F100-PW-220/E/229 Engine Life Management Plan and Part Lifing Programs

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Agenda

Topics of Discussion:

- *Engine Life Management Plan (ELMP) Overview*
- *F100 Engine Rotor Life Extension Program*
- *F100-PW-229 Engine Enhancement Program*
- *Prognostic Health Management and Usage Base Lifing Initiative*

Engine Life Management Program (ELMP) Overview

ELMP Proactively Identifies Activities to Improve Cost of Ownership and Safety Metrics

Spheres Of Influence: Configuration | Engine Operation | Maintenance

Supporting Initiatives

Configuration:
- Retirement for Cause
- Common Engine Configuration
- CEMS Maintenance
- IPB Update
- ERLE
- EEP

Engine Operation:
- Pacer
- PHM

Maintenance:
- RFC Closed loop process
- TO Update
- ACI / Trending

Parallel Improvement Programs

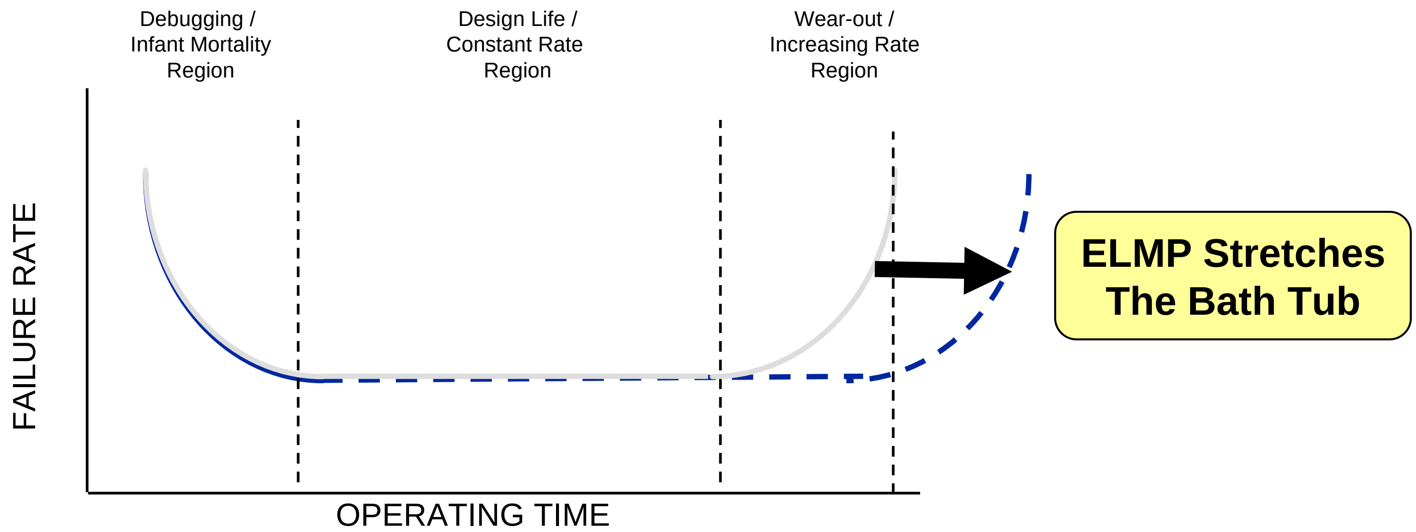
- •Component Improvement Program (CIP)
- GSE Tasks

Growth / Study Initiatives

- P-SAR Initiatives

ELMP Overview

ELMP is a Pro-Active Approach that Extends Normal Reliability Life Cycle

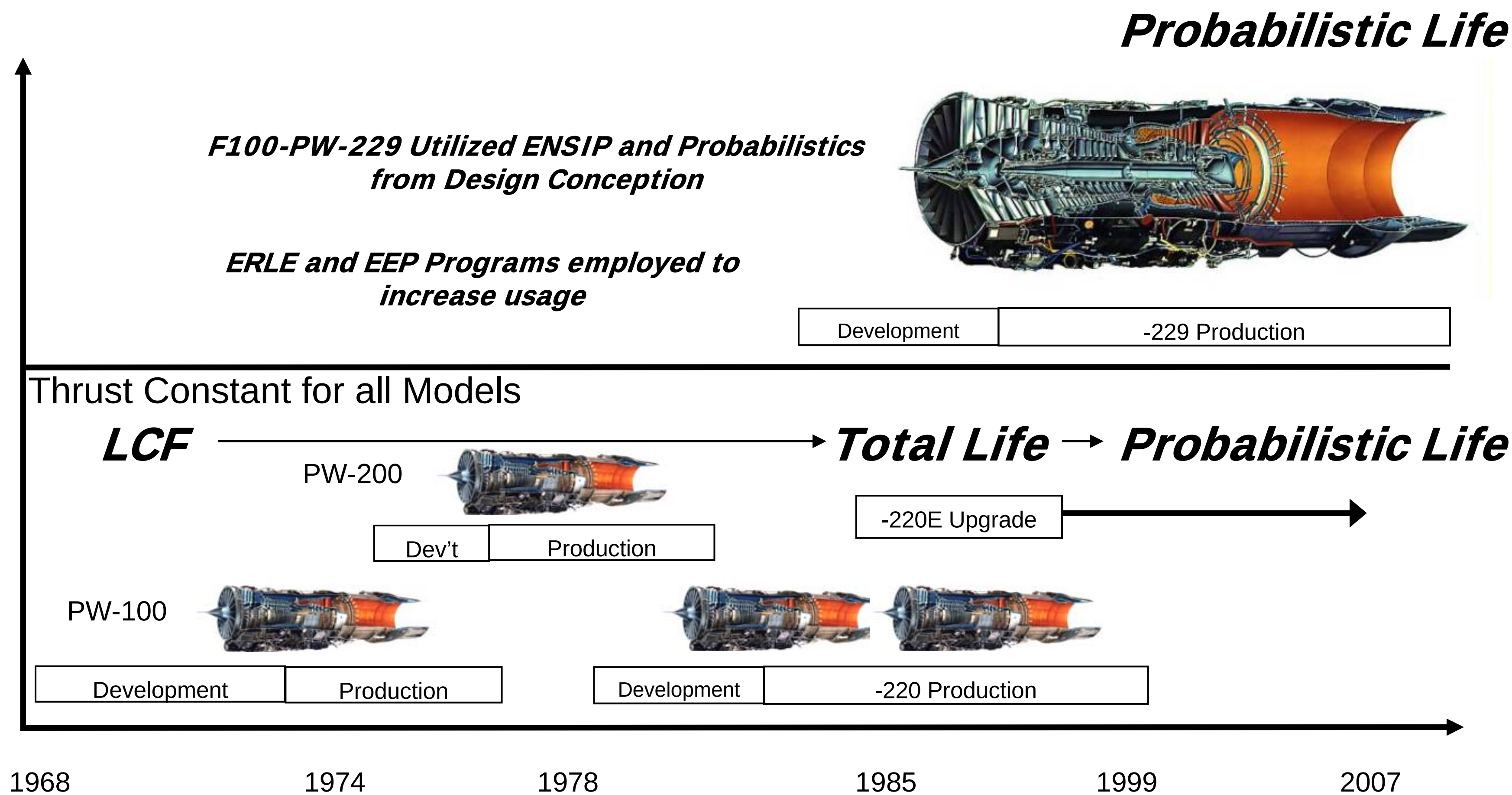


Objective - *An Engine Life Management Plan (ELMP) is a comprehensive methodology for managing and sustaining systems throughout the F100 design life*

Task Benefits - *Goals of enhanced system safety, reliability, and supportability, while reducing the cost per flying hour*

Lifing Methodology Progression

The Lifing Philosophy of the F100 Engine has Gone Through Many Iterations Since Initial Service Release



Lifing Methodology Progression

Evolution of Lifing Philosophy Allowed Parts to Safely Remain on Wing Longer

- Initial parts designed for 1800 TAC usage
- Requirement for 4000 TAC engine drove redesign and lifing approach
  - ENSIP design philosophy introduced for new parts
  - Retirement For Cause extended current part usage
    - Operation beyond LCF limit
    - Enhanced ECI inspections
- Life Limit (LCF & F/M) employed during 1993 lifing update
  - Enhanced ECI inspection coupled with LCF lives
- Probabilistic design approach used to supplement Engine Structural Integrity Plan (ENSIP)

Lifing Methodology Progression

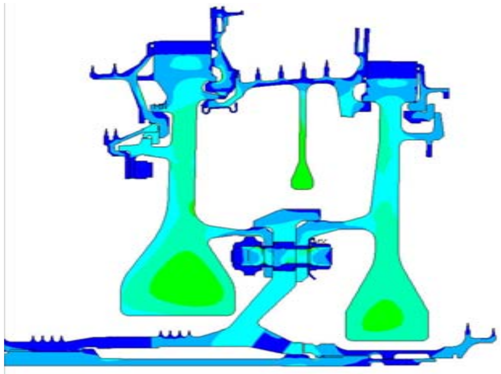
Evolution of Lifing Philosophy Allowed Parts to Safely Remain on Wing Longer Cont.

- ERLE program introduced – 3rd interval usage
  - Successful field experience leveraged
  - Enhanced ECI inspection utilized
  - Use of Probabilistic design methodology expanded
- EEP program introduced – 6K inspection interval
  - Draws on success of ERLE program
  - Local feature redesigned to allow extension
- Usage Based Lifing – Next step
  - Subset of PHM
  - Employs actual engine performance data to calculate fatigue damage
  - Significant increase in on-wing time possible

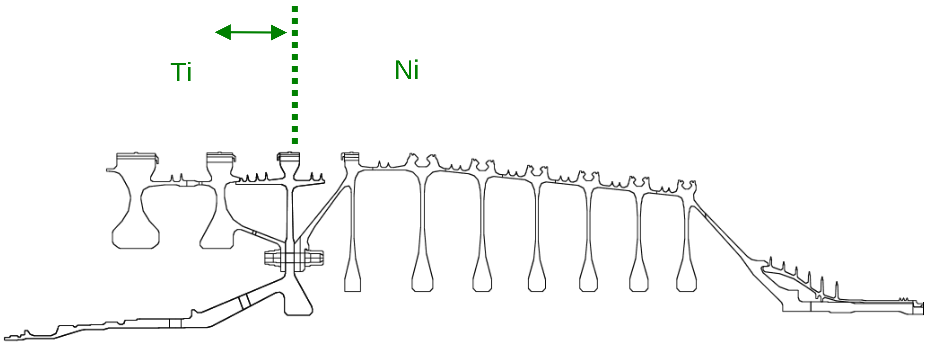
F100-PW-220 & PW-229 Engine Rotor Life Extension (ERLE)

Rotating Hardware Extensions to a Third Interval by Utilizing Lifing Methodology Changes

- Ground rules established using deterministic and probabilistic methods
- F100 rotating hardware selected based upon ROI of extending hardware for 3rd interval
- Hardware was analyzed using the latest inputs
- Expected completion date of Feb 2011
- Initial results have been reviewed with USAF



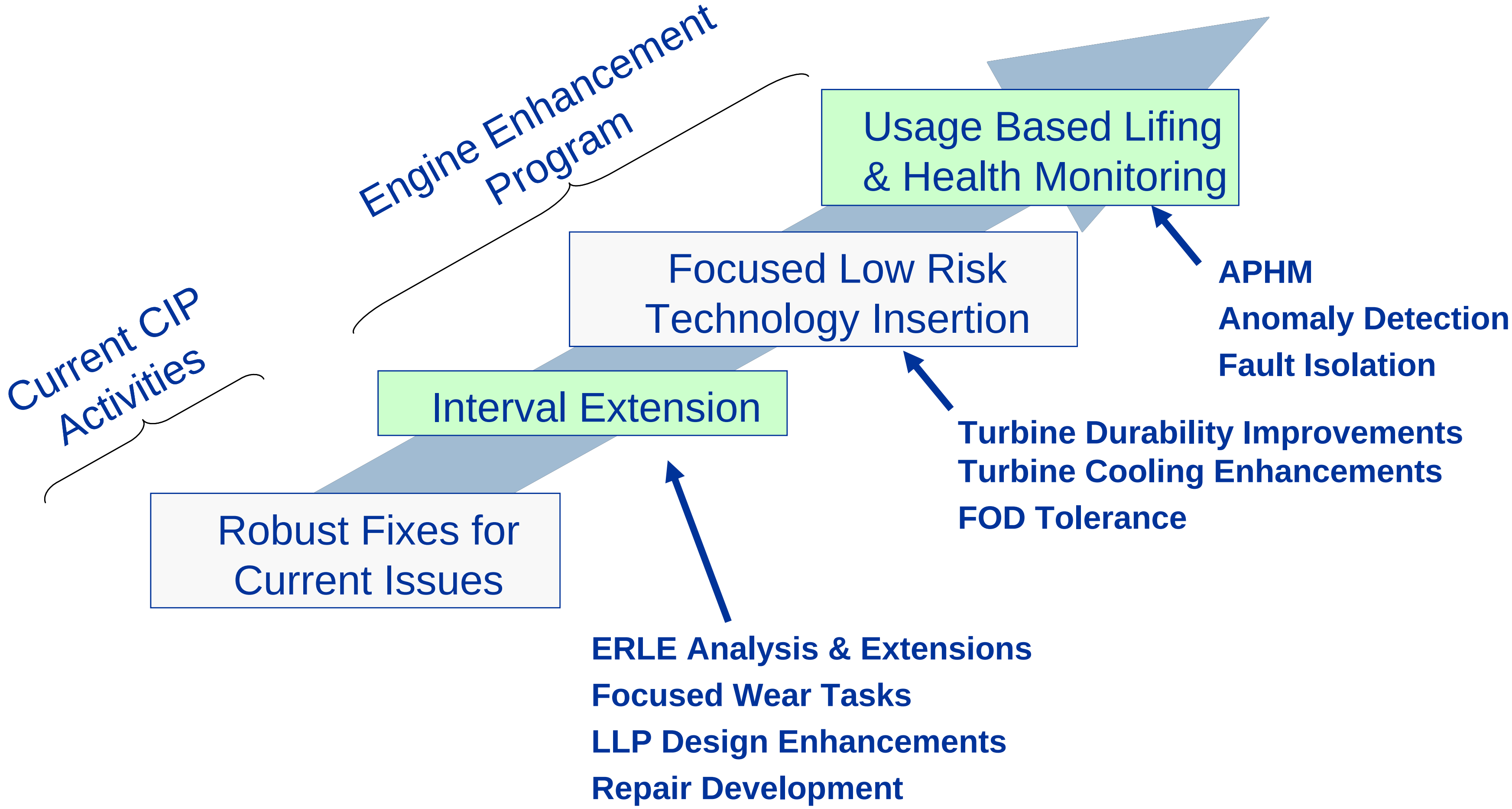
F100 HPT



F100 HPC

F100-PW-229
Engine Enhancement Package (EEP)

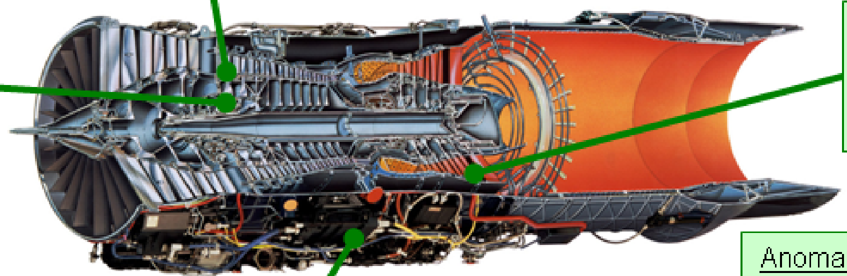
EEP Builds On Lifing Advancements Along with Robust Configuration of Current CIP Tasks



Prognostic Health Monitoring

Substantial improvement possible in all ELMP categories with EHM

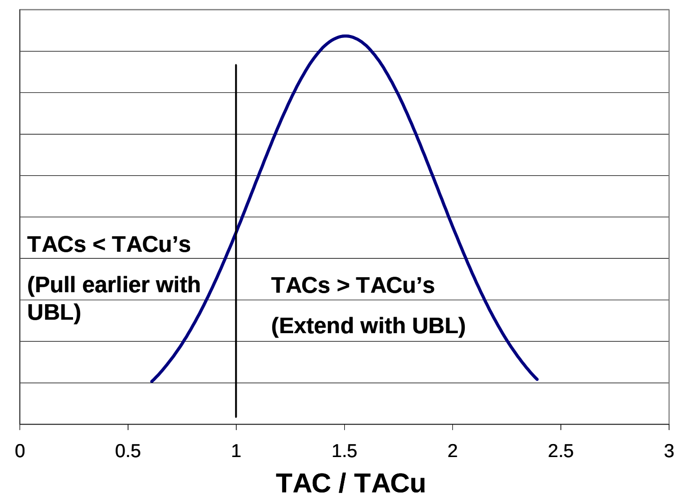
	EHM Tools Benefits (CIP & EEP as baselines)			
Fleet Metric (-220/-229)	*Usage Based Lifing* (life limited parts)	*Anomaly Detection*	*HCF Airfoil UBL*	*Turbine Durability UBL*
ETOC ($M)	√	√	√	√
IFSD/100K	√	√		
MMH/EFH		√	√	√
MTBR (EFH)		√		
UER	*Increased Rate*	*Positive Impact*	*Prediction Only*	*Prediction Only*
SER	*Positive Impact*	*No Impact*	*No Impact*	*No Impact*



Usage Based Lifing

Usage Based Lifing Extends Time Between Scheduled Depot Visits

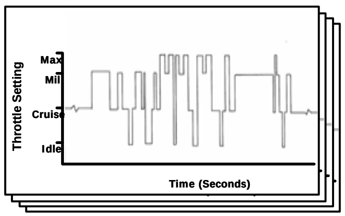
- Conventional TAC or cycle based lifing estimates the life used by comparison to conservative design missions
- Usage Based Lifing calculates the life used for each engine, each LLP, based on actual usage ("TACu")



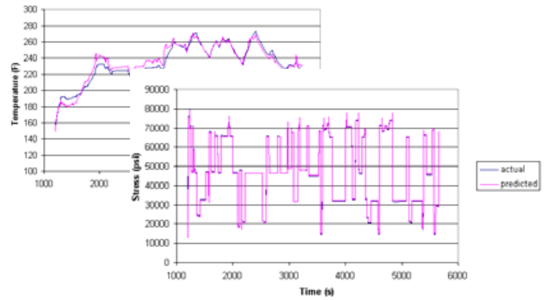
Studies have shown that the majority of engines are flown "easier" than design missions

- Actual TACs ("TACu's") were less damaging than the conservative design mission TACs
- On average, engines could have flown 50% longer to reach design mission damage

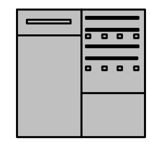
Definition of TACU - LCF



Continuous Data
Continuous data from engine control system and engine model



USAGE ALGORITHMS
Convert Continuous Data to Stress and Temp



LCF SYSTEM
Converts T, σ to LCF Life

TACU will have equivalent damage as a TAC as defined by the deterministic design for a location / mode (LCF / FCGR).

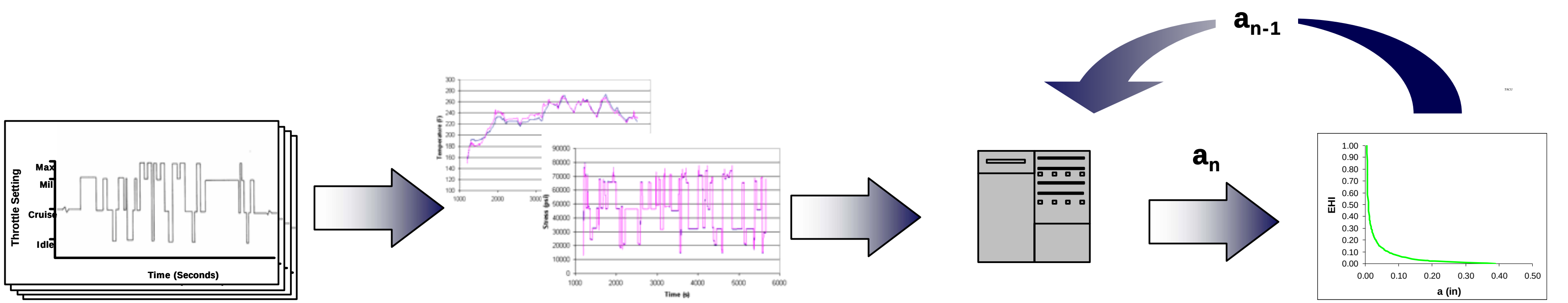
$$D_n = \frac{1}{Nf}$$

$$D_{cum} = \int_0^n D_n$$

$$TACU = TAC_{DESIGN} * D_{cum}$$

N_f – Cycles to Failure, D_n – Damage Cycle n, D_{cum} – Damage Cumulative, TAC_{DESIGN} – Design life in TACS

Definition of TACU
Fatigue Crack Growth (FCGR)



Continuous Data
Continuous data from engine control system and engine model

USAGE ALGORITHMS
Convert Continuous Data to Stress and Temp

FCGR SYSTEM
Converts T, σ to crack growth (a)

$$EHI = f(a, a_{crit}, n_{crit})$$

$$TACU = TAC_{DESIGN} * EHI$$

Engine Health Indicator
Generated during design phase provides basis for Remaining useful life

In Crack Growth, unlike LCF, a prior flights starting flaw size is required to calculation the current flights crack growth.

F100-PW-220 Qualitative Observations

Focus On Development Of Oxidation/Erosion Algorithms

OXIDATION/EROSION

- Dominant distress mode for HPT airfoils
- Empirical correlations based on burner rig testing

CREEP

- Empirically derived

TMF

- Not a driver in F100 fleets

Combinational ITADS Identifies Anomalies

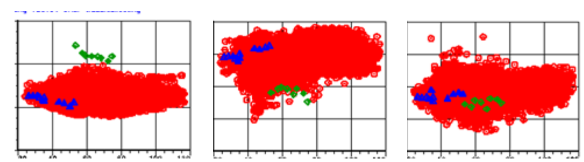
Continuous Improvement in Anomaly Detection and Fault Isolation

Recorded data shows potential to streamline the troubleshooting procedure, save cost and time, avoid engine events.

- Temperature Sensor Fault
- Compression System Bleed Anomaly
- Anti-Ice System Anomaly
- Variable Compressor Vane Anomaly

1) Fault detected

2) Performance trends analyzed



3) Symptoms analyzed, pattern matched

Parm1 ↑	Parm2 ↓	Parm3 ↔

4) Isolate source: Compressor Bleed Anomaly

5) Direct Maintenance

F100-PW-220/E/229 Engine Life Management Plan and Part Lifing Programs

Summary

The F100 Engine Life Management Plan (ELMP) activities continue to extend the engine design life (bathtub curve)

P&W continues to evolve lifing strategies to extend useful part lives

EHM scheduled for field demonstration leading to incorporation of an advanced PHM system

F100

Powering Freedom