Strategy for Design and Implementation of Prognostic and Health Management Systems for Optimal Value

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Changing the Way We Manage Engines

Prognostic and Health Management Tools Enable the Transition to Condition Based Maintenance

GO FROM:

- Single parameter "Total Accumulated Cycle" (TAC) lifing
- Scheduled inspections
- "Reactive maintenance"
- General troubleshooting

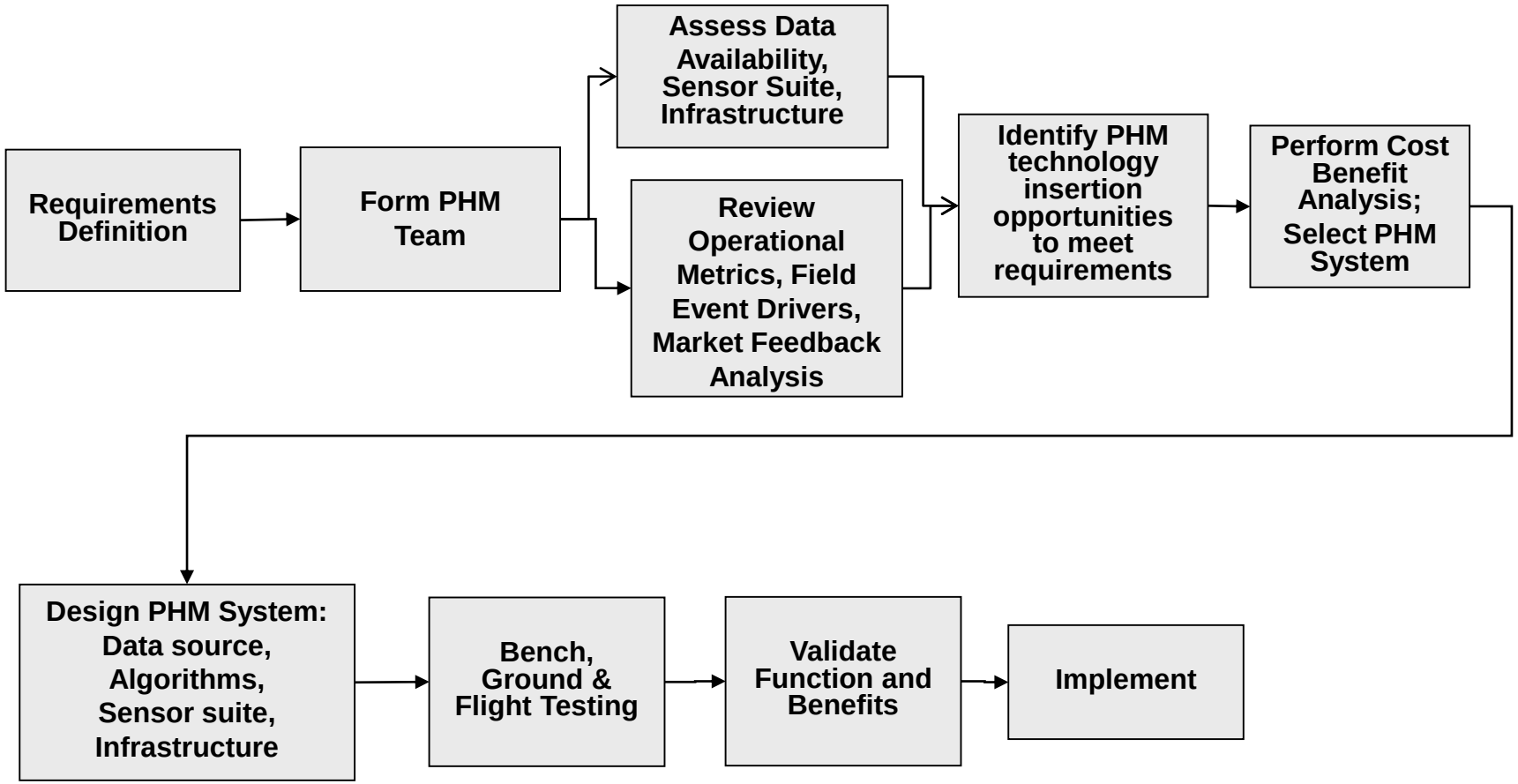
Enablers

- Usage Based Lifing
- Usage Driven Inspection
- Advanced Anomaly Detection & Fault Isolation

TO:

- Accumulated damage & remaining useful life calc
- Maintenance before failure through prediction
- On condition inspection and maintenance
- Targeted troubleshooting and maintenance success verification

How We Get There: Prognostics and Health Management Development Process



Form PHM Team

Implementation requires an integrated effort to produce a competitive product that delights the customer

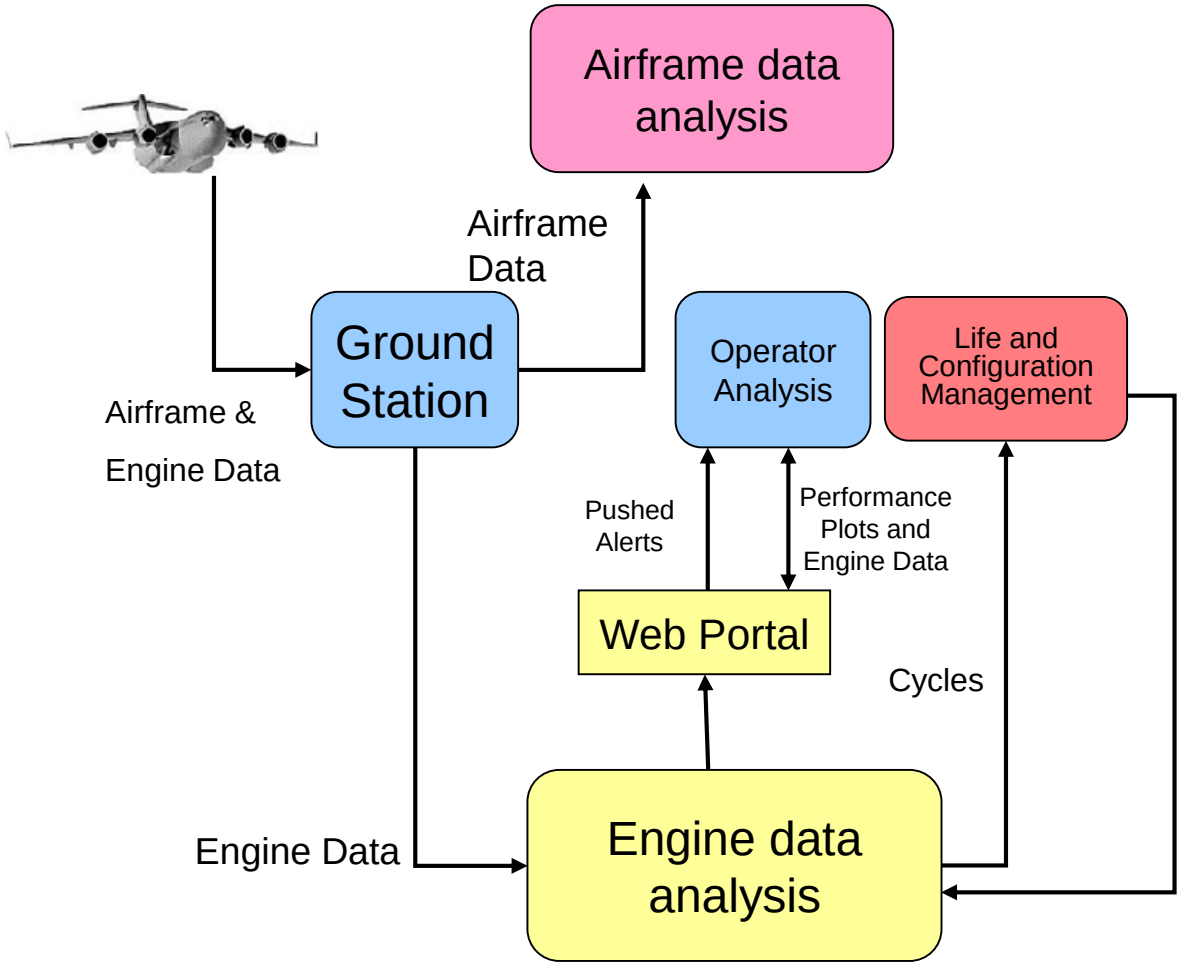
Assess Data Availability

Data availability influences benefit potential

Availability	Steady State Snapshot	Event Transient Snapshot	Full Flight Transient Data
Functionality	Gaspath Trending	Event Diagnosis, Fault Isolation	Physics Based Damage Accumulation
Benefit	• Correct anomaly prior to more severe secondary damage • Streamlined troubleshooting • Workscope optimization	• Streamlined troubleshooting • Improved root cause analysis	• Safely consume design life

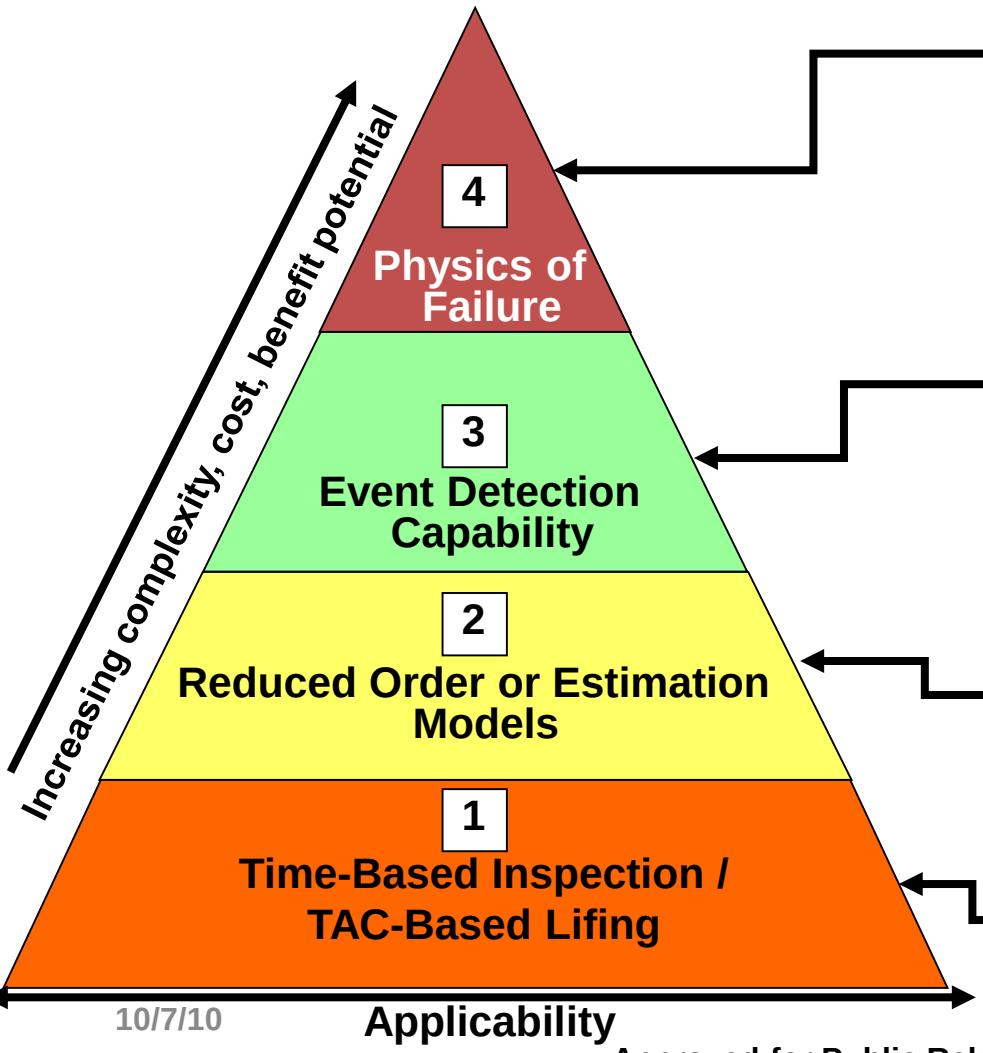
Assess Infrastructure

Information flow from analysis tools to engine management tools allows for full benefit potential



Target PHM Capability

Consider Data Availability, Sensor Suite, and Infrastructure



Future PHM Potential

Functionality:

- Advanced Reasoning utilizes structural transfer models / damage accumulation algorithms / sensed data to project remaining life from detected damage state.

Maintenance Action:

- For cause based on remaining life capability.

Target for New Development Engines

Functionality:

- Advanced sensor suite (inlet /exit debris monitor; blade passage frequency; vibration, etc.) provides damage detection capability.

Maintenance Action:

- Inspection for cause, based on detected damage state limits.

Target for Legacy Engines

Functionality:

- Usage Based Lifing, Usage Driven Inspection

Maintenance Action

- Extended interval between inspections, extended Scheduled Engine Removal (SER) interval

Current Status for Legacy Engines

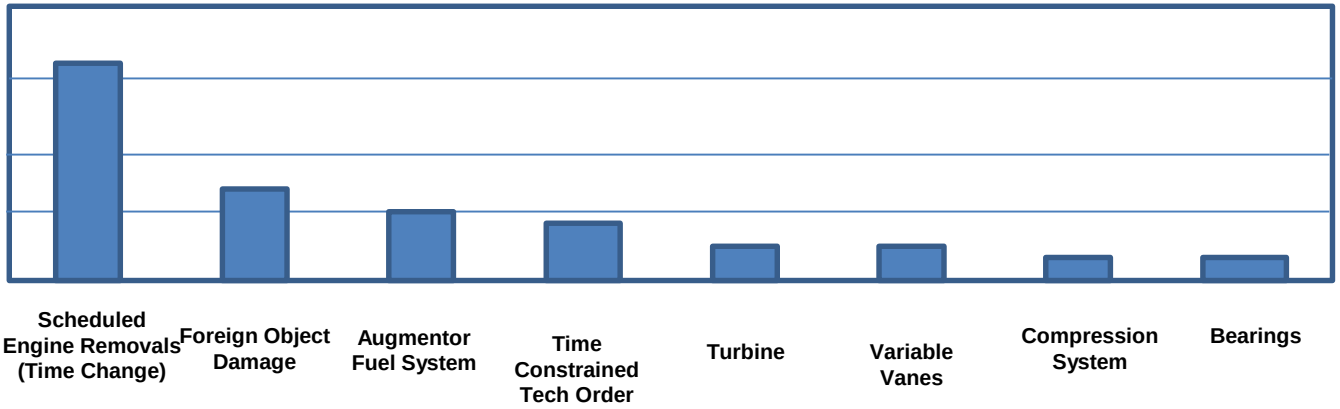
Functionality:

- Scheduled Inspections, TAC-based lifing

Review Engine Removal and Inflight Shutdown Drivers

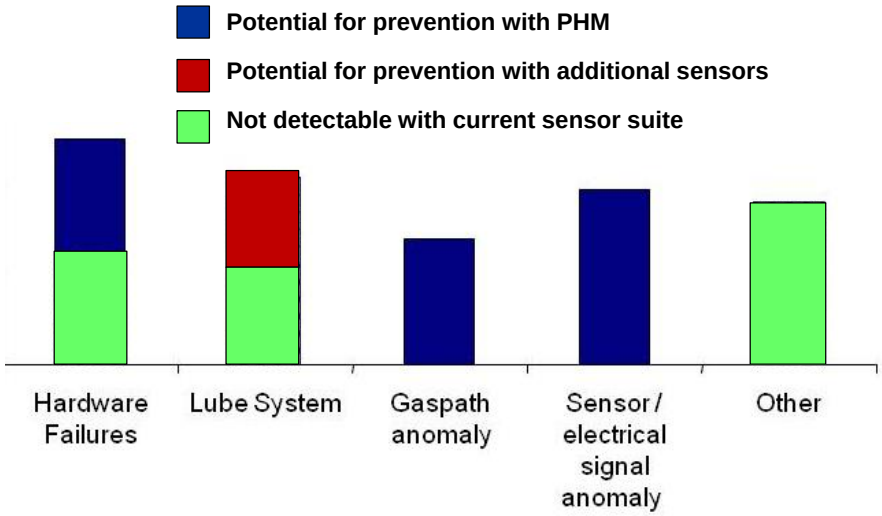
Leverage Reliability, Maintainability, and Safety metrics to target technology insertion

Notional Engine Removal Drivers



Engine Removal Drivers

Potential to prevent with improved lifing methods, anomaly detection, and sensor technology



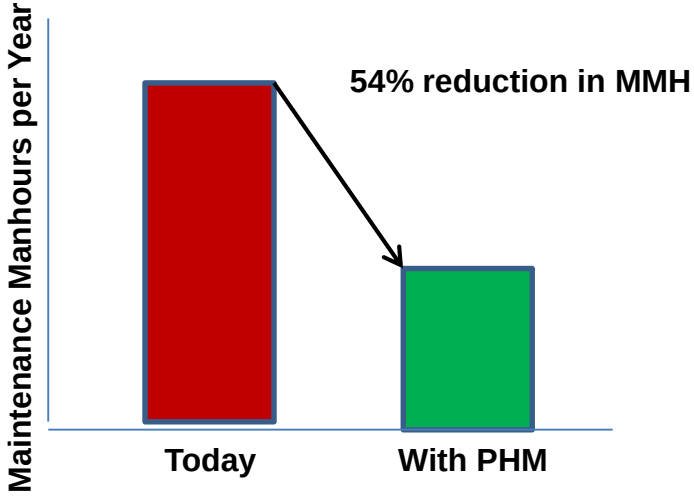
Inflight Shutdown Drivers

Identify Maintenance Manhour Drivers

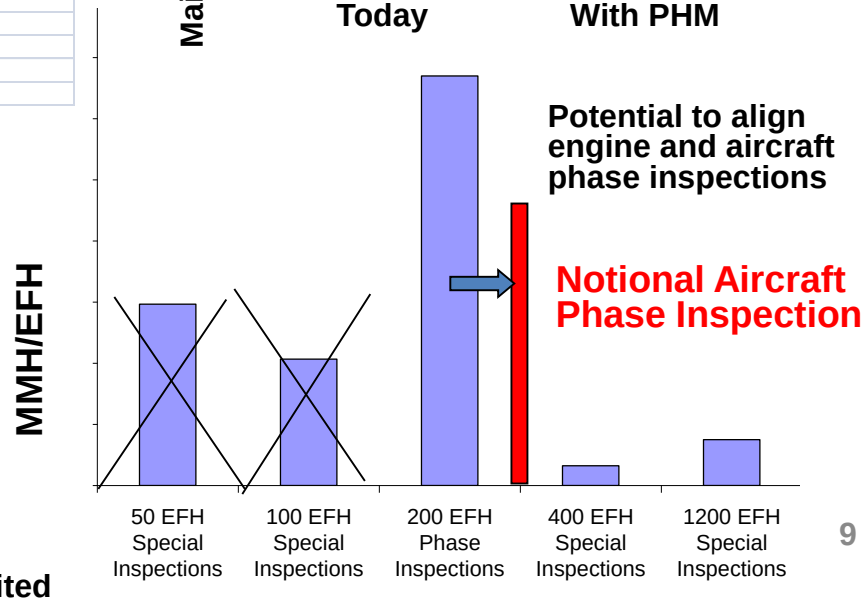
All engine inspections reviewed to quantify potential PHM benefit

Notional T.O. Inspections	Interval	Minutes	PHM Initiatives: Anomaly Detection	Turbine Durability Algorithm	Oil Sensors	Blade Health Sensors	Vibe Sensor
Compressor Variable Vane insepction	200 hours	15	1				
Electrical cables for connector security	200 hours	5					
Engine oil tank damage and oil leakage	200 hours	0.4			1		
Ignition Exciter check	200 hours	2					
Main Oil Filter for particles and damage	200 hours	20			1		
Insp and lube primary convergent nozzle flexible shafts	200 hours	180					
Borescope Fuel Manifold for leaks	200 hours	30	1				
Ignition Systems Analysis	200 hours	180					
Augmentor Module	200 hours	103	1				
Combustor and fuel nozzles	50 hours	45	1				
Bearing seal air supply manifold assy for cracks	50 hours	30					1
1st turbine rotor blades , 1st and 2nd vanes	50 hours	45		1		1	
Turbine rotor blades	50 hours	45		1		1	
Visual main igniters	50 hours	30	1				
Visual main oil filter housing for cracks	50 hours	1					1
Turbine duct and vane support for cracks	50 hours	1					1
Bleed Air Manifolds	100 hours	10	1				
Borescope 3rd Turbine stator vanes	100 hours	45		1			

Quantify Impact on MMH and inspection tempo



Quantify Impact on inspection tempo



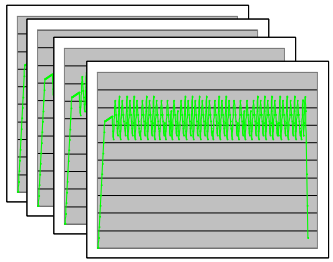
Market Feedback: "If you could align engine phase inspections with aircraft phase inspections, that would be huge for us. "

Identify PHM Technologies: Usage Based Lifing

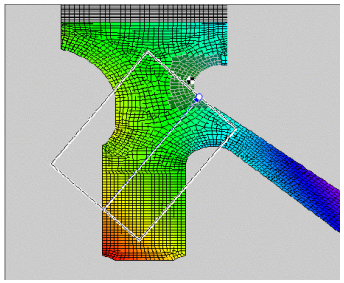
Use actual mission data and regressed representations of design tools to more accurately track life consumption

Design

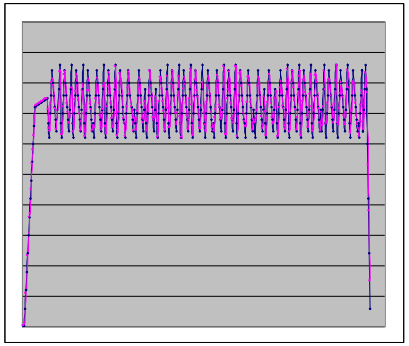
Design Mission Data



Performance files generated in design phase which feed lifing



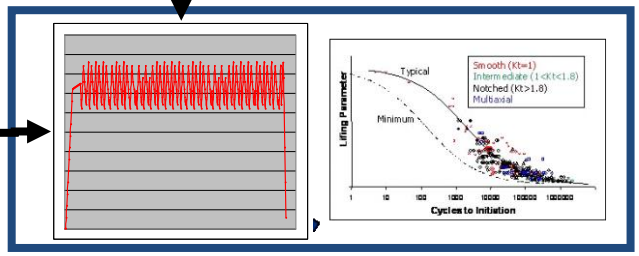
Component models predict stress and temperature for design mission



Stress / Temp regressed to performance parameters from design mission

Operation

http://www.safran-group.com/IMG/jpg/fadec.jpg

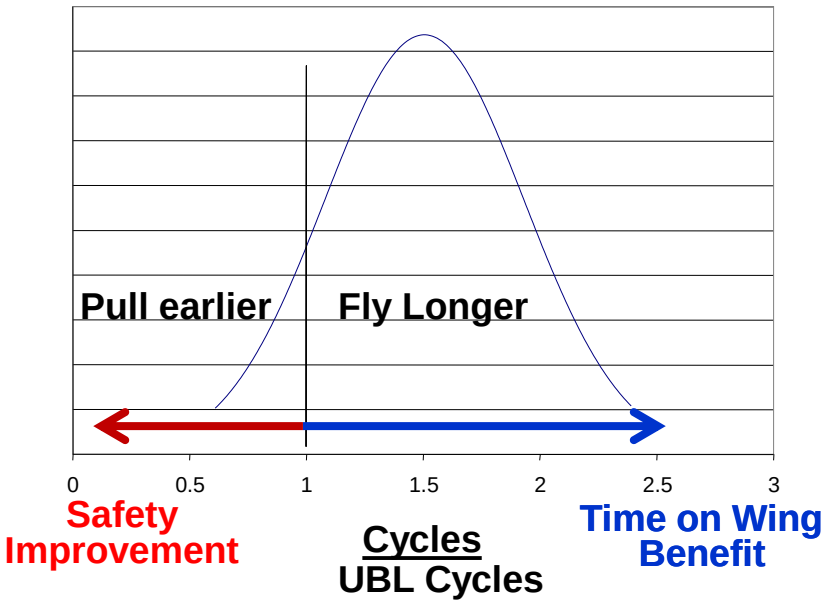


Stress / Temp Calculated from actual mission run life consumed calculated

Mission Specific damage calculated

PHM Technology: Usage Based Lifing

Study showed ~90% of engines are flown "easier" than design missions



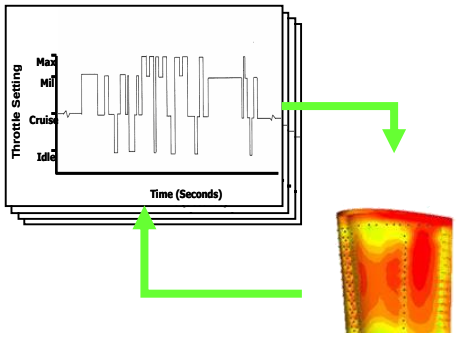
- Conventional cycle based lifing estimates the life used by comparison to conservative design missions
- Usage Based Lifing calculates the life used for each engine, each Life Limited Part, based on actual usage

Usage Driven Inspection

Use actual mission data and damage models to manage turbine durability

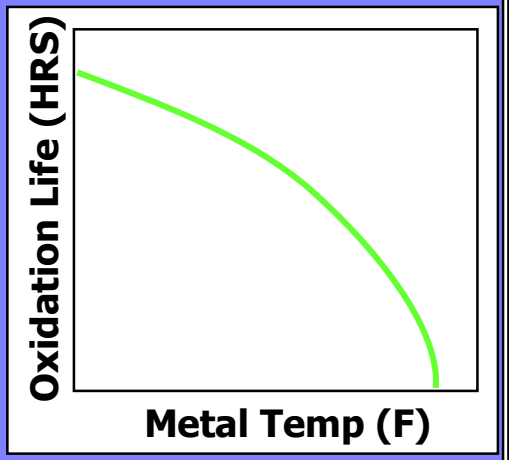
Predicted Metal Temp

Leverages 3D aero Models to correlate engine parameters to metal temp



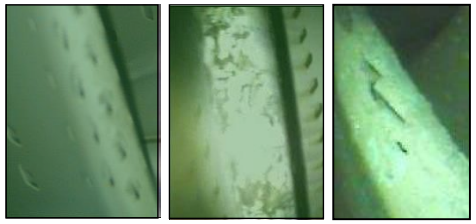
Life Consumption

Converts time at temp to oxidation life consumed.



Borescope Feedback

Calibrates predicted damage to observed damage for worst blade. Uses qualitative scales for damage.



0.00" erosion **0.05" erosion** **Burn Through**

Provide flexibility in inspection or maintenance action timing.

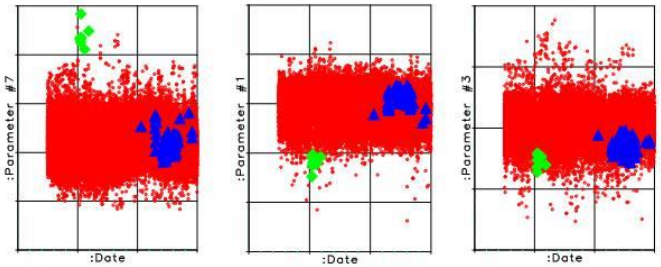
Advanced Anomaly Detection and Fault Resolution

Use engine health trending parameters to target troubleshooting and verify success of maintenance actions

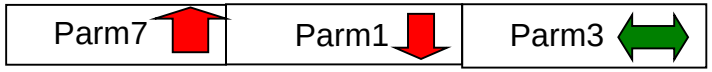
Notional Tech Order Troubleshooting Tree

1) Temperature Sensor Fault
2) Compression System Bleed Anomaly
3) Anti-Ice System Anomaly
4) Variable Compressor Vane Anomaly

1) Performance Trending, Automated Alert



3) Pattern Matching



4) Fault Isolation — Compressor Bleed Anomaly

5) Directed Maintenance

6) Trending to confirm success

Validate PHM System in the Field

Field Evaluation Validates Benefits

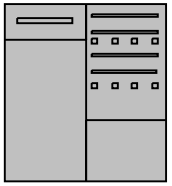
Validate infrastructure

Data Download

Data Transfer

Local Analyst

Server

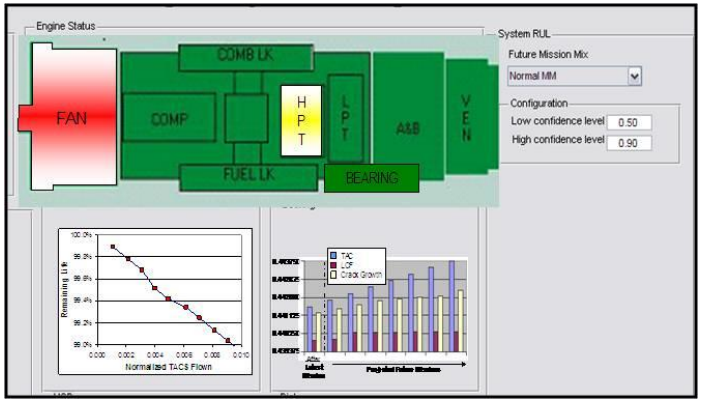


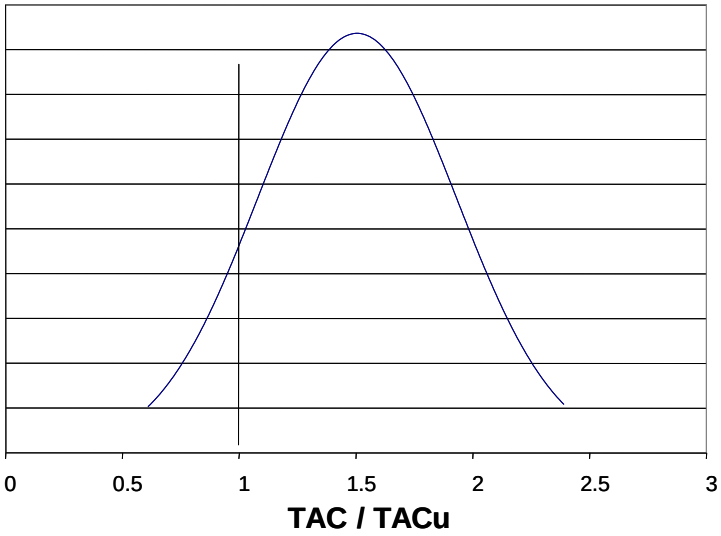
Data Push

Data storage, PHM Analysis

Validate data acquisition

Web Tool





Validate Benefits

Remote Analysts

Positive Impacts to Operational Metrics

Expert knowledge of engine state provides safe operation at a reduced cost

	EHM Tools Benefits			
Fleet Metric	*Usage Based Lifing (life limited parts)*	*Advanced Trending and Diagnostics*	*Usage Driven Inspection (Turbine Durability, Airfoil High Cycle Fatigue)*	*Advanced Sensors / Damage Detection*
Engine Total Ownership Cost	√	√	√	√
Inflight Shutdown per 1000 Engine Flight Hour	√	√		√
Maintenance Manhours per Engine Flight Hour		√	√	√
Mean Time Between Removals		√		
Unscheduled Removals	*Increased Rate*	*Reduced Rate*	*Prediction Only*	*Prediction Only*
Scheduled Removals	*Positive Impact*	*No Impact*	*No Impact*	*No Impact*

PHM Provides Value Across Life Cycle

Early Payback Makes PHM A Wise Investment Strategy At All Phases