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über

"Recent advances in control of laminar shear flows gained by direct numerical simulation"

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Recent advances in control of laminar shear flows gained by direct numerical simulation

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Examples of flow control in subsonic and supersonic unstable shear flows investigated by high-order DNS are discussed. For **subsonic swept-wing flow** 'smart' suction for laminar flow control is presented that combines suction through micro-slits and the technique of Distributed Flow Deformation where the flow is stabilized by the distributed excitation of tightly-spaced stable crossflow vortices. Results for suction panels are shown that have a significantly better performance than the otherwise ideal homogeneous suction at the same suction rate. Moreover, 'pinpoint suction' can be used to directly attack secondary instability of nocent crossflow vortices.[1-2] In a second example the **basic sound generation past a jet engine** is shown. The simulation includes the nozzle end, modeled by a finite flat splitter plate with different Mach numbers above and below the plate. Behind the nozzle end, a combination of wake and mixing layer develops. Due to its instability, roll-up and pairing of spanwise vortices occur, with the vortex pairing being the major acoustic source. As a first noise-reduction approach, rectangular notches at the trailing edge are investigated. They generate longitudinal vortices and a spanwise deformation of the flow downstream of the nozzle end, leading to an early breakdown of the large spanwise vortices and accumulations of small-scale structures. The emitted sound is lower than without notches.[3-4]

In the first example of supersonic flow **effusion cooling in a hypersonic boundary-layer flow** by discrete slits and holes is investigated. For an adiabatic Mach-6 boundary layer it was found that two-dimensional slits are better than holes due to the lower blowing velocity. Slit blowing causes a destabilization of 2nd-mode disturbances, and a complete stabilization of 1st modes despite the generated maxima of the spanwise vorticity inside the boundary layer. Hole blowing gives rise to counter-rotating streamwise vortices, with a noticeable laminar-flow destabilization only for large spanwise hole spacings.[5] The **effect of discrete roughness on a hypersonic boundary-layer flow** is discussed in the second case. BiGlobal secondary linear stability theory is applied to a Mach 4.8 flow altered by three-dimensional 'pizza-box' type roughness elements. The steady primary state in flow crosscuts is extracted from accompanying spatial DNS employing the immersed-boundary technique for the roughness element that roughly is 0.5 boundary-layer thicknesses high. A comparison of the stability-theory results past the element with unsteady DNS, where time-periodic perturbations are introduced upstream of the roughness element, shows excellent agreement for the amplitude distribution. The downstream recirculation region and the horseshoe vortex are found to be of minor importance regarding flow destabilization, rather the trailing vortices and the subsequent streaks lead to strong convective shear-layer instabilities in the wake of the element. The two-dimensional theory helps to verify and validate DNS for this complex flow and allows for efficient stability-parameter scans.[6]

[1] M.J. Kloker (2008) Advanced laminar flow control on a swept wing – useful crossflow vortices and suction. *AIAA-2008-3835* (Seattle), 10 pages.

[2] G. Bonfigli, M.J. Kloker (2007) Secondary instability of crossflow vortices: validation of the stability theory by direct numerical simulation. *J. Fluid Mech.*, Vol. 583, pp. 229-272.

[3] A. Babucke, M.J. Kloker, U. Rist (2008) DNS of a plane mixing layer for the investigation of sound generation mechanisms. *Computers & Fluids 37*, 360-368.

[4] A. Babucke, M.J. Kloker, U. Rist (2008) DNS of a square-notched trailing edge for jet-noise reduction. *AIAA-2008-763* (Reno), 11 pages.

[5] J. Linn, M.J. Kloker (2009) DNS of film cooling in hypersonic boundary-layer flow. In *High Performance Computing in Science and Engineering '08* (eds. Nagel, Kröner, Resch), Springer, 16 pages.

[6] G. Groskopf, M.J. Kloker, O. Marxen, G. Iaccarino (2008) BiGlobal secondary stability theory for high-speed boundary-layer flows. *Center for Turbulence Research (Stanford University) – Proceedings of the 2008 Summer Research Program*, 17 pages.