National Institute of Standards Technology Road-mapping Workshop

Current PHM Challenges and Vision

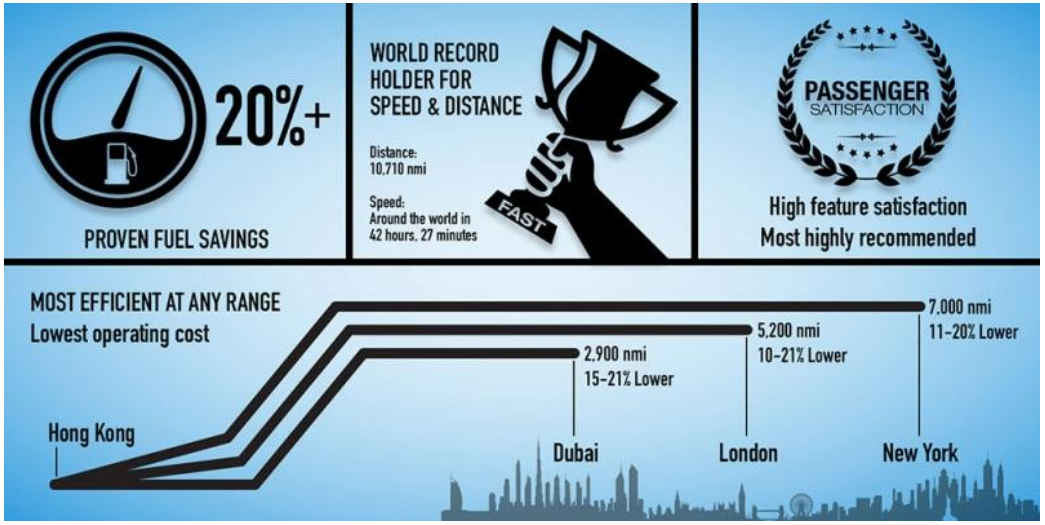
Al Salour Ph.D., Boeing Technical Fellow, 314-232-1743

November 19th, 2014

The Boeing Company

- **Boeing is the world's largest aerospace company and leading manufacturer of commercial jetliners and defense, space and security systems.**
- **A top U.S. exporter, the company supports airlines and U.S. and allied government customers in 150 countries.**
- **Boeing employs more than 169,000 people across the United States and in more than 65 countries.**
- **More than 12,000 Boeing-built commercial jetliners are in service worldwide, which is roughly 75 percent of the world fleet.**
- **86.6B Revenues in 2013**

Boeing Company Commercial Products – 787



Boeing Company Commercial Products: 777X & 737

The 777X is Boeing's newest family of twin-aisle airplanes. to respond to market needs and customer preferences.

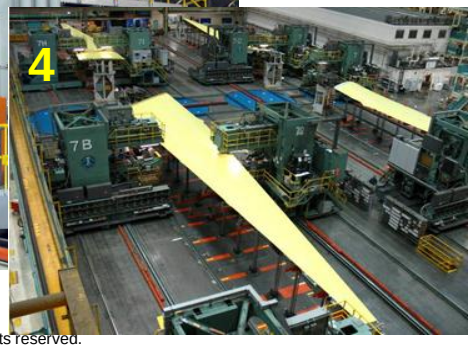
Boeing has delivered more than 7,500 737s.

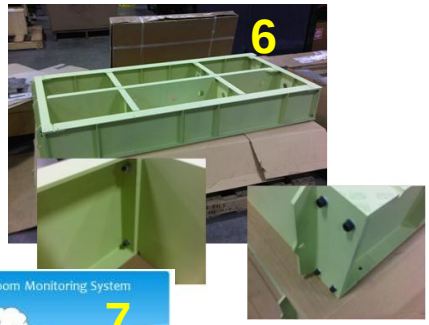
Boeing Company Military Product – F/A-18 G

The Growler's flight attributes enable it to perform escort jamming as well as the traditional standoff jamming mission. Growlers will be able to accompany F/A-18s during all phases of a attack missions.

Prognostics and Health Management in Aerospace

1. On-Board Parts/Components Health Management
2. Flight worthiness
   - Seats
   - Oxygen Generators
   - Life Jackets
3. Manufacturing process
4. Machinery
5. Facilities Infrastructure
6. Structure
7. Environmental Health Monitoring





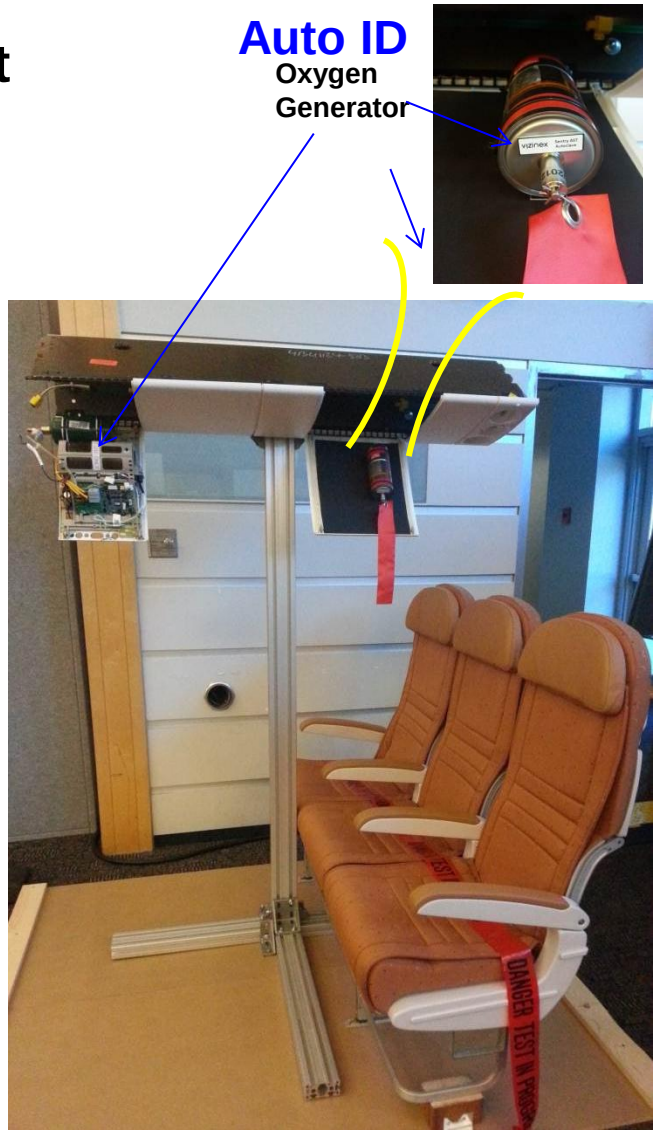
Clean Air

Military Aircraft Maintenance Procedures

- **Optimized Organizational Maintenance (OOMA) stations**
  - Database system
  - Service center aircraft maintenance log books
- **Manual and electronic methods for tracking removal, record keeping and traceability**
  - Assembly Service Records (ASR)
  - Scheduled Removal Component (SRC)

Aircraft Readiness Log (ARL)

- **Validate Equipment Availability for Aircraft Flight Readiness**



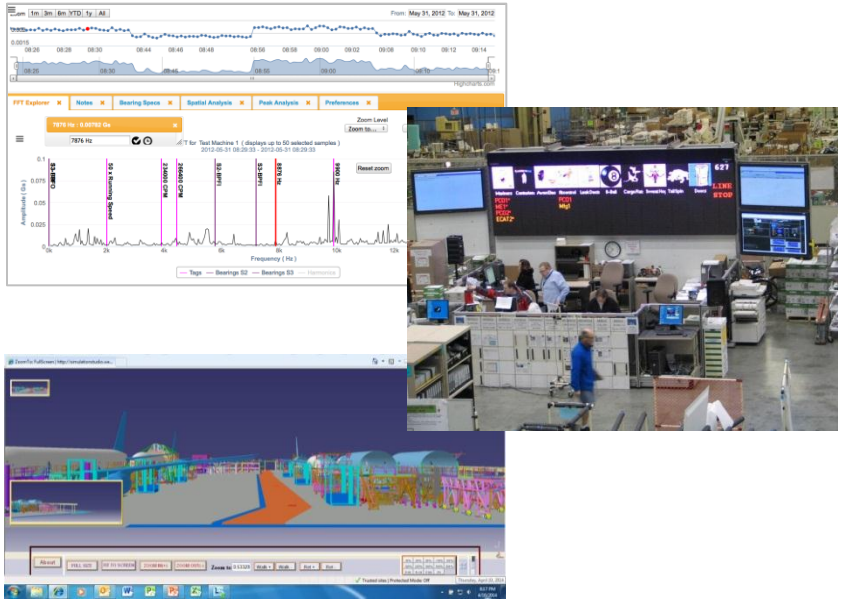
Birth Record data:
- Supplier Part Number
- Serial Number
- Date of Manufacture
- Supplier Cage Code

Manufacturing Process – Analytics & Visibility

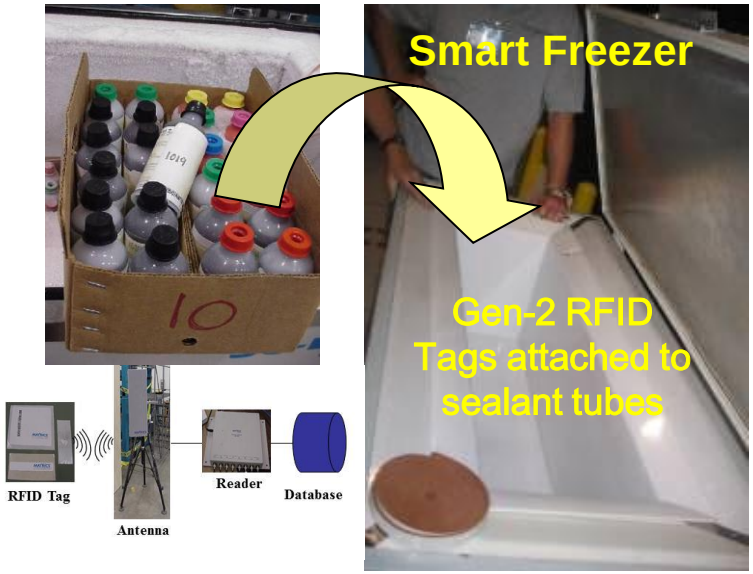
Real time actionable data for production mechanics

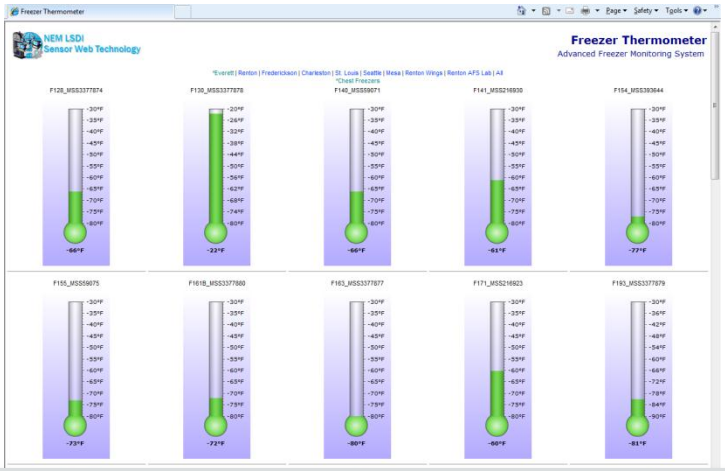
Development
- Sensor Fusion
- Data Acquisition
- Analysis Tools
- System Integration
- Forecasting & Predictions

User Application
- Data Visibility
- Actions & Decisions



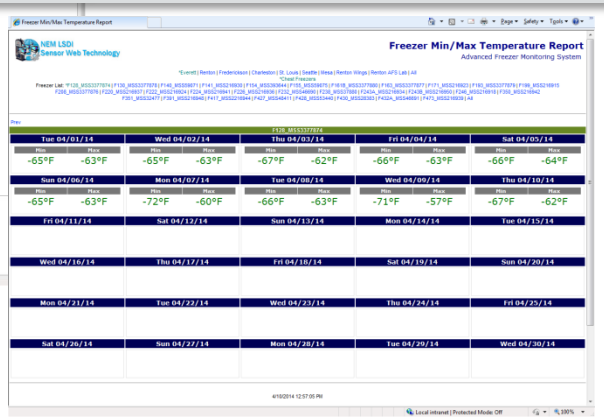
Sensor & Device Platforms – Process Control
Freezer Health Monitoring

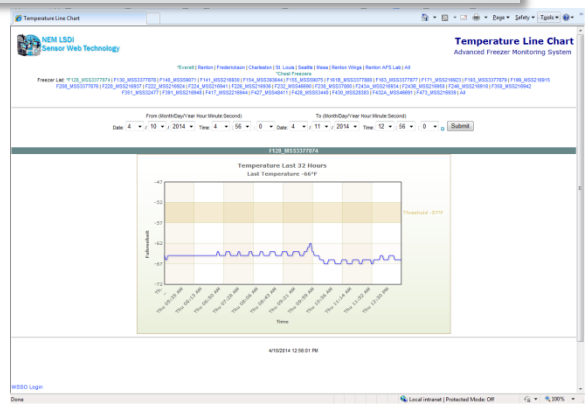




Freezer Thermometer in Real Time

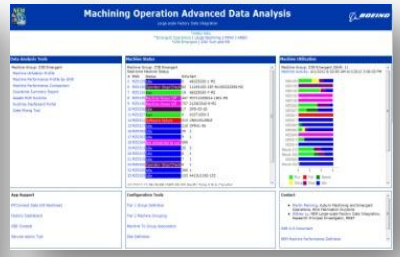
Temperature Recorder, Min/Max Data, Data History

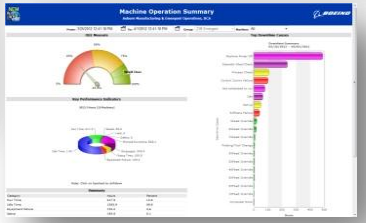




Manufacturing Process – Large Scale Data Integration

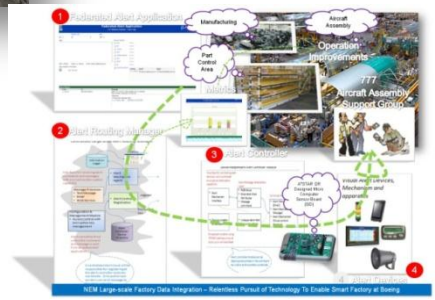
Fabrication Operations



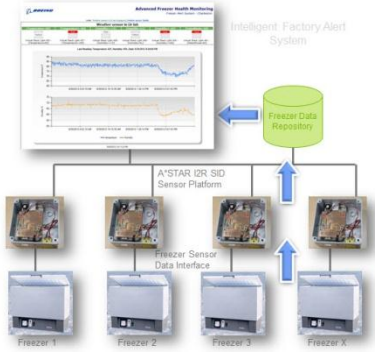


- Machine control
- Throughput information
- Downtime and reasons

Major Assembly, Join, and Final Assembly



- Aircraft Assembly Visibility
- Intelligent Factory Alert System
- Kits Delivery from Parts Control Areas
- Accountability



Condition Based Maintenance (CBM) Monitoring Techniques

Boeing utilizes off-the-shelf CBM systems as well as its own advanced data analytics for condition based machine health monitoring

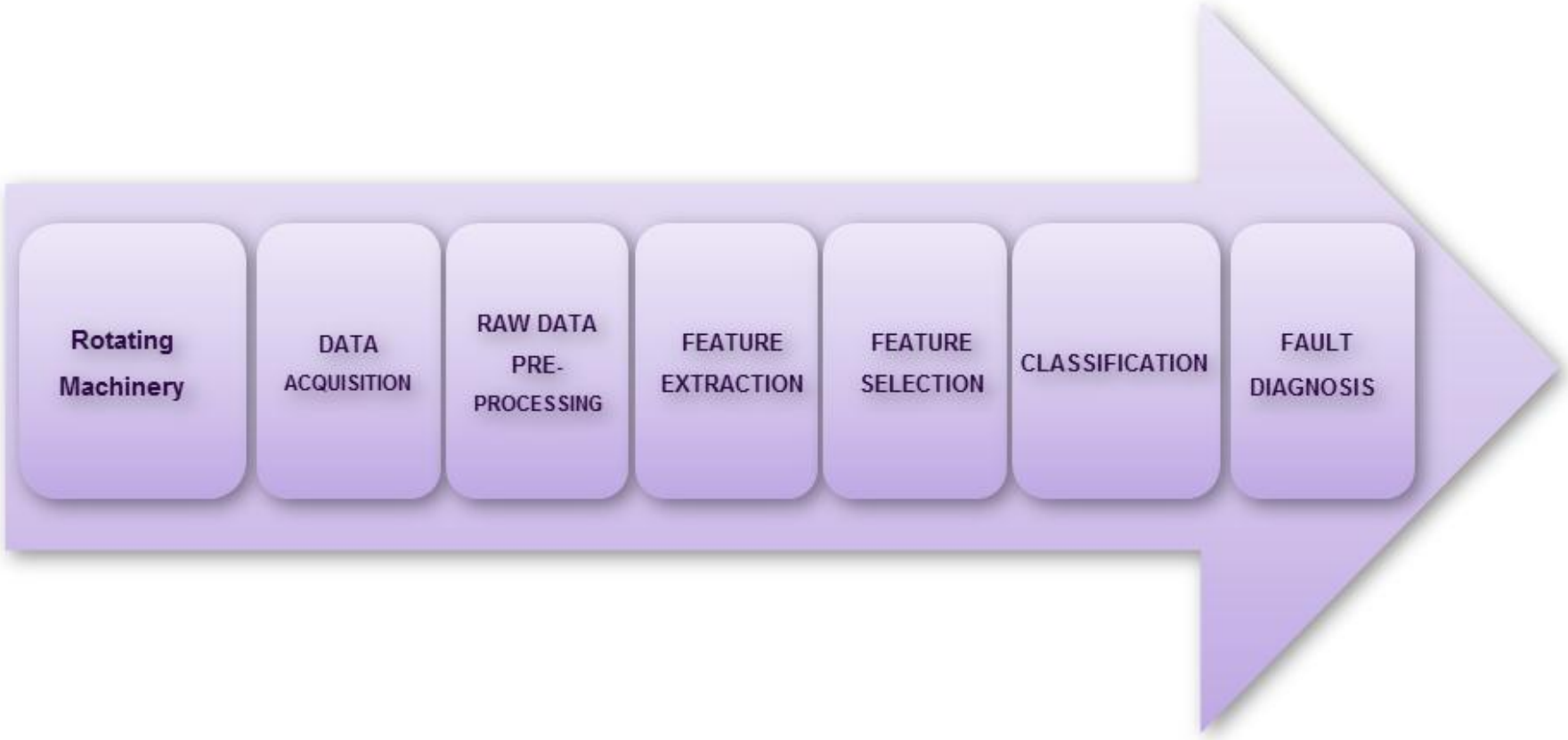
MT-Connect

CBM Analysis Tool

Sensor Platform

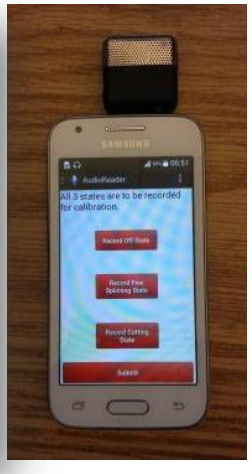
OPC based Machine Controllers

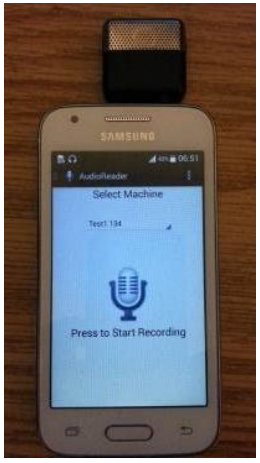
Health Monitoring Diagnosis Steps



Use of Mobility Devices in Health Monitoring

Monitors: Fault State



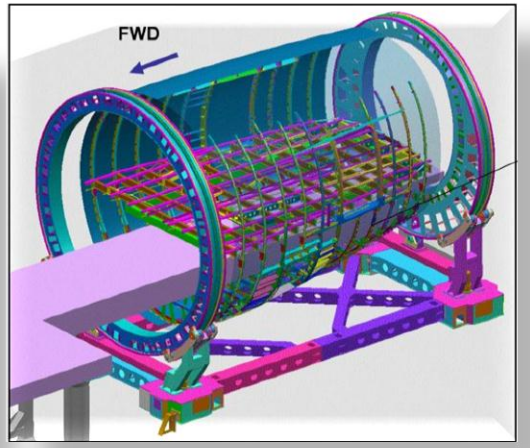


Acoustic Sensors

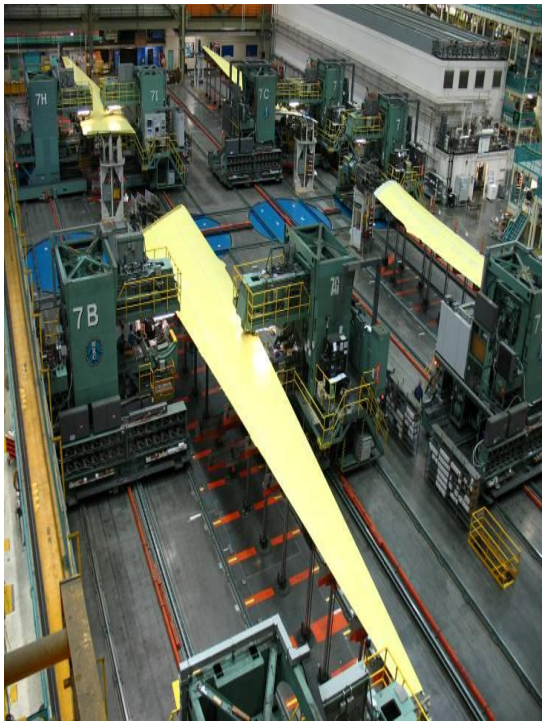
- Calibrate/Train
- Take Measurement
- Process Data
- Analyze Recording
- Initiate response

Wireless Devices & Networks for Data Acquisition

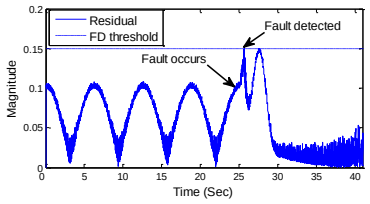
Wireless Gauges for Airplane Programs

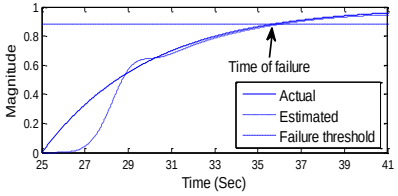


Sensor & Device Platforms – Machine Health Monitoring



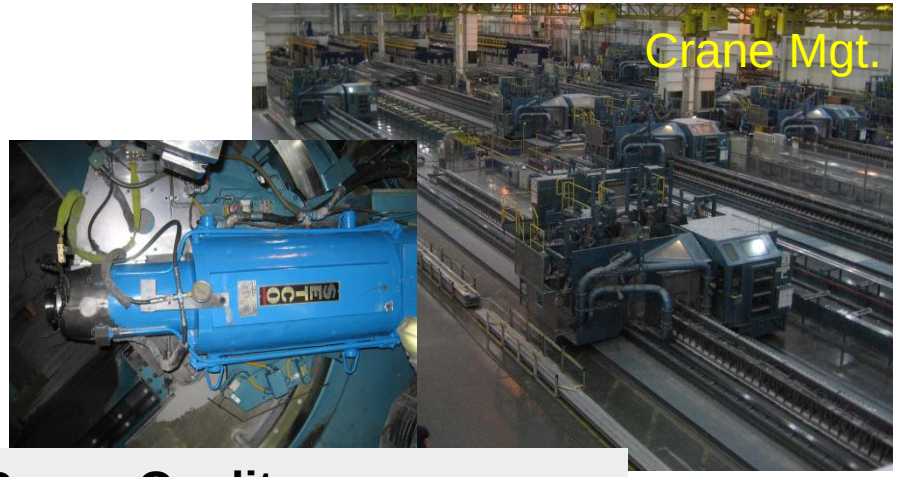
Machine Health & Performance "OEE" Monitoring in Real Time





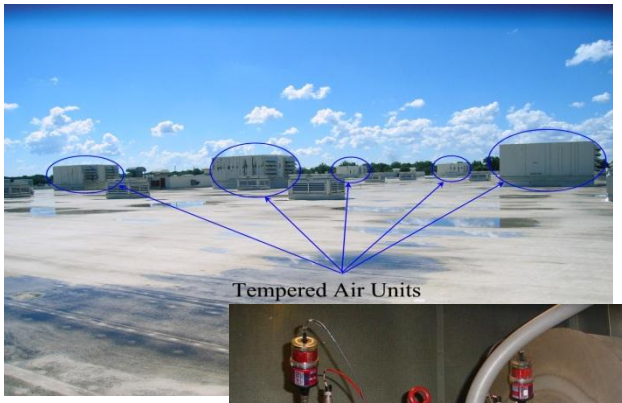
Facilities Infrastructure Health Monitoring

Large Factory Infrastructure



Power Quality, Temperature, Humidity Compressed Air

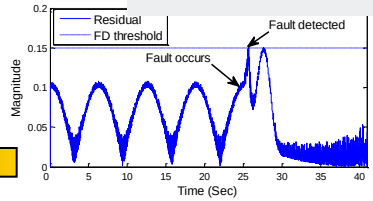
Tempered Air System

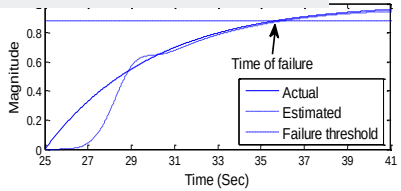


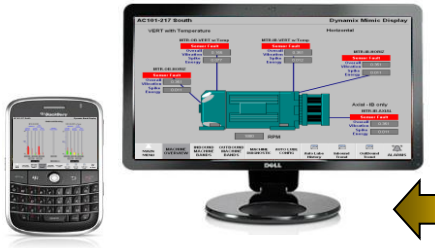
Instrumented Motor

PLC and data acquisition system

Fault detection and time to failure





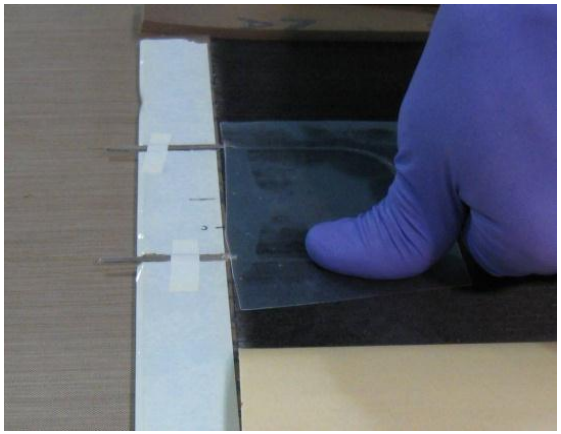


User interface

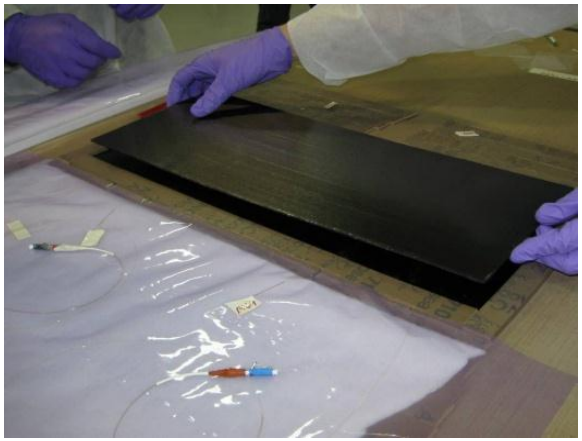
Structure Health Monitoring – Fiber Optic Sensing

A variety of strain sensors are available for measurement of structural strain. Fiber optic sensors have advantages of small profile, lightweight and high sensitivity.

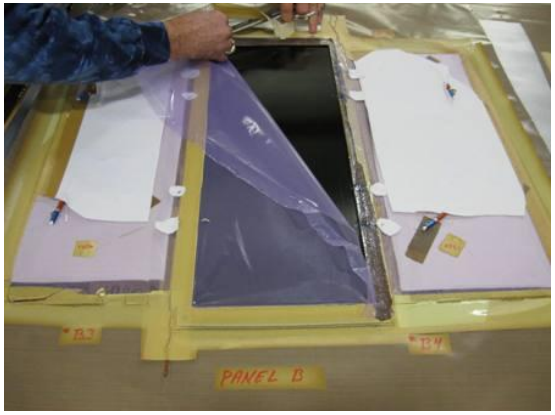
Fibers Threaded Through Sleeves



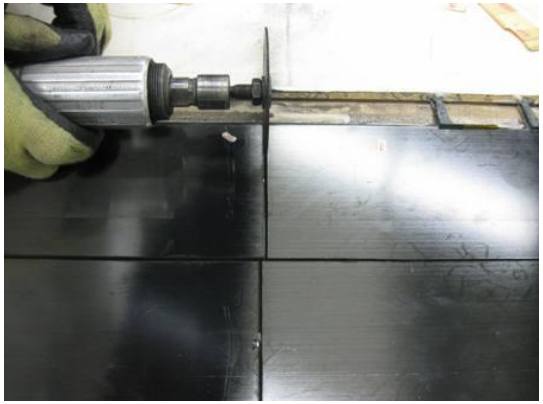
Mylar Film Holds Fibers in Place



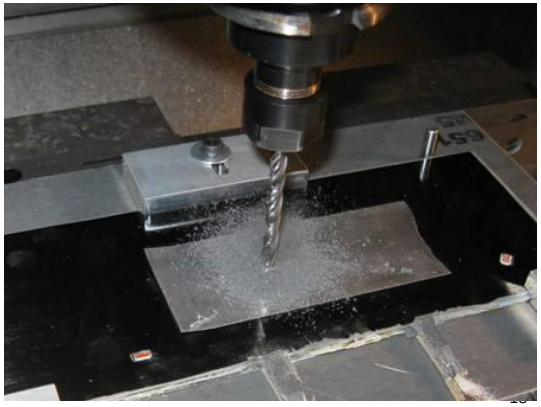
Panel Put in Place



Cured laminate being un-bagged

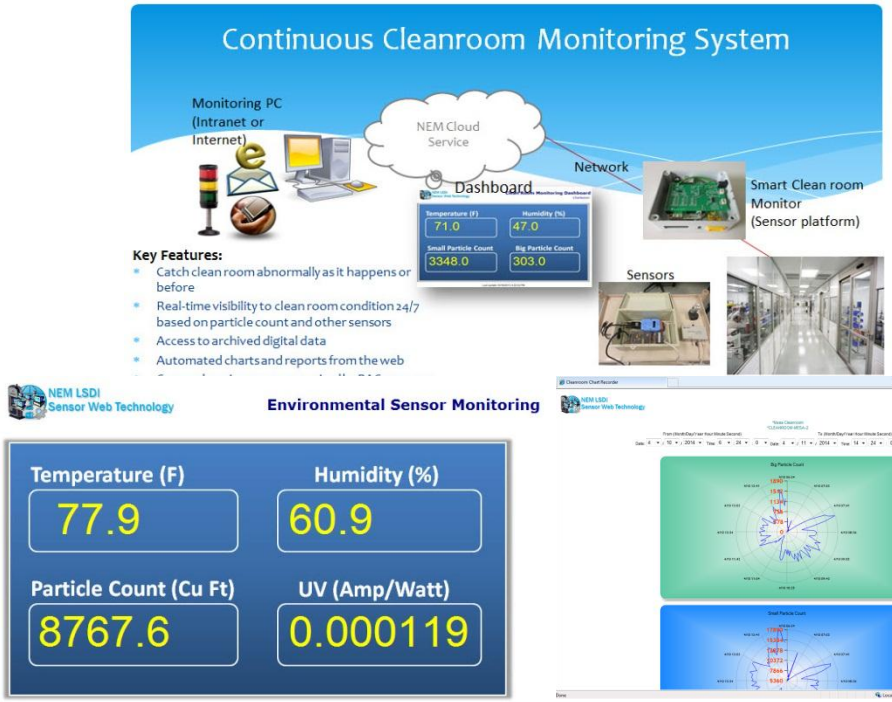


Trim to size



Perform other fabrication steps

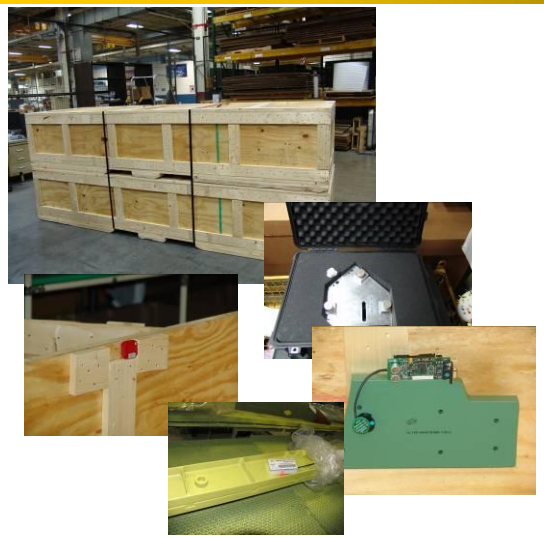
Sensor & Device Platforms – Environmental & Clean Room Health Monitoring



- Environmental values reported in “Real Time”
- Data collection & history used in process control & trends
- Interfaces to Production and Quality systems

Sensor Development to Monitor Aircraft Sub-Component Product Life-cycle

Typical Sensors & Controls: RFID; GPS; Vibration; Temperature; Humidity; Strain Gauge



Sensor adaptation to spares shipped in containers from Boeing to service centers

SHM sensors and digital part DNA sensors added to parts assembled in factory

Digital Thread on board aircraft

Repair Center

Sensors to monitor parts returned from field for rework