Integration of FE Model Validation, Uncertainty Analysis and Design Improvement using the FEMtools® Framework Toolbox

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Overview

- What is FEMtools
- FEMtools Framework
- Applications
- Dealing with uncertainty
- Model validation and updating
- Summary

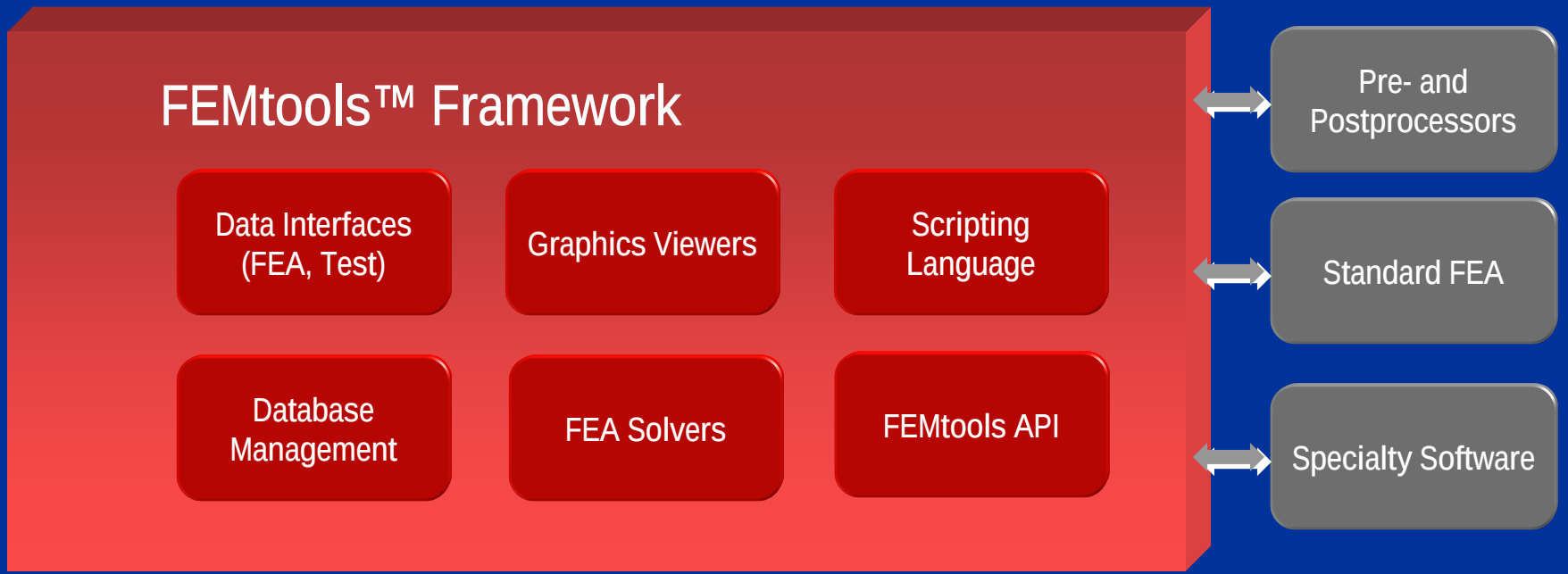
What is FEMtools?

- Multi-functional CAE software providing analysis and scripting solutions for a growing number of applications in the areas of:
  - Data management
  - Test-analysis integration
  - FEM pre- and postprocessing
  - Finite element analysis
  - Process integration and automation
  - Design improvement
- How
  - Framework
  - Add-on application modules

FEMtools Framework

- CAE-based (structural FE models, CFD models,...)
- Solver independent
- Adherence to standards (Windows UI, OpenGL, Basic scripting, ...)
- Customizable user interface
- Open database
- Unlimited extendibility, customization, integration and automation via scripting and FEMtools API
- Platform independent (Windows, Linux and Unix)

FEMtools Framework



Data Interfaces

- Integrated direct, bi-directional interfaces: NASTRAN, ANSYS, I-DEAS , ABAQUS, MSC.Marc, Universal File, Custom file formats,...
- Direct import/export of data tables (MS Excel, MATLAB,...).
- Verification of database integrity.
- No limitation of FE model size.
- Transformation of external databases into an internal relational database.
- Automatic creation of sets of elements based on topology, material or geometry.

Database Management

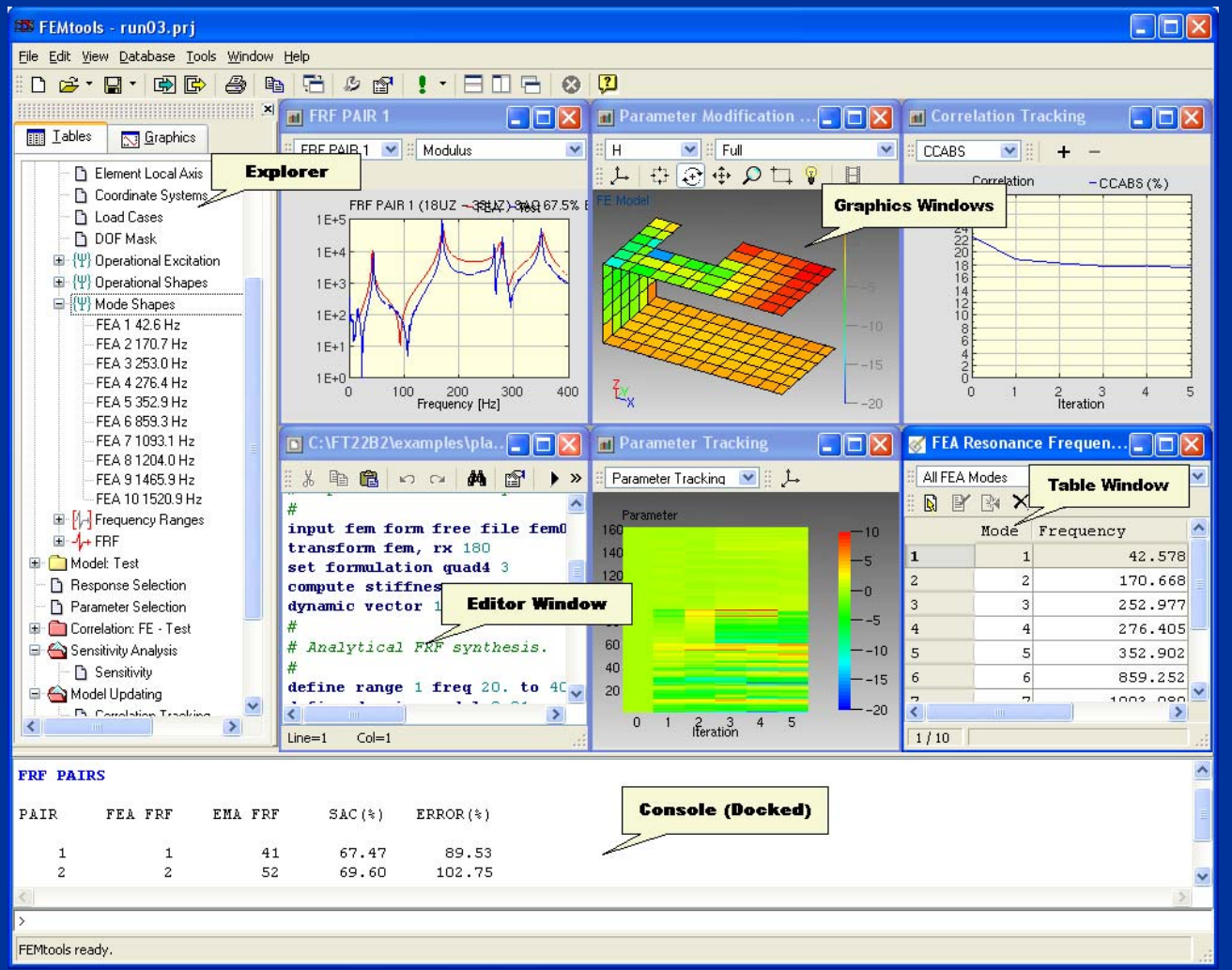
- Database explorer using tree-lists
- Multi-model architecture
- Spreadsheet-style table editing
- Conversion of engineering units
- Model mapping tools
- Results conversion (scaling, expansion, reduction, normalization,...)
- Data sets (definition of sets, Boolean operators,...)
- Parameter and response definition
- Mesh conversion tools (coordinate transformation, conversion between element types, shape deformation, ...)

Finite Element Analysis

- Internal element library (lumped mass, beams, plates, shells, volume elements, damper element).
- Isotropic, orthotropic and anisotropic material models.
- Constraint equations (SPC, RBAR, RBE2, RBE3, MPC).
- Use integrated FEMtools sparse solvers or pilot external standard FEA solvers.
- Linear static analysis, real and complex eigenvalue analysis
- Support of master DOF with back-expansion.
- FRF synthesis from FEA or test modes.
- Displacements, velocities and accelerations for harmonic nodal and pressure loads.

FEMtools Framework

User Interface and Graphics



Scripting and API

- Integrated script editor with color coding.
- 160+ functions for advanced mathematical programming (array operators, complex numbers, sparse matrices, regular expressions,...).
- 240+ FEMtools API functions for database access, analysis, user interface programming, licensing and process control.
- Functions for launching and controlling external tools with OLE automation.
- Easy exchange of matrices with complementary software like e.g. Matlab.
- Access to Framework data interfaces, analysis modules and graphics.

FEMtools Add-on Tools

- Pre-test planning
- Structural Dynamics Modification – Synthesis
- Model mapping
- Local and global shape correlation analysis
- Internal sensitivity analysis – Variational analysis or integration of external tools (e.g. Nastran SOL200)
- Internal optimizers and parameter estimators or integration of external optimizers (e.g. DOT, Matlab Optimization Toolbox,...)
- Probabilistic analysis (Monte Carlo sampling)

Some Example Applications

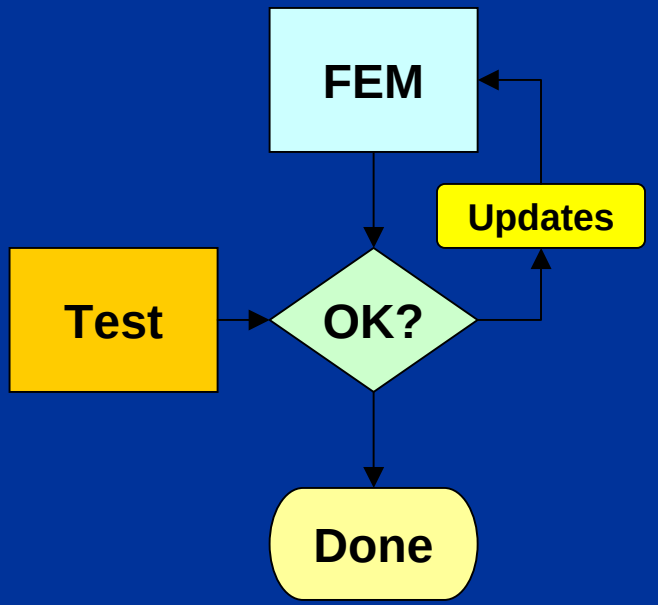
- Force identification (inverse analysis)
- FE model validation (correlation, sensitivity, updating)
- Error localization - damage detection - Monitoring – QA
- FE model reduction
- Material identification
- Design space exploration (perturbation, stochastic,...)
- Variational Analysis
- Topology, size and shape optimization
- Uncertainty analysis - Robust Design
- ...

Third-Party Projects in Progress

- ***SmartCoupling™***: A new solution for multi-physics analysis coupling (CFD-Structural, Stamping-FEM,...)
- ***ASW™***: Automatic Spot Weld mesh connection
- ***BOW™***: Body-in-white Optimization Wizard
- ***Laminator™***: Easy Design Optimization of Laminates
- ***Resonalyser™***: Material identification from vibration testing

Validation and Updating of FE Models

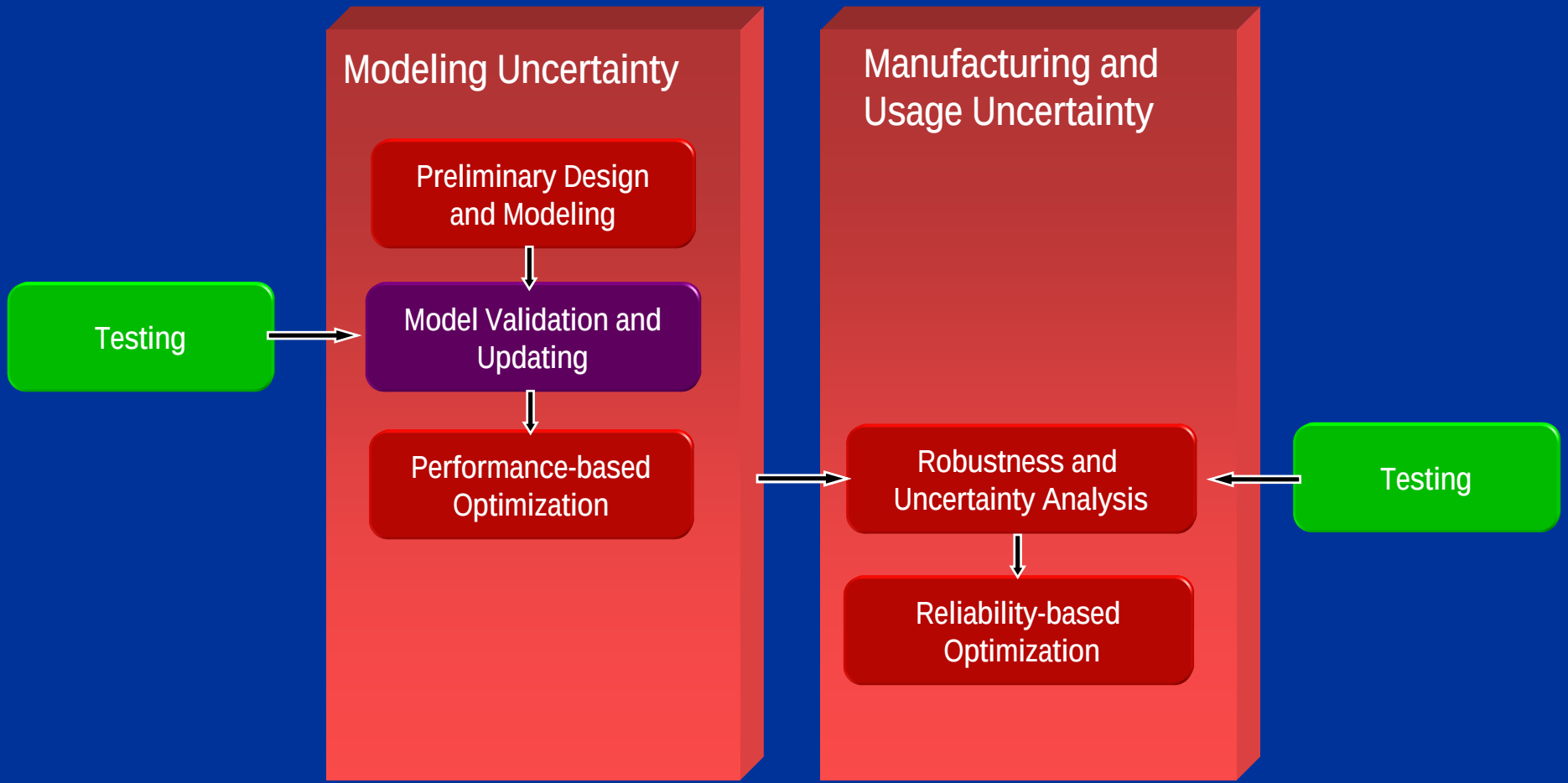
- Why?
  - Uncertainty
  - Simplification
  - Missing information
  - Errors
  - Making reduced models
- How?
  - Comparison with test
  - Manual property updating
  - Automated FEM property updating using special type of multi-objective optimization



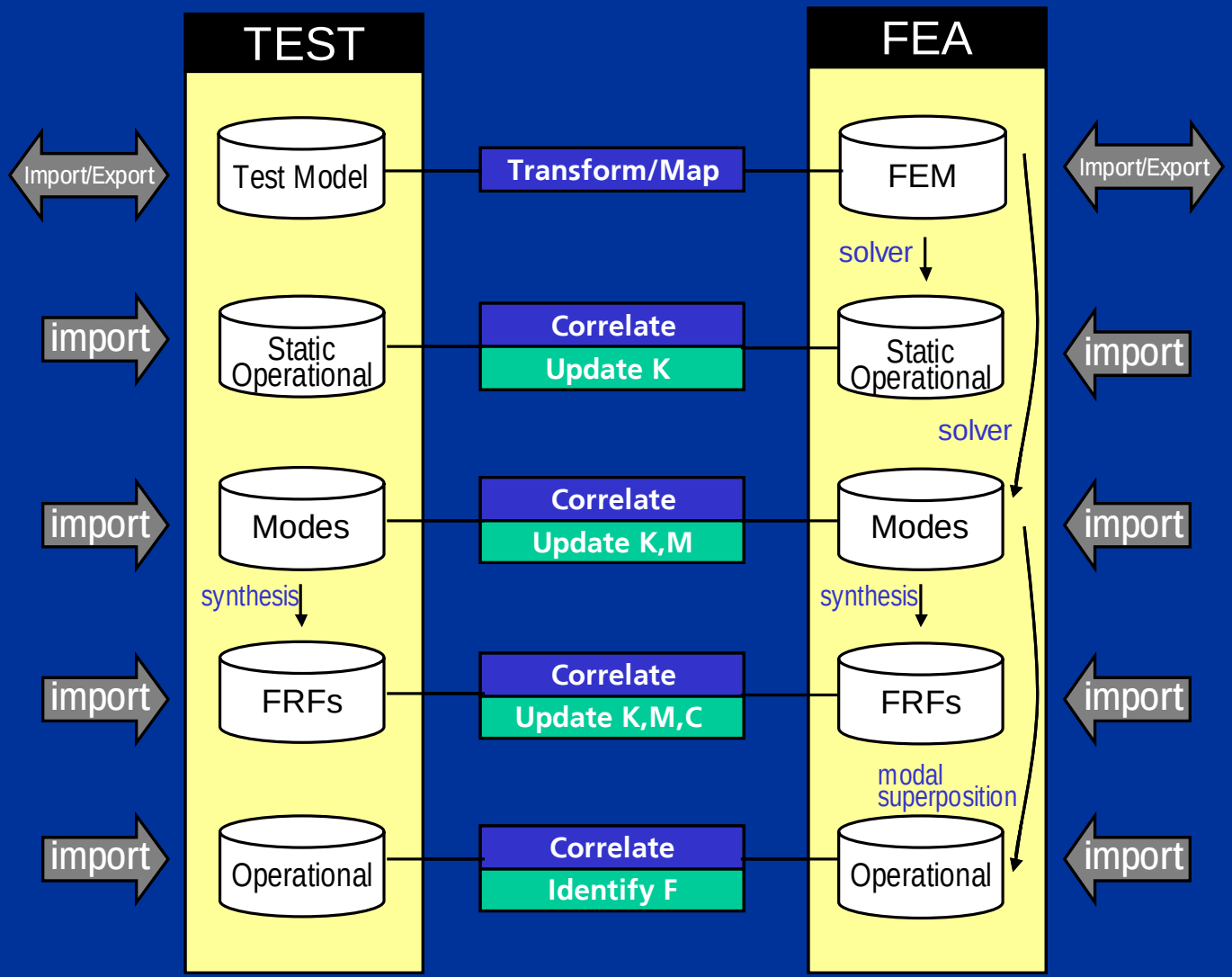
FE Analysis Uncertainties

- Physical element properties
  - Boundary conditions
  - Joint stiffness
  - Material properties
  - Equivalent geometry
- Meshing
  - Element types and formulation
  - Model simplification
  - Mesh density
  - “As tested” vs “as designed”
- Data mistakes
  - Typing errors
  - Units
- Analysis
  - Non-linearity
  - Master DOF selection
  - Lumped vs. coupled mass
  - Integration steps
  - Damping
- Manufacturing tolerances
  - Thickness tolerances
  - Bonding
  - Casting
  - Fiber alignments
- In service variations
  - Temperature
  - Humidity
  - Loads variations

Dealing with Uncertainty



Correlation and Updating - Overview



Objective Functions

- Deterministic

$$\mathrm{Min}(E = \{\Delta R\}^t [C_R] \{\Delta R\} + \{\Delta P\}^t [C_P] \{\Delta P\})$$

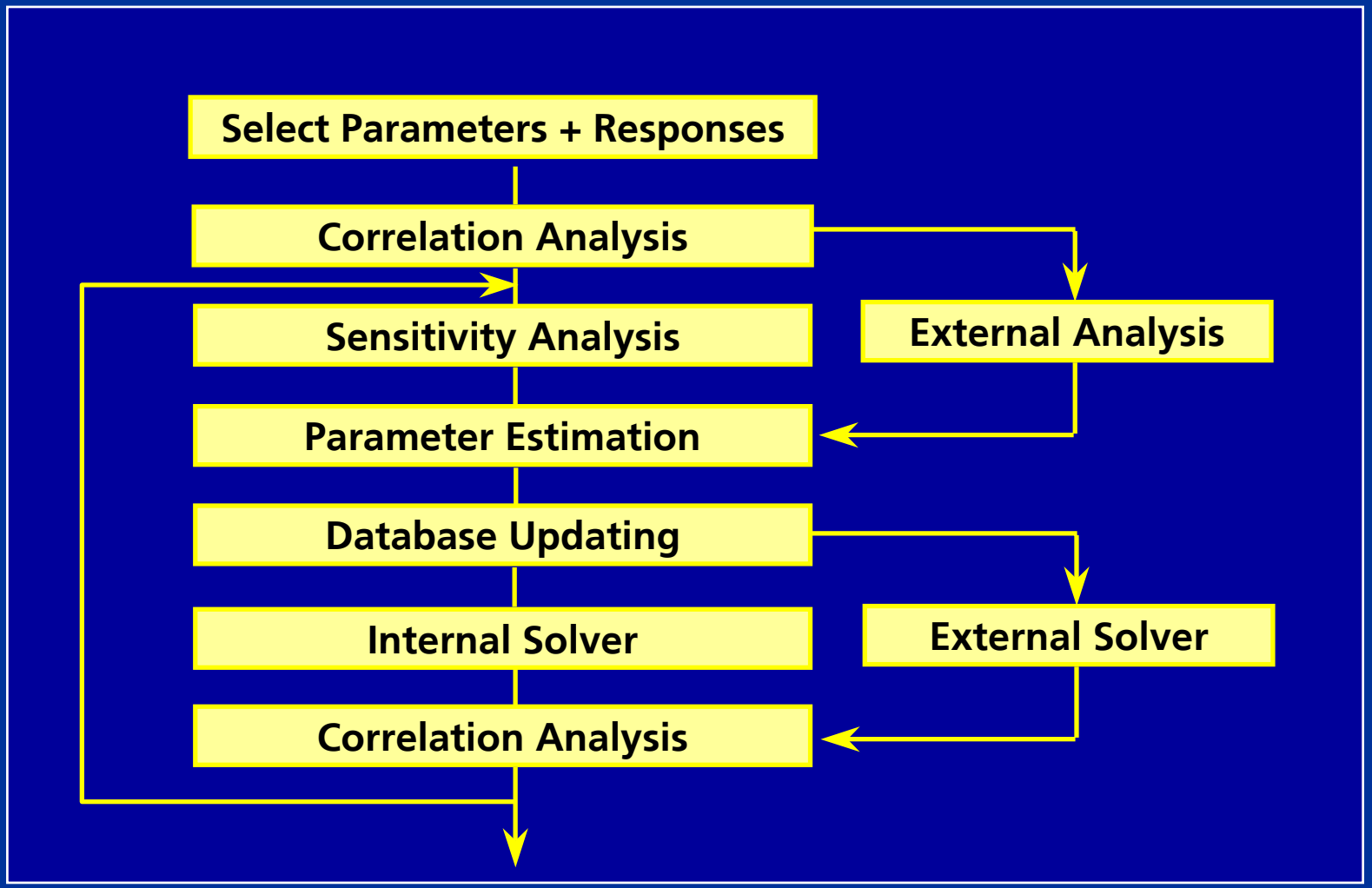
$$g_i(P) \leq 0 \quad ; P_{\min} \leq P \leq P_{\max}$$

- Probabilistic

$$d_M = (\mu_a^R - \mu_e^R)^t \, COV_p^{-1} \, (\mu_a^R - \mu_e^R) + (\mu_o^P - \mu_u^P)^t \, COV_p^{-1} \, (\mu_o^P - \mu_u^P)$$

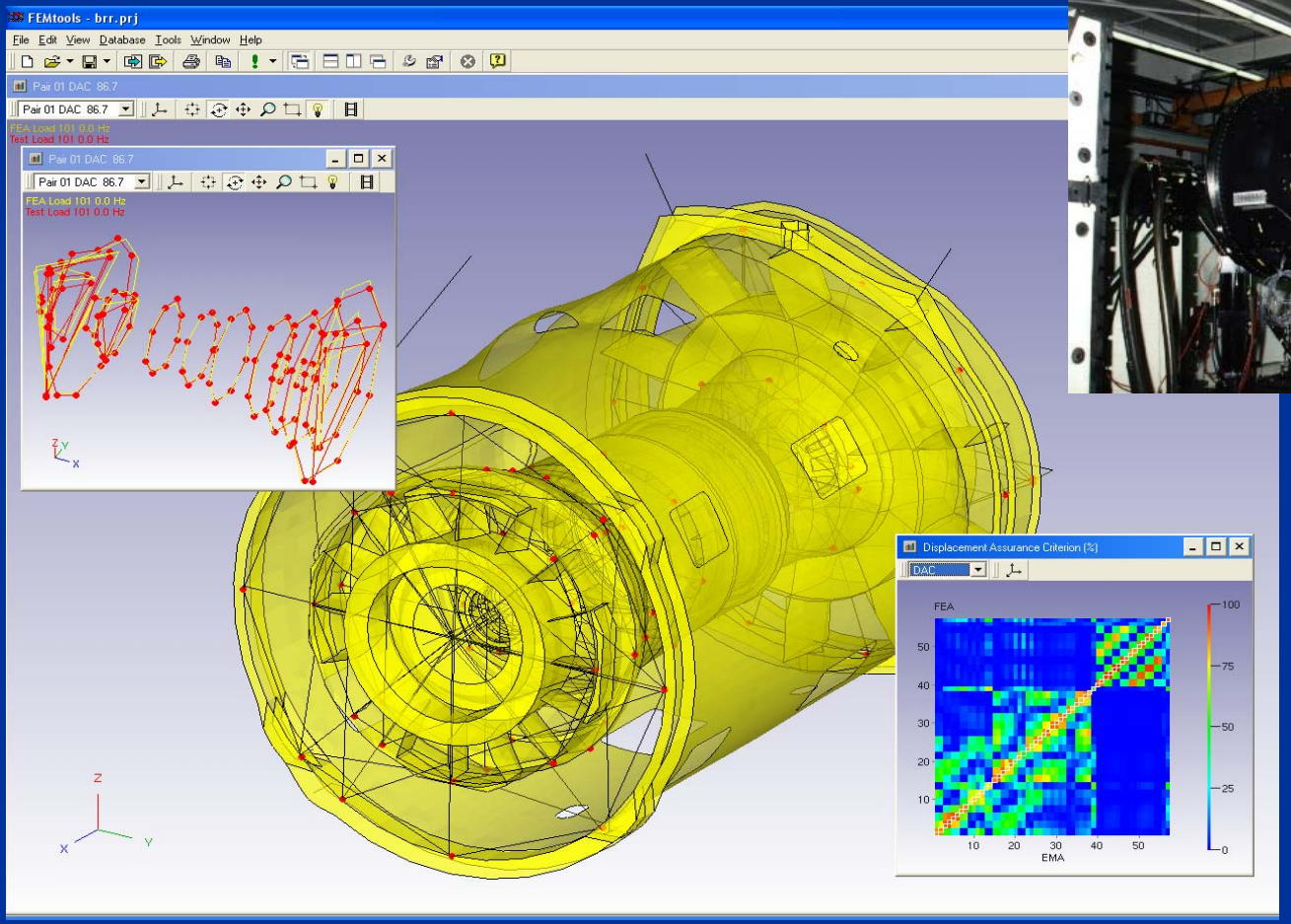
$\mathrm{Min}(d_M)$; Shape and size of point clouds

Automated FE Model Updating



Validation and Updating of FE Models

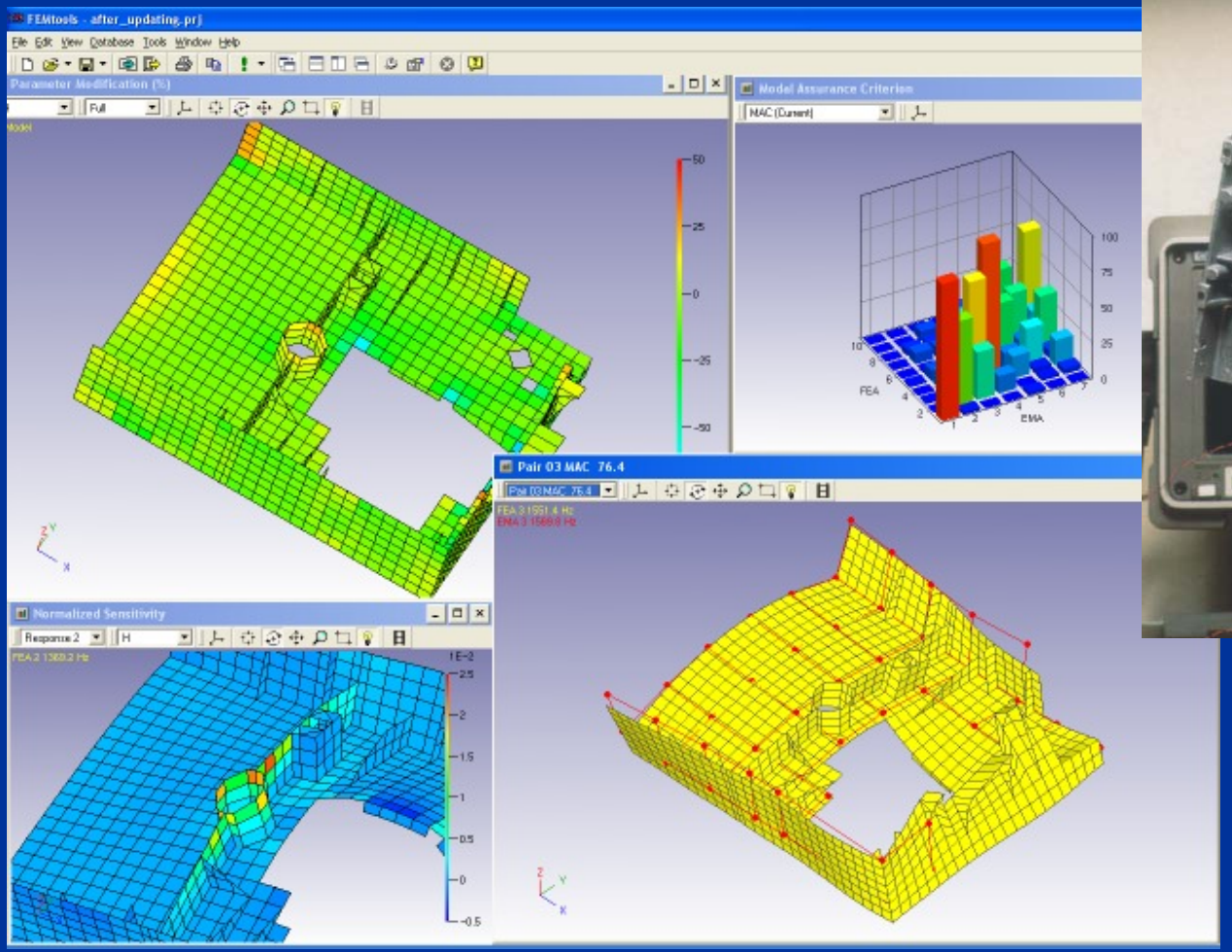
Industrial Example



Updating of stiffness parameters using experimental static displacement data (Courtesy Rolls-Royce, Dahlewitz, Germany).

Validation and Updating of FE Models

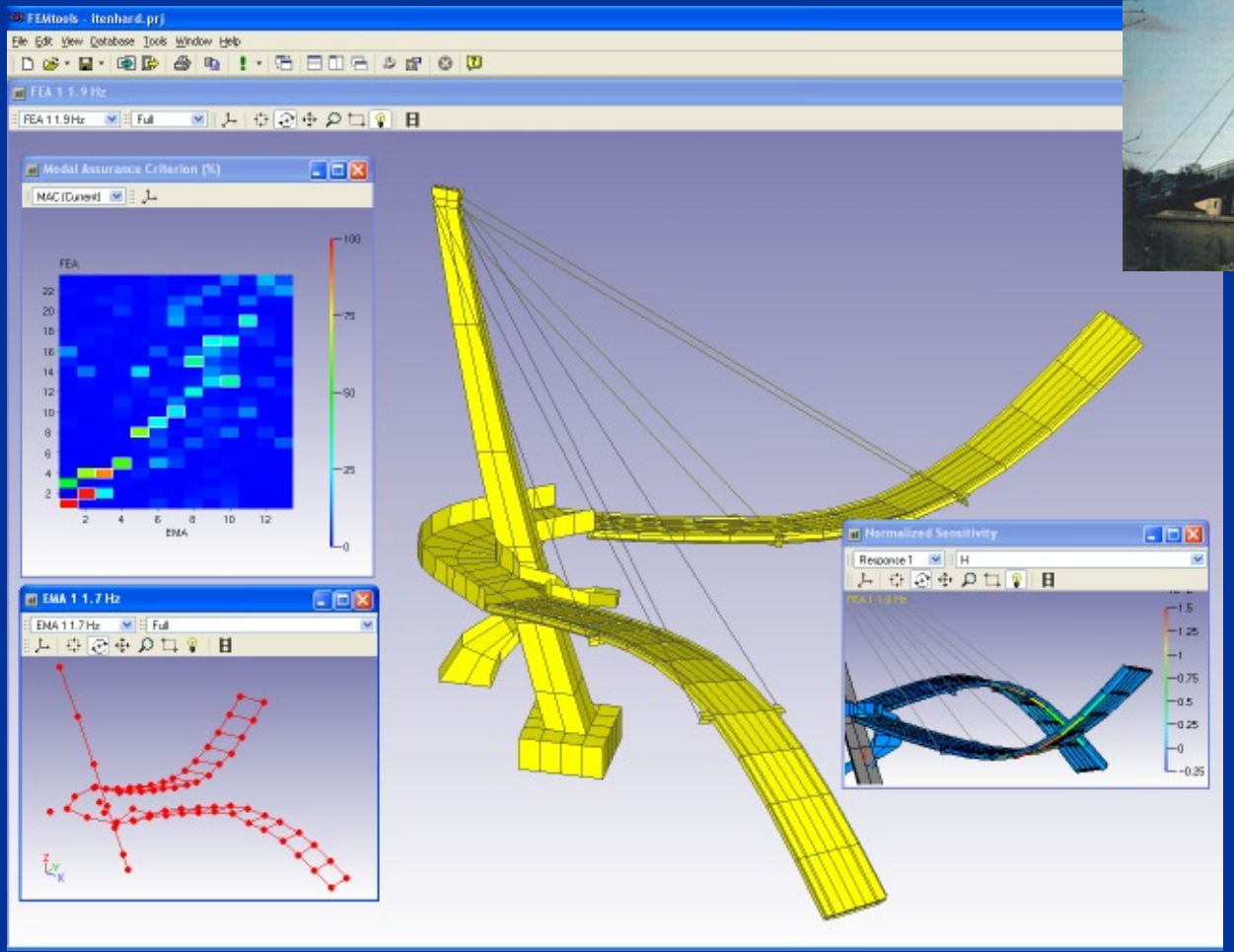
Industrial Example



Updating of physical element parameters of hard disk cover using experimental modal data (resonance frequencies, mode shapes).

Validation and Updating of FE Models

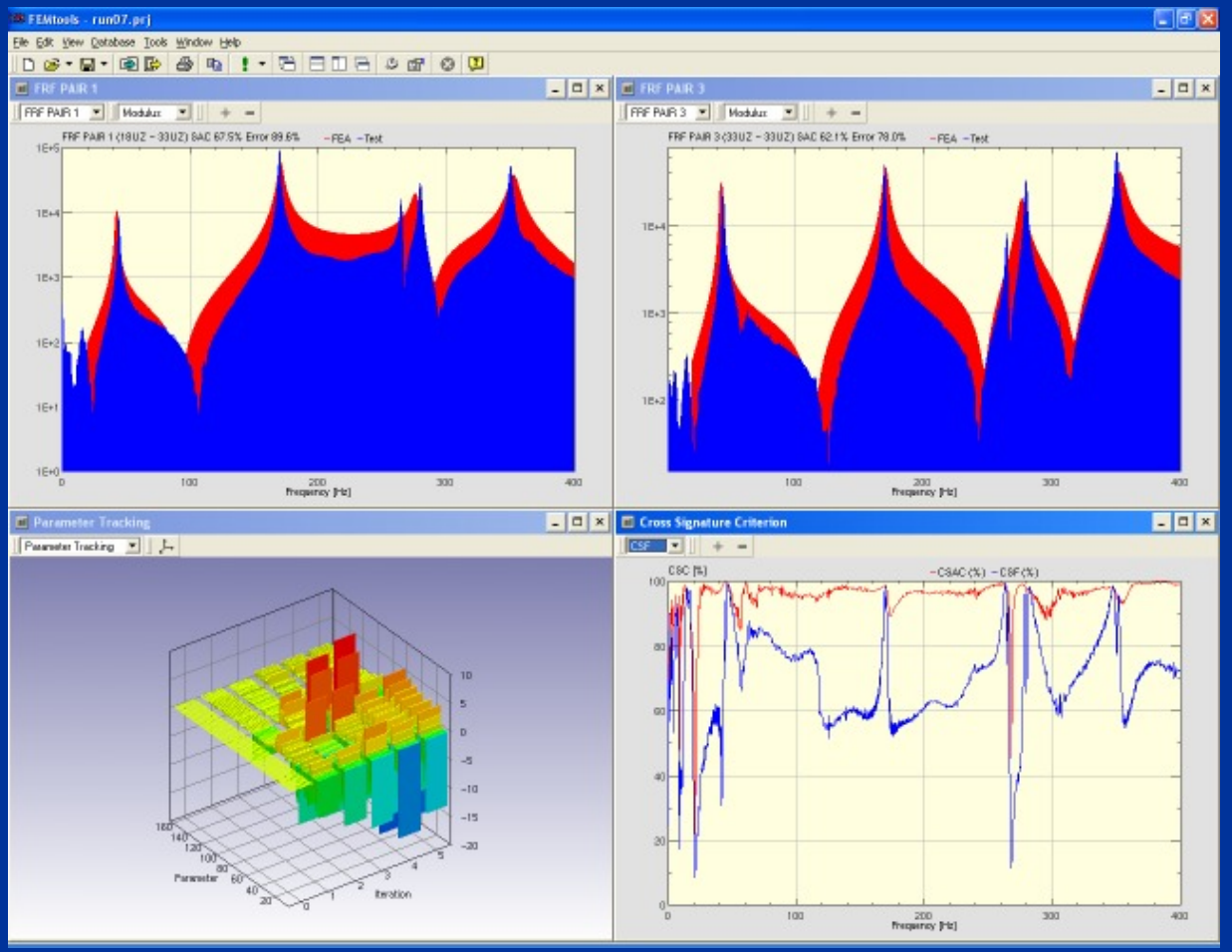
Industrial Example



Correlation of FEA with modal test data and sensitivity analysis of a footbridge (Courtesy EMPA, Switzerland).

Validation and Updating of FE Models

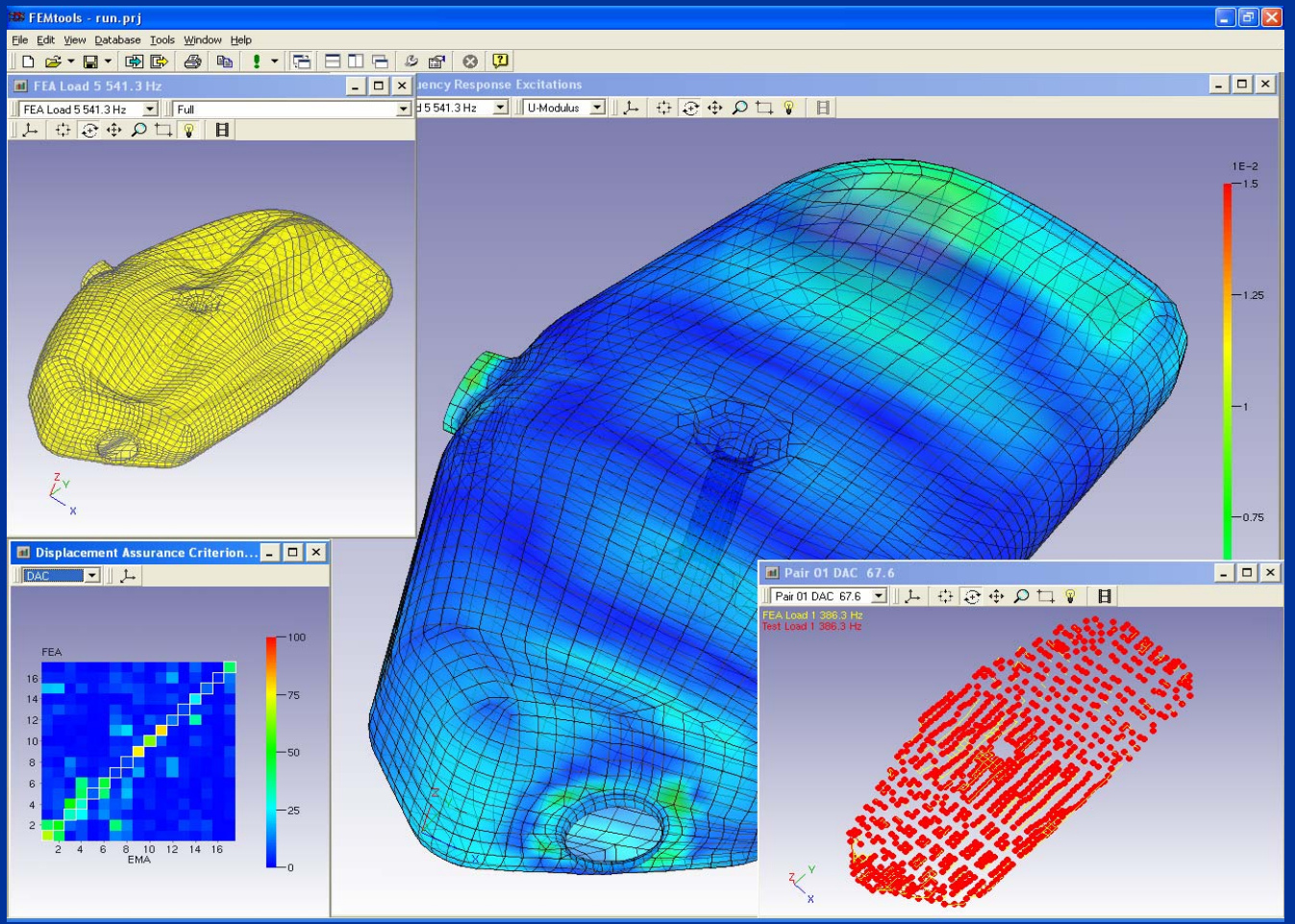
Industrial Example



Updating of physical element parameters and modeling of damping using Frequency Response Functions directly.

Harmonic Force Identification

Industrial Example



Identification of distributed pressure forces in a muffler cavity based on laser scanning measurements of operational shapes (ODS) at the outside surfaces. (Courtesy Faurecia, France).

Current Challenges for CAE

- How to treat complexity?
- How to treat uncertainty?
- Need for “smarter” simulation models (not bigger)
- Validation of simulation models (reliability, completeness, effectiveness)
- Bridging test and analysis
- Reduce time to build, and refine models
- Control cost of the simulation and optimization

Summary

- FE model updating requires access to a suite of generic and dedicated tools
- FE model updating is an optimization process
- Optimization processes need to include uncertainty analysis
- FEMtools Framework can be used as a rapid CAE application development platform

For More Information…

- http://www.femtools.com
  - Product information
  - Recent Papers : http://www.femtools.com/products/papers.htm
  - Trial version

- E-mail

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