

## Reliability Analysis Now and Then

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## **Reliability in Theory**



Reliability (ISO/IEC 2382-14): ability of an item (system) to perform a required function, under stated conditions, for a stated period of time.

## **Reliability In Practice**



Reliability (ISO/IEC 2382-14): ability of an item (system) to perform a required function, under stated conditions, for a stated period of time.

## **Design for Reliability**





## **Reliability In Practice**



Reliability (ISO/IEC 2382-14): ability of an item (system) to perform a required function, under stated conditions, for a stated period of time.

## **Design for Reliability**



## Feeding KID for Reliability-Centered Decision Making





Input Knowledge, Information and Data (KID)

- Failure Data
- Expert Knowledge
- Physics-based models
- Monitored Signals
- Images
- Inspection Reports



**Maintenance:** When? What?

## **Reliability-Centered Decision Making for Maintenance**



## Input Knowledge, Information and Data (KID)

- Failure Data
- Expert Knowledge
- Physics-based models
- Monitored Signals
- Images
- Inspection Reports

• ...



## **Reliability-Centered Decision Making for Maintenance**

**Artificial** 

Intelligence **(AI)** 



## Input Knowledge, Information and Data (KID)

- **Failure Data** ٠
- Expert Knowledge ٠
- Physics-based models •
- **Monitored Signals** •
- Images ٠
- **Inspection Reports** ٠





# Reliability Quantification: Prognostics The Challenge

## Reliability Quantification: Prognostics $\rightarrow$ The Challenge



# Reliability Quantification: Prognostics $\rightarrow$ The Challenge KID Validation





# Reliability Quantification: Prognostics $\rightarrow$ The Challenge KID Validation















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## Reliability Quantification: Prognostics $\rightarrow$ The Challenge Confidence



Intelligence

# Reliability Quantification: Prognostics $\rightarrow$ The Challenge Confidence



### Sources of uncertainty:

1) noise on the measurements

- 2) stochasticity of the degradation process
- 3) unknown future operating conditions
- 4) Modeling error, i.e. inaccuracy of the

prognostic model used to perform the prediction



# Reliability Quantification: Prognostics → The Challenge Confidence



Mean Variance Estimator
Deep Ensemble
Monte Carlo Dropout
...

It will fail in the interval (55, 60) hours with probability 90%,



# Reliability Quantification: Prognostics $\rightarrow$ The Challenge Confidence



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# Reliability Quantification: Prognostics $\rightarrow$ The Challenge Consistency with Domain Knowledge



## Reliability Quantification: Prognostics $\rightarrow$ The Challenge Consistency with Domain Knowledge



# Predictive Reliability Quantification: Prognostics $\rightarrow$ The Challenge Explainability





# Reliability Quantification: Prognostics → The Challenge Explainability





## **Conclusion: the ESREL Answer to the Grand Challenge**



## Post-prognosis decision making, RUL control and prescriptive maintenance

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### RUL Control problem: Remaining Useful Life (RUL)



1. Remaining Useful Life, RUL(t), is a random variable that expresses the time remaining before system degradation reaches a maximum level  $D_{max}$ .

2. Assigning a given desired RUL profile requires controlling the degradation process.



#### Using Prognosis Information for Decision-Making

What do we use the prognosis information for ?

 $\Rightarrow$  Post-prognosis decision making

- Classical use : predictive maintenance decision-making
- More comprehensive use : prescriptive maintenance, i.e. managing the degradation and controlling the RUL (Feedback from system-individual remaining useful life information on the system operation)
  - At the item level :
    - Derating the system
    - Modifying its operation and control rule
    - Jointly scheduling revenue missions and maintenance actions to manage the deterioration and lifetime
  - At the fleet level :
    - Sharing the load among the fleet items
    - Taking advantage of degrees of freedom offered by the flot heterogeneity

Post-prognosis decision-making : key enabler for prescriptive maintenance in the Pronostics and Health Management framework



#### RUL controller proposition





#### RUL controller proposition





#### RUL controller proposition



How to design this RUL controller properly?



#### Simulation Results : Application to a Wind-Turbine









#### Post-prognosis Load Allocation

#### Post-prognosis decision-making strategy for a multi-stack fuel cell system



#### Jian Zuo's PhD Thesis



#### Post-prognosis Scheduling of Revenue Missions and Maintenance

## Post-prognosis scheduling of revenue missions and maintenance actions on a fleet of assets



Elodie Robert's PhD Thesis

