NUMERICAL INVESTIGATIONS REGARDING CONTACT MODELING FOR EVALUATING THE MODAL CHARACTERISTICS OF A LOW PRESSURE TURBINE ROTOR BLADING

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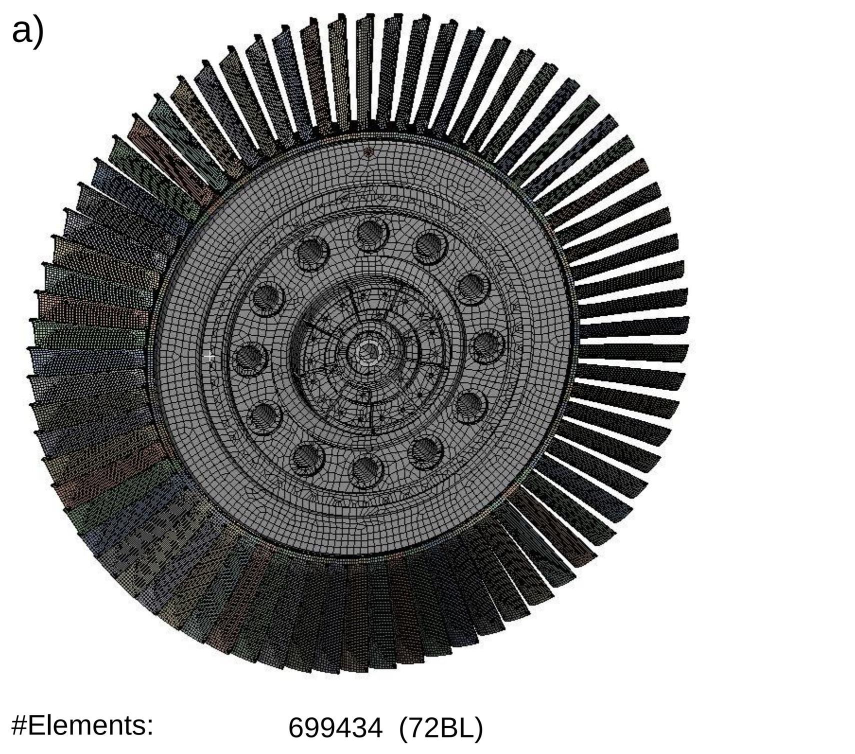
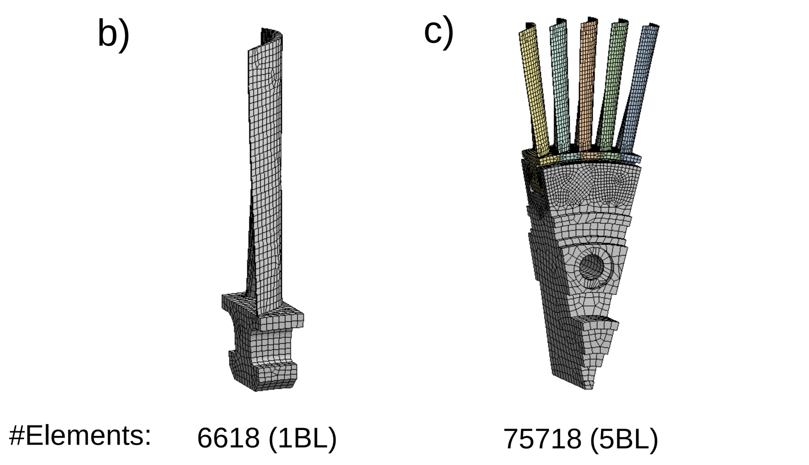
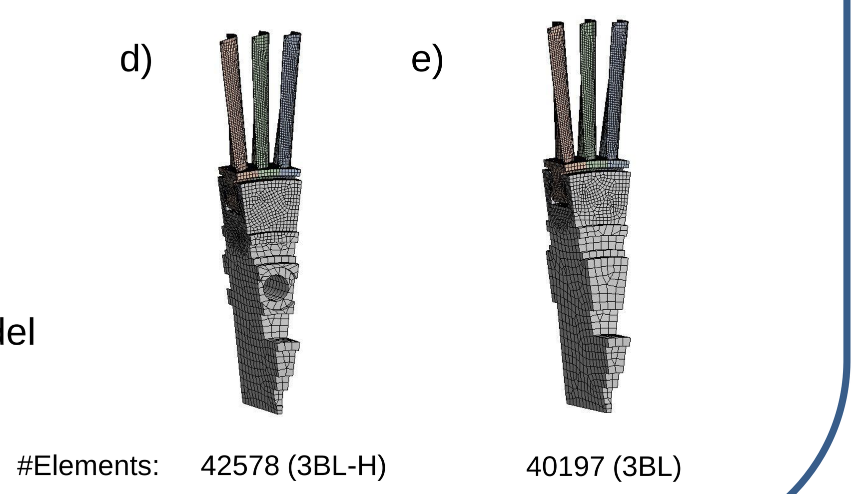
ABSTRACT

For a serious prediction of vibration characteristics under operating conditions of any structure a detailed knowledge of the modal characteristics is essential. The quality of numerical results is strongly depended on boundary conditions and coupling conditions. Based on the model of a low pressure turbine rotor of an aero engine this poster presents different numerical models for modal characterization. A big challenge in the FE modeling process is the coupling between rotor disk and rotor blades. In general, software packages for finite element analysis provide a number of contact models and formulations. In a detailed study different contact models and formulations like Pure Penalty, Normal and Augmented Lagrange and Multi Point Constraint (MPC) were applied and investigated. The combination of contact type such as bonded, no separation, frictional or frictionless contact with formulation type is of particular importance. Eigenvalues and mode shapes of the blades are presented and illustrated as the results of the numerical analysis and can be compared with experimental data which were generated in a separate study. The modal characteristics of the blades are of particular interest especially for further aero elastic investigations. All investigations were performed on different simplified models as well as on the assembling model of the turbine rotor. Evaluated modal characteristics are prepared and shown in a way to provide a better understanding for the importance of using correct contact models for an efficient numerical analysis. Finally, a simplified numerical model with a sufficient quality can be recommended which shows a minimum deviation of the numerical results compared to experimental evaluated data.

FE - MODELS





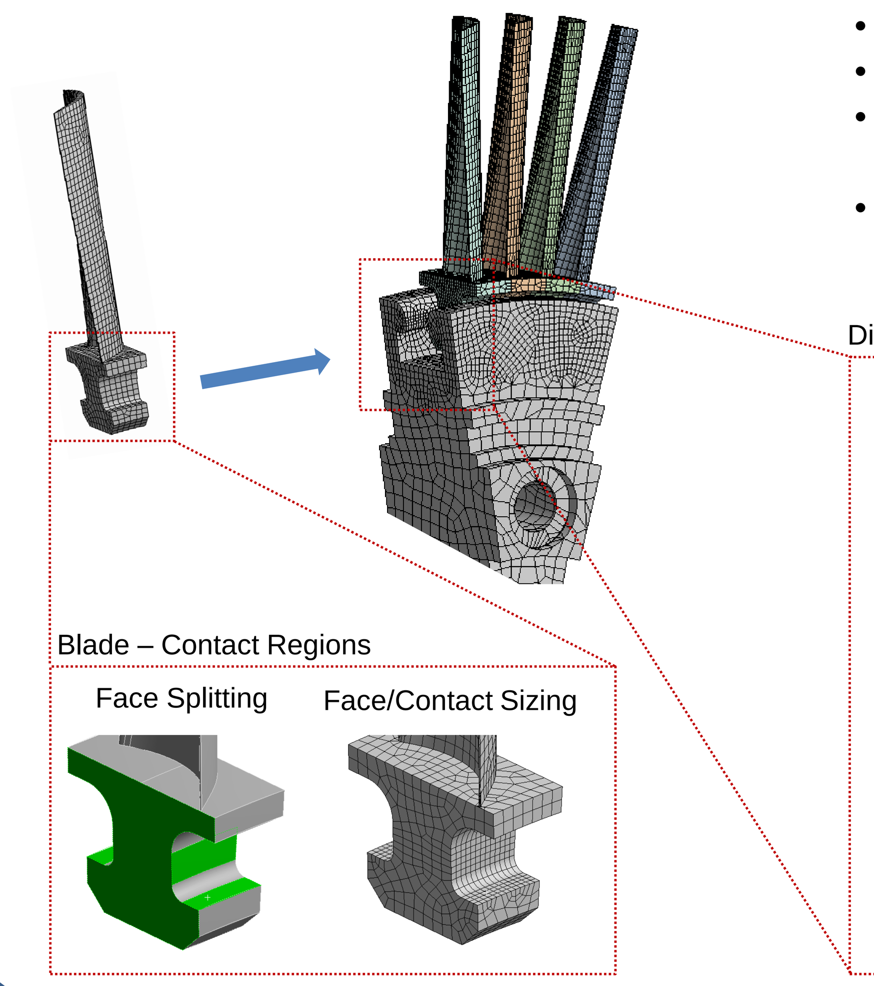


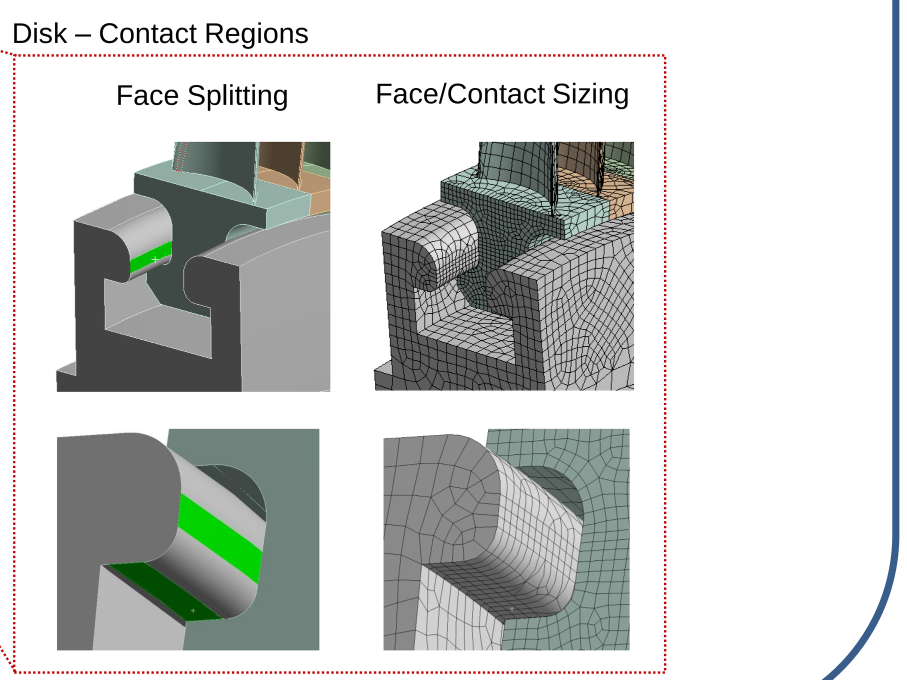
- Fully assembled low pressure turbine rotor model
- Simplified models (1 – 5 blade models)
- Hexagonal dominated mesh
- Quad elements

BL … Blade H … (Bore) Hole

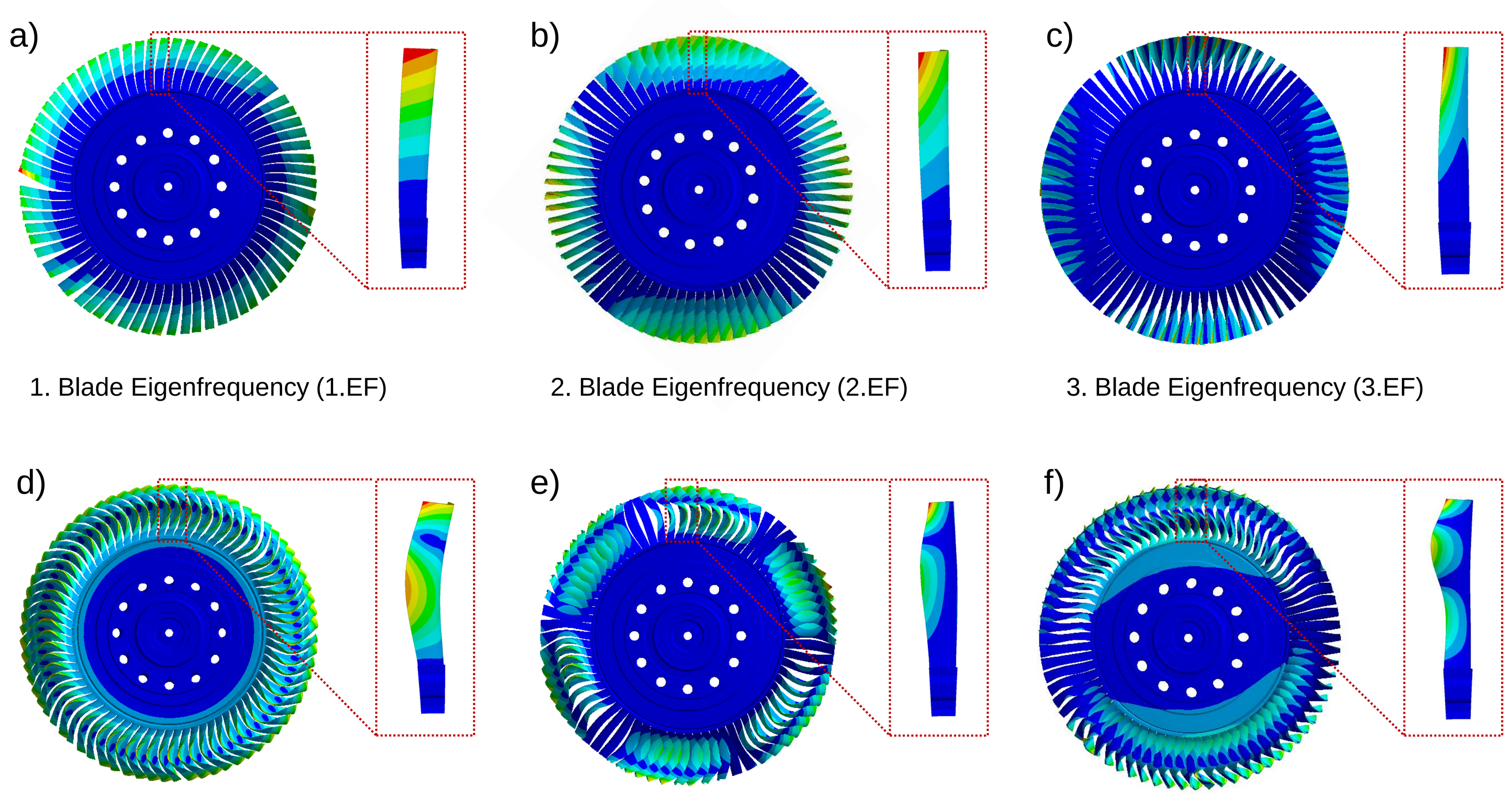
CONTACT REGIONS AND BOUNDARY CONDITIONS

- Face splitting of all contact faces
- Contact (face) sizing
- Application of different contact types on selected faces
- Symmetric boundary conditions in circumferential direction





MODE SHAPES



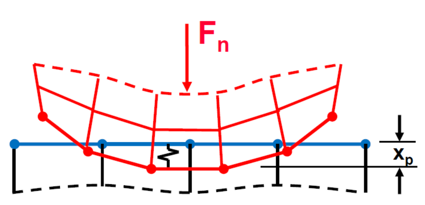
1. Blade Eigenfrequency (1.EF)
2. Blade Eigenfrequency (2.EF)
3. Blade Eigenfrequency (3.EF)
4. Blade Eigenfrequency (4.EF)
5. Blade Eigenfrequency (5.EF)
6. Blade Eigenfrequency (6.EF)

CONTACT FORMULATIONS*

Pure Penalty (PP):

$F_n = k_n \cdot x_p$

k_n … contact stiffness
x_p … penetration



- Introduces a force that has penetrated across the target surface with the express purpose of eliminating the penetration

Augmented Lagrange (AL):

$F_n = k_n \cdot x_p + \lambda$

- Similar to pure penalty method
- Adds an internally calculated term λ
- This augmentation reduces sensitivity to contact stiffness

Normal Lagrange (NL):

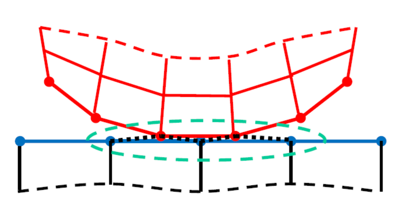
F_n = DOF

- Adds an extra degree of freedom (DOF) to satisfy contact compatibility
- Solves directly with zero penetration

Problems:
– long calculation time
– chattering (because no penetration is allowed)

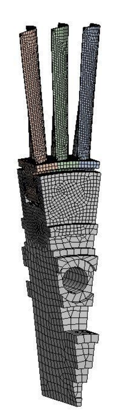
Multi Point Constraint (MPC):

- Internally adds constraint equations to „tie" the displacement of contacting surfaces



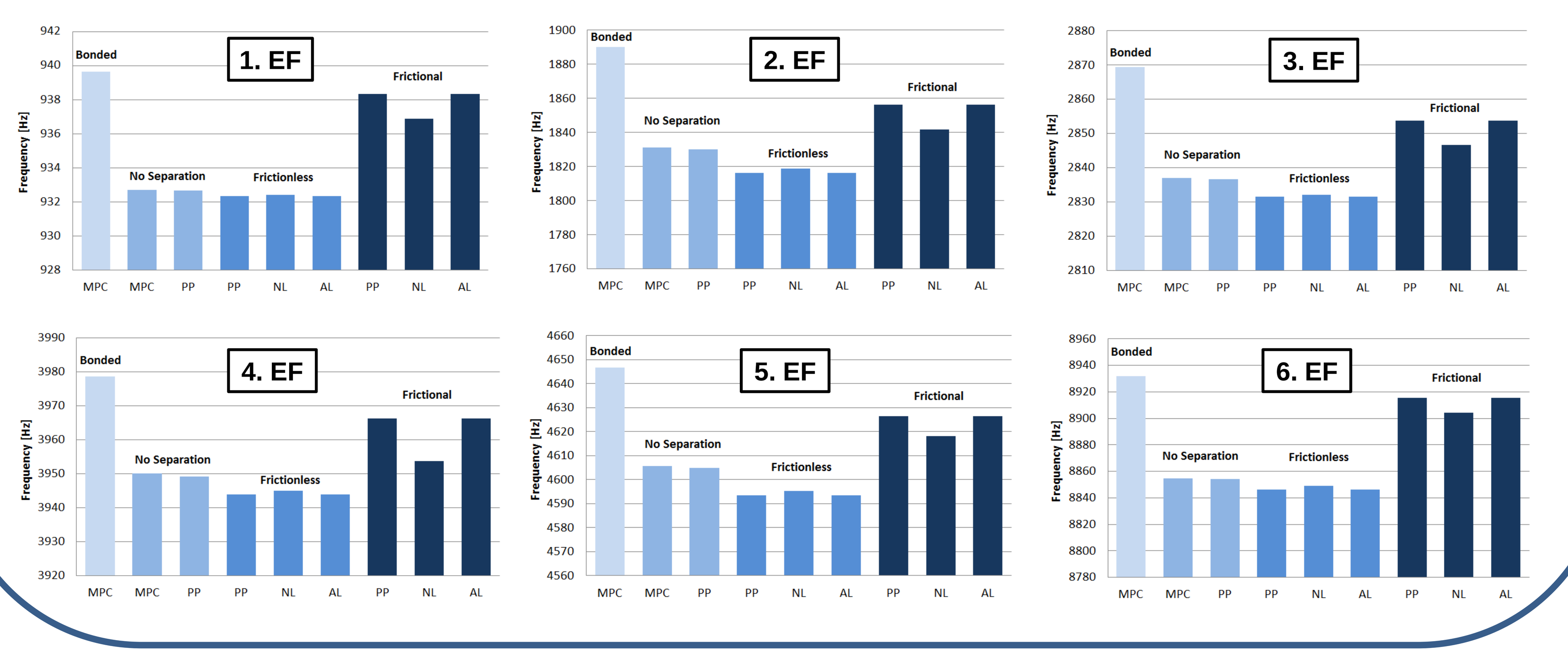
*Source: Ansys; Customer Training Material; Lecture 3; Introduction to Contact; Dec 2010

BLADE MECHANICS - EIGENFREQUENCIES – CONTACT FORMULATION STUDY



- Contact types and formulations are applied to the particular contact faces
- Detailed results are comparing suitable connections and are illustrated representatively for the 3 blade model including bore hole

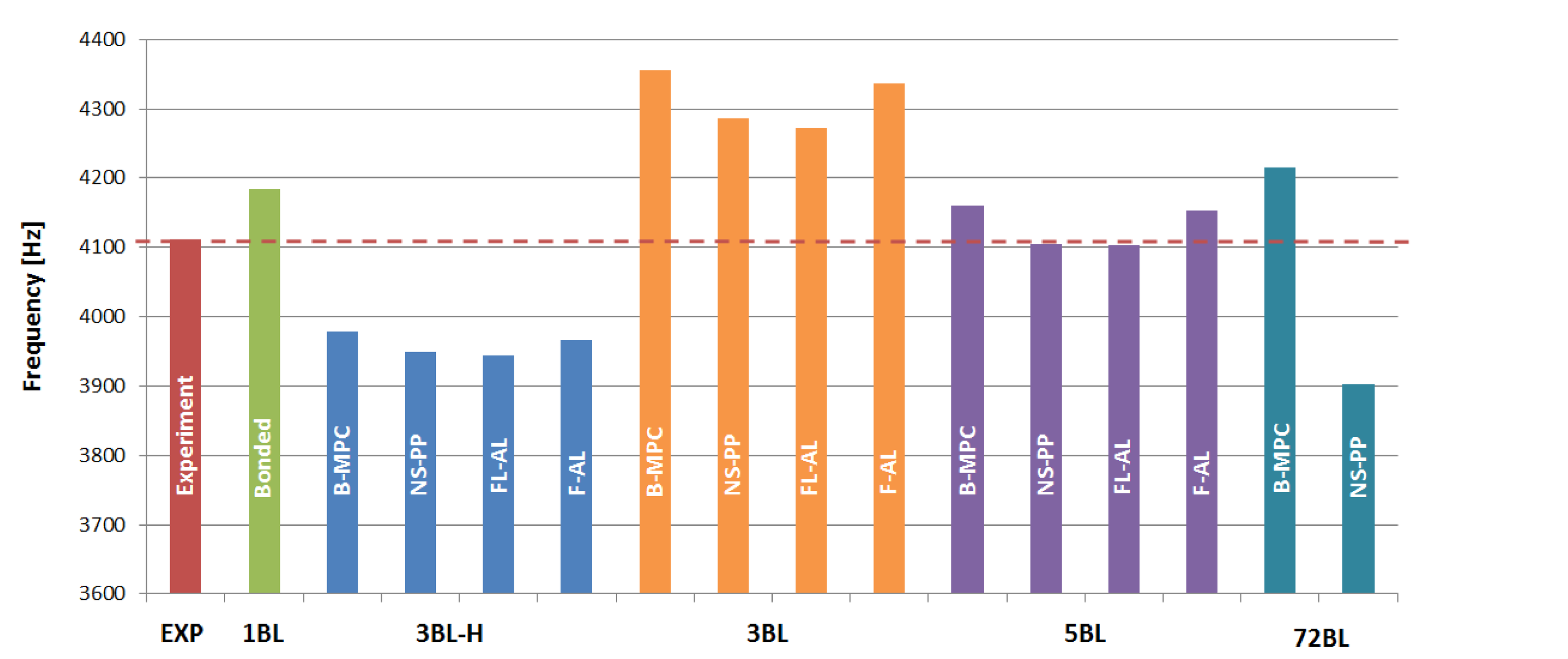
Type	Bonded	No Separation		Frictionless			Frictional		
Formulation	MPC	MPC	PP	PP	NL	AL	PP	NL	AL
1. EF	940	933	933	932	932	932	938	937	938
2. EF	1890	1831	1830	1816	1819	1816	1856	1842	1856
3. EF	2869	2837	2837	2832	2832	2832	2854	2847	2854
4. EF	3979	3950	3949	3944	3945	3944	3966	3954	3966
5. EF	4647	4606	4605	4594	4595	4594	4626	4618	4626
6. EF	8932	8855	8854	8846	8849	8846	8915	8904	8915



EIGENFREQUENCIES – DEVIATION OF THE NUMERICAL RESULTS

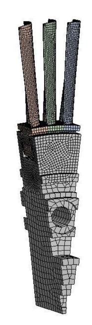
- The results of all numerical models are compared with experimental evaluated eigenfrequencies
- The experimental results were determined with different experimental modal analysing methods
- Results of the 4th eigenfrequency are illustrated representatively

EXP	1BL	3BL-H				3BL				5BL				72BL	
EXP	B	B-MPC	NS-PP	FL-AL	F-AL	B-MPC	NS-PP	FL-AL	F-AL	B-MPC	NS-PP	FL-AL	F-AL	B-MPC	NS-PP
962	-8,9%	-2,3%	-3,0%	-3,1%	-2,5%	-2,3%	-3,7%	-4,0%	-2,7%	-2,3%	-3,7%	-3,7%	-2,4%	2,0%	-10,2%
1650	5,4%	14,6%	10,9%	10,1%	12,5%	15,7%	11,5%	10,4%	13,2%	15,3%	11,1%	10,8%	14,1%	17,2%	13,6%
2741	3,1%	4,7%	3,5%	3,3%	4,1%	5,5%	4,2%	3,8%	4,8%	5,3%	3,9%	3,8%	4,9%	-1,5%	-3,8%
4112	1,8%	-3,2%	-4,0%	-4,1%	-3,5%	5,9%	4,2%	3,9%	5,5%	1,2%	-0,2%	-0,2%	1,0%	2,5%	-5,1%
4776	23,2%	-2,7%	-3,6%	-3,8%	-3,1%	1,1%	0,6%	0,3%	0,5%	-1,8%	-2,8%	-2,9%	-2,1%	-4,7%	-8,8%



BL … Blade H … (Bore) Hole EXP … Experimental result

CONCLUSION



Different models of a low pressure turbine rotor were investigated in a detailed study relating contact modeling and contact formulation. The results of numerical and also experimental evaluated eigenfrequencies are shown and compared directly. In view of continuing aero elastic investigations where the model should be coupled with CFD, the 3 Blade – Model including the bore hole can be recommended based on the results shown in this poster. The model guarantees a sufficient quality of results with a minimum deviation of experimental results under considering element numbers and computing time which is important for further investigations. Depending on the contact formulation the eigenfrequencies show less deviation compared to each other and therefore a bonded or no separation contact is recommended due to shorter computing times and better convergence of the contact.

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