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NUMERICAL INVESTIGATIONS FOR OPTIMIZING THE AERO-ACOUSTICAL DESIGN OF MODERN LP-TURBINES

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Abstract

The growth in demand for aviation means that further improvements are required so that aviation can meet the ambitious customers' requirements within environmental limits. The aero-engine manufacturers are setting themselves challenging projects and research programs to decrease significantly the most important measurable indicators for environmental issues, exhaust and noise emissions. MTU Aero Engines is playing its part in more than 40 projects.

In this presentation some insights are given related to the aero-acoustical design process in the frame work of a technology program. Challenged by the objective to get a significantly quieter design than earlier LPT variants, up-graded prediction methods and a state-of-the-art 3D-CFD modelling approach have been successfully applied to perform and evaluate low noise design features. In a first step the key parameters especially for tonal noise generated by viscous wake interaction between blades and vanes have been identified. According to this, design variants and their influence on noise have been investigated numerically whereas the parametric study focus on the effects of rotor/vane numbers and 3D-design features (e.g. lean, sweep, bow) of the last turbine stage with exit guide vanes. Each cascade is computed separately; the result is presented in sound power level scale related to the turbine exit plane. Concluding from that a favourable choice of rotor/vane numbers (apart from cut-off design) combined with 3D-airfoil design can significant reduce the turbine noise by 5-7 dB. Finally the potential of noise reduction have been balanced with performance and costs. The developed low noise design measures, now technological ready, can be incorporated into new products and are applicable to optimize both existing and future turbine designs.

INTRODUCTION

Modern civil aircrafts are in average less than half as noisy as aircrafts of the 1st generation. This progress had been achieved mainly by the high bypass turbofan technology which affects an extensive success in reducing the engine noise especially the jet noise. With the increasing demand for aviation further improvements are required in reducing the environmental impact of each flight. Industry initiatives such as ACARE (Advisory Council for Aeronautics Research in Europe) have been developed to provide strategic direction for the whole aviation industry. MTU Aero Engines is committed to supporting this effort and is setting challenging targets to minimize the impact of its products on the environment. Progress towards these targets is described on the following pages.

TECHNOLOGY ROADMAP

MTU's technology programmes are grouped into three distinct time frames. Within 'near term' projects technologies are acquired to upgrade modern engines of the 2nd generation and to optimize the conventional low noise design measures which are available 'off-the-shelf'. In the framework of 'mid term' projects technologies are developed which will be available in the 10 year time frame (launched in the year 2000) for the next engine generation. The technology is currently on demonstration stage e.g. to be validated in the SILENCER (SIgnificant Lower aircraft Environmental Noise Community ExposuRe) program. 'Vision 2020' describes the range of emerging or as yet unproven technologies aimed at future generation of aero engines which will make a major contribution towards achieving the ACARE targets amongst others half current perceived average noise levels.

NUMERICAL INVESTIGATION

This chapter covers design features investigated numerically within an internal funded 'near term' project challenged by the objective to get a significantly quieter low pressure turbine (LPT). For the parametric study two calculation methods have been applied which are outlined in the following:

Semi-Empirical Method (TCLOW)

TCLOW is used to predict optional LP compressor or LP turbine noise in the pre-design phase of the development process. This approach is assumed to lead to results which are as accurate as possible both in terms of absolute levels as well as in terms of the influence on the noise characteristics of main design parameters. It's modeling accounts for the main tonal noise generation mechanism the viscous wake interaction of the blades and vanes. The general structure of the method is as follows:

The tonal noise of each azimuthal mode generated by wake interaction between each vane/blade cascade of the LPT is calculated separately assuming an empirical wake correlation **[1]** to calculate the unsteady blade loading according to Kemp and Sears **[2]**. Lowson‘s **[3]** theory is used to determine the sound power level (PWL) of each cascade. Then the impacts of all modes per cascade are being summed up to get the total PWL of each cascade at harmonics of their blade passing frequencies (BPF, 2BPF, etc.) taken into account the transmission loss due propagation through the cascades. The tonal portions are then being ordered into 1/3 octave bands and summed up to get the total PWL spectrum. An empirical directivity is applied to calculate the far field sound pressure levels (SPL).

The main input parameters are geometric data that can be taken from a cross-sectional drawing of the LP module e.g. hub and tip radii of all blades and vanes, the axial distances between them and the axial chord lengths together with aerodynamic parameters available from stationary aerodynamics calculations e.g. rotational speed, average densities, sound speeds and axial velocities at the various cascades.

CFD Method (Lin3D)

The time-linearised Euler code Lin3D originally developed at MTU for flutter and forced response calculation purposes have also the capability to optimize the aero-acoustical design for LP-compressors or -turbines. A more detailed description of the method is given in **[4]**. Here only the main features and the application to sound field calculations are described.

Lin3D calculates the unsteady flow field based on the steady solution assuming small harmonic perturbations in the flow field. Each cascade is treated separately. A wave approach is applied to describe the unsteady flow field at the axial boundaries that corresponds to the spinning mode description of the sound field in the annular duct. Non-reflecting boundary conditions are forced by eliminating the modes reflecting back into the calculation domain. The modelling allows to compute the tonal noise emission of a stator- rotor configuration generated by both, interaction of the downstream moving wake disturbances with following grids and interaction of pressure disturbances (potential field) caused by steady loading and by thickness of the grid profiles of neighboring rows. The used viscous wake model for calculating turbine noise is the same as for TCLOW. The potential flow field is derived from a steady Euler solution of the cascade generating the disturbances. A single frequency is treated, being constant within the whole flow field regime in the relative frame of reference. A straightforward method is used to take into account multiple reflections between the blade/vane cascades including scattering of modes.

The output is a set of sound pressure amplitudes of azimuthal modes radiated into the upstream and downstream directions. The sound power of each mode order is determined by integrating the axial intensity component over the cross-sectional area at the axial boundaries of the calculation regime.

Focus of Computation

The computation is based on a 6-stage LP turbine for an advanced aero-engine powering civil aircrafts. A cross-sectional scheme of the turbine, together with the blade and vane numbers, is shown in **Fig. 1**. The under lied turbine is designed to cut-off the blade passing frequency (BPF) generated by the last stage in the speed range relevant for the landing (Approach) and take-off flyover (Cutback) condition. Therefore the scope of the parametric study is to investigate the potential in reducing both cut-on tones, the 2^{nd} harmonic of the BPF (=2BPF) affected by the stator (V6) wakes interacting with the rotor (B6) and the BPF tone induced by rotor wakes interacting with the EGV. In view to investigate further beneficial measures for noise reduction the parametric variation is predominantly studied at Cutback speed.

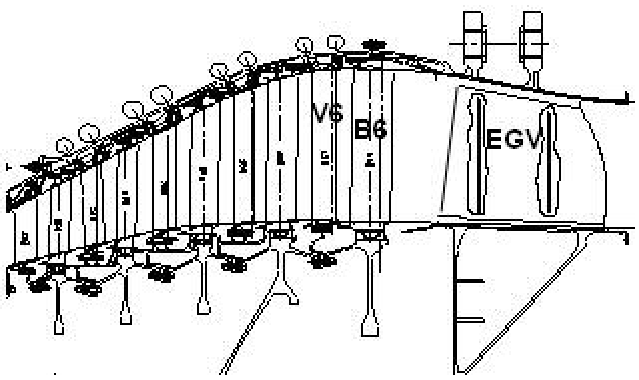

Fig. 1: LP-turbine general arrangement

Calculation Results

In a first step, calculations are performed with TCLOW by varying key parameters as vane or blade airfoil (abbr.: A/F) counts and the axial spacing between the last rotor and the EGV. This pre-processing is applied to get first trends and to make the parametric study by Lin3D more efficiently. From these results we learned that a higher vane and blade count around V6/B6=180/115 is expected to be more effective to bring the BPF tone down than an increased axial spacing up to twice the (blade) chord length. Consequently the results performed by Lin3D described in the following are concentrated to study the low noise potential by varying and optimizing the A/F counts and 3D-design. The results are presented in sound power level scale (PWL) related to the turbine exit plane.

Lin3D Results

Fig. 2 points out the influence of spacing for a favourable higher count of stator vanes and blades V6/B6=180/115 compared with reference V6/B6= 156/101. For the case "center of gravity" the axial positioning of the rows had not be changed so that for the assumption t/l=const. a higher A/F count broaden the inter-row gap. Obviously for that case the influence of spacing takes more effect than the pure increase of the A/F count. The achieved margin to reduce 2BPF is 1.6 dB.

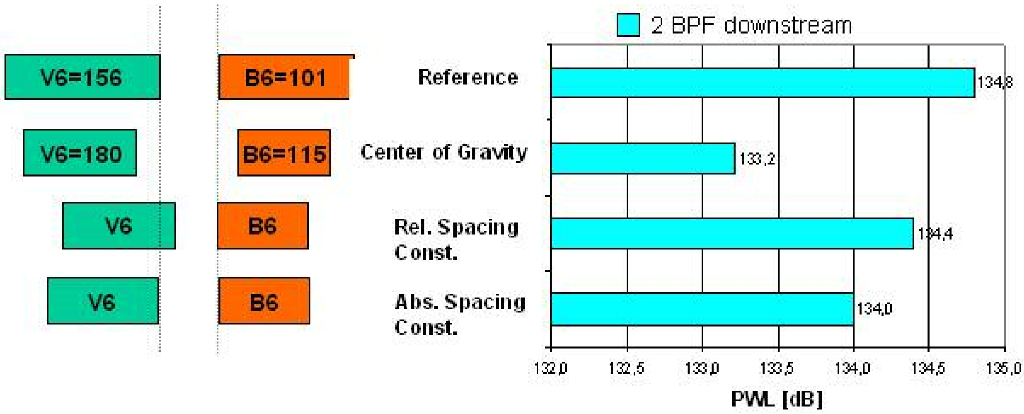

Fig. 2: Effect of increased V6 and B6 counts on 2BPF

Also the impact on noise reduction by increasing the EGV count is shown in **Fig. 3**. The BPF tone due wake interaction with the EGV is well reduced in order of magnitude 7 dB by increasing the A/F count from 13 to 18 assuming t/l=const. whereas the margin includes 0.8 dB reduction influenced by spacing.

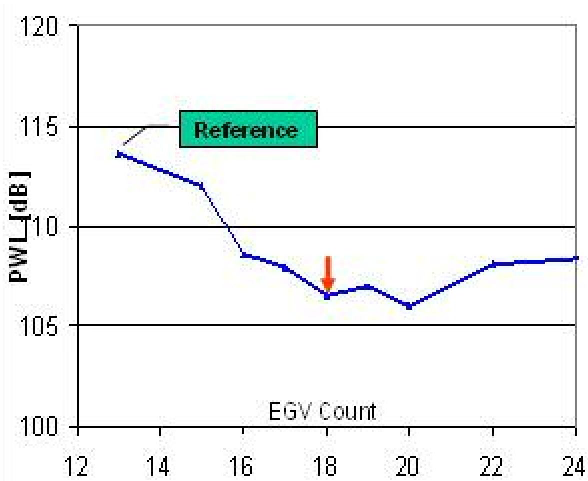

Fig. 3: Effect of increased EGV count on BPF

The results outlined in **Fig. 4** are performed by varying the lean angle of the stator vanes over the suction side based on the design of favourable higher A/F count V6/B6=180/115. Obviously the 2BPF tone due wake interaction with the blade is expected to be significant reduced by about -5 dB at 10º lean. Comparing with margins derived by varying each parameter (A/F count, lean) separately it seems that in combination they are cumulated whereas the effect of lean dominates.

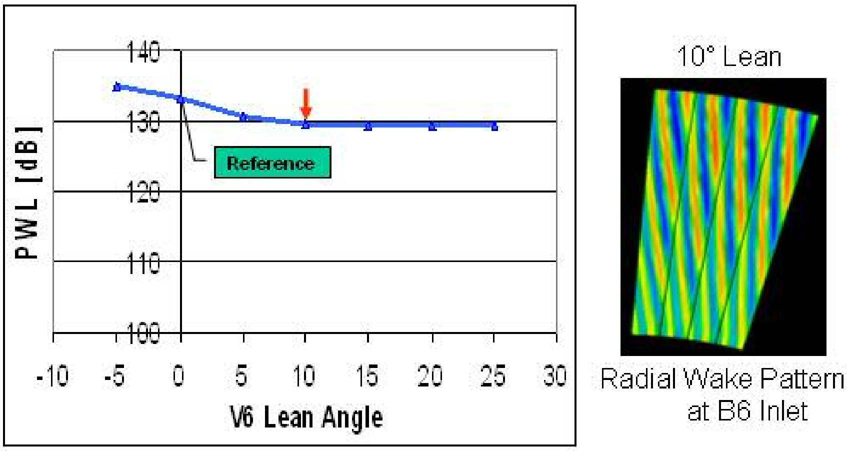

Fig. 4: Effect of leaned V6 on 2BPF

The physical relationship is depicted on the right sight of the chart. Noise reduction occurs because lean changes the number of wake intersections experienced by a given A/F row, in that case the rotor blades B6. The change in the number of intersections alters the distribution of the phase of the unsteady pressure induced on the blades as a result of stator wake impingement. Since the stator-rotor tone levels are related to the surface integrals of the blade unsteady surface pressure, the more phase variations there is in the blade unsteady pressure, the more cancellations will occur in the integral resulting in weaker interaction tones.

The results presented in the following correspond to 3D-design variations (lean, bow, sweep) at the EGV exclusively. Based on the reference A/F count EGV=13 the results derived by varying each parameter separately indicate that only for high lean angles the BPF tone is expected to be reduced significantly. An airfoil design, in turn, with axial or tangential bow is beneficial but the margin for practical bow values is predicted about 40% lower than for a modified leaned EGV. No reduction is predicted by varying the sweep angle. The combination of a favourable A/F count with an optimized leaned design with axial bow can improve the acoustical design. For the case EGV=18, lean=30º, axial bow=5mm the predicted reduction of the BPF tone is about 7 dB which is clearly driven by an increased A/F count.

Trade-off

The potential of the investigated measures have been balanced with performance and costs to evaluate their feasibility for incorporating in existing engines. Thus a high effectiveness to lower the noise is expected by increasing the A/F counts combined with lean at a minimum risk to redesign the last stage. For the case of modifying the EGV or an increase of the axial spacing between the last rotor and the EGV though requires a higher expense on designing and manufacturing but these measures are also feasible on a low risk level in every respect.

SUMMARY

Potential measures to reduce significant the wake induced tonal noise generated by the last stage and the EGV of a LPT have been carried out by a state-of-the-art 3D-CFD tool. Concluding from the computational predictions, an approximately 15% increased number of stator vanes and blades combined with 10° leaned vanes is expected to reduce the 2BPF (7366 Hz) by amount 70% (-5 dB PWL) assuming the original EGV design. The BPF (3683 Hz) is expected to be reduced by 80% (-7 dB) by providing approximately 40% more EG-Vanes designed with 10° lean and 5mm axial bow based on the referenced design of the last stage.

These technological proven features are applicable to upgrade and optimize existing and future turbine designs respectively. The findings obtained by the parametric study are helping us to move towards industry targets such as those adopted by ACARE.

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