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Extended Abstract

PAPER TITLE
"Investigation of the impact of unsteady turbulence effects on the aeroelastic evaluation process of a LPT rotor blade".

Names & Affiliations of All Authors:
Jan Ph. Heners,
MTU Aero Engines AG, Munich
Damian Vogt,
ITSM Institute of Thermal Turbomachinery and Machine Laboratory, University of Stuttgart
Christian Frey, Graham Ashcroft
Institute of Propulsion Technology, German Aerospace Center (DLR), Cologne

Name of Corresponding Author: ***Jan Ph. Heners***

Email of Corresponding Author: janphilipp.heners@mtu.de

OBJECTIVES
Aeroelasticity, Unsteady Aerodynamics, NLH-Method

BACKGROUND AND INTRODUCTION
The growing demand in turbomachinery design to evaluate the aeroelastic behavior of both turbine and compressor blades leads to an increasing need for efficient and fast numerical methods to resolve transient effects in turbomachinery flows. From an aeroelastic point of view, frequency domain approaches, as for example the nonlinear Harmonic Balance (HB) formulation proposed by [1] and [2], seem obviously to be an attractive choice to face the requirements concerning both performance and efficiency to predict aeroelastic phenomena in an industrial design process.

By choosing a reduction of the unsteady flow problem, which is the basic idea of a nonlinear harmonic (NLH) approach, naturally the question arises which unsteady effects are worth of being resolved and which can be neglected. Since taking into account the unsteady behaviour of turbulent quantities (as e.g. turbulence kinetic energy k or turbulent dissipation rate ω) can lead to numerical instabilities, these unsteady effects were often neglected in NLH-approaches in similar studies in the past by exploiting a so called frozen eddy-viscosity (μ_t) approach [3]. In contrast to [3], this work considers the unsteady turbulent effects by the consequent use of developed Lanczos-type filters as first proposed in [4] and compares the obtained pressure distributions to the solutions obtained from the nonlinear time domain solver and of the frozen-μ_t approach.

In this context, this paper evaluates the impact of unsteady effects in the considered turbulence models on the stability and capability of the chosen HB-method are discussed in the context of an aeroelastic design framework.

METHODOLOGIES
The main objective of this work is to compare different nonlinear HB-approaches - one neglecting and one considering unsteady effects in the employed turbulence models - with a conventional nonlinear solution of the unsteady Reynolds-Averaged Navier-Stokes (URANS) equations in the time domain. The finite-volume flow solver TRACE [5] allowing for the unsteady analysis of turbomachinery flows in both time and frequency domain is therefore applied to the aeroelastic analysis of a 1.5 stage LPT-configuration. Since the applied HB-approach may be interpreted as a reduced approximation limited to the quality of the associated nonlinear formulation in the time domain, the solution of the conventional unsteady time domain solver is used in this work as a benchmark for the applied HB-solvers. Both time and frequency domain methods solve in this context the URANS problem for the vector of conservative flow variables (e.g. density ρ, momentum ρu and total energy ρE) by making use of an residual formulation.

The different solver approaches rely on equivalent settings concerning discretization schemes and enable a van-Albada limiter to prevent undesirable oscillations in the presence of shocks. All computations consider turbulent effects by including the well known k-ω- turbulence-model and make use of a proper transition model [6] to resolve the transition process from laminar to turbulent in the boundary layer.

In order to avoid unphysical oscillations in the turbulent quantities caused by Gibb's phenomenon in the chosen HB-approach, a filter method based on the Lanczos-filter is developed and applied in the course of the HB-simulations considering the unsteadiness in the turbulent quantities k and ω. During the reconstruction from frequency to time domain, the ringing associated to Gibb's phenomenon causes critical overshoots in both k and ω potentially leading to negative values and affecting the stability of the numerical algorithms in an unfeasible and unphysical fashion. As in signal processing, this problem can be met by the use of special filter techniques during the inverse Fourier-transformation (IFT) avoiding overshoots in presence of discontinuities or high gradients in the signal as e.g. for k and ω in the wake of an upstream blade row. In the course of this work, the impact of the application of the developed Lanczos-filter on the solution of the flow field and on the unsteady surface pressures of the rotor blade in particular, is therefore also analyzed and discussed in an aeroelastic context.

MAIN RESULTS

In order to demonstrate the capability of the developed filter method and to estimate the influence of unsteady turbulence effects, unsteady simulations of a 1.5 stage LPT configuration are performed. In a subsequent step, the pressure fluctuations associated to the first harmonic of the engine order related to the upstream vane row are analyzed on the surface of the rotor blade row.

The resulting fluctuation amplitudes of the surface pressure on the suction side of the rotor are shown in Fig. 1 where high amplitudes are colored in red and areas of low amplitudes are colored in blue. The benchmark solution of the conventional nonlinear URANS-solver in the time domain is shown on the left. Furthermore, the solution of the HB-solver neglecting unsteady effects in the turbulence model by referring to a frozen μ_t-approach is presented in the middle. Finally, the result for the HB-solver considering unsteady turbulence by taking advantage of the developed filter method is shown on the right of Fig. 1. The pressure amplitudes obtained from the frozen μ_t- approach in the middle of Fig. 1 show major differences in both quality and quantity compared to the time-domain solution on the right. In particular, areas close to the trailing edge show large deviations in the surface pressure amplitudes.

SUMMARY AND CONCLUSION

The results presented in this work underline on the one hand the importance of considering unsteady effects in the turbulence kinetic energy k and the turbulent dissipation rate ω while pursuing a frequency domain approach in an aeroelastic analysis framework. Including the unsteadiness in the employed turbulence model leads to results of higher quality and higher physical plausibility in the analysis of unsteady pressure distributions representing a key aspect of the aeromechanical evaluation process. In terms of reduction of the flow problem to be solved in turbomachinery, it is therefore not feasible to neglect these unsteady effects during the solution process in order to save numerical effort and computational time.

On the other hand, it is shown, that the numerical behavior of the analyzed HB-solver concerning stability and robustness can be affected in a positive way by application of a developed filter method in the IFT called during the solution process of the frequency domain solver. The capability of this advanced solution technique is demonstrated and approved by the application to a 1.5 stage LPT configuration being representative for common aeroelastic design tasks in an industrial environment.

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