Multiphysics Simulation using Implicit Sequential Coupling

&

Fluid Structure Interaction of Gas Turbine Exhaust Ducts

July 17th, 2008

Agenda

Multiphysics Simulation using Implicit Sequential Coupling
Fluid Structure Interaction of Gas Turbine Exhaust Ducts

July 17th, 2008

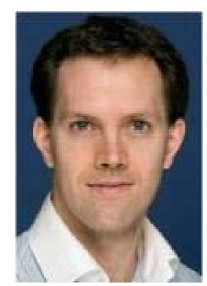
9am PDT (Los Angeles) / 12n EDT (New York) / 5pm BST (London)

- **Welcome & Introduction (An Overview of NAFEMS North American Activities)**
  - Matthew Ladzinski, *NAFEMS North America*
- **Multiphysics Simulation using Implicit Sequential Coupling**
  - Stephen Scampoli and John Stokes*, ANSYS*
- **Fluid Structure Interaction of Gas Turbine Exhaust Ducts**
  - Johan Gullman-Strand*, Ødegaard & Danneskiold-Samsøe A/S*
- **Q&A Session**
  - Panel
- **Closing**


Ladzinski


Scampoli


Stokes


Gullman-Strand

THE INTERNATIONAL ASSOCIATION
FOR THE ENGINEERING ANALYSIS
COMMUNITY

An Overview of NAFEMS NA Activities

Matthew Ladzinski
NAFEMS
North American Representative

Planned Activities in North America

- Webinars
  - New topic each month!
    - CCOPPS: Creep Loading of Pressurized Components – Phenomena and Evaluation (July 23rd)
    - Complexity Management: New Perspectives and Challenges for CAE in the 21st Century (August 14th)
  - Recent webinars:
    - Management of Design Analysis
    - CCOPPS: Fatigue of Welded Pressure Vessels
    - Applied Element Method as a Practical Tool for Progressive Collapse Analysis of Structures
    - AUTOSIM: The Future of Simulation in the Automotive Industry
    - A Common Sense Approach to Stress Analysis and Finite Element Modeling
    - The Interfacing of FEA with Pressure Vessel Design Codes (CCOPPS Project)
    - Multiphysics Simulation using Directly Coupled-Field Element Technology
    - Methods and Technology for the Analysis of Composite Materials
    - Simulation Process Management
    - Simulation-supported Decision Making (Stochastics)
    - Simulation Driven Design (SDD) Findings

To register for upcoming webinars, or to view a past webinar, please visit: www.nafems.org/events/webinars

Planned Activities in North America

NAFEMS NA 2008 Regional Summit

NAFEMS 2020 Vision of Engineering Analysis and Simulation

- ***NAFEMS 2020*** will bring together the leading visionaries, developers, and practitioners of CAE-related technologies and business processes
- Goal: Provide attendees with the best "food for thought and action" to deploy CAE over the next several years
- Location: Embassy Suites Hotel & Convention Center, Hampton, Virginia
- Date: October 29-31, 2008

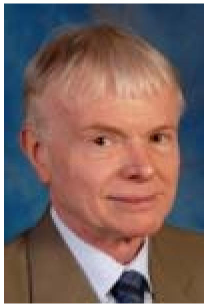
Anticipated Publish Date of Agenda: July 25th, 2008

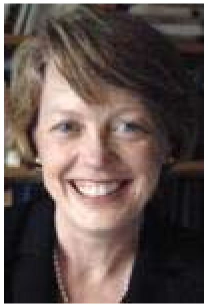
For more information, visit:

www.nafems.org/nafems2020

Keynote Presenters for NAFEMS 2020

- **Prof. Ahmed Noor**, *Old Dominion University (Director of ODU's CAEE)*
- **Prof. Thomas J.R. Hughes**, *University of Texas at Austin*
- **Dr. Takeshi Abe**, *Ford Motor Company*
- **Mary Boyce**, *MIT*
- **Joel Orr**, *Cyon Research*

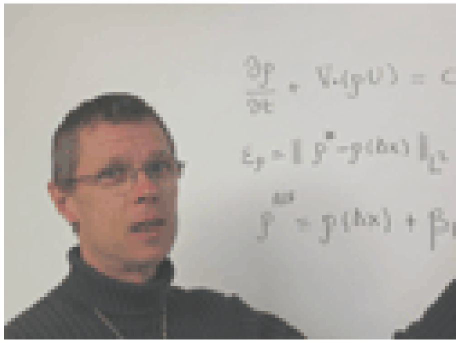



Planned Activities in North America (cont.)

2-Day Short Course on V&V for Aerospace, Civil and Mechanical Engineers

Finite Element Model Validation, Updating, and Uncertainty Quantification for Linear and Non-linear Models

- Goal: Attendees will learn the latest techniques for evaluating the accuracy of computational models over a range of parameter values, how to design validation experiments that will determine the simulation range of validity, and how to calibrate model parameters to reflect the measured response from experiments – event for non-linear models
- Location: Hampton Roads Convention Center
  Hampton, Virginia
- Date: October 27-28, 2008



For more information, visit:

www.nafems.org/nafems2020

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Q&A Session

Using the Q&A tool, please submit any questions you may have for our panel.

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Thank you!

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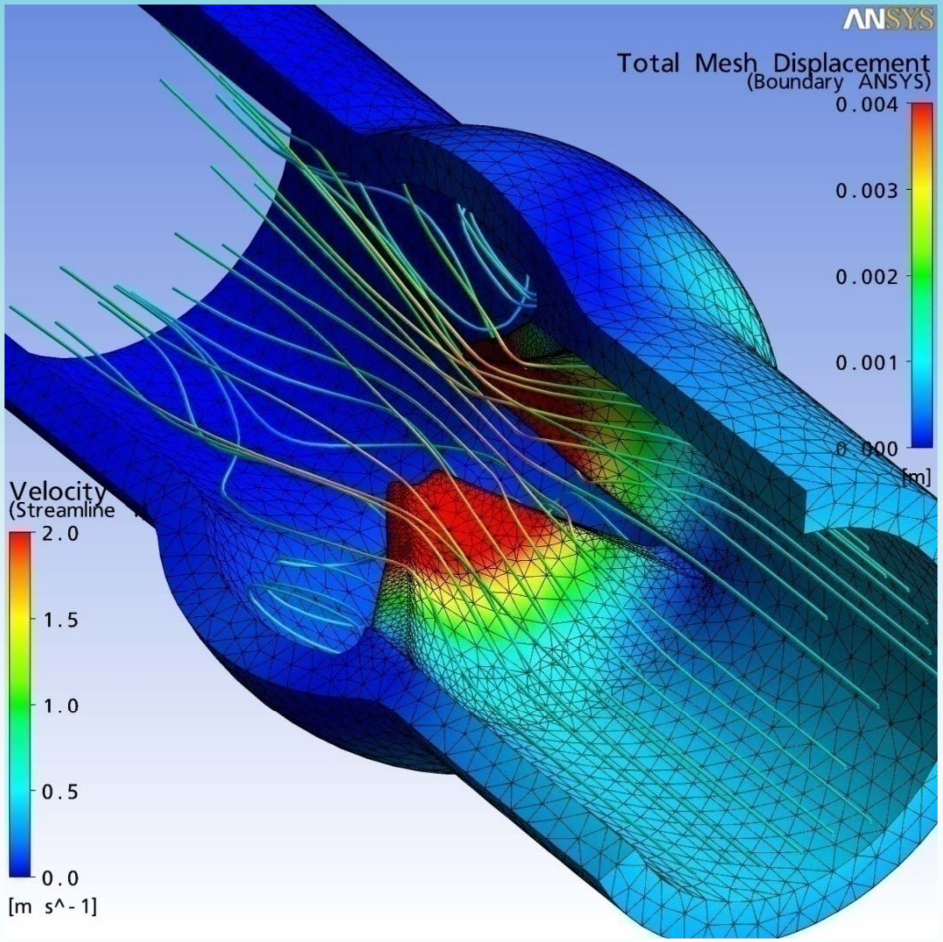
Multiphysics Simulation using Implicit Sequential Coupling

Stephen Scampoli
Lead Product Manager

John Stokes
CFX Product Manager

Agenda

- **Multiphysics**
  - Overview
  - Methods of coupling physics
    - Direct coupling
    - Load transfer
- **Multiphysics Examples**
  - Electrostatic actuation
  - Induction heating
  - Fluid-structure interaction
- **Conclusions**



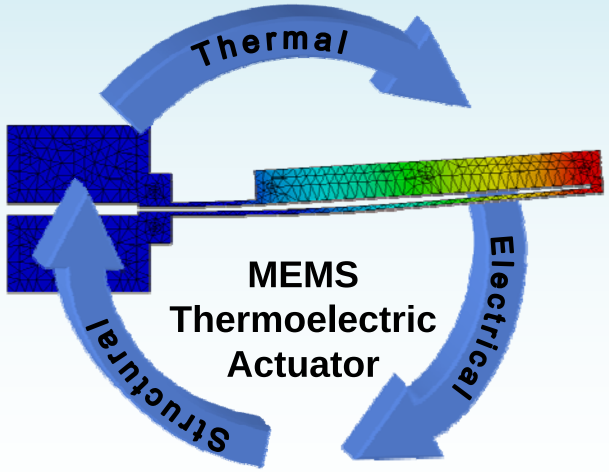
Fluid-structure interaction of a three-lobe valve

Multiphysics

Multiphysics -
Why You Need to Consider It

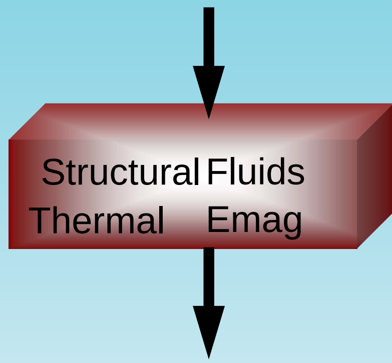
- **You can't afford to ignore coupled physics when:**
  - The real world is a multiphysics world
  - Your design depends on coupled physical phenomena
  - You are faced with small error margins and/or stack-up effects
  - Physical testing is too costly

Innovative companies are moving beyond single physics analysis



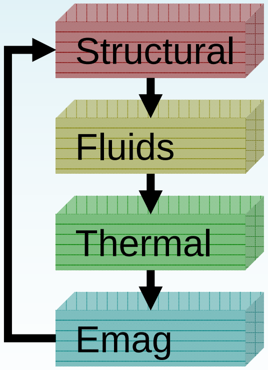
Methods of Coupling Physics

- **Direct Coupling**
  - A single analysis employing a coupled-field element containing all the necessary DOFs to solve the coupled-field problem.

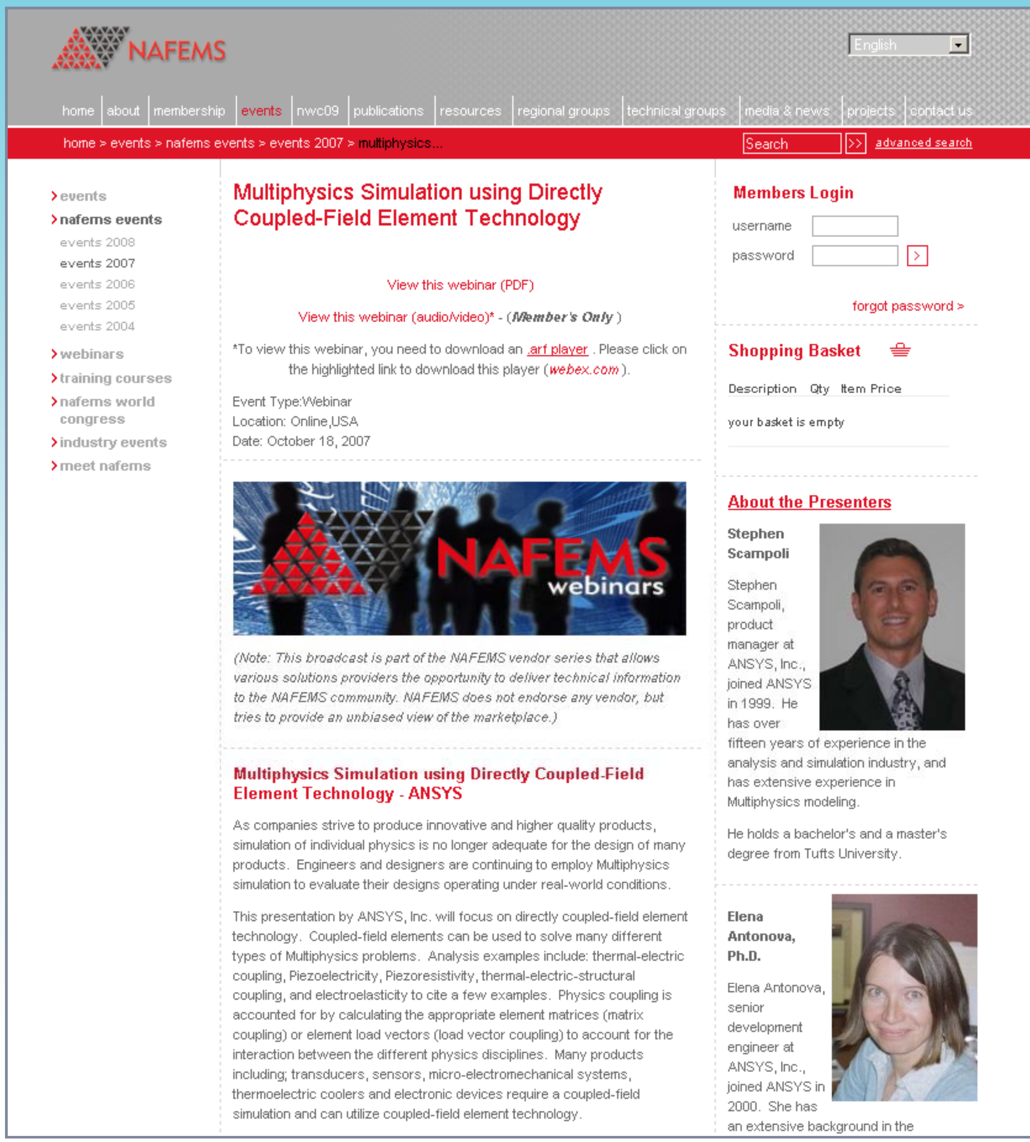


Direct Coupling
- Element-level coupling
- Highly coupled physics
- Single model & mesh

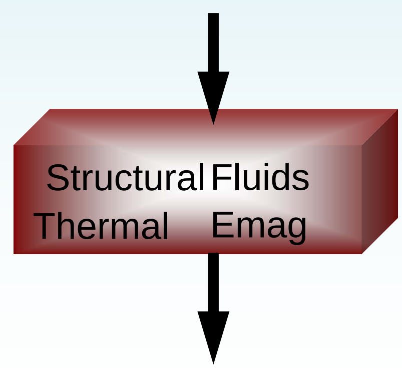
- **Load Transfer**
  - Two or more analysis are coupled by applying results from one analysis as loads in another analysis.



Load Transfer
- Sequential solution
- Separate model & mesh
- Separation of expertise

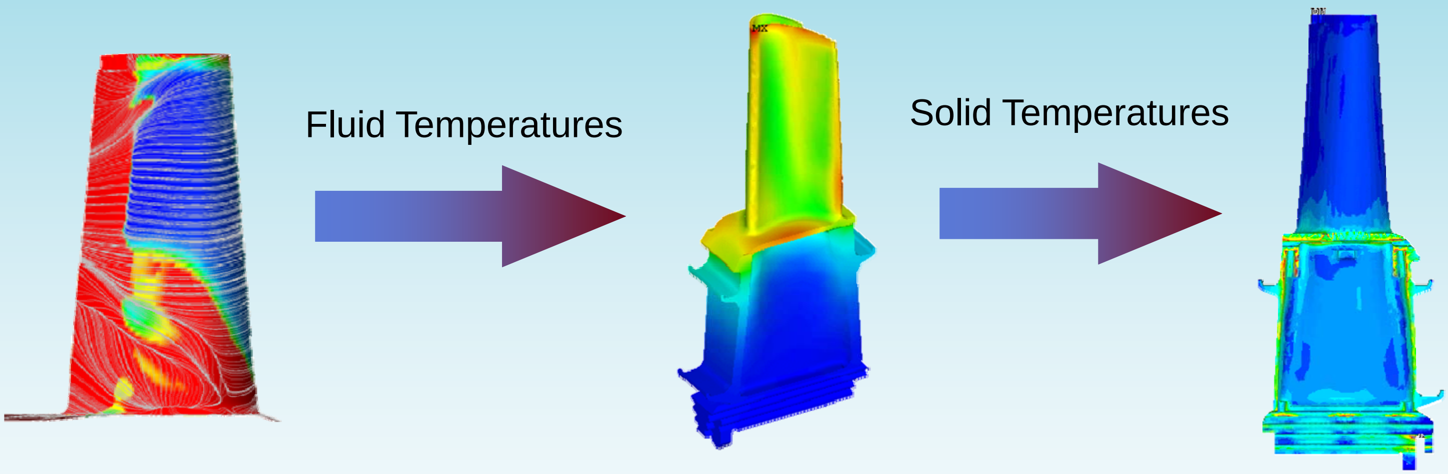


- **Direct Coupling**
  - More information can be found on direct coupling on the NAFEMS website.
  - http://www.nafems.org/events/nafems/2007/MPDCFET/



Load Transfer Options

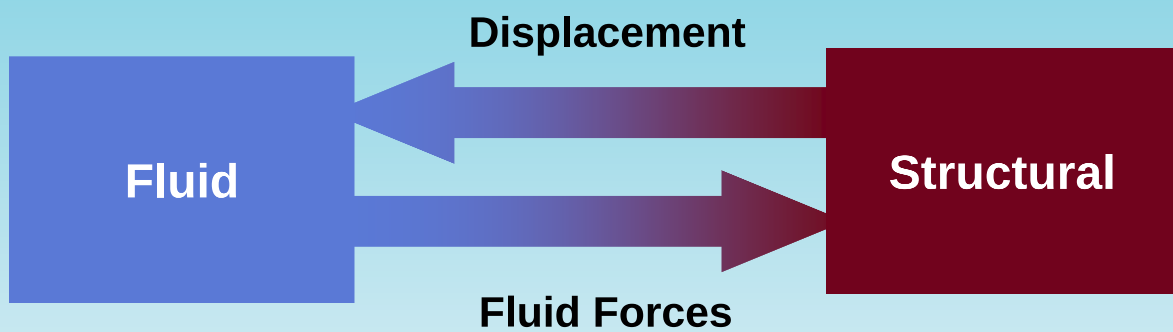
- **One-way Load Transfer**
  – One-way data exchange sufficient

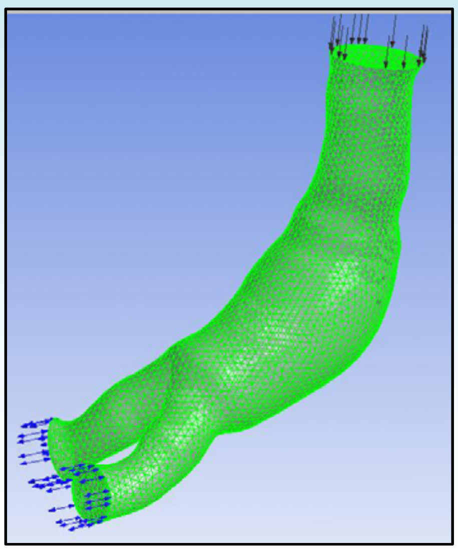


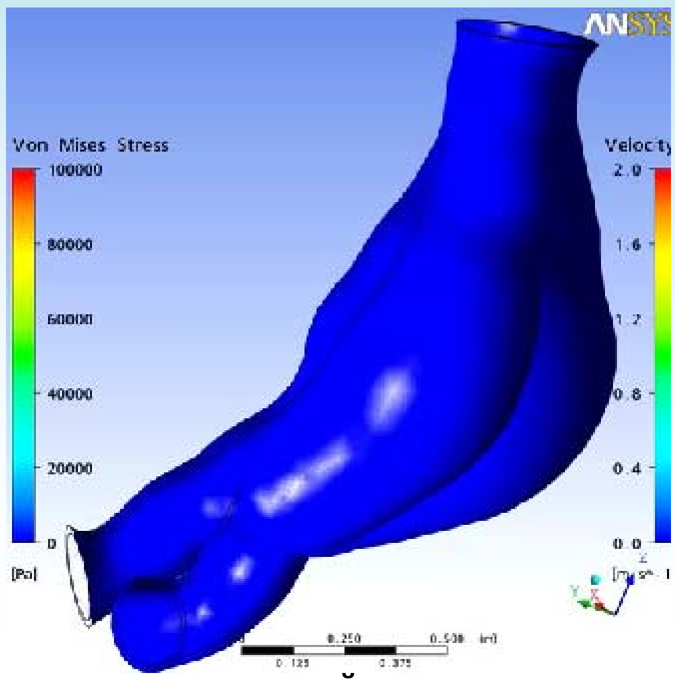
- **Two-way Load Transfer**
  – Two-way data exchange required
  – *Implicit sequential coupling*

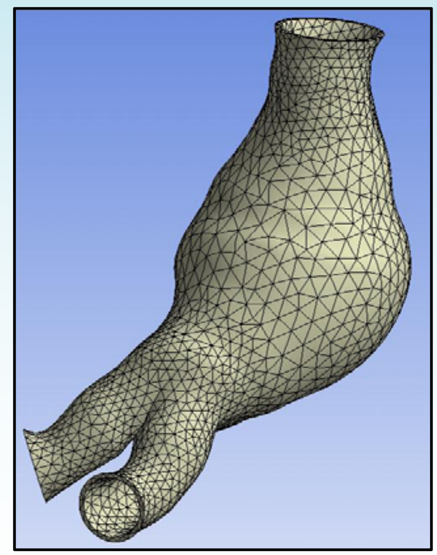
Implicit Sequential Coupling

- **Implicit Sequential Coupling**



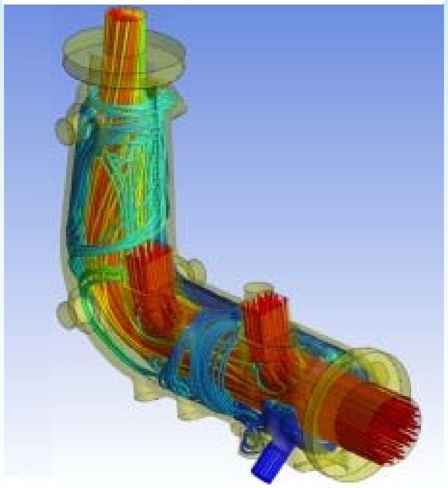






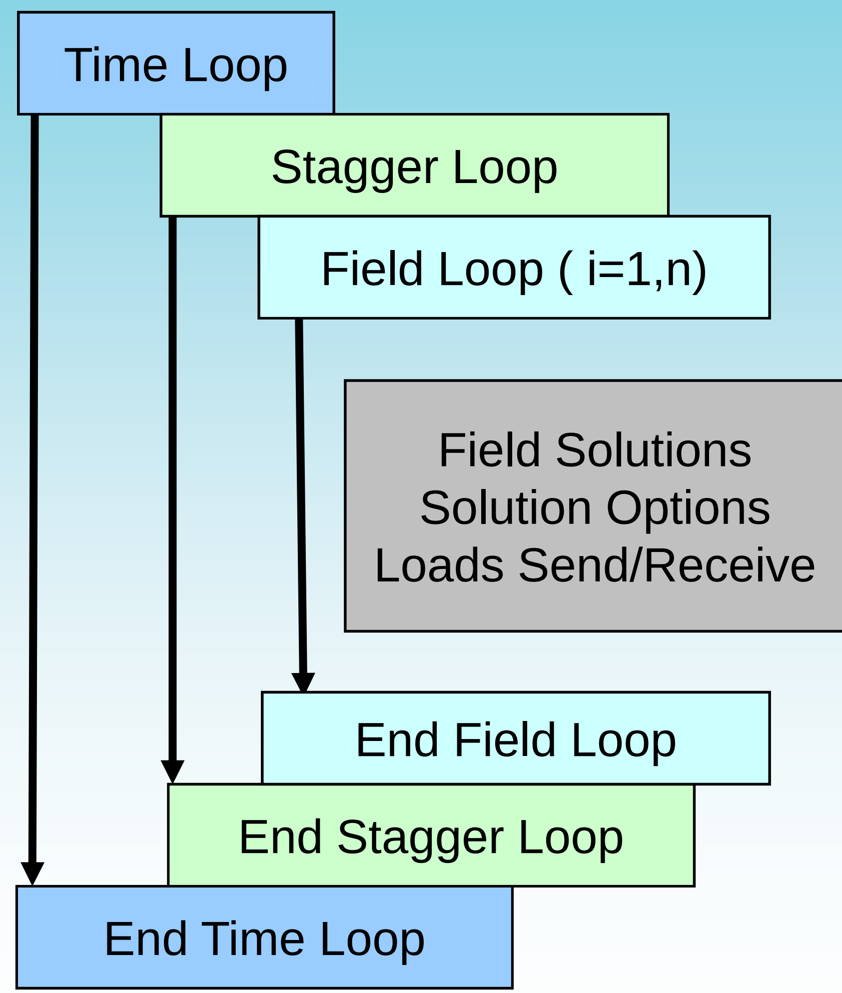
Load Transfer Advantages

- **Solution Efficiency**
  - Dissimilar mesh interface
    - Independent mesh for each physics
    - Surface and volumetric load transfer
    - Independent solver options for each analysis
  - Collaboration between physics experts
    - Independent users can setup each physics discipline.



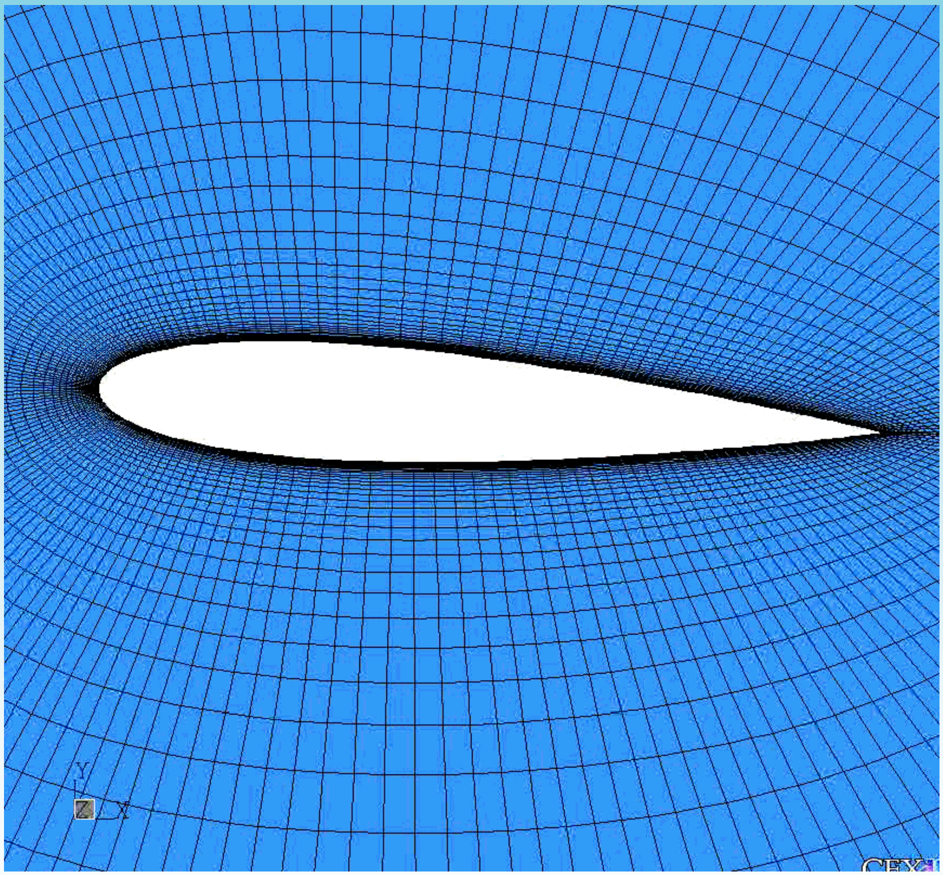
Implicit Sequential Solution

- **Time Loop**
  - Static analysis
  - Harmonic analysis
  - Transient analysis
- **Stagger Loop**
  - *Implicit coupling* of the physics disciplines within the time loop
  - Stagger iterations – convergence of the loads transferred
- **Field Loop**
  - Individual physics solutions
  - Dissimilar mesh interface
  - Automatic morphing
    - Non-structural elements



Mesh Morphing

- **FSI Mesh Morphing**
  - Displacement is diffused into interior of mesh
  - ***Mesh Stiffness***
    - Constant
    - Wall distance based
    - Control volume based
  - Variable stiffness preserves:
    - Geometrical features
    - Boundary layer



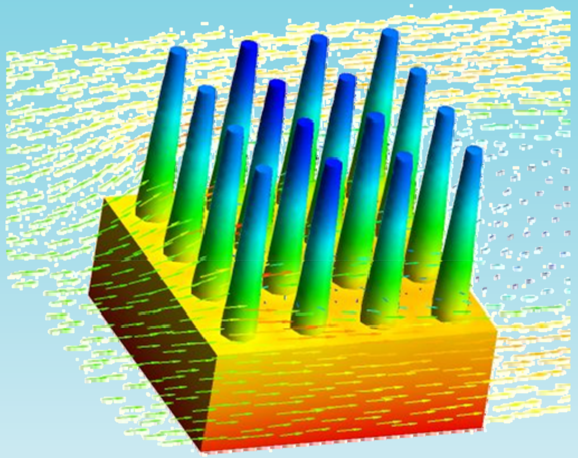
Variable mesh stiffness – preserves boundary layer

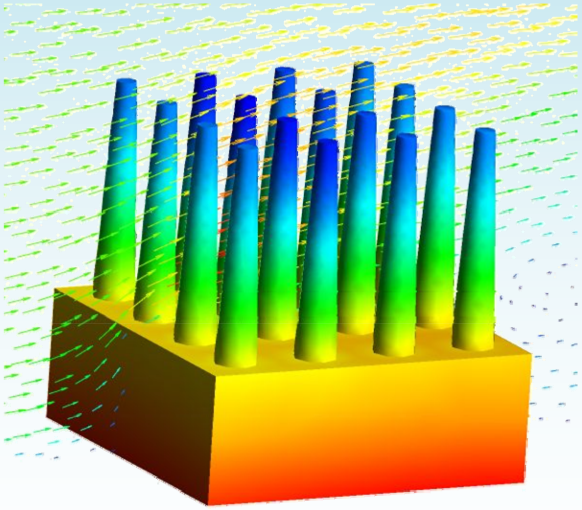
Loads Transferred

Physics Discipline	Loads Transferred between Physics Disciplines	
	SEND	RECEIVE
Structural	Displacement	Force, Temperature
Thermal	Temperature, Heat Generation, Heat Flux	Displacement, Heat Generation
Electric Field	Force, Heat Generation	Displacement, Temperature
Magnetic	Force, Heat Generation	Displacement, Temperature
Fluid (CFX)	Surface Force, Surface Temperature	Displacement, Surface Temperature
HF Electromagnetic	Heat Generation	Temperature

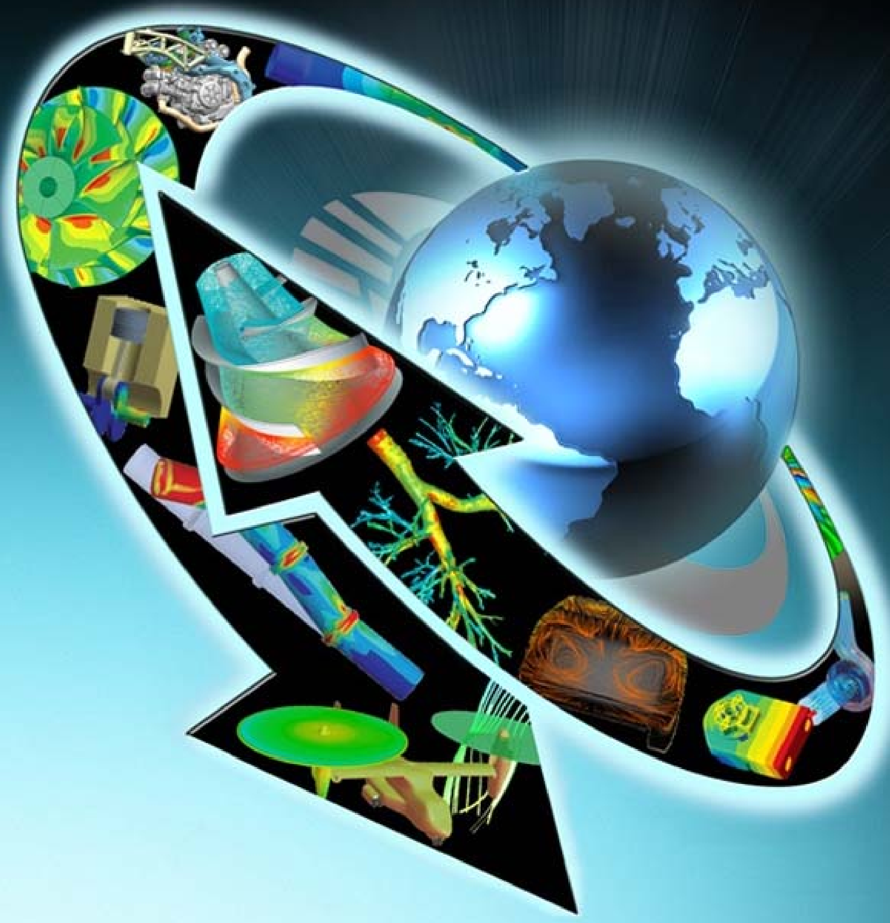
Multiphysics Applications

- Thermal Stress
- Joule Heating
- Induction Heating
- Electromagnetic-structural Coupling
- Electrostatic-structural Coupling
- Microwave Heating
- Fluid-structure Interaction





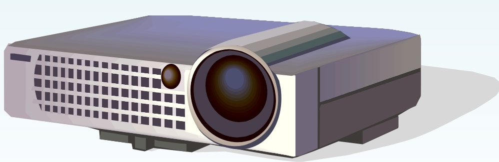
Multiphysics Examples

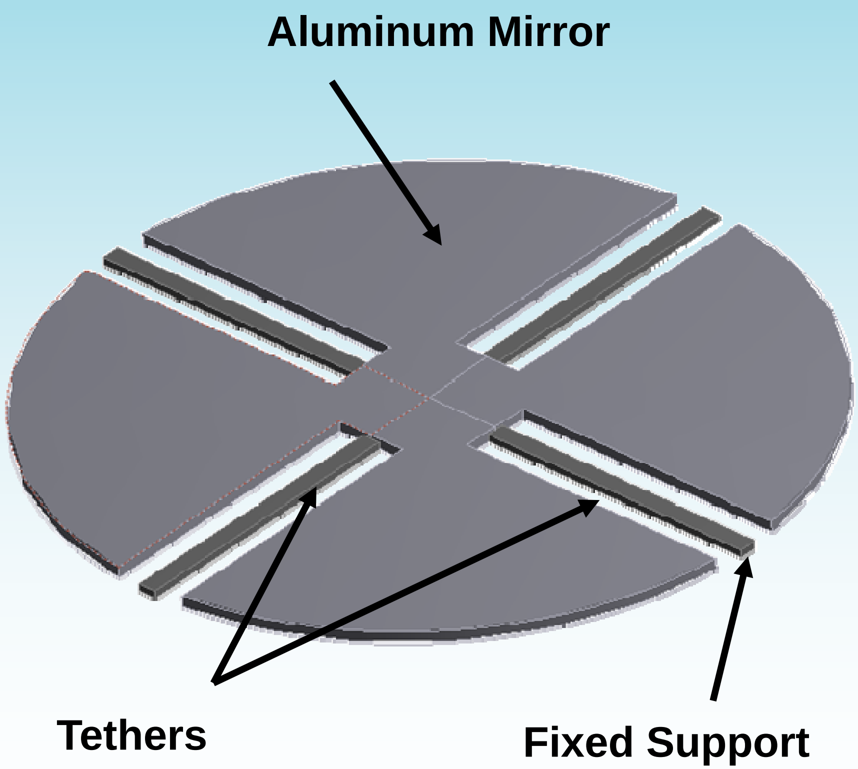


MEMS Micromirror

- Electrostatic actuation of a MEMS micro-mirror, aluminum mirror deforms based on electrostatic forces.

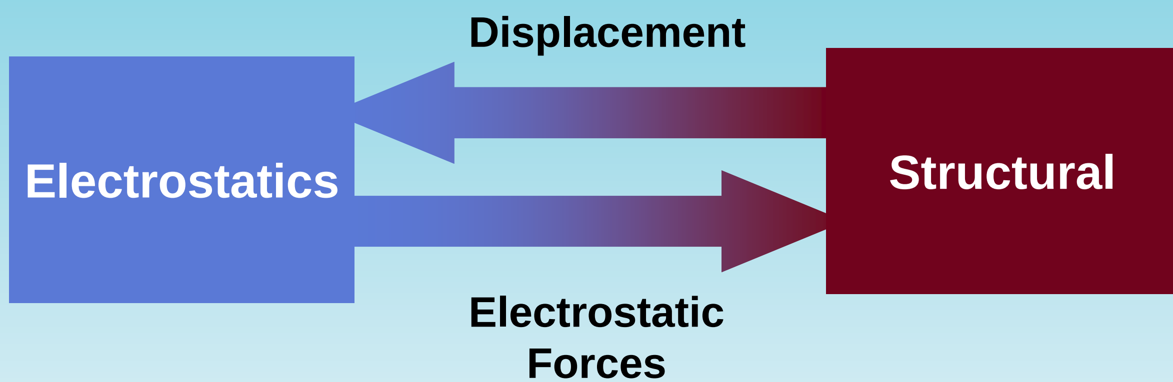
A MEMS micromirror forms the basis for DLP (Digital Light Projection) technology. A coupled electrostatic-structural is required to evaluate the positioning of the mirror.



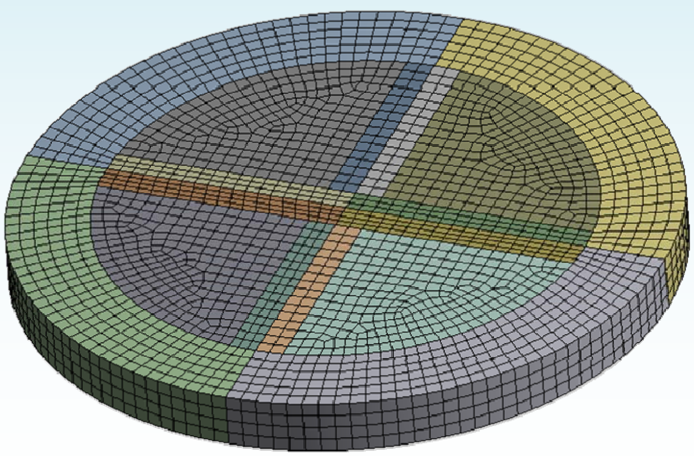


MEMS Micromirror

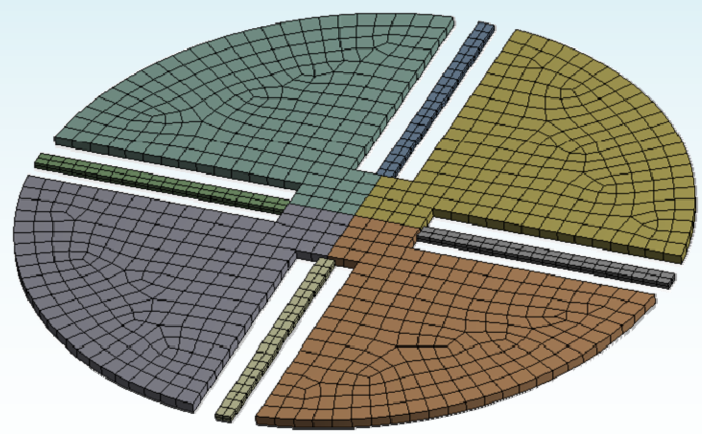
- **Implicit Sequential Solution**



Electrostatic Model

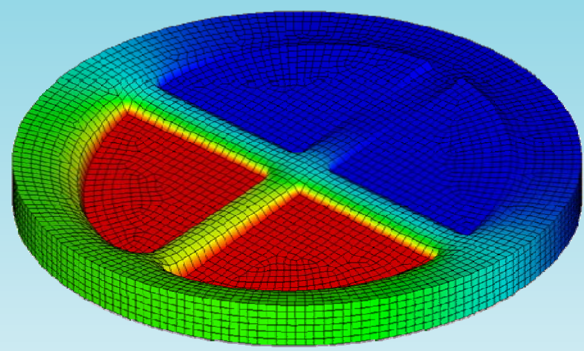


Structural Model

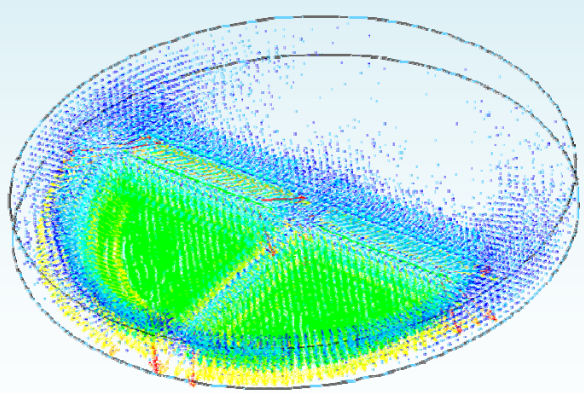


MEMS Micromirror

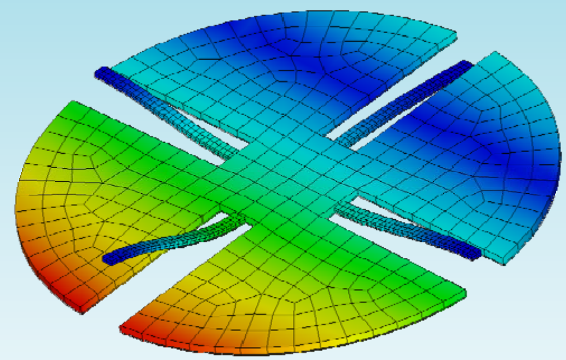
- **Electrostatic and Structural Results**



Electric Potential

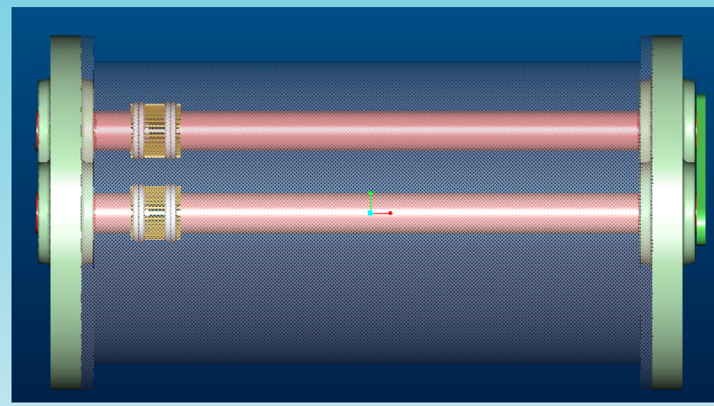


Electric Field

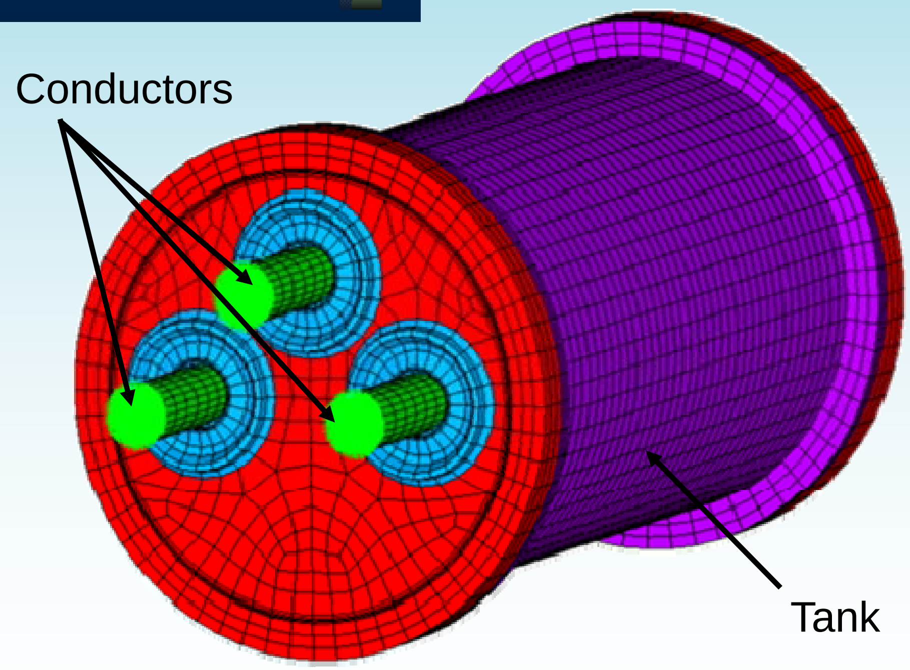


Structural Displacements

Buss Bar



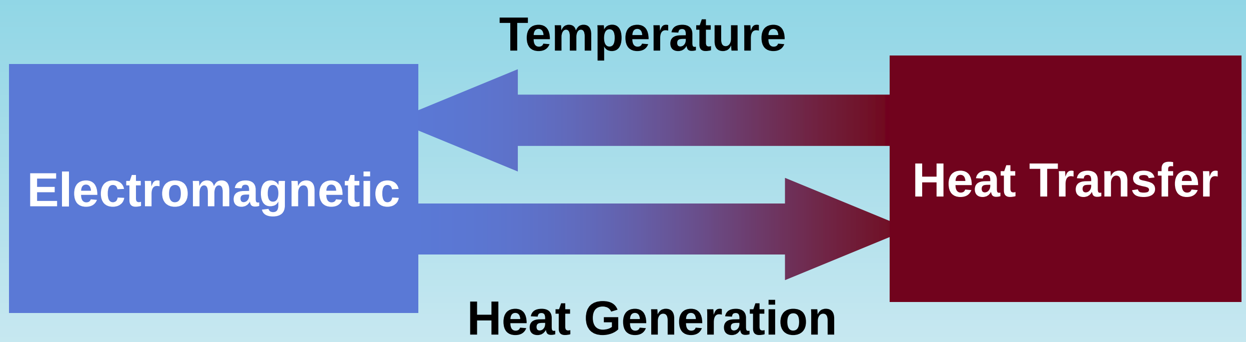
- **Coupling electromagnetics and heat transfer**
- **Three phase AC current in conductors**
- **Induced eddy currents in tank**
- **Temperature dependent resistivity**
- **Conduction, convection and radiation heat transfer**

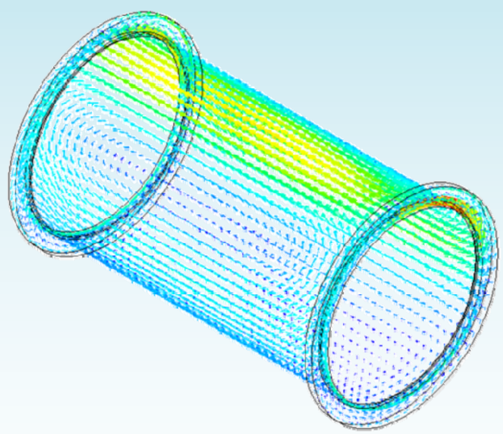


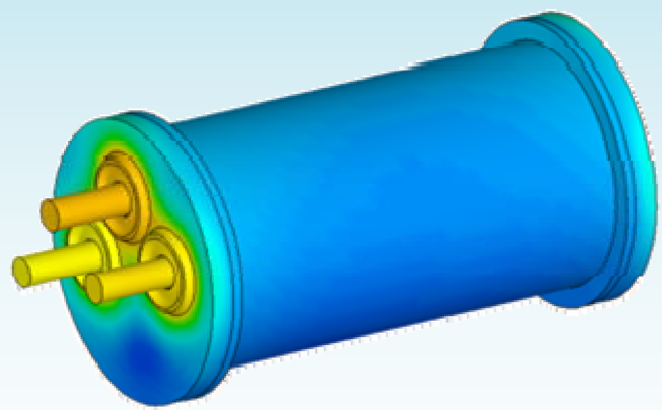
Model courtesy Taesung Software & Engineering, Inc.

Bus Bar

- **Implicit Sequential Solution**





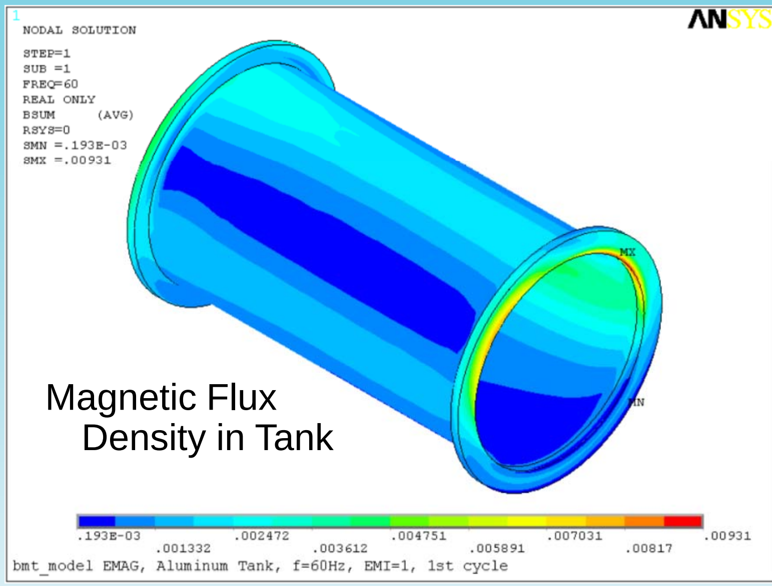


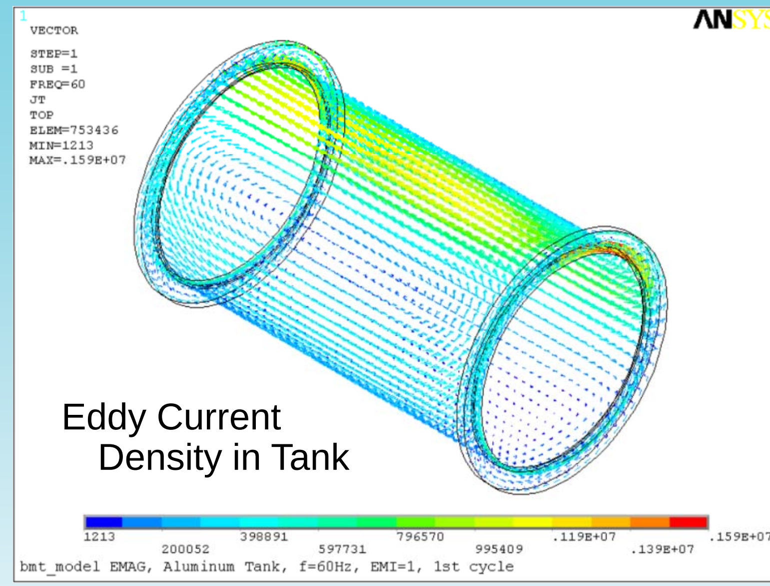
- Eddy Current Density
- AC (Harmonic Solution)

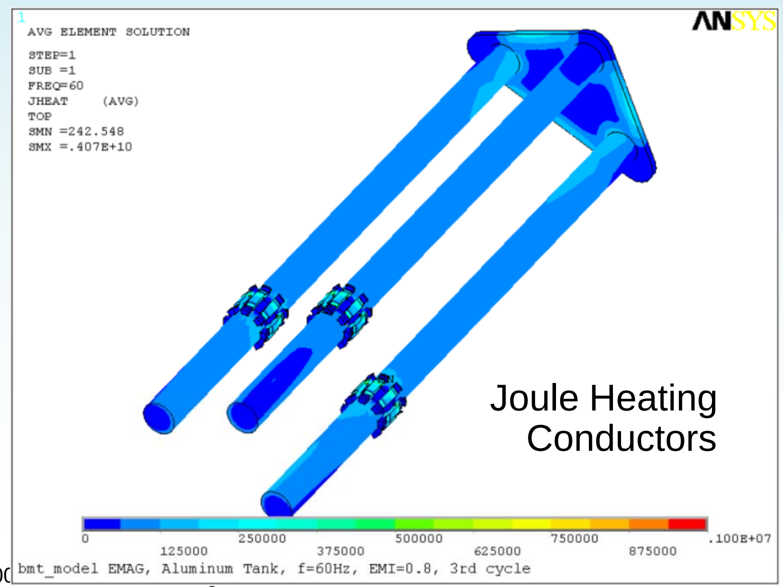
- Temperature
- Steady State

Model courtesy Taesung Software & Engineering, Inc.

Bus Bar

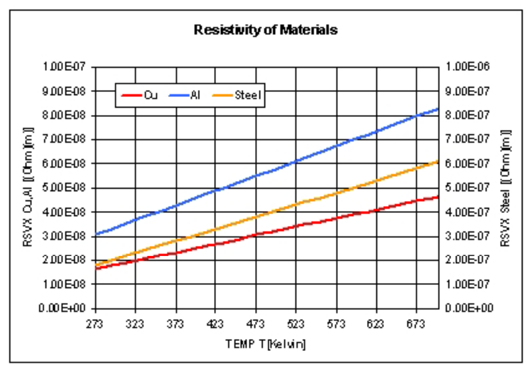






Temperature Dependence of Electrical Resistivity

$$RSVX(T) = RSVX_{293}\cdot\left(1+\alpha\cdot\Delta T+\beta\cdot\Delta T^2+\gamma\cdot\Delta T^3+\ldots\right)$$



Linear Isotropic Dependence is Applied

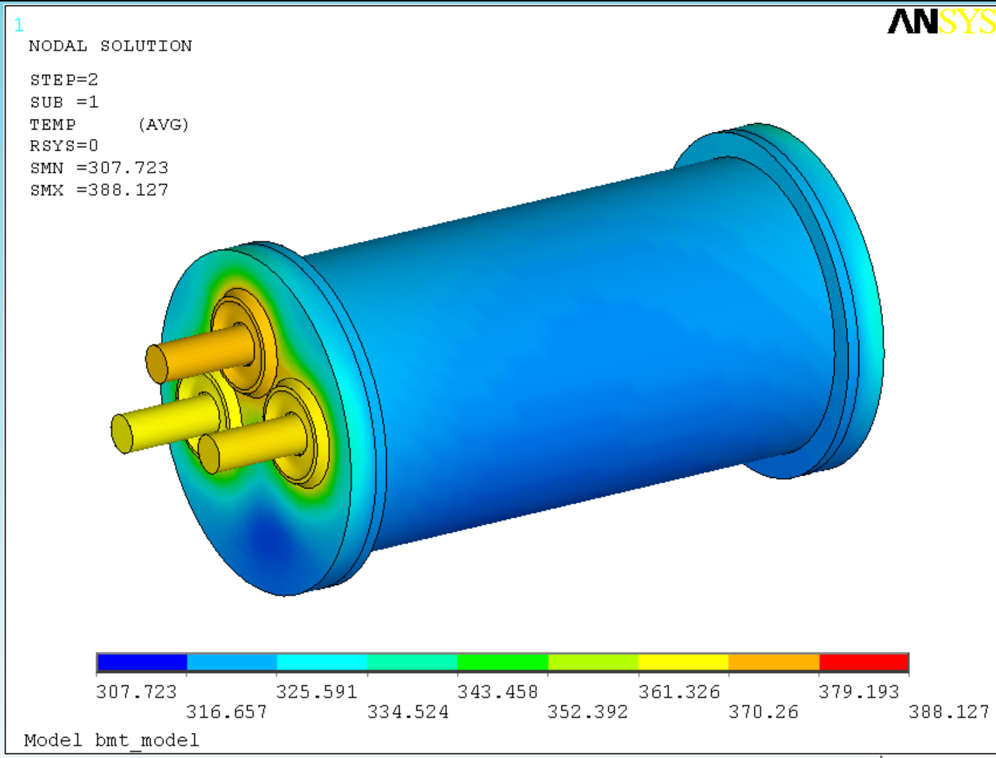
$$RSVX(T) = RSVX_{293}\left(1+\alpha\cdot\Delta T\right)$$

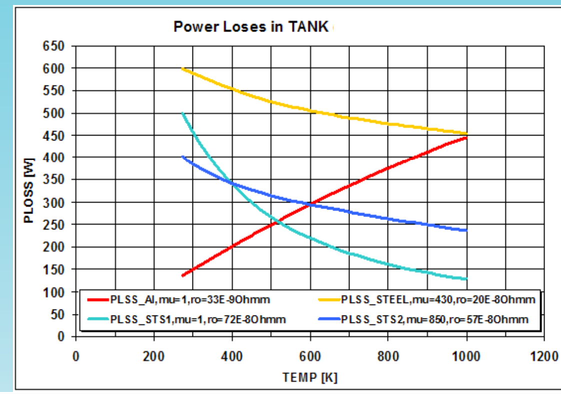
Valid for Interval: T = 273K~ 423K

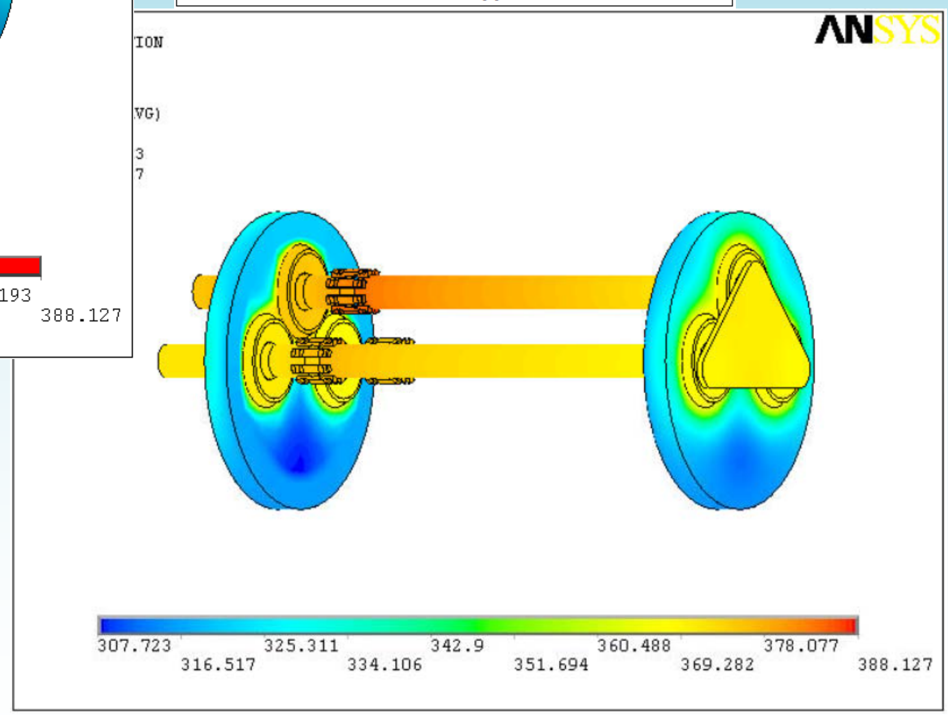
Copper:	$RSVX_{293}$	= 17,8E-9 Ω·m
	ALFA	= 0,00393 1/K
Aluminum:	$RSVX_{293}$	= 33,0E-9 Ω·m
	ALFA	= 0,00370 1/K
Steel:	$RSVX_{293}$	= 200E-9 Ω·m
	ALFA	= 0,00500 1/K

Model courtesy Taesung Software & Engineering, Inc.

Bus Bar





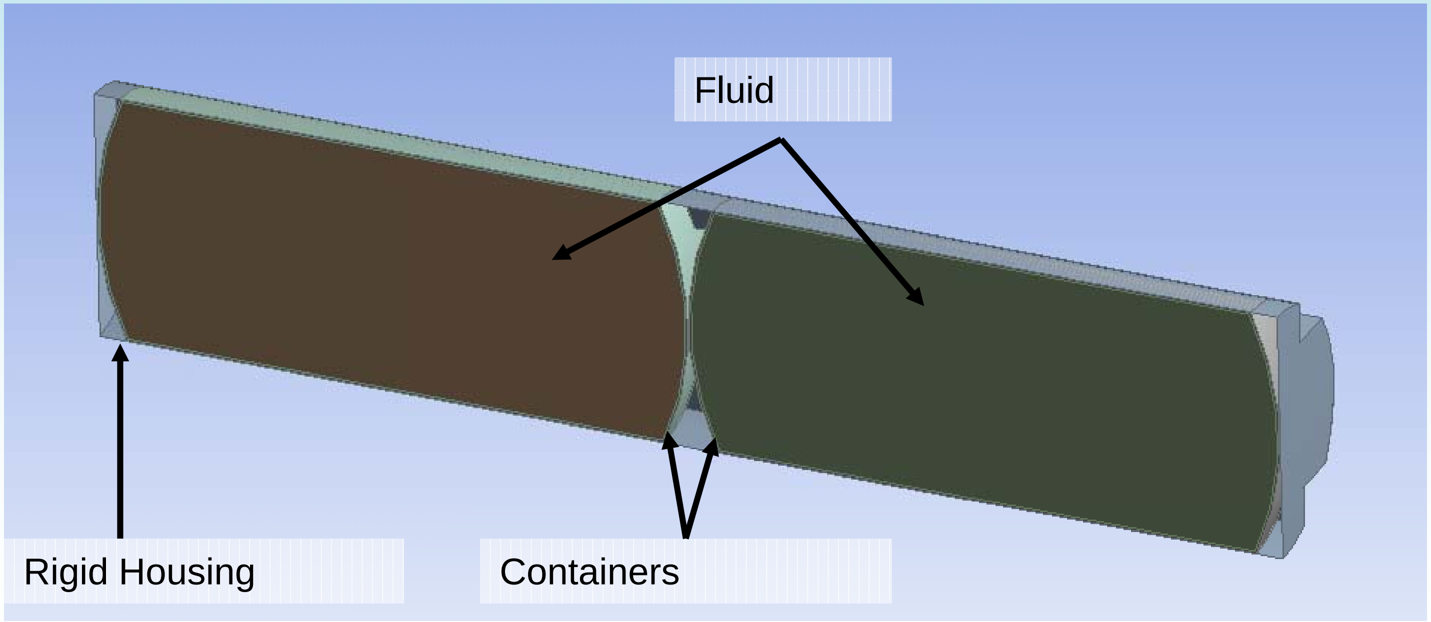


Temperature Distribution

Model courtesy Taesung Software & Engineering, Inc.

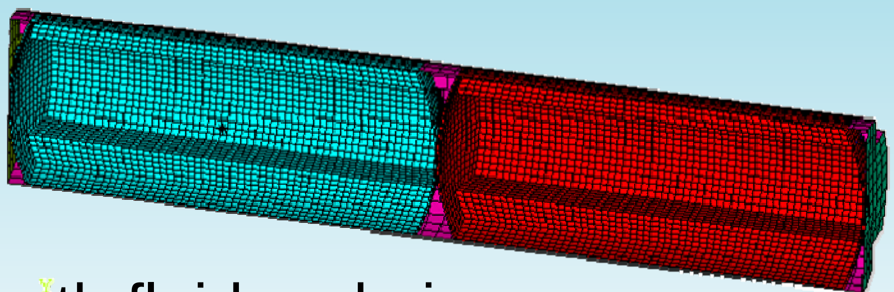
Tank Sloshing

- **Tank Sloshing**
  - Objective is to determine the response of two containers undergoing acceleration
  - FSI needed since response of sloshing fluid coupled with the enclosure not known beforehand.

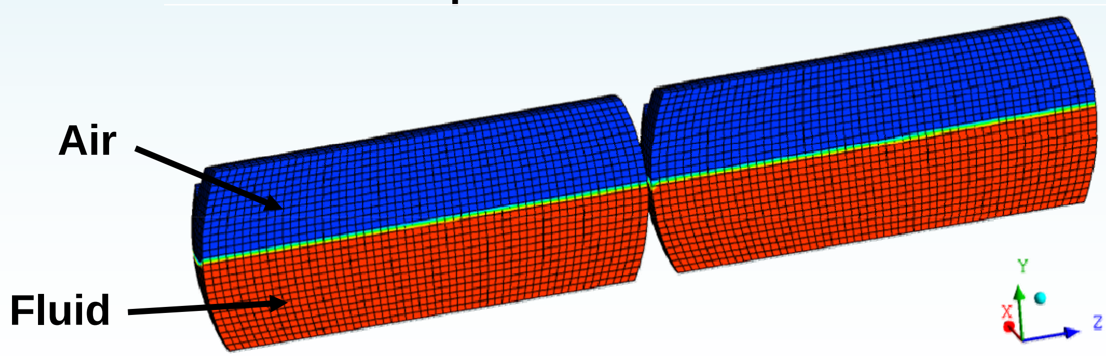


Tank Sloshing

- **Structural Model**
  - Containers modeled with solid-shell elements
  - Multi-linear isotropic hardening plasticity
  - Nonlinear contact

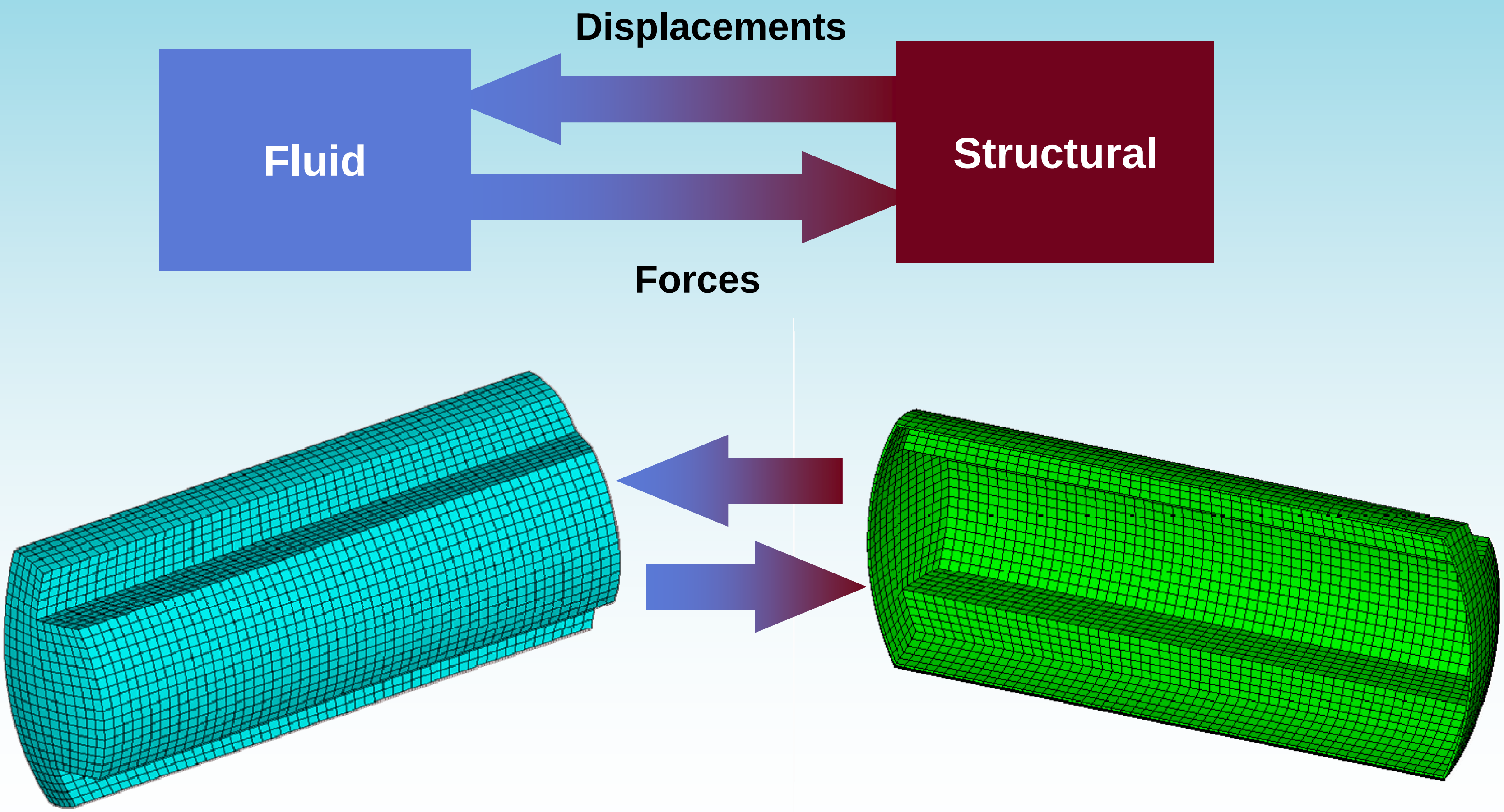


- **CFD Model**
  - Two domains modeled with fluid and air
  - Fluid is assumed to take up half of tank



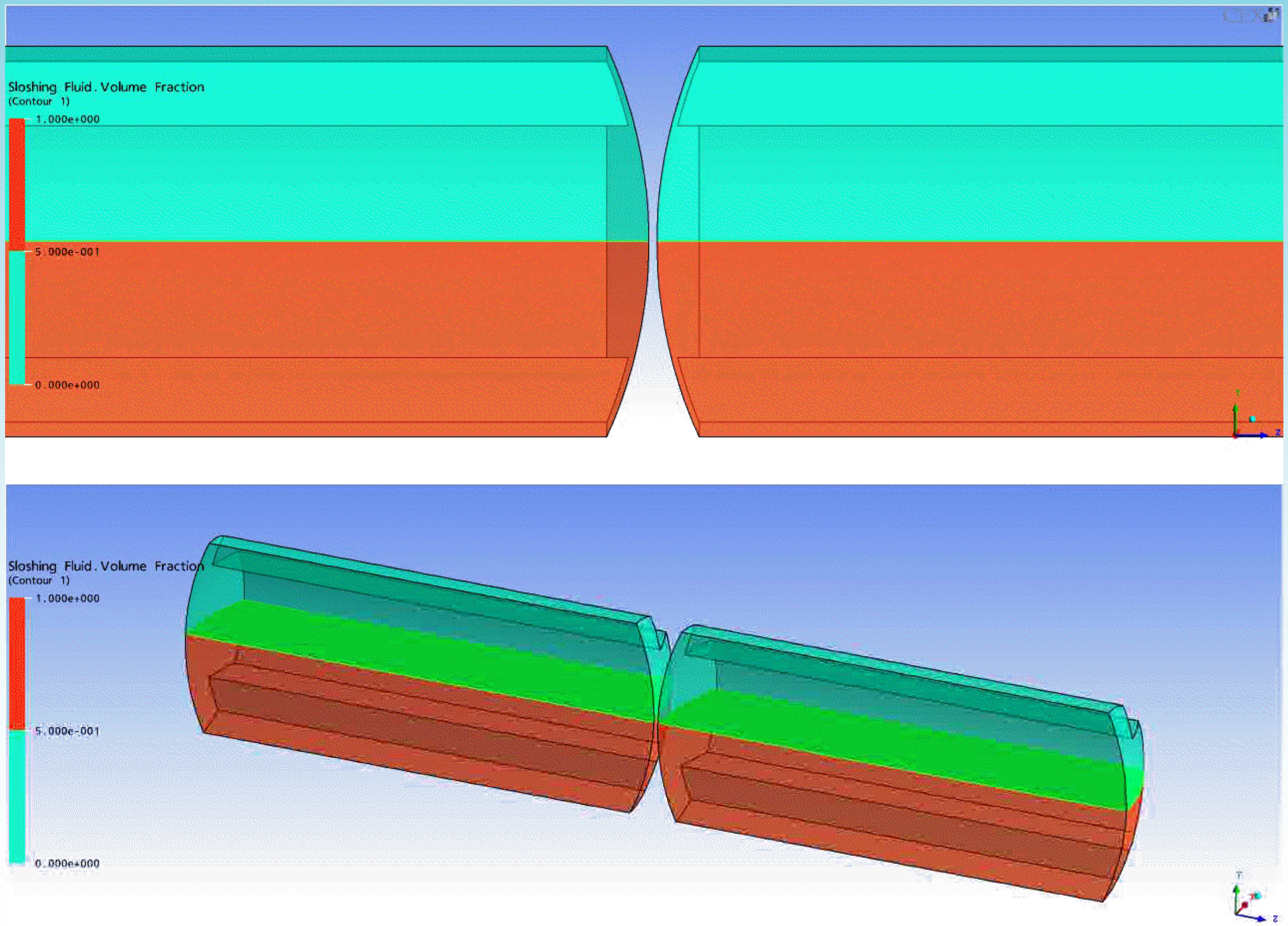
Tank Sloshing

- **Implicit Sequential Solution**
  - Transient 1.5 s



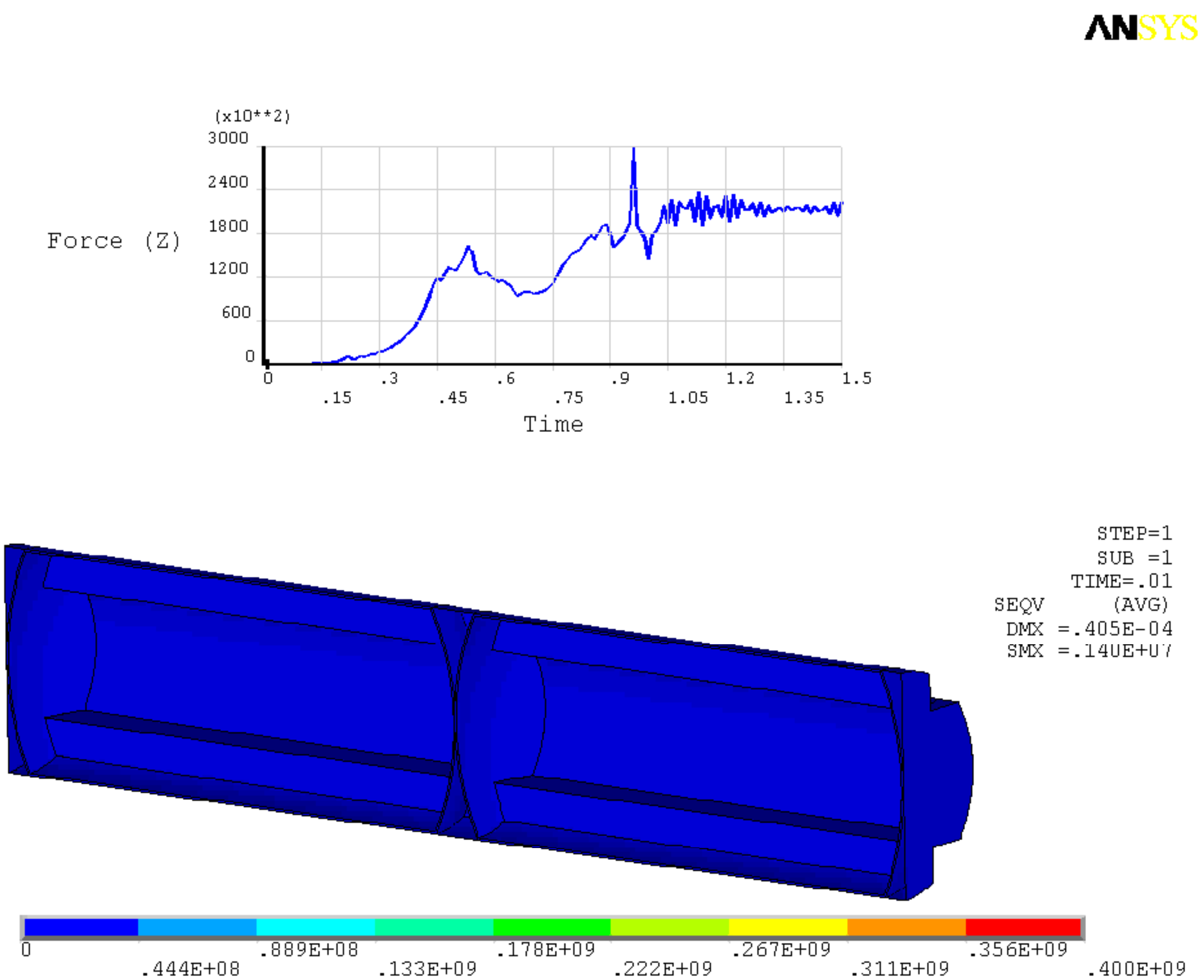
Tank Sloshing

- **CFD Results**



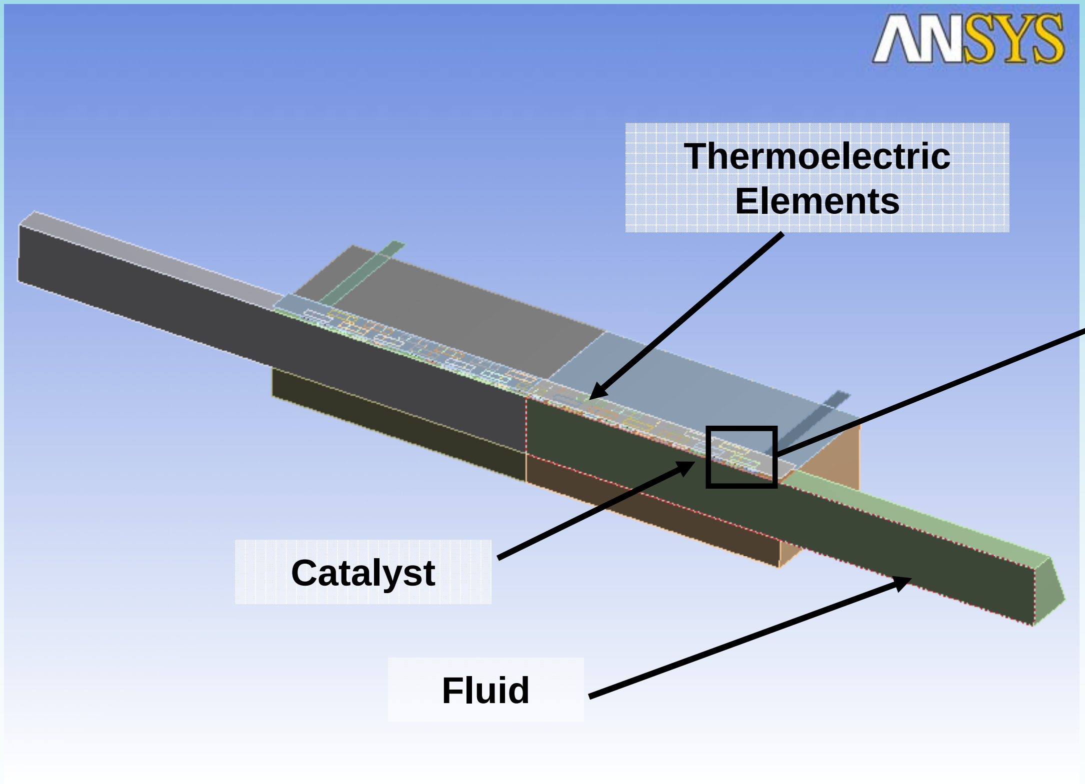
Tank Sloshing

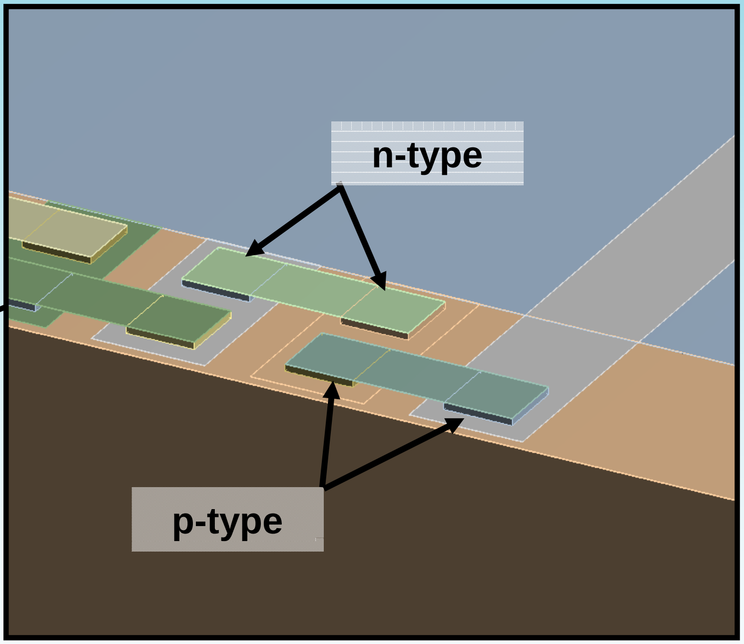
- **Structural Results**



Thermoelectric MEMS Device

- **Conversion of Heat into Electrical Energy**
  - Coupling of thermoelectric analysis and fluid flow with combustion

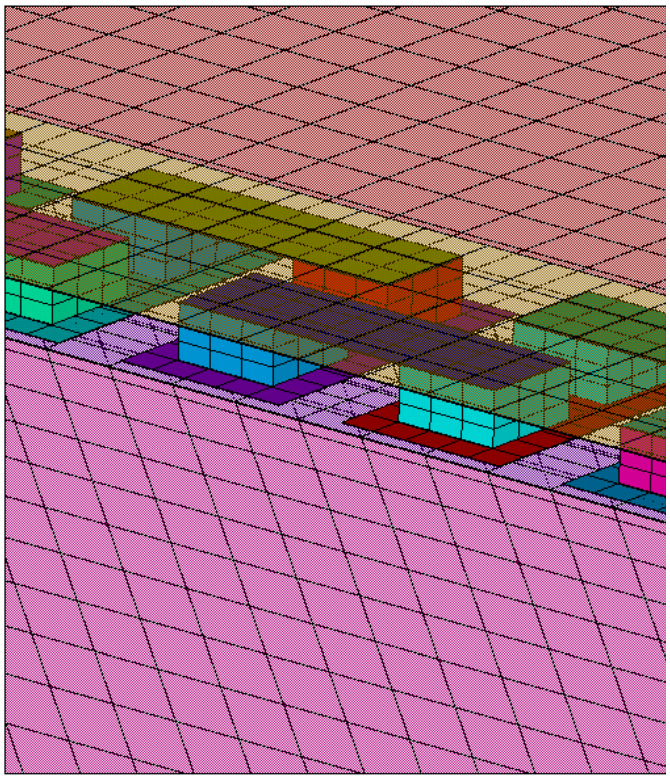


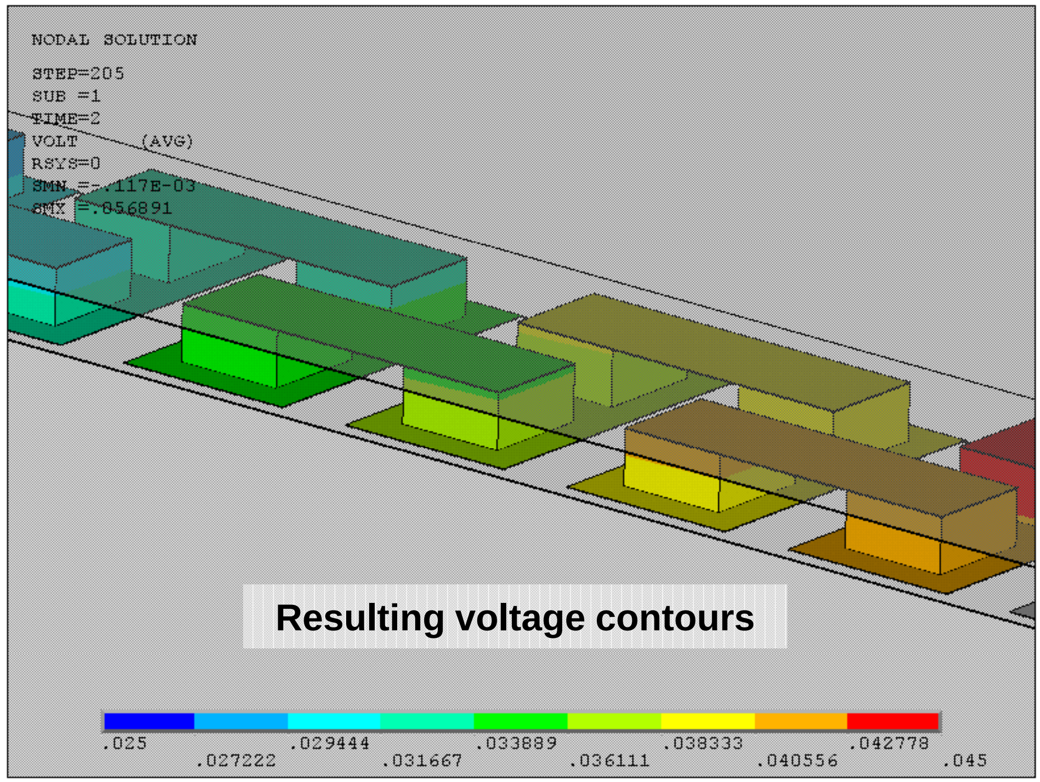


Each unit has n-type and p-type semiconductors.

Thermoelectric MEMS Device

- **Thermoelectric Model**
  - Direct coupled field elements
  - Convection and radiation to ambient at top of device
  - Temperatures passed to CFD model

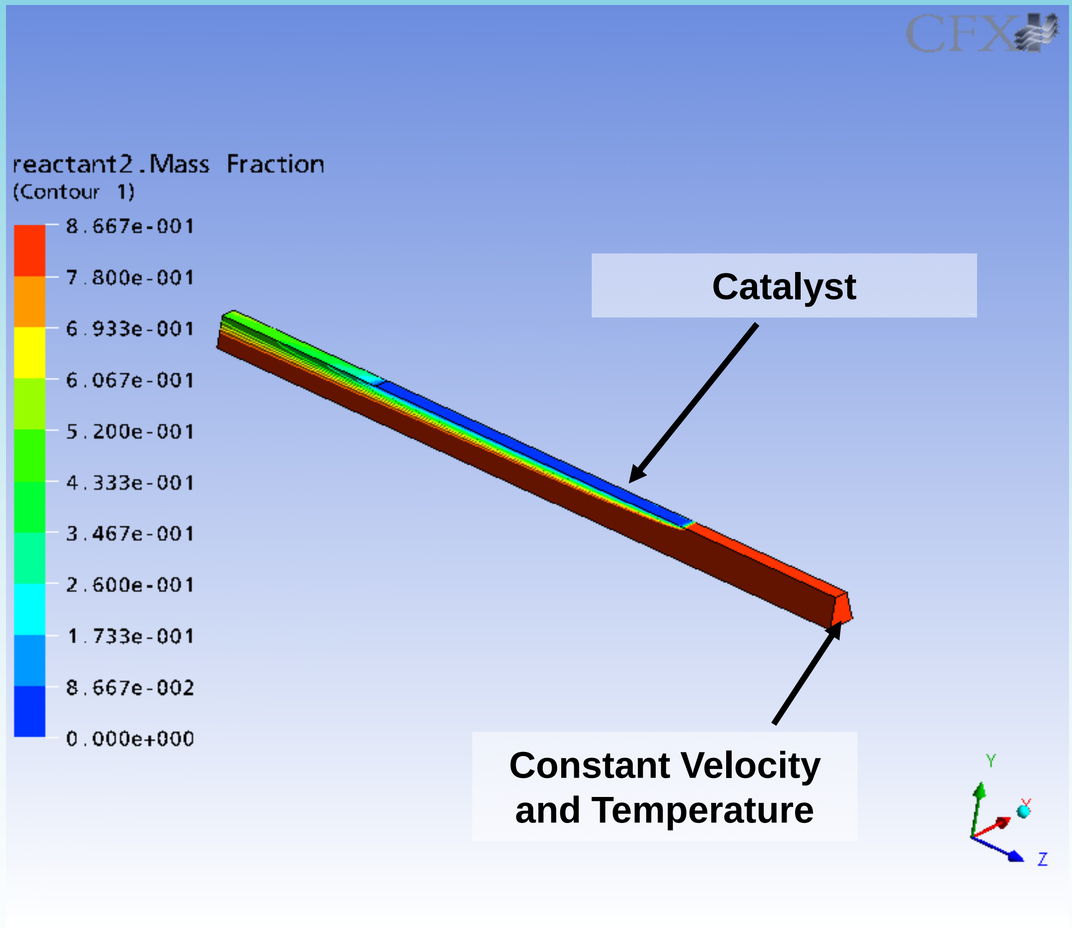




Resulting voltage contours

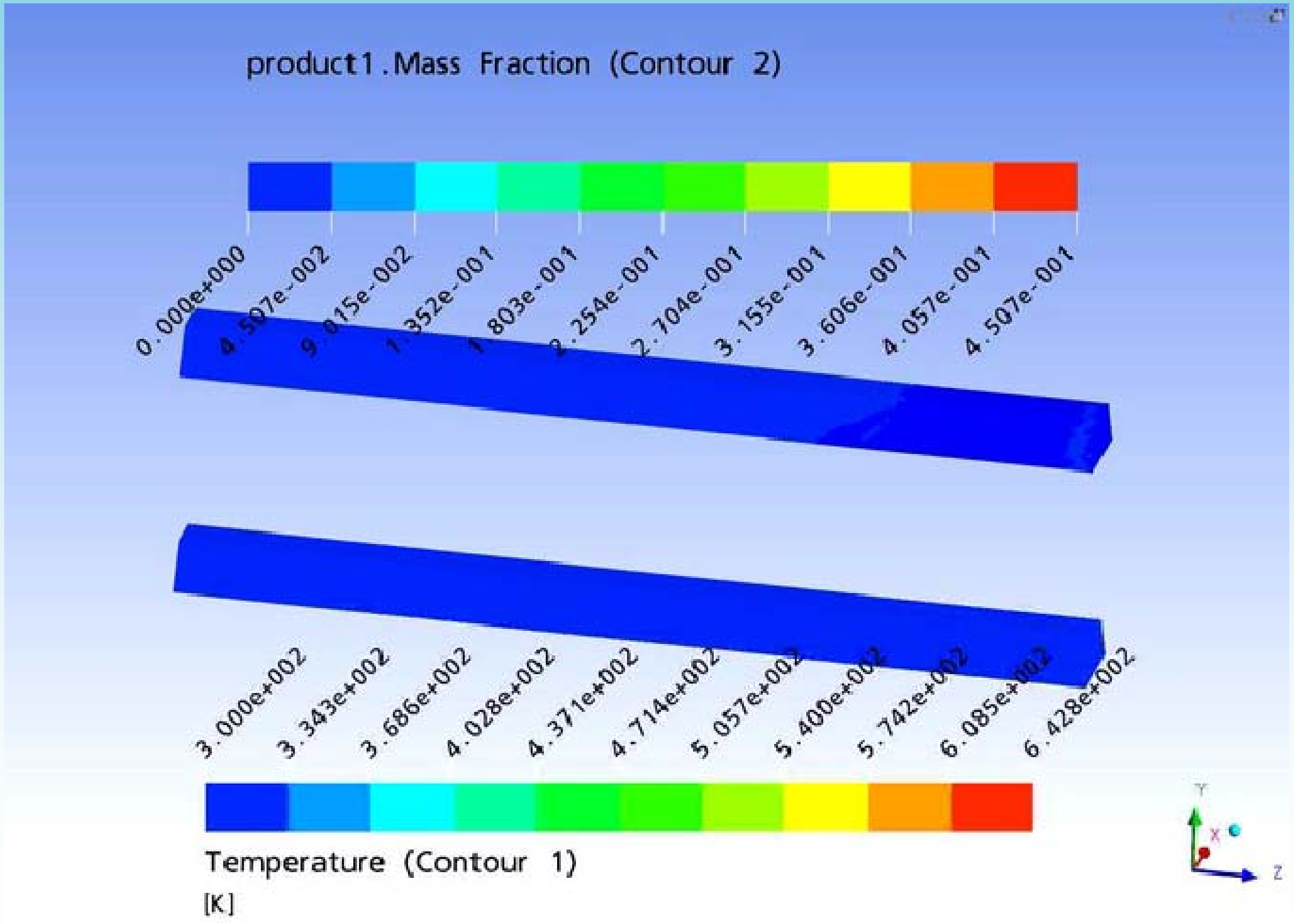
Thermoelectric MEMS Device

- **CFD Model**
  - Laminar flow
  - Catalyst under membrane
    - Causes surface reaction
    - Provides heat source for MEMS device
  - Heat fluxes to thermoelectric model.



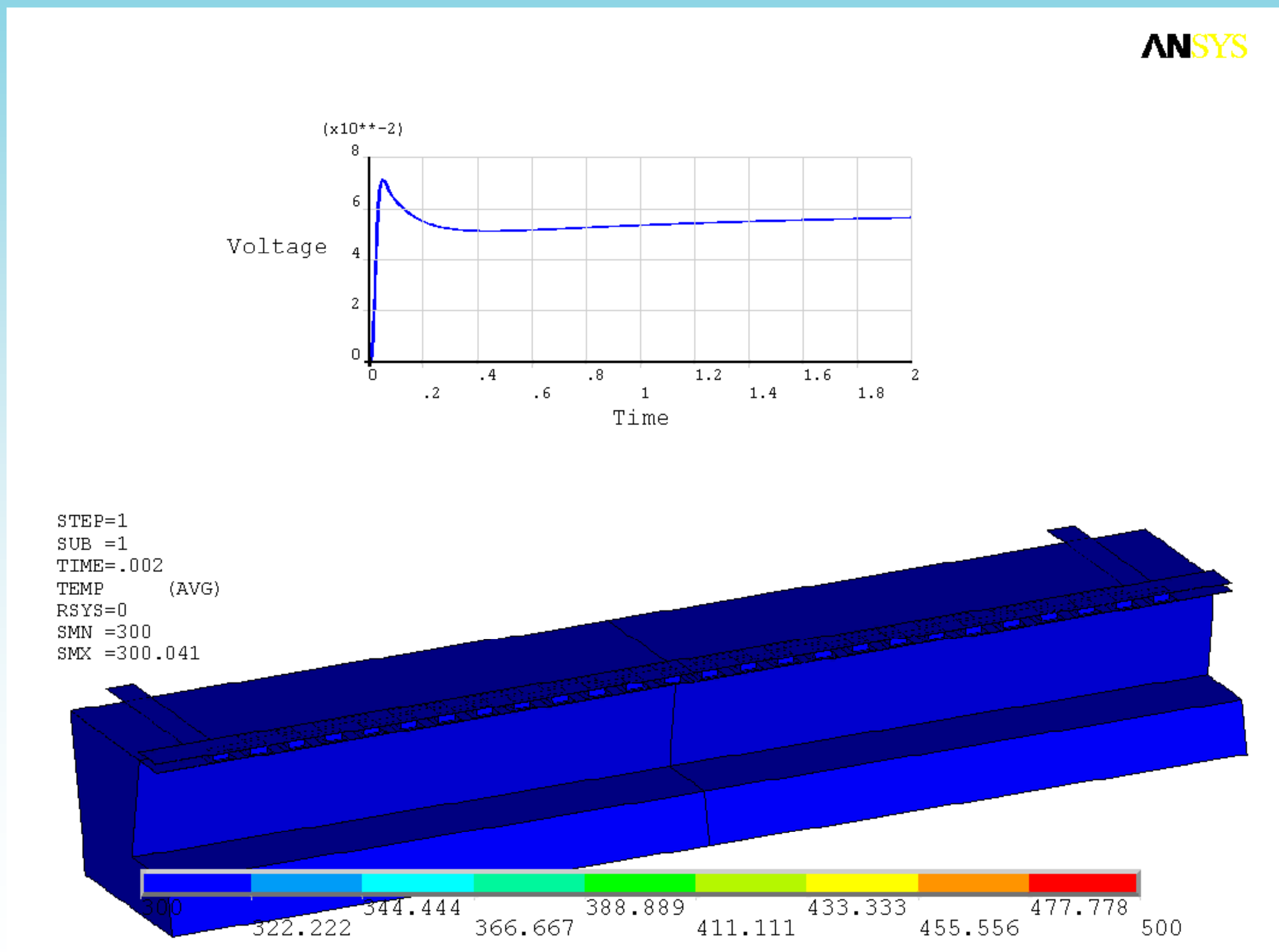
Thermoelectric MEMS Device

- **Mass Fraction and Temperature**



Thermoelectric MEMS Device

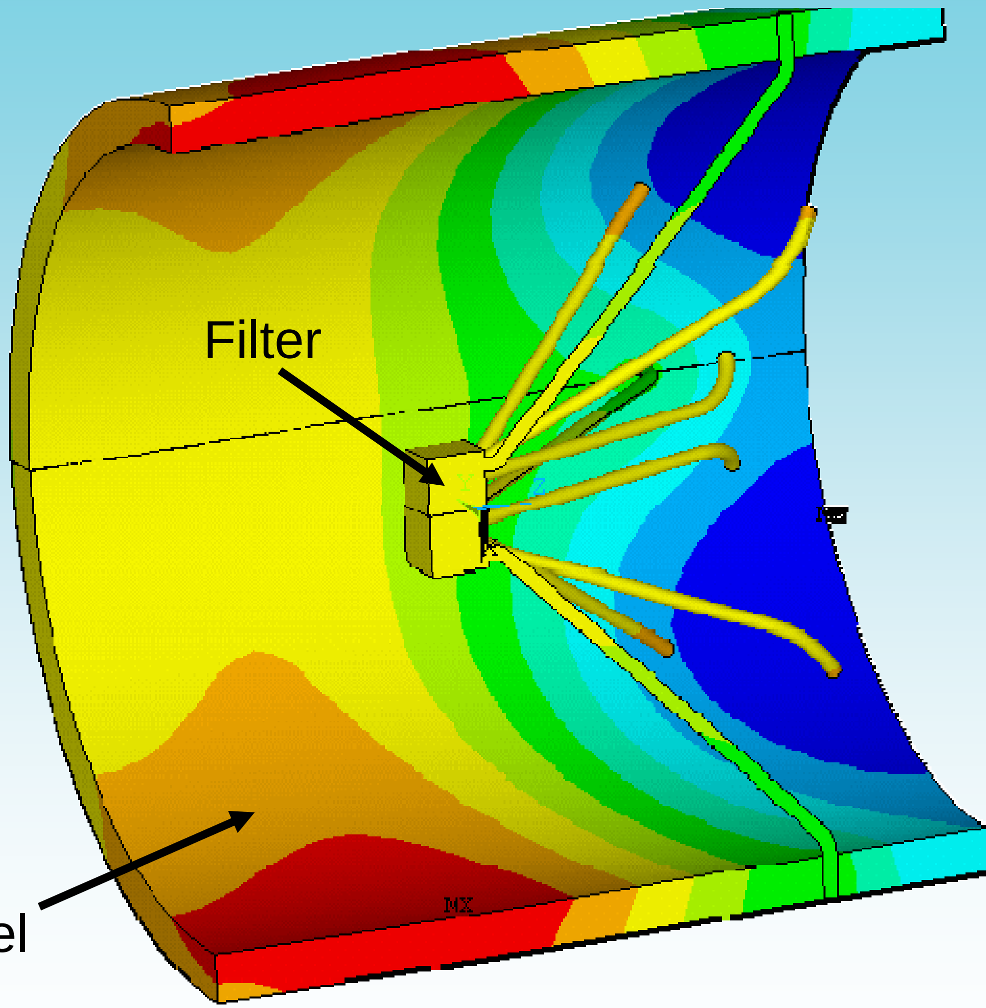
- **Voltage and Temperature**



Inferior Vena Cava Filter

- **Inferior Vena Cava (IVC) filters prevents the passage of large life-threatening emboli to the lungs.**

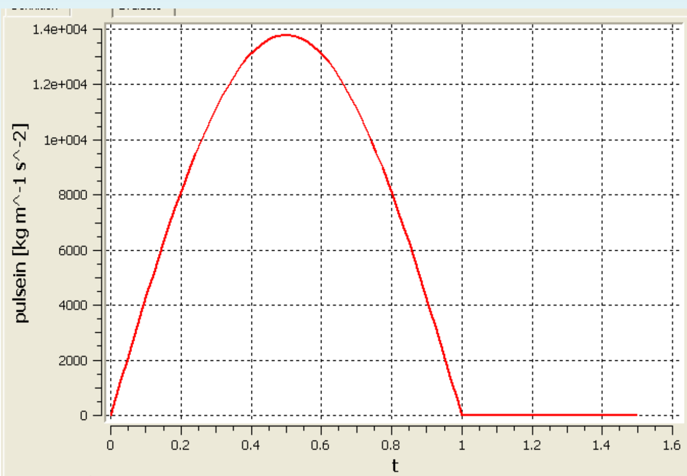
- **Analysis Provides:**
  - Understanding of the filter-vessel-flow interaction
  - Opportunity for design iterations to modify flow field, limit filter deformations reduce filter stresses, etc.

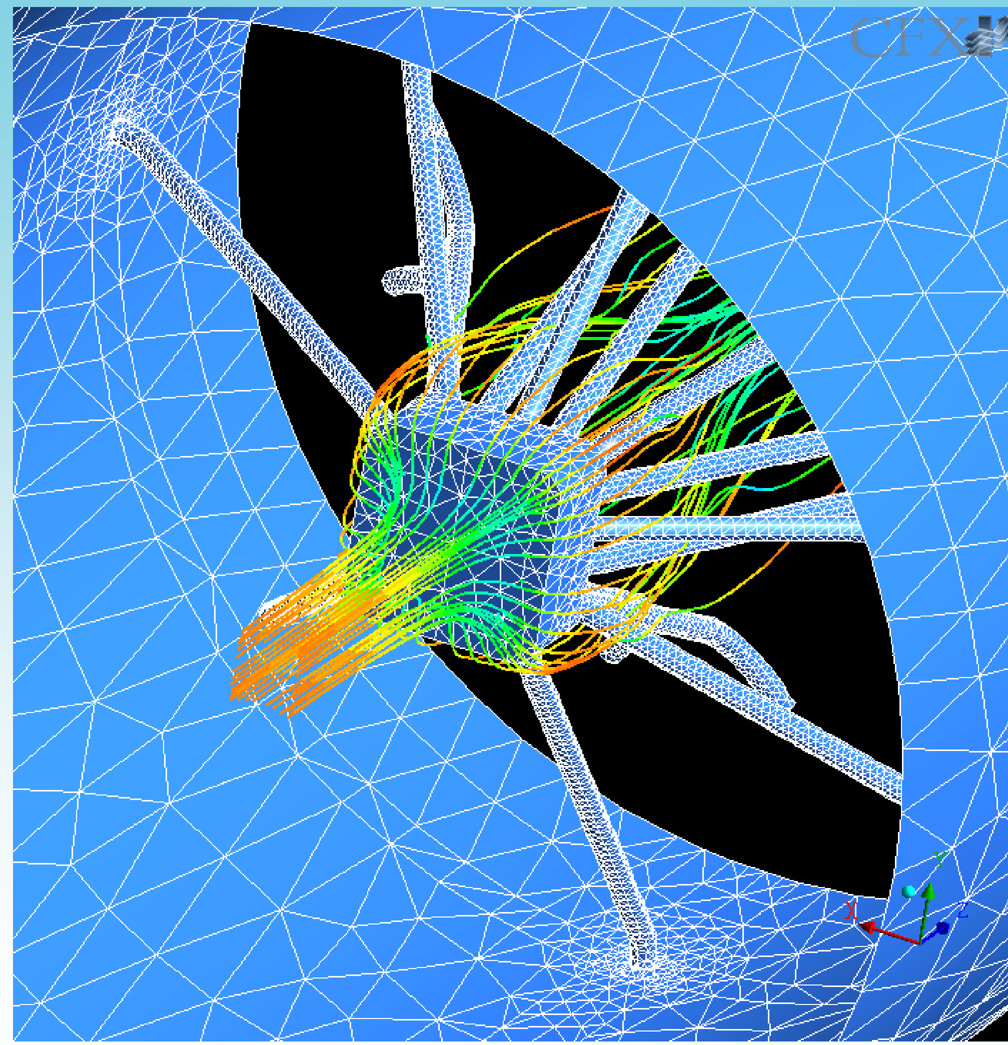


Model courtesy of Computer Aided Engineering Associates, Inc.

Inferior Vena Cava Filter

- **Solid surfaces act as interface between fluid and solid domains**
- **CFD solution provides unsteady pressure loads**
- **Solid deformations provide a new boundary for CFD**

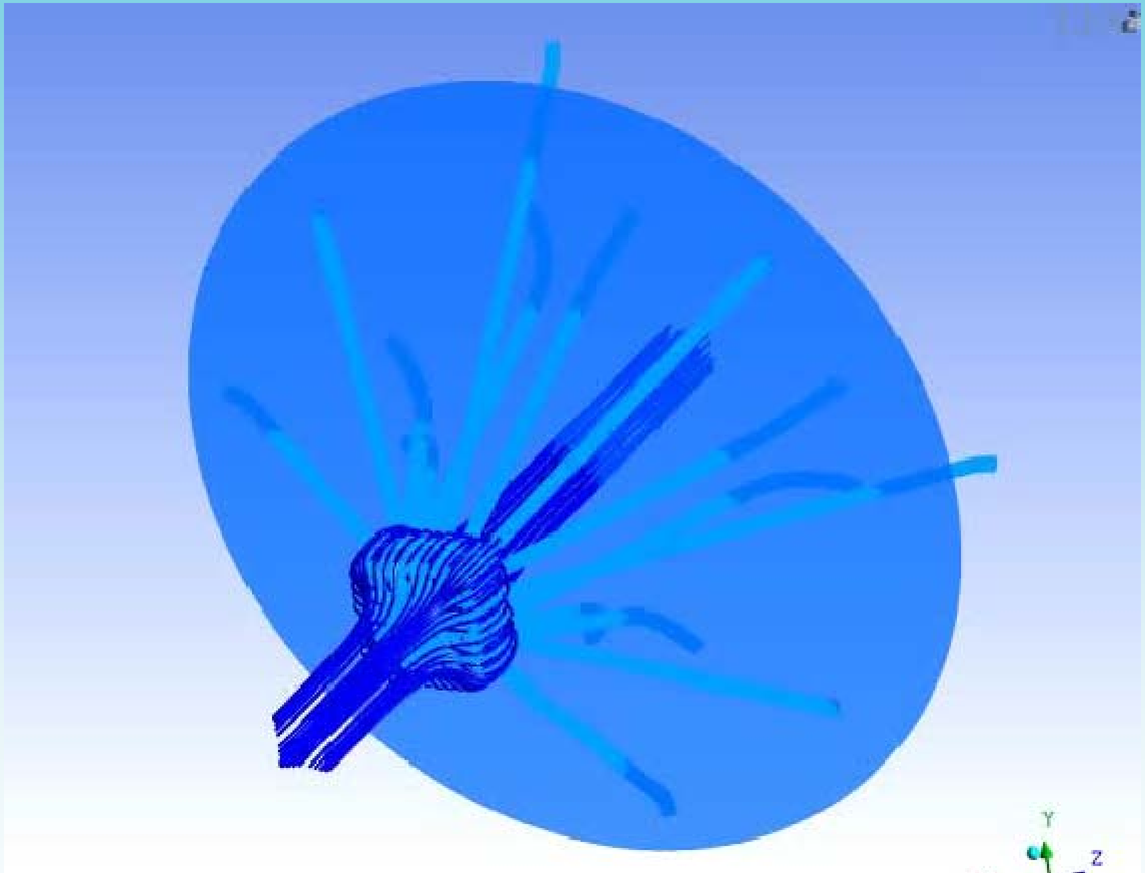




Model courtesy of Computer Aided Engineering Associates, Inc.

Inferior Vena Cava Filter

- **Blood Flow Model**
  - Density as a function of unsteady pressure pulse
  - Weakly compressible
  - Non-Newtonian fluid
- **Moving Mesh Capability**
  - Accommodates deformed solid boundaries

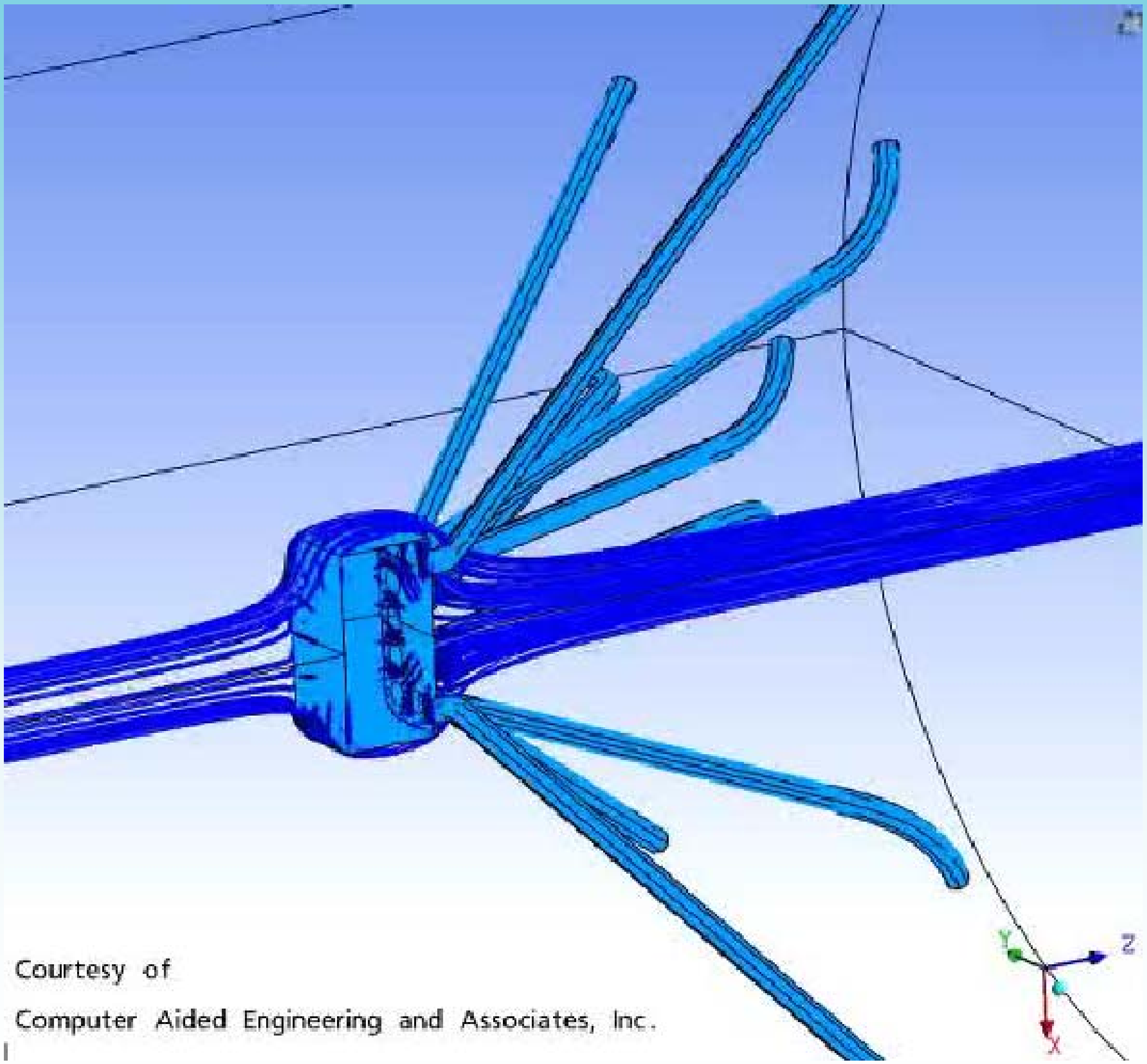


Courtesy of

Computer Aided Engineering and Associates, Inc.

Inferior Vena Cava Filter

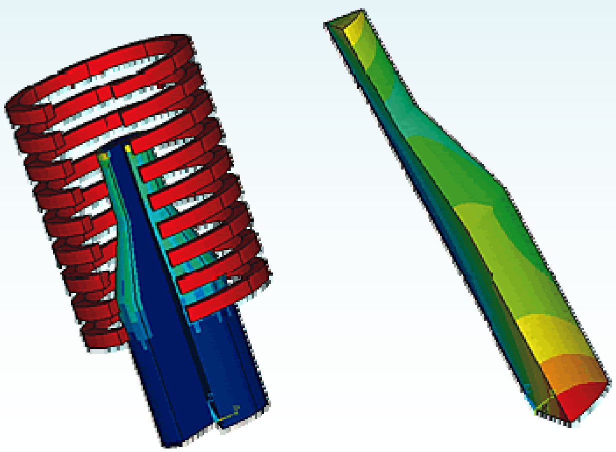
- Transient Streamlines
- Filter Deformations
- Fluid Pressures on Filter



Conclusions

Conclusions

- Implicit sequential coupling can be used to solve a wide variety of multiphysics problems
- Implicit coupling ensures accuracy
- A dissimilar mesh interface allows for collaboration and solution efficiency
- Multiphysics simulation reduces engineering assumptions



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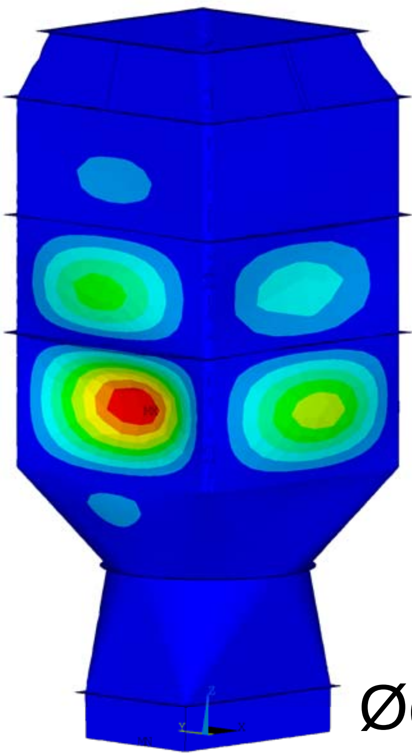
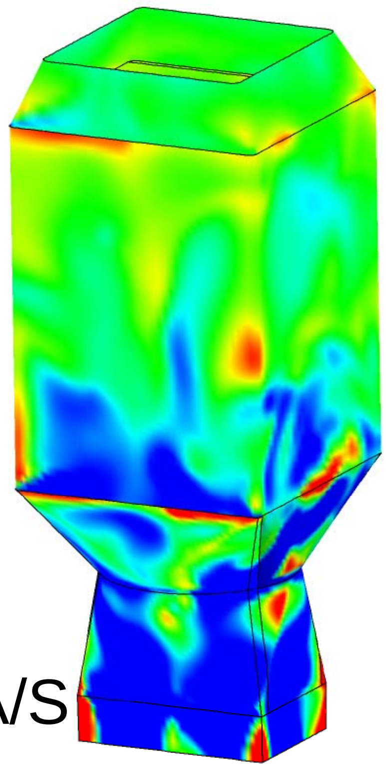
FSI modelling in industrial applications



Johan Gullman-Strand
Kenny Krogh Nielsen
Lars Voxen Hansen

Ødegaard & Danneskiold-Samsøe A/S



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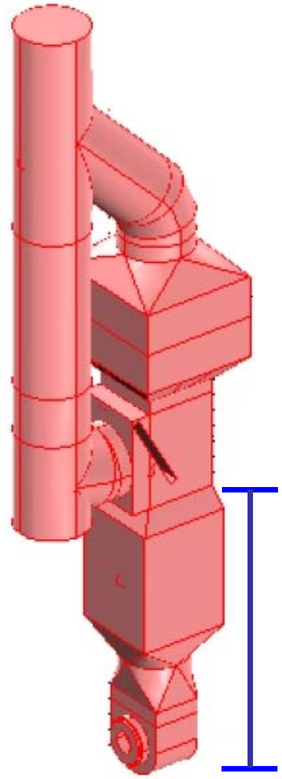
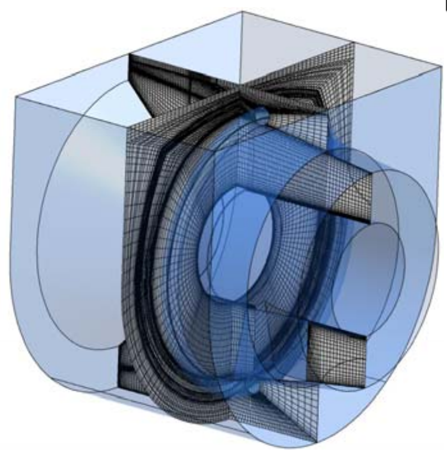
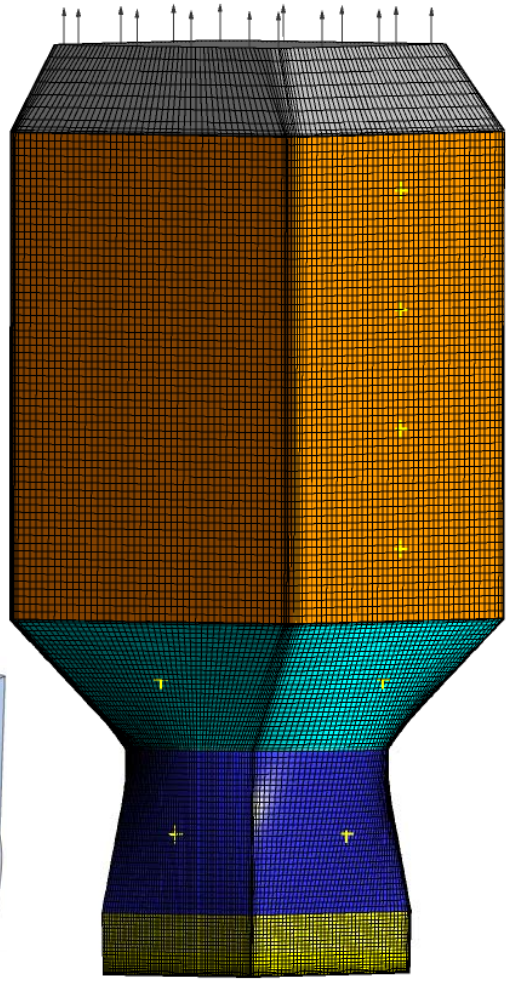
Exhaust duct
Investigation Approach

- Site measurements
- Acoustic analysis
- DES
- Unsteady RANS with K-ω SST
- CFD coupled to FEM through ”quasi” one-way FSI (time resolved).
- Done using CFX 10+ANSYS Prep 7
- Automatic coupled calculations. CFD and FEM solved simultaneously in a coupled manner.







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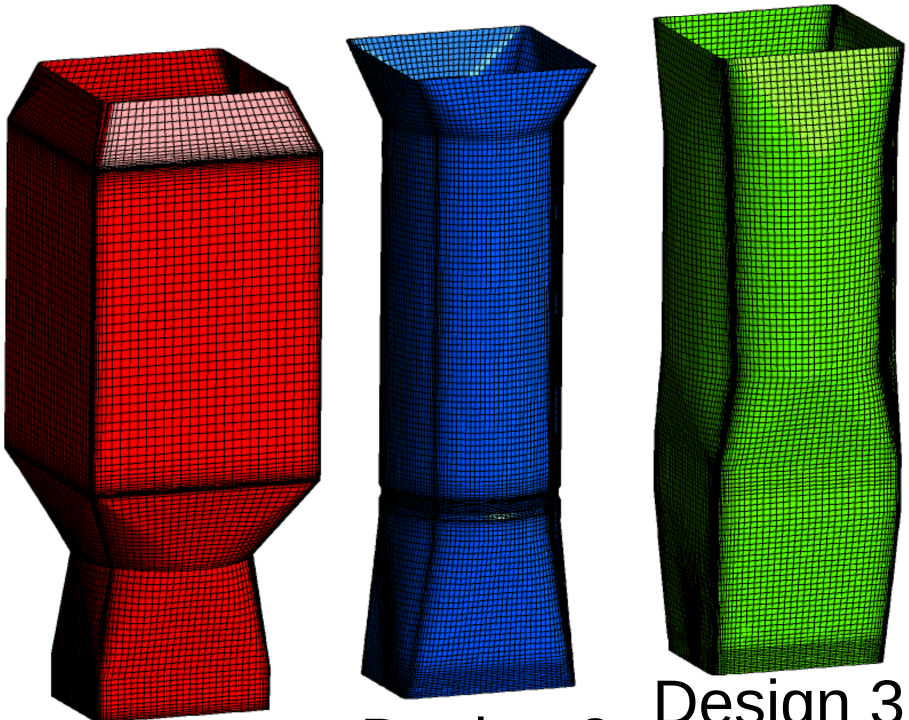
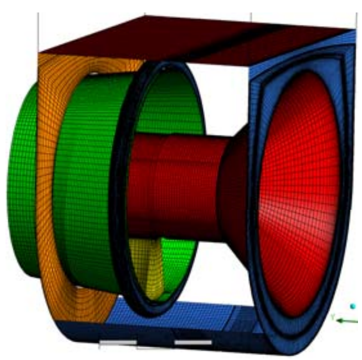
Design comparisons

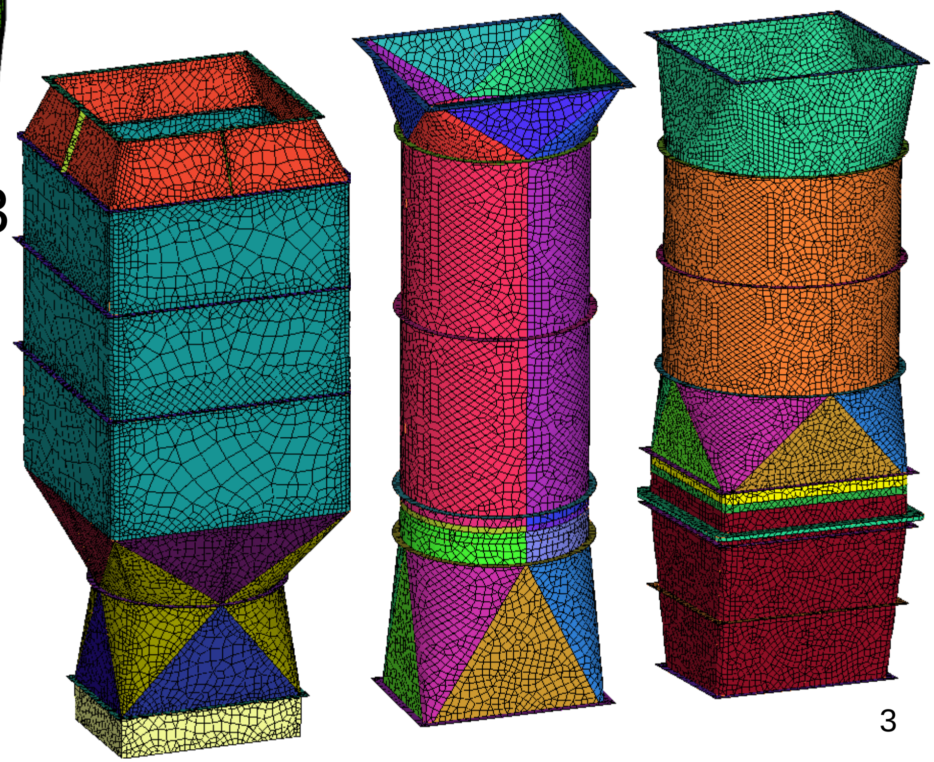
CFD mesh (volume)



Design 1 Design 2 Design 3



FEM mesh (surface)



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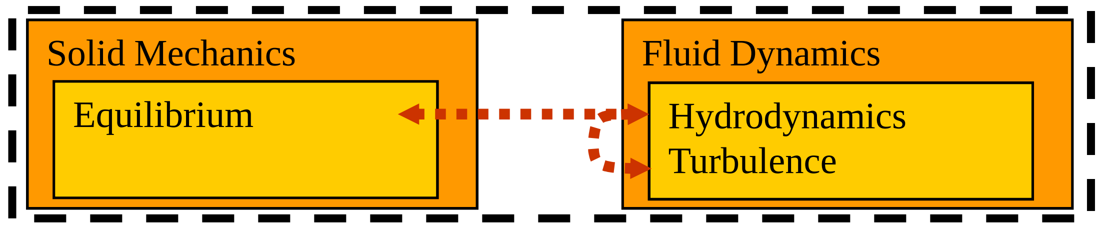
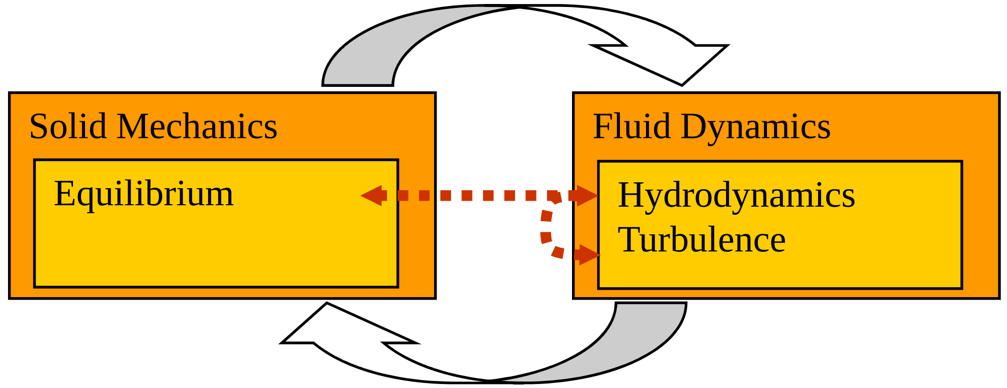
Fluid-Structure Interaction Overview

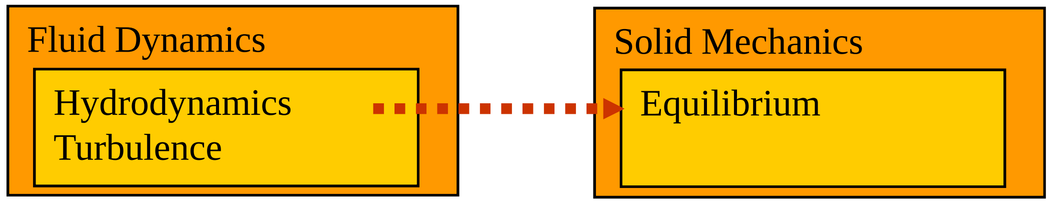
- Direct coupling



- Iterative coupling
  - Two-way
  - Quasi one-way



- Sequential coupling
  - One-way



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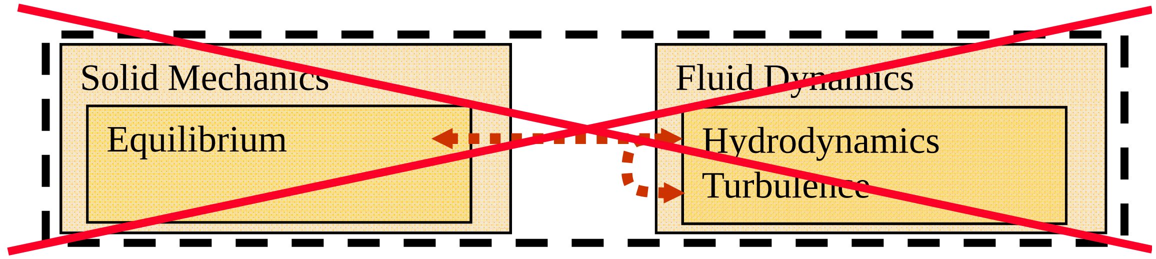
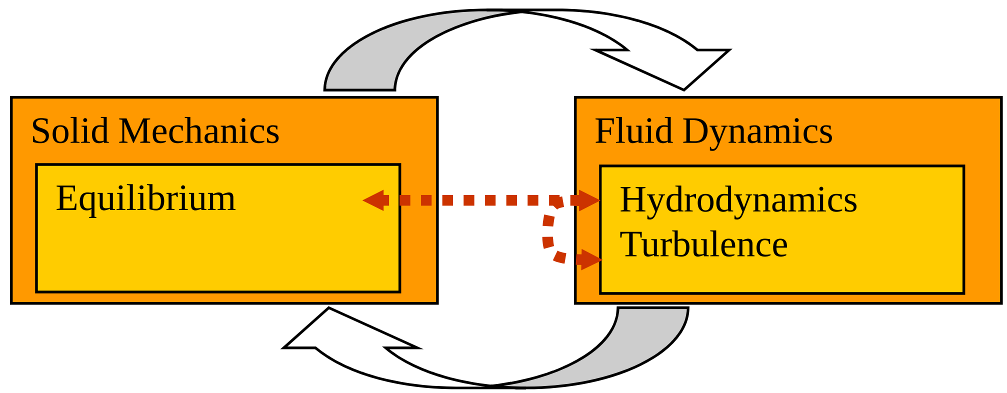
Fluid-Structure Interaction Overview

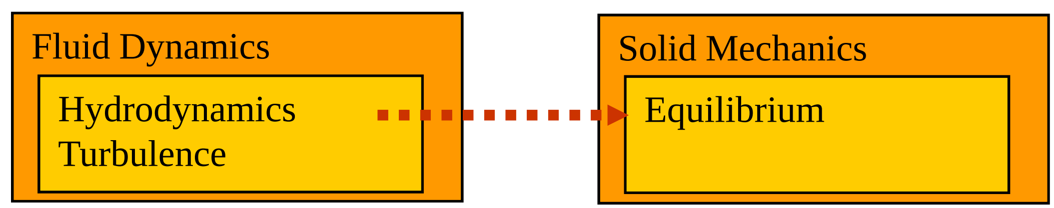
- Direct coupling



- Iterative coupling
  - Two-way
  - Quasi one-way



- Sequential coupling
  - One-way



Choice of coupling

- Iterative coupling
  - CFX 10 & 11
  - Prep 7 interface or ANSYS 11
  - Useful for large deformations
  - Heavy computations

- Sequential copuling
  - CFX 11
  - Prep 7 interface
  - Useful for small deformations
  - One heavy CFX computation, possibly many ANSYS computations
  - Needs a lot of CFX Postprocessing

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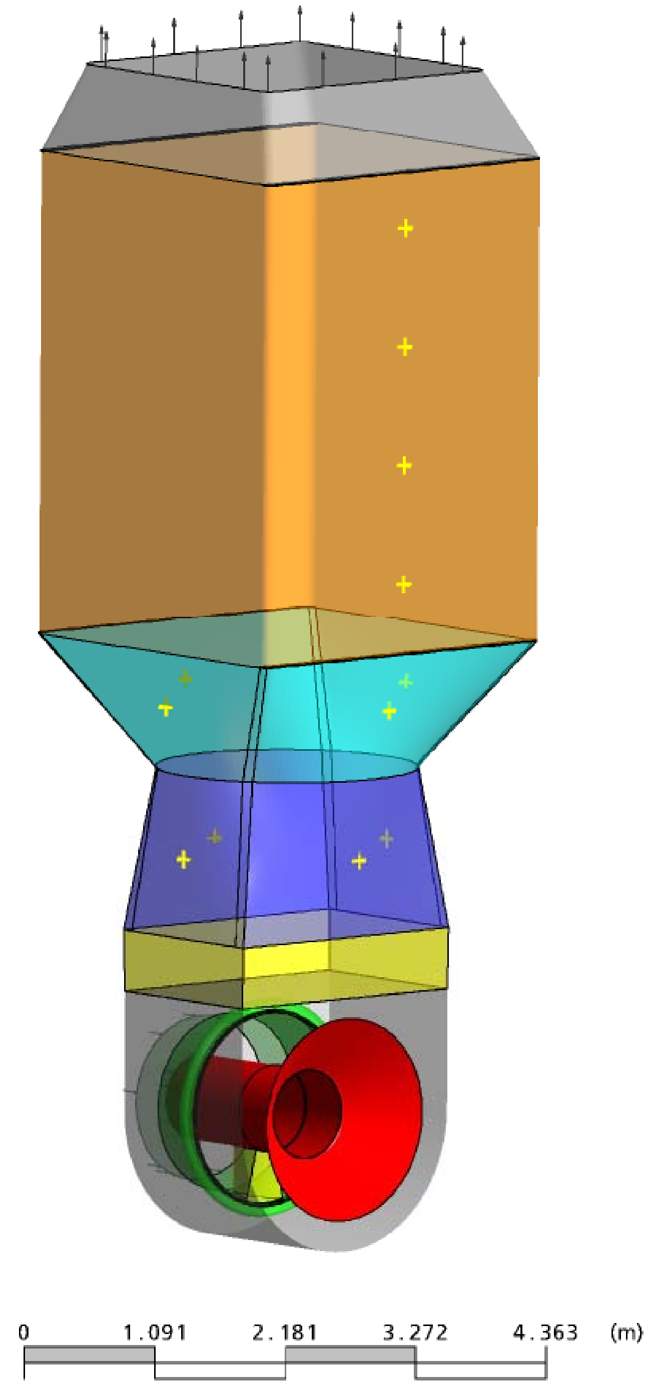
Overview of CFD setup

- Hexahedral elements
  - 1.54 Mnodes
- Steady computations
  - RANS + K-ω SST
- Unsteady computations
  - URANS + K-ω SST
  - DES (LES + URANS + K-ω SST)
  - FSI (URANS + K-ω SST + FEM)
- Isothermal, air at 500 ^{0}C
- Incompressible flow



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Results – DES region

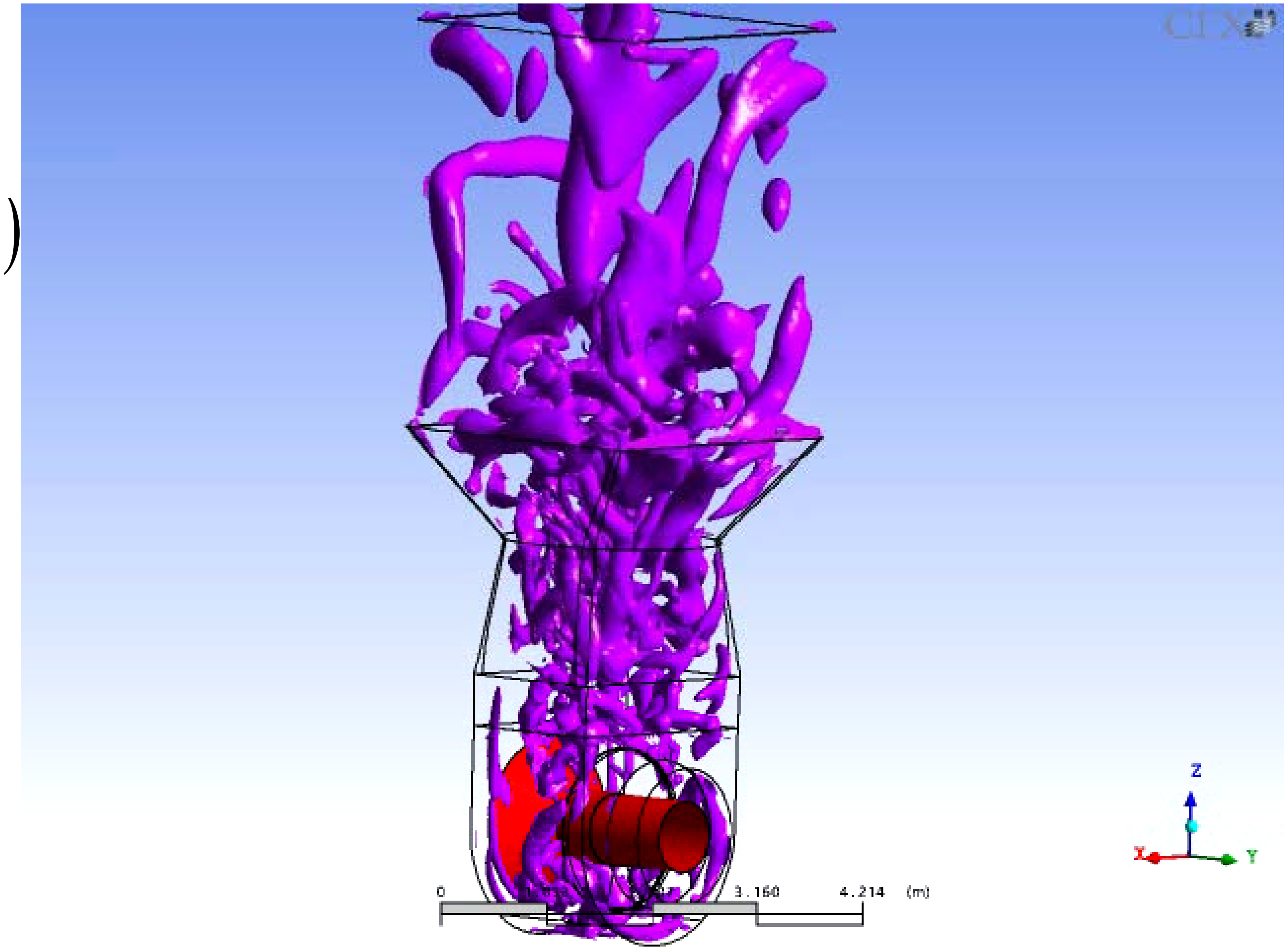
Iso-contour of

$$Q = -\tfrac{1}{2}\left(S_{ij}S_{ji} - \Omega_{ij}\Omega_{ji}\right)$$

$$Q = 50(D/U)^2$$

Hence, a measure of strong turbulent motion.

Duration: 0.25 s
Time step: $2.5 \cdot 10^{-4}$ s



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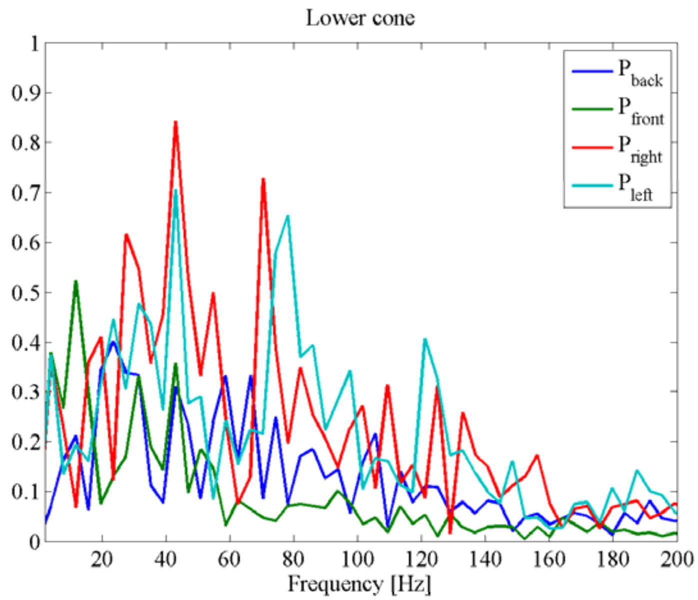
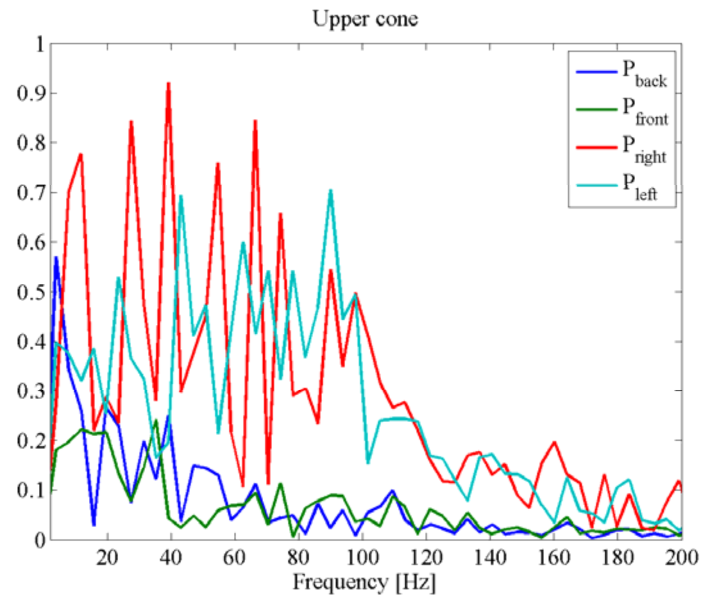
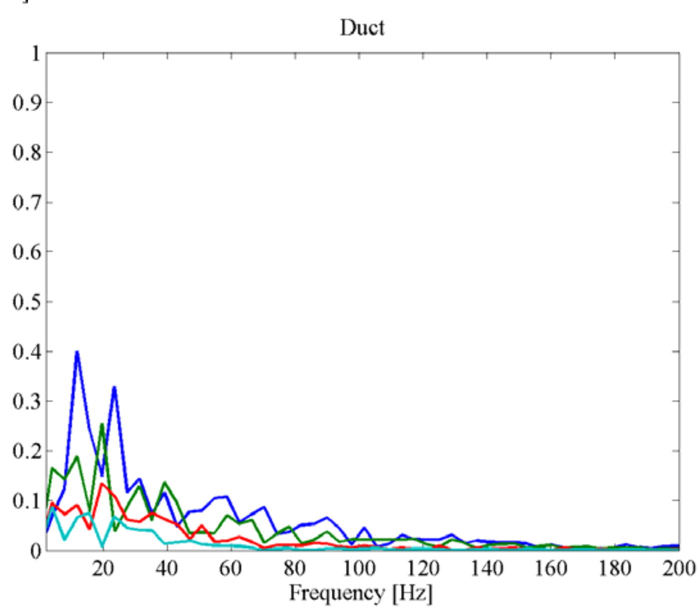
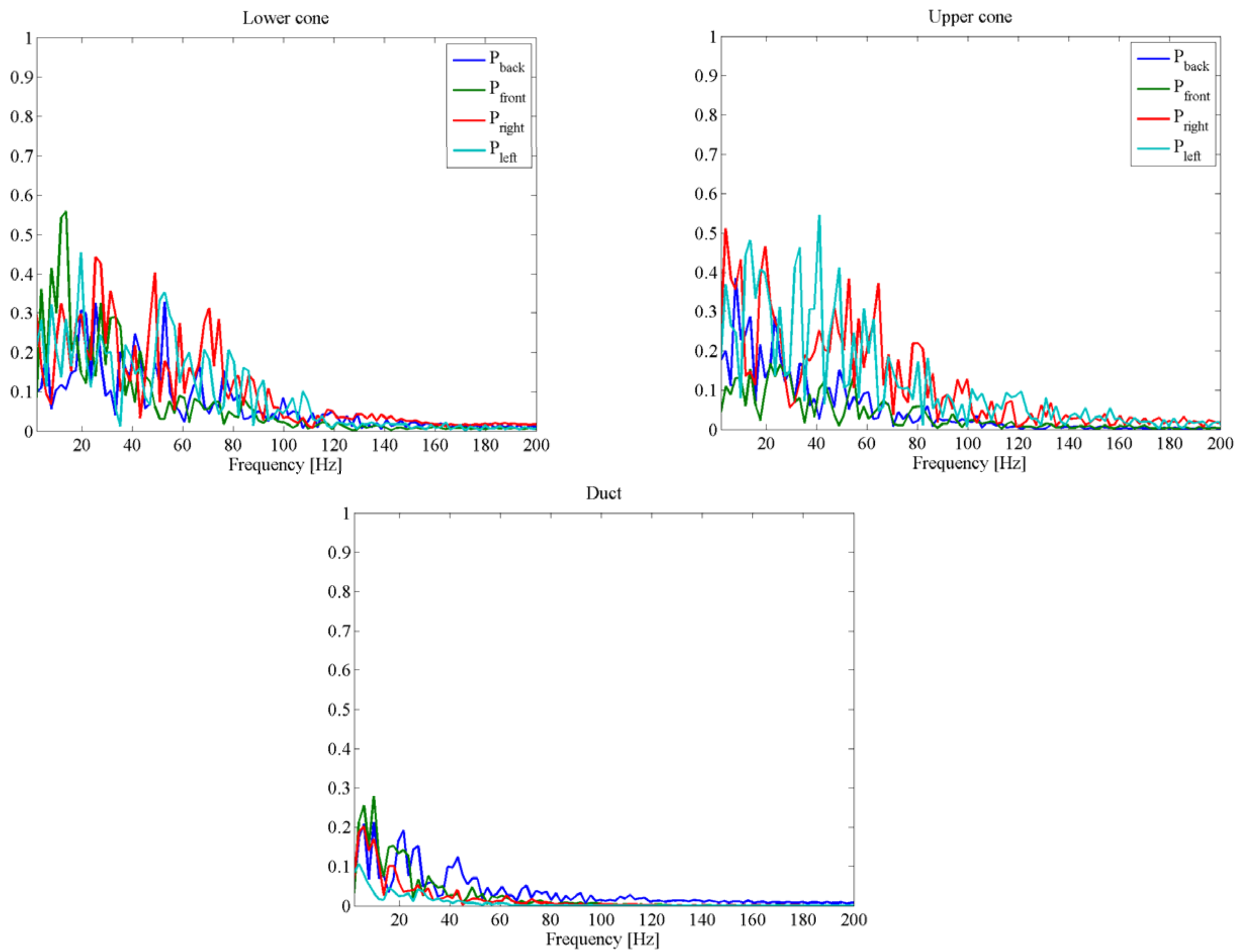
FFT of pressure - DES







FFT of pressure - URANS



CFD method performance

	RANS	URANS	DES
Time step	-	1 ms*	0.25 ms
CPU time	1 h	12 h	6 days
Model size	800 knodes	800 knodes	1.54 Mnodes

6 node cluster running ANSYS CFX 10.0 on Windows XP

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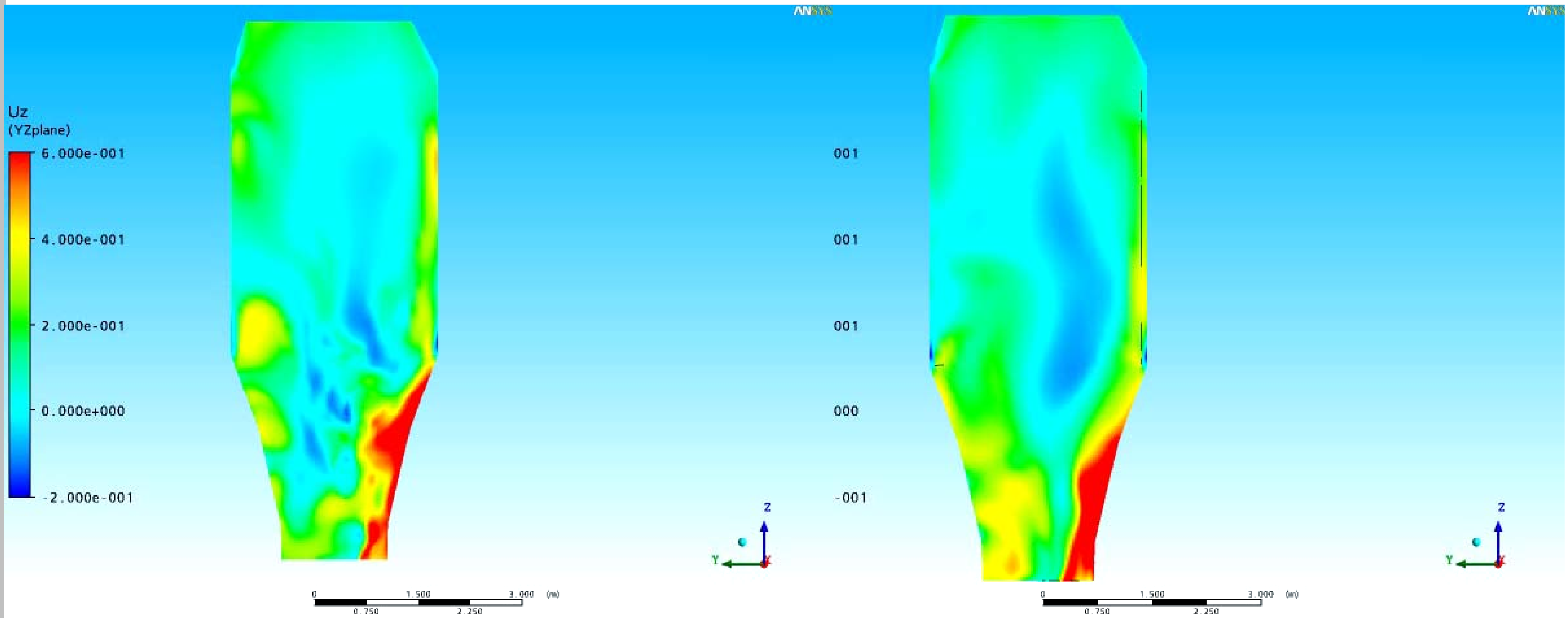
Results - Vertical velocity



DES

URANS

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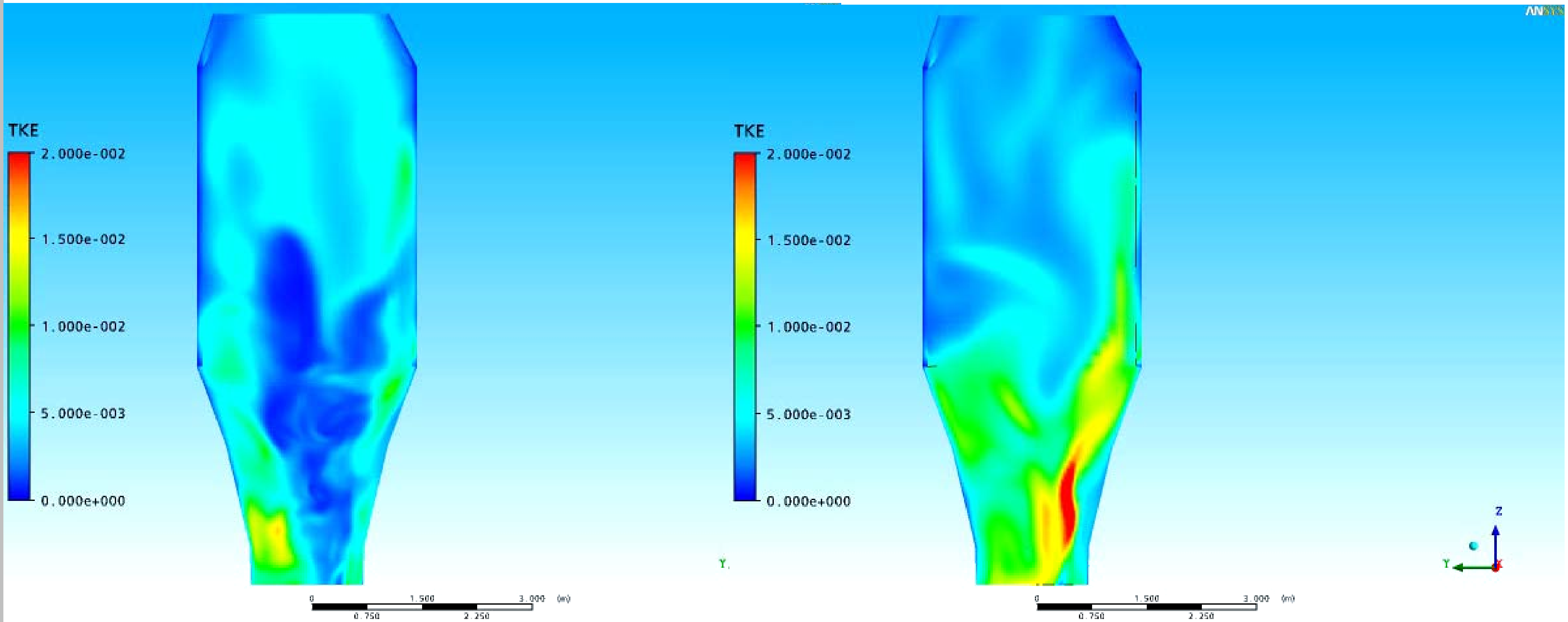
Turbulence kinetic energy



DES

URANS

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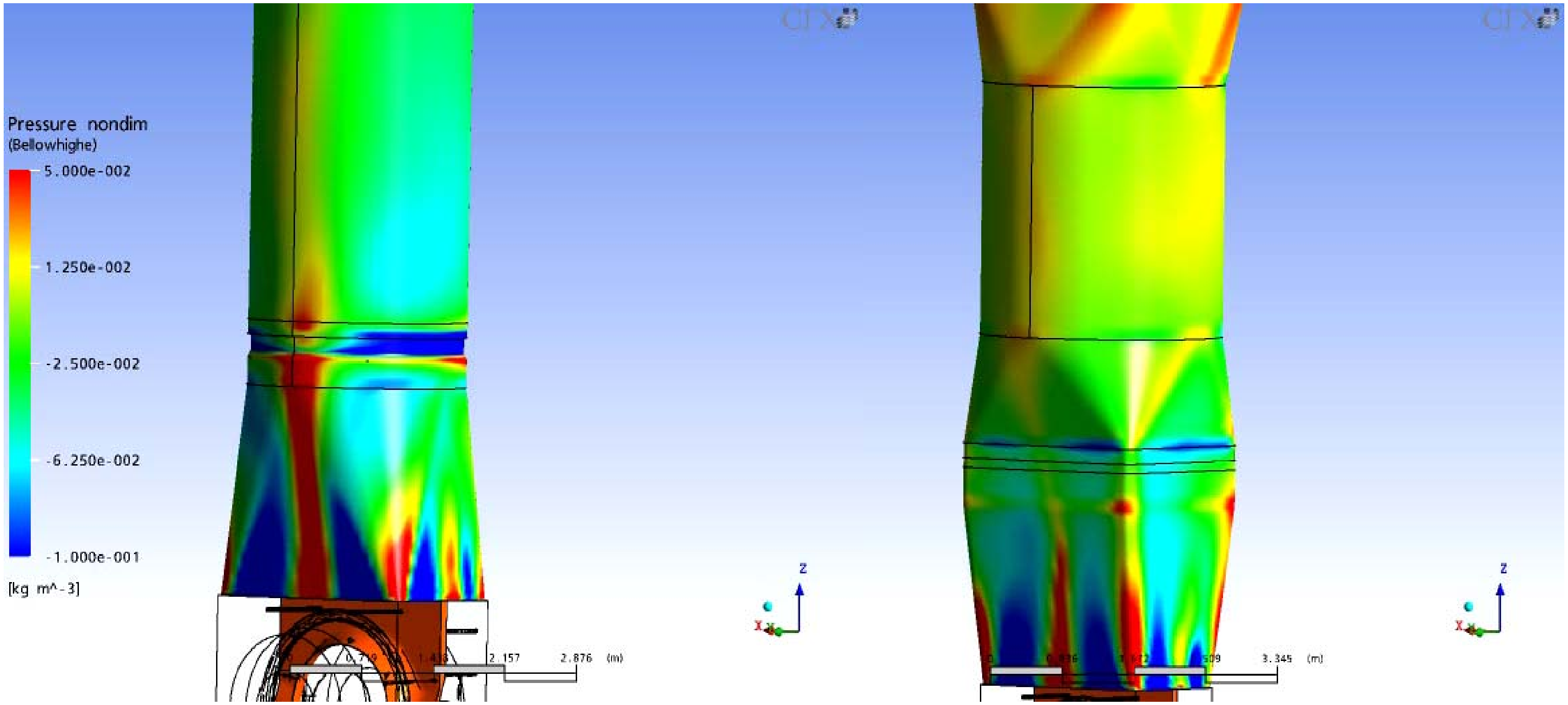
Resultat – Wall pressures



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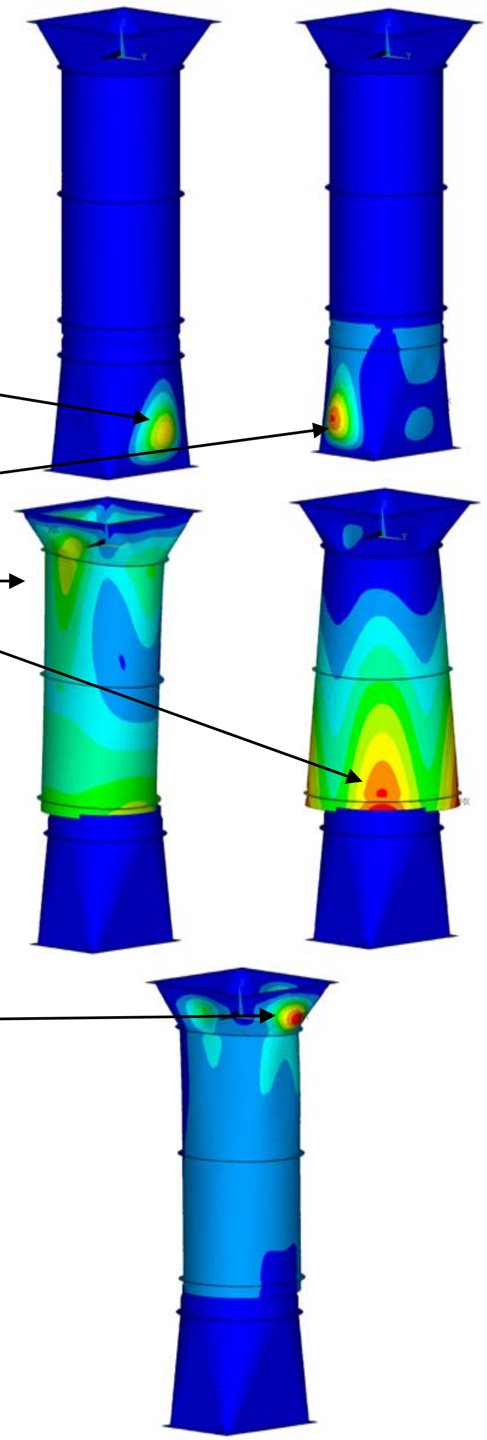
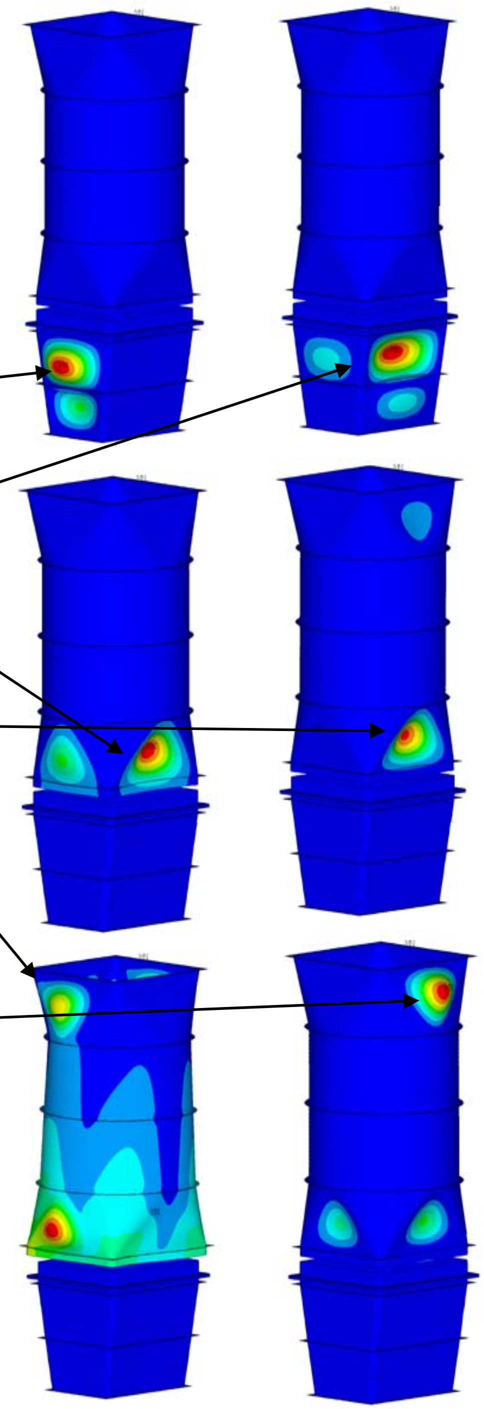
Modal Analysis

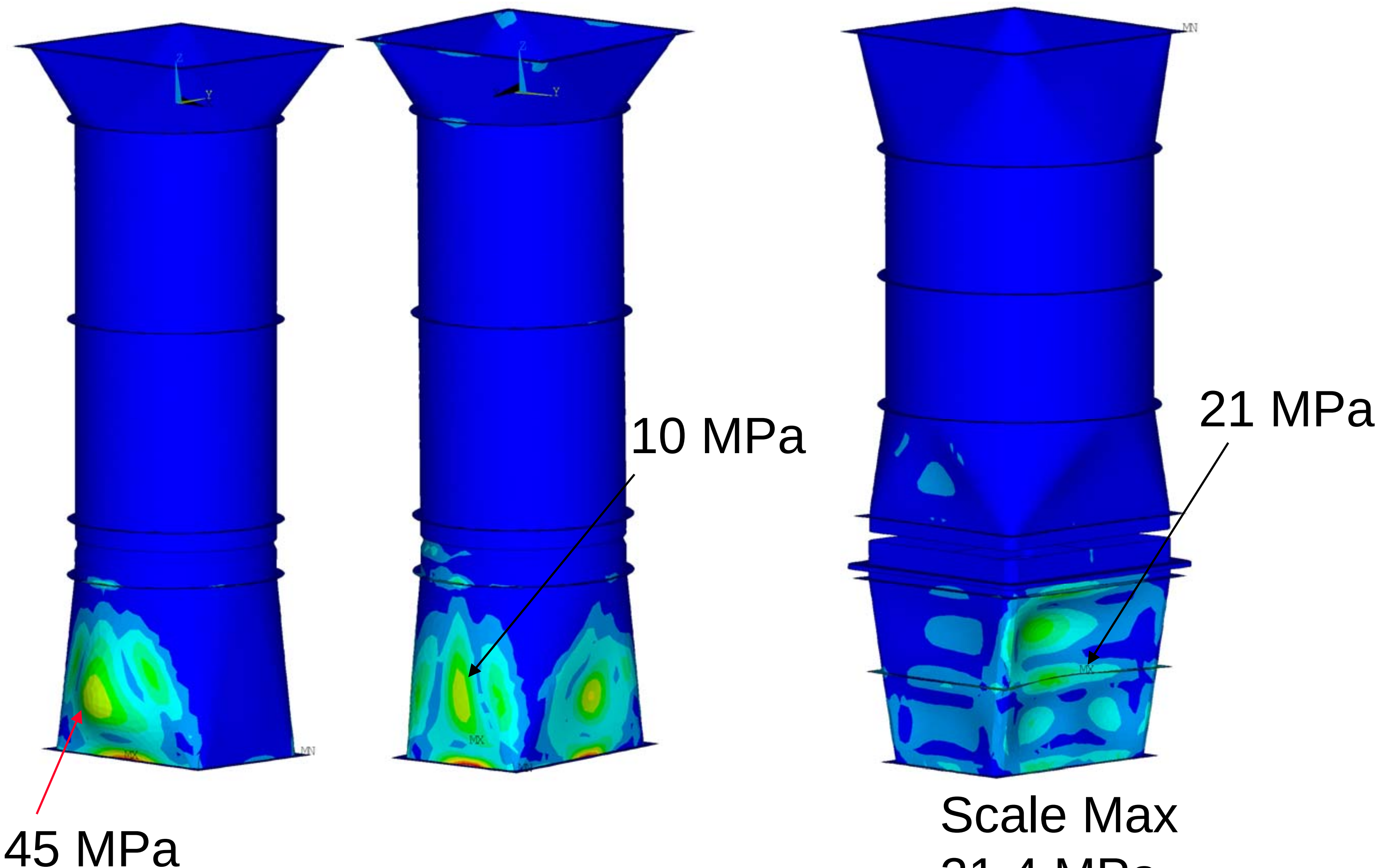
Mode	freq.
1	16.980
2	17.306
3	24.039
4	25.536
5	26.389
6	27.657
7	29.150
8	30.418
9	33.498
10	33.820
11	33.942
12	34.984
13	36.192
14	42.591
15	44.685
16	45.884
17	48.787
18	51.676



Mode	freq.
1	18.897
2	19.279
3	21.201
4	21.614
5	22.656
6	22.722
7	23.571
8	24.118
9	24.895
10	26.609
11	27.169
12	27.261
13	27.479
14	27.662
15	27.703
16	28.011
17	28.092
18	28.138
19	28.146
20	33.202



FSI Response



Scale Max
21.4 MPa

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Conclusions

- DES possible but not within short timespan
- Simple interface between FEM & CFD
- Large data volumes for adeqaute time series (>300GB)
- Important to thoose the appropriate level of interaction.
- FSI excites non-symetric mechanical modes.
- Possible to evaluate many design when the methodology has been established.

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Thank you!

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