TurbomacHinery AeRomechanical UniverSity Training

An Aeroelastic Reduced Order Model for A Mistuned Blisk

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Thesis Work performed at the Institute of Aeroelasticity of German Aerospace Center (DLR) under the supervision of Gerrit Sinapius
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Objective

This project aimed to implement mistuning onto aerodynamic influence coefficients of a tuned system using structural mistuning parameters obtained from CMM method [1]. The accuracy of the implementation was verified by performing flutter stability analysis of the mistuned system and comparing the predicted aerodynamic damping values with the values obtained from CFD computation. It is the first step of building a more robust reduced order model of a mistuned system for statistical analysis and forced response analysis.

Background

Mistuning is regarded as a structural problem but it was shown by He et al. [2] that aerodynamic coupling due to unsteady flow has a great influence on the forced response of the mistuned system.

About the Author

Maximilian Hertanto has followed the study track of Aeromechanical and Material Design within THRUST master program and will graduate in September 2014. He would like to pursue a career in the industry.

SETUP

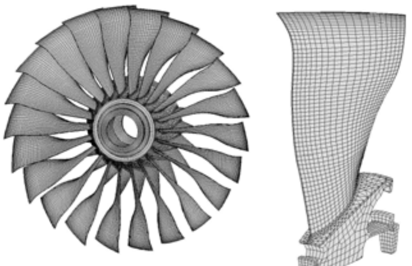

Fig. 1: DLR-UHBR Fan*

Finite Element Analysis
• FE mesh (hexahedra, tetrahedra, wedges)
• Preload (cold-to-hot): Non-linear static analysis (centrifugal + steady pressure effect)

*Developed by the Institute of Propulsion Technology, DLR Cologne

The test case is the DLR-UHBR fan, which was developed by the Institute of Propulsion Technology of DLR. It has 22 blades and is made of titanium alloy. The FE model of a single sector has (see **Fig. 1**) 20,640 degrees of freedom and the rotor is constrained at the disk. The stiffness and mass matrices of a sector model were extracted from the FEM tool to build the reduced order model.

CFD computations were performed using TRACE, DLR in-house solver. For steady simulation, the fan was set to rotate at 100% nominal speed (OP) and followed by a stator with 38 blades (see **Fig. 2**). The CFD mesh of one sector consists of 2 million nodes. A cold-to-hot calculation was conducted iteratively in order to determine the preloaded shape of the fan blade for the unsteady simulations.

Time-linearized unsteady simulations were conducted to compute the aerodynamic damping and aerodynamic influence coefficients. The first two modes (**1F** and **2F**) were selected for a total of 44 computations (22 IBPAs for each mode).

A two sector CFD model was created to validate the aerodynamic damping computed using the reduced order model (ROM) by applying an alternate mistuning pattern.

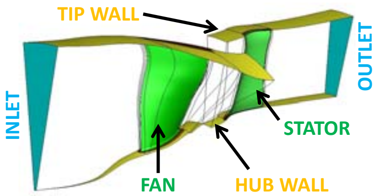

Fig. 2: Single sector CFD mesh topology

CFD (TRACE**)
• 3D CFD mesh with G3DMESH**
• Steady simulation at 100% nominal speed
• Time-linearized unsteady simulation
• Output aerodynamic damping and aerodynamic influence coefficients

**DLR in-house CFD tool

AEROELASTIC REDUCED ORDER MODEL

Here, the reduced order model is based on the Component Mode Mistuning (CMM) method [1]. Modal analysis of the full annulus was performed using a single sector model with a cyclic symmetry approach. Only modes in the frequency range of interest were retained in the analysis (1F and 2F) which were blade-dominated modes (see red box in **Fig. 3**). Mistuning was then introduced into the equation of motion (EOM) by projection of perturbed modal stiffness of cantilevered blade modes. The mistuning was assumed to be small (< 2%) and proportional to the modal stiffness of the cantilevered blades. Using the EOM defined in modal coordinates as shown in **Eq. 1**, mistuning superposition factor (***q***) can be used to build mistuned modes from tuned modes for structural part.

$$\left[-\omega^2 M + (K+\Delta K)\right]\cdot q = 0 \quad \text{and} \quad \Phi_{mist} = \Phi_{tuned}\cdot q \qquad \textbf{Eq. 1}$$

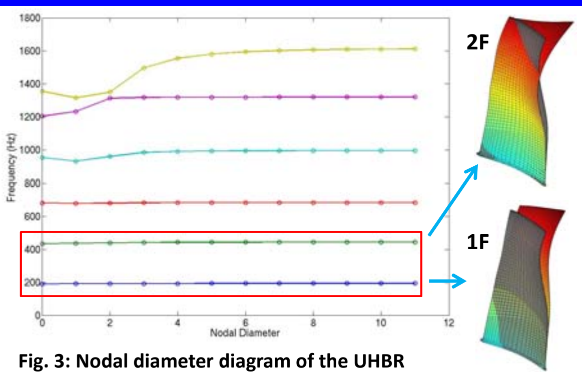

Fig. 3: Nodal diameter diagram of the UHBR

The aerodynamic influence coefficient matrix obtained from TRACE was included in the EOM. It was also mistuned using ***q*** and the new EOM was put into state space representation [3], see **Eq. 2**. The damping values were obtained by taking the real part of the eigenvalues of A matrix and divided by the reference eigenfrequency (**ω_0**).

$$\left[-\omega^2 M + (K+\Delta K) - p_{ref}\cdot A_0 \cdot C\right]\cdot q = 0$$

$$\gamma = q^H \cdot p_{ref}\cdot A_0 \cdot C \cdot q$$

$$A = \begin{bmatrix} 0 & I \\ -\mu^{-1}\cdot(\kappa + \Re(\gamma)) & -\dfrac{\mu^{-1}\Im(\gamma)}{\omega_0} \end{bmatrix} \qquad \textbf{Eq. 2}$$

RESULTS

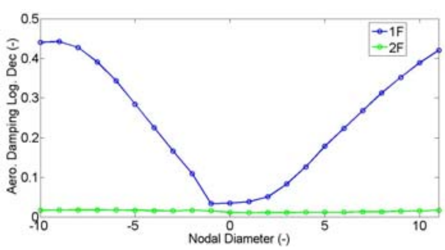

Fig. 4: Aerodynamic damping of tuned UHBR fan

Fig. 4 shows the logarithmic decrement of aerodynamic damping of the tuned fan. **Fig. 5** shows the comparison of aerodynamic damping of mode 1 of the tuned system and mistuned systems where one was superimposed using the ROM and the other one was computed from TRACE with the two sector model by directly applying the mistuned modeshapes. For the mistuned system, the damping is ordered according to the most dominating tuned nodal diameter.

The applied mistuning pattern was alternate mistuning where the normal modes of each odd-numbered blade was mistuned by +1% and even-numbered blades were kept at their nominal values.

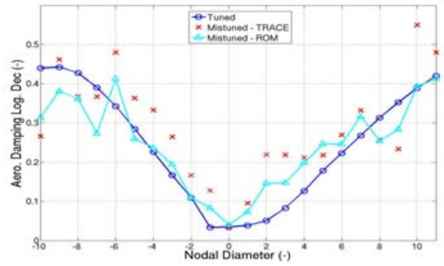

Fig. 5: Aerodynamic damping of mode 1 of the tuned and mistuned systems computed using ROM and TRACE

[1] Lim, S.-H., Bladh, R., Castanier, M. P., and Pierre, C., 2007, "A Compact, Generalized Component Mode Mistuning Representation for Modeling Bladed Disk Vibration," AIAA Journal, **45**(9), pp. 2285-2298.
[2] He, Z., Epureanu, B. I., and Pierre, C., 2007, "Fluid-Structural Coupling Effects on the Dynamics of Mistuned Bladed Disks," AIAA Journal, **45**(3), pp. 552-561.
[3] Yang, M.-T., and Griffin, J. H., 2001, "A Reduced Order Model Mistuning Using A Subset of Nominal Modes," ASME J. Eng. Gas Turbines Power, 123(4), pp. 893-900.

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