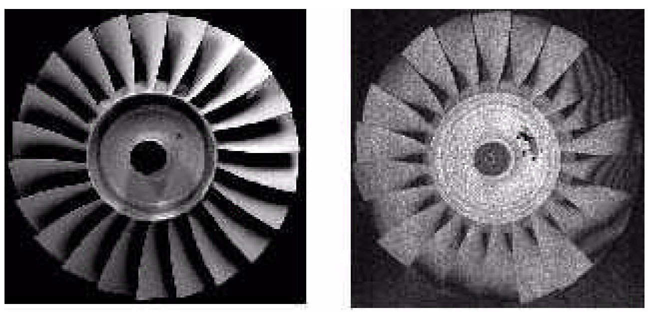
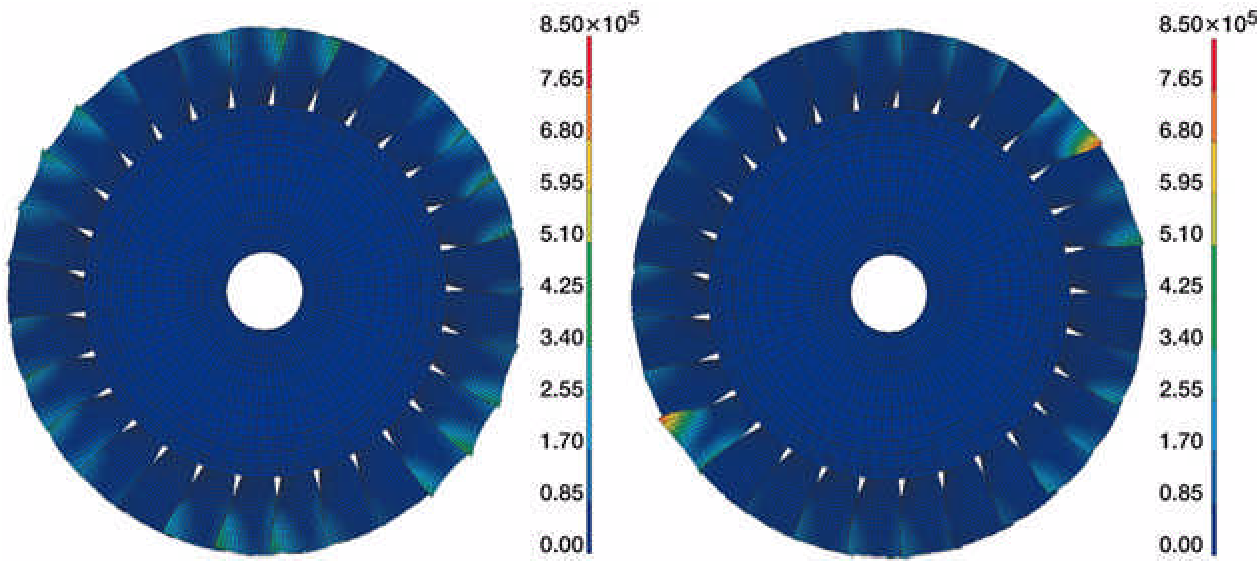
Advanced Vibration Analysis Tools and New Strategies for Robust Design of Turbine Engine Rotors

The adverse effects of small, random structural irregularities among the blades, called mistuning, can result in blade forced-response amplitudes and stresses that are much larger than those predicted for a perfectly tuned rotor. Manufacturing tolerances, deviations in material properties, or nonuniform operational wear causes mistuning; therefore, mistuning is unavoidable. Furthermore, even a small mistuning can have a dramatic effect on the vibratory behavior of a rotor because it can lead to spatial localization of the vibration energy (see the following photographs). As a result, certain blades may experience forced response amplitudes and stresses that are substantially larger than those predicted by an analysis of the nominal (tuned) design. Unfortunately, these random uncertainties in blade properties, and the immense computational effort involved in obtaining statistically reliable design data, combine to make this aspect of rotor design cumbersome.



Spatial localization of mistuned bladed disks. Left: Turbine engine rotor. Right: Localized vibration.

Since the 1960's, several researchers have documented the effects of mistuning on blade vibrations by analyzing representative lumped-parameter models, using numerical, statistical, and perturbation methods. Unfortunately, to accurately represent an actual bladed disk design with a lumped-parameter model, one must perform a difficult parameter identification, which becomes infeasible as the number of model degrees of freedom increases. Hence, for models to gain practical usefulness, accurate finite element models of rotor designs must be employed in mistuning studies.



Forced response predictions for an industrial rotor by TURBO-REDUCE. Left: Tuned. Right: Mistuned.

To address this issue, a team from the NASA Glenn Research Center and the University of Michigan, Ann Arbor, made several efforts to generate reduced-order models systematically from finite element models using component model synthesis methods (refs. 1 to 4). In CMS, the original structure is subdivided into small substructures, or components, for which normal modes are computed independently. The global structure is then represented by a truncated set of component modes that are assembled in a systematic fashion through compatibility constraints. This process yields highly reduced order models for bladed disks that are based on finite element models of arbitrary complexity. The effort has been particularly focused on the development of a valuable computer code named TURBO-REDUCE, which is based on a computationally efficient reduced-order modeling technique for the vibration analysis of mistuned bladed disks. The phenomenon of mode localization is well captured by the TURBO-REDUCE code (see the preceding figure). TURBO-REDUCE is a FORTRAN 77 computer code that has the modular features, computational efficiency, and practical implementation needed for the realistic modeling of a mistuned assembly of blades. Since the code is being actively used in industry, TURBO-REDUCE represents the current state of the art.

References

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