Enhancing aircraft corrosion risk management *via* microclimate simulation

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6th July 2018
Aircraft Airworthiness & Sustainment Australia Conference
Brisbane Convention & Exhibition Centre

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Introduction

- $238M/year AUD [1], $10B USD/year [2]
- Monitoring corrosion essential due to
  - Perpetuated aircraft lifecycles
  - Manufacturer guarantees must be increasingly stringent
- Useful to predict corrosion-prone zones & estimate corrosion rates
  - Can help inform inspection schedules
  - Focus on the former

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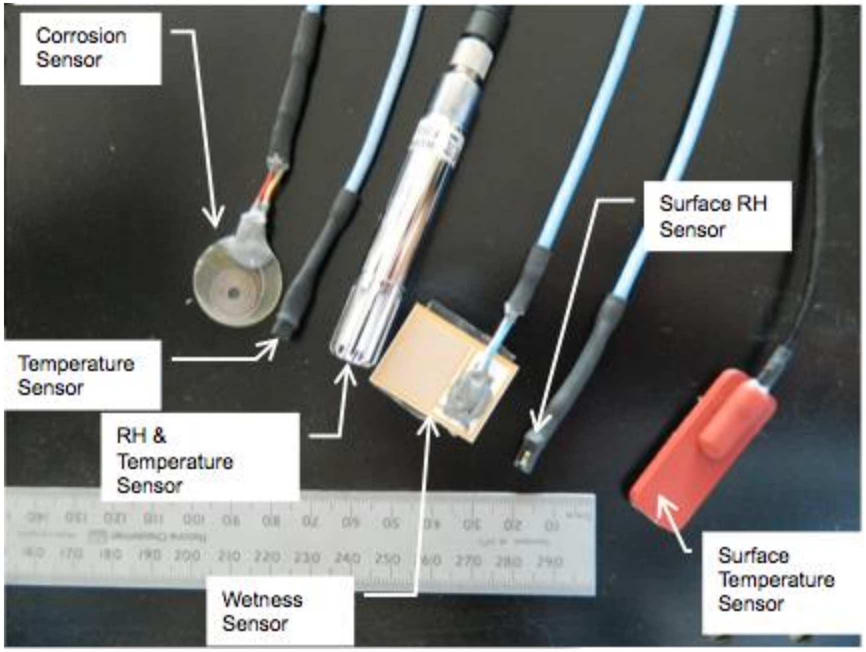
[1] Cassidy, M., Waldie, J.M.A. & Jacob, J. (2014). “Cost of Australian Defence Force Aircraft Corrosion Report” (internal document), BAE Systems Australia Ltd.

[2] Herzberg, E. (2010). “Cost of Corrosion to DoD”. 2010 DoD Maintenance Symposium & Exhibition, Tampa Bay, Florida, 15-18 November 2010.

Predicting corrosion-prone zones

- Option 1 – Measure then Predict
  - Instrument test aircraft with microclimate sensors
    - Temperature
    - Relative humidity
    - Instrument each bay
  - Internal microclimate model fitted to the measurements
  - Reasonable approach – but not fully predictive
    - Given mission/usage profiles
    - Given location for aircraft
    - Sensor maintenance cost for the test aircraft
    - Some aircraft are difficult to retrofit



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Predicting corrosion-prone zones

- Option 2 – Measure & Simulate
  - Massive increase in computer power in recent decades

<table>
<tr><th>‘KNOWNS’</th><th>ESTIMATES</th><th>OUTPUTS</th></tr>
<tr><td>Aircraft geometry (bay sizes & shapes)</td><td>Salt types accumulated on hull</td><td rowspan="6">T, RH distribution within each bay during flight

Surface moisture distribution on hull

May be used as inputs to corrosion models

May help to design inspection schedules</td></tr>
<tr><td>Hull construction</td><td>Storage conditions (hours exposed)</td></tr>
<tr><td>A/C & venting systems</td><td>Hangar conditions (T, RH)</td></tr>
<tr><td>Ground conditions (e.g. T, RH)</td><td></td></tr>
<tr><td>Conditions at cruising altitude</td><td></td></tr>
<tr><td>Mission profiles</td><td></td></tr>
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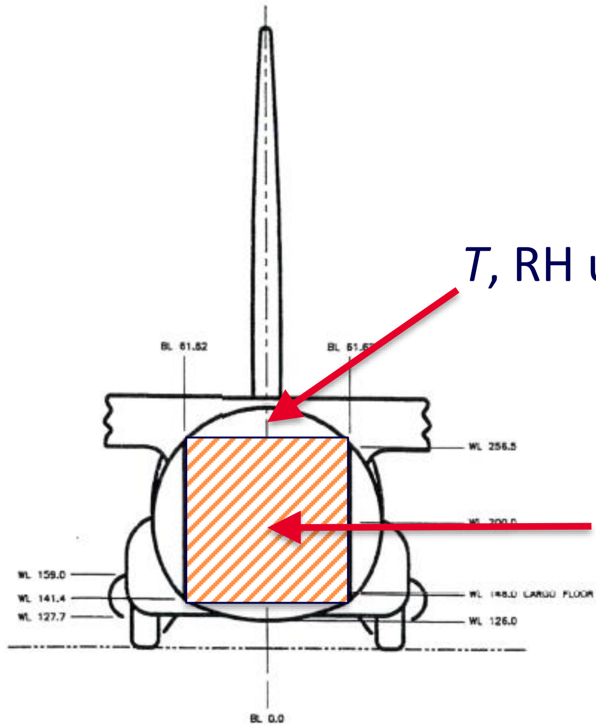
  - *Once simulation works*…backup to predictive model w.r.t. changes location, mission profile, *etc*. as less data required to update it

Simulation – background

- Aircraft are multi-bay environments



- A/C bays are human occupied, thus well-controlled *T*, RH
- In both cases, simulation predicts *T* & RH in unpressurised bays

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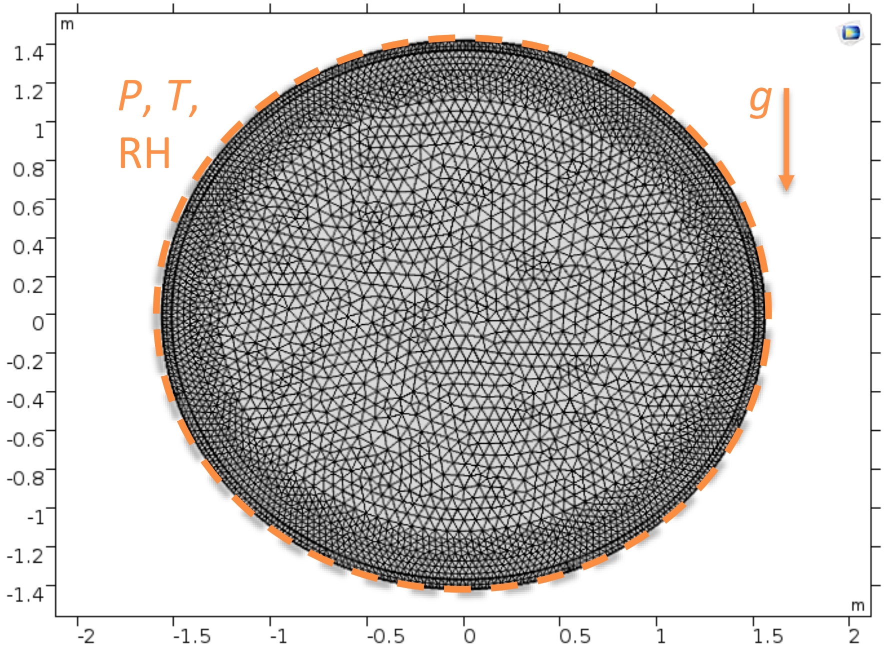
Simulation – Inputs

- COMSOL Multiphysics 5.3a
  - Commercial FE code
  - 2-D to start with (3-D later)
- Data inputs
  - Measured data for *T* (C130)
  - Correlation for *P* *vs*. altitude
  - Correlation for humidity *vs*. altitude
- Submodels
  - Heat transport model
  - Condensation model



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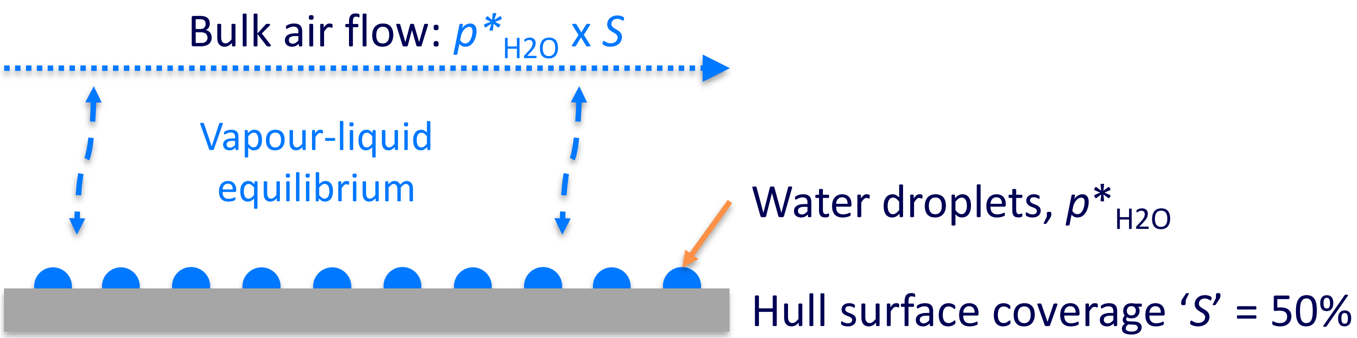
Simulations – Heat transport submodel

Hull property	Estimates required	Controls
Mass of hull	Hull thickness Void space *Not always available*	Hull temperature Air temperature to an extent
Hull 'permeability' to air	Flowrate of air through hull/psi *Unknown – test rig being designed*	Rate of mixing between external air (dry, cold) & internal air (humid, warm)
Hull surface area	Approximate internal geometry of hull *Unknown – need to estimate*	Fraction of hull covered by droplets

Simulations - Condensation submodel

- Preliminary model – proof of concept only
- Assume droplet shape (hemispherical) & diameter (80 µm) [3]



- Variable simulated – 'surface coverage fraction' *S* (%)
- $S = p_{H2O}/p^*_{H2O}$
- Water drains away, *i.e*. lost to aircraft, at *S* > 1
- Key parameter – salt species deposited on hull
  - Decides droplet size & initiation of condensation & evaporation
  - *Data source needed – working on it*

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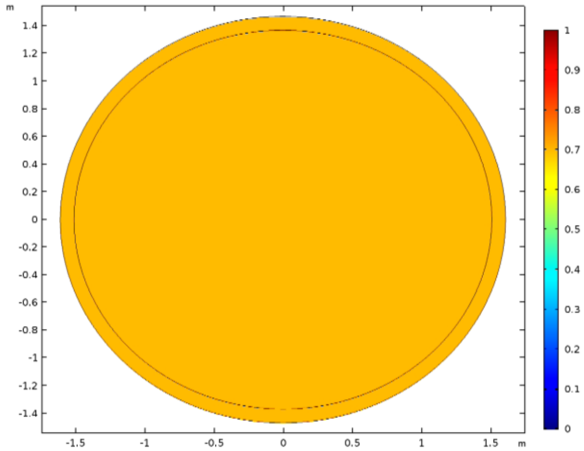
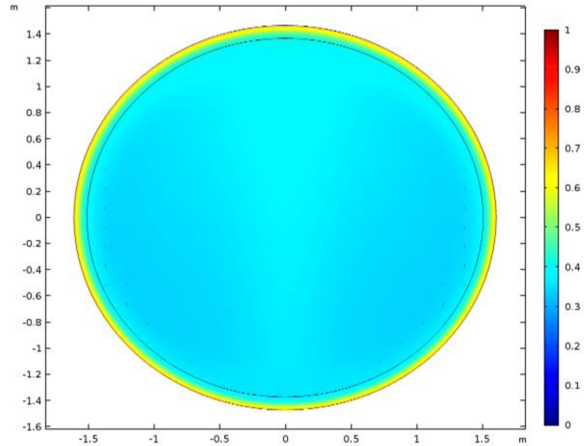
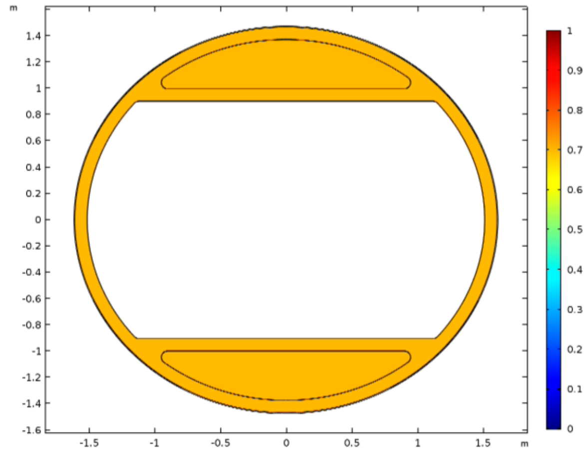
[3] I. S. Cole, D. Lau, and D. A. Paterson, "Holistic model for atmospheric corrosion Part 6 – From wet aerosol to salt deposit," Corros. Eng. Sci. Technol., vol. 39, no. 3, pp. 209–218, 2004.

Results – what simulations predict

- *T* changes in line with RH, only RH but ask me later…
- Single unpressurised bay, RH, ascent video
- Single unpressurised bay, RH, descent video
- Triple bay, RH, whole flight







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Discussion

Single bay result	Ascent	Cruising	Descent
Air temperature	±5°C	Uniform	±30°C
Air relative humidity	±5%	Uniform	±25%

- Several assumptions in this simplified model
  - Testing these involves many simulation runs
  - Currently a research tool – will be for some time
- But once we have simulation designed & validated
  - Easier to extend to different aircraft locations (outside climate)
  - Different flight profiles (flight length, exterior weather)
  - Different flight schedules (day/night, flights per year)

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Conclusions

- 2-D microclimate simulation created for C130 transport aircraft
- *T*, RH vary strongly within bays
  - Single bay result - descent > ascent > cruising
  - Multi-bay results will be different
- When complete - distributions will (hopefully) help with design of aircraft corrosion inspection schedules

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Future work

- Early days – many, many things to do
- Rebuild simulations in 3-D form
    - Based on a real aircraft bay configuration – still somewhat simplified
    - General bay sizes & shapes
    - General hull construction
    - A/C/venting systems
- Validate simulation
    - Test predictions against real microclimate measurements
- Working with BAE Systems to obtain these data (thank you!)

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