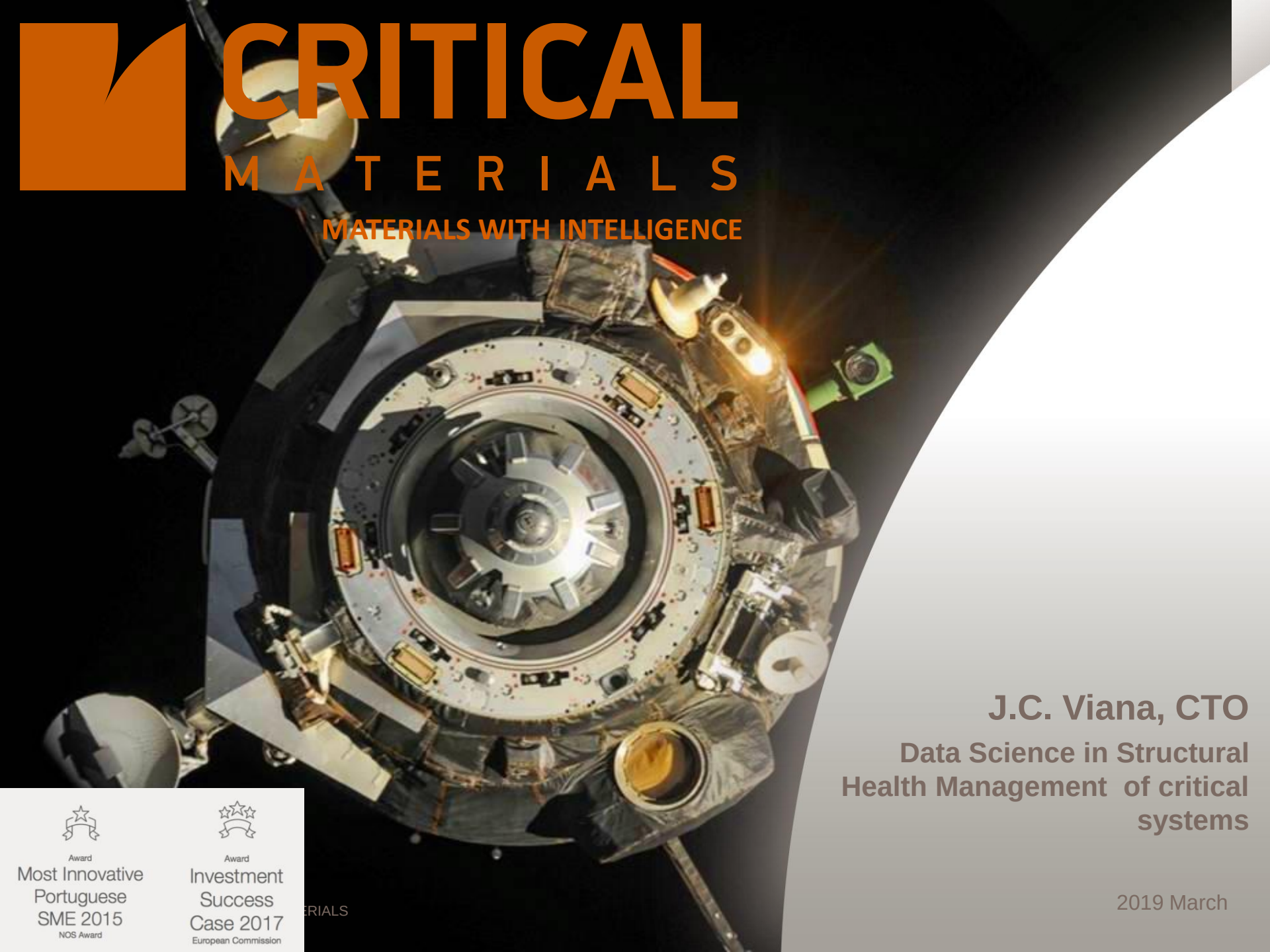
CRITICAL MATERIALS

MATERIALS WITH INTELLIGENCE



Award
Most Innovative Portuguese SME 2015
NOS Award

Award
Investment Success Case 2017
European Commission

J.C. Viana, CTO

Data Science in Structural Health Management of critical systems

2019 March

CRITICAL MATERIALS

AGENDA

1. SHM – STRUCTURAL HEALTH MONITORING

2. APPLICATION OF DATA SCIENCE

3. SOME CHALLENGES

CRITICAL MATERIALS

HAZARDS AND DISASTERS

bird strikes!

lightning strikes!

ice formation!

hail!

lightning strike!

tool drop

blade failure

tower collapse

in-flight structural failure of a F-15C

ASSETS/EQUIPMENT







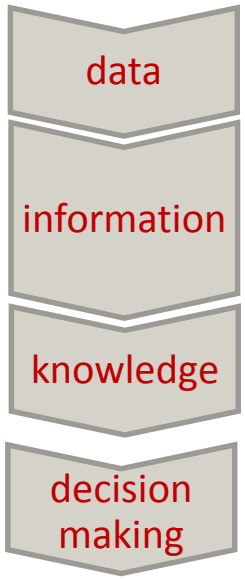

- 15% to 20% of equipment failures are age related
- 80% to 85% failures are totally time-random events, not predictable, but their start can be detectable


Failure is not an option
CRITICAL
MATERIALS
MATERIALS WITH INTELLIGENCE

SHM - STRUCTURAL HEALTH MONITORING

KNOWING THE CONDITION OF CRITICAL SYSTEMS

monitoring their behaviour	→ sensors
diagnosing their condition prognosing their conditions	→ algorithms
management of all this information	→ aggregation fusion



monitoring → diagnosis → prognosis → prescription

SHM - STRUCTURAL HEALTH MONITORING

monitoring

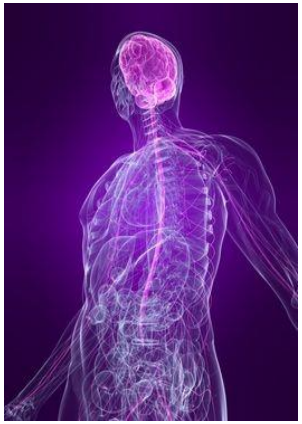
Symptoms:

- temperature
- hacke
- tiredess

Analysis:

- blood pressure
- blood analysis
- ECG

Embedded sensing system



diagnosis

Guess:

- system
- disease
- organ
- severity

prognosis

- time to get good
- next query
- remaining life

prescription

- exercise
- medicine
- therapy

monitoring → diagnosis → prognosis → prescription

SHM - STRUCTURAL HEALTH MONITORING

monitoring

Symptoms:

- temperature
- noise
- damage

Analysis:

- vibration
- oil debris analysis

Embedded sensing system

diagnosis

Guess:

- system
- fault type
- localize
- severity

prognosis

Remaining life

MTBM/MTBF

prescription

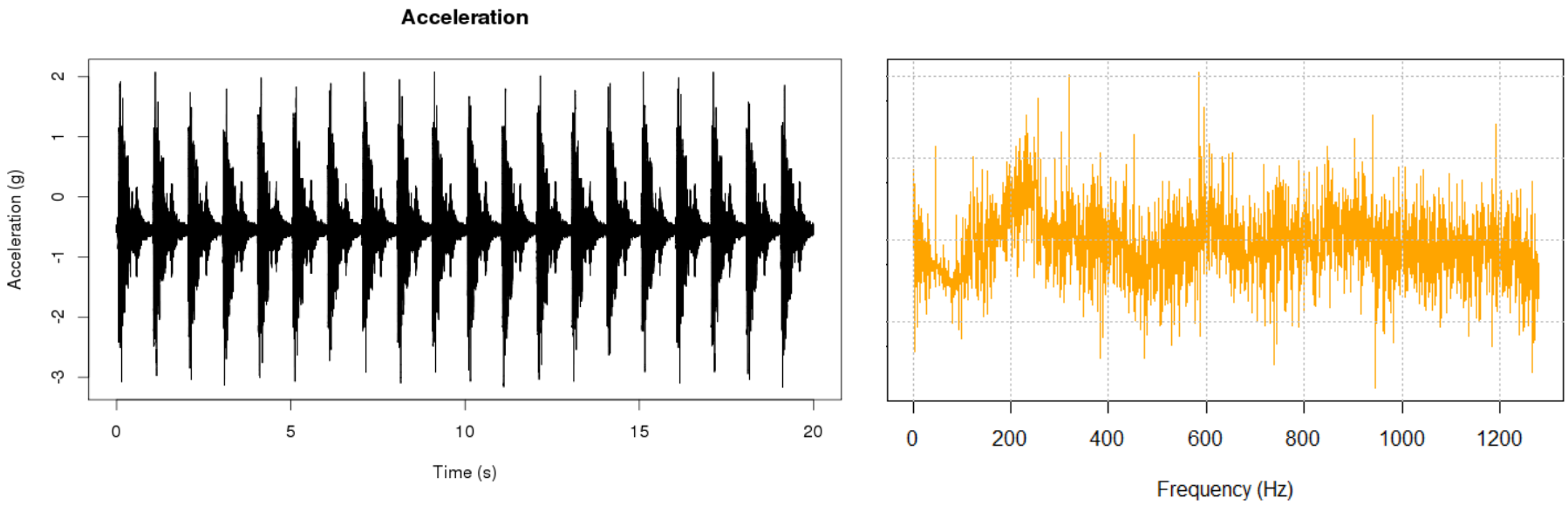
inspection

maintenance

monitoring → diagnosis → prognosis → prescription

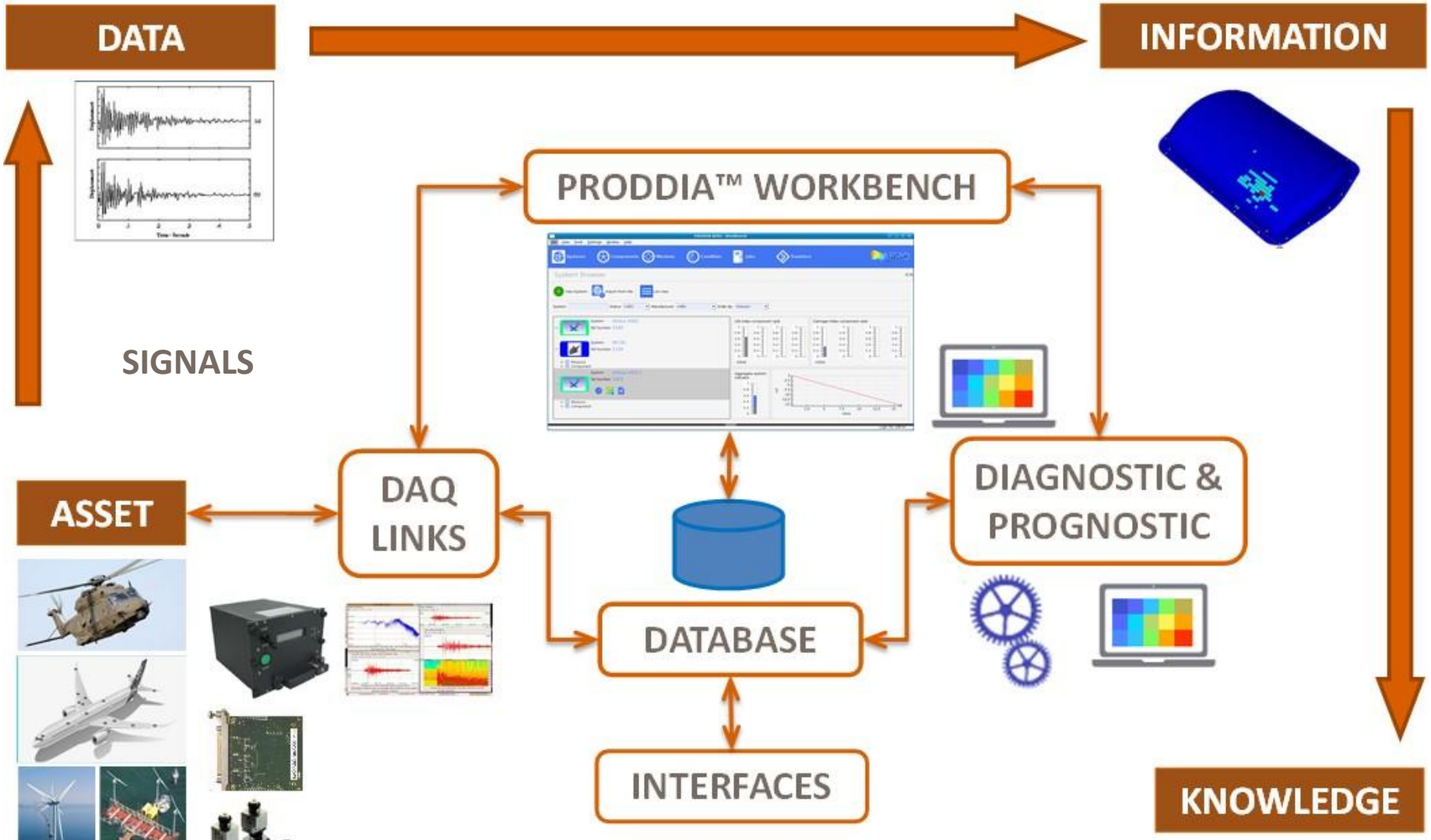

but sensors do not measure damage
CRITICAL
MATERIALS
MATERIALS WITH INTELLIGENCE

CHALLENGES I



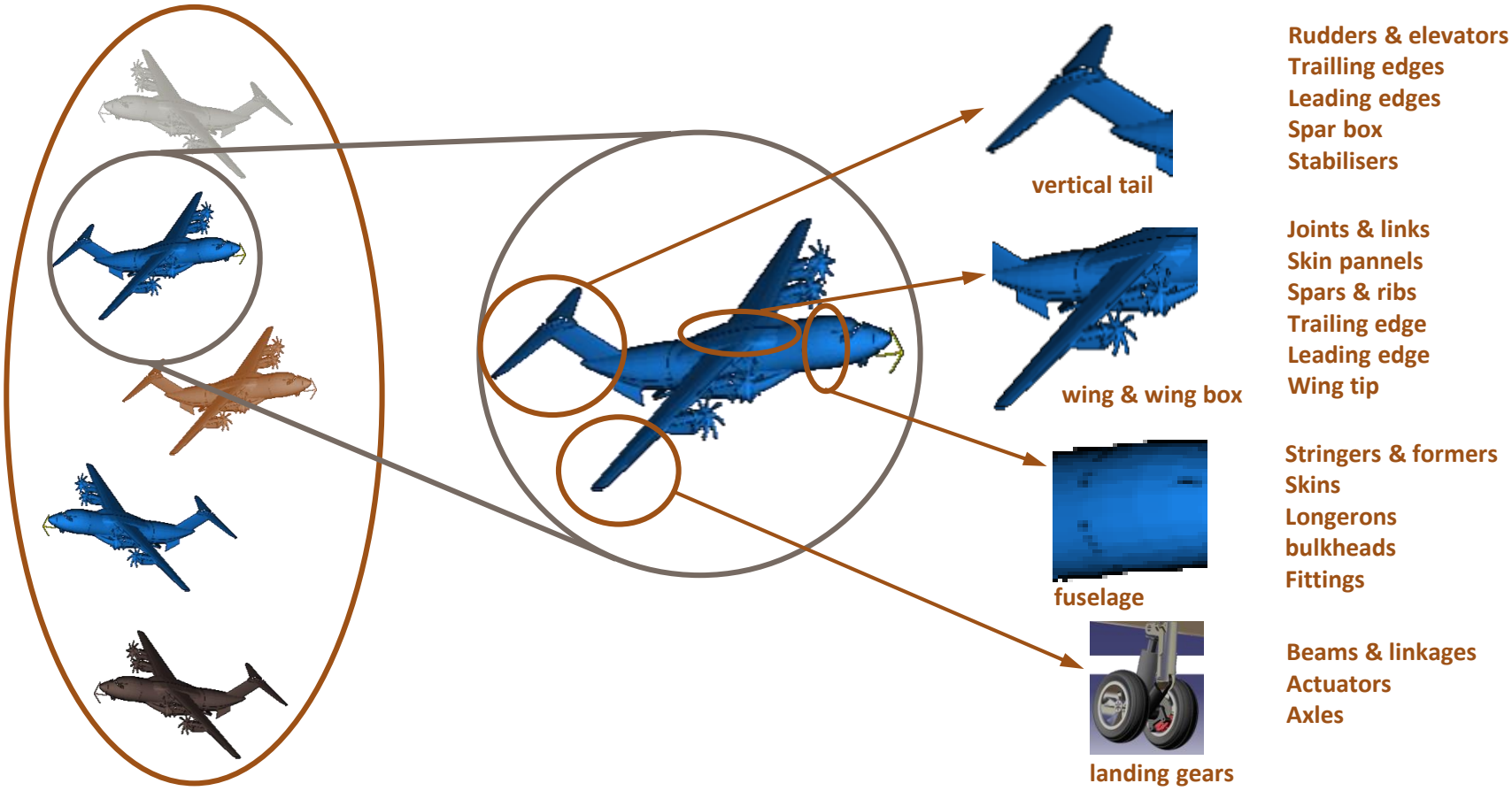
- How to transform sensor signals into valuable data?
- How to extract useful information from sensor data?
- How to detect failure / evaluate damage from sensor data?
- How to fuse data from various sensors types?

SHM - STRUCTURAL HEALTH MANAGEMENT



SHM - STRUCTURAL HEALTH MANAGEMENT

ABOVE FLEET FLEET SYSTEM SUB-SYSTEM COMPONENT



Rudders & elevators
Trailling edges
Leading edges
Spar box
Stabilisers

Joints & links
Skin pannels
Spars & ribs
Trailing edge
Leading edge
Wing tip

Stringers & formers
Skins
Longerons
bulkheads
Fittings

Beams & linkages
Actuators
Axles

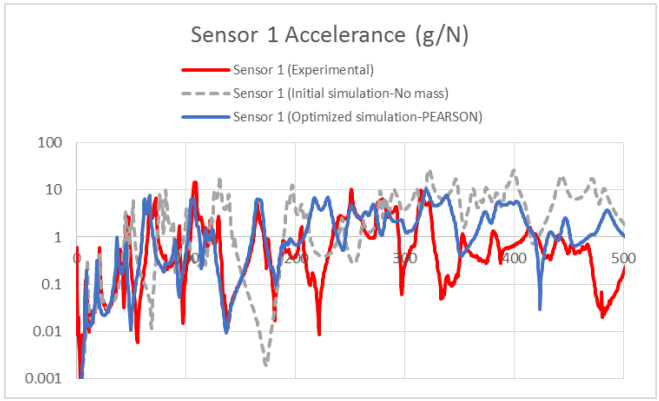
to IVHM – INTEGRATED VEHICLE HEALTH MANAGEMENT

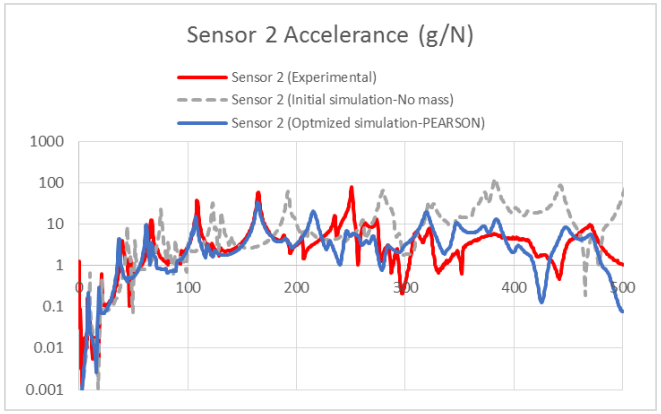
CHALLENGES II

- How to integrate physical and digital data?
- How to deal with huge amounts of data (quality, latency)?
- How to fuse data from different assets?

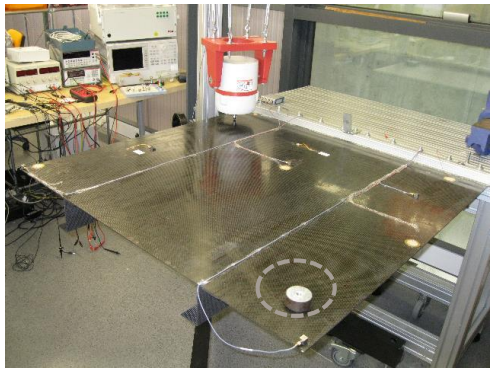
SHM AND DIGITAL TWINS

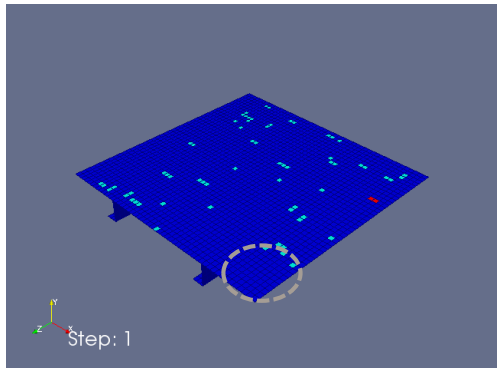
Model adjustment - Data matching technology





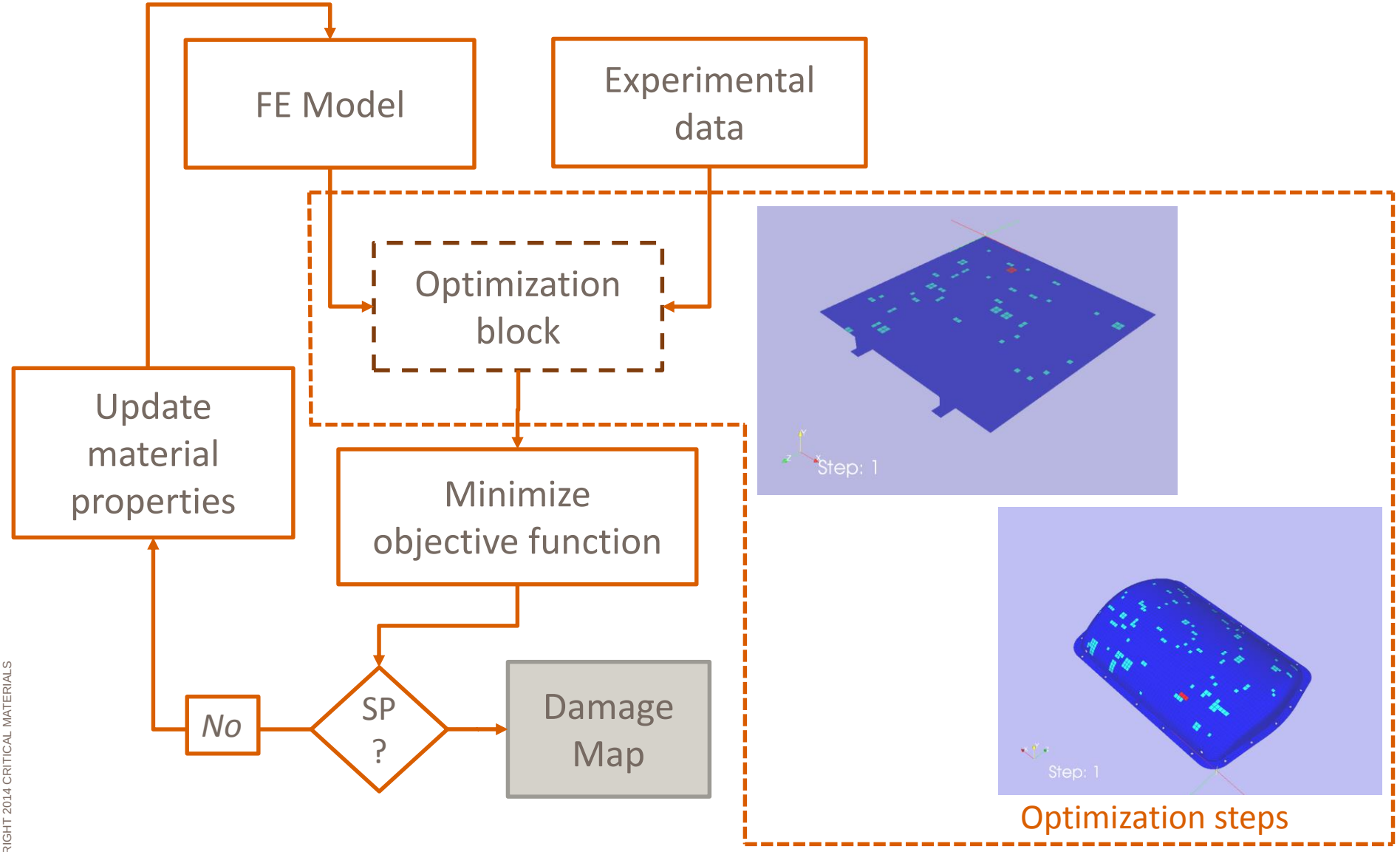
Damage Cases – Detected by digital twin operation





- The Digital Twin enables the localization and estimates the damage severity and size.
- Combines data from **sensors (Acc)** with a **FEM model** and a **Global nonlinear Optimization method** (*Particle Swarm Class)*

SHM AND DIGITAL TWINS

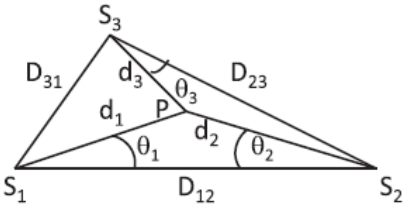


SHM AND OPTIMIZATION

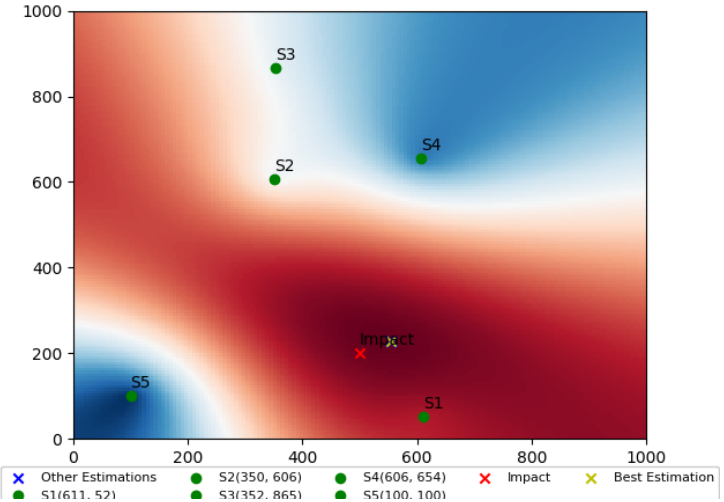
Impact location based on Acoustic Emissions

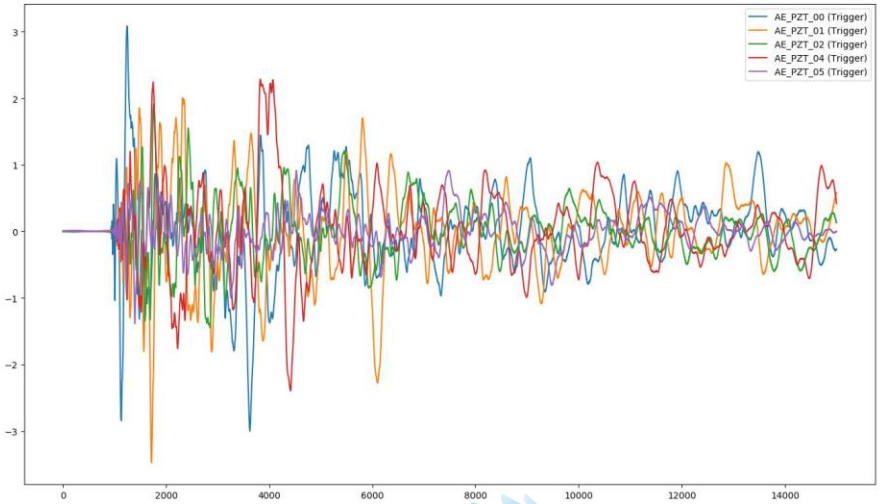
- PZT sensors
- Algorithm base on DToA (diference in time of arrival);
- Isotropic and anisotropic materials
- Optimization procedure

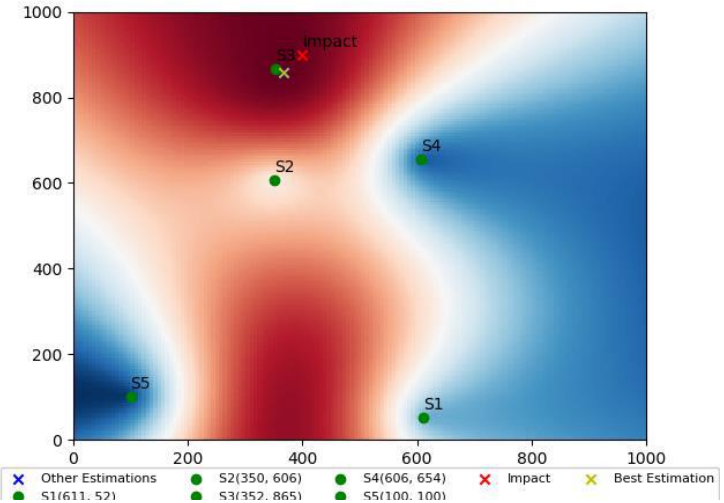
$$\begin{cases} E(x_0, y_0) = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \sum_{k=1}^{n-1} \sum_{l=k+1}^{n} \left[t_{ij}(d_k - d_l) - t_{kl}(d_i - d_j) \right]^2 \\ t_{ij} = t_i - t_j \\ d_i = \sqrt{(x_i - x_0)^2 + (y_i - y_0)^2}, (x_0, y_0) = impact\ position \end{cases}$$



$$\begin{cases} E(x_0, y_0) = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \left[c(\theta_i)c(\theta_j)t_{ij} - \sqrt{(x_i - x_0)^2 + (y_i - y_0)^2}\, c(\theta_j) + \sqrt{(x_j - x_0)^2 + (y_j - y_0)^2}\, c(\theta_i) \right]^2 \\ d_i = \sqrt{(x_i - x_0)^2 - (y_i - y_0)^2} = c(\theta_i)t_i \end{cases}$$



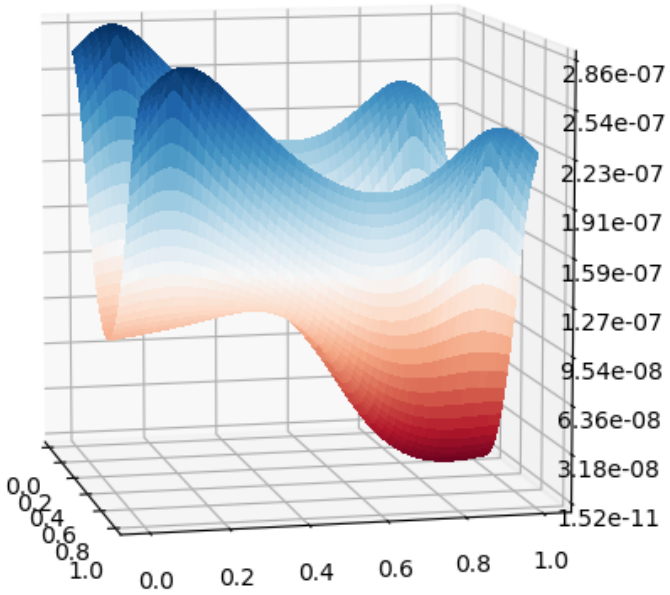




SHM AND OPTIMIZATION

Optimization of sensor location

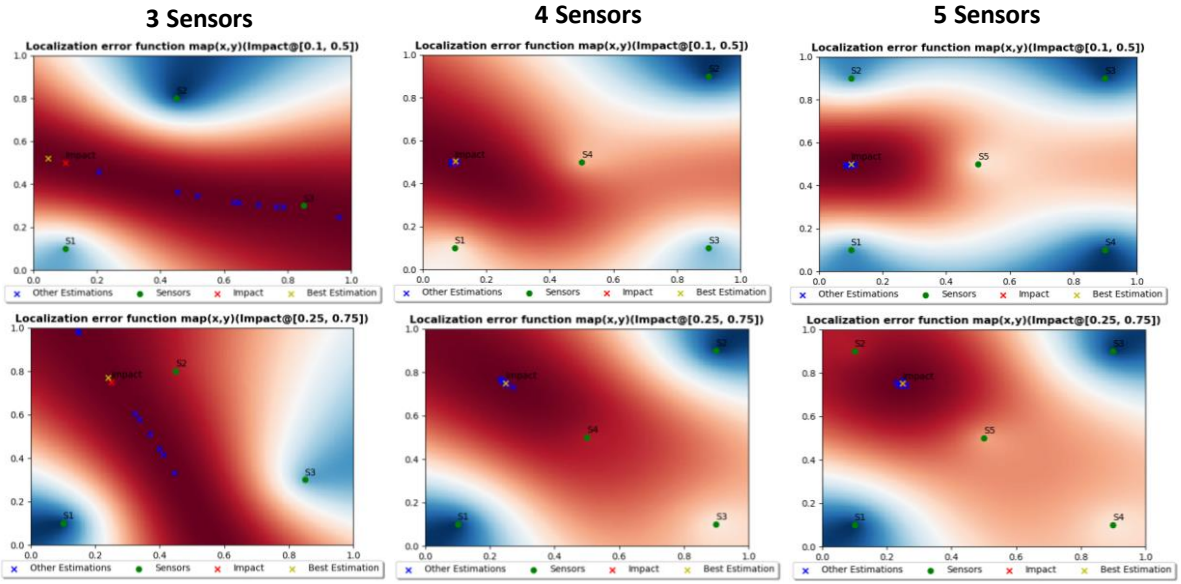
Error maps for 5 sensors with impact @ (0.5, 0.9)



Local minima
(Requires a global optimization method)

Number of sensors (3, 4, 5)

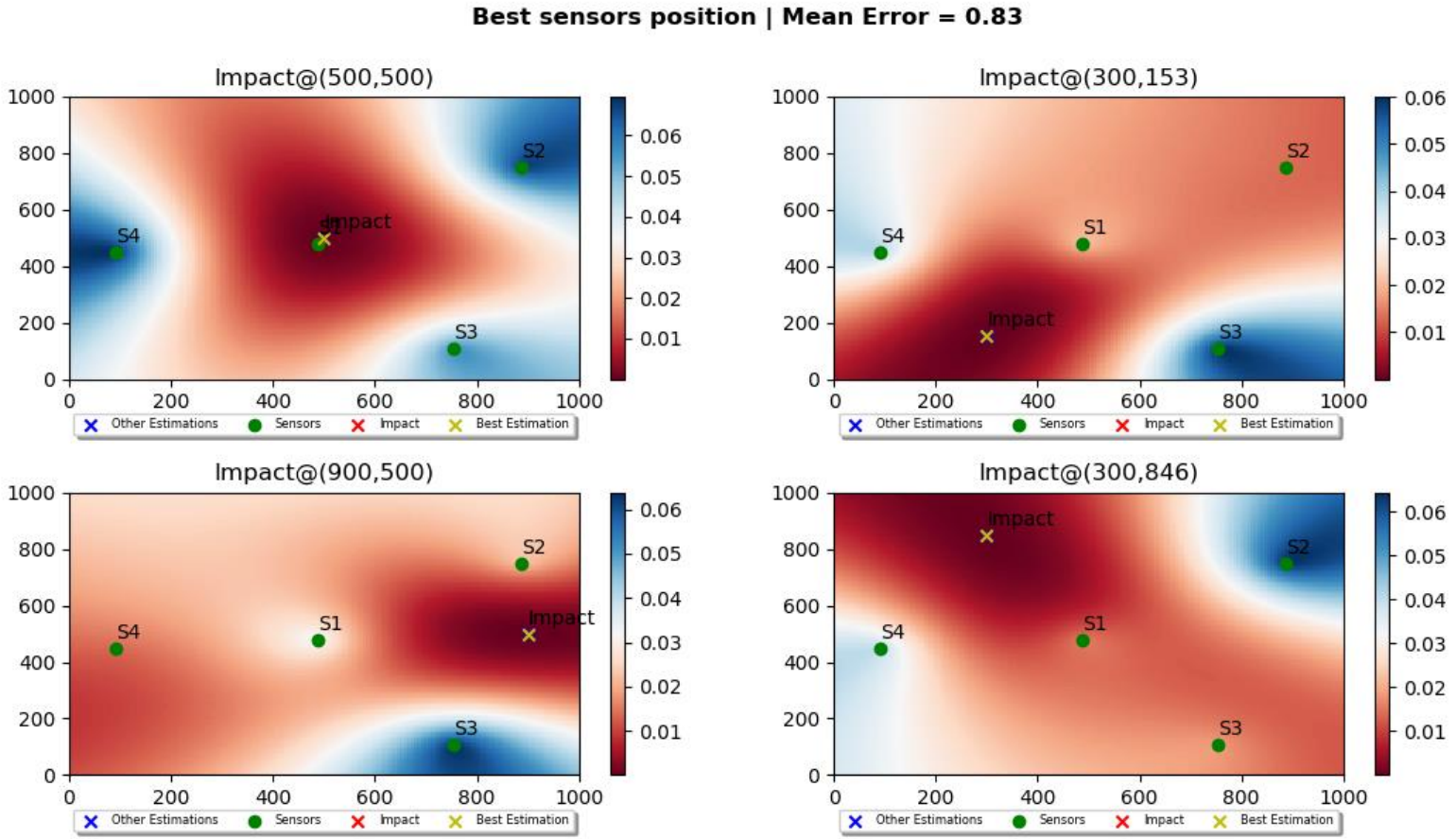
Impact@ (0.1, 0.5)



Impact@ (0.25, 0.75)

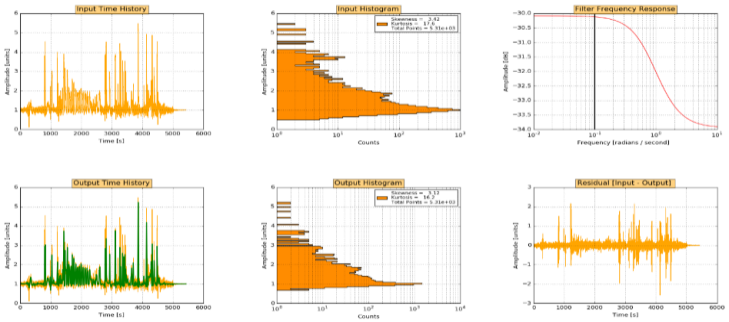
Optimization of sensor location

Position of sensors

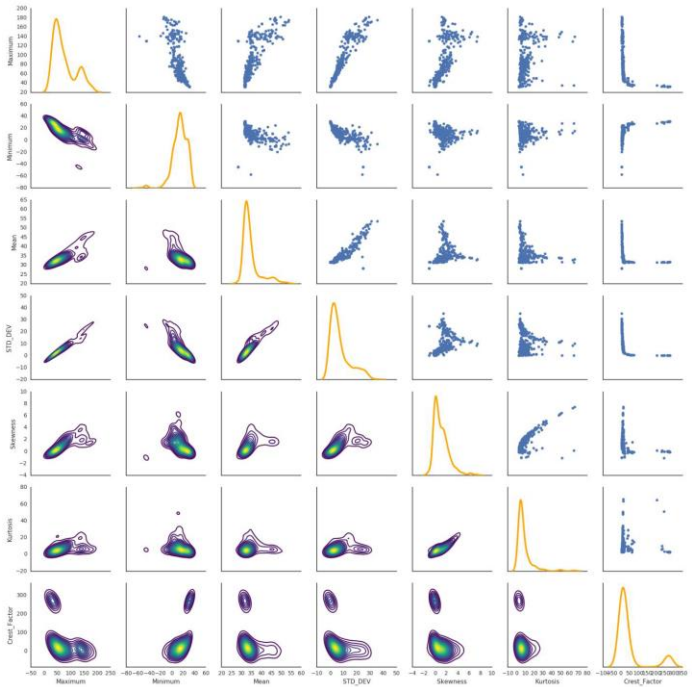


SHM AND MACHINE LEARNING

Flight profiles



Flight maneuvers classification

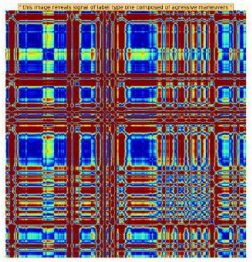


1. Regression with Deep Neural Networks
2. Classification with Deep Neural Networks
   - 2D Texture Image Classification with CNN
   - Time Series Classification with RNN
3. Natural language descriptions with Deep Neural Networks
   - 2D Texture Image caption description with LSTM, CNN

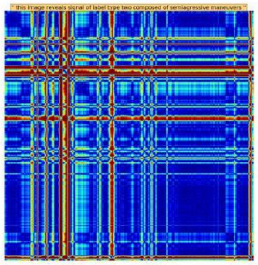
Keras

TensorFlow

Recurrence plots



Aggressive flight

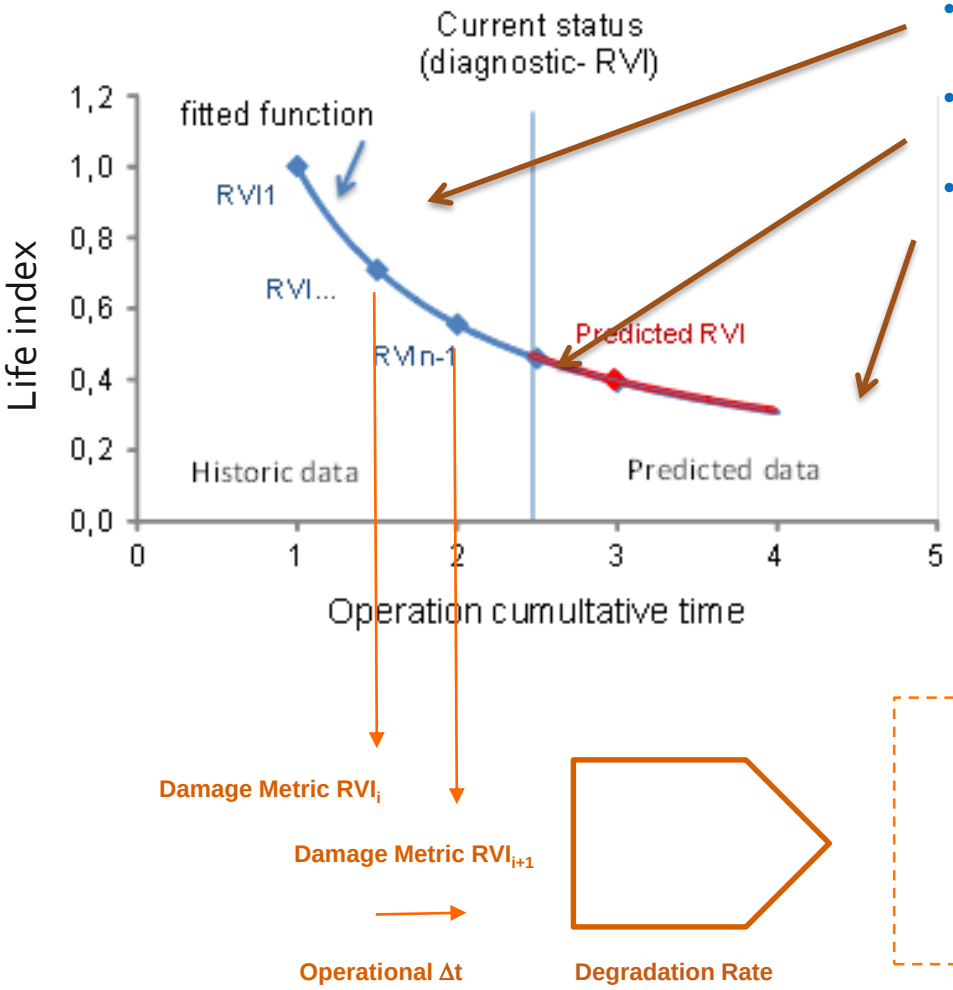


Semi-aggressive flight

A.M. Moura, P.J. Antunes, J.C. Viana, G.R. Dias, B. Serrano, D. Duarte, J. Cardoso, R. Basto, F. Machado, V. Infante, C. Mills, Application of Machine Learning Techniques for the Fatigue Life Estimation of Critical, Components, 9th European Workshop on Structural Health Monitoring, July 10-13, 2018, Manchester, UK

SHM AND MACHINE LEARNING

Health Prognosis



- The diagnostic data is collected over time, RVI
- RVI data is fitted by numerical function
- Fitted function extrapolates the damage status

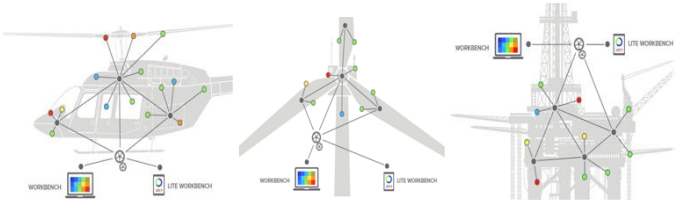
This function is updated every time the current state is assessed (diagnostic), being built a new damage function.

SHM AS A CYBER-PHYSICAL SYSTEM

CRITICAL MATERIALS

MATERIALS WITH INTELLIGENCE

SHM - STRUCTURAL HEALTH MANAGEMENT



Sensor signals

DAQ node

Database node replica

Database node replica

Replication data

Database ops from WB

Create/control ops

Database ops from PC

Mobile Workbench UI

Workbench UI

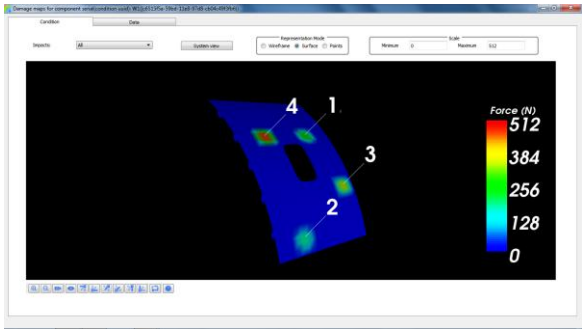
Workbench UI

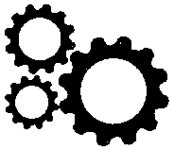
Processing Center

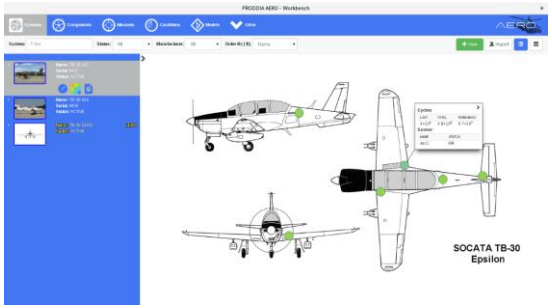
Processing Center

Processing Center

SHM as a CPS







Processing layer - IT platform

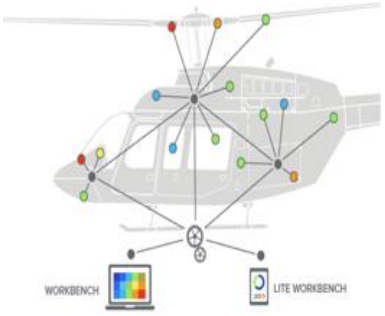
HMI
Presentation Layer

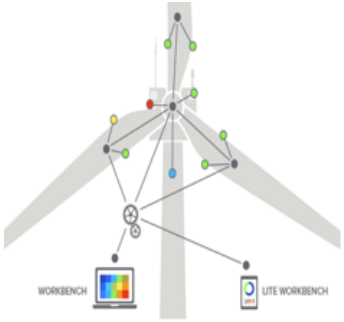
Reasoner:
Condition monitoring, Health assessment, Decision support

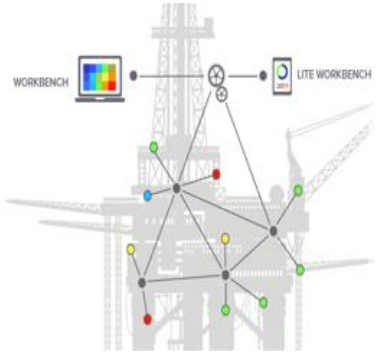
Data manipulation

Database

Communication layer







Device layer - Edge

Communications

DSP

DAQ

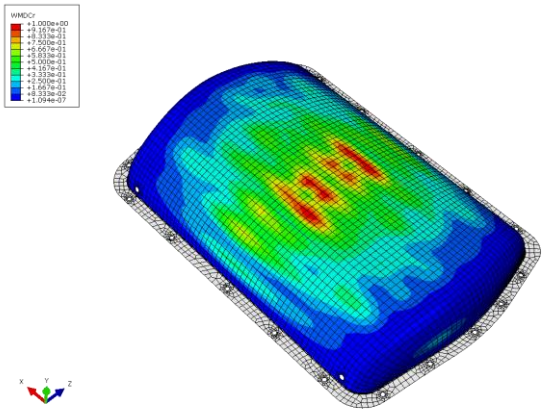
Power management

Instrumented asset
Sensing network

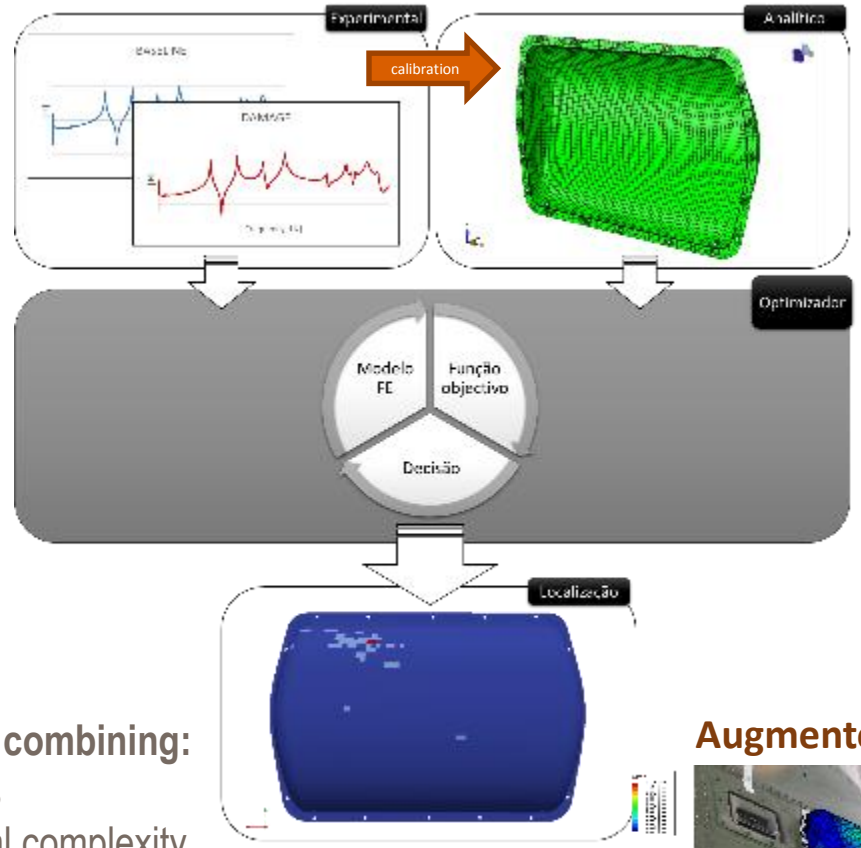
SHM as PaaS

Systems Integration

Sensor position



Damage characterization



Digital twin

IoT and Data Analysis combining:

- Big data analytics
- Physical structural complexity
- Cyber-physics approach
- Materials engineering

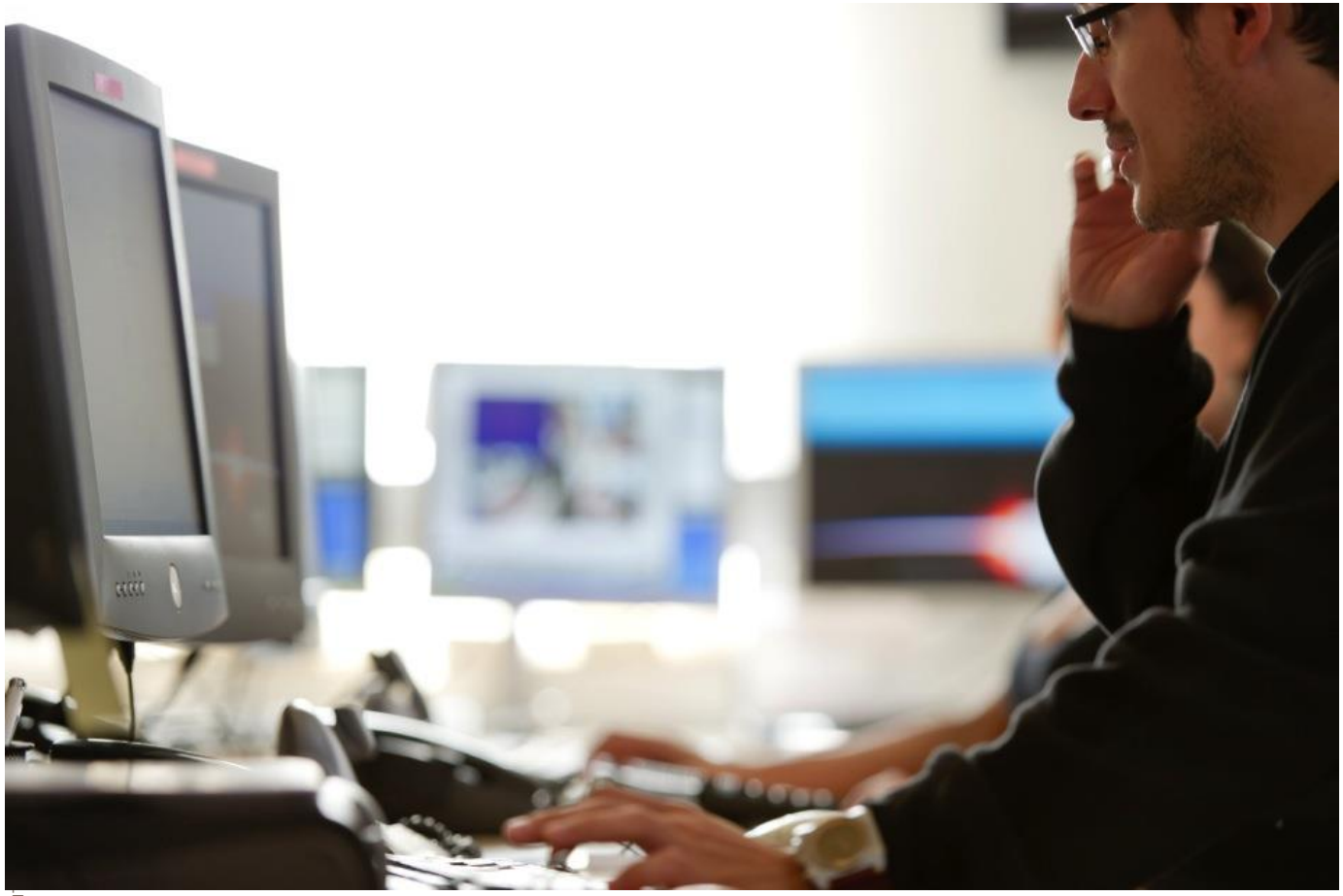
GE Digital Alliance Partner

Predix

industrial IoT platform (PaaS)

Augmented reality

CHALLENGES III



- Interoperability
- Big data
- IoT
- Reasoning tools
- Operational intelligence
- Business model

UBIQUITOUS SHM SYSTEMS

DATA
components
sub-system
vehicle
fleet
company
country
everywhere

real/experimental data
virtual/simulated data

time data

DATA ANALYTICS
DATA CENTERS
DATA COMPUTATION

SENSING

CONDITION MONITORING

DIAGNOSTIC & PROGNOSTIC

STRUCTURAL HEALTH MANAGEMENT

DATA ANALYTICS

PHYSICAL MODELS

DIGITAL TWINS

DECISON-MAKING

CYBER-PHYSICAL SYSTEMS

AUGMENTED REALITY

CRITICAL MATERIALS

MATERIALS WITH INTELLIGENCE

J.C. Viana, CTO

jviana@critical-materials.com

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