## ABSTRACT

The autonomous structural integrity monitoring system (ASIMS) is an aircraft flight data acquisition system that has been designed to fill the void in commercially available data recorders to monitor corrosive environments. Running off of battery power the system will collect flight data autonomously independent of any aircraft systems. This unit is designed to interface with other data acquisition cards and multiple sensor types, to be placed in remote hard to access areas of aircraft, spacecraft, launch vehicles, ships, and ground vehicles to monitor the health of structural components. The current sensors capable of integrating with the ASIMS include up to eight electrical sensors and sixteen fiber optic sensors ranging from moisture detection, relative humidity, temperature, pressure and static strain measurements.

The ASIMS is currently being tested on a 767-300ER vehicle under a cooperative agreement with Delta Air Lines. The current flight-testing is providing valuable information for system improvements.

## INTRODUCTION

Typically, the majority of the cost for maintaining aging aircraft structure can be associated with corrosion prevention and control. For Boeing's commercial transport aircraft, approximately 70% of the total person-hours spent inspecting the airframe during a scheduled maintenance is corrosion related, with only 30% for fatigue cracks and other damage. Additionally, the major portion of the cost of inspecting aircraft for corrosion damage is associated with obtaining access to hidden parts of the airframe. In addition, there is the added cost associated with incidental damage that is done to the structure while gaining access to the hidden areas. There is a clear need to develop in-situ sensors and the diagnostics and prognostics algorithms to monitor corrosion environments to provide early warning of the onset of corrosion in hidden parts of aircraft.

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The autonomous structural integrity monitoring system (ASIMS) is an aircraft flight data acquisition system that has been designed to fill the void in commercially available data recorders to monitor corrosive environments. To perform these functions a rugged, small, and lightweight data acquisition unit has been constructed, and is currently being further upgraded. Running off of battery power the system will collect flight data autonomously independent of any aircraft systems. This unit is designed to interface with other data acquisition cards and multiple sensor types, to be placed in remote hard to access areas of aircraft, spacecraft, launch vehicles, ships, and ground vehicles to monitor the health of structural components. The current sensors capable of integrating with the ASIMS include up to eight electrical sensors and sixteen fiber optic sensors ranging from moisture detection, relative humidity, temperature, pressure and static strain measurements.

The ASIMS will be tested on several platforms and current algorithm development is being conducted concurrently for military and commercial aircraft. As structure types between some military and commercial applications are similar, corrosion information may be shared and algorithms developed jointly. As a whole, information learned from either military or commercial application will allow better algorithm development for corrosion predictions.

Another advantage of the ASIMS is the function of the system is twofold. First, the system may be used as a quick look inspection method for hard to reach areas. Sealed avionics bays will not need to be opened up to determine if moisture is present. Since seals are not broken, moisture is less likely to enter the area. Areas that are hidden will not have to be disassembled, thus saving substantial labor. The second function of the ASIMS is that of a virtual flight laboratory. The ASIMS can continually take data, which provides essential information for a long-term health management system. Sensor information may be input into an Open System Architecture for Condition Based Maintenance (OSA-CBM), a dual use science and technology program that has developed an industry-military common, open architecture to implement CBM strategies, conformed to the proposed ISO/DIS 13374 standard. The health management system would allow real time operations and maintenance decisions to be made. Thus, maintenance and repairs would be performed on a need basis, rather than a timed basis.

## SYSTEM

The ASIMS system includes the main acquisition unit, several sensor types and a power supply. The ASIMS operates autonomously from its own battery supply. Operating from a separate power source relieves the necessities of connecting to the airframe’s power bus. The ASIMS’s operation is programmable by the user to determine the sampling rate and monitoring period of the ASIMS implementation. This allows the user to determine which and how many sensors are to be monitored and how often. Another advantage is that battery life may be conserved by monitoring static environmental measurements on a long-term basis (for example, measuring a parameter once per hour rather than continuously). The ASIMS’ design to operate autonomously also alleviates any flight crew interface. This drastically lowers the barriers to accessing and implementing experiments on aircraft.

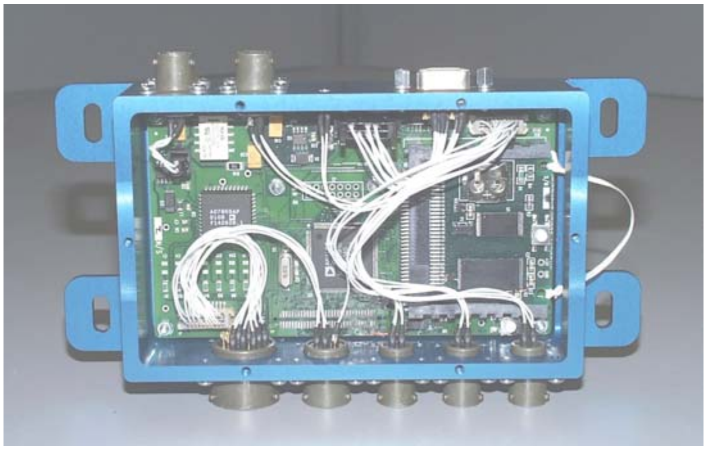


Figure 1. ASIMS data acquisition board.

## Data Acquisition Unit

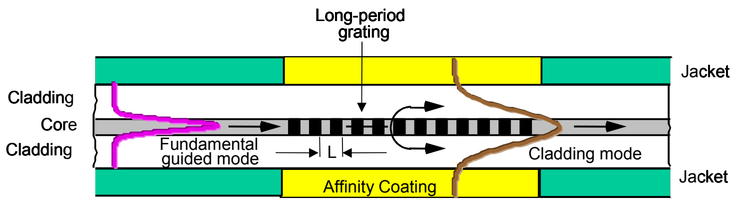
The main acquisition board shown in figure 1 performs the functions of system controller (autonomous operation, peripheral power management, etc), data acquisition, data conversion (ADC and data manipulation or preprocessing), data storage, time keeping, and provides a user interface to the system.

The design of the main acquisition unit was driven by the need to operate in a flight environment on as small a battery as possible. The microprocessor is not only the controller for the system but also the device used to perform the math functions necessary to process sensor data. Data is stored in flash non-volatile memory. This gives the user the flexibility to store data on an acquisition unit with the freedom of not needing a backup battery. The user interface is implemented over a serial port; this allows the use of any PC with a serial port (virtually all) to be used to communicate with the acquisition unit. This also provides the opportunity for a portable or laptop PC to be used to connect the user to the acquisition unit for data download or data acquisition configuration changes [1].

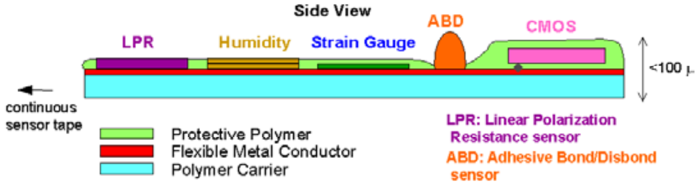
## Sensors

The ASIMS has been designed to interface with numerous sensor types (shown in figure 2) separated into two groups; analog output and digital output devices. Analog output sensors are monitored by the ASIMS through an Analog to Digital Converter (ADC). Presently, inexpensive yet highly reliable, small and accurate analog electrical sensors are available for temperature, pressure and relative humidity, among others. The ASIMS is capable of monitoring up to eight analog channels at sample rates up to 10 kHz. Any sensor capable of outputting a voltage (or being conditioned to) can be monitored by the ASIMS. For example, a fiber optic system developed by Blue Road Research is capable of transferring wavelength data for Bragg grating sensors into voltage output. Current fiber optic sensor types include relative humidity, moisture, temperature and pressure fiber optic sensors. This sensor system has been incorporated into the ASIMS system.

Luna Innovations Fiber Optics



Analatom Solid State Sensor



Blue Road Research Fiber Optics

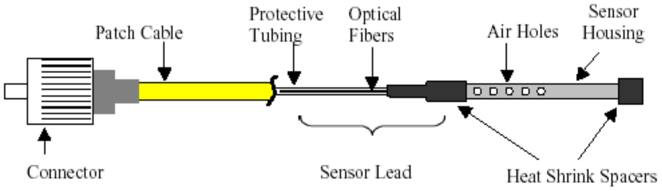


Figure 2. Various integrated sensor types.

The ASIMS is also capable of interfacing with up to four serial (RS-232) devices. Any device with a serial port can be communicated with using the ASIMS. Examples of this kind of devices are sensors recently developed by Analatom Incorporated and Luna Innovations. Each of these devices performs measurements when requested by the ASIMS and returns a digital reply. The digital reply can be either stored as a raw value or further manipulated by the on board DSP. Analatom Incorporated has a solid-state sensor system that measures corrosion. Luna Innovations sensor types include Long Period Grating (LPG) sensors and Extrinsic Fabry_Perot Interferometric (EFPI) fiber optic sensors.

Each of these sensor systems are currently kept separate while evaluation of the various sensors is under way. This open architecture allows flexibility and growth in the system.

## Power Supply

The ASIMS can operate on a DC power supply as low as 8 VDC and as high as 40 VDC. Efficient operation, or low power draw, was a primary consideration during the design of the ASIMS. As a result, power consumption during data gathering operations is less then 1.5 watts (current prototypes run at 30% less power).

The standby current necessary for ASIMS operate is less then 300 mA. Duracell D2/3A cells were chosen for the battery supply, primarily due to their success in a previous flight test program. The batteries are not rechargeable but are readily available and inexpensive. Twenty cells are chosen to power the ASIMS through a typical experiment

## INSTALLATION

On 26 August 2002 the ASIMS was installed onto a 767-300ER. This airplane was 12 years olds and in the hanger for its 2nd Heavy Maintenance Visit (second "D" check). At "D" checks floor panels, blankets, and duct work are all removed making installation of the various sensors much easier and not effecting the plane schedule.

The following locations were chosen for initial sensor and system placement by Delta Air Lines personnel (see Table I).

TABLE I. SENSOR AND SYSTEM PLACEMENT

| STA | STA | STR | Position | Box/Sensor Description |
|---|---|---|---|---|
| 434 | 456 | N/A | Cargo Sidewall | **ASIMS Data Acquisition Box** |
| 412 | 434 | 37R | Skin, Above Stringer | Pressure & Temperature Sensor Pair |
| 412 | 434 | 36L | Skin, Above Stringer | RH & Temperature Sensor Pair |
| 390 | 412 | 37R | Skin, Above Stringer | RH & Temperature Sensor Pair |
| 434 | 456 | N/A | Cargo Sidewall | **Battery Box** |
| 434 | 456 | N/A | Cargo Sidewall | **Luna F/O Demodulation Box** |
| 434 | 456 | 35L | Skin, Above Stringer | F/O Temperature Sensor |
| 390 | 412 | 35R | On Top of Stringer | F/O Temperature Sensor |
| 412 | 434 | 37L | Skin, Above Stringer | F/O Pressure Sensor |
| 434 | 456 | 37R | Skin, Above Stringer | F/O RH Sensor |
| 390 | 412 | 35R | On Top of Stringer | F/O RH Sensor |
| 434 | 456 | 35L | Inside Stringer | F/O Pressure Sensor |
| 434 | 456 | N/A | Cargo Sidewall | **Analatom Demodulation Box** |
| 412 | 434 | 37R | Skin, Above Stringer | Corrosion Sensor |

Notation from the above chart is as follows. The station (STA) shown for the installation locations in the two left columns form the bay in which the sensors were installed. In the third column, "Above "or on top" indicates the outboard direction from the stringer. The sensors were installed near the stringer. As noted, all sensors are located in the forward cargo bay compartment in the cargo sub floor. The sensors are placed at or near the STA 434 stinger splices that connect Section 41 to Section 43. This area was selected due to the number of corrosion repairs as well as its close proximity to a mounting location to a sidewall compartment that can be easily accessed during layover visits. Items shown in **bold** are system components.

While locations were initially called out for several different sensors, installation proved much more difficult. The initial packaging of the fiber optic sensors was not rugged enough to handle maintenance floor activities. Of the initial 9 sensors installed onto the airplane, only 2 sensors survived the replacement of ductwork and paneling. As a result of this, the fiber optic systems were not installed onto the airplane until better packaging was used on the fiber optic sensors. (New packaging is now developed which is much more rugged.) Thus, the installed system included:

- Data acquisition system
- Battery

- Solid State Demodulation Box (Analatom, Inc)
- 6 analog sensors
- 1 solid state corrosion sensor

Figures 3-5 indicate where the system and sensors are located in the forward cargo bay area.

Figure 3. Boxes installed inside cargo wall.

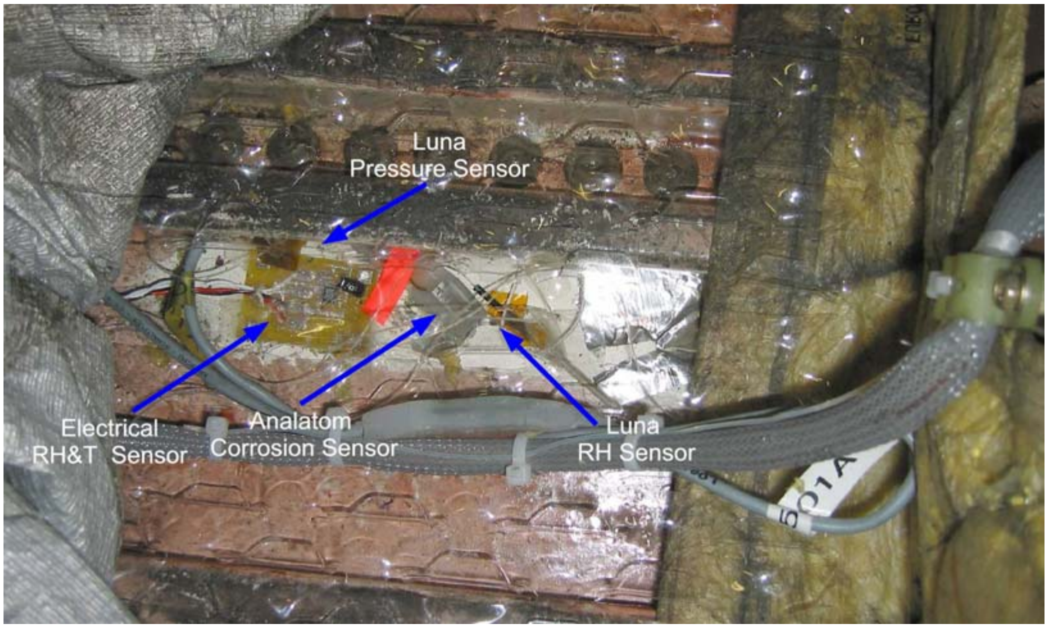


Figure 4. Final sensor installation between station 412 and 434.

Figure 5. Bay with insulation and ductwork after sensor installation (taped orange X is where several sensors are located).

## RESULTS

Data was taken at a rate of once every 10 minutes initially. With the installed system configuration the battery lasted much longer than the necessary 50 days. As a result, batteries are only changed every other data download. Data download could occur less often but data and system analysis would be delayed. Data download with the currently installed system is at 9600-baud rate. To not disrupt the service of the airplane access to the airplane was limited to 60 minutes. During this time panels would be removed, data was downloaded, batteries were changed and panels replaced. With the 9600-baud rate the number of data points downloaded within the specified time was limited. Current improvements of the system have achieved 115K-baud rates, as well as removable memory modules.

Data is currently downloaded directly to an excel spreadsheet with engineering units. A typical raw set of data would appear as in Table II.

TABLE II. TYPICAL RAW DATA SET

| Corrosion | Temp | RH | Temp | RH | Temp | Pressure | Time |
|---|---|---|---|---|---|---|---|
| 0 | 19.058 | 92.962 | 18.214 | 82.434 | 19.110 | 14.25 | 1/9/03 16:51 |
| 0 | 19.191 | 91.267 | 18.747 | 84.715 | 19.376 | 14.28 | 1/9/03 17:01 |
| 4329 | 19.369 | 93.483 | 20.347 | 84.455 | 19.465 | 14.31 | 1/9/03 17:11 |
| 0 | 19.191 | 88.723 | 19.103 | 80.673 | 18.843 | 14.28 | 1/9/03 17:21 |
| 1081 | 19.325 | 92.918 | 18.703 | 79.402 | 19.021 | 14.28 | 1/9/03 17:31 |
| 2951 | 19.236 | 91.353 | 17.903 | 76.175 | 19.510 | 14.28 | 1/9/03 17:41 |
| 0 | 19.147 | 84.162 | 18.258 | 77.610 | 19.465 | 14.28 | 1/9/03 17:51 |

Corrosion is a resistance measurement of the corrosivity of the environment. From this one can begin to determine the probability of corrosive activity occurring in the sensor location.

Temp is the temperature in degrees Celsius while Pressure is the pressure in PSIA. Using the Temp and Pressure parameters one can establish if the airplane was on the ground or flying during sensor interrogation. The temperature sensors were also critical in monitoring the actual temperature for both the electronic boxes and the sensors. The fiber optic electronic boxes currently have a limitation of warmer than 0 degrees Celsius due to the laser. At colder temperatures these units do not provide enough power to obtain a stable reading from the fiber optics. This problem is currently being worked. The temperatures in the cargo bay area do drop below freezing at times.

The sensor locations on the cargo bay belly skin also revealed that sensors placed directly on the skin would see temperatures in extreme of –40 degrees Celsius. As a result, selected sensors must survive much more extreme environments than the system boxes themselves.

RH is the relative humidity of the area. Relative humidity and moisture are known accelerators of corrosive activity. The relative humidity sensors chosen for this initial application were not packaged properly for their locations. Analog sensors have the distinct detrimental characteristic in that once they are submersed in water they either lose their calibration or else the stop functioning all together. The RH sensors in this application appear to have gotten wet at some stage and as a result, the calibration is not correct, although they are changing as expected with temperature changes and landings.

## CONCLUSIONS

The installation of a prototype ASIMS onto a commercial vehicle was successful. Several lessons were learned and recommendations for future work were obtained. They include:

- Package fiber optics sensors for more extreme environments. This includes both fiber optics to handle people stepping on the fibers and kinking the fibers.
- Package analog sensors for aqueous environments. Sensors inevitably are coated with corrosion inhibiting compounds, water and or hydraulic fluid.
- Monitor moisture rather than relative humidity in most locations. Plugged drain holes and pooled water are more of a corrosive instigator than relative humidity.
- Develop smaller systems. Current work is involved with making the system much lighter with a smaller footprint.
- Require less airplane access time. New prototypes developed use not only higher data transfer rates but also the technology for removable memory cards.

## REFERENCES

1. A. Trego, and D. Smith, 2002, "Battery Operated Health Monitoring System," Fifth Joint DoD/FAA/NASA Conference on Aging Aircraft Proceedings, San Francisco, Ca. September 2002.