Parametrically Uniform Mesh Adaption for Unstructured Grids

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Abstract: Grid tailoring and adaptation is essential for rapid aerothermal computational fluid dynamic (CFD) analysis without sacrificing quality results. Industry standards use this approach with structured CFD solvers such as NASA Ames' Data Parallel Line Relaxation[1] (DPLR) and NASA Langley's Langley Aerothermodynamic Upwind Relaxation Algorithm[2] (LAURA). For complex reentry vehicles such as the Dream Chaser® spaceplane, these adaptation methods can be impractical. New development at Sierra Space has shown promise in using a combination of Non-Uniform-Rational-B-Spline (NURBS) surfaces and parametric coordinate definitions to tailor any unstructured grid to a bow shock produced by unstructured solvers like FUN3D[3] and US3D.

Keywords: Numerical Algorithms, Computational Fluid Dynamics, Mesh Adaptation, Aerothermal.

1 Introduction

Parametrically Uniform Mesh Adaptation (PUMA) utilizes an initial solution's iso-surface defined bow shock and characterizes it using a Non-Uniform-Rational-B-Spline (NURBS) surface. Using this surface, an unstructured grid can be represented by a three dimensional parametric space. The parametric coordinates can be altered to get the desired effect, such as collapsing to a bow shock. The final step is to map the coordinates back to physical space. This technique has been benchmarked against classical aerothermal computational fluid dynamics (CFD) cases such as a cylinder and sphere in hypersonic flow. Initial testing has been performed on the Dream Chaser® spaceplane with promising results. PUMA combines the ease of unstructured mesh generation with the convenience of automated grid tailoring used by structured codes, while minimizing excessive dissipation of the solution through the bow shock.

2 Problem Statement

For simple geometries like a capsule, a surface mesh can be generated, then extruded outwards to some arbitrary far-field distance. This type of mesh is known as a structured mesh, where by construction it is built with a global sense of order concerning cell connectivity. For complex geometries, volume cells are often constructed through Delaunay triangulation, which produces irregular cell connectivity.

For structured grids, the globally consistent order of cell connectivity is exploited to expand or contract the mesh, effectively refining areas of interest in the solution space. This requires all nodes be assigned to a unique grid line and any surface node must have a direct line from the surface to the grid boundary (k-line).

For unstructured grids, development of a new mesh adaptation method does not alter mesh connectivity or grid-point count and is described below. With exception to proprietary grid file formats, this method of mesh adaptation can be used for most Finite Element or Finite Volume solvers. PUMA involves the following steps:

1. Characterize the shock-front surface as a Non-Uniform-Rational-B-Spline (NURBS) surface
2. Define a three-dimensional parametric space based on the NURBS surface
3. Map each grid point from the mesh into parametric space
4. Alter parametric coordinates to get the desired effect
5. Map back into physical space, export mesh file

With an analytical expression for the shock front itself, the space inboard and outboard of the shock front are defined as a third dimension in parametric space. Three methods have been developed: vanishing point, vanishing line, and surface normal. Illustrated in Figure 1, the green line represents the NURBS surface for the shock front, $G_{x,y}$ are example grid points within the grid, and the black lines represent the direction of mesh adaptation for the example grid points. Each of these methods requires a non-linear solve to convert the Cartesian coordinates for each grid point to parametric space.

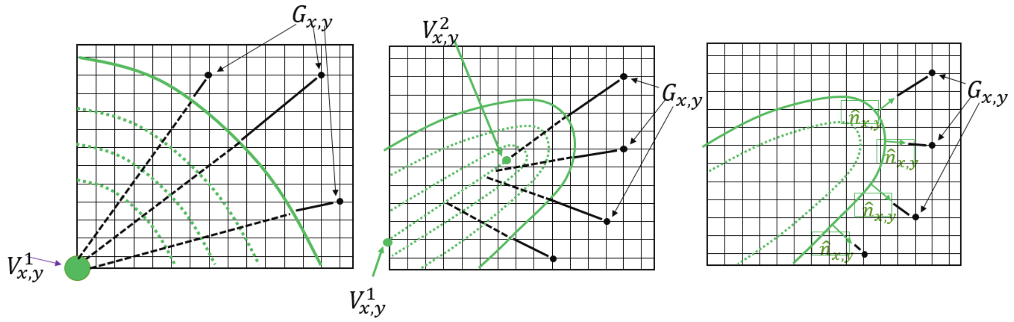

Figure 1: Parametric Space Definitions- Vanishing Point (Left), Vanishing Line (Center), Surface Normal (Right)

To understand how these techniques worked in practice on a complicated geometry, PUMA was used on a Mach 10 CFD solution of the Dream Chaser® spaceplane. Figure 2 shows the progression of two PUMA adaptations

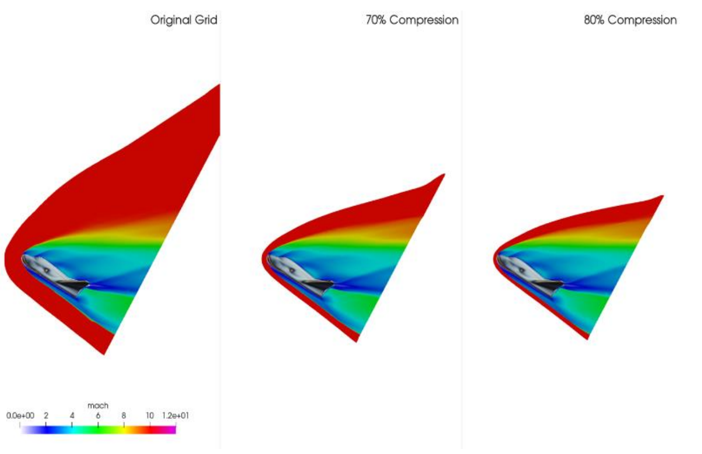

Figure 2: PUMA adaption results for Dream Chaser® spaceplane at Mach 10

3 Conclusion and Future Work

PUMA has shown to be robust and effective method to compress unstructured grids to the bow shock. Several improvements and additional capabilities are currently underway. Several areas under development are to improve the shock characterization with surface orientation and curvature constraints. Additionally, improvements can be made to the mesh adaptation using the distance from the shock to the vehicle surface.

References

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