Lightning Interactions with Composite Aircraft
Presentation Summary

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1. Introduction
2. Lightning Voltage
3. Lightning Current
4. Materials
Boeing 747, Japan, 2008*
Sydney, Australia, 2007*
Boeing 737, Denver, USA, 2015*
Embraer E195, Rionegro, Columbia, 2011*
*Images from YouTube videos
Each commercial airliner will be struck, on average, more than once per year.

Aircraft often trigger lightning in charged regions by creating a path to ground.

Aircraft act as Faraday Cages: lightning enters, travels along the outside surface, and exits keeping everything inside safe.
This was not a problem for traditional metal aircraft, but modern aircraft are made from lighter and stiffer non-conductive carbon composites.

To understand this better, consider the two main components of a lightning arc:
- Voltage (~10,000,000,000 V)
- Current (~30,000 A)
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Voltage essentially allows the lightning arc to ‘travel’ over distance: 3,000,000V for 1m

Voltage can causes some damage but this is minimal, e.g. localised surface burns

Can demonstrate this using a high frequency 350,000V ~mA Tesla Coil to represent the voltage of a lightning arc
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*Tesla Coil interactions with a conductive metal model aeroplane*

*Tesla Coil interactions with a non-conductive cardboard model aeroplane*
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5. Miscellaneous
Current is what essentially causes the ‘damage’ to a medium or material during a strike.

A 30,000A lightning arc results in a force of 1,000,000,000Pa reaching 30,000°C within 200µs.

This is not very easy to reproduce, and ‘direct effect lightning’ can only generated within a few laboratories worldwide.
The Morgan-Botti Lightning Laboratory is the only university-based direct effects lightning laboratory in Europe.

Initiated in 2011, completed in 2014, fully operational in 2015, with support from Airbus and the Welsh Government.

Designed to meet EUROCAE ED84 aerospace lightning standard.
‘Standard’ lightning strike (D): 100,000A (~50,000V) within 100 µs

‘Worst case’ lightning strike (A): 220,000A (~60,000V) within 200 µs

Output of 5 to 12GW; equivalent to the output of a nuclear power station within the same timeframe
A Tesla Coil was used to demonstrate lightning voltage on conductive and non-conductive model aeroplanes.

Can now demonstrate the effect of lightning current on a conductive model aeroplane.

Note: This is a demonstration within the context of this presentation, and not what happens in real life!
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Lightning can be very destructive for non-conductive materials and the current method of protection is to make the material conductive.

In aerospace, non-conductive carbon composites are made conductive by adding a metallic mesh surface layer.

Typically, these meshes are copper (Airbus) or aluminium (Boeing).
Can demonstrate this protection by assessing how lightning interacts with different types of material:

- aluminium
- carbon composite
- carbon composite & copper mesh
The metallic mesh protects the underlying composite by diverting the lightning along the surface:

- aluminium
- carbon composite
- carbon composite & copper mesh
Although this is an established lightning protection system which works, it is not ideal.

Metallic meshes consist around 3% of an aircraft’s skin and sub-structure weight, and counters weight-saving initiatives.

New materials and technologies are emerging, and our lab helps characterise their behaviour during lightning strikes.
In order to do this, we have a lot of diagnostic equipment:
- Current, voltage measurements
- Pressure, temperature probes
- High speed photography
- Stills photography
- Thermal imaging
- Transient light
- Spectroscopy
- Displacement measurement
- Optical, electron microscopy
- Electron microscopy
- Etc., etc. …
Example 1, Spectroscopy: Light-based technique which can be used to deduce energy, temperature and element interactions

Example 2, Deflection: Techniques to understand mechanical shock, deflection, oscillation and damage due to lightning interactions

Funders: Protest Project (Airbus), Innovate UK; Sensor development (Cardiff University), NRN Advanced Engineering and Materials
Spectroscopy of lightning strikes to various materials, showing element interactions:
Deflection of an aluminium plate following a 100kA lightning strike (initial shockwave):