A Method for Geometry-Sensitive, CFD Solver Independent Mesh Adaptation

N. Wyman*, P. Galpin** and T. Hansen***

Corresponding author: nwyman@cadence.com

* Cadence Design Systems, Inc., USA.
** ISimQ Ltd, Canada.
** ISimQ GmbH, Germany.

Abstract: A new method for geometry-sensitive CFD solver-independent mesh adaptation that respects a priori specified boundary layer mesh refinement is presented. The method seeks to control numerical error in the discrete solution by minimizing interpolation error based on the CFD solver discretization. An adaptation sensor, including control over mesh size increases with each adaptation, is used to define a target size field for an updated discrete mesh conforming to the underlying CAD geometry.

Keywords: Mesh Adaptation, Computational Fluid Dynamics.

1 Introduction

Mesh generation and, in particular, fit-for-purpose mesh generation is repeatedly stated as a bottleneck in the CFD simulation workflow. The NASA CFD Vision 2030 Study [1] outlines a basic set of capabilities for CFD by the year 2030 including management of numerical errors and uncertainties along with a high degree of automation for the overall analysis process.

2 Problem Statement

Unstructured meshing can automate much of the mesh generation process, however controlling numerical errors due to the discrete mesh requires adaptation to the developing solution. A mesh adaptation procedure has been developed which utilizes a pre-defined mesh topology with re-meshing to an updated continuous size field. Adherence to the underlying geometry is maintained and mesh quality is ensured.

From a cubic fit of solution values, an estimate of interpolation error, ε, and thus the truncation error for the CFD solver discretization can be defined [2]:

$$\varepsilon\left(\frac{h}{2}\right) = |\emptyset^L - \emptyset^H| = \frac{h}{8}\left|\left[\frac{\partial\emptyset}{\partial x_2} - \frac{\partial\emptyset}{\partial x_1}\right]\right| \qquad (1)$$

We define a scalar adaptation sensor proportional to the tensor truncation error estimate, ε, as the product of the local edge length raised to an exponent, *p*, and the difference of the derivatives parallel to the edge vector, h. The exponent, *p*, provides short edge protection at solution discontinuities (e.g. shocks). Another important property of p>1 is to ensure that multiple scales are resolved in the solution.

$$S = \left|\vec{h}\right|^p \left|\left[\hat{\vec{h}} \cdot \overrightarrow{\frac{\partial\emptyset}{\partial x_2}} - \hat{\vec{h}} \cdot \overrightarrow{\frac{\partial\emptyset}{\partial x_1}}\right]\right| \qquad (2)$$

Knowing the current edge length and S value, the value for the updated edge length, h_target, can be directly computed to meet a threshold sensor value, S_thresh, as:

$$h_{Target} = |\vec{h}| \sqrt[p]{\frac{S_{Thres}}{S}} \qquad (3)$$

The selection of the sensor threshold, S_thresh, allows control of the adapted mesh size by utilizing the concept of continuous mesh complexity introduced by Loseille and Alauzet [3]. Locations in the current mesh above S_thresh are exported as a point cloud used as input to the continuous size field.

To validate the mesh adaptation approach, heat transfer of a round jet impinging on flat and wavy heated plates (with comparison to a structured hex mesh sequence). Application in industrial settings will be demonstrated using external automobile and axial turbine time-accurate RANS simulation.

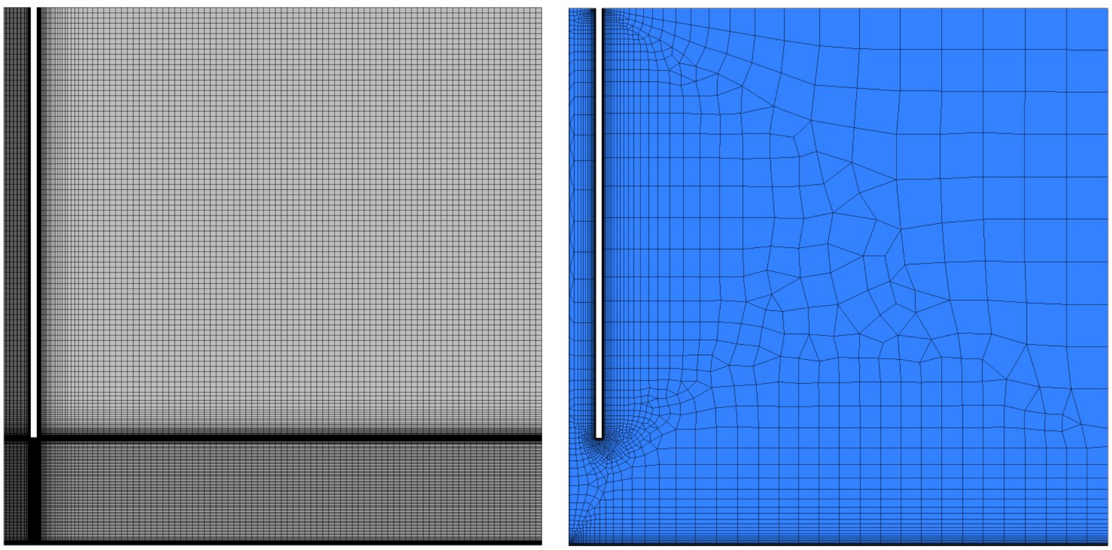

Figure 1: Medium baseline structured hexahedral (left) and initial unstructured hex-dominant (right) meshes for the axisymmetric jet impingement case.

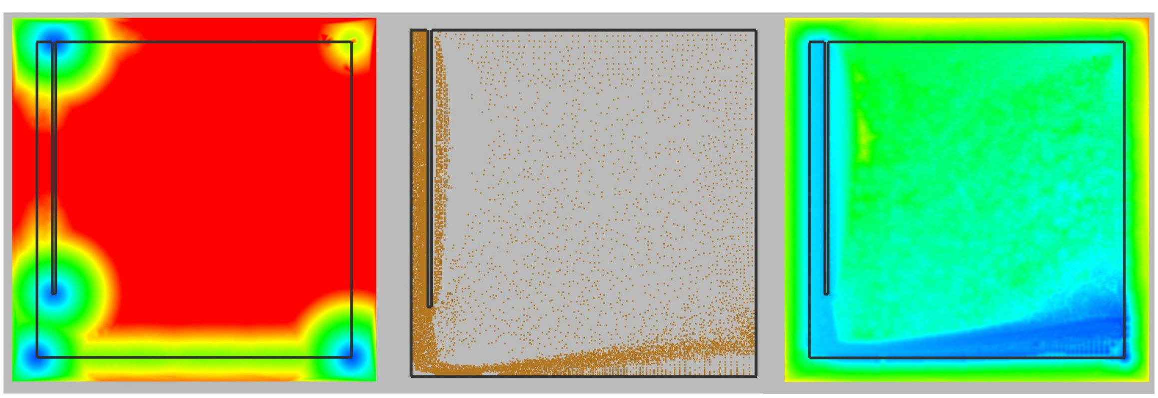

Figure 2: Initial mesh continuous size field (left), Cycle 9 adaptation point cloud (center) and Cycle 9 continuous size field (right)

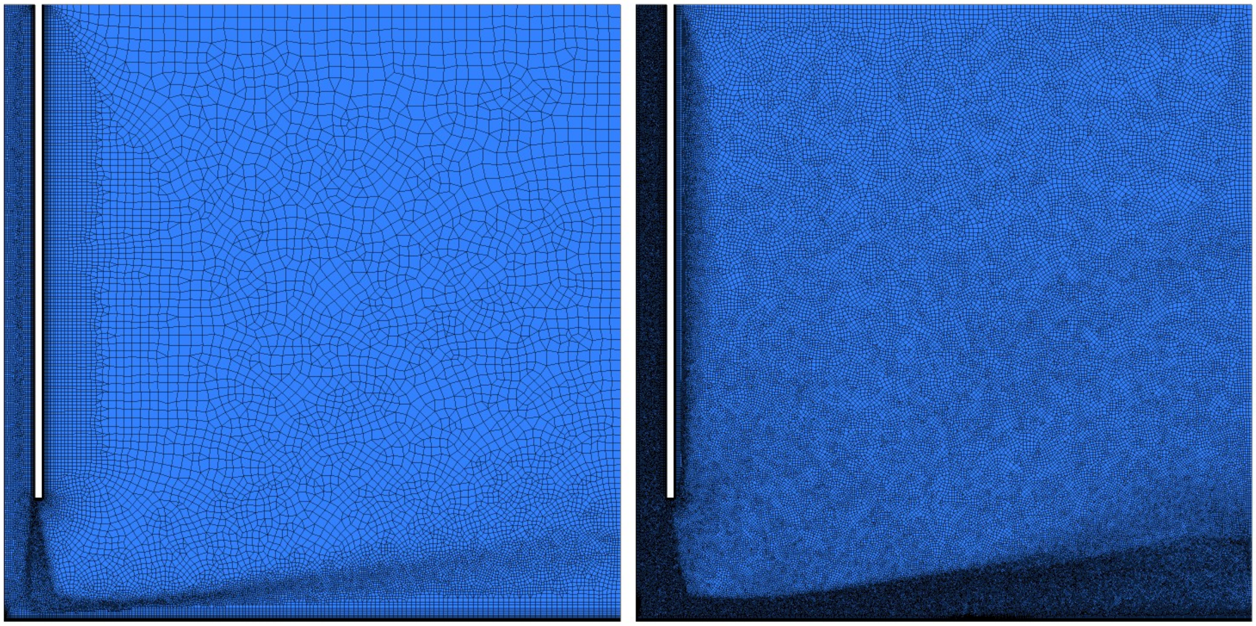

Figure 3: Adapted mesh at Cycle 5 (left) and Cycle 9 (right). The boundary layer mesh structure is retained.

3 Conclusion and Future Work

A mesh adaptation procedure which maintains geometry associativity and anisotropic quasi-structured boundary layer mesh behavior has been developed and demonstrated on three cases. The method uses an estimate of truncation error of the discretization scheme to automatically control numerical error caused by the discrete mesh. The procedure was shown to be practical and computationally efficient on engineering problems while requiring minimal user intervention.

References

[1] Slotnick, J., Khodadaoust, A., Alonso, J., Darmofal, D., Gropp, W., Lurie, E., Mavriplis, D., "CFD Vision 2030 Study: A Path to Revolutionary Computational Aerosciences," NASA Technical Report CR-2014-218178, 2014.

[2] Delaga, J.M. "Adjoint and Truncation Error Based Adaptation for Finite Volume Schemes with Error Estimates," 53rd AIAA Aerospace Sciences Meeting, Kissimmee, FL, January 2015.

[3] Loseille, A. and Alauzet, F., "Continuous Mesh Framework Part I: Well-Posed Continuous Interpolation Error," SIAM Journal on Numerical Analysis, Vol. 49, No. 1, 2011, pp. 38-60.