Forum TERATEC 24

Unlock the future

Overview of digital twins' usage at Michelin
application to support the design of rubber manufacturing processes

Vivien Clauzon, Thibault Dairay
Michelin – R&D Simulation & Datascience department

Contents

A wide range of digital twins at Michelin

- **From virtual homologation…**
- **… to connected tires**

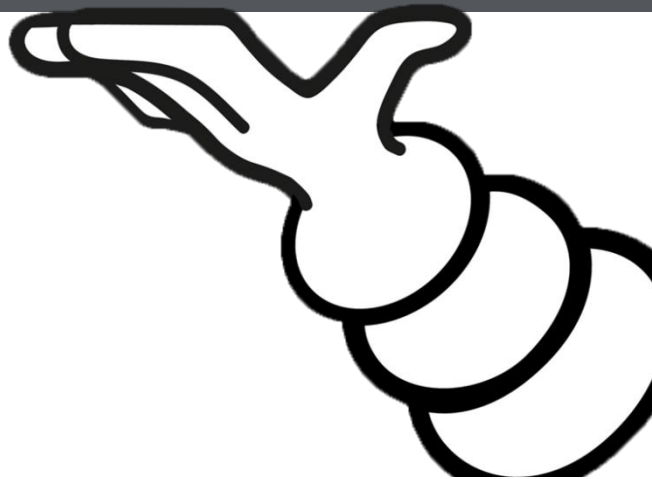
Focus on rubber manufacturing processes

- **From high-fidelity FEA simulations…**
- **… to fast and tailored digital twins**

**FEA: Finite Element Analysis*

MICHELIN

A wide range of digital twins at Michelin



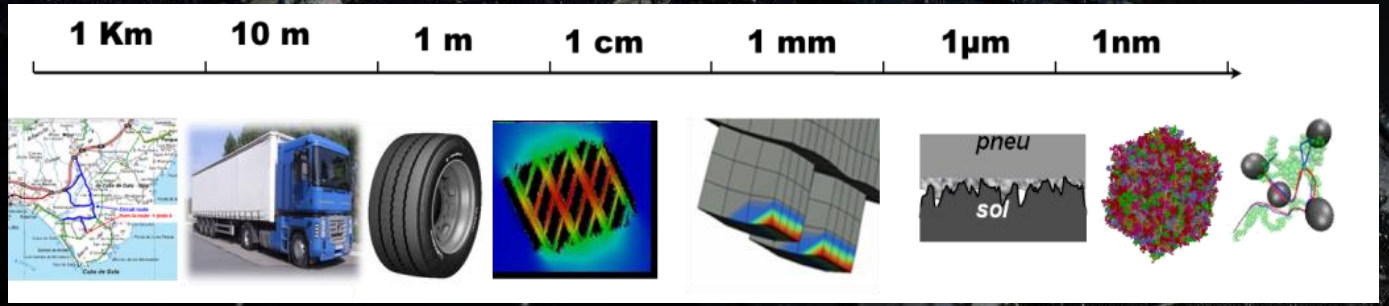
Simulations from molecule to vehicle

Product performance

- virtual tire as a product
- virtual vehicle & tire co-design

Material conception levers

- optimize material recipe
- virtual material for simulation



Services & usage

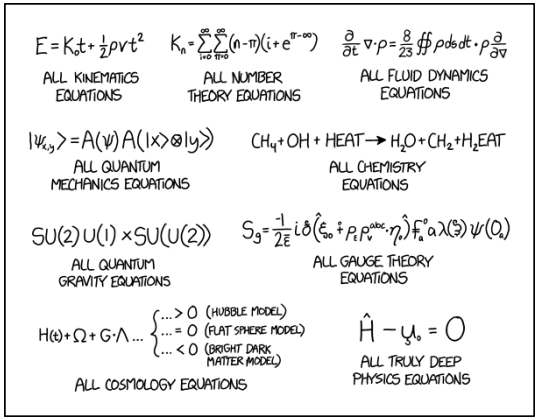
- predictive maintenance
- real time condition assessment

Tire conception levers

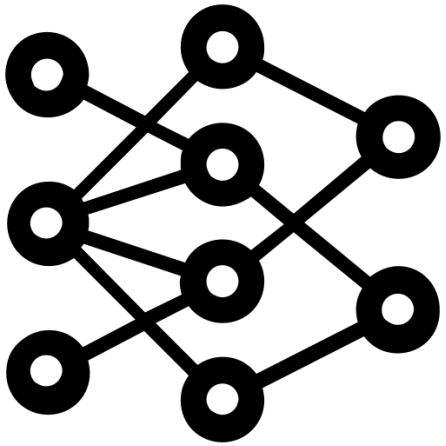
- real-time performance prediction
- early integration of industry contraints

Models in engineering

Physics-based



Machine learning



When equations-based world description meets real world observations through data assimilation and machine learning

From Virtual homologation…

Noise & Vibrations Performance

Excitation → **Tire Response** → **Propagation** → **Perception**

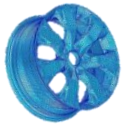
Road unevenness

Road indentation

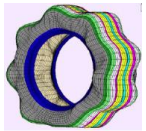
Non-uniformity

Coupling

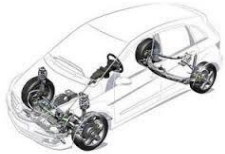
Wheel



Tire



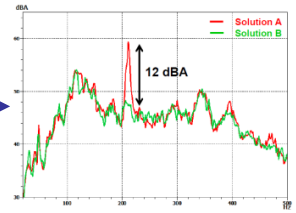
Cavity



Vehicle

Interior Noise / Vibration

Ears & internal organs

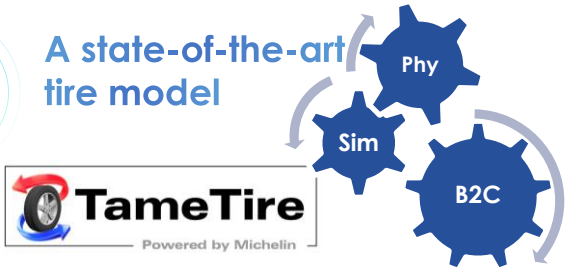


From Virtual Homologation…

Rethink car development with driving simulators

1

A state-of-the-art tire model



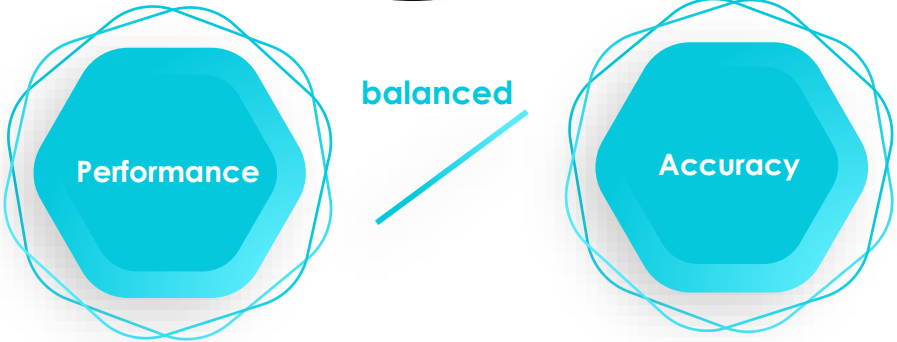
2

A fitting process from real and/or virtual data

3

Running in Real Time

1 ms to compute the 4 tires



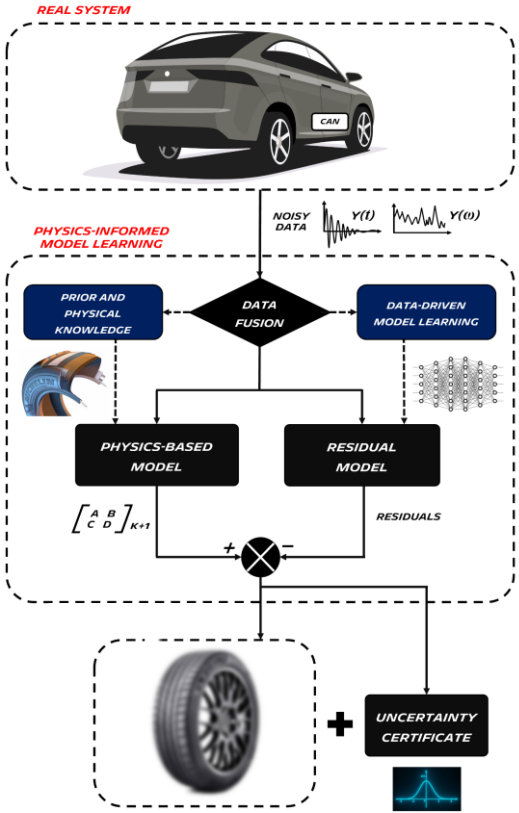
…To connected tires

Combining sensors data

With tire physics knowledge

Thanks to data fusion

To estimate tire state



Leveraging tire physics knowledge and tire databases

And data-driven model learning

To connected tires

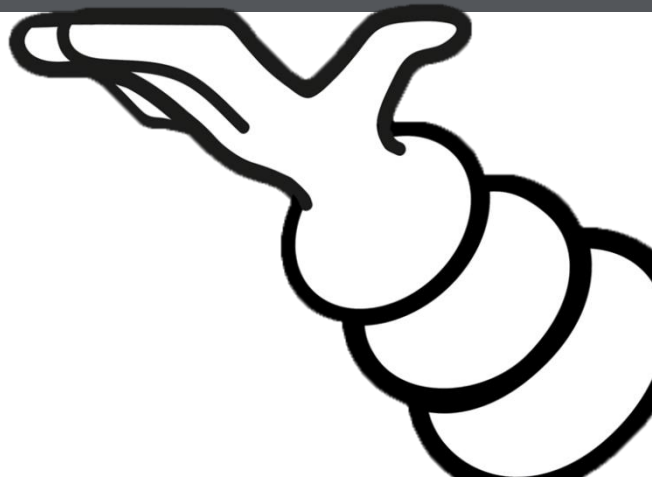
« My car tells me when my tires need to be changed »

Monitor & Predict → ***Advise for Tires*** → ***Book the Service***

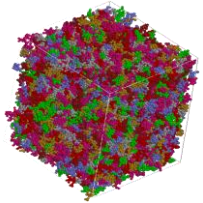
SmartWear — Tire & usage info — OEMs

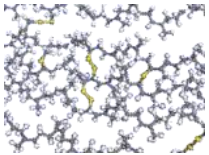
- ✓ ***Customer retention through Improved drivers' experience & satisfaction to the brand***
- ✓ ***Improve revenue from aftersales through traffic generation***
- ✓ ***Tire Life Cycle improvement***

Focus on rubber manufacturing processes

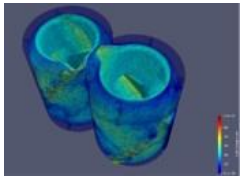


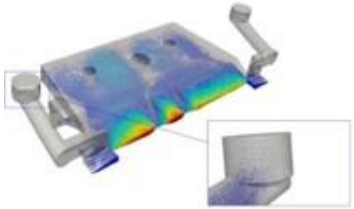
Simulation for research & product design

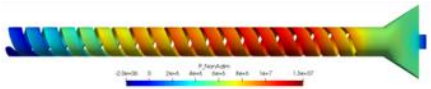




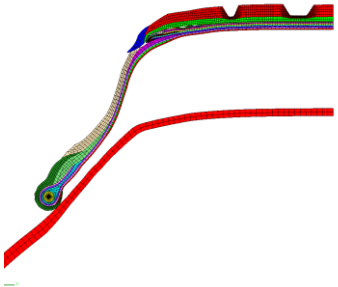
Materials



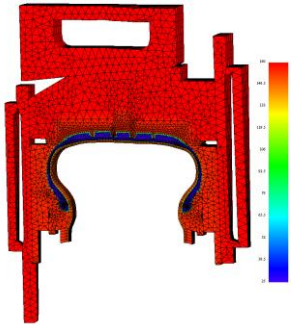


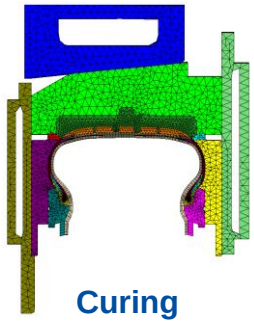


Manufacturing process

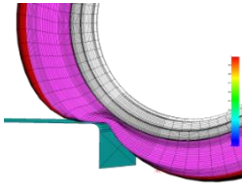


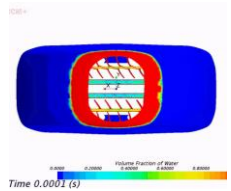
Green tire

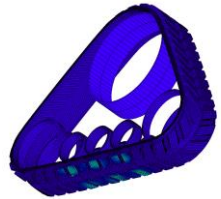




Curing

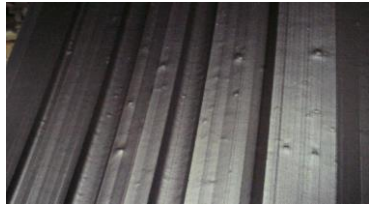






End product performances

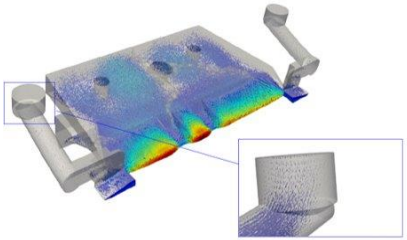
Rubber manufacturing processes

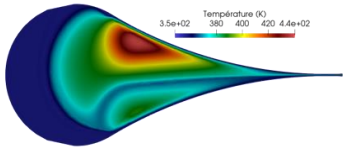


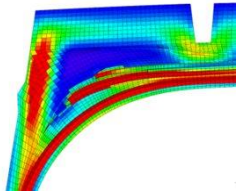
« c'est pas sorcier » (2003)

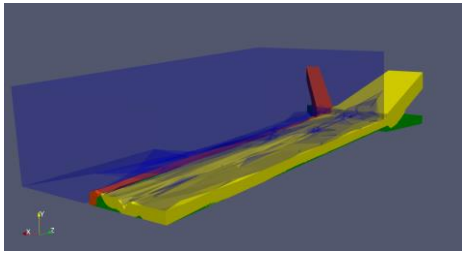
Multiple processes: cylinder tools, calender, mixer, extruder, cooling belts…

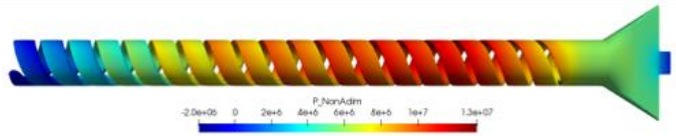
From high-fidelity FEA simulations…

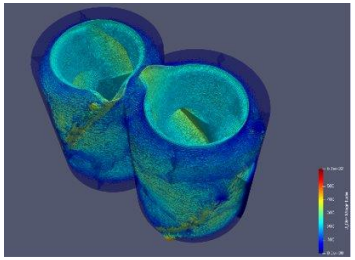


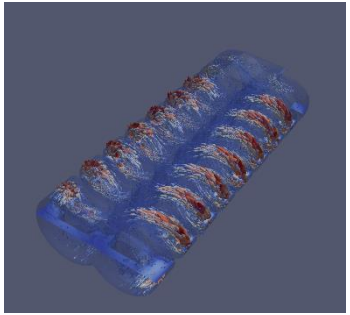


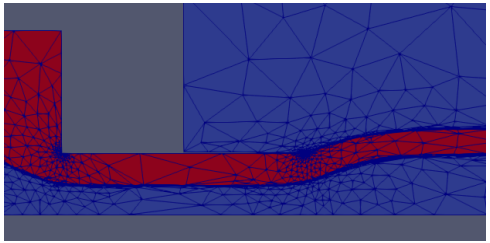




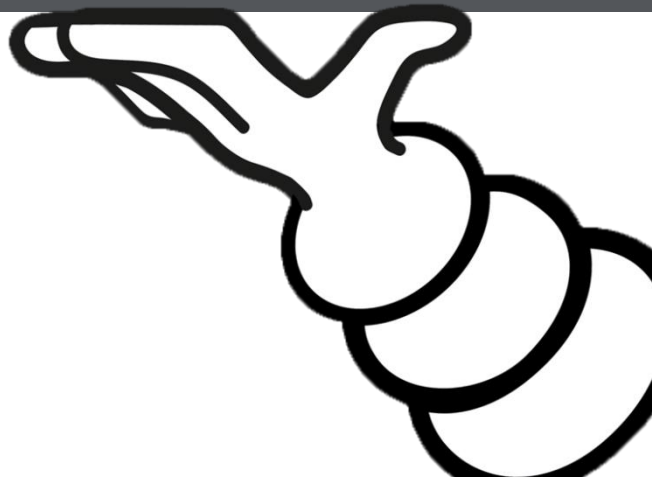








So far, so good. Is it enough though ?

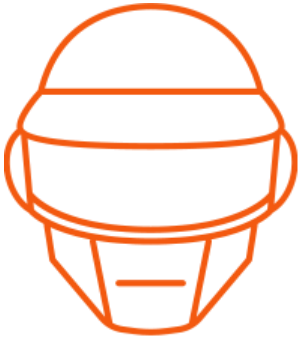


What levers on results for end-users ?

- Barely mesh size :
  - time constrained (conception loops are time boxed)
  - model constrained
- Model choices like material law, contact modelisation, stationnary or not, axi or 3D, ... (but again many constraints)

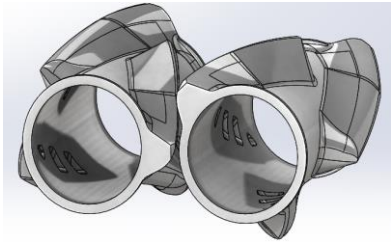
But we needed to

- Go **faster**
- Be more precise using collected **measures and data** !
- Give **more levers** and perform more multivariate analysis



…To fast & tailored digital twins…

A decision-making assistant for mixing line process

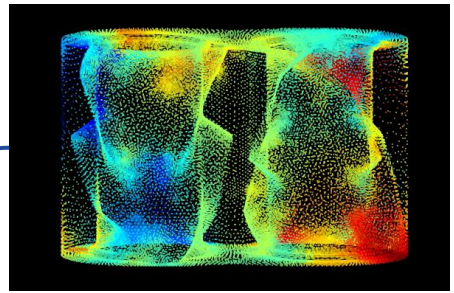


***Choose** a factory ; **Define** process parameters ; **Analyse** mix. properties*

Original computational core

- Modelling of internal mixer is inaccurate but fast (minutes)
- 3D physics-based simulations are accurate but slow (days)

Trade-off: use 3D physics-based simulations as a **data generator for ROM**



ROM: Reduced Order Modelling

Fast & tailored digital twin decision-making assistant for mixing line process

Offline Simulation database

$\approx 10^3$ quasi-static simulations

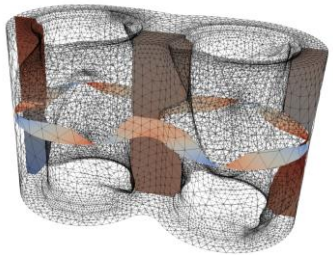
POD dim. reduction

Regression problem in the reduced space

Inhouse FEM solver MEF++

Reduced basis

Predictions of velocity & pressure fields



https://fr.wikipedia.org/wiki/MEF%2B%2B

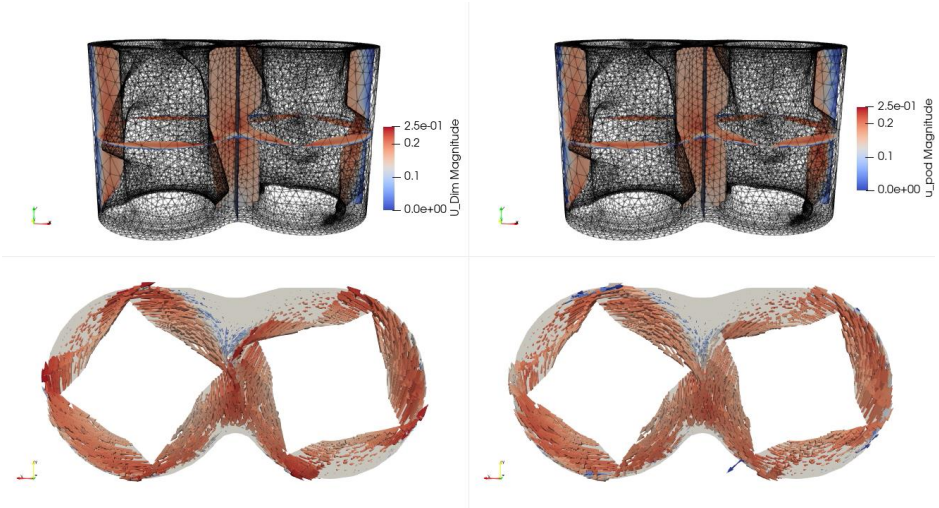
Fast & tailored digital twin decision-making assistant for mixing line process

Materials and process parameters → 3D mixer ROM → Pressure, velocity fields, power

One rotor revolution

$t_{SIMU} \approx 12$ h

$t_{ROM} \approx 50$ s

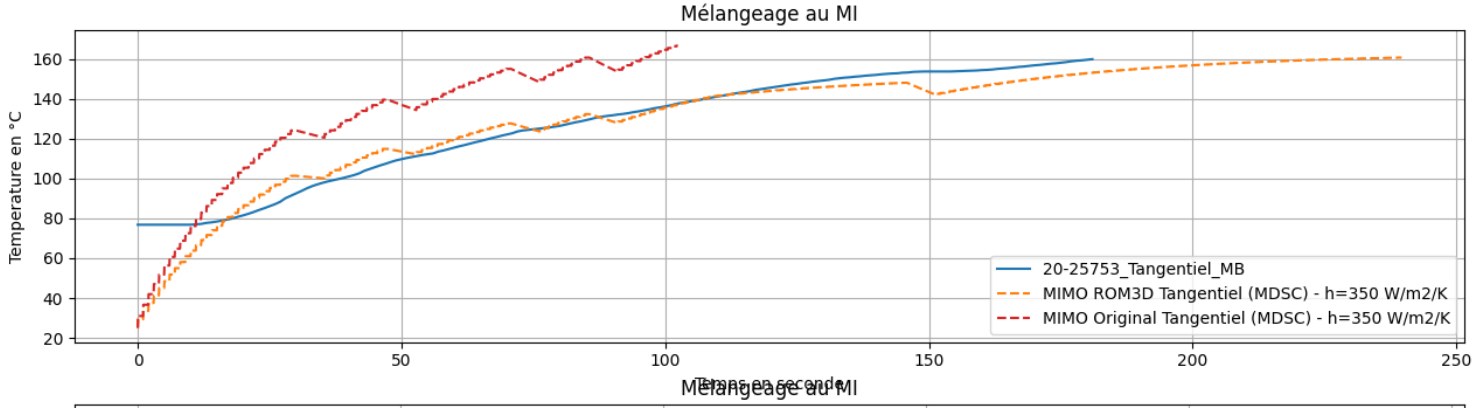


MEF++ ROM

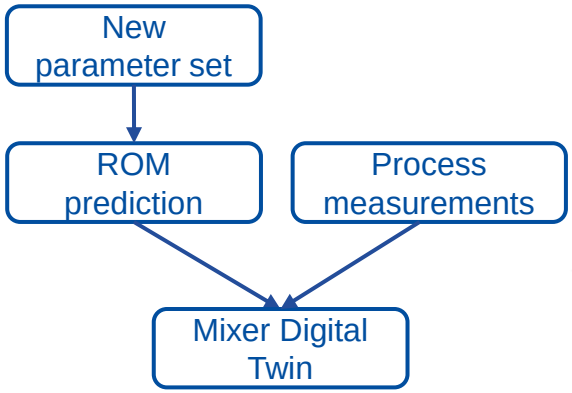
Fast & tailored digital twin decision-making assistant for mixing line process

Updated computational core Version 1

- 3D ROM simulations are more accurate and fast

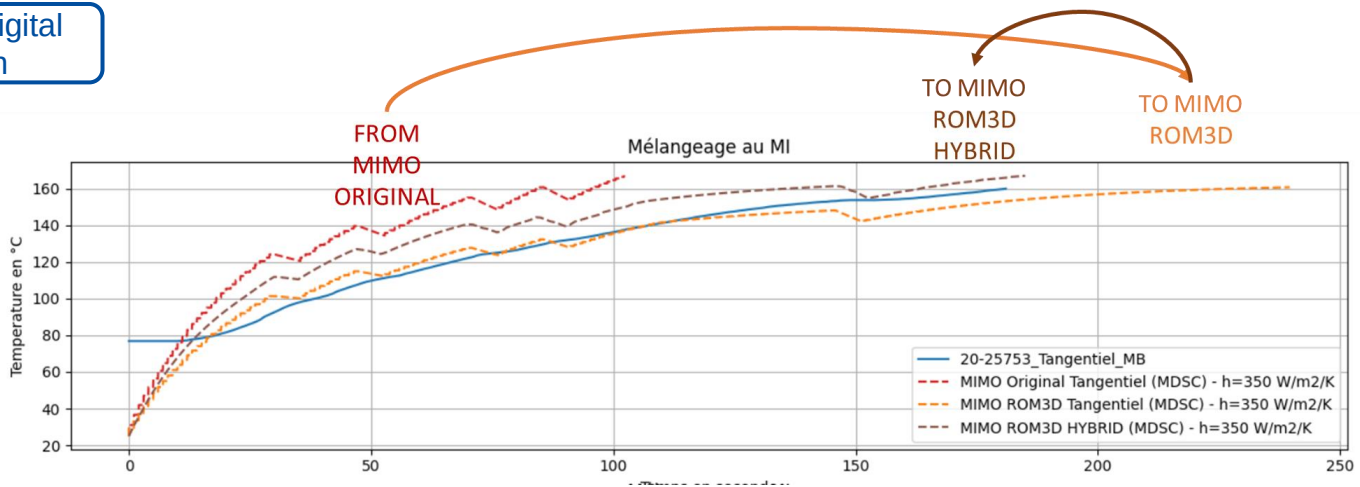


Fast & tailored digital twin decision-making assistant for mixing line process



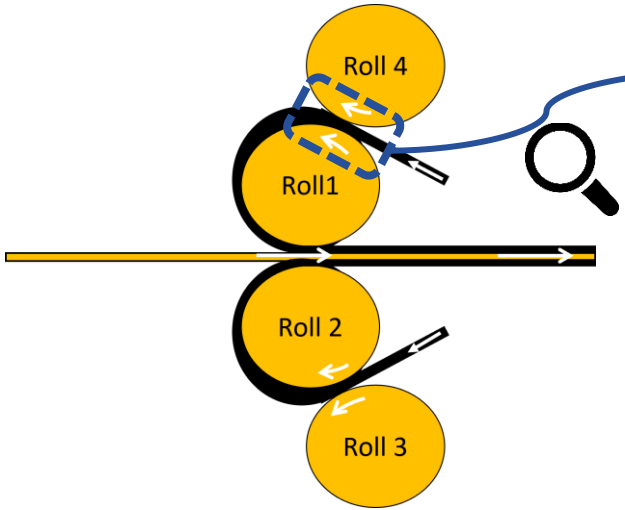
Updated computational core Version 2

- 3D ROM digital twins are more accurate and still fast

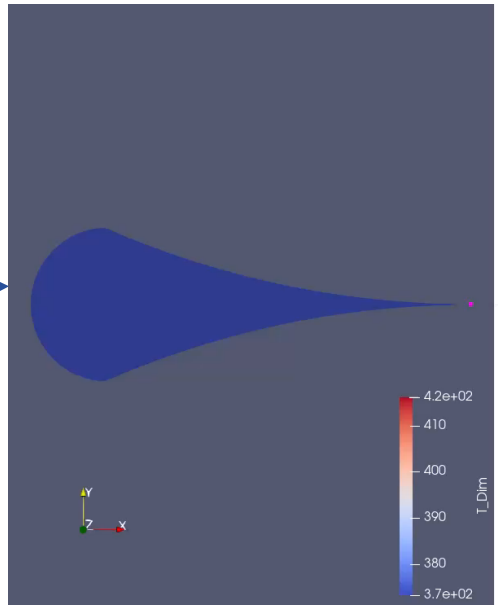


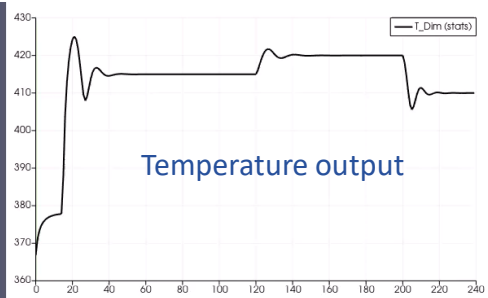
Towards real time process actuation…

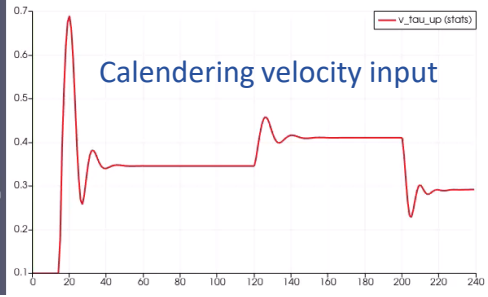
Calendering process



Model-based automatic control of temperature







PhD Thesis T. Bou Hamdan

Université de Poitiers

Forum TERATEC 24

Thank you

Overview of digital twins' usage at Michelin
application to support the design of rubber manufacturing processes

HIGHLIGHTS

- **Digital twins at Michelin**: when **equations-based world** description meets **real world observations**

- **A wide range of applications**
  - From tire **virtual homologation**…to **connected tires**
  - **Focus on rubber manufacturing processes**
    - When physics-based simulation meets reduced-order modelling and optimization to **build efficient decision-making assistants**