Fan Design Using Multi-Parameters Sampling Process With PERMAS/VISPER

PERMAS Users' Conference

Stuttgart 2018

PROJET FINANCÉ PAR L'ANR - PROJECT FUNDED BY THE ANR

I. Introduction

- Frame of this work - Pepito Project
- Objectives of this work

II. Fan Design based on Robust Parametrization

- Parameters definition on rotor Profiles
- Using VisPER for Complex Geometry Parametrization (Fan design)

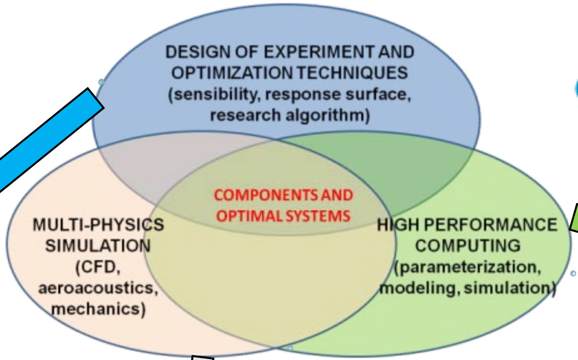
III. Mesh Morphing and Results

IV. Results and Analysis

V. On going Works and Perspectives

I. INTRODUCTION

- Frame of this work : PEPITO Project



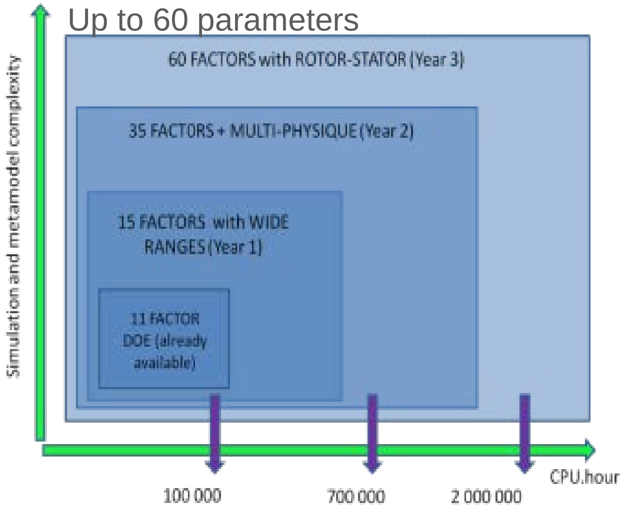
DESIGN OF EXPERIMENT AND OPTIMIZATION TECHNIQUES (sensibility, response surface, research algorithm)

COMPONENTS AND OPTIMAL SYSTEMS

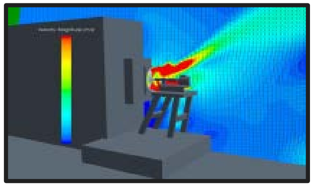
MULTI-PHYSICS SIMULATION (CFD, aeroacoustics, mechanics)

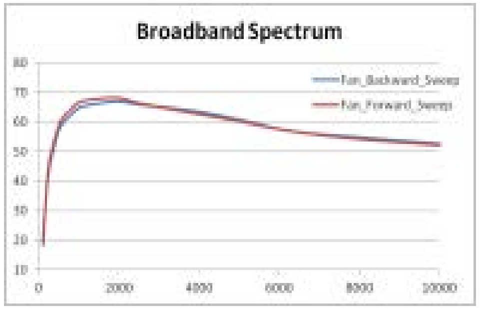
HIGH PERFORMANCE COMPUTING (parameterization, modeling, simulation)

Design of Experiment and Optimization
Up to 60 parameters

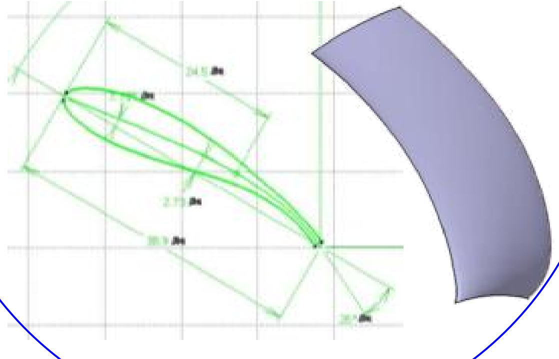


Simulation 1D et 3D - multi physics



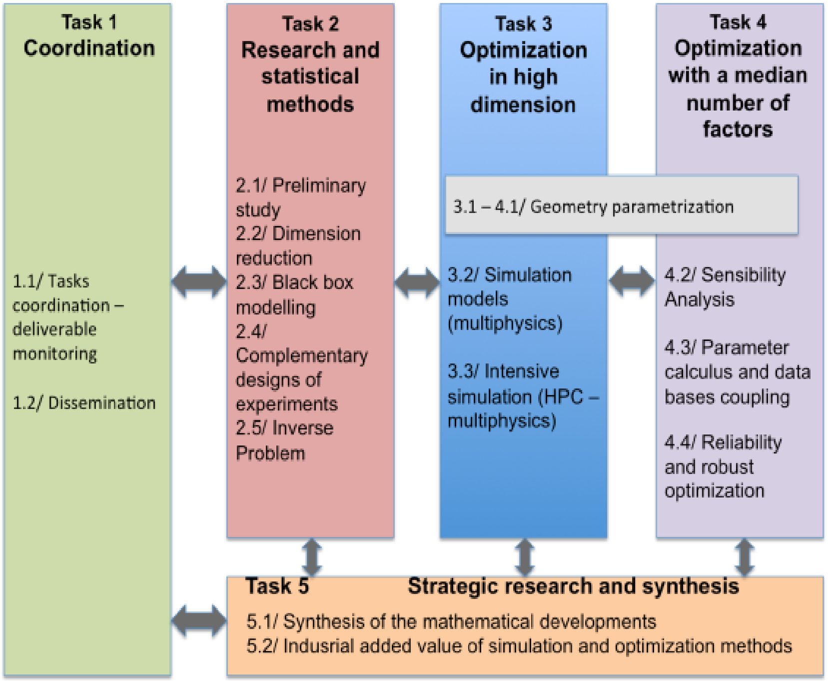


Parametrization, Mesh morphing, sensibility analysis, derivative and optimization



I. INTRODUCTION

- Frame of this work : PEPITO Project Organization
  - Collaborative and multi-disciplinary work based on the experience of diverse consortium's partners
  - The Technical and scientific areas to be covered by the project are :
    - The Data processing and optimization for large dimensions
    - Multiphysics simulation for rotating machines
    - High performance computing



Task 1 Coordination

1.1/ Tasks coordination – deliverable monitoring

1.2/ Dissemination

Task 2 Research and statistical methods

2.1/ Preliminary study
2.2/ Dimension reduction
2.3/ Black box modelling
2.4/ Complementary designs of experiments
2.5/ Inverse Problem

Task 3 Optimization in high dimension

3.1 – 4.1/ Geometry parametrization

3.2/ Simulation models (multiphysics)

3.3/ Intensive simulation (HPC – multiphysics)

Task 4 Optimization with a median number of factors

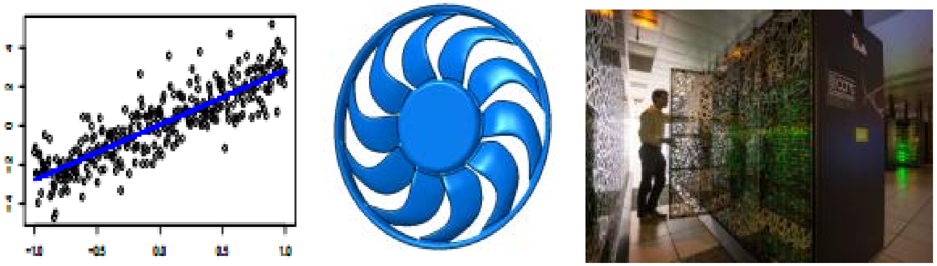
4.2/ Sensibility Analysis

4.3/ Parameter calculus and data bases coupling

4.4/ Reliability and robust optimization

Task 5 **Strategic research and synthesis**

5.1/ Synthesis of the mathematical developments
5.2/ Indusrial added value of simulation and optimization methods



I. INTRODUCTION

- General Purpose of Fan Design and Optimization

  - Experiment with drastic approach using highly parametrized geometries with a large number of parameters (up to 60) and multi-physics (fluid-structure) simulations and optimization to find an optimal design of turbomachinery.

  - Provide more efficient cooling modules, which can save energy thanks to a low impact on the vehicle drag and with a reduced electrical consumption for fan systems.

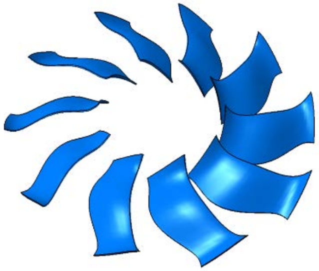
  - Find the best compromise between efficiency, acoustics, mechanical robustness and packaging by using CFD and FEA methodologies to accelerate the simulation turn-over during Design of Experiment (DoE) or iterative optimization loops.

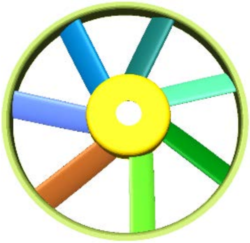
  - To achieve this, geometrical parametrization of fan blades and Mesh Morphing are experimented for a large number of parameters

I. INTRODUCTION

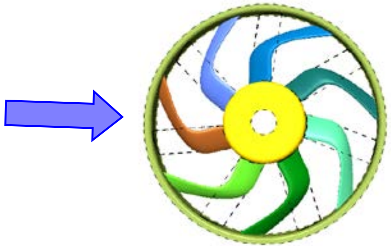
- Objectives of this Work

  - Using geometrical parametrization of fan blades and Mesh Morphing for designing and optimization of complex system (turbomachinery) from a large number of parameters





Undeformed Initial Mesh



Mesh obtained after geometrical parametrization and Morphing

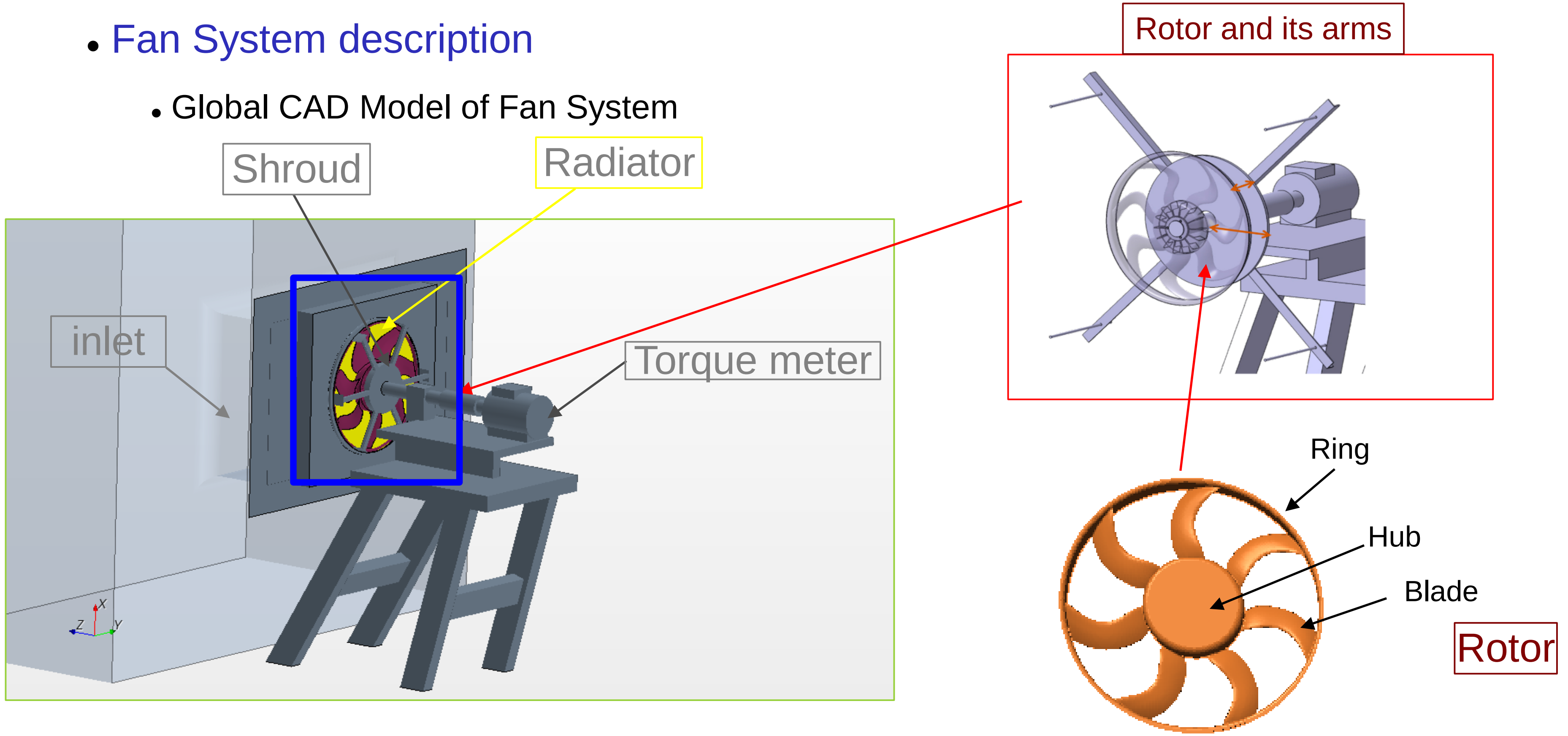
Innovative design: not intuitive, not given by current theory

  - Analyze the validity and the robustness of the obtained rotors by evaluating mechanical characteristics such as the linear static deformation under the effect of centrifugal forces and resulting eigenmodes.

  - Demonstrate the capability of FEA Software **PERMAS/VisPER** for geometric parametrization and mesh morphing combined with mechanical and fluid-structure analysis

II. FAN PARAMETRIZATION

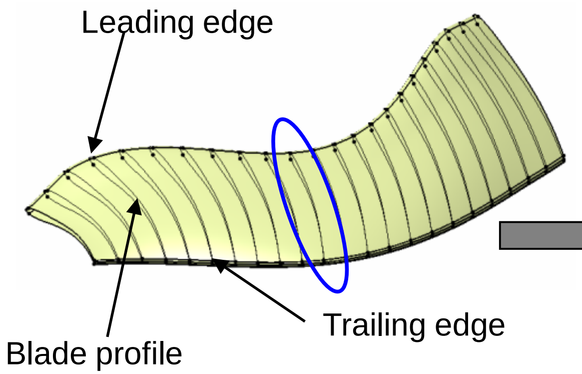
- Fan System description
  - Global CAD Model of Fan System



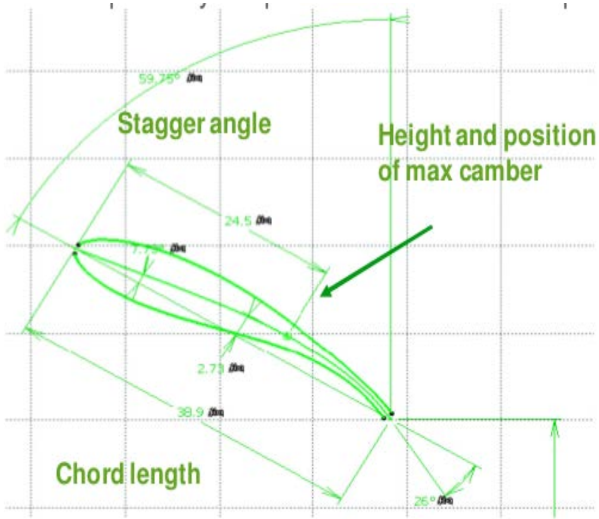
- In the case of this study geometric parameters will only be defined on the rotor part of the fan system

II. FAN PARAMETRIZATION

- Geometric Parameters definition on Rotor for Parametrization
  - Fans systems are particularly well-suited for numerical optimization as multiple geometrical parameters (diameters, chords, camber, profile thickness, etc.) can be used to describe their geometry.
  - To parametrize the rotor characteristics, the blade is subdivided into sections and the geometric parameters are defined on section profiles



Single blade subdivided into equidistant sections from the hub to the ring of the rotor



Isolated profile and some geometric parameters definition

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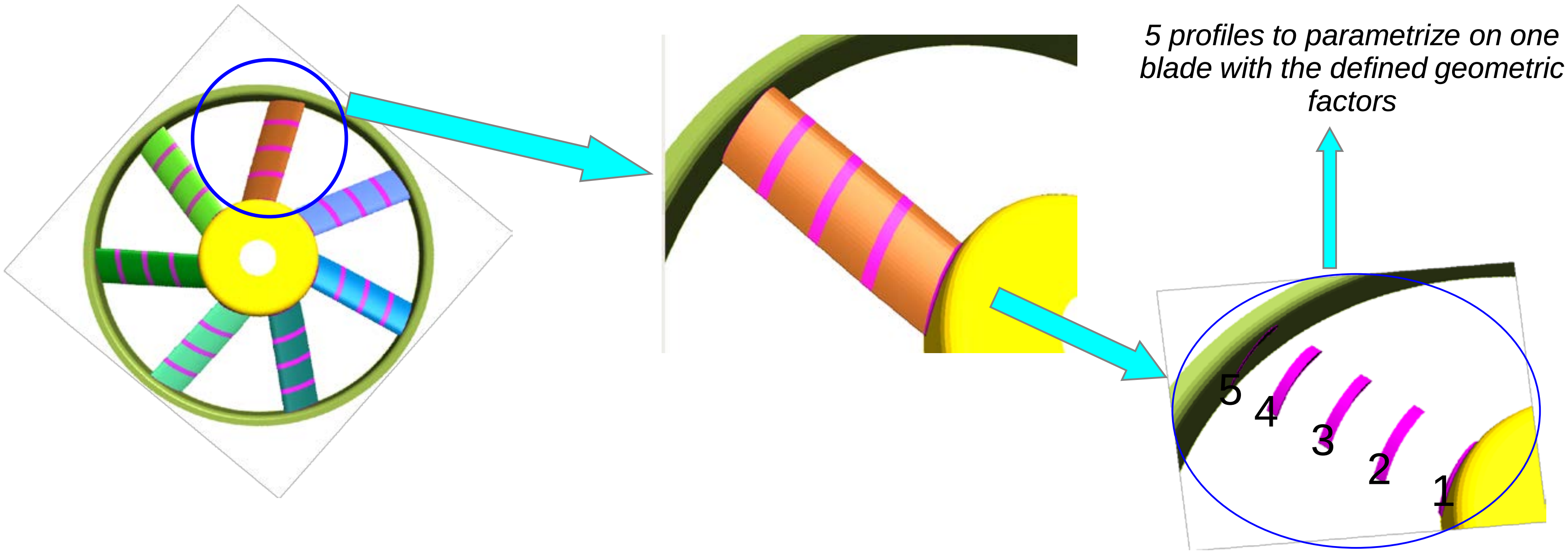
II. FAN PARAMETRIZATION

- Geometric Parameters definition on Rotor for Parametrization
  - To control optimally the shape of the blades, each blade is subdivided into 5 equidistant sections profiles where the geometric factors are defined



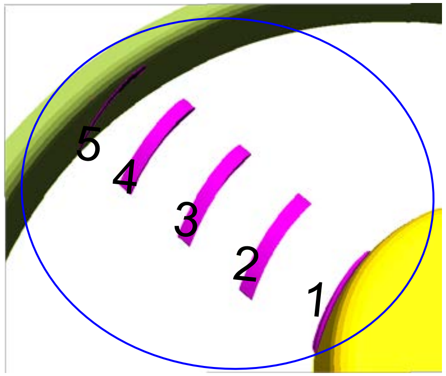
5 profiles to parametrize on one blade with the defined geometric factors

  - Set of geometric parameters out the various profile factors are chosen with specified well known rules provided by our industrial partner

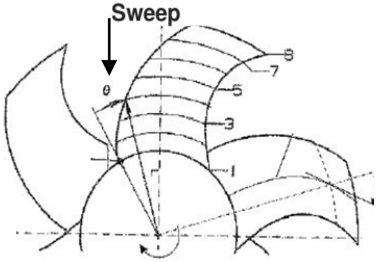
II. FAN PARAMETRIZATION

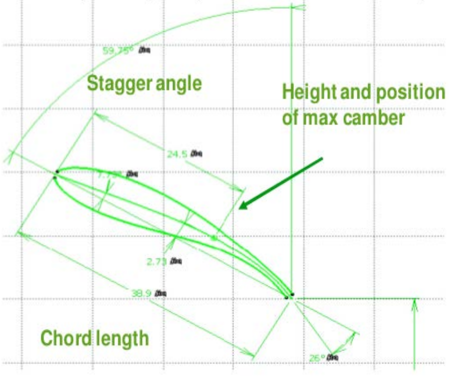
- Geometric Parameters definition on Rotor for Parametrization
    - 12 relevant geometric parameters are defined on the profiles on the profiles of the rotor

Variable Name	Airfoil sections on which variables are parametrized
Chord	R1, R2, R4, R5
Stagger angle	R1, R2, R4, R5
Camber	R1, R2
Sweep Angle	R3, R5



- Each parameter defined on the airfoil profile parametrized by using nodes set that defines it geometrically





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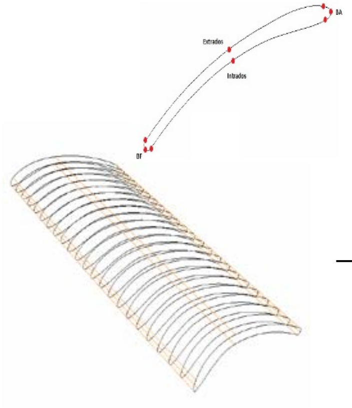
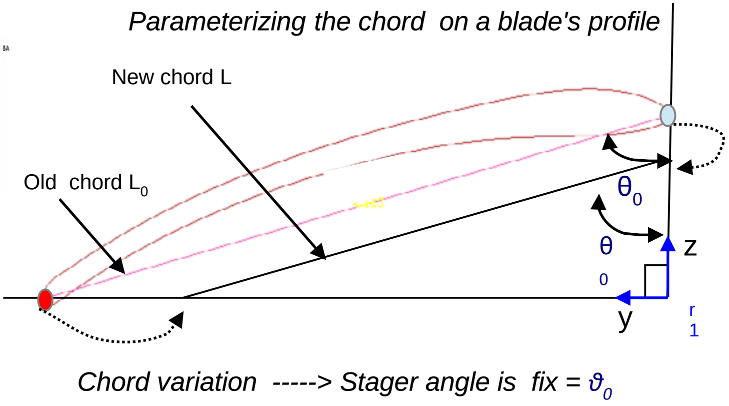
II. FAN PARAMETRIZATION

- Using VisPER to set up the parameters
  - Modeling the geometric factors of the the blade profiles is done by GUI ***VisPER***
    - Steps :
      - Identify and select the set of nodes that define the geometric factor being parametrized
      - Write the mathematical relation between the nodes based on the definition of the parameter
  - Simple example : parameterizing the Chord length based on the profile skeleton

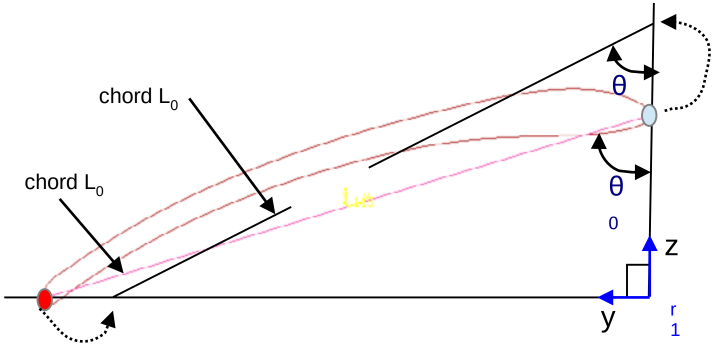


Parameterizing the chord on a blade's profile



Chord variation -----> Stager angle is fix = ϑ_0

Parameterizing stagger angle on a blade's profile



Stagger angle variation -----> chord is fix = L_0

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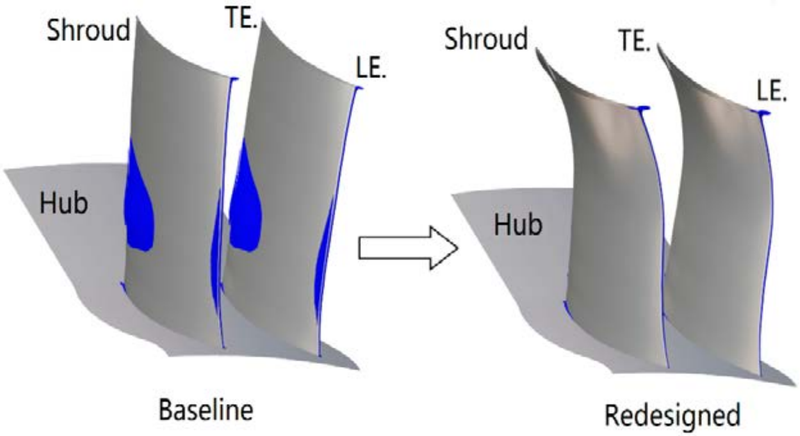
III. MESH MORPHING

- Mesh Morphing set up in PERMAS
  - Mesh Morphing aims to deform the reference initial mesh (undeformed mesh) by propagating the wall shape deformations induced by the parameters variations through the whole mesh

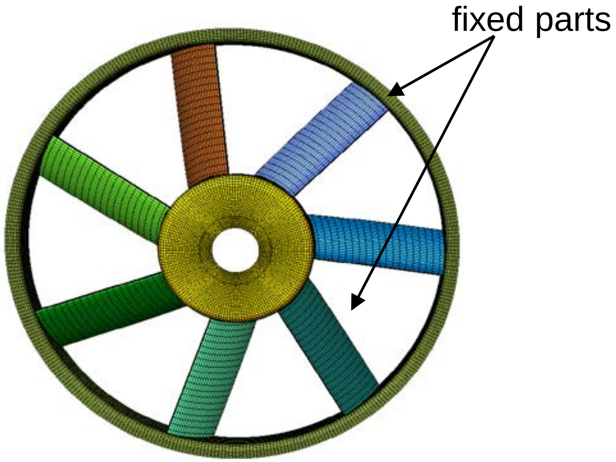


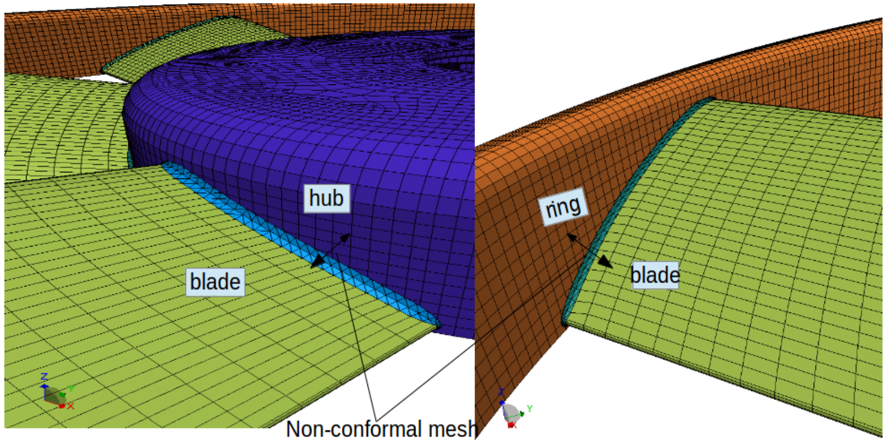
  - The important features of the mesh morphing and geometric parametrization are:
    - It is independent of the structure and the mesh
    - It avoids re-meshing each geometry provided by a set of independent geometrical parameters
    - It achieves a continuous displacement field, which is independent from mesh topology and density, and preserve grid connectivity.

Fan Design Using Multi-Parameters Sampling Process With PERMAS/VisPER

III. MESH MORPHING

- Mesh Morphing set up in PERMAS
  - The novelty of the morphing model in PERMAS software is the capability to allow to isolate non-deformable parts, to preserve geometrical properties between deformable and fixed domains





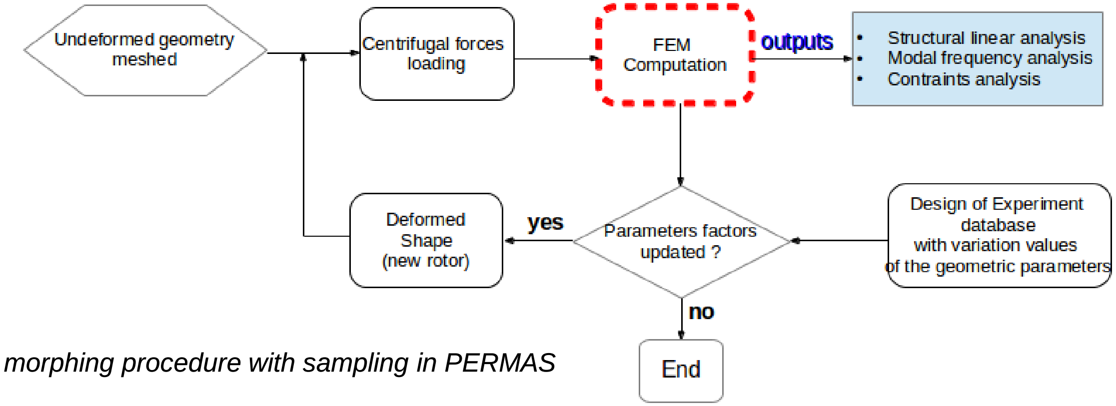
Incompatible meshes between the blades and the hub and the ring

- Mesh Morphing in PERMAS can handle any volumetric type of grids (Hexaedron, tetrahedron, pyramids and incompatible meshes)

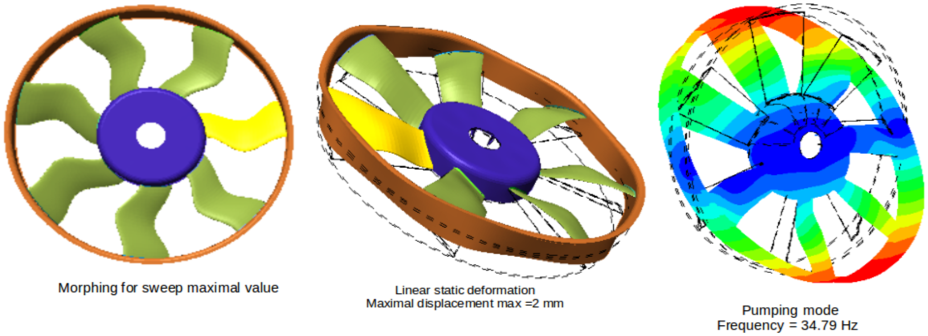
- During the Mesh Morphing processing, PERMAS checks the mesh quality of the obtained deformed

III. MESH MORPHING

- Mesh Morphing set up in PERMAS
  - Mesh Morphing in PERMAS is usable with the UCI solution SAMPLING coupled with structural analysis according to the diagram below



Mesh morphing procedure with sampling in PERMAS



Morphing for sweep maximal value

Linear static deformation
Maximal displacement max =2 mm

Pumping mode
Frequency = 34.79 Hz

Example of Mesh morphing and structural analysis

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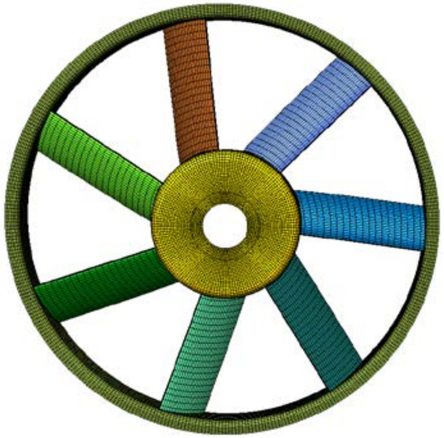
III. MESH MORPHING

- Mesh Morphing application on the Turbomachinery
  - Mesh Morphing starts with an initial reference mesh where the parameters are set



Reference structure Mesh with 87534 cells

- Variations of the geometrical parameters on the blades have been provided through an LHS design of experiment (DoE), with 900 samplings, meaning 900 different forms of rotors

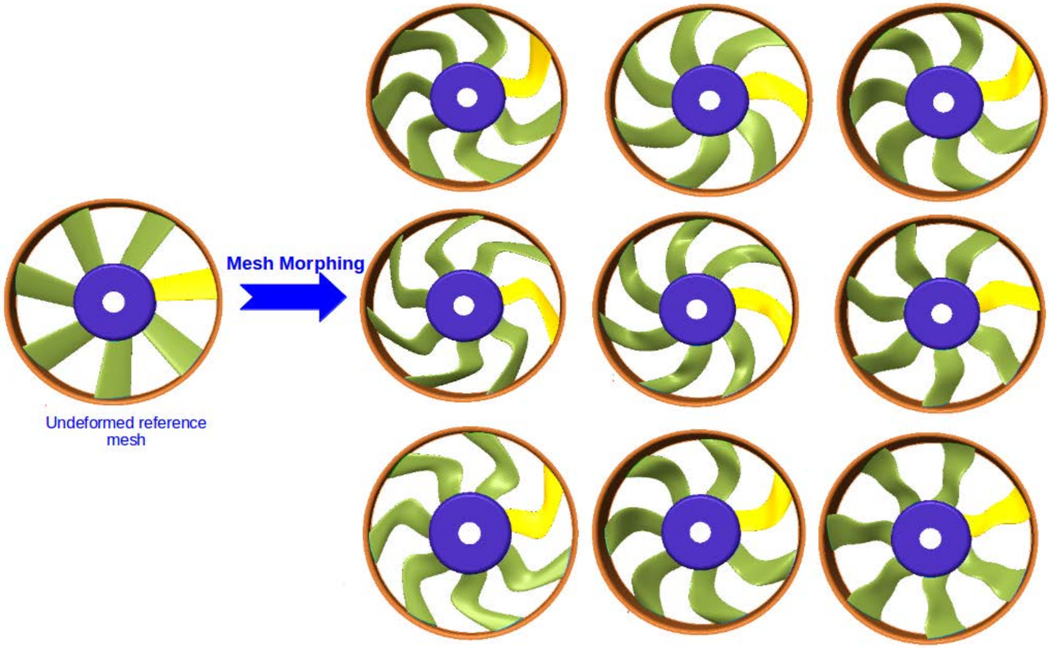
Sweep 3	Sweep 5	Stagger	Chord	Hmax
0.31	0.56	0.08	0.12	-0.65
0.70	-0.18	-0.99	0.78	0.97
-0.97	-0.81	-0.07	-0.59	0.64
-0.16	-0.51	-0.38	-0.22	-0.91

Example of DoE

- The rotor is constituted with 7 blades, and the 12 parameter variables are parametrized on one blade

IV. RESULTS AND ANALYSIS

- Design of Experiment test and Shapes
  - A sampling solver is applied to the 900 samples of the design of experiment.



Nine morphing examples out of the 900 of the DOE database

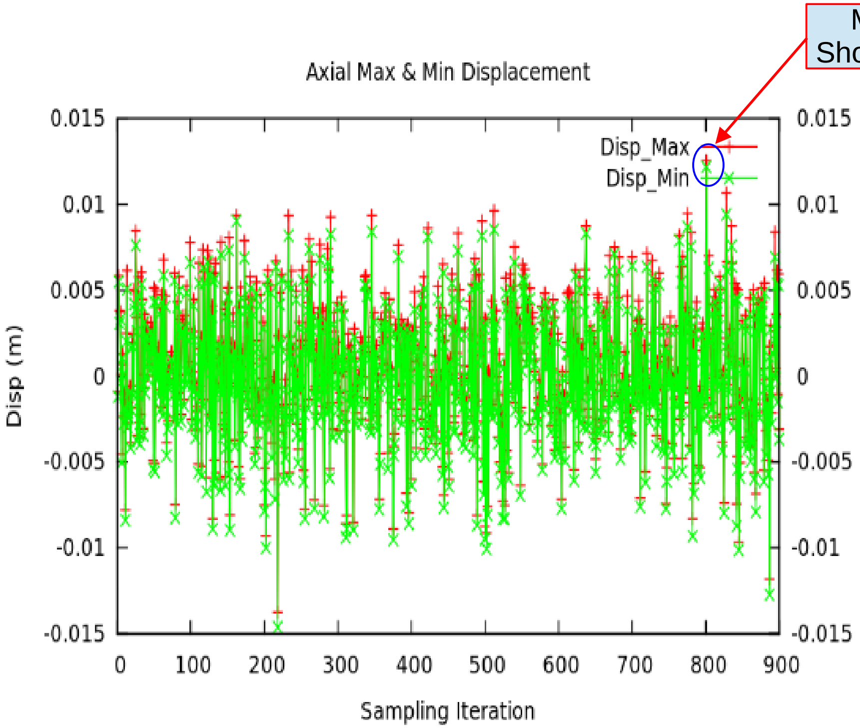
- **Smooth transformations in space** that preserved the quality of surface mesh and the global structure mesh.

- **Large variations of some parameters** (up ±50% of initial value) have been successfully morphed.

- **Very low computational time** : The mesh morphing processing in PERMAS combined with structural analysis to **25h51 min for the 900 samples** **(~ 1 min 44 sec for each run with static and modal analysis computation).**

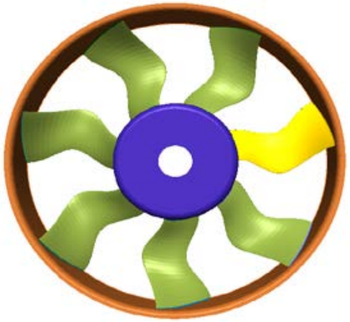
IV. RESULTS AND ANALYSIS

- Mesh Morphing Results and Analysis : Static linear deformation global analysis

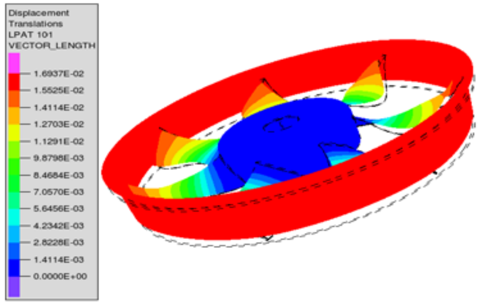


Positive and negative maximum static deformation for the 900 runs

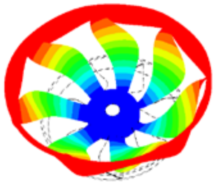
Mesh Shape and Modal visualization of the shoot 801



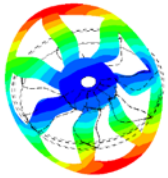
Mesh shape for 801th shoot



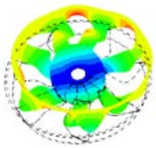
Linear static deformation (DispMax = 0.0126 m)



First Mode
f1=33.11Hz



Second Mode
f2=50.01Hz



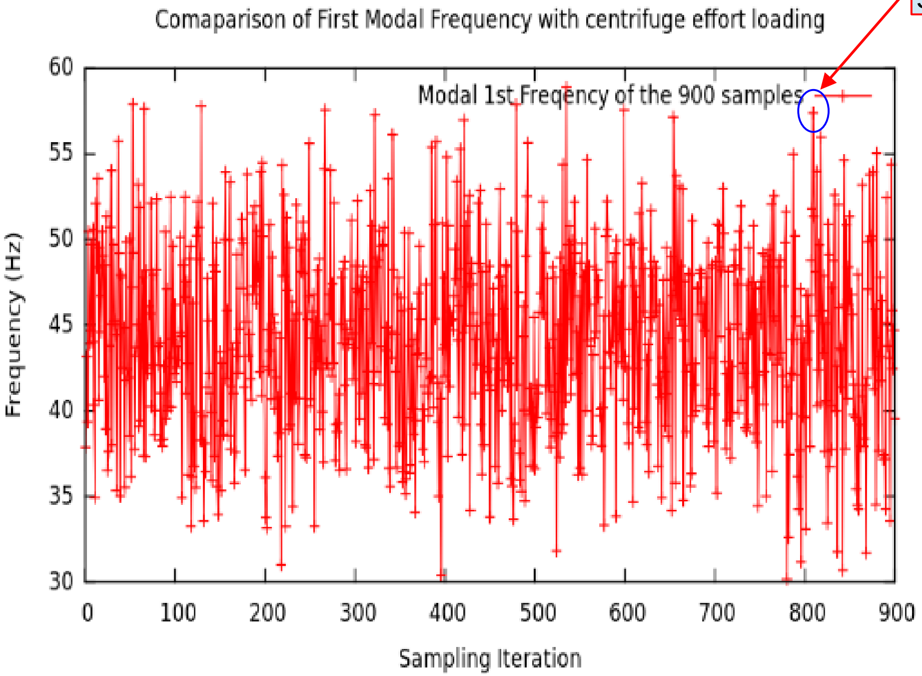
Third mode
f3=84.35Hz

- Depending on the set of parameters, the displacement can vary roughly between ±15 mm

IV. RESULTS AND ANALYSIS

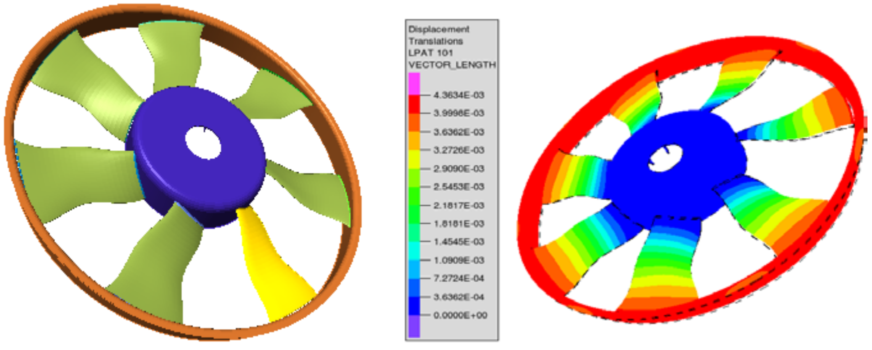
- Mesh Morphing Results and Analysis

Max : Shoot 535



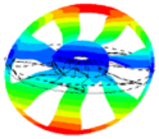
first modal frequency

Mesh Shape and Modal visualization of the shoot 535

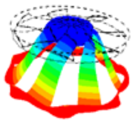


Mesh shape for 535th shoot

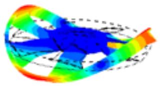
Linear static deformation (DispMax = 0.000545 m)



First Mode
f1=58.65Hz



Second Mode
f2=42.69Hz

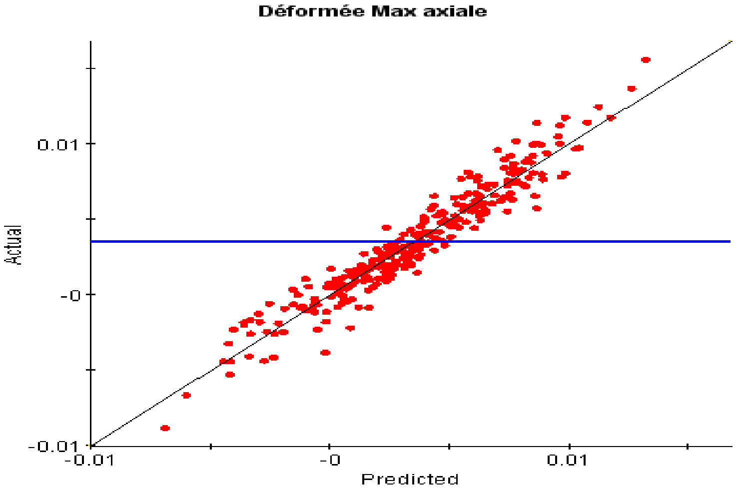


Third mode
f3=64.35Hz

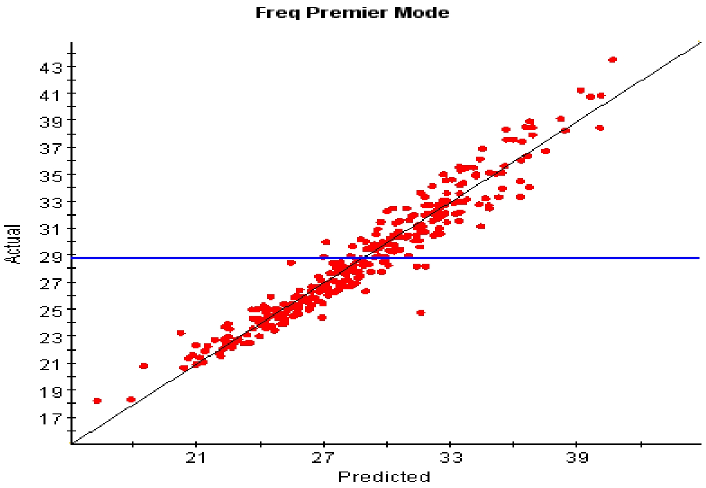
- Depending on the set of parameters, the first mode frequency goes roughly from 30 Hz to 60 Hz

IV. RESULTS AND ANALYSIS

- Meta-Model Validation and error assessment



Correlation between meta-model prediction and test population for axial displacement (m)



Correlation between meta-model prediction and test population for first mode frequency (Hz)

Parameters	Objectives	Meta-model	Simulation	Errors
Limited range (50%)	Max positive displacement (mm)	8,3	8,1	-2,5%
	Max negative displacement (mm)	-8,7	-7,7	-13,0%
	Max frequency (Hz)	43,4	43,9	1,0%
	Min frequency (Hz)	22,5	22,9	2,0%
Full range (100%)	Max positive displacement (mm)	17,5	14,5	-20,1%
	Max negative displacement (mm)	-20,1	-36,1	44,2%
	Max frequency (Hz)	46,8	44,6	-4,9%
	Min frequency (Hz)	3,6	14,3	75,2%

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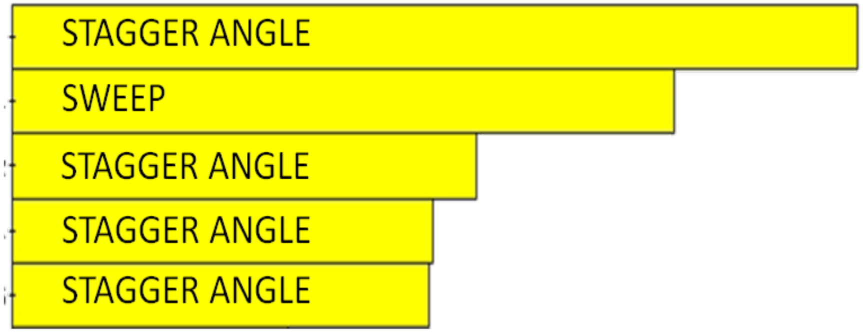
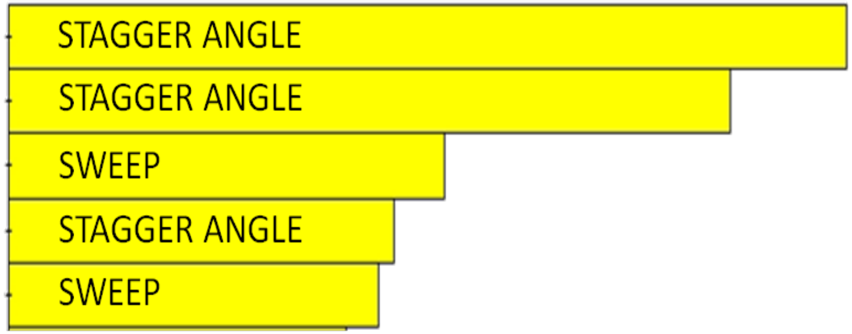
IV. RESULTS AND ANALYSIS

- Sensibility Analysis with Geometrical Parameters
  - A sensibility analysis can be done using the results of these study. It reveals the most important parameters to adjust when real optimization objectives are assigned.



Global effect (averaged gradient) for displacement

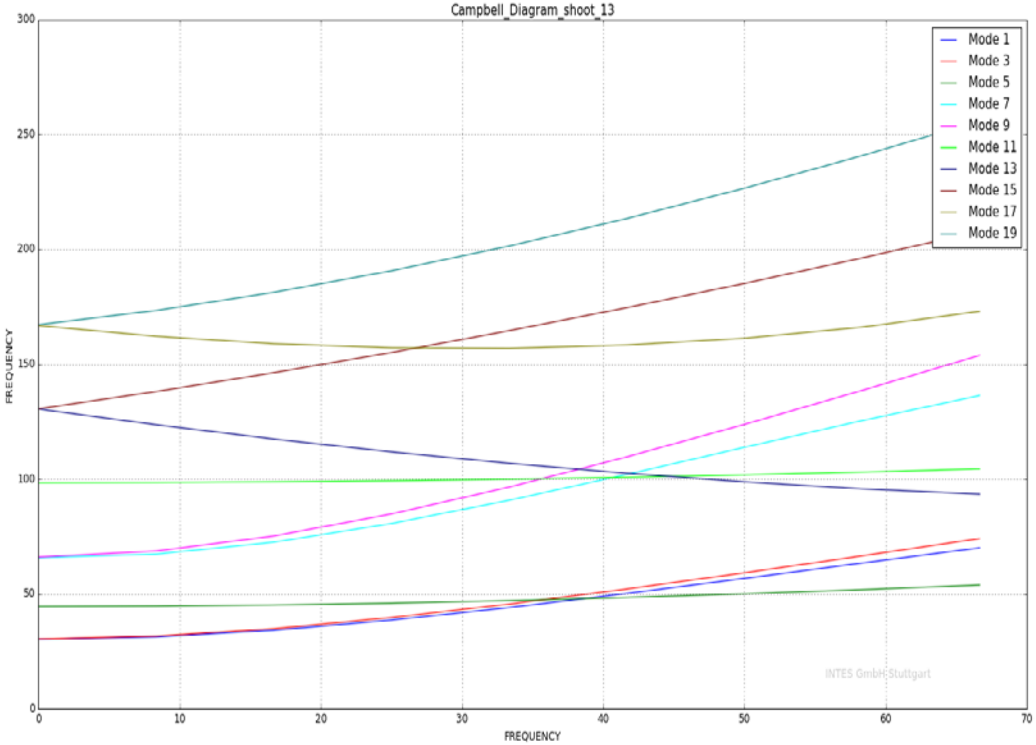


Global effect (averaged gradient) for first mode

IV. RESULTS AND ANALYSIS

- Campbell Diagram
  - Possibility to incorporated Campbell diagram in the mesh morphing procedure

Morphed Mesh - Shoot 13



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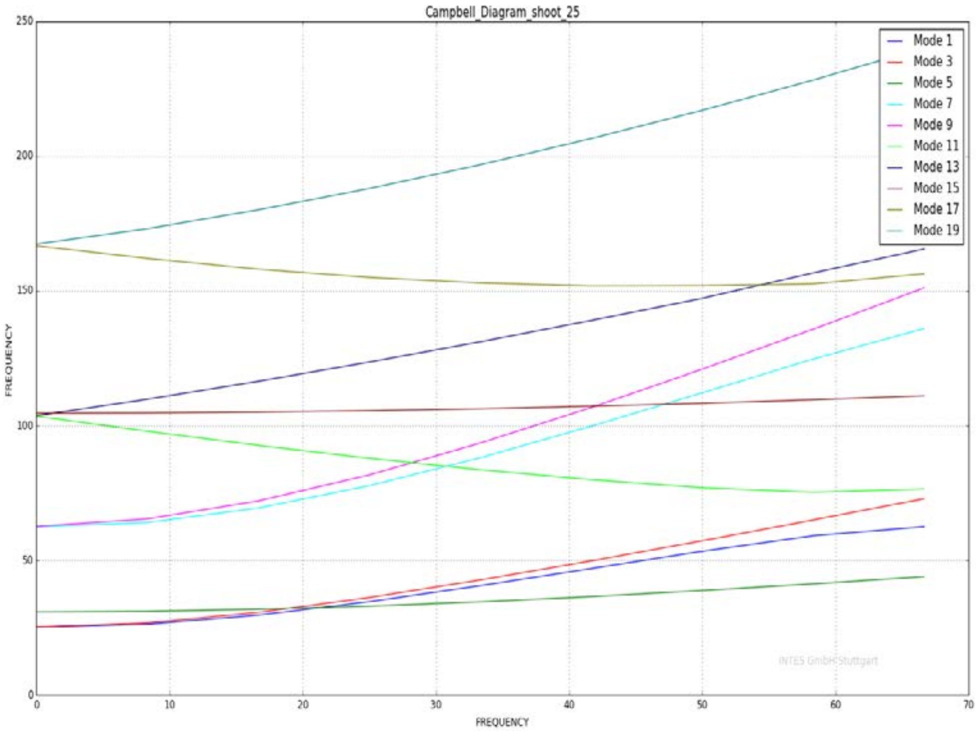
IV. RESULTS AND ANALYSIS

- Campbell Diagram
  - Possibility to incorporated Campbell diagram in the mesh morphing procedure

Morphed Mesh - Shoot 25



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V. CONCLUSION AND PERSPECTIVES

- This work allows to show :
  - High level Geometric Parametrization capability for complex geometries with user interface **VisPER**
  - Complex Parametrization independent of the structure mesh
  - Complex Mesh morphing with large number of parameters used for complex modes analysis and static analysis in one single run with **PERMAS**
  - Mesh morphing can be used for shape optimization to get optimal design with very accurate definition of geometrical parameters with wide mesh deformation capability
  - Verification of mesh quality during the morphing process
  - Automated mesh morphing process
  - Low computational cost of sampling process for a relative large number of parameters
- Perspectives :
  - Increase the number of parameters to 30 on the rotor and add the stator parameters (***on going work***)
  - The mesh morphing process and optimization coupled with steady or unsteady CFD data for fluid-structure simulation for vibro-acoutics and sound radiation analysis