POLITECNICO MILANO 1863

DIPARTIMENTO DI MECCANICA

SIGMA Lab: Structural integrity under extreme loads

(May 2018)

POLITECNICO DI MILANO, ITALY

DIPARTIMENTO DI MECCANICA

SIGMA Lab

Structure Impact proGnosis Monitoring MAterial LABoratory

Our research team inside Politecnico di Milano
SIGMALab, http://www.giglio.faculty.polimi.it

Politecnico di Milano ...since 1863... → 12 departments – more than 1300 Researchers/Professors – more than 37.000 students

↓

Department of Mechanical Engineering → More than 105 people as permanent staff – more than 100 PhD students – approximately 9-10 M€ of annual funding (Mainly from EU and Industry)

http://www.mecc.polimi.it/

↓

Research lines → Dynamics and Vibration of Mechanical Systems, Ground Vehicles, History of Technology, *Machine Design,* Manufacturing and Production Systems, Materials, Measurements and Experimental Techniques, Methods and Tools for Product Design

↓

•Structural Integrity of Mechanical Components and Systems – SI ←

↓

SIGMA Lab ***Structure Impact proGnosis Monitoring MAterial LABoratory***

Research group (devoted to research in defense field)

SIGMALab, at a glance

POLIMI/SIGMALab team has 15 years of expertise in mechanical design of systems and structure under extreme conditions**. SIGMALab** have strong links to **EDA** programmes as coordinator of a number of projects on structural health monitoring (SHM): HECTOR – ASTIANAX – SAMAS (ongoing). **SIGMALab** have lead several national projects about **terminal ballistic, explosion and vulnerability** together with Italian MoD (SUMO, SUMO2) and national enterprises (LEONARDO)

SIGMALab have accomplished several research activities with academic and industrial partners and customers (included **security and defense**).

SIGMALab: People

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Our mission:

Main aim of the research team is an advanced engineering approach for the **assessment, new design and optimization of mechanical and aerospace components**. Research activities and topics concern with several aspects related to:

- **assessment and optimization** of components under spectrum loads and extreme loads (ballistic damage, etc.);
- **monitoring, diagnosis and prognosis** of critical structures subject to degradation, under fatigue loads and impact loads;
- **application of novel probabilistic approaches** in structural integrity design (flaw tolerant approach, reliability methods, vulnerability, etc.).

Experimental investigations and numerical-analytical investigation allow to individuate models able to simulate components under contingent-extreme loads in order to optimize their behavior.

SIGMALab: outlook of the research team

Our vision: a reference team for tailored assessment of critical components under extreme conditions

More that 15 years of challenging research activities with academic and industrial partners and customers (included security and defense).

SIGMALab: research Areas

SIGMALab is active in several research topics related to defense field, but conventionally we have created two main research programmes. Each area develops original and advanced technology platforms at the state of the art in order to deliver the best solutions for challenging problems. The areas merge in several activities.

Structural integrity under extreme load

- Large deformation and failure, ballistic and low velocity impact, explosion, crack and damage, delamination, etc
- Definition of optimal protection
- Material calibration exploiting innovative constitutive law
- Numerical modelling (FEM, DEM, meshless, etc)
- Analytical modelling
- Experimental testing (from micro to full cale)

Model-based Structural Health Monitoring and prognosis

- Investigation of different state of art sensor technologies for SHM
- Numerical and analytical modelling for SHM system training
- Machine learning and pattern recognition for diagnosis
- Bayesian filters and Monte-Carlo methods for prognosis
- Experimental SHM verification and performance qualification

SIGMALab: research Areas

New entries for SIGMALab research topic

Energy

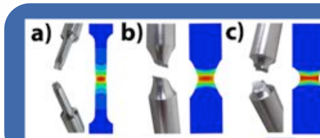
- SIGMALab team is working in order to provide dedicated solutions both for O&G and renewable energy (explorative drilling and innovative solar troughs).

Reliability and statistical approaches for structural integrity

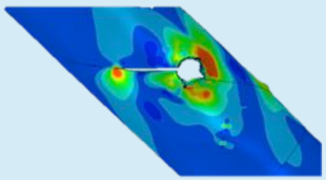
- Numerical and analytical modeling
- Machine learning and pattern recognition for cheap approximation of complex FEM responses
- Monte-Carlo simulation schemes for uncertainty effects quantification
- Advanced optimization schemes (evolutionary algorithms, etc.)

Outlook of the framework: a fit for purpose / multidisciplinary technology platform

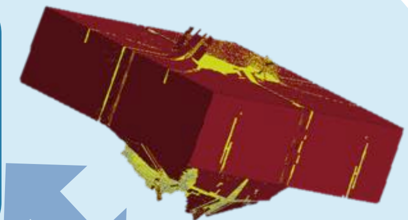
A deep investigation both in practical aspects and state of the art

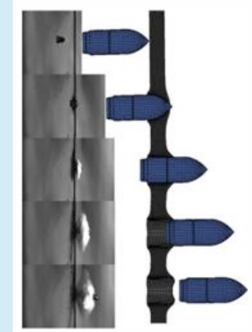


Material calibration



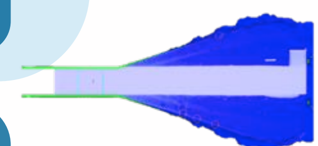
Numerical and analytical modelling / algorithm



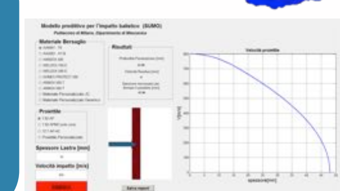


Experimental Tests

Validation of the modelling / algorithm approaches



Definition of predictive models/methods
Design optimisation
Structural Health Monitoring (monitoring, diagnosis and prognosis)
Fitness for purpose

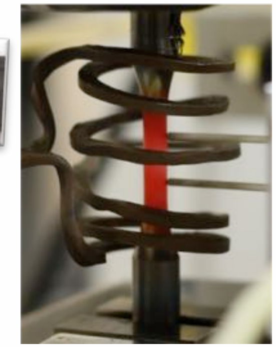


Outlook of the framework: a fit for purpose / multidisciplinary technology platform

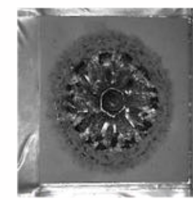
Experimental Tests

Test on **coupon and small specimens** to determine mechanical behavior

Metal Composite and Ceramic: plasticity, damage - Access to fully equipped materials lab including: quasi-static tension, compression and torsion testing at different temperatures, hardness measurements, fatigue testing, optical microscopy, scanning electron microscopes with coupled EDS and EBSD probes, X-ray diffractometer, CT scan, HIP - test under quality system



Test on **subsystem** also in presence of extreme loading condition

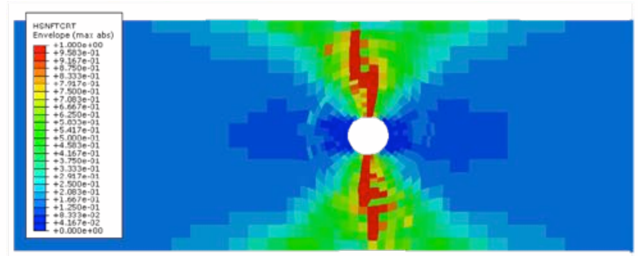


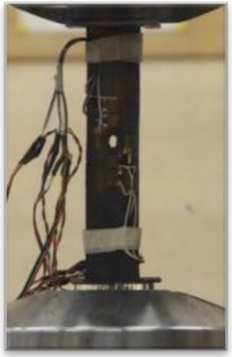
Test on **full-scale components** even for certification purpose

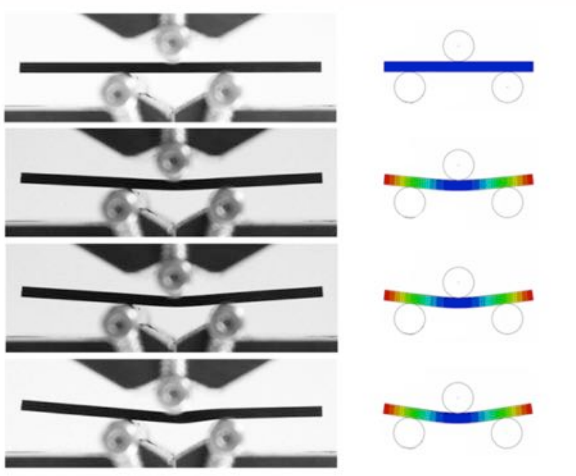
Outlook of the framework: a fit for purpose / multidisciplinary technology platform

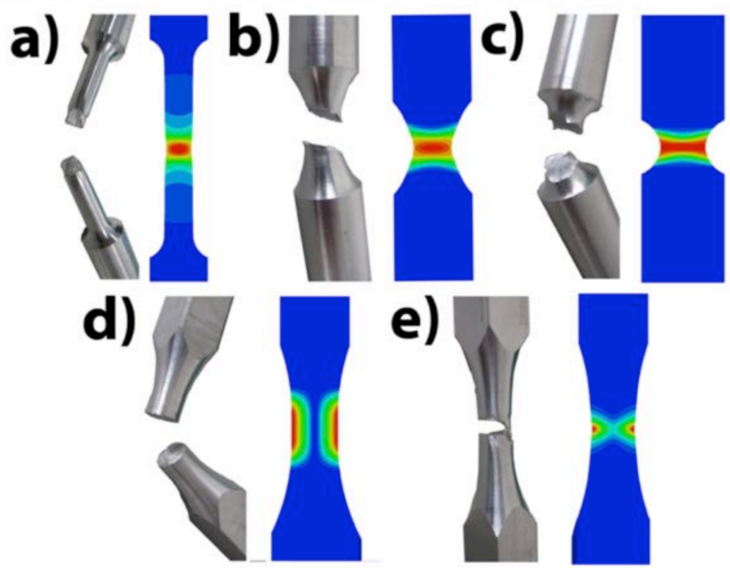
Material calibration

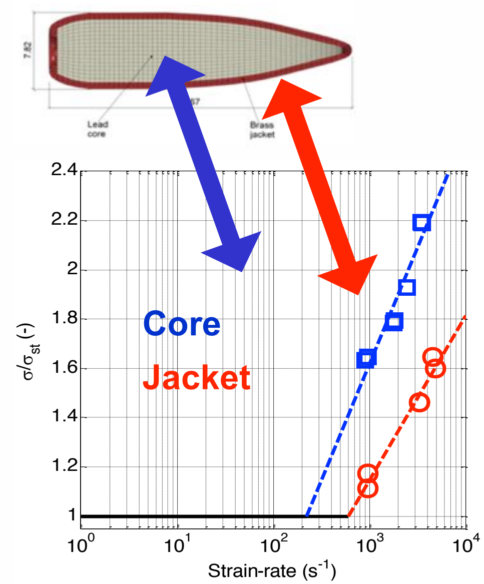
- Material behaviour: focus on **metal - ceramic – composite**
- Inverse methods for **calibration** of mechanical properties
- Definition of **constitutive models** able to describe high plasticity, ductile/brittle failure, strain rate, delamination, etc
- Creation of ad-hoc routine





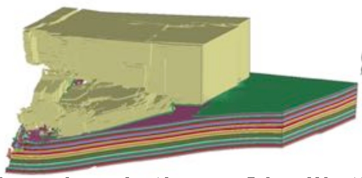


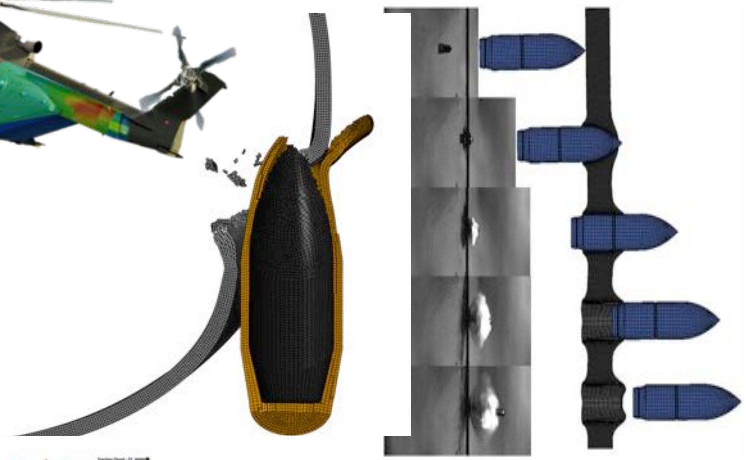




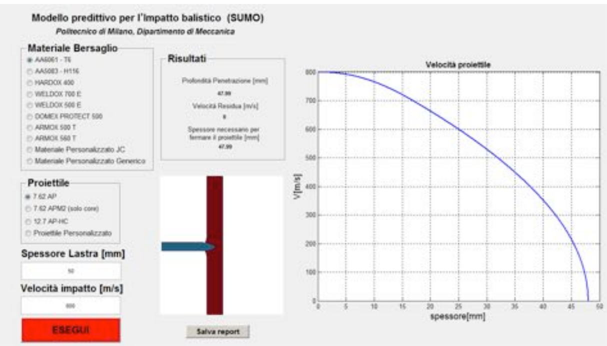
Outlook of the framework: a fit for purpose / multidisciplinary technology platform

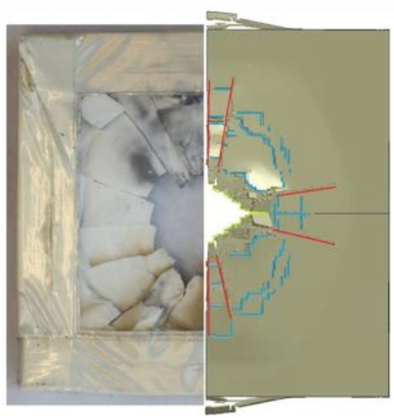
Modelling

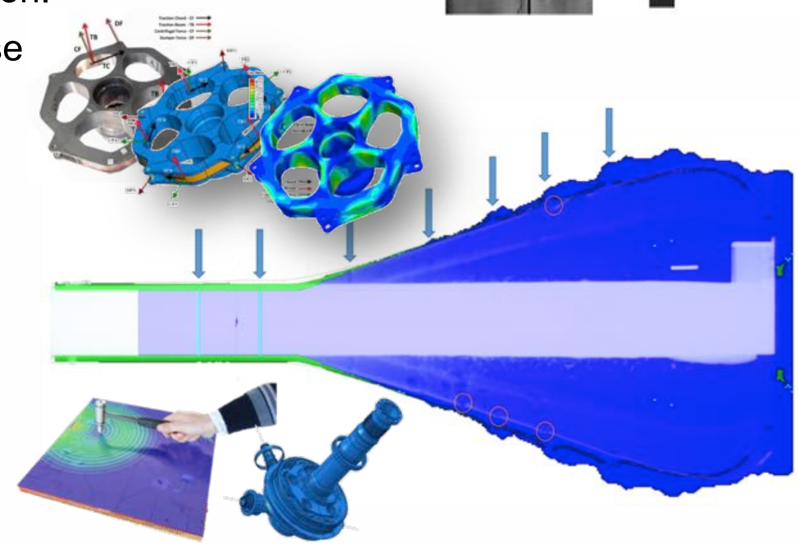




- Creation of **analytical models** for simulation of ballistic impact against Metal (cavity expansion) – Composites (energy balance and wave theory) – Ceramic (modified Bernoulli equation)
- Creation of **numerical models** (ABAQUS – Ls-Dyna)
  - ✓ large plasticity, high strain rate, high temperature and pressure, fracture and damage criteria, large fragmentation, delamination.
  - ✓ Lagrangian, ALE, SPH, perydinamics and in general expertise in mesh-free methods and coupling with lagrangian element.



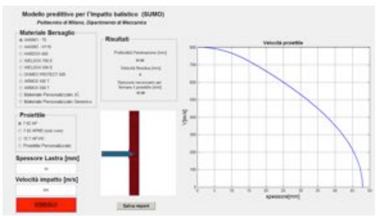




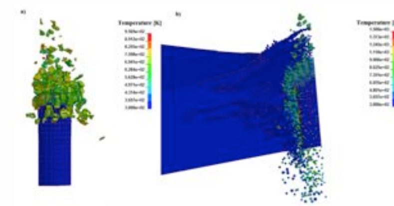
Outlook of the framework: a fit for purpose / multidisciplinary technology platform

Definition of predictive methods

Numerical and analytical modelling



Why are so important

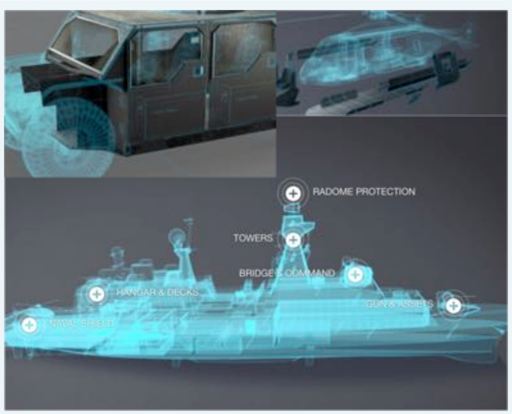


- Better **understanding of the physical phenomena** involved
- Better understanding of **effects of several parameters** (in highly non-linear environment)
- Possibility to perform **"virtual test"** when experimental approach is **unsafe and/or unfeasible**
- Reduction of the number of the experimental tests (time and costs reduction) and **better design of testing activities**
- Possibility to perform **optimization process and fitness for purpose** approach

The role of “Virtual test” in the design and assessment of innovative products aimed to defense system

Requirement:

Performances as a function of treats and operational conditions



Design and optimization

- Experience (*not always reliable*)
- Experimental testing (*time consuming and costly*)

Virtual test

- Predictive models
- Virtual tests
- **Reducing costs / uncertainties / development time**
- **Increasing fitness for purposes**
- **Optimization**

Validation

Certification, assessment of the finesses for purpose **???**

Possible unfitting that require another interaction with the design phase

More direct progress toward a fitted and reliable product

Final product

Outlook of the research activities: from actual requirements to R&D

Efforts have been spent in this field starting from three actual tasks:

LEONARDO

- Assessment of the residual life and strength of helicopter T/R shafts after ballistic perforation (thin walled structure – aeronautical components): ***Ballistic damage tolerance tests on the NH90-T129A tail rotor shafts***
- Evaluation of an optimized procedure for prediction of low caliber bullet penetration in thick armor plate (ground vehicle, civil structure, etc.): ***SUMO***

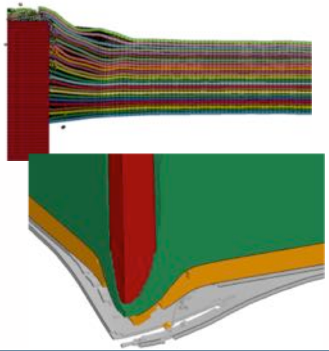
SUMO - P.N.R.M. (Italian National Project for Military Research), completed in 2013:

SvilUppo di un MOdello predittivo per l'impatto balistico

Development of a predictive model for ballistic impact

MINISTERO DELLA DIFESA

- Investigation in modeling low caliber bullet penetration in multilayer armor (composite – ceramic - metal): **SUMO 2**

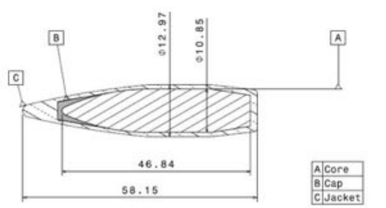


SUMO2. P.N.R.M. (Italian National Project for Military Research), work in progress:

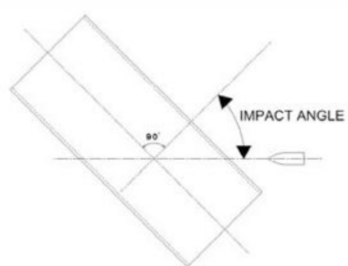
SvilUppo di una Metodologia analitica, numerica e sperimentale per la progettazione di protezioni balistiche cOmposite multistrato.

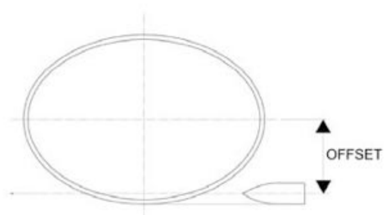
Development of a predictive model for multilayer protection

- Identification of the threat: projectiles



- Identification of other important parameters necessary to study the impact on the transmission rotor shaft: offset and the impact angle.
- Development of a reliable test program
- Step1: ballistic damage
- Step2: assessment of the residual strength



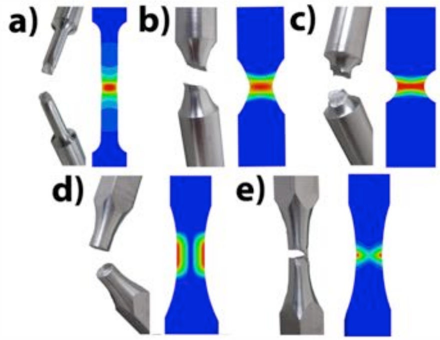


Step1: ballistic test

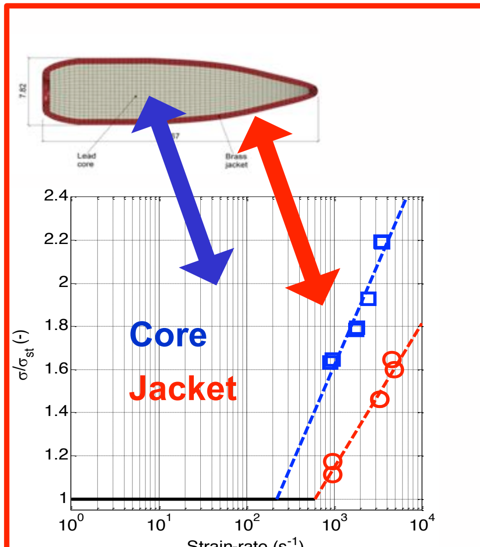
Ballistic damage tolerance tests on the NH90-T129A tail rotor shafts
Numerical modelling: an accurate insight in the physical phenomena

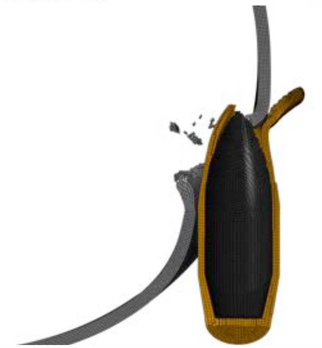
- *Numerical simulations are carried out using **Abaqus\Explicit and LS-DYNA solvers***
- *Projectile and target are geometrically modeled with the correct impact parameters: impact angle, initial velocity and spin, predefined residual stress, etc.*
- *Suitable elements type is chosen*
- *Algorithm to consider contact, erosion and deletion are evaluated*
- *Adiabatic heat effects are considered*
- *Presence of friction between bullet and target is generally neglected*

Focus on material calibration



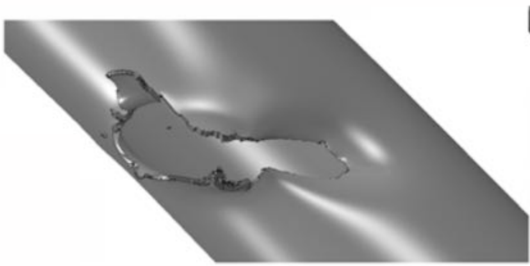
A "state of the art" fracture criteria developed in collaboration with M.I.T. which allow the definition of phenomenological models able to describe failure under several loading conditions



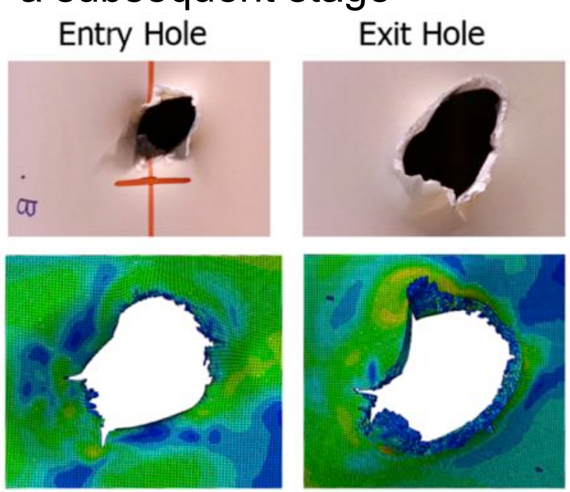


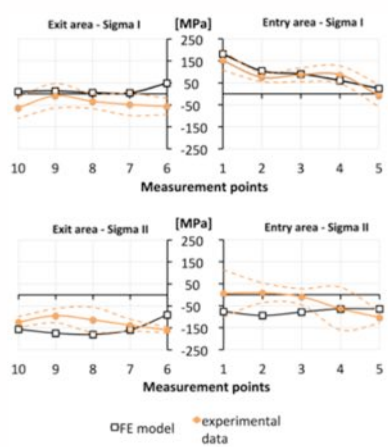
Ballistic damage tolerance tests on the NH90-T129A tail rotor shafts
Predictive method and exploitation of the models

Error in bullet residual velocity calculation: 0.4%



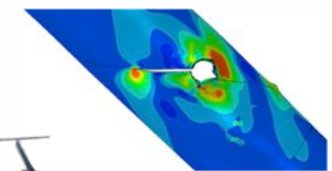
Correct simulation of dimensions and shape of the damages and state o stress: a correct "test bed" for a subsequent stage





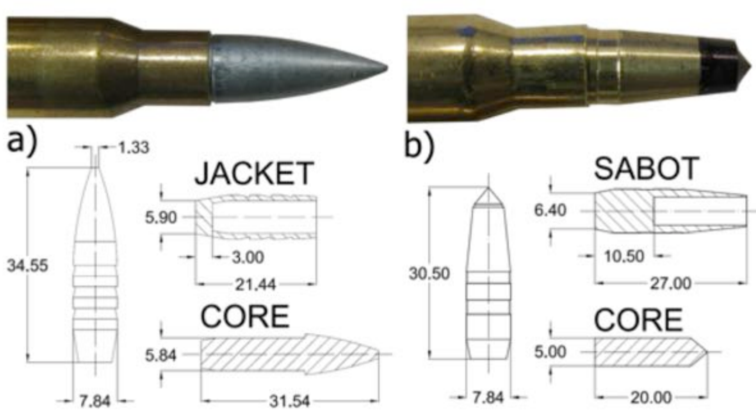
Step 2: residual strength

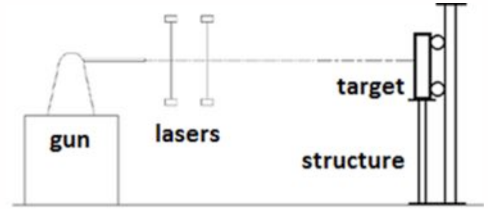
Assessment of the integrity in damaged condition: mission survivability on actual helicopters



SUMO: ballistic experimental tests

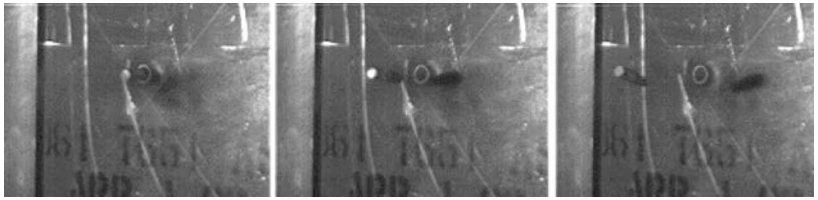
- Identification of the projectiles: AP small caliber





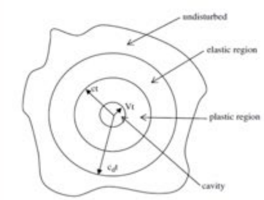
Ingresso

Uscita



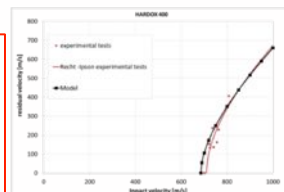
- Identification of materials and thicknesses: aluminium alloy (6061 T6) and structural/ballistic steel (Weldox 700, Hardox 400, Armox 500T) with different thicknesses and projectile velocity in order to verify the predictive capability of the models both in case of complete penetration (residual velocity) and arrest (penetration depth)
- Identification of models and approach available in literature (pros and cons, lack, possible improvements)

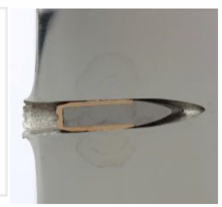
Analytical models based on spherical-cavity expansion .They allow predicting a large number of parameters involved in the mechanics of penetration, without the need to solve complex equations or to set empiric constants.



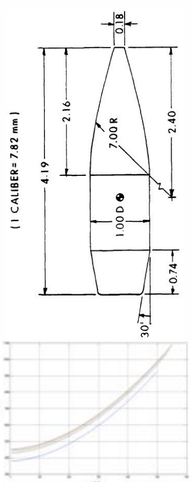
Validation in ballistic limit assessment

Validation in thick plates impact





Improvement

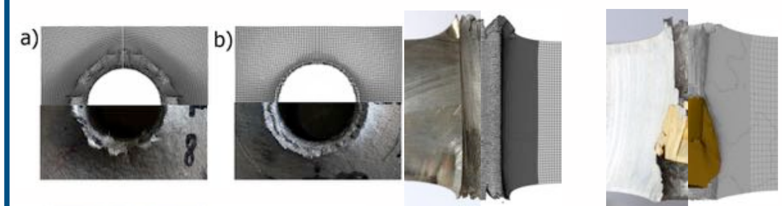


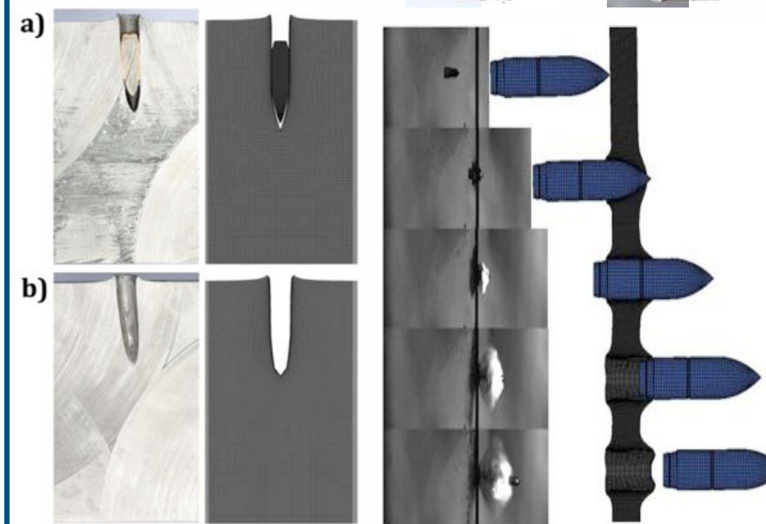
Shape of actual projectiles

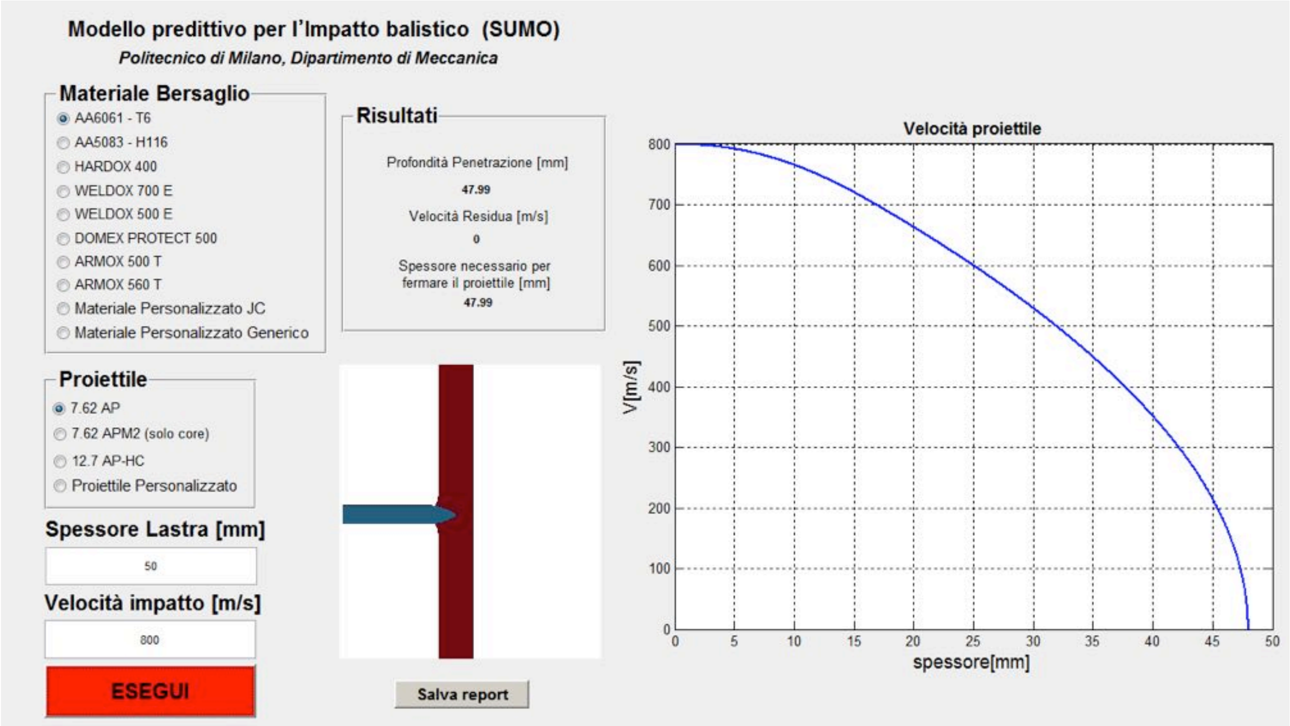
Generalized methodology for calibration of material constants

Model based on spherical-cavity expansion

Numerical FE Models. Very accurate capable to replicate not only velocity and energy features but also shape and damage morphology



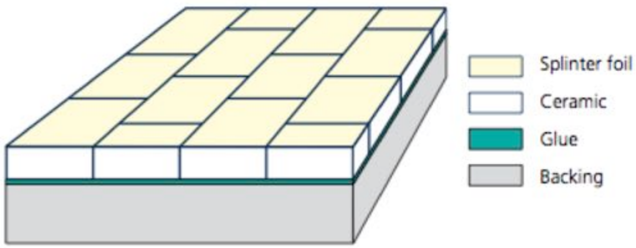




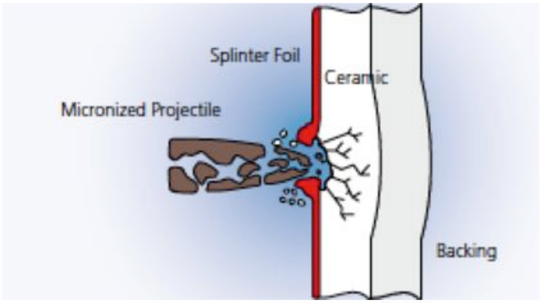
The final result of the SUMO project is the generation of a software application for the design of ballistic protections (armour). It's fitted for mono-layer metallic armour but a simplified approach for multilayer metallic armour has also been evaluated. The programme runs on a Windows platform and can be used for industrial purposes delivering reliable and effective data for preliminary design purposes

SUMO2 Multilayer armor (composite- metallic - ceramic) - work in progress

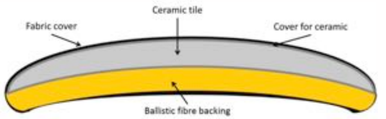
Design of **multilayer protection** have to satisfy several requirements regarding the **level of protection**, the **weight**, the **cost** and the **fitting**, etc



At present, **ceramic, composite** and also a small layer of **metal** material can be used in conjunction to satisfy this goal. **Past experience and experimental tests** play a key role in the proper selection and evaluation of armour but the **high level of uncertainties and the variability and range of the threats** makes the correct tailoring a very complex task.

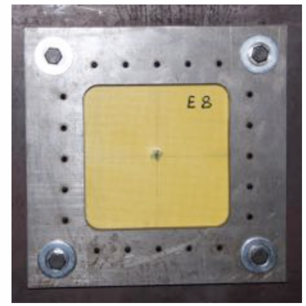


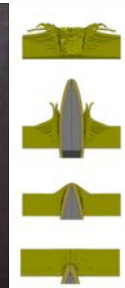
SUMO2 is aimed to the development of **predictive methods** as “virtual test” in order to define an affective procedure to select the most appropriate materials and layer arrangement, thus performing an **optimal and tailored design** according the type of threats for which the protection is required.



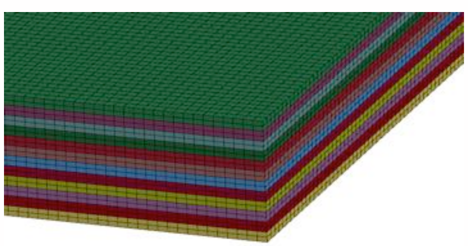
SUMO 2
Step 1, focus on single material: composite

Development and experimental validation of predictive models aimed to simulate the most used composite materials: Kevlar®29 and Dynema HB50 targets

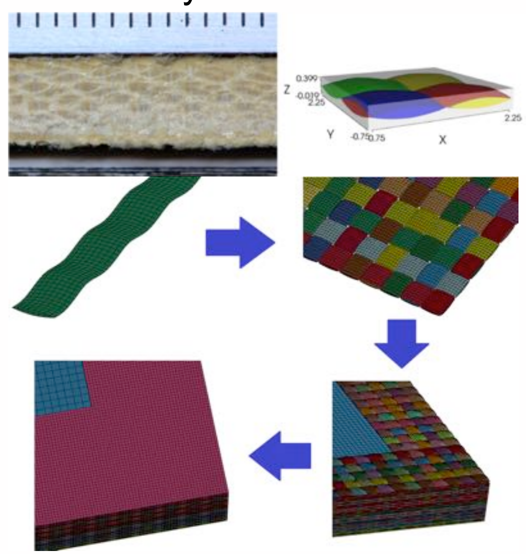




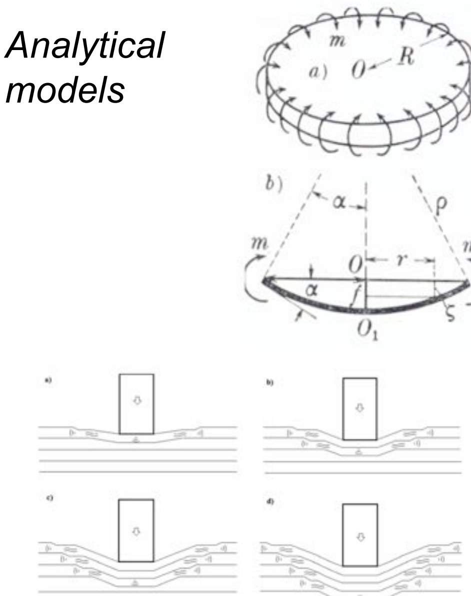
Macro-homogenous: every layer composing the plates is assumed a homogenous material, without distinction between yarns and the matrix; hence, physical properties are homogenous, the same in every point of the layer, but with orthotropic mechanical properties.



***Meso-heterogeneous*:** the yarns and the matrix are reproduced individually

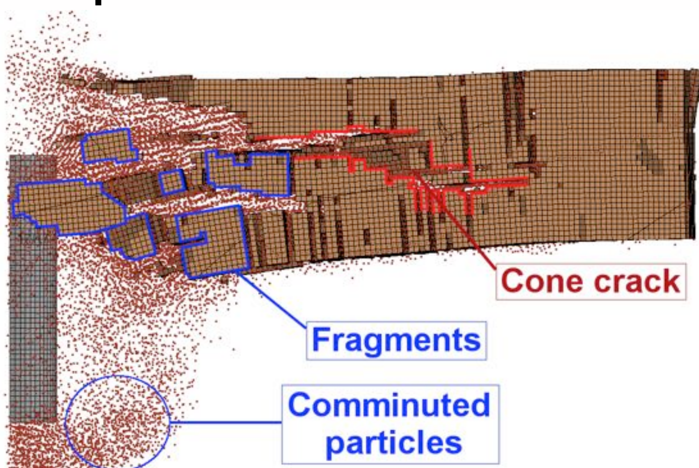


Analytical models

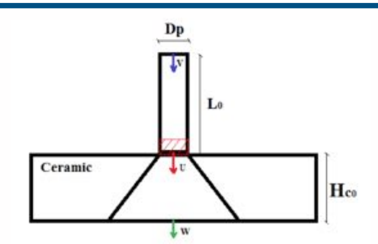


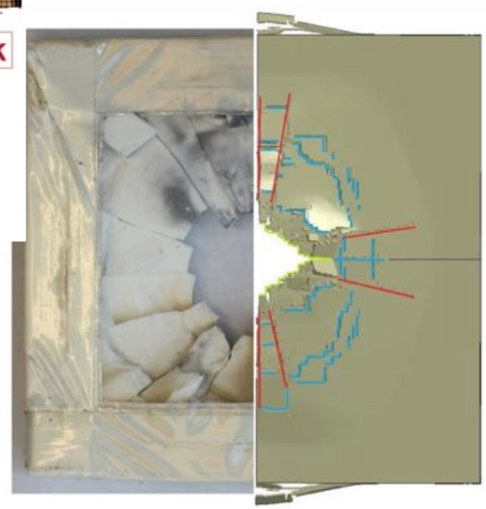
Step 1, focus on single material: ceramic

- Numerical innovative approaches to reproduce large fragmentation both of the bullet and the ceramic tiles
- **Ceramic tile failure simulated by mean of an adaptive solid mesh to SPH**



Analytical models

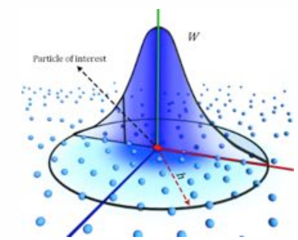




Meshfree methods

No predefined connections.

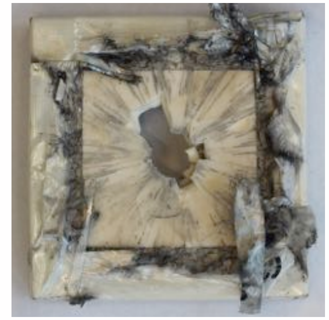
Shape functions definition depends only on node position.

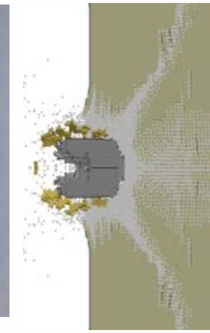
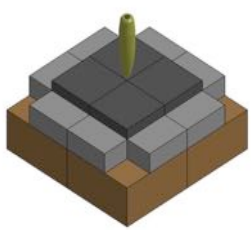
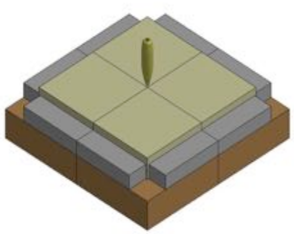
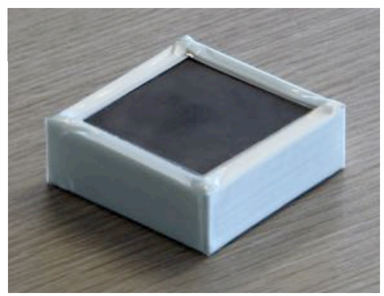
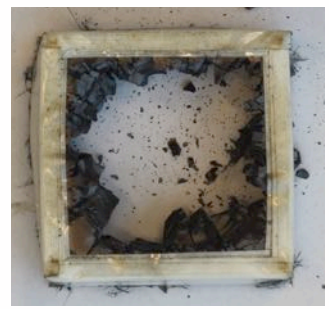


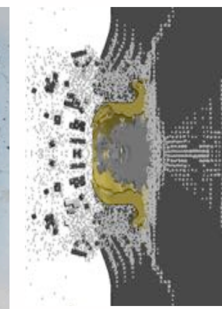
- SPH
- Peridynamics
- DEM
- EFG, …

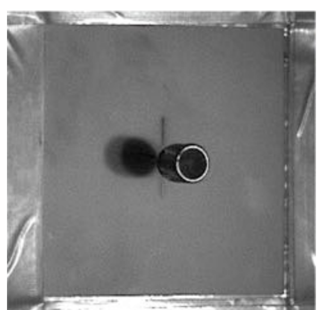
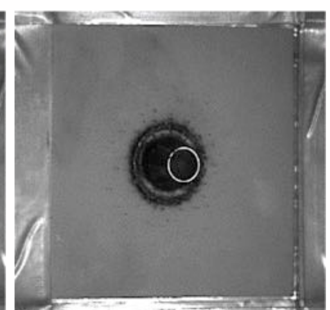
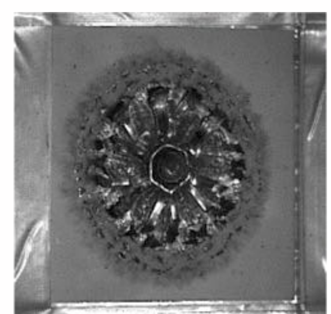
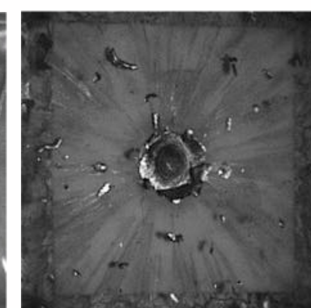
SUMO 2
Step 1, focus on single material: ceramic

- Experimental validation
- **Alumina 99%**
- **Silica carbide**

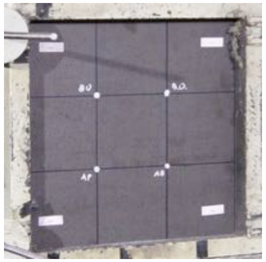



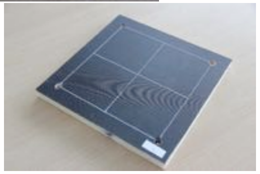






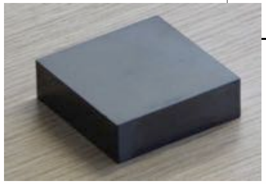


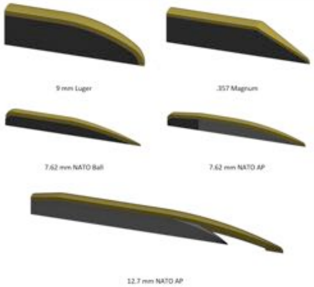
SUMO 2
Step 1, focus on actual threats







Material	Sub-category	Treat
Metals	Monolayer: Ramor 500	7.62 mm NATO Ball 7.62 mm NATO AP
	Multilayer: Ramor 500 + AA6061-T6	7.62 mm NATO Ball 7.62 mm NATO AP 12.7 mm NATO AP
Composite	Kevlar 29/Epoxy	9 mm Luger .357 Magnum 7.62 mm NATO Ball 7.62 mm NATO AP
	Dyneema HB50	9 mm Luger 7.62 mm NATO Ball 7.62 mm NATO AP 12.7 mm NATO AP
Ceramicc	Allumina	9 mm Luger 7.62 mm NATO Ball 7.62 mm NATO AP 12.7 mm NATO AP
	Silica Carbide	9 mm Luger 7.62 mm NATO Ball 7.62 mm NATO AP



9mm Luger

0.357 Magnum

7.62mm NATO Ball

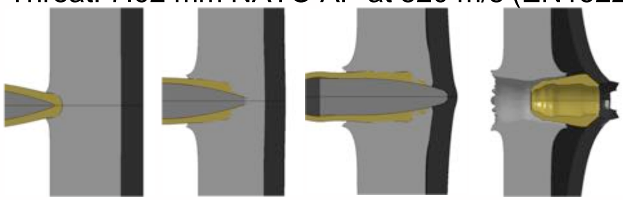
7.62mm NATO AP

12.7mm NATO AP

SUMO 2
Step 1, focus on single material: assessment

Protection: 10 mm AA6061-T6 Plate + 3 mm Ramor 500 Plate

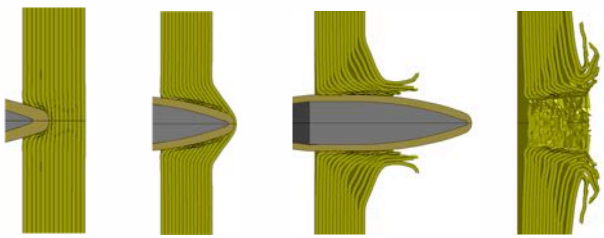
Threat: 7.62 mm NATO AP at 820 m/s (EN1522 FB7 Class)

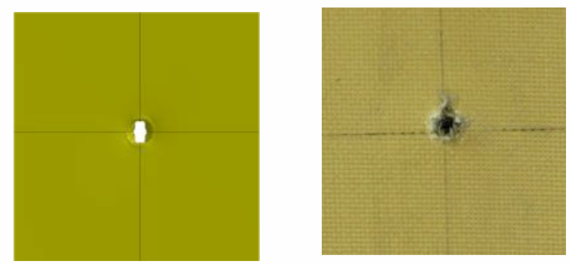


Experimental: 655.13 m/s Analytical: 753 m/s Numerical: 644.10 m/s

Protection: 6.5 mm Kevlar29/Epoxy Panel (14 Layers)

Threat: 7.62 mm NATO AP at 820 m/s (EN1522 FB7 Class)

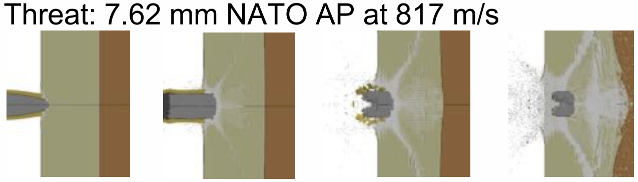


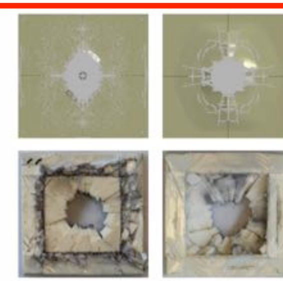


Experimental: 807.16 m/s Analytical: 776.1 m/s Numerical: 797.89 m/s

Protection: 15 mm Alumina Plate

Threat: 7.62 mm NATO AP at 817 m/s

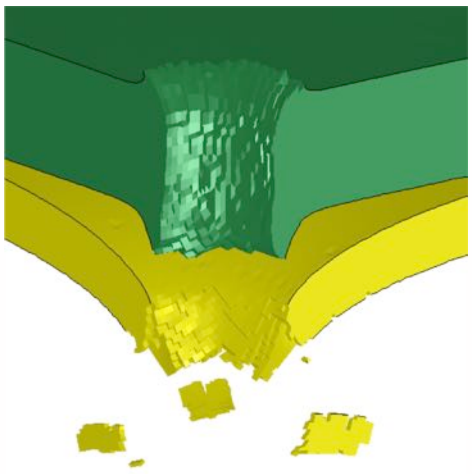


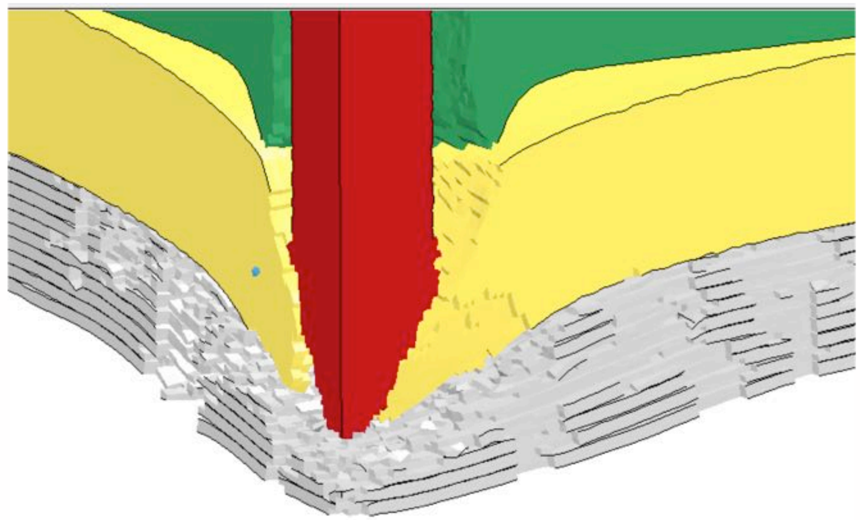


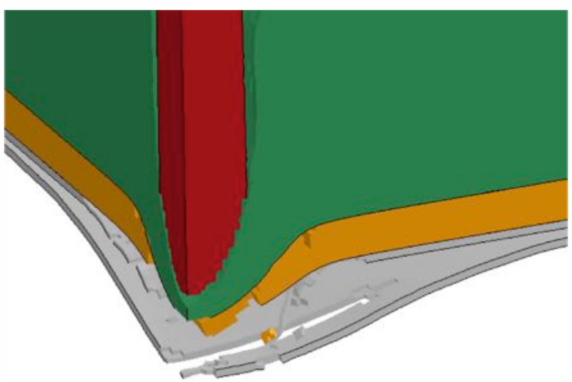
Experimental: 76.17 m/s Analytical: 309.8 m/s Numerical: 186 m/s

SUMO 2
Step 2 – multilayer protection – work in progress

Development of a complete predictive methods for multilayer protection







- Starting from the knowledge of the single material (phase 1)
- Investigation in the interaction between several materials
- Definition of predictive models for optimization process

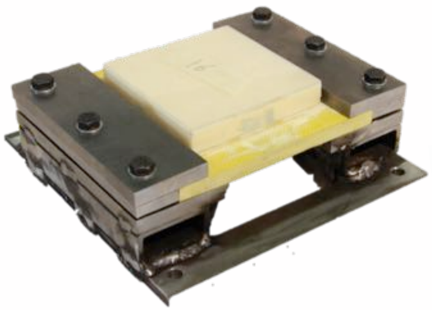
- **Reducing costs / uncertainties / development time**
- **Increasing fitness for purposes**

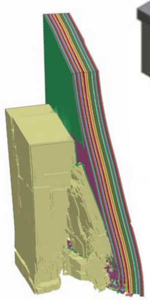
SUMO 2
Step 2 – multilayer protection – work in progress

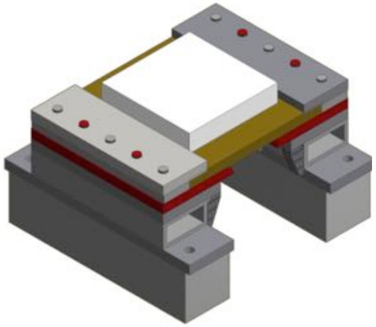
Multilayer ceramic – composite

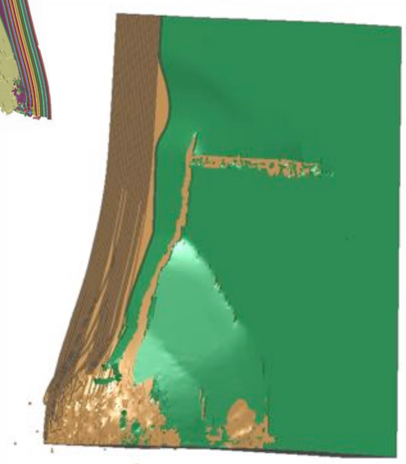
Multilayer ceramic – metals

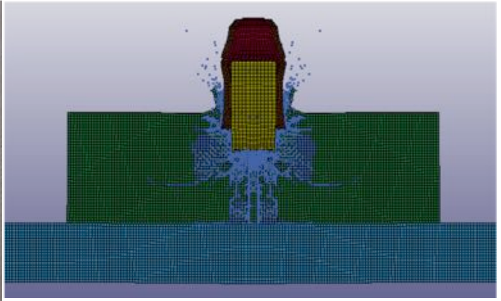
- Development of numerical and analytical modelling approaches with focus on fragmentation of the bullet



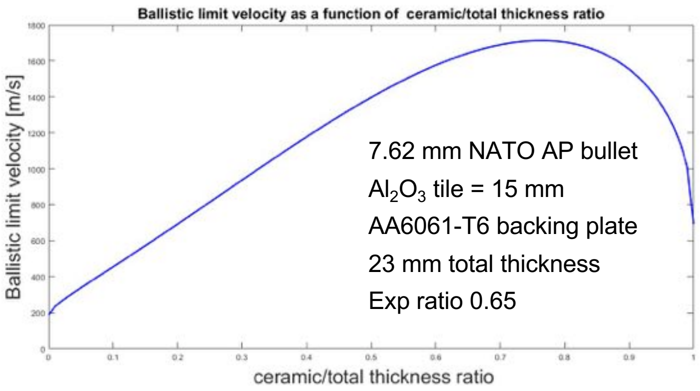








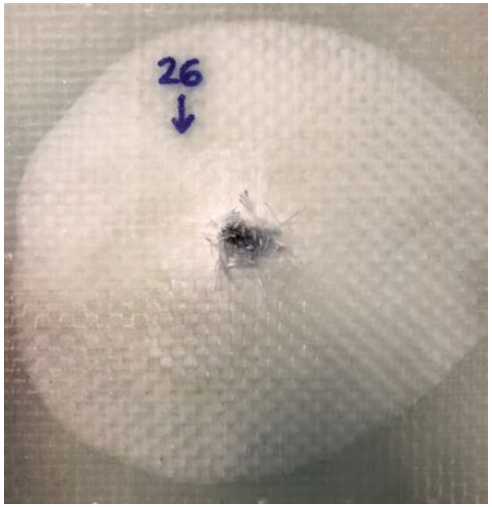
- Focus on optimization procedure



- Different type of composites materials are considered: kevlar-epoxy (with different technological process and microfiller), ballistic glass fiber
- Experimental tests on specimens for calibration of mechanical properties (tensile, three point bending, indentation).
- Exploitation in ballistic and low velocity impact

Focus on nanofiller

- EM behaviour
- Structural behaviour

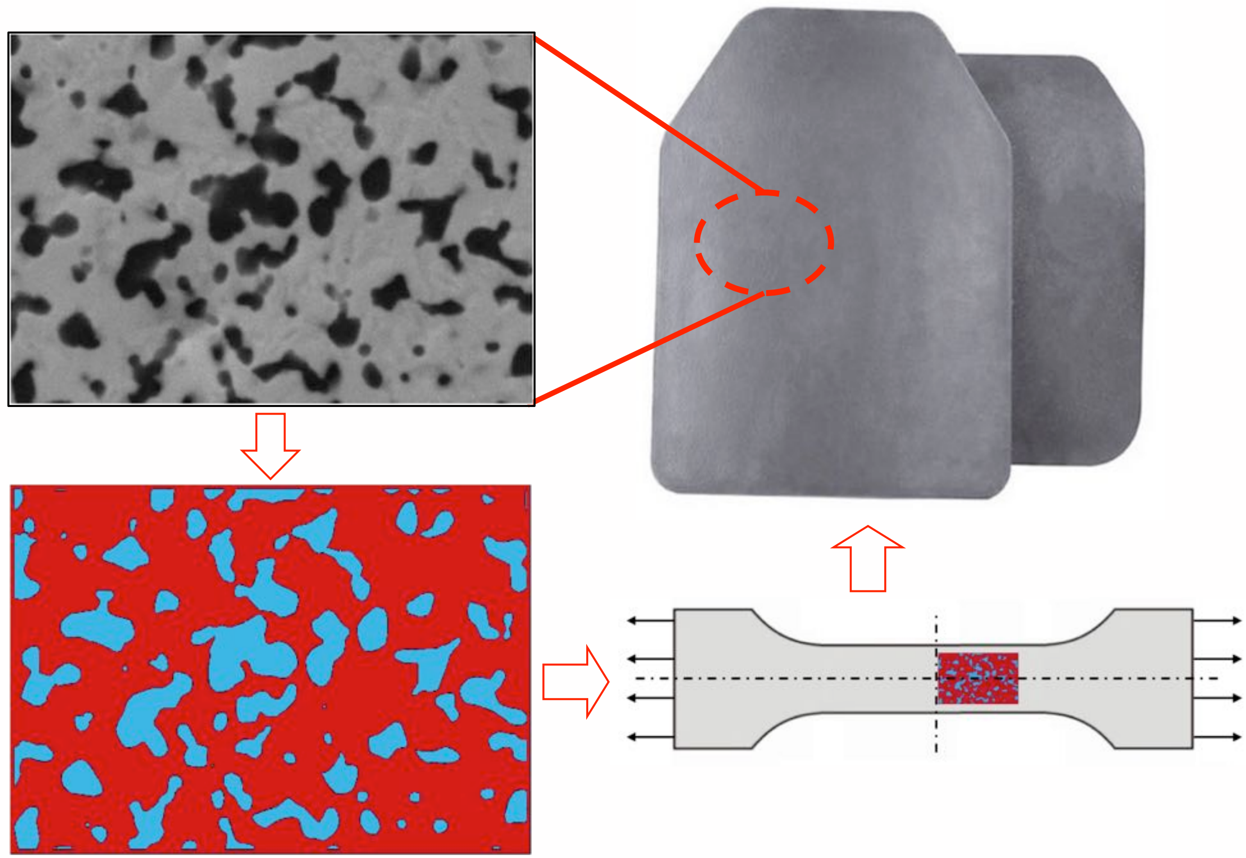


Ceramic metal particle reinforced composite: a preliminary research on innovative promising technique

Development of Composite properties of macroscopic material from Constituent data in microstructured-based model for optimization purpose

Material: Al_2O_3/Ti particle reinforced composite

Process technology: Spark Plasma Sintering

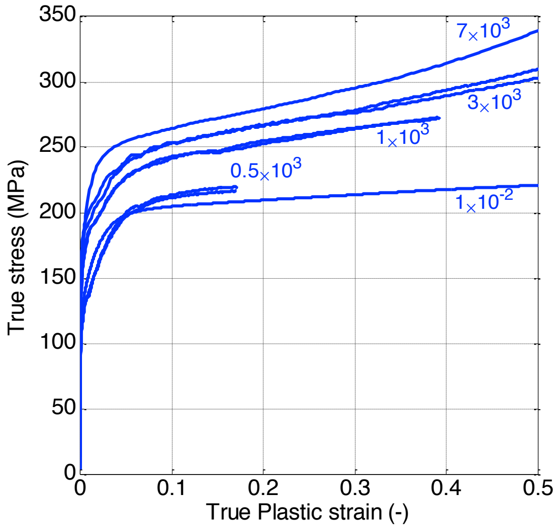


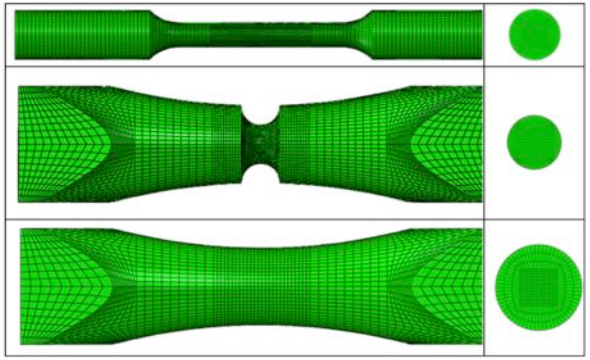
Basic and applied research on Explosion Material Calibration

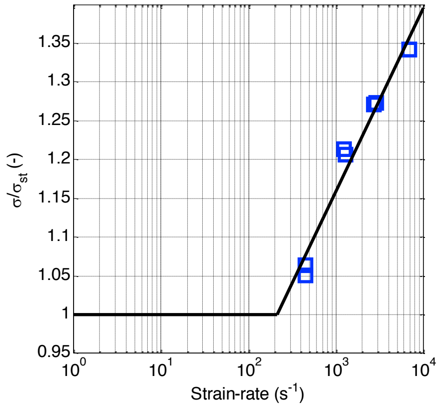
Several activities to simulate the explosion phenomena

Confined explosion: in deep investigation on mechanical behavior of material of the confinement box

- Plasticity
- Failure
- Strain rate and temperature dependency



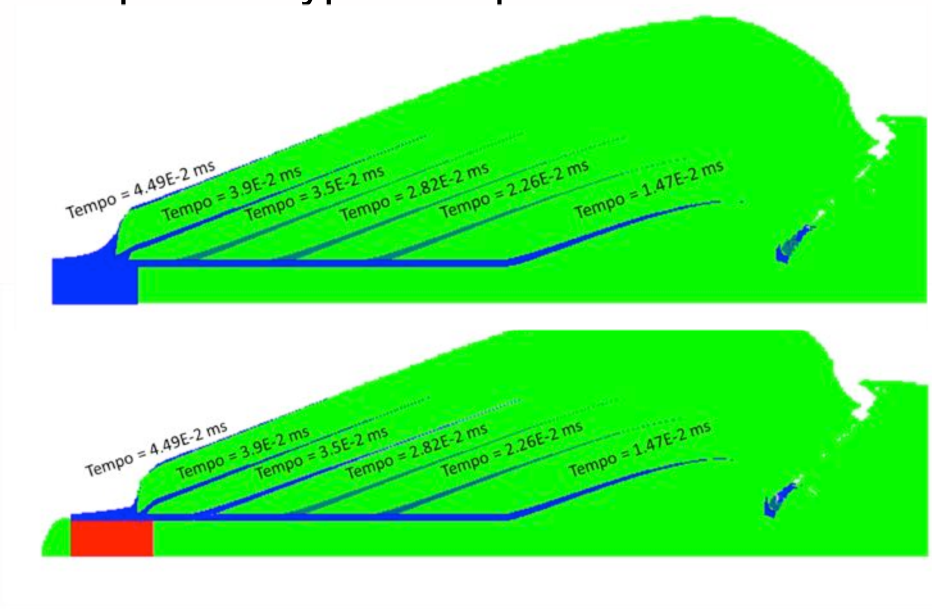


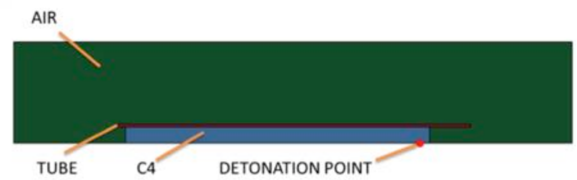


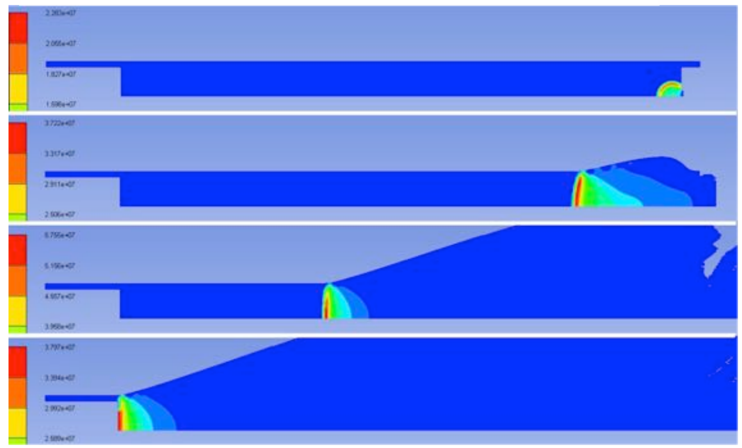
Several activities to simulate the explosion phenomena

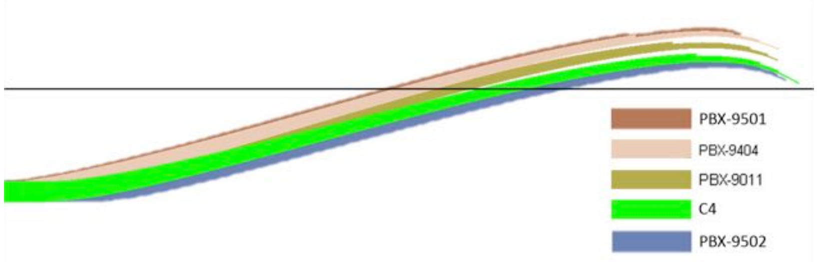
Confined explosion

- Eulerian – Lagrangian analyses
- Investigation on several confinement options / type of explosive







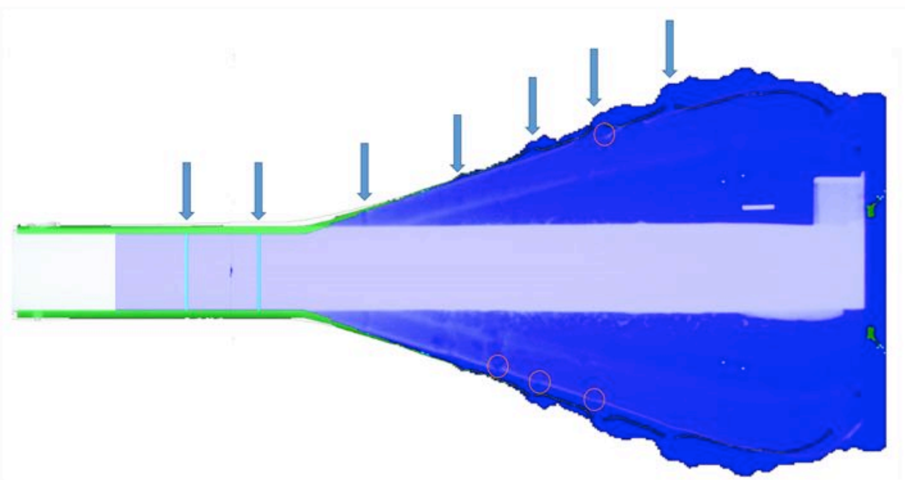


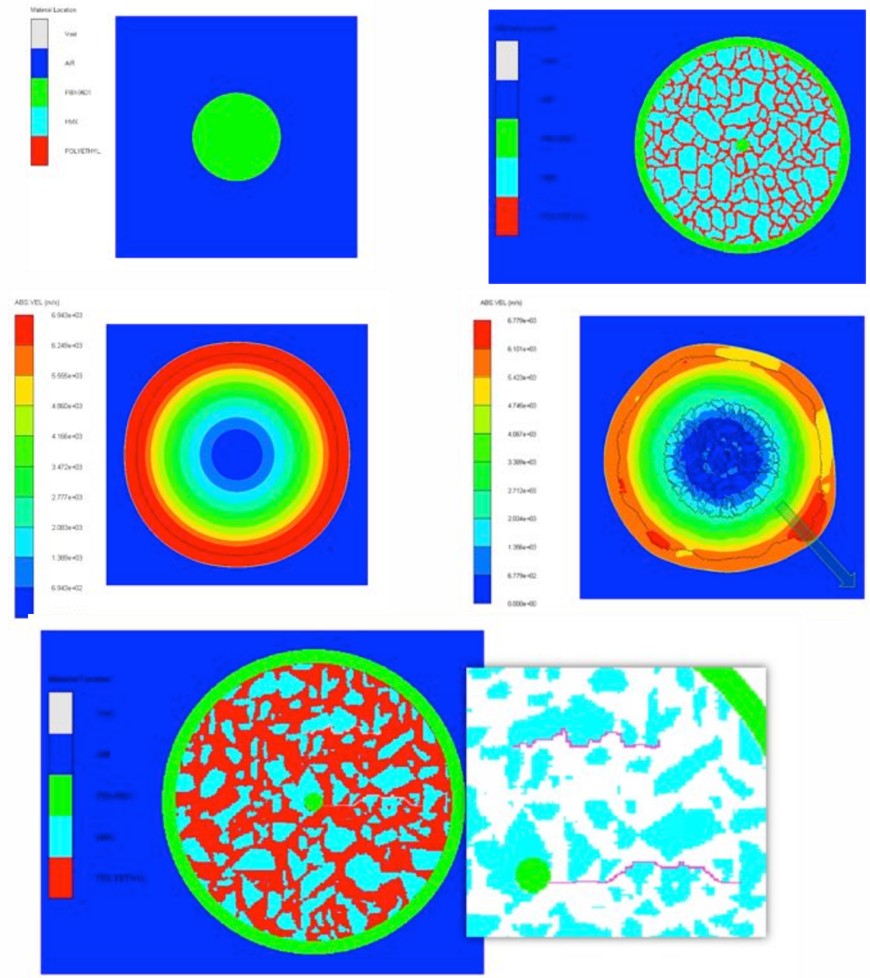
Basic and applied research on Explosion
Simulation of a Confined explosion

Several activities to simulate the explosion phenomena

Confined explosion

- Effect of the inhomogeneity's in the PBX, presence of internal cracks
- Comparison with experimental data





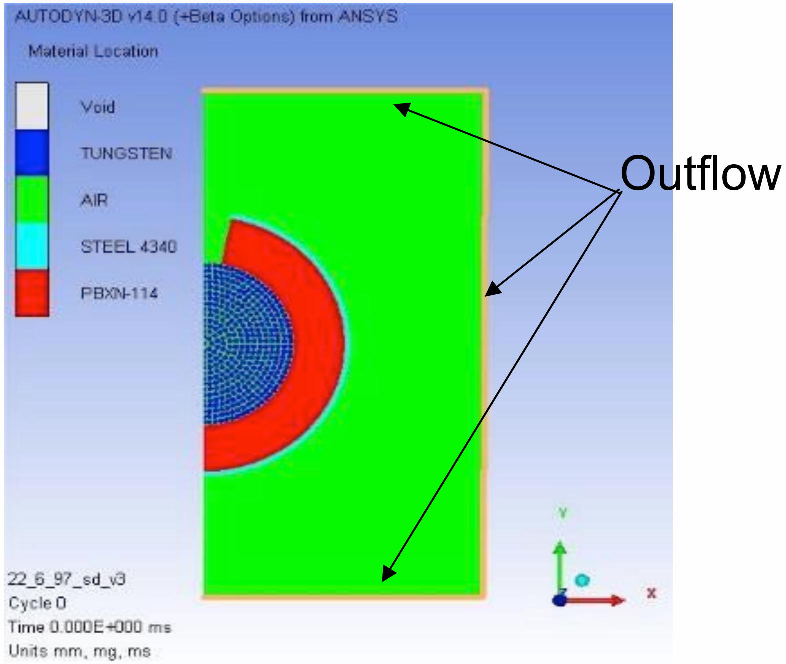
Basic and applied research on Explosion
Simulation of a Directional explosion

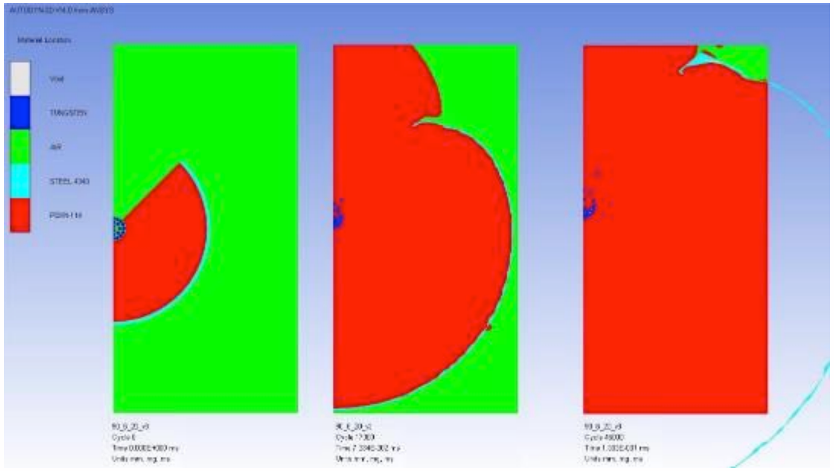
Several activities to simulate the explosion phenomena

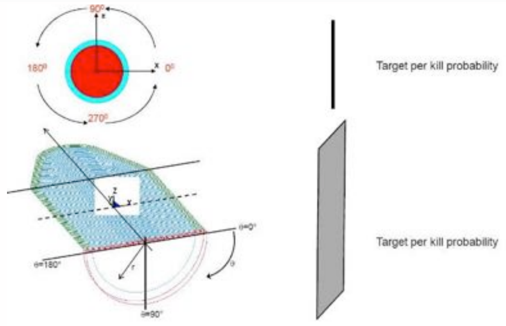
Directional explosion

Analyses on:

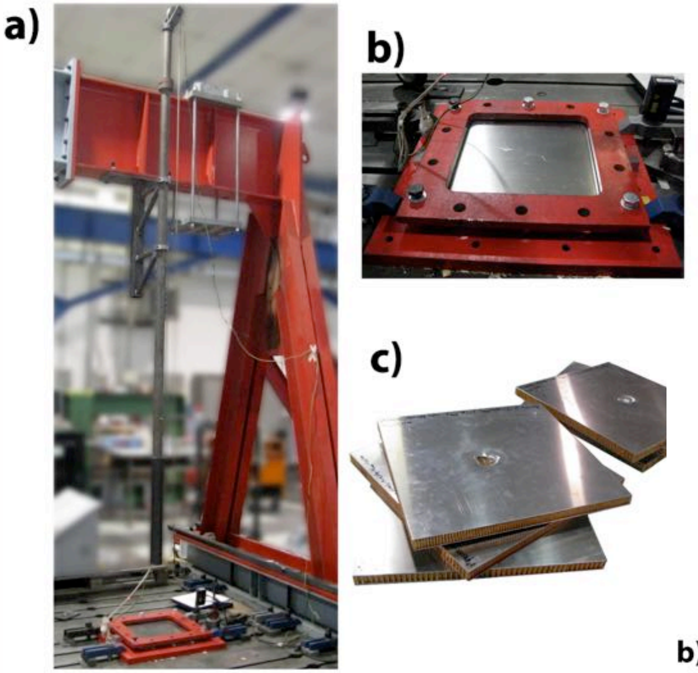
- Detonation points
- Rod diameters
- Aperture angles
- Analyses of the target kill probability





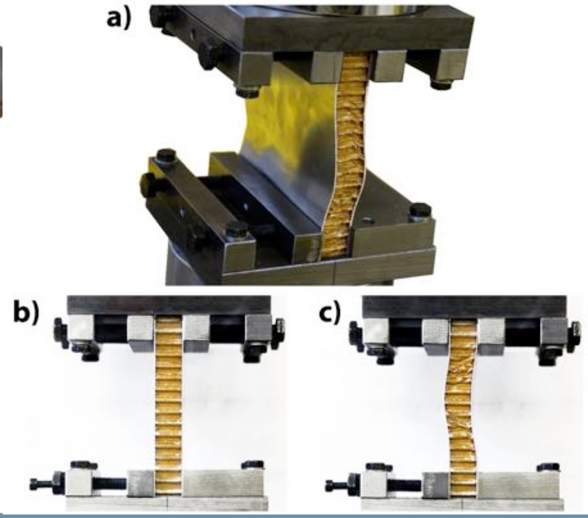


<u>Impact and CAI test</u>: Complete set-up, design and manufacturing of the test rigs.



1) (a) test rig for the drop test; (b) focus on the rigid frame for panel grounding and (c) examples of sandwich panel specimens after impact tests.

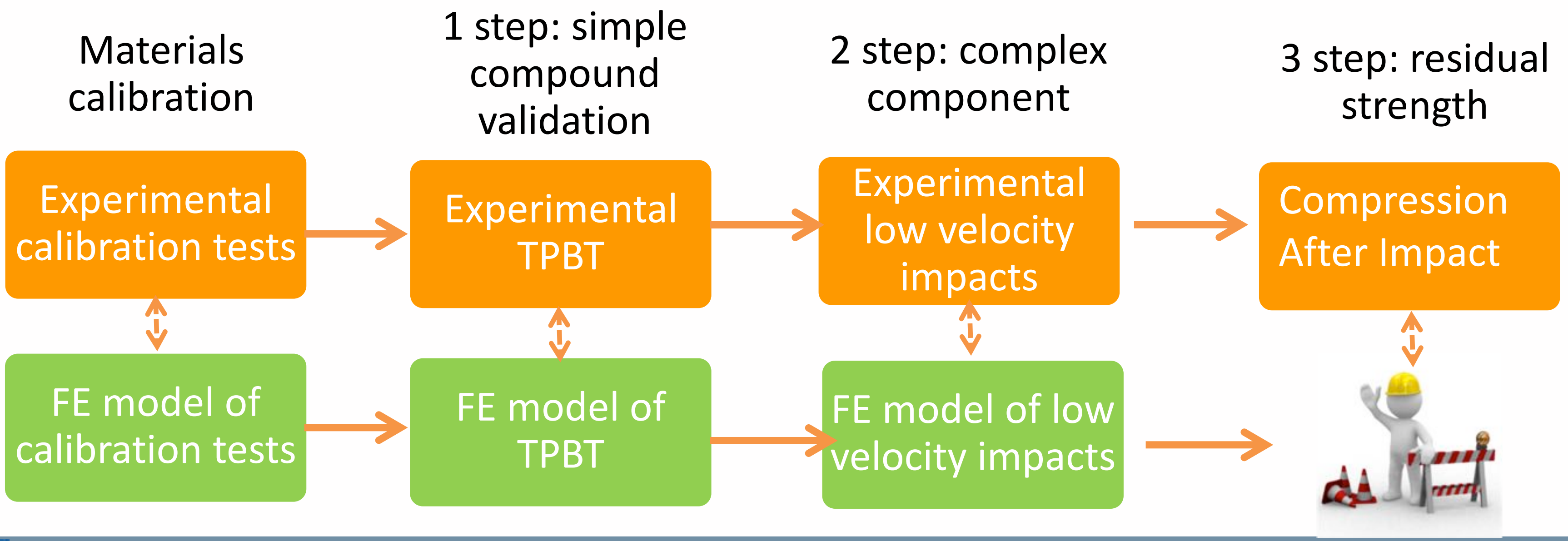
2) Coordinate measure machine with the indication of the profile measured paths.



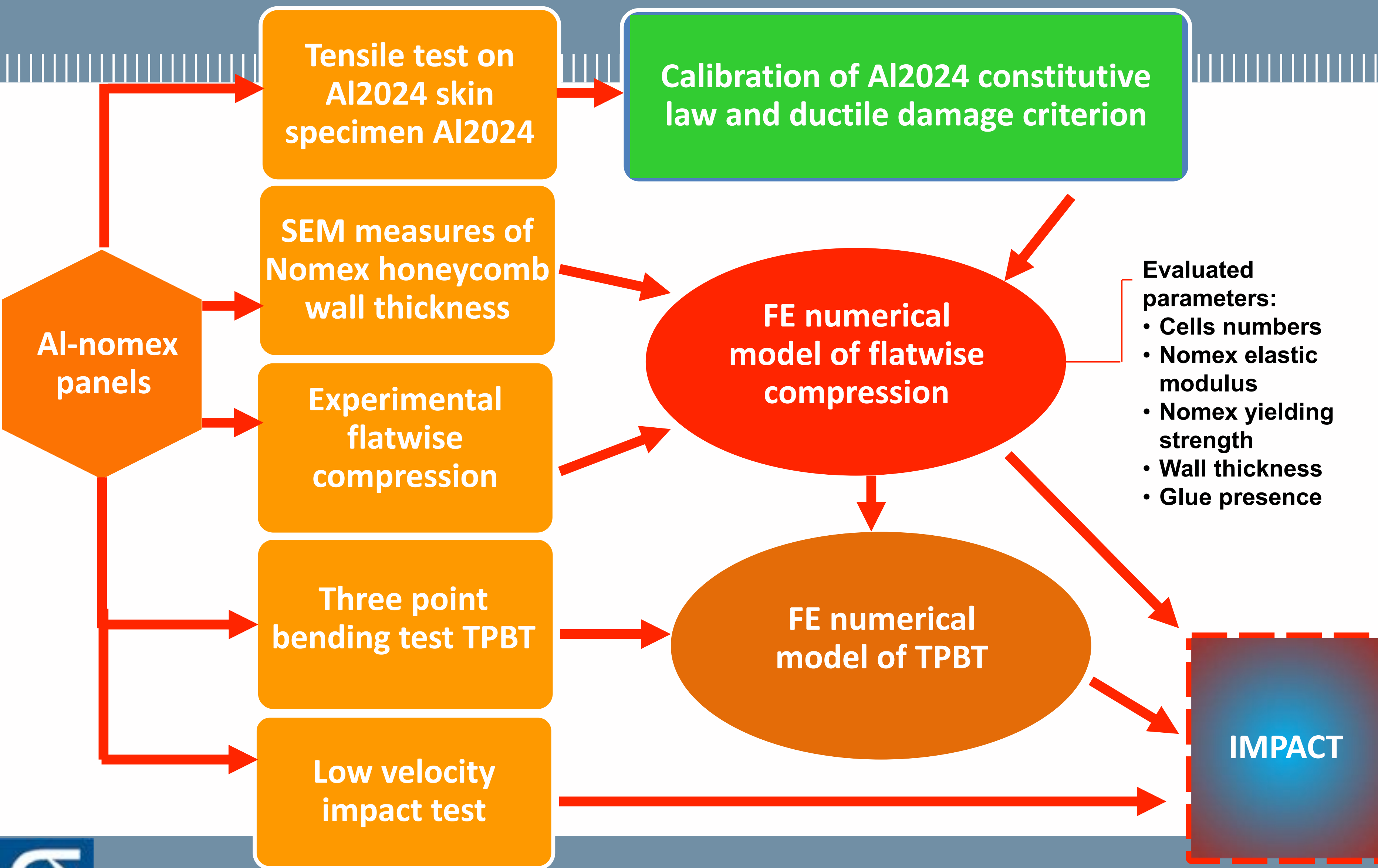
3) Compression After Impact (CAI) test, (a) Prospective view of a sandwich panel specimen and the gripping system during a compression test, (b) orthogonal view of an uncompressed panel and (c) orthogonal view of a compressed panel.

Other cases: low velocity impact (numerical)

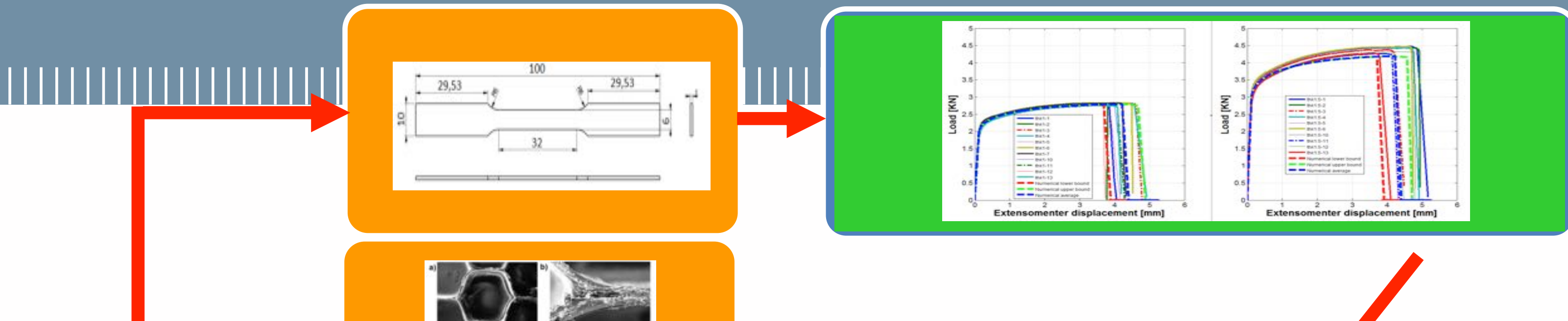
- The final research objective is to create **versatile finite element models able to reproduce damage at a micromechanical level for low velocity impacts**.
- The idea is to **highlight a methodology** in order to build a complex model (for impacts), validating it **step by step**, increasing the complexity level of the simulation
- At present the numerical models were exploited comparing numerical results of low velocity impacts with data obtained from an experimental campaign (in the future CAI)

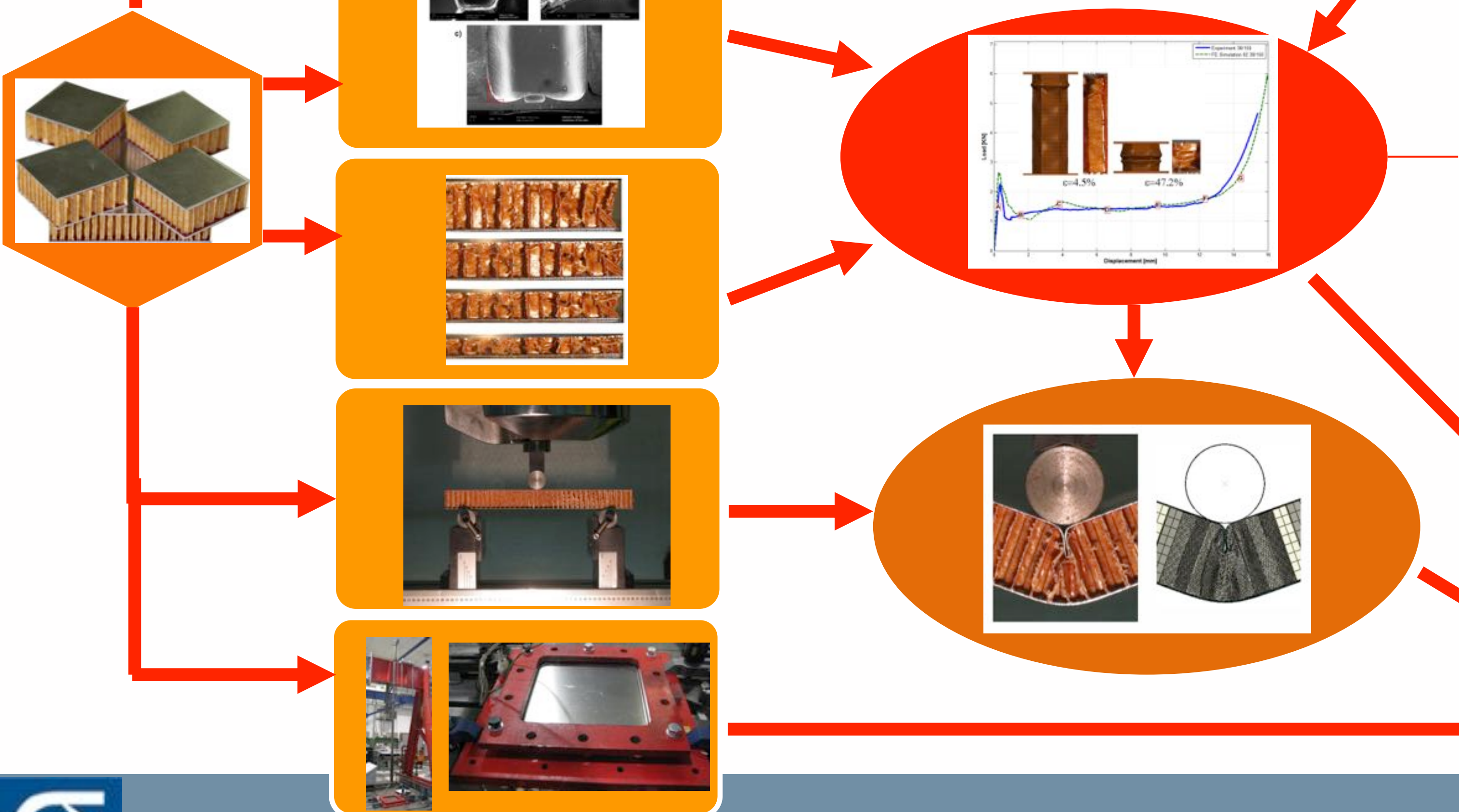


Other cases: low velocity impact (numerical)



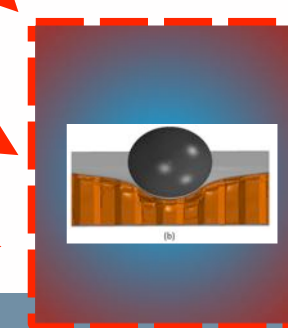
Other cases: low velocity impact (numerical)

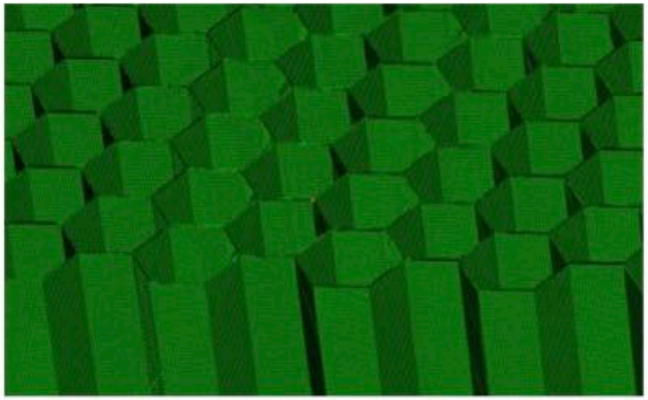




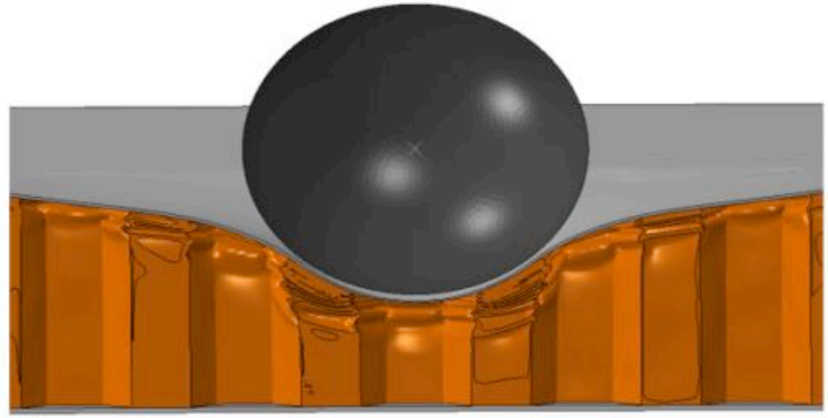
Evaluated parameters:

- Cells numbers
- Nomex elastic modulus
- Nomex yielding strength
- Wall thickness
- Glue presence

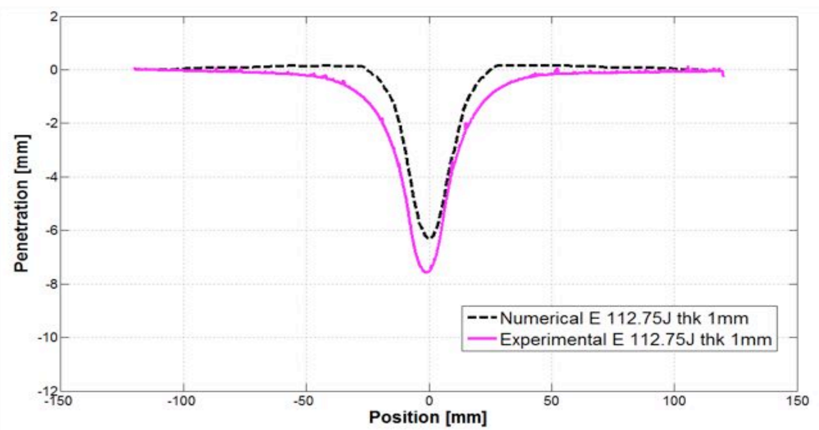


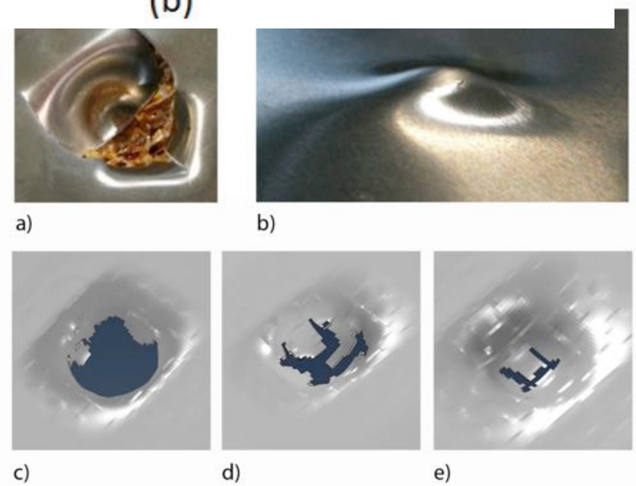


(a)



(b)



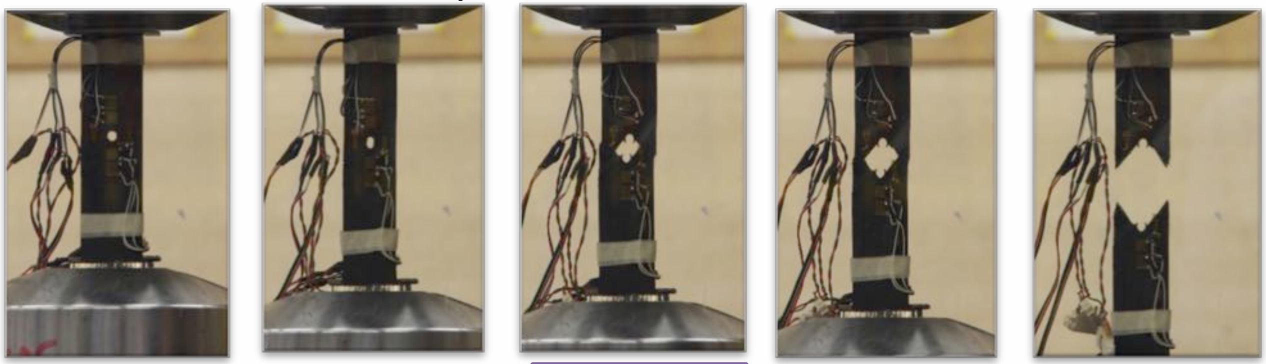


Onset of failure 185J exp vs 173J FEM

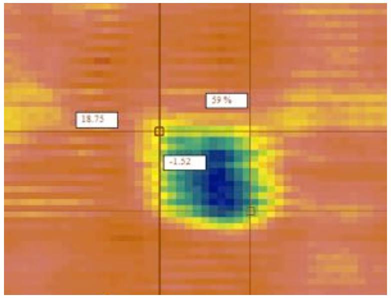
Other cases: low velocity impact on sensorised CFRP panel (work in progress)

Impact on Monitored CFRP plate starting from an accurate mechanical characterization of laminated carbon fibre composites

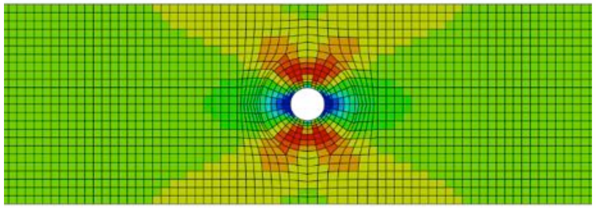
- Tensile test on notched specimen



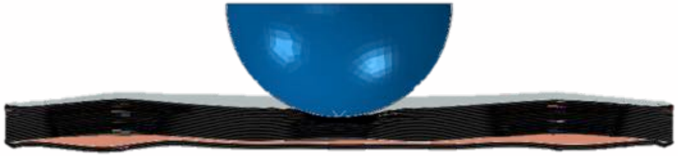
- NDT



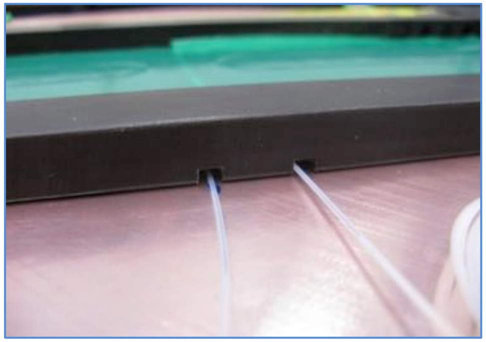
- Virtual test



- FE model of low velocity impacts

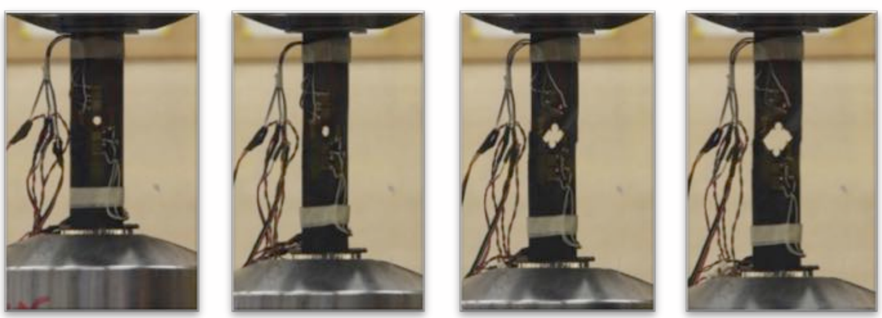


- Embedded sensors (FBG)

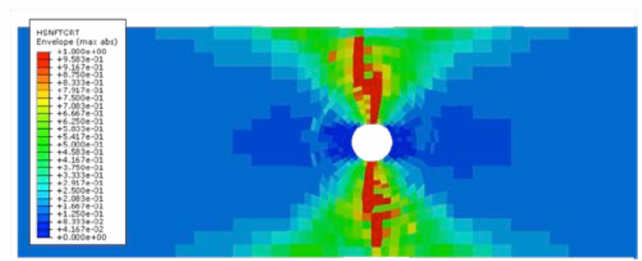


Other cases: low velocity impact on sensorised CFRP panel (work in progress)

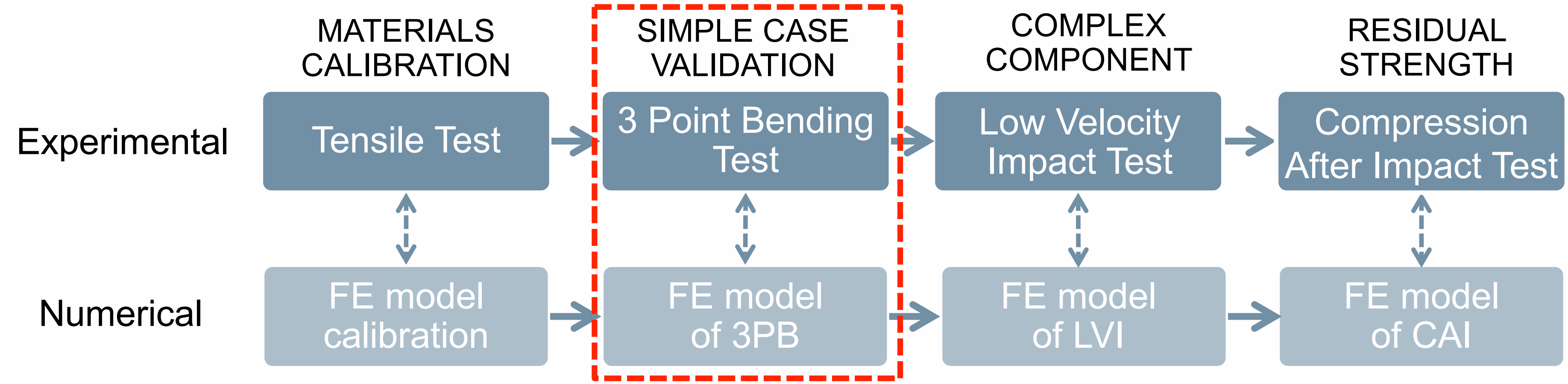
	MATERIALS CALIBRATION	SIMPLE CASE VALIDATION	COMPLEX COMPONENT	RESIDUAL STRENGTH
Experimental	Tensile Test	3 Point Bending Test	Low Velocity Impact Test	Compression After Impact Test
Numerical	FE model calibration	FE model of 3PB	FE model of LVI	FE model of CAI



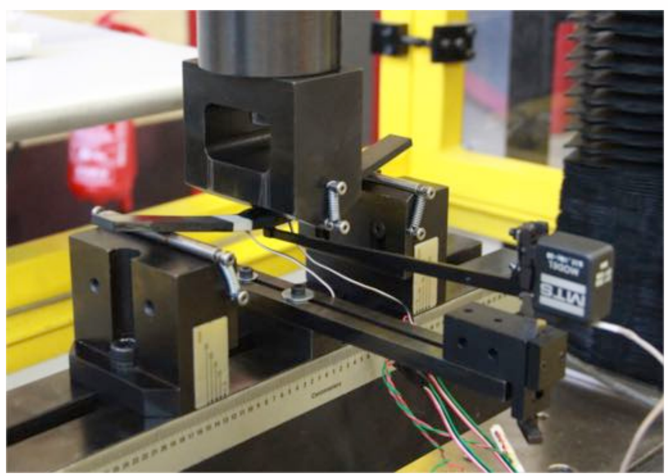
Tensile test on standard and open-hole specimens

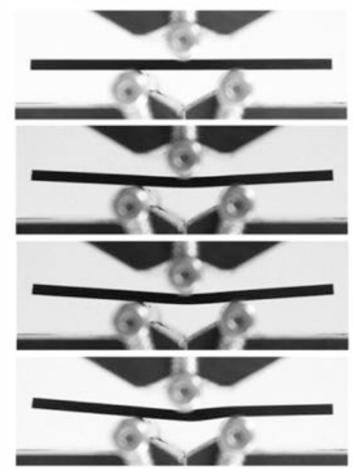


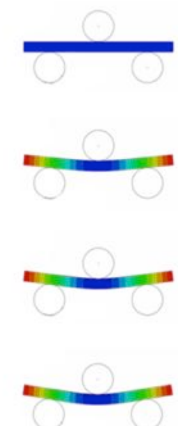
Other cases: low velocity impact on sensorised CFRP panel (work in progress)



3 Point Bending Test with different span configurations

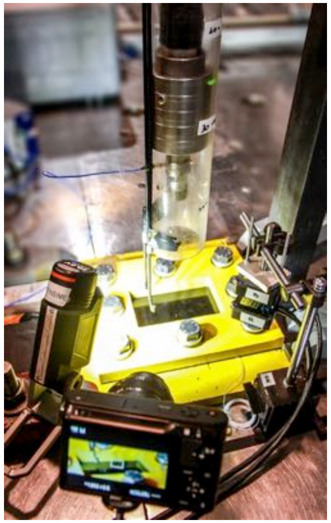


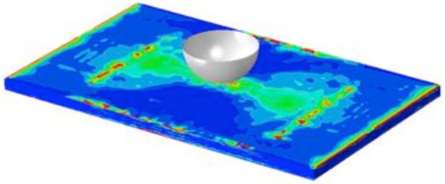




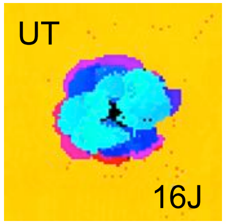
Other cases: low velocity impact on sensorised CFRP panel (work in progress)

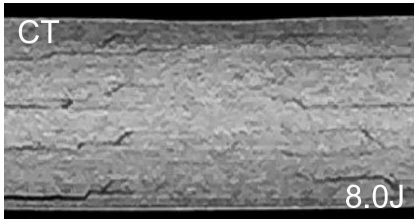
	MATERIALS CALIBRATION	SIMPLE CASE VALIDATION	COMPLEX COMPONENT	RESIDUAL STRENGTH
Experimental	Tensile Test	3 Point Bending Test	Low Velocity Impact Test	Compression After Impact Test
Numerical	FE model calibration	FE model of 3PB	FE model of LVI + Analytical model of LVI	FE model of CAI

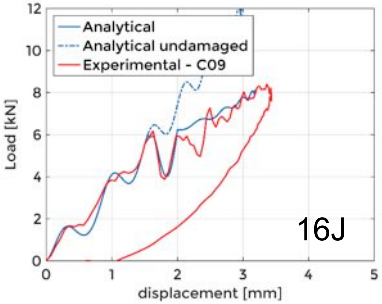


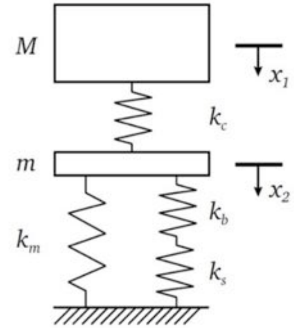


Ultrasonic and Computed Tomography Damage Assessment



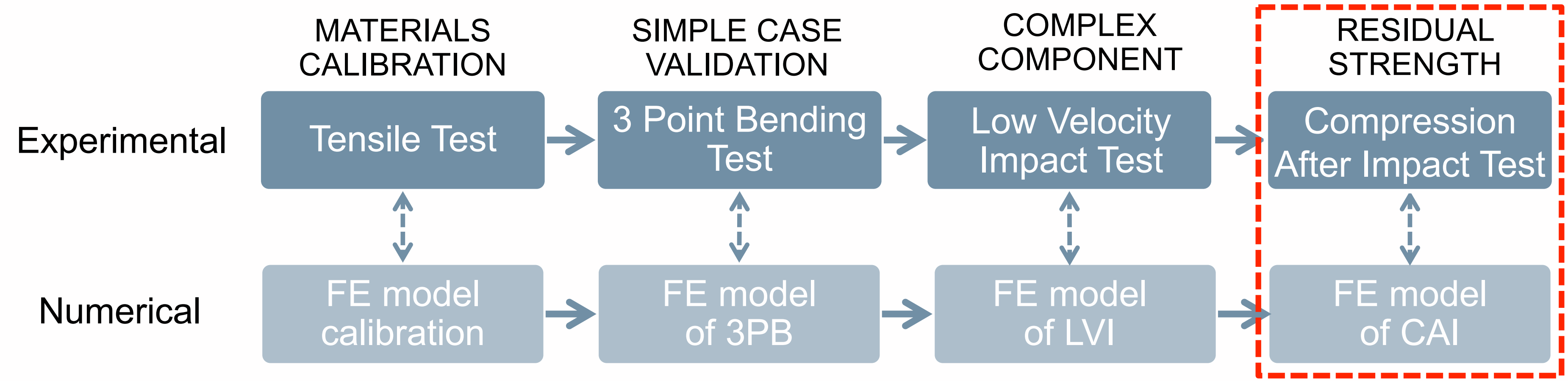


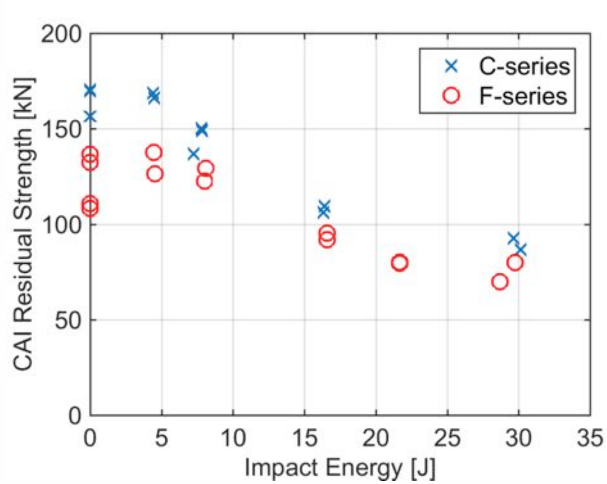


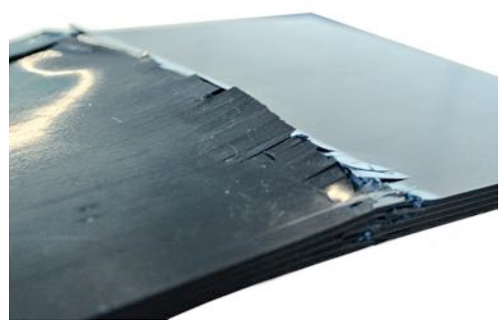


$$P_{cr} = \sqrt{\frac{32\pi^2 D^* G_{IIc}}{n+2}}$$

Other cases: low velocity impact on sensorised CFRP panel (work in progress)

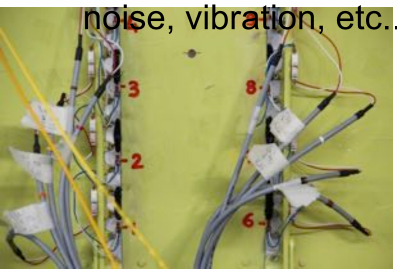


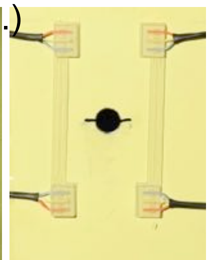


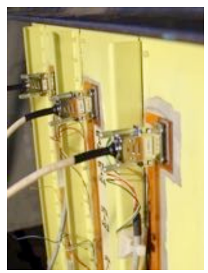


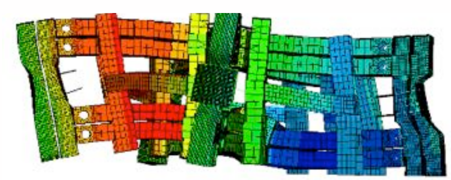
Other cases: experimental tests

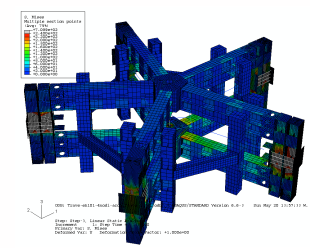
- Laboratory of Mechanical Department allow tests of specimens - components up to full scale large/complex systems
- Availability of: *servo hydraulic testing techno*logy (actuators and digital controls) – measurement system (forces, strain, displacement, accelerations, crack propagation, etc) - *NDT Technologies – qualification certificates for testing procedure – dedicated and qualified personnel*
- Experiences with *design, installation and use of several sensors technologies* (Strain Gauges, Fiber brag, Crack gages, CVM, Lamb Waves, thermal, acoustic noise, vibration, etc..)



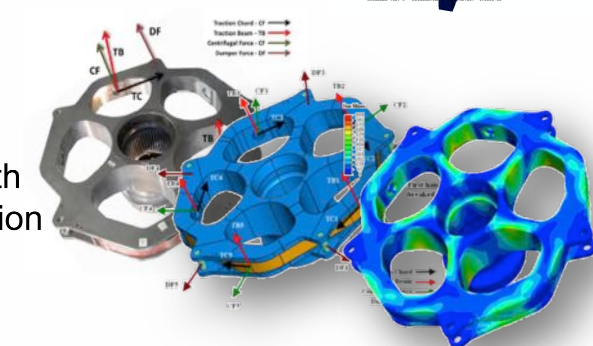






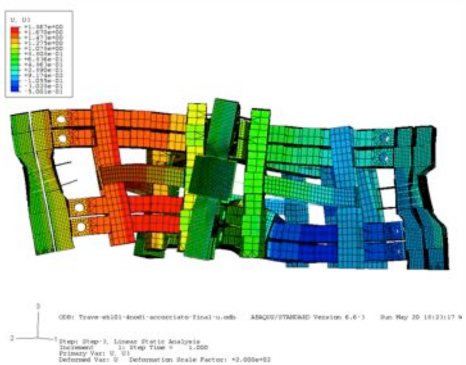


- Availability of *workshop service* for in house design and building of service structures and items to carry on innovative tests
- Advanced numerical modelling methodology for structural optimization/assessment (virtual testing) - Numerical simulations laboratory both for test rig assessment and optimization (also in critical condition) and correlation of the experimental data
- Dedicated long term experience on full scale helicopter components test
- Expertise in certification tests (FAA)

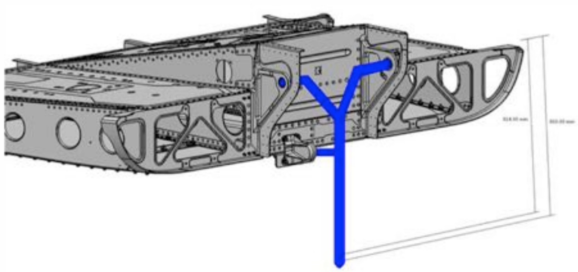


Other cases: experimental tests

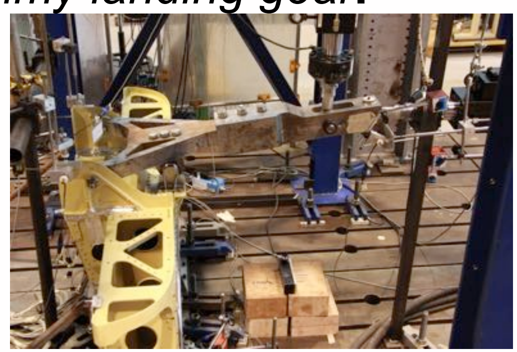
Static test of the AW101 composite MR/H: *Set-up of the test and assessment by analysis of the test rig in case of actuator breakdown*



AW 169 Nose Landing Gear Installation Static Test: set up of the test, design and manufacturing of test rig and dummy landing gear.

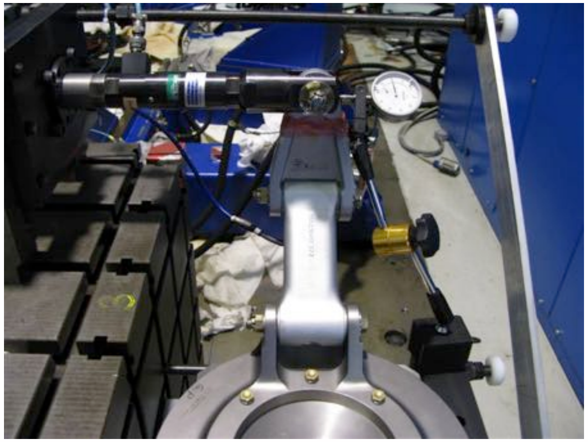


LEONARDO



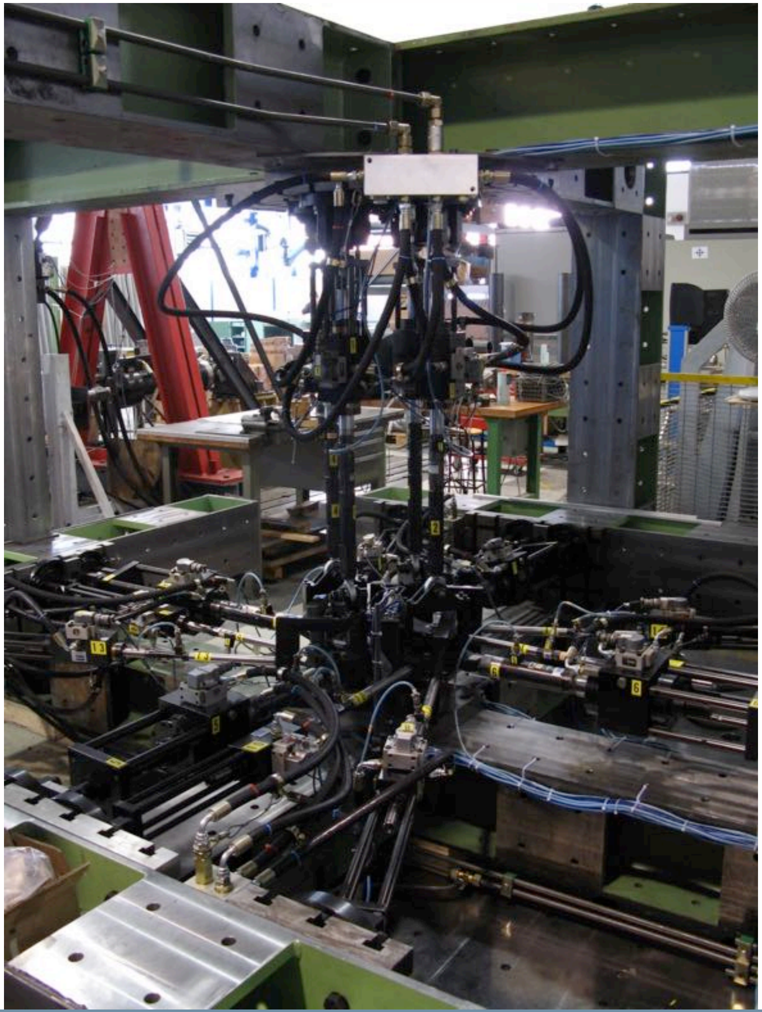
Other cases: experimental tests

AW 109 Swashplate Rotating Assy Fatigue Test



AW 139 M/R Lower Scissor Lever Fatigue Test

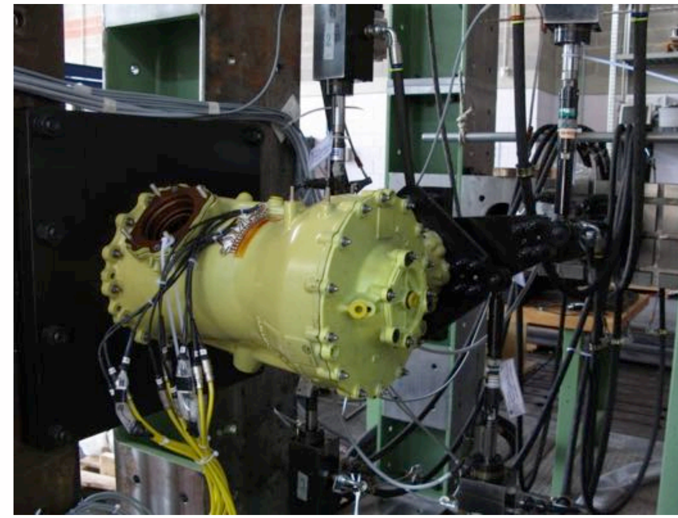
Fatigue test of the AW 139 tail rotor hub assy



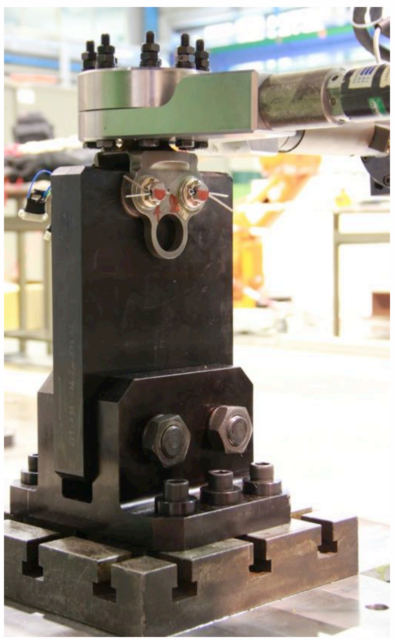
LEONARDO

Other cases: experimental tests

Sea King Tail pylon fold joint upper hinge fitting fatigue test



NH 90 Input case Fatigue test



LEONARDO

AW 609 inboard Spindle Fatigue Test **(FAA certification)**

Static test of the AW 609 composite wing rear spar **(FAA certification)**

Rock Drilling

- physical complexity of drill bit-rock interaction,
- fracture mechanics,
- crack propagation of rocks, etc.

Primary objectives

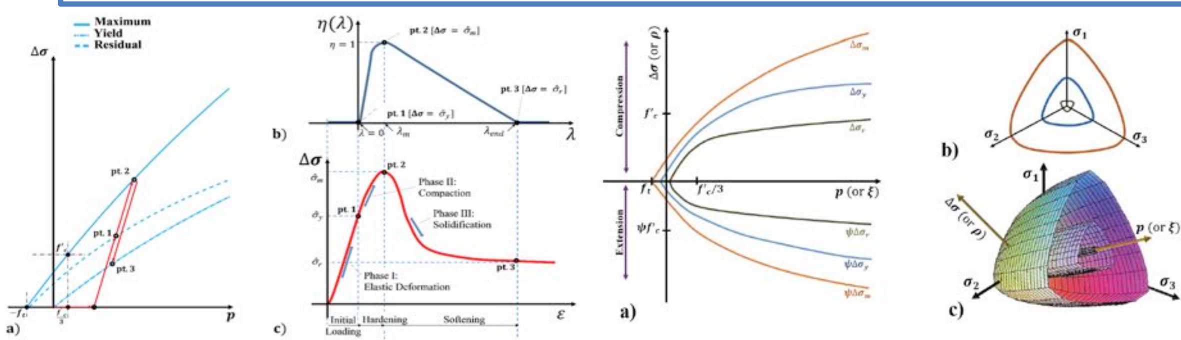
- Investigate numerically the response of a medium strength rock under on laboratory loading
- Calibrate material modeling and numerical approach - Methods
- Exploit methods to design and asses innovative drilling technique

Numerical Methods

FEM | DEM | SPH

Constitutive models

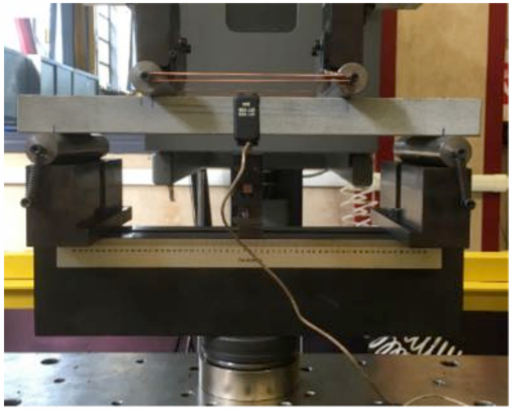
Mohr-Coulomb - Drucker-Prager - Karagozian and Case Concrete (KCC) Model



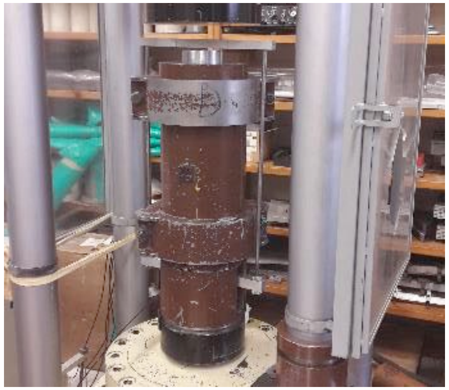
UC Test

Brazilian Test

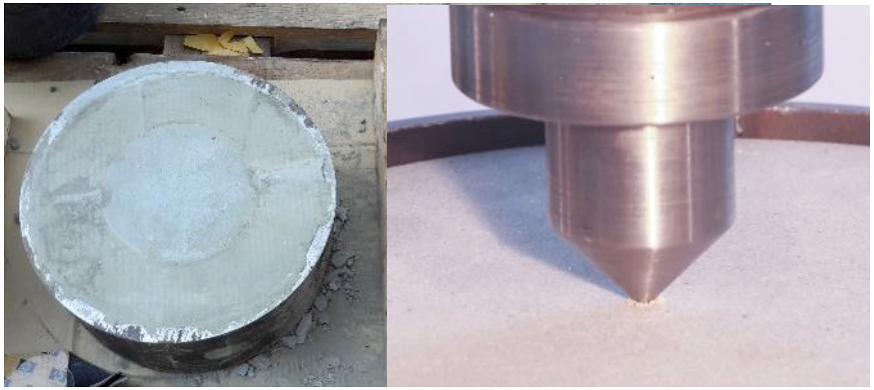
Flexural Test



TXC Test

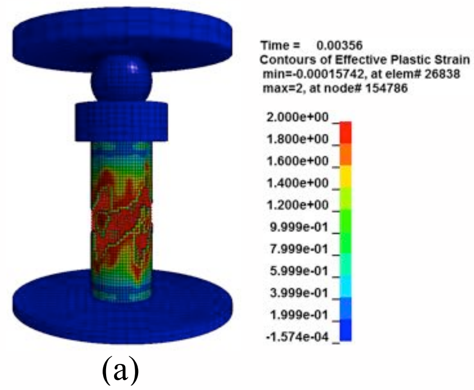


Punch Penetration Test

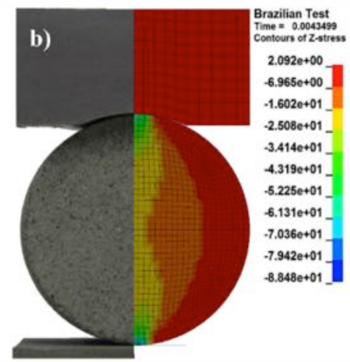


Drilling

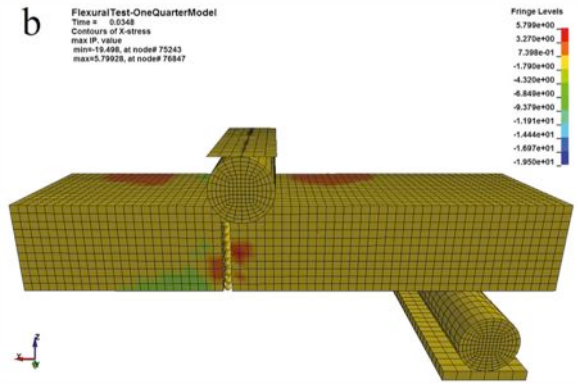
UC Test



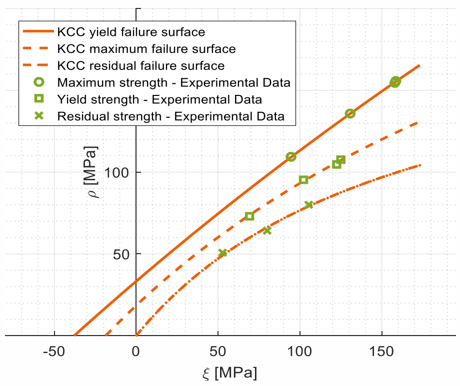
Brazilian Test

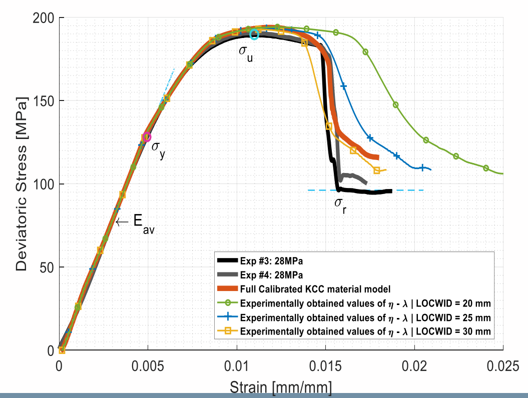


Flexural Test

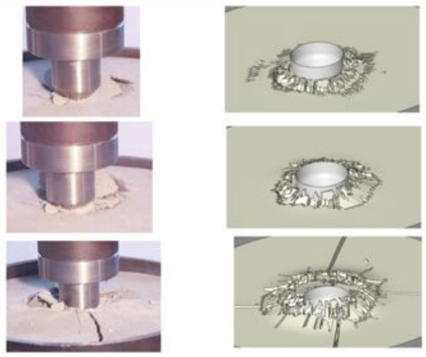


TXC Test





Punch Penetration Test



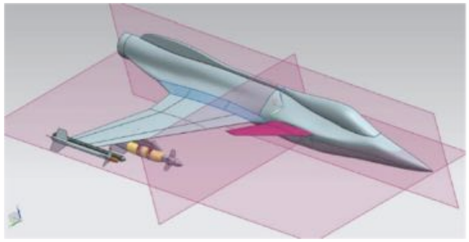
Project: ISSA

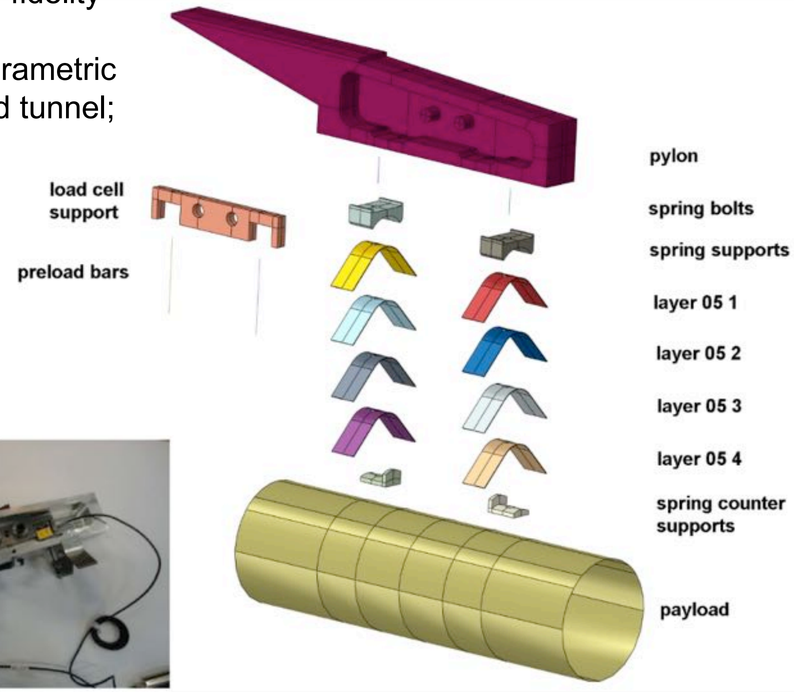
European Defence Agency Tendering procedure, Ad Hoc Research & Technology Project, No B 1190 ESM2 GP "Integrated Simulation of Non-Linear Aero-Structural Phenomena Arising On Combat Aircraft In Transonic Flight", ISSA 2013-2016

The scope of ISSA is to create an environment of validated linear and high-fidelity analytical methods and tools for the investigation of LCO, mainly focusing on fighter external store configurations flying in transonic conditions.

- Develop high-fidelity methods for the simulation of LCO, based on the coupling of CFD/CSM models that include aerodynamic and structural non-linearity;
- Develop methods for the linearization of the phenomenon and the application of linear tools currently in use to industry, corrected using the results of high-fidelity simulation;
- Upgrade an existing aeroelastic wind tunnel model with the addition of parametric pylon-store systems, designed to investigate LCO phenomena in the wind tunnel;

POLIMI contribution is mainly related to non-linear structural analyses and linearization methodology



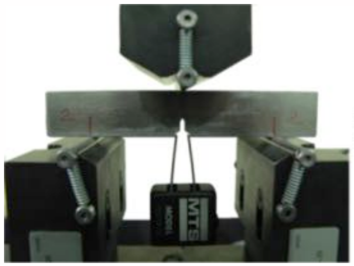


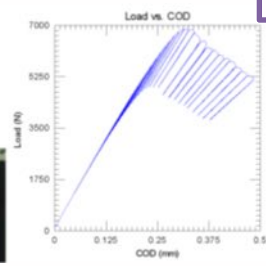
Some past activities at a glance

Assessment of a Ti6Al4V helicopter Main Rotor Hub under fatigue loads.

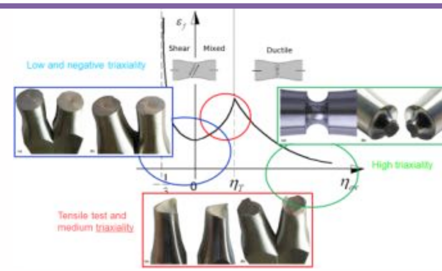
Ductile failure models: definition and calibration (in collaboration with M.I.T.)

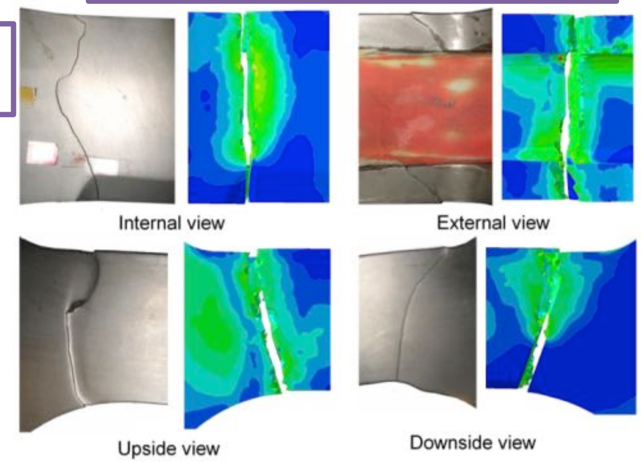
Comparison: experimental-numerical results



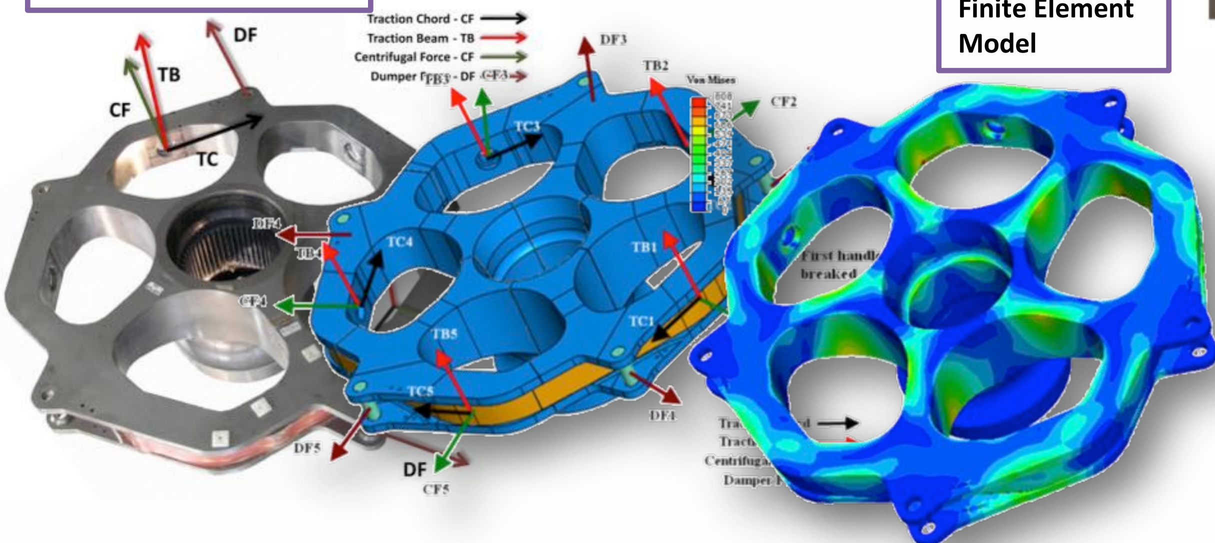


Fracture mechanics





Finite Element Model

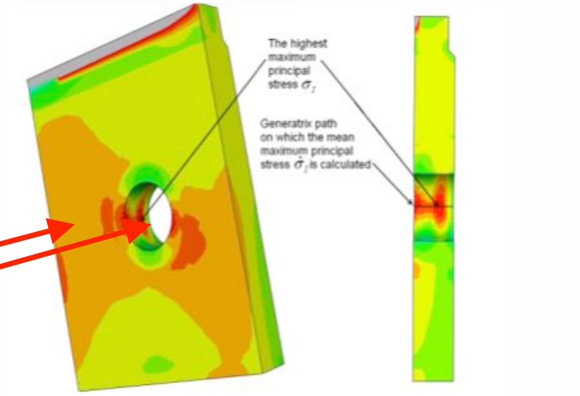


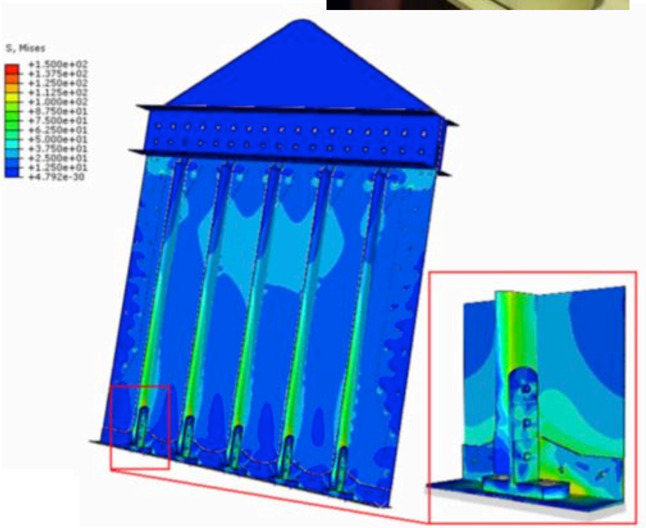
Experimental “full scale” Tests

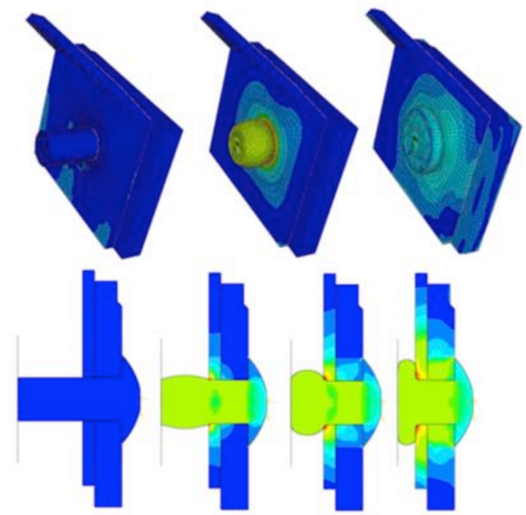
Comparison: experimental-numerical results

Analysis on the effect of rivets cold driving process on fatigue life of a bolted joint for metallic helicopter frame.

Experimental Tests “full scale”



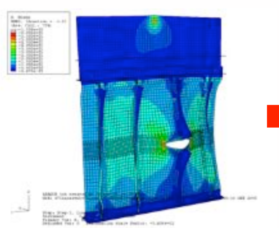


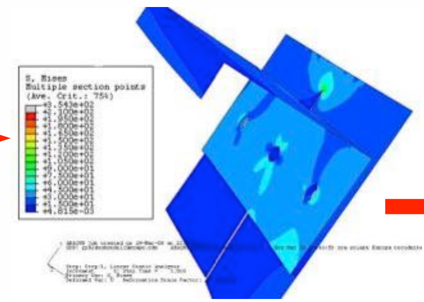


Finite Element Model **(submodeling)**

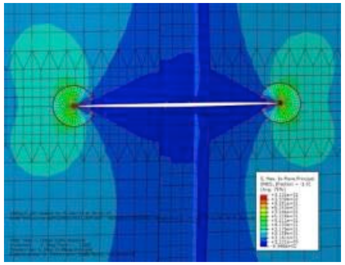
Some past activities at a glance

Damage tolerance behaviour of artificial cracks (on the skin with different configurations) during fatigue load in metallic helicopter frame.

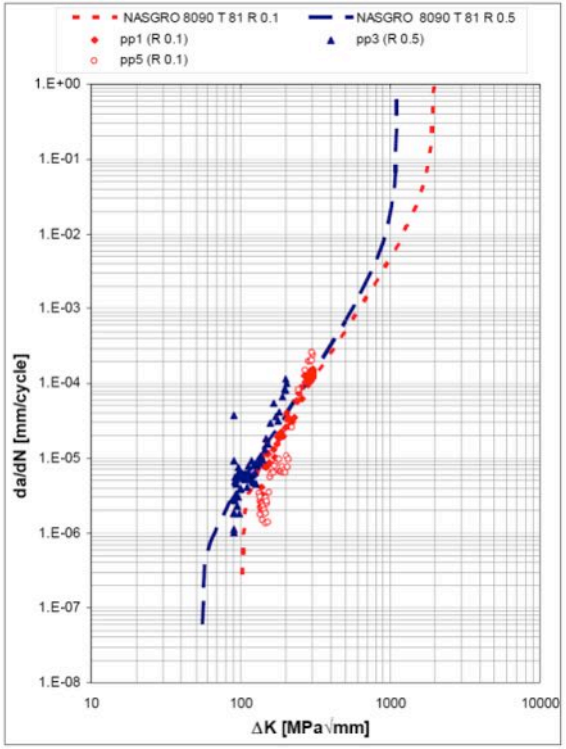


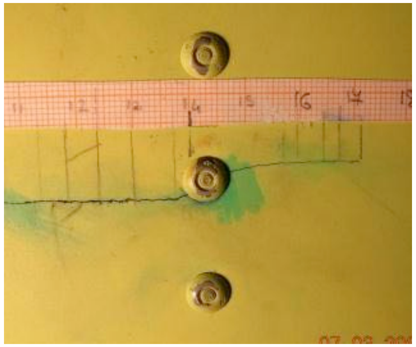


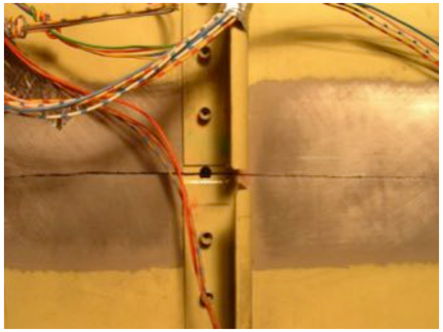
Finite Element Model (submodeling)



Comparison: experimental-numerical results





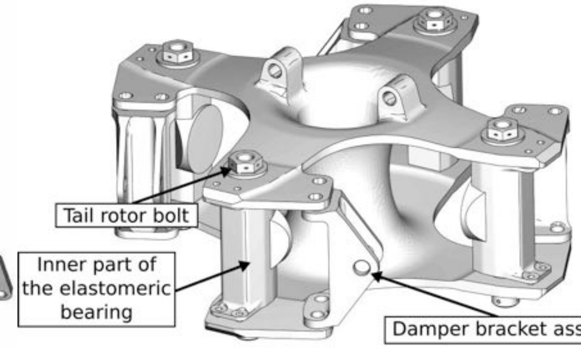


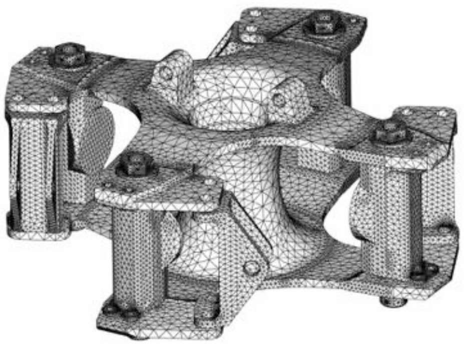
Experimental Tests “full scale”

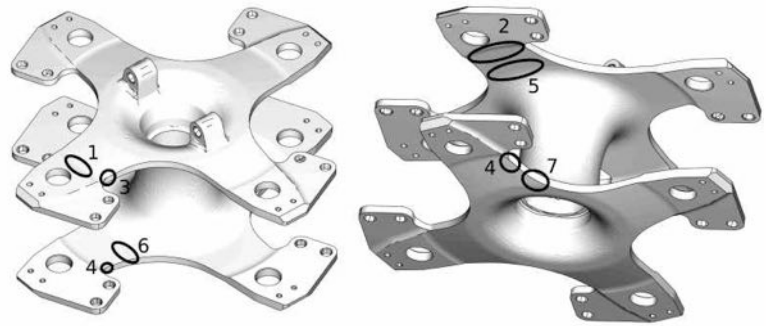
Material Calibration: fracture mechanics

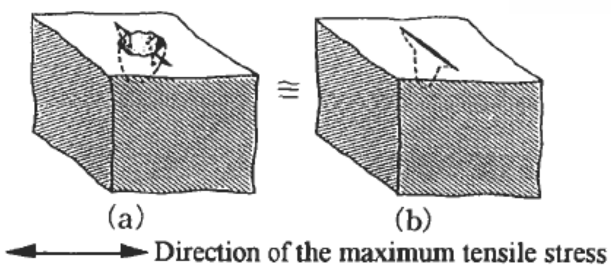
$$\frac{da}{dN} = \frac{C\Delta K^{n}\left(1-\frac{\Delta K_{th}}{\Delta K}\right)^{p}}{\left(1-\frac{K_{\max}}{K_{C}}\right)^{q}}$$

Definition of a flaw tolerance procedure to evaluate the behaviour of non-propagating cracks (flaws) nucleated from defects inside critical helicopter components.









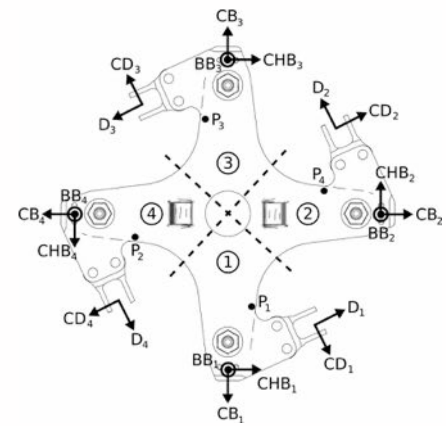
$$\Delta K = \beta \cdot \Delta\sigma \cdot \sqrt{\pi \cdot \sqrt{area}}$$

Finite Element Model

$$\Delta K_{th} = \Delta K_1 \cdot \sqrt{\frac{\sqrt{area}}{\sqrt{area} + \sqrt{area_0}}} \cdot \left[\frac{1-R}{1-f}\right]^{1+R\cdot C_{th}^{p}} / (1-A_0)^{(1-R)C_{th}^{p}} \quad , R \geq 0$$

$$\Delta K_{th} = \Delta K_1 \cdot \sqrt{\frac{\sqrt{area}}{\sqrt{area} + \sqrt{area_0}}} \cdot \left[\frac{1-R}{1-f}\right]^{1+R\cdot C_{th}^{m}} / (1-A_0)^{\left(C_{th}^{p} - R\cdot C_{th}^{m}\right)} \quad , R < 0$$

Material Calibration: fracture limit conditions

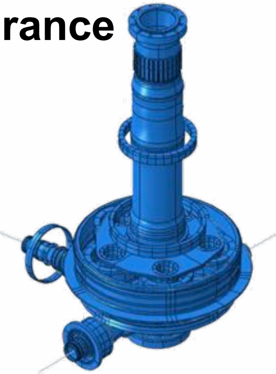


$$\eta = \frac{\Delta K_{th}}{\Delta K}$$

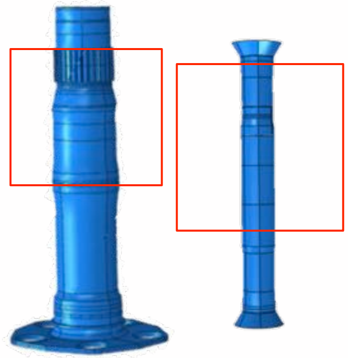
Assessment of the component numerical results

Some past activities at a glance

Develop an operational methods that provide high reliability in the design of primary components of a military helicopter rotor system: Flaw Tolerance



Numerical model of the mast and design of a specimen that reproduces exactly the most critical stress field



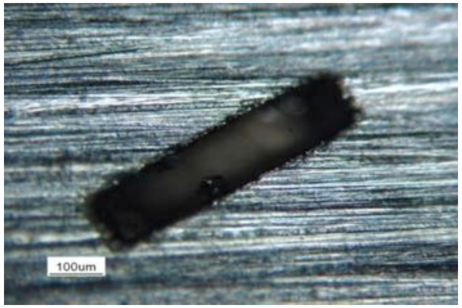
Numerical modelling: the defects were insert on the FE

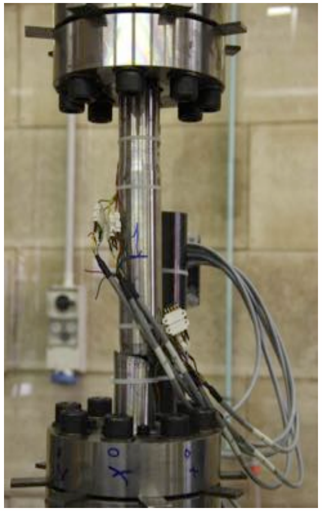
models using both XFEM and Sub-modeling

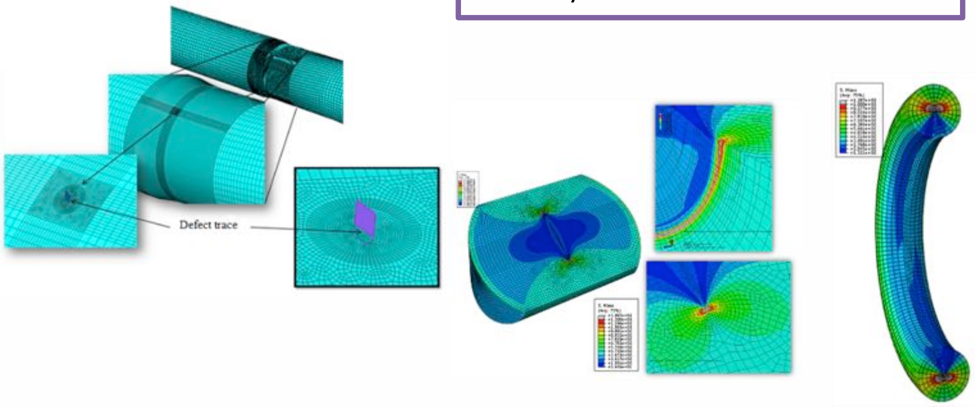
technique. Stress

Intensity Factors were obtained

Application of the Flaw Tolerance on the mast and experimental assessment



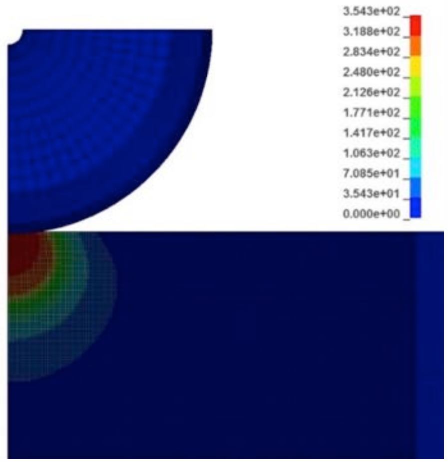




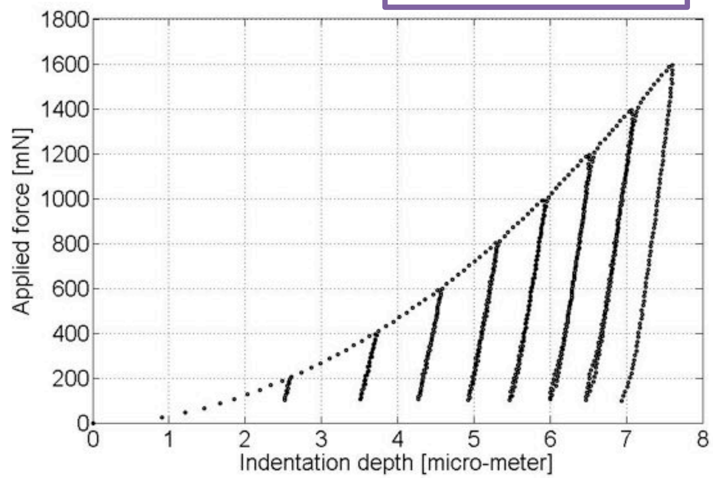
Some past activities at a glance

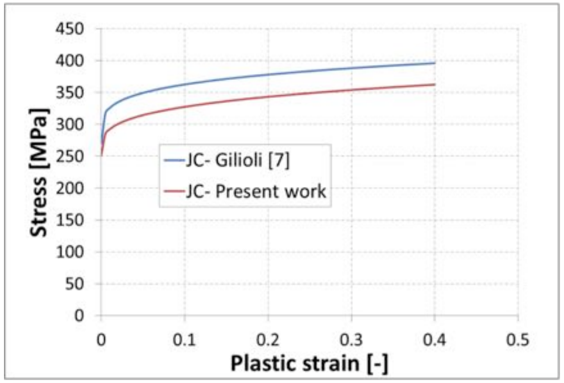
Use of micro-indentation for determining elastic-plast properties and fracture toughness of bulk and film ma a special focus on collectors of lithium-ion batteries

Finite Element Model for inverse method

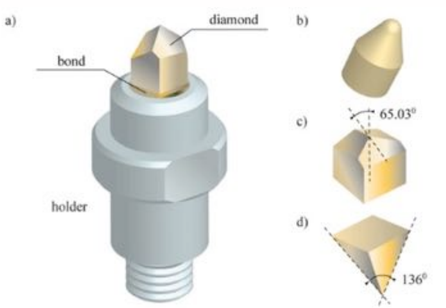


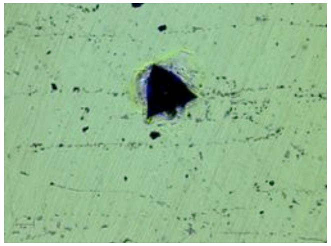
Experimental tests

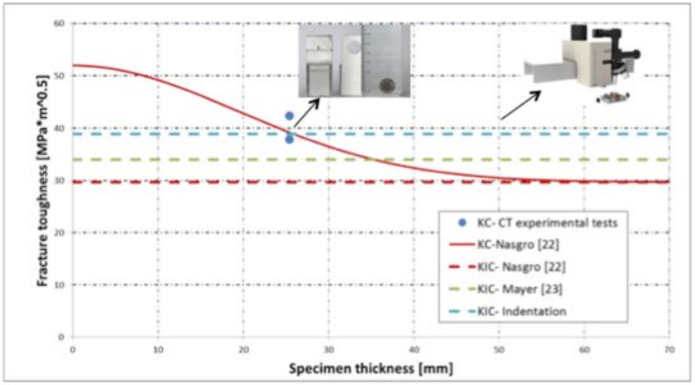




Comparison of present technique with classical approach

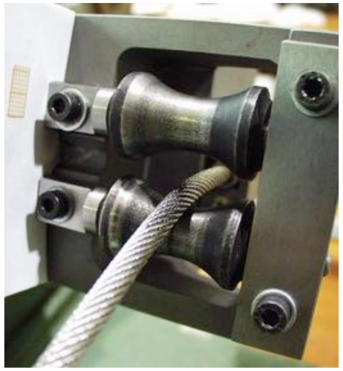


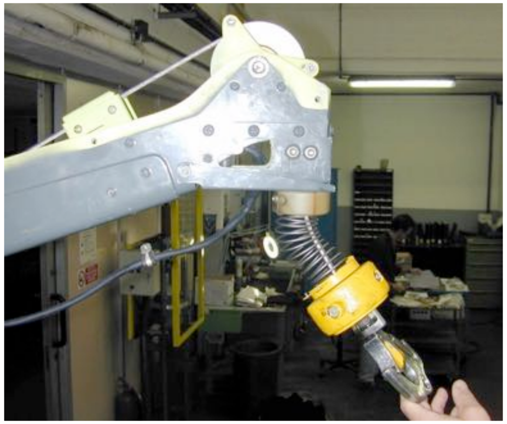




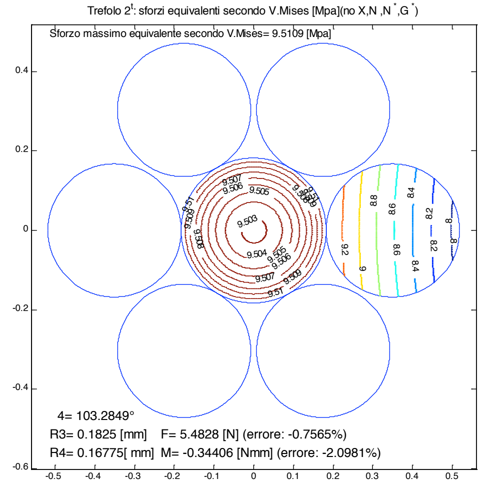
Fatigue assessment of a wire rope for helicopter hoist

Experimental fatigue test



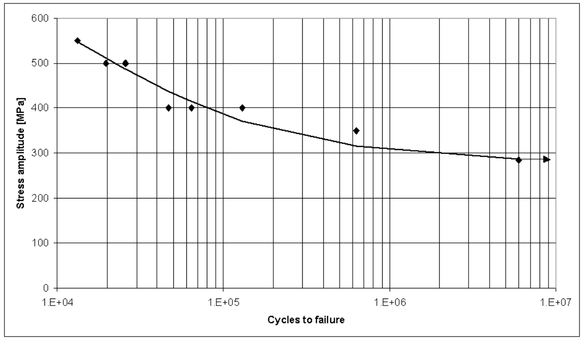


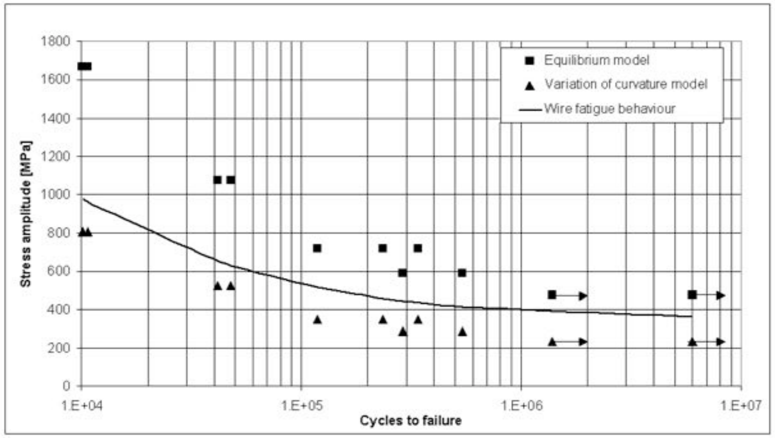
Analytical model



Comparison between experimental fatigue life and predicted one

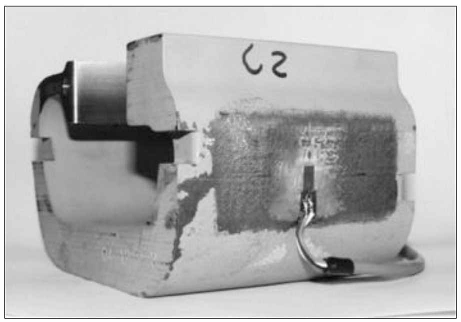
Single wire behaviour



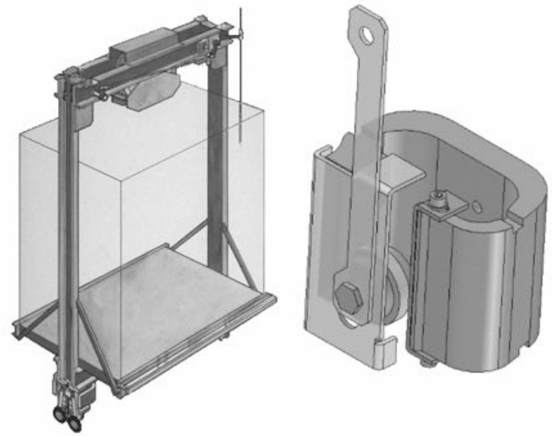


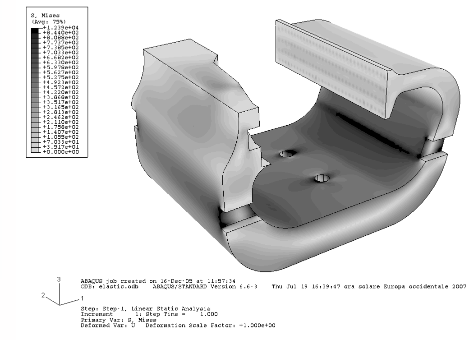
Experimental and numerical damage evaluation of a lift safety gear

Experimental fatigue tests with strain gauges and accelerometers

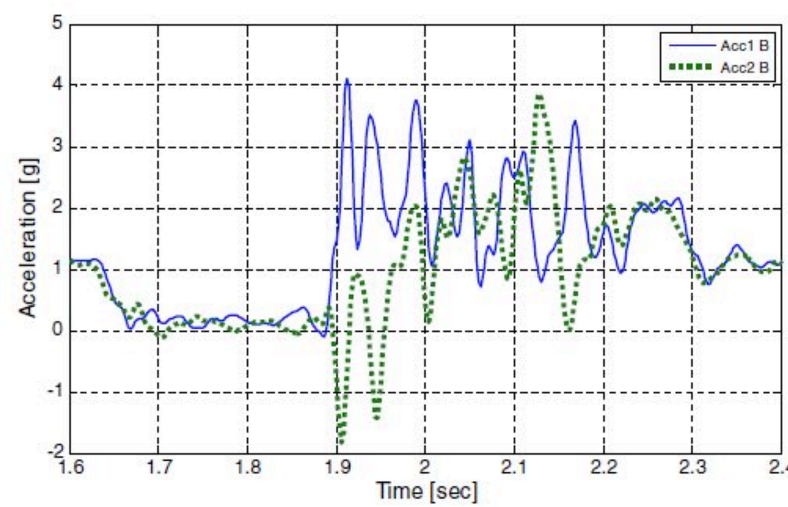


Numerical model of the safety gear

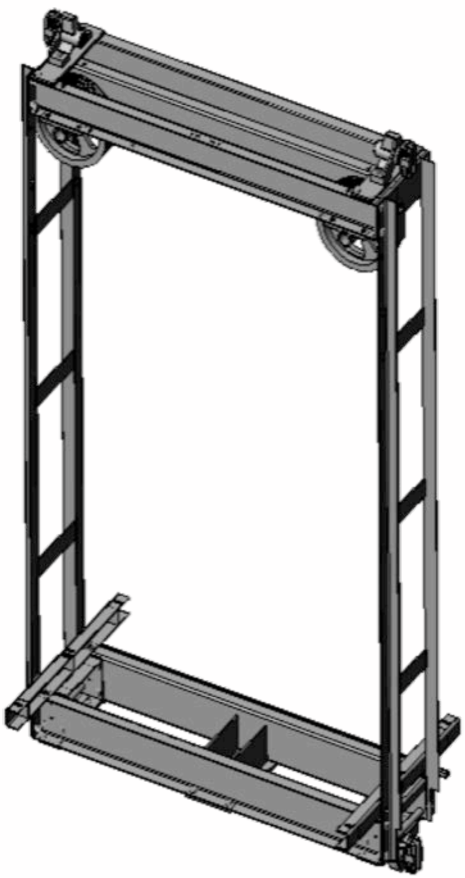




Elaboration from accelerometers measurements: deceleration level and non simultaneity in the safety gear application



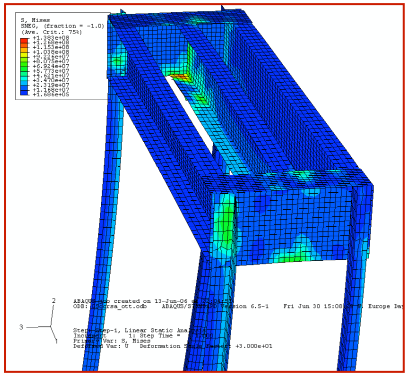
Analysis and optimization of a frame for elevators

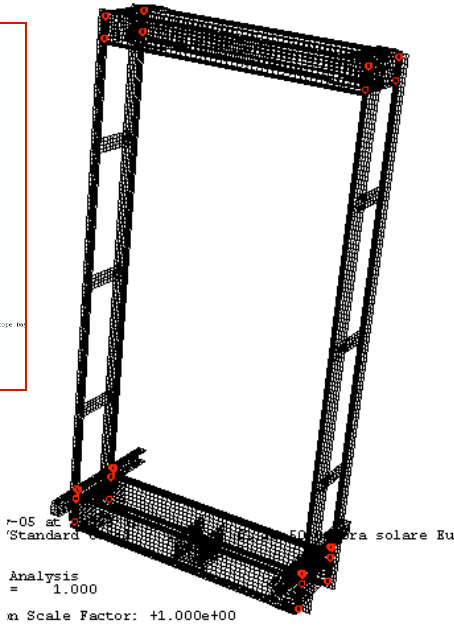


Analytical model

Numerical model

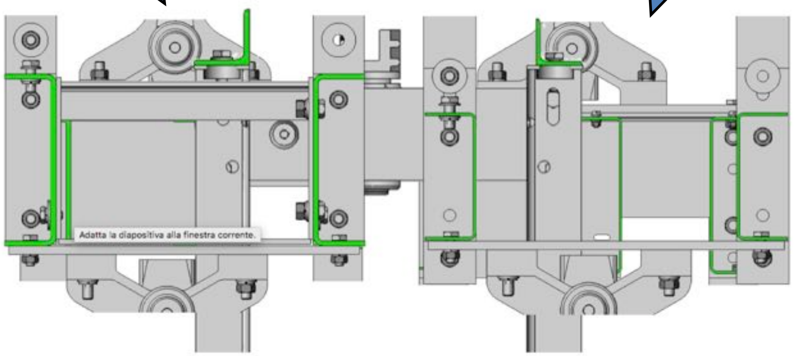
Optimization under critical condition: activation of safety devices





Starting structure

Optimised structure – 40% of weight



Maximum stresses and deflection are used as constrains according to standard and regulation

P.N.R.M. (Italian National Project for Military Research),

Consortium: Italy (Politecnico di Milano)

OPTY-V

Ottimizzazione di una ProTezione "underbodY" per Veicoli nei confronti di una carica sepolta (OPTY_V)

Improve and optimize survivability in under-body blast attack by means of advanced numerical modeling

VULNUS

Analisi della VULNerabilità di costrUzioni in calceStruzzo soggetti ad impatti ed esplosioni – VULNUS

Define a methodological approach for survivability analysis of concrete structure subjected to impact and explosion

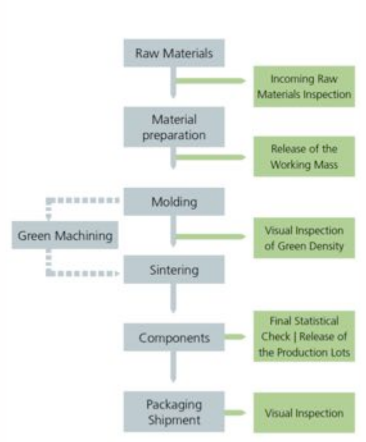
P.N.R.M. (Italian National Project for Military Research),

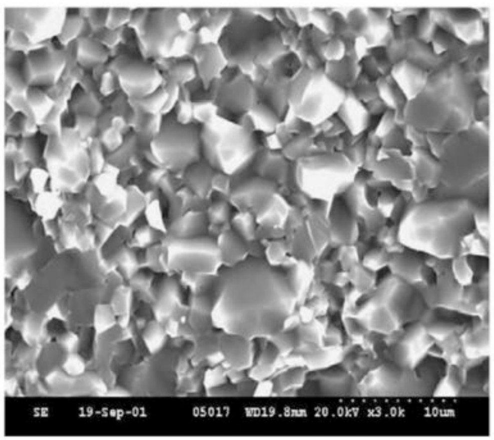
Consortium: Italy (Politecnico di Milano – Bitossi)

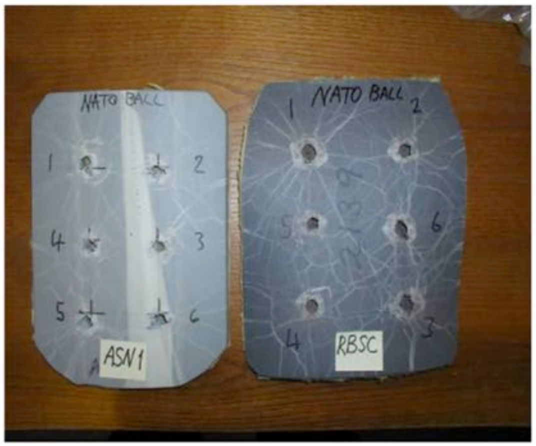
AIDENTITI

IdentificAzIone una metoDologia Efficace per la correlazione del processo tecNologico, proprieTà fisiche e mIcrostrutturali e prestazione balisTica di piastrelle ceramIche

Identification of an effective methods in order to correlate technological process, physical and microstructural properties and ballistic performance of ceramic tiles





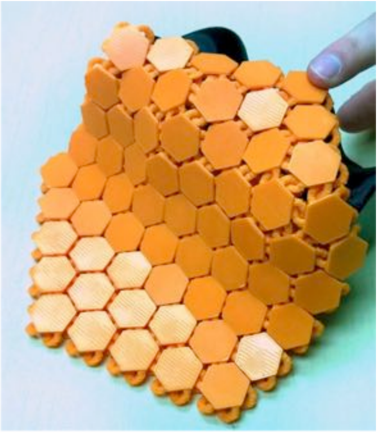


PADR Preparatory action for defense research

Role: subcontractor in the consortium

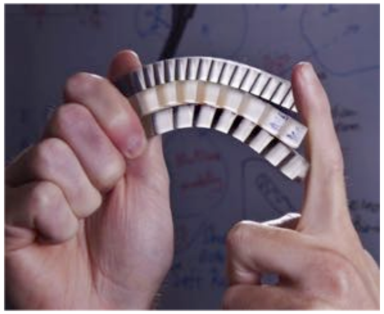
INCA

A project for the development of an innovative personal protection aimed to explore the best technologies in "soft armour", "hard plate" and "CBRN"



ROLE of POLIMI

POLIMI will use his expertise in modelling terminal ballistic event to create analytical and numerical models to investigate on the behaviour of several solutions against high speed bullets. Focus on the reproduction of the back-face signature of bullets and fragments – Optimization



- C. Mapelli, A. Manes, M. Giglio, D. Mombelli, (2013), *" Structural Effect of ballistic impact on a shaft by means of crystallographic investigation"* SDHM Structural Durability and Health Monitoring, Vol. 9, Issue 2, pp. 181-199
- A. Manes, D. Lumassi, L. Giudici, M. Giglio, (2013), *"An experimental-numerical investigation on aluminium tubes subjected to ballistic impact with soft core 7.62 ball projectiles*" Thin-Walled Structures 73,, 68-80
- A. Manes, A. Gilioli, C. Sbarufatti, M. Giglio, (2013)"Experimental and numerical investigations of low velocity impact on sandwich panels" *Composite Structures*, 99, pp. 8-18,
- M. Giglio, A. Gilioli, A. Manes, L. Peroni, M. Scapin (2012), *"Investigation about the influence of the mechanical properties of lead core and brass jacket of a NATO 7.62 mm ball bullet in numerical simulations of ballistic impacts" Dymat (2012)- 10th International Conference on the Mechanical and Physical Behaviour of Materials under Dynamic Loading*, EPJ Web of Conferences, Volume 26, 04010
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- A. Manes, R. Porcaro, H. Ilstad, E. Levoldd, M. Langseth, T. Børvik, (2012) "The behaviour of an offshore steel pipeline subjected to bending and stretching" *Ships and Offshore Structures*, pages 371-387 Volume 7, Issue 4,
- V. Bedogni, A. Manes (2012)" An experimental investigation of the effect of the placement angle on the collapse of ice screw anchors" *Engineering Failure Analysis,* 26 ,139–150
- M. Giglio, A. Gilioli. A. Manes (2012) “Numerical Investigation Of A Three Point Bending Test On Sandwich Panels With Aluminum Skins And Nomex^{tm} Honeycomb Core” *Computational Materials Science, 56,, 69–78*
- M. Giglio, A. Manes, A. Gilioli, (2012) "Investigations on sandwich core properties through an experimental–numerical approach " *Composites Part B: Engineering,* 43 ,, 361–374
- M. Giglio, A. Manes, F. Viganò, (2012) " Numerical simulation of the slant fracture of a helicopter's rotor hub with ductile damage failure criteria "*Fatigue and Fracture of Engineering Materials and Structures*, Volume 35, Issue 4, pages 317–327
- M. Giglio, A. Manes, F. Viganò, (2012) " Ductile fracture locus of Ti-6Al-4V titanium alloy" *International journal of mechanical sciences* 54, 121–135
- M. Giglio, A. Manes, (2011) " Terminal ballistic effect on the crack growth assessment of a helicopter rotor drive" *Engineering Fracture Mechanics* Volume 78, Issue 8, Pages 1542-1554

Selected papers on Structural integrity under extreme load

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- Bresciani, L.M., Manes, A., Ruggiero, A., Iannitti, G., Giglio, M. Experimental tests and numerical modelling of ballistic impacts against Kevlar 29 plain-woven fabrics with an epoxy matrix: Macro-homogeneous and Meso-heterogeneous approaches (2016) Composites Part B: Engineering, 88, pp. 114-130.
- Amiri, S., Chen, X., Manes, A., Giglio, M. Investigation of the mechanical behaviour of lithium-ion batteries by an indentation technique (2016) International Journal of Mechanical Sciences, 105, pp. 1-10
- Bresciani, L.M., Manes, A., Romano, T.A., Iavarone, P., Giglio, M. Numerical modelling to reproduce fragmentation of a tungsten heavy alloy projectile impacting a ceramic tile: Adaptive solid mesh to the SPH technique and the cohesive law (2016) International Journal of Impact Engineering, 87, pp. 3-13
- Salvetti, M., Gilioli, A., Sbarufatti, C., Dragan, K., Chalimoniuk, M., Manes, A., Giglio, M. Analytical Model to Describe Damage in CFRP Specimen When Subjected to Low Velocity Impacts (2016) Procedia Engineering, 167, pp. 2-9.
- Manes, A., Giglio, M. A numerical optimization of lightweight multilayer armour (2015) Annual Forum Proceedings - AHS International, 4 (January), pp. 2453-2460.
- L. M. Bresciani, A. Manes, M. Giglio, (2015),*" An analytical model for ballistic impacts against plain-woven fabrics with a polymeric matrix" International Journal of Impact Engineering,* 78 ,138- 149
- A. Gilioli, A. Manes, M. Giglio, T.Wierzbicki,(2015) "*Predicting ballistic impact failure of aluminium 6061-T6 with the rate-independent Bao-Wierzbicki fracture model* " *International Journal of Impact Engineering*, Volume 76, Pages 207–220
- A. Manes, L.M. Bresciani, M. Giglio*, (2014) "Ballistic performance of multi-layered fabric composite plates impacted by different 7.62 mm calibre projectiles"* DRAFT 2014, International Symposium on Dynamic Response and Failure of Composite Materials, Procedia Engineering 88 ,208 – 215
- A. Gilioli, C. Sbarufatti, A. Manes, M. Giglio, (2014) "Compression after impact test (CAI) on nomextm honeycomb sandwich panels with thin aluminium skins " *Composites Part B: Engineering* , 6, 313–325
- A. Manes, M. Pagani, M. Saponara, D. Mombelli, C. Mapelli, M Giglio, (2014) , "*Metallographic characterisation of Al6061-T6 aluminium plates subjected to ballistic impact"* Materials Science & Engineering A 608 207–220
- A. Manes, F. Serpellini, M. Pagani, M. Saponara; M. Giglio, (2014),*"Perforation and penetration of aluminium target plates by armour piercing bullets"*, International Journal of Impact Engineering 69, 39- 54

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