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ACCURATE INCORPORATION OF NON-TO-POINT MATCHED COMPUTATIONAL BLOCKS INTO FULL NAVIER-STOKES COMPUTATIONS ON STRUCTURED GRIDS

*** Boris Epstein**[1] **and Sergey Peigin**[2]

[1] The Aacademic College of Tel-Aviv-Yaffo
64044, Tel-Aviv, Israel
epstein@mta.ac.il

[2] Israel Aerospace Industries
70100, Ben-Gurion Airport, Israel
speigin@iai.co.il

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ABSTRACT

The paper handles the problem of accuracy loss of CFD solutions stemming from the use of computational domains with a heterogeneous discretization within the sub-domains. The problem occurs, e.g. where high-order numerical schemes are tailored with low order schemes, or where the same order approximations are applied to blocks with different grid resolution. The problem is especially troublesome for implementation of high accuracy CFD solutions since 3D tailoring of heterogeneous discretizations frequently brings loss of accuracy not only locally but on a global scale.

Specifically we focus on the following case. Consider a structured multi-block computational grid around an aerodynamic configuration intended for the solution of full Navier-Stokes equations. Structured grids have important advantages which make them highly competitive for practical CFD. They may provide high accuracy solutions without need in complicated data structures (such as linked lists or graphs) for their implementation, which make them suitable for high efficiency parallel computing [1]. Structured grids are also indispensable for CFD driven aerodynamic shape design since they allow for fast and consistent grid movement.

Structured grids are easy to compose of point-to-point (PP) matched blocks. Unfortunately, the use of PP grids for complex aircraft configurations becomes problematic due to the following reason. The nature of PP matching requires the propagation of the discrete topology of a block from aircraft surfaces to the outer boundaries of the grid (”computational infinity”). For complex aircraft configurations, the construction of such grids requires considerable human resources in terms of time and expertise. The regularity of the grids is frequently low, and the overall number of grid points becomes prohibitively high.

The above considerations brought a number of researchers, especially in industry, to the idea of using non-point-to-point (NPP) structured grids that is grids in which block boundaries are not necessarily point-matched. NPP grids may significantly facilitate use of structured grids, but the approach appeared somewhat flawed for the following reasons. Firstly, in order to ensure the conservativity of numerical fluxes, it is necessary to tailor neigbouring blocks with different cell partition. This usually requires the

exact adjustment of neighbouring boundary block cells, located from both sides of the joint boundary. The corresponding grid-generating procedure becomes sophisticated in the three-dimensional case. The second class of problems is associated with the implementation of high accuracy characteristic numerical schemes like in [1]-[3] in the case where the neighboring blocks possess different grid resolution on the both sides of the joint boundary. To maintain a high-order discretization across the inter-block boundary, the current flow solution is usually interpolated which inevitably introduces high amounts of artificial dissipation and may severely affect the accuracy of computations.

Within the framework of a time-iterated finite-volumes scheme of [2] in this work we propose a new approach to the problem of NPP. In the vicinity of each NPP inter-block boundary, we form time-independent auxiliary clusters of minimum volume in such a way that 1) each cluster contains boundary cells from the neighbouring blocks of different resolution 2) the cluster boundary is composed of cell faces which belong to only one of the neighbouring blocks. Thus the original inter-block boundary is ”swallowed” by the cluster. In each time step, the residual computation is done in three stages. In the first stage, the residuals are calculated at the ”non-boundary” (regular) numerical cells, i.e. at the cells which do not belong to any of the above described clusters. Note that such cells constitute the vast majority of cells. The calculation is performed in a regular way as if the grid was of PP type (specifically, by means of the ENO flux interpolating scheme, see [2]). In these cells, no information ”across the block boundary” is needed for the residual calculation, so the block localized numerical procedure is not affected by the distinction in grid resolution between the neighbouring blocks.

It is important that already in the course of the first stage, numerical fluxes were also determined at the outer boundary of the above clusters since this boundary is composed of faces of the regular cells. In the second (”collection”) stage, the cluster residuals are computed. This is feasible since the numerical fluxes at the cluster boundary, are available from the first-stage computation stage as just explained in the previous paragraph. The overall cluster flux balance is thus composed of the fluxes at the cell faces which constitute the cluster boundary.

In the last, third (”distribution”) stage, the residuals at the ”irregular” cells which belong to one of the clusters, are determined by minimizing algebraically the flux disbalance in an appropriate norm. Note that the optimization is performed for each cluster separately, and thus the number of optimization parameters is low. After the third stage, the residuals are calculated at all numerical cells of the composed grid, and the solution is advanced ”in time” by the usual time integrating procedure.

The method allows to automatically preserve the conservativity of the numerical scheme by placing simple constraints upon the optimization process. As a result, the cell tailoring procedure usually typical of NPP schemes became redundant. The hybrid calculation of residuals did not change the stability properties of the basic ENO numerical scheme, and ensured sufficiently high level of accuracy on actually less resolved grids. The time expenditure for the residual handling at ”irregular” cells (Stages 2 and 3) appeared negligible and did not harm the high parallelization efficiency of the method. The results which include a number of numerical tests for two-and three dimensional wings indicate accuracy and robustness of the method and its applicability to full-scale Navier-Stokes computations in engineering environment.

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