MARKET-ORIENTED CLIENT-CENTRIC TECHNOLOGY DRIVEN

HTEC
LUXEMBOURG

ANSYS CONFERENCE & USERS' MEETING

# LARGE ANTENNA STRUCTURES: CASCADED SIMULATIONS AND BOTTOM-UP VALIDATION

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STUTTGART, 20 OCTOBER 2011

# Agenda

Part 1:

- Introduction
- Modeling & simulation cascades
  - Components
  - Assembly
  - Control system modeling
  - Radio-frequency simulations
- Iteration loops Analysis - Design

Part 2:

- Validation campaign
  - Test approach
  - Measurement setup
- Measurement evaluation
  - Outputs
  - Panel results
  - Yoke results
- Conclusion

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# Large Ground Antennas for Satellite Communication

- HITEC Luxembourg Engineering Group main activities:
  - Antenna system according to customer requirements
    - from 3.5 m up to 18 m diameters
    - from 2GHz up to 30GHz
  - Limited motion (geostationary satellites)
  - Full motion (LEO and MEO satellites)
  - Transportable antenna system

## Partners & Clients

Lockheed Martin — We never forget who we're working for®

ASTRA TechCom Services

microwave mirad

VINASAT 1

SES

CARROSSERIE COMES & CIE

NATO OTAN NAMSA

esa

COSPAL Composites

European Satellite Navigation Industries

P&T Luxembourg

T-Systems

LE GOUVERNEMENT DU GRAND-DUCHÉ DE LUXEMBOURG
Ministère de l'Économie et du Commerce extérieur

# Large Ground Antennas for satellite communication

- Subject development:
  - Antenna system for Deutsches Zentrum für Luft- und Raumfahrt (DLR) in Weilheim
  - 13m reflector operating in Ka-band (20-30Ghz)
  - 2 axes, full motion
- Cooperation between:
  - SES Astra TechCom Services: RF and system design

ASTRA TechCom Services

  - HITEC Luxembourg : Electro-mechanical system design

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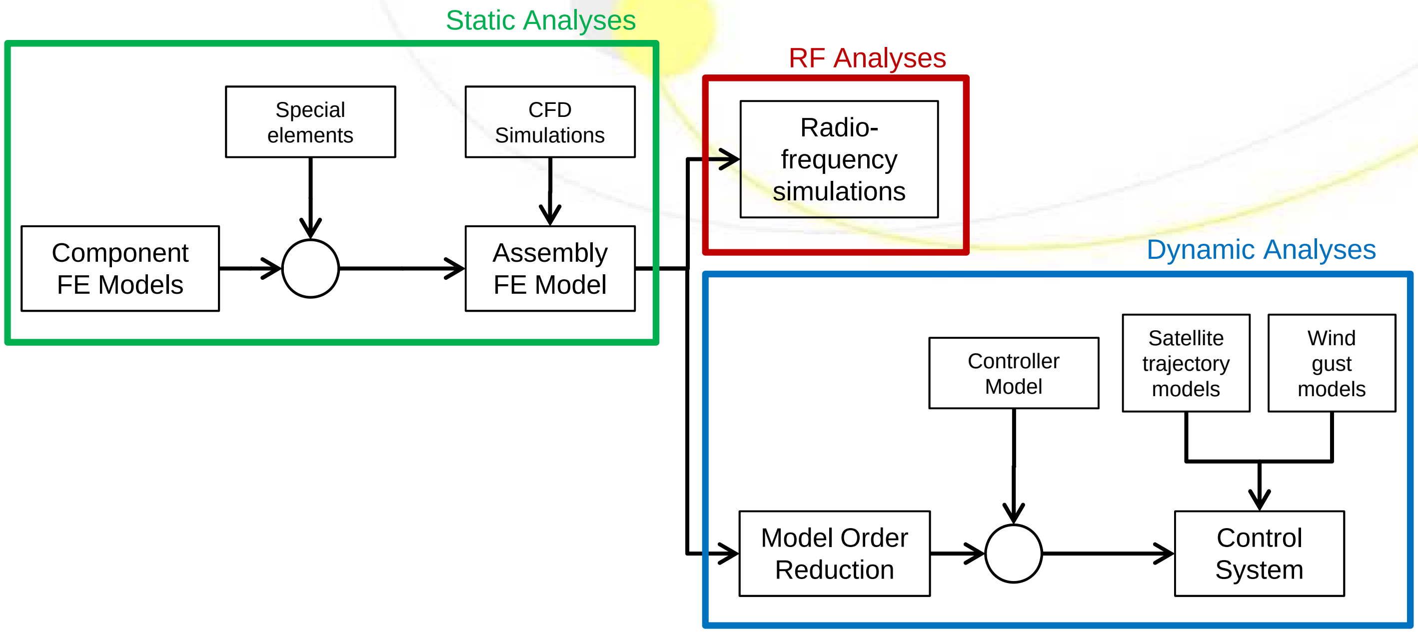
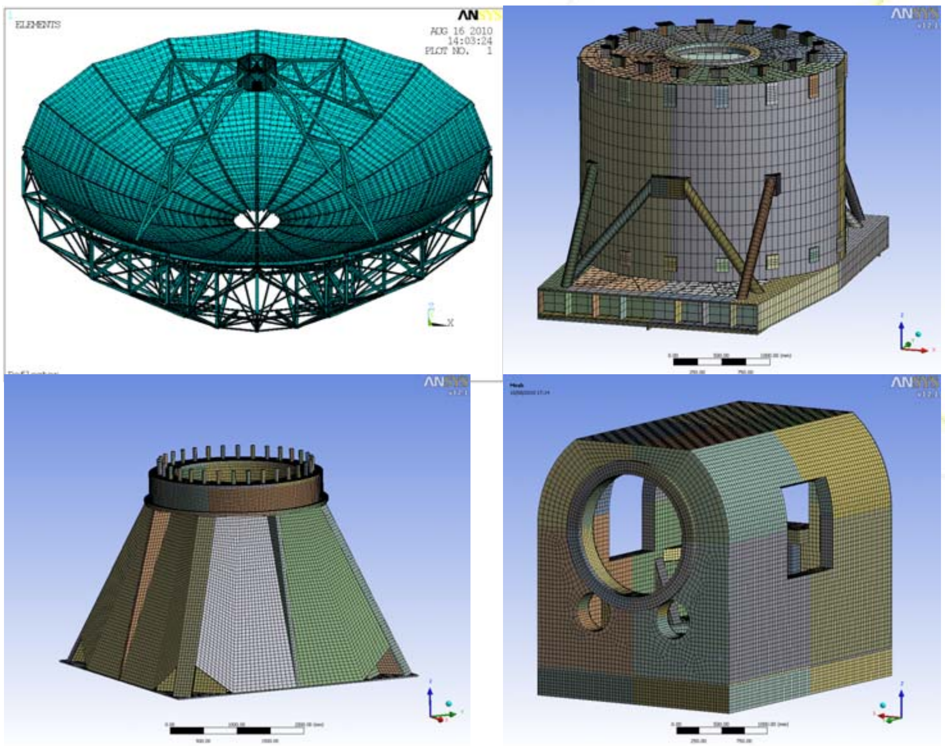
- As part of a design cycle, three main areas of modeling and simulation are involved:
  - Static analyses for structural integrity of the design and approximate performance
  - Dynamic analyses for system performance under various load cases
  - RF evaluation to compare RF performance against specifications

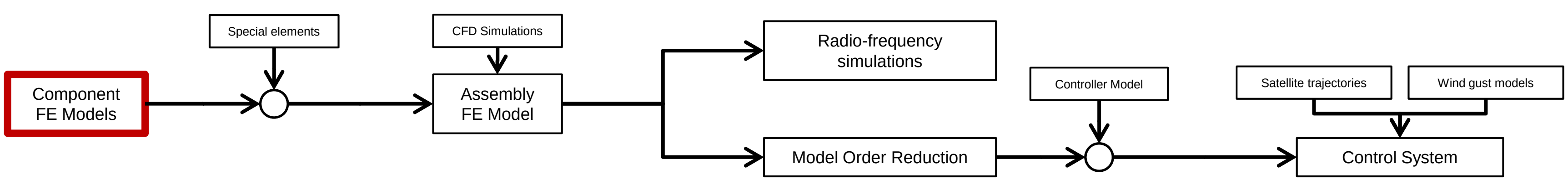



This results in cascaded design and simulation loops

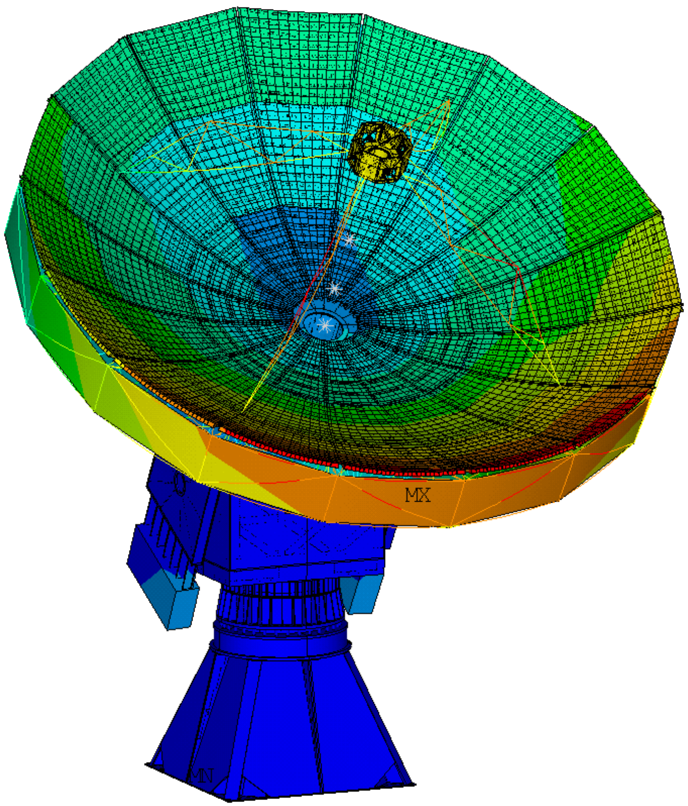
# COMPONENT FE MODELS



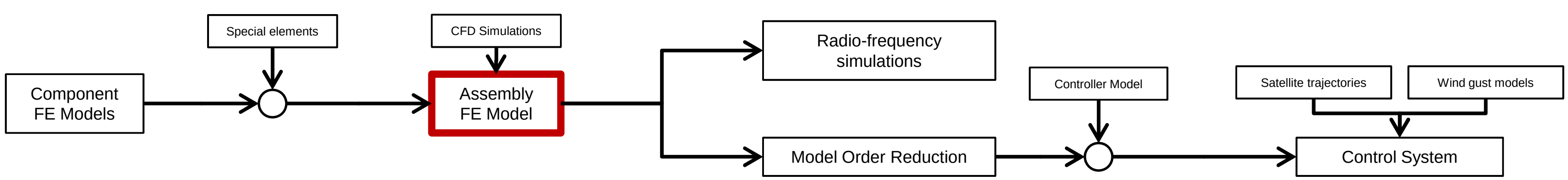
- Generation of FE models of individual antenna components
- Inputs:
  - Rough load estimates
- Outputs:
  - Deformations at critical points
  - Stress distribution
- But:
  - Uncertainties at interfaces between components
  - Few specifications at component level



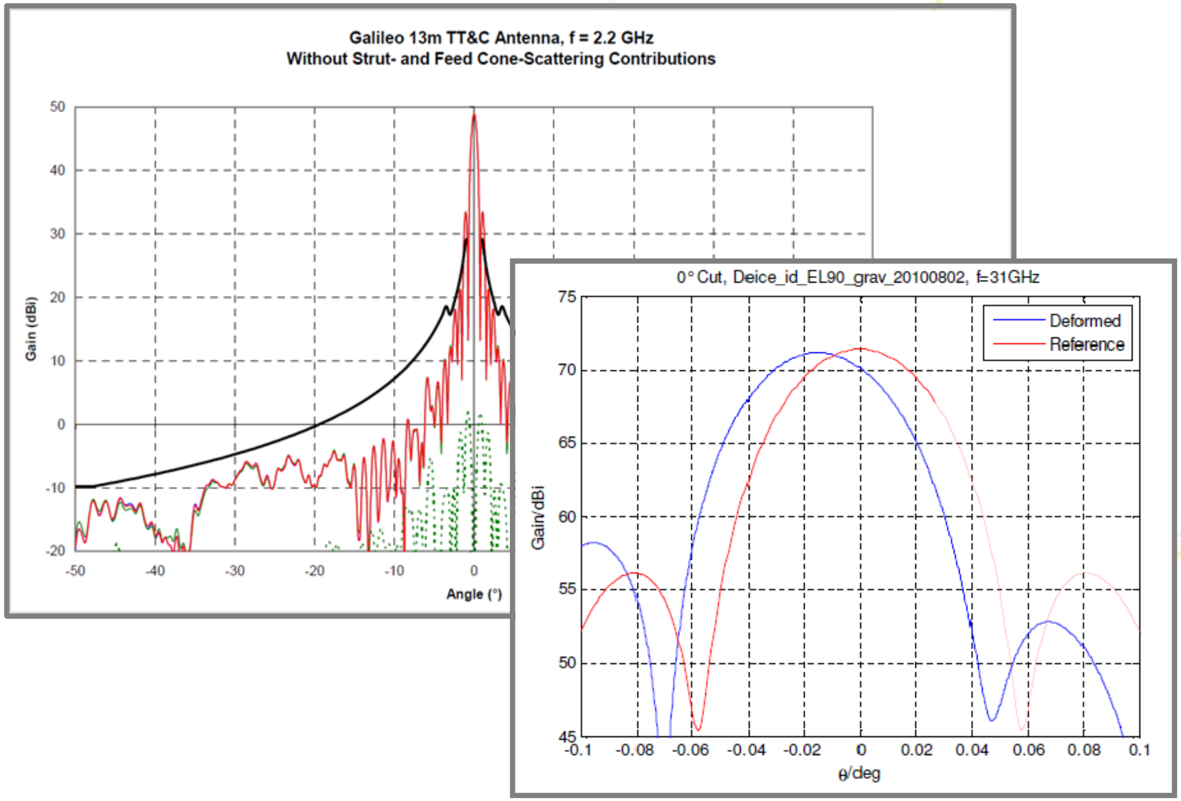
# Assembly model



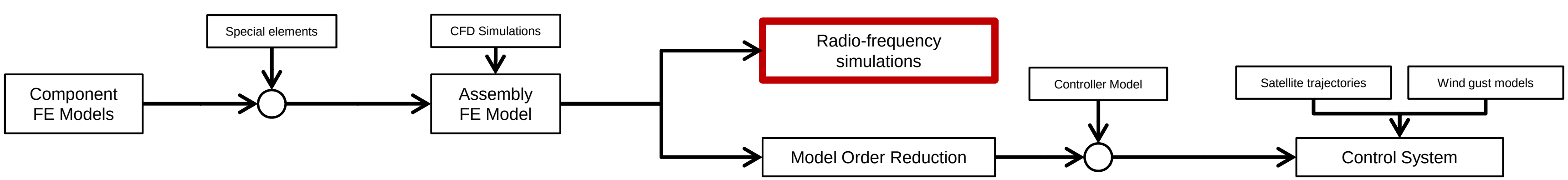

- Integration of:
  - Antenna components
  - Connecting elements (bearings, drive train...)
- Inputs:
  - Gravity
  - Wind loads, usually pressure distributions from CFD
  - Thermal loads
- Outputs:
  - Deformations of reflector optics
  - Stress levels
  - Behaviour at connections



# RADIO-FREQUENCY SIMULATIONS



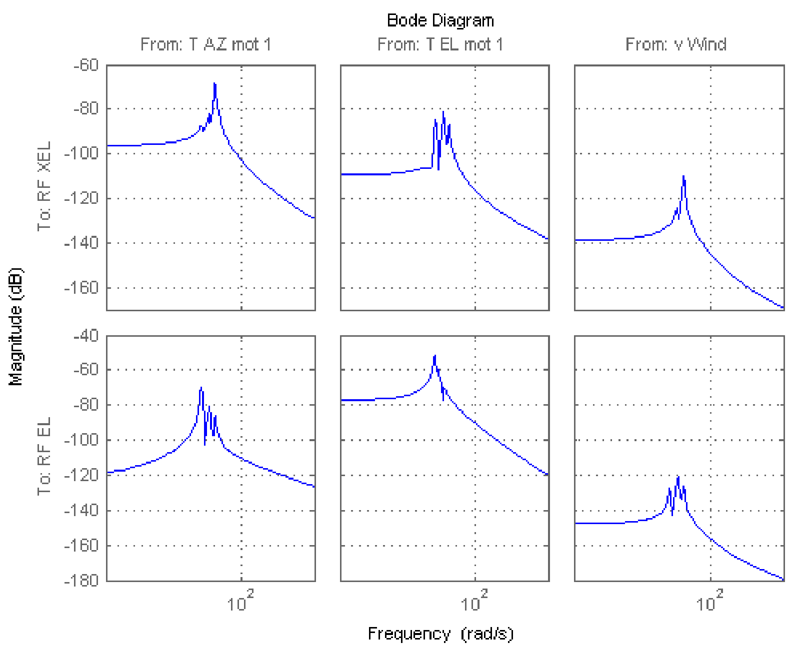

- Analysis of the impact of structural deformations on the radiation pattern
- System performance evaluation
- Inputs:
  - Deformed reflector shape
  - Position of sub-reflector
- Outputs:
  - Antenna gain reduction
  - Beam tilt



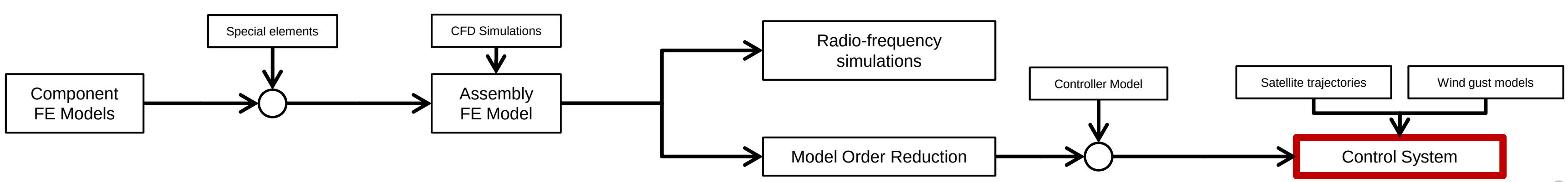
# Control system simulations

$$\dot{x} = Ax + Bu$$

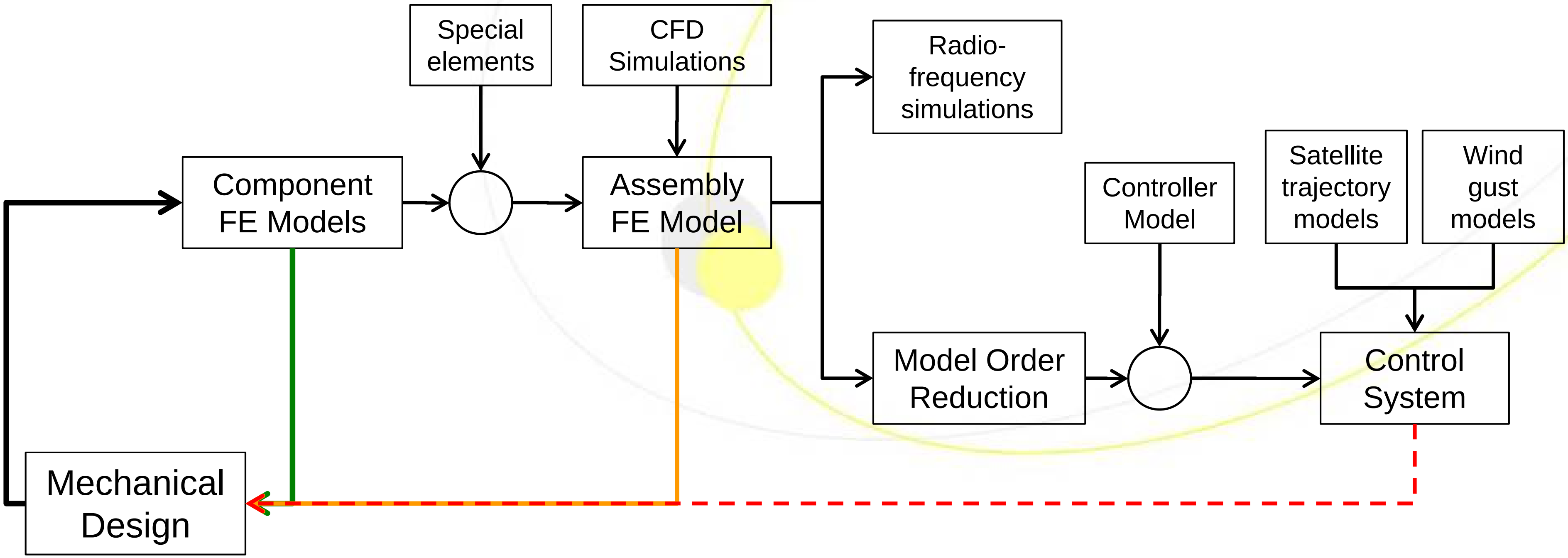
$$y = Cx + Du$$




- Integration of reducer-order structural model and axis controllers
- Inputs:
  - Satellite trajectories projected onto antenna axes
  - Dynamic wind gust models
- Outputs:
  - Antenna axis movements
  - Deviation of antenna beam from target



# Design iterations

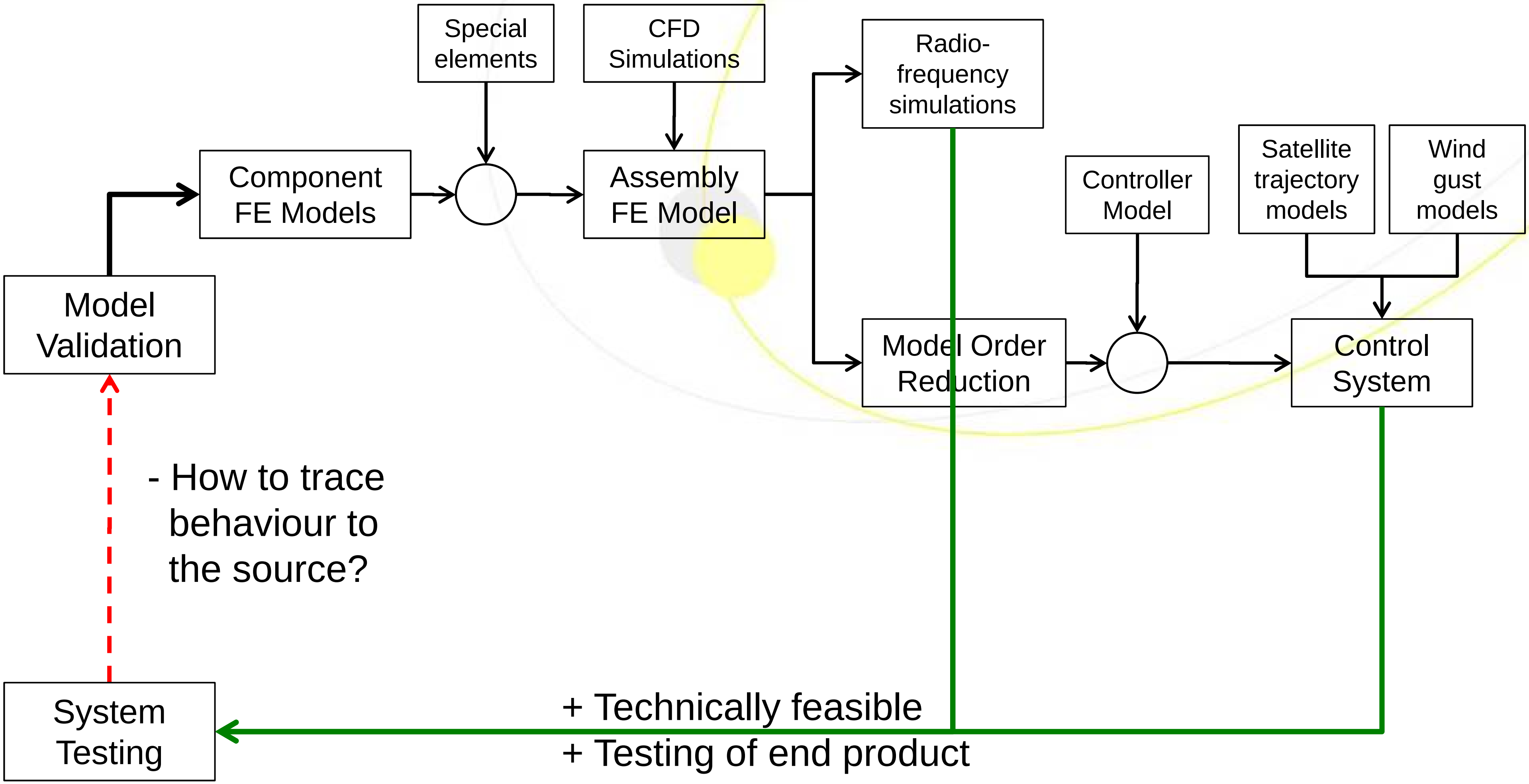



Best insight into components

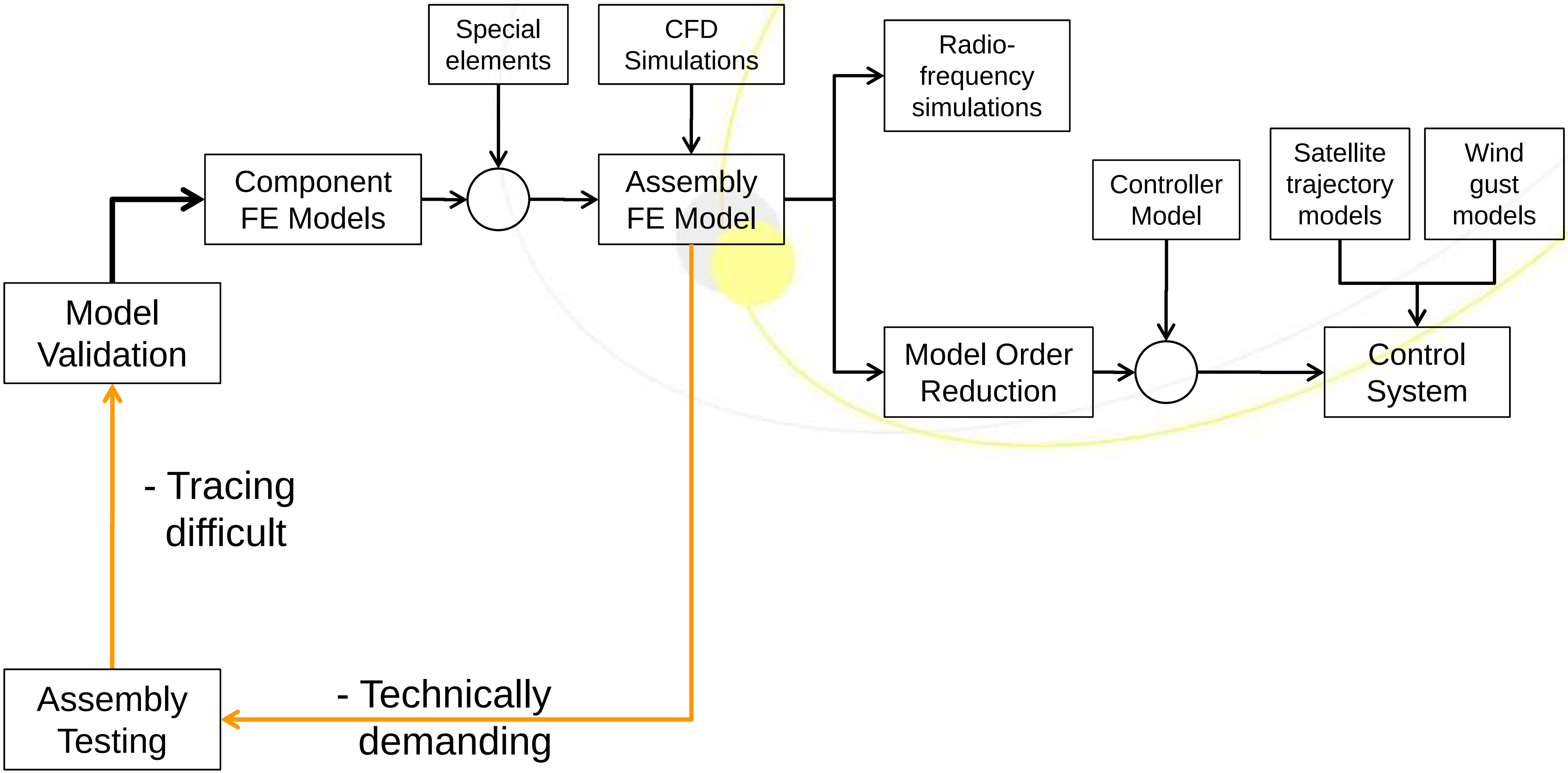
Complex interaction between components

How to draw conclusions from control system output to mechanical design?

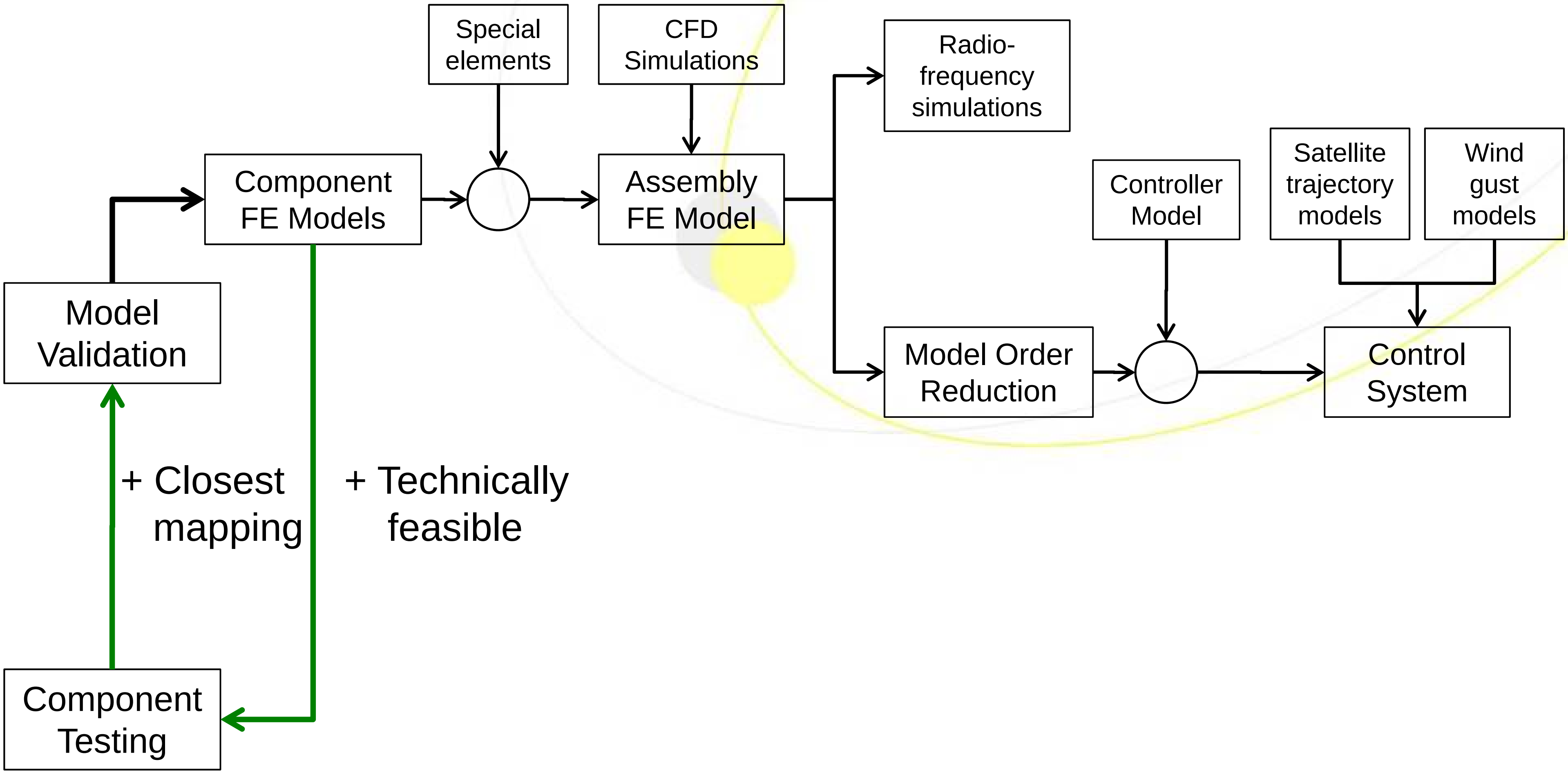
# Validation loops



# Validation loops

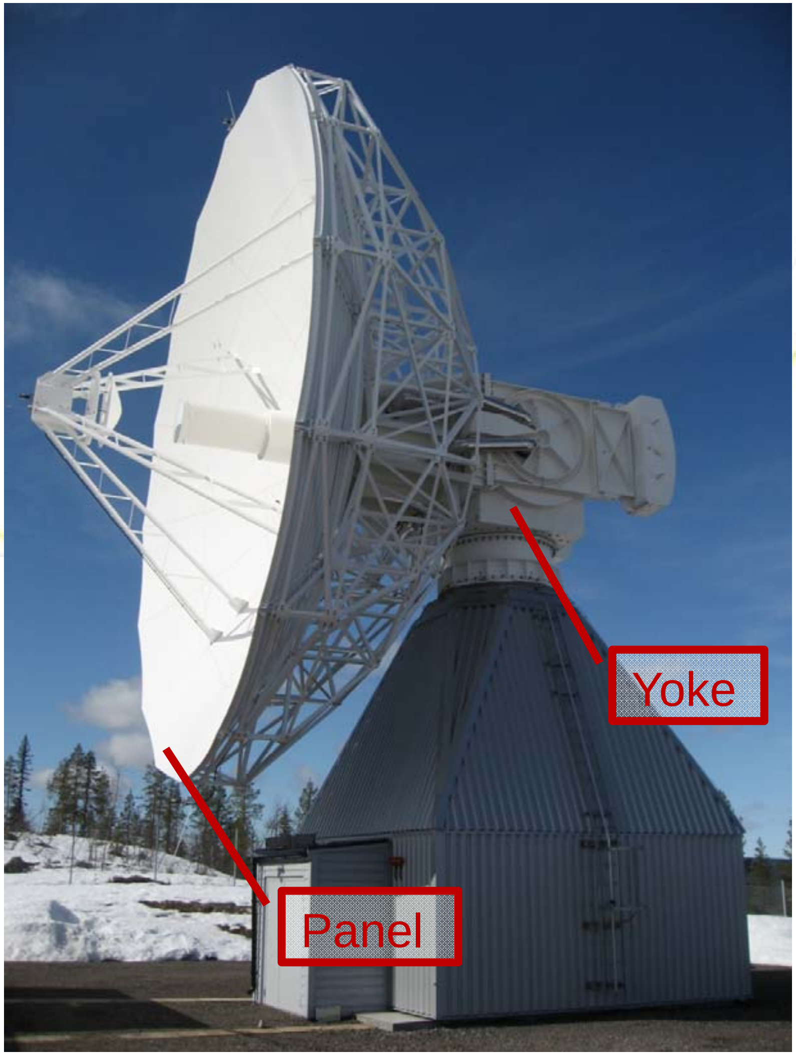


# Validation loops



# Validation campaign

- Component testing:
  - Highly rigid
  - Large dimensions & weight
- Static testing is not technically feasible:
  - How to apply the boundary conditions?
  - How to measure minuscule deformations?
- Modal testing is quite promising:
  - Comparably simple boundary conditions
  - Measurable movement with reasonable loads
  - Plus: abundant data when using Scanning Vibrometers
- Component selection:
  - Yoke: connection between antenna axes
  - Panel: reflector optics



## Validation Campaign

A validation campaign has been launched in cooperation with:

- Polytec GmbH
  - Execution of modal tests using the Polytec 3D scanning laser vibrometer PSV-400
- Vrije Universiteit Brussel, Prof. Vanlanduit
  - Modal analysis of measurement data set

Polytec

Vrije Universiteit Brussel

Validation tasks:

- Measurement of frequency response functions (FRF) under (almost) free-free conditions
- Modal analysis of FRF for:
  - comparison with simulation results
  - and model validation

# Panel setup

- Suspension by rubber cords
- Excitation by shaker, stinger and force transducer
- Excitation signal: Pseudo random
- Frequency range: 25 - 500 Hz
- ~500 measurement points

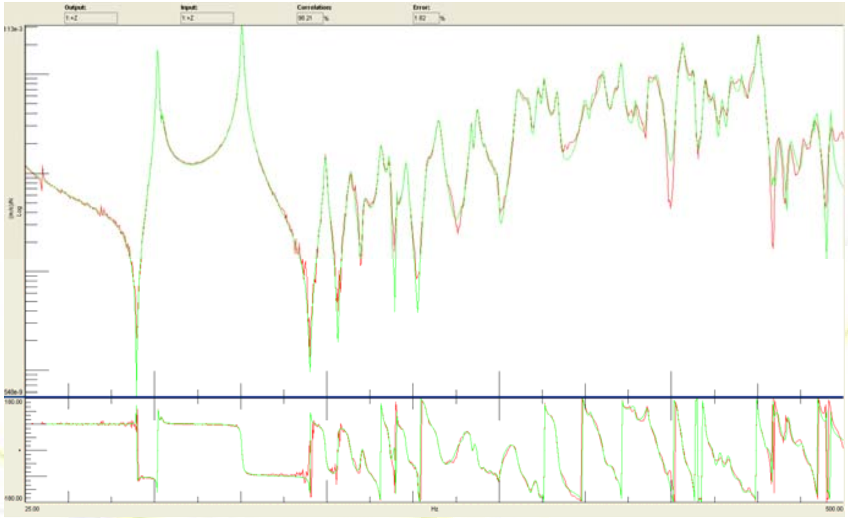
# Yoke Setup

- Excitation by shaker, stinger and force transducer
- Prevent lateral movement by straps
- Excitation signal: Pseudo random
- Frequency range: 50 -  400 Hz
- ~2000 measurement points

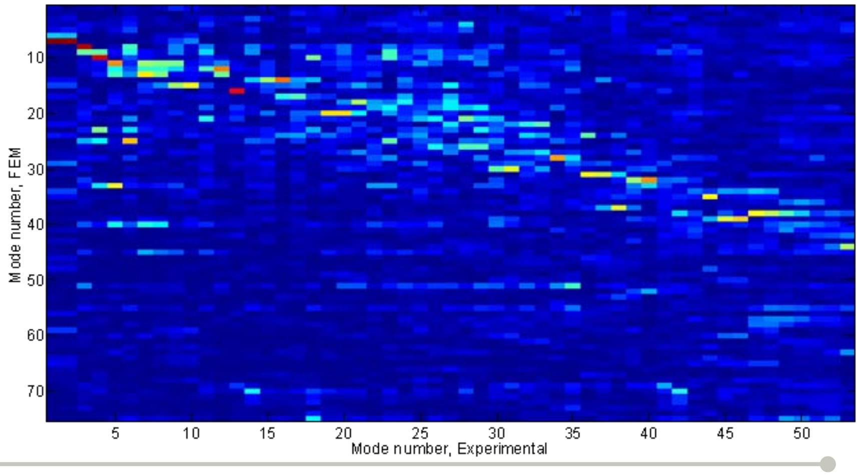
# Measurement evaluation

- Modal analysis:
  Curve fitting process to determine:
  - Mode shapes
  - Resonance frequencies
  - Modal damping
  - Mode synthesis (FRF)
- FEA – experiment correlation:
  - Calculation of Modal Assurance Criterion (MAC) matrix
  - Comparison of matching measured and simulated modes
- Model updating

Measured & fitted FRF



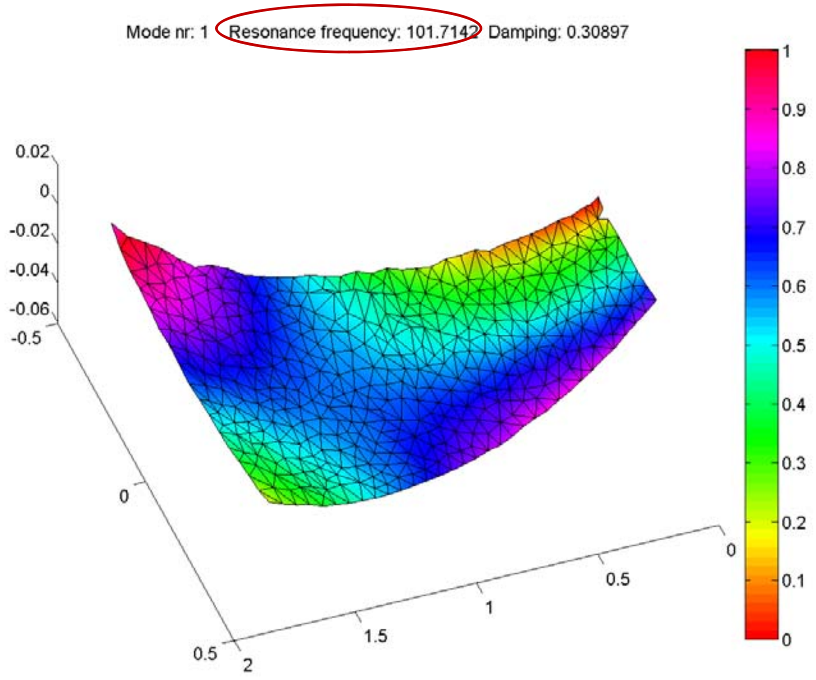
MAC matrix

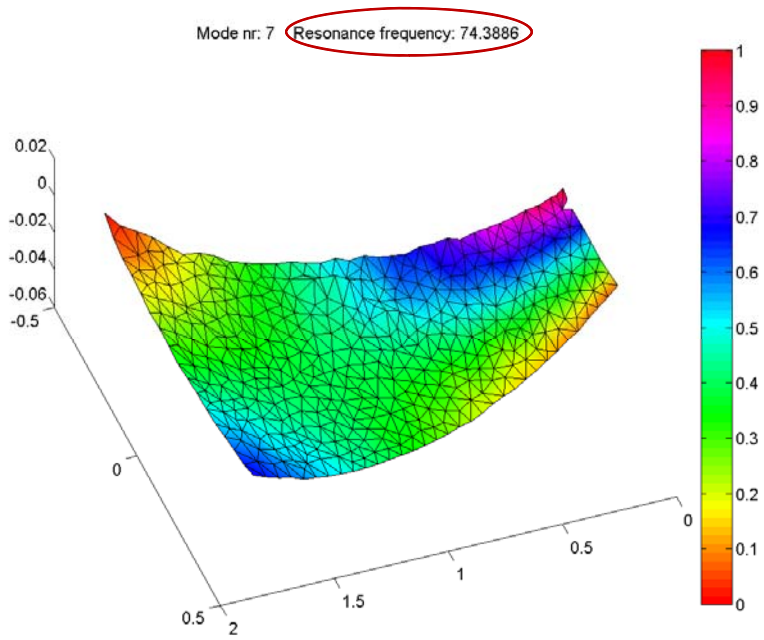


# Panel results – Example 1

- Mode shapes match very well (only 180° phase shifted)
- Significant difference in resonance frequency

Experiment (101Hz) MAC = 0.98 Simulation (74Hz)

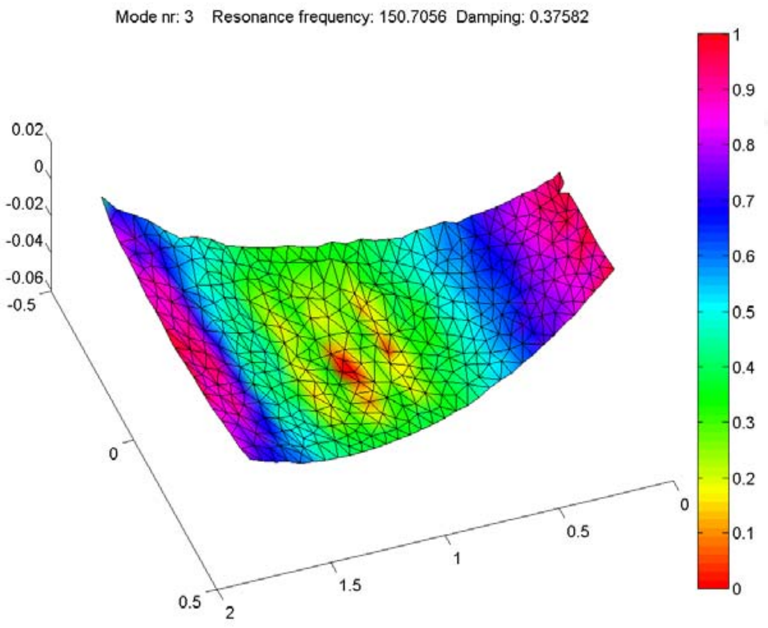


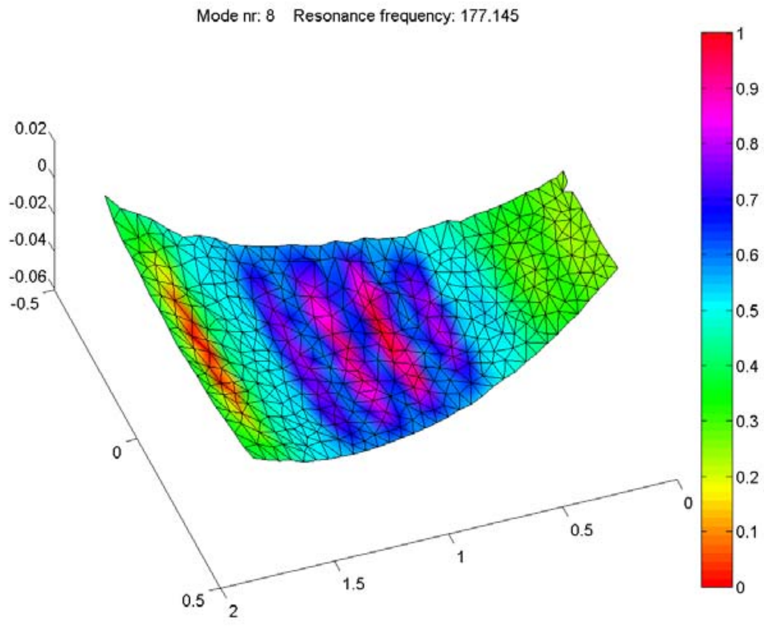



# Panel results – Example 2

- Mode shapes match very well (only 180° phase shifted)
- Noticeable difference in resonance frequency

Experiment | MAC = 0.92 | Simulation

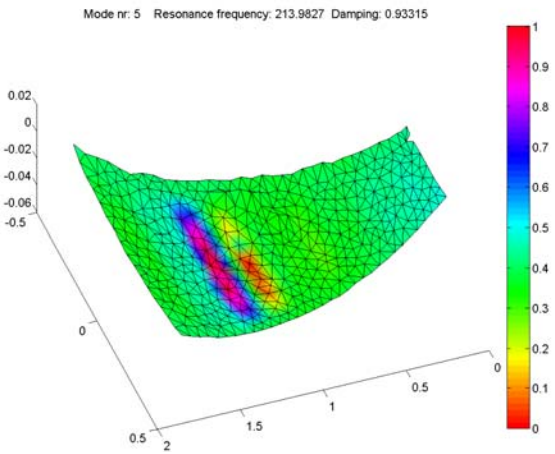


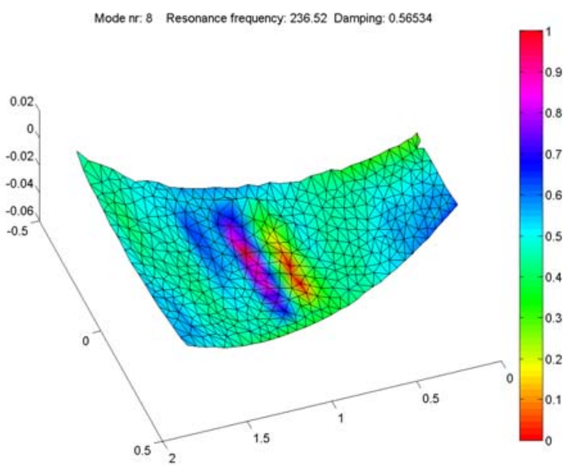



# Panel results – Example 3

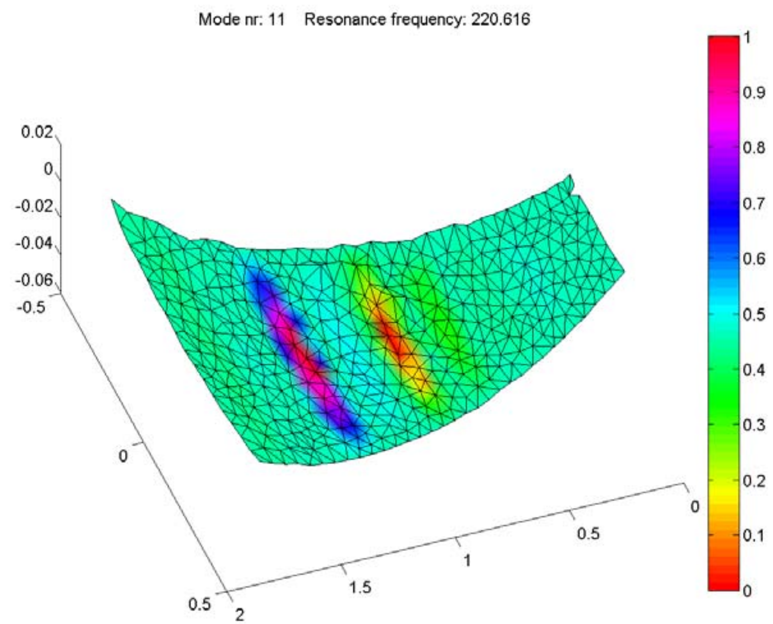
- Simulated mode is correlated to 2 measured modes
- In structures consisting of rib reinforced sheets, local modes occur in the sheet in areas enclosed by ribs
- Local modes can be uncoupled e.g. due to small dimensional differences (rib positions, welds, ...)
- Notice that resonance frequencies between uncoupled modes are very close

Experiment



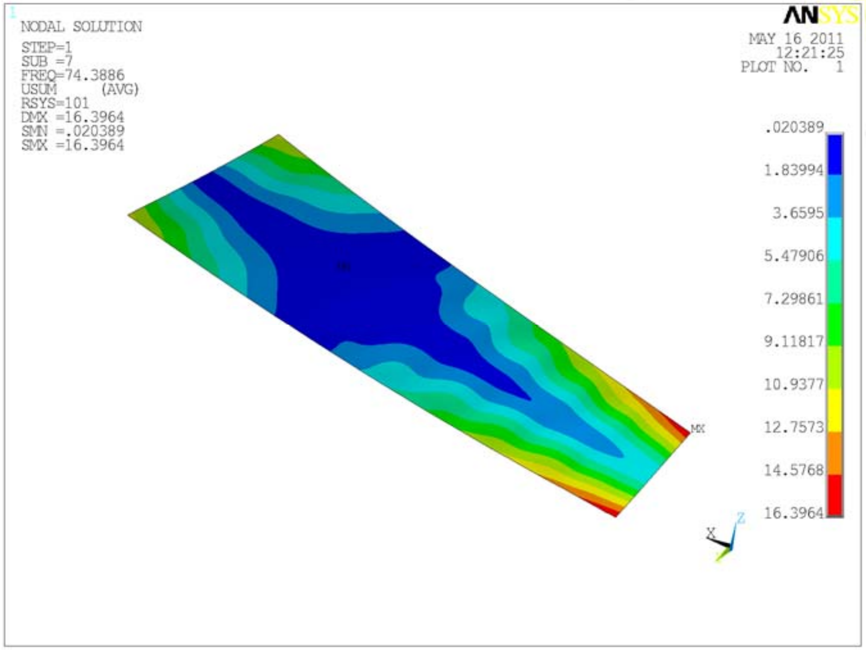



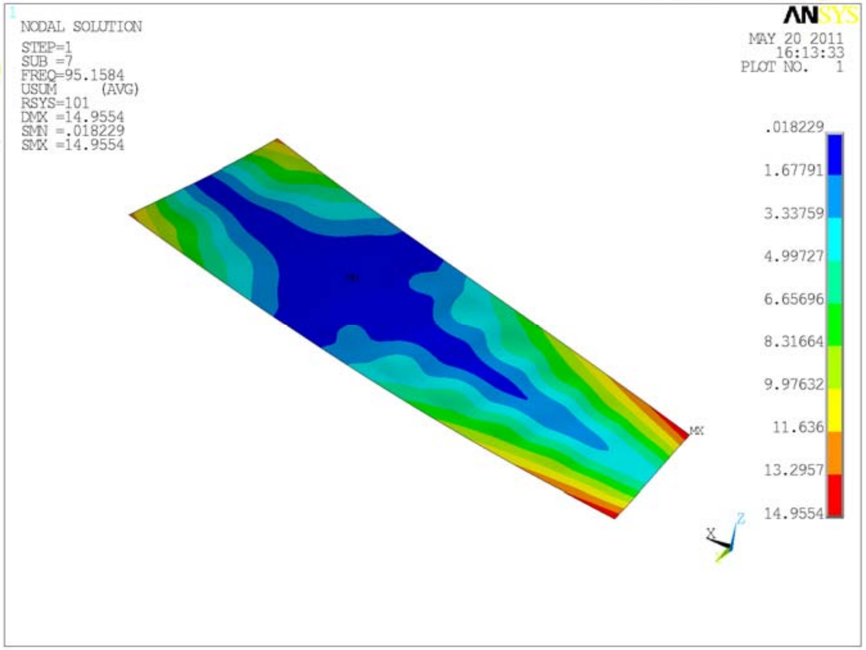

Simulation



# Panel results – After model update

- Initial model:
  - First torsion mode at 74Hz
  - Measured: 101Hz
- Updated model:
  - First torsion mode at 95Hz
  - Mode shapes and MAC values unchanged
  - Generic result for shell-beam panel modelling method!



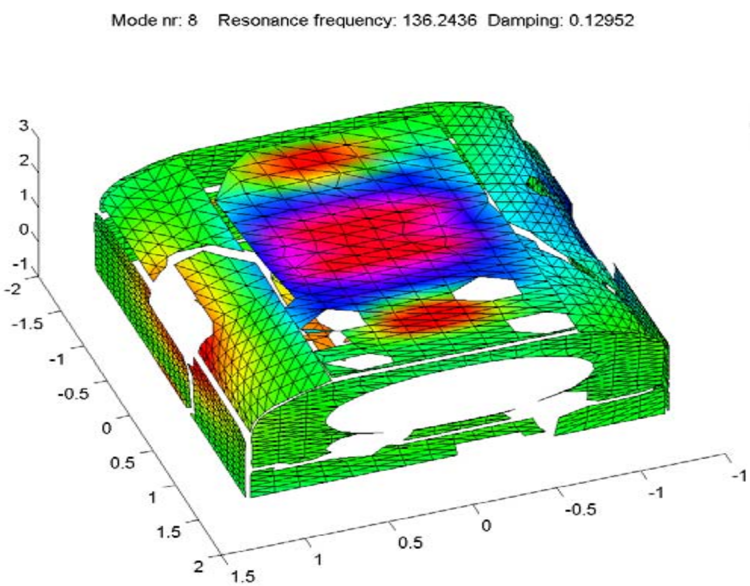
# Yoke results – Example 1

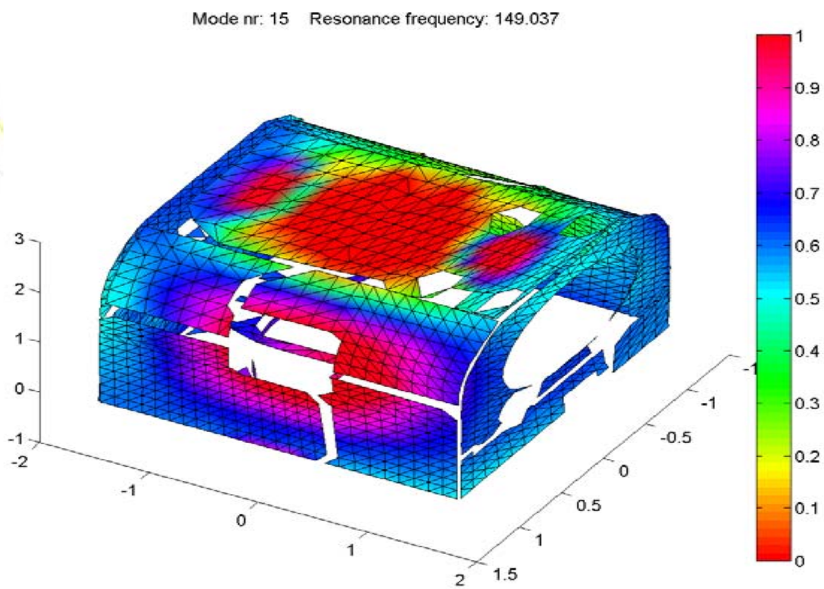
- Global mode shapes match well
- Frequencies very close

Experiment

MAC = 0.96

Simulation

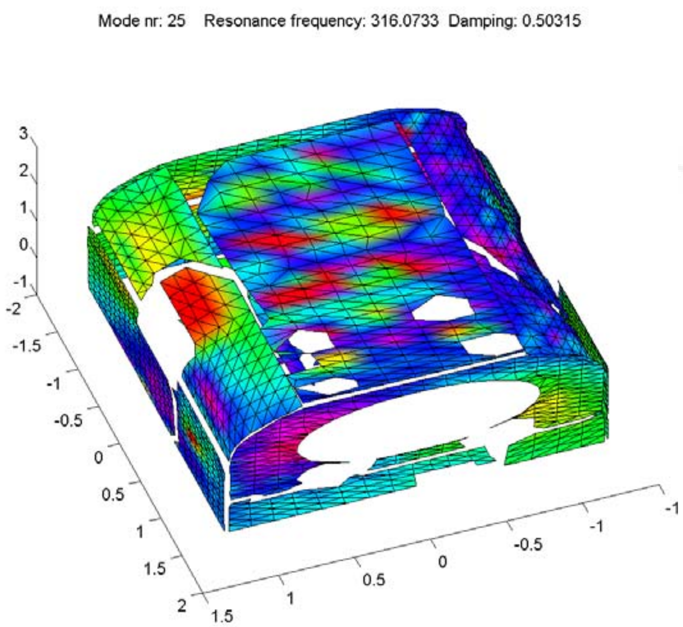


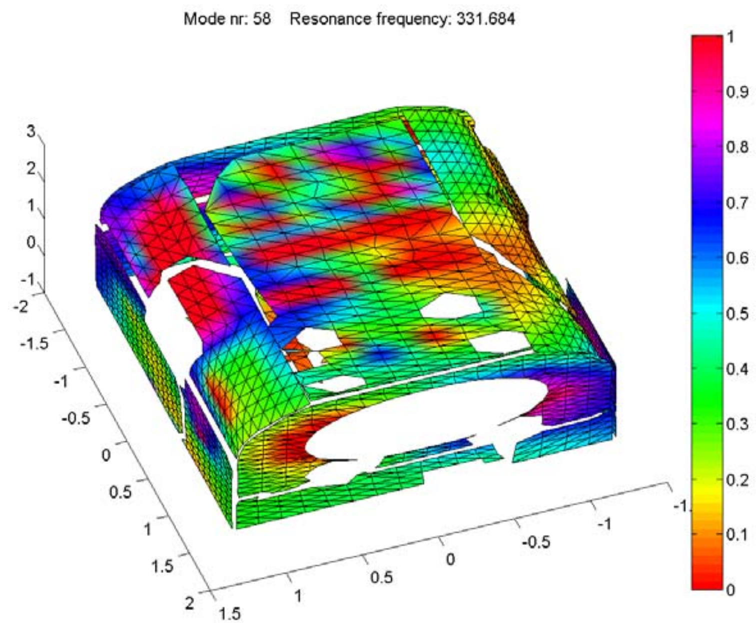



# Yoke results – Example 2

- Some local mode shapes match well
- Close resonance frequencies

Experiment — MAC = 0.96 — Simulation



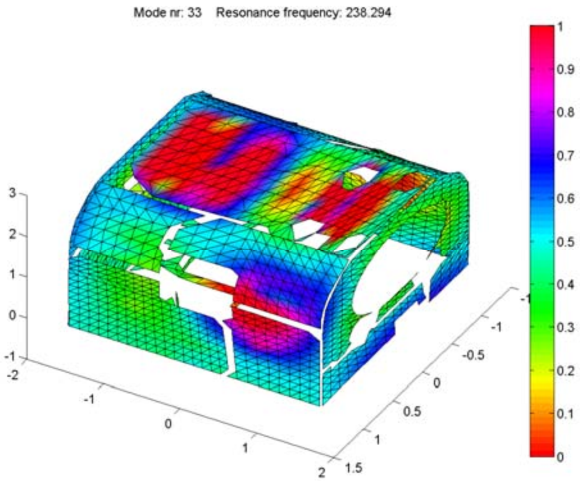



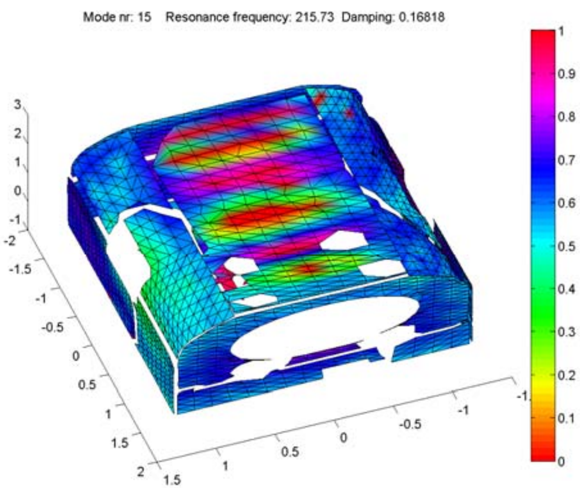
![HITEC Luxembourg]

## Yoke results – Example 3

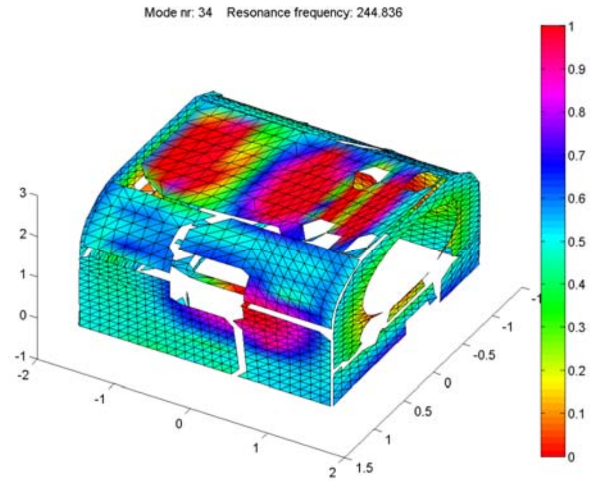
- Many local modes closely spaced in frequency
- Many local modes uncoupled from simulation to measurement and vice-versa

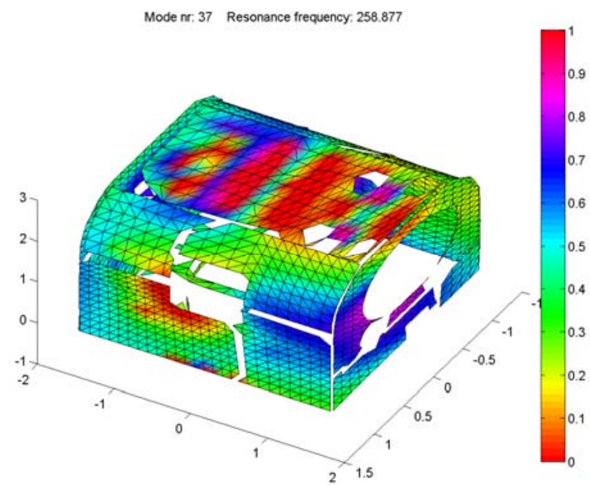
Experiment




Simulation



# Conclusion

- Complex modeling & simulation process:
  - Many components and connections
  - Various disciplines with cascaded analysis tasks
  - Many antenna performance criteria rely on downstream models
- Model validation:
  - Bottom up approach
  - Starting with component validation
- Modal testing:
  - Well suited for analyzing large and highly rigid structures
  - Good level of detail, especially using scanning laser vibrometry
- Comparison of measured and calculated data:
  - Identification of matching “global” mode shapes and frequencies
  - Targeted model updating
  - Some difficulties in comparing “local” modes due to uncoupling
- Main goal of validating the overall component behavior has been reached

For further information please visit our website

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