20 years of methodologies applied to the welding of large components

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AFM-SNS 26th of March 2015

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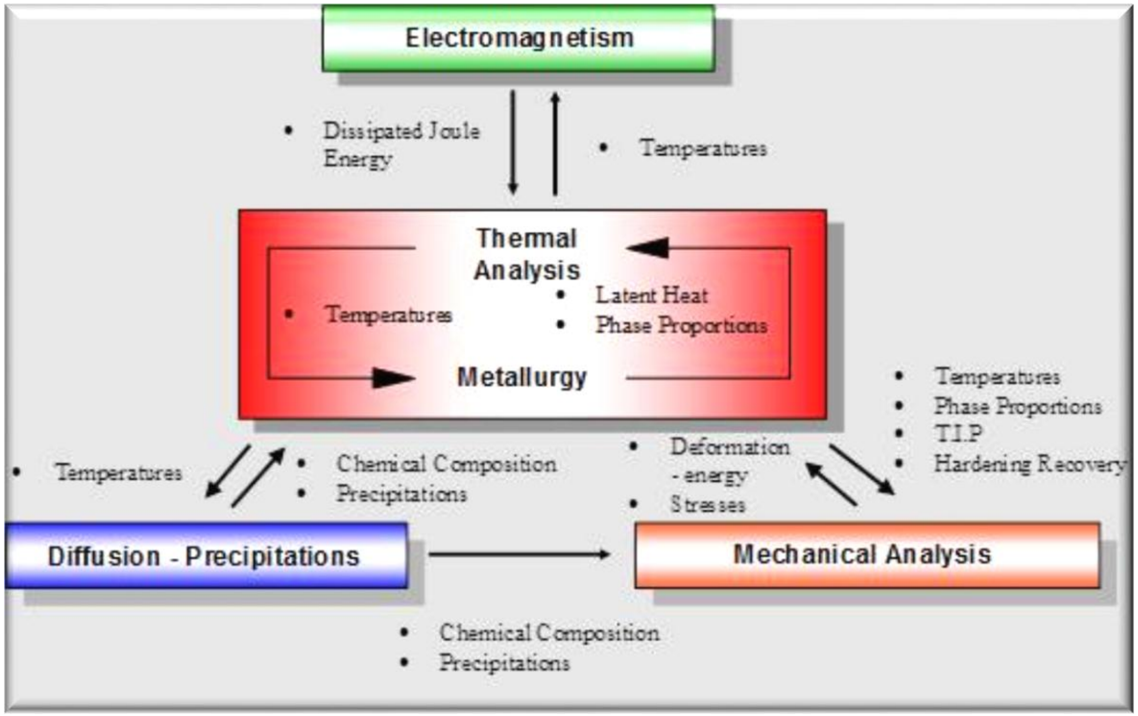
Introduction

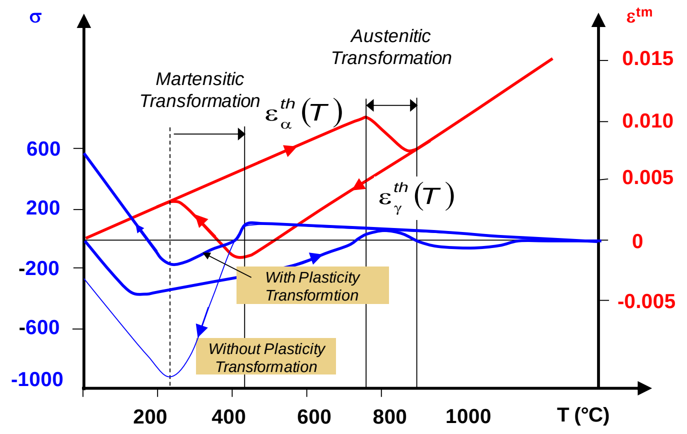
Welding simulation: Treasure hunting, Graal quest?

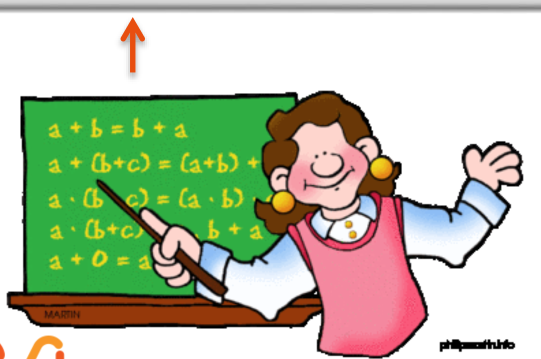
- Welding simulation in its 30ies:
- The needs are there:
  - Worldwide competition
  - The profits are done with added value parts
- The means are almost available
  - Computer power
  - Dedicated software
  - Knowledge (methods)

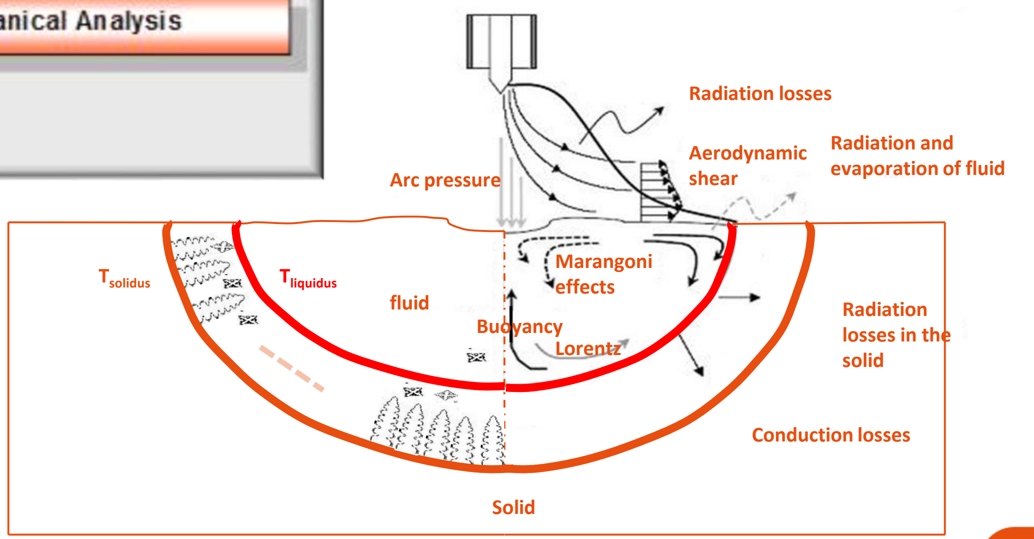
- Next years challenge: Impact of manufacturing on service life of components and assemblies.

Physics should not be a bottleneck





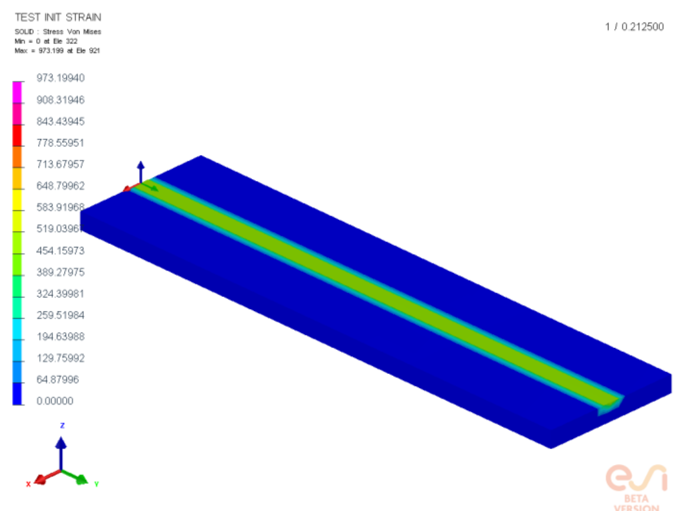


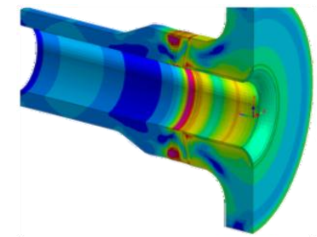


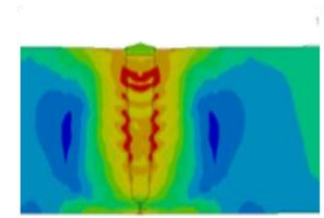
What is a large object?

From the eyes of a welding simulation persona

- Components size
  - Nuclear component
  - BIW
  - …
- Welding length
  - Multipass
  - Additive Manufacturing







- Large components with long welds
  - Heat exchanger
  - Turbines
  - Complex designs (Iter Vaccum chamber, ships, cars...)

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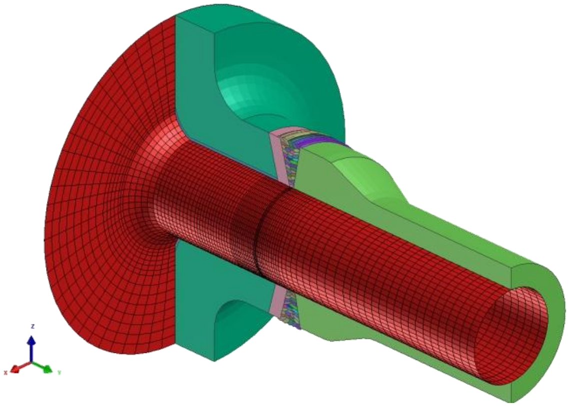
What is expensive?

- Model description:
  - CAD 2 Mesh
  - Process definition

- Solution:
  - Physics:
    - Heat transfer
    - Metallurgy
    - Mechanical
    - ...
  - Numeric
    - Element types
    - Coupling or chaining?
    - Methods
  - Solving

- Analysis of results
  - Extract information: G(Stress, strain, temperature, internal var...) = F(X, t)
  - Virtual reality visualization tools

Example: Service life assessment of a welded large component



- Pre-heat to 160° C
- Deposit Cladding Layer
- Deposit Buttering Layer
- Post Weld Heat Treatment for Stress Relief
- Root pass of Groove Weld
- Continue Groove welding until all beads are deposited
- Release Clamps
- Post-weld Machining of Groove weld
- **Service Cycle (Temperature, Pressure)**

Joint	Source	Initial Time	End Time	Velocity	EPUL	Efficiency
J01_LOAD	NA	0.000	1900.000	NA	NA	NA
J02_LOAD	NA	1900.000	3800.000	NA	NA	NA
J03_LOAD	NA	228000.000	467000.000	NA	NA	NA
J04_LOAD	NA	467000.000	468000.000	NA	NA	NA
J05_LOAD	NA	468000.000	469000.000	NA	NA	NA
J06_LOAD	NA	469000.000	470000.000	NA	NA	NA
J07_LOAD	NA	470000.000	471000.000	NA	NA	NA
J08_LOAD	NA	471000.000	472000.000	NA	NA	NA
J09_LOAD	NA	472000.000	473000.000	NA	NA	NA
J10_LOAD	NA	473000.000	474000.000	NA	NA	NA
J11_LOA[illegible]	NA	474000.000	475000.000	NA	[illegible]	[illegible]
J12_LOA[illegible]	[illegible]	475000.000	476000.000	NA	[illegible]	[illegible]
J13_LOAD	[illegible]	[illegible]	[illegible]	NA	[illegible]	[illegible]
J14_LOAD	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
J15_LOAD	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
J16_LOAD	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
J17_LOAD	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
J18_LOAD	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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J20_LOA[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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J28_LOAD	NA	491000.000	492000.000	NA	[illegible]	[illegible]
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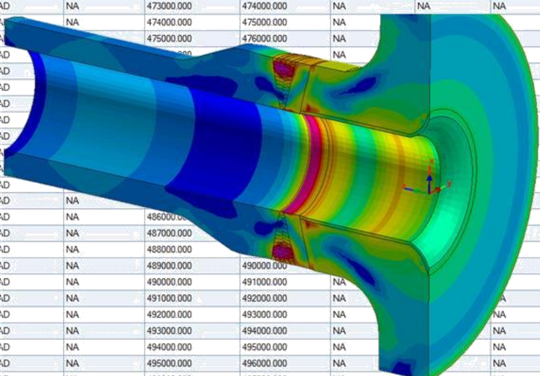
J30_LOAD	NA	493000.000	494000.000	NA	[illegible]	NA
J31_LOAD	NA	494000.000	495000.000	NA	[illegible]	NA
J32_LOAD	NA	495000.000	496000.000	NA	[illegible]	NA
J33_LOAD	NA	496000.000	497000.000	NA	[illegible]	NA
J34_LOAD	NA	497000.000	498000.000	NA	NA	NA
J35_LOAD	NA	498000.000	499000.000	NA	NA	NA
J36_LOAD	NA	499000.000	500000.000	NA	NA	NA
J37_LOAD	NA	500000.000	501000.000	NA	NA	NA
J38_LOAD	NA	501000.000	502000.000	NA	NA	NA
J39_LOAD	NA	506000.000	510000.000	NA	NA	NA

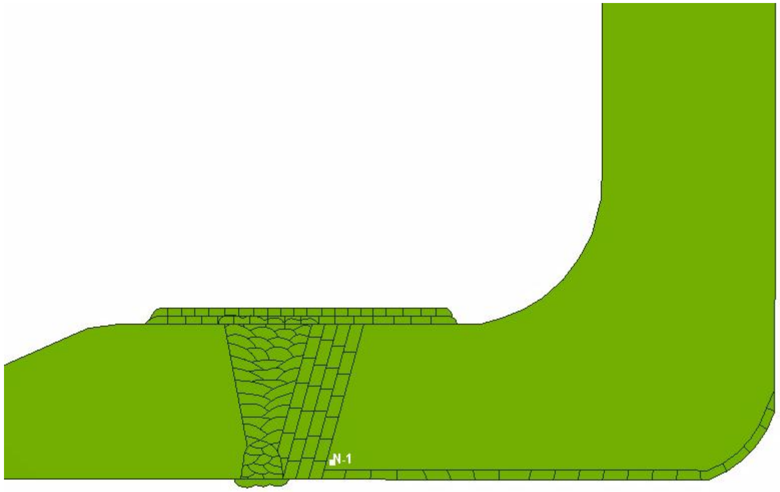


CLAD_THERMAL_CYCLE

PWHT_THERMAL_CYCLE

WELD_THERMAL_CYCLE

SERVICE_THERMAL_CYCLE



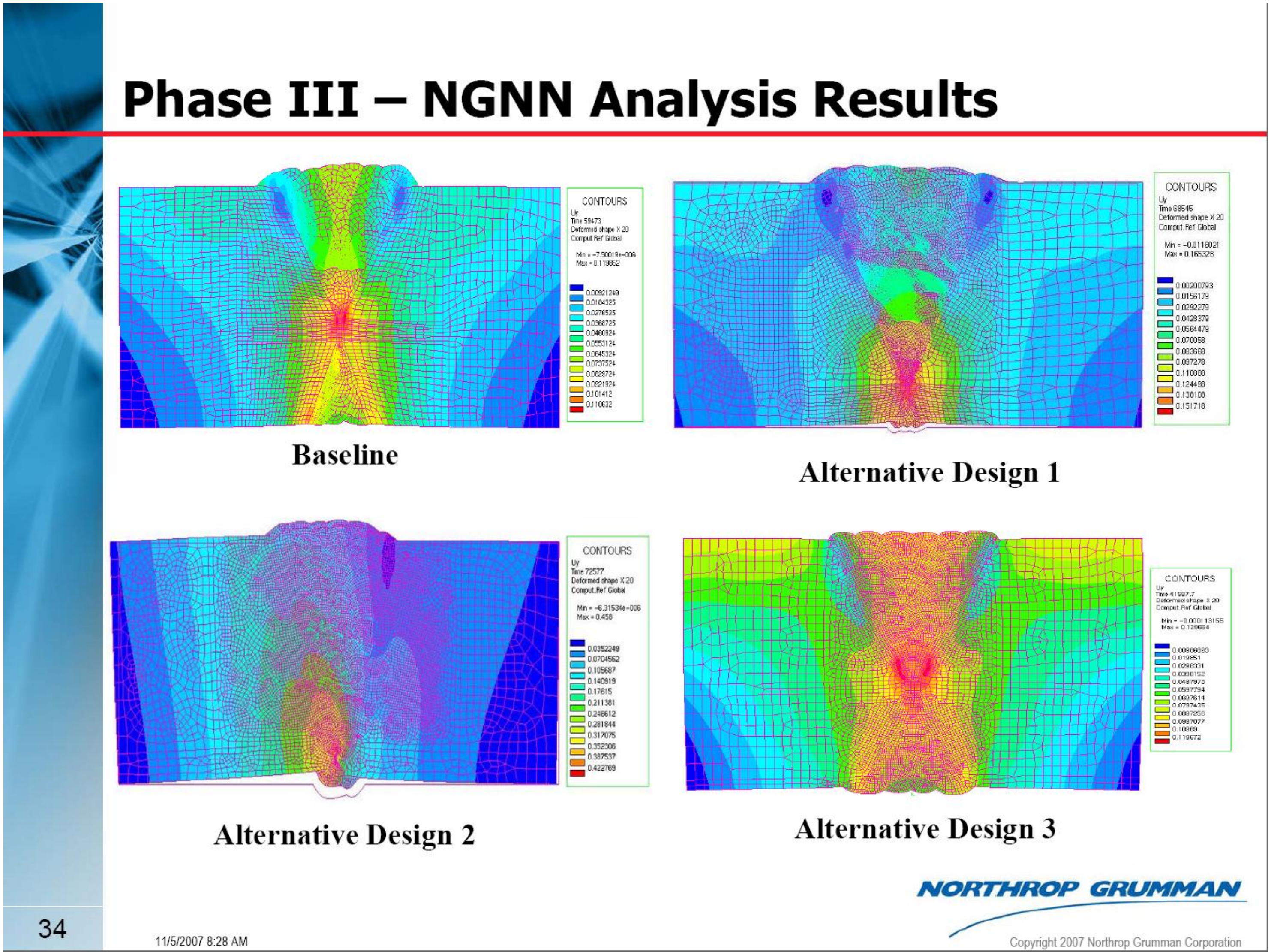
1: Be simple

Keep It Simple Stupid (KISS)

- 2D models
  - Multi-pass
- Welding of shells 2.5 D
  - Automotive
- (Pass grouping)
  - Multi-pass in 3D
- (Super-elements)
  - Turbines
- Inherent strain and Thermal cycle methods
  - Very Large components

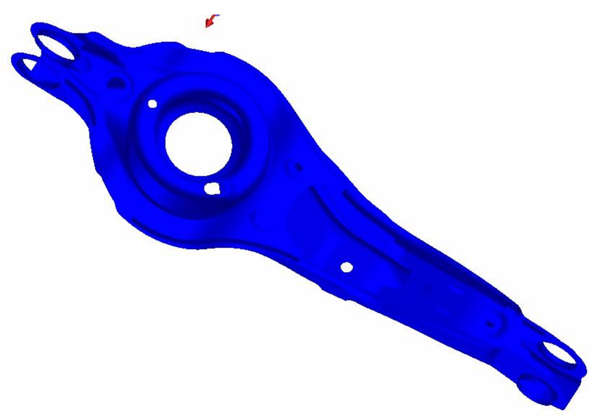
Transient Welding Modeling

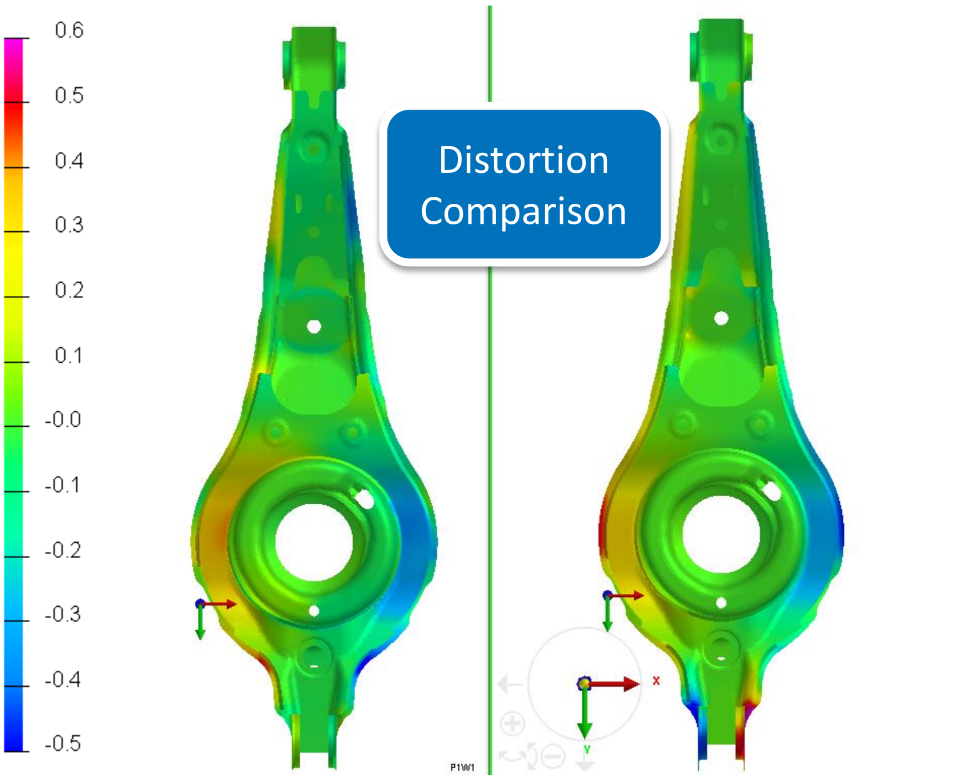
Process optimization for Multi-Pass Welding of thick components



Welding of shells 2.5D

Simplified methodologies (automotive)





Detail Design	Early feasibility
10 Hours	15 Minutes
DMP 10 CPU	DMP 10 CPU

2: Be specific

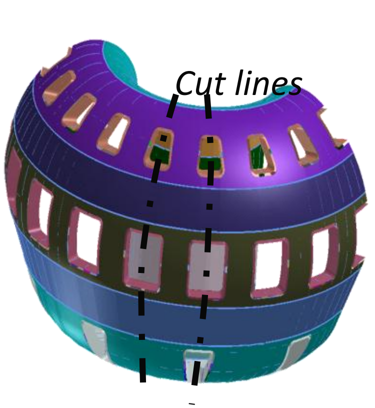
Usage of the welding process specificities

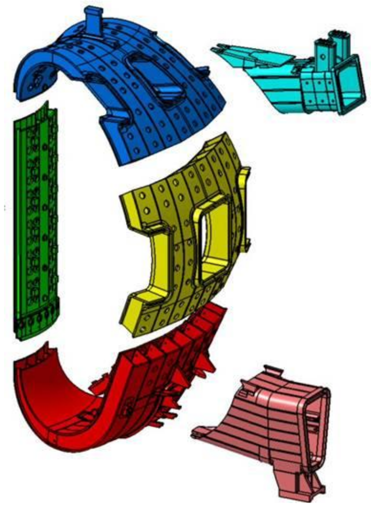
- Stationary process
  - Steady state computation
    - Ariane tank
      - Modelization of Residual stresses in Aluminum welded joints, J.P. Bonnafé, C. Destandau, Aérospatiale Les Mureaux, France, 25-28 September **1995**

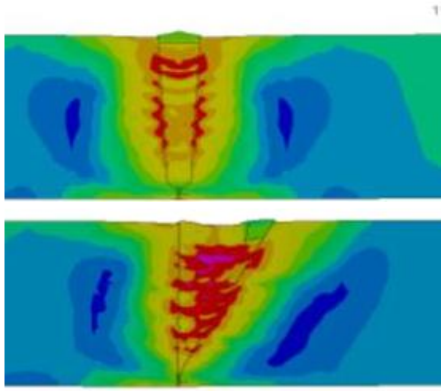
- Local process: Local-global methods
  - DSIGN project 1998-2001:
    - S.A. Tsirkas, P. Papanikos, K. Pericleous, N. Strusevich, F. Boitout, J.M. Bergheau, « Evaluation of distortions of laser welded shipbuilding parts using a local-global finite element approach », Science and Technology of Welding and Joining, Vol. 8, 2, The Institute of Materials, **2003**, pp. 79-88.
  - B. Souloumiac, F. Boitout, J.M. Bergheau, « A new local global approach for modelling of welded steel component distorsions », Proc. of 6th Int. Seminar on Numerical Analysis of Weldability, UK **2001**, and Mathematical modelling of Weld Phenomena 6, edited by Pr. H. Cerjak, The Institute of Materials, London, **2002**,pp 997-1013.

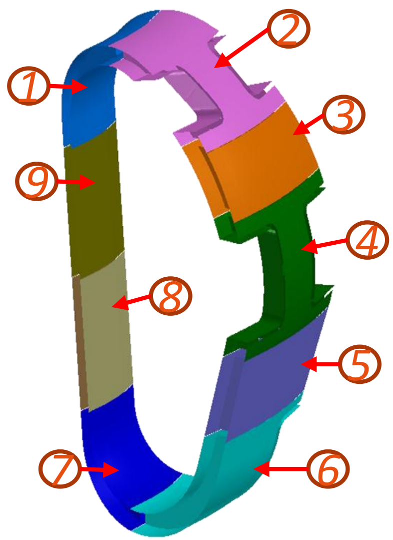
Local-Global method

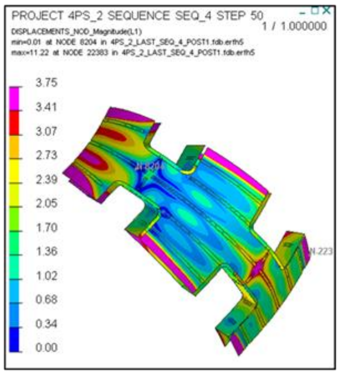
ITER Vaccum chamber

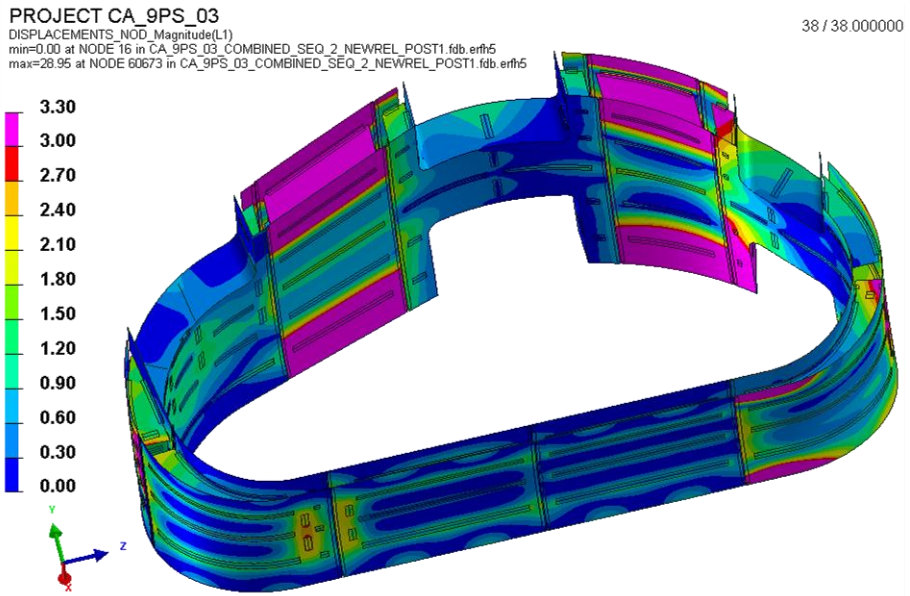












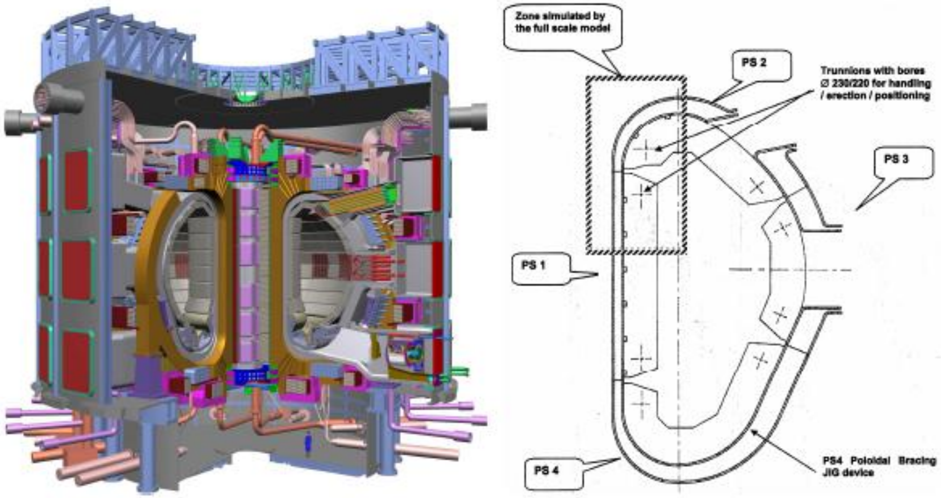


Fig. 1 The fusion reactor and the vacuum vessel with zone for the full-scale model

Fig. 3 The PS1 main manufacturing sequences

Fig. 4 The PS2 main manufacturing sequences

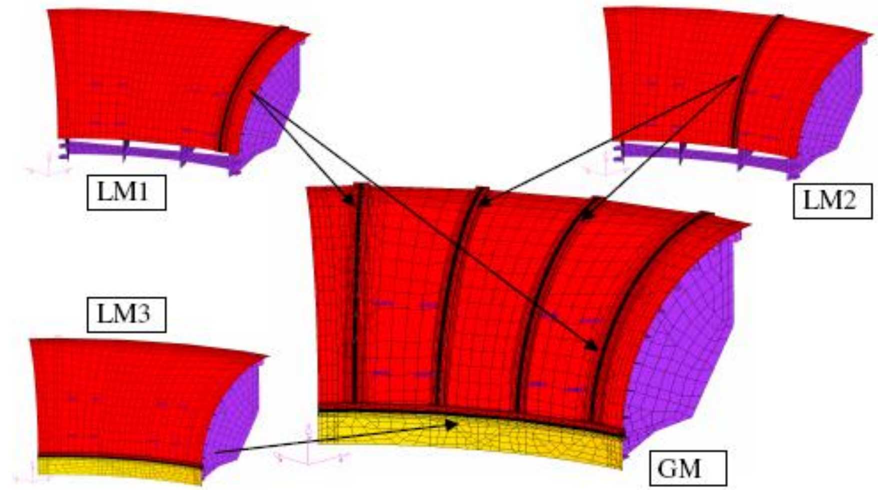


Fig. 6 PS2 (inner shell) local and global models

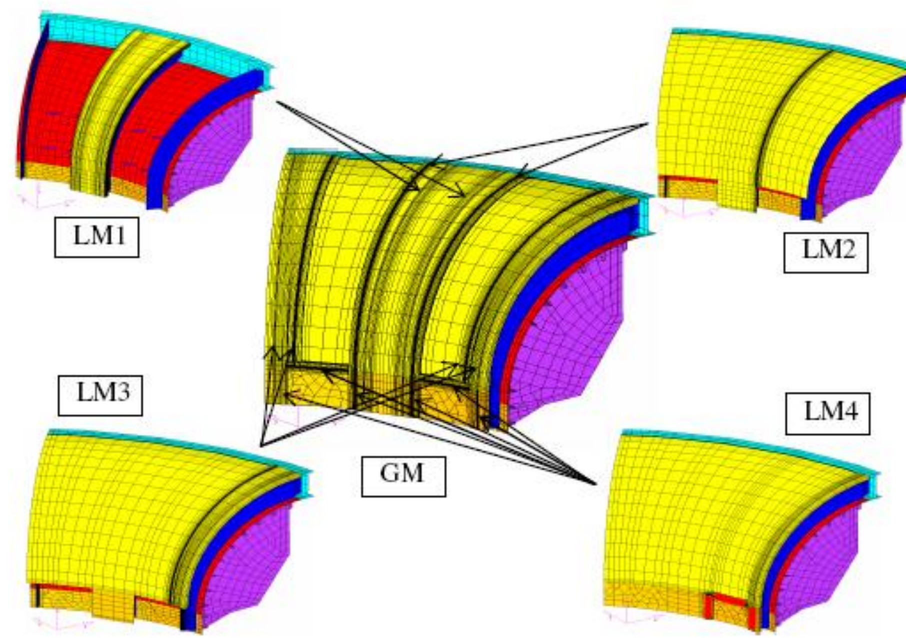


Fig. 7 PS2 (outer shell) local and global models

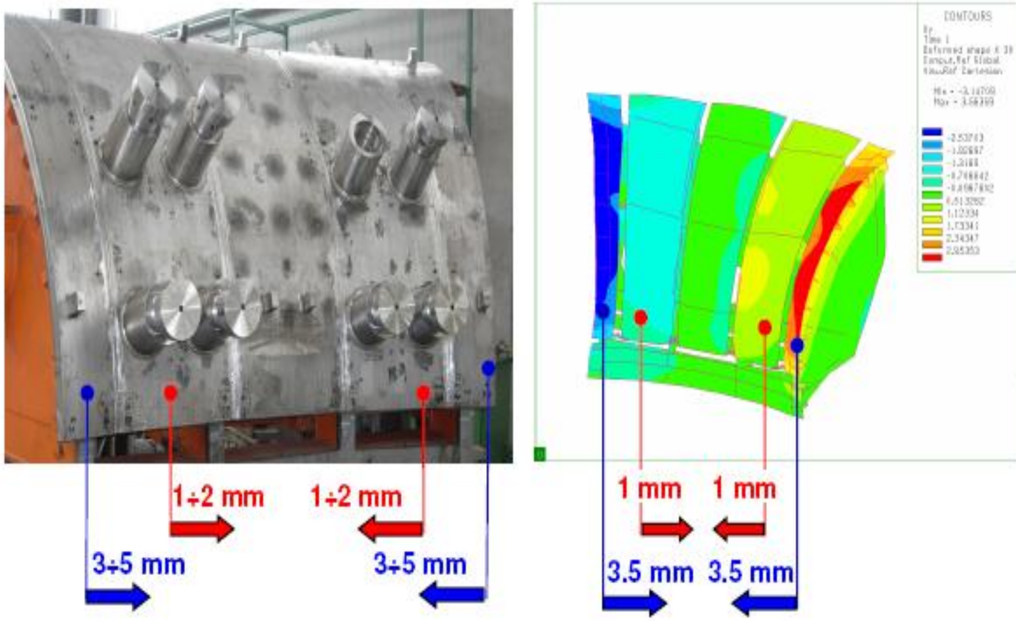


Fig. 9 Comparison of measured and computed shrinkages after PS2 outer shell welding

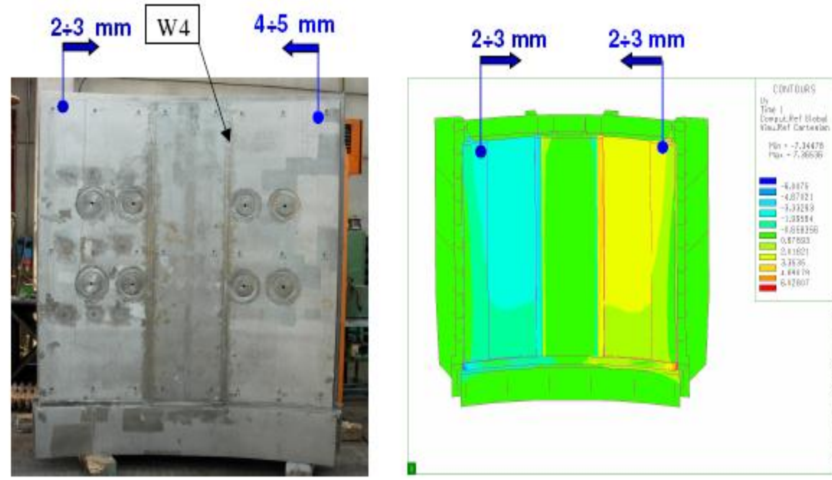


Fig. 8 Comparison of measured and computed shrinkages after PS1 welding

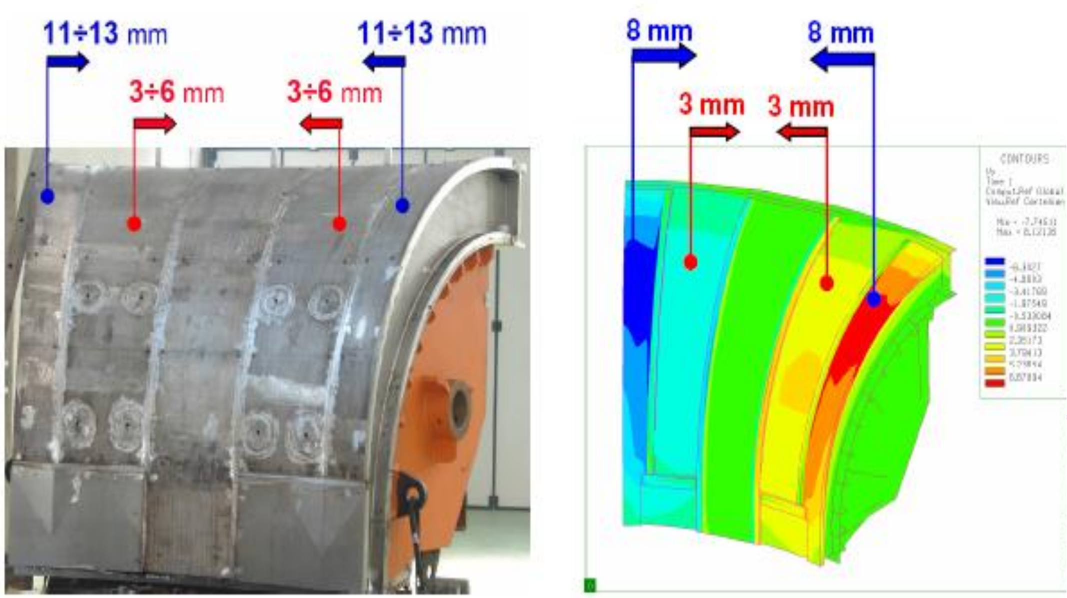


Fig. 10 Comparison of measured and computed shrinkages after PS2 inner shell welding

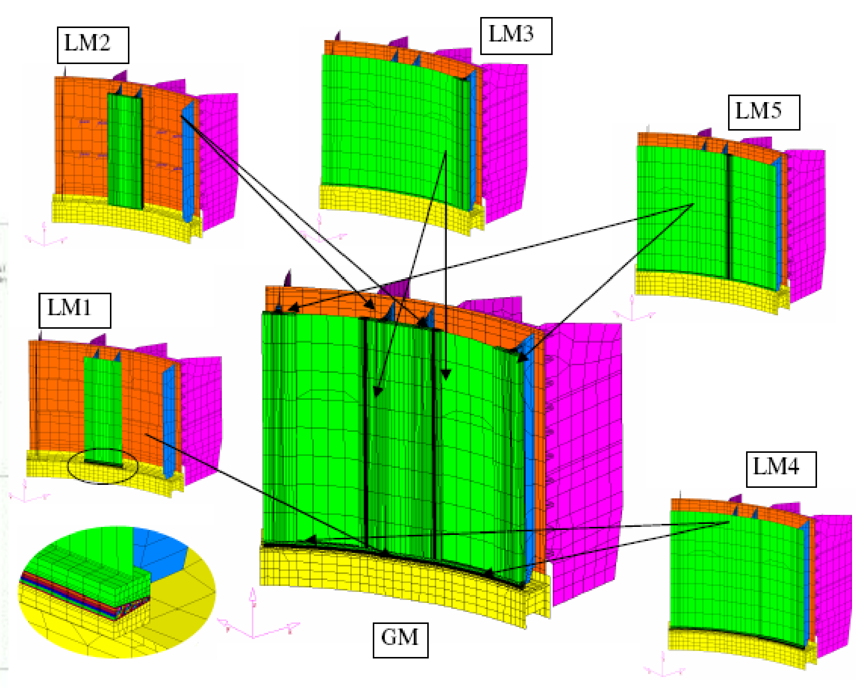


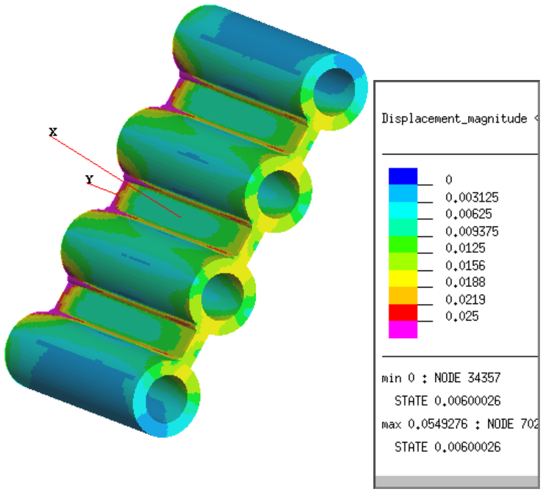
Fig. 5 PS1 local and global models

3: Be an applied mathematician

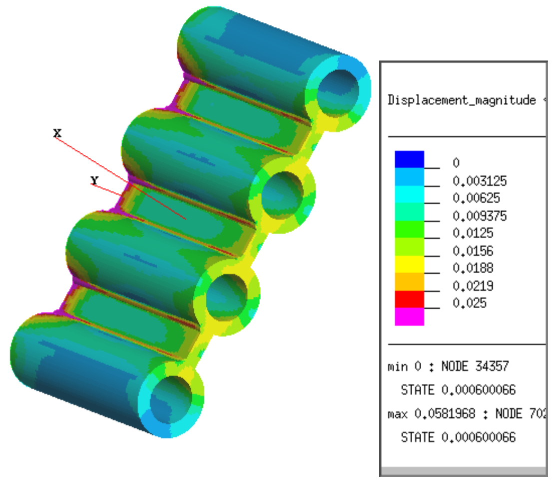
Use numerics

- Explicit formulation

IMPLICIT: CPU ~ 2h DMP8

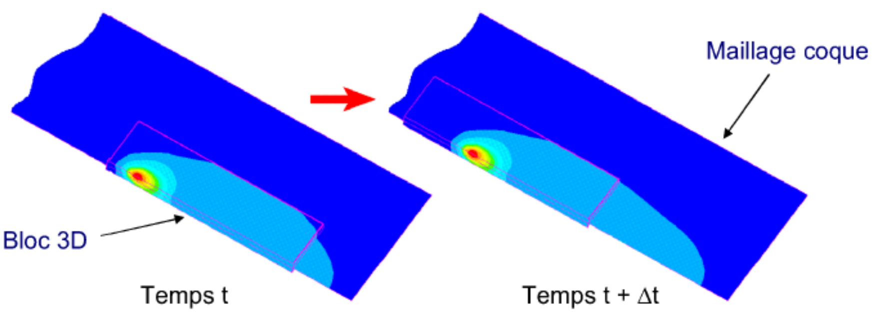


Phase de soudage
Facteur echelle temps mecanique x1000
CPU : DMP32 = 35min
Memoire = 14Mb



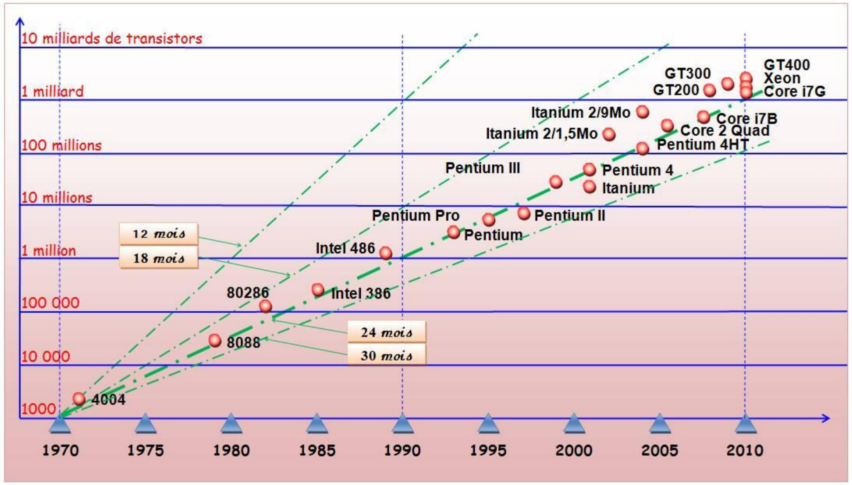
Phase de soudage
Facteur echelle temps mecanique x10 000
CPU : DMP32 = 10min
Memoire = 14Mb

- Multiscale
  - Local mesh refinement

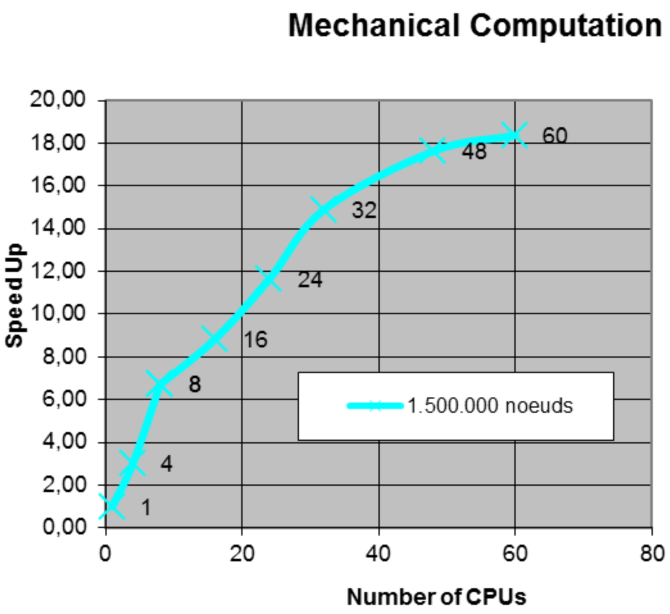


4: Be a computer power user

Moore law

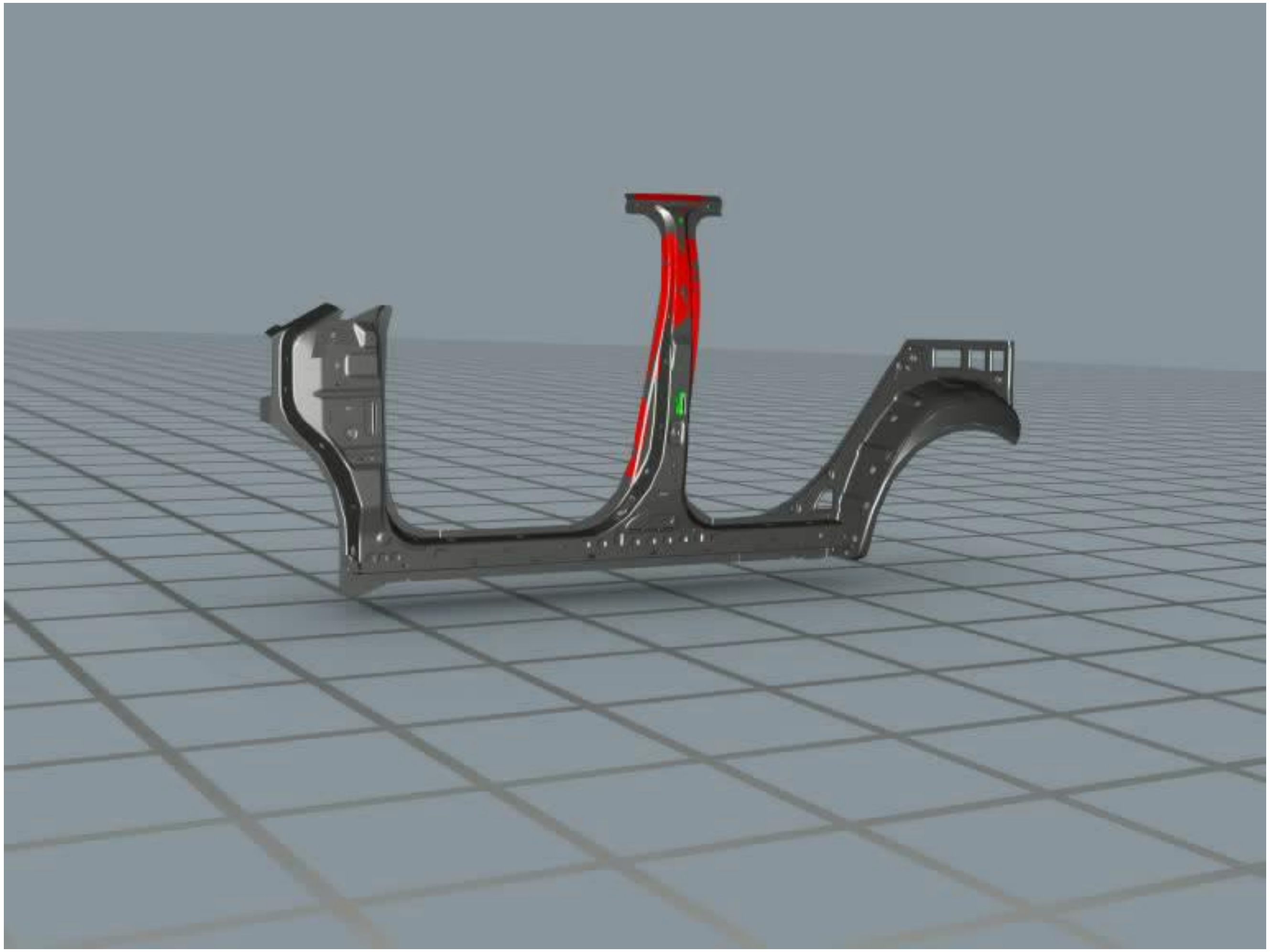


- Parallelization
  - SMP/DMP
    - Speed-up
  - Solvers (direct/iterative)
    - “robustness” vs RAM consumption
  - GPU
  - …



Don’t forget the analysis..

Virtual reality 3D for Assembly



Conclusion

- Remark 1:
  - All models are made more and more complex until they reach the limits. *Engineers have a tendency to try to push the envelop (even if it is not necessary)*.
- Remark 2:
  - The limit of a chain is the limit of the weakest part. Welding of large components limitation is not necessarily the *solving* limit.
- Remark 3:
  - Welding simulation has greatly improved in 30 years, the challenge is not anymore simulate the welding operation, but the full manufacturing itself. The skill of the engineer is still a ***must-have*** to select methods and assumptions with a global vision.

THANKS

Papers

- D. Dubois, J. Devaux, J.B. Leblond, “Numerical simulation of a welding operation : calculation of residual stresses and hydrogen diffusion”, Proc. of ICPVT 5, **1985**
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- P. Duranton, J. Devaux, V. Robin, P. Gilles and J.M. Bergheau, ***3D modelling of multipass welding of a 316L stainless steel pipe***, Proceedings of the International Conference on Advances on Materials and Processing Technologies, AMPT**2003**, pages 974-977
- Modelization of Residual stresses in Aluminum welded joints, J.P. Bonnafé, C. Destandau, Aérospatiale Les Mureaux, France, 25-28 September **1995**