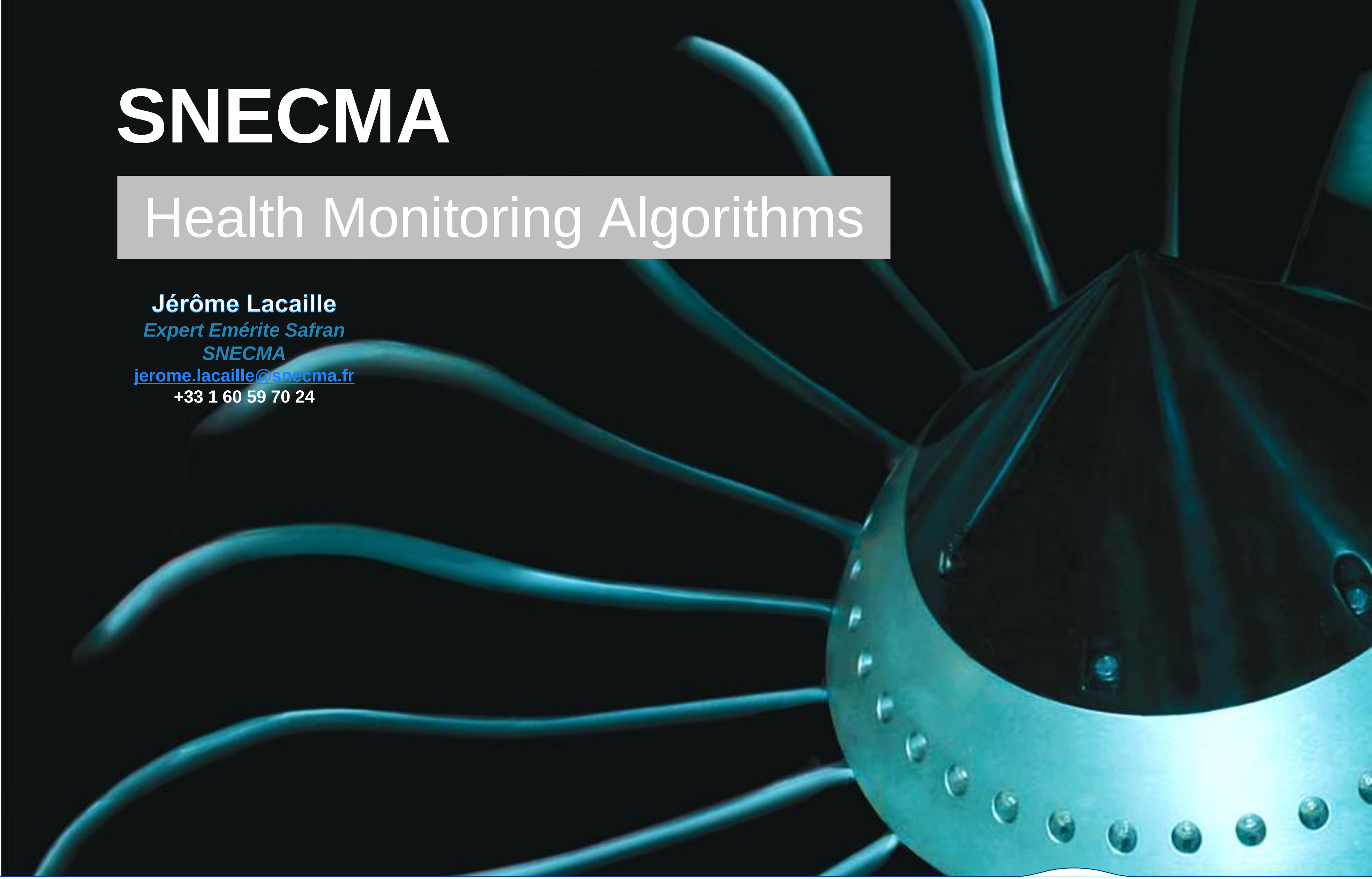

SNECMA

Health Monitoring Algorithms

Jérôme Lacaille
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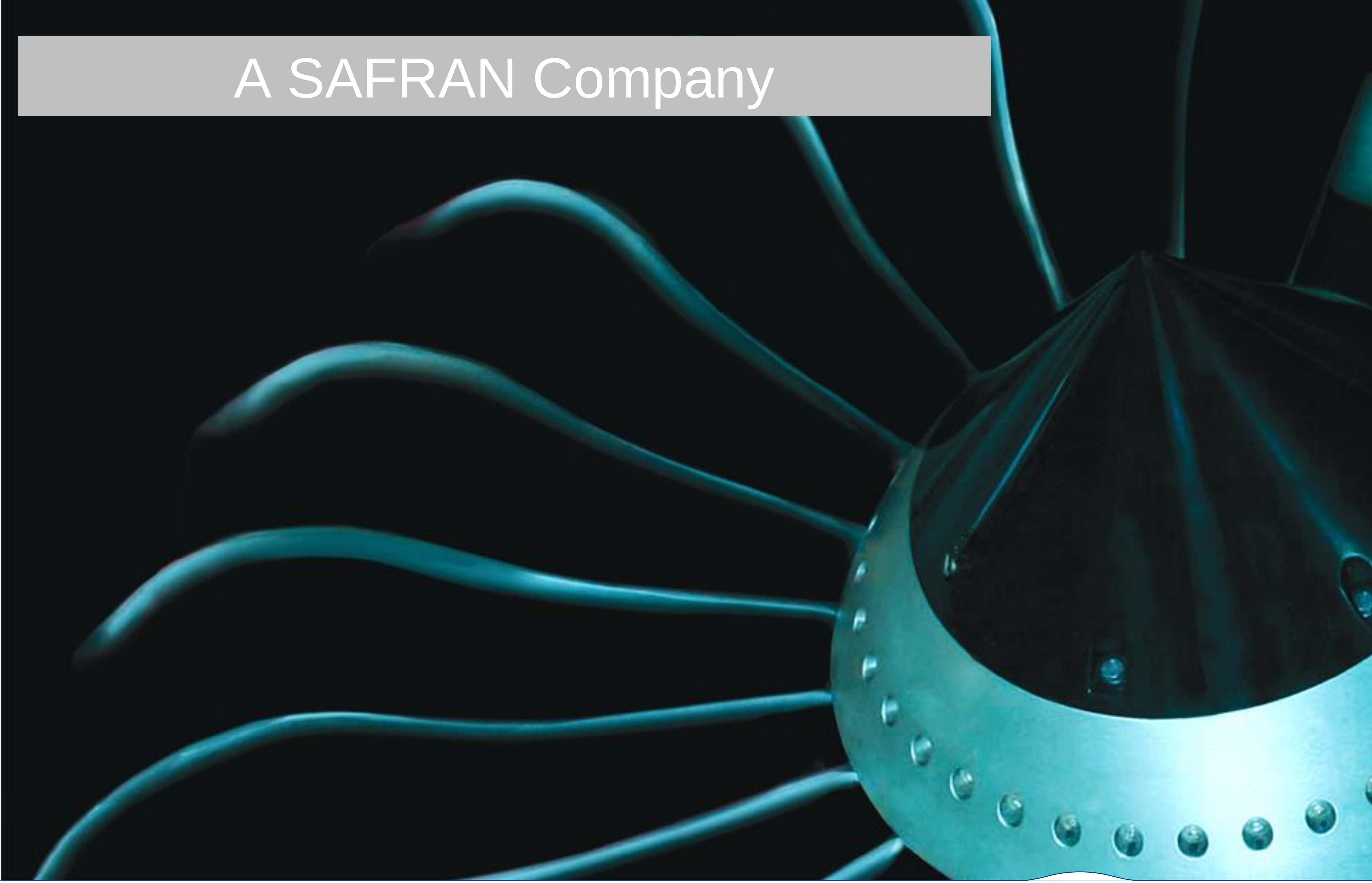
A SAFRAN Company



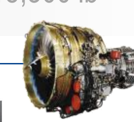
PROPULSION: FROM 9 GRAMS TO 135 TONS OF THRUST

(1) PowerJet (50-50 Snecma/NPO Saturn)
(2) CFM International (50-50 Snecma/GE)
(3) EPI (ITP, MTU, Rolls-Royce, Snecma)
(4) In cooperation with GE

Satellites	Ariane 5	Ariane 5	Ariane 5
PPS ® 1350	HM7B	Vinci	Vulcain ® 2
90 mN	64.8 kN	180kN	1340 kN (main stage)

Alpha Jet	Mirage F1	Rafale	Mirage 2000	A400M
Larzac ®	Atar	M88	M53	TP400 (3)
14kN	49kN	75kN	95kN	11 000 hp

Citation Longitude	SSJ100	737	A320	A320neo	737 MAX	C919	A340	747	A380	777
Silvercrest	SaM146(1)	CFM56-7B(2)	CFM56-5B(2)	LEAP-1A(2)	LEAP-1B(2)	LEAP-1C(2)	CFM56-5C(2)	CF6(4)	GP7200(4)	GE90(4)
9,500 to 12,000 lb	13,500 to 17,800 lb	19,500 to 27,300 lb	21,600 to 33,000 lb	21,500 to 33,000 lb	21,500 to 28,000 lb	21,500 to 30,000 lb	31,200 to 34,000 lb	52,500 to 72,000 lb	70,000 to 85,100 lb	93,700 to 115,300 lb



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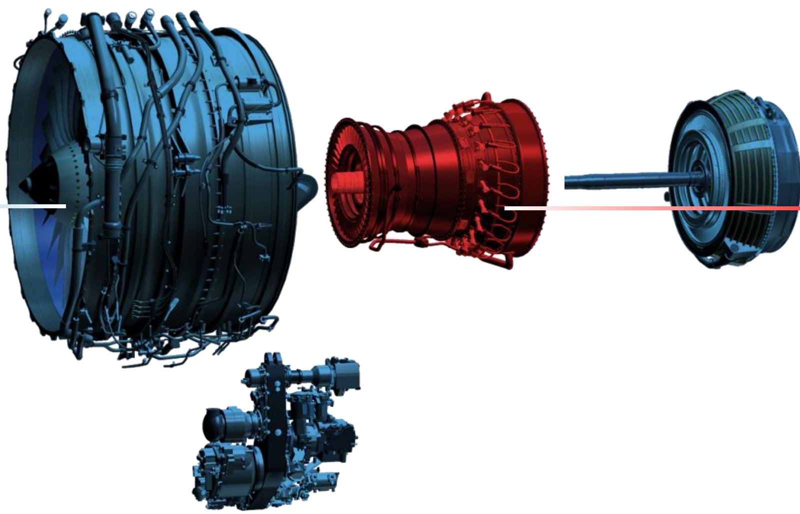
CFM INTERNATIONAL

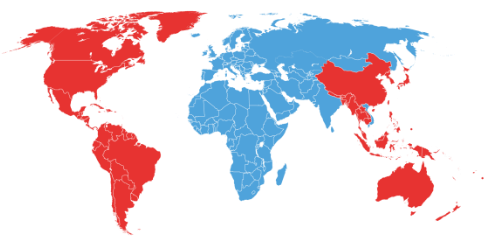
Design, development, production, sale and support of commercial aircraft engines in the 18,000 to 50,000 lb thrust range

Fan
Accessory gearbox
Low-pressure turbine

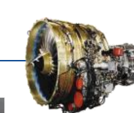


Core engine

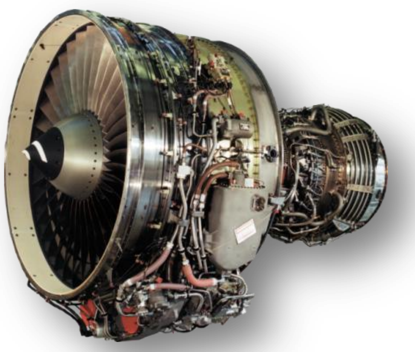
Sales zones



CFM is an equally-owned subsidiary of Snecma (Safran), France and GE, United States.



CFM56, the world's best selling commercial engine



CFM56-5B

Over 95 million flight-hours to date*

5,500* engines in service with 130 operators

Thrust range: 21,600 to 32,000 lb

Applications: Airbus A318, A319, A320, A321

A320

** As of December 31, 2012*

CFM56-7B

More than 176 million flight-hours to date*

9,180* engines in service with 190 operators

Thrust range: 19,500 to 27,300 lb

Applications: Boeing 737-600, 737-700, 737-800, 737-900

Boeing 737-800

** As of December 31, 2012*

CFM is an equally-owned subsidiary of Snecma (Safran group, France) and GE (United States).

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LEAP, CFM'S NEW-GENERATION ENGINE

Featuring innovative technologies that have been proven effective (new materials, 3D aero, etc.), the LEAP engine combines performance, reliability, environmental-friendliness and reduced operating costs.

- Fuel consumption and CO_2 emissions: 15% lower than CFM56 TI engines
- NOx: 50% margin versus the CAEP/6 standard
- Noise: Compliant with anticipated Chapter 5 regulations
- Same reliability as CFM56 with equivalent maintenance costs

Thrust range: 20,000 to 33,000 lb

More than 4,350 orders and commitments as of December 2012

Airbus A320neo

Boeing 737 MAX

Comac C919

Selected to power the Airbus A320neo, Boeing 737 MAX and Comac C919

Service entry in 2016

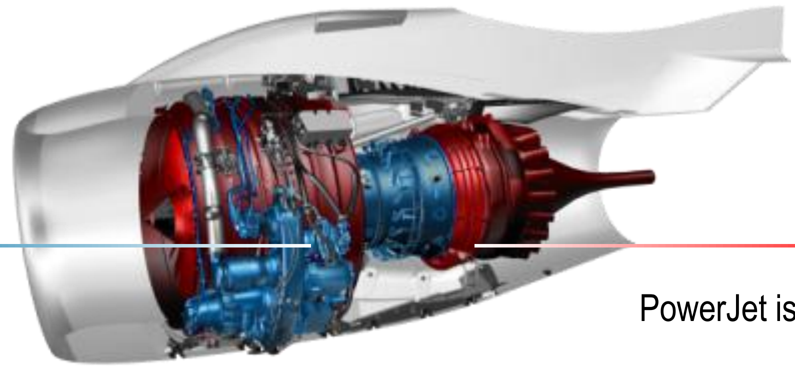
CFM is an equally-owned subsidiary of Snecma (Safran group, France) and GE (United States).

SaM146 engine
design, production, sale and support

SAFRAN Snecma

Core engine
Accessory gearbox
Control system

Snecma is responsible for propulsion system integration and flight tests



SATURN

Fan
Low-pressure compressor
Low-pressure turbine

NPO Saturn is responsible for final engine assembly and ground tests

PowerJet is an equally-owned subsidiary of Snecma (Safran), France and NPO Saturn, Russia

SSJ100-75

SSJ100-95

SaM146 1S18

EASA certification: January 17th, 2012

Thrust range: 16,100 to 17,800 lb

Applications: SSJ100-95LR, SBJ (EASA certified on February 3th, 2012)

SILVERCREST, THE NEW-GENERATION BUSINESS JET ENGINE

SILVERCREST
THE NEW GENERATION BUSINESS JET ENGINE

Designed to power super mid-size and large business jets

Innovative solutions to simplify engine architecture and reduce the parts count, for significant benefits:

- Specific fuel consumption 15% lower than current engines
- 50% reduction in NOx (nitrogen oxides) in compliance with CAEP/6
- Noise: Up to 20 EPNdb margin vs. Stage 4 requirements

Thrust range: 9,500 to 12,000 lb

Super midsize business jets

Large business jets

Long-range business jets

Selected to power the Cessna Citation Longitude

Service entry in 2017

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Snecma

COMBAT AIRCRAFT ENGINES

M88

Over 310 engines in service

Over 230,000 flight-hours

Thrust: 75 kN

Applications: Dassault Rafale air force (C/B) and naval (M) versions

Rafale

As of December 31 2012

M53

Over 580 engines produced for 9 air forces

Nearly 1.8 million flight-hours

Thrust: 95 kN

Applications: Dassault Mirage 2000 C/B, Mirage 2000 N/B
Mirage 2000-5/-9

Mirage 2000 N/B

As of December 31 2012

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Europrop International

European consortium grouping ITP (Spain), MTU Aero Engines (Germany), Rolls-Royce (UK) and Snecma Safran (France).

Europrop International is responsible for engine integration and program management

SAFRAN Snecma

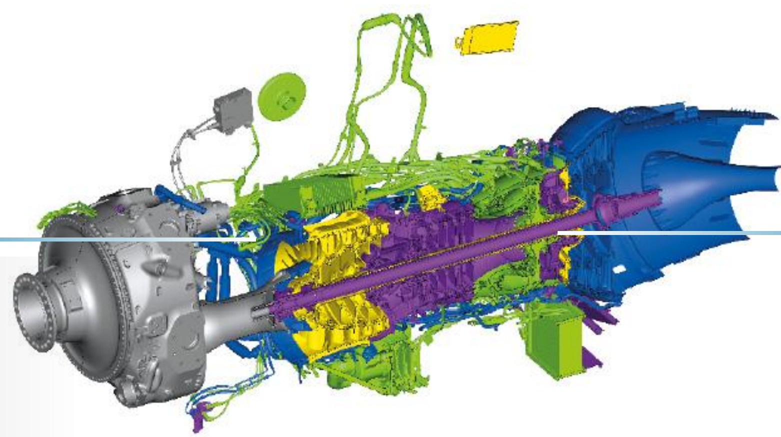
- Combustor
- High-pressure turbine
- Accessory gearbox

Workshare: 32%

Rolls-Royce

- Intermediate casing
- High-pressure compressor
- Inter-turbine casing

Workshare: 25%



MTU Aero Engines

- Intermediate-pressure turbine
- Intermediate-pressure compressor

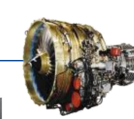
Workshare: 22%

ITP GRUPO Industria de Turbo Propulsores, S.A.

- Inlet casing
- Low-pressure turbine
- Exhaust casing

Workshare: 21%

A400M



SAFRAN Snecma

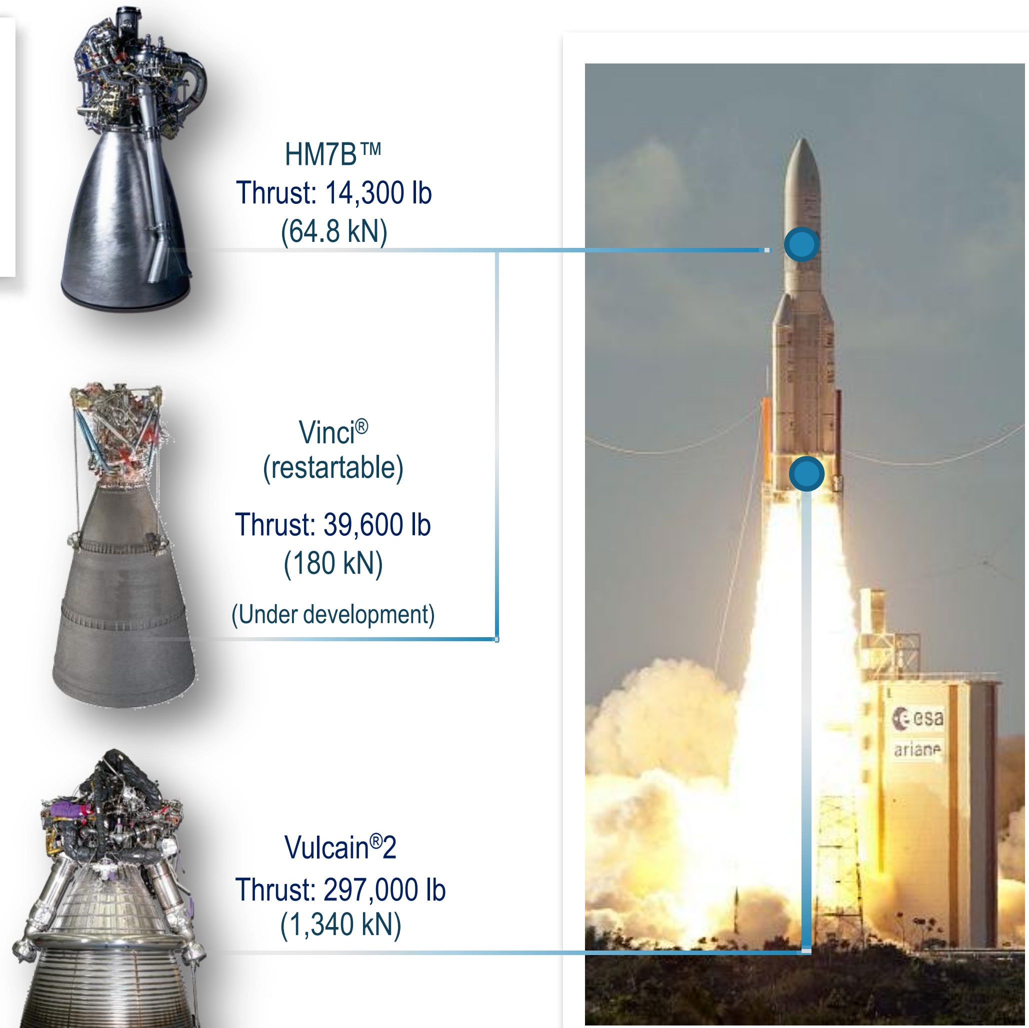
Liquid Propulsion for Launchers

Over 60 years of experience in liquid rocket propulsion, including 30 years on the Ariane 1 to 5 launchers

More than 1,200 engines launched.

European cryogenic propulsion prime contractor: Vulcain®2 and HM7B™ for Ariane 5, the world's leading commercial launch vehicle.

Prime contractor for development of the propulsion system on a new restartable upper stage for Ariane 5, powered by the new Vinci engine.



Ariane 5 ECA

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EngineLife®
We care for your engines
the same way we build them

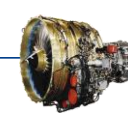
3 Support services spanning the entire life cycle

- Engine life operating support
- In-shop engine maintenance — 8 engine overhaul centers
- Component repair — 12 parts repair centers of excellence

Global MRO market positions

- CFM56 — No. 2 worldwide for shop visits
- GE90 — No. 1 worldwide for high-pressure and low-pressure compressors
- GP7200 — No. 1 shop to provide HPC servicing

More than 24,000 engines & subassemblies repaired to date



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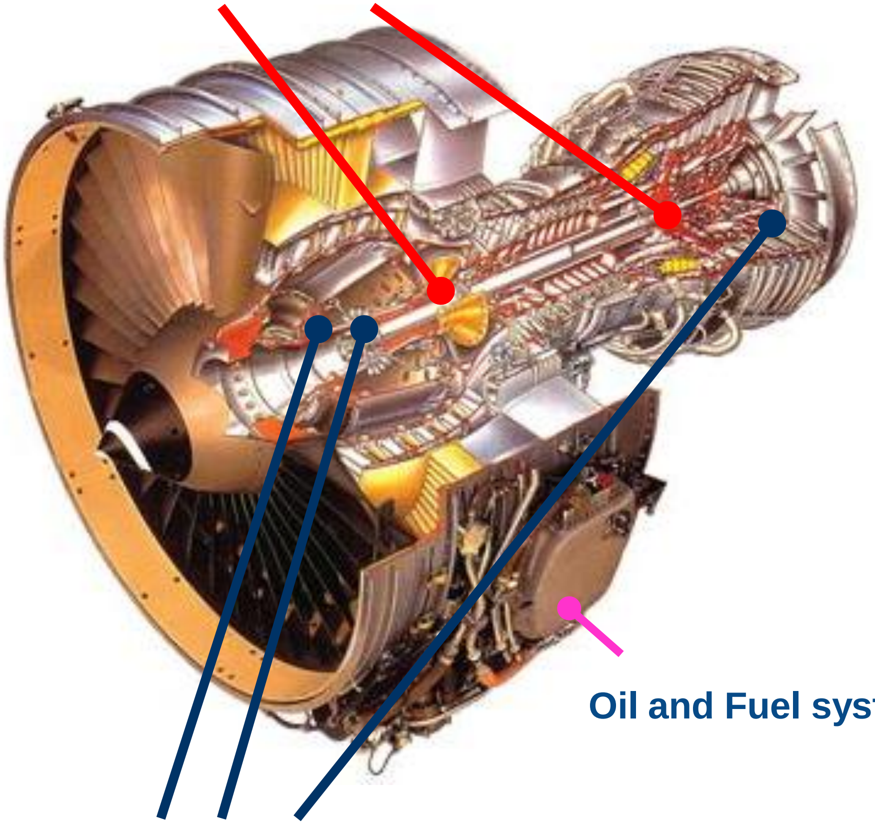
Prognostic & Health Monitoring

Safran Aircraft Systems

SAFRAN Snecma

On Board Sensors

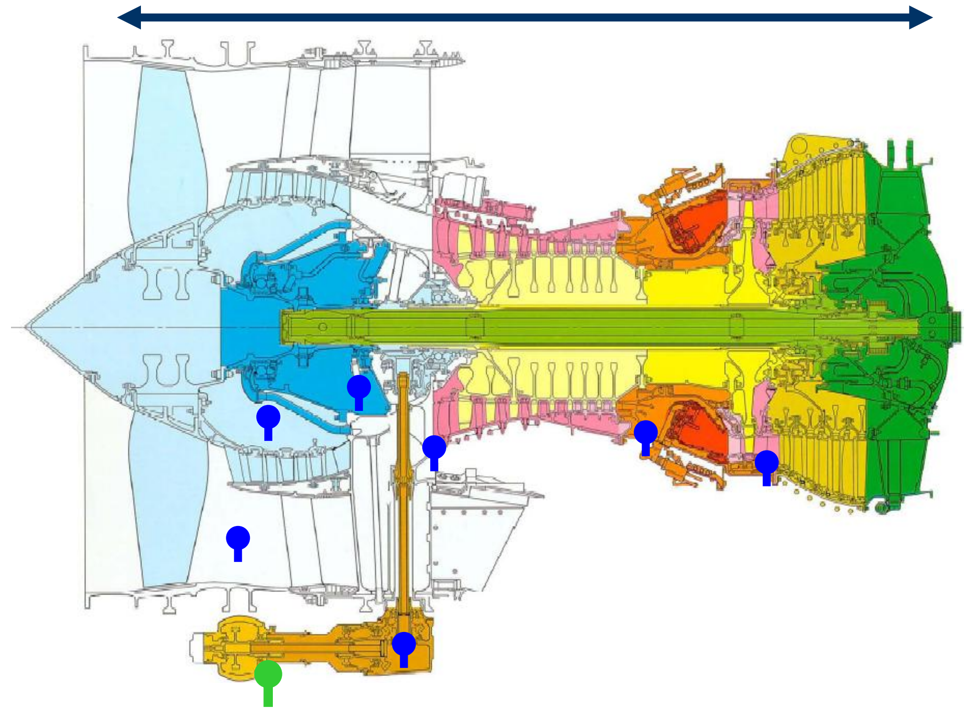
HP shaft
2 bearings (15000 to 22000 rpm)



LP shaft
3 bearings (5000 to 8000 rpm)

Oil and Fuel systems

Around 20 disks with 20 to 80 blades each



Equipments assembled on an Accessory Gear Box (AGB).

Sensors:

accelerometers, tachometers, pressures, temperatures, flows …

Condition Monitoring Process

➔ On board

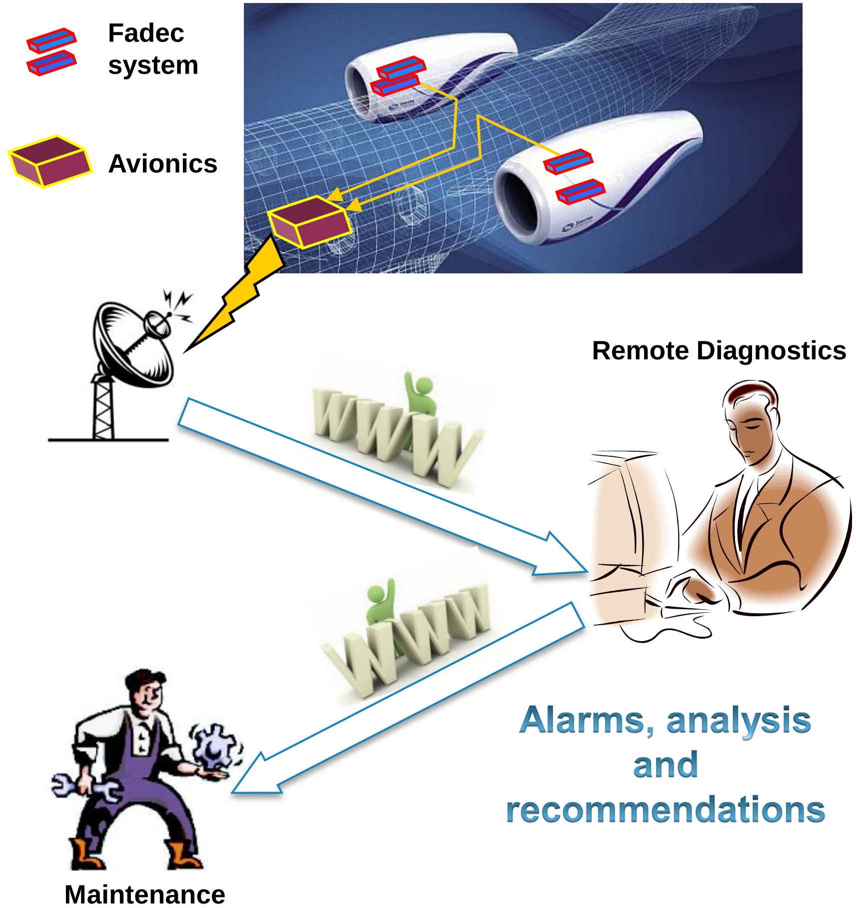
- Monitoring function located in the engine control system
- Data transfer using aircraft system (ACMS)

➔ Transfer to the ground

- 3 possibilities (depending on the application)
  - During the flight (ACARS or SATCOM)
  - End of the flight (GSM or WiFi or manual)
  - Scheduled time

➔ On ground

- Ground Monitoring System (GMS) with Web portal
- Client Support Center (CSC)



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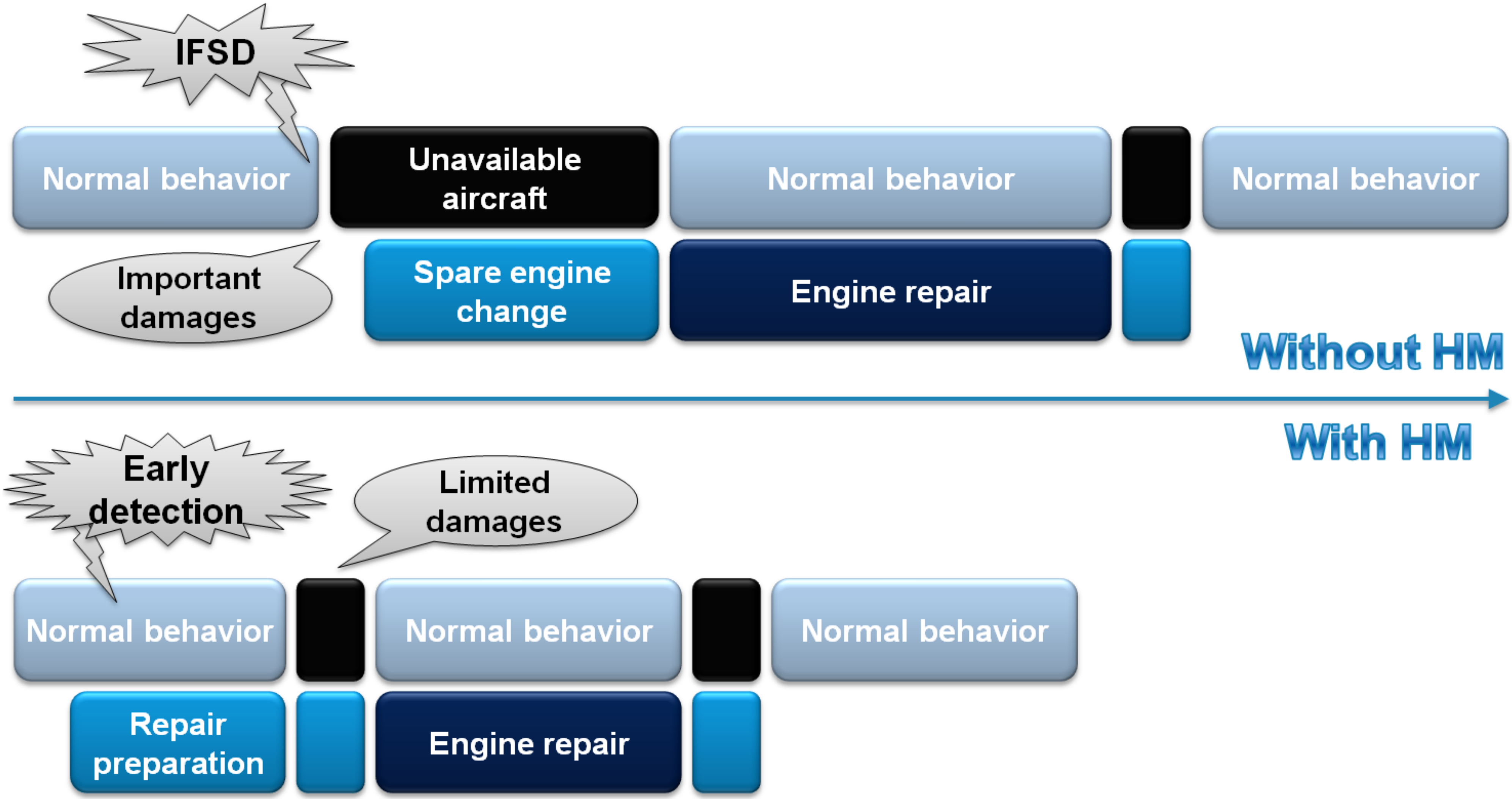
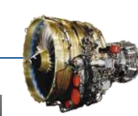
Storyboard of Damage Repair





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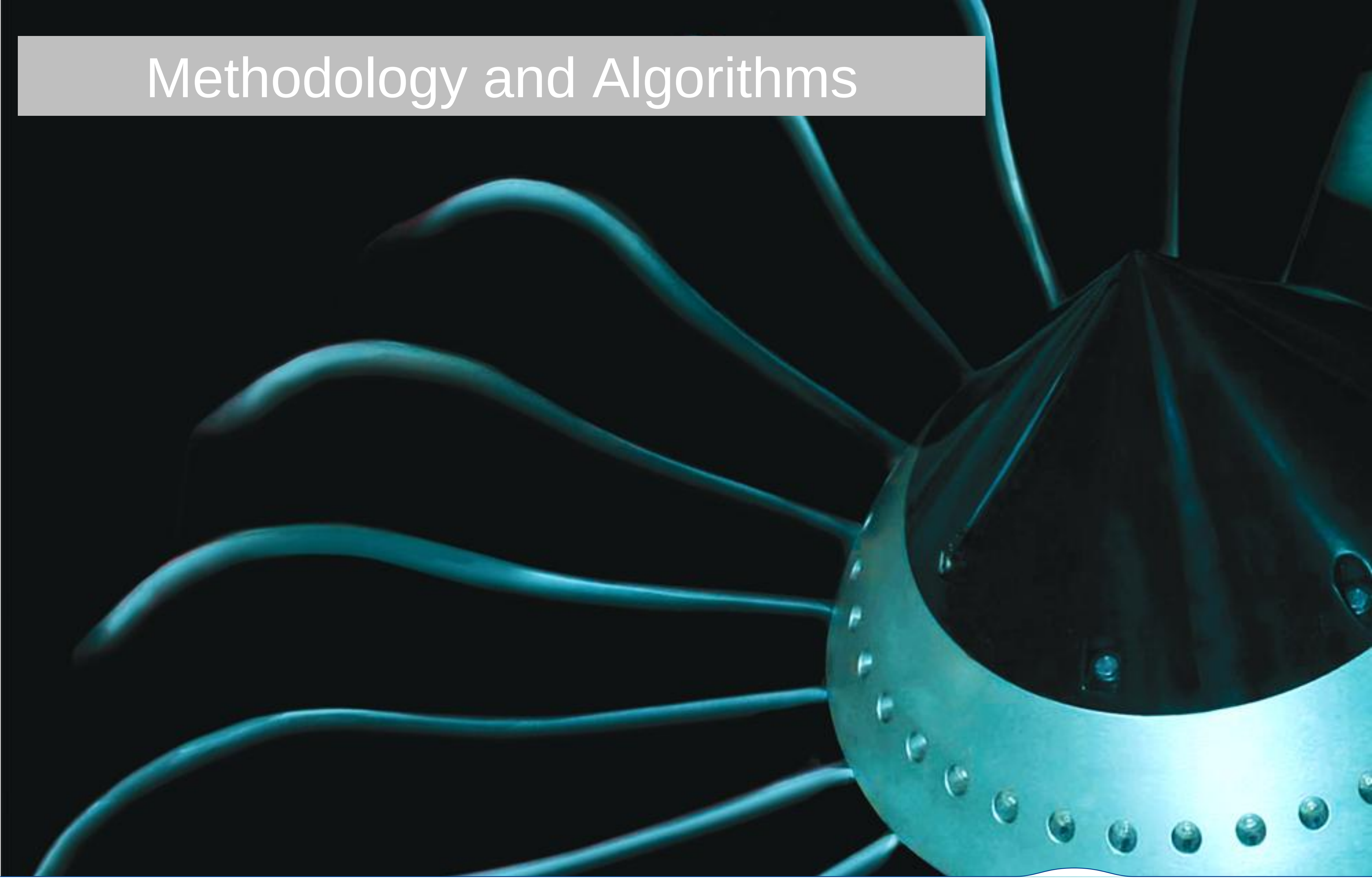
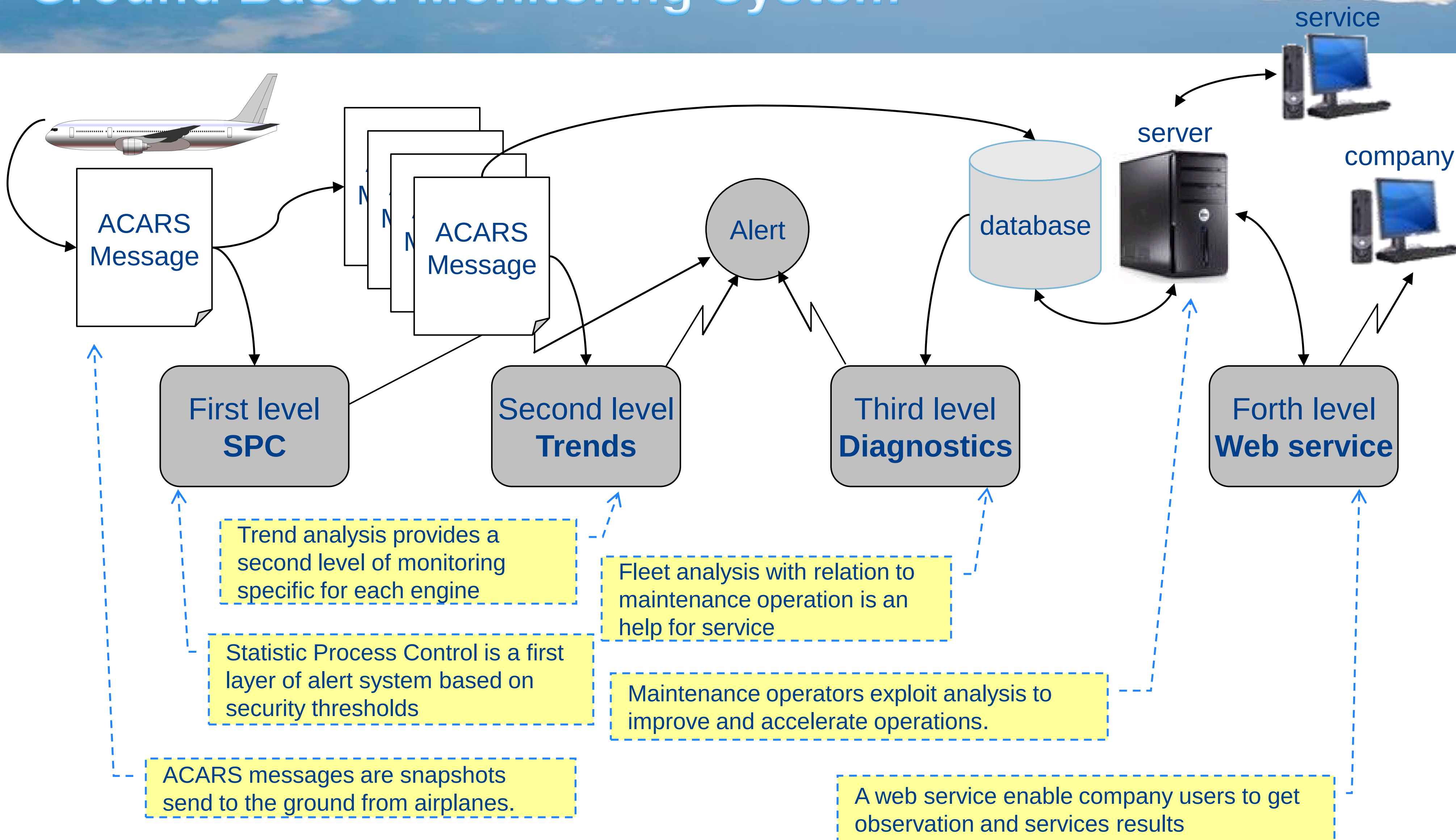
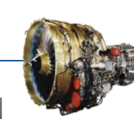
Methodology and Algorithms



Ground Based Monitoring System





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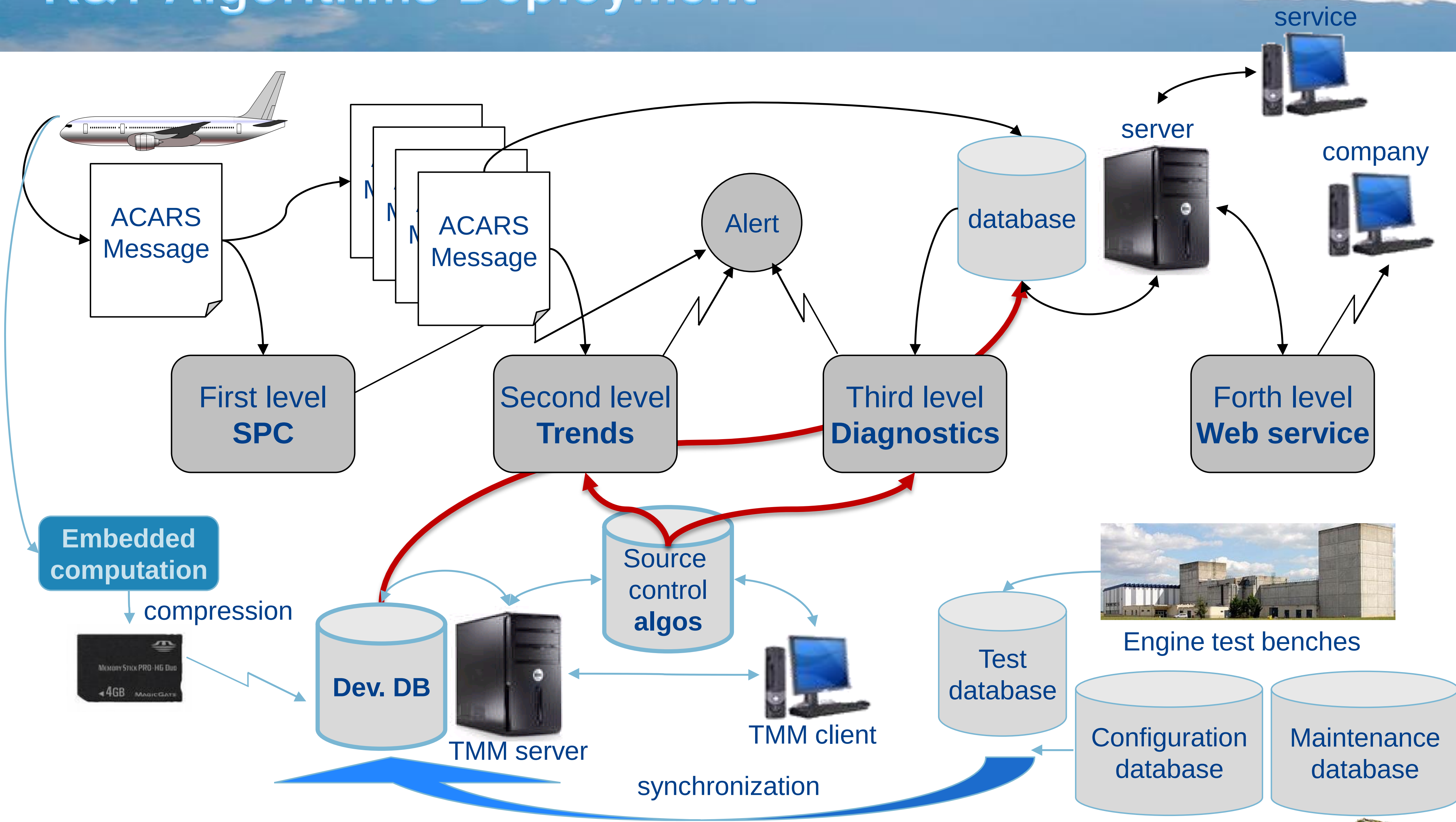
R&T Algorithms Deployment



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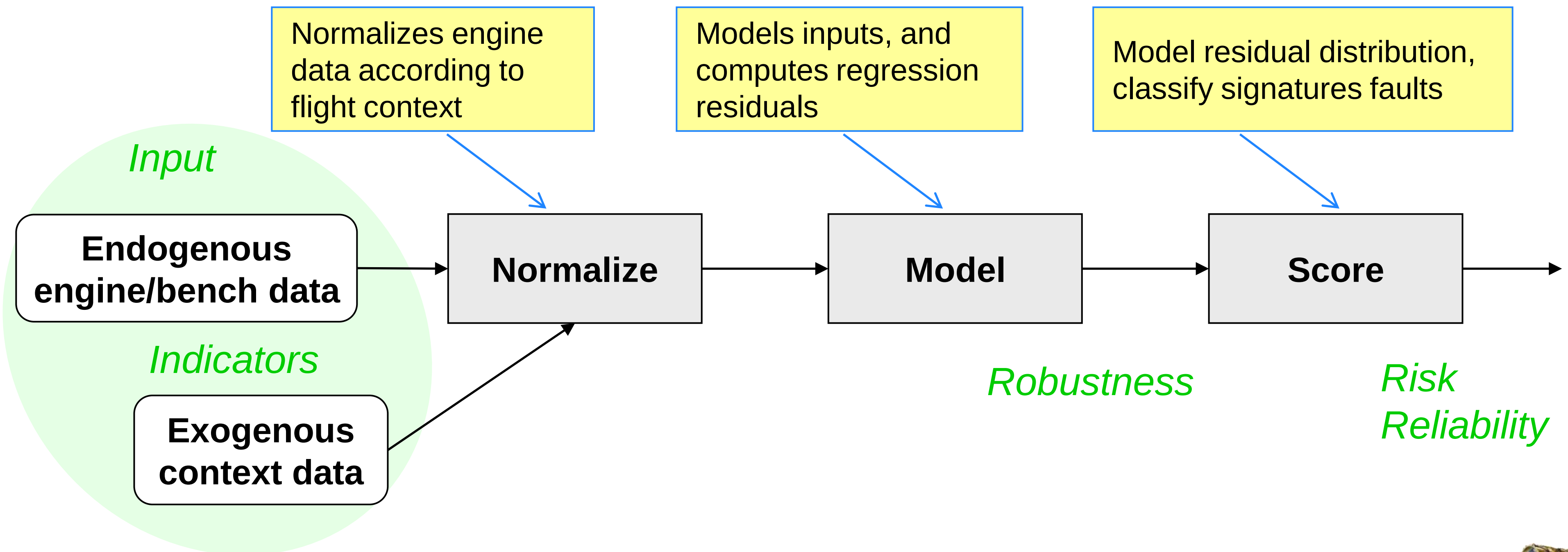
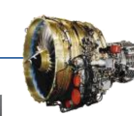
Diagnostic Algorithm

Once endogenous and exogenous sets of inputs defined

- The diagnostic is the computation of a likelihood according to a conditional data model
- The quality of the model depends on the calibration dataset
  - A robustness (capacity of generalization) may be computed by cross validation





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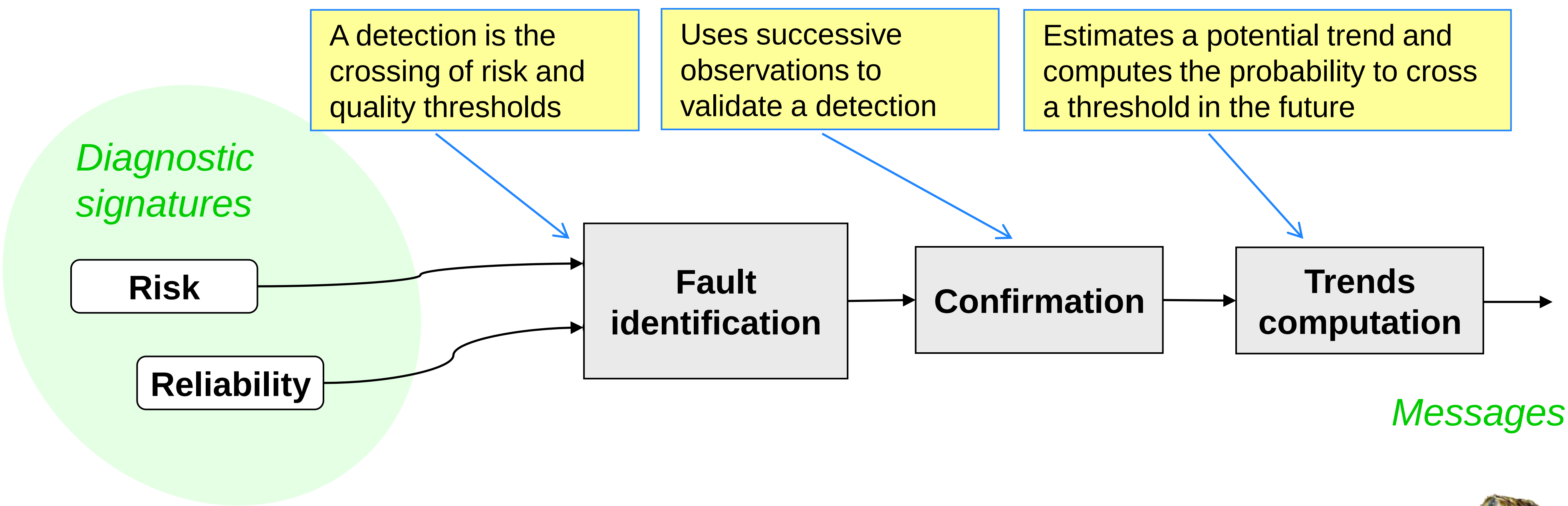
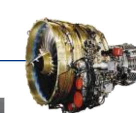
Prognostic Algorithm

→ The prognostic is the result of

- A detection
  - High risk and good quality
- A confirmation of the detection
  - Successive detections
- An anticipation
  - By estimation of the increasing rate of scores

The confirmation methodology helps adjust PFA (false alarm rate) and POD (probability of detection) performance indicators according to the specs.





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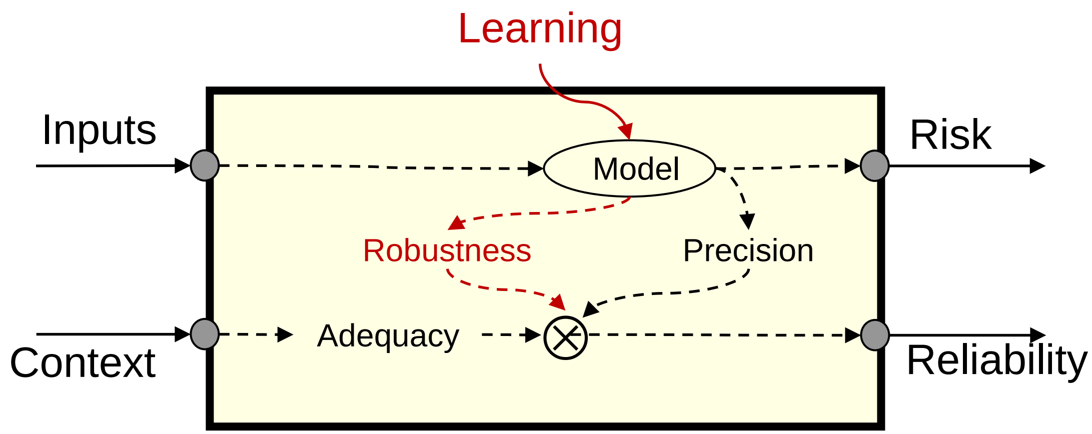
Risk and Reliability

- **Each diagnostic algorithm produces three outputs**
  - The risk
    - Is the probability to be unusual
  - The precision
    - The variance of the risk (reliability information)
  - The adequacy
    - The probability that the computation is done in a context that corresponds to the calibration dataset
  - The robustness
    - Is the generalization error computed by cross-validation



$$\begin{cases} \text{Risk}(t) = 1 - \text{P}(X = x_t | U \approx u_t) \\ \text{Precision}(t) = \text{tr}[\text{var}(X | U \approx u_t)] \\ \text{Adequacy}(t) = \text{P}(U \approx u_t) \end{cases}$$

- U is the exogenous data
- X is the endogenous data
- (u_t, x_t) is the current observation

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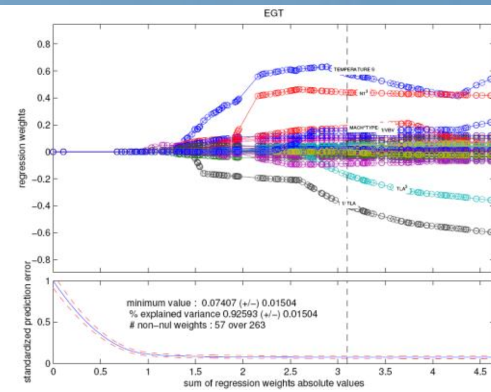
Mathematic Methods

➔ Identification & selection of important parameters

- Vibration (HF) analysis, features extraction
- Variable selection, mutual information,

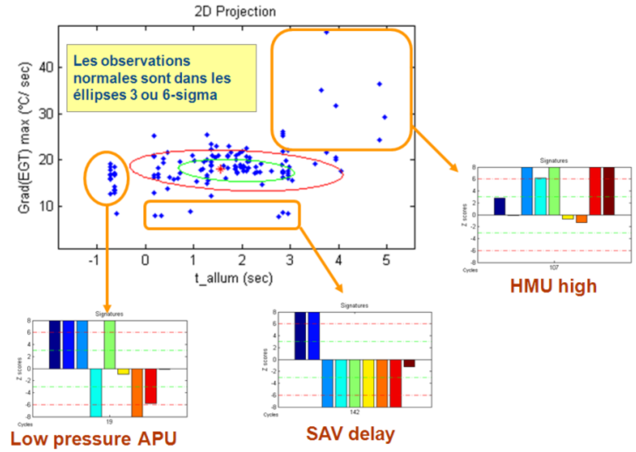


➔ Learning of normal behavior

- Likelihood scores, extreme values, statistic tests

➔ Abnormality signature classification

- Auto-organizing maps, outliers detection
- Auto adaptive classification

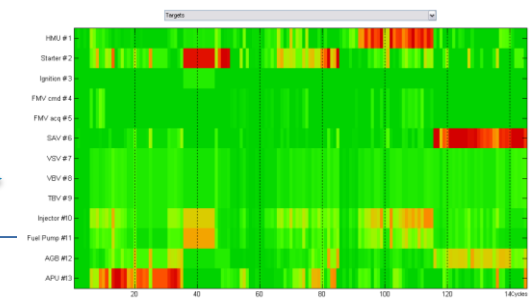


➔ Trends detection and failure anticipation

- Regressions, filters (*KF), importance sampling (PF)

➔ Reliability management and diagnosis fusion

- Bayesian models, statistics, logical inference (Fuzzy)



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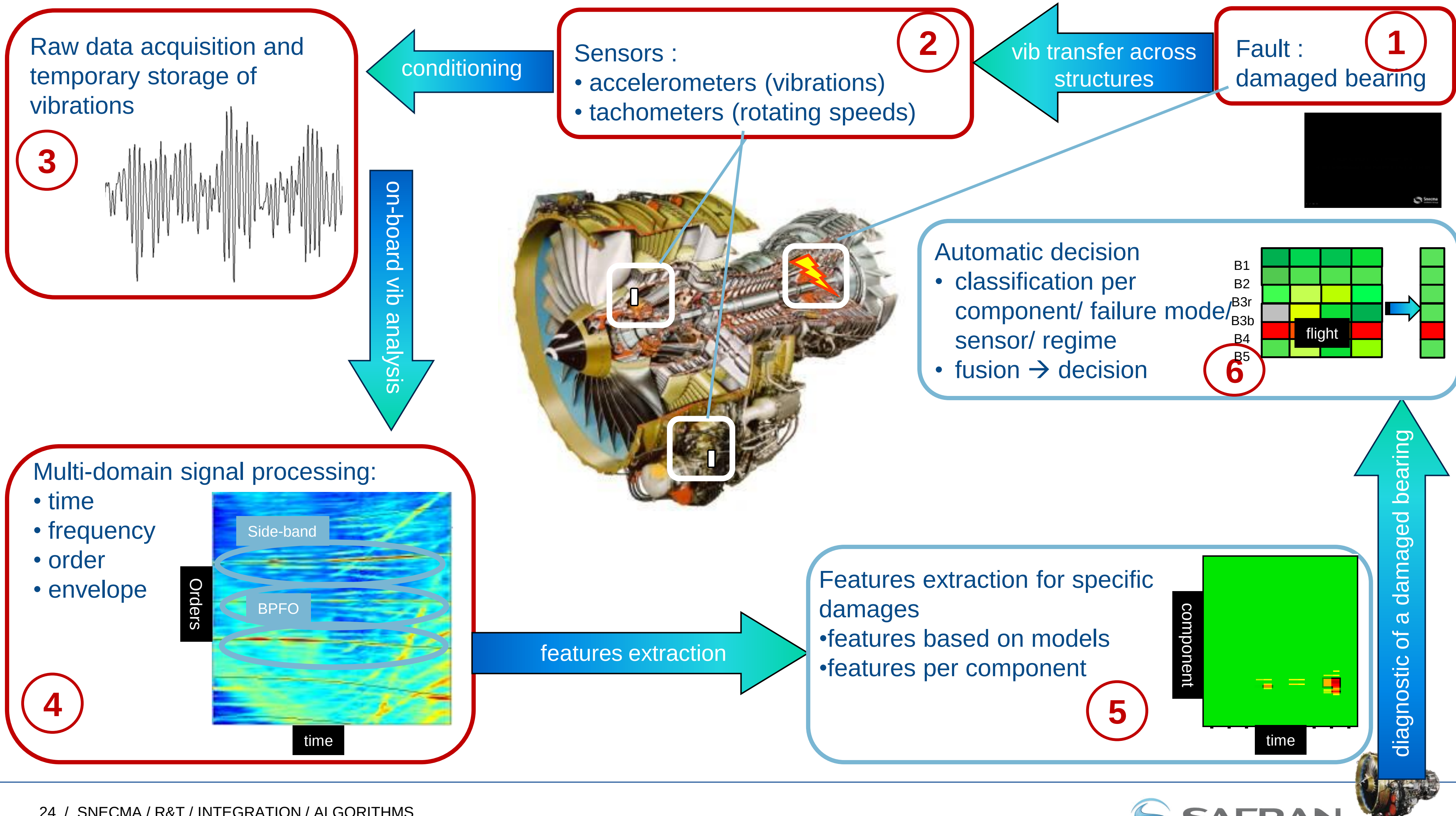
Bearing Monitoring Process Overview



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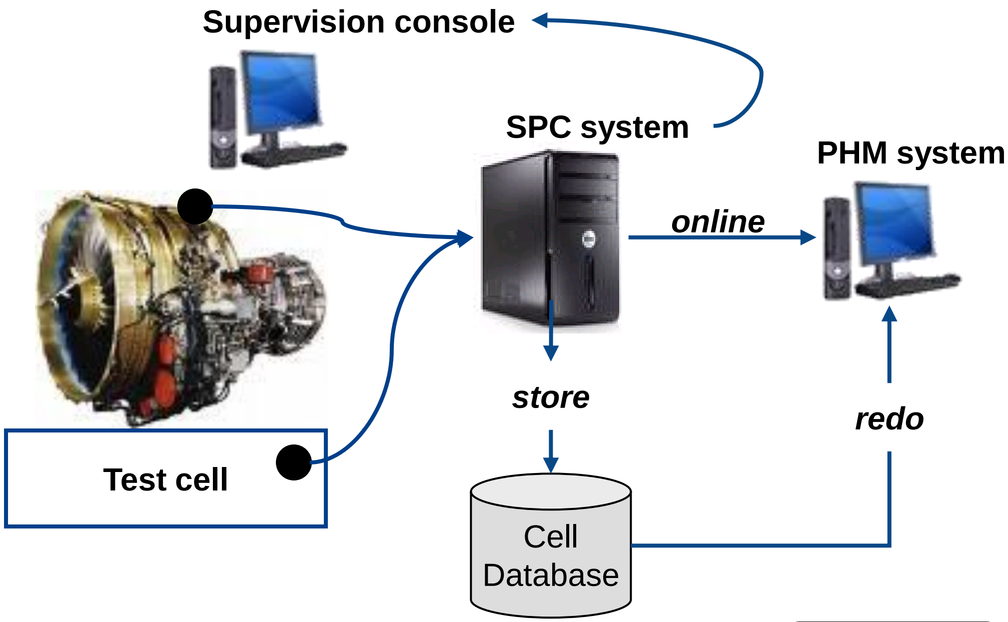
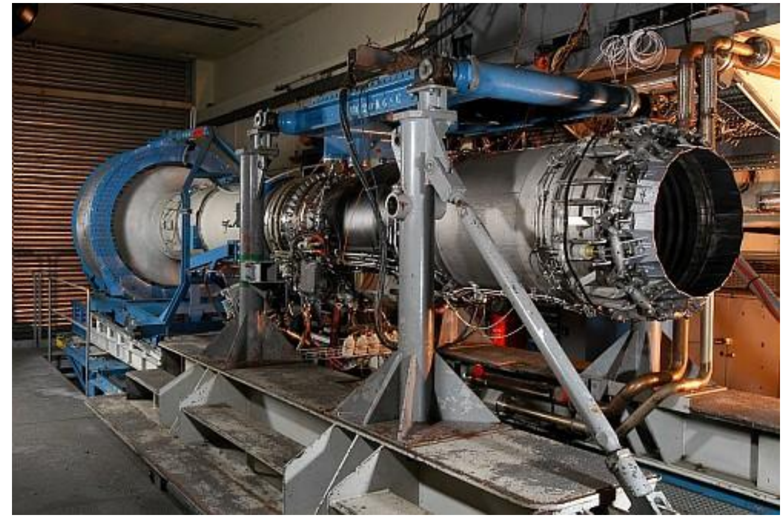
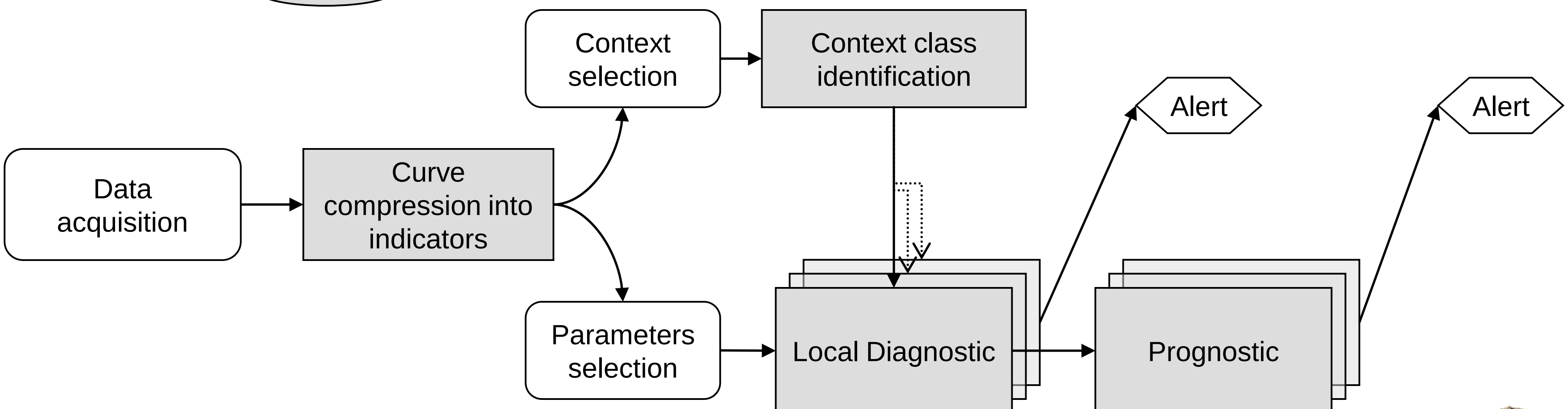
Bench Test Anomaly Detections

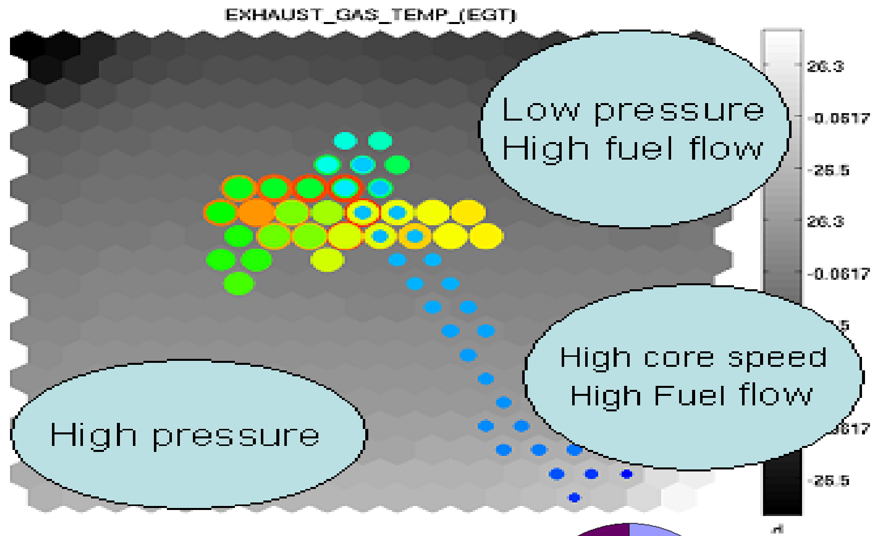


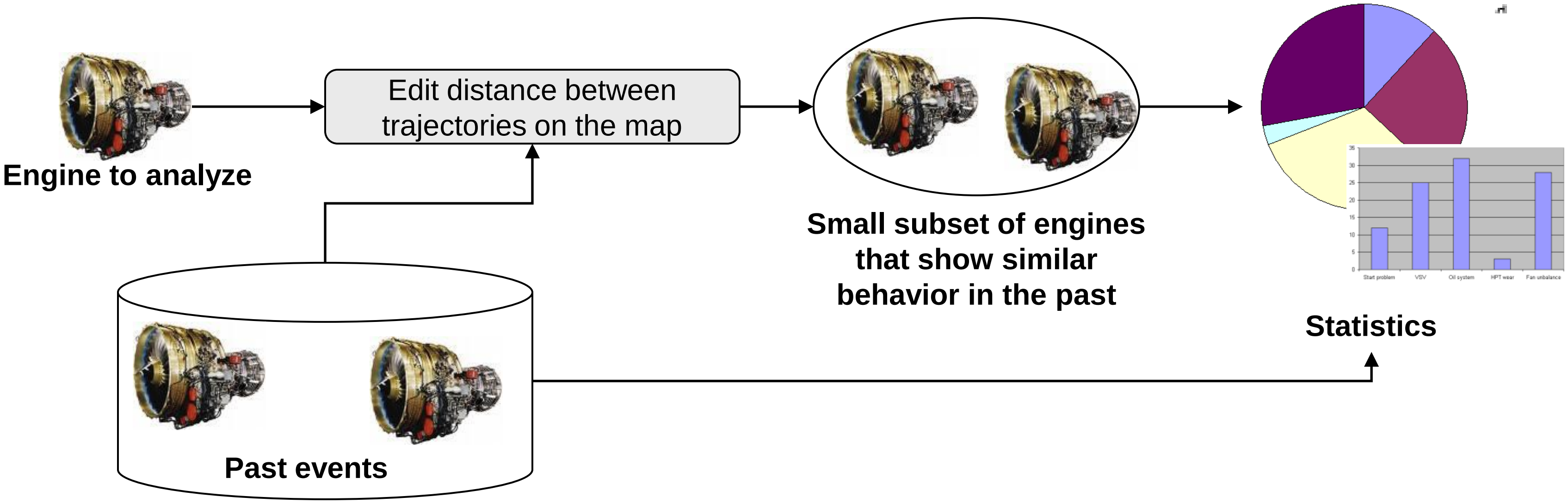




Fleet Mapping

- **Using a fleet of engines and a historic database, the state of each engine is compressed in a 2D space that conserve distance order.**
  - Each engine trajectory may be drawn on the map.
- **Trajectories comparisons allow the computation of statistics.**





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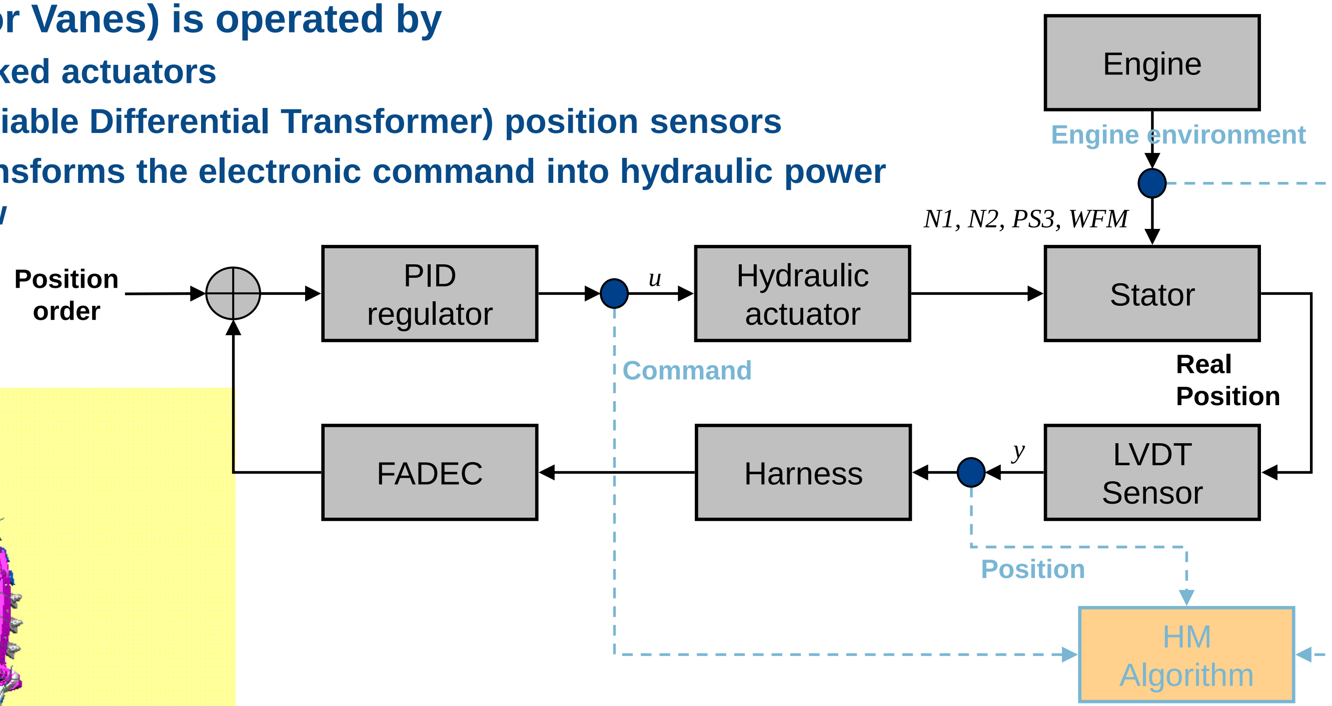
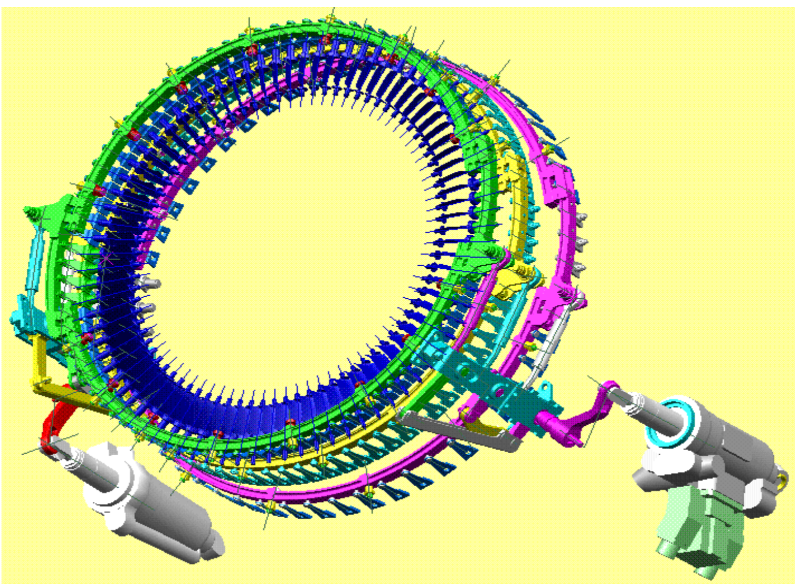
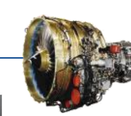
Control Loop Monitoring

- The VSV (Variable Stator Vanes) is operated by
  - two mechanically linked actuators
  - two LVDT (Linear Variable Differential Transformer) position sensors
  - a servovalve that transforms the electronic command into hydraulic power by means of fuel flow





- The algorithm analyzes the behavior of the control loop
  - The normal behavior is modeled on ground, producing a reference
  - The algorithm automatically compute a local model on line
  - Then it compares the new behavior to the reference



Thank you …