High fidelity CAE simulations for real time Digital Twin

Prof. Marco Evangelos Biancolini

University of Rome Tor Vergata,
Department of Enterprise
Engineering, Rome, Italy

biancolini@ing.uniroma2.it

Outline

- Who are we?
  - University of Rome Tor Vergata
  - RBF Morph
- An overview on Digital Twin
- Running and past projects
- An efficient optimization of air intake based on machine learning and mesh morphing

Who are we?

- Partnership between University of Rome "Tor Vergata" and RBF Morph: academic and industrial synergy
- Multi-sectoral CAE analysts, focused on high fidelity multi-physics problems
- Cutting edge technologies, academic research driven by industrial needs
- Privileged position: clear idea of the direction taken by industry, deep knowledge of the technologies available now or in the future

Who are we? Tor Vergata

- Established in 1982, counting 39.000 students, 1362 professors, 985 Administrative staff and technicians, 600 hectares of university campus.
- Department of Enterprise Engineering composed by 90 full time employees, 80 contract researchers. Research team, from Machine Design Group, involved in **several national and international research projects**.
- Focus on:
  - Structural and fluid dynamic shape optimization (automotive, nautical, **aerospace**, biomedical).
  - Static and dynamic fluid structure interaction.
  - Advanced use of RBF (image analysis of deformations, flow fields interpolation).
  - Large-scale **high-fidelity** numerical simulations of flows in complex geometric configurations.
  - Reduced Order Models and Digital Twin.

Who are we? RBF Morph

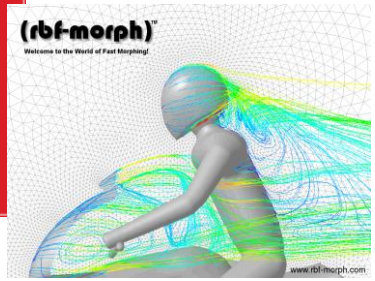
- RBF Morph is an ISV, **pioneer and world-leading provider** of numerical **morphing** techniques and CAE solutions. Inception in 2008 as on-demand solution for a Formula 1 top team
- **Start Up** founded at the beginning of 2016 to grow the business of the advanced mesh morphing software RBF Morph.
- **Software line** composed by Fluent add-on, Standalone RBF Morph, RBF Morph ACT extension for mechanical.
- Technical Partner of ANSYS Inc. since 2009 (OEM since 2012)

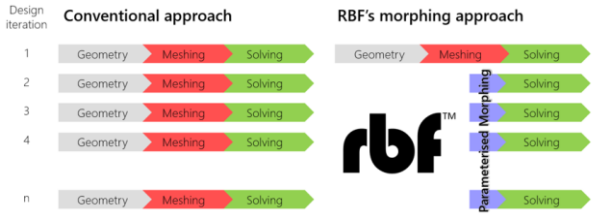
http://www.rbf-morph.com/

RBF Morph makes the CAE model **parametric** with respect to the **shape.**

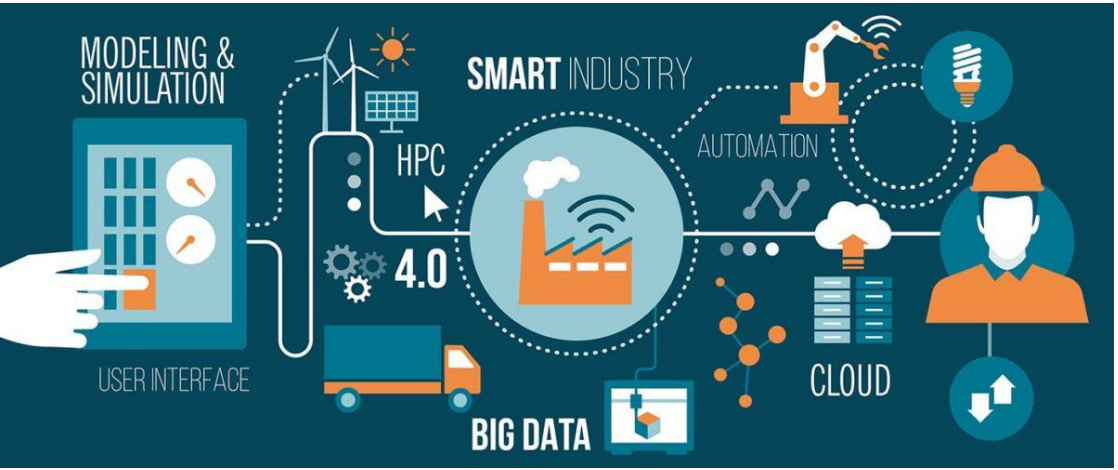
Works for **any size of the mesh.**

Shape parameters can be steered with the **optimizer of choice.**





Advanced CAE and industry 4.0?



- Digital twins
- Shape parametric CAE
- Multi-physics
- Big Data (simulated, acquired)
- 3d printing support
- Optimization
- HPC - cloud
- Reduced order models

Digital Twin yesterday-today-tomorrow

- Digital Twins are nothing new. Today we talk about DT a lot. But we have experience of DT daily use. ABS / ESP in our car. The Prius Hybrid (year 2004)!
- The governing equations of the physics of the twin were previously written by hand and then embedded in the electronics. Software components made up of great skills (for example vehicle dynamics). Telemetry and racing strategies in Formula 1. Advanced control systems on board the products.
- **Matlab Simulink**

Digital Twin yesterday-today-tomorrow

- System integration according to standards (an example are the FMU defined according to the FMI protocol *functional mockup interface*)
- Generic purpose IIoT platforms are available
- Twinning of industrial assets intended for the optimization of service, performance and maintenance
- **GE Predix**

"Digital twin eliminates the guesswork when determining the best way to service critical physical assets—from engines to power turbines. Easy access to this unique combination of deep knowledge and intelligence about your assets paves the road to optimization and busines transformation."

Colin Parris, Vice President
GE Software Research

Digital Twin yesterday-today-tomorrow

- Integration of high fidelity CAE (FEA, CFD, FSI) and system simulation ones (Modelica)
- Combination of AI, Machine Learning and numerical simulation (ROM)
- Hybrid twins combining historic Big Data (when available) with synthetic Big Data by simulation – data fusion
- **ANSYS Twin Builder**

An overview on Digital Twin: a multi-sectoral multi-physics challenge

- What is a digital twin?
- Predix Technology GE
- Ansys Twin Builder
- Functional Mock Up Interface
- Digital Twin Consortium

What is a digital twin?

- A digital twin is a digital copy of an existing and working physical asset.
- It's connected with the actual state of the asset, remembers its history
- It allows to evaluate more about the current status of the asset. Can be used to forecast its evolution

What is a digital twin?

- With a DT we can represent a **component**, a **system** of components or a system of systems: pumps, engines, power plants, production lines or fleet vehicles.
- Underlying modelling for the definition of a digital twin can be **statistical processing** of actual data (data driven) or created by **physical modelling** (Physics-informed Machine Learning).
- The twin represents the **actual working environment** of the asset, the age and the configuration; a bidirectional stream of data is a key for a proper **sync of the twin** and the asset (IIoT).

Power plant

Three pistons pump

Fleet Vehicles

PREDIX TECHNOLOGY BRIEF

https://www.ge.com/digital/applications/digital-twin

PREDIX TECHNOLOGY BRIEF

Digital Twin

For Industrial Intelligence that analyzes the past, understands the present, and predicts the future

Asset-centric companies are seeking to move from a reactive to a proactive, digital approach to optimize and transform their business.

Industrial companies are realizing that to thrive they need to optimize their operations, improve lagging productivity, and develop innovative new business models.

Sensor capabilities, affordable data storage and computing, analytics, and ubiquitous network connectivity are creating opportunities for companies to connect their assets and collect their data. Progress in analytics, models, and machine learning is creating even more possibilities for better insights. And yet, many industrial companies underestimate the complexity of connecting the physical and digital worlds, operating without a platform, methodology, or approach.

What's needed is a new way to build apps optimized for understanding physical assets.

Digital twins build the bridge from the physical to the digital worlds, providing understanding of each unique asset over time. They combine the data from sensors and devices with analytics, models, and material science for a constantly improving digital model of industrial components and assets, and even entire processes and plants. As more digital twins run on the platform, the industrial learning system feeds back data to the individual digital twins, improving fidelity.

"Digital twin eliminates the guesswork when determining the best way to service critical physical assets—from engines to power turbines. Easy access to this unique combination of deep knowledge and intelligence about your assets paves the road to optimization and business transformation."

Colin Parris, Vice President
GE Software Research

Predix Digital Twin Fast Facts

- A radical new approach to industrial asset and systems intelligence
- Represent a wide variety of complexity: From spark plugs to engines, to a power generation unit, to an entire power plant
- Multi-level data and intelligence across the life cycle of parts, assets, and systems: Design, Build, Run, Operate, and Service
- Asset and system knowledge, early warnings, predictions, learnings, and optimization

PREDIX

Predix is the only platform and learning system optimized for digital twins

Predix is GE Digital's platform for the Industrial Internet. Predix empowers domain experts and developers to build and run digital twins using a set of sophisticated data and modeling techniques. These digital twins are used to create innovative outcome-based industrial applications.

Digital twins on the Predix platform provide a new approach to asset and system intelligence. Digital twins provide a rich, constantly evolving picture of machines and operations, capturing everything from components to functions to entire processes and plants. They capture the entire lifespan of an asset, as well as entire asset classes, and gain insights into past and present performance and future intelligence. Furthermore, digital twins are an ideal software object to perform simulations, allowing for scenario testing and further optimization.

Whether you are an asset manufacturer or asset operator, Predix-powered digital twins offer a unique, highly accurate digital representation of your assets and systems across their **design, build, run, operate and service** lifecycle, removing barriers to insight and innovation.

Think about the possibilities.

Roadmap to digital twin-enabled industrial apps

Build asset/system: Data scientists package asset data and intelligence, applying analytics, models, and machine learning. Predix provides standard toolkits to help accelerate the build process.

Run: The platform runs and persists digital twins for each asset/system.

Consume: Apps and developers access context data, APIs, and insights from the digital twin.

Get started by meeting our world-class team of asset and system experts and data science and machine learning professionals. Uncover relationships between your data and key business drivers, exploring new monetization opportunities:

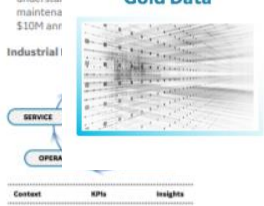
ge.com/digital/services/advisory-services

Outcomes that matter

Aviation

- A bearing anomaly detection for jet engines gives a 15-30 day heads-up on potential failures
- Lifing prediction for stage 1 blades leads to $44M in savings in engine maintena
- Dynamic nance sch understa maintena $10M ann

Industrial



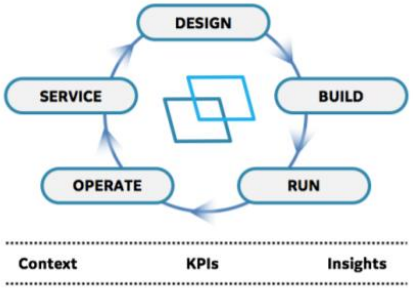
Digital twins provide the analytical and predictive power to expose new business opportunities and better operational methods.

ge.com/digital/predix

02 2017 - v.1

PREDIX

Industrial Lifecycle of an Asset



ANSYS Twin Builder

https://www.ansys.com/it-it/products/digital-twin/ansys-twin-builder

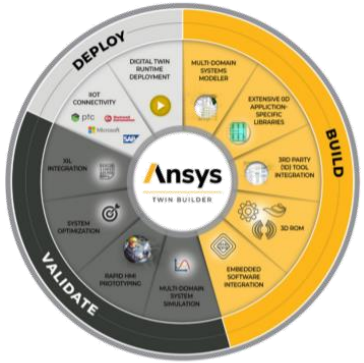
Ansys

DIGITAL TWIN

Ansys Twin Builder

Simulation-Based & Hybrid Analytics

/ Build, Validate and Deploy Simulation-Based Digital Twins

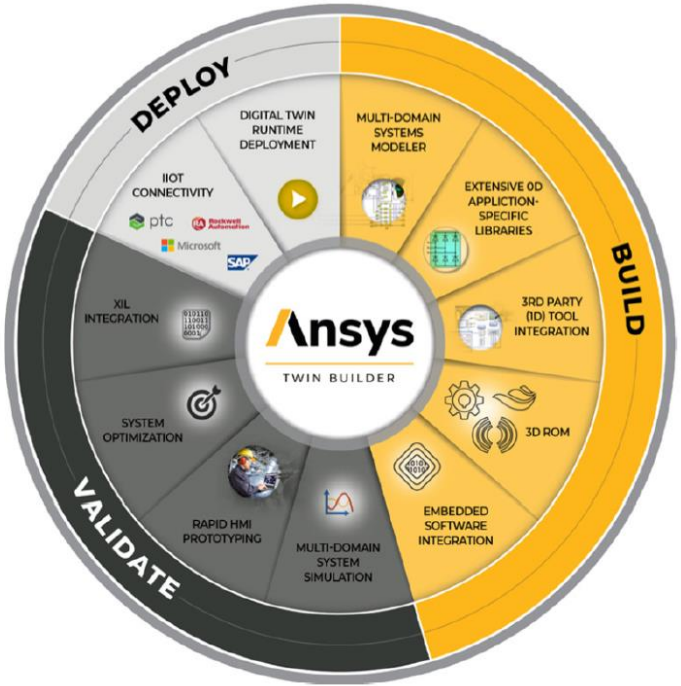


Ansys Twin Builder is a multi-technology platform that allows engineers to create simulation-based digital twins – digital representations of assets with real-world sensor inputs. Twin Builder improves predictive maintenance outcomes to save on warranty and insurance costs and optimize your product's operations.

To build your system quickly and easily, Twin Builder combines the power of a multidomain systems modeler with extensive 0D application-specific libraries, 3D physics solvers and reduced-order model (ROM) capabilities. When combined with embedded software development tools, Twin Builder allows you to reuse existing components and quickly create a systems model of your product.

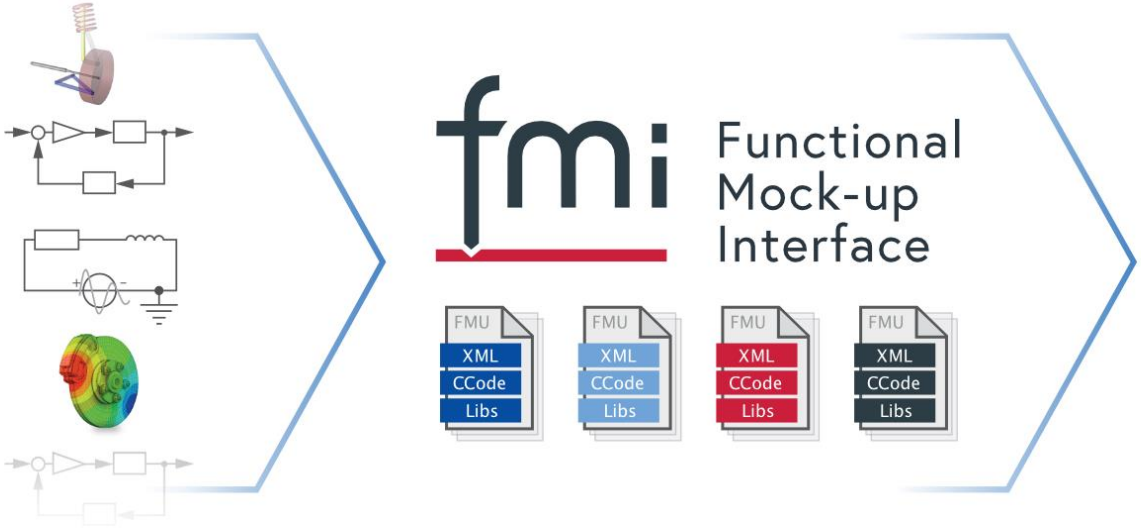
To validate your system and ensure expected performance, Twin Builder combines multidomain systems simulation capabilities with rapid human-machine interface (HMI) prototyping, systems optimization and XiL validation tools.

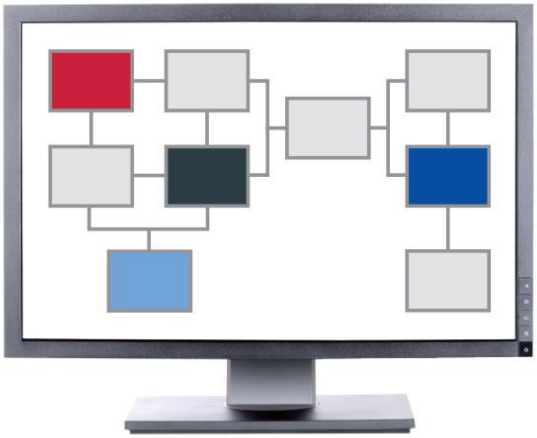
To connect your twin to test or real-time data, Twin Builder easily integrates with industrial internet of things (IIoT) platforms and contains runtime deployment options, allowing you to perform predictive maintenance on your physical product. It is the only product that offers a packaged approach for your digital twin strategy.

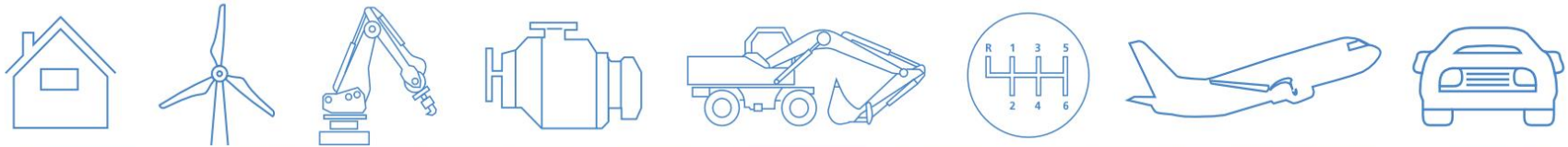


Functional Mock-Up Interface

https://fmi-standard.org/







Digital Twin Consortium

https://www.digitaltwinconsortium.org/glossary/glossary.html

digital twin CONSORTIUM

Founding Members

Ansys AUTODESK. Bentley DELL Technologies

GE Digital lendlease Microsoft NORTHROP GRUMMAN

WORKING GROUPS | INITIATIVES | RE | INITIATIVES | RESOURCES

- Aerospace & Defense
- FinTech
- Healthcare & Life Sciences
- Infrastructure
- Manufacturing
- Natural Resources
- Security & Trustworthiness
- Technology, Terminology & Taxonomy (3T)

- Definition of a Digital Twin
- Global Ecosystem Expansion
- Glossary of Digital Twins
- Member Digital Marketplace
- Open Source
- Security & Trustworthiness
- Use Case Reference Library
- Value-Innovation-Platform (VIP)

Relevant projects

- **RBF4AERO**: Innovative Benchmark Technology for Aircraft Engineering Design and Efficient Design Phase Optimization
- Aircraft **shape optimization** with DOE-based, evolutionary and genetic algorithms.

RBF4AERO

- **Adjoint**-based optimization
- **Multi-physics** studies: steady and unsteady Fluid-Structure interaction (**FSI**) with 2-way and modal superposition methods
- **Icing** with Constrained and On-the-Fly approaches
- **Solver agnostic** (Nastran, Ansys, Fluent, StarCCM+, CFD++, Numeca, OpenFoam, SU2)

Relevant projects

https://youtu.be/eThibFzEPNI

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  Ph
- Ai
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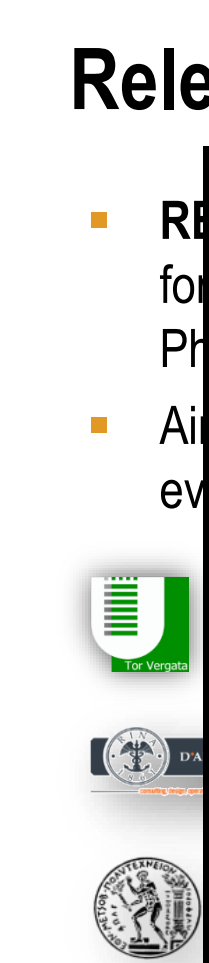


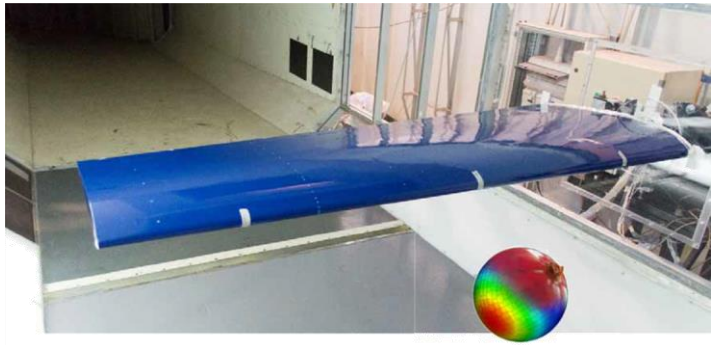
steady
2-way

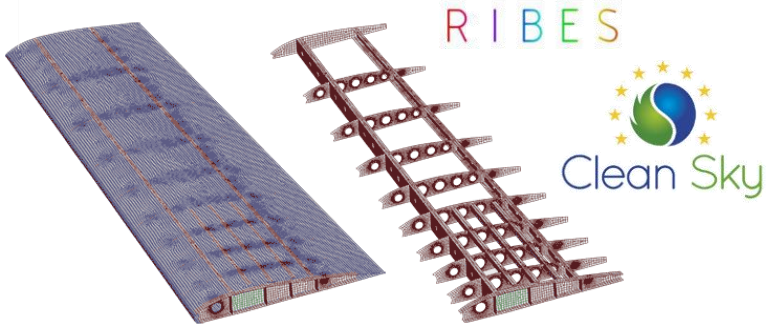
fly

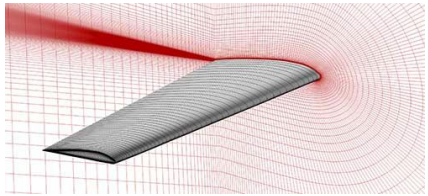
Relevant projects

- **RIBES**: **R**adial basis functions at fluid **I**nterface **B**oundaries to **E**nvelope flow results for advanced **S**tructural analysis
- Software development for **FSI**: Development of a novel load mapping procedure, development of a structural optimization procedure
- **WT** validation: **Design** of a scaled test article with realistic **wingbox** configuration. Definition of an aeroelastic experimental campaign

http://ribes-project.eu/



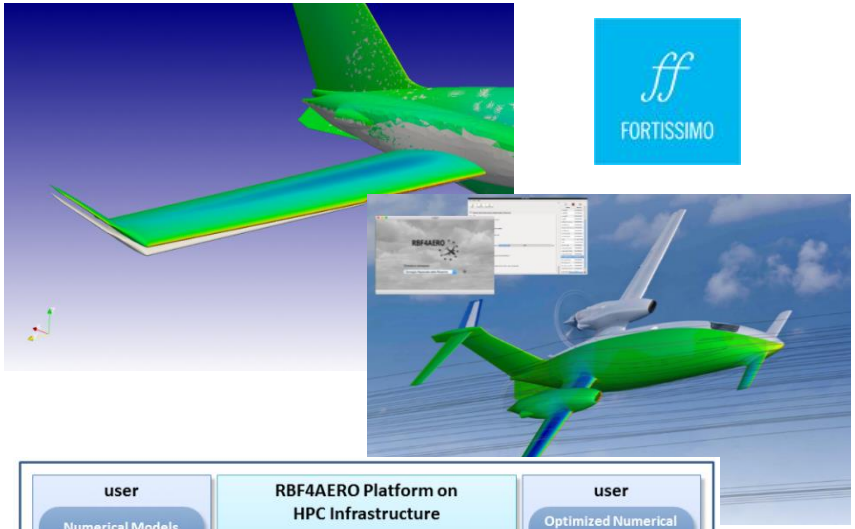


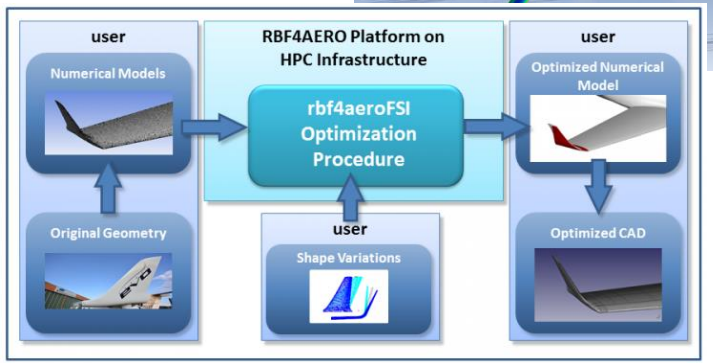


Relevant projects

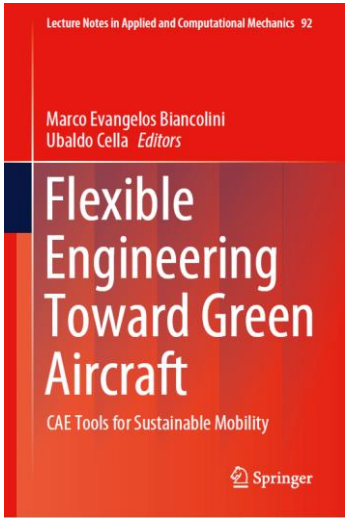
- **FORTISSIMO 2** : Cross-Solver Cloud-based Tool for Aeronautical FSI Applications
- WP609: “Cloud-Based HPC tool to tackle FSI by means of High fidelity simulations”
- Piaggio Aero test case for **FSI winglet optimisation**
- UTV, RINA, NTUA, CNR, CINECA

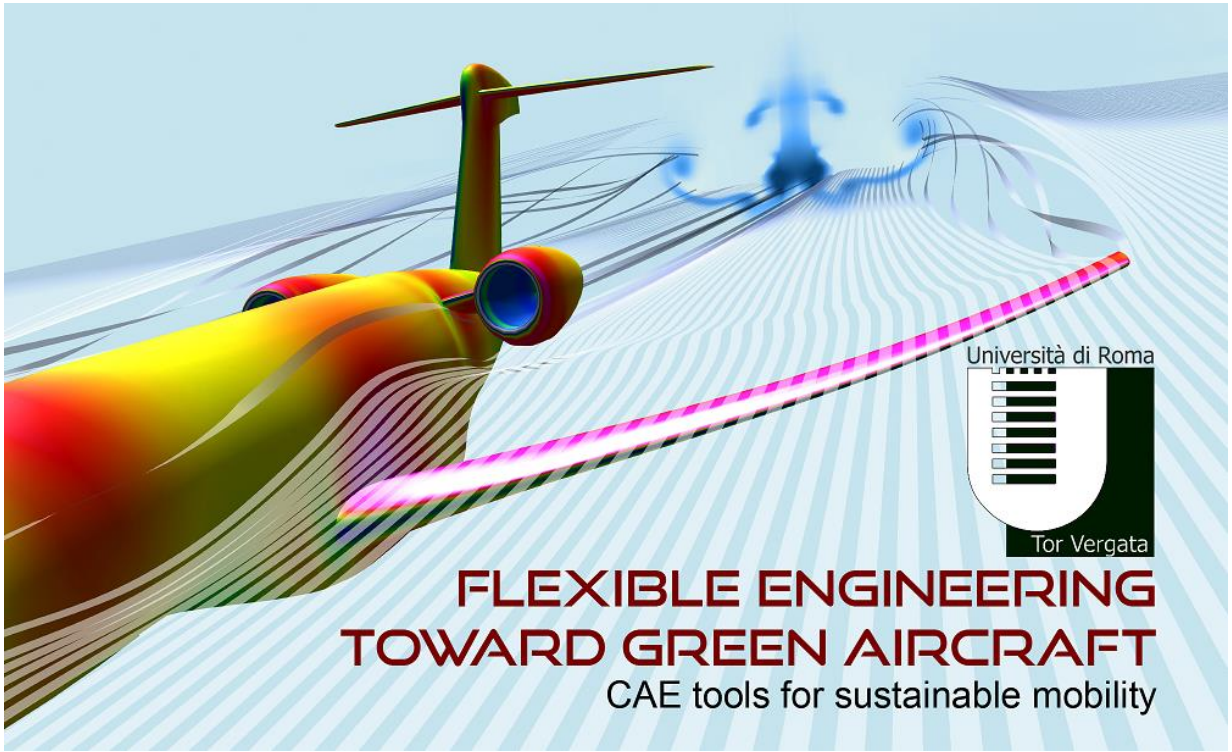
https://www.fortissimo-project.eu/en/success-stories/906/crosssolver-cloudbased-tool-for-aeronautical-fsi-applications





Relevant projects





https://www.springer.com/gp/book/9783030365134

DIGITAL TWINS AEROSPACE 4

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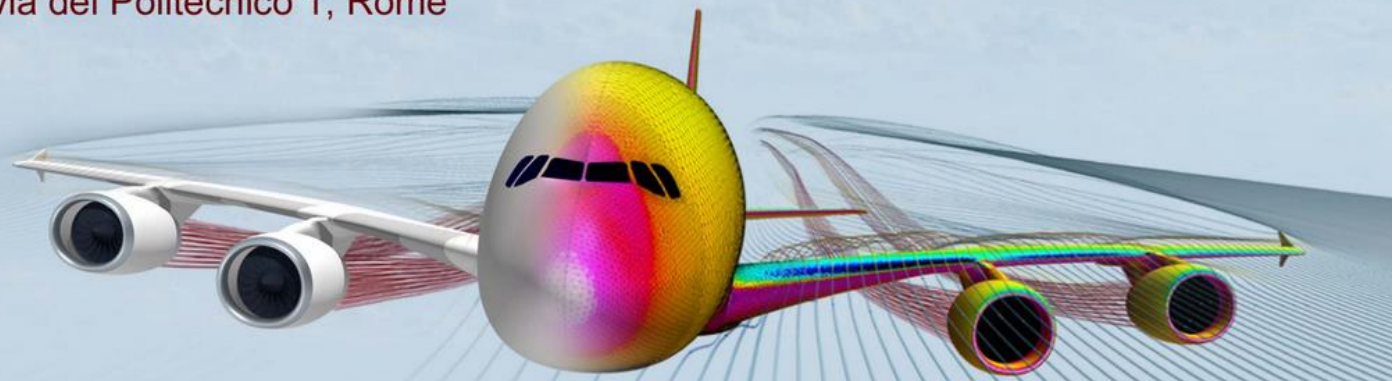
UNIVERSITÀ
DEGLI STUDI
DI ROMA

CAE modelling of future mobility

December 14, 2022, 9.00 - 14.00

University of Rome "Tor Vergata", aula Leonardo
via del Politecnico 1, Rome



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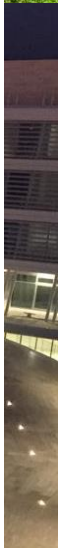
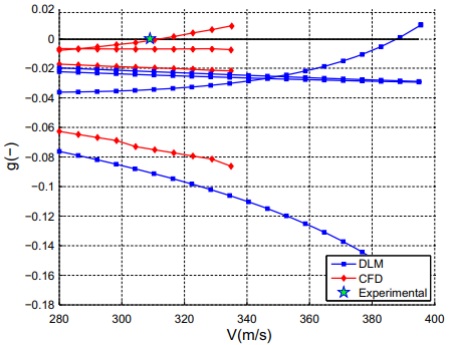
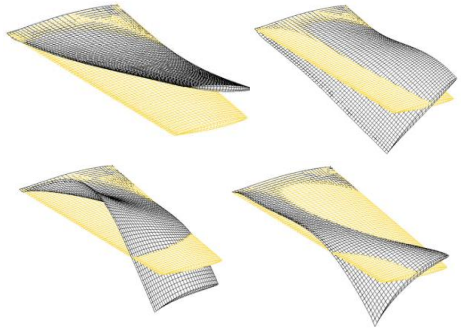


ROM & Digital Twin

- Active on Reduced Order modeling (**ROM**) since 2016[1].
  Mesh morphing is a key-enabler of the technology.
- ROM generated for the unsteady aerodynamics by means of a modal based approach: flutter identification
- Aircraft Digital Twin





[1] Castronovo, P., Mastroddi, F., Stella, F., & Biancolini, M. E. (2016). Assessment and development of a ROM for linearized aeroelastic analyses of aerospace vehicles. CEAS Aeronautical Journal, 8(2), 353–369. https://doi.org/10.1007/s13272-017-0243-6

ROM & Digital Twin

https://youtu.be/YDzGC6fnf4A

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[1] Castronov
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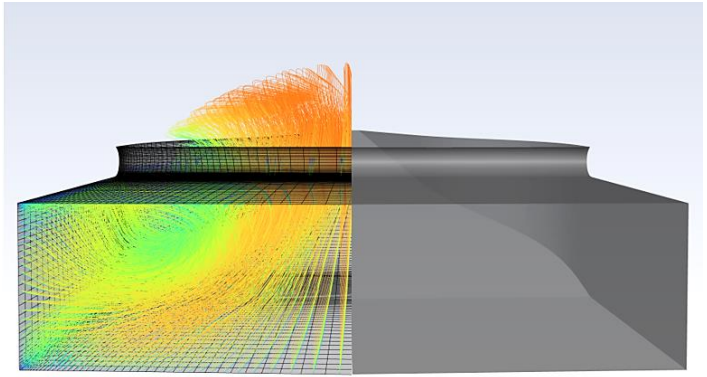
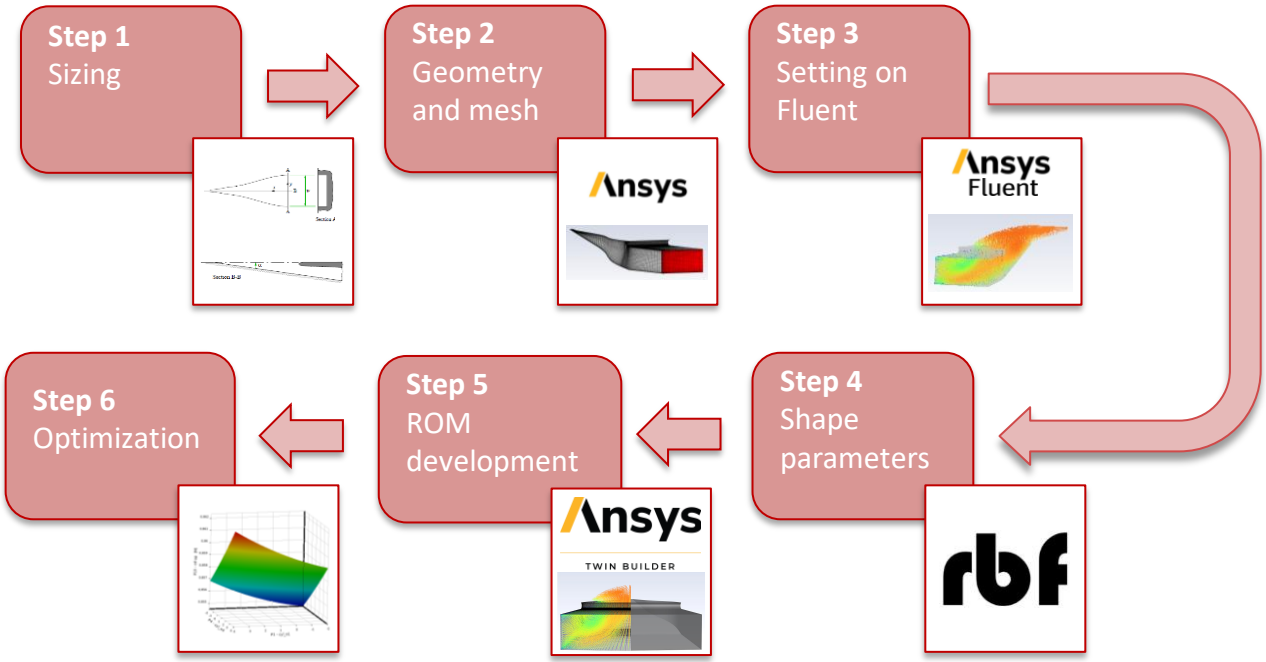
Optimization of a NACA intake

- This activity is focused on the generation of a digital twin from numerical simulations and high fidelity models of a **Naca air intake**;
- The aim is to create an accurate and reliable model that allows to **evaluate in real time** both **scalar** quantities and **field** quantities, such as the distribution of speed or pressure in the domain of interest;
- In this study the focus is on the optimization of the air intake efficiency.

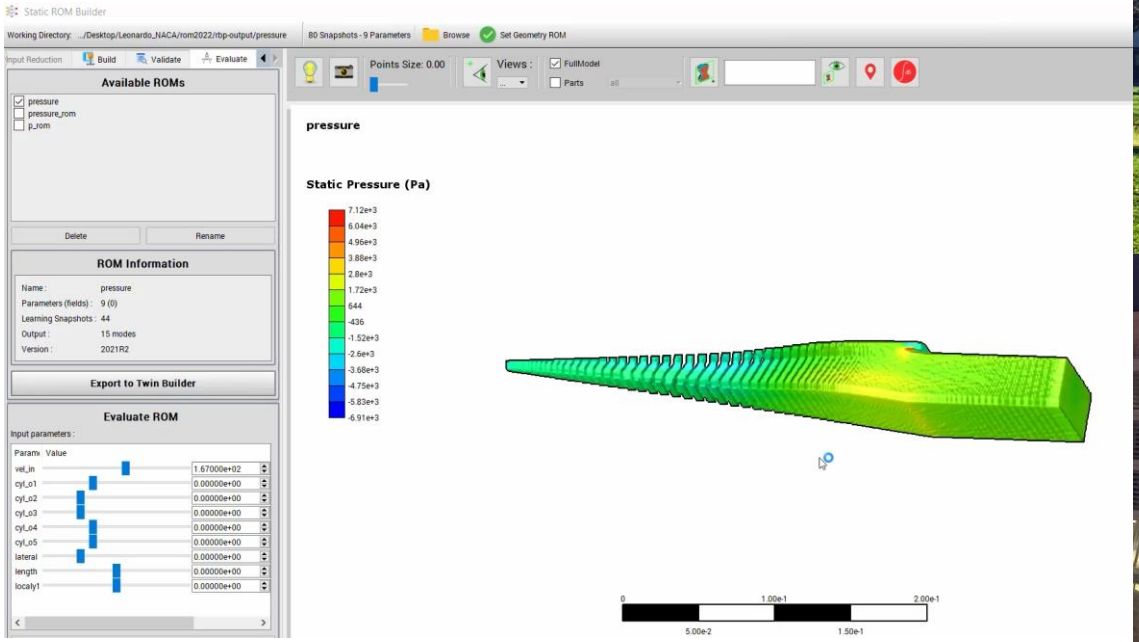


Optimization workflow



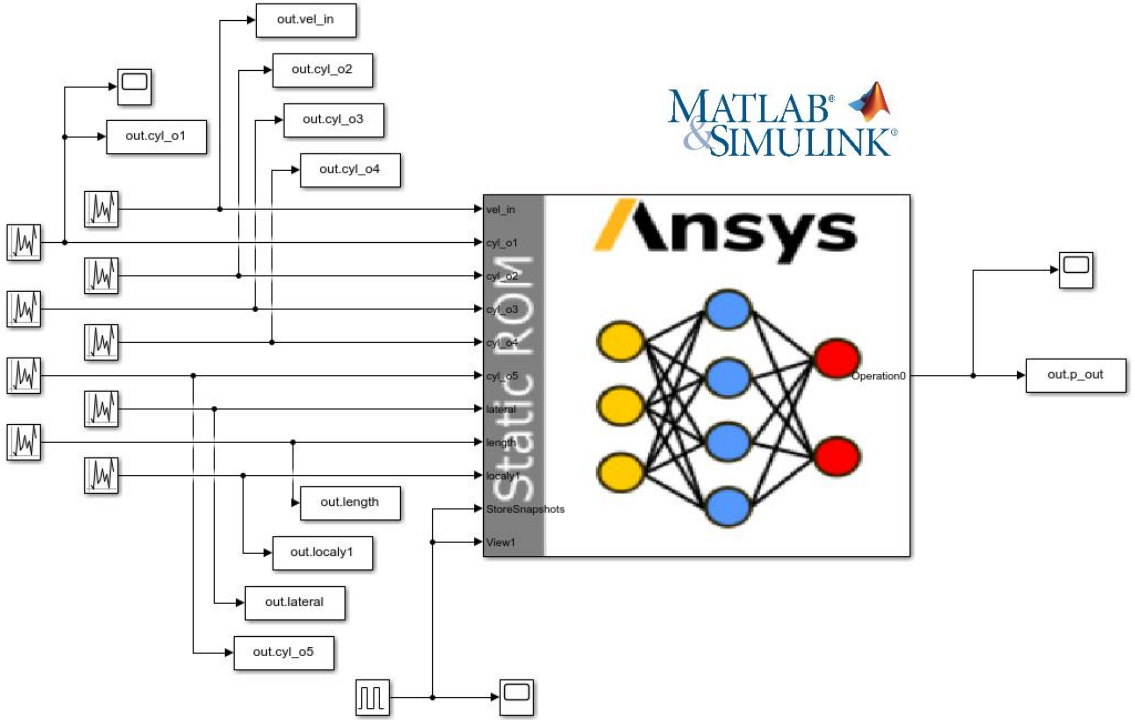
ROM Development

- Snapshots collection (80 DPs)
- Static ROM is created using Ansys Twin Builder:
  - Decomposition algorithms (POD) are used to reduce the number of variables
  - Machine learning allows to correlate each set of input parameters to the output quantities
- It allows to evaluate in real time both field quantities and scalar outputs



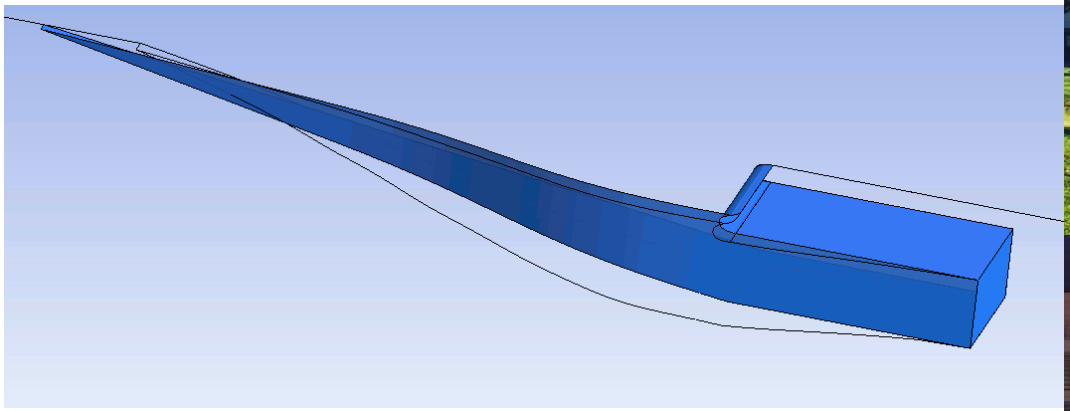
Optimization dashboard

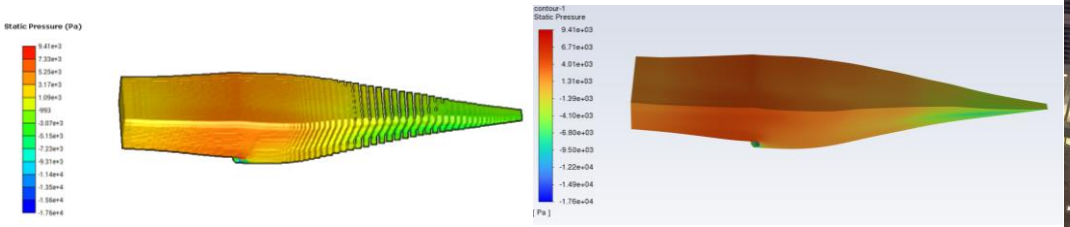
- The tool allows to export the model as FMU
- The FMU model can be integrated with other Simulink models
- In this application the FMU model is linked to an **optimization algorithm** in Matlab - Simulink environment



Optimization result

- The pressure of the optimized shape is 3 times higher vs baseline
- The approximation error of the ROM vs CFD is less than 3%
- The high fidelity validation CFD at optimized shape is a restart of the ROM





Conclusions

- High fidelity CAE can be distilled in real time accurate Digital Twins by adopting
  - Data compression (ROM)
  - Mesh morphing (RBF)
  - Upfront snapshots evaluation (HPC)
- Obtained DT can be used for
  - Interactive design dashboard
  - On board control systems

Thanks for the attention

Marco Evangelos Biancolini

University of Rome Tor Vergata, Department of Enterprise Engineering, Rome, Italy

biancolini@ing.uniroma2.it