Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

Helicopter Fatigue Life Monitoring in the 21st Century

Symposium on

Condition-Based Maintenance
for Highly Engineered Systems

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Life Cycle

OPERATIONAL USAGE

DEGRADATION
time
loads
environment
(corrosion, erosion,
humidity,
temp. etc.)

Fatigue Life Monitoring
is Looking at...

REMEDIES
sched. maintenance
periodical inspections
operational limitations
replacements
repairs/mods
finite lives

…Safety,
Economy,
Readiness…

Fatigue Life

- **On-Condition Items**
  - ‘Damage Tolerant’ design
  - periodical inspections and repairs (if necessary)
  - non-finite fatigue life
  - finite economical life
  - inspection intervals based on operational usage estimate (done by manufacturer)
- **Lifed Items**
  - finite ‘Safe Life’
  - no in-service inspections
  - based on statistics (99%/95%-rule)
  - finite life based on operational usage estimate (done by manufacturer)

Fatigue Life

Typical for helicopter components

- **Lifed Items**
  - finite ‘Safe Life’
  - no in-service inspections
  - based on statistics (99%/95%-rule)
  - finite life based on operational usage estimate (done by manufacturer)

Fatigue Life calculation

material testing

- full scale components
- sub components
- coupon specimens

reduction factor for variance in testresults

'safe life' in number of cycles

design loads

- mission type/mix
- events per mission
- loads per event

reduction factor for variance in usage

safe 'exchange rate' in cycles/FH

Safe Life (FH)

Fatigue Life calculation

material testing

- full scale components
- sub components
- coupon specimens

design loads

- mission type/mix
- events per mission
- loads per event

reduction factor for variance in testresults

reduction factor for variance in usage

‘safe life’ in number of cycles

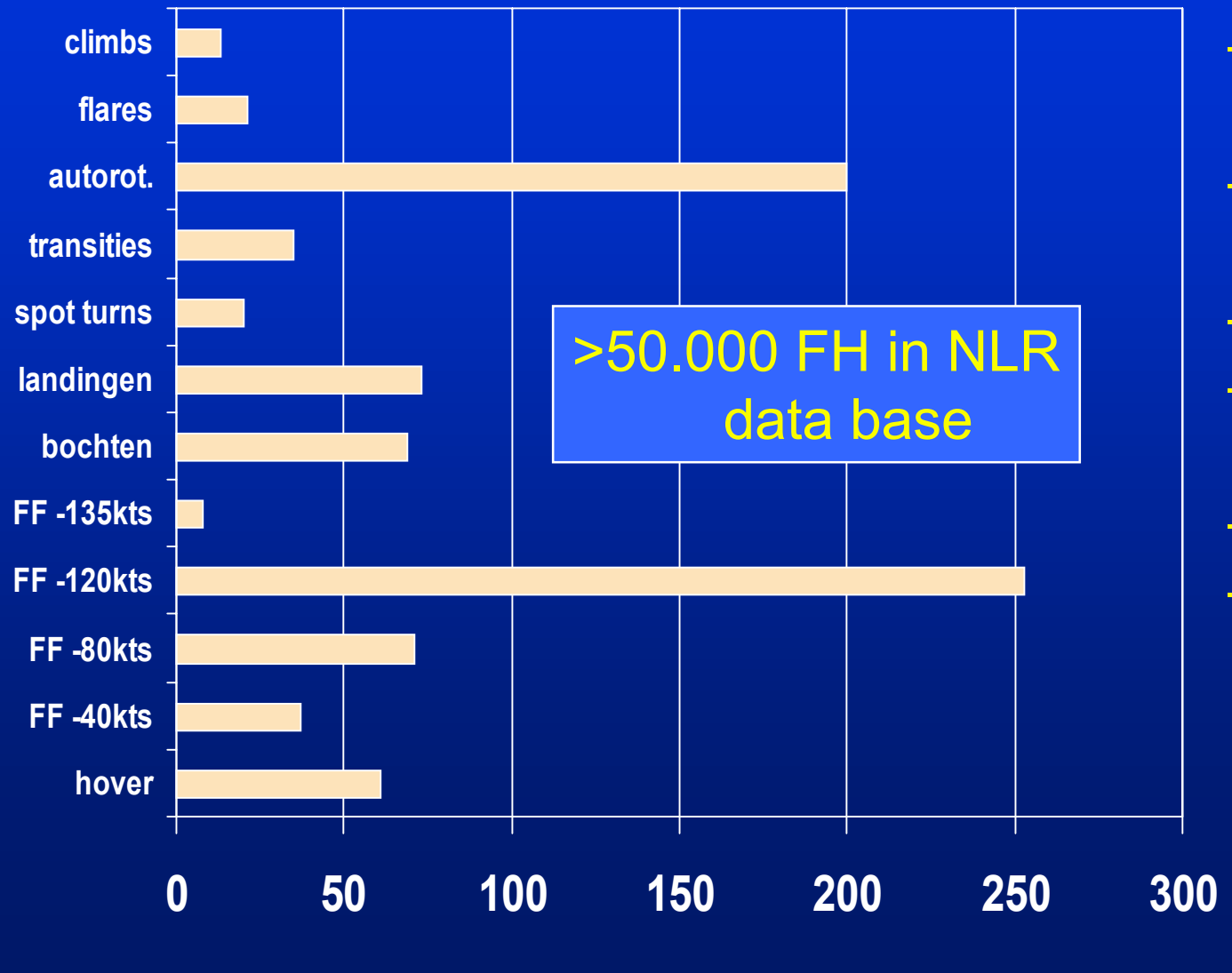
Safe Life (FH)

safe ‘exchange rate’ in cycles/FH

RNLN Fatigue Life Monitoring...

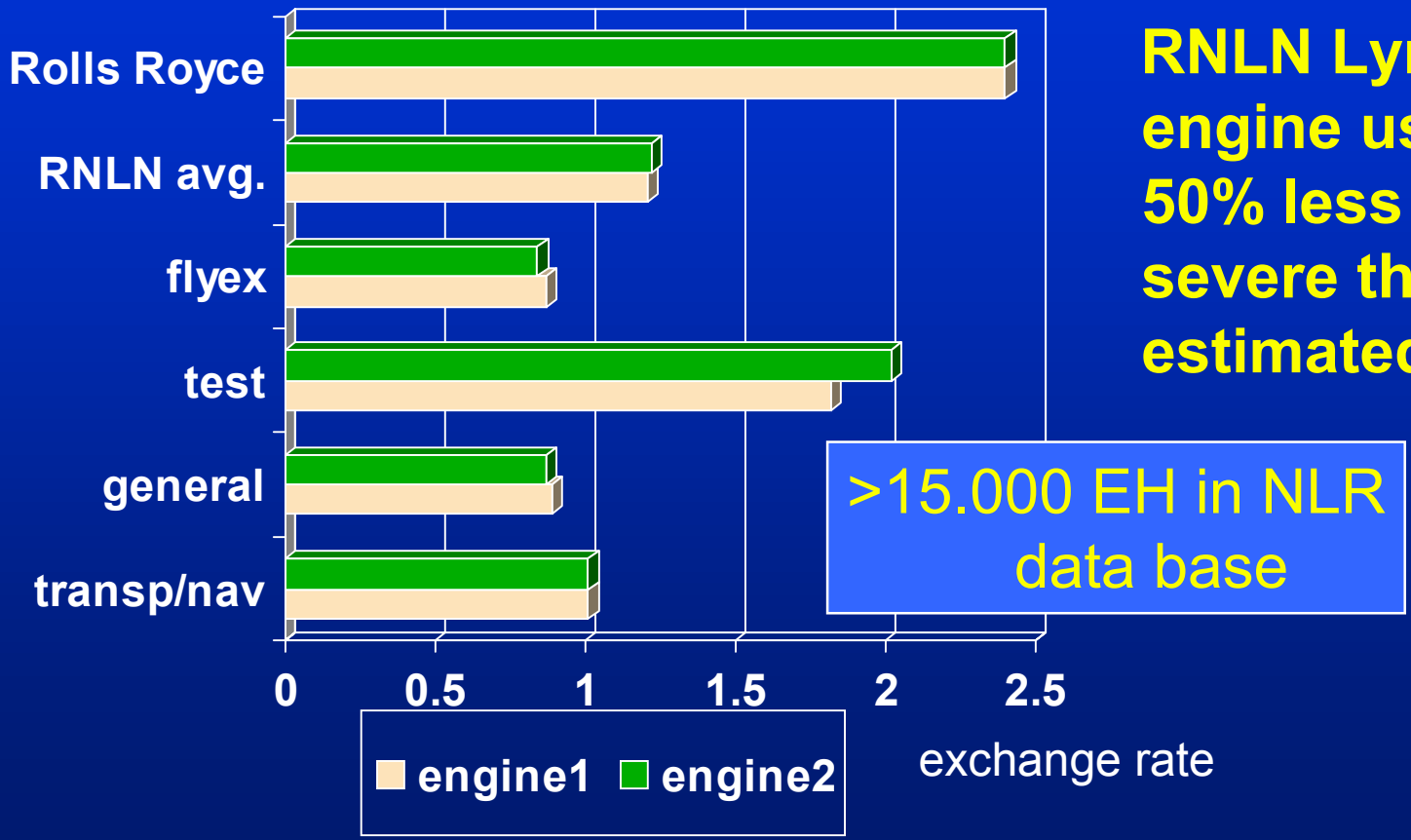
- **Lynx Usage Monitoring**
- **Lynx Gem Cyclic Life Control**
  - Rolls Royce Gem engine
- **Lynx AIDA**
  - multichannel retrofit system

RNLN Lynx Usage Monitoring



- Less high-speed flight
- less hover time
- less # Indngs
- lower ratio deck/land
- more autorot.
- more avg speed FF

RNLN Gem Cyclic Life Control



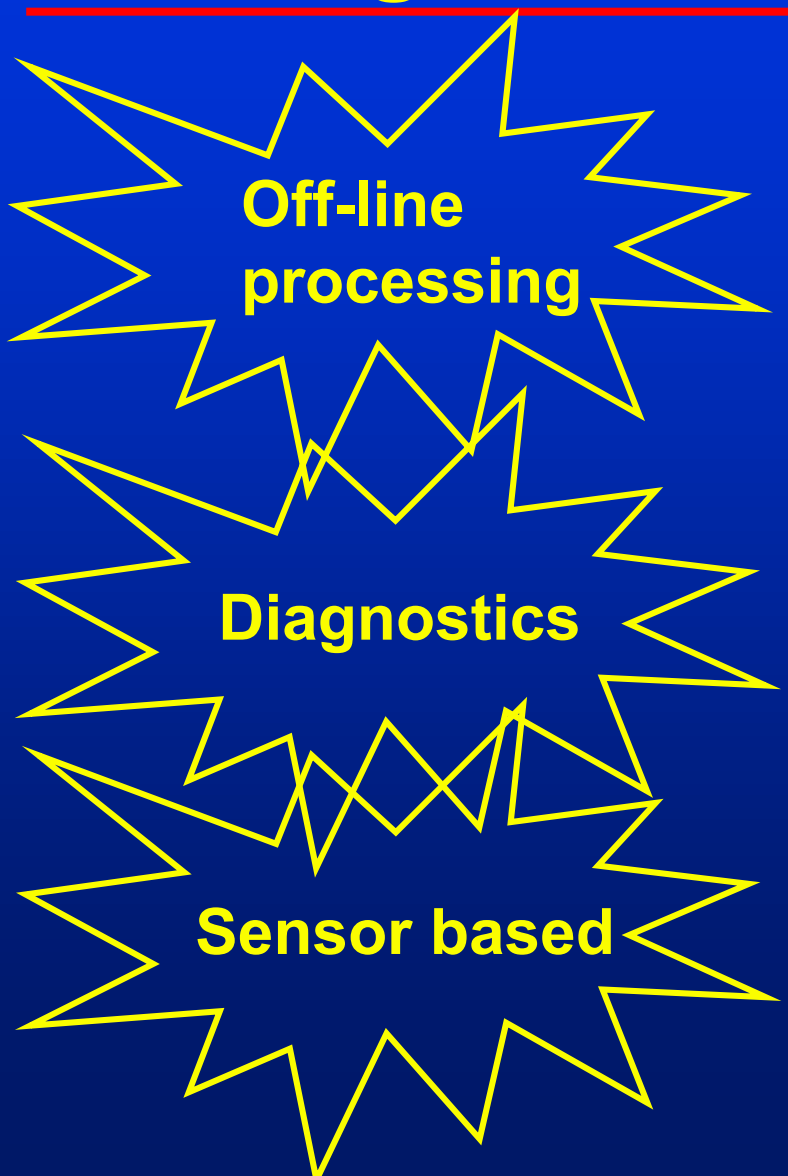
RNLN Lynx engine usage is 50% less severe than estimated

>15.000 EH in NLR data base

RNLN Lynx AIDA

- **Nr monitoring**
  - audio/visual warnings
  - signal: 1 x RPM
- **Gem engine Cyclic Life Control**
  - Individual Aircraft Tracking
  - Rolls-Royce Service Bulletin
  - signals: 4 x RPM ($Nh_{1,2}$ + $Nf_{1,2}$)
- **Usage Monitoring**
  - CLUMS data-base
  - lifting frame, sponson
  - signals:
    - 2 discretes (WoW, Radalt)
    - 15 analogue (alt, speed, φ,Nr, Nh, Nf, Tq, Sponson strains, spares)

Fatigue Life Monitoring - Now -

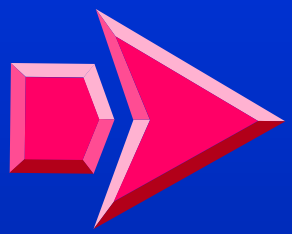


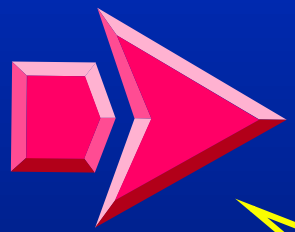
Fatigue Life Monitoring -Transition-

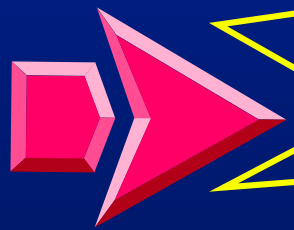
Off-line processing

Diagnostics

Sensor based







On-line processing

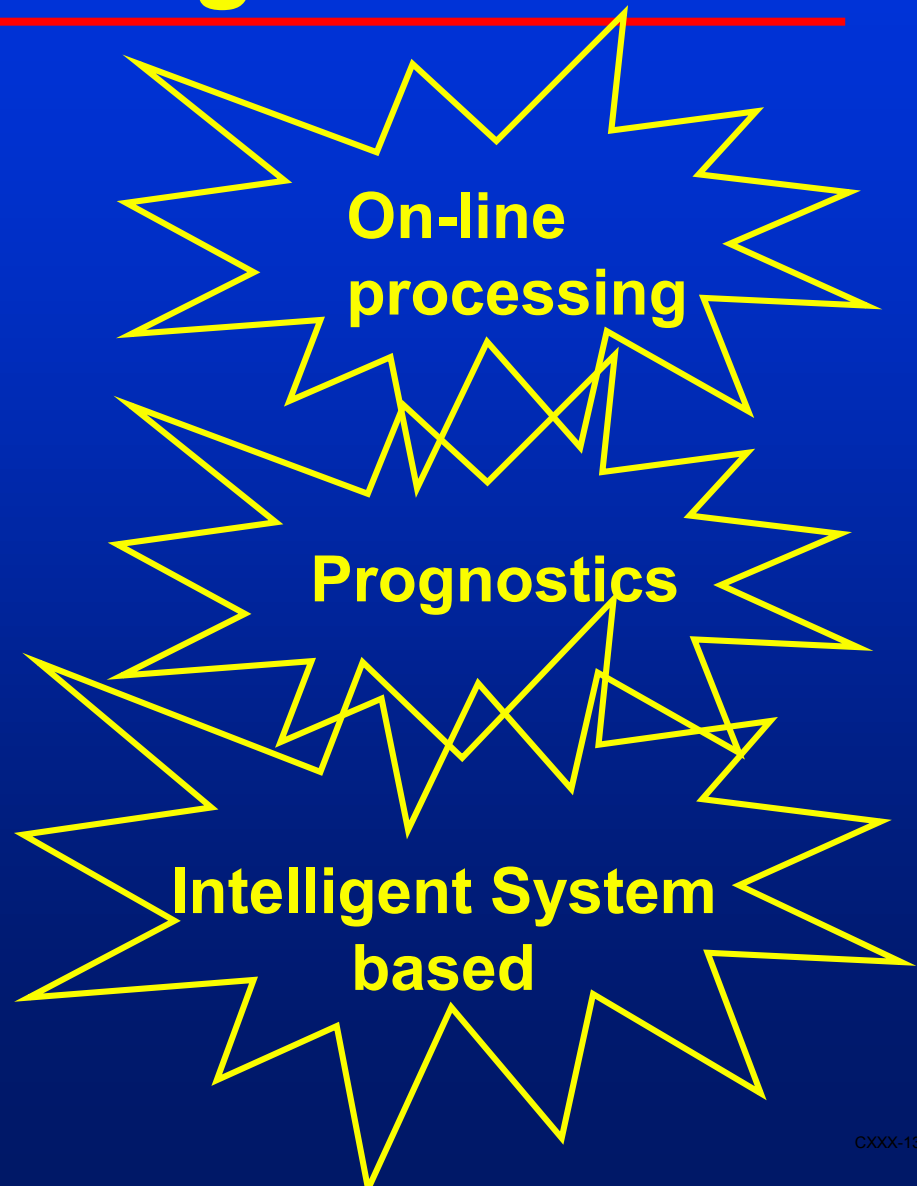
Prognostics

Intelligent System based

Fatigue Life Monitoring - Future -

Prognostics and Health Management (PHM) systems

- **Intelligent Load Monitoring ILM**
  - virtual strain sensors
  - neural networks
- **Data Mining**
  - autom. regime recognition
  - engine prognostics
- **Reasoners**
  - model, rule, case based
  - genetic algorithms



ILM example - Now -

Off-line Assessment of:

- **Landing Type**
  - deck/land
  - harpoon Y/N
- **Landing Regime**
  - running
  - MPOG
  - T.O. and Landing Weight statistics
- **Limit Load Exceed.**
- **Vibration Level**
- **Damage accumulation**

ILM example - Future -

PHM will enable:

- Elimination of strain sensors
- Strains derived from configuration, flight and environmental data
- On-line calculation of accumulated damage
- Prognostics for fleet and mission planning

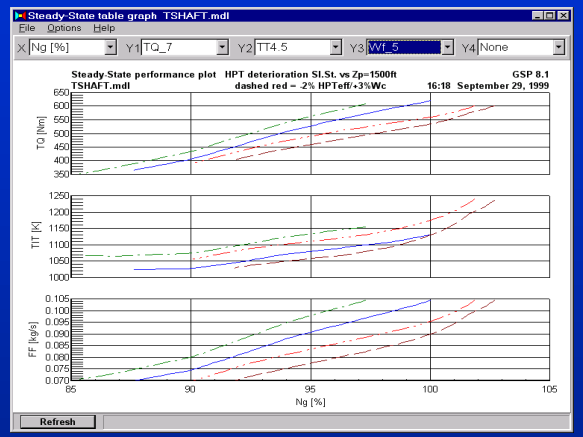
Engine prognostics

Problem: HPT Deterioration

Sea-Level efficiency - 2% with massflow +3%

Deterioration effect is hidden due to flight condition changes (causing variation in performance data)

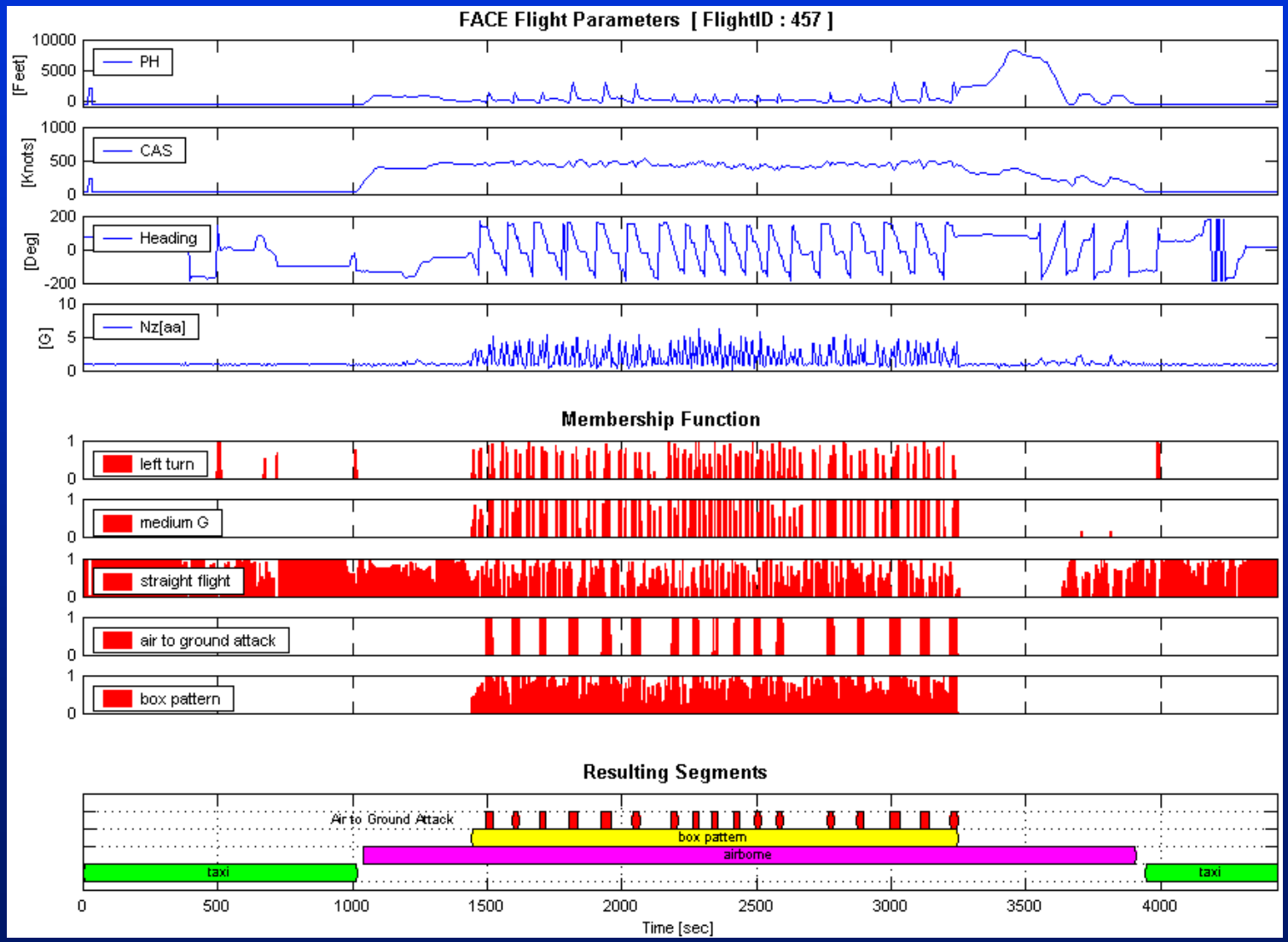
GSP Turboshaft model



Prediction of Deterioration Effects

Data Mining finds Known AND Unknown relations

Data Mining example - Fighter -



Finally

- **Better understand 20th century technology as a basis for future developments**
- **21st century goal: Transition of emerging fixed-wing PHM technologies to the rotary-wing environment**
- **R&D Structural Integrity $$ will shift from the traditional**

Mechanical and Materials Engineering

to

***IT, Quality Assurance and Certification* areas**