Advances in Engine Prognostics

Engine Advances Track

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Presented By:

Link C. Jaw

Scientific Monitoring, Inc.

8777 E. Via de Ventura Dr., Suite 120

Scottsdale, Arizona 85258

link@scientificmonitoring.com

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Historical perspective – control complexity

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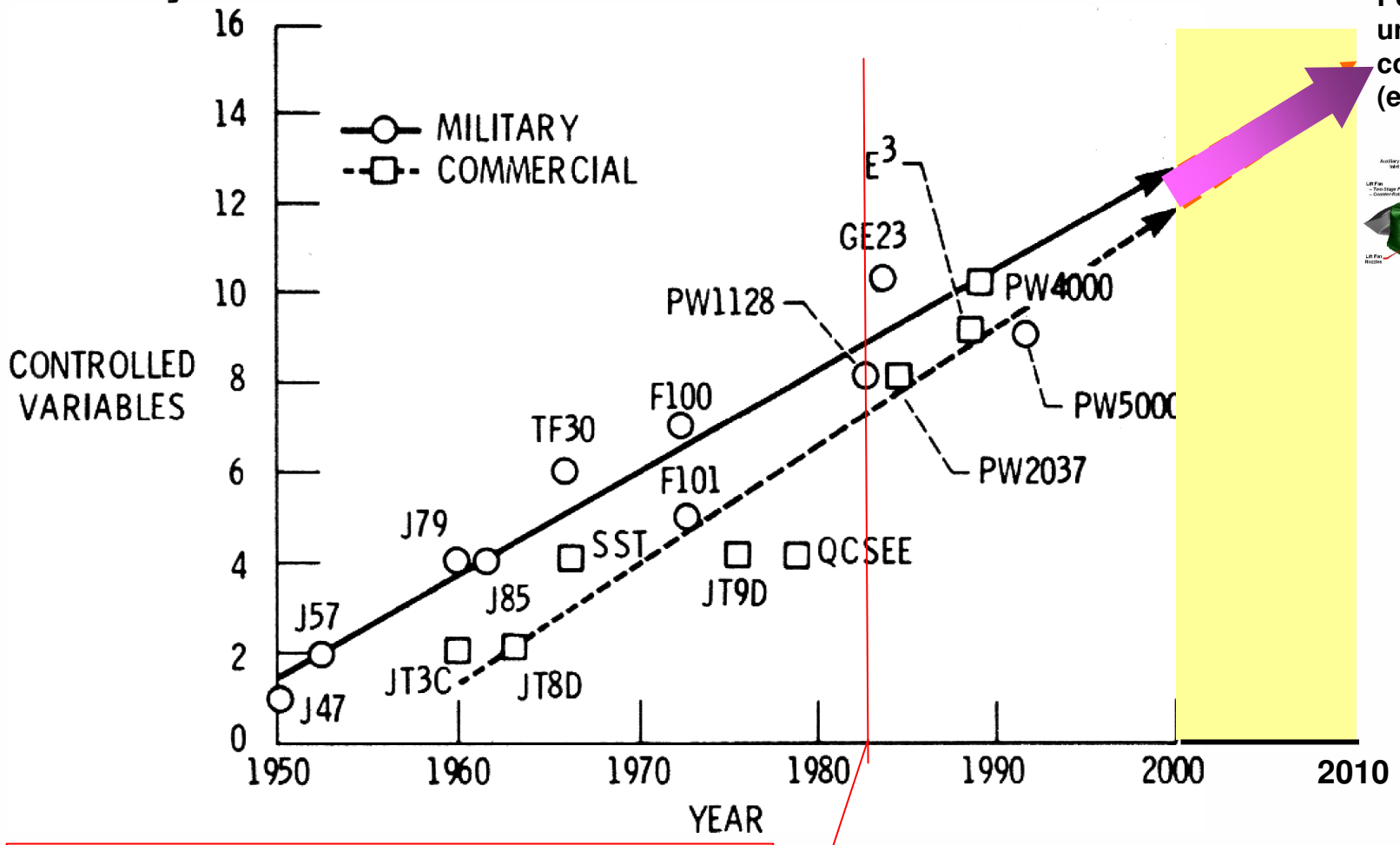
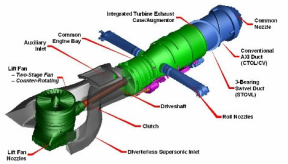


Possible with unconventional configurations (e.g., F135)



Ref.: Merrill, W., Lehtinen, B., and Zeller, J., "The Role of Modern Control Theory in the Design of Controls for Aircraft Turbine Engines," *Journal of Guidance, Control, and Dynamics*, Vol. 7, No. 6, 1984.

Historical perspective – monitoring capability

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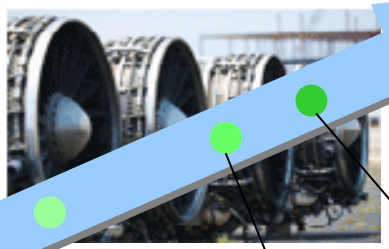
Know what to fix before it breaks

Fix when it broke

GE I-A

JT-9D



CFM56

GE90

Trent 900

V2500

PW2037

1940

1970

2000

Historical perspective – maintenance technology

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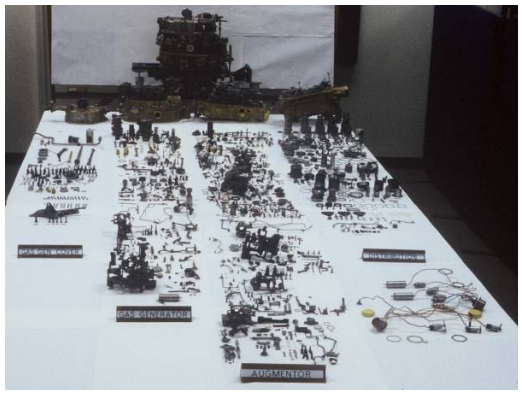
PW F-100 Fuel Control Parts



Reactive → Preventive → Predictive → CBM/PHM → **Condition-based & Reliability-centered**

Repair or fix when problems appear

Periodic/routine inspections & monitoring

Analysis of failure modes and root causes, fault prediction

Trend-based analysis, reliability analysis and improvement, logistics integration

Airplane support examples

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- A Boeing perspective – 787 GoldCare®
  - Airplane business solution
  - Improved airplane availability & efficiency
  - Reduced life cycle cost
  - Integrated material management
  - Tailored services
  - A global team of MRO suppliers

- An Airbus perspective – Tailored Support Package ®
  - Increasing fleet availability
  - Reducing operating costs
  - Full component support
  - Material & logistics
  - Tailored engineering and maintenance solution
  - MRO Network partners

Engine support examples

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- Engine OEM perspective – TotalCare®
  - Helps customers concentrate on their core business
  - Maximizing operational reliability
  - Minimizing financial risk and costs (an agreed $/FH fee)
  - Comprehensive suite of engine aftercare services:
    - Operational support
    - Repair & overhaul
    - Information & management
  - Total component and logistics asset management

- MRO perspective – Total Operations, Support, Maintenance
  - Greater aircraft availability
  - Lower costs
  - Repair & overhaul service
  - Integrated material management
  - Total support services:
    - Total Material Operations (TMO ®)
    - Total Engine Support (TES ®)
    - Total Component support (TCS ®)
    - Total Technical Support (TTS ®)

Value proposition: performance-based comprehensive support

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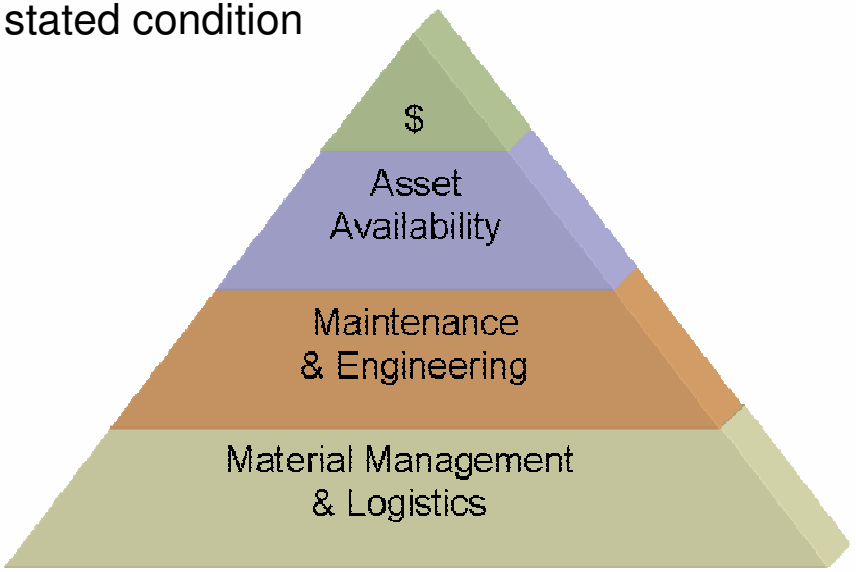
- Performance guarantees
  - Availability
    - Measure of the degree to which an engine or system is in operable state at any time
  - Reliability
    - Probability an engine or system performs its intended function for a specified interval under stated condition
- Predictable financial risks
  - Cost cap
    - Maximum amount paid for capability
  - Revenue sharing
    - Cost per usage basis ($/FH)



Comprehensive Support (CS) needs effective monitoring

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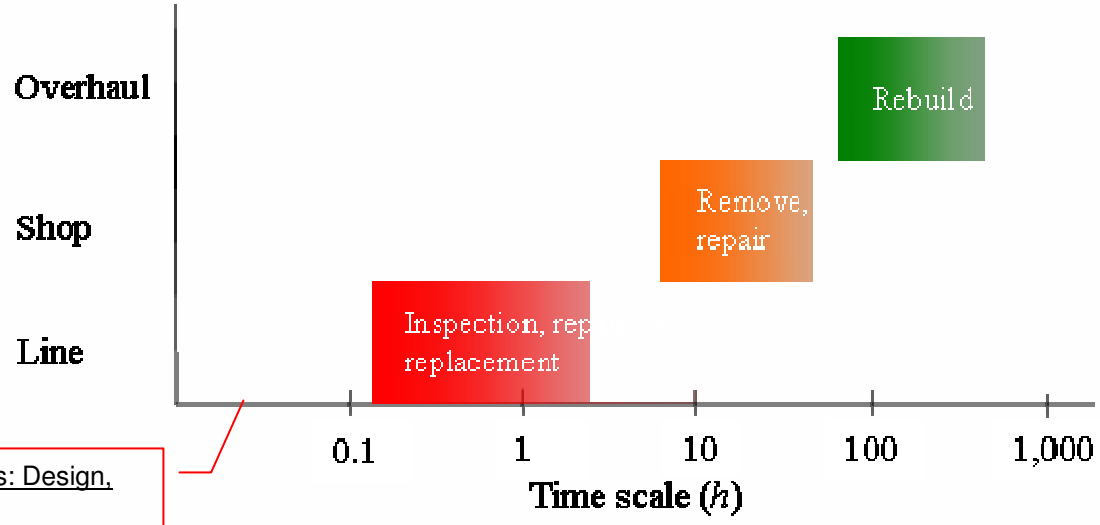
- CS requires that performance metrics (e.g., availability & reliability) are directly related to the financial outcomes
- Condition based maintenance (CBM) or Engine Condition Monitoring (ECM) capability enables CS
  - Diagnostics
  - Prognostics
  - Planning & logistics
  - Time scale of urgency



Ref: Jaw, L. C. with Mattingly, J. D., Aircraft Engine Controls: Design, System Analysis, and Health Monitoring, AIAA, 2009.

CBM means to know where we are on the capability curve

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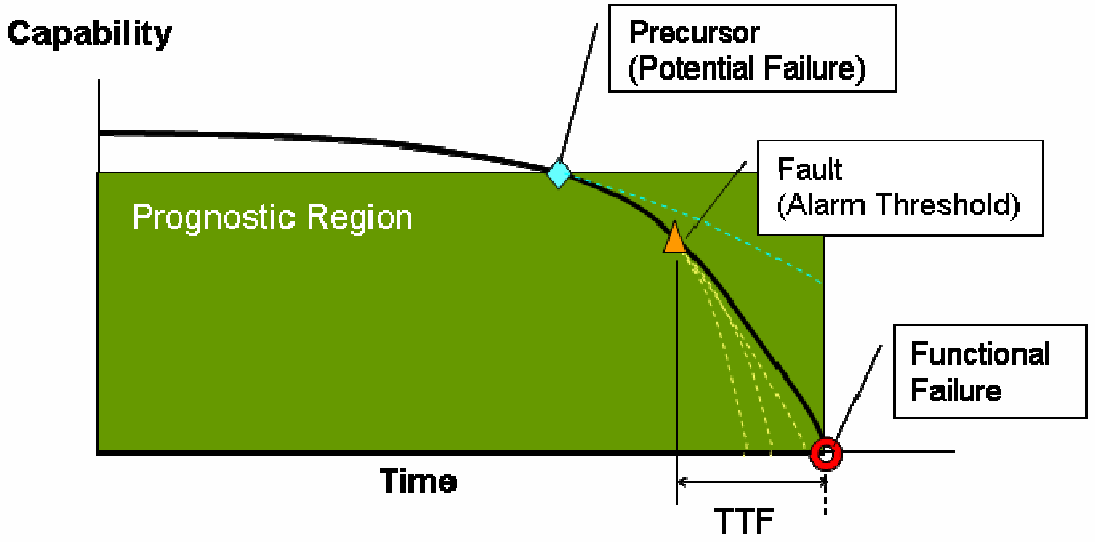
- Detect faults as soon as they are detectable
- Effective isolation to root-cause components or LRUs
- Improved prediction of failures or in-flight events
- Improved estimate of time-to-failure and remaining useful life
- Recommendations for maintenance/logistics and operations



Prognostics is a risky business

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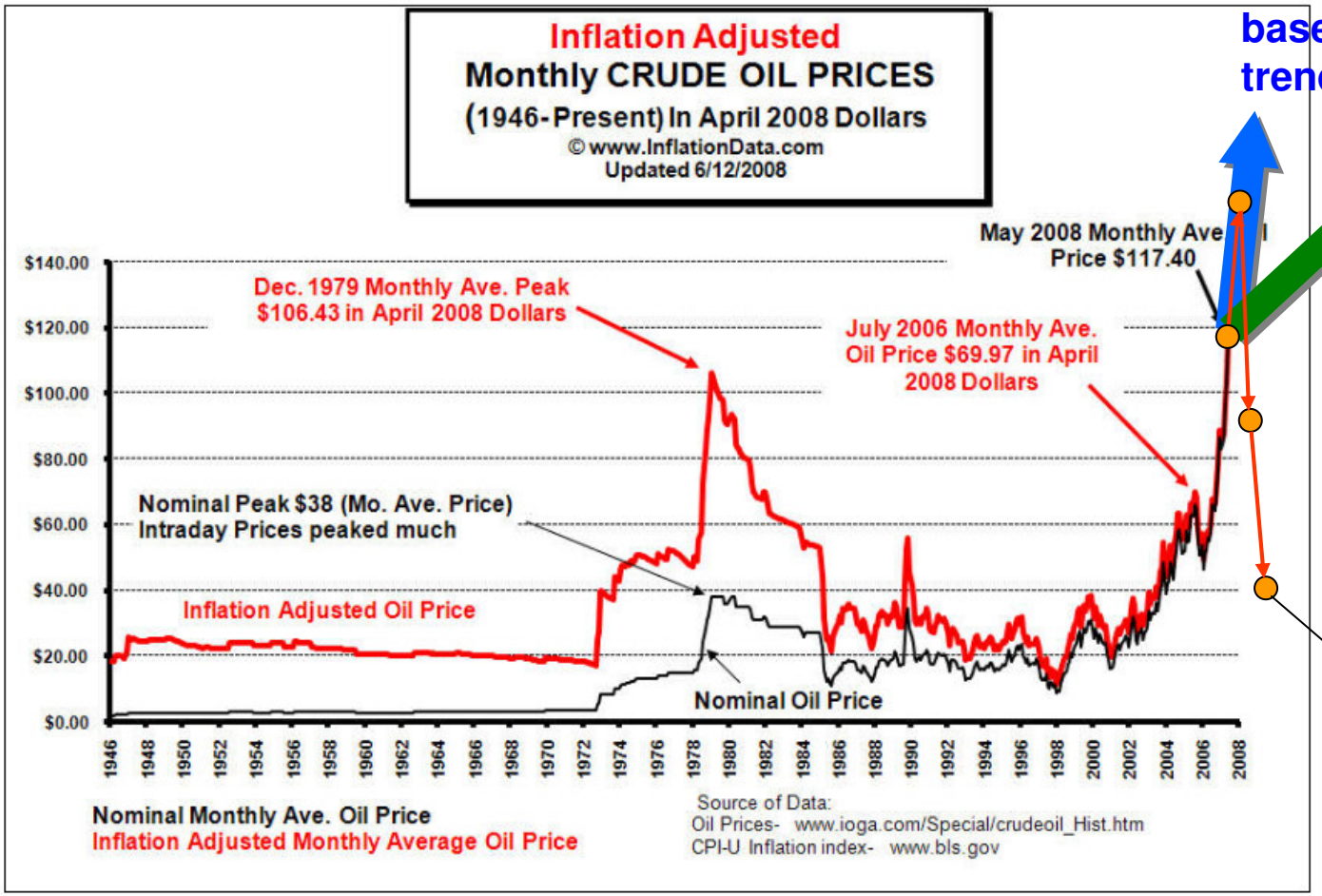


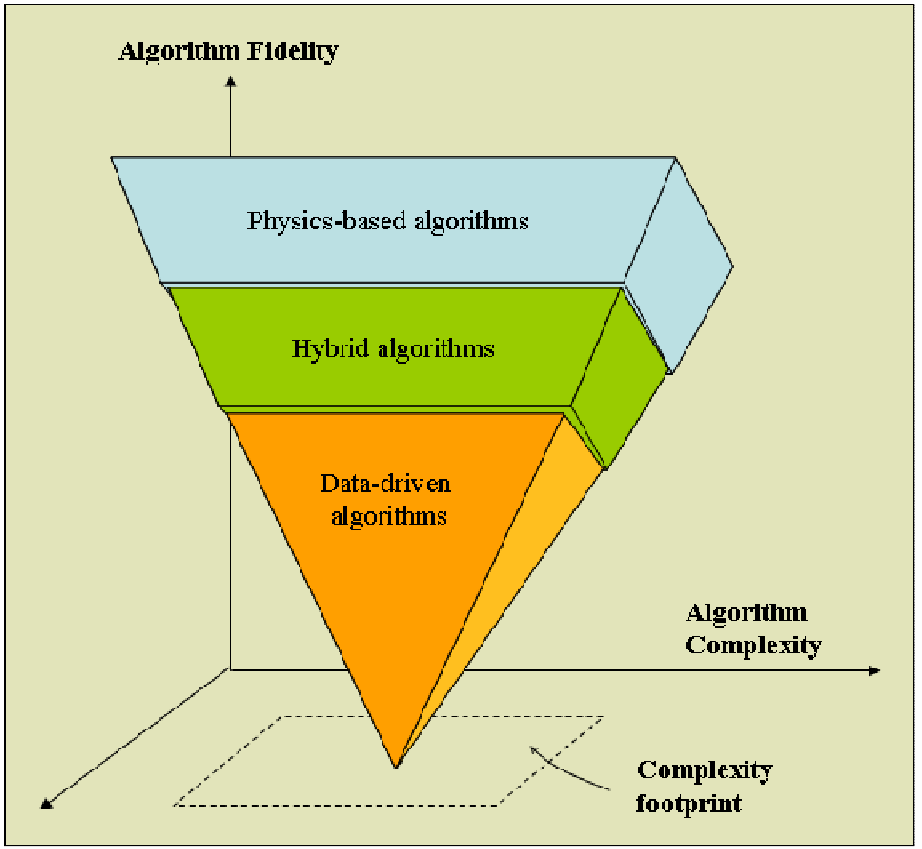
Prediction based on 2-yr trend

Prediction based on 10-yr trend

You know what has happened!

How to improve prediction accuracy

- Need a consistent methodology
- Observe data
- Use models
- Develop rules
- Adjust models
- Adjust rules
- Contingency



Data-driven CBM/ECM example – Part A

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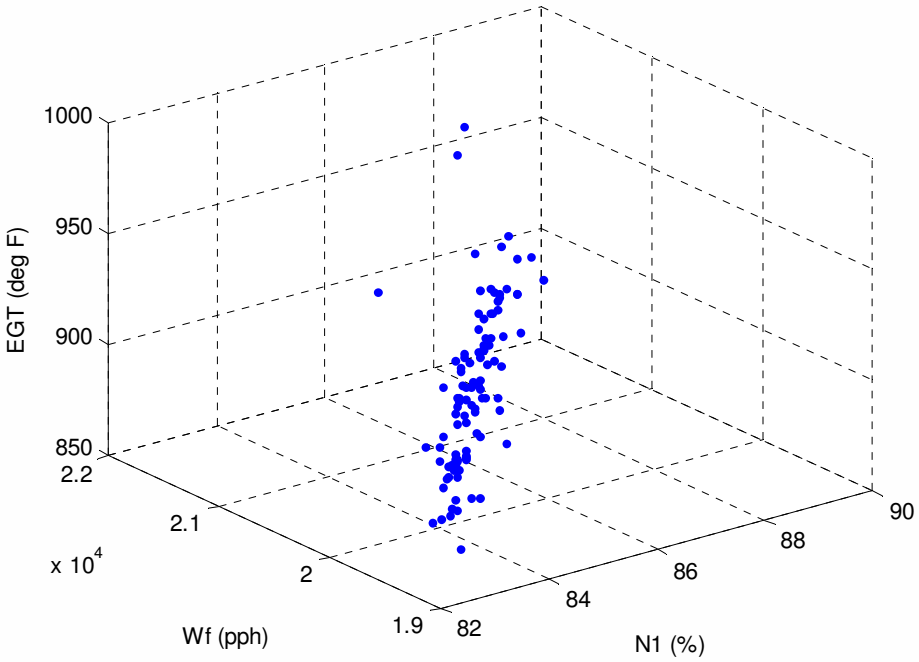
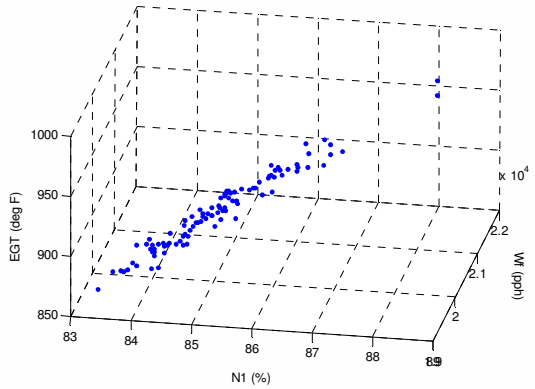
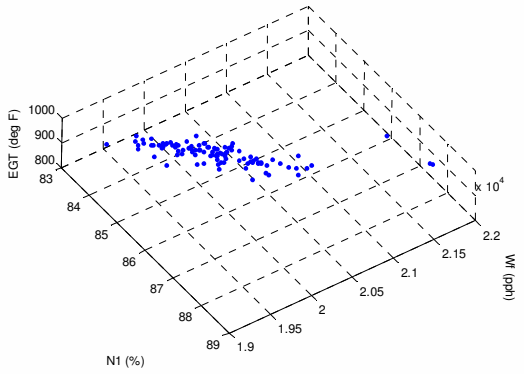
- Put data in a multi-dimensional space
- A simplified example: 3 engine variables (N1, Wf, EGT)

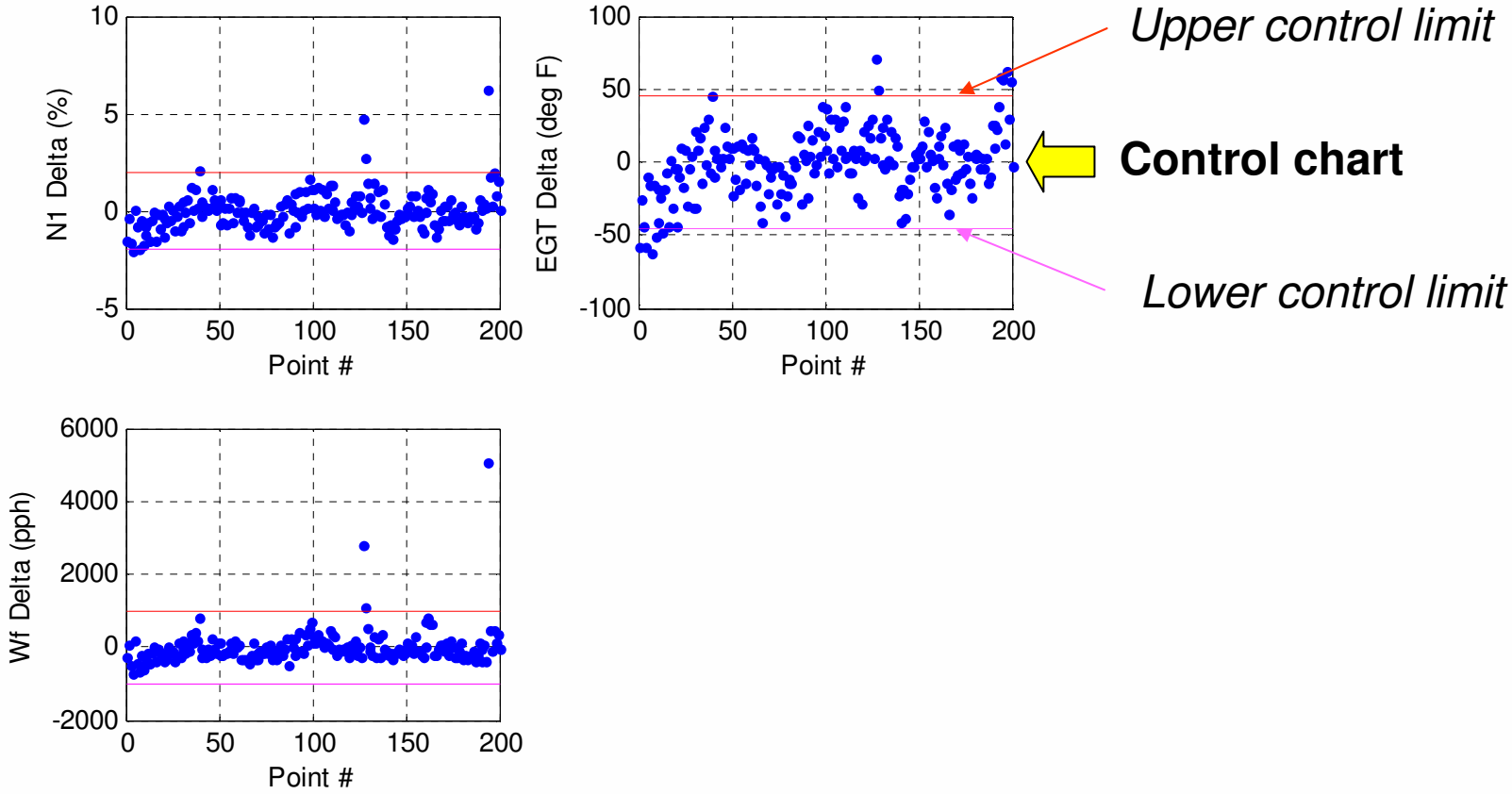






Data-driven CBM/ECM example – Part B

- Create a trend chart for the residual of each variable
- Set alarm thresholds or control limits (red & pink lines)



Data-driven CBM/ECM example – Part C

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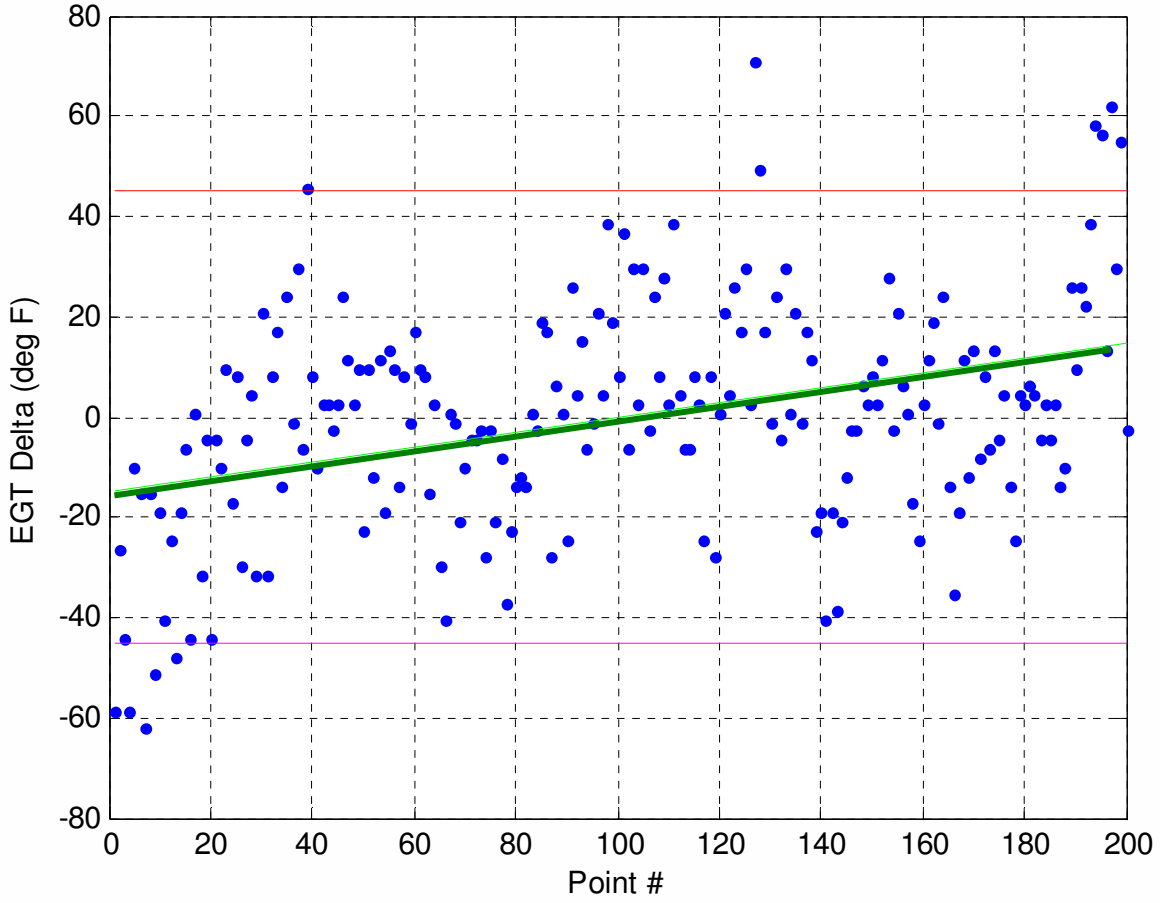
- Calculate the trend line (green line)



Model-based CBM/ECM example

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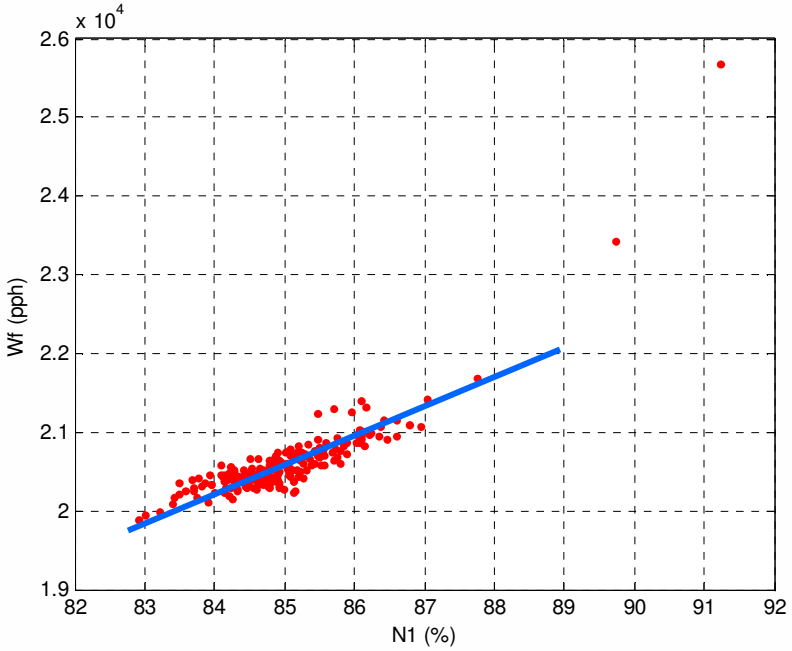
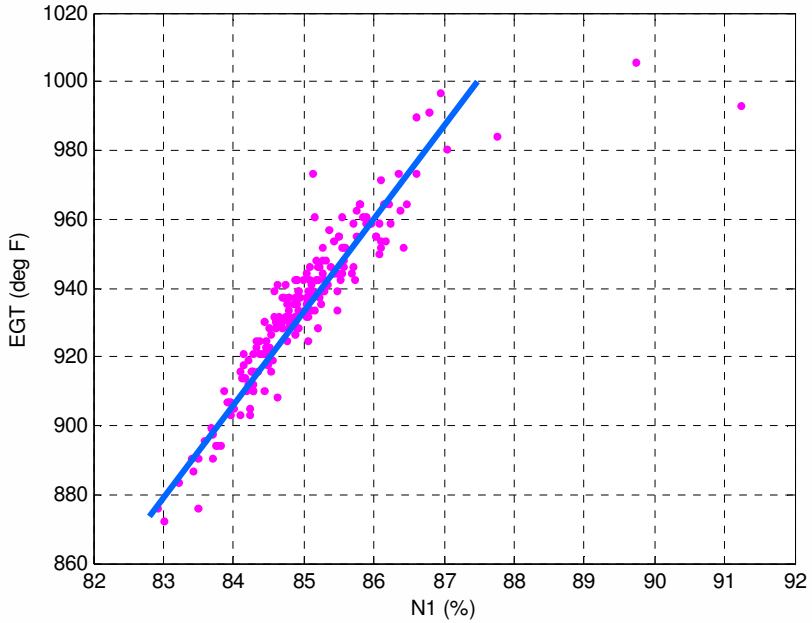
- Identify functional relationships in the form of models
- Calculate the baseline for each relationship
- Create control charts as in data-driven approach





Comparison between data-driven and model-based approaches

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- A commercial airplane example – Environmental Control System
- Monitoring accuracy is defined as the ratio of correct detection to the number of confirmed faults

Fault Type	Data-driven	Model-based
Fan air modulating valve	92%	100%
Pressure sensor	53%	80%
Ram air inlet door	20%	100%
Pressure regulator and shut-off valve	0%	100%

Conclusions

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- Airlines and operators want *guaranteed performance* and *predictable financial risk*
- MROs need to provide comprehensive support (CS)
- CBM/ECM is a key capability that aligns the two groups in a common value
- Adaptive models and agile responses provide confidence
- Integration at the vehicle/system level streamlines usability

Thank You!

SMI helps operators, OEMs, and MROs implement CS solutions

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iTrend ™ enabled monitoring solutions

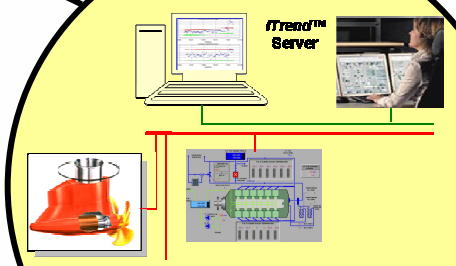
Boeing Airplane Health Management (AHM)

Monitoring Software

iTrend™

Engine monitoring

Monitoring Service



Ship power & propulsion

Monitoring Appliance

Speaker background & contact information

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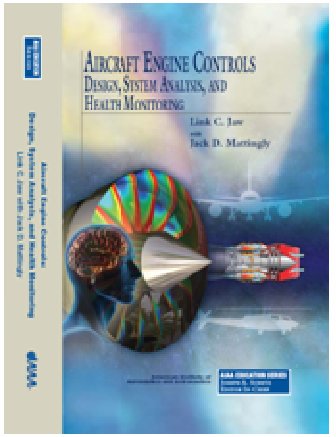
- Dr. Jaw is the President and Founder of Scientific Monitoring, Inc. (SMI)
- He has more than 20 years of industry experience in controls & monitoring
- He has been awarded 10 U. S. patents
- He used to work for Garrett Turbine Engine Company (now Honeywell Int'l)
- He received a Ph.D. in Aeronautics and Astronautics from Stanford University
- He received an M.S. in Aerospace Engineering from the Univ. of Michigan
- He completed executive management short courses at Dartmouth College
- He is the primary author of the book on Aircraft Engine Controls: Design, System Analysis, and Health Monitoring, to be published by AIAA (American Institute of Aeronautics and Astronautics) in August 2009



Contact: Dr. Link C. Jaw
President
link@scientificmonitoring.com
Scottsdale, Arizona, **U. S. A.**
Phone: +1 480 752-7909 Ext. 103