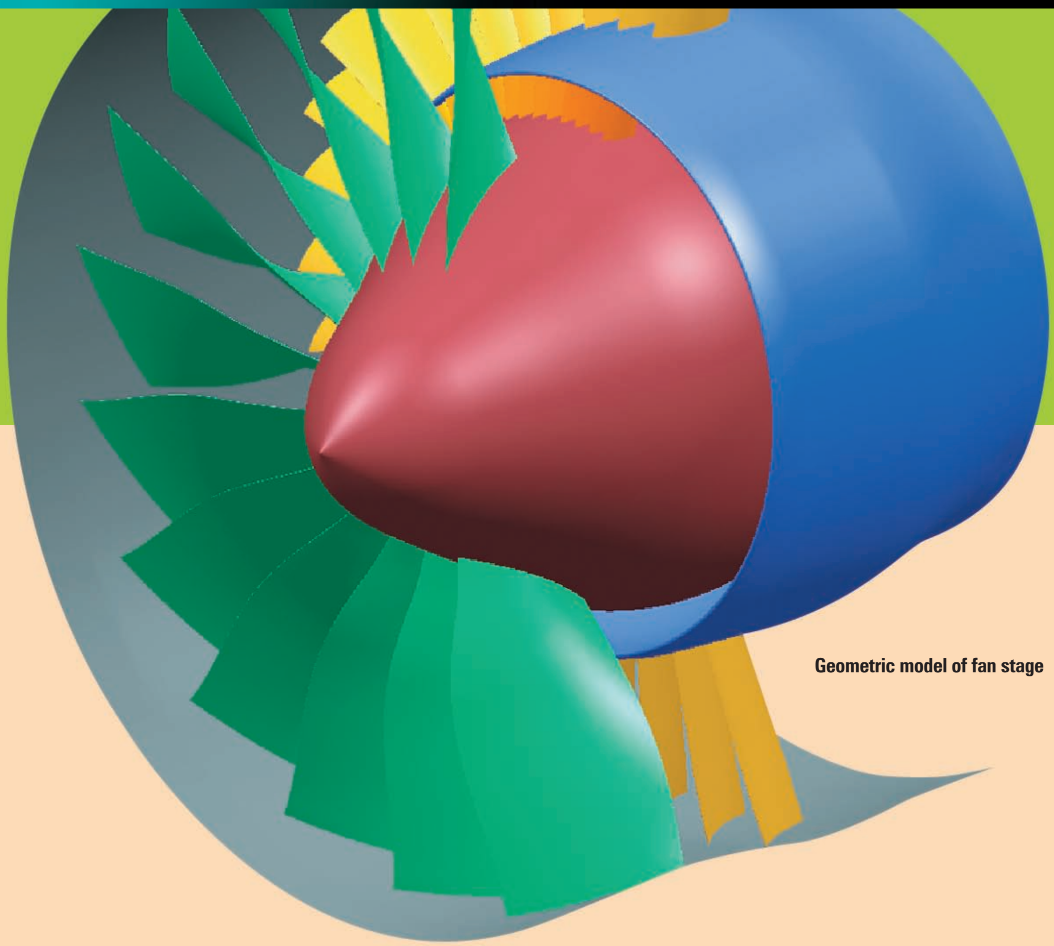

Geometric model of fan stage

Designing Quieter Fans for Turbo-Jet Engines

Simulation enables researchers to develop an efficient engine fan that produces less acoustic noise.

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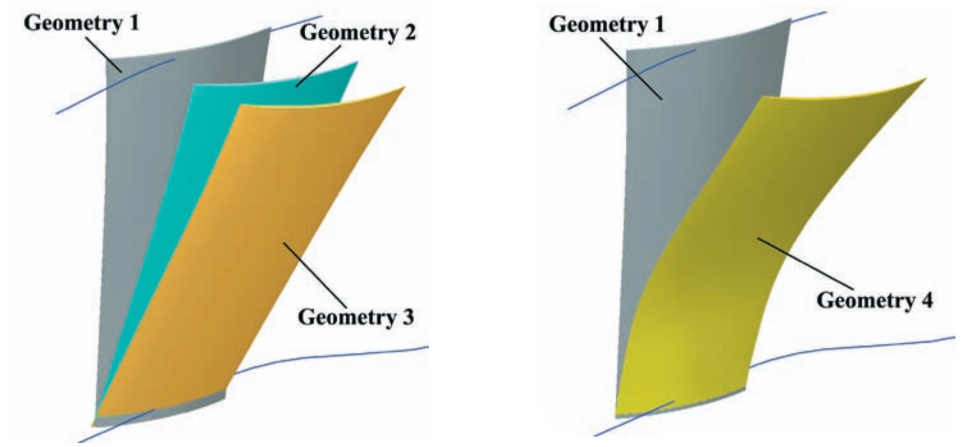
Because of stringent international standards for harmful emissions and noise levels, companies that design and develop gas turbine engines are faced with the task of creating engines that attain high levels of ecological efficiency. To meet these requirements, numerical modeling of processes that occur within an engine is needed to obtain an in-depth understanding of what occurs and to determine the factors causing this behavior. For aircraft engines with a high by-pass ratio, the acoustic noise produced by a fan stage is the main contributor to the total noise level of the engine.

To address these noise requirements, we used ANSYS CFX computational fluid dynamics (CFD) software to estimate aerodynamic and acoustic efficiency for different fan stage geometries.

To develop fan exit guide vane (FEGV) geometries, the area-averaged amplitude of unsteady pressure difference on the FEGV mid-surface was considered to be the main rotor-stator acoustic source. The amplitude was obtained from a 3-D unsteady CFD calculation of the fan stage. Good agreement between calculation results and experimental data has been found using this approach, according to the reference literature.



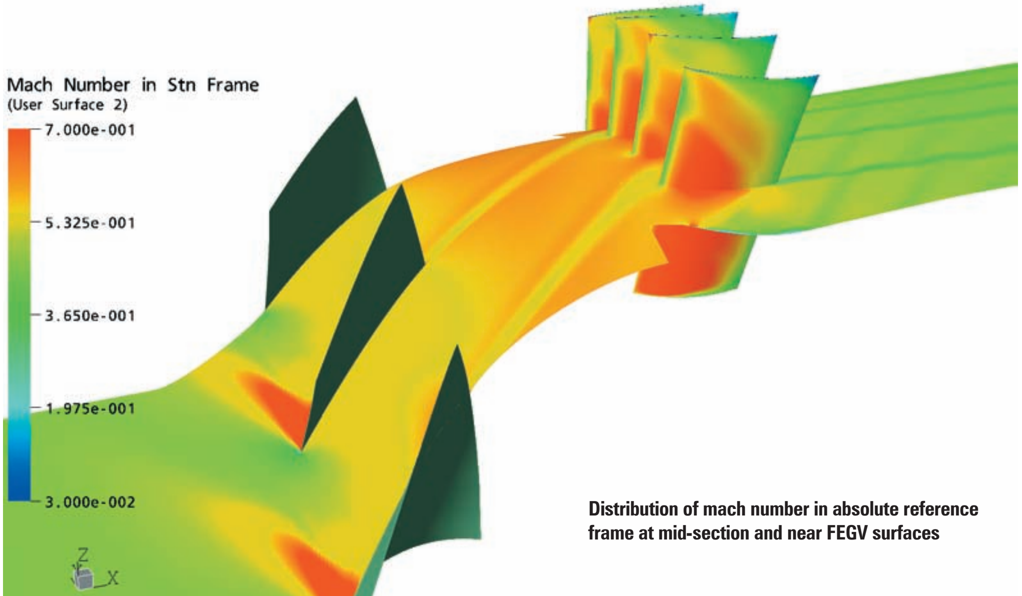
FEGV shapes

This fan was designed for a new advanced turbo-jet engine. Inlet guide vanes (IGV) and FEGV were scaled by 20 percent to decrease the size of the analysis domain. The resulting domain contained one fan blade passage, two FEGV passages and four IGV passages. The grid model consisted of approximately 1.5 million nodes. Four different geometries of the exit guide vanes were investigated.

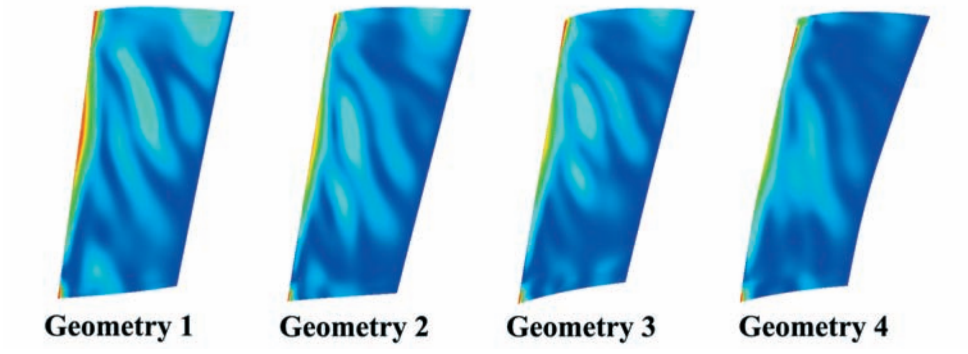
The radial design (no lean angle) was selected as the initial geometry. Vanes with 20-degree and 30-degree lean angles were chosen as the second and the third geometries, respectively. The vane with a curvilinear axis along the vane height was used as the fourth geometry type.

All CFD calculations were performed using ANSYS CFX (CFX-5.6) since this software solution provides good results for unsteady flows. An unsteady CFD calculation of the fan stage was performed and, as a result of this calculation, an unsteady pressure difference between the pressure and suction surfaces was found on the vane mid-surface. Then the pressure difference on the mid-surface was exposed to Fourier transformation. The distribution of the single blade passing frequency (BPF) amplitude along the vane mid-surface was calculated for all geometry variants.

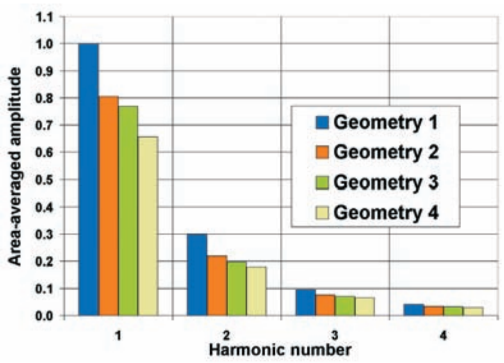
Area-averaged amplitudes of dimensionless pressure difference for the first four BPF harmonics were calculated. Amplitudes of the second to the fourth harmonics, for the fourth geometry, were reduced by 30 to 40 percent in comparison to initial geometry. This corresponds to an estimated reduction of the noise levels due to the rotor-stator interaction in the source region by 4.5 dB for the second harmonic and by 3 dB for the fourth harmonic.



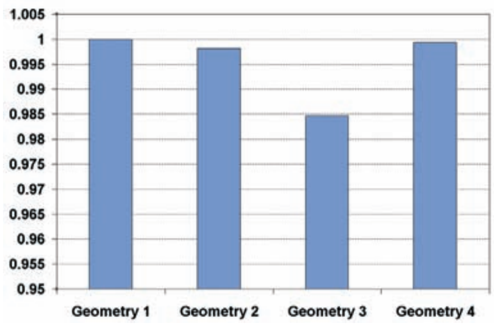
Distribution of mach number in absolute reference frame at mid-section and near FEGV surfaces



Distribution of first BPF harmonic amplitude along FEGV mid-surface

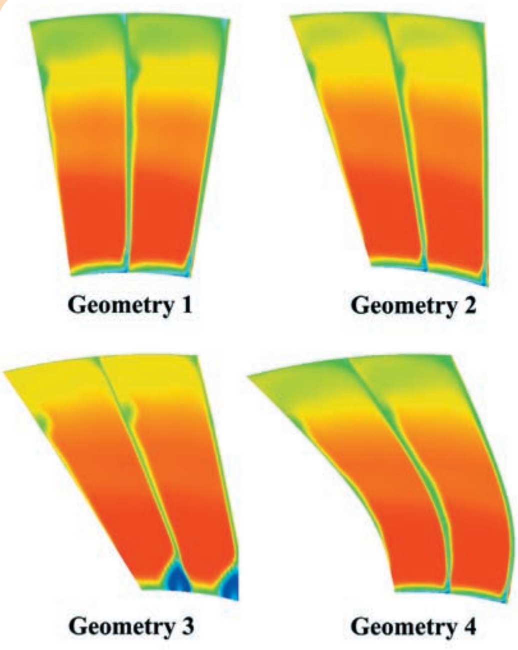


Area-averaged amplitude of unsteady pressure difference



Relative efficiency of four variants of FEGV

The fan stage efficiency level is almost identical for the first and the fourth FEGV geometries. To explain the cause of decreasing fan stage efficiency for other geometries, the distribution of total pressure at FEGV outlet section was determined for all variants. Significant total pressure losses for the third geometry are generated by a vortex flow behavior, which exists in the hub region for this FEGV shape. The fourth geometry was designed after obtaining calculation results for the third geometry and, therefore, high total pressure losses at the hub region were avoided in the fourth design. By using ANSYS CFX in this way, we were able to design an efficient fan that produced less noise. ■



Total pressure at FEGV outlet

References:

Yamagata A., Kodama H., Tsuchiya N.: CFD Prediction of Unsteady Pressures Due to Fan Rotor-Stator Interaction, ISABE 2003, No. 2003-1130.

Tsuchiya N., Nakamura Y., Goto S., Kodama H., Nozaki O., Nishizawa T., Yamamoto K.: Low Noise FEGV Designed by Numerical Method Based on CFD, ASME, Turbo-Expo 2004, GT-53239.