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ABOUT THE GENERATION OF UNSTRUCTURED MESH FAMILIES FOR GRID CONVERGENCE ASSESSMENT BY MIXED MESHES

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Abstract. This work describes properties of the mixed mesh approach that are especially suitable for generating families of meshes to assess the grid refinement convergence of CFD solvers. The paper outlines how a regular grid refinement is achieved throughout the domain. The distributions of characteristic grid quality metrics are compared and a grid convergence study is outlined for a commonly used case for outer aerodynamics, the Boeing CRM configuration of the 5th AIAA Drag Prediction Workshop.

1 INTRODUCTION

The assessment of the order of a simulation method is a crucial step during the verification and validation process of the simulation software. Even the best mathematically derived formulation has to prove the rate of convergence with increasing mesh resolution for designated applications.

For applications of CFD for aerodynamics of aircrafts a series of five workshops has been organized under the governance of the American Institute of Aeronautics and Astronautics (AIAA) [1]. A major focus of the comparisons of solvers for simulation accuracy was laid on the grid convergence, for which families of grids have been provided, both structured and unstructured ones. A major conclusion of all workshops has been the highly demanding generation of unstructured mesh families.

While for structured meshes the generation of self-similar grids with different but regularly refined grid resolutions is straight forward, for unstructured hybrid meshes this is a more complicated task. Due to the – in most cases – fully automatic generation a distinct control on local mesh resolution and there influence into other parts of the mesh is hard to control.

This paper outlines the usability of the mixed mesh approach for the purpose of generating families of meshes for grid convergence assessment. Block-unstructured mixed meshes provide structured meshes in the near field of the aerodynamic boy where viscous effects dominate and a high resolution normal to the wall is needed. In contrast to pure block-structured meshes, limitations of topologies are overcome by locally using unstructured mesh element types, mainly prismatic elements. For the outer field an a priori defined anisotropic field triangulation is applied to allow for maximum flexibility and to minimize the effort of user input.

2 THE MIXED MESH FRAMEWORK

The meshing framework used is the formerly structured multi-block grid generation MegaCads developed at DLR [2]. In recent years unstructured capabilities have been introduced. Among these are a parabolic marching procedure to generate prismatic layers based on the same mathematical approach as used in the elliptic smoothing of structured blocks [3][4], the linking to a number of volume triangulation codes including the SIMMETRIX software [5] used within this work, and a memory efficient way to specify a priori a smooth anisotropic metric field for the triangulation smoothly adopting to the underlying structured and quasi-structured elements [6].

Figure 1 shows a view on the grid family around the Boeing Common Research Model (CRM) [7] depicting the meshing strategy by coloring the different types of grid elements. The boundary layer regions of the wing are meshed with structured mesh blocks. The implicit anisotropy of the structured meshes allows for much less grid points than in unstructured meshes while retaining a high grid density in circumferential direction. For the grid family the number of cells in each direction is multiplied by a factor of 1.5 for adjacent grid levels, while the cell sizes are reduced by the same magnitude. The portion of the fluid volume meshed by structured elements is not changed in order to obtain self-similar meshes

The wing tip and the fuselage are covered by prismatic elements, since for these objects usually the generation of a suitable block-structured topology is more challenging, sometimes impossible. The outer flow field is filled with tetrahedrons. The used method derives a smooth anisotropic metric field based on the anisotropy of the adjacent structured hexahedrons and quasi-structured prisms. This anisotropic metric field is inherently responsible to achieve the self-similarity and grid family properties in the unstructured domain of the meshed volume.

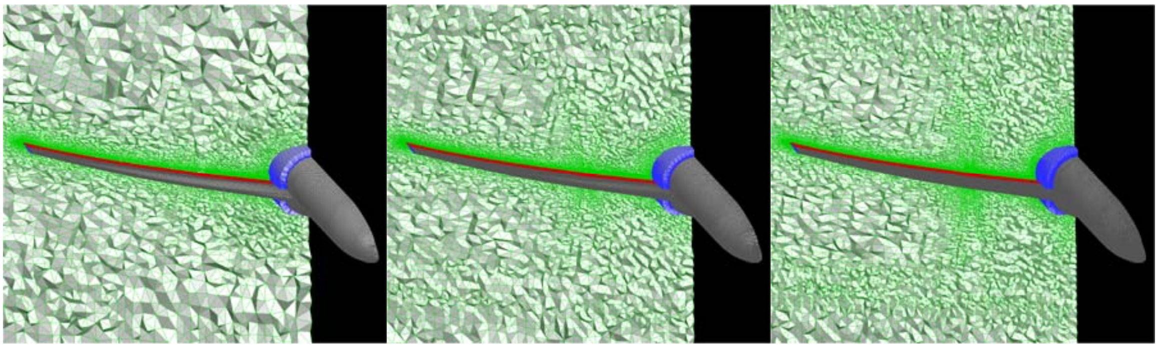

Figure 1: Family of grids around the Boeing CRM configuration, left to right: coarse – medium – fine; colors indicate cell type: red=hexahedrons, blue=prisms, green=tetrahedrons

3 GRID CONVERGENCE OF THE BOEING CRM CASE

3.1 Grid quality indicators

The selection of indicators for a priori grid quality assessment has to respect the type of solver later on used for the simulation. For finite element methods (FEM) most commonly used are indicators that look for the shape of single elements and detecting badly shaped cells like slivers, needles, and hats that inherently disrupt the numerical accuracy of the solution. For the targeted finite volume (FVM) flow solver these element based metrics are of less significance since for the flux computations needed the relationship of neighboring elements is at least as important. Knupp [8] introduced algebraic grid quality metrics based on the Jacobian of elements, which are the transformation matrices from computational into physical space. They are more representative, since the averaging of the cell based Jacobians for a common grid node provide an indication for the smoothness of the surrounding cells. In the following two of the metrics provided by Knupp's MESQUITE library are used to show the comparability of the generated grids in the sense of self-similarity for a family of grids. **Figure 2** shows the histogram of the variations of the "local size" quality metric for the three generated meshes around the Boeing CRM. A value of one indicates that all elements surrounding a grid node have the same size. The counts of grid nodes in the histogram are normalized by the number of overall grid points and are plotted on a logarithmic axis to more precisely inspect the behavior of the different grid levels at values of the lower quality metric values. The figure shows that the distributions of the "local size" quality metric is nearly identical for all three mesh levels indicating that the characteristics of the grid are not depending on the grid size in this respect. **Figure 3** shows a histogram for the vertex based condition number, which is an average of the condition numbers of the Jacobians of the elements surrounding a grid node. Since the targeted meshes are anisotropic high values of are expected since the value directly reflects the anisotropy of the grid. The histogram shows that the generated grids show similar distributions of anisotropy in the mesh and therefore the needed self-similarity.

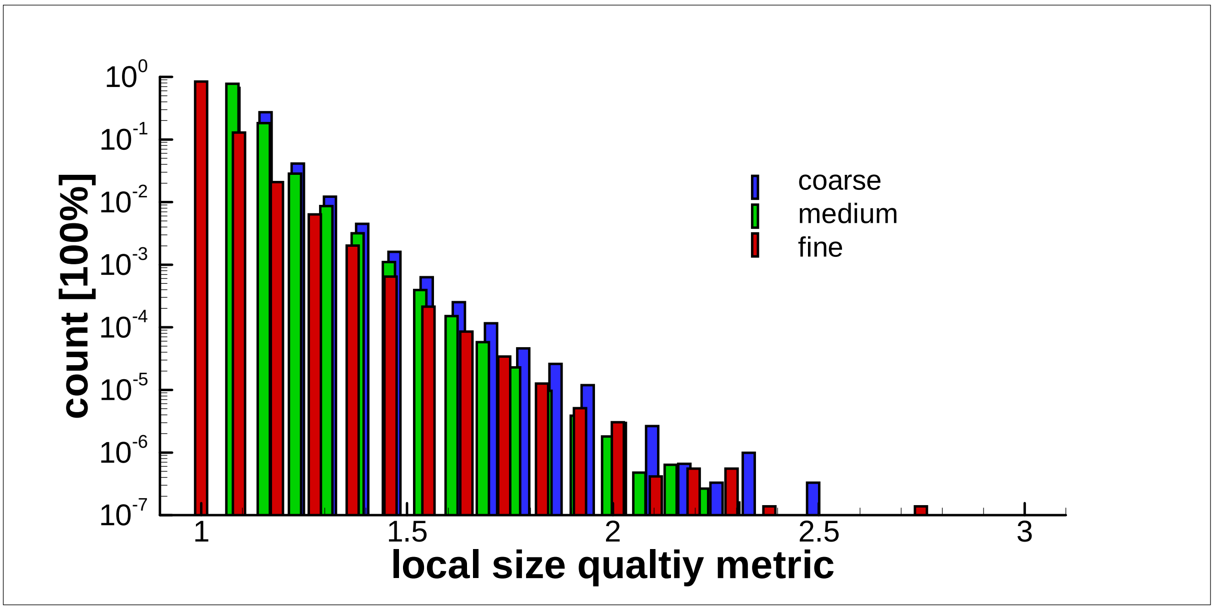

Figure 2: historgamms of local size variation of the cells around a grid node for three mesh levels of the grids around the Boeing CRM.

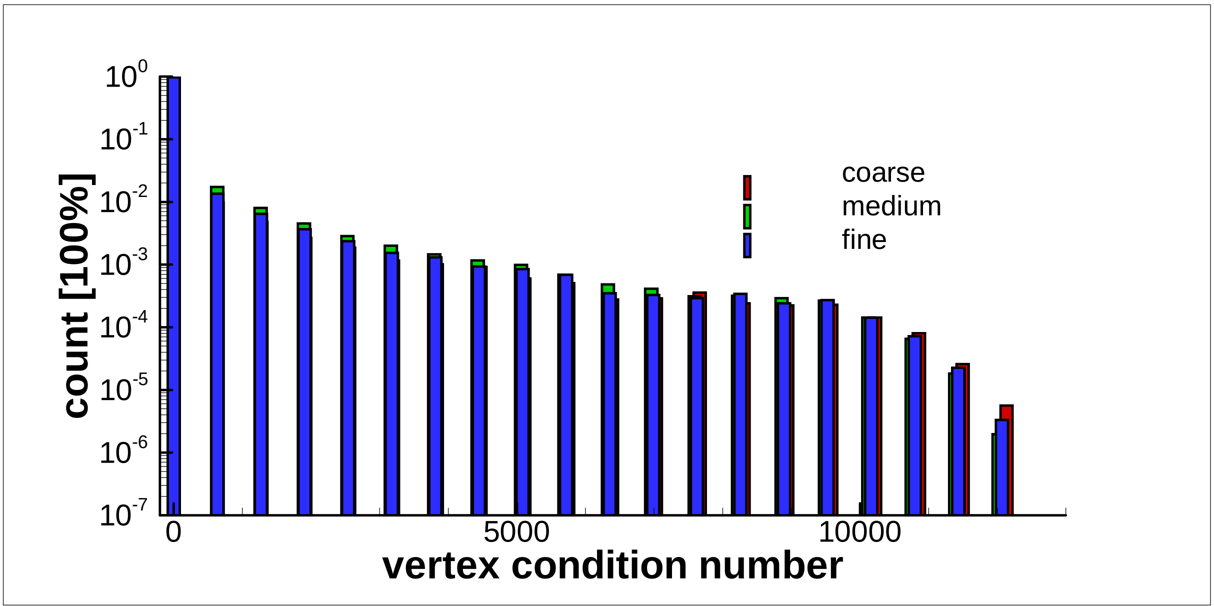

Figure 3: Histogram of the vertex based condition number variation for three mesh levels of the grids around the Boeing CRM.

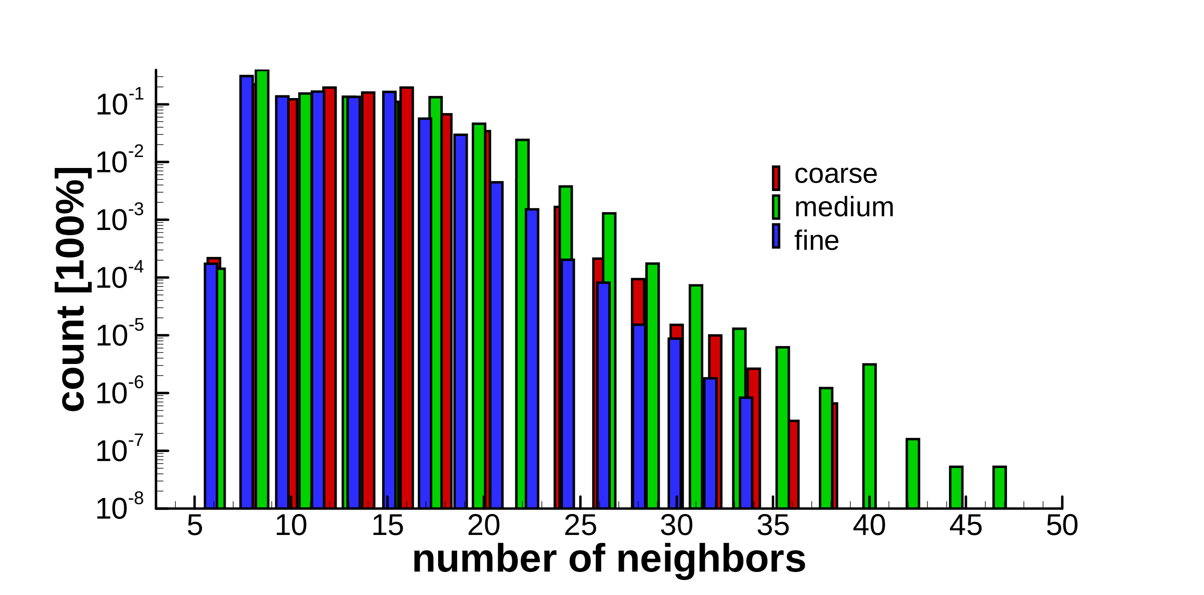

Figure 4: Histogram of the variation of the number of neighbors of a grid node for three mesh levels of the grids around the Boeing CRM.

Another important indicator of the suitability of a grid for CFD is the local number of neighbors to a grid node. Meshes often degrade the simulation quality by having local hot-spots of the neighboring node count. Especially hybrid meshes where the anistoroby of quasi-structrured cells is not respected can have up to 200 neighboring nodes and the flux computations are comprised by this. **Figure 4** shows the distribution of the number of neighboring nodes and – again – shows that the characteristics of the three mesh levels are very similar.

3.2 Grid convergence assessment

The final contribution will contain an assessment of the grid convergence of the second order finite volume CFD solver TAU. The assessment will be made based on overall aerodynamic characteristics and on the contributions of local parts to show the suitability of the mixed mesh approach for such studies in global and local effects.

4 CONCLUSIONS

The mixed meshing approach allows for the generation of mesh families for the assessment of grid convergence behavior of CFD solvers. The use of block-structured cells in near wall regions inherently possesses this capability. The derivation and usage of an adjacent smooth anisotropic metric field for the flow field triangulation promotes the self-similarity of the structured part of the mesh into the unstructured part.

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