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A Path to Enabling a Wider Use of Controlled-Accuracy 3D CFD-CHT in Industry and Academia

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In RANS-based CFD, meshing remains a time-consuming part of any 3D simulation. Automatic mesh generation remains a holy grail of CFD, with each situation still requiring considerable human intervention before resulting in an acceptable grid. No matter how many tools are introduced to facilitate mesh generation around complex geometries, the fact remains that CFD and CHT have “singular features” such as boundary and thermal layers, shock waves, vortices, shear layers, and separated flows that render the coupled and highly nonlinear Navier-Stokes equations ill-conditioned. These singular phenomena cannot be identified nor localized before launching a solution and hence no grid could claim to be able to, without knowing where the locations of the particular physics are, capture all such features with great fidelity. The “systematic or brute force refinements” to reach a mesh-independent solution advocated by some CFD standards committees and mandated by many scientific Journals will be shown to be akin to “looking where the light is instead of where the keys are”. These approaches may, at great cost, gradually lead to a better solution but by no means to an optimal one. The lecture will strive to demonstrate that the most logical, and perhaps only, way of building efficient grids ought to be by coupling mesh generator and solver.

What is often not realized is that CFD is a 1D science! That statement may sound exaggerated but when given due consideration, may be quite enlightening:

- A 3D boundary or thermal layer has a steep gradient normal to the body and then much lower gradients in the other 2 directions;
- A 3D shock wave has a steep gradient across it and then much lower gradients in the other 2 directions;
- The same can be said for vortices, shear layers, separated flow, and other singular phenomena.

Thus, refining a grid systematically or solely based on a unidirectional gradient may be a misuse of computational resources. It is, more or less, an academic exercise not suitable within an industrial context.

The lecture will present:

- A posteriori error estimator(s) based on the Hessian of the solution, using multiple criteria in combination for multidisciplinary problems,
- Striking examples from a wide range of single-discipline and multi-disciplinary low- to high-speed (subsonic, transonic, supersonic, and hypersonic) flow problems, magnetohydrodynamics, and in-flight icing,
- A demonstration that no matter what the initial grid is (coarse, fine, very fine), the final adapted anisotropic grid(s) will be statistically identical,
- A demonstration that by the often-advocated systematic refinement to demonstrate mesh independence, the finest grid may yield a worse solution of localized quantities of interest such as peak heat loads or shear stress!
- Finally, an often-neglected area of CFD is body surface smoothness. Quite often mesh optimization is applied to a grid with a surface tessellation still in need of smoothing “before” solving. The same Hessian adaptation criterion can be applied to the surface with a substantial improvement to surface integral quantities such as lift and drag, a fact not recognized in recent comparison workshops that resort to brute force refinement.