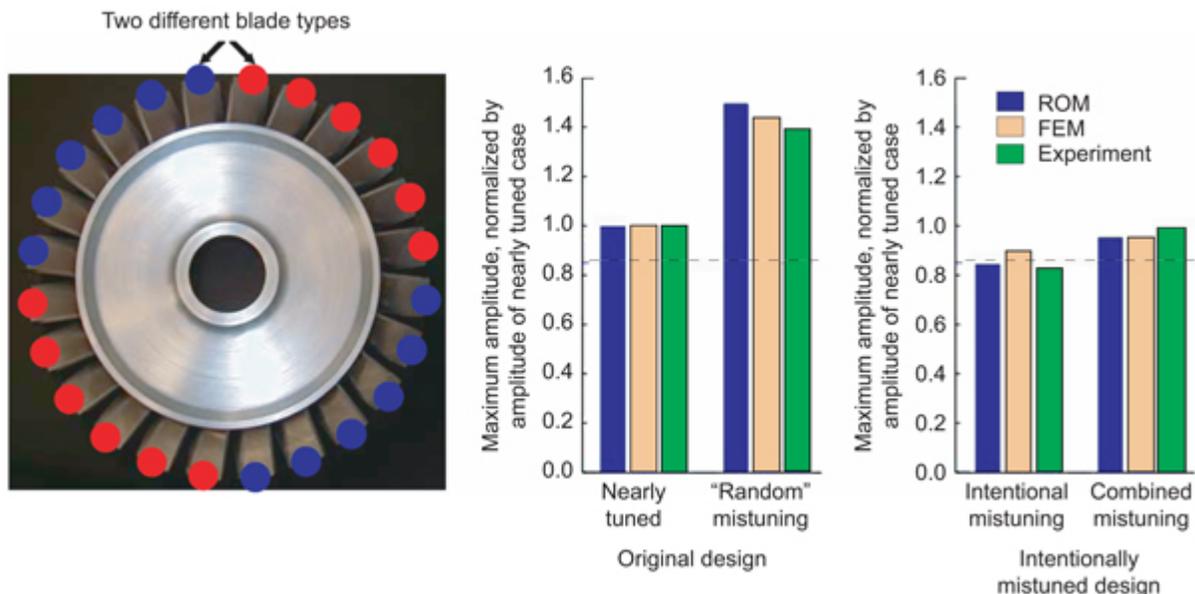


# Advanced Vibration Analysis Tool Developed for Robust Engine Rotor Designs

The primary objective of this research program is to develop vibration analysis tools, design tools, and design strategies to significantly improve the safety and robustness of turbine engine rotors. Bladed disks in turbine engines always feature small, random blade-to-blade differences, or mistuning. Mistuning can lead to a dramatic increase in blade forced-response amplitudes and stresses. Ultimately, this results in high-cycle fatigue, which is a major safety and cost concern. In this research program, the necessary steps will be taken to transform a state-of-the-art vibration analysis tool, the Turbo-Reduce forced-response prediction code, into an effective design tool by enhancing and extending the underlying modeling and analysis methods. Furthermore, novel techniques will be developed to assess the safety of a given design. In particular, a procedure will be established for using natural-frequency curve veerings to identify ranges of operating conditions (rotational speeds and engine orders) in which there is a great risk that the rotor blades will suffer high stresses. This work also will aid statistical studies of the forced response by reducing the necessary number of simulations. Finally, new strategies for improving the design of rotors will be pursued.



*Experimental study validated finite-element model and reduced-order model predictions for a test case.*

Long description of figure. Numerical simulations have shown that intentional mistuning can (1) yield greatly reduced forced-response levels relative to the original (tuned) design and (2) make a design more robust with respect to unavoidable, random mistuning. Photograph shows two different blade types. Bar charts give data for original and intentionally mistuned designs, showing maximum amplitude normalized

by amplitude of nearly tuned case versus nearly tuned, "random" mistuning, intentional mistuning, and combined mistuning for ROM, FEM, and experiment.

Several methods have been investigated, including the use of intentional mistuning patterns to mitigate the harmful effects of random mistuning, and the modification of disk stiffness to avoid reaching critical values of interblade coupling in the desired operating range. In the short term, the computational tools, analysis methods, and design assessment techniques will allow engineers to evaluate and improve rotor designs in the early design stages. In the long term, the new design strategies will help pave the way for eliminating high-cycle fatigue in turbine engines.

Research activities for this project have focused on the following three areas:

1. Development of methods for analyzing curve veerings and identifying critical regions in a natural-frequency versus engine-order map
2. Investigation of strategies for intentional mistuning pattern selection, with an emphasis on efficiently reducing the design space
3. Approximation of mistuned amplitude bounds and estimation of blade stress increases due to mistuning.

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## References

1. Castanier, Mathew P.; and Pierre, Christophe: Using Intentional Mistuning in the Design of Turbomachinery Rotors. *AIAA J.*, vol. 40, no. 10, 2002, pp. 2077-2086.
2. Castanier, M.P.; Pierre, C.; and Bladh, R.: Investigation Into Using Tuned Free Response Information to Predict Mistuned Forced Response of Bladed Disks. Proceedings of the 7th National Turbine Engine High Cycle Fatigue Conference, Palm Beach Gardens, FL, May 2002.
3. Bladh, R.; Castanier, M.P.; and Pierre, C.: Effects of Multistage Coupling and Disk Flexibility on Mistuned Bladed Disk Dynamics. *J. Eng. Gas Turbines Power*, vol. 125, no. 1, 2003, pp. 121-130.
4. Lim, Sang-Ho, et al.: A Compact, Generalized Component Mode Mistuning Representation for Modeling Bladed Disk Vibration. AIAA-2003-1545, 2003.

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