Research and Innovation at Safran Group

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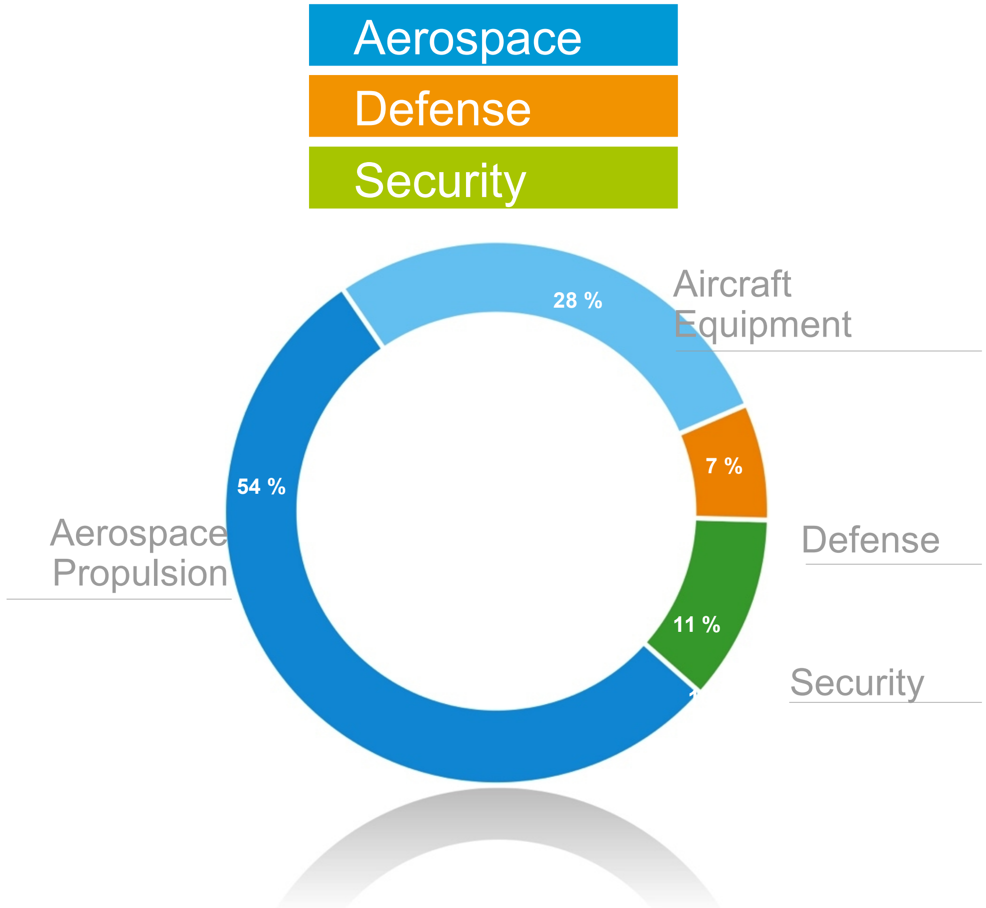
SAFRAN AT A GLANCE

*As of December 31, 2015

- An international **high technology** group
- **17,4 Billions € revenues**
- **More than 70 000 employees in** 60 countries
- 3 core businesses:



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Research and innovation at Safran Group: from strategy to technology

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A STRONG TECHNOLOGY BASE TO BACK SAFRAN MARKET POSITIONS

Safran

Propulsion	Equipements	Defense & Security

Propulsion

#1 WW
- Single aisle aero-engine
- Helicopter aero-engine

#2 WW
- Space Propulsion

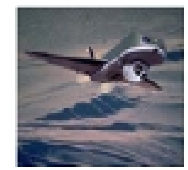
#4 WW
- Military Engine

Equipements

#1 WW
- Landing gear
- Wiring
- Power transmission

#2 WW
- Engine nacelles
- Wheels & brakes

Defense & Security



#1 WW
- Biometric and ID solutions
- Helicopter Flight Control

#2 WW
- Detection

#3 WW
- Inertial navigation systems
- Optronic systems: #1 Europe

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SAFRAN TECHNOLOGY DRIVERS

Aeronautics

- Efficient, environmentally friendly propulsion and critical systems for next generation aircraft and rotorcraft
- Optimized energy systems for aircraft, more electric and hybrid networks
- Connected secure embedded systems and data analytics-based services

Space and Defense

- Reliable, more affordable propulsion technologies for launchers and spacecraft
- Armed forces “sensor to shooter” capabilities in a network-centric environment

Security

- Biometrics-based identification and secure transactions in the connected world
- Security of human and goods flows at borders, harbors, airports

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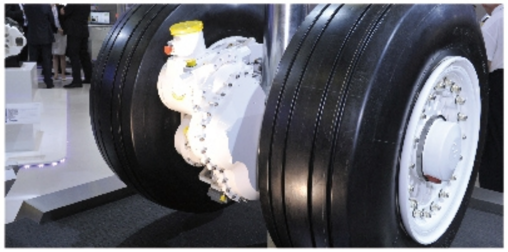
A SAMPLE OF SAFRAN INNOVATIONS

Electrical Green Taxiing

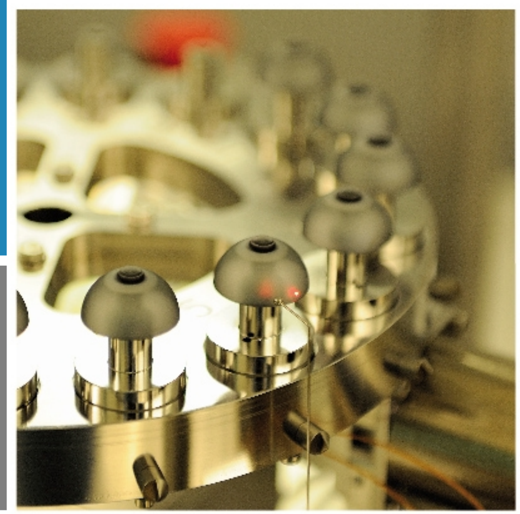


Patroller drone

Leap Engine

Sensors for identification & navigation

Hemispheric Vibrating Gyrometer



Finger on the fly

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R&D AT THE CORE OF THE STRATEGY

2.1 billion
euros in 2015

Invested in research & development, more than 12% of sales

more than 21%
of the Group's staff members

Involved in R&D, including more than 450 PhDs, and 185 doctoral students

900
Patents

Filed by Safran in 2015

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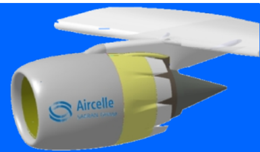
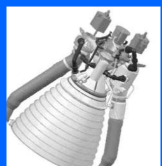
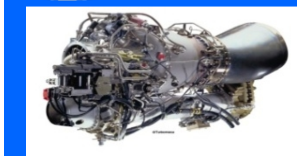
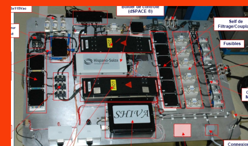
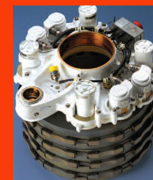
SAFRAN R&T DOMAIN STRUCTURE: DESIGNED TO EMULATE SYNERGIES

Turbomachinery & Propulsion Systems



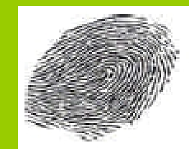



Electrical Systems Power Electronics Mecatronics

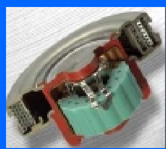
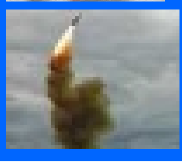




Sensors & Information Technologies



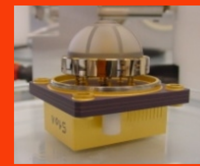


Solid propulsion & Energetical Materials

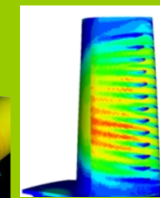
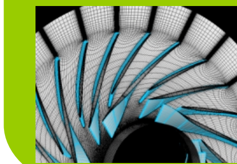
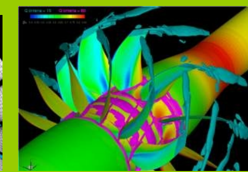




Embedded Electronics & Systems

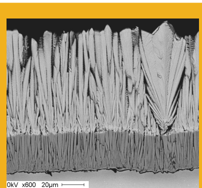




Modeling & Simulation for engineering

Materials & Processes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STRONG SUPPORT FROM ACADEMIA

Common Labs:

- LCTS de Bordeaux (Composites Thermostructuraux)
- CERFACS de Toulouse (Mécanique des fluides et combustion)
- IPES Lyon (Electronique de Puissance)
- SHEFFIELD University **(GB)** (Advanced Manufacturing)

Collaboration with worldclass institutes:

- ONERA,
- CNRS,
- CEA,
- IVK (Belgique)
- PPRIME

International collaborations:

- USA (Stanford, VirginiaTech, GeorgiaTech)
- Russie (CIAM,VIAM,…),
- Canada (Polytechnique Montréal, Sherbrooke)
- Singapore (A*STAR)
- Chine (BUAA)
- India: IISc Bangalore, IIT Delhi

230 PhD

Networks:

- INCA Combustion Avancée
- MAIA Méthodes Avancées en Mécanique
- IROQUA Réduction du Bruit
- POCA Electronique de Puissance
- HAIDA Aérodynamique des Turbomachines

Foundations:

- Fondation de Recherche pour l'Aéronautique et l'Espace
- IRT St Exupery Toulouse
- IRT SystemX Saclay
- IRT M2P ,Lorraine,
- VedeCom, Satory

Chair support:

- X Innovation
- INSA Lyon
- ISAE- HEC
- Centrale Paris – SupElec
- ESPCI
- Telecom ParisTech
- Mines ParisTech
- Institut d'Optique

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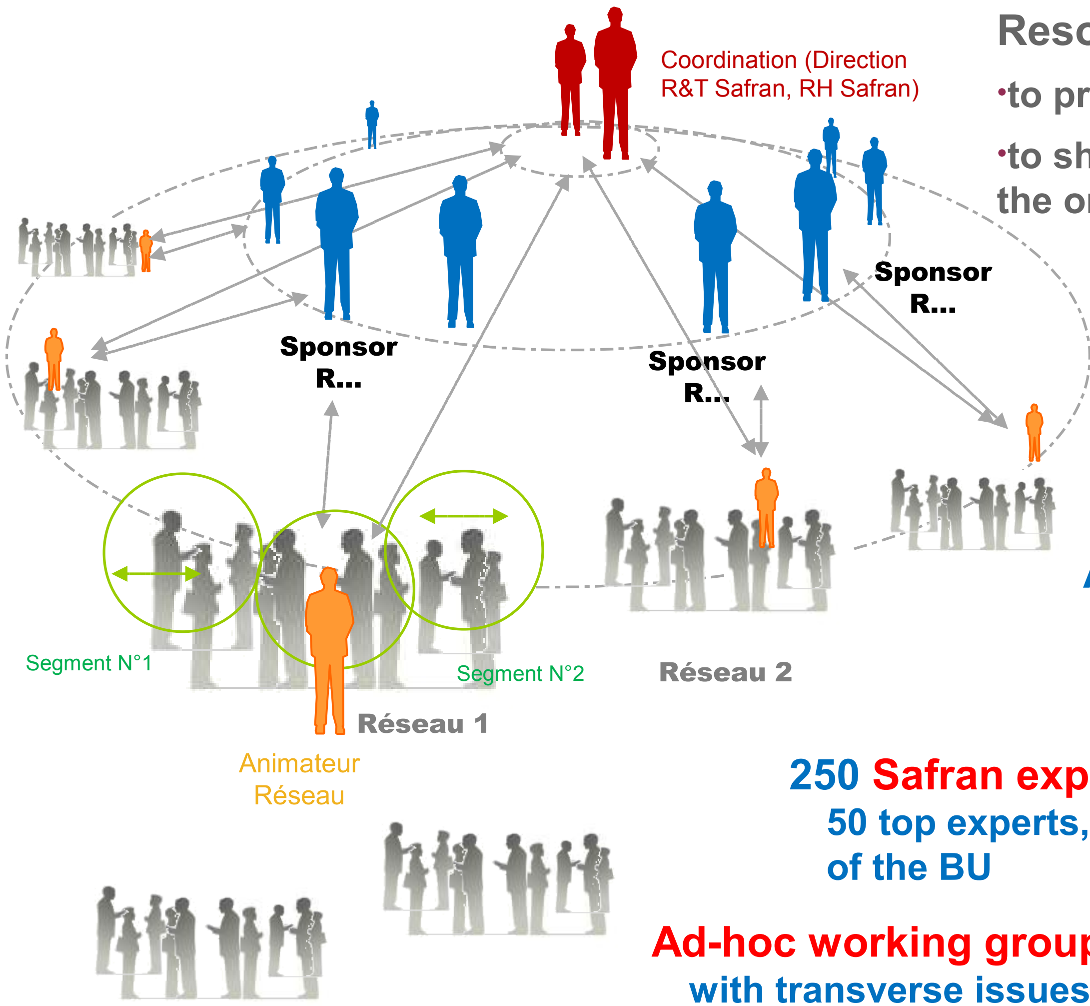
EXPERT NETWORKS



A Joint program of R&T and Human Resources Safran Directorates

- to promote and reward the technical careers
- to share the benefit of technical expertise across the organizational borders

11 domain networks : objectives defined in line with the technology strategy of Safran with a sponsor at technical executive level

A facilitator (one expert among each network) manages the activities of the network

250 Safran experts : 200 senior experts and 50 top experts, selected among 1000 experts of the BU

Ad-hoc working groups to deal with transverse issues

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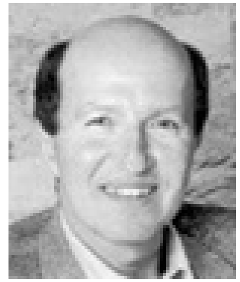
SAFRAN HIGH SCIENTIFIC COUNCIL



Mathias Fink

Nikos Paragios

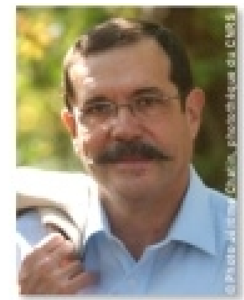
Philippe Marcus

Albert Benveniste

Daniel Eylon

Alain Combescure

Sébastien Candel



Alain Aspect

High level scientific survey
Expertise on critical domains
Recommendations for new scientific collaborations
Evaluation of Safran experts networks

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SAFRAN TECH: A NEW SET OF RESEARCH FACILITIES

➔ **March 2014:**
Centre Safran Composites
Itteville (Essonne)

➔ **November 2014:**
SAFRAN TECH
Paris Saclay University Campus

➔ **SAFRAN Advanced Casting Research Center under construction at Gennevilliers**

- state-of-the art facility covering the whole turbine blade manufacturing process

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SAFRAN TECH

2015: 300 p

La maîtrise des systèmes et des technologies

Energétique & propulsion
Pierre-Alain Lambert

Systèmes Electriques & Electroniques
Dominique Aléjo

Les matériaux et composants

Technologies et applications des capteurs
O. Vancauwenberghe

Direction Matériaux et Procédés Groupe
Ludovic Molliex
Olivier Delcourt

Les méthodes et outils numériques

Modélisation et simulation
Frédéric Feyel

Technologies du Signal et de l'Information
Daniel Duclos

Safran Composites
Marc Gouny

Centre de compétences Fabrication Additive
Thierry Thomas

Plateforme Fonderie des aubes
Hugues Joubert

Safran Céramiques
Projet

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MAIN AREAS OF RESEARCH

Systemic and technology mixed approach of propulsion and on board energy

Modeling & simulation, seamless digital product life management

Next generation materials & processes

High performance electronics and mechatronics

Smarts sensors and data engineering

Advanced turbines

Smart Factory

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SAFRAN TECH Research Directions

A Few Samples….

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ADVANCED TURBINES

SAFRAN Advanced Casting Research Center under construction at Gennevilliers plant

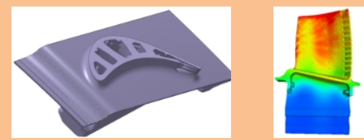
- 4 500 m²
- state-of-the art machines covering the whole turbine blade manufacturing process

ADVANCED HIGH PRESSURE TURBINE BLADES

1800°C Class HP Turbine Blade

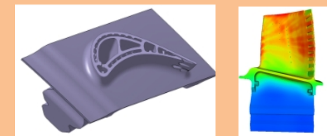
- Advanced cooling technology
- New generation Single Crystal Superalloy
- New Thermal Barrier Coating

Advanced Cooling Technology



Hub section   Skin temperature

Conventional cooling circuit



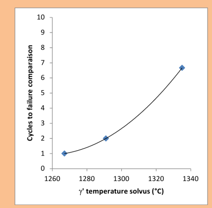
Hub section   Skin temperature

Advanced cooling circuit

- ***Increasing the turbine inlet temperature by reducing the metal temperature***

New Generation Single Crystal Superalloy

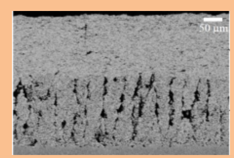
γ - γ' microstructure of a new superalloy



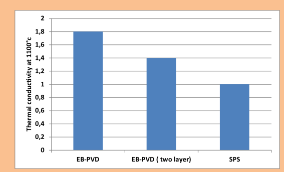
Thermal cyclic creep life versus γ' temperature solvus

- ***Improved creep life and thermo-mechanical fatigue life***

New Thermal Barrier Coating



Suspension Plasma Spray Thermal Barrier Coating (CEA DAM partnership)



Thermal conductivitty of new thermal barrier coating

- ***Lower conductivity to reduce metal temperature***
- ***More resistance in severe environment conditions (dust, sand, volcanic ashes)***

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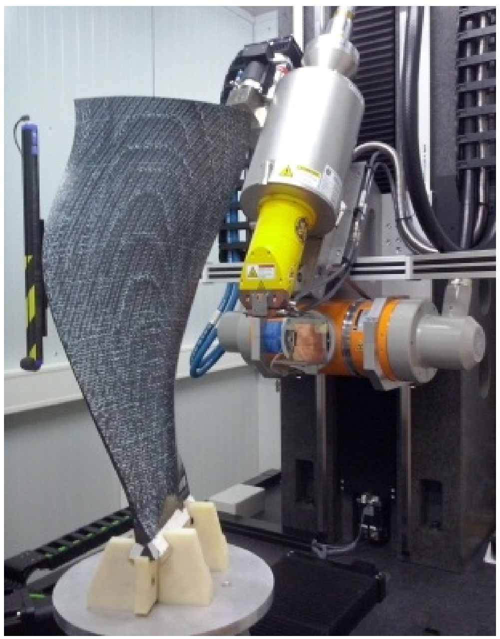
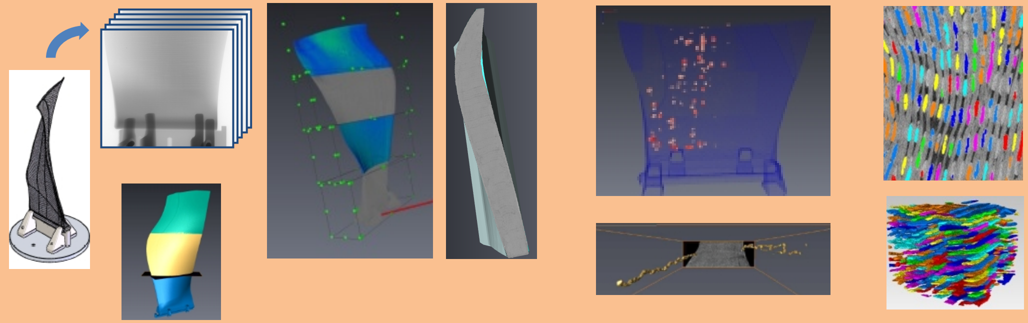
SMART & CONNECTED FACTORY

Innovative **Non Destructive Testing** (NDT) techniques required to control internal material properties of Leap Engine Composite Fan Blade:

•X-ray Computed Tomography 3D Image Acquisition
•Automatic Image Processing Tools



X RAY TOMOGRAPHY & IMAGE PROCESSING



3D Image reconstruction | **Image Registration** | **Automatic Detection & Analysis** | **Weaving Structure Analysis**

X-Ray Tomography 3D Image Production

- 3D Image reconstruction from 2D X-ray projections.
- 3D Image registration with CAD model
- 3D image restauration and normalization

3D Image Analysis for NDT and Expertise

- Automatic detection and characterization of porosity, foreign objects and glass tracers
- Automatic extraction of weaving structure and properties
- Image and indications enhancement for operators and NDT experts

➢ ***Robust high detection performance with low false alarm rate***

➢ ***Rapid generation of NDT reports and NDT data management services***

➢ ***Data for real time industrial process monitoring (Machine Learning)***

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ADDITIVE MANUFACTURING

A Disruptive Technology to Produce Metal Parts

TURBOMECA Production Line with LBM process

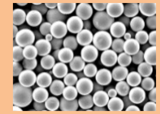
Ardiden 3 injector

Ardiden 3 swirler

- Increased design freedom, new shapes
- Shorter time to first part
- Weight & Cost reduction opportunities
- Well suited to aeronautical production volume

SAFRAN ROADMAP « 3P» :
Best Combination of Powder – Process - Part

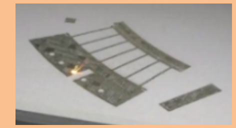
POWDER



- **Supply chain robustness (Ti, Ni, Fe, CoCr, Al base alloys)**
- **New materials, gradient materials**
- **Marker to avoid pirated copy**

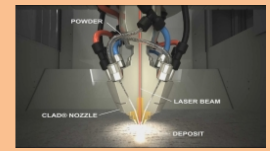
PROCESS

- Powder bed technology (LMD, EBM)



Part layer

- Powder spray (LMD, ColdSpray)



- Powder sintering (**MIM**, SPS) => an other path to direct manufacturing
- **Process Simulation**
- **Monitoring in-situ**

PARTS

Typical Development Parts

Mechanical properties
- Between cast and forged

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CERAMICS MATRIX COMPOSITES

CMC ON TURBOFAN

- Allow higher temperatures
- Reduce cooling flow rates
- Reduce weight (÷2 to 4)

Aft Pylon Fairing on A380

With DGA and Airbus

1990’ Carbon-Ceramic Rafale nozzle flaps
650°C x 1000 hours

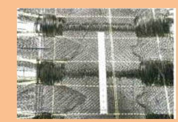
SAFRAN TURBOFAN APPLICATION TARGETS

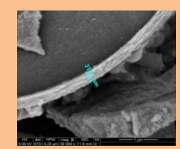
1300°C		1100°C	800°C
Combustor Liners	Turbine Shrouds	LPT Blades	Exhausts

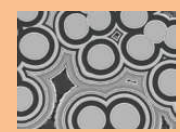
Life duration : 30,000 to 80,000 hours

SAFRAN WIDE RANGING PLAN ON CMC

- ❑ **Long durability ceramic Fibers**
  - **Silicon carbide, Oxides,..**
- ❑ **Fibrous preform design and manufacturing**
- ❑ **Interphases**
- ❑ **Ceramic Matrix : densification processes**
  - **Chemical Vapor Infiltration**
  - **Slurry introduction**
  - **Melt Silicon Infiltration**
  - **Pre-ceramic Polymer Impregnation and Pyrolysis, …**
- ❑ **Environmental Barrier Coating**







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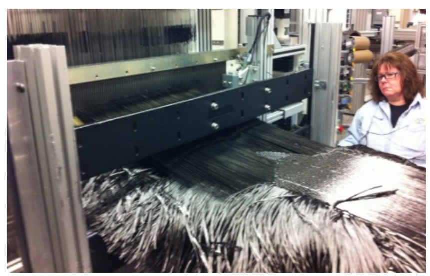
ADVANCED COMPOSITES FOR ENGINE PARTS

3D WOVEN PREFORMS

3D Woven Preforms developed by SAFRAN and AEC (Albany Engineering Composites) used on LEAP production for fan blades and fan case

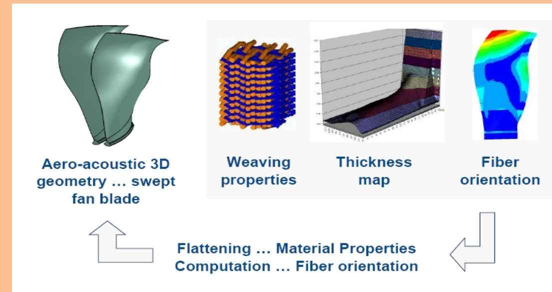
Robust and Cost Effective Technology allowing weight reduction and bird impact resistance

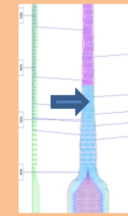
Others Safran applications developed with this technology with **Carbon or SiC fiber**



Preform definition cycle

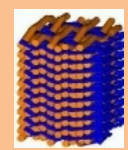
Preform defined by the Design Office, Material laboratory and weaving specialists





Optimisation of patterns depending on loading conditions

- Airfoil Tip
  - High energy impact
  - Pattern optimised for impact résistance

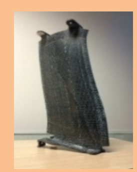


- Dovetail
  - Centrifugal loading
  - Pattern optimised for stiffness and fatigue

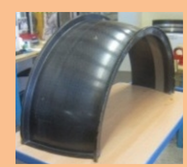
Future of the technology

CMC LPT Blade

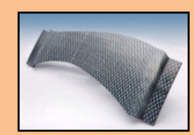
OGV



Booster Casing



Platform



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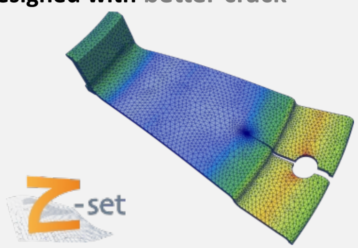
MODELING & SIMULATION CHALLENGES
RUPTURE MECHANICS

In order to improve performance and reliability of aeronautical structures, Safran and its partners constantly push the boundaries of its material and structural models.

✓safer designs
✓lower maintenance costs
✓improved engine efficiency

Z-cracks drives 3D crack propagation simulations under extreme and complex thermo-mechanical loads

→ critical parts can then be designed with better crack resistance.



Z-cracks is part of the Z-set non-linear Finite Element suite and uses cutting-edge INRIA / Distene meshing tools.

Z-cracks is developed by Onera and Mines ParisTech.

✓ **increasingly *high-fidelity* and *multi-scale* models**
✓ **ever-more *realistic mission profiles*, with *high-cycle*, *high-temperature* and *multiaxial* loads**
✓ **different time scales from thermal and mechanical *impact* to *creep*.**

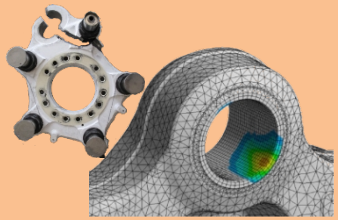
1. Overspeed safety system

Full 3D blade shedding simulation (TurboMeca / LaMCoS)

> Safe flight
Blade-shedding in case of *emergency*:
✓turbine blades in helicopter engines are *designed* to break in a *controlled way* when loaded beyond a pre-set safety limit.
✓this *protects* the engine from further damage.

Innovative numerical tools will allow
✓choosing the *safest damage-tolerant* design option,
✓well *before* the final certification tests.

2. Improving safety margins



Fracture test of a piston housing prototype.
Prediction of the crack initiation (Messier-Bugatti-Dowty)

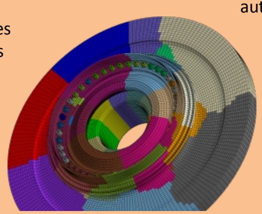
> Safe touchdown
Emergency landing:
✓*all* landing gear components *must* withstand extreme loads.

Novel damage models:
✓*validated* experimentally,
✓*predict* potential weak sites
✓*early* on in the design stage.

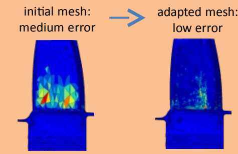
Safety margins can thus be determined with *higher confidence levels*.

3. Control of calculation cost and precision

> Lower cost
Massively parallel computing:
✓faster return-times
✓faster development cycles
✓lower development costs



> Precision control
On-the-fly model adaptivity:
automatic error-based mesh refinement.



Error maps and mesh adaptivity (Onera / Snecma)

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KEY MISSIONS, KEY TECHNOLOGIES, KEY TALENTS

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