DfR Solutions

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Vehicle Prognostics to Enable Optimized Maintenance and Logistics

DfR Solutions

August 22, 2008

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Introduction

- Current
  - Diagnostics – what has gone wrong already
  - “Check Engine Light” when something goes wrong
  - Scheduled maintenance
  - Warehouse of parts
- Future
  - Prognostics – what will go wrong if not fixed soon
  - “Maintain Engine Light” when something would go wrong on the next mission
  - Material Condition drives maintenance
  - “Just in Time” Maintenance and Logistics

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Onboard Prognostics

- Sensors on mission critical components
- Onboard prognostics software
  - Lifetime prediction models
  - Wear accumulation data
- Data output capability
  - Fleet health monitoring
- Integrated material system
  - Maintenance parts arrive just in time

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Operation of Prognostics

- Complex component life prediction model
  - Physics of failure and data driven
- Data is monitored during each mission
- Cumulative wear is reported out after each mission
  - Related to product life
  - Warning can be set when life falls below a certain percent

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CONOPS – Clutch Disk

- Physical analysis reveals a harmonic on the drive shaft that varies with clutch thickness
  - 1kHz = 1" thickness
  - 2kHz = 0.5 " thickness
- A tuning fork is mounted on the drive shaft to monitor Clutch disk thickness
  - Initial thickness 1.00 inches
- Clutch consumption
  - During 1 hour paved road mission
    - 0.03"
  - During 1 hour off road mission
    - 0.09"
- When the clutch wears to a certain point (based on logistics lag time) a new clutch will be automatically ordered and maintenance scheduled
- Maintenance
  - Scheduled at 0.30" clutch thickness
  - Performed at 0.20" clutch thickness (two mission safety buffer)

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Application – Wheel bearings

- Can not monitor directly
- Life is based on many conditions
  - Stress of mission
    - Accel. and decel.
    - Rough or smooth roads
    - Abrupt shock (rocks or nearby explosions)
  - Age of bearing
  - Weight of vehicle (load)
  - Environment (heat, humidity, contamination, etc.)
- Prognostic model developed using
  - Physics of failure
  - Empirical data
- Sensors on vehicle to monitor enough data to feed model
- Life consumption based on operational characteristics of each mission
- Logistics details selected by user
  - Parts ordering at XX% of life
  - Maintenance scheduled at XX% of life
  - Maintenance performed at XX% of life

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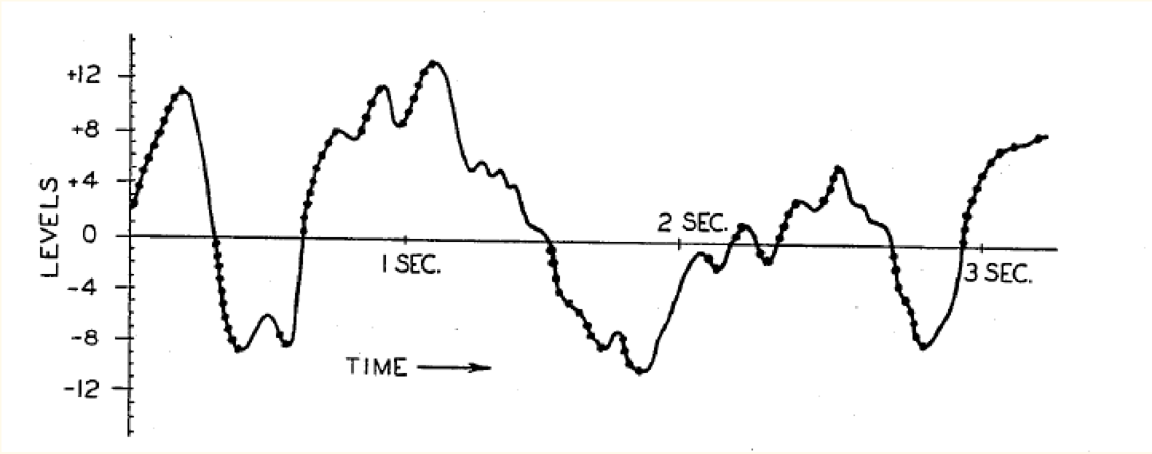
No Two Missions are Alike

- The mission stress profiles vary from minute to minute
- It is impossible to make an accurate estimate (it is possible to make a worst case estimate)
- Worst case estimate results in frequent, unnecessary maintenance



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Degradation Modeling

- A Physics of Failure model can be made for any wearout mechanism
- Bearings:

$$L = \left[\frac{f_c Z^{a_1} D_a^{a_2} \left(i \cos \alpha \right)^{a_3}}{P} \right]^p$$

  - Z = number of balls
  - Dn= ball diameter in inches
  - i=number of rows
  - α = contact angle
  - *P* =bearing load in pounds – measured by a sensor
  - *L*=number of million revolutions that a specified percentage of bearings will fail, if the percentage is 10 then L=L10 and is termed the rating life – measured by a sensor
  - *p, a1, a2, a3, a3, fc,* are unknown parameters that must determined from available data – measured by sensors

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Applicability

- Cumulative damage models based on Physics of Failure can be applied to virtually any circumstance
  - Electronics
    - Circuits
    - Packages
    - Boards
    - Modules
  - Mechanics
    - Dynamic systems – engines, suspensions, actuators
    - Statics systems – spars, airframe/seaframe, bridges
  - Complex systems
    - Electro-hydraulic

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Logistics System Integration

- Vehicle prognostics integrates with logistics system
  - Automate Just In Time Logistics
  - Parts ordered to arrive immediately before maintenance operation
- Reduced warehousing for common maintenance items
- Reduced maintenance costs as component life lengthened through continuous monitoring

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Implementation

- Existing Systems
  - Sensors integrate seamlessly at major system interconnections
  - Phased implementation
    - Sensors and onboard computer
    - Wireless Data Integration
    - Logistics integration
- New Start
  - Build in the entire system
  - Interface with existing logistics software

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Summary

- Onboard Prognostics based on Physics of Failure allows
  - Just in time maintenance
  - Just in time logistics
- Reduces mission risk
- Reduces downtime
- Reduces warehousing costs
- DfR Solutions develops mission specific:
  - Prognostics
  - Sensors
  - Software
  - **Solutions**

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Best Regards,
Dr. Craig Hillman, CEO

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