

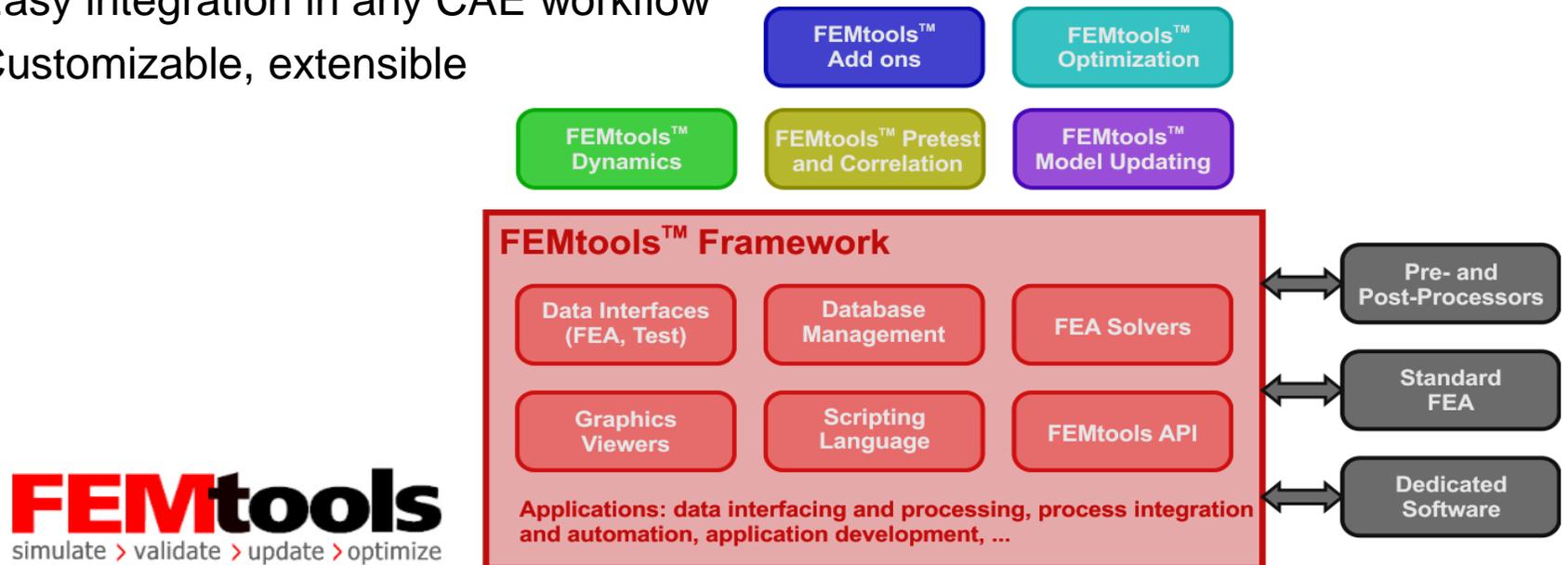
Orders-based Validating and Updating of Rotating Machinery FE Models

E. Dascotte
Dynamic Design Solutions (DDS) NV

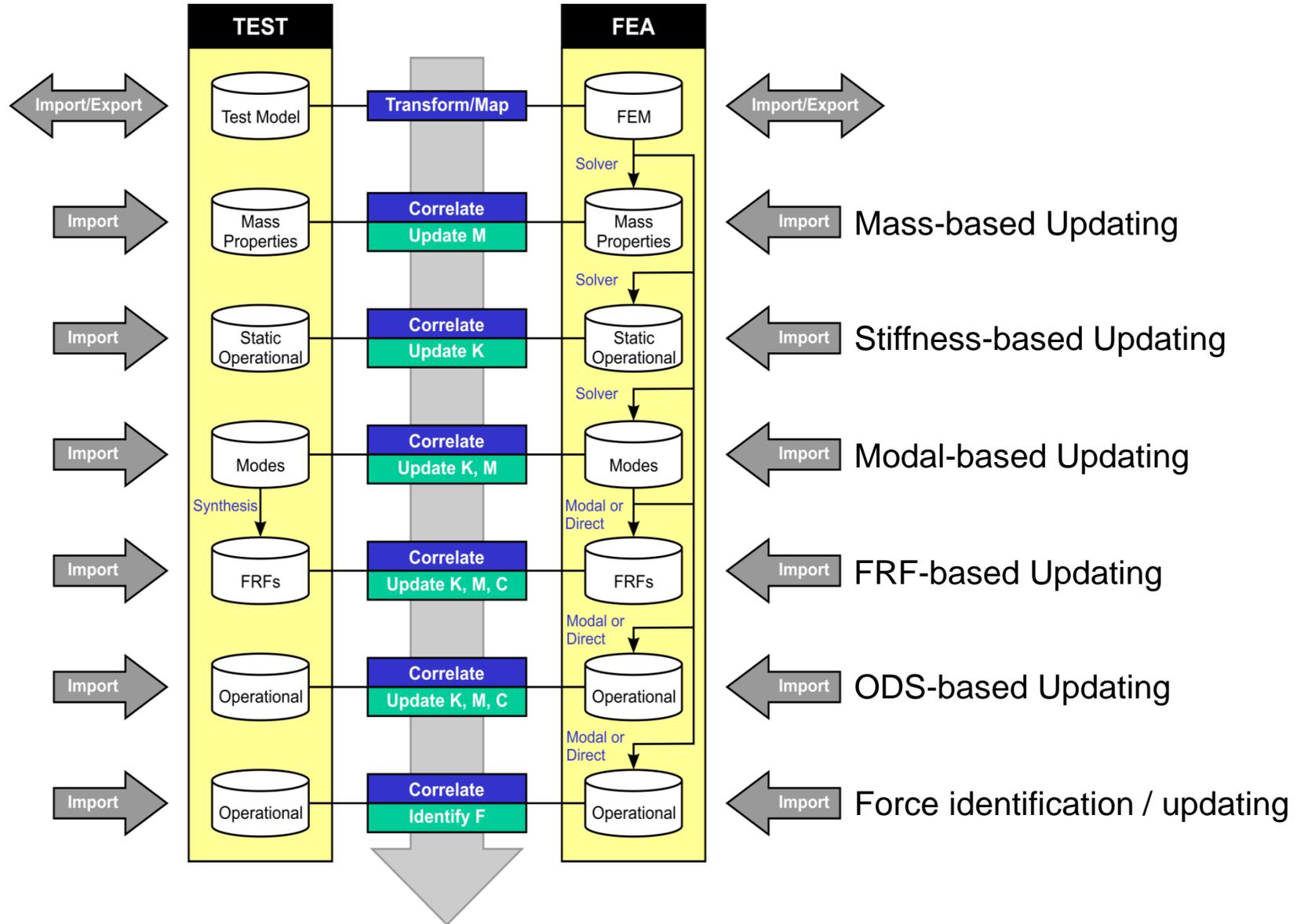
IMAC XLI
Austin, TX, Feb. 13-16, 2023

Dynamic Design Solutions – Company Profile

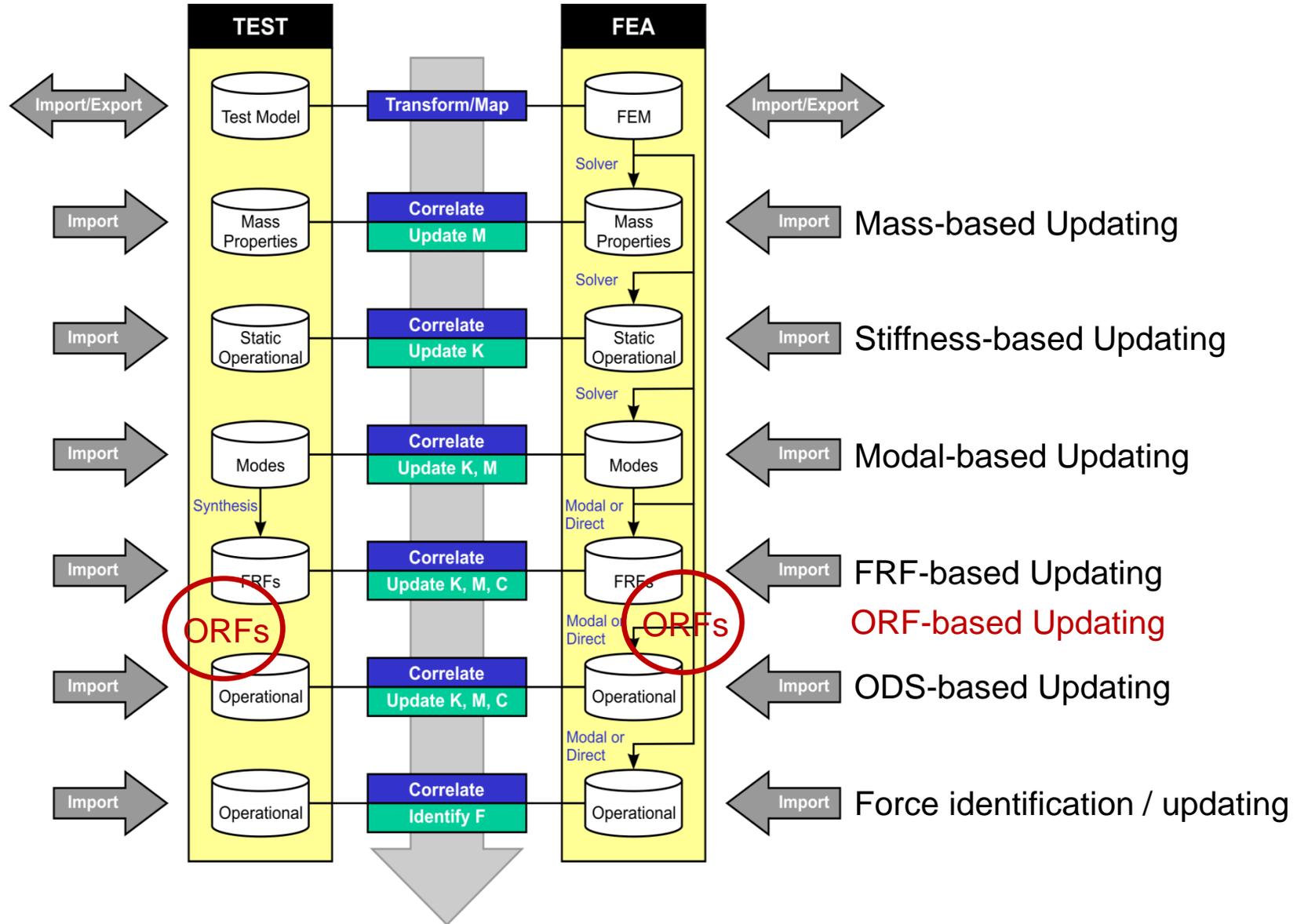
- CAE software development and services
- Specializing in structural dynamics, integration of FEA with testing, validation and updating of finite element models
- Main product is “FEMtools”
 - multi-functional, cross-platform and solver-independent CAE software suite providing analysis and scripting solutions
 - Neutral, open database combining FE and test data
 - Easy integration in any CAE workflow
 - Customizable, extensible



Different Types of FE Model Validation and Updating

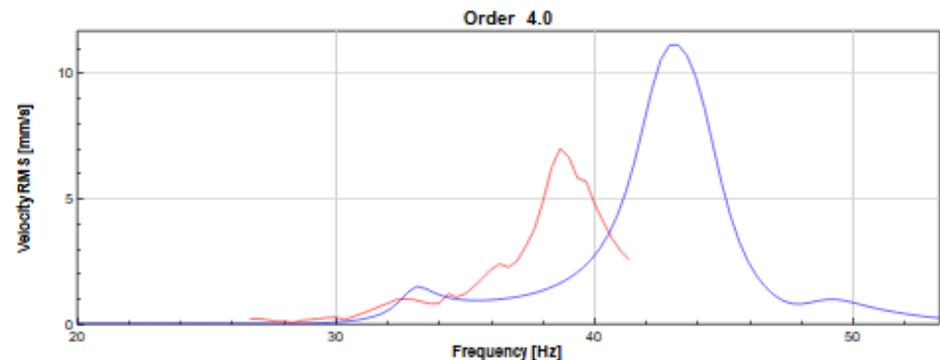
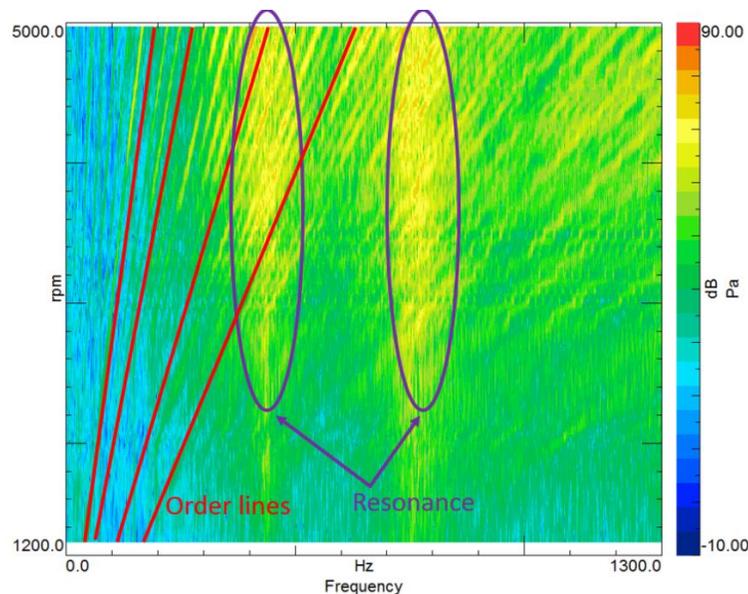


Different Types of FE Model Validation and Updating

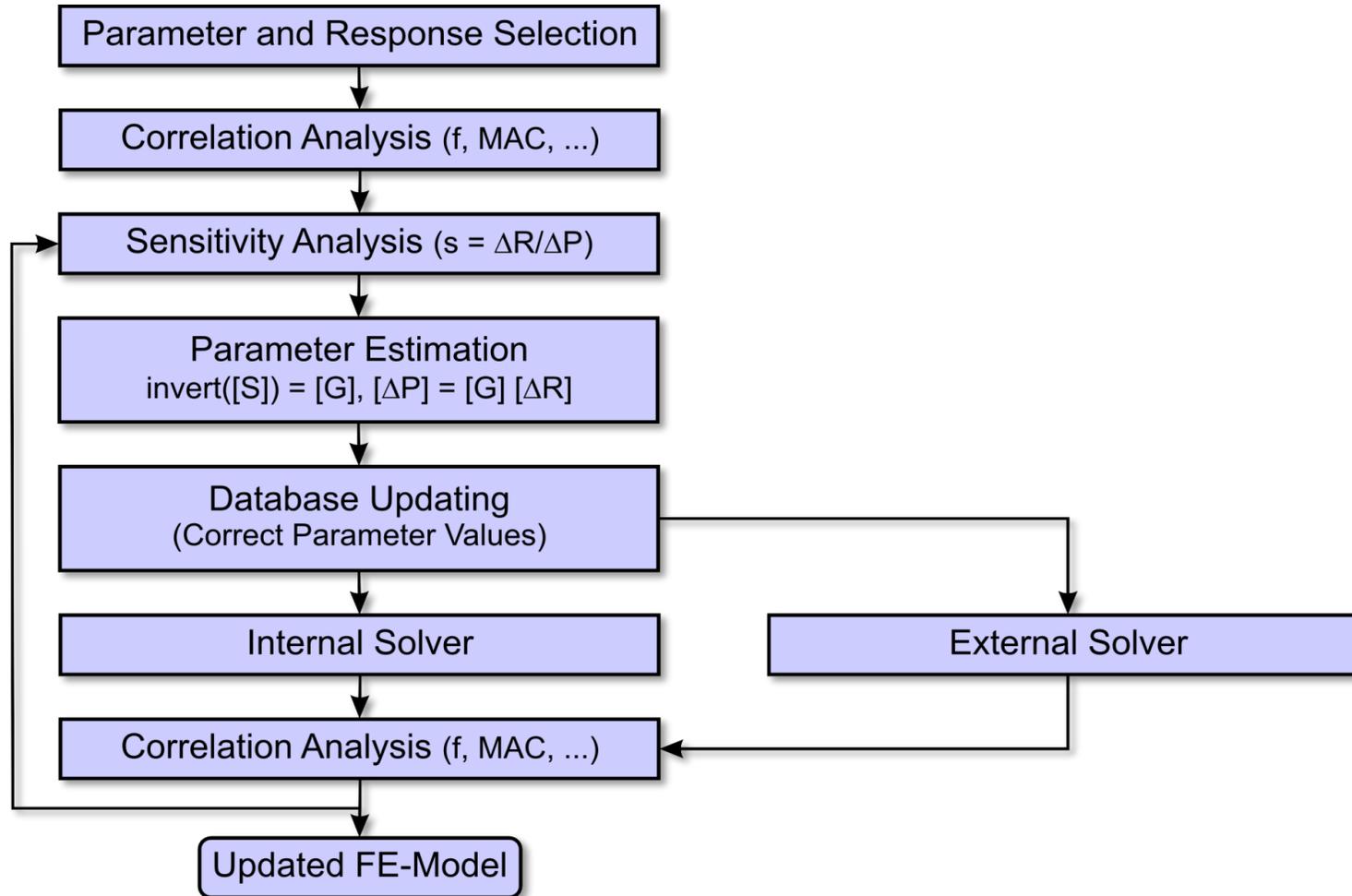


What are orders? What are Order Response Functions

- Order number is the ratio of the events per revolution relative to the first order.
- Orders Response Functions are the vibration amplitude as a function of RPM (or Hz)
- Test ORF can be obtained from run-up/down vibration testing and order tracking.
- Simulation ORF are obtained using modal-based response analysis with excitation functions per order.

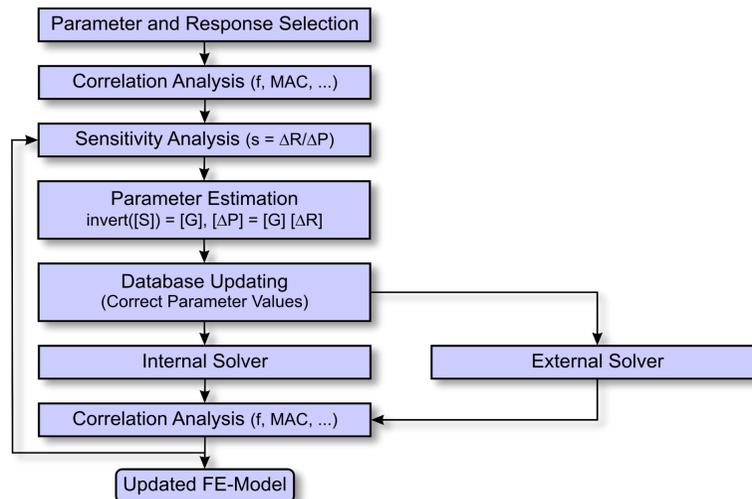


Model Updating Challenges



ORF-Based Correlation and Updating (FEMtools OCU)

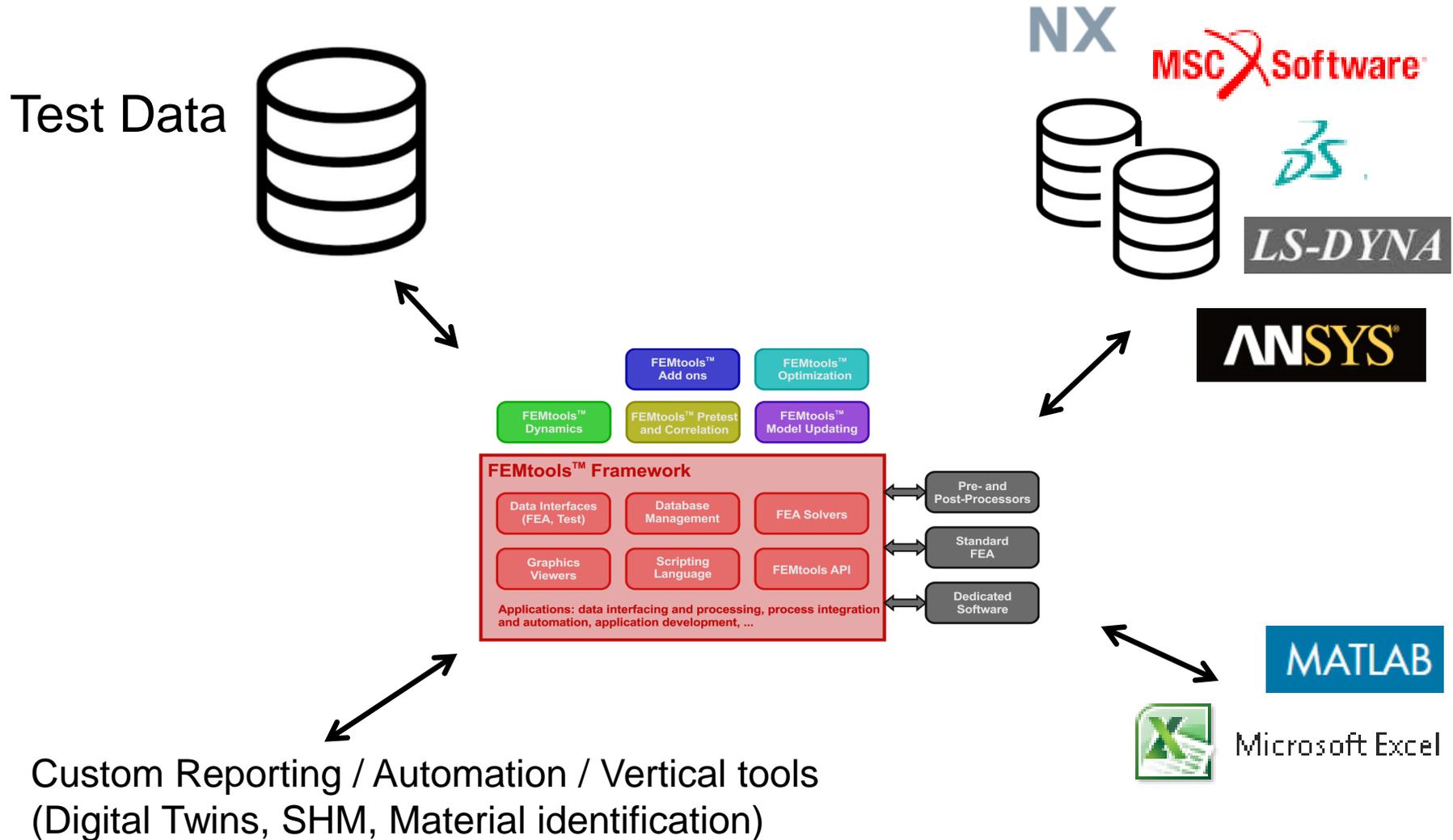
- Step 1: Updating the modal model
 - Generate FE model and compute mode shapes
 - Import test model and pair FE and test model (identify DOF pairs)
 - Create crop model from FE model and mode shapes at DOF pairs (truncation)
 - Use OCU to update the crop modal base (+ forces)
- Step 2: Updating the FE model
 - Use generic FE model updating using modal-based approach with the updated crop modal base as targets



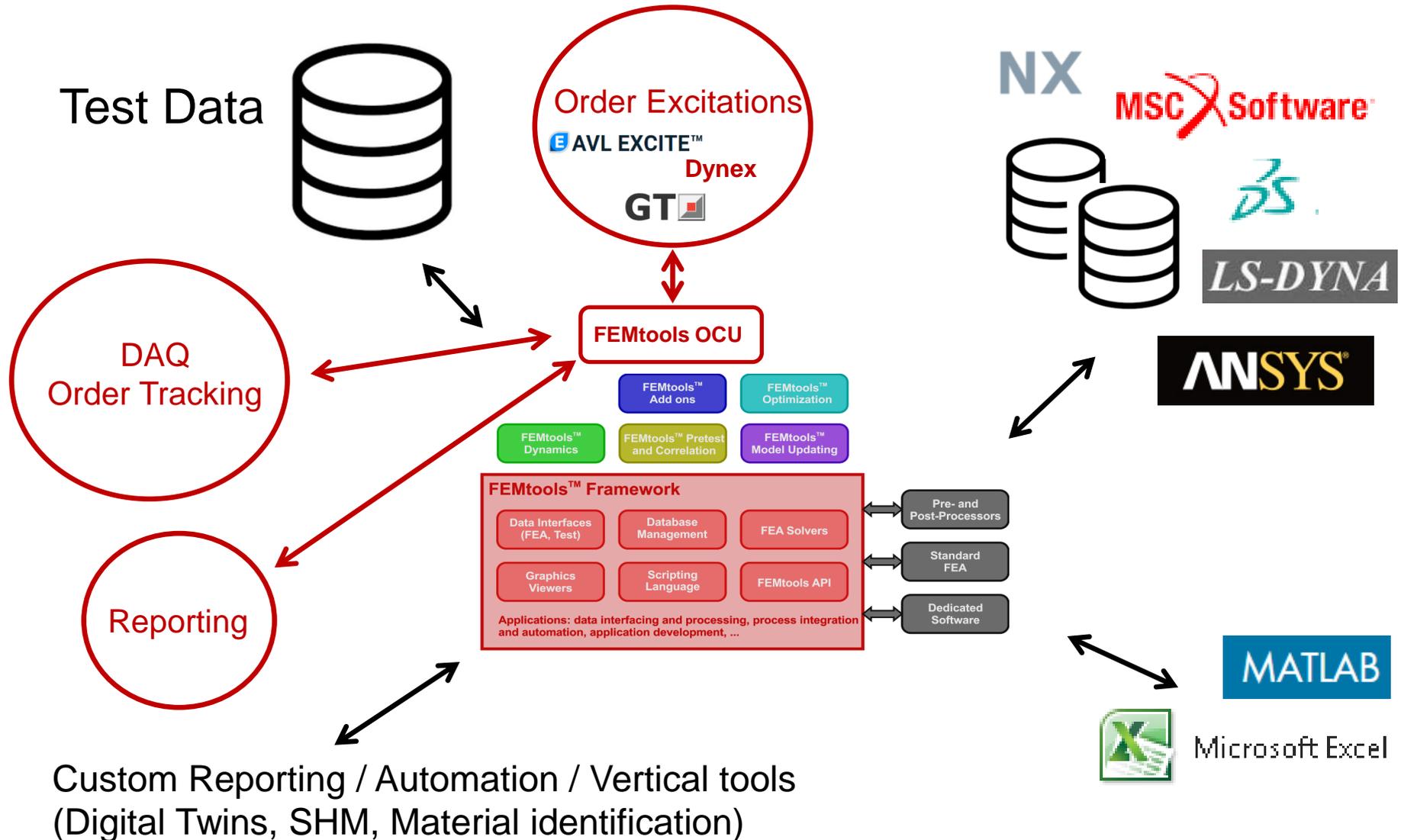
FEMtools OCU – Overview

- A dedicated applet developed in FEMtools Script to work with ORFs from test and simulation.
- Developed in collaboration with engine development specialists.
- A new “Orders Response Analysis” solver optimized for speed. For example: re-analysis reduced from ~5s to ~0.5s enabling near real-time updating of ORFs when modifying parameter like frequency, damping, mode amplitude and force amplitude.
- Order Response Functions (ORF) are selected as the reference responses if excitation is due to the rotation of the system (EMA, OMA, ODS do not apply).
- The main goal is to obtain the changes needed to the FE modal base and forces to fit simulation with test. The modified FE modal base can be used as the target test modal base for FE model updating (2-step approach).
- FEMtools OCU combines all data in a single interactive app.

FEMtools as an Integration Tool



FEMtools as an Integration Tool



FEMtools OCU – Workflow

- Data preparation
 - Create or import a “cropped” FE data. This is an FE model and modal base truncated using FEMtools Framework commands to the load and response nodes.
 - Import loads.
 - Import the test model (~ as cropped FEM).
 - Import measured order responses.
 - Import the configuration file to specify load and response locations, labels, mapping between FE and test, speed setting, color settings.
 - (import measured ODS) *optional*
 - (import modal parameter changes file) *optional*
- Launch interactive OCU panel
 - Automatically computes the ORFs for given loads and settings.
 - Scripts can be launched for loading data, saving modal parameters, saving graphics and text files for reporting.

FEMtools OCU – Workflow

Angular domain Excitation

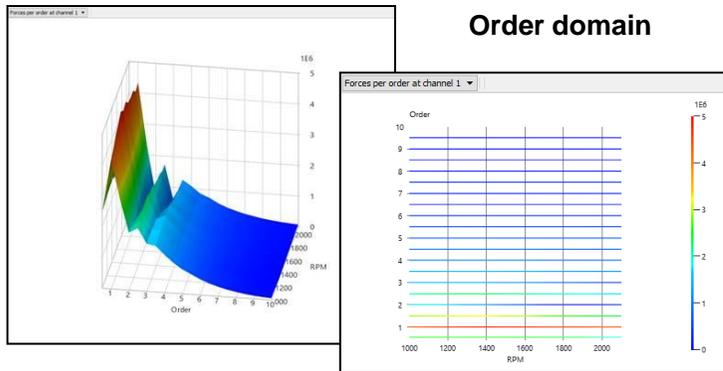


FFT

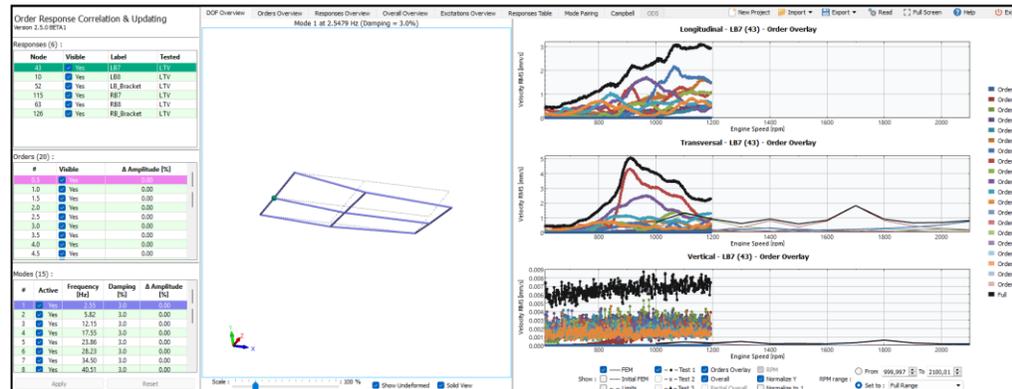
Cropped FE Model

Measured Order Responses
(Order Tracking)

Order domain

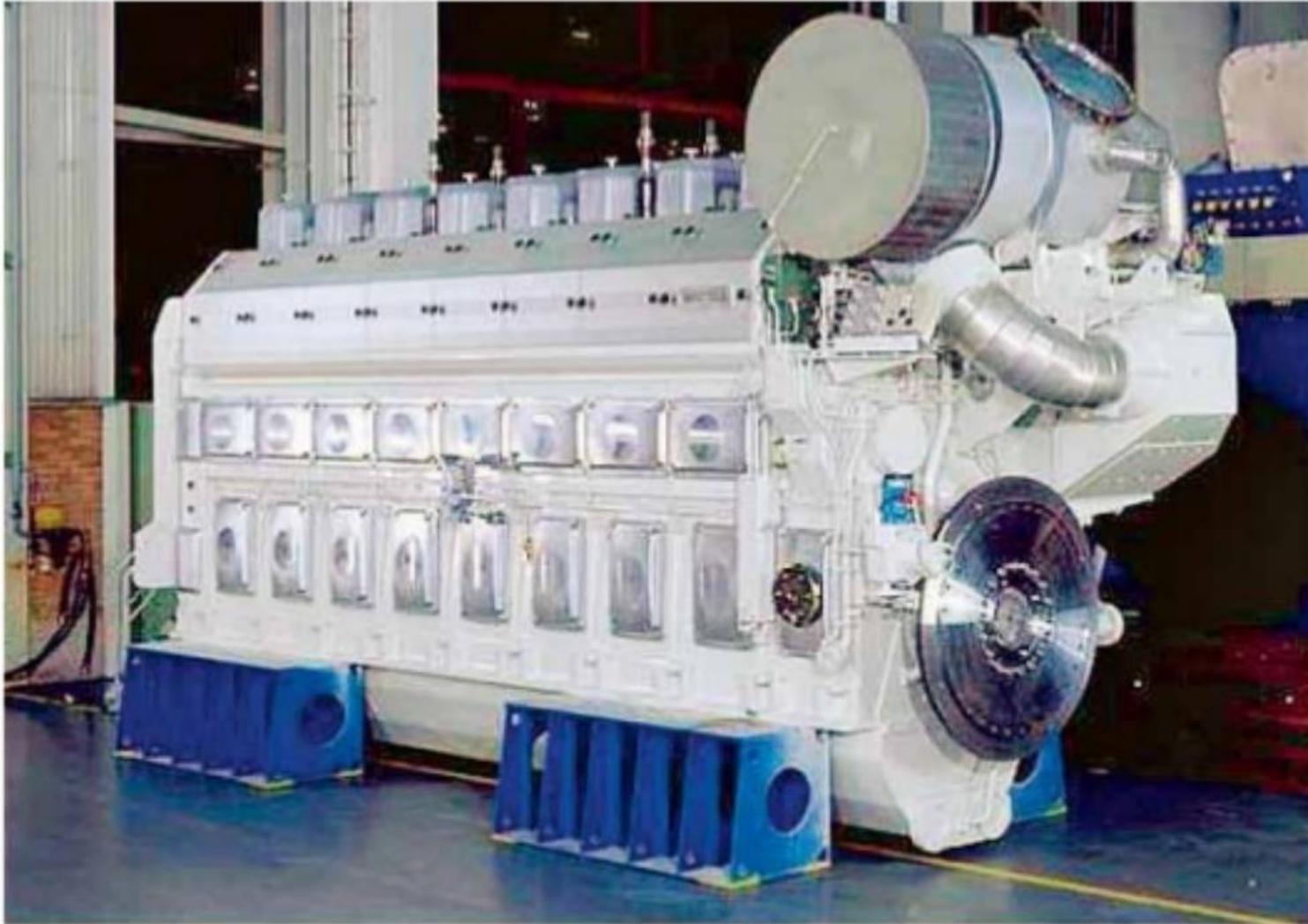


FEMtools OCU



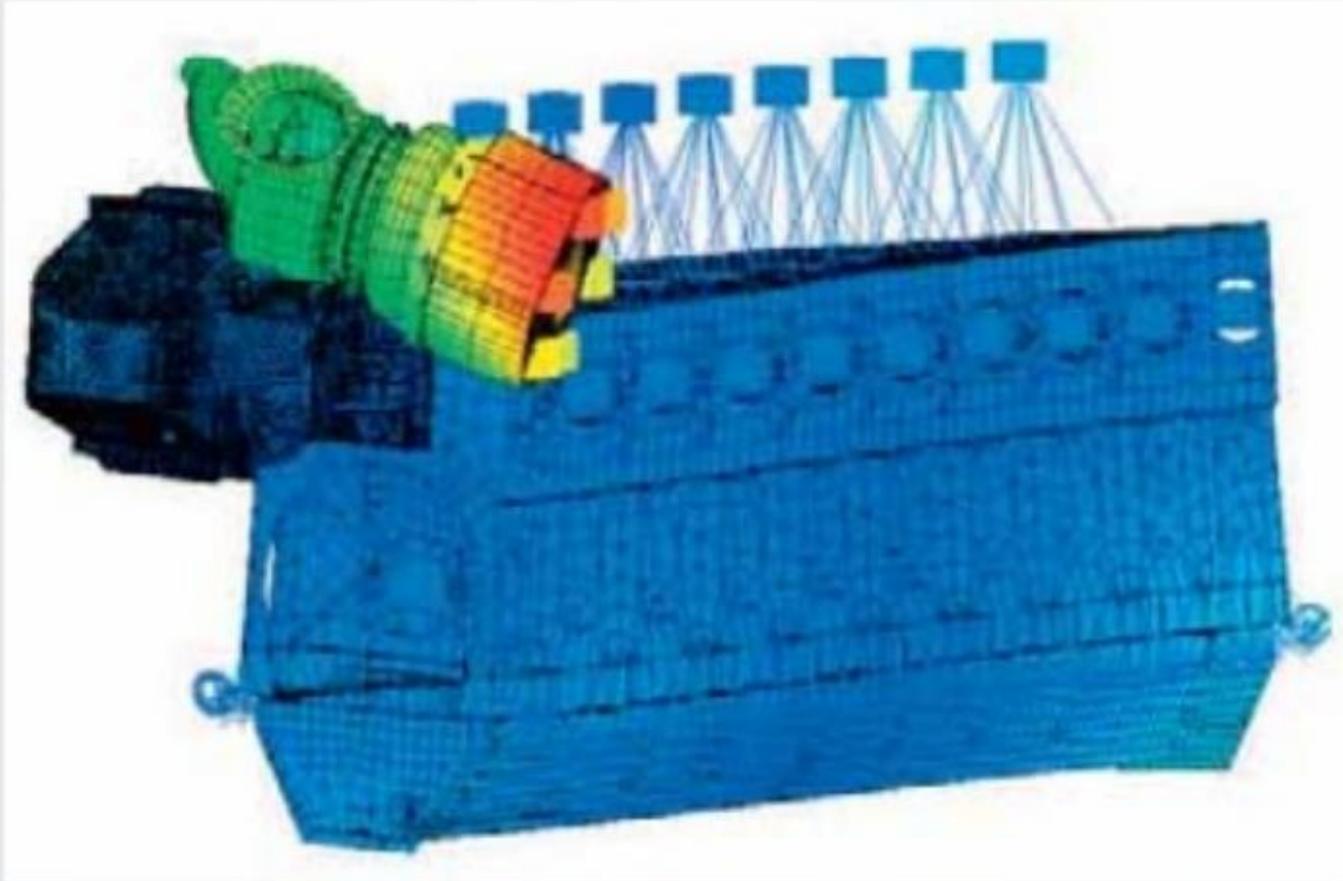
Test and Analytical data shown
for different RPM ranges.
(Demo purposes only)

Marine Diesel Engine Example Case



Wärtsilä 8L46 engine with ABB TPL Turbocharger

Marine Diesel Engine Example Case (FE Model)



Typical torsion mode marine diesel engine (image provided by Wärtsilä Finland Oy)

DOF Overview

Order Responses Correlation and Updating

File Edit View Database Tools Add-ons Window Help

Model Updating

Order Response Correlation & Updating
Version 2.1 BETA 1

Responses (37):

Node	Visible	Label	Tested
653	Yes	TCCa_T	LTV
601	Yes	TCFa	LTV
301	Yes	A3a	LTV
309	Yes	C3a	LTV
460	Yes	CACb_T_R	LTV
903	Yes	TCa-br_R	LTV
110	Yes	C1b	LTV
302	Yes	A3b	LTV
305	Yes	B3a	LTV
306	Yes	B3b	LTV

Orders (20):

#	Visible	Δ Amplitude [%]
0.5	Yes	0.00
1.0	Yes	0.00
1.5	Yes	0.00
2.0	Yes	0.00
2.5	Yes	0.00
3.0	Yes	0.00
3.5	Yes	0.00
4.0	Yes	0.00
4.5	Yes	0.00
5.0	Yes	0.00

Modes (74):

#	Active	Frequency [Hz]	Damping [%]	Δ Amplitude [%]
1	Yes	0.00	2.5	0.00
2	Yes	0.06	2.5	0.00
3	Yes	0.07	2.5	0.00
4	Yes	0.12	2.5	0.00
5	Yes	1.61	2.5	0.00
6	Yes	1.85	2.5	0.00
7	Yes	2.09	2.5	0.00
8	Yes	34.19	2.5	0.00

DOF Overview

Mode 1 at 0.0003 Hz (Damping = 2.5%)

FEMtools OCU - Workflow De...

Scale: 100% Show Undeformed Solid View

Longitudinal - TCCa_T (653) - Order Overlay

Transversal - TCCa_T (653) - Order Overlay

Vertical - TCCa_T (653) - Order Overlay

Velocity RMS (mm/s)

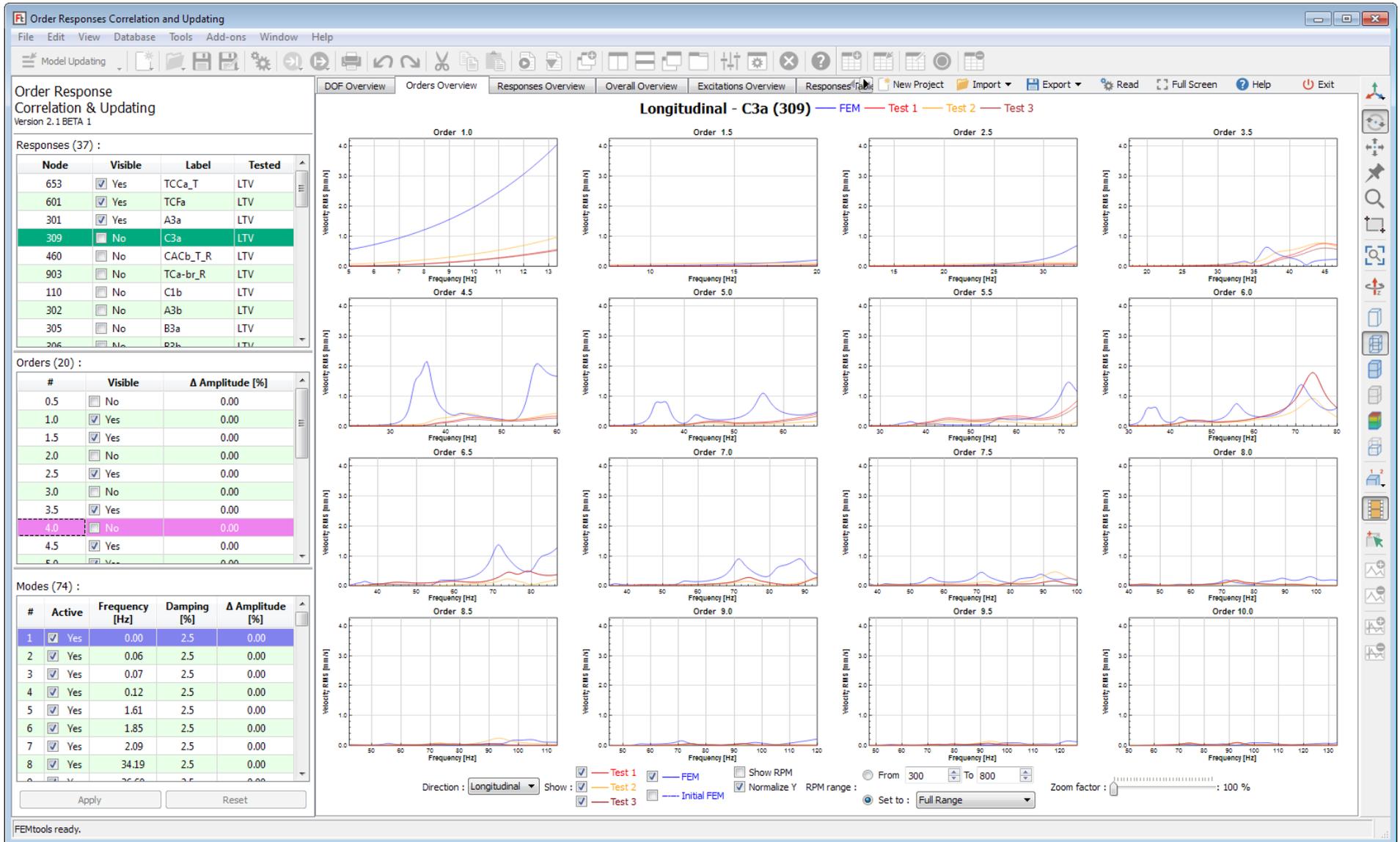
Engine Speed (rpm)

Order 0.5, Order 1.0, Order 1.5, Order 2.0, Order 2.5, Order 3.0, Order 3.5, Order 4.0, Order 4.5, Order 5.0, Order 5.5, Order 6.0, Order 6.5, Order 7.0, Order 7.5, Order 8.0, Order 8.5, Order 9.0, Order 9.5, Order 10.0, Full

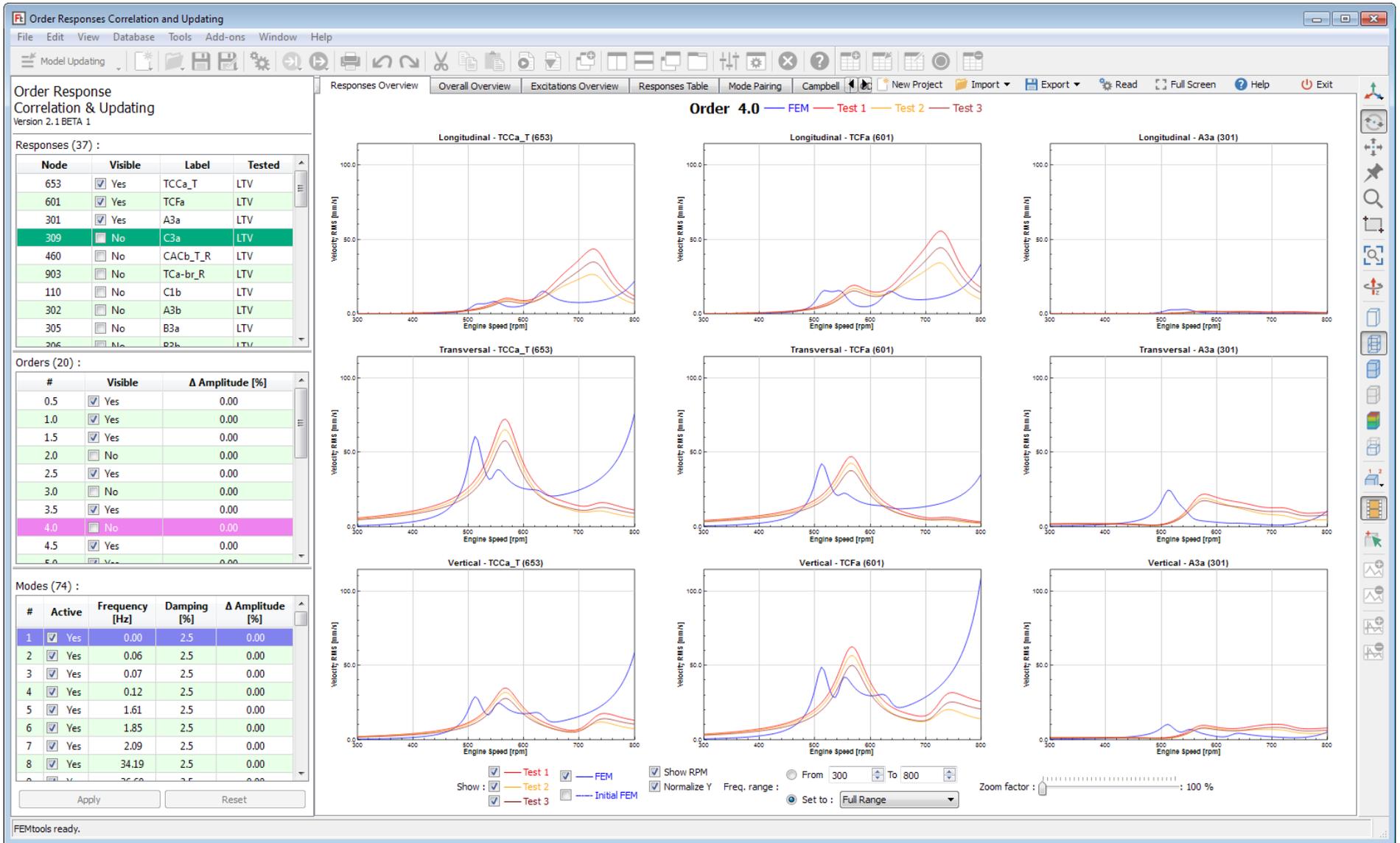
FEM -•- Test 1 Orders Overlay RPM
 Initial FEM -x- Test 2 Overall Normalize Y RPM range: From 300 To 800
 Limits -▲- Test 3 Partial Overall Normalize to 1 Set to: Full Range

FEMtools ready.

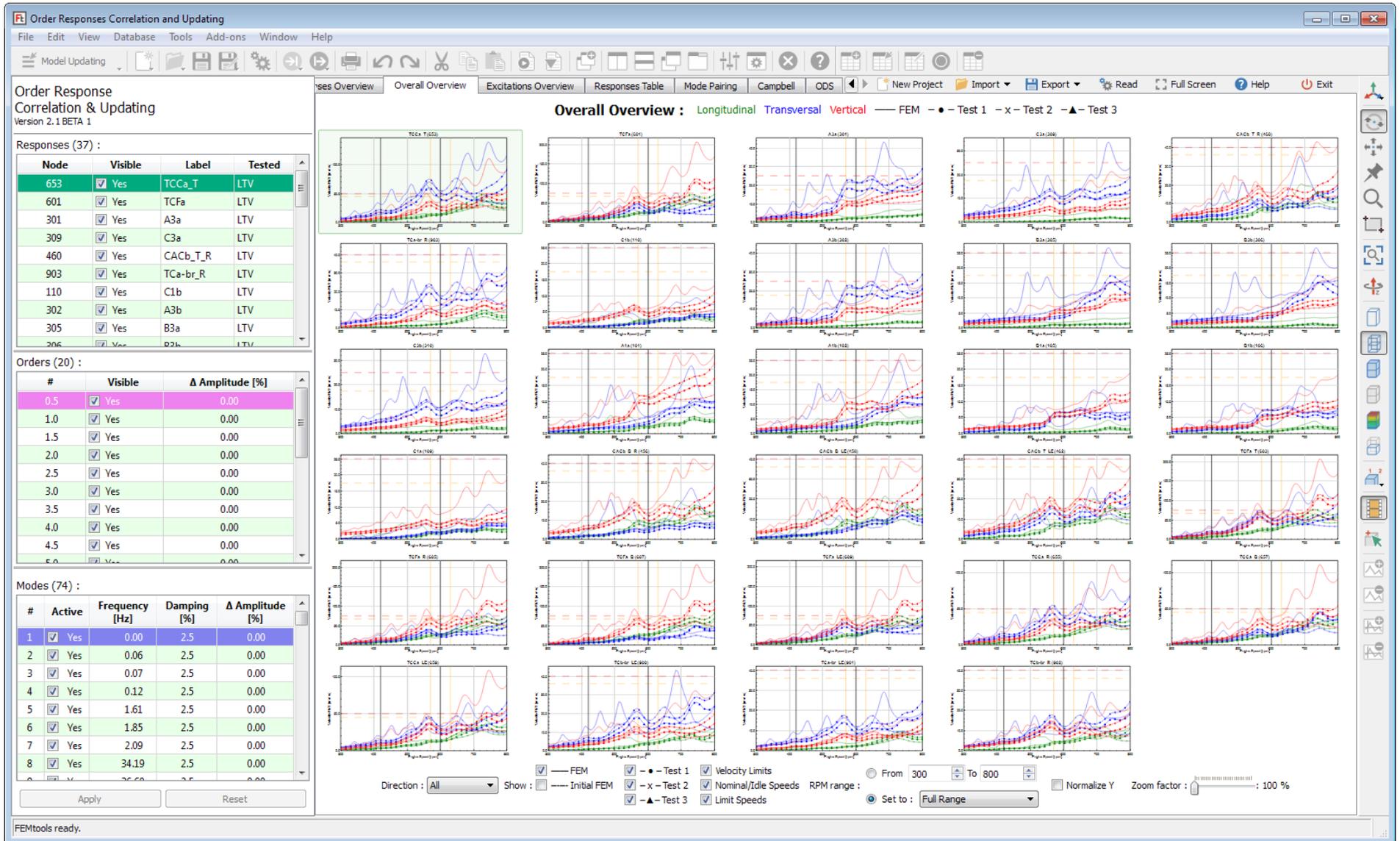
Orders Responses Overview



Orders Responses Overview



Overall Overview



Excitations Overview

Order Responses Correlation and Updating

File Edit View Database Tools Add-ons Window Help

Model Updating

Order Response Correlation & Updating
Version 2.1 BETA 1

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301	<input checked="" type="checkbox"/> Yes	A3a	LTV
309	<input checked="" type="checkbox"/> Yes	C3a	LTV
460	<input checked="" type="checkbox"/> Yes	CACb_T_R	LTV
903	<input checked="" type="checkbox"/> Yes	TCa-br_R	LTV
110	<input checked="" type="checkbox"/> Yes	C1b	LTV
302	<input checked="" type="checkbox"/> Yes	A3b	LTV
305	<input checked="" type="checkbox"/> Yes	B3a	LTV
206	<input checked="" type="checkbox"/> Yes	D2k	LTV

Orders (20):

#	Visible	Δ Amplitude [%]
0.5	<input checked="" type="checkbox"/> Yes	0.00
1.0	<input checked="" type="checkbox"/> Yes	0.00
1.5	<input checked="" type="checkbox"/> Yes	0.00
2.0	<input checked="" type="checkbox"/> Yes	0.00
2.5	<input checked="" type="checkbox"/> Yes	0.00
3.0	<input checked="" type="checkbox"/> Yes	0.00
3.5	<input checked="" type="checkbox"/> Yes	0.00
4.0	<input checked="" type="checkbox"/> Yes	0.00
4.5	<input checked="" type="checkbox"/> Yes	0.00
5.0	<input checked="" type="checkbox"/> Yes	0.00

Modes (74):

#	Active	Frequency [Hz]	Damping [%]	Δ Amplitude [%]
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5	<input checked="" type="checkbox"/> Yes	1.61	2.5	0.00
6	<input checked="" type="checkbox"/> Yes	1.85	2.5	0.00
7	<input checked="" type="checkbox"/> Yes	2.09	2.5	0.00
8	<input checked="" type="checkbox"/> Yes	34.19	2.5	0.00

Excitations Overview

All Points : Longitudinal Transversal Vertical Excitation(s)

Excitation Node : All Direction : All Normalize Y Show RPM Zoom factor : 100 %

FEMtools ready.

Mode Pairing

Order Responses Correlation and Updating

File Edit View Database Tools Add-ons Window Help

Model Updating

Responses Overview Overall Overview Excitations Overview Responses Table Mode Pairing Campbell ODS

New Project Import Export Read Full Screen Help Exit

Order Response Correlation & Updating

Version 2.1 BETA 1

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Modes (74):

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7	Yes	2.09	2.5	0.00
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Apply Reset

Min FEM : 1 Max FEM : 74 Min Test : 1 Max Test : 30

FEMtools ready.

Modal Assurance Criterion (MAC)

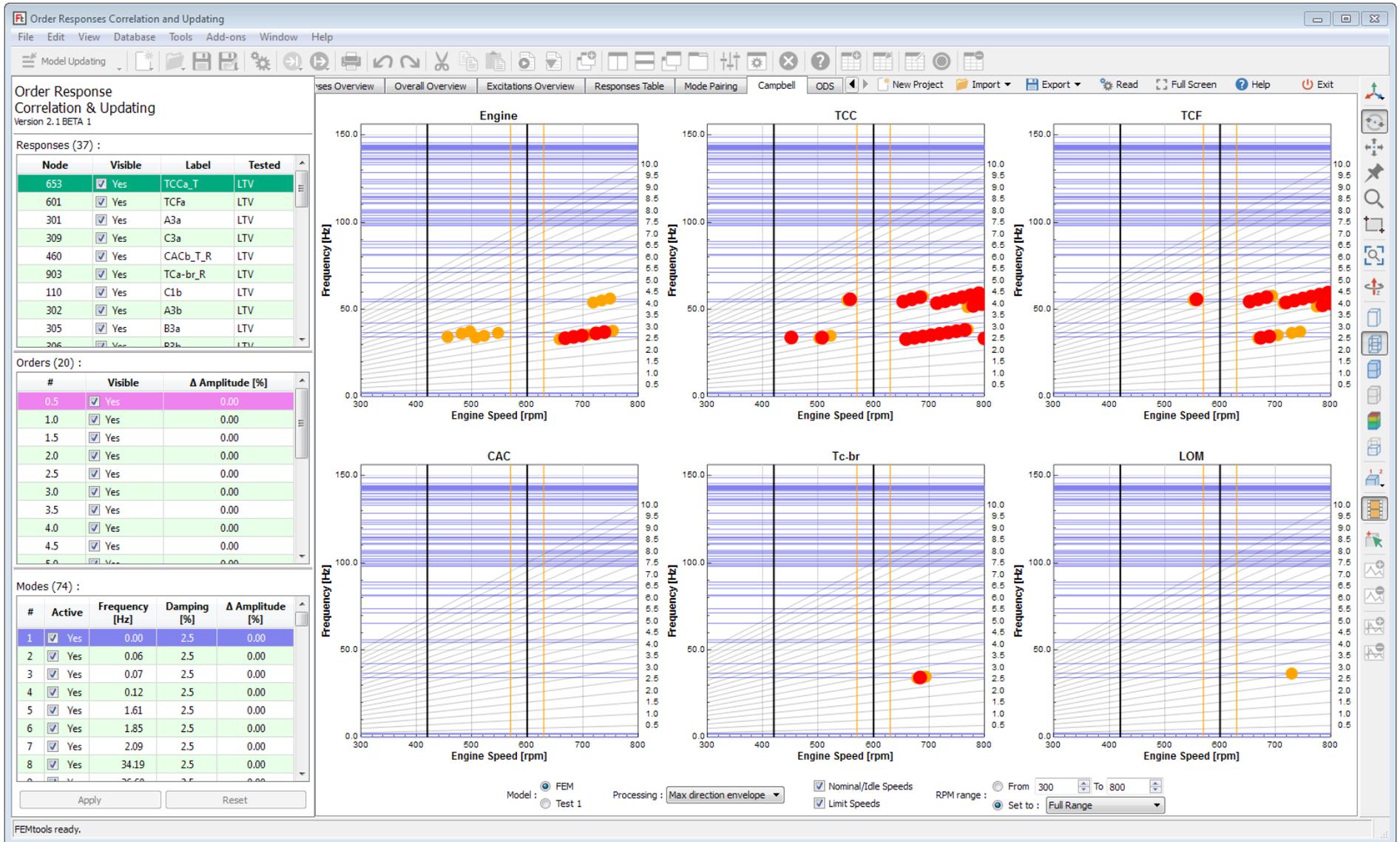
FEM mode 1: 0.00 Hz
Damping: 2.50 %
Δ Ampl: 0.00%

Test mode 1: 0.00 Hz
Damping: 3.00 %
Δ Ampl: 0.00%

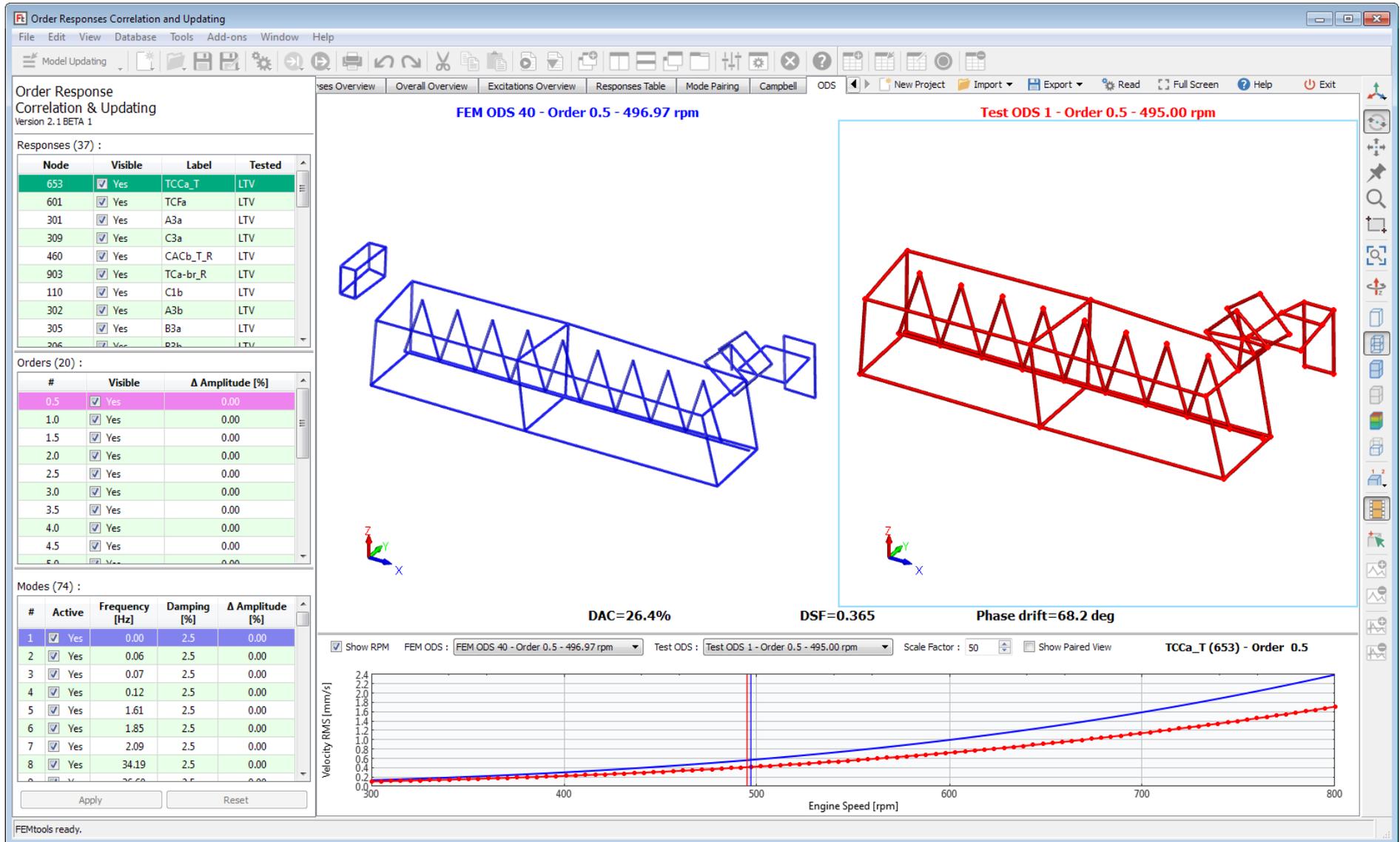
MAC: 100.00%
Δ Freq: -38.58%

Auto Pair... Create Pair Delete Pair Transpose Pairs

Campbell Diagram

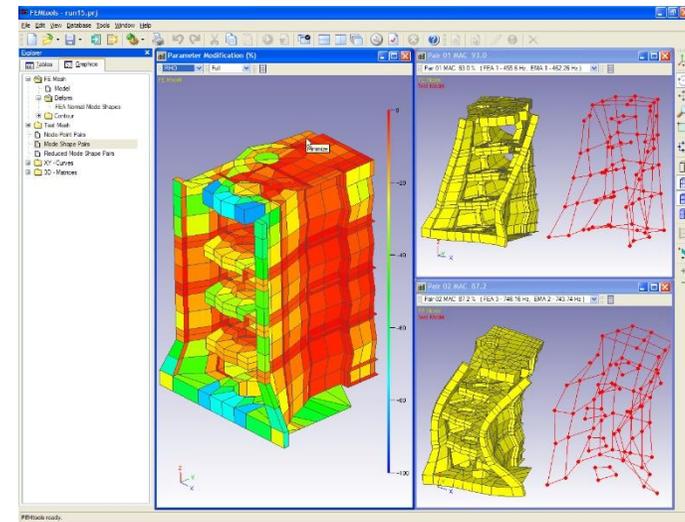
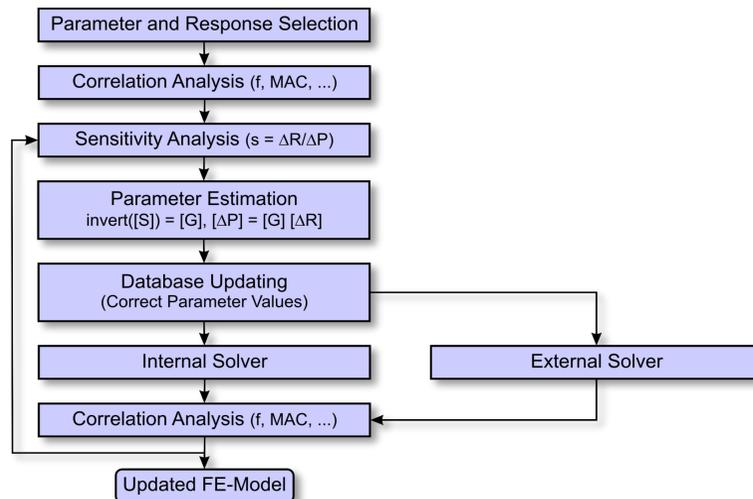


ODS Correlation



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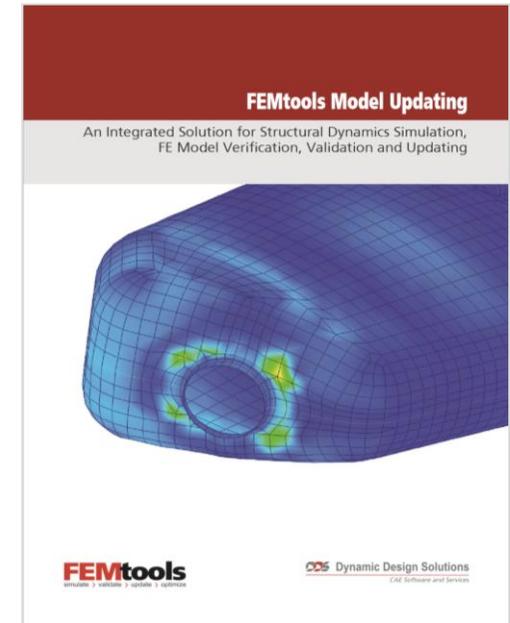
Next Steps

- Review workflow with potential users
 - Test and simulation processes
 - Validation requirements
 - Reporting needs
 - ...
- Pilot installations for trial and evaluation
- Interface development for excitations (GT-suite, AVL Excite,...)
- Extended interactive configuration and customization
- Data management and file repository (HDF5?)
- Integrate complementary tools
 - Order tracking
 - Automated parameter optimization (DOE/RSM, genetic algorithm, gradient,...); possibility to loop back to FE parameter updating

Contact Me!

For More Information...

- Exhibition hall, booth 503
- Technical papers
 - <http://www.femtools.com/products/papers.htm>
- Webinars
 - www.femtools.com/webinars
- Technology course
 - <http://www.femtools.com/courses>
 - Next course
 - March 29-31, 2023 (Leuven, Belgium)
 - For courses on Modal Testing and Analysis, see www.navcon.com
- E-mail
 - info@femtools.com



www.femtools.com

