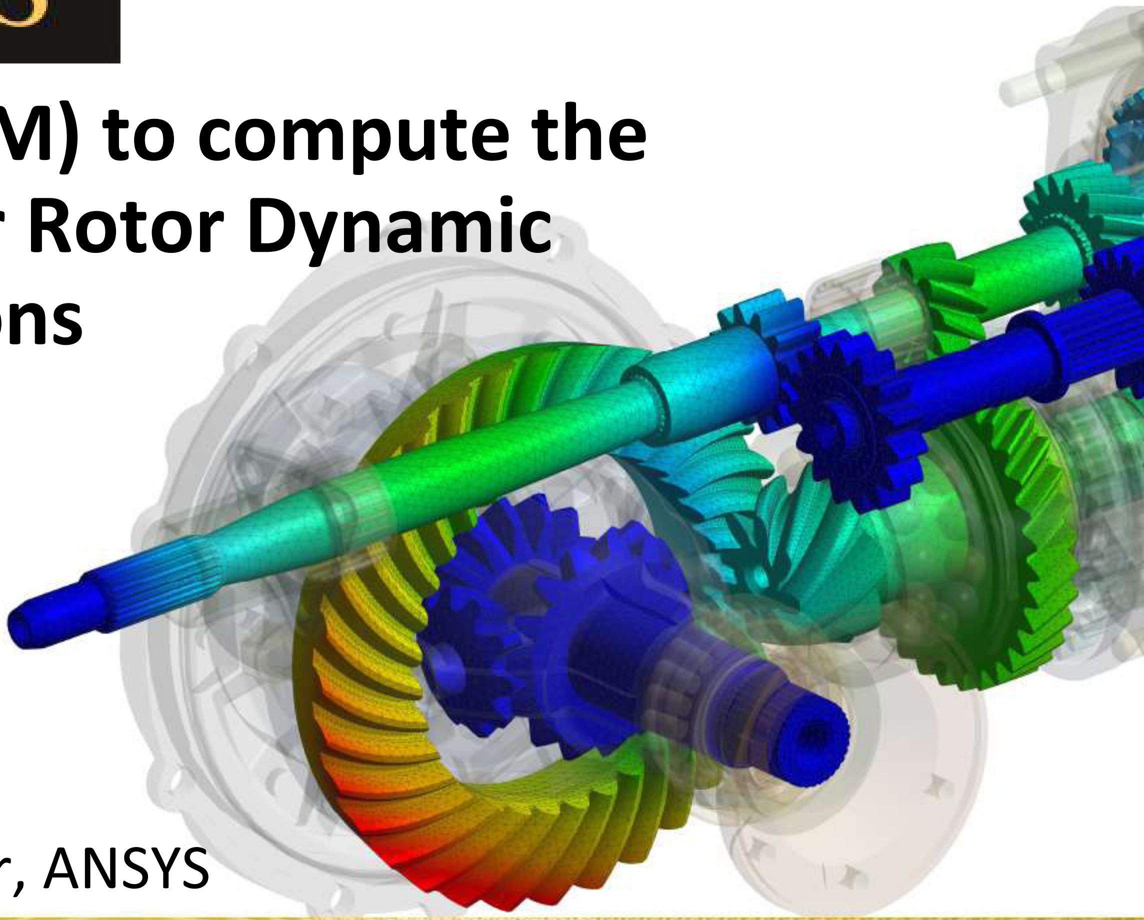
ANSYS

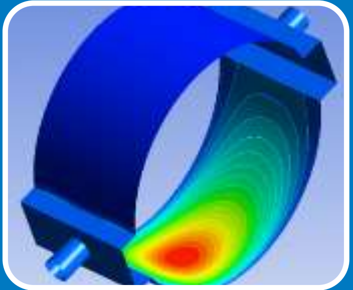
Meta-Model Method (ROM) to compute the Bearing Coefficients for Rotor Dynamic Applications



Johannes Einzinger, ANSYS

Agenda

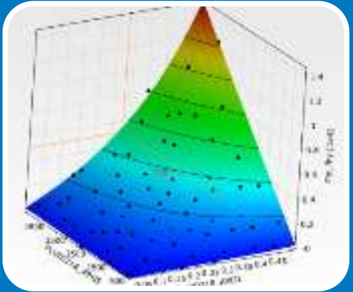
Application Areas of Fluid Film Bearings



Modelling

3D Navier-Stokes (CFD)

Reynolds Equation (Mechanical)

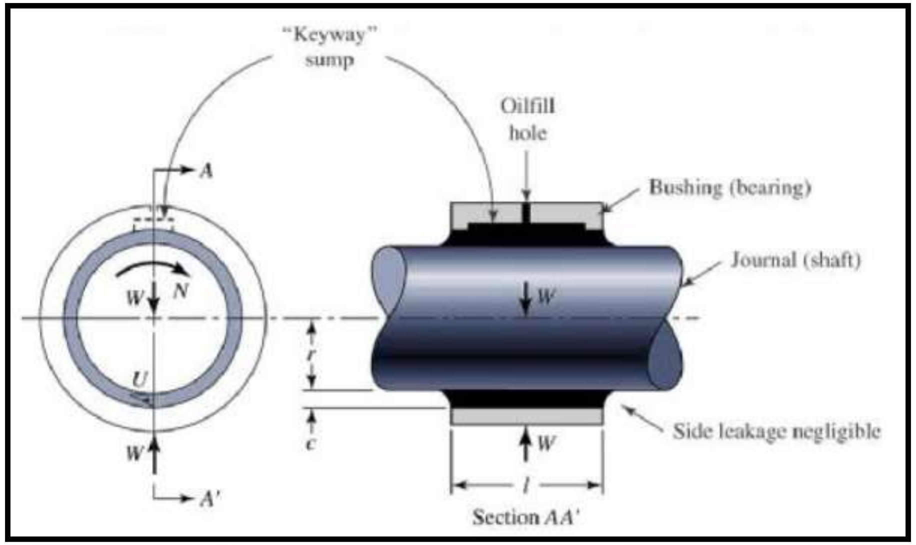


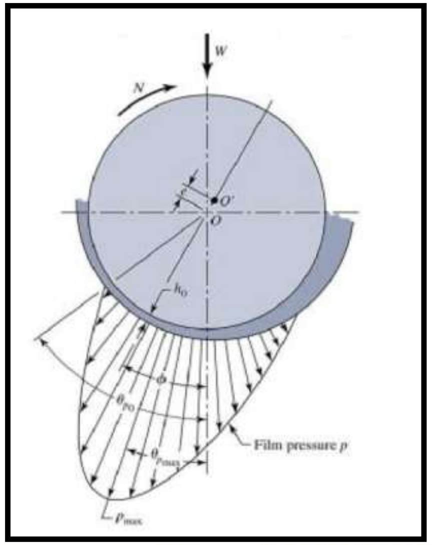
Reduced Order Model

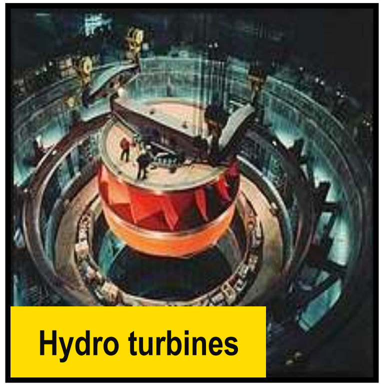
Application Areas of Fluid Film Bearings

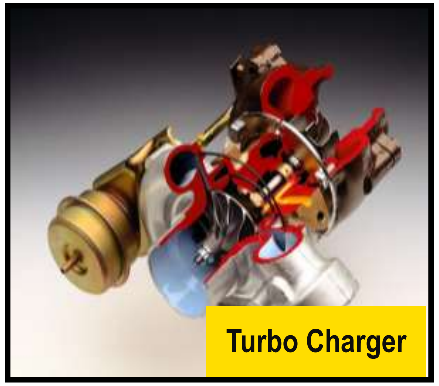
- **Why Fluid Film Bearings?**
  - Simple Construction
  - Good Damping Characteristics
  - High Load and Speed
  - High Precision Applications

- **Critical to Machines overall Reliability!!**

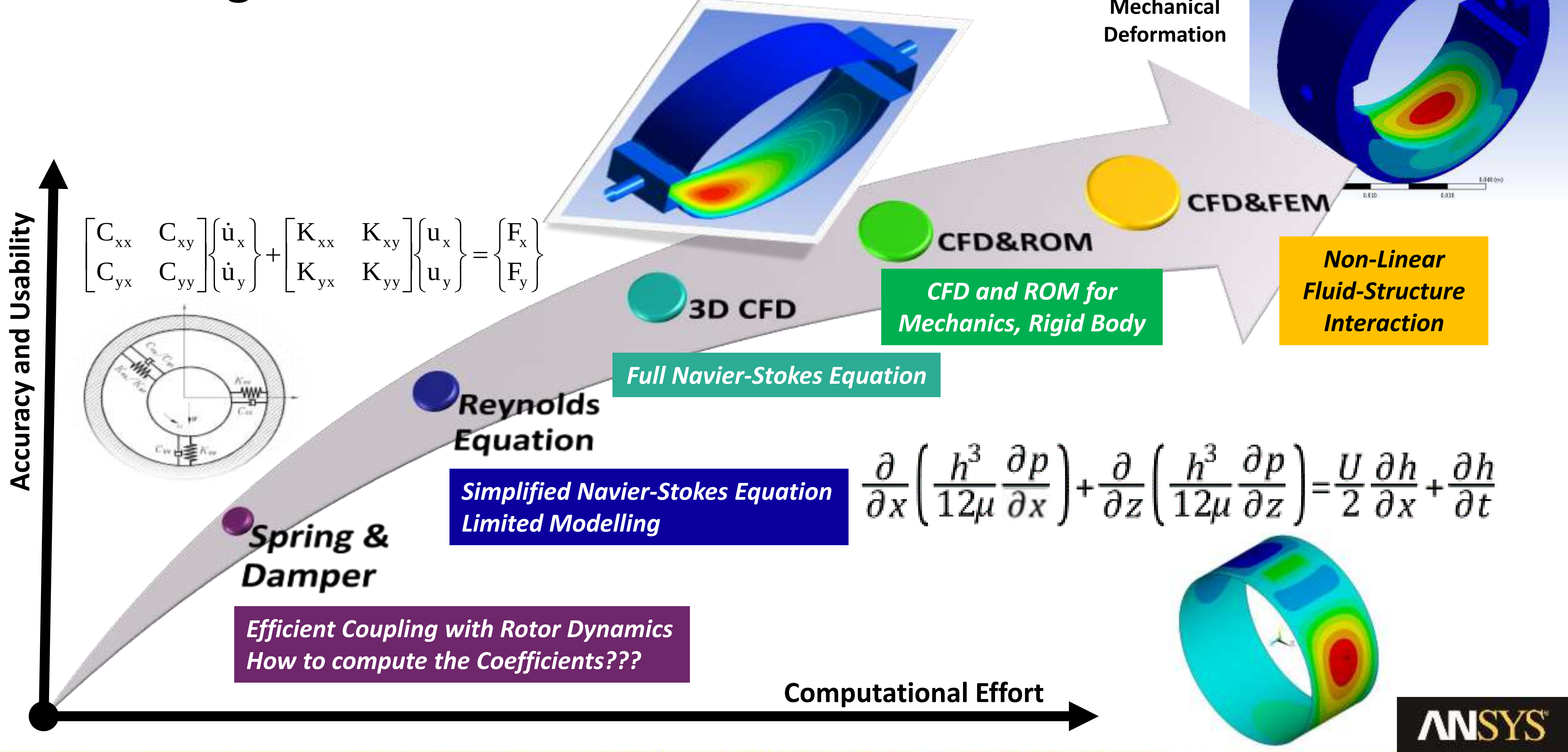








Modelling – Overview



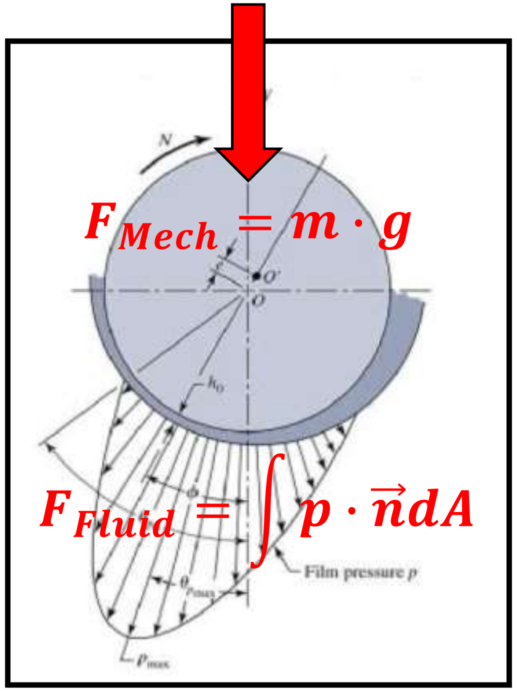
Simulation Procedure

- **Stiffness and Damping is wrt to Equilibrium Position:**
- **Calculate Equilibrium Position**
- **Stiffness Coefficient:** $\begin{bmatrix} K_{11} & K_{12} \\ K_{21} & K_{22} \end{bmatrix} = \begin{bmatrix} \frac{\partial F_1}{\partial x_1} & \frac{\partial F_1}{\partial x_2} \\ \frac{\partial F_2}{\partial x_1} & \frac{\partial F_2}{\partial x_2} \end{bmatrix}$

  Repeat Simulation with varied Position → $K = \frac{\Delta F}{\Delta x}$

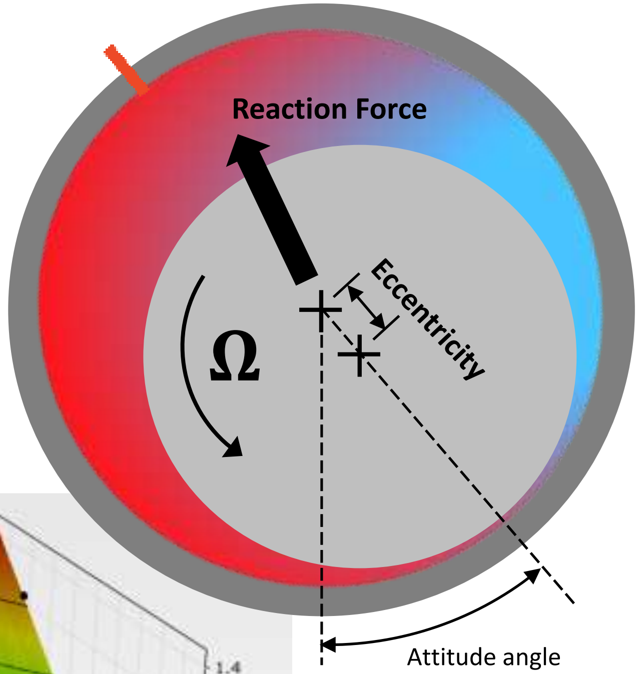
- **Damping Coefficient:** $\begin{bmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \end{bmatrix} = \begin{bmatrix} \frac{\partial F_1}{\partial \dot{x}_1} & \frac{\partial F_1}{\partial \dot{x}_2} \\ \frac{\partial F_2}{\partial \dot{x}_1} & \frac{\partial F_2}{\partial \dot{x}_2} \end{bmatrix}$

  Repeat Simulation with varied Velocity → $C = \frac{\Delta F}{\Delta \dot{x}}$

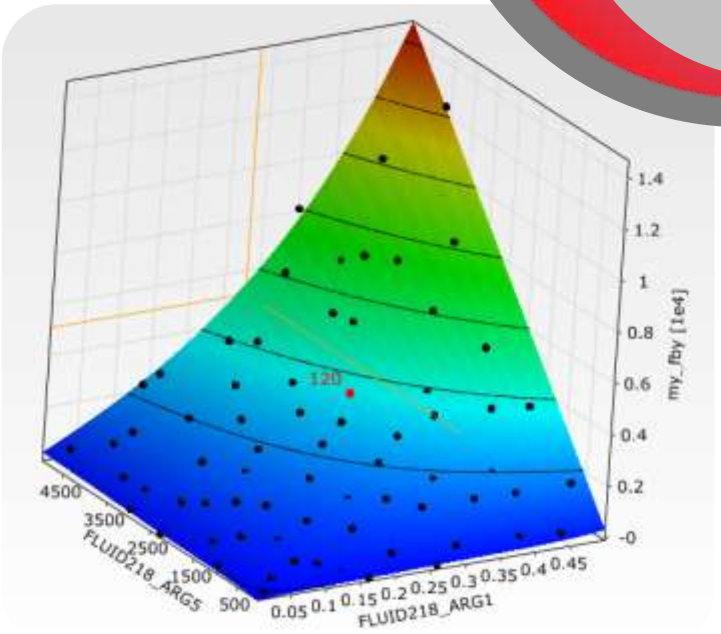


2-Way-Coupled Fluid-Structure Interaction!
High Computational Effort!

Reduced Order Model (ROM) Approach



- **Design of Experiments**
  - **Variation of Eccentricity, Attitude Angle, …**
  - **Measure Reaction Force**
- **Response Surface is calculated (=ROM)**
  - **Reaction Force** ***= f(Eccentricity, Attitude Angle, …)***
- **Optimization to find**
  - **Eccentricity, Attitude Angle, …**
  - **For given External Force**
- **Stiffness is Derivative of Response Surface**
- **Damping is calculated at Equilibrium**



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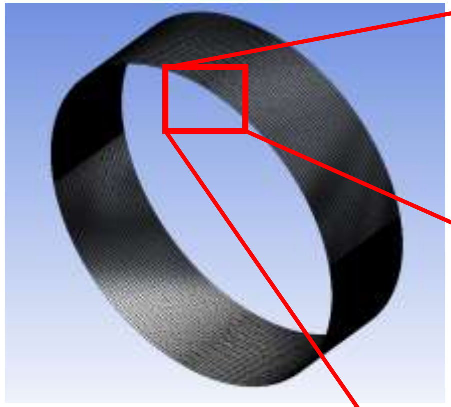
3D Navier-Stokes in CFX

- **3D Resolution & Kinematics**

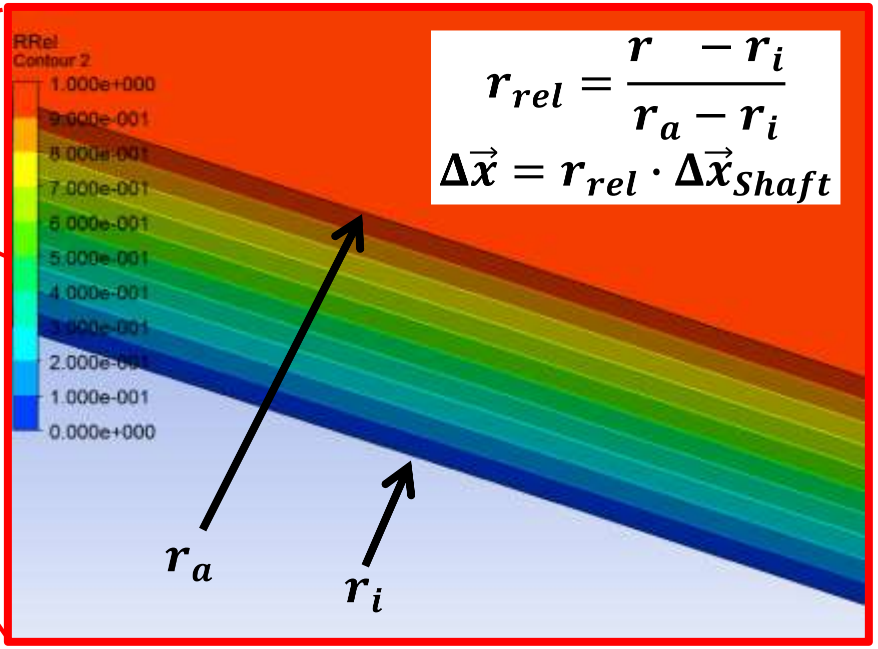
- **Steady Simulation**
- **Re-Meshing for each Position**
- **<u>Mesh Morphing</u>**

- **Transient Simulation**
- **<u>Mesh Morphing</u>**

- **→ Analytical Mesh Morphing**



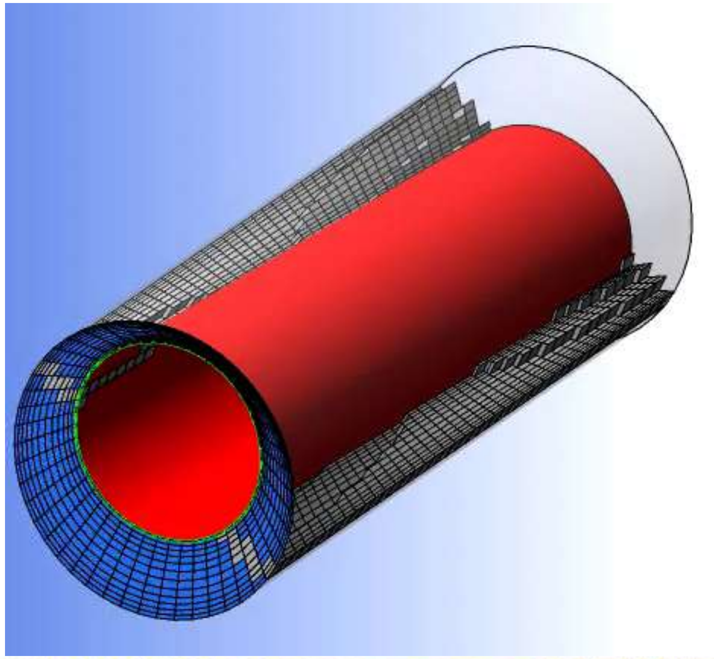
Mesh Displacement in Domain

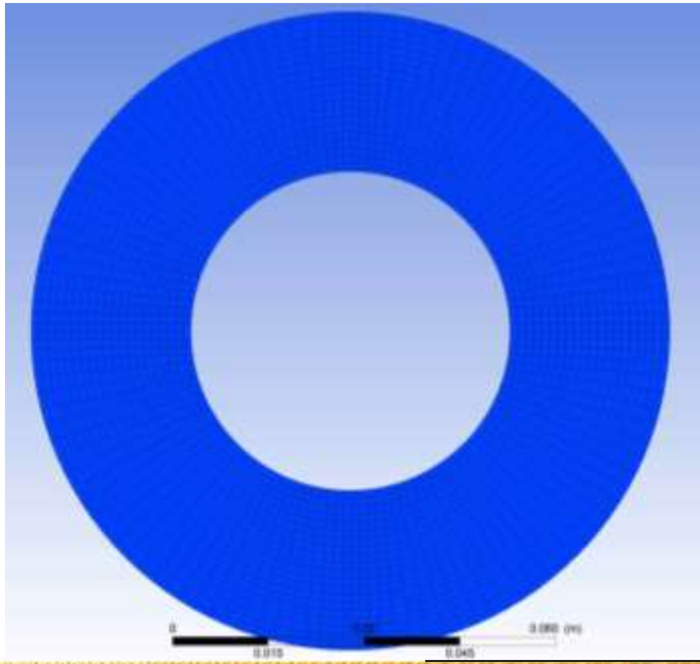


$$r_{rel} = \frac{r - r_i}{r_a - r_i}$$

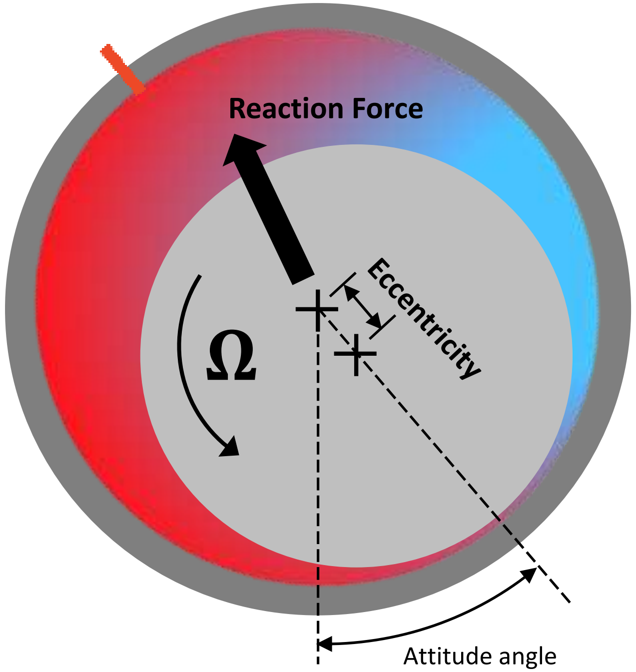
$$\Delta\vec{x} = r_{rel} \cdot \Delta\vec{x}_{Shaft}$$

Outlook:
Analytical Mesh Morphing





Equilibrium

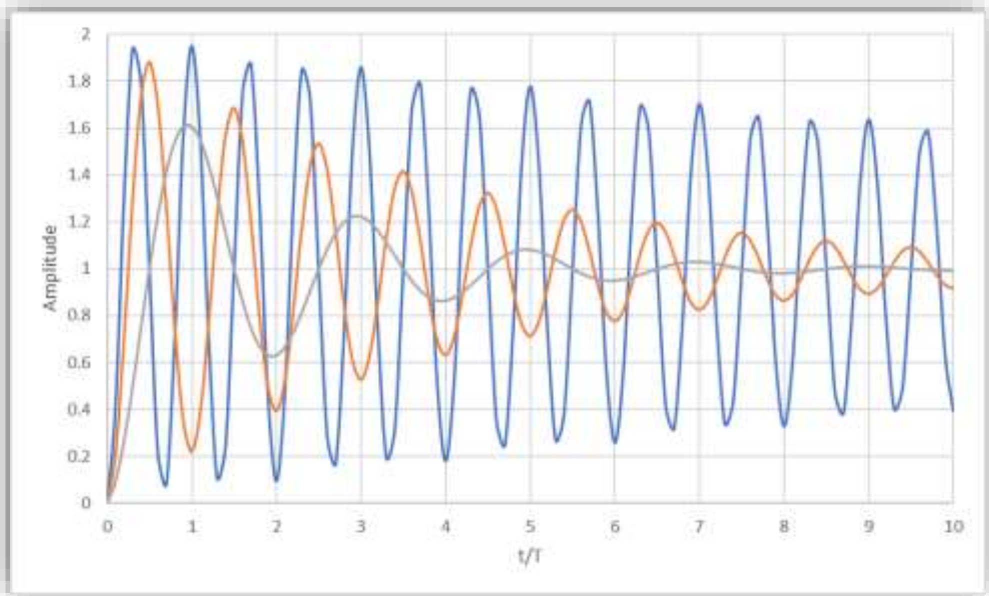


- **Steady State: Design of Experiments**
  - **Variation of Eccentricity, Attitude Angle, …**
  - **Measure Reaction Force**
  - **Get Equilibrium from Response Surface**

- **2-Way-Coupled FSI with Rigid Body**
  - **Rigid Body Dynamics is solved in CFX!**

$$m \cdot \ddot{x} + \underbrace{d \cdot \dot{x}} = F_{Fluid} - m \cdot g$$

Artificial Damping to avoid overshoots, zero for Equilibrium!

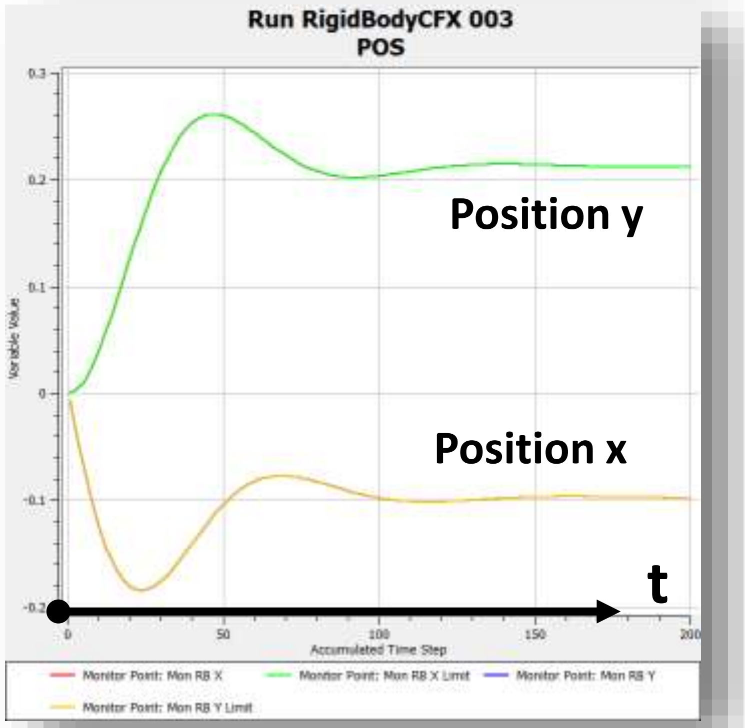


Steady State
Just Fluid Damping
+Artificial Damping

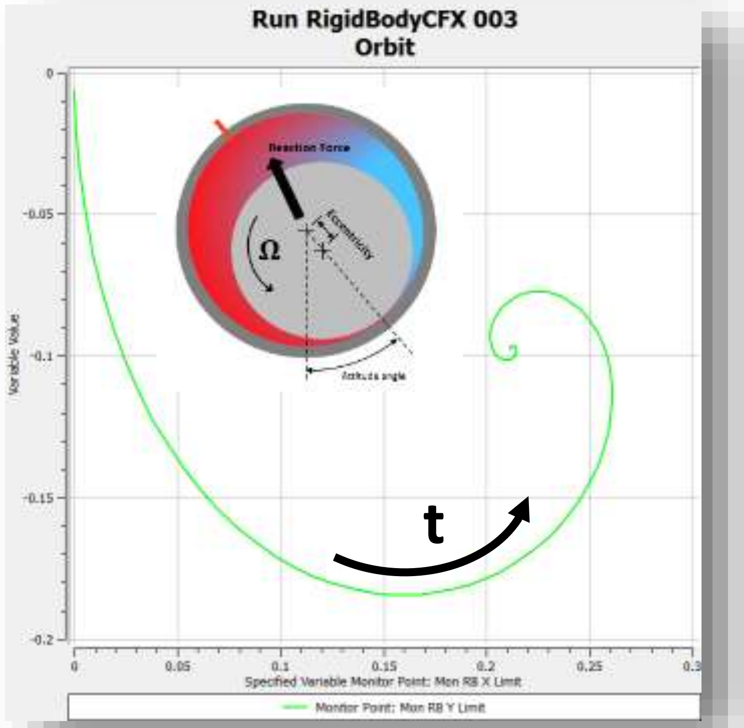
  June 19, 2018

ANSYS

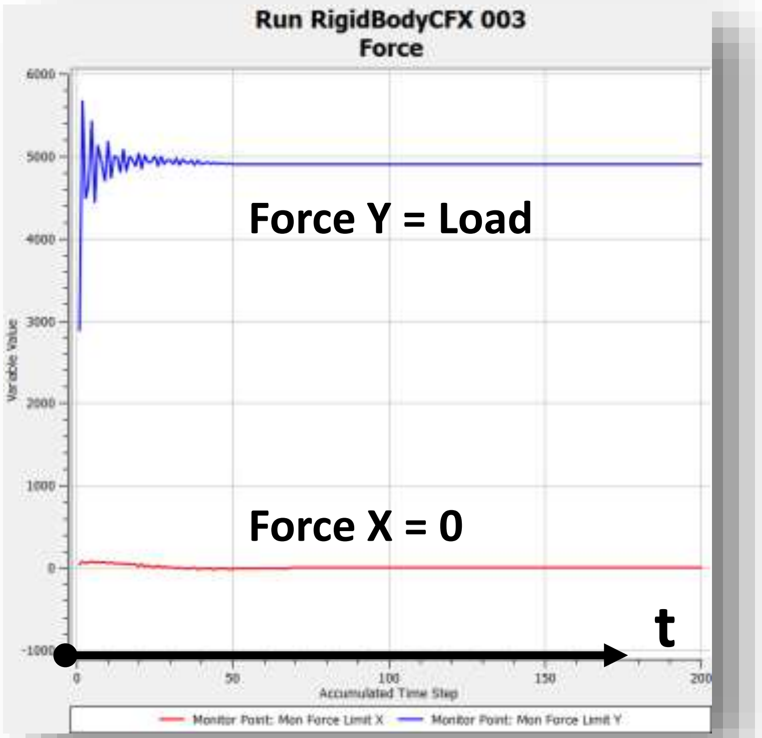
Result: 2-Way-Coupled FSI with Rigid Body



Position, constant for increasing Time
→ Steady equilibrium



Orbit Plot
Position in X-Y Plane



Force, constant for increasing Time
→ Steady equilibrium

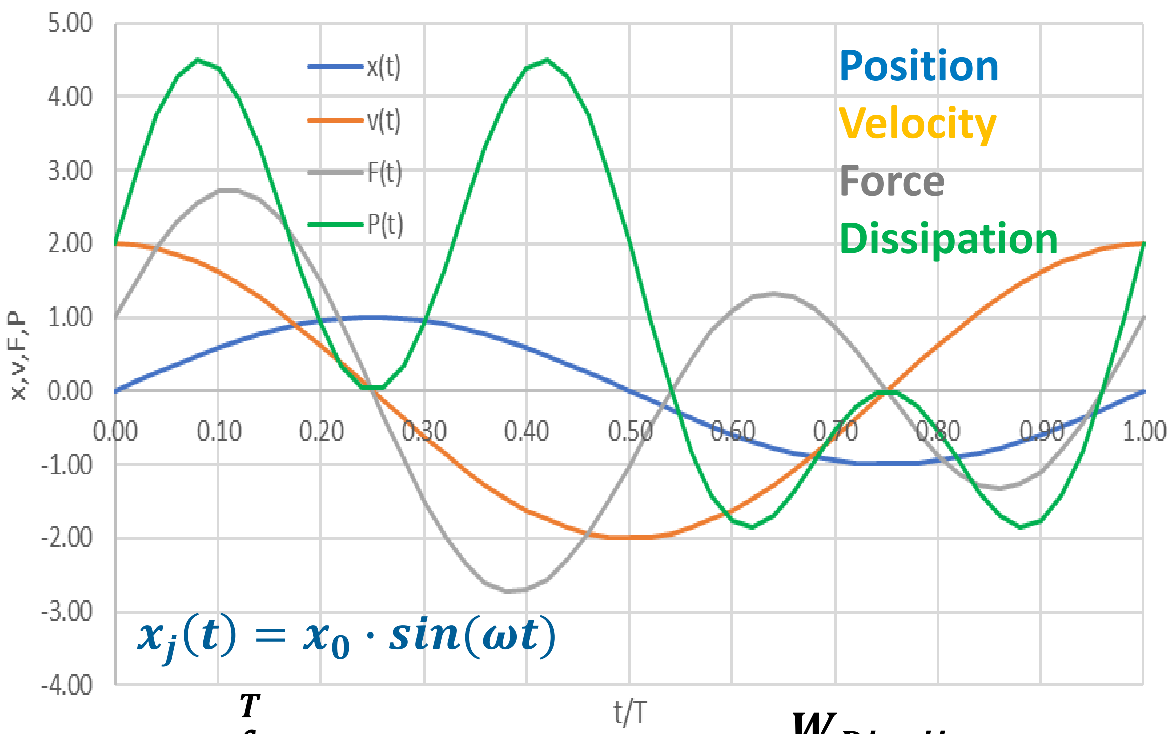
ANSYS

Calculate Stiffness and Damping

- **Calculate Equilibrium Position**
- **Stiffness Coefficient:** $\begin{bmatrix} K_{11} & K_{12} \\ K_{21} & K_{22} \end{bmatrix} = \begin{bmatrix} \frac{\partial F_1}{\partial x_1} & \frac{\partial F_1}{\partial x_2} \\ \frac{\partial F_2}{\partial x_1} & \frac{\partial F_2}{\partial x_2} \end{bmatrix}$

Repeat Steady Simulation with varied Position → $K = \frac{\Delta F}{\Delta x}$

- **Damping Coefficient:**
  - **Transient Simulation with oscillating Shaft (one for x and one for y) until periodic Result**
  - **Dissipation Work: integrate Force x/y and Velocity x/y over one Period**
  - **Normalization → Damping**



$$x_j(t) = x_0 \cdot sin(\omega t)$$

$$W_{Diss,ij} = \int_0^T F_j \cdot \dot{x}_i \cdot dt \qquad C_{ij} = \frac{W_{Diss,ij}}{\omega \cdot x_i^2}$$

Bearing Model – Mechanical

Outline

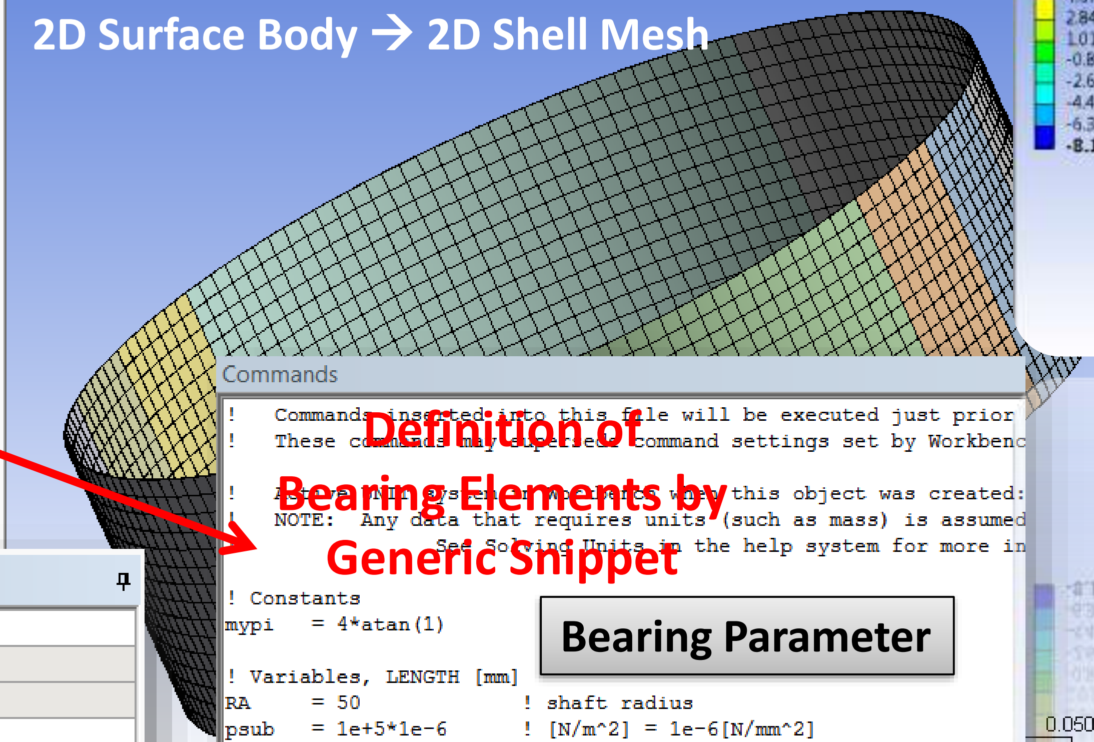
Filter: Name

- Project
  - Model (A4)
    - Geometry
    - Coordinate Systems
    - Connections
    - Mesh
    - Named Selections
    - Static Structural (A5)
      - Analysis Settings
      - FLUID218
      - Solution (A6)
        - Solution Information
        - FORCE
        - OBJECTIVE
        - PRES

Details of "FLUID218"

File		
File Name		
File Status	File not found	
Definition		
Suppressed	No	
Target	Mechanical APDL	
Input Arguments		***Input Parameter:***
ARG1	0.5	***Eccentricity***
ARG2	-90.	***Attitude Angle***
ARG3	0.	***Velocity X***
ARG4	0.	***Velocity Y***
ARG5	4000.	***Speed of Revolution***

2D Surface Body → 2D Shell Mesh

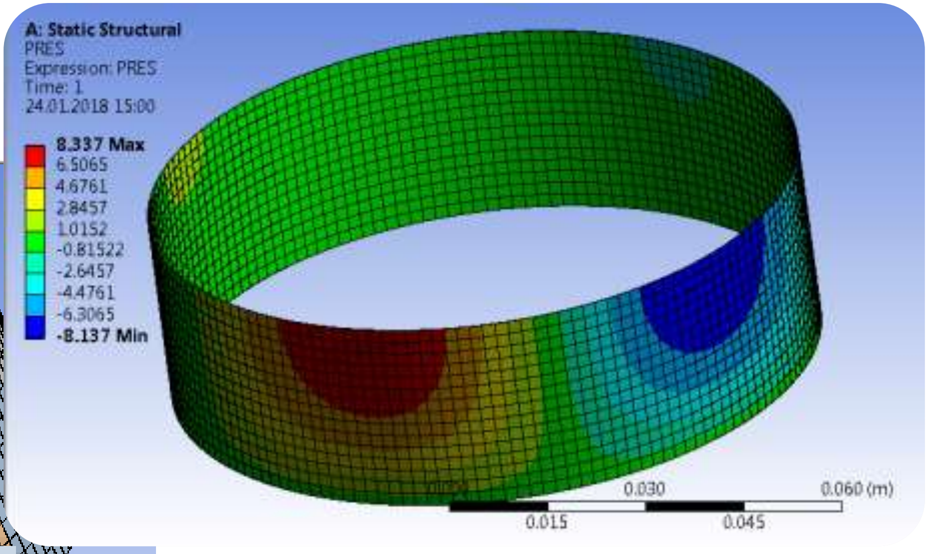


Commands

Definition of Bearing Elements by Generic Snippet

```
!   Commands inserted into this file will be executed just prior
!   These commands may supersede command settings set by Workbenc

!   Active UNIT system in Workbench when this object was created:
!   NOTE:  Any data that requires units (such as mass) is assumed
!          See Solving Units in the help system for more in

! Constants
mypi    = 4*atan(1)

! Variables, LENGTH [mm]
RA      = 50               ! shaft radius
psub    = 1e+5*1e-6        ! [N/m^2] = 1e-6[N/mm^2]
mymu    = 1e-3*1e-6        ! mu=1e-3[Pa s] = 1e-9[MPa s]
mydens  =  900*1e-9        ! dens=900[kg/m^3] = 900*1e-9[kg/mm^3]
my_rpm  = arg5             ! speed of revolution
wshaft  = my_rpm*mypi/30
myext   = 0.01

*afun,rad
Xpos    = arg1*cos(mypi*arg2/180)  ! XX=X/myext
Ypos    = arg1*sin(mypi*arg2/180)  ! YY=Y/myext
Xvel    = arg3*RA*wshaft
Yvel    = arg4*RA*wshaft
! ***************************************************************
```

Bearing Parameter



Output Parameter

Results	
my_fbx	4768.9
my_fby	4935.5
my_So	0.43692
my_SoX	0.3036
my_SoY	0.31421

ANSYS

Calculate Stiffness and Damping

Vary Equilibrium Position with Δx, get Reaction Force and calculate Stiffness:

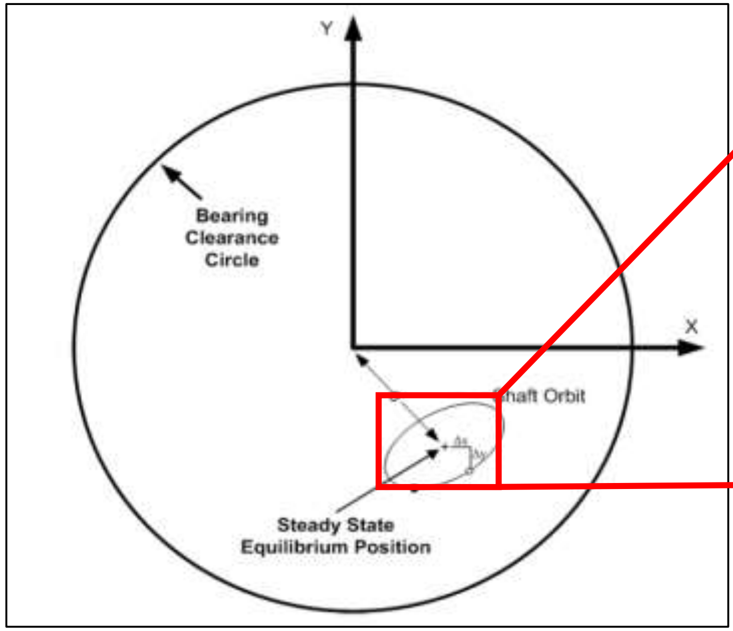
$$K_{ij} = \frac{F_j(x_{eq} \pm \Delta x_j) - F_{j,eq}}{\Delta x_i}$$

$$\frac{\partial}{\partial x}\left(\frac{h^3}{12\mu}\frac{\partial p}{\partial x}\right)+\frac{\partial}{\partial z}\left(\frac{h^3}{12\mu}\frac{\partial p}{\partial z}\right)=\frac{U}{2}\frac{\partial h}{\partial x}+\frac{\partial h}{\partial t}$$

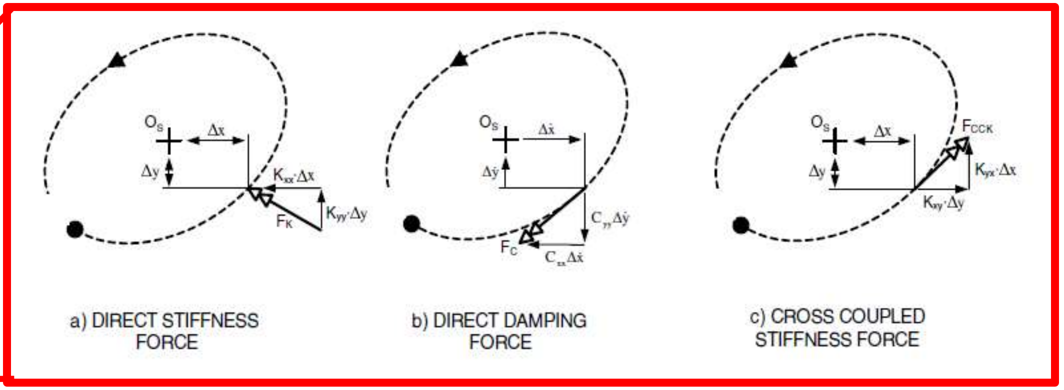
Shaft Velocity can be applied in steady State Simulation!
Calculate Reaction Force and Damping

$$\frac{\partial h}{\partial t} \sim \Delta\dot{x}_i$$

$$C_{ij} = \frac{F_j(x_{eq}, \Delta\dot{x}_j) - F_{j,eq}}{\Delta\dot{x}_i}$$

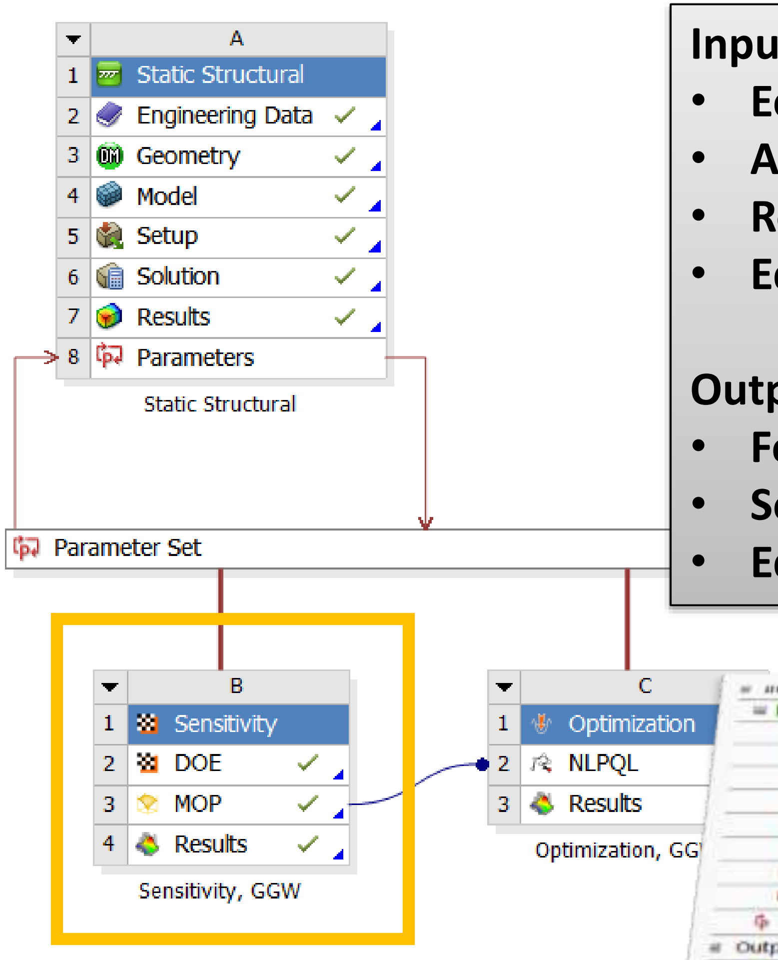


Equilibrium Position



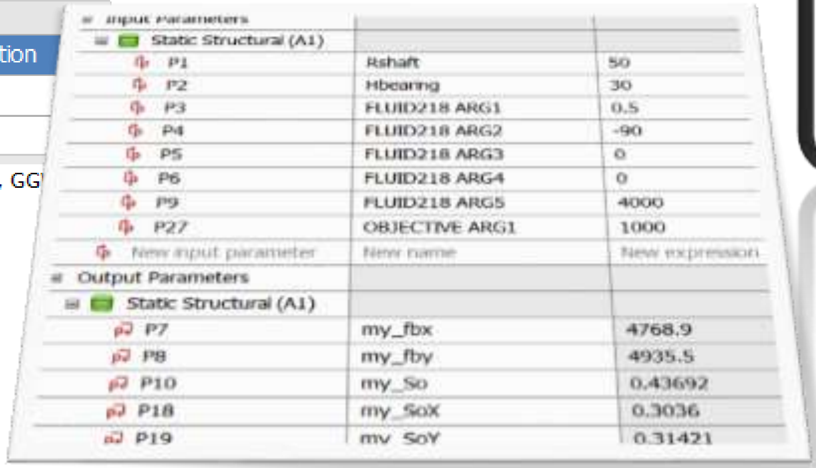
Perturbation and Induced Forces

Reduced Order Model / Response Surface

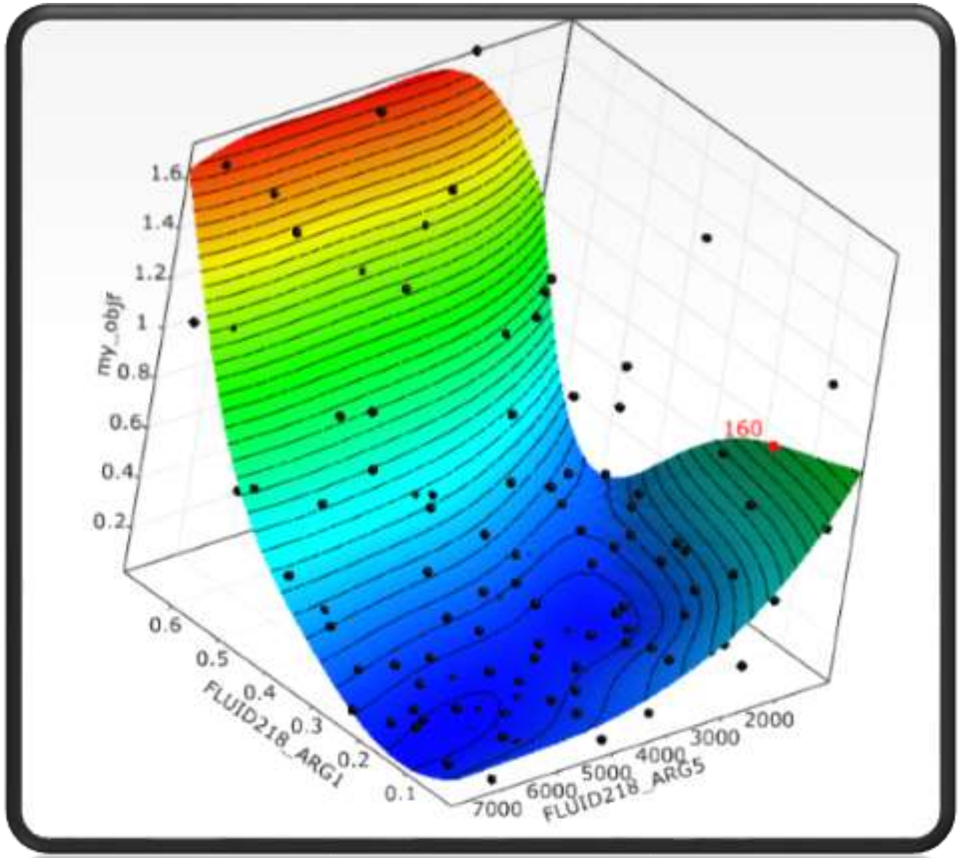


Input:
- **Eccentricity**
- **Attitude Angle**
- **Rotational Speed**
- **Equilibrium Force (see later)**

Output:
- **Force X,Y**
- **Sommerfeld-Number**
- **Equilibrium Objective (see later)**



Input Parameters		
Static Structural (A1)		
P1	Rshaft	50
P2	Hbearing	30
P3	FLUID218 ARG1	0.5
P4	FLUID218 ARG2	-90
P5	FLUID218 ARG3	0
P6	FLUID218 ARG4	0
P9	FLUID218 ARG5	4000
P27	OBJECTIVE ARG1	1000
New input parameter	New name	New expression
Output Parameters		
Static Structural (A1)		
P7	my_fbx	4768.9
P8	my_fby	4935.5
P10	my_So	0.43692
P18	my_SoX	0.3036
P19	my_SoY	0.31421



Reaction Force = *f(Eccentricity, Attitude Angle, …)*

Response Surface = ROM
(Meta-Model of Optimal Prognosis)

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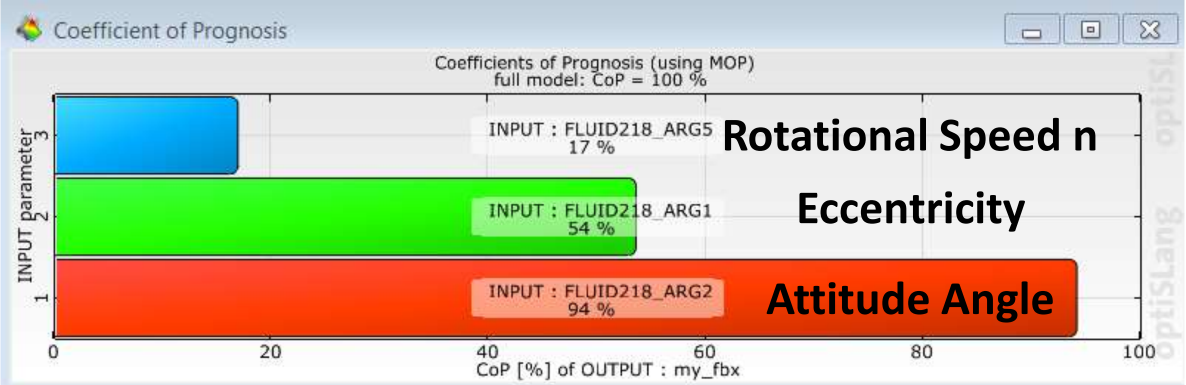
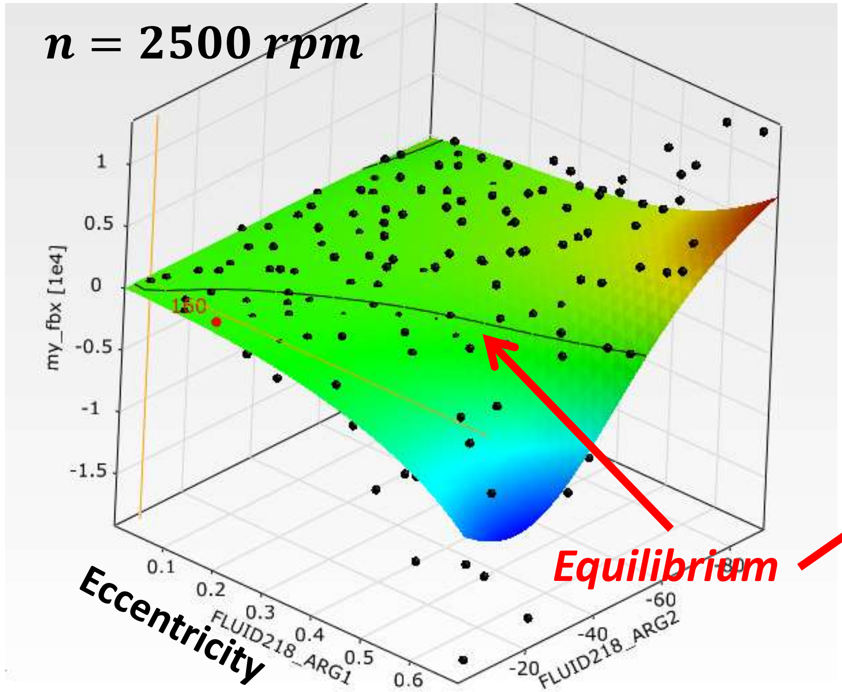
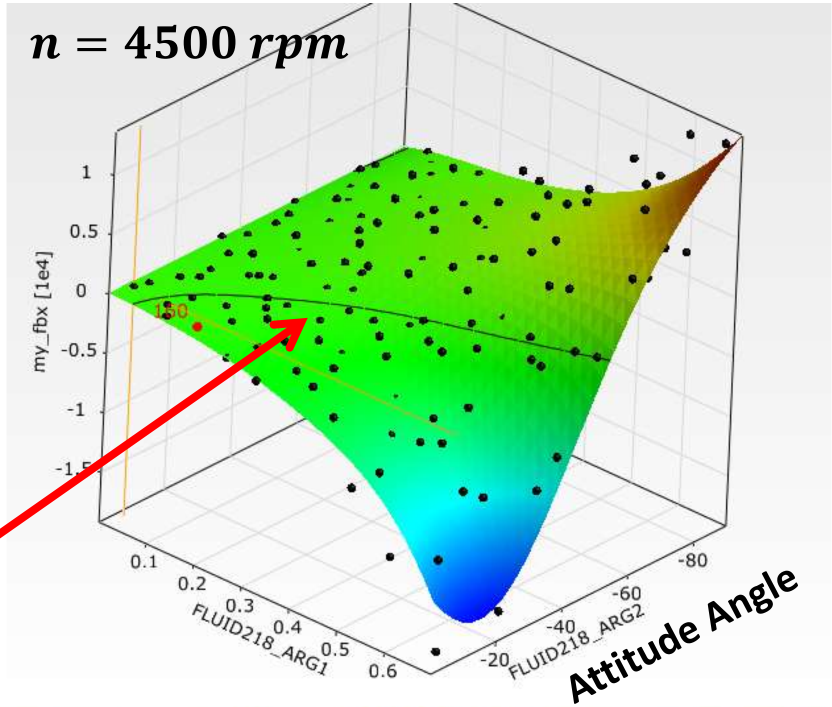
Reaction Forces X



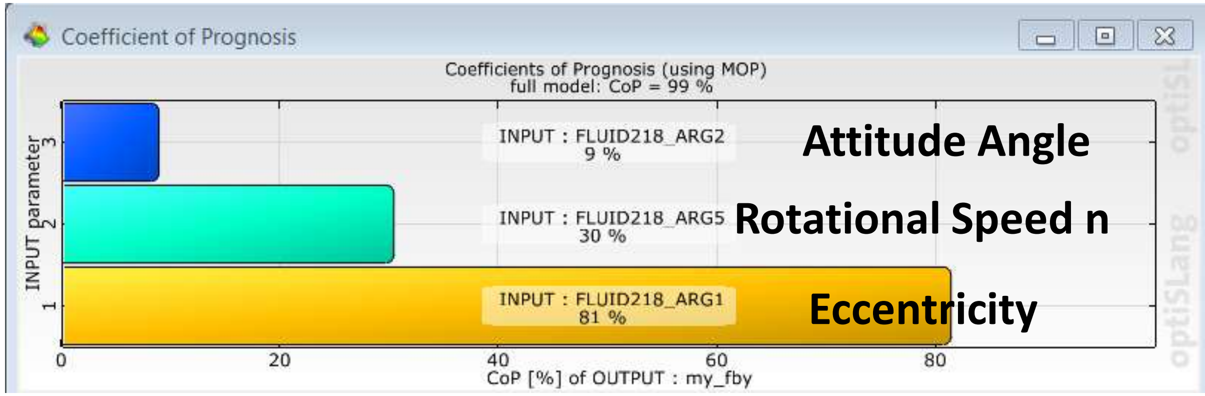
Equilibrium: Reaction Force X=0

Reaction Force X depends on Eccentricity, Attitude Angle and Rotational Speed



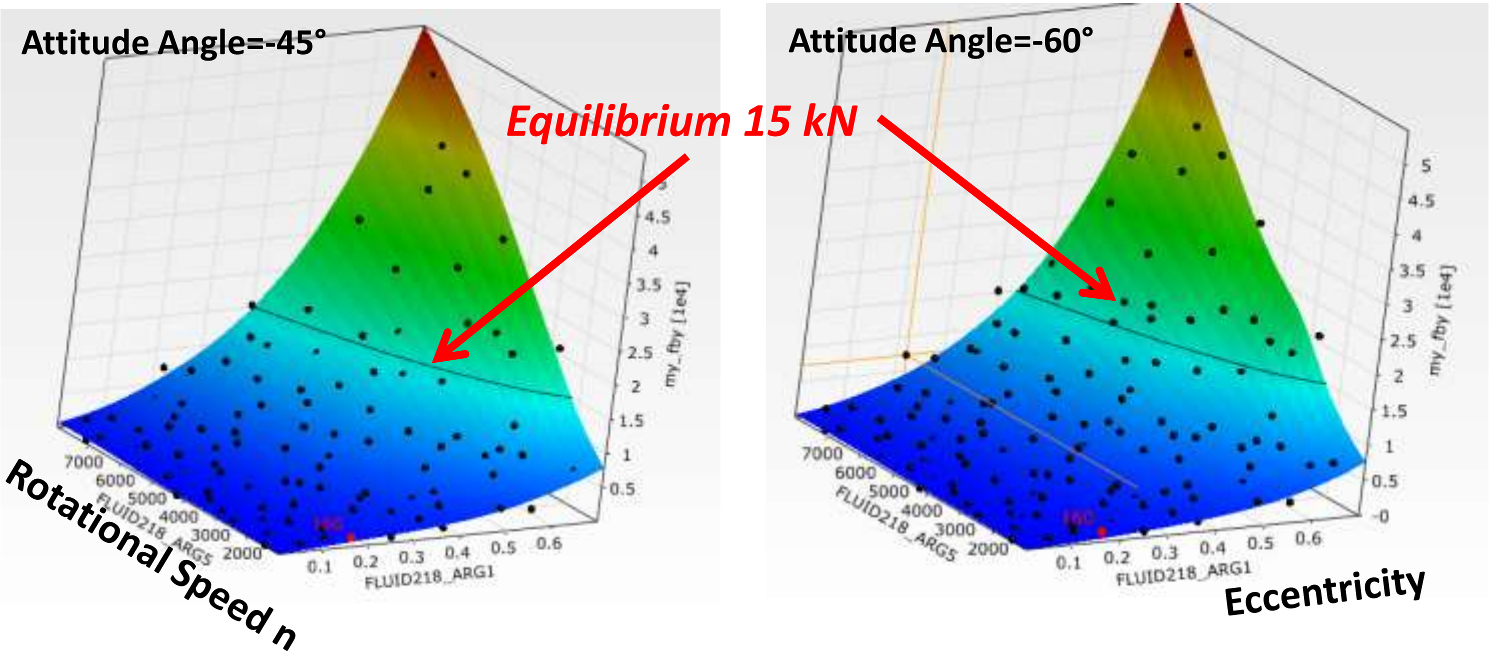


Reaction Force Y



Equilibrium Force = Reaction Force Y

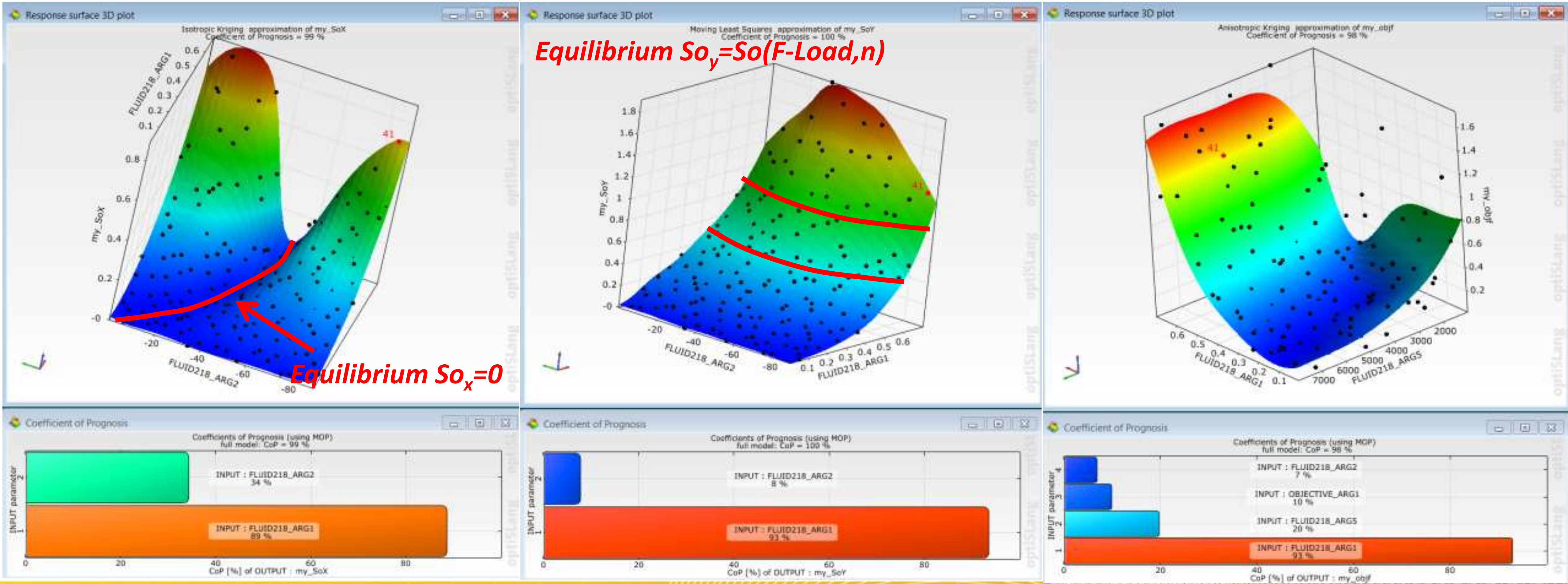
Reaction Force Y depends on Eccentricity, Attitude Angle and Rotational Speed



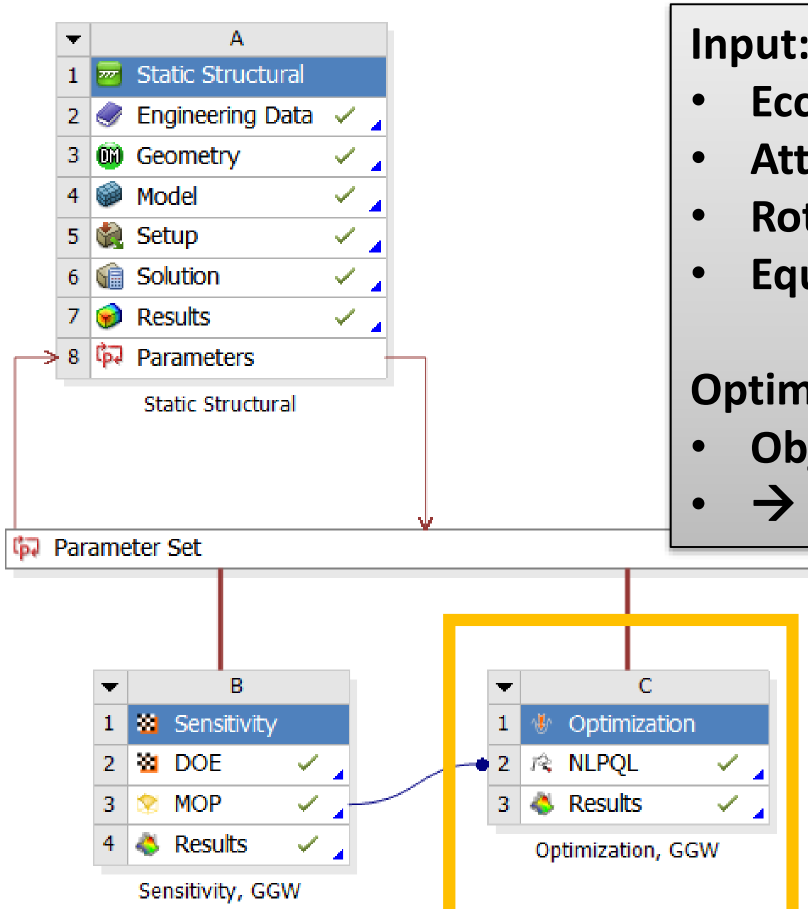
Sommerfeld Number $So = \frac{p_m \cdot \Psi^2}{\eta \cdot \omega} \sim \frac{\boldsymbol{F}}{\boldsymbol{\Omega}}$

Number of relevant Parameter reduced by non-dimensional Analysis
So_x shows Line for all Equilibrium Positions
So_y shows Equilibrium on Axis for non-dimensional Load

$$\boldsymbol{Objective} \sim \frac{1}{\Omega}\sqrt{F_x^2 + \left(F_y - F_{Load}\right)^2}$$



Find Equilibrium Position



Input:
- **Eccentricity = ?**
- **Attitude Angle = ?**
- **Rotational Speed = 5000 rpm**
- **Equilibrium Force = 7000 N**

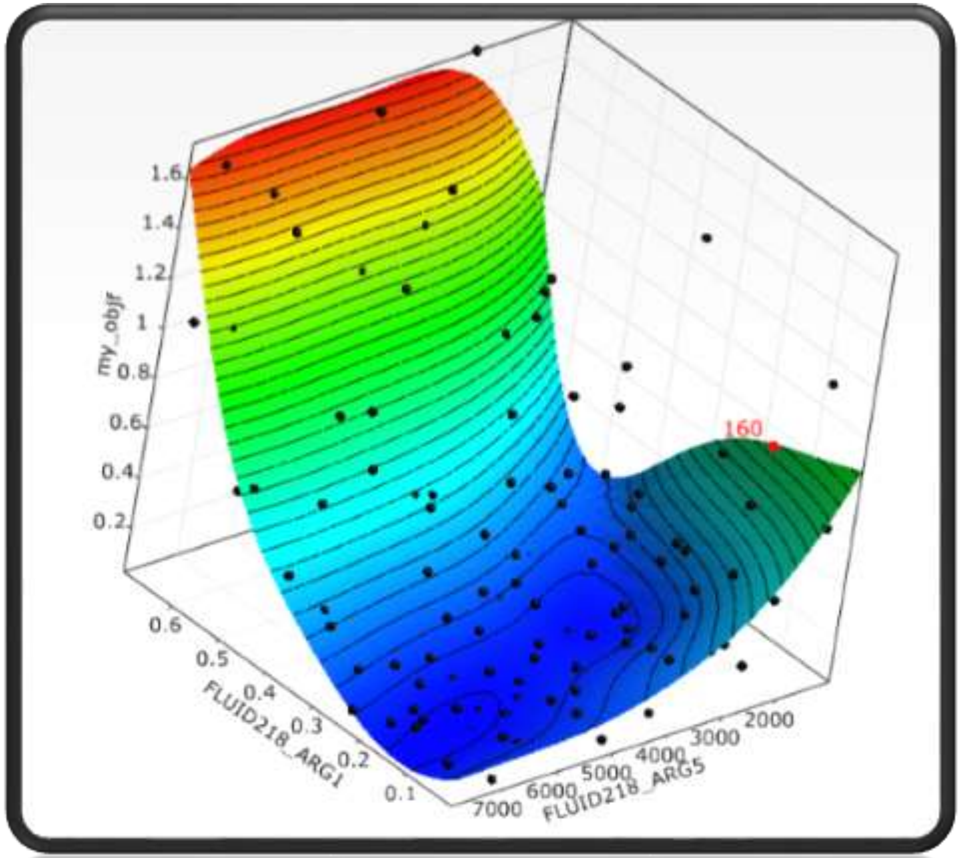
Optimization:
- **Objective → 0**
- **→ Equilibrium**

Optimization on Response Surface → Equilibrium

Optimum/Equilibrium is validated by Simulation!!!

my_objf (calculated)
0.0528057
my_objf (MOP)
0.0626903

Relative Difference
0.5%
CoP = 98%



Reaction Force = *f(Eccentricity, Attitude Angle, …)*

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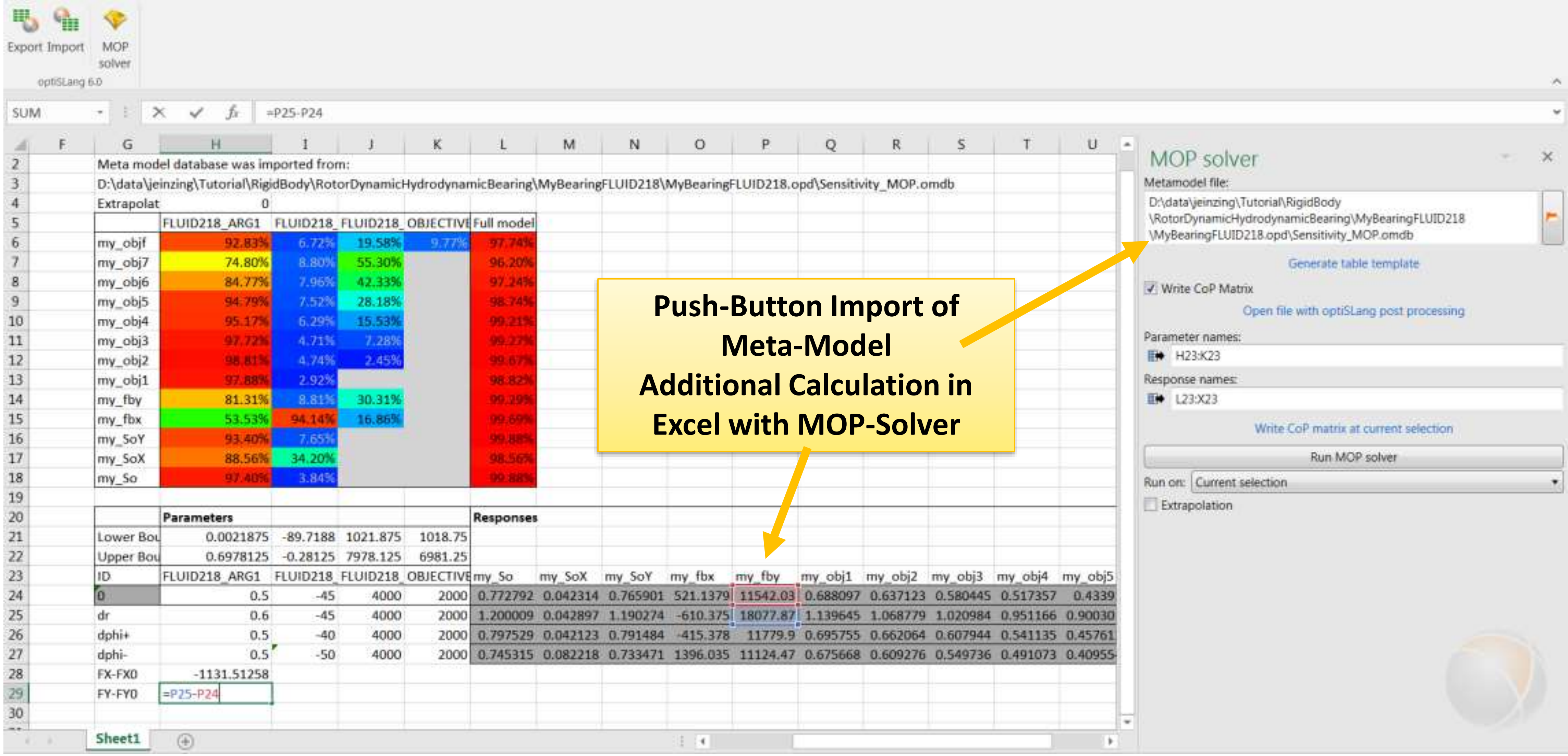
optiSLang Usability



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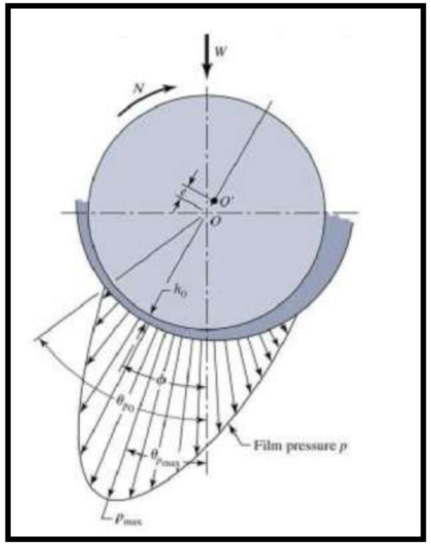
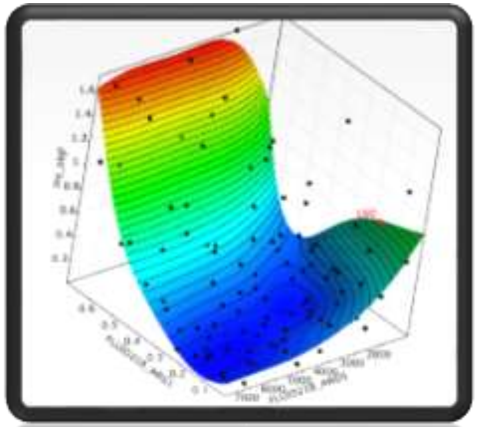
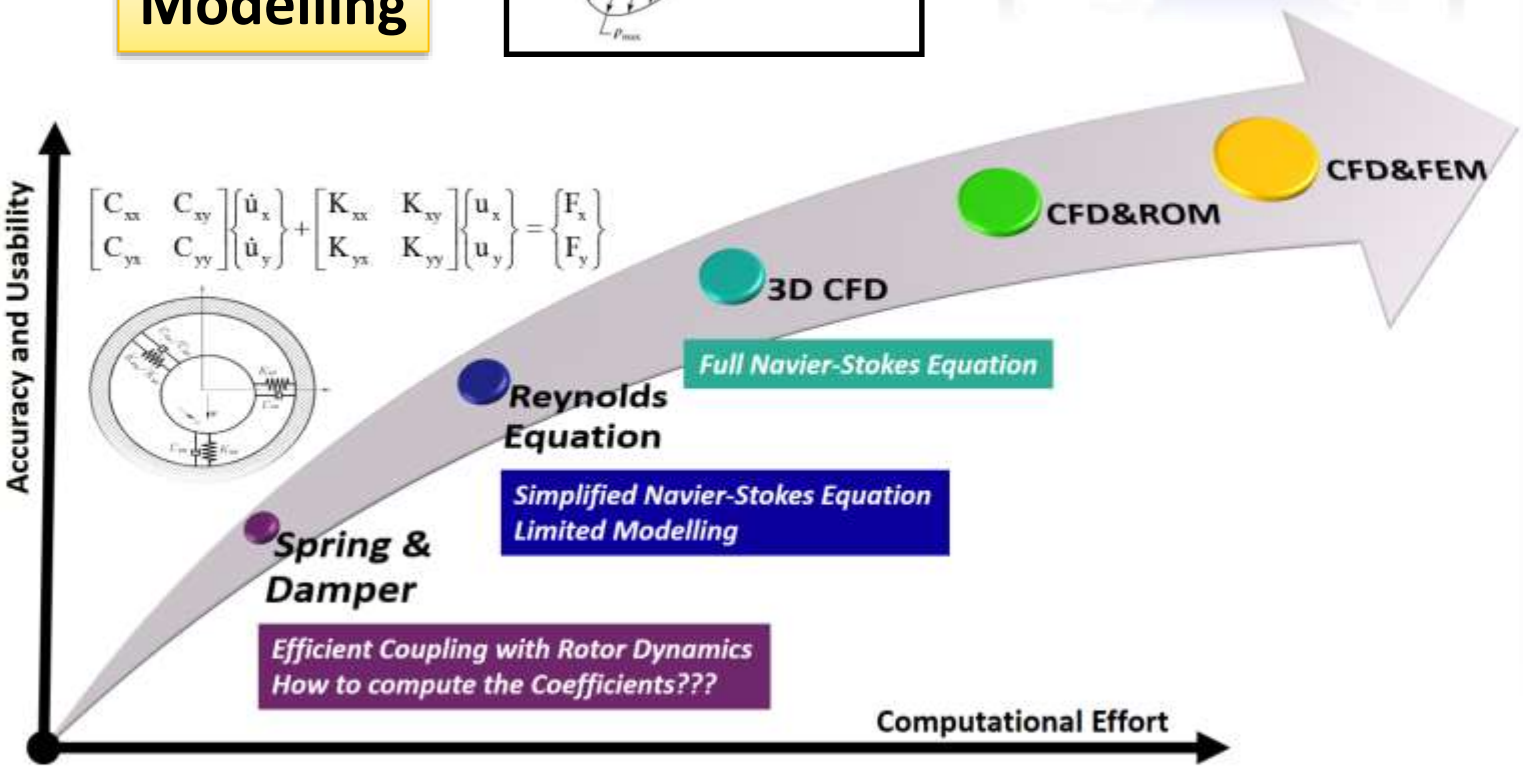
Summary





Calculate Equilibrium: Reduced Order Model is much more efficient than 2-Way FSI !!!

Modelling



$$\begin{bmatrix} C_{xx} & C_{xy} \\ C_{yx} & C_{yy} \end{bmatrix}\begin{Bmatrix} \dot{u}_x \\ \dot{u}_y \end{Bmatrix} + \begin{bmatrix} K_{xx} & K_{xy} \\ K_{yx} & K_{yy} \end{bmatrix}\begin{Bmatrix} u_x \\ u_y \end{Bmatrix} = \begin{Bmatrix} F_x \\ F_y \end{Bmatrix}$$

- **Design of Experiments**
- Variation of Eccentricity, Attitude Angle, …
- Measure Reaction Force

- **Response Surface is calculated (=ROM)**
- Reaction Force = *f(Eccentricity, Attitude Angle, …)*

- **Optimization to find**
- Eccentricity, Attitude Angle, …
- For given External Force

- **Stiffness is Derivative of Response Surface**

- **Damping is calculated at Equilibrium**

ANSYS

