1 Significance of the Technology

The Luna Sensor Suite for Aircraft Corrosion Monitoring (LS2A) is being used for evaluating the effectiveness of corrosion control practices and tracking corrosion of individual aircraft.[1] The system has been valuable in identifying the causes of airframe corrosion and is an enabling technology for condition based maintenance (CBM) for corrosion. The LS2A system continuously records environmental conditions and atmospheric corrosivity to estimate corrosive damage within an aircraft. Without individual aircraft corrosion severity measurements, airframes may either be maintained more frequently than necessary or corrosive conditions may not be detected before significant corrosion damage occurs. In either case, maintenance costs will be lower and aircraft availability will be higher when using CBM and LS2A monitoring. The LS2A system meets the need for improved maintenance practices using individual aircraft tracking to address the escalating costs of corrosion.

The LS2A system is a corrosion monitoring platform that measures both environmental and corrosion related parameters to continuously quantify the severity of the environment within an airframe. By measuring specific parameters including relative humidity, surface temperature, air temperature, contaminants, and aluminum corrosion rate, the LS2A is capable of tracking the severity of conditions that cause corrosion. While the system is designed specifically for aerospace applications where corrosion increases maintenance costs and labor, the LS2A platform can be used to monitor and survey corrosion severity for industrial facilities, ground equipment, storage, and distributed assets such as power transmission or pipelines and ground vehicles. The LS2A helps owners and operators to preserve high value assets that must function in harsh environments.

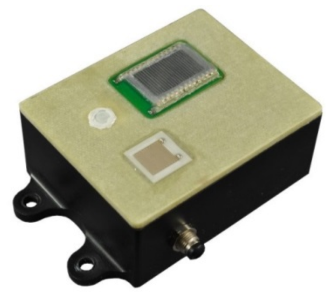


Figure 1. Luna's LS2A Corrosion Monitoring Sensor Node.

2 Case Studies

The LS2A technology has been used to meet a number of military aircraft needs. Three such use cases include 1) structural monitoring for more efficient H-53K maintenance and sustainment, 2) evaluation of the impact of operational tempo and corrosion control strategies on a B-52 deployed in the South Pacific, and 3) assessing the efficacy of aircraft covers on Navy F-18s and dehumidification of Air Force HH-60s.

2.1 CH-53K Use Case

NAVAIR and Sikorsky are developing integrated health monitoring systems for the new CH-53K King Stallion helicopter. The CH-53K will be the largest and heaviest helicopter in the US military. The US Navy is implementing structural health monitoring for this aircraft to enable condition based maintenance. Datasets are collected from a number of on aircraft monitoring systems including the Luna LS2A and this information is consolidated in a fleet management system. By obtaining corrosion and structural health information using aircraft monitoring integrated with network based data management, the Navy can more effectively allocate limited maintenance resources to achieve availability and service life objectives on

Figure 2. The Navy's CH-53K heavy lift rotorcraft.

[1] F. Friedersdorf, C. Andrews, J. Demo, and M. Putic, "Sensing Systems and Methods for Determining and Classifying Corrosivity," US Patent 9,518,915, 2016.

this new platform. By moving from schedule based corrosion management to condition based processes, maintenance man-hours (MMH) for inspection and corrosion prevention can be applied based on individual aircraft need. Through corrosion monitoring and individual aircraft tracking, the Navy can make informed decisions to prioritize or defer non-destructive inspections and maintenance to achieve reduced costs and increased aircraft availability.

Similarly, corrosion monitoring with the LS2A system has been shown to enable reduced maintenance costs and improved aircraft availability. The Navy has performed a benefit analysis for the CH-53K. If a CH-53K has six sensors and enters depot every 6 years (both Navy estimates), that equates to one sensor per year, or ~$5,000 per year per aircraft in sensor costs. The cost of a MMH was assessed using the average hourly wage of an E-5, estimated in 2016 at $47.99.[2,3] According to Navy estimates, a fleet of 200 helicopters would save 250,000 MMH per year by using corrosion sensing. **That's 1,250 MMH per year per aircraft, meaning that the LS2A enables offsetting a single MMH for $4; a <u>12x return on investment</u>**.

2.2 B-52 Deployment

In February 2014, Boeing installed four LS2A sensor nodes on a B-52 aircraft. While the initial intent of the effort was to evaluate the efficacy of lightening hole patches, the value of monitoring corrosive conditions relative to operational tempo quickly became apparent. The sensor nodes were installed in four locations on the lower longeron within the aft wheel well, with two nodes each on the left and right-hand sides of the aircraft. Sealing patches were used to cover lightening holes on the lower right side longeron, while the left side longeron lightening holes were left exposed. The aircraft was deployed to the Pacific for a period of approximately 9 months to evaluate the effects of operations and the value of the lightening hole patches.

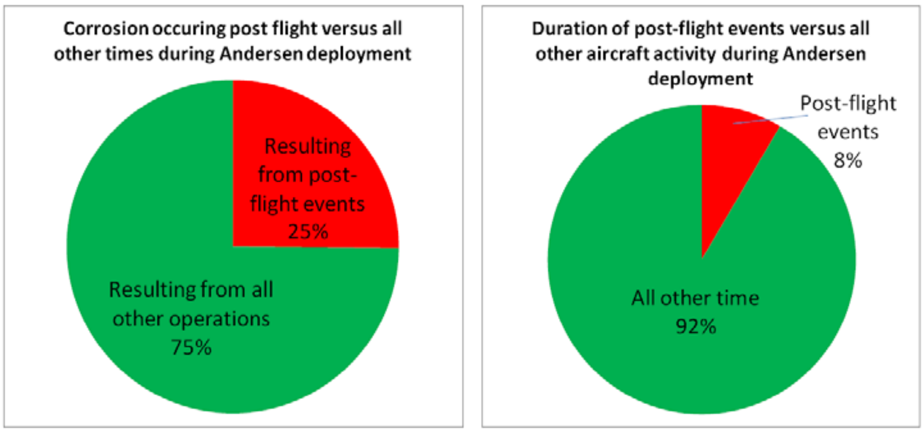


Figure 3. Percentage of total cumulative corrosion that occurs 12 hours following a landing and corrosion that occurs during all other times (left). Percentage of total time for post-flight events (right).

A key result obtained from the deployment testing indicated that corrosion was accelerated immediately after flight activities. Corrosion did not occur at low the temperatures and humidities present during flight. However, immediately following flight, the cold soaked structure on the ground in the humid tropical marine environment resulted in very high corrosion rates. In fact, it was observed that 25% of the total corrosion that occurred during deployment was associated with these post-flight conditions (within 12 hours after landing), even though the time of these post-flight events only

[2] "A model for analyzing aircraft maintenance man-hour costs and the impact of expert systems", Schanz, Keith E. Monterey, California. Naval Postgraduate School, 1995
[3] http://comptroller.defense.gov/Portals/45/documents/rates/fy2016/2016_k.pdf

accounted for 8% of the total deployment time (Figure 3). This study also avoided unnecessary costs by demonstrating that lightening hole patches had no corrosion protection benefit. **The LS2A systems were used to demonstrate that lightening hole patches were ineffective and that operational tempo is a significant factor for assessing corrosion severity. Only the LS2A system is capable of making these types of aircraft corrosion measurements.**

2.3 Aircraft Cover/Dehumidification Evaluations

To reduce corrosive contaminants and moisture within airframes during periods of aircraft inactivity, maintenance organizations have begun evaluating the use of aircraft covers and mobile dehumidification units (MDU). For example, the Air Force Corrosion Prevention and Control Office (AFCPCO) sponsored a short study on F-15C/D aircraft to evaluate mobile dehumidification unit performance using LS2A corrosivity and environmental sensor nodes. The relative humidity, air and surface temperature, aluminum corrosion rate, total aluminum mass loss, and contaminant accumulation were measured within F-15 airframes. The efficacy of the dehumidification units for specific operating modes and positions within the airframe were determined.

For these short duration tests, corrosive contaminant accumulation and corrosion were insignificant, and the primary parameters of interest for the MDU study were RH and air temperature. It was found that the dehumidification units were effective at reducing humidity locally, but this benefit did not extend very far within the structure (Figure 4). **Use of the LS2A sensor nodes allowed for quantitative determinations of the effectiveness and extent of dehumidification within the airframe.**

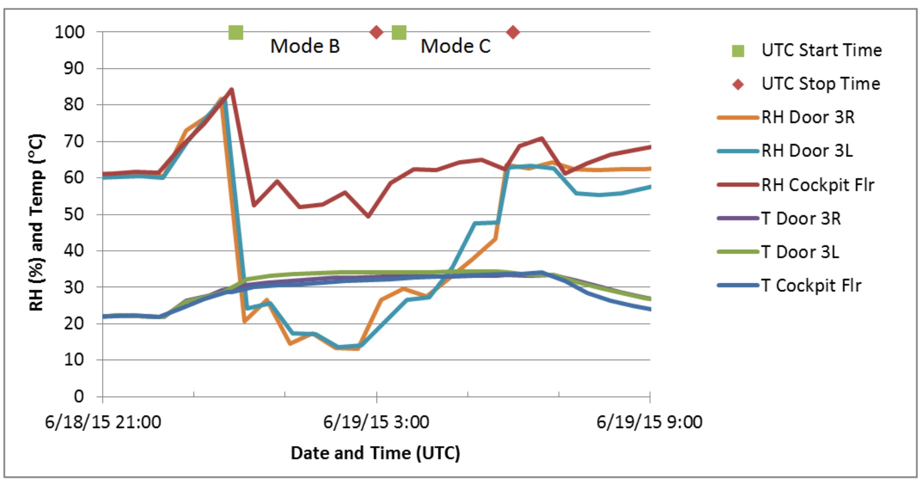
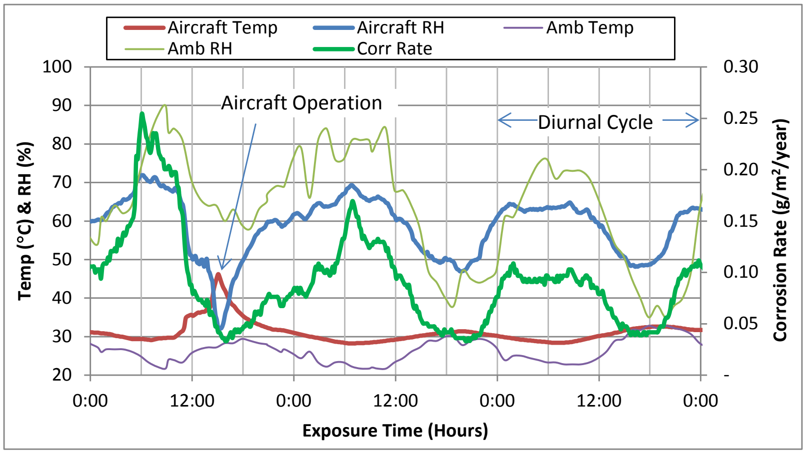


Figure 4. On-aircraft RH and air temperature during operation of two dehumidification modes.

3 Technology Description

The Luna Sensor Suite for Aircraft Corrosion Monitoring is a wired or wireless sensor node capable of autonomously monitoring the corrosion severity in difficult to access areas within an airframe. The patented and ANSI standardized technology includes sensor elements to monitor a set of parameters and provide a classification of corrosivity. In addition to providing a simple severity classification, the nodes maintain time-based sensor data with internal storage for future access and engineering analysis. Data from the sensor nodes can be accessed via RS-485 wired or IEEE 802.15.4 wireless interfaces.

LS2A sensor nodes can be distributed throughout an airframe at critical locations such as corrosion "hotspots" to evaluate the extent of corrosion activity and prioritize corrosion inspections and maintenance. Corrosivity classification models are included within the system so that maintainers can access useful information without the need for post processing or expert analysis. Maintenance engineers can evaluate the time-history of exposure for an individual aircraft to establish operational dependencies, daily and seasonal exposure trends, and basing effects. This can be done for a single hotspot within an aircraft or comparisons can be made at the squadron or fleet wide level. The small size, light weight, and flexible configuration of the system provide an ideal platform for retrofit to existing assets or integration with new aircraft. Billions of dollars each year are spent on maintenance due to corrosion; the LS2A system is an important part of any corrosion prevention and control program.



Key features of the LS2A corrosion monitoring systems are:

- **Continuous monitoring of environmental conditions and corrosion rates within an airframe**
- **Easily installed using adhesive bonding or mechanical fastening**
- **Modular system to support a variety of transducers**
  - **Environmental parameters**
  - **Coating performance**
  - **Galvanic corrosion**
- **Corrosion classification outputs with no need for post processing or expert interpretation**
- **Simple data records reported in engineering units**

Table 1. LS2A parameter descriptions.

Parameter	Description
Sensor Channels	Up to six channels of data
Sensors	Relative humidity
	Air temperature
	Surface temperature
	Wetness / conductivity
	Corrosion rate
Interface	RS-485
	IEEE 802.15.4
Sampling Rate	Factory setting is thirty minutes for long term environmental and corrosion monitoring. Every two minutes is suggested for accelerated laboratory tests. User selectable.
Power	3.7 VDC lithium ion battery
Dimensions	3.02” (4” with mounting flange) x 2.39” x 1.42”; 10.3 in^3 (7.7 cm (10.2 cm with mounting flange) x 6.1 cm x 3.6 cm; 169 cm^3)
Weight	150 g (5.29 oz) without battery, 172.5 g (6.08 oz) with battery

For more information and pricing visit http://devstore.lunainc.com/collections/luna-sensor-suite.