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Monitoring Aircraft Microclimate and Corrosion

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Abstract

CSIRO, Boeing, DSTG and the RAAF have undertaken a number of monitoring programs of microclimate and corrosion within different internal spaces in a number of aircraft. Past programs have looked at conditions within an RAAF-707 (sub-floor area) and an Air New Zealand 747 (sub-galley). The current program looks at a number of spaces in two RAAF C-130s based at Richmond, NSW. The spaces include Empennage, Cargo door and above LH Main Wheel Well. Monitoring of the C130s is now in its second year of engagement.
The data derived in each monitoring program includes the ambient air relative humidity, surface relative humidity, ambient air temperature, surface air temperature, surface wetness and corrosion as measured by a corrosion sensor. This data allows relationships between microclimate, wetness and corrosion to be established as well as relationships between base location, flight patterns, position in aircraft and microclimate to be derived. It is observed that in some cases wetness and corrosion are directly related to microclimate and are associated with such phenomena as condensation or "rain in plane". In other cases there is no apparent microclimatic cause for wetness or corrosion events. The relevance of the data to the corrosivity of different aircraft spaces, base locations and flight patterns is reviewed and implications for maintenance are assessed using the current data from the C130s. Work is progressing on deriving generic software for predicting aircraft internal microclimate from flight path, time of day and month of year using this data.

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1. Introduction

Corrosion within airframes is a significant problem for both commercial and military aircraft [1]. The extent of corrosion on both bare and painted metals is highly dependent on both the duration and frequency of wetness events [2]. Thus it is necessary to understand the factors that control corrosion in Aircraft in order to effectively maintain them. The traditional "one size fits all" approach to maintaining aircraft is expensive, time consuming and fails us in important areas that are hard to inspect.

Sensor installations allows us the possibility to tailor maintenance to actual usage [3-5]. They permit the buildup knowledge of the conditions within the airframe and its relationship to the outside environment. Through a series of monitoring programs the authors of this paper have built up empirical knowledge of the internal microclimates within the airframes of aircraft and their response to the outside environment and usage of the aircraft. However as yet there is no general model that can predict internal

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microclimates as a function of position in the aircraft and the aircraft usage. This paper describes a monitoring program involving two RAAF C130 aircraft. The installation of the sensors, collection and analysis of the data and simulation and modelling will be described and we will discuss their implications

2. Methods:

A CSIRO designed and built data logger and sensor package was deployed in two RAAF C130J aircraft designated A and B. Both C130J aircraft had a system deployed in the Empennage, while A also carried a system in the top of the left hand side wheel well and at the top of the rear ramp. The locations are indicated in the following diagram.

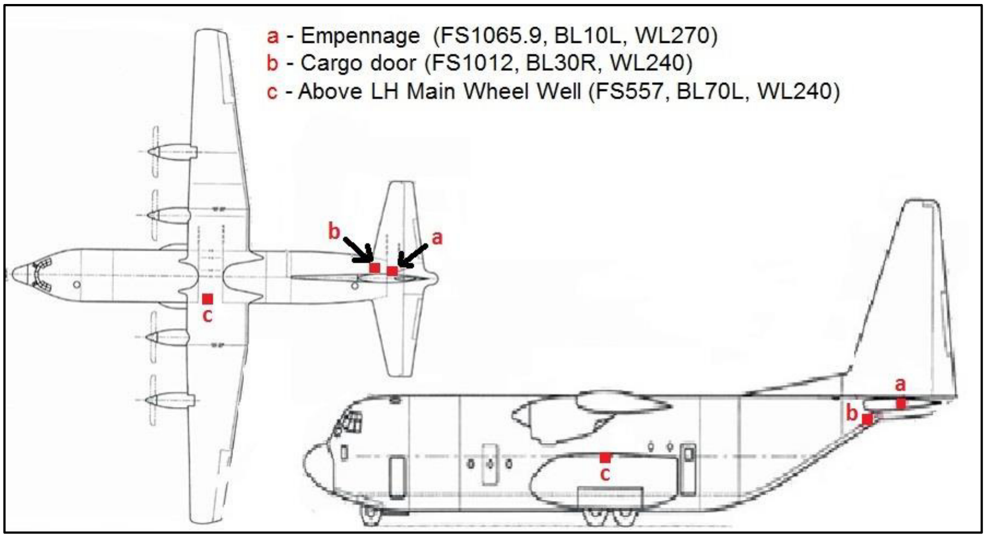

Fig. 1. Locations of data loggers on C130 aircraft.

The sensor package includes Air relative humidity (RH) and Temperature, Pressure, Surface RH, Surface Temperature, Wetness and a Corrosion Sensor. Full details of sensors and past monitoring programs can be found in the papers Cole et al [6,7].

3. Monitoring Results

Data has been collected from plane A in 3 locations between November 2013 to November 2015 and plane B in one location from October 2013 to May 2015. The Corrosion sensor shows three types of variations:

- Random variations due to temperature and other fluctuations
- Systematic but low level variations due to RH
- Significant variations associated with significant wetness on the sensor producing significant readings

It is desirable to only analyze the significant variations, so a “cut off” value was determined below which the values were deemed to be noise. Of the Significant variations there were four types of events found:

- 1a Corrosion event independent of Flight
- 1b Event started independent of Flight but terminated with a Flight
- 2a Event started with Flight and terminated with Flight
- 2b Event started with Flight and terminated independently of Flight

Corrosion event 1a starts on the ground in the early morning, around 4am, when the humidity is high (around 84%) and the wetness sensor shows wetness. The event stops around the middle of the day when the plane warms up and the air dries.

Event 1b starts the same as 1a but stops when the plane takes off on a flight and the dry air in the troposphere mixes with the planes internal air.

Corrosion events 2a and 2b occur post flight as the cold airframe lands and the warm moist air on the ground enters into the compartments in the plane and condensation occurs on the cold metal surfaces. Event 2a is terminated when the plane takes off again and the dry air of the troposphere enters the compartments. Event 2b continues until the environment around the plane allows the drying of the compartments on the plane. This may take a significant time depending on the local climatic conditions and could last more than 24 hours.

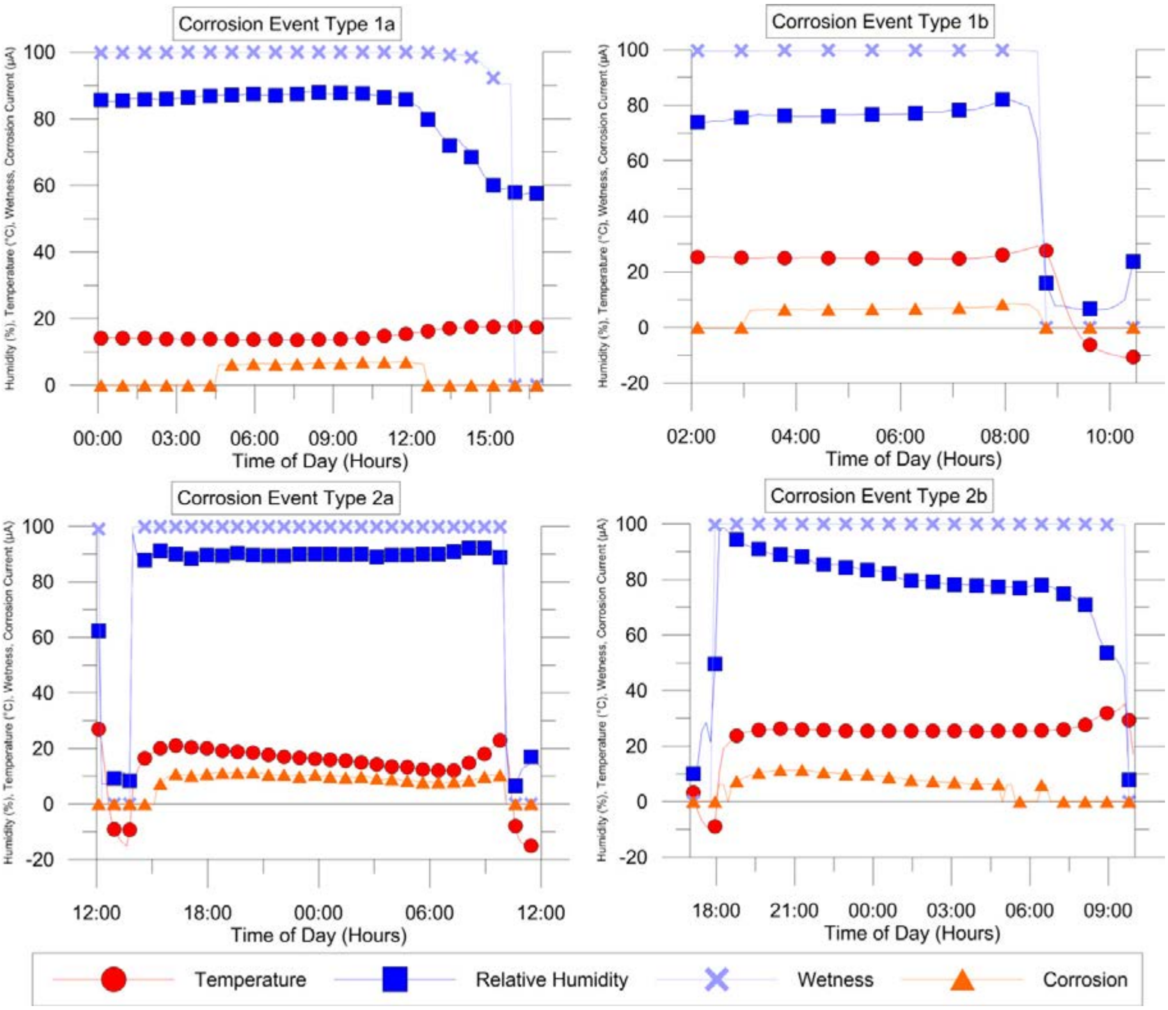

Fig. 2. Environmental conditions associated with Corrosion Events Types 1A, 1B, 2A and 2B.

Twenty corrosion events occurred between 31/01/2015 and 04/08/2015 in the Empennage of C130J-B. The most common corrosion events happen when the plane is on the ground (Type 1a). Eighteen of the twenty events are of this type. The two others start when the plane is on the ground, but end when the plane takes off (Type 1b). The entry of dry and cold air of the troposphere into the Empennage compartment cause these events to stop.

Table 1. Number of Significant Corrosion Events in the C130 planes.

Significant Corrosion Event	Plane A Empennage	Plane A Cargo Door	Plane A Wheel Well	Plane B Empennage
1a	3	0	5	34
1b	1	0	1	12
2a	1	0	0	5
2b	1	0	2	13

4. Modelling Aircraft micro-Climate

In order to predict the occurrence of corrosion and thus the overall accumulation of damage and required maintenance it is necessary to develop models that can generalize the empirical data given above. Such models would model micro-climates in a range of the aircraft and aircraft spaces and for a range of flight paths and base locations. Surprisingly allow a considerable amount of work has been undertaken modelling air flow patterns [8-10], particularly in the passenger cabin, to the authors' knowledge no systematic models of microclimatic in spaces in the aircraft have been derived previously. This part of the paper will present such a model and importantly defining the critical components of the model and how they vary with aircraft space and flight path. The first part of the model addresses temperature variations during flights. Flights will be split in four stages: when the plane rises, when it flies at a constant altitude, when it lands, and when it's on the ground.

4.1. Ascent stage

This stage is ruled by the following equations: The first equation defines the rate of change of the temperature of surfaces in the air space while the second defines the interaction between the temperature of the surface and the air in the space. The third term is more complex and looks at both the buffering effect of the surface on final temperatures in the spaces and the effect of pressure changes.

$$\beta_s \frac{dT_s}{dt} = T_f - T_s \tag{1}$$

$$T_f = \frac{\beta_s T_s + \beta_a T_a}{\beta_s + \beta_a} \tag{2}$$

$$dT_{ai} = \frac{\gamma - 1}{\gamma} T_1 P_1^{\frac{1}{\gamma}-1} P_e^{-\frac{1}{\gamma}} dP_e + (T_f - T_a)\frac{1}{\beta_a} dt \tag{3}$$

with:
-T_a: temperature inside the unpressurized compartment of the aircraft
-T_s: temperature of the surface of the compartment
-T_f: final temperature reached by T_a and T_s when the plane reaches a constant altitude
-β_a: conduction time for the air inside the aircraft
-β_s: conduction time for the aircraft's surface

4.2. Flight at a constant altitude

During flight there is heat transfer from the pressurized cabin, the unpressurised spaces that surround it and the environment outside the plane. These are modelled by a standard heat transfer equation using an explicit Euler scheme:

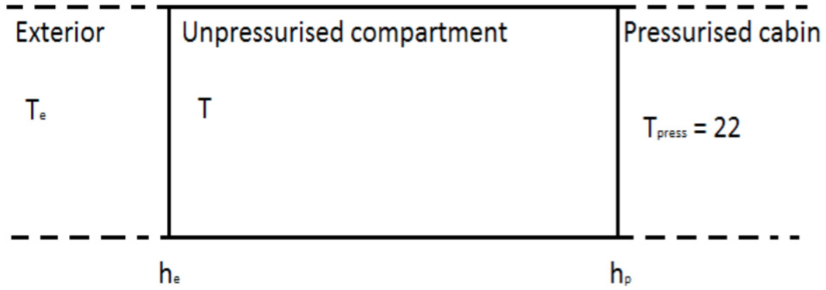

Fig. 3. Diagram of compartment model in C130.

During this stage, the only phenomenon that occurs is conduction from the exterior and from the pressurised cabin

$$\frac{dT_a}{dt} = -h_e(T_a - T_e) - h_p(T_a - T_p) \tag{4}$$

with:
-T_e: Temperature outside
-T_p: Temperature from pressurised cabin
-h_e and h_p: heat transfer coefficient

4.3. Descent stage

This stage is quite similar to the ascent one. The first three equations are the same as for the ascent stage equations 1, 2 and 3, so they're solved the same way. Here are the additional equations ruling that stage that accounts for changes in the volume occupied by air caused by temperature changes as the plan descends:

$$dV_i = \frac{\left(d(T_1 / T_{ai})\right)^{\frac{1}{\gamma-1}}}{dT_{ai}} dT_{ai} \tag{5}$$

$$dT_a = V_i dT_{ai} + (T_{ai} - T_e) dV_i \tag{6}$$

Then is introduced the fractional volume change due to heating or cooling of air inside the aircraft *Vi*

$$V_i = \left(\frac{T_{a0}}{T_{a_{i1}}}\right)^{1/\gamma - 1} \tag{7}$$

4.4. Plane on the ground

This stage is ruled by the same equation as the stage in flight.

5. Results

The major constants in all the equations are the factors β_a (ascent) and β_a (descent) which regulate how the surface interactions with the bulk volume and the buffering effect of the surface on temperature. These parameters are derived empirically by varying β_a from 0 to 1 with a step of 0.01, for both the ascent and the descent will be tried in order to find the two values of β_a (ascent) and β_a (descent) that fit the best the data. Figure 4 is an example of the best curve obtained compared to the one given by the data while figure 5 shows the effect of varying β_a on the temperature in flight. It is clear that the value of β_a is crucial in determining the temperature variation.

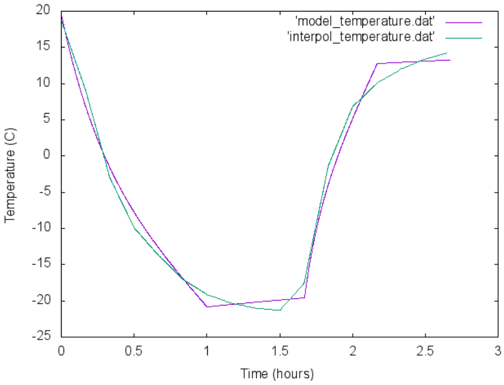

Figure 4. Best Fit of model to temperature variation in flight

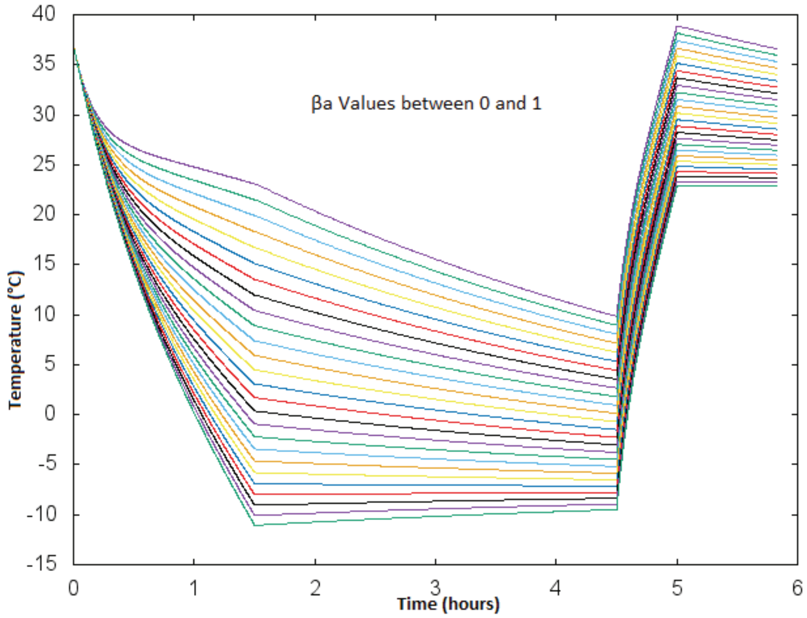

Figure 5. Effect of varying β_a on temperature during flight

To develop a predictive model it is desirable to define β_a for different spaces and if necessary for different flight sequences and flight paths. In Figure 6 the variation of β_a for a flights in the data outlined in section 3 is given as a function of the difference between ground and sky temperature (the surface in the space will be at the ground temperature prior to take off). The graph demonstrates that the parameter does appear to be correlated with the difference of temperature between the ground and the sky.

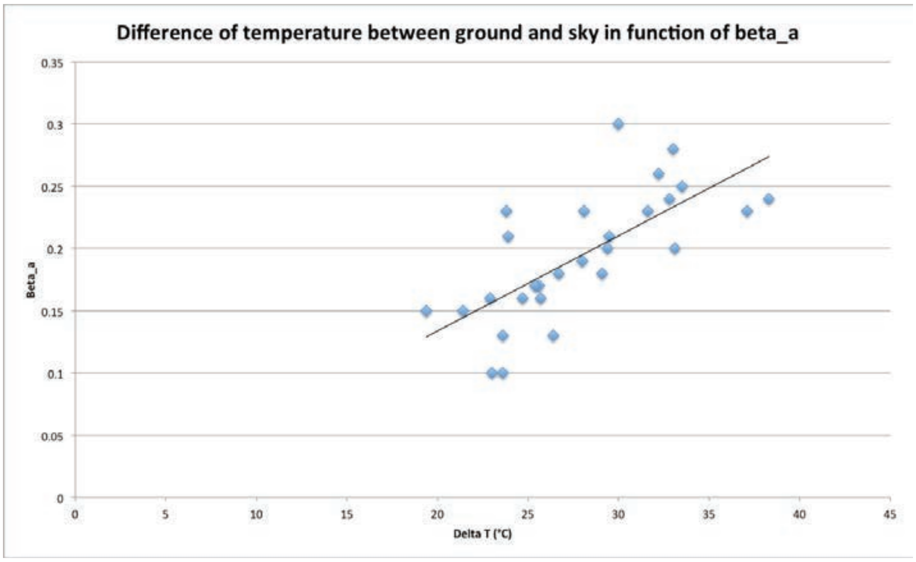

Figure 6. Relationship between β_a and difference in temperature between ground and sky.

This data indicates that a linear relation may exist between β_a and Delta T. If only the ascent stage is considered (not shown for space reasons) then this linear relationship is stronger. The data thus indicates that this “damping factor” may be linked to the temperature difference of the metal surface and the exterior temperature. However the model does require refinement to consider what “sky temperature” is best used or if this should be varied as the plane rises (use of temperatures at a variety of altitudes) and if other factors may affect the dependence. If an equation for β_a can be derived for location conditions then the temperature variation can be predicted independent of direct measurement.

Water content model

Given a knowledge of temperature with time the variation of humidity in the compartment can be calculated using the following equations.

$$MR = \frac{m_w}{m_a} \tag{8}$$

$$w = 0.622\frac{e}{p} \tag{9}$$

$$e_{sat}(T) = e_{sat}(0).10^{\frac{aT}{b+T}} \tag{10}$$

with:

MR the mixing ratio that will characterize the air exchanges between the compartment and the outside

m_w and m_a the mass of water vapour and dry air while w = 1000 MR and e the partial pressure of water vapour and p the atmospheric pressure with $e_{sat}(0)$ = 6.11 hPa and a=7.5 K^{-1}, b=237.3 K.

It's possible to introduce the relative humidity.

$$RH = \frac{e}{e_{sat}(T)} \tag{11}$$

And finally the mixing ratio is obtained with the following formula:

$$w = r \times RH \times w_{sat} \tag{12}$$

The partial pressure of vapour is known at several altitudes, so it's possible to interpolate this data in order to get the partial pressure of vapour at any altitude, and then to get the MR at any altitude. Mixing ratio is a preferred parameter in understanding moisture variations as it is independent of variations in temperature and pressure. If MR and temperature are known then RH, condensation and salt wetting can be readily calculated and from wetness thus calculated corrosion events determined.

In figure 11 the mixing ratio as estimated is compared to the data measured on a C-130 tail

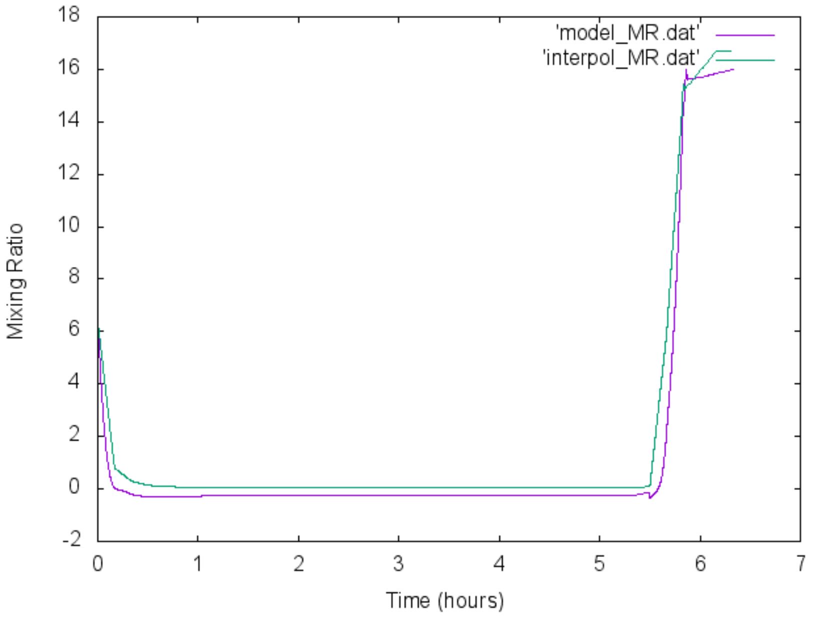

Figure 7. Modelling and measured variation of mixing ratio in C130 tail during a flight

Conclusion

The paper has briefly outlined when corrosion events occur in an aircraft and then set out a mathematical model to estimate the conditions in the various spaces in an aircraft that can lead to these corrosion events. The formulation of temperature variation and of moisture variation appears accurate for measured spaces in a C130 aircraft. The mathematical formulation for temperature and thus for moisture is highly dependent on the interaction of temperature of the surfaces of spaces with the air in the spaces and in particular on the role of the surfaces in "damping" the variations in the air. This parameter β_a was derived from data analysis in this paper, but to have a predictive model, the parameter must be estimated from the nature of the airspace and the local on ground and in sky climate. An initial analysis indicates that this may be possible as β_a appears to show a relationship with the difference in the on ground and the in sky temperature.

A final aim of this work is to write a piece of software capable of predicting the effect of the theatre of operations on aircraft corrosion. The user would input a list of typical representative arrival and departure airports by three letter IATA airport code, together with number of flights and, if desired, month of year (to allow for seasonal fluctuations) and time of day. The program would use climate summary data from selected meteorological stations, including mean and standard deviation of temperature as a function of time of day and month of year, and including cumulative probability distribution of relative humidity as a function of time of day. Typical flight trajectories can be derived and used to generate microclimate predictions within individual aircraft cavities.

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