WATER INGRESS IN COMPOSITE MATERIALS

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Critical Issue

- Damages & weakens composite material
- Financial burden
- Time consuming part replacement
- No solution to mitigate moisture

Figure 1: Representation – Moisture in composite materials in an aircraft elevator
The subject of study

Revolutionary material that contributes to a greener planet:

Composites

Biggest issue of composites that weakens and adds weight:

Moisture and water ingress!

A new aspect of study

Many practical experiments conducted with immersed composites:

- Take up to 5 years!
- & No solutions found yet!

Why not study water ingress in computational fluid dynamics & research mitigation pathways?

Brilliant Idea!
Key points

- Reasons and effects of moisture
- Detection and removal methods
- ANSYS – CFD Simulations
- An insight on mitigation pathways
Importance of composites materials

High strength-to-weight ratio and reduces fuel consumption

Widely used in the military industry since 1960s

A380 uses composites as primary load-carrying structure

Figure 2: A380 Composites Applications

Image source: Airbus
Composites explained

- **Composites**: Fibres + Resin

- **Fibres**: Strong in tension, acts as reinforcement

- **Resin**: Surrounds and binds the fibres together and allows to sustain a desired shape

- **Stronger, stiffer and lighter material than any other individual one**

- **Kevlar, Glass Fibres, Carbon Fibre Reinforced Polymers**

*Figure 3: Composites & CFRP Sandwich Model*

*Image source: FAA*
Reasons of water ingress

- Voids
- Loose fasteners
- Defect in the material

Figure 4a: Voids in composites
Figure 4b: X-Ray – Water presence in CFRP of A320 Elevator

Image source: Google Image & LTM
Diffusion

- **Fick’s law of Diffusion**: transport of molecules from a region of higher concentration to a region of lower concentration

- Capillary

- Transport of water molecules

*Figure 5: Fick’s Law of Diffusion Theoretical Moisture Absorption Plot*

*Image source: Wong, K. J., 2013. Moisture absorption characteristics and effects on mechanical behaviour of carbon/epoxy composite : application to bonded patch repairs of composite structures. HAL.*
Effects of water ingress

- Weight Increase
- Weaker Material
- Layer Delamination
- Skin Disbonds
- Cracks

Figure 6: Different defects in CFRP

Image source: Olympus
Detection & Removal

- X-Rays
- Active Thermography
- Passive Thermography
- Vacuum
- Ultrasonic Vibration
- Water Egress Channel

Figure 7: Active Thermography of Radome
Figure 8: Example of Vacuum

Image source: LTM & Google Image
Figure 9: Importance of meshing – Coarse and fine mesh respectively

Figure 10: Mesh convergence study – CFX and Fluent
CFD Analysis - Ansys FLUENT

Ansys 2D Design – Elevator Top Surface – Variation in Pressure Contours due to increasing number of affected fastener holes

Ansys 2D Design – Elevator Top Surface – Variation in Velocity Contours due to increasing velocity inlet

Ansys 2D Design – Elevator Cross-Sectional Area– Variation in Velocity Contours due to different sizes and locations of voids inside the composites
Comparison of different composites – Ansys CFX

<table>
<thead>
<tr>
<th>AS4-3k</th>
<th>CFRP Epoxy</th>
<th>Kevlar CFRP</th>
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Figure 10: Pressure and Velocity Contours of different materials – CFX – 3D simulations
Figure 11: 3D simulations of an elevator affected by 4 loose fasteners – Total deformation animation
Mitigation Pathways – Possible Concepts

Hydrophobic Films: Thin water repellent films made of polyvinyl fluoride or polyether ether ketones films.

Teflon fluoropolymer resins: Hydrophobic resin. Teflon resins also have high tensile strength and good fatigue life.

Use of natural fibres: Good advantages which contribute to a greener planet.

<table>
<thead>
<tr>
<th>Film</th>
<th>Manufacturer</th>
<th>Thickness/Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tedlar</td>
<td>DuPont</td>
<td>25.4-μm thick (both surfaces plasma treated)</td>
</tr>
<tr>
<td>PEEK-1</td>
<td>VICTREX PEEK™, APTIV film, 25.4-μm thick (surface plasma treated)</td>
<td></td>
</tr>
<tr>
<td>PEEK-0.5</td>
<td>VICTREX PEEK™, APTIV film, 12.7-μm thick (surface plasma treated)</td>
<td></td>
</tr>
<tr>
<td>Teflon</td>
<td>DuPont</td>
<td>25.4-μm thick (no surface treatment)</td>
</tr>
</tbody>
</table>

Figure 12: Example of thin hydrophobic film
Figure 13: List of existing hydrophobic films
Conclusion

- CFX is seen not to provide accurate results while Fluent is, especially for 2D designs, FSI does not take material into consideration and thus not reliable;

- 3D designs easily simulated on CFX rather than Fluent, there are several other software-based limitations;

- Future scopes of analysis: ABAQUS, Molecular Dynamics Simulation (MDS), Lattice Boltzmann simulation (LBM).

ANSYS enables elementary, yet rapid, studies: a good scope to catalyse future research. Mitigation pathways should be tested experimentally under real flight conditions and corroborated via high fidelity CFD simulations.