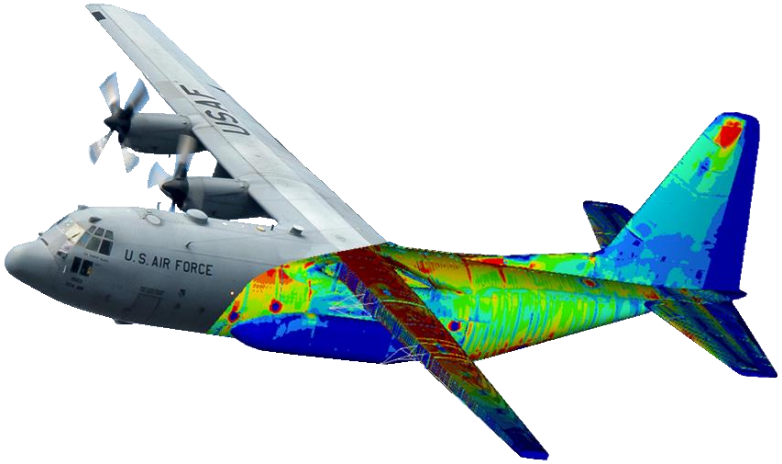
AF Life Cycle Management Center



Aging Aircraft Health Monitoring for Condition Based Maintenance

Presented by:

Timothy A. Floyd, P.E.

C-130 MECSIP Engineer

Agenda

- Objective
- CBM+ Strategy
  - Three Pillars of CBM+
- CBM+ Initiatives
  - Organic AFIRM as Integrity “One Stop Shop”
  - Corrosion Sensing and Monitoring (SBIR)
  - C-130 Legacy L/ESS
  - Metadata Mining (SBIR)
  - Neural Network Analysis(SBIR)
- Success Stories from RCM/MSG-3/CBM+
- Summary

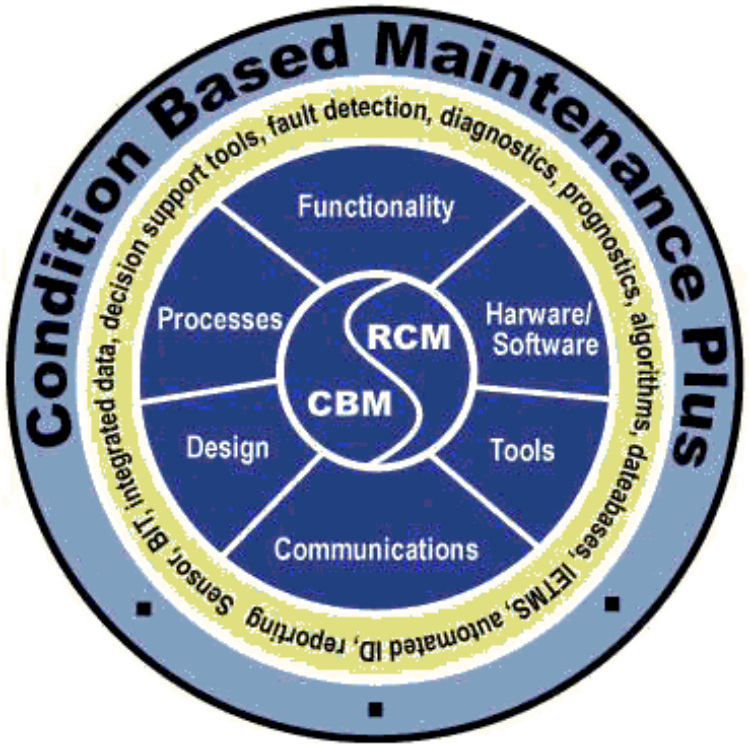
Objective

To Build a World Class C-130 Maintenance, Repair, and Overhaul (MRO) Activity that Maximizes Aircraft Availability and Minimizes Costs While Maintaining OSS&E.

Office of the Assistant Secretary of Defense for Logistics and Readiness Defines CBM+ as:

"Condition Based Maintenance Plus is the application and integration of appropriate processes, technologies, and knowledge-based capabilities to achieve the target availability, reliability, and operation and support costs of DoD systems and components across their life cycle."

http://www.acq.osd.mil/log/mpp/cbm+.html



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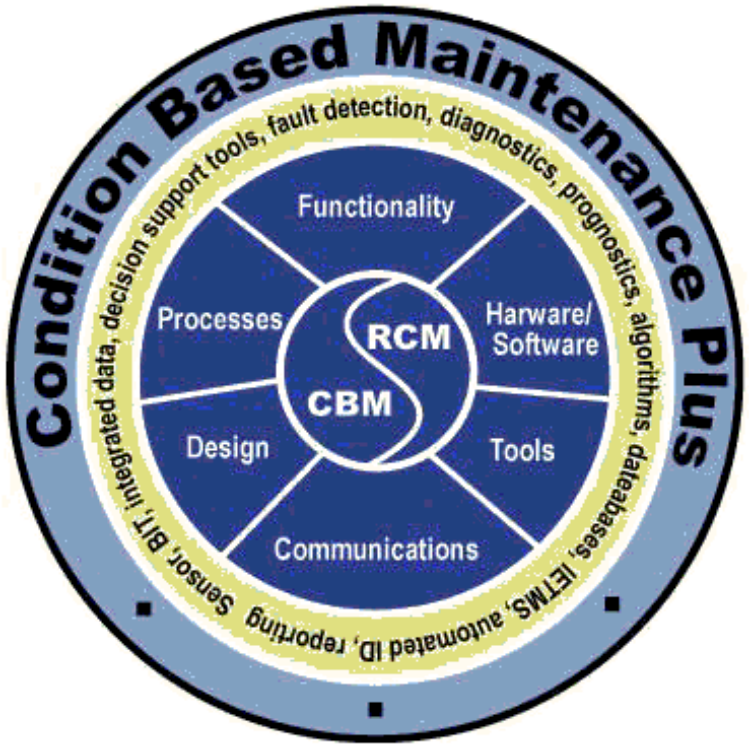


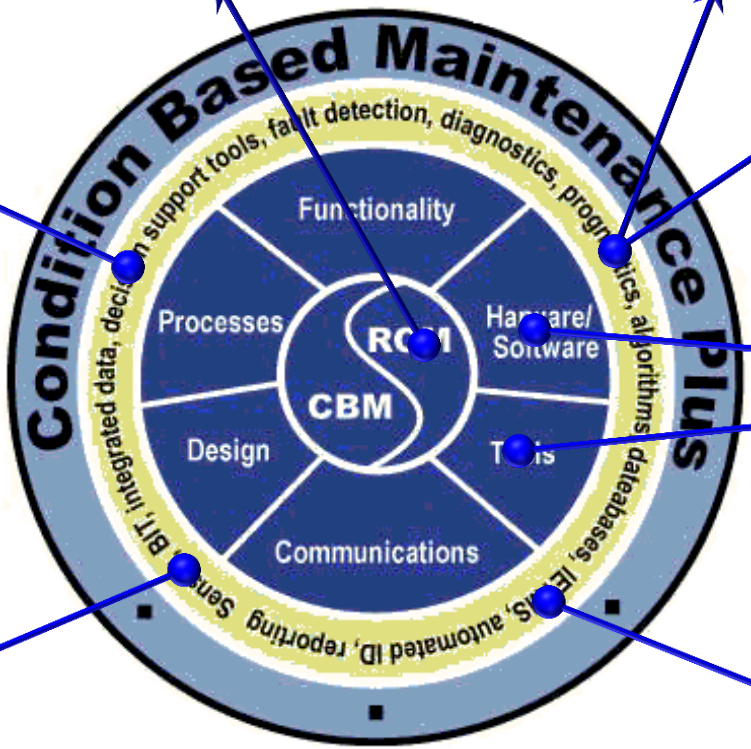
How Are We Getting There?

C-130 Nose-to-Tail RCM Analysis Complete 9/30/14

Data Fusion and Neural Networks SBIR

C-130 Corrosion Sensor Trial; 1st Install Aug 2014

Analatom Metadata Mining SBIR



AIRCAT, SMR, MERCMS, MECSIP, SAFETY All Transitioning to Organic AFIRM-M; AGILE Development Underway

C-130 Legacy L/ESS 1st Install Completed Feb 2014

C-130 IETMs Now an Official Tech Data Source

C-130's Three Pillars of CBM+

TACTICAL AIRLIFT DIVISION

C-130 Health and Usage Monitoring Systems

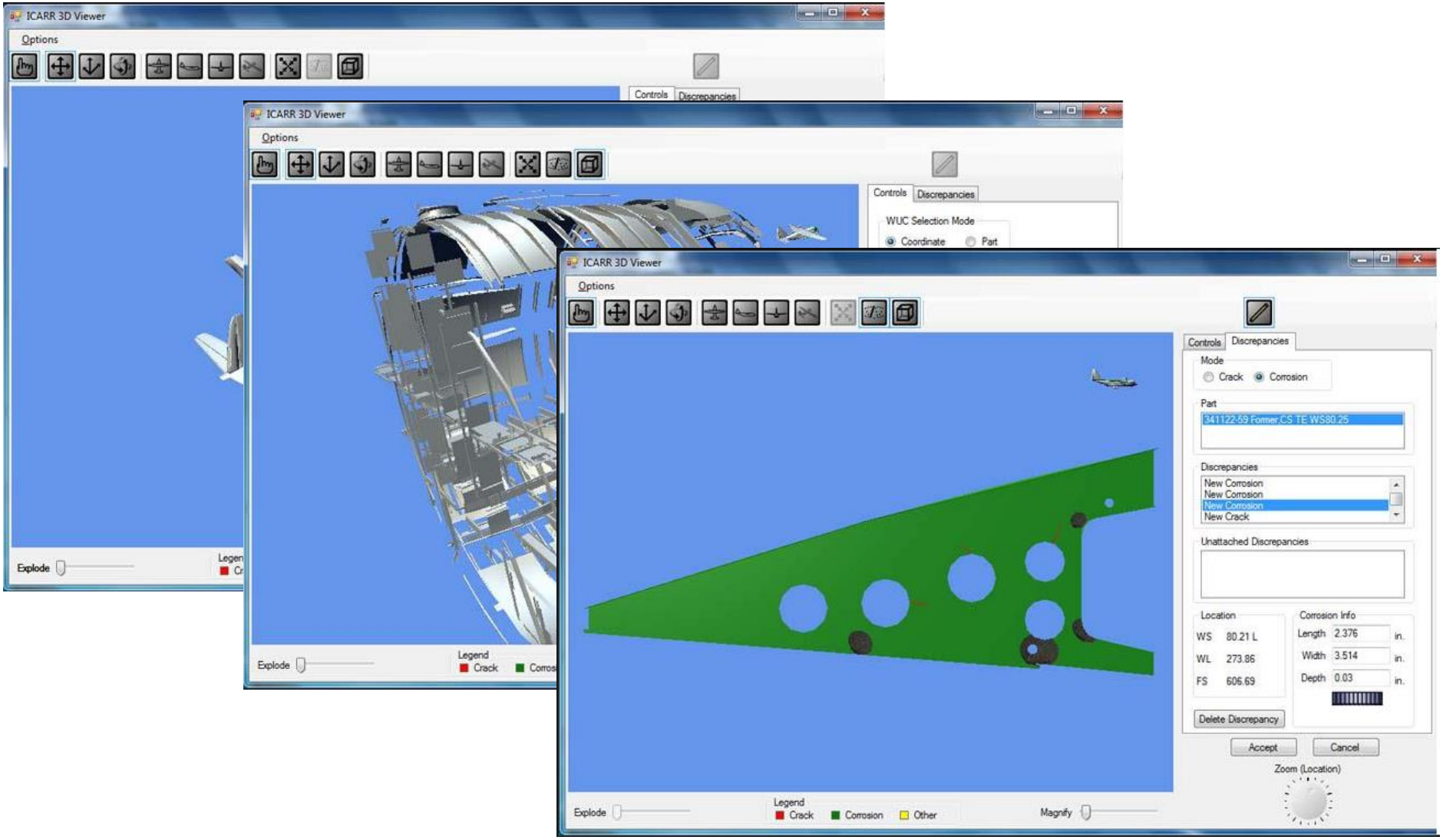
- **Corrosion Status Accounting**
  - Sensing when corrosion is taking place
  - Scheduling and Registering Repair
- **Structural Health Monitoring**
  - NDI Results Feed FEM/DADTA
  - Prognostics Merge Scheduled MX and ASIP Intervals
- **Propulsion System Health**
  - Leverage CEMS and EHMS Data
  - Integrate Nacelle Data into Propulsion Life Prediction
- **Avionics Diagnostics**
  - Capture and Analyze BIT Data
  - LRU Trend Analysis
- **Mechanical Systems Life Remaining**
  - Fusion of MECSIP and ASIP Data
  - Allow Neural Networks to Learn Cause and Effect

C-130 Maintenance Data Collection Systems

- **Field Maintenance Data - NDE**
  - Paint a True Picture for Reliability Centered Maintenance Analysis
  - Analyze Trends for Root Cause Identification/Mitigation
- **Organic Depot Maintenance Data - NDE**
  - Capturing MRO Effectiveness
  - Rebaselining Aircraft Repair Status
- **Contractor Depot Maintenance Data**
  - Ability to Categorize Common LRU MRO Activity against MDS
  - Fuse with Field Data to Uncover Potential Failures Missed in ATP
- **Repair Action Details**
  - Accurately Capture Corrective Action's Impact on Useful Life
  - Update Aircraft Configuration to Account for Future Depot Repair
- **Supply System Cross Reference/Data Cleanse**
  - Discovers Errors in WUC Records
  - Lengthens Event Horizon for Predicting Supply Shortfalls

Inspection, Corrosion, Repair And Reporting (ICARR-3D)

TACTICAL AIRLIFT DIVISION



C-130 Prognostic Software Engine

- **Metadata Mining**
  - Semi-Automated Analysis of ALL Data Using C-130 Custom Filters
  - Facilitates Intelligent Decision Making Process in MRO Activities
- **Data Fusion**
  - Automated Data-Driven Abnormality Detection
  - Multiple Source/Multiple Level Data Fusion Across MRO Enterprise
- **Neural Network Analysis**
  - Maintenance Event Characterization and Tracking
  - Translates Modeled Behavior Into Predictive Maintenance Activity
- **Statistical Probability**
  - Predict 90% of Upcoming Maintenance with 90% Confidence
  - Establish an Iterative Process to Refine Model with Each Aircraft
- **Accurate Simulations**
  - Build FEMS for Each MDS to Account for Structural Variations
  - Unique FEMS Feed Custom Simulations Based on Mission L/ESS

CBM+ Initiatives

- Organic AFIRM as Integrity “One Stop Shop”
- Corrosion Sensing and Monitoring (SBIR)
- C-130 Legacy L/ESS
- Metadata Mining (SBIR)
- Neural Network Analysis(SBIR)

Organic AFIRM as Integrity "One-Stop-Shop"

- **Cornerstone for C-130 CBM+**
- **Multi-Platform Capability, Scalable for Individual Aircraft**
- **MUST Retain Aircraft Unique Engineering Software**
  - **Structural Health Algorithms (AIRCAT)**
- **Compiles ASIP, AVIP, MECSIP & PSIP Data**
- **Interfaces with USAF Data Systems**
  - **CAMS, REMIS, G081, GCSS, PDMS, LIMS-EV, JRAMS, Etc.**
- **Platform for Incremental Capability Development and Deployment**

MULTI-PLATFORM **AFIRM-M** AGING FLEET INTEGRITY & RELIABILITY MANAGEMENT U.S. AIR FORCE

A/C Usage	Corrosion	Maintenance Data	Force Management	Fleet Assessments	Component Tracking
• IAT • L/ESS • Usage Data	• Reports • Presentations • Action Items • Paint Scores	• Historical Data • Field Findings • Fleet Repairs	• FSMP • DTA Results • Fatigue Test Data	• Aborted Flights • Reliability Reports • Underperforming Component List	• Mission Critical Items • Critical Safety Items • Top 10 NMC Drivers

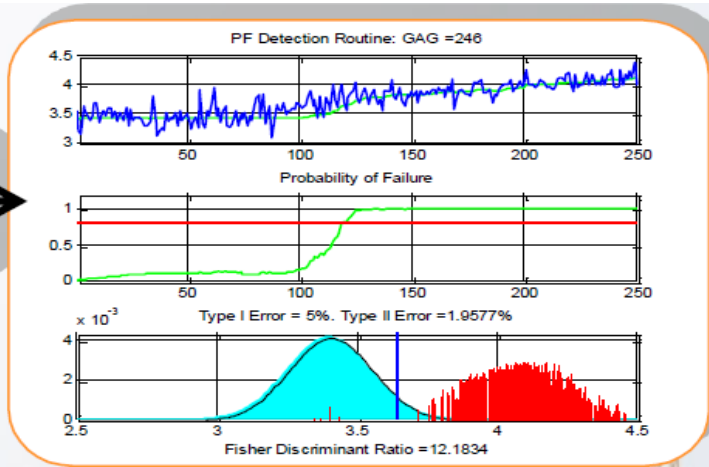
Corrosion Sensing and Monitoring (SBIR)

TACTICAL AIRLIFT DIVISION

- **Accurately Characterize Aircraft Corrosion Using µLPR**
  - **It's Important to Note We are NOT Measuring Corrosion Depth**
  - **Current TRL Only Allows Determination of Corrosion Rate**
- **Transition Laboratory Results Into Fieldable Hardware**
- **Develop Predictive Statistics for Coating Compromise**
- **Will Allow C-130 Corrosion Mgr. Unprecedented Visibility**
  - **Scheduled Maintenance**
  - **Environmental Conditions**
  - **Coating Integrity**

$$\begin{cases} x_d(t+1) = f_b\left(x_d(t) + n(t)\right) \\ x_c(t+1) = f_t(x_d(t), x_c(t), \omega(t)) \\ \text{Features}(t) = f(x_d(t), x_c(t), v(t)) \end{cases}$$

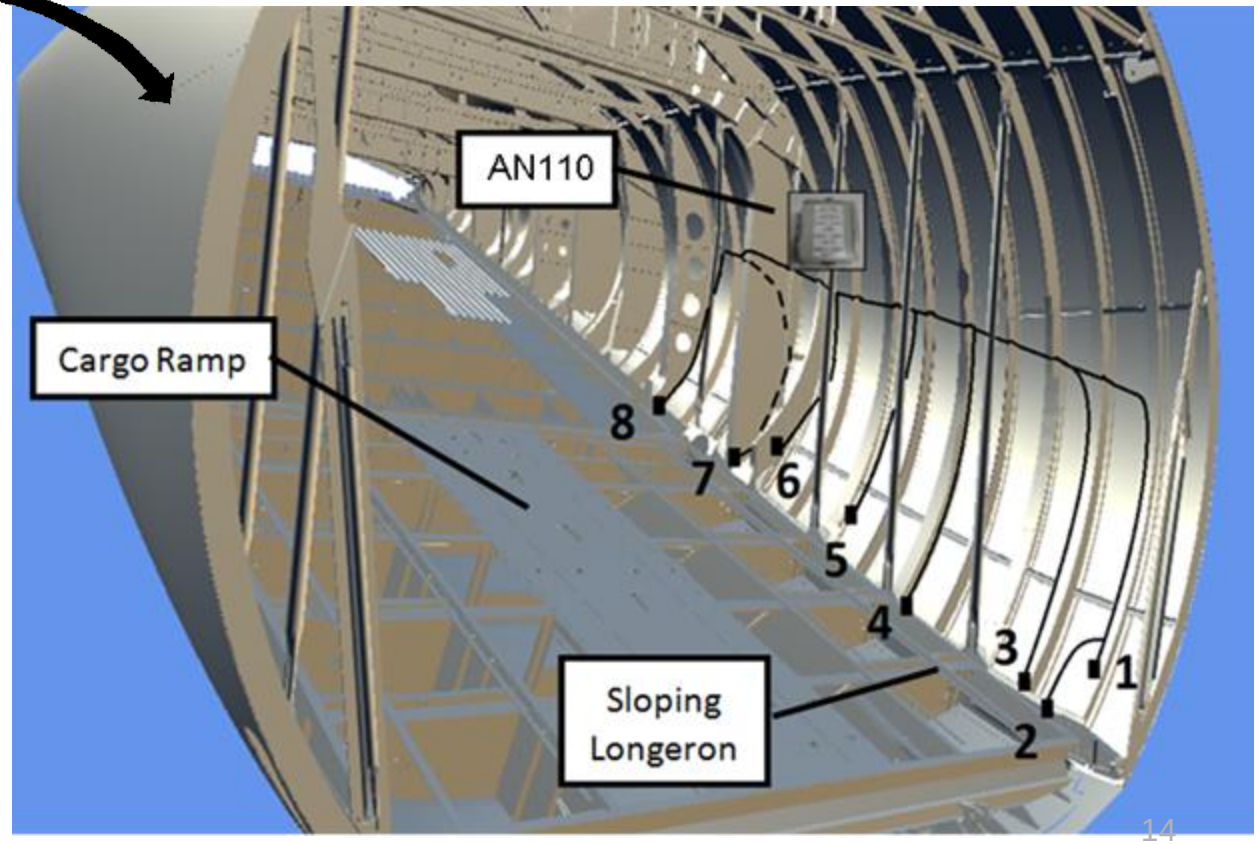
Particle Filter



Sensor Data - Corrosion Sensors Placement

Sloping longeron and surrounding structure chosen for the high rate of water intrusion and corrosion. Wiring will be installed underneath aircraft insulation.

(CARGO COMPARTMENT LOOKING AFT)



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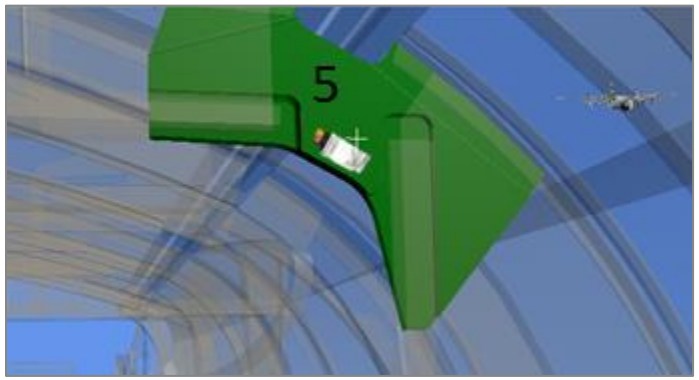
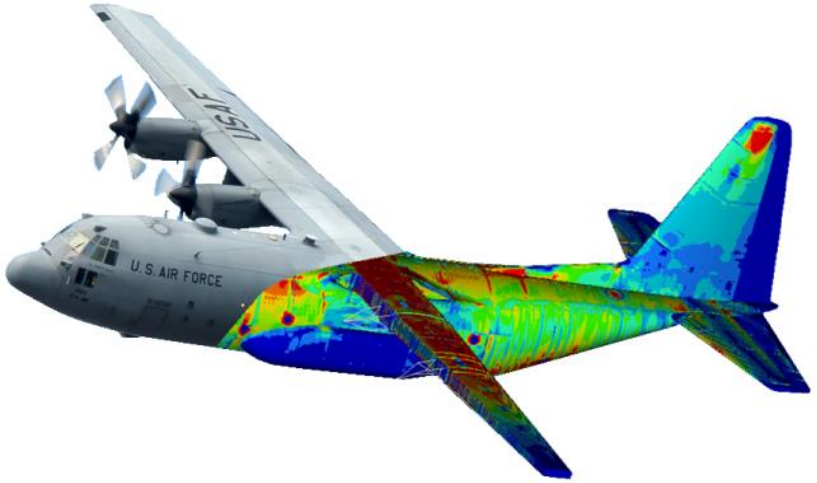


The FS 946 gusset fitting experiences significant stress and has a long history of cracking.

The cargo ramp area sloping longeron experiences high stress particularly when the cargo ramp is open in flight. It is often found deformed during Depot maintenance.

Legacy C-130 L/ESS

- **Suite of Sensors Installed to Record Loads/Environment Spectrum Survey (L/ESS) Data**
  - **System Monitors 25 Discrete Locations**
  - **Uses a Combination of Strain Gauges, Load Bridges, and Pressure Transducers**
  - **Refines Flight Characterizations for Improved Actual Flight Hour to Equivalent Flight Hour Translation**
  - **End Goal of MIL-STD-1530C Compliant L/ESS (20% of Fleet, All MDS Covered)**



Metadata Mining (SBIR)

- **Current T.O. 1C-130A-06 WUC Based Data is Unreliable**
  - **Approximately 60% of Data Records Are Removed**
- **Maintenance Write-ups Contain Errors/Misspellings**
  - **Current Systems Make No Attempt to Decrypt Vernacular**
  - **Systems Don't Cross Reference Text with How Mal Code**
    - **Write-Up States R2 LRU with a 799 How Mal (Doesn't Make Sense)**
- **System Uses Advanced Artificial Intelligence Algorithms**
  - **Similarity Groupings and Common Maintenance Associations Stored in a Single, Dynamic Information Repository**
  - **Complex, Non-linear Conceptual Associations and Links Discovered within Millions of Independent Text Maintenance Documents**

Neural Network Analysis (SBIR)

- **USAF Scientific Advisory Board Finding:**
  - **"The integrity programs (ASIP, MECSIP, AVIP, and PSIP) are the main avenues for implementation of improved data driven CBM processes."**
- **DF&NN Data-driven Predictive Maintenance (DPM) Tools**
  - **Dual Node Network (DNN) technical architecture**
  - **Data-driven Anomaly (ANOM) detection, characterization, and tracking**
  - **Bayesian Fusion Node (BFN)**
  - **Smoking Gun (SG) Pattern Discovery**
  - **Abnormal Event & Context Visualization**

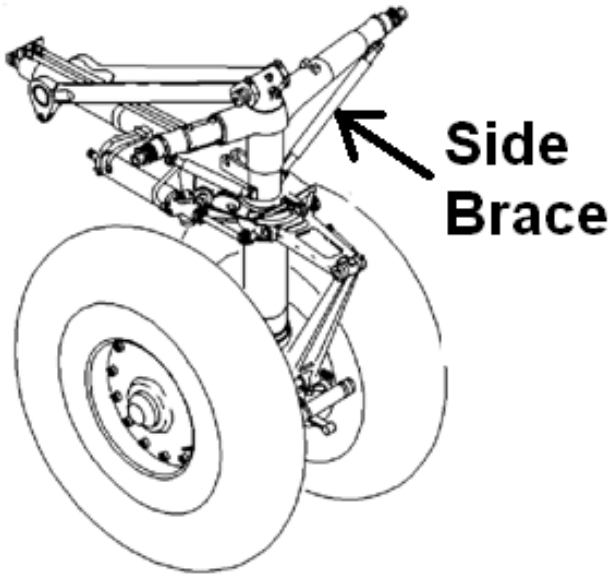
While these processes may not completely stem the cost growth for sustainment of the aging USAF fleet, they can certainly provide cost and time reductions from the systems currently used by the USAF sustainment enterprise.

Neural Network Analysis (SBIR)

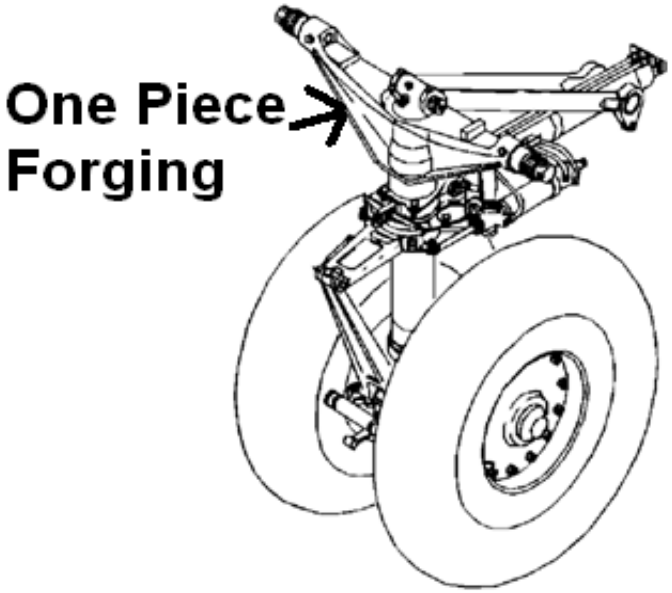
- **The DPM system is based upon a proven data-driven abnormality detection system at TRL 7**
  - **Learns Normal & Detects Abnormal Unknown-signature Behavior for Thousands of Variables in Near Real Time**
  - **Provides Context for Abnormal Clusters with Characterizations to Which Recommended Responses can be Tagged**
  - **Affordably Adaptive via Retraining for Changing Operational States with New Training Sets Specified Over Time via Automated Cluster**
- **Proposed Way Ahead**
  - **Identification, Access, Management, and Analysis of Data for DPM**
  - **Learn Normal Behavior, Detect & Characterize Abnormal Behaviors, and Test Performance Using Off-Line Historical Aircraft Data**
  - **Detect & Characterize Unknown Abnormal Aircraft Data Behaviors and Perform a Blind Test Using Data with Unknown Signatures**
  - **Abnormal Event Track Relationship, Impact, and Process Assessment Plus Maintenance Management**

RCM Success Stories

- **Old Style NLG Shock Strut is No Longer in Use, Yet Time Change Requirement Remains in 1C-130A-6**
  - **1C-130A-6 (H-Model TO) Requires TCI at 60 Months**
  - **1C-130J-6 (J-Model TO) Requires TCI at 120 Months**
  - **$1.49M in Annual Savings**



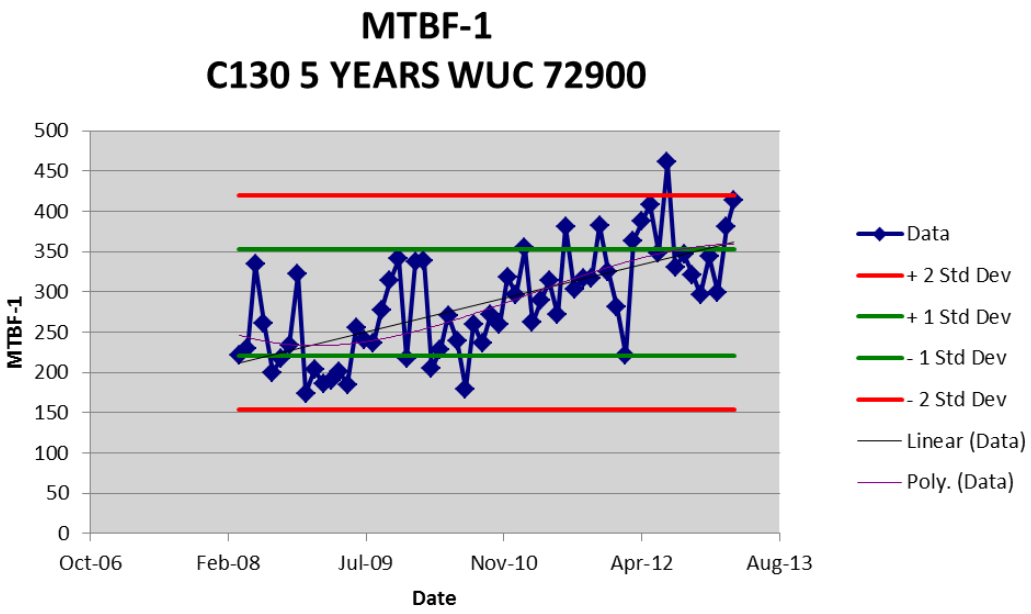
Old Style



New Style

RCM Success Stories

- **APN-169 R/T Premature Failures**
  - **Expected MTBF-1 => 400 Flight Hours**
  - **FY 08 MTBF-1 ≈ 175 Flight Hours**
  - **Engineering Traced Root Cause to Improper Klystron Tube Adjustment**
  - **Current Annual Savings of $10.1M**



Year	2008	2009	2010	2011	2012	2013
Failures	914	1232	1156	916	761	146
avg/mo	102	103	96	76	63	49
Mo	9	12	12	12	12	3
Repair cost	$ 17,449.00	$ 17,449.00	$ 17,449.00	$ 17,449.00	$ 17,449.00	$ 17,449.00
Cost per year	$ 21,264,514.67	$ 21,497,168.00	$ 20,171,044.00	$ 15,983,284.00	$ 13,278,689.00	$ 10,190,216.00

Summary

- **C-130 Program Office is Pursuing CBM+ as a Cost Saving Initiative**
  - **Current Fiscal Environment is an Impediment**
  - **Complete C-130 Nose to Tail RCM Analysis Complete in Sep 2014**
  - **RCM Analyses are Currently Producing Savings**
    - **Manpower Savings Allow the Field More Record Time, Yields Better Data**
    - **Cost Savings Validate ROI and Improve Overall Program, Feeds Future Initiatives**
  - **Utilizing SBIR Process to Maximize Dollars**
  - **Organic Software Solution Fields Capability Quicker and More Efficiently Than OEM/Contractor Proprietary Packages**
    - **Easily Scalable Across USAF Enterprise**



Questions?