case of impact with aircraft components following collisions."

Source: EASA Drone Collision Task Force; Oct. 2016

Drones – Threat Specifications

Drone Class	Threat Type	Element	Weight (g)	Density (kg/m3)	Dimensions (mm)/Typical Shape	Quantity	Max speed (m/s)	Zd-max (m)	Zd-lim (m)
Large	Tl	Drone	3500	-	450x450x301	-	20	5000	500
	Tm	Battery	670	2000	Parallel piped	1			
	Th	Motor	106	4000	Cylinder	4			
Medium	Tl	Drone	1500	-	290x196x290	-	20	5000	500
	Tm	Battery	462	2000	Parallel piped	1			
	Th	Motor	56	4000	Cylinder	4			
Small	Tl	Drone	500	-	328x382x89	-	18	1000	150
	Tm	Battery	130	2000	Parallel piped	1			
	Th	Motor	15	4000	Cylinder	4			
Harmless	Tl	Drone	250	-	200x200x140	-	18	1000	150
	Tm	Battery	65	2000	Parallel piped	1			
	Th	Motor	7.5	4000	Cylinder	4			

Source: EASA Drone Collision Task Force; Oct. 2016

Threat Type:
- Tl: Threat: **low** density
- Tm: Threat- **medium** density
- Th: Threat- **high** density

Altitude:
- Zd-max: Maximum flyable altitude capability above sea level.
- Zd-lim: Max altitude limited by hard-coded software limitation

Drones – What is different ?

- Hard Particle FOD at altitude
- Unlikely to affect more than 1 engine
- Limited data available so far, but may strike at unusual high altitudes
- High Mass
- Uncontrolled materials (Lithium, Silver (?), Copper, traces of Cl, S)

Source: EASA Drone Collision Task Force; Oct. 2016

Discussion