

Detached-Eddy Simulation of a Linear Compressor Cascade with Tip Gap and Moving Wall

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Results are presented of Detached-Eddy Simulation (DES) based on the Wilcox $k-\omega$ turbulence model of the linear compressor cascade with a tip gap and moving endwall (“Virginia Tech Cascade”) intensively studied in the experiments of W.J. Devenport with co-workers at the Virginia Polytechnic Institute. The flow is extremely challenging for DES in terms of both physics and numerics. First, due to the geometry peculiarity (narrow tip gap), simulations require a “protection” of the turbulent boundary layer on the moving endwall from the premature switch of DES to its LES mode. Although a tool for such a protection is currently available, as of today, it has been tested only on some relatively simple flows and it is not warranted that it works properly in the complex real life flows. Second, at least at some velocities of the endwall movement, the tip leakage vortex, after crossing the inter-blade passage, may interact with the boundary layer of the “next” (downstream) blade. In other words, the vortex with some “turbulent content” (resolved turbulence) may interfere with the boundary layer treated in RANS mode. This situation is not typical for DES applications in the external aerodynamics and it has not yet been studied in depth. Finally, an interaction of the tip-clearance vortex and tip separation vortex with the trailing edge vortices is possible as well, which imposes severe demands on the numerical resolution in the blades’ near wake region. Thus the flow is a valuable test case for evaluation of DES in turbomachinery, in general, and of its capability of predicting of highly loaded blade rows in near stall and stalled airfoil performance, in particular.

Along with DES, baseline, Steady RANS (SRANS), solutions are obtained with the use of two turbulence models (one-equation model of Spalart-Allmaras and Wilcox $k-\omega$ model) on two grids, “coarse” (with ~1.8 million nodes) and “fine” (with ~5 million nodes).

All the computations are conducted with the use of the NTS general purpose CFD code.

A general conclusion based on the SRANS computations performed on the two grids is that the approach does not predict the flow with a sufficient accuracy, and that the discrepancy

with the data is most probably “objective”, i.e., is caused by a deficiency of turbulence modeling rather than by numerical inaccuracies.

As far as DES is concerned, with the coarse grid it fails to support any fine-scale turbulent activity. In contrast to this, with the fine grid, it does sustain turbulence in the LES regions of DES and provides qualitatively correct representation of all vortical structures typical to the flow. This is supported by Fig.1, where we compare the snapshots of the swirl isosurface from our DES with the fine grid LES of CTR [1]. In terms of agreement with the experimental data on the mean flow characteristics, although DES is close to the CTR LES performed on the much larger grid (see Figs.2, 3), it still does not provide a satisfactory representation of the data. It should be also noted that in this respect DES is not superior over the SRANS prediction on the same grid (not shown), which is incomparably less costly computationally. Therefore, a search of the ways to improve DES capabilities, other than a straightforward grid-refinement that seems to be impractical from the industrial application standpoint, should be continued. One of them is an improvement of the resolution provided by LES on a given grid via a more rational choice of the subgrid length scale accounting for the grid anisotropy and peculiarities of the velocity field.

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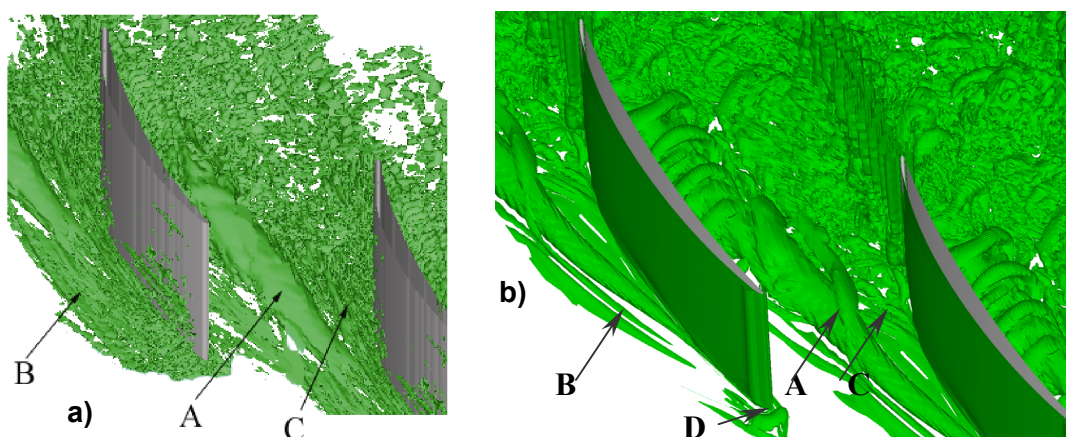


Fig.1. Swirl (λ_2) iso-surfaces from instantaneous flowfields of LES [1] (a) and from present DES (b) showing the major vortical structures: A – Tip-Clearance Vortex (TCV), B - counter-rotating passage vortex, C – trailing-edge vortices, D- horseshoe vortex

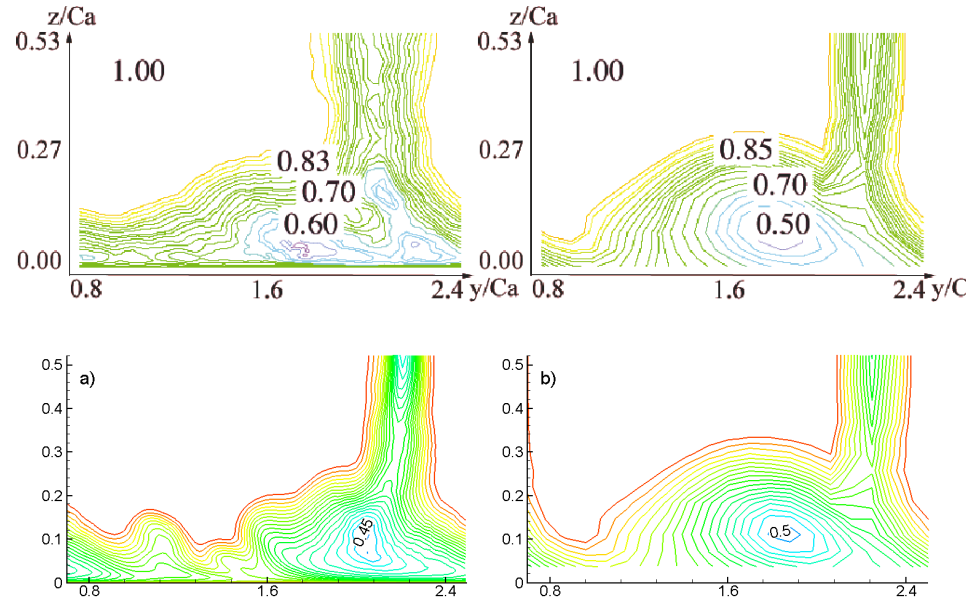


Fig.2. Comparison of mean streamwise velocity normalized by the local maximum velocity at $x/c_a = 1.51$. Contour levels are from 0.5 to 1.0 by 0.025.
Top frames: fine grid LES [1] (left), experiment [2, 3] (right).
Bottom frames: current DES (left), experiment [2, 3] (right).

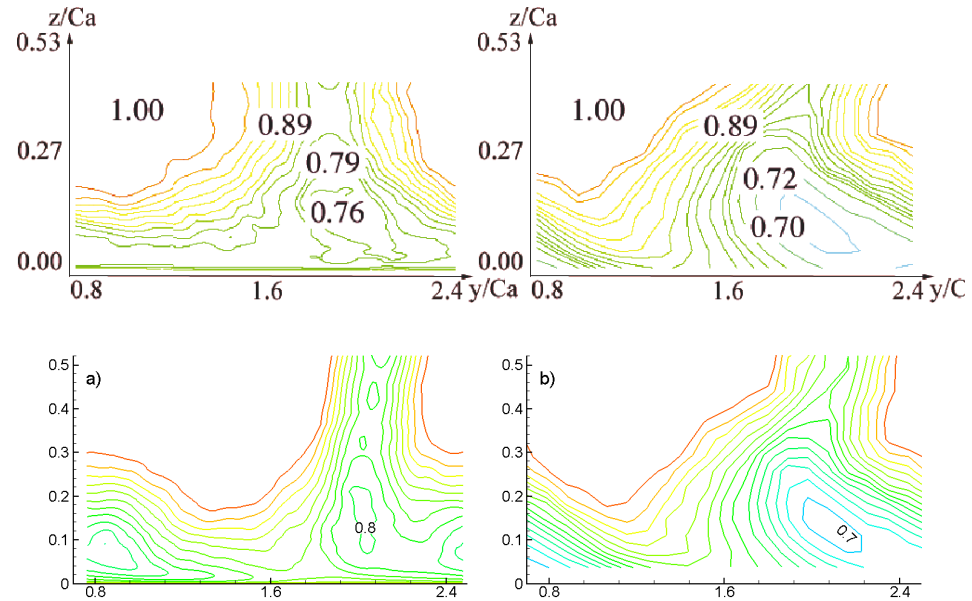


Fig.3. Same as in Fig.2 at the wake section $x/c_a = 2.74$

References

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