Improvement of parallel SAMCEF Mecano using MUMPS solver

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Overview

- SAMTECH, who we are
- The past: History of MUMPS in SAMCEF
- The present: "Gigadof" challenge in Maaximus
- The future: use of PETSC and MUMPS for large eigen-value problems
- Conclusions

Who we are

- European Leader in CAE
- Development and engineering services
- Strong link with aerospace & aeronautic
- Active in automotive, wind turbine and electric industry

Our numbers

Our turnover

- 18 millions € in 2006
- 23 millions € in 2008

Our employees

- 250 persons
- 3 activities (SAMTECH, OPEN ENGINEERING, GDTECH)
- 12 branches in six European countries
- 2 Asian branches (China, Japan)

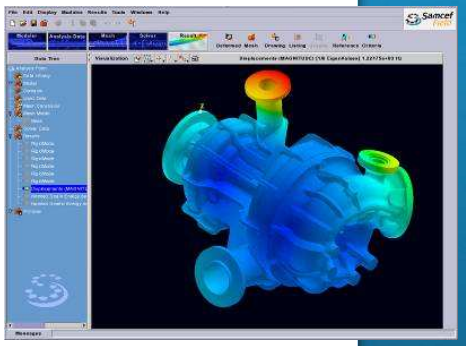
Our history

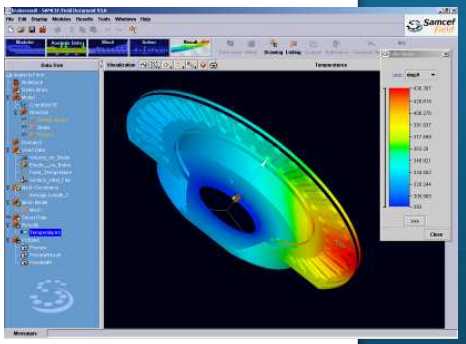
- First line of the FE code « SAMCEF » in 1967
- First customer in aeronautic in 1977
- 9th subsidiary in 2009

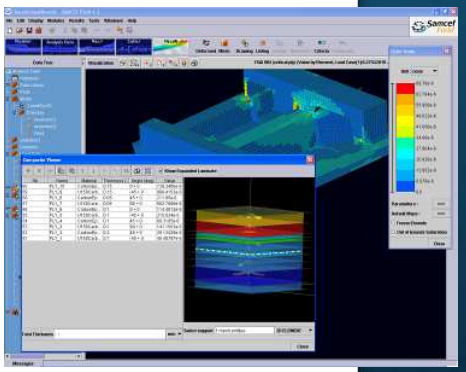
Standard Analyses in Structures Simulation

- Stress Analysis (linear and non-linear)
- Heat Transfer (conduction, convection, radiation)
- Linear Dynamic analysis (free vibration, harmonic, transient, random, fluid-structure interaction)
- Transient Analysis (non linear simulation in time domain)
- Rotor dynamics
- Optimization

On Metallic and composite structures

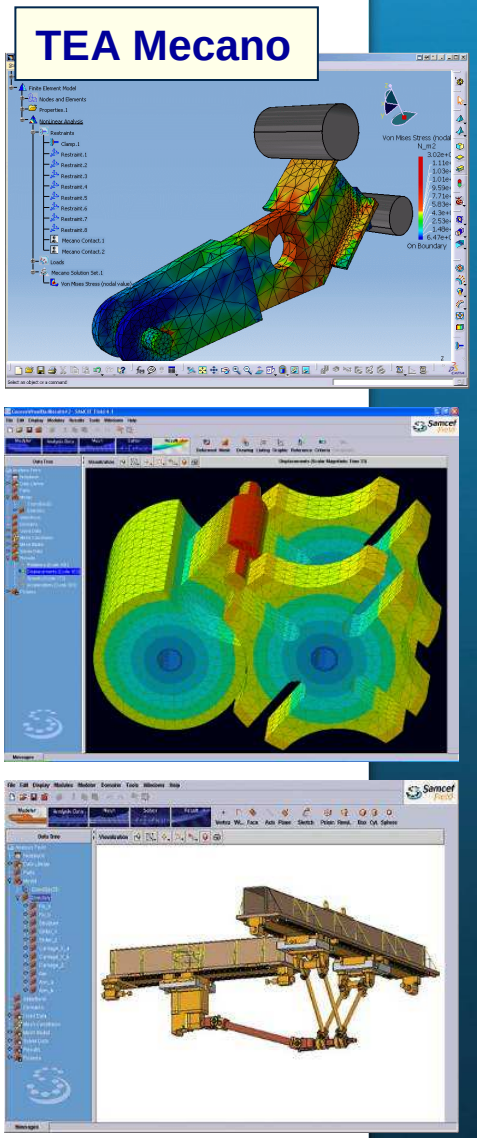






Advanced Analyses in Structure Simulation

- Thermo-elasto-visco-plastic analysis
- Simulation of thermal ablation process
- Wound composite structures
- Mixing 2D-axisymetrical and 3D models
- Mixing finite elements and mechanisms
- Openness and rapid adaptation
  - User material
  - Link to proprietary codes



Our references

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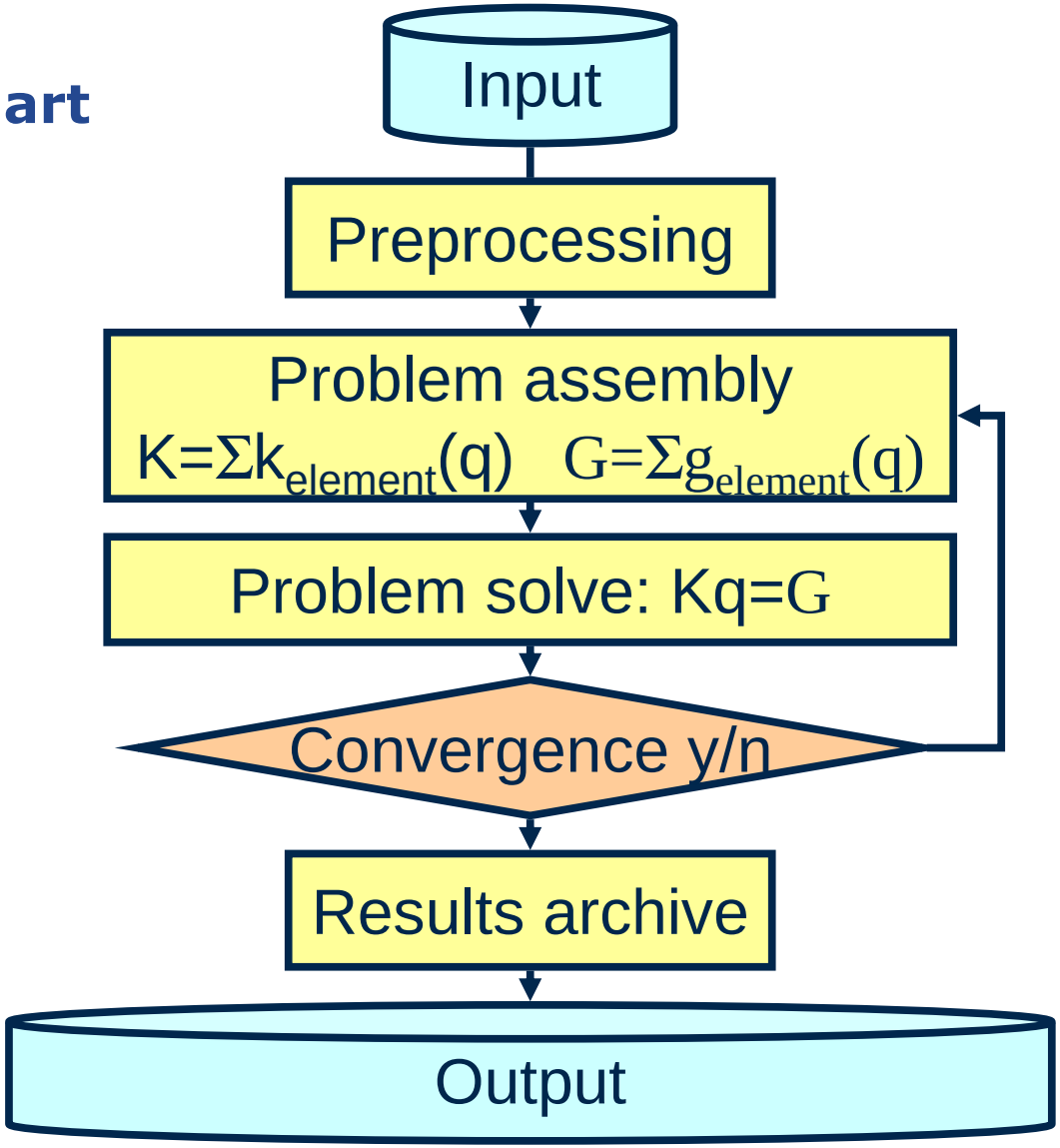
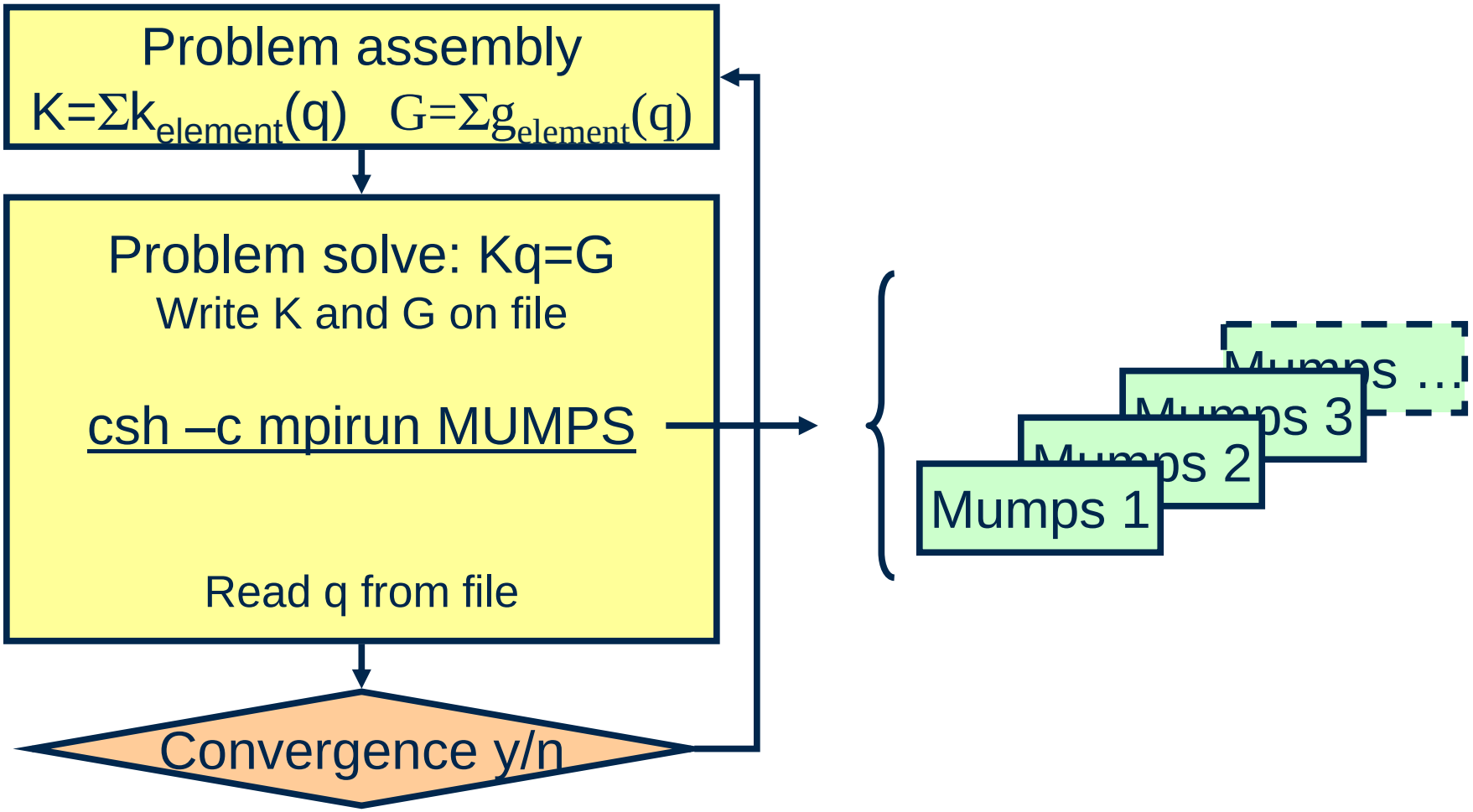
Flow chart

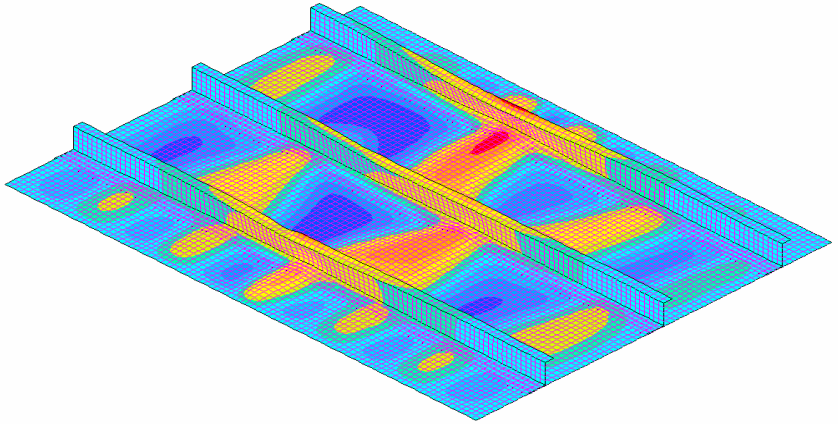


SAMCEF v11 (2005)



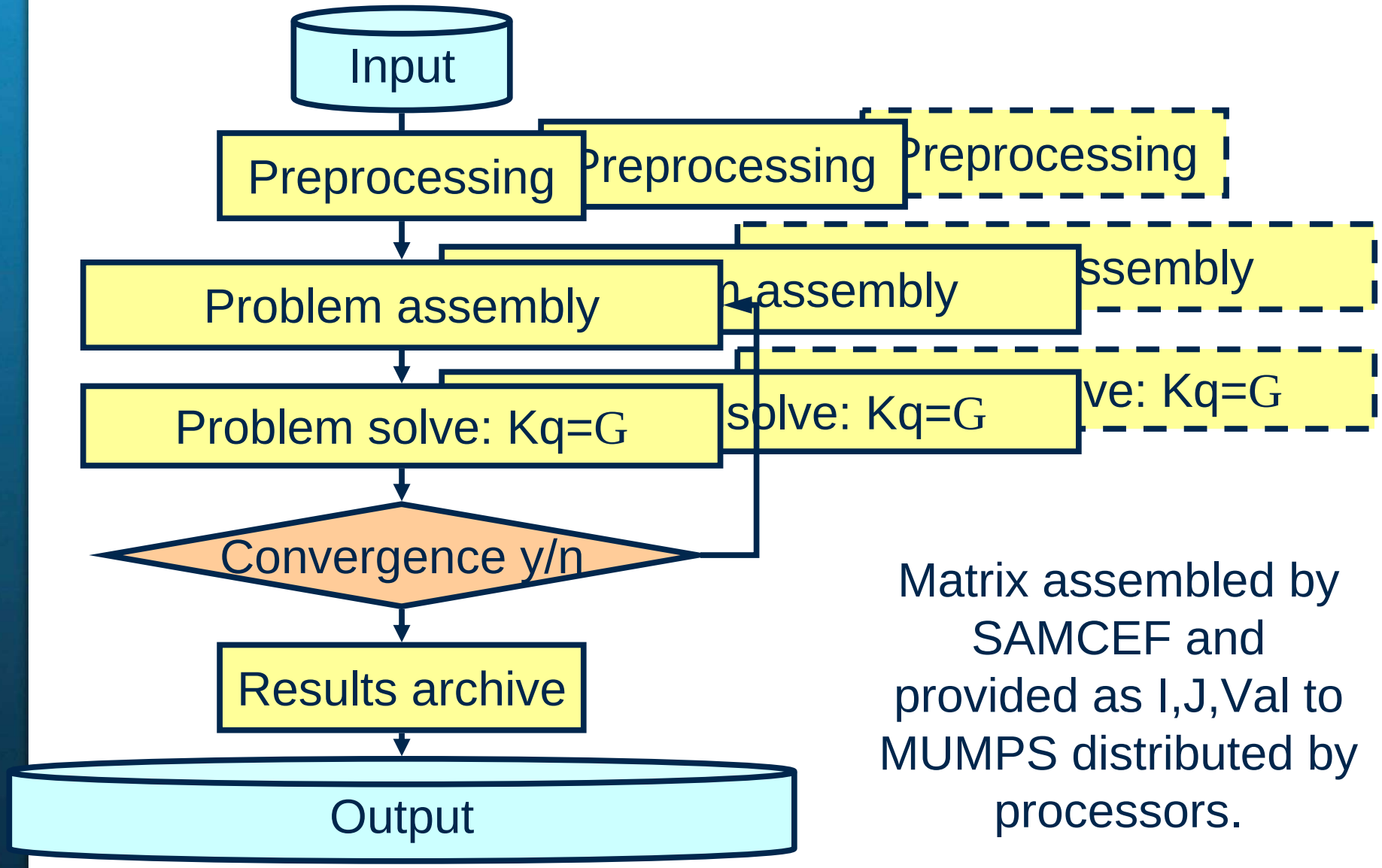
SAMCEF v11 (2005)

- **Airbus NL benchmarks, 3 large scale models**
  130 k elements, 260 k and 560k (3.624 Mdof)
- **Use of external parallel solver MUMPS**
- **8 h 0' elapsed time on HP**
- ***"Despite significant efforts by HP (hundreds of CPU hours, hardware replaced etc.), it has 'so far' only been possible to run the 560k shell model using Mecano" Airbus***



Lsm560k = 10 x

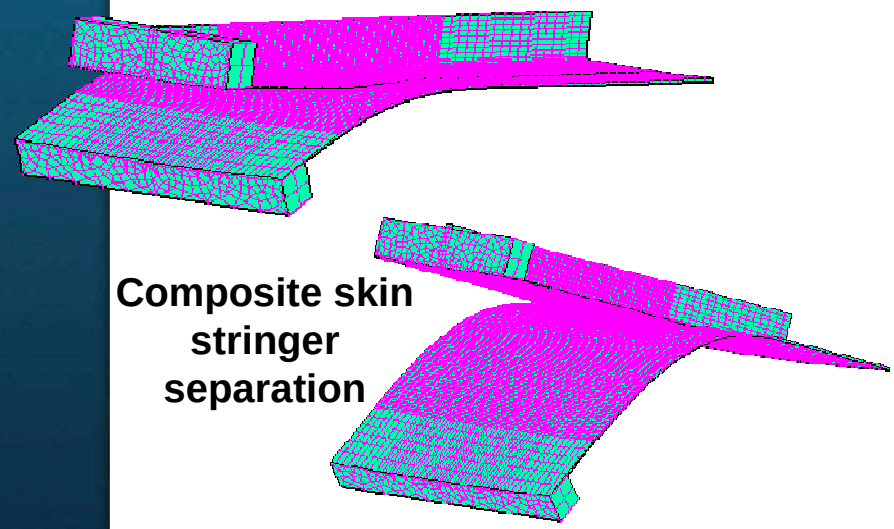
SAMCEF v12 (2007)

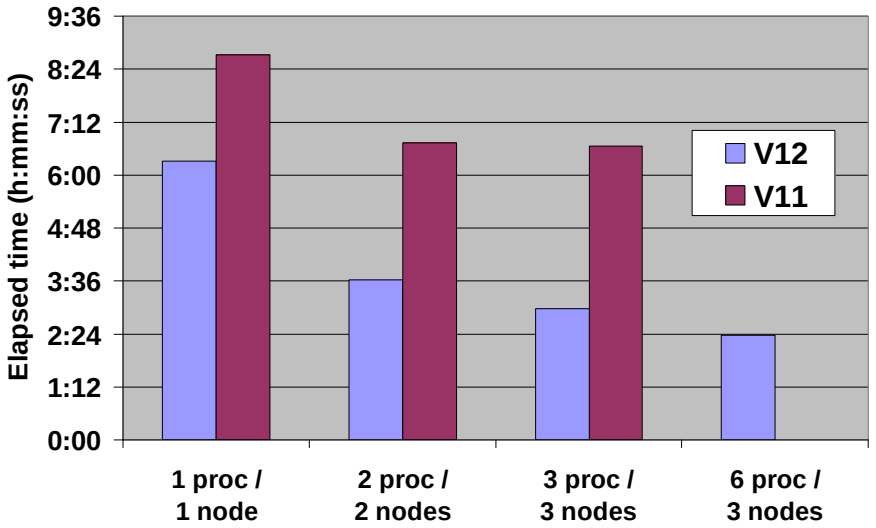


Matrix assembled by SAMCEF and provided as I,J,Val to MUMPS distributed by processors.

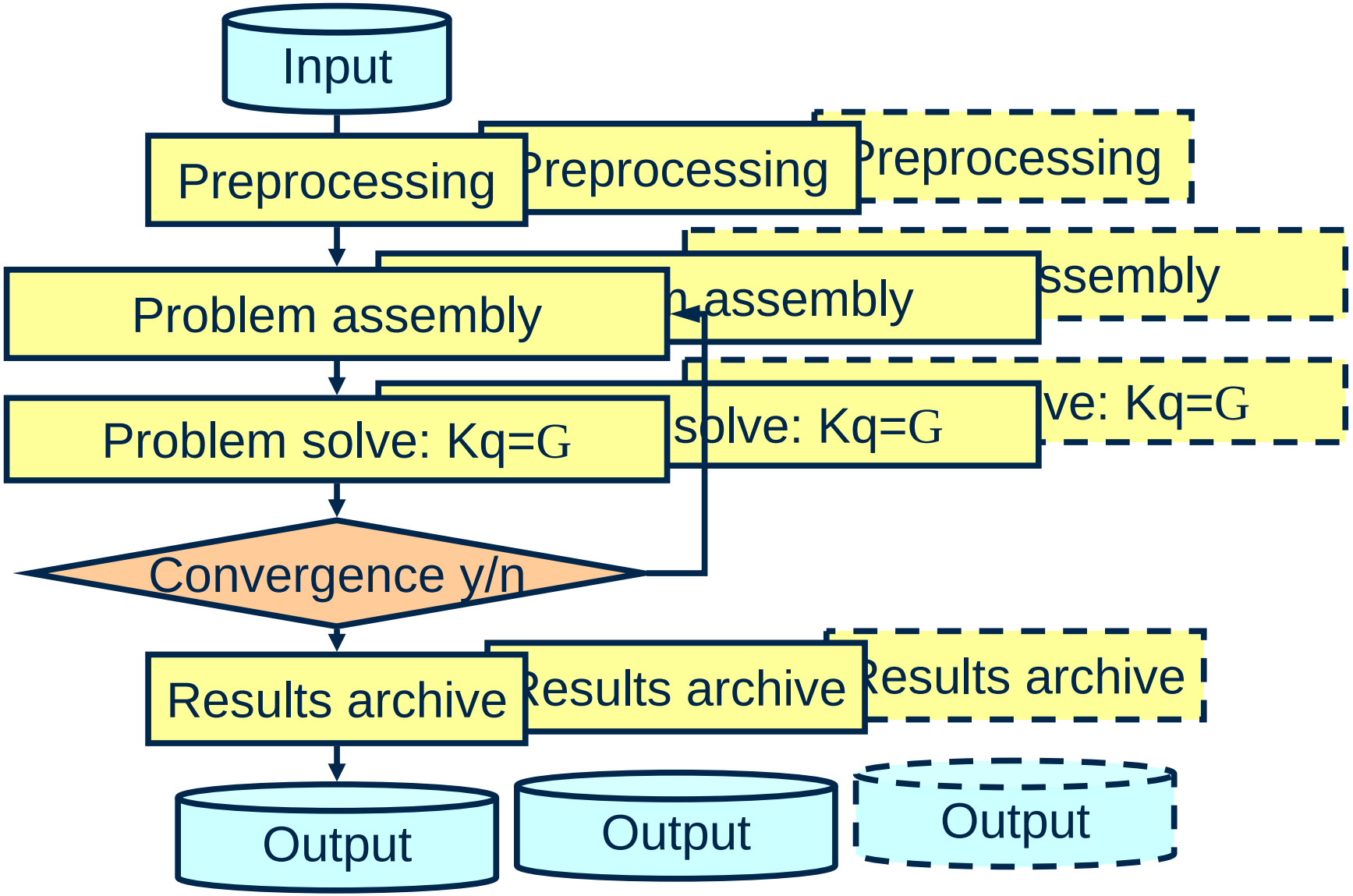
SAMCEF v12 (2007)

- In-depth software modification
- Integration of MUMPS solver
- Parallel treatment of elements (material law integration, matrix and force update…)



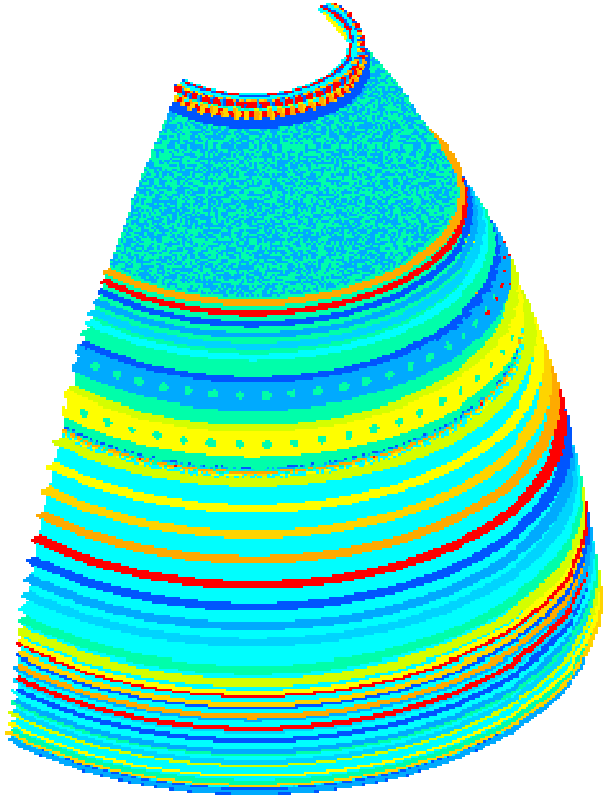


SAMCEF v13 (2009)



SAMCEF v13 (2009)

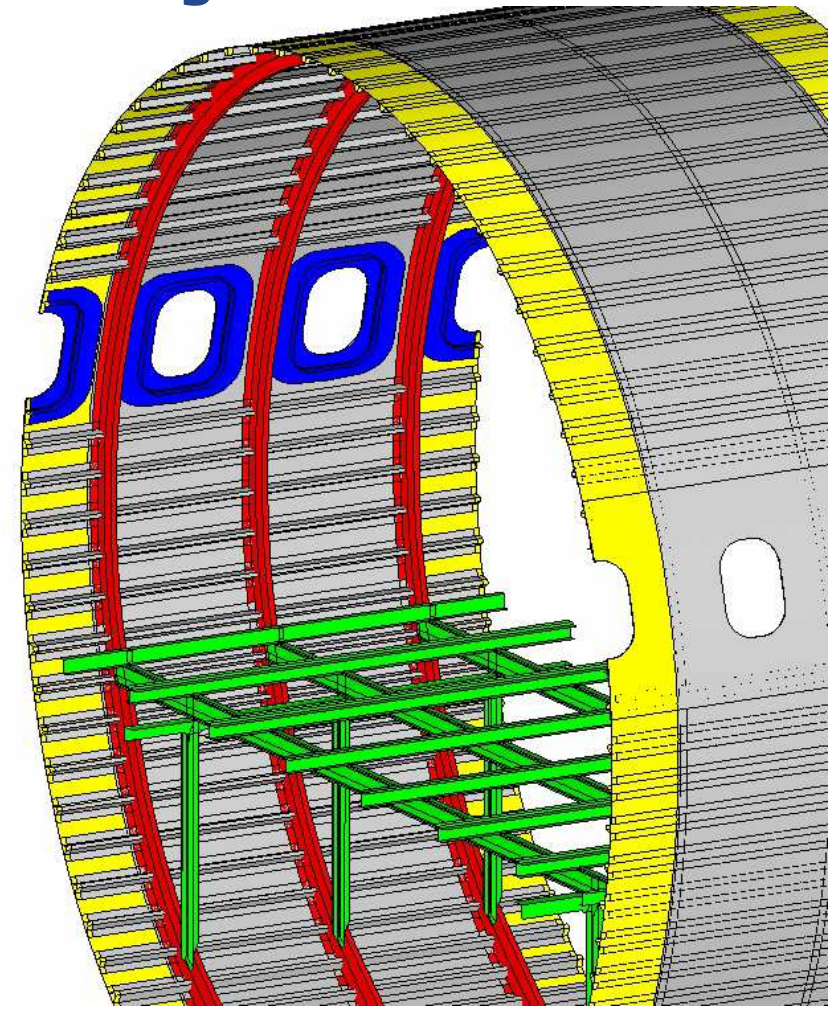
- **Parallel treatment of results**
- **Bottleneck for large model**
- **Indirect benefit du to the split of data-base**
- **Post processing adapted**



- 4 750 000 DOFs
- 1 073 380 Elements
- Cluster of 6 PC Linux (Xeon)
- V12.1 → 53 H 39 Min
- V13.1 → 22 H 32 Min

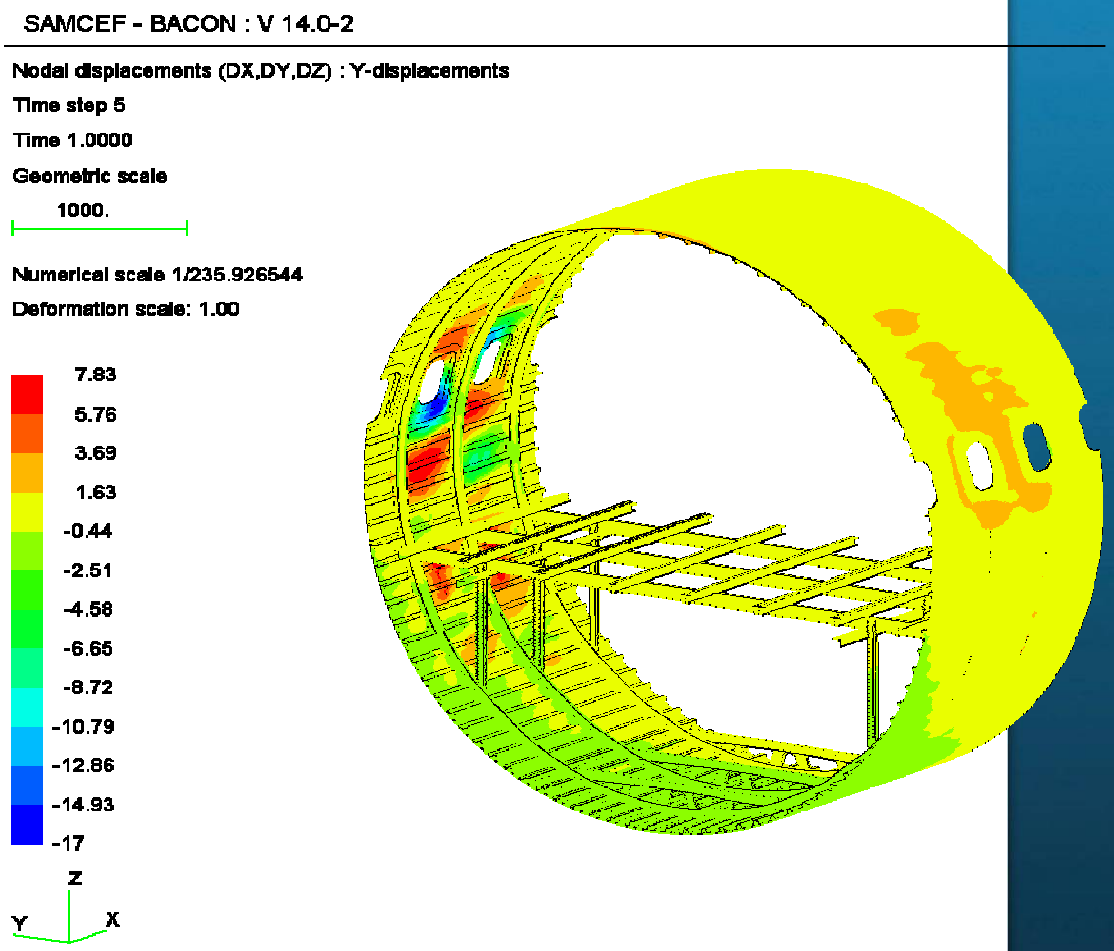
SAMCEF v14 (2011)

- Maaximus, the "Gigadof" challenge
- Calculate a fuselage made of, as much as possible, identical single barrels
- Identification of new limitations
- "standardisation" of long integer version



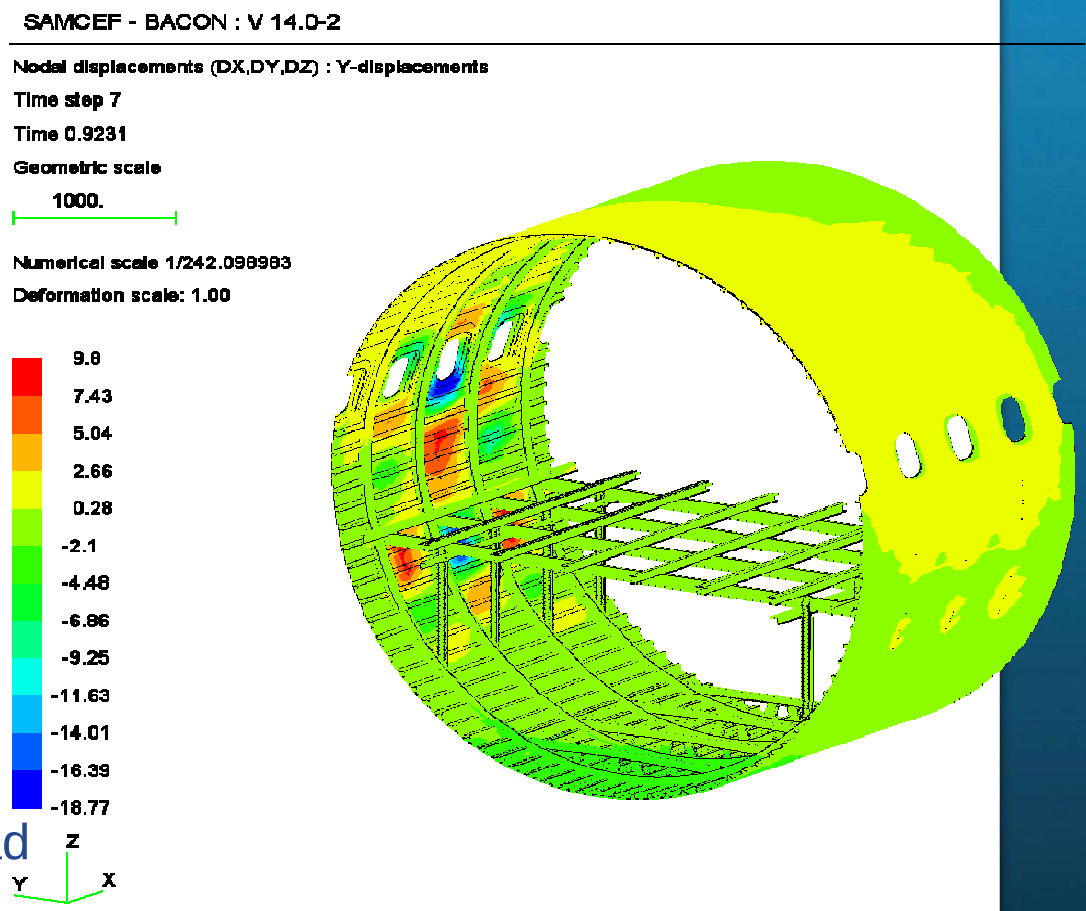
B1 Benchmark

- 3 sections of fuselage
- 13,956,620 dof's
- 1,891,176 shell elem.
- 2322011 elem. In total
- 7 h 24' on a cluster of 8 nodes, up to 100% of prescribed load
- 5 time steps, 1 rejected, 19 iterations
- Intel(R) Core(TM) 2.67 GHz
- 12 Gb per node



B1 Benchmark

- 4 sections of fuselage
- 18,580,217 dof's
- 2,521,568 shell elem.
- 3,092,810 elem. In total
- 28 h 30' on a cluster of 10 nodes.
- 7 time steps, 5 rejected, 57 iterations up to 91% of the load
- Intel(R) Core(TM) 2.67 GHz
- 12 Gb per node



Large eigen-value problem

- **Find many vibration modes of large-scale problems.**
- **Typically need 1000 modes.**
- **Number of degrees of freedom (DOF) may be more than 10 million.**
- **Algorithms:**
  - Generalized eigenvalue problem.
  - Shift-and-invert in parallel.
  - Direct sparse linear system solver.
- **Development objective: Scalable code both in CPU and memory.**

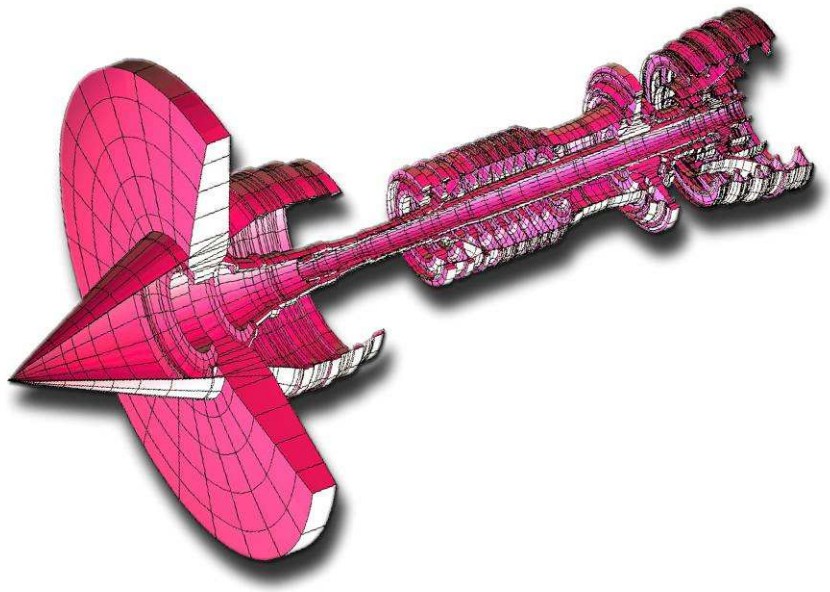
Parallel Software Architecture

- **PETSc [Argone, USA] – linear algebra solver interface.**
- **SLEPc [Univ of Valencia, Spain] - eigensolver.**
- **MUMPS [INRIA, France] – linear system solver.**
  - Options: Pastix [INRIA, France], SuperLU [LBNL, USA].
- **Matrix is always distributed.**
- **Various partitioners may be used:**
  - (Par)Metis, block, (pt)Scotch

Gains due to Parallel Implementation

- **Multi-etage problem with cyclic symmetry.**
  - 5 MLN DOF, 402 MLN of entries.
  - 456 modes requested.
- **Gains compared with original (sequential) DYNAM.**
  - nonsymmetric MUMPS solver.
  - 8 OpenMP threads in Intel MKL.

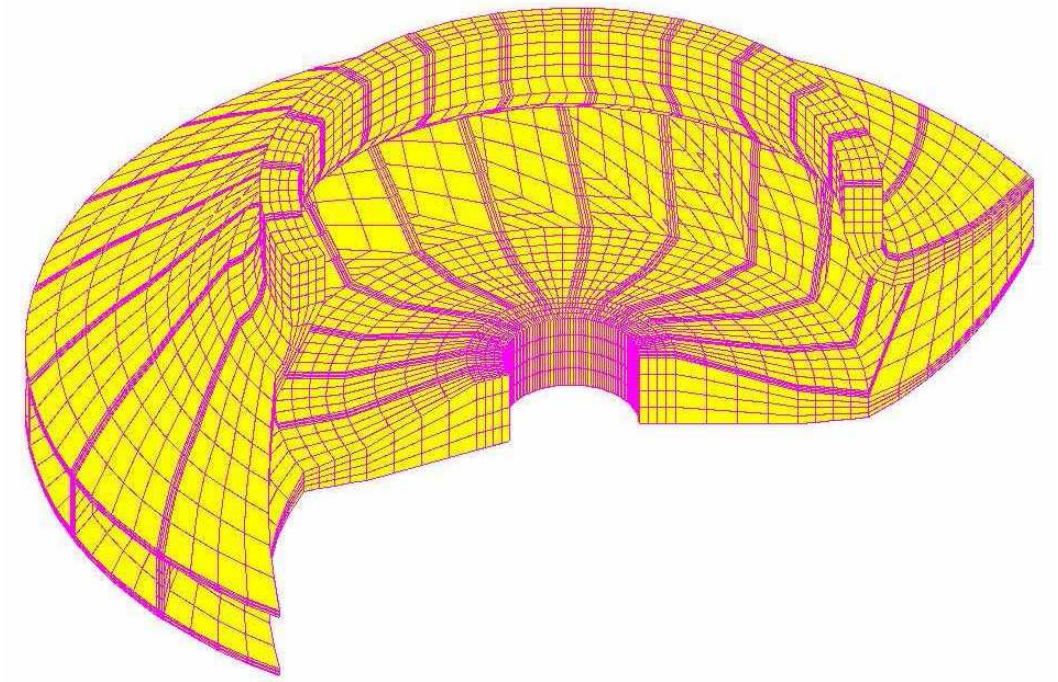
MPI procs	Speedup	MUMPS, %
20	12.0	43
30	16.7	45
40	18.8	51
80	26.5	58



This

Issues and Future Work

- **Solve large-scale eigenvalue problems: 20+ MLN DOF.**
  - Symmetric MUMPS solver has been used.
  - Maximum sparsity is extracted from the mass matrix.
  - Sequential ordering runs out of space -> parallel ordering has been used.



Conclusions

- **Thanks to MUMPS's team.**
- **Several improvements of MUMPS since 2005 are used in SAMCEF**
  - Out of core
  - Possibility to provide user's allocated memory to MUMPS
  - …
- **Wish list**
  - Static condensation $\mathbf{K}_{rr}^{*} = \mathbf{K}_{rr} - \mathbf{K}_{rc}\mathbf{K}_{cc}^{-1}\mathbf{K}_{cr}$
  - ➢ Extension to Mass matrix $\mathbf{M}_{rr}^{*} = \mathbf{M}_{rr} - \mathbf{M}_{rc}\mathbf{K}_{cc}^{-1}\mathbf{K}_{cr} - \mathbf{K}_{rc}\mathbf{K}_{cc}^{-1}\mathbf{M}_{cr} + \mathbf{K}_{rc}\mathbf{K}_{cc}^{-1}\mathbf{M}_{cc}\mathbf{K}_{cc}^{-1}\mathbf{K}_{cr}$
  - Intensive use of Lagrange's multiplyers
  - ➢ Possibility to take it into account in the ordering ?
  - ➢ Mode of elimination "deterministic"

Thank you for your time.

Any questions ?