Geometry Intelligence and Fast RBF for Real-Time CAE Optimisation

Dr. Marco Evangelos Biancolini

Prof. University of Rome Tor Vergata

Founder of RBF Morph srl

Ansys SELECT TECHNOLOGY PARTNER

rbf®

TOR VERGATA UNIVERSITÀ DEGLI STUDI DI ROMA

Agenda

- About Us – Past And Running Projects
- Radial Basis Functions – Data Science And Geometrical Intelligence
- Parameter-Based And Parameter-Free Shape Optimisation
- Digital Engineering
- Two Industrial Examples: Dallara Formula Car, Vespa Engine
- Conclusions
- Next Steps

dallara

PIAGGIO

Ansys SELECT TECHNOLOGY PARTNER

rbf

TOR VERGATA UNIVERSITÀ DEGLI STUDI DI ROMA

About Us

Past and Running Projects

Research Team at rbfLAB

rbf.LAB


Marco Evangelos Biancolini


Corrado Groth


Andrea Chiappa

LivGemini


Leonardo Geronzi


Andrea Baldini

rbf


Emanuele Di Meo


Stefano Porziani

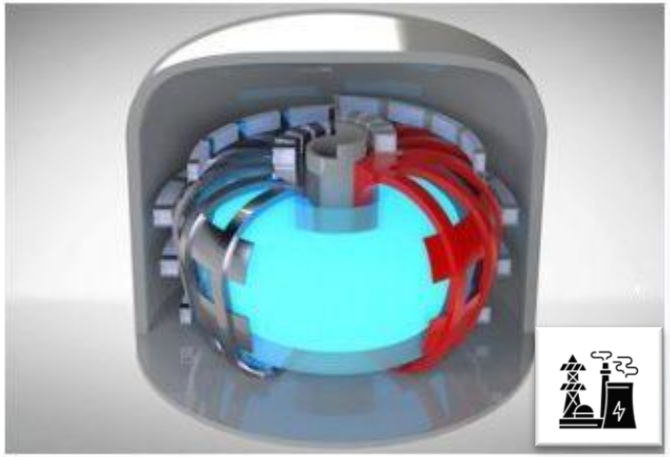

Ubaldo Cella

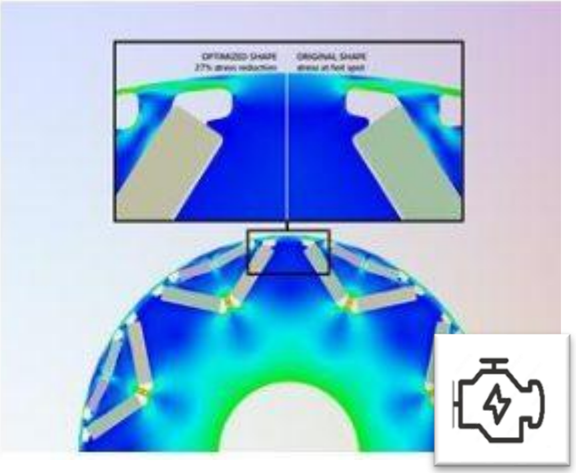

Carlo Brutti

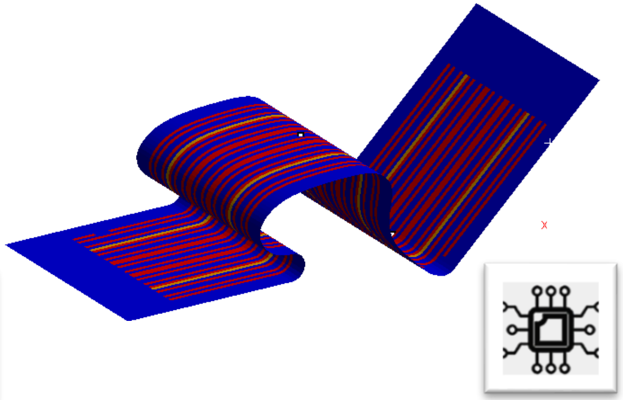

Giovanni Lombardi

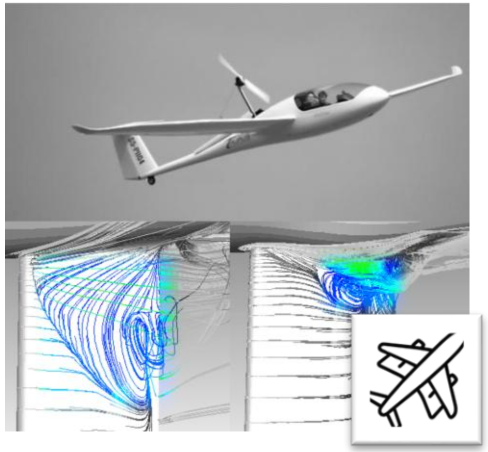
Ansys SELECT TECHNOLOGY PARTNER | rbf | TOR VERGATA UNIVERSITÀ DEGLI STUDI DI ROMA

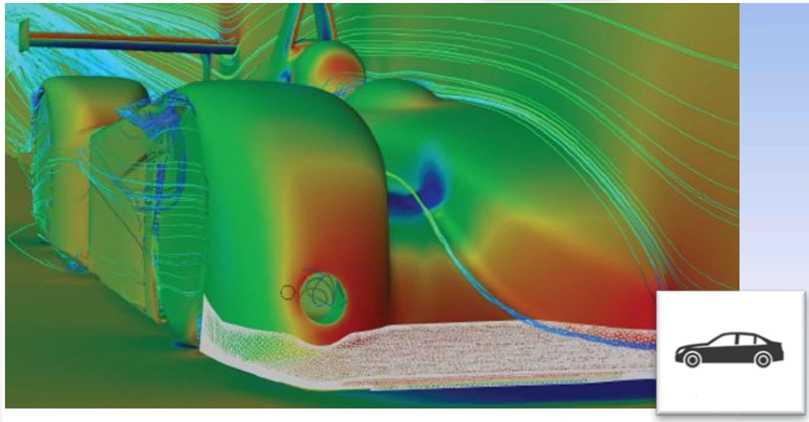
Research and Industrial sectors

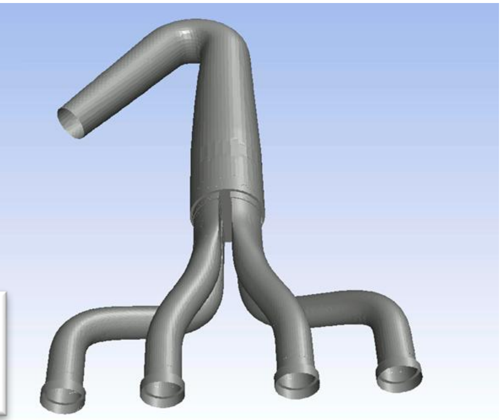












EU-funded research projects 2013-2026

Funded by
the European Union

RBF4AERO

FORTISSIMO

RIBES

CloudiFacturing

spinner
next generation spine experts

MEDITATE

EUROfusion

ff4EuroHPC

ff+

Ansys
SELECT TECHNOLOGY PARTNER

rbf®

TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

Radial Basis Functions

Data Science and Geometrical Intelligence

Radial Basis Functions (RBF) in a nutshell

source points

radial basis

$$s(\mathbf{x}) = \sum_{i=1}^{N} \gamma_i \cdot \varphi(\|\mathbf{x} - \mathbf{x}_{\mathbf{k}_i}\|) + h(\mathbf{x})$$

polynomial

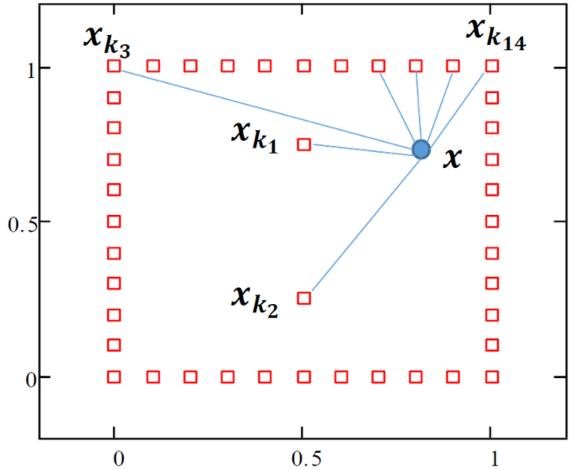
e.g. $h(\boldsymbol{x}) = \beta_1 + \beta_2 x + \beta_3 y + \beta_4 z$

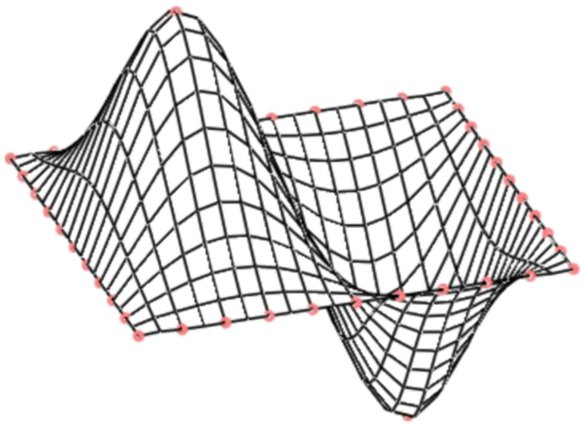
weight

shift of the target point to the i-th data site

RBF	φ(r)
Spline type (Rn)	r^n, *n odd*
Thin plate spline	$r^n \log(r)$ *n even*
Multiquadratic (MQ)	$\sqrt{1+r^2}$

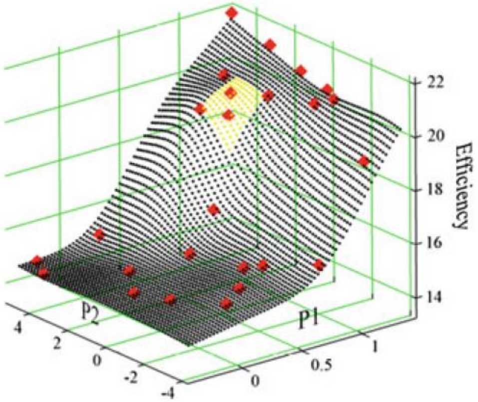
RBF are a very powerful mathematical tool able to interpolate **everywhere** in the $\mathbb{R}^n$ space a function given at scattered **source points**

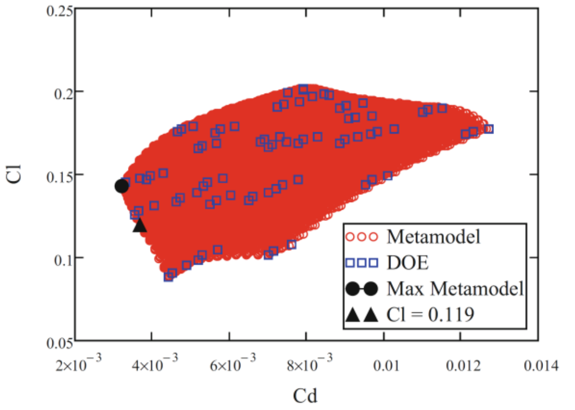




Interpolators in multi-dimensional spaces

- **Data science** problems
  - Inference $\mathbb{R}^n \Rightarrow \mathbb{R}^m$
  - Gaussian RBF is recognized as the "RBF neural network"
  - Useful for **surrogates** in **optimisation**
- 3D space manipulation (shape deformation, data mapping)
  - Field manipulation is a key enabler for **geometric intelligence**
  - Mapping is a key enabler for multi-physics and as a "morphing extender"

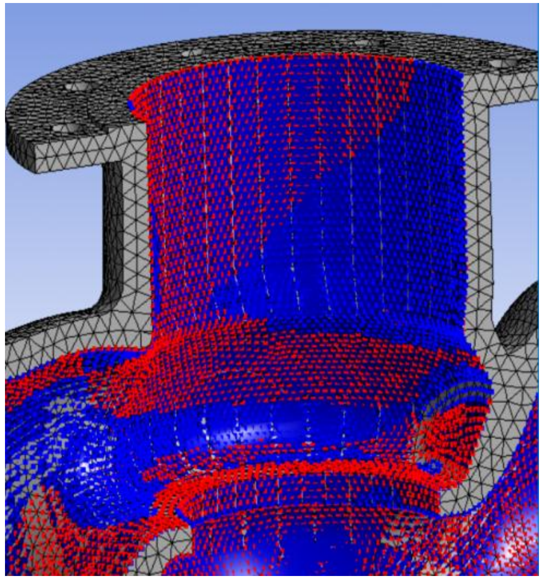




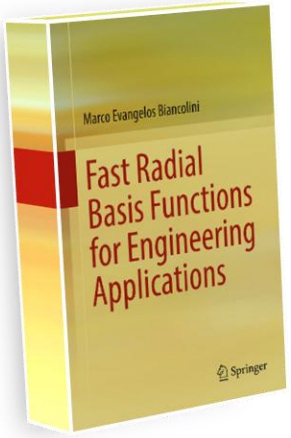
Shape Optimisation

Parameter-based and Parameter-free Workflows

RBF Mesh Morphing



- We adopt **Radial Basis Functions** (RBF) to drive mesh morphing (smoothing) from a list of source points and their displacements
  - Surface shape changes
  - Volume mesh smoothing
- RBF are recognized to be one of the **best mathematical tool** for mesh morphing

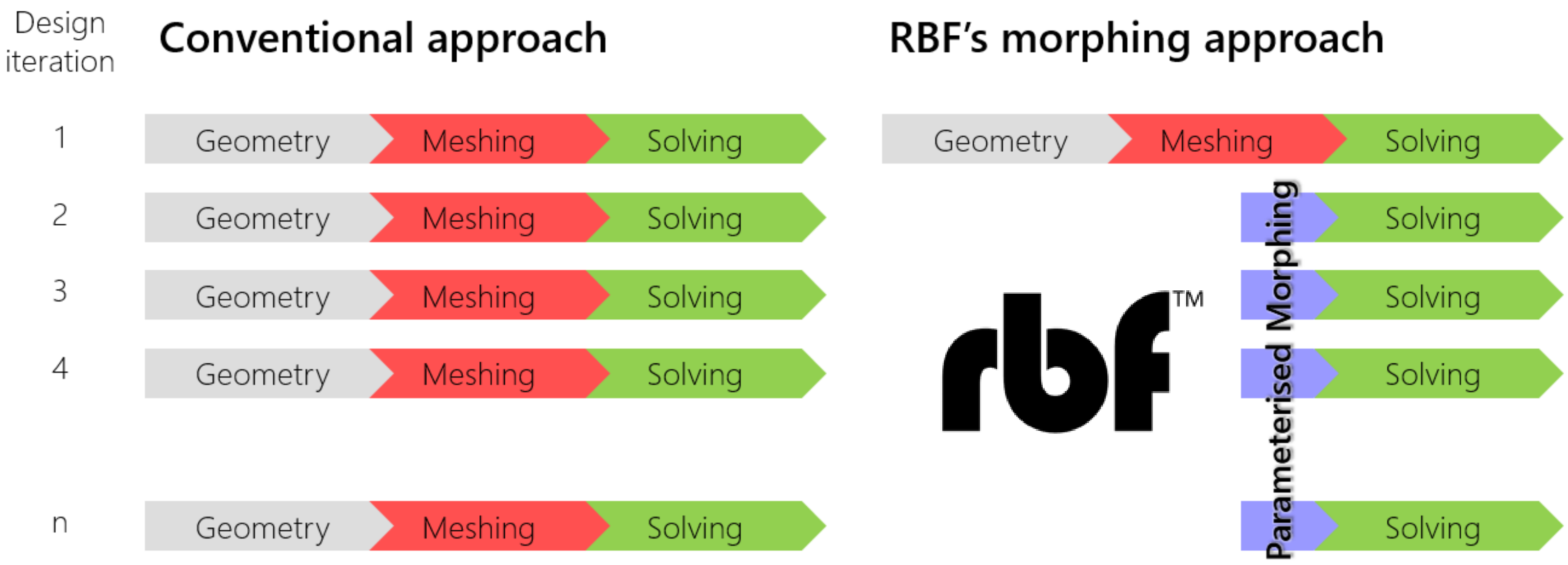


$$
\begin{cases}
s_x(\boldsymbol{x}) = \sum_{i=1}^{N} \gamma_i^x \varphi(\|\boldsymbol{x} - \boldsymbol{x}_{s_i}\|) \\
s_y(\boldsymbol{x}) = \sum_{i=1}^{N} \gamma_i^y \varphi(\|\boldsymbol{x} - \boldsymbol{x}_{s_i}\|) \\
s_z(\boldsymbol{x}) = \sum_{i=1}^{N} \gamma_i^z \varphi(\|\boldsymbol{x} - \boldsymbol{x}_{s_i}\|)
\end{cases}
$$

Ansys SELECT TECHNOLOGY PARTNER
rbf®
TOR VERGATA UNIVERSITÀ DEGLI STUDI DI ROMA

Parameter-based Shape Optimisation

- Morphing is a **key enabler** for optimisation and Digital Twins
- The turnaround time of the optimization is usually **reduced by a factor five** (weeks becomes days)

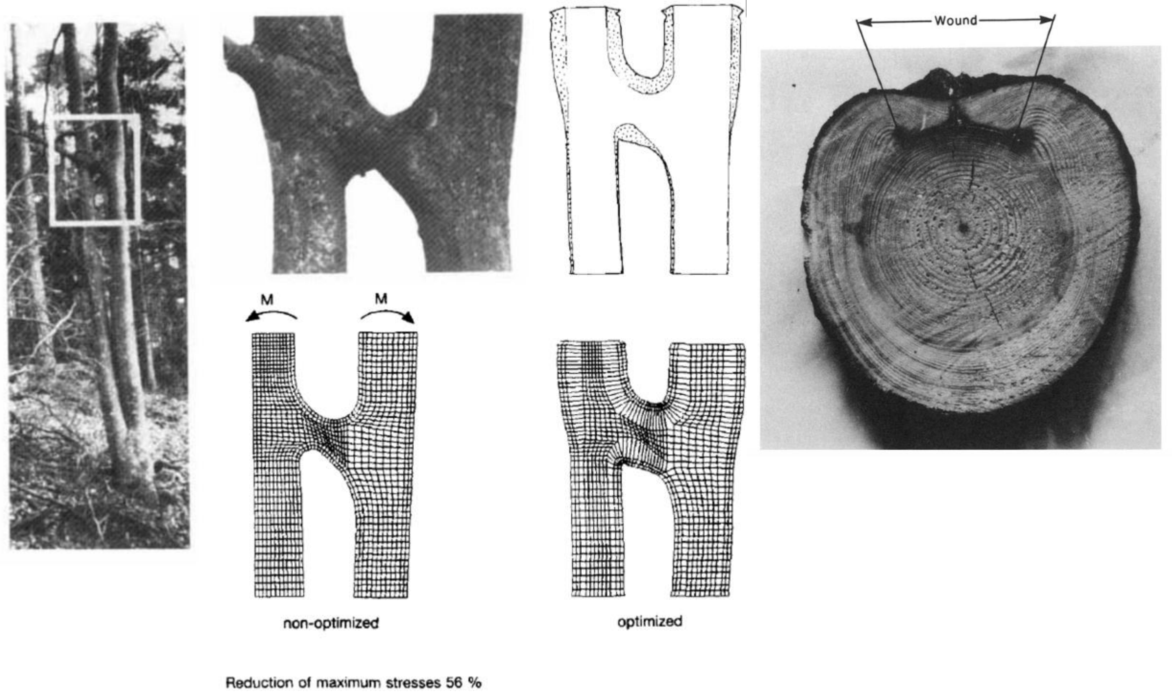


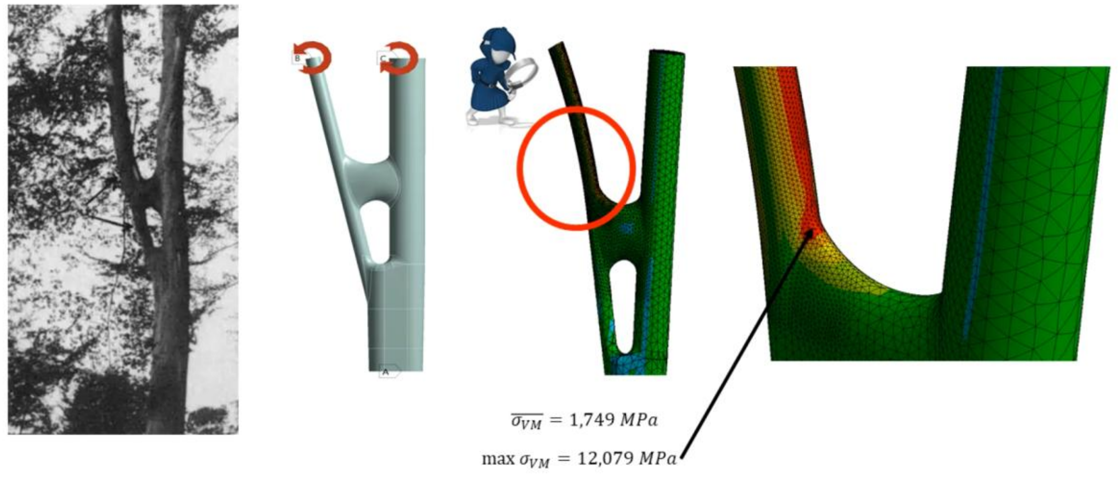
Parameter-free Shape Optimisation

- The **BGM** (biological growth method) approach is based on the observation that **biological** structures growth is driven by **local level of stress**.
- Bones and trees' trunks are able to **adapt the shape** to mitigate the stress level due to external loads.
- The process is driven by stress **value at surfaces**. Material can be **added or removed** according to local values.

$$\dot{\varepsilon} = k\left(\sigma_{Mises} - \sigma_{ref}\right)$$

- Was originally proposed by Mattheck & Burkhardt in 1990



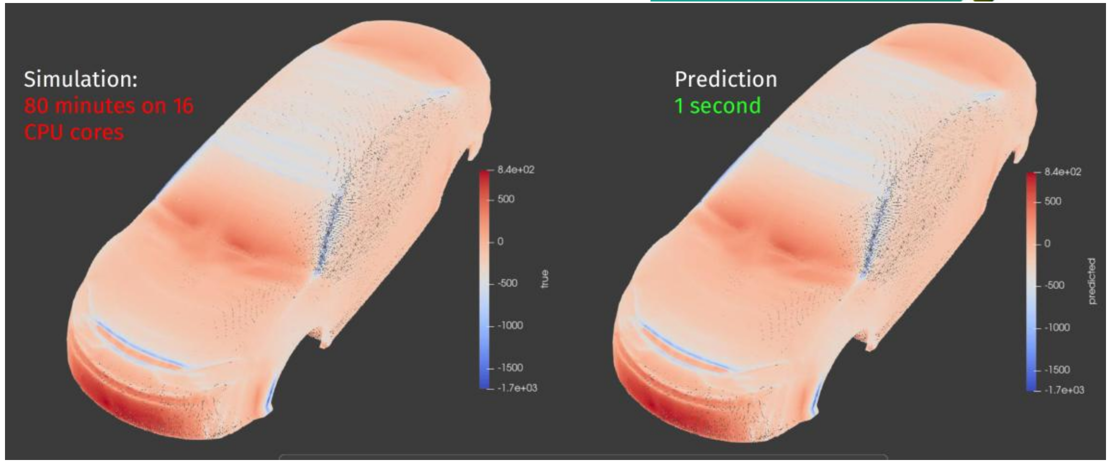


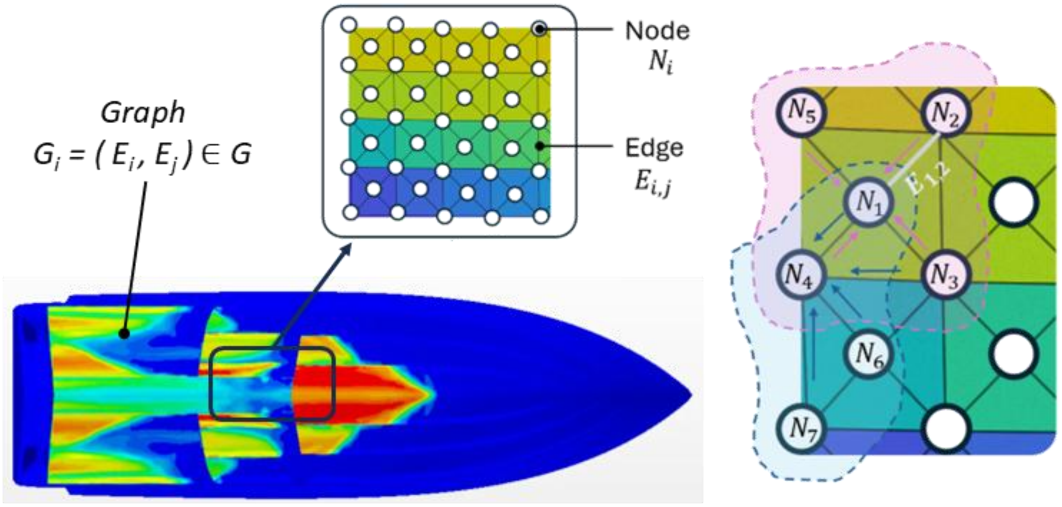
Digital Engineering

Real Time Interactive CAE Models

Digital Engineering Applications

- **Digital Twin** – digital replica of asset useful at design and operation
- CAE adoption is evolving: single verification, design variations, automated optimisation, **parametric space exploration** (snapshots)
- **Machine learning** is the reference for AI based approach
- High/medium fidelity simulations allow to generate the training data: **synthetic datasets**





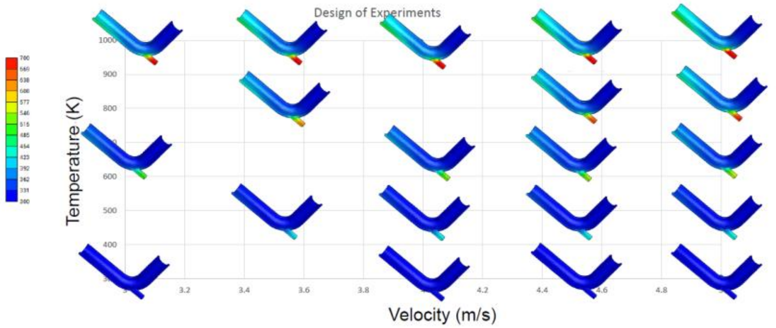
Ansys SELECT TECHNOLOGY PARTNER

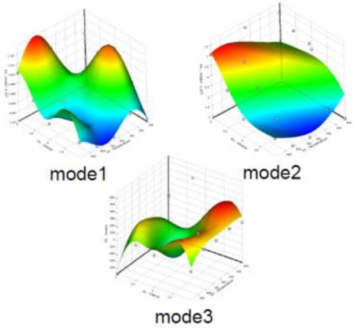
rbf®

TOR VERGATA UNIVERSITÀ DEGLI STUDI DI ROMA

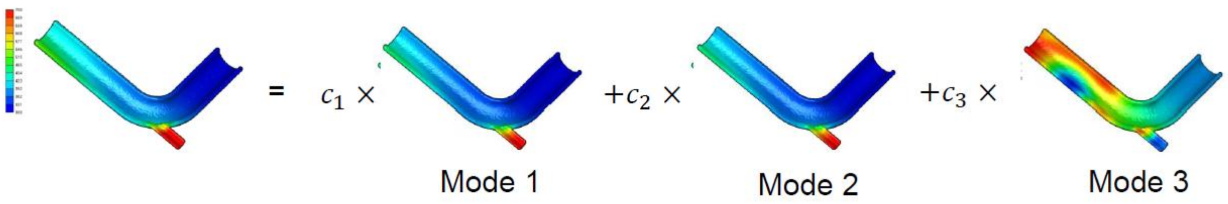
Interactive Digital Twins

- **Reduced Order Models** (ROM) are compressed (POD) ready to be inferred (RBF)
- Functional Mock-Up Units (**FMU**) make the models portable
- Unity rendering
  - Meta Quest 3 AR/VR
  - Apple VisionPro?

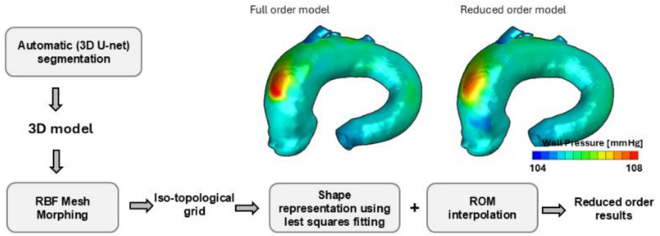


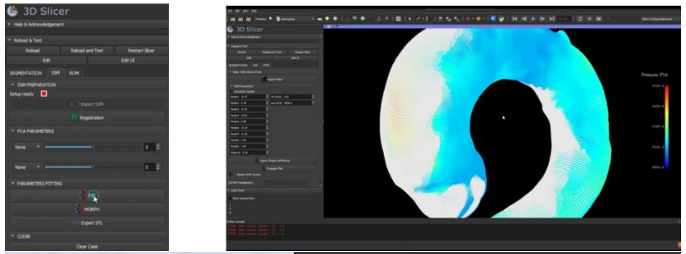


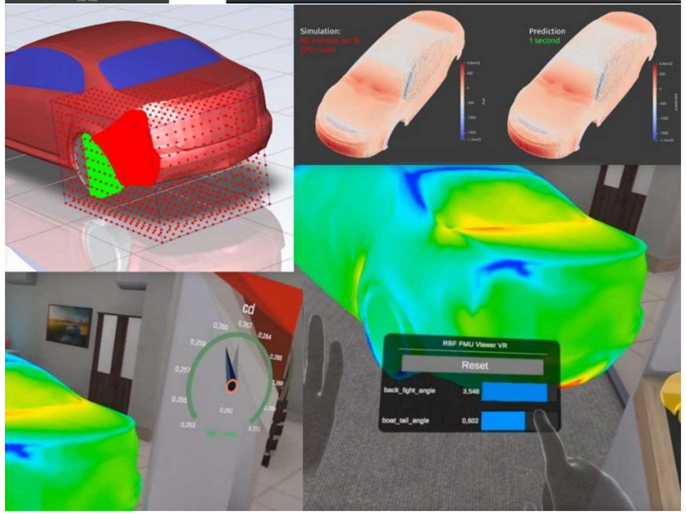
POD+RBF = ROM

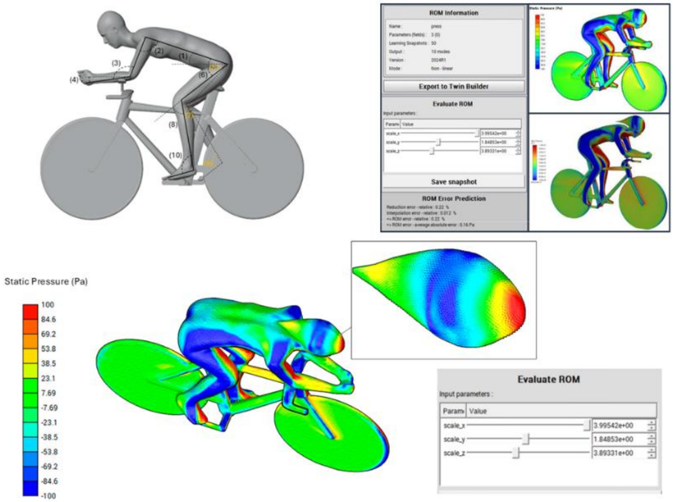


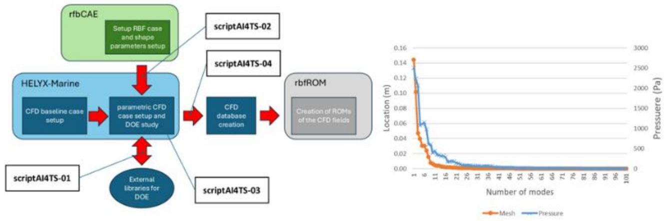
Digital Engineering Examples

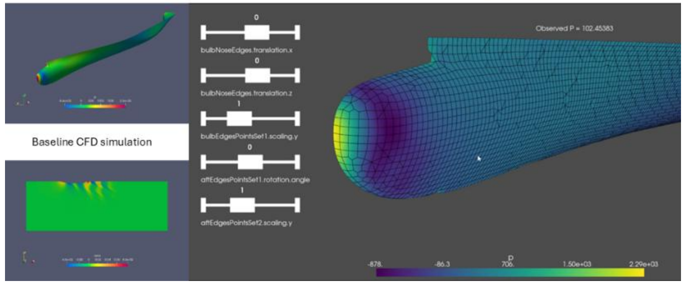


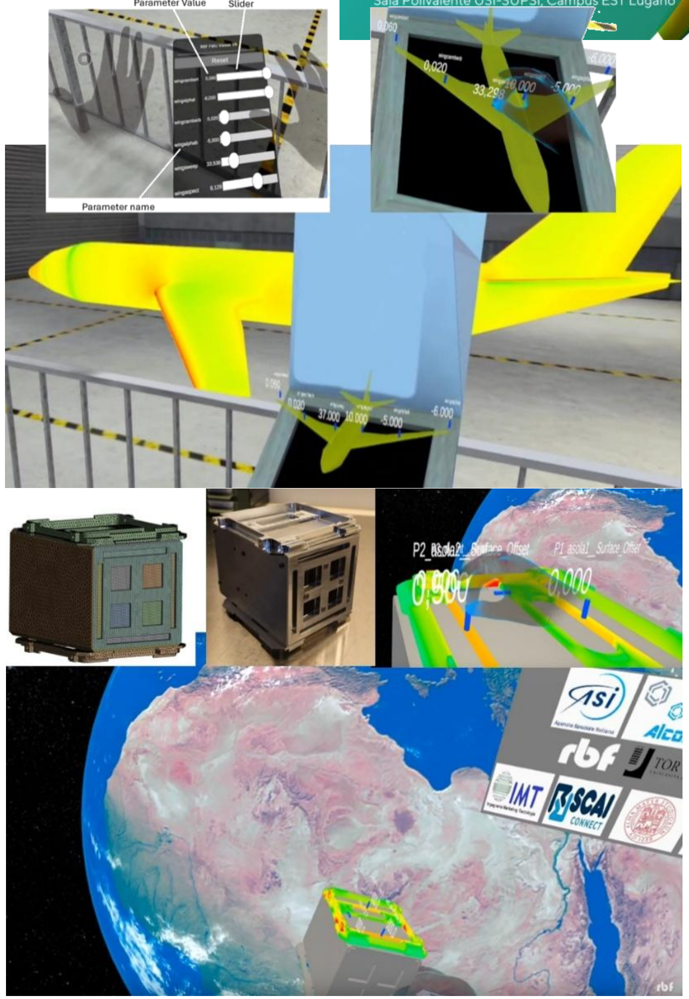












Ansys SELECT TECHNOLOGY PARTNER

rbf®

TOR VERGATA UNIVERSITÀ DEGLI STUDI DI ROMA

Two Detailed Industrial Examples

Dallara Formula Car - Vespa Engine

The need for speed...

dallara

PIAGGIO

Lap time reduction of a race car by a better flow penetration

Extended durability of an internal combustion engine

Ansys SELECT TECHNOLOGY PARTNER rbf® TOR VERGATA UNIVERSITÀ DEGLI STUDI DI ROMA

…requires limitless performances …

dallara

Lap time reduction of a race car by a better flow penetration

PIAGGIO

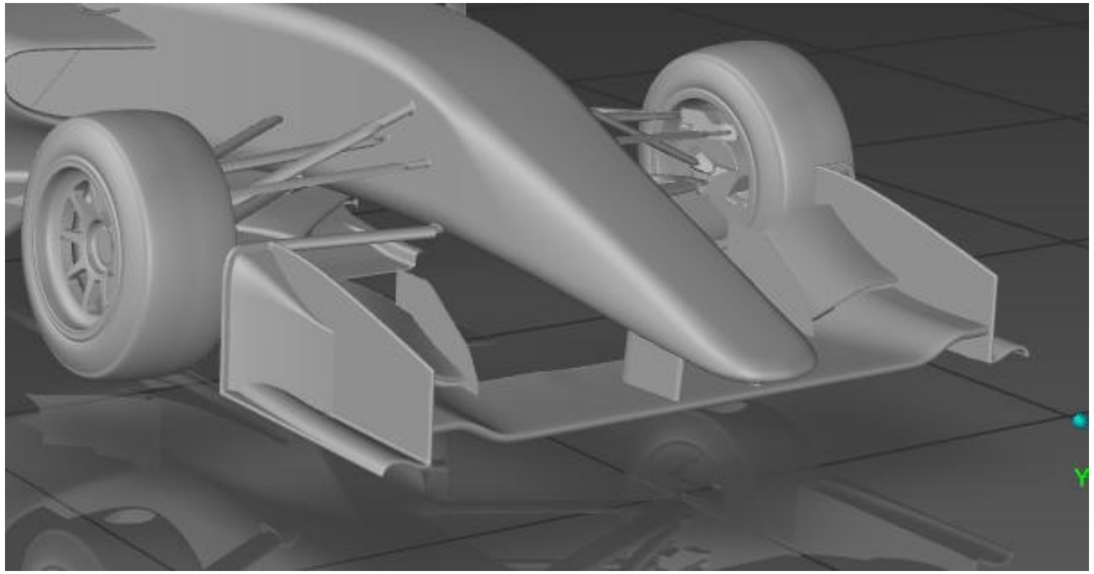
Extended durability of an internal combustion engine

Ansys SELECT TECHNOLOGY PARTNER

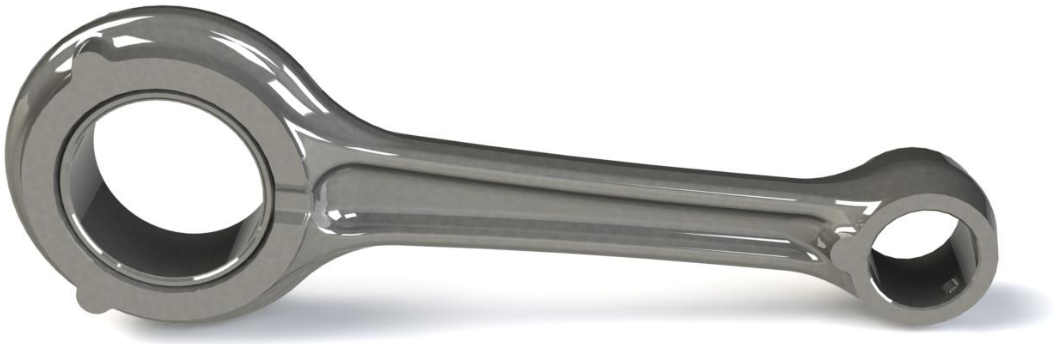
rbf®

TOR VERGATA UNIVERSITÀ DEGLI STUDI DI ROMA

...to be achieved by acting on KPIs...

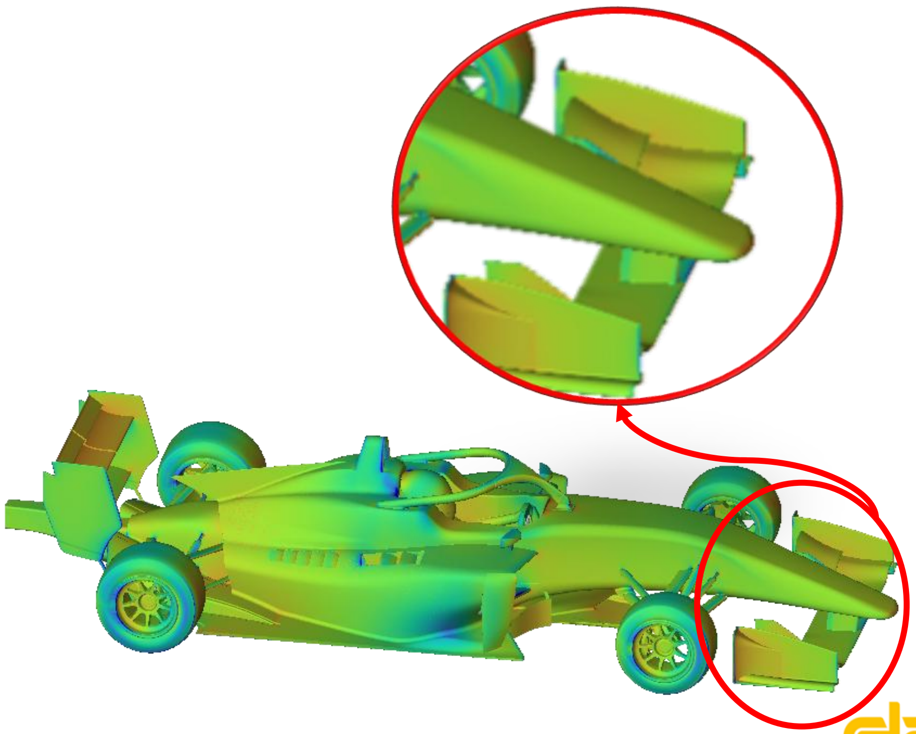


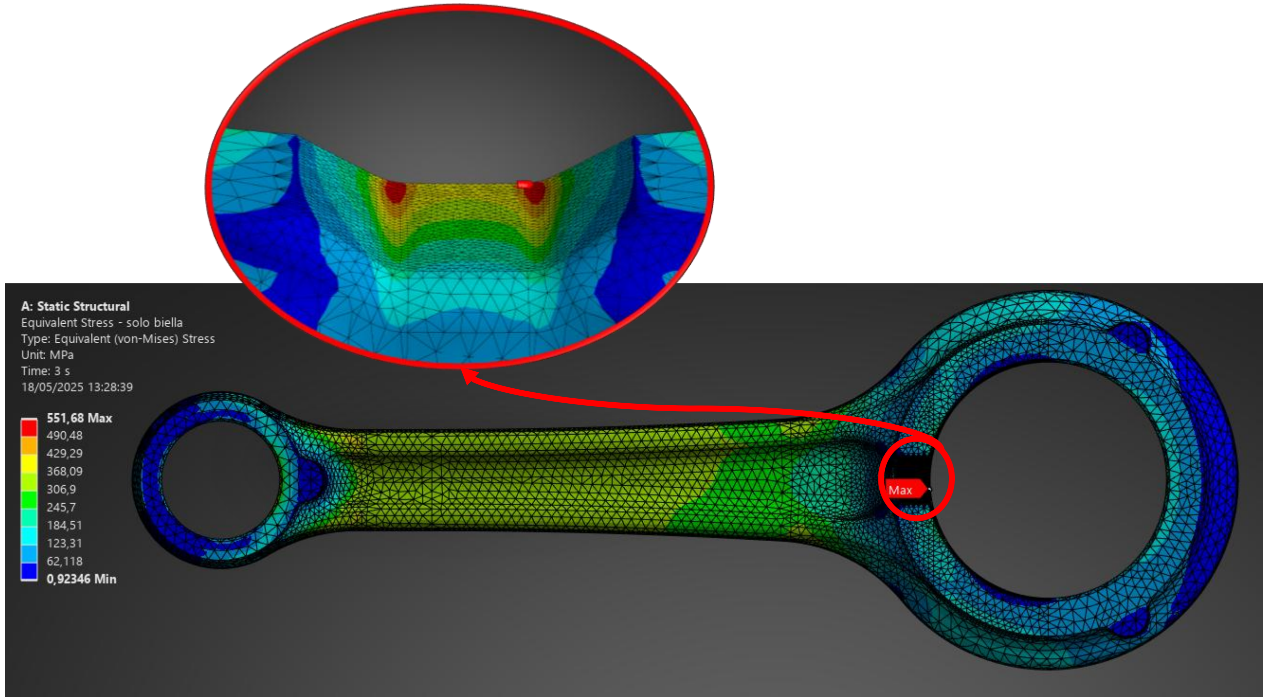
Tweak the design of the front wing to gain 0.15 drag counts



Reduce connecting rod stress by 15% to increase its fatigue life

...precisely predicted by CAE simulation.





dallara

PIAGGIO

Fluent CFD provides best in class solution for external aero

Mechanical FEA is the industry standard for stress prediction

Ansys SELECT TECHNOLOGY PARTNER

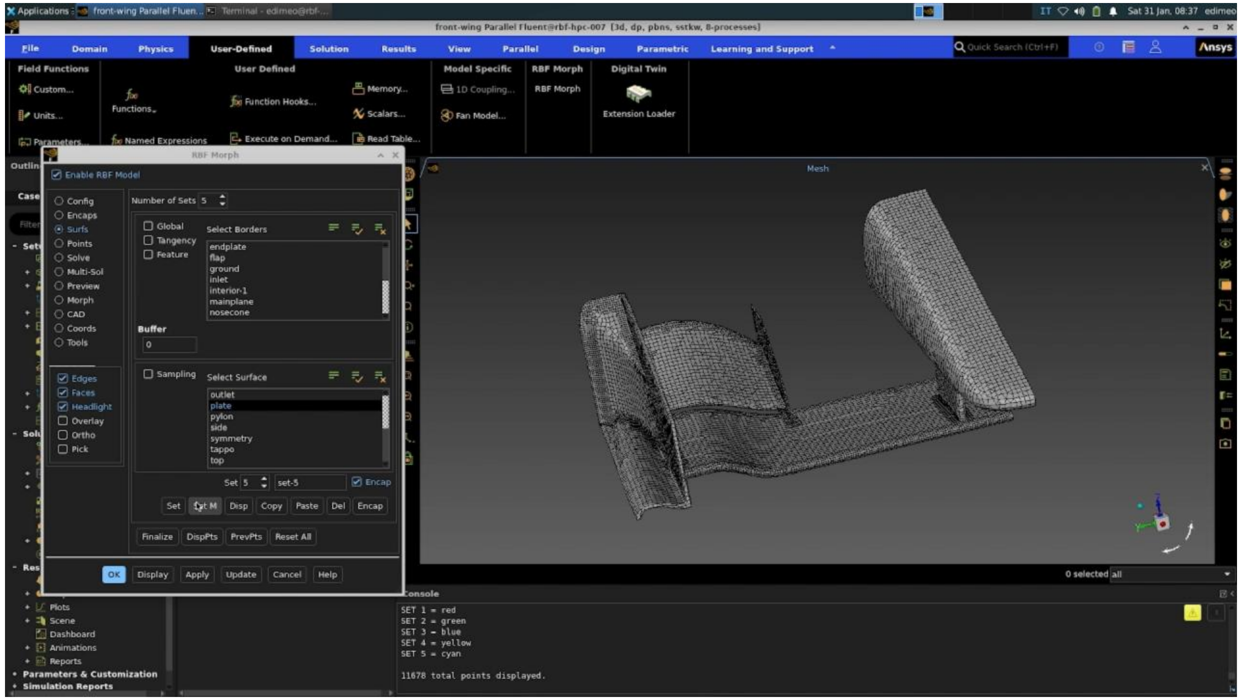
rbf

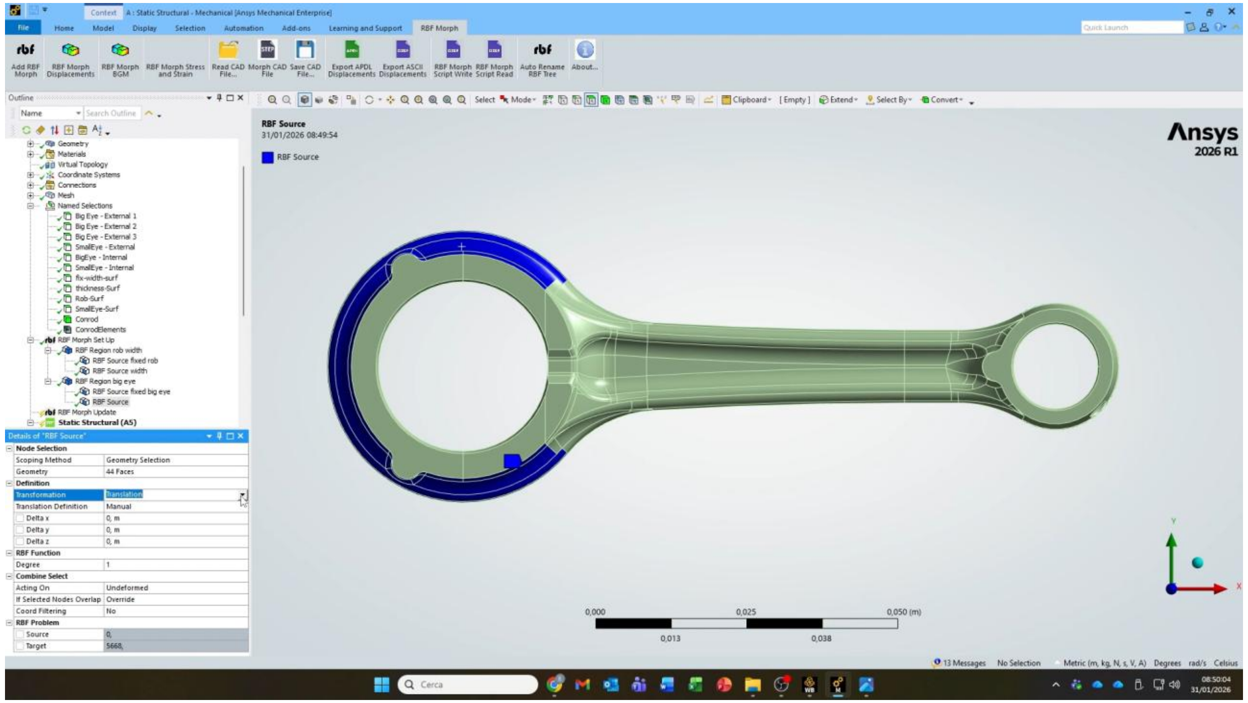
TOR VERGATA UNIVERSITÀ DEGLI STUDI DI ROMA

Parameter-based Shape Optimisation

We need Shape Intelligence to identify new designs

Step #1: define the RBF shape parameters





dallara

Shape parameters are defined interacting with Fluent **GUI and TUI**

PIAGGIO

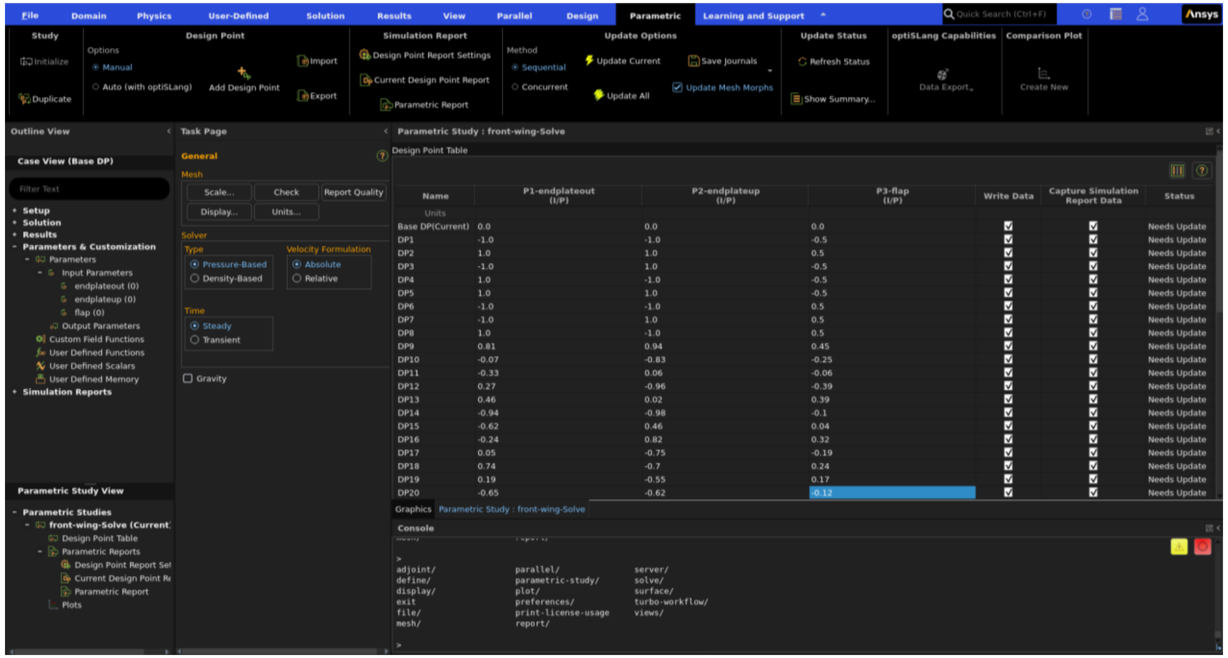
Shape parameters are defined in the **morphing tree** inside Mechanical

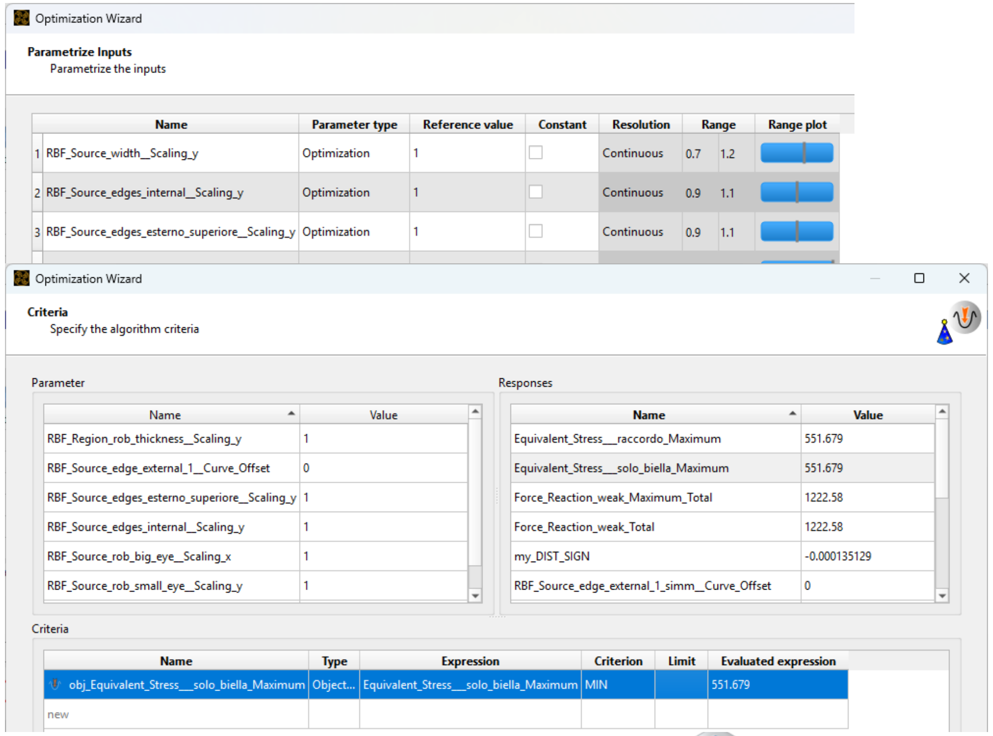
Ansys SELECT TECHNOLOGY PARTNER

rbf

TOR VERGATA UNIVERSITÀ DEGLI STUDI DI ROMA

Step #2: automate design exploration





dallara

PIAGGIO

The Fluent optimisation is steered by **optiSLang** stand alone

The Mechanical optimisation is steered by **optiSLang** within Workbench

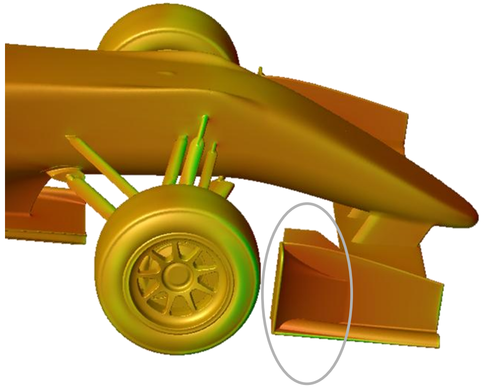
Ansys SELECT TECHNOLOGY PARTNER

rbf®

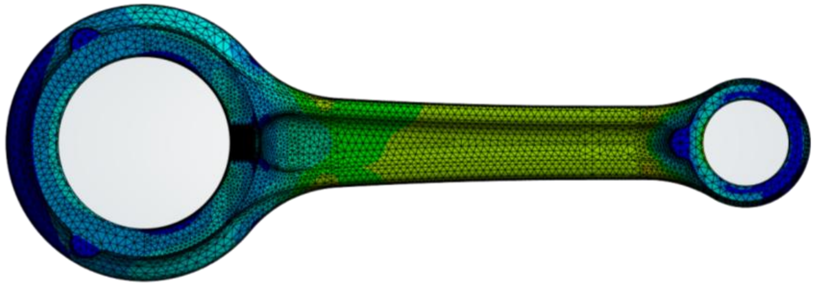
TOR VERGATA UNIVERSITÀ DEGLI STUDI DI ROMA

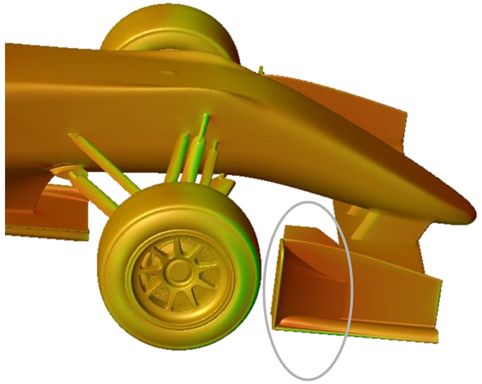
Step #3: validate the results

-0.19 drag points gain

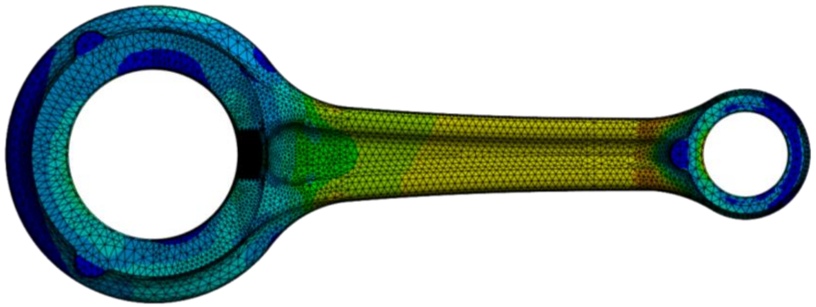


Baseline Design





Optimised Design



-17.4% Hotspot Stress reduction

Front Wing	P1	P2	P3	Cd
Baseline	1	1	1	0.4333
Optimised	-0.81	0.93	0.45	0.4247

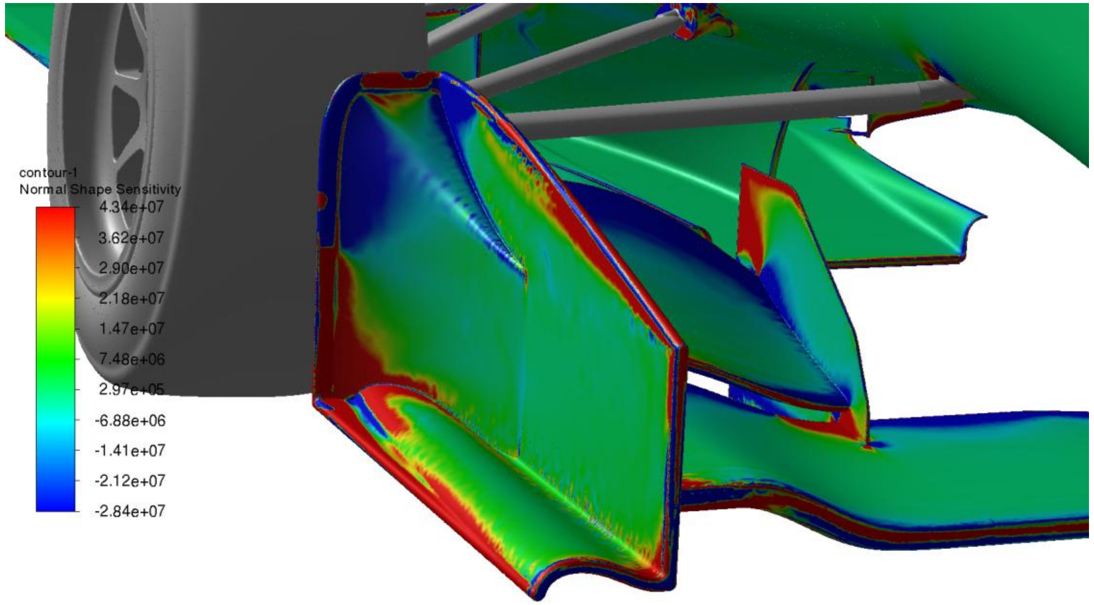
Conrod	P1	P2	P3	P4	P5	P6	P7	σ_{VM} [MPa]
Baseline	1	1	0	1	1	1	1	551
Optimised	1.23	0.78	-0.087	1.102	0.781	0.995	0.954	455

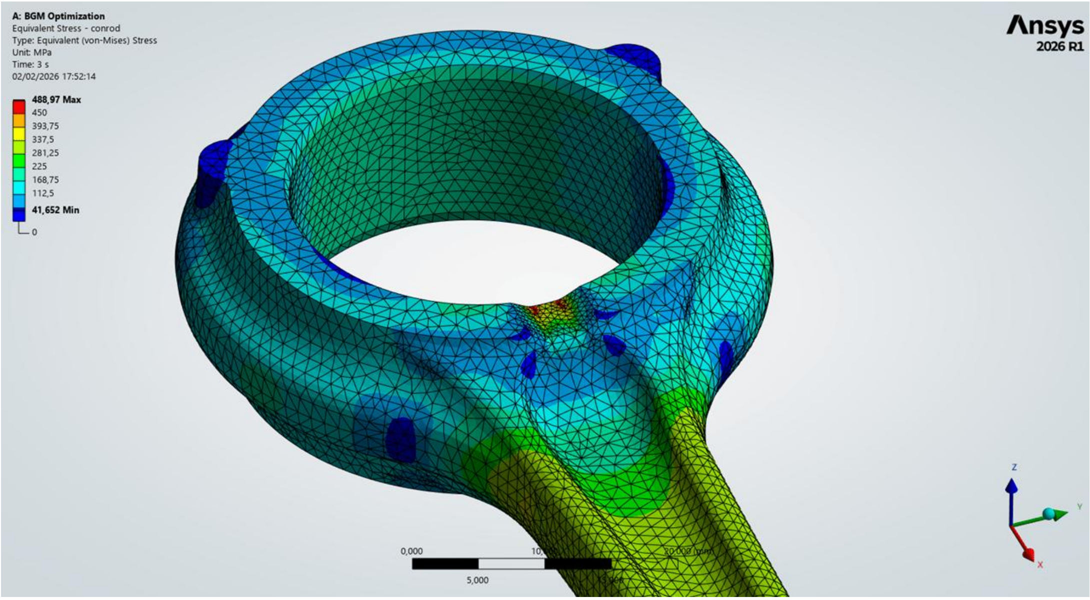
Parameter-free Shape Optimisation

The standard optimisation workflow allows to reach the KPI targets.

Can we refine it more?

Step #4: switch to parameter-free





RBF Morph Fluids offers a strong integration with the **adjoint solver**. **Surface are sculpted** whilst geometrical constraints are respected.

The BGM (**biological growth method**) allows to reduce the stress. **Manufacturing constraints** are easily applied.

Ansys SELECT TECHNOLOGY PARTNER

TOR VERGATA UNIVERSITÀ DEGLI STUDI DI ROMA

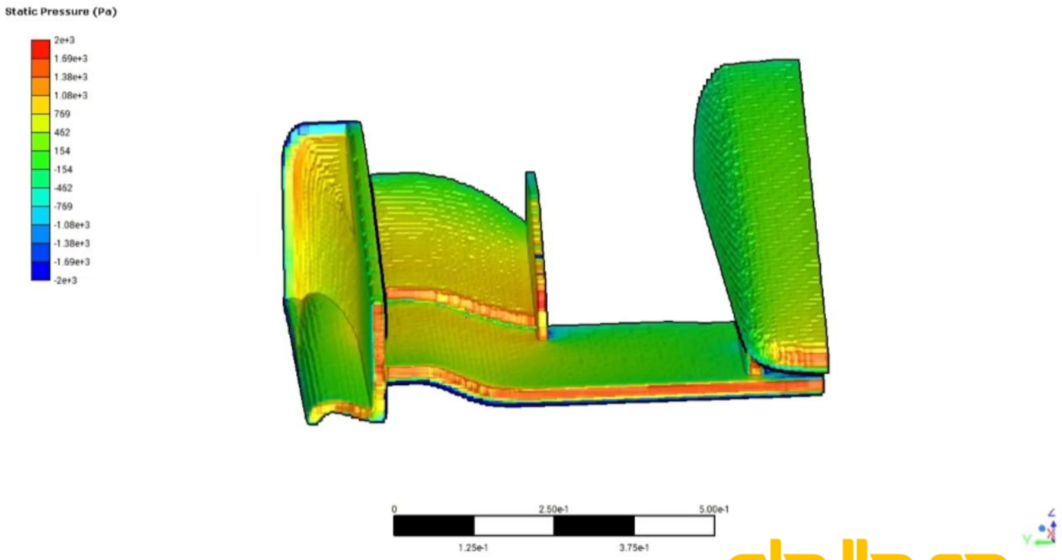
Interactive Shape Optimisation

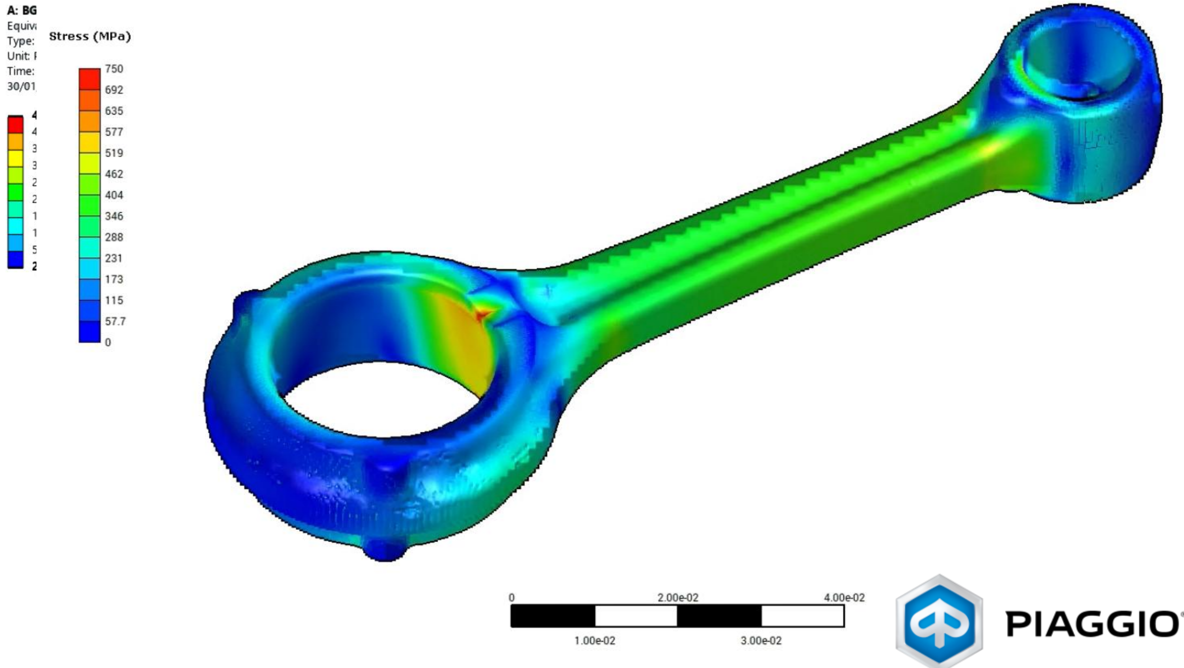
The automated refinement works well but we want manual control.

Can we enable an interactive AI assisted approach?

Ansys SELECT TECHNOLOGY PARTNER rbf® TOR VERGATA UNIVERSITÀ DEGLI STUDI DI ROMA

Step #5: interactive ROM with Twin Builder



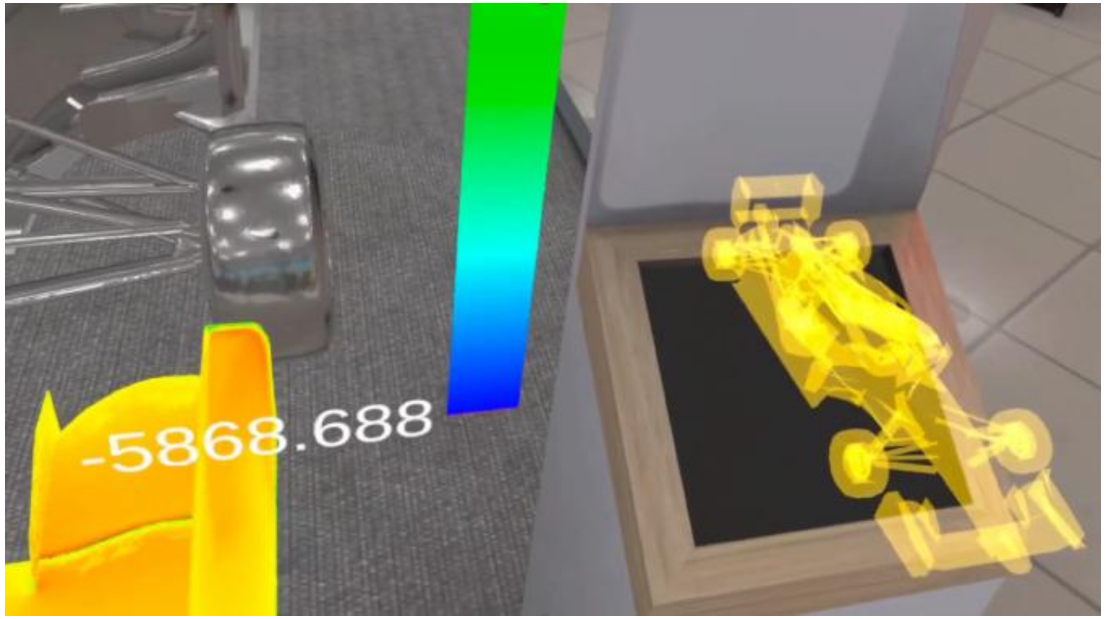


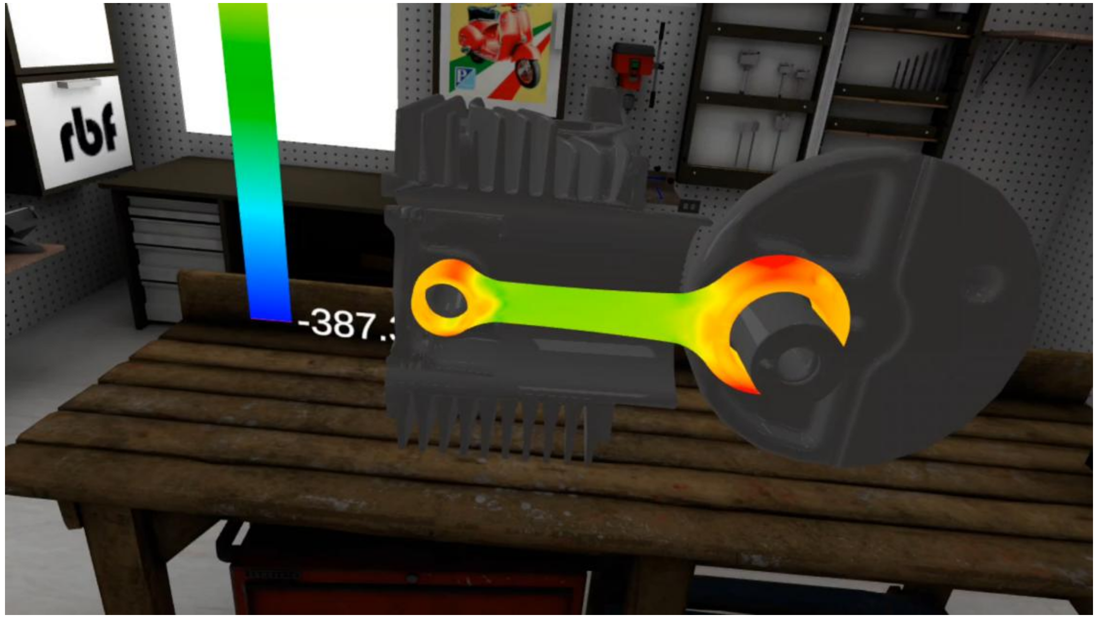
RBF Morph Fluids quickly creates **snapshots** to train the AI based ROM of Twin Builder by feeding the standard and the GPU solver of Fluent.

The parametric FEA model allows the automated creation of snapshots to train the **AI based ROM** of **Twin Builder**.

Ansys SELECT TECHNOLOGY PARTNER rbf® TOR VERGATA UNIVERSITÀ DEGLI STUDI DI ROMA

Step #6: the ROM is published as a VR experience





The functional mock-up units generated by Twin Builder can be imported in rbfVR Publisher and deployed in rbfVR Player.

Are you willing to improve further the design?

Have a try and wear the VR device!

Conclusions

- Radial Basis Functions help **Digital Engineering** by providing **geometric intelligence** and an effective **inference** tool
- Parameter-free and parameter-based shape optimisation is possible
- Two industrial examples, Formula 3 car aero drag reduction and fatigue optimisation of a connecting rod of a **scooter engine**, have been demonstrated
- Roadmaps toward an **AI based approach** were presented
- Interactive VR implementation has been shown
- Next Steps?

Next steps? Aeronautical

SPOTLIGHT

Revolutionizing aerodynamic design with a VR-enabled workflow

by Andrea Lopez[1], Marco Camponeschi[2], Marco E. Biancolini[1,2]
1. University of Rome Tor Vergata - 2. RBF Morph

The aerospace industry is undergoing a rapid digital transformation, embracing innovative technologies to streamline design workflows, increase efficiency, and drive innovation like never before. One of the most exciting breakthroughs is the integration of virtual reality (VR) with reduced order models (ROMs), to enable real-time aerodynamic design exploration.

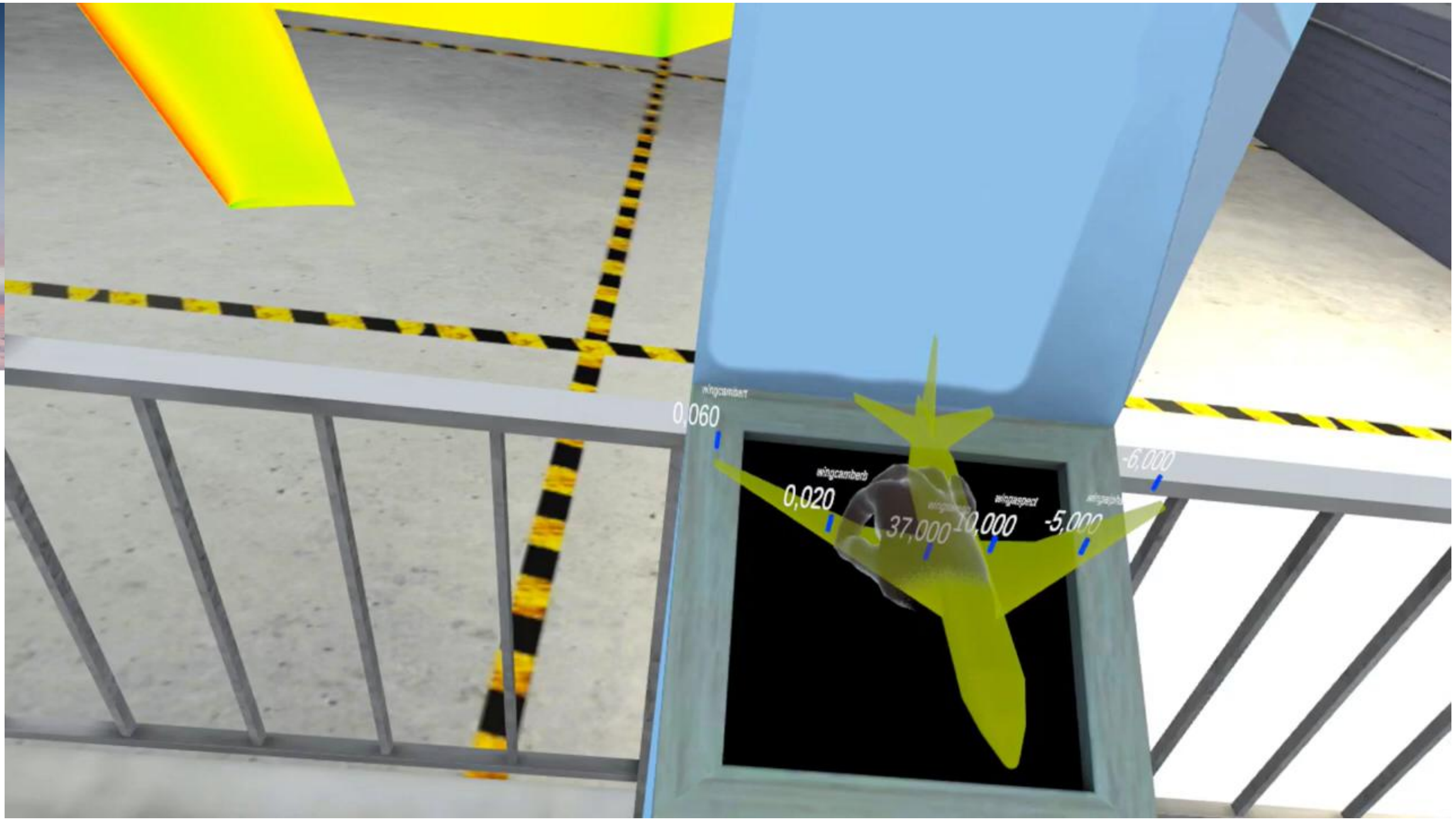
Traditionally, engineering workflows have been slow and resource-intensive, with design iterations relying on lengthy computational fluid dynamics (CFD) simulations. This article presents a game-changing approach – one that seamlessly links CAD modelling, CFD, and ROMs within an interactive VR dashboard. The result? A fast, immersive, and intuitive tool that allows engineers to explore designs in real-time, making the whole process more dynamic and efficient.

Bridging the gap: from CAD to VR

Aerodynamic performance optimization has traditionally been a highly iterative process. Engineers must analyse multiple design variants using high-fidelity CFD simulations, which are accurate but computationally expensive and time-consuming. Integrating VR and ROMs into the workflow helps overcome these challenges by providing a real-time design environment with interactive parameter exploration.

By incorporating CAD parameterization and mesh morphing, engineers can seamlessly

ENGINSOFT



Ansys SELECT TECHNOLOGY PARTNER

rbf

TOR VERGATA UNIVERSITÀ DEGLI STUDI DI ROMA

https://www.enginsoft.com/bootstrap5/images/expertise/2025/futurities2025-1-rbf.pdf

Next steps? Space

engineering proceedings

MDPI

Proceeding Paper

The Payload Design of the CUbesat Solar Polarimeter (CUSP), for Space Weather and Solar Flares X-Ray Polarimetry

Giovanni Lombardi [1,2,*], Sergio Fabiani [1], Ettore Del Monte [1], Emanuele Di Meo [2], Andrea Lopez [2], Marco Camponeschi [3], Marco E. Biancolini [2], Daniele Brienza [4], Immacolata Donnarumma [4], Silvia Natalucci [4], Andrea Terracciano [4] and Emanuele Zaccagnino [4]

1 INAF-IAPS, via del Fosso del Cavaliere 100, I-00133 Rome, Italy; sergio.fabiani@inaf.it (S.F.); ettore.delmonte@inaf.it (E.D.M.)
2 Dipartimento di Ingegneria dell'Impresa "Mario Lucenti", Università degli Studi di Roma "Tor Vergata", Via Cracovia 50, I-00133 Rome, Italy; emanuele.dimeo@rbf-morph.com (E.D.M.); lopez@ing.uniroma2.it (A.L.); biancolini@ing.uniroma2.it (M.E.B.)
3 RBF Morph, Via Antonio Rosmini 4, I-00077 Rome, Italy; marco.camponeschi@rbf-morph.com
4 ASI, Via del Politecnico snc, I-00133 Rome, Italy; daniele.brienza@asi.it (D.B.); immacolata.donnarumma@asi.it (I.D.); silvia.natalucci@asi.it (S.N.); andrea.terracciano@asi.it (A.T.); emanuele.zaccagnino@asi.it (E.Z.)
* Correspondence: giovanni.lombardi@inaf.it

Abstract: The CUbesat Solar Polarimeter (CUSP) project is a CubeSat mission orbiting the Earth aimed to measure the linear polarization of solar flares in the hard X-ray band by means of a Compton scattering polarimeter. CUSP is a project in the framework of the Alcor Program of the Italian Space Agency aimed to develop new CubeSat missions. It is approved for a Phase B study. In this work we describe some design solutions adopted for the most important design drivers of the payload. In particular, we report on the payload preliminary multi-physical design, including an orbital thermal environment preliminary assessment and a implementation of the static/dynamic finite element analysis. Moreover, a method for topology optimization of relevant components is discussed.

Keywords: CUSP, space weather, solar flare, mechanical design, multi−physical analysis, payload

check for updates

Academic Editors: Umberto Galietti, Gabriele Arcidiacono, Enrico Armentani, Davide Castagnetti, Vigilio Fontanari, Aurelio Somà and Nicola Bonora

Published: 10 March 2025

Citation: Lombardi, G.; Fabiani, S.; Del Monte, E.; Di Meo, E.; Lopez, A.; Camponeschi, M.; Biancolini, M.E.; Brienza, D.; Donnarumma, I.; Natalucci, S.; et al. The Payload Design of the CUbesat Solar Polarimeter (CUSP), for Space Weather and Solar Flares X-Ray Polarimetry. *Eng. Proc.* **2025**, *85*, 37. https://doi.org/10.3390/engproc2025085037

1. Introduction

The **CUbesat Solar Polarimeter** (CUSP) [1] is a CubeSat mission in low Earth orbit, specifically conceived to measure the linear polarization of solar flares in the hard X-ray range (25–100 keV) through a Compton scattering polarimeter. This cutting-edge mission is expected to provide new insights into magnetic reconnection and particle acceleration mechanisms occurring within the Sun's flaring magnetic structures, which are crucial processes underlying space weather dynamics.

Hard X-ray polarimetry offers a unique observational window into the physical mechanisms responsible for particle acceleration, as well as the temporal evolution of magnetic configurations during solar flares. These data are essential for refining current models of solar activity and understanding its influence on the heliosphere. Such improved knowledge will contribute to the development of more accurate space weather predictions, which are essential to mitigate the risks for satellite systems, communication infrastructures, and terrestrial power grids.

CUSP is developed within the framework of the **Alcor Program**, a strategic initiative led by the Italian Space Agency (ASI) to promote innovative CubeSat missions. Having

Ansys SELECT TECHNOLOGY PARTNER rbf® TOR VERGATA UNIVERSITÀ DEGLI STUDI DI ROMA

https://www.mdpi.com/2673-4591/85/1/37

Next steps? Healthcare


electronics

MDPI

Article

The Hemodynamic Effect of Modified Blalock–Taussig Shunt Morphologies: A Computational Analysis Based on Reduced Order Modeling

Eirini Kardampiki [1,†], Emanuele Vignali [2,†], Dorela Haxhiademi [3], Duccio Federici [4], Edoardo Ferrante [1], Stefano Porziani [5], Andrea Chiappa [5], Corrado Groth [6], Margherita Cioffi [1], Marco Evangelos Biancolini [6], Emiliano Costa [1] and Simona Celi [2,*]

1 RINA—Registro Italiano Navale ed Aeronautico, 00128 Rome, Italy; eirini.kardampiki@rina.org (E.K.); edoardo.ferrante@rina.org (E.F.); margherita.cioffi@rina.org (M.C.); emiliano.costa@rina.org (E.C.)
2 BioCardioLab, Fondazione Toscana Gabriele Monasterio, 54100 Massa, Italy; evignali@ftgm.it
3 Critical Care Unit, Fondazione Toscana G. Monasterio, 54100 Massa, Italy; dorela@ftgm.it
4 Paediatric Cardiosurgery Unit, Fondazione Toscana G. Monasterio, 54100 Massa, Italy; duccio.federici@ftgm.it
5 RBF Morph, Monte Compatri, 00040 Rome, Italy; stefano.porziani@rbf-morph.com (S.P.); andrea.chiappa@rbf-morph.com (A.C.)
6 Department of Enterprise Engineering, University of Rome Tor Vergata, 00133 Rome, Italy; corrado.groth@uniroma2.it (C.G.); biancolini@ing.uniroma2.it (M.E.B.)
* Correspondence: s.celi@ftgm.it; Tel.: +39 0585 493644
† These authors contributed equally to this work.

Citation: Kardampiki, E.; Vignali, E.; Haxhiademi, D.; Federici, D.; Ferrante, E.; Porziani, S.; Chiappa, A.; Groth, C.; Cioffi, M.; Biancolini, M.E.; et al. The Hemodynamic Effect of Modified Blalock–Taussig Shunt Morphologies: A Computational Analysis Based on Reduced Order Modeling. *Electronics* **2022**, *11*, 1930. https://doi.org/10.3390/electronics11131930

Academic Editor: Cheng Siong Chin

Received: 19 May 2022
Accepted: 17 June 2022
Published: 21 June 2022

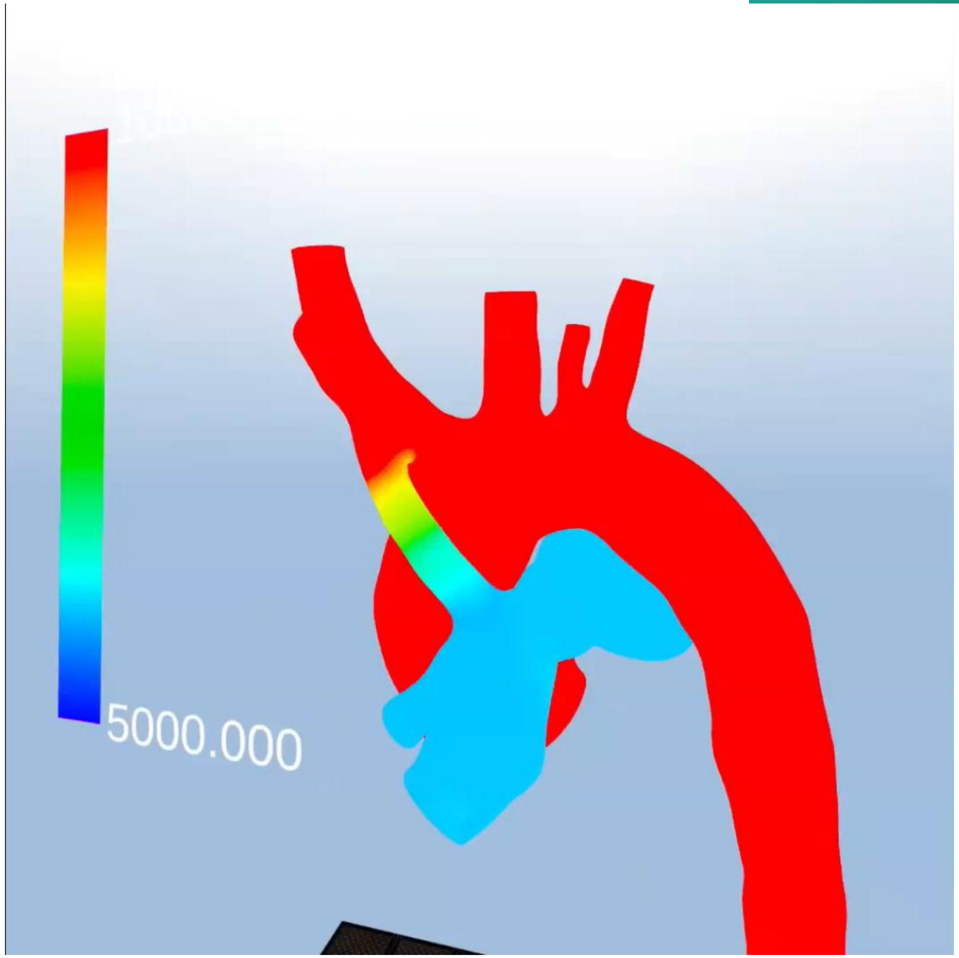
Abstract: The Modified Blalock Taussig Shunt (MBTS) is one of the most common palliative operations in case of cyanotic heart diseases. Thus far, the decision on the position, size, and geometry of the implant relies on clinicians' experience. In this paper, a Medical Digital Twin pipeline based on reduced order modeling is presented for fast and interactive evaluation of the hemodynamic parameters of MBTS. An infant case affected by complete pulmonary atresia was selected for this study. A three-dimensional digital model of the infant's MBTS morphology was generated. A wide spectrum of MBTS geometries was explored by introducing twelve Radial Basis Function mesh modifiers. The combination of these modifiers allowed for analysis of various MBTS shapes. The final results proved the potential of the proposed approach for the investigation of significant hemodynamic features such as velocity, pressure, and wall shear stress as a function of the shunt's morphology in real-time. In particular, it was demonstrated that the modifications of the MBTS morphology had a profound effect on the hemodynamic indices. The adoption of reduced models turned out to be a promising path to follow for MBTS numerical evaluation, with the potential to support patient-specific preoperative planning.

Keywords: computational fluid dynamics; reduced order modeling; hemodynamics; Modified Blalock–Taussig Shunt; RBF mesh morphing; Medical Digital Twin

1. Introduction

Congenital heart defects are currently present in about 9 of every 1000 live-born children [1,2]. Several of these pathologies, such as pulmonary atresia and Tetralogy of Fallot, are linked with cyanotic heart diseases in which low levels of oxygen in the blood are encountered. Especially in the case of the pulmonary atresia, the pulmonary valve plane is absent, leading to full blockage of the blood flow towards the lungs. Among the most diffused approaches to tackle these complications, the modified Blalock–Taussig shunt (MBTS) is a surgical procedure which consists of implanting a synthetic shunt between the subclavian and pulmonary artery. The MBTS is frequently adopted for the treatment of newborn children suffering from pulmonary hypoperfusion triggered by congenital heart diseases [3]. In this way, sufficient levels of oxygenated blood are delivered to the

Electronics **2022**, *11*, 1930. https://doi.org/10.3390/electronics11131930 https://www.mdpi.com/journal/electronics

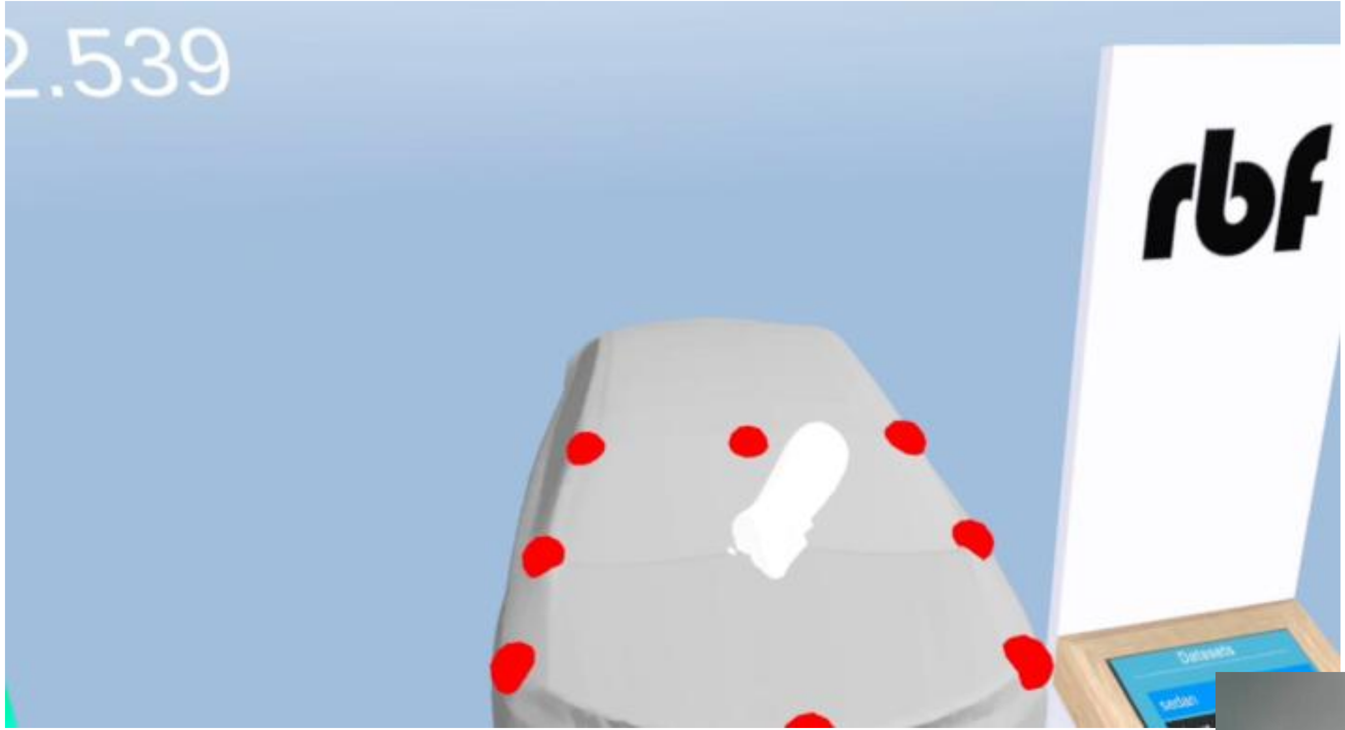


Ansys SELECT TECHNOLOGY PARTNER

rbf

TOR VERGATA UNIVERSITÀ DEGLI STUDI DI ROMA

https://www.mdpi.com/2079-9292/11/13/1930



Next steps? FreeMorph

https://www.logitech.com/en-eu/products/vr/mx-ink.html

Ansys SELECT TECHNOLOGY PARTNER
rbf®
TOR VERGATA UNIVERSITÀ DEGLI STUDI DI ROMA

Many thanks for your attention!

marco.biancolini@rbf-morph.com

https://www.linkedin.com/in/marcobiancolini/

https://www.youtube.com/@RbfMorph

https://www.rbf-morph.com/
https://www.rbfcae.com/
https://www.rbflab.eu/

Ansys SELECT TECHNOLOGY PARTNER

TOR VERGATA UNIVERSITÀ DEGLI STUDI DI ROMA