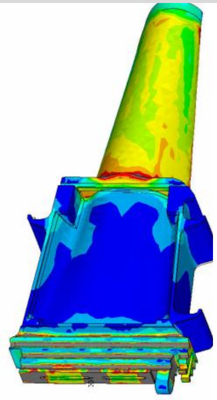
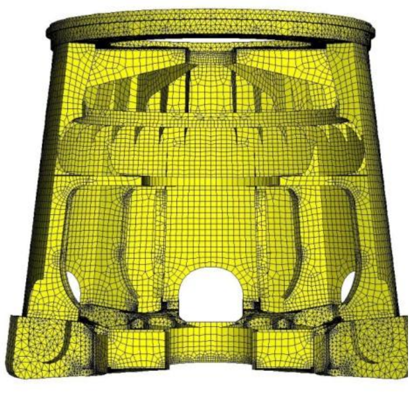
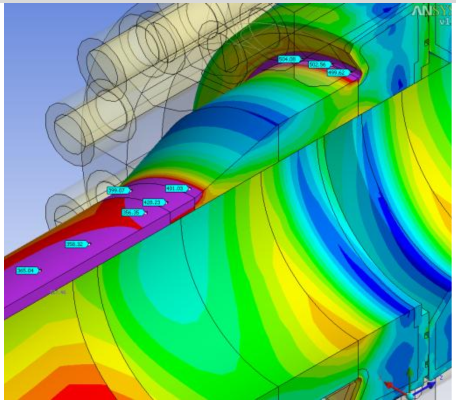
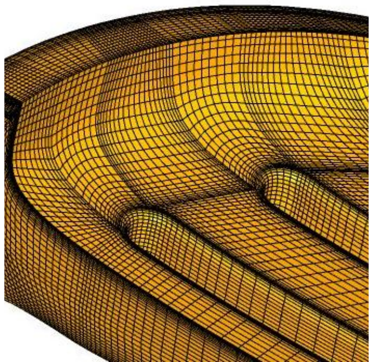
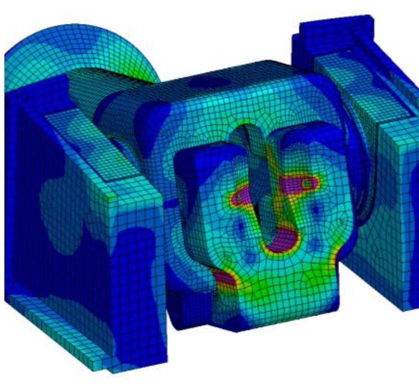
Key partner in Design Process Innovation

TERATECH 2013 FORUM

Ecole Polytechnique , June 25-26, 2013

S.Odorizzi

Evolution and Challenges of Engineering Simulation

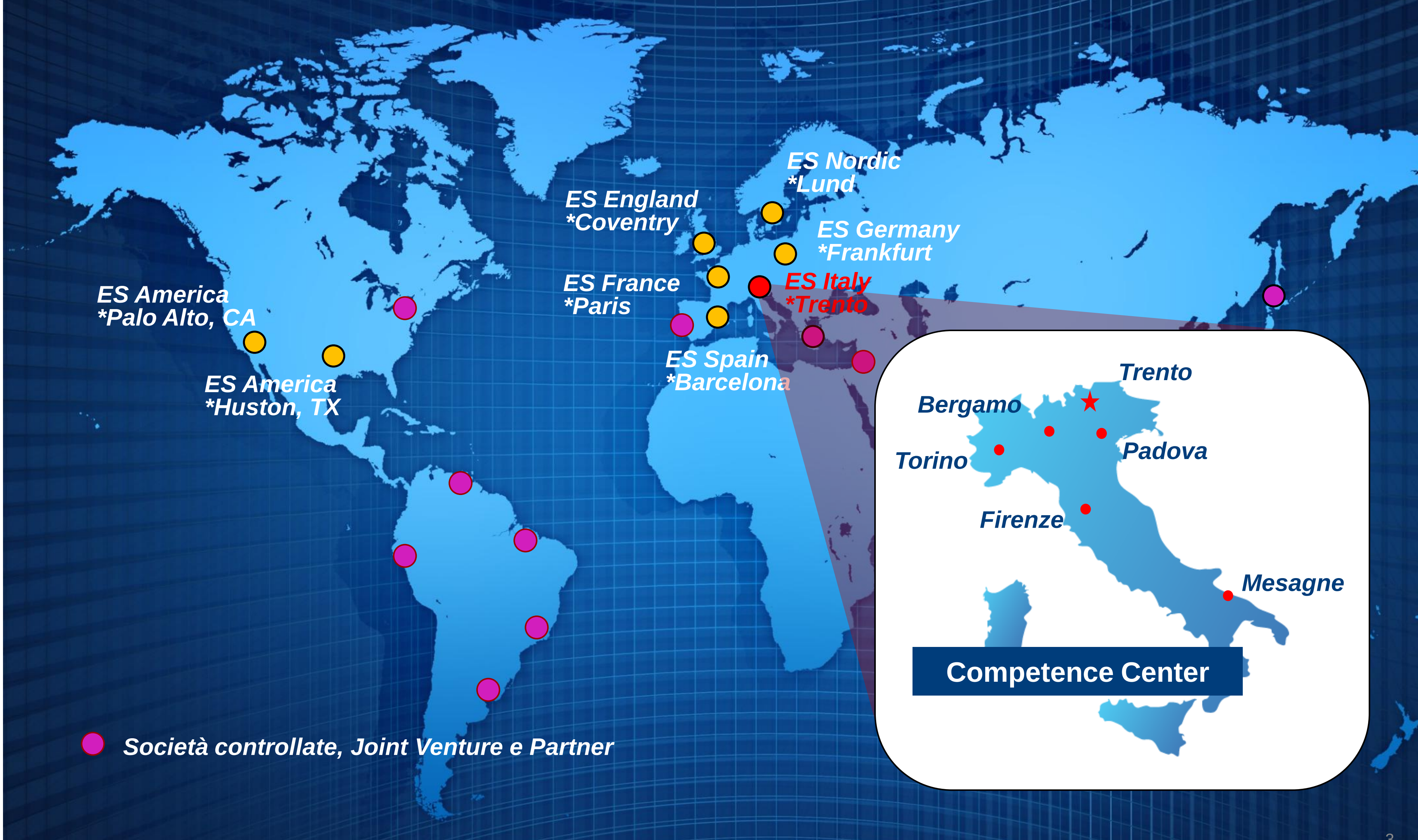






ABOUT ENGINSOFT

- **Type: private company.**
- **Founded in 1984 on the basis of other activities/structures in place since 1973**

- **ACTIVITIES**
- Leading group (in Italy) in CAE/iDP/PIDO
- Subsidiaries/partnerships all over Europe and in the USA
- Software dev. sales; consultancy, research projects, education
- Participation in industrial research projects (EU or national funding): MIUR acknowledged laboratory, and EU RTD performer

GLOBAL PRESENCE



TOPICS

- **Engineering simulation today**
- **Back to the outset**
  - …since then
- **A case history**
- **Engineering Simulation vs Design Process (the challenge we face today)**
  - At component level
  - At system level
  - At managemet level
- **Barriers to the introduction of HPC (as to Engineering Simulation)**
- **Conclusions**

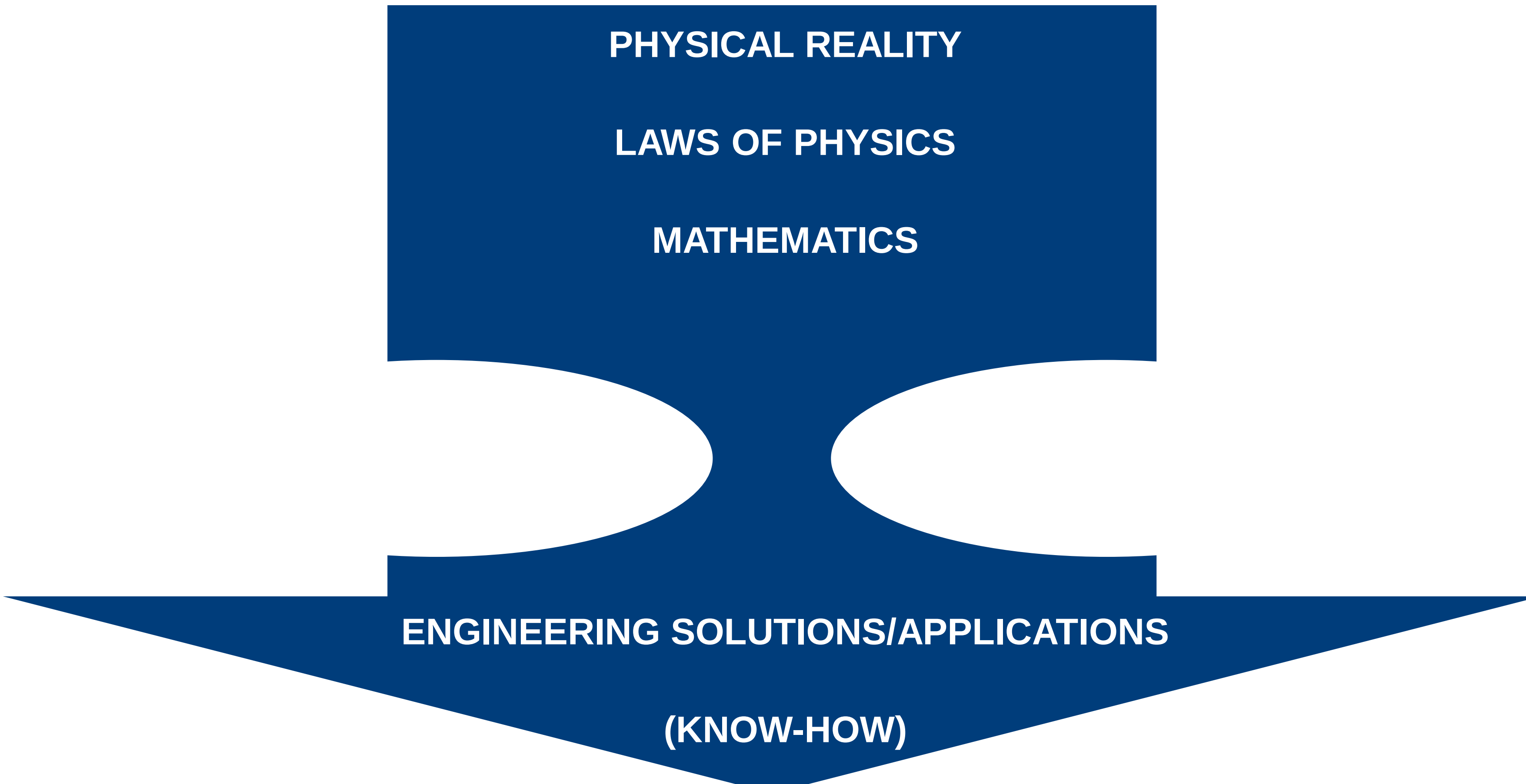
ENGINEERING SIMULATION TODAY

- **"…. Simulation will not just be "simulation as usual"**; rather, it will be focused on the modeling of complex, inter-related engineering systems and on the acquisition of results that meet specified standards of precision and reliability. Hence engineering simulation will develop new methods, devices, procedures, processes and planning strategies. All these will be **key elements for achieving progress in engineering and science**" (1)
- **The HPC perspective**

(1) "**Revolutionizing Engineering Science through Simulation**", 2006, Report of the **National Science Foundation Blue Ribbon Panel on Simulation-Based Engineering Science**

BACK TO THE OUTSET

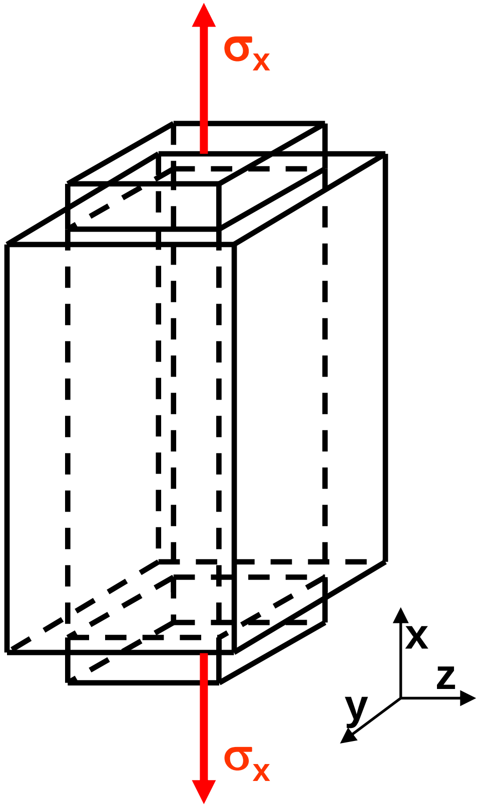
(engneering the real world)



BACK TO THE OUTSET – CONT.

$$\begin{cases} \frac{\partial \sigma_x}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + X = 0 \\ \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \sigma_y}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + Y = 0 \\ \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \sigma_z}{\partial z} + Z = 0 \end{cases}$$

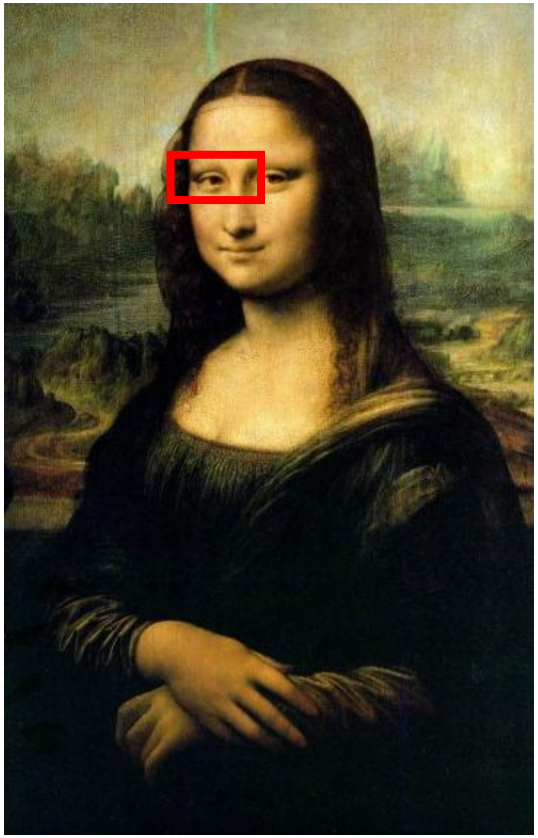
$$\begin{cases} \Delta\sigma_x + \frac{m}{m+1}\frac{\partial^2\psi}{\partial x^2} + 2\frac{\partial X}{\partial x} = \frac{1}{m+1}\Delta\psi \\ \Delta\sigma_y + \frac{m}{m+1}\frac{\partial^2\psi}{\partial y^2} + 2\frac{\partial Y}{\partial y} = \frac{1}{m+1}\Delta\psi \\ \Delta\sigma_z + \frac{m}{m+1}\frac{\partial^2\psi}{\partial z^2} + 2\frac{\partial Z}{\partial z} = \frac{1}{m+1}\Delta\psi \\ \Delta\tau_{xy} + \frac{m}{m+1}\frac{\partial^2\psi}{\partial x\partial y} + \frac{\partial Y}{\partial x} + \frac{\partial X}{\partial y} = 0 \\ \Delta\tau_{yz} + \frac{m}{m+1}\frac{\partial^2\psi}{\partial y\partial z} + \frac{\partial Z}{\partial y} + \frac{\partial Y}{\partial z} = 0 \\ \Delta\tau_{zx} + \frac{m}{m+1}\frac{\partial^2\psi}{\partial z\partial x} + \frac{\partial X}{\partial z} + \frac{\partial Z}{\partial x} = 0 \end{cases}$$

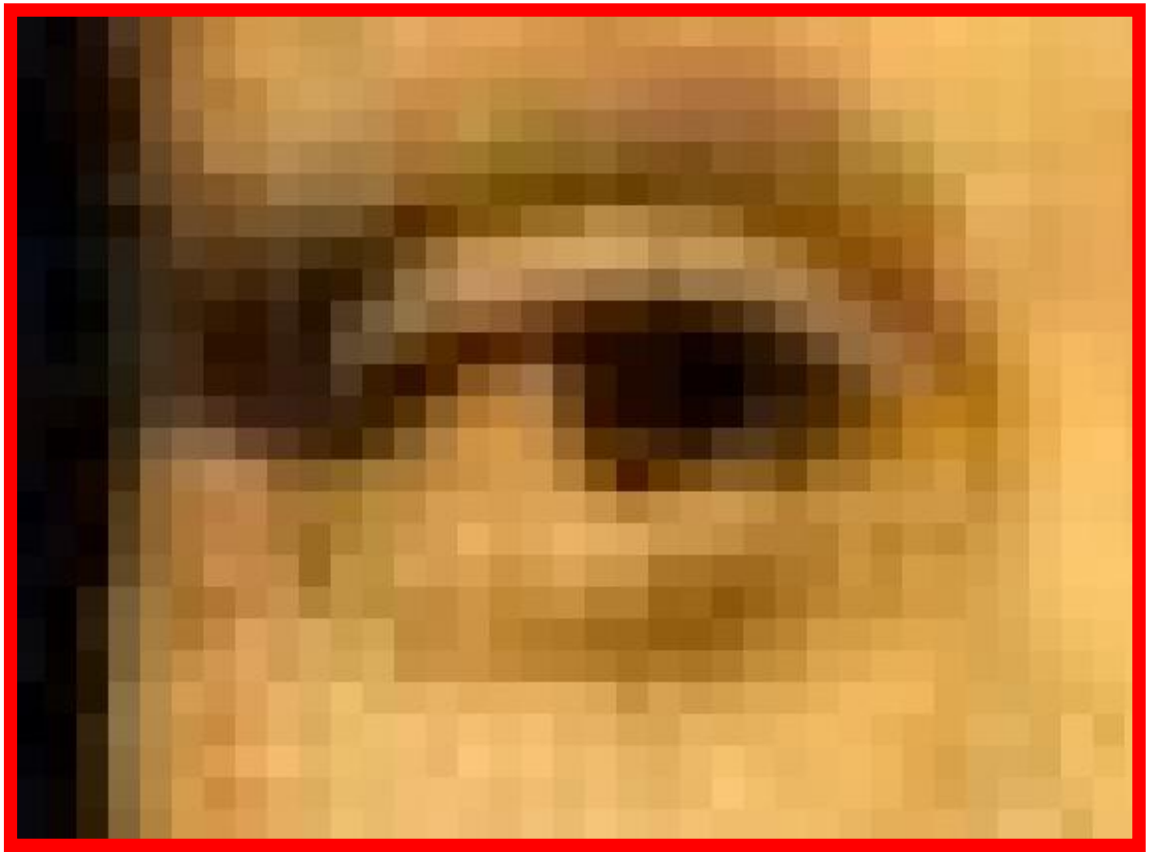


DESIGN SYNTHESIS (KOW-HOW, EXPERIENCE)

BACK TO THE OUTSET – CONT.

(the numerical approach)





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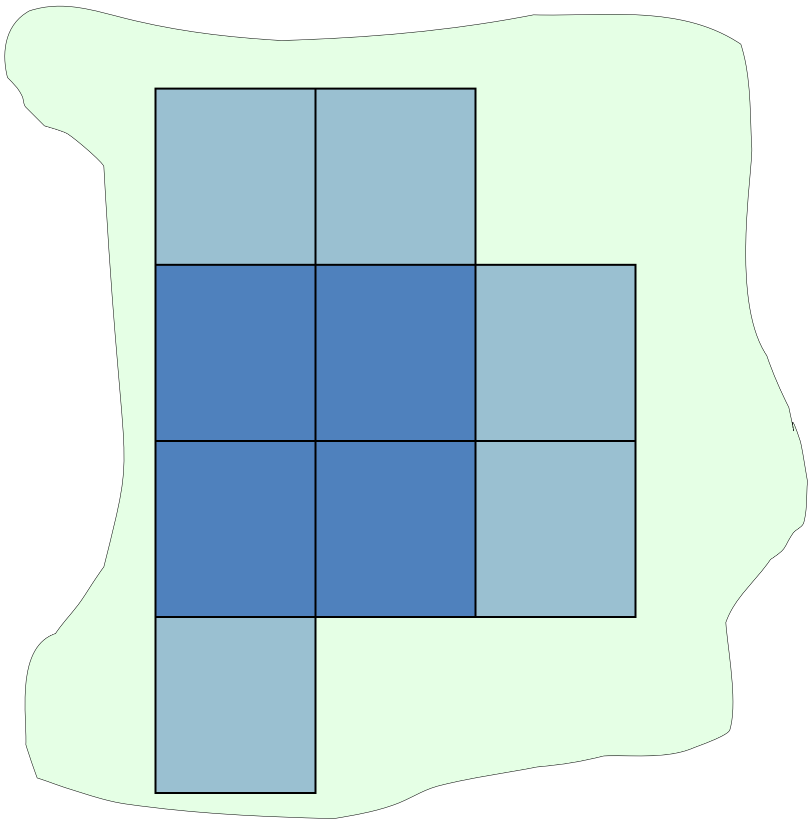

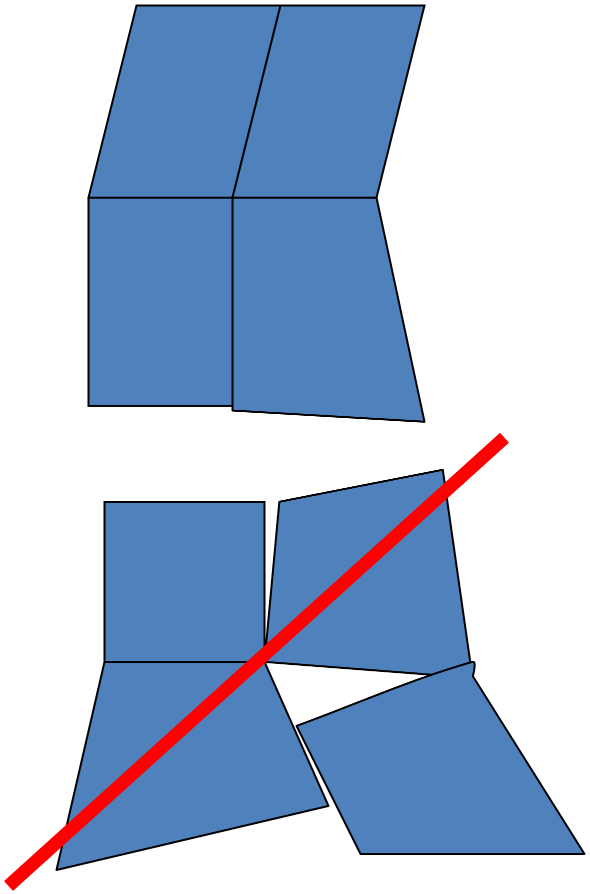

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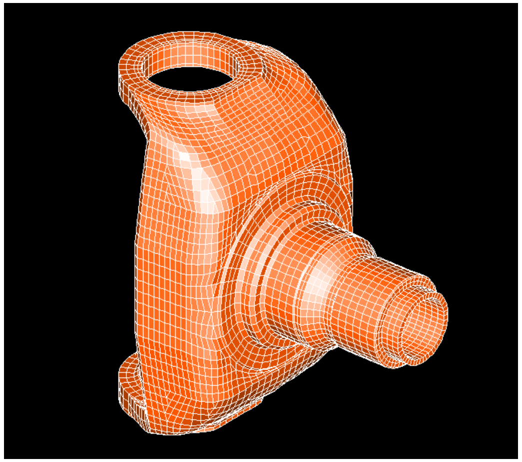
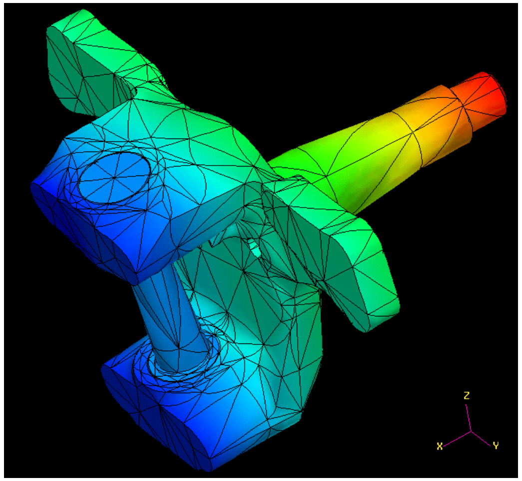
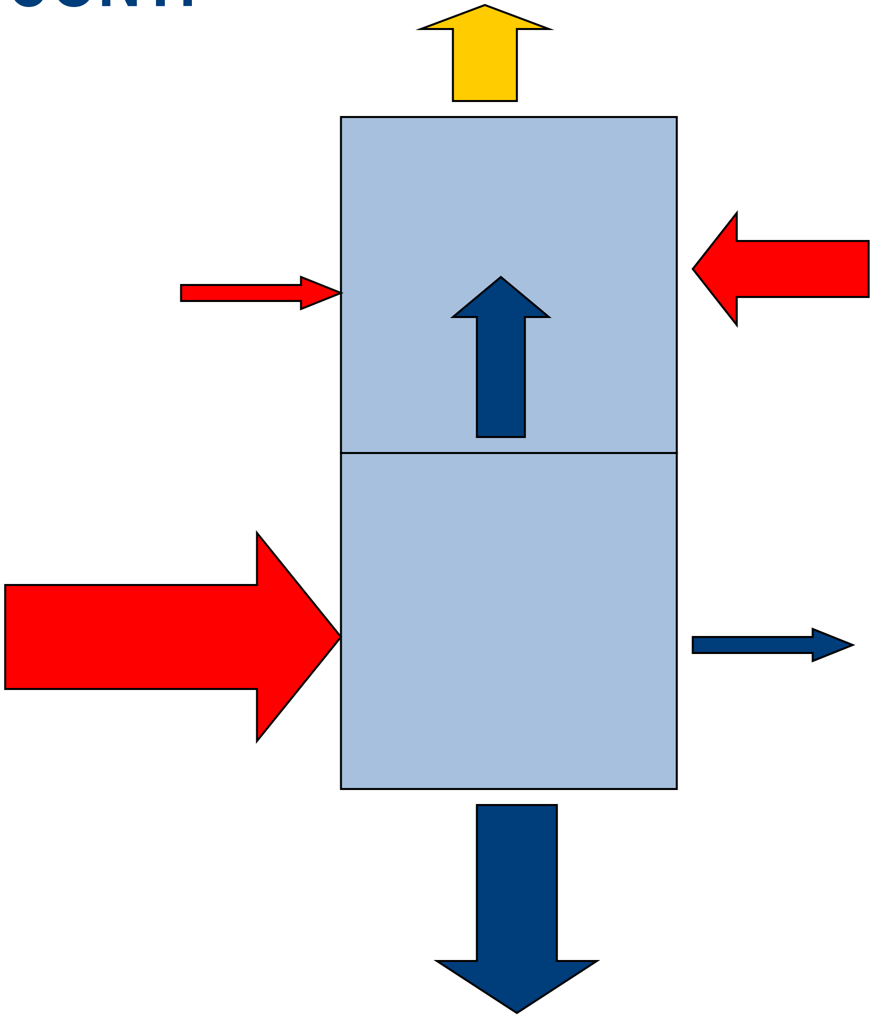
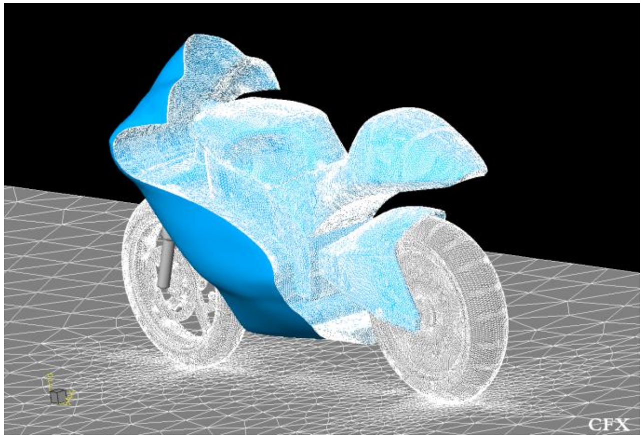


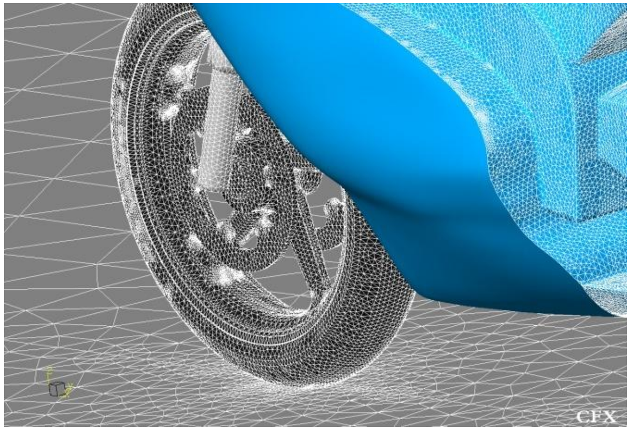




BACK TO THE OUTSET – CONT.

(the numerical approach)





- **Utterly simplified approach**
  - Complexity turned into a sequence of elementary operation
  - The limit is the computing power
- **A common approach**
  - To different disciplines
  - Stadardization (QA)
- **Knowledge transferability**
  - Building on excellence

SINCE THEN

- **In a single generation …**
  - we have collectively changed the world of engineering design;
  - we have watched the initial limited-scope industrial CAE evolve into the current advanced synergetic technologies, whose combined force is causing a true revolution in modern engineering practices and in related scientific fields.
  - Today **Engineering Simulation is radically changing the way products are designed and produced**.

A CASE HISTORY

(Courtesy of Campagnolo)

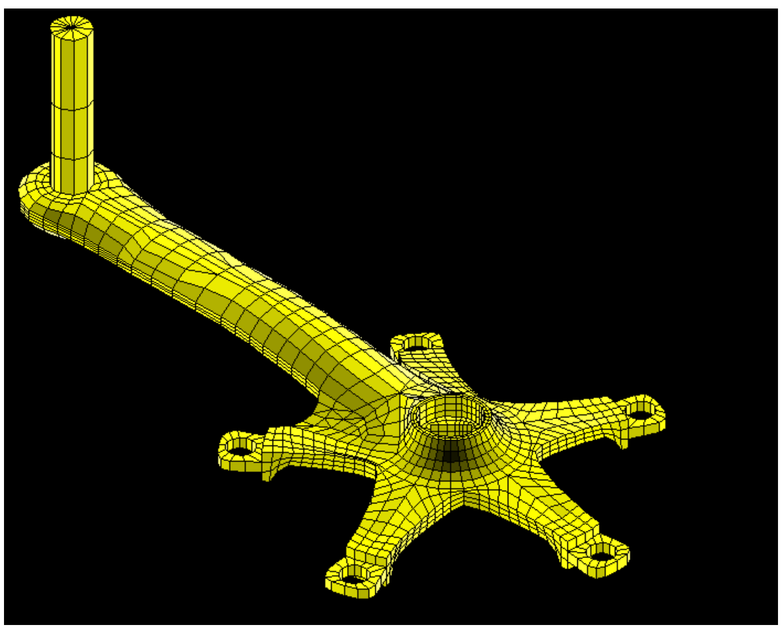
Campagnolo S.r.l. designs, produces and distributes high-end components for racing bikes..

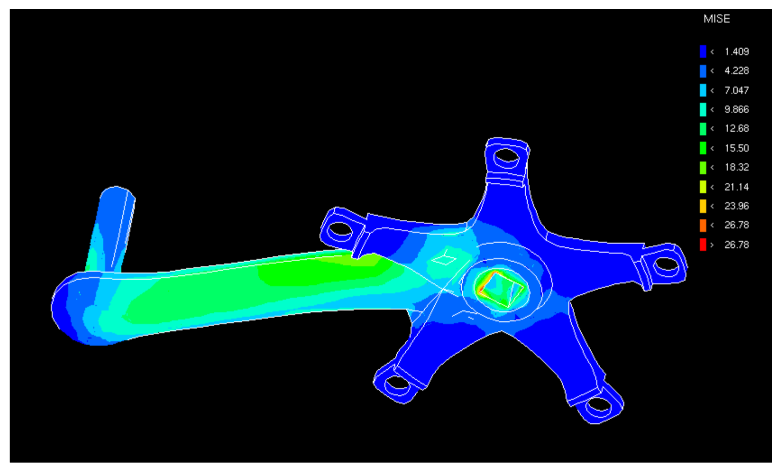
Campagnolo S.r.l. was founded in Vicenza in 1933 by Commendatore Tullio Campagnolo. The company soon expanded, focusing on the three fundamental concepts that would also characterize its future â€“ performance, technological innovation, and quality of products and services

It is present in over 30 countries

Campagnolo has a total workforce of around 700 employees.

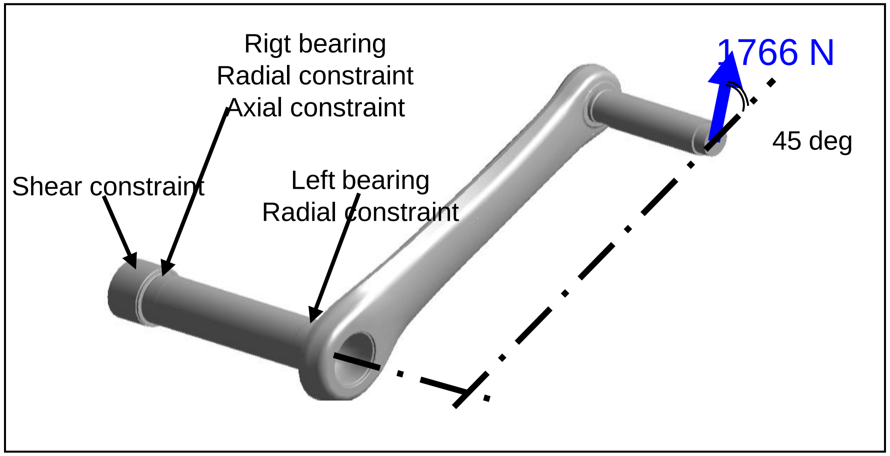
PRODUCT-PROCESS INTEGRATION: A PEDAL CRANK





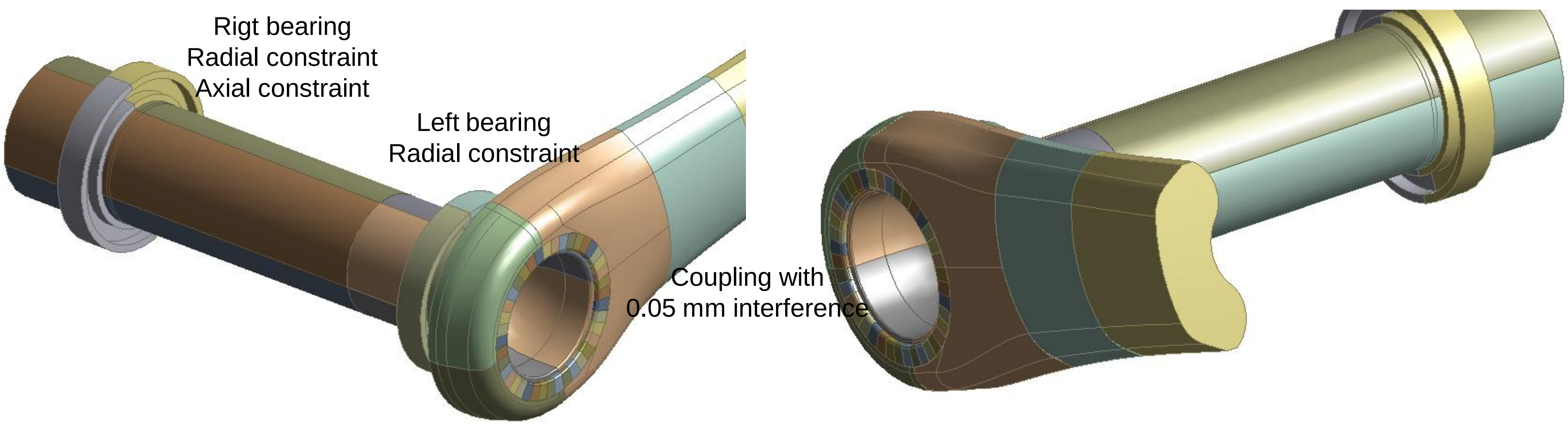
1985 – One of the first examples of semi-automatic (interactive) mesh generation (4 weeks man-work !) – 5000+ dof – A template for years.

A CASE HISTORY – CONT.

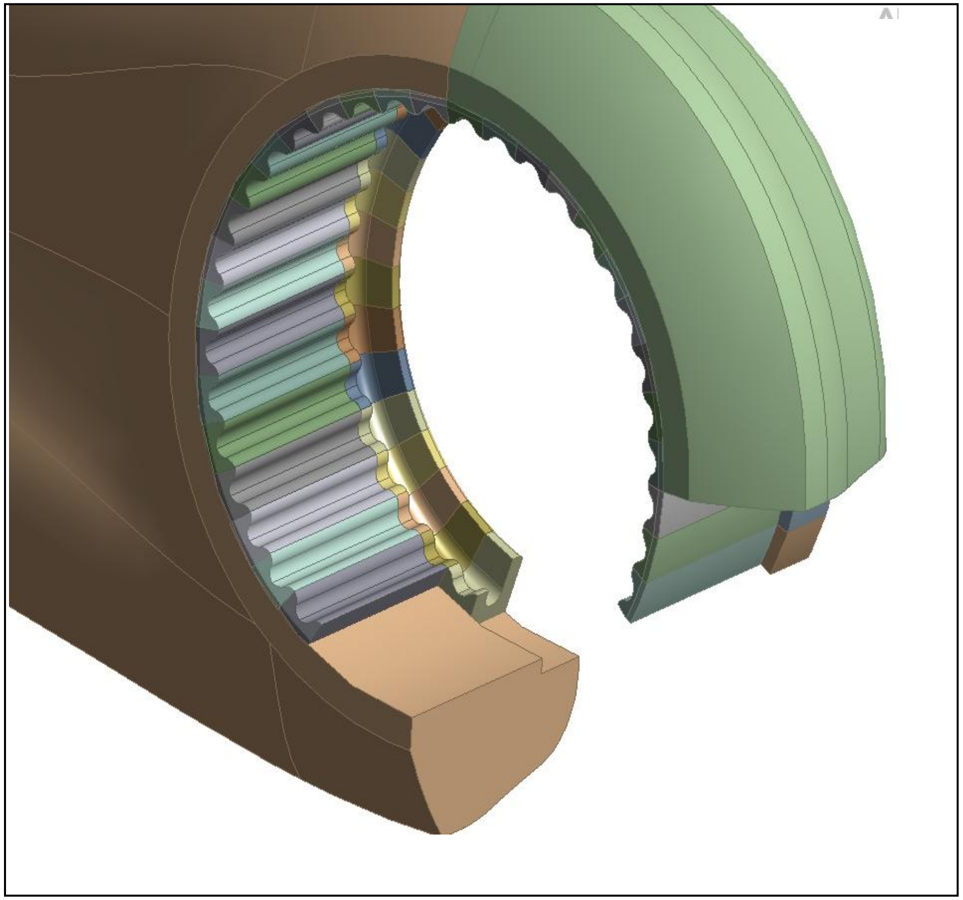


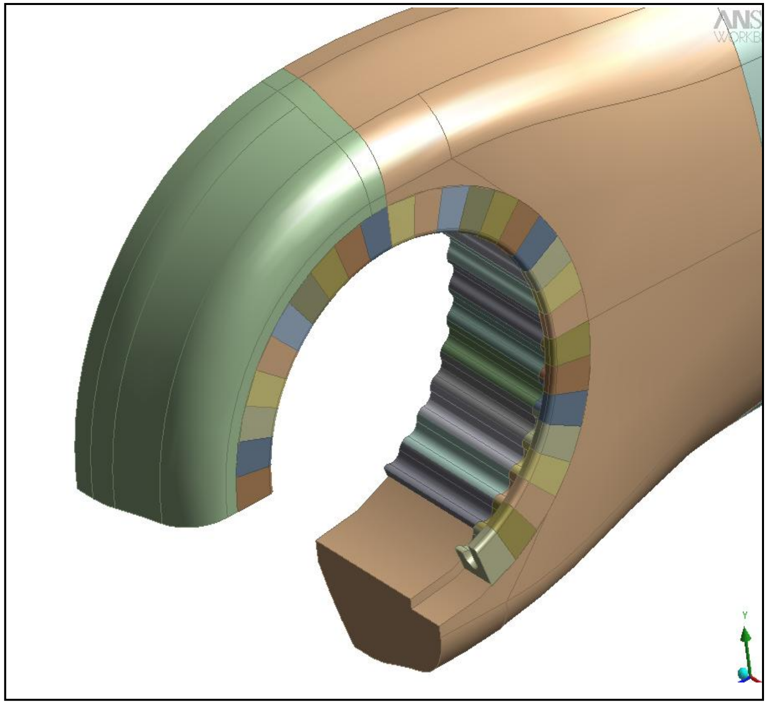
2006 – Objective: fatigue life analysis, including coupling with support.

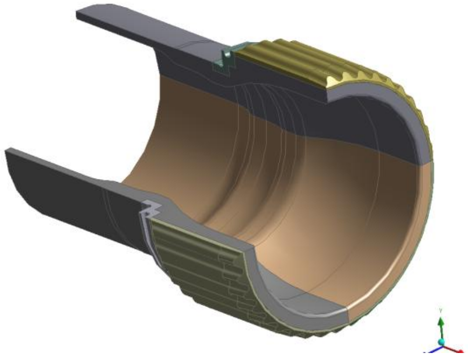
- All non-linear contacts simulated
- Analysis of interferences
- Semi-automatic mesh generagion (5 millions + dof)
- 8 GB RAM 4.5 H elapesed time each loading condition
- 1 week for the entire project



A CASE HISTORY – CONT.







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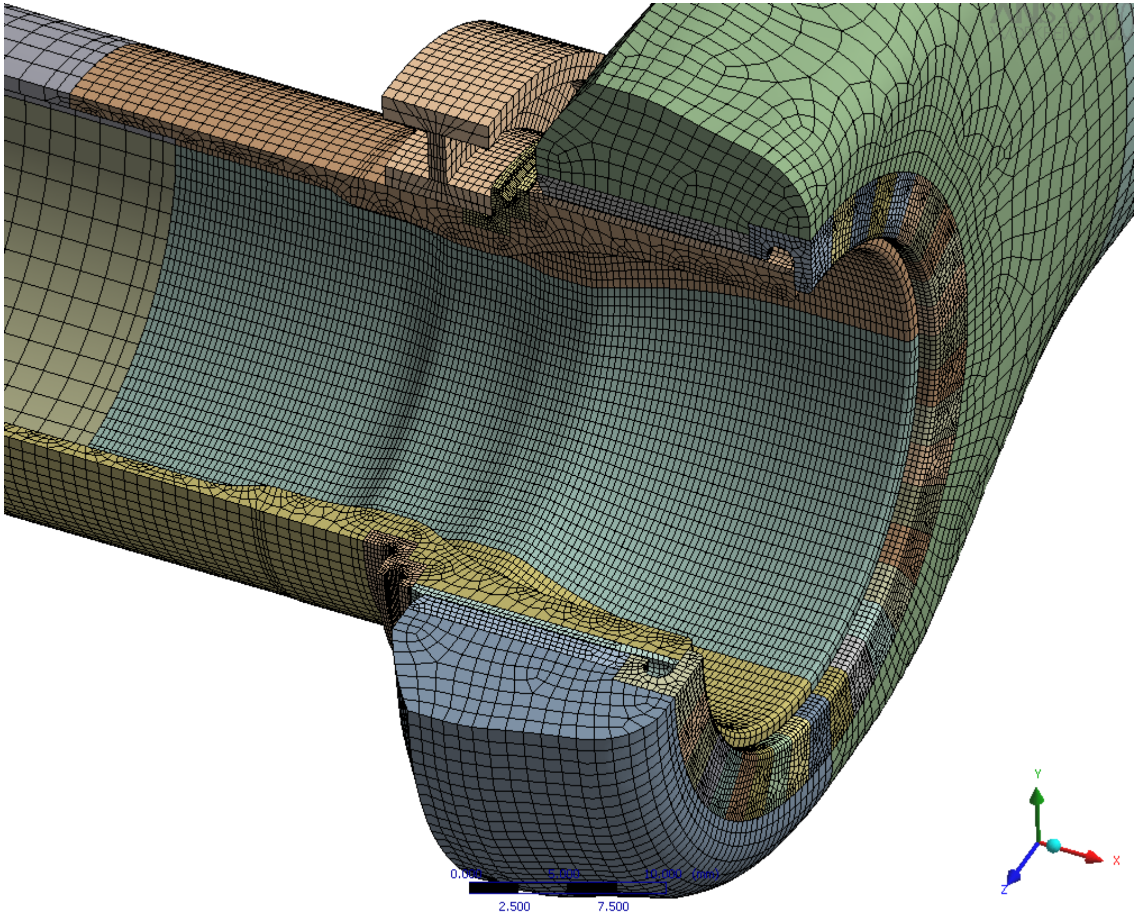

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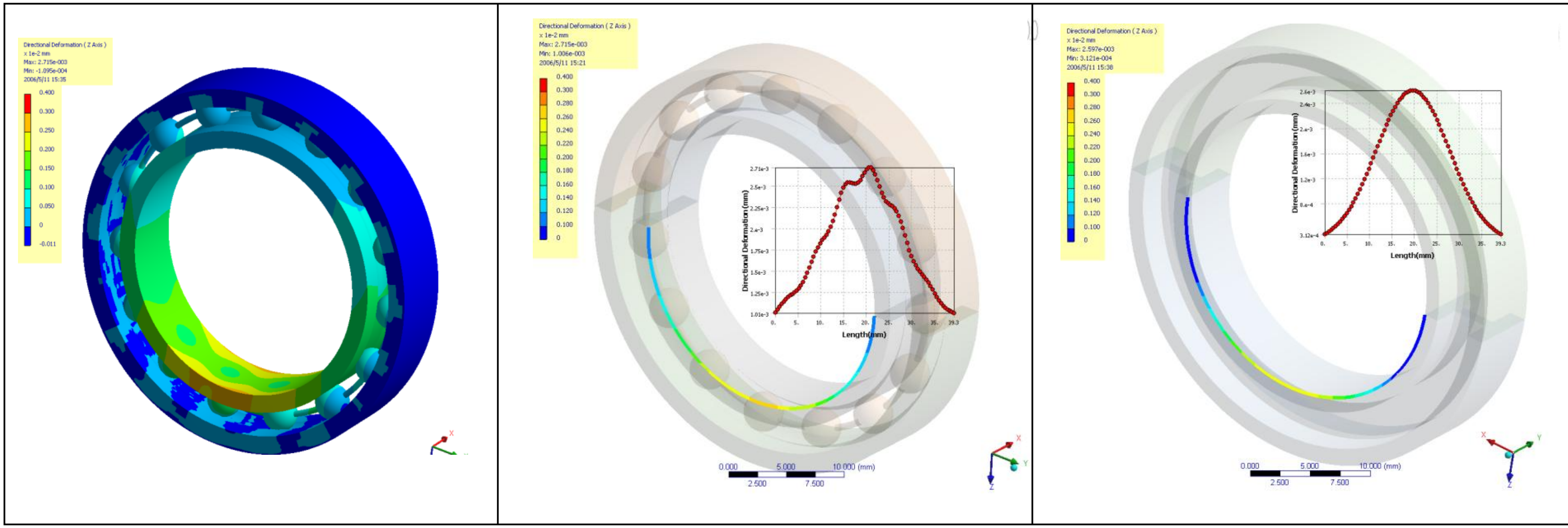
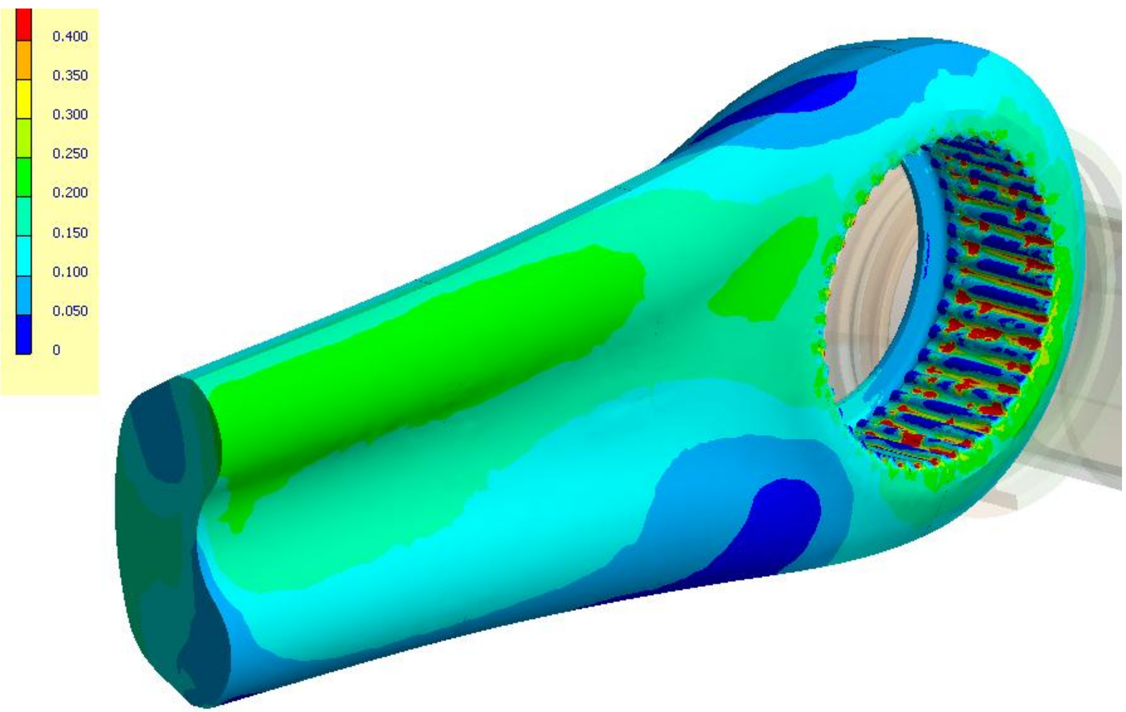
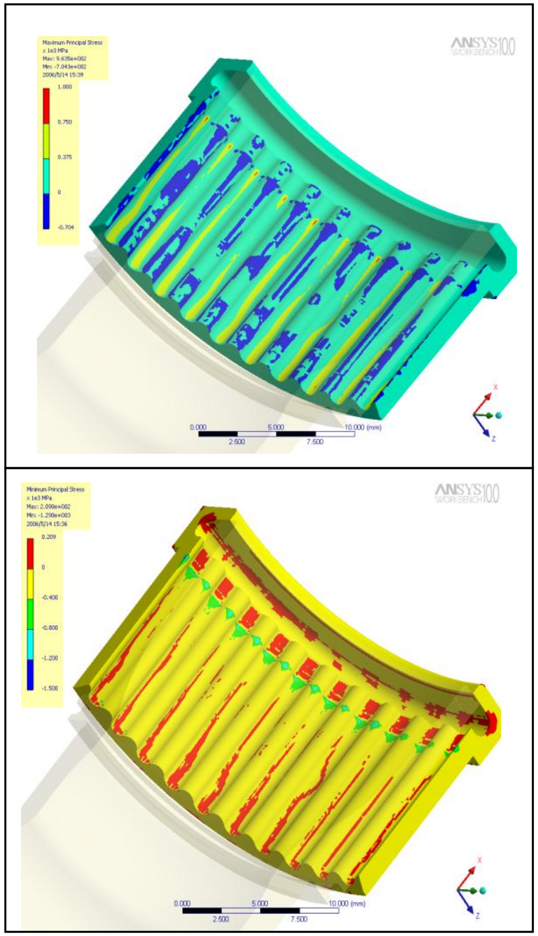


2006 – Detail of the bearing – Design (by analysis) for equivalent radial and axial stiffness

A CASE HISTORY – CONT.

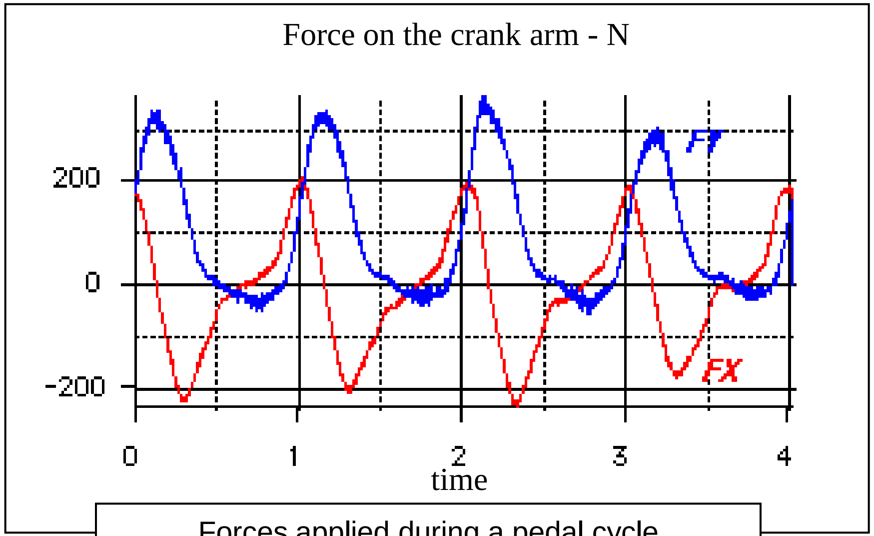




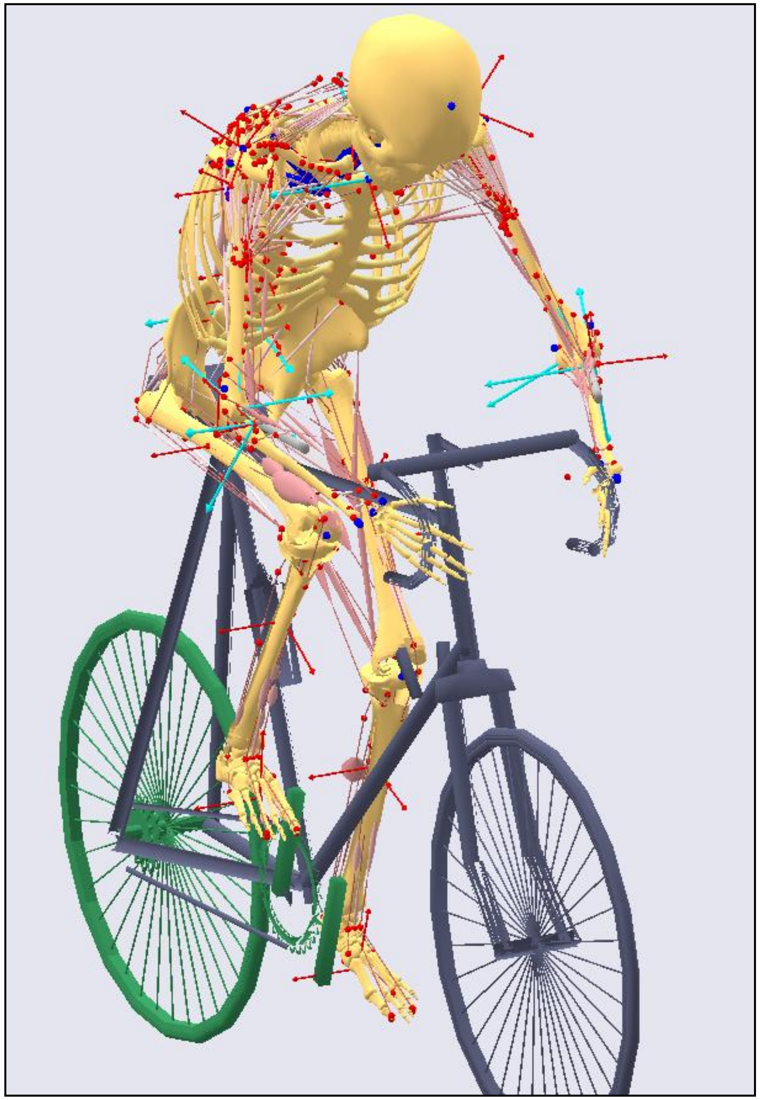
2006 – Post-processig. Detail (tension vs compression) at the ‘1000 teeth’ joint

A CASE HISTORY – CONT.

2011 – Design forces coming from both physical and virtual experiments

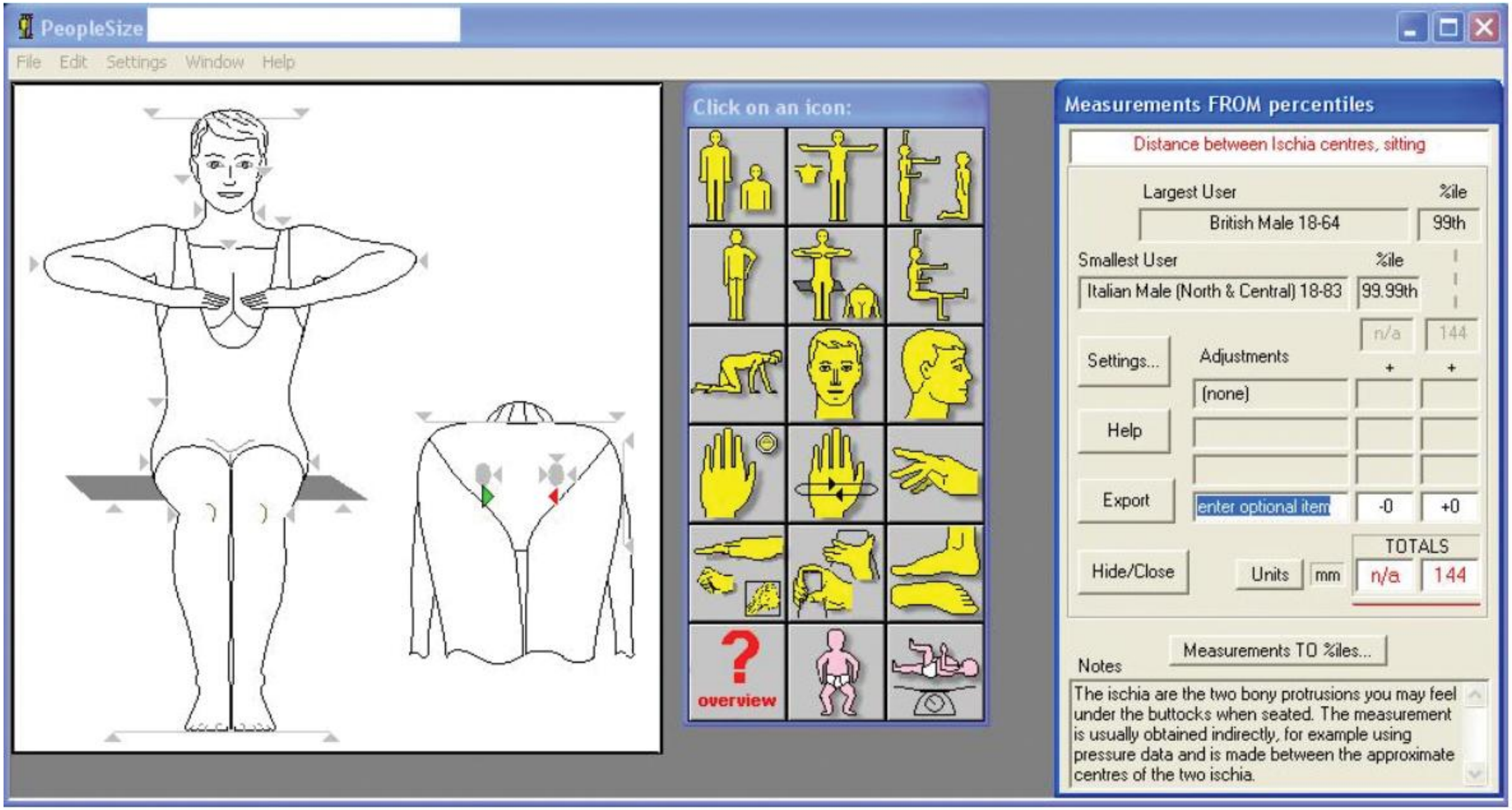


Forces applied during a pedal cycle
(blue = tangential force, red = normal force)



A CASE HISTORY – CONT.

2011 – Antropomorphic characteristics of cycling population from a data-base of 5000+



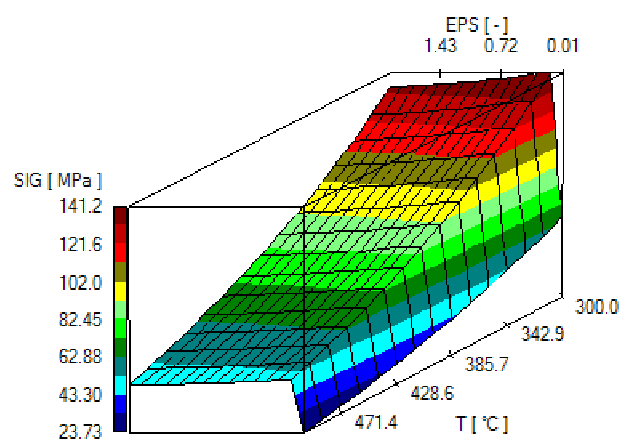
A CASE HISTORY – CONT.

2011 – Material selection and design requirements

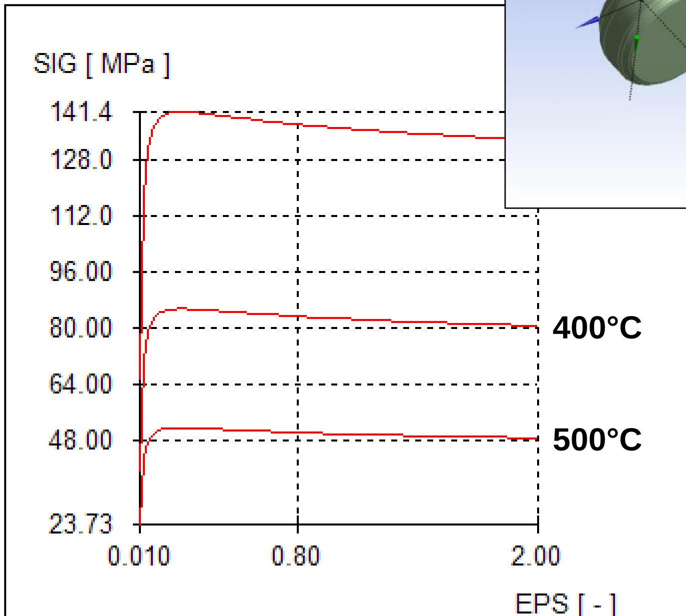
AA 2014 (ALCu4,4SiMnMg – WN: 3,1255) - Chemical composition

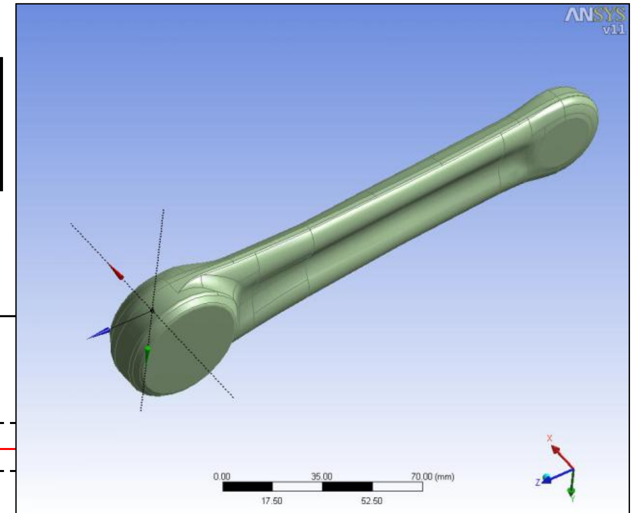
Alloying Addition	Si	Mg	Cu	Zn	Mn	Cr	Fe	Ti
Percentage %	0,84	0,51	4,46	0,25	0,79	0,10	0,70	0,15

Temperatura °C	E GPa	$R_{p0.2}$ MPa	R_m MPa	A %
25	72	400	462	13
150	70	348	374	-
300	54	48	65	-



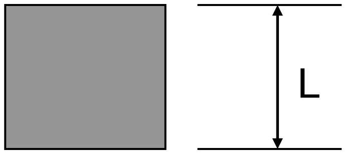
Results of the tensile tests (average on three tests)

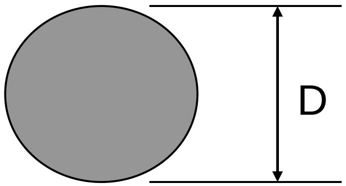




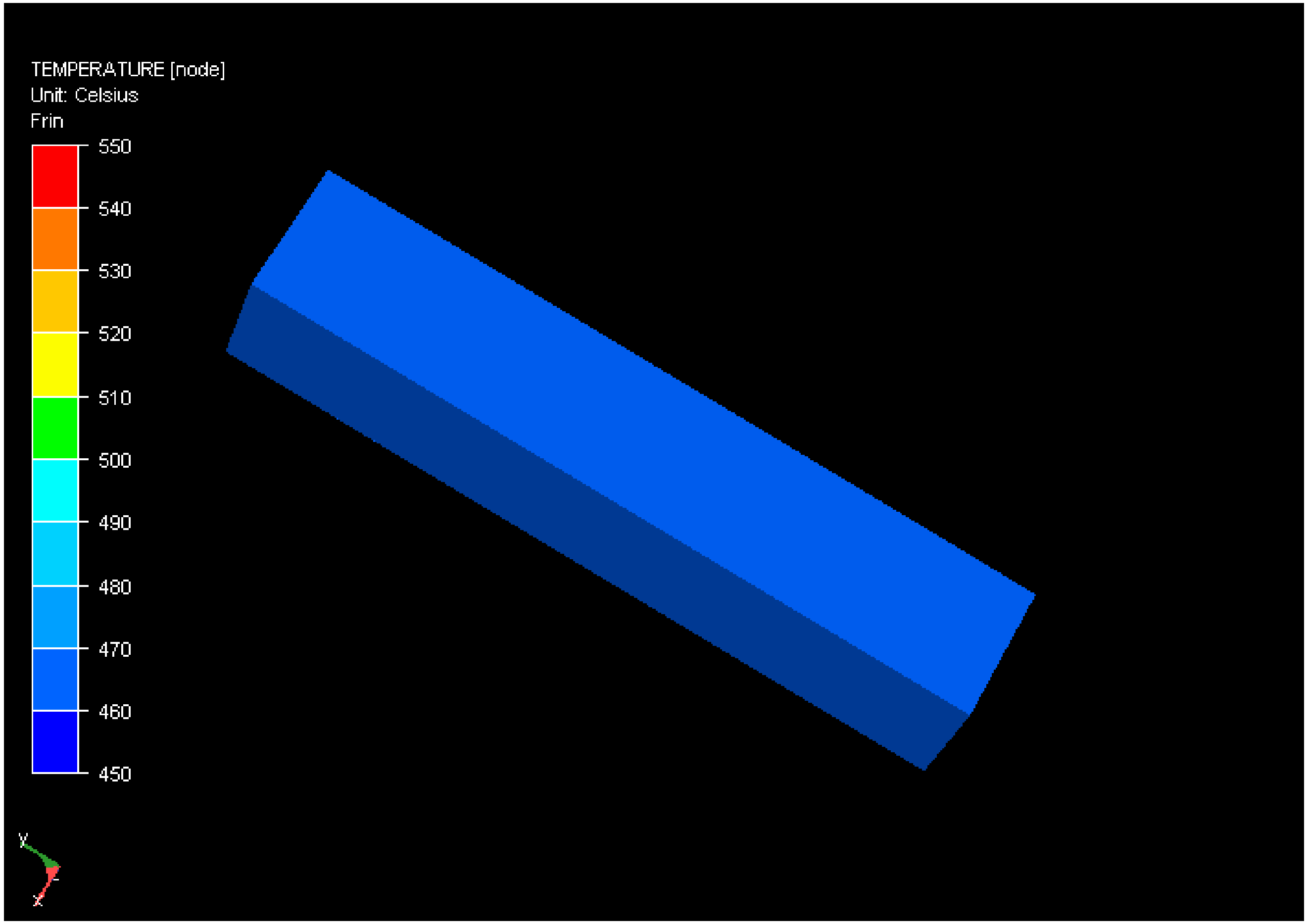
A CASE HISTORY – CONT.

- **Forging process (billet choices)**
  - First choice: square billet
    - ✓ Size: L = 32 mm, H = 170 mm, M = 487,4 gr
    - ✓ Process: one operation
  - Second choice: cylindrical billet
    - ✓ Size: D = 28 mm, H = 200 mm, M = 344,6 gr
    - ✓ Process: three operations
  - Final/targer weight: 267.2 gr





A CASE HISTORY – CONT.



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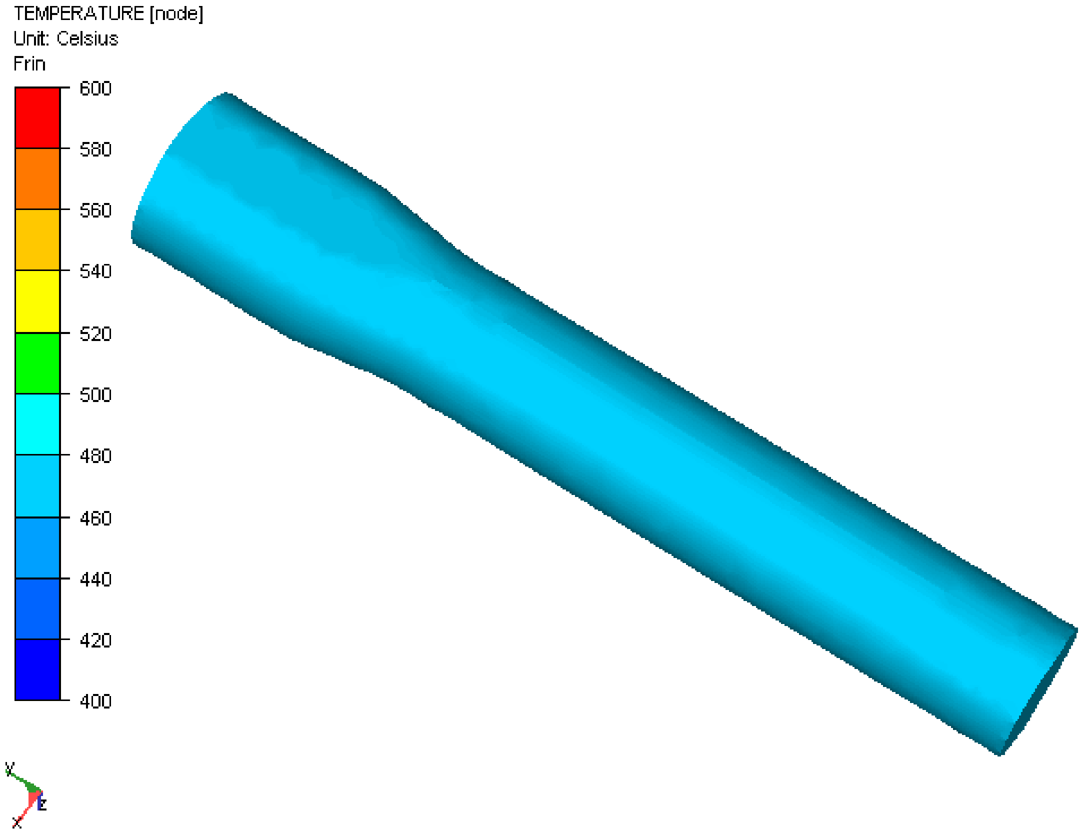

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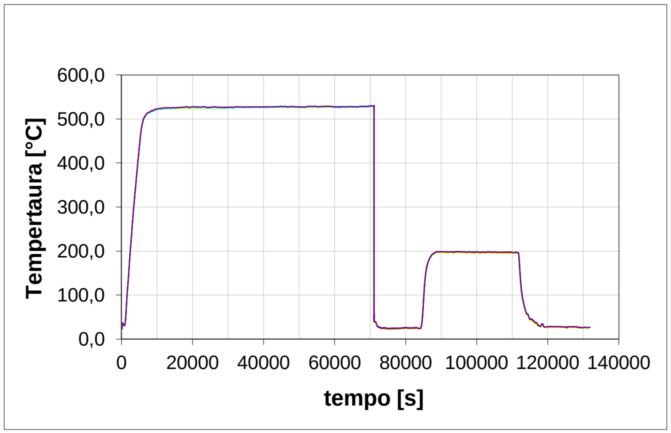
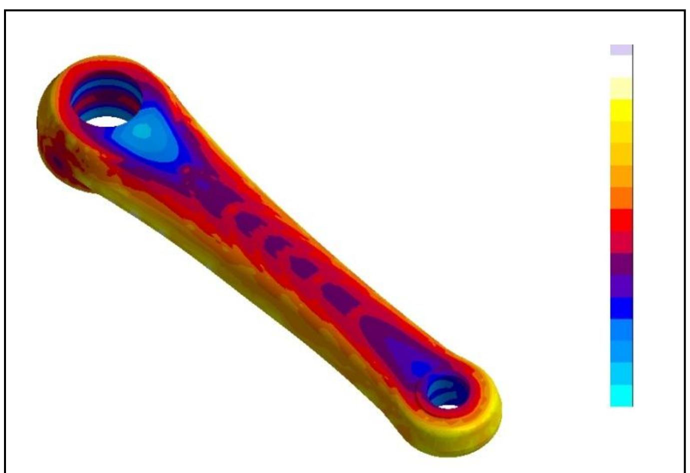
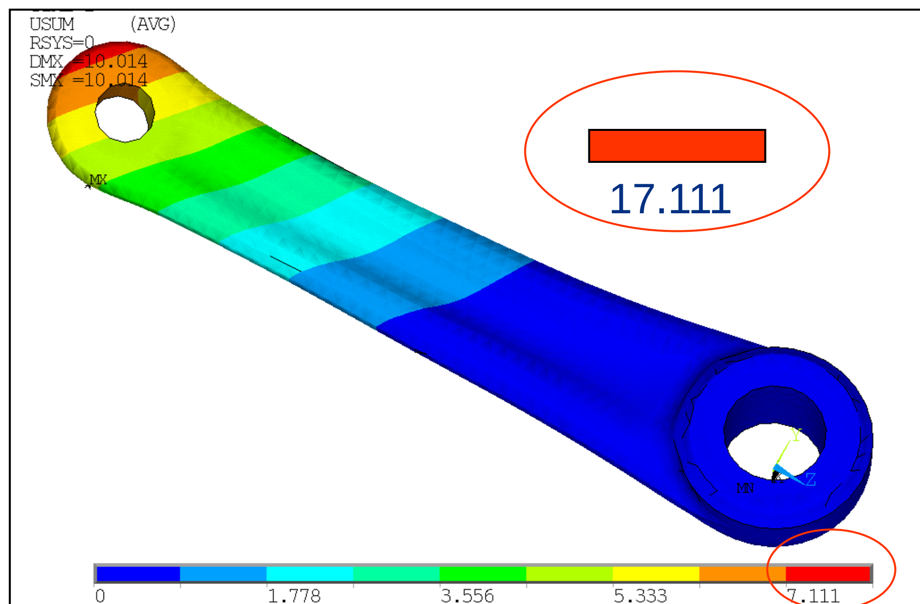
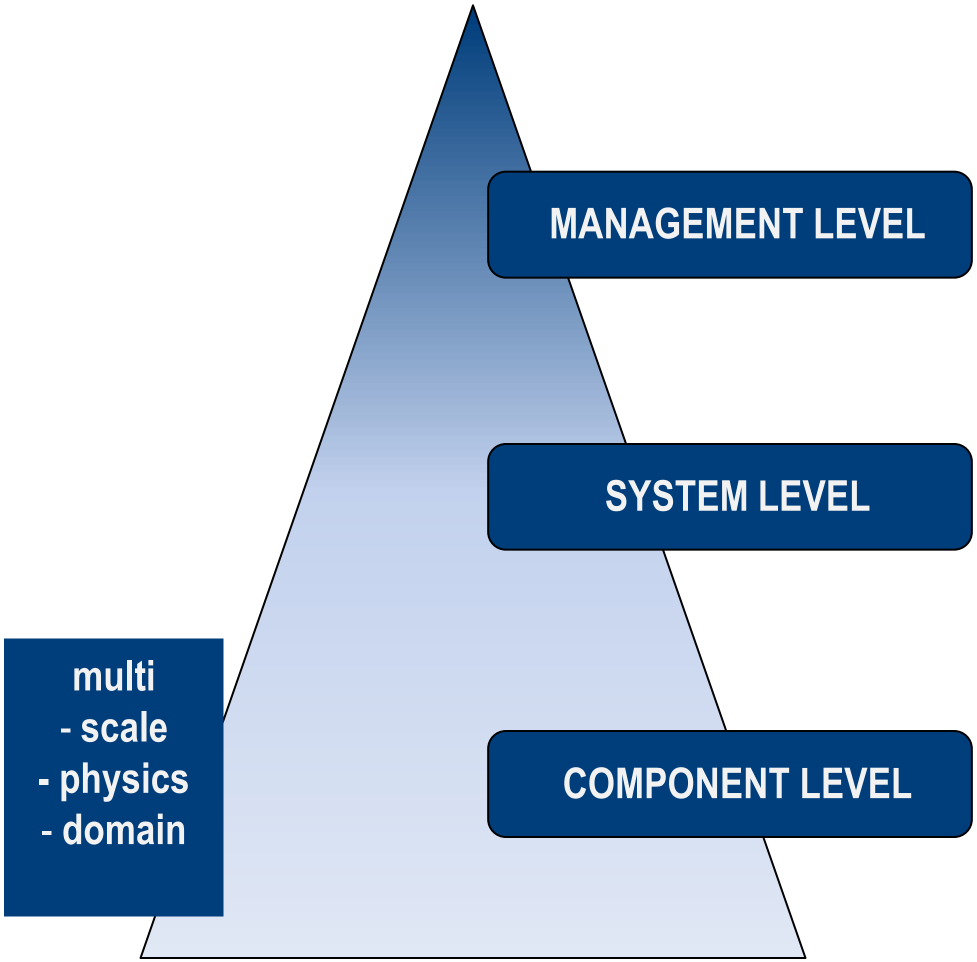




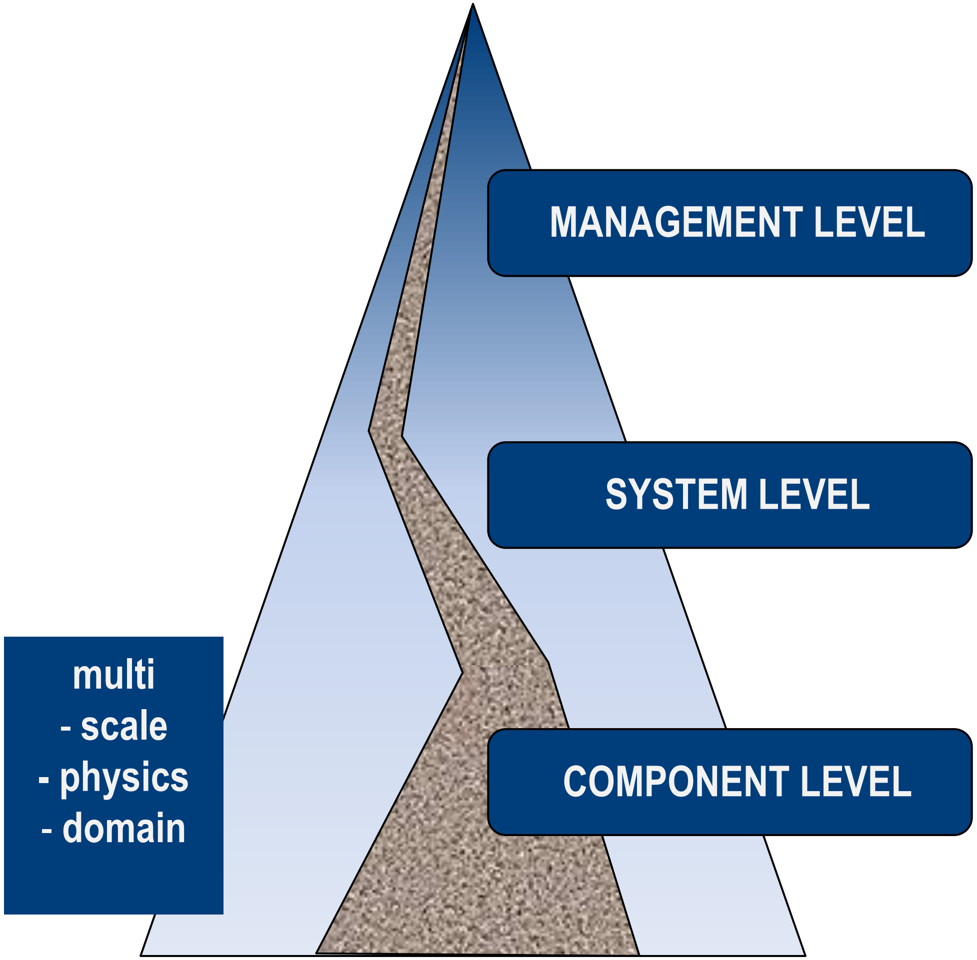
- **Heat treatment**
  - Solutioning at 540 °C in 4h
  - Water Quenching with medium temperature at 25 °C
  - Aging at 170 °C in 3h
- **Residual stresses and mechanical properties**
- **Realistic final stress distribution an fatigue analysis**



ENGINEERING SIMULATION VS DESIGN PROCESS



ENGINEERING SIMULATION VS DESIGN PROCESS



THE CHALLENGE WE FACE TODAY

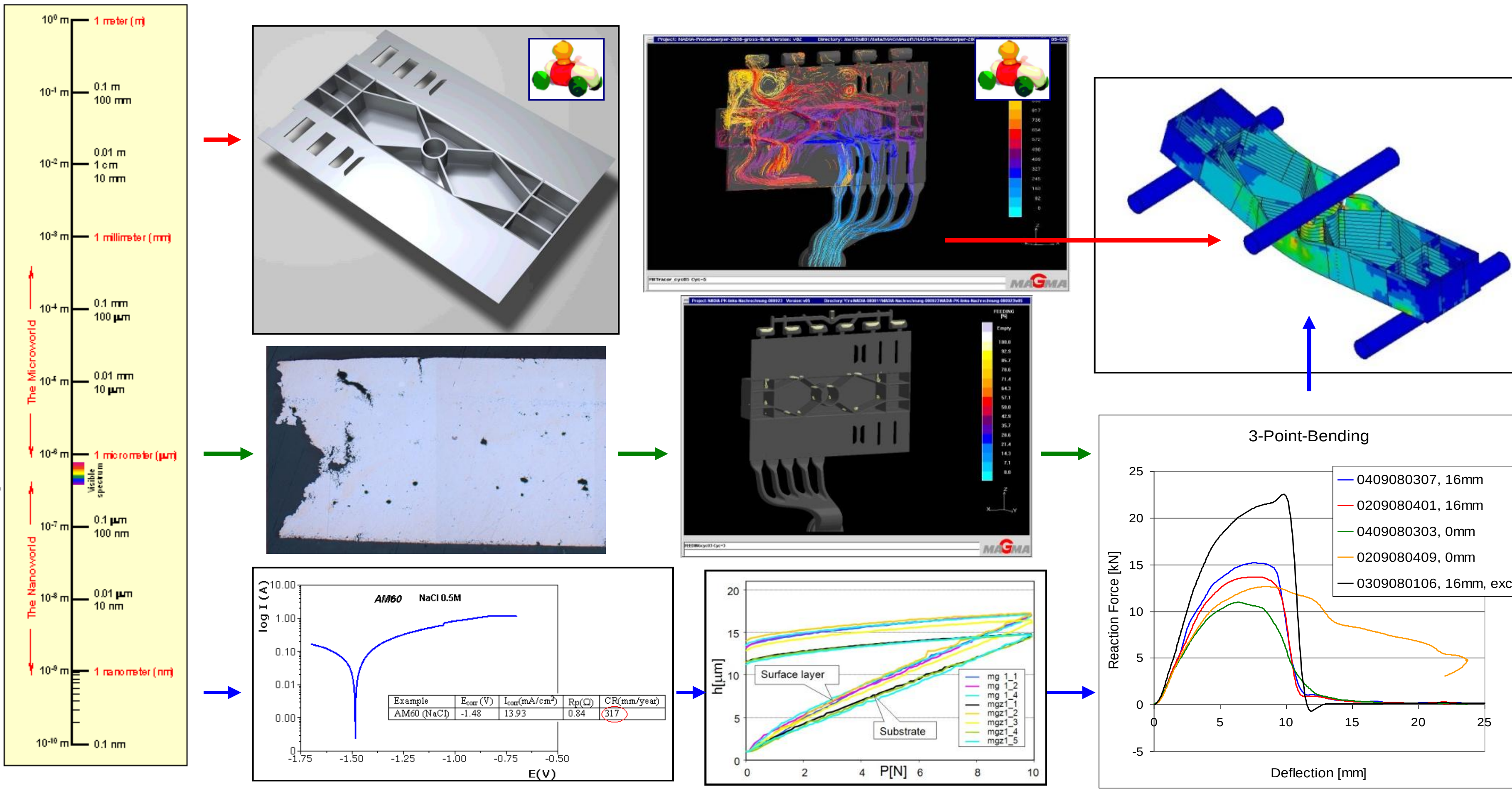
- **To transform existing (commodity) products into effective toos of the design process tailored to the needs of each individual organization**
  - ensure that our simulation processes are complete, starting from the conceptual design phase right through the entire design (and production) chain
  - ensure that processes are reliable and robust
  - focus on ways to detect defects before they become problems
  - create models that produce consistent results
  - never loose focus of the big picture in which we operate
  - …

AT COMPONENT LEVEL – GROWING COMPLEXITY

- **“Multi”-x approaches**
  - Multi-scale models
    - With respect to the size scale (“from nano to macro”)
    - With respect to the time scale
  - Multi-physics and/or multi-domain approaches and/or multi-phase approaches, including different (multi) numerical approaches (FEM, BEM, FD, CV, Semi-analytical, …), and domain dimensions (from 0/D to 3/D, n/D)
    - Un-coupled approaches
    - Fully coupled approaches
  - Multi-disciplinary approach (inter-related systems; design chain)
  - Multi-objective design/optimisation, including multi-partnered collaborative design;
- **Complexity in terms of problem size and type of analysis**

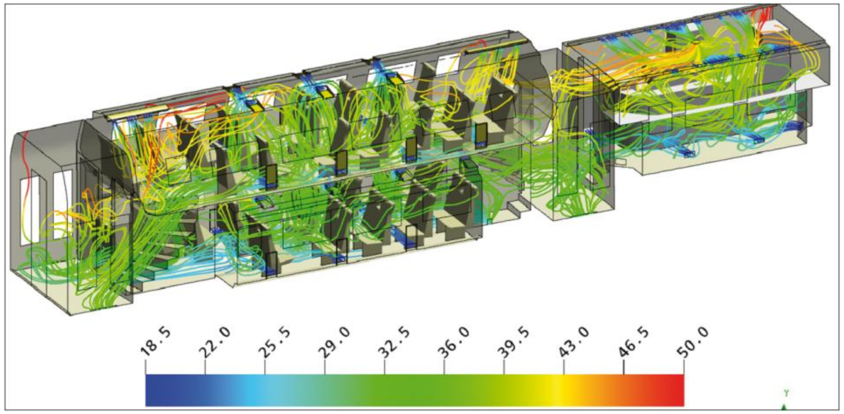
AT COMPONENT LEVEL – GROWING COMPLEXITY – CONT.

Multi-scale approach. 2011 – Magnesium ‘crash’ component – Source: NADIA EC co-funded project



AT COMPONENT LEVEL – GROWING COMPLEXITY – CONT.

Multi-scale approach. 2012 – Computational Mechatronics: micro-crontrolled based systems



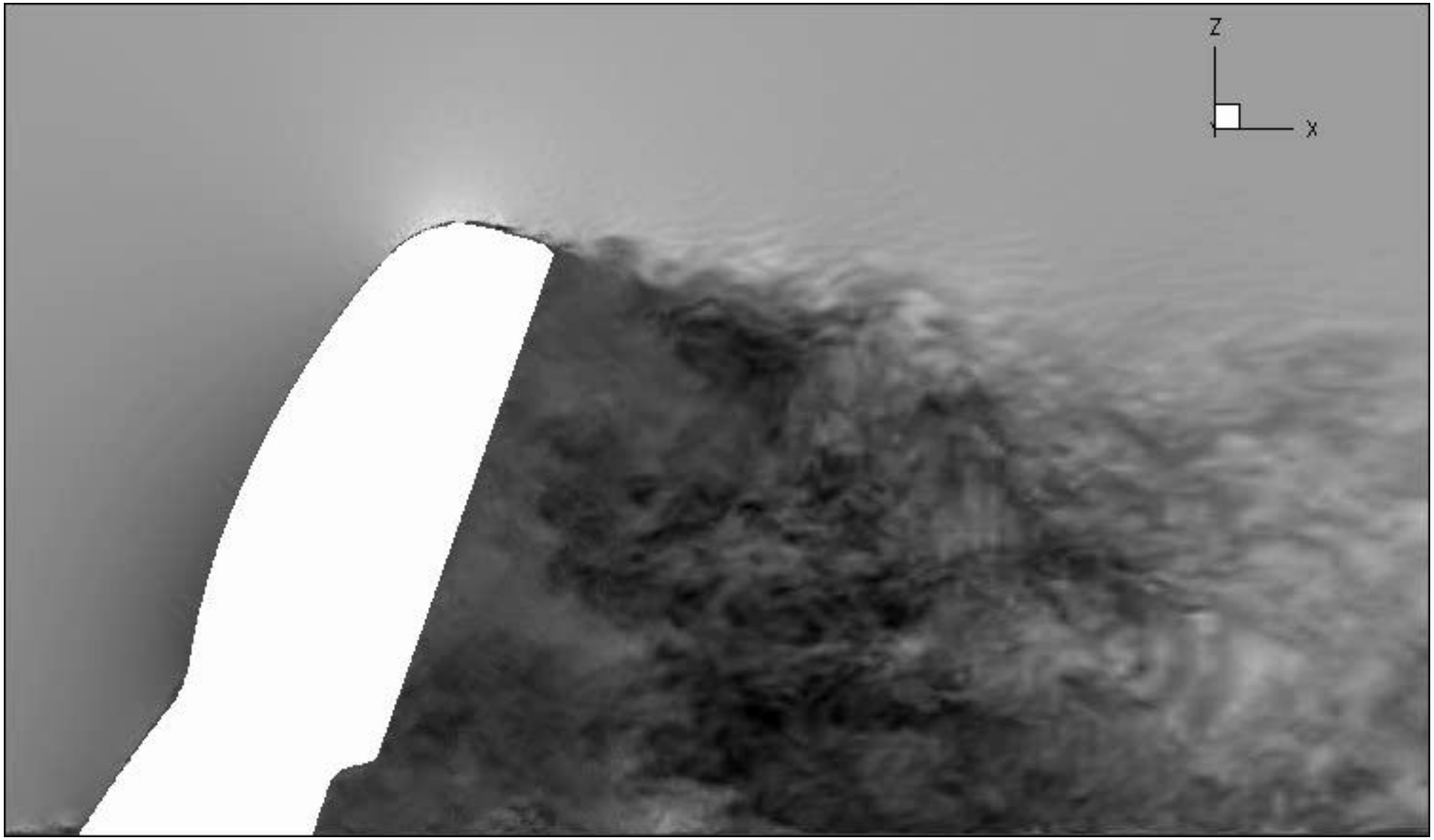
CASE STUDY: Validation of a control algorithm in HVAC application (courtesy of AnsaldoBreda) In a distributed parameter process, the measurements made by the sensors may exhibit quite complex **deterministic** data patterns, that in general cannot be well described with stochastic processes, …while a FEM model can reproduce them accurately, thus producing a more reliable **sensitivity analysis.**

Rationale

- System governed by microcontrollers = embedded digital control system + multi-physical machine or process
- The validation of a system governed by microcontrollers cannot be made without taking into consideration the embedded control firmware
- The validation of the firmware cannot be made without taking into consideration its embedding physical system
- **The answer is the numerical co-simulation of both, i.e. the Computational Mechatronics**

AT COMPONENT LEVEL – GROWING COMPLEXITY – CONT.

Car mirror.Turbulence (LES) – Courtesy of Cascade Inc. – Palo Alto



AT COMPONENT LEVEL – GROWING COMPLEXITY – CONT.

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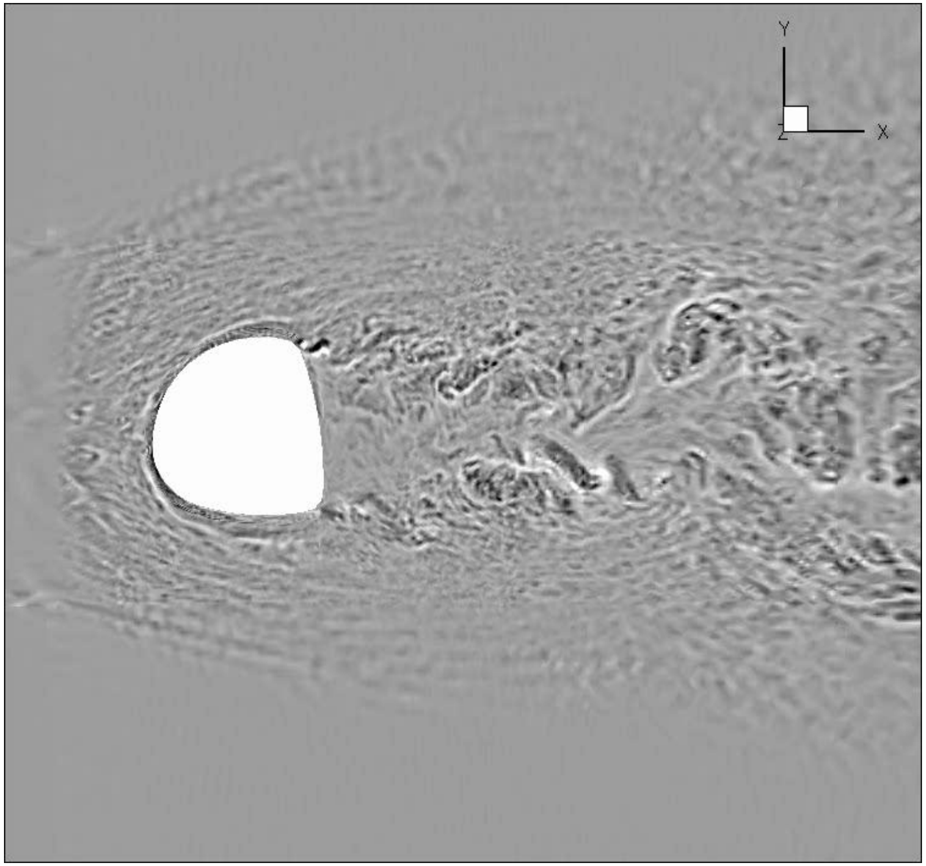
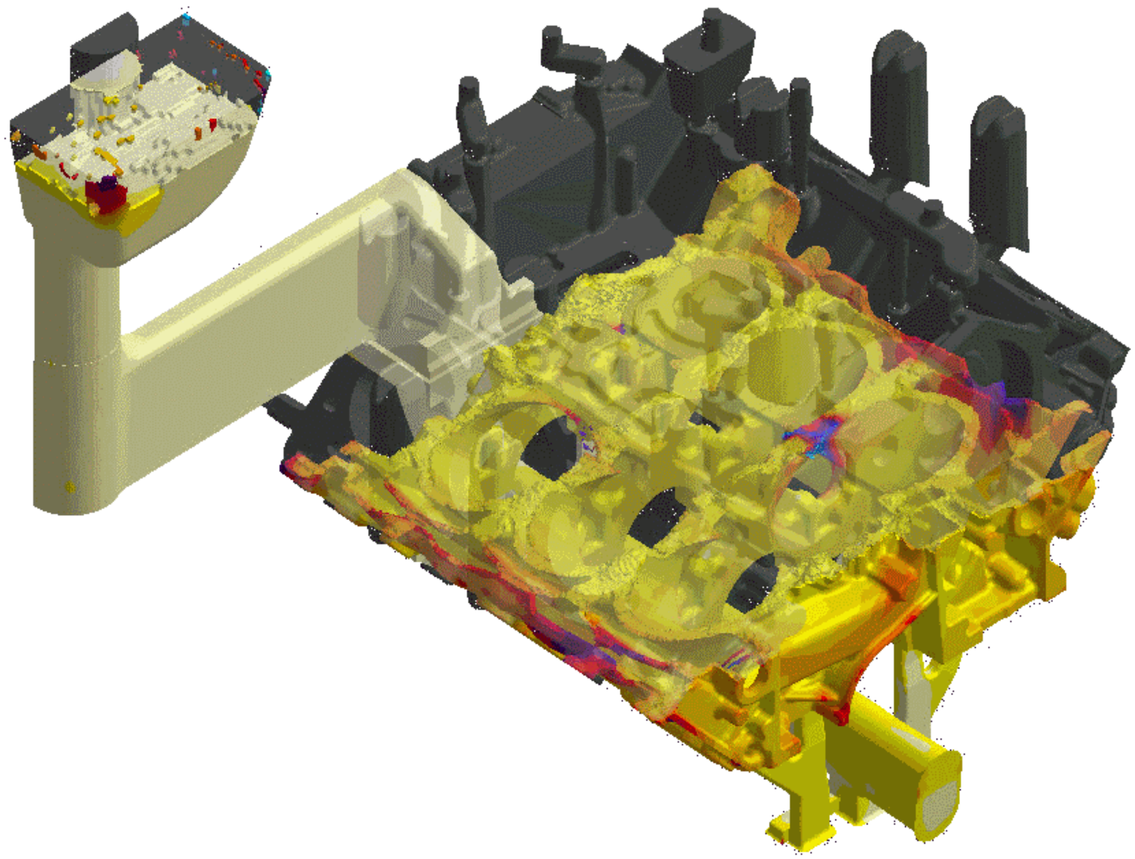


AT COMPONENT LEVEL – GROWING COMPLEXITY – CONT.

Cast-iron enginblock - (filling sequence) – Courtesy of AUDI



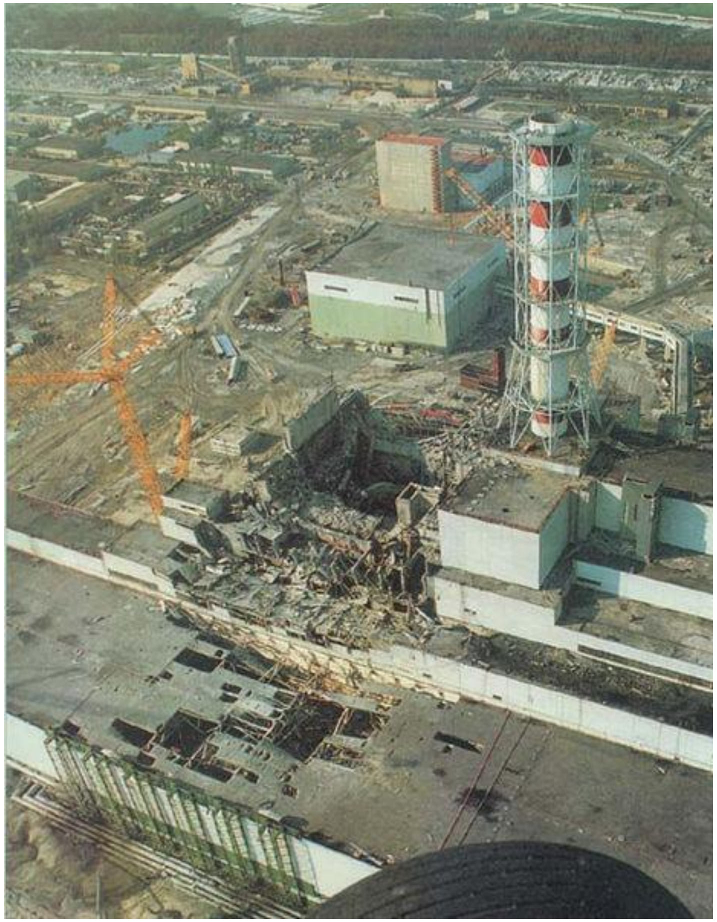
AT SYSTEM LEVEL – GROWING COMPLEXITY

Chernobyl – Shelter Self Confinement – Courtesy of CIMOLAI

- **Chernobyl disaster** (locally Ukrainian: Чорнобильська катастрофа, *Chornobylska Katastrofa – Chornobyl Catastrophe*) was a catastrophic nuclear accident that occurred on 26 April 1986 at the Chernobyl Nuclear Power Plant in Ukraine (then officially Ukrainian SSR), which was under the direct jurisdiction of the central authorities of the Soviet Union. An explosion and fire released large quantities of radioactive contamination into the atmosphere, which spread over much of Western USSR and Europe. It is widely considered to have been **the worst nuclear power plant accident in history**, and is one of only two classified as a level 7 event on the International Nuclear Event Scale (the other being the Fukushima Daiichi nuclear disaster in 2011).[1] The battle to contain the contamination and avert a greater catastrophe ultimately involved over 500,000 workers and cost an estimated 18 billion rubles, crippling the Soviet economy.

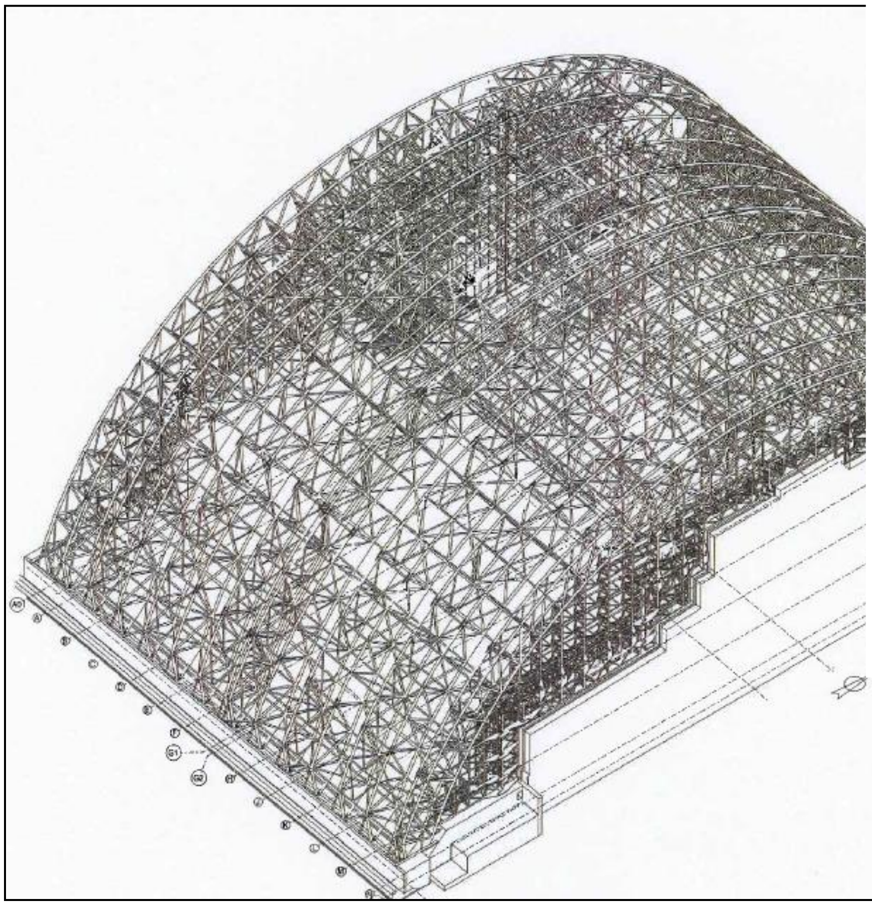
PROJECT	ПРОЕКТ
SHELTER IMPLEMENTATION PLAN (SIP) NEW SAFE CONFINEMENT DESIGN, CONSTRUCTION AND COMMISSIONING CONTRACT N° SIP08-1-001	ПЛАН ОСУЩЕСТВЛЕНИЯ МЕРОПРИЯТИЙ (ПОМ) НОВЫЙ БЕЗОПАСНЫЙ КОНФАЙНМЕНТ КОНТРАКТ НА ПРОЕКТИРОВАНИЕ, СТРОИТЕЛЬСТВО И ВВОД В ЭКСПЛУАТАЦИЮ № SIP08-1-001
EMPLOYER	ЗАКАЗЧИК
THE STATE SPECIALIZED ENTERPRISE "CHERNOBYL NPP"	ЧАЕС ГОСУДАРСТВЕННОЕ СПЕЦИАЛИЗИРОВАННОЕ ПРЕДПРИЯТИЕ "ЧЕРНОБЫЛЬСКАЯ АЭС"
ENGINEER THE PROJECT MANAGEMENT UNIT (PMU)	ИНЖЕНЕР ГРУППА УПРАВЛЕНИЯ ПРОЕКТОМ (ГУП)
ЧАЕС BECHTEL	Battelle . . . Putting Technology To Work
CONTRACTOR	ПОДРЯДЧИК
NOVARKA, a Joint Venture made of : VINCI Construction Grands Projets (VCGP, leader) and Bouygues Travaux Publics (ByTP, member)	NOVARKA Совместное предприятие NOVARKA в составе: VINCI Construction Grands Projets (VCGP-ведущая фирма) и Bouygues Travaux Publics (ByTP - участник)

Project Name	Originator	Sub-division	SIP Task	Task Breakdown Code	Type of Document	Serial Number	Revision	Internal
Наименование проекта	Автор	подразде ление	Задача ПОМ	Шифр позадачной разбивки	Тип документа	Серийный номер документа	Редакция	Revision

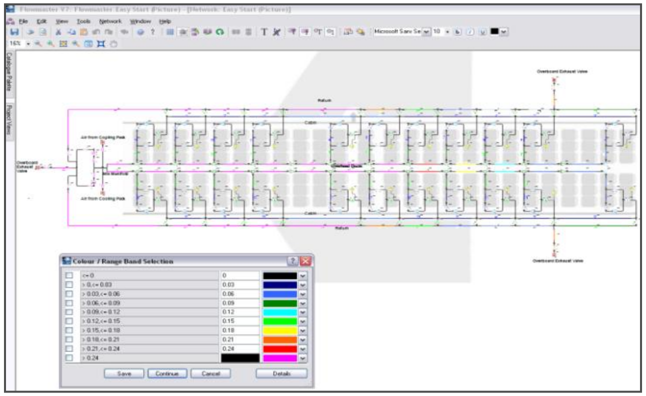


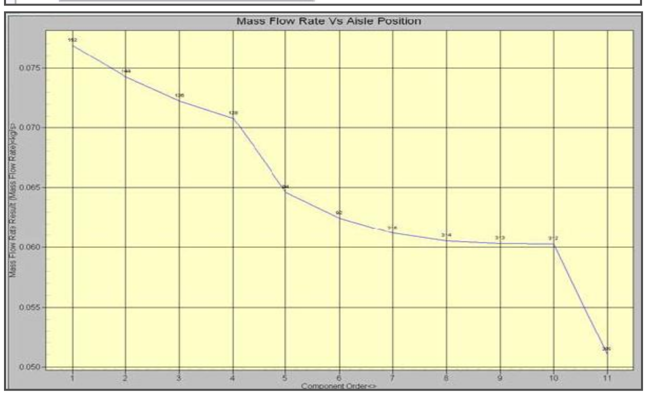
AT SYSTEM LEVEL – GROWING COMPLEXITY – CONT.

Chernobyl – Shelter Self Confinement – Courtesy of CIMOLAI

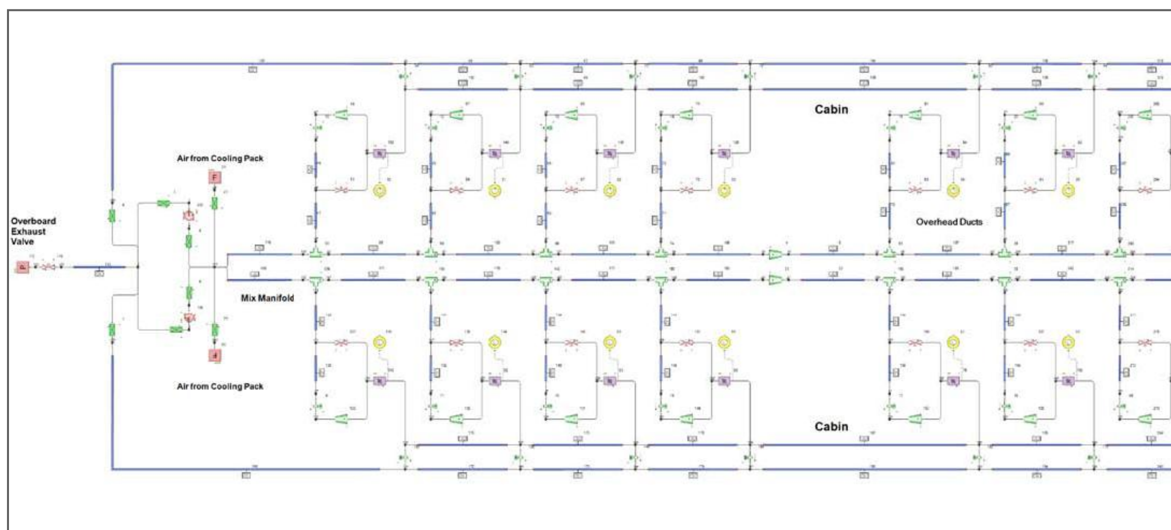


AT SYSTEM LEVEL





- **Highly non-linear behaviours**
  - Tuning the system
  - Sensitivity analysis
  - Real-time answers
- **Qualifying the single component**
- **Mastering the equations**



Ex: Aircraft cabin conditioning and pressurisation

AT MANAGEMENT LEVEL

- Process integration
- …and multi-objective design optimization
- Knowledge capture and management
  - (PDM-PLM)
- Business intelligence, business analytics, visual analytics
  - MCDM, Data-Mining, …
- Uncertainty quantification and mitigation
  - Forward uQ (robust design)
  - Bacward uQ
- QA
  - Six-sigma approaches
  - Reliability
- DDDSS

AT MANAGEMENT LEVEL – PIDO/MDO

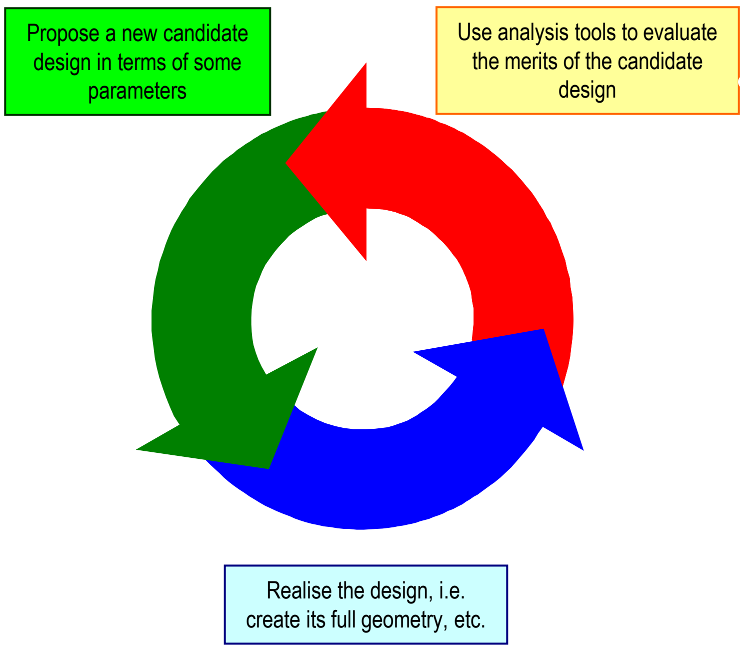
- **Process integration and design optimization**
  - According to DARATECH: *"Process integration and design optimization (PIDO) comprises software and services intended to help users* ***automate and manage the setup and execution*** *of digital prototyping, simulation and analysis tools;* ***optimize one or more aspects*** *of a product design* ***by iterating*** *analyses of the design* ***across a range of input parameters toward a specified set of target conditions****; and* ***integrate or coordinate*** *analysis results from multiple physical domains in order to yield* ***a more holistic model of product performance****."*

DARATECH, Inc.
Engineering IT Market Research & Technology Assessment

AT MANAGEMENT LEVEL – PIDO/MDO – CONT.

(Preconditions)

Recent research on how human designers work (1) supports the view that



humans use a basic Generate-Realise-Evaluate process structure which is similar to that which underlies automated search

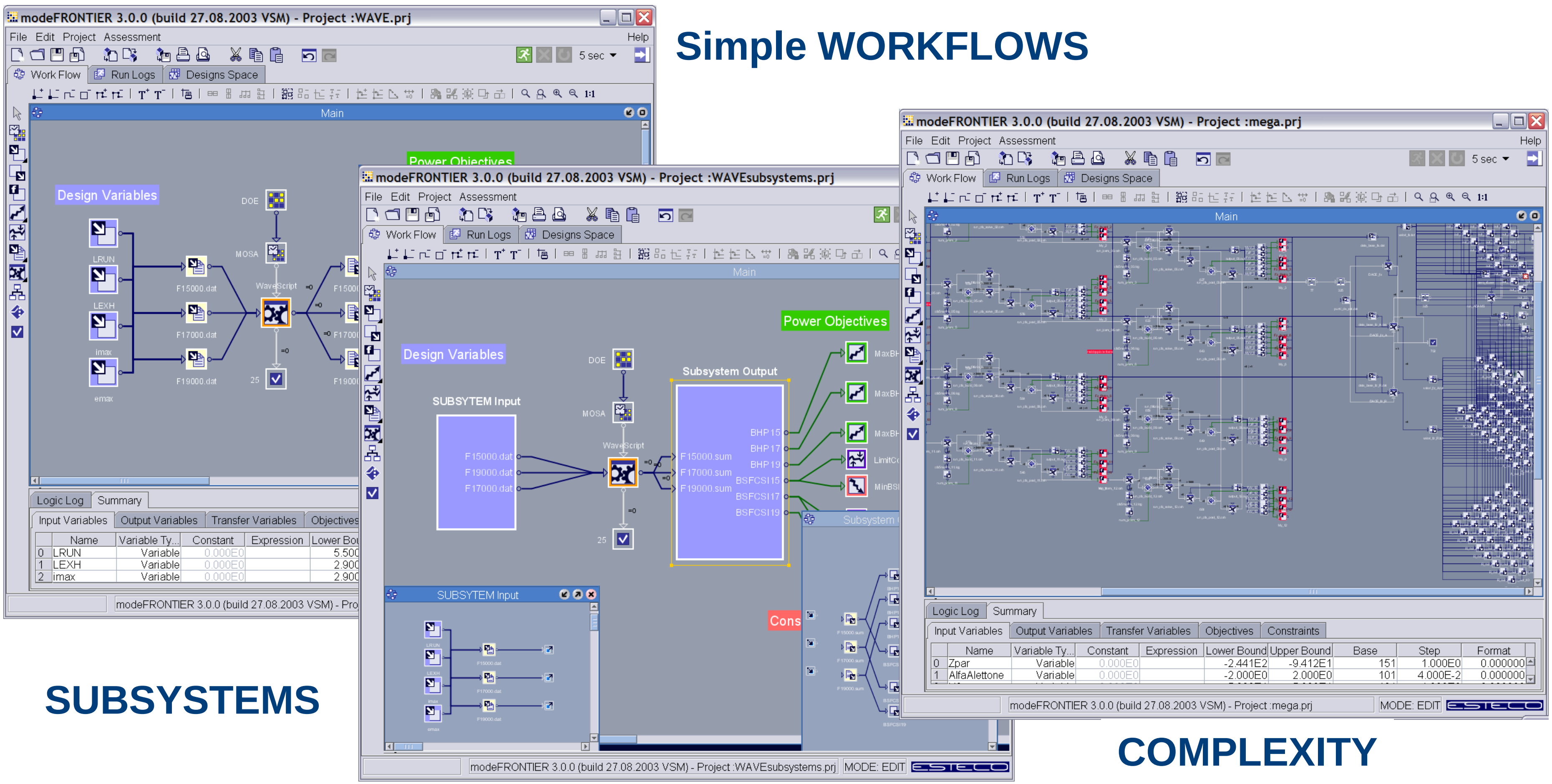
this suggests that solution methods can be structured so that the human searcher can be freely interchanged with automated search

(1) AHMED, S, BLESSING, L T M, WALLACE, K M - The relationships between data, information and knowledge based on a preliminary study of engineering designers, DETC 99, ASME Design Theory and Methodology, Las Vegas, Nevada, USA, 1999

AT MANAGEMENT LEVEL – PIDO/MDO – CONT.

(Process integration - workflow)

Simple WORKFLOWS

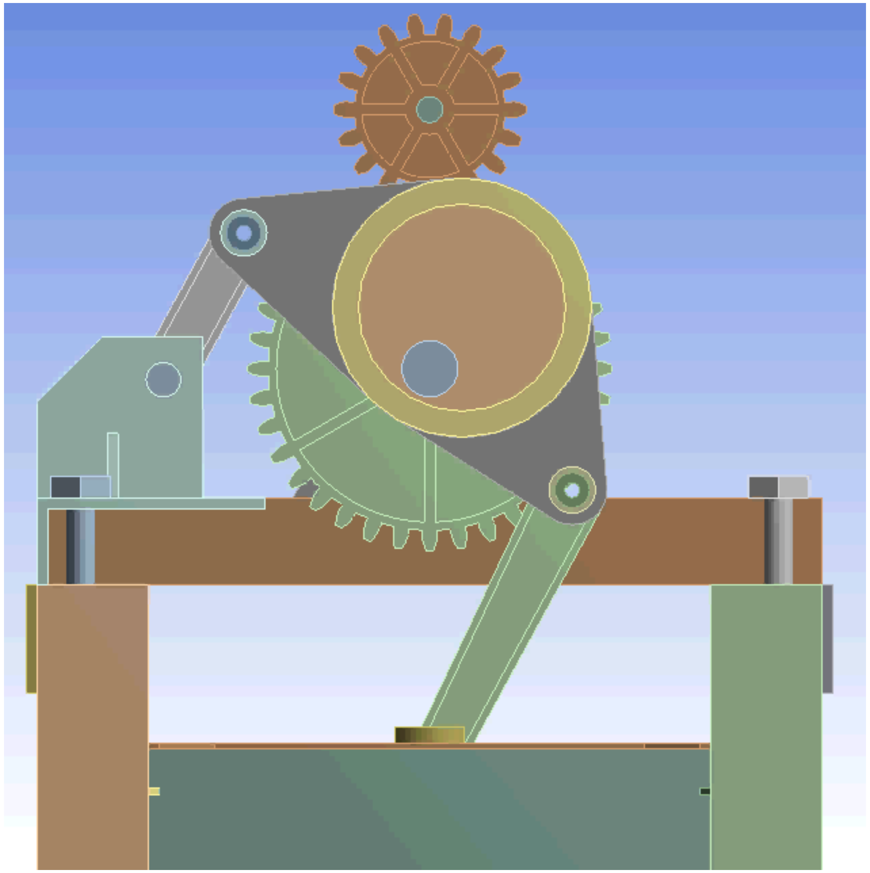


SUBSYSTEMS

COMPLEXITY

AT MANAGEMENT LEVEL – PIDO/MDO – CONT.

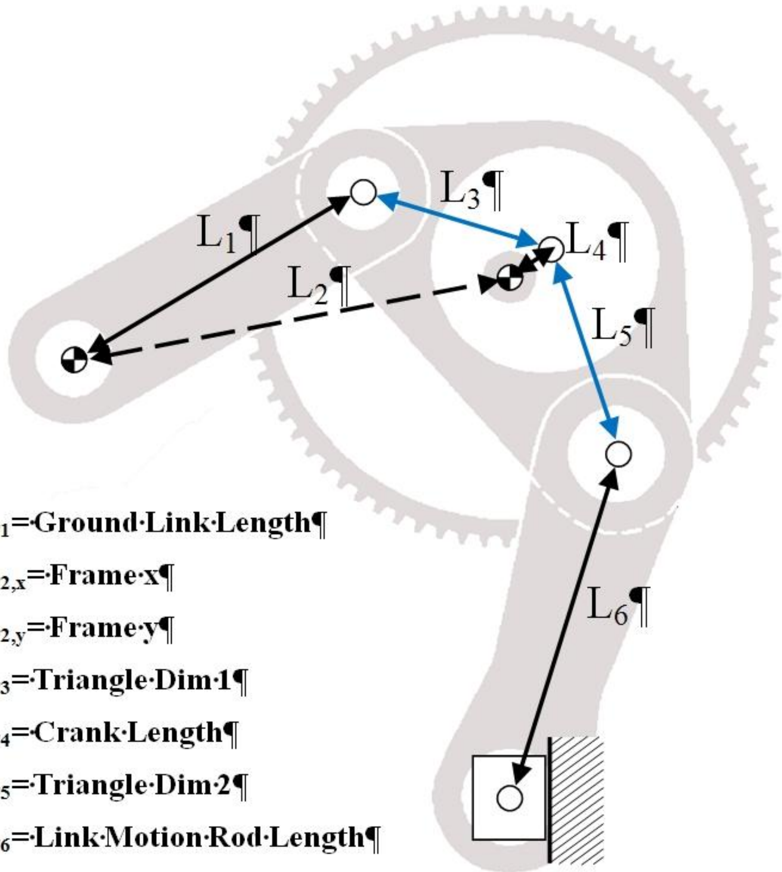
(Ex: Optimization of a mechanical press for sheet metal forming)



- DECREASE punch velocity during the working stroke
  - softer impacts increase both press and die life
  - allow higher punch penetration
- DECREASE punch acceleration during the working stroke
  - uniform punch speed gives more efficient material flow and so higher product quality
- DECREASE punch jerk during the working stroke
  - reduce noise and vibrations

AT MANAGEMENT LEVEL – PIDO/MDO – CONT.

(Ex: scheme, parameters, and optimization process set-up)

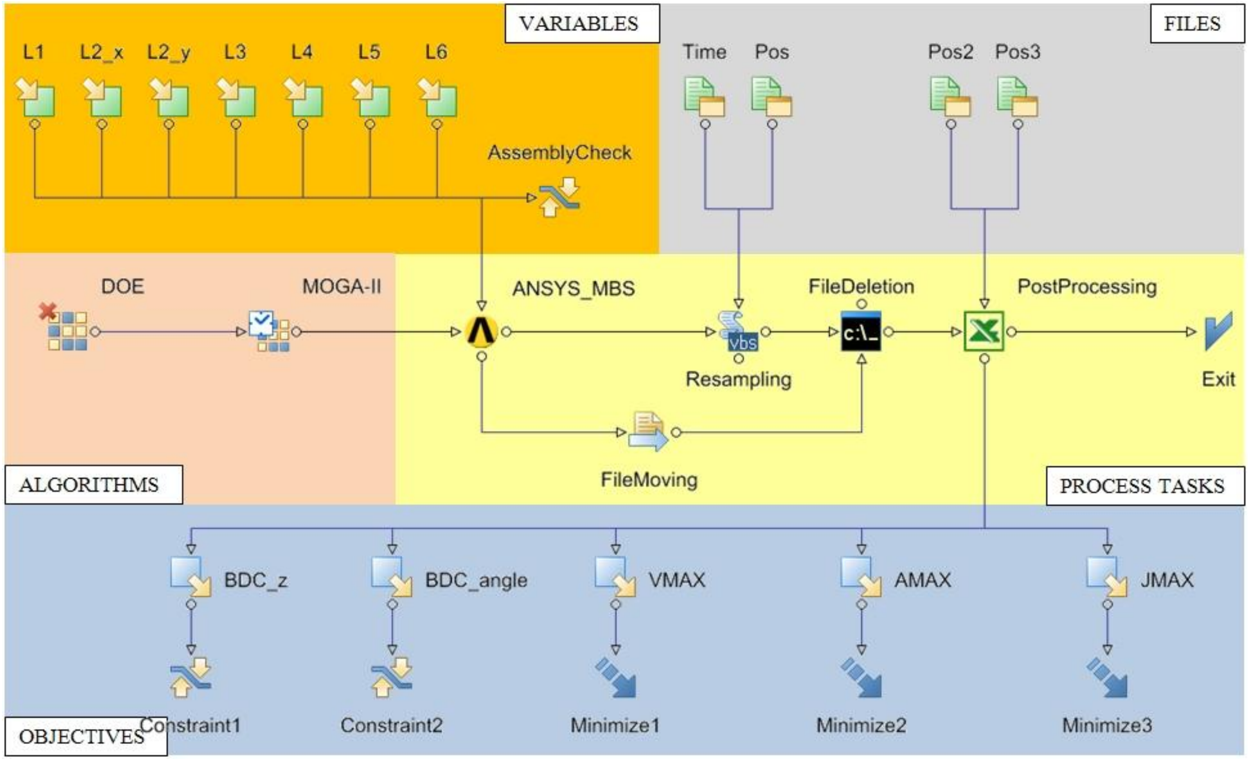


L_1=Ground·Link·Length¶
$L_{2,x}$=Frame·x¶
$L_{2,y}$=Frame·y¶
L_3=Triangle·Dim·1¶
L_4=Crank·Length¶
L_5=Triangle·Dim·2¶
L_6=Link·Motion·Rod·Length¶

- **6 independent dimensions** govern the mechanism response
- **constraints** on dimensions keep the assembly possible
- **Kinematics** is faithfully simulated through a parameterized multibody model (rigid
- **Initial values** are taken from an existing design
- A **Multi-Objective Optimization Algorithm** is requested to improve 3 objectives while playing with 6 parameters

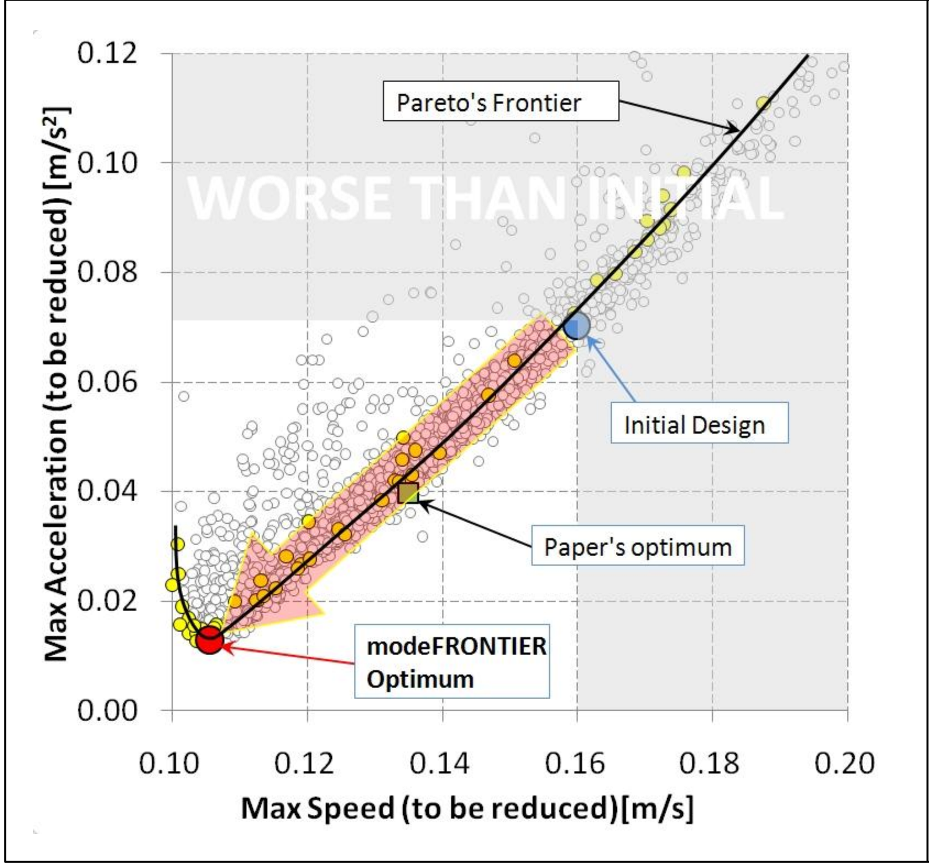
AT MANAGEMENT LEVEL – PIDO/MDO – CONT.

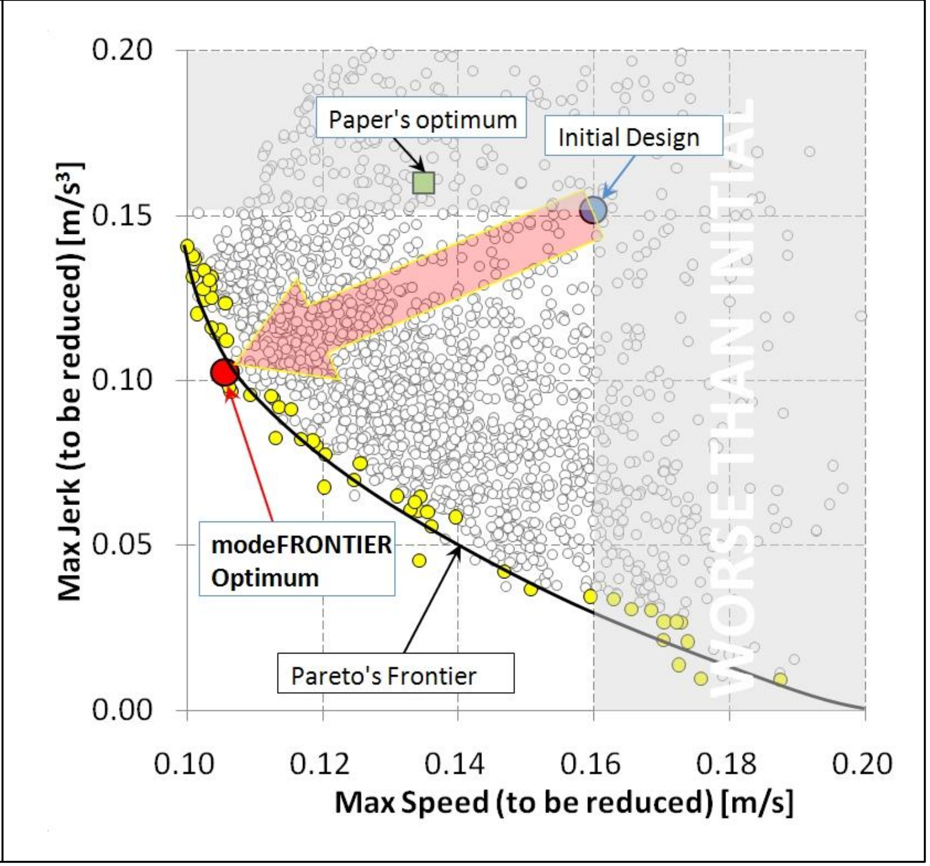
(Ex: Problem logic - workflow)



Going to compare mF results with those obtained in *Bojan Vohar,Karl Gotlih et Joze Flasker, Optimization of Link-Drive Mechanism for Deep Drawing Mechanical Press", Journal of Mechanical Engineering n. 48 (2002), pp. 601-612".*

AT MANAGEMENT LEVEL – PIDO/MDO – CONT.

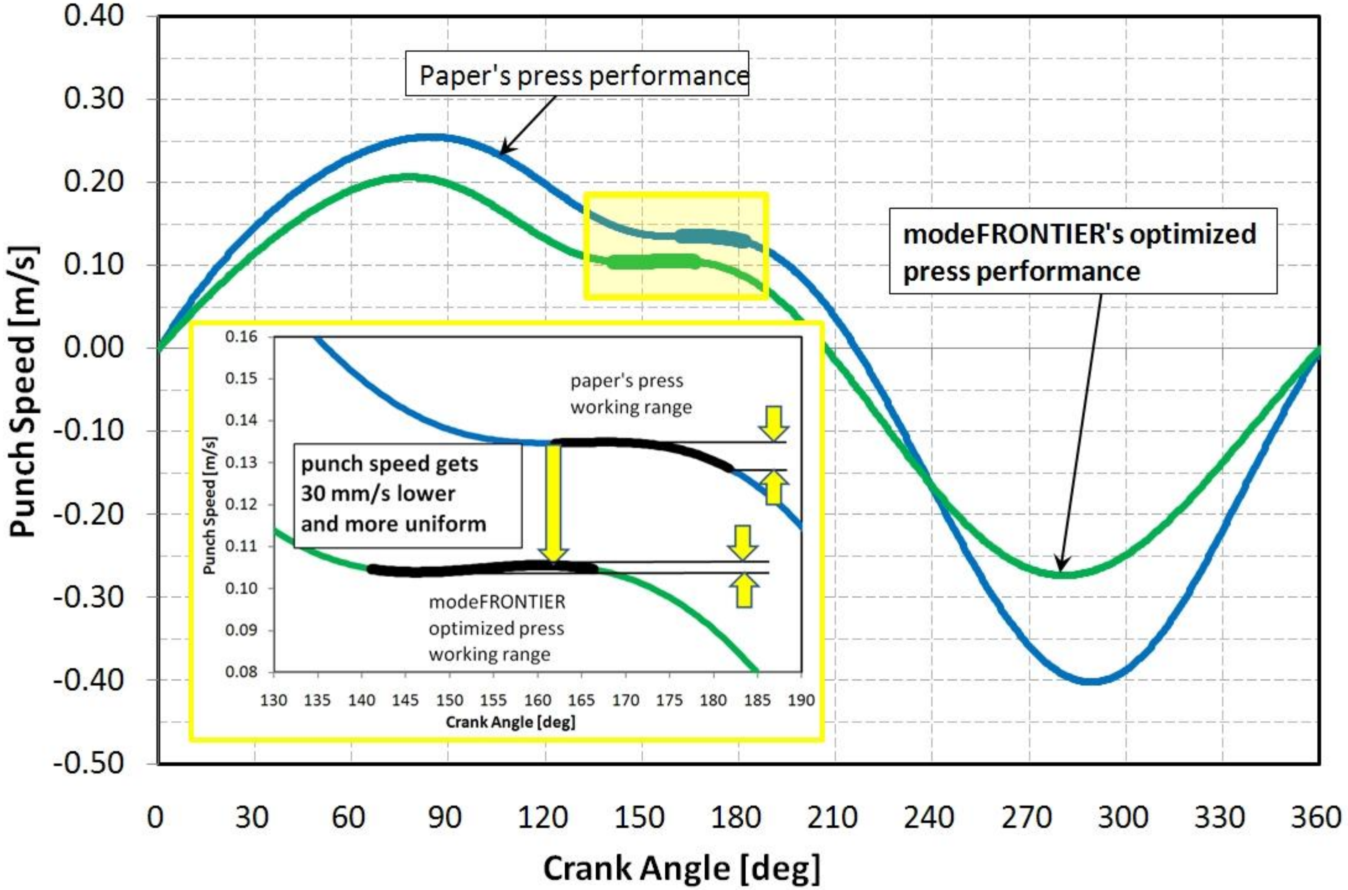




Optimal design reached after about **2000 runs** – much better than ref.

AT MANAGEMENT LEVEL – PIDO/MDO – CONT.

(Ex: Optimized kinematical performances)



BARRIERS TO THE INTRODUCTION OF HPC (AS TO E.S.)

- **Knowledge/Attitude of practitioners**
  - **SBES** (simulation based engineering science) is **a combination of domain-specific engineering science, applied mathematics and computer science.** The report (May 2006) of the National Science Foundation Blue Ribbon Panel on Simulation-Based Engineering Science, titles "**Revolutionizing Engineering Science through Simulation**", uses the expression "**crisis of knowledge explosion**", referring to the **dramatic expansion of the knowledge base required to advance modern simulation**. The expansion ignores the traditional boundaries between academic disciplines, which have long been compartmentalized in the rigid organizational structures of today's universities.
  - **Validation**. What **level of confidence can one assign a predicted outcome** in light of what may be known about the physical system and the model used to describe it? The twentieth century philosopher of science Karl Popper asserted that a scientific theory could not be validated; it could only be invalidated. **Verification processes, on the other hand, are mathematical and computational enterprises. They involve software engineering protocols, bug detection and control, scientific programming methods, and, importantly, a posteriori error estimation.**

BARRIERS TO THE INTRODUCTION OF HPC

- **Inadequacy of commercial software. Business model/policy of software vendors**
  - **Poor scalablity** and/or non-homogeneous scalability in the different application sectors (see general purpose software)
  - Inadequacy of **algorithms** (Too often the impact of algorithms on reducing the time complexity (number of operations) and space complexity (size of memory) is unappreciated
  - Hardware dependency
  - Inadequate **data visualization** (dynamic management of data, robustness, efficienty and flexibility) - New methods for **interactively visualizing** largescale,time-dependent data are needed. In addition, we need methods for visualizing vector and tensor fields, **field data collected experimentally from multiple sources, and the ability to visualize data from both a global and local perspective**.
  - Optimization requires **multiple** CAE **software licences**
  - **…**

BARRIERS TO THE INTRODUCTION OF HPC

- **Application context**
  - **Legacy software** remains a persistent problem because the lifetime of a computational science application is significantly greater than the three- to five-year life cycle of a computing system
  - **QA** procedures
  - Information is being created at an exponential rate. In SBES the use and generation of immense data sets are integral components.
  - Engineers need assistance (from engineering simulation) in **making complex decisions fast**, have often to deal with **over-specified situations**.
  - **Metamodelling** is often preferred in the day-to-day design
  - HPC as an exception
  - …

CONCLUSIONS

- Within the next decade or two **we will get to a point of science fiction becoming science fact** where design engineers will be spending all their time imagining product variants and product innovations and the computers will be churning away in the background spitting out predictions they review in real time.
- The challenges of making progress, however, are as substantial as the benefits. We need
  - to find methods for linking phenomena in **systems that span large ranges of time and spatial scales**
  - to be able to describe **macroscopic events** in terms of **subscale behaviors**.
  - **better optimization procedures** for simulating **complex systems**, procedures that can account for uncertainties.
  - frameworks for **validation, verification**, and uncertainty quantification.
  - methods for rapidly generating **high-fidelity models** of **complex geometries** and **material properties**.

TANKYOU FOR YOUR ATTENTION