White Paper

ANSYS Fluent Mosaic Technology Automatically Combines Disparate Meshes with Polyhedral Elements for Fast, Accurate Flow Resolution

Transitioning between varying types of mesh elements in complex geometries and flow tegimes has long been a major simulation challenge. ANSYS Mosaic technology meets this challenge by automatically connecting different types of meshes with general polyhedral elements. Poly-Hexcore, the first application of Mosaic technology, fills the bulk region with octree hexes, keeps a high-quality layered poly-prism mesh in the boundary layer and conformally connects these two meshes with general polyhedral elements. The resulting simulation is faster with greater solution accuracy while using less RAM.

Introduction

Accuracy and solution time are two of the most critical concerns in computational fluid dynamics (CFD) simulation, and both are highly dependent on the characteristics of the mesh. Different types of meshing elements are needed to deliver optimal performance in resolving different geometries and flow regimes. But transitioning between varying types of elements has long been a challenge. The transition zone has typically relied on non-conformal interfaces or on pyramids/tetrahedra, but these come with issues regarding mesh quality and excessive cell count. So it has often been necessary to compromise on a common element type in order to minimize transitions.

ANSYS is addressing this challenge with the introduction of Mosaic technology that automatically connects different types of meshes with general polyhedral elements. The initial implementation of this technology maintains layered elements on the boundary layers, fills the bulk region with computationally efficient and highly accurate hexahedral elements, and conformally connects these two meshes with high-quality polyhedral elements without putting excessive numbers of elements in the transition zone. Mosaic mesh-connecting technology has the potential to deliver exciting new combinations of meshing elements that will help meet the challenge of increasing part complexity and accuracy requirements for years to come.

CFD Meshing Challenges

Computational Fluid Dynamics (CFD) solvers are more efficient with a highly orthogonal mesh, yet geometries are steadily increasing in complexity and it can be difficult to achieve orthogonality on irregular geometries. Each element type has its pluses and minuses, so CFD meshing technology has evolved over the past four decades to use different types of elements that are best suited for specific application spaces. Engineers want to match the optimal mesh elements for each area of the geometry and volume, but building the transition between these areas can be a difficult challenge. As a result, they may use fewer element types than optimal in order to reduce time and effort to acceptable limits.

Hexahedral Elements

In the early days of CFD, geometries were relatively simple and hexahedral or quadrilateral elements were the primary element choice. Hexahedral meshes are very efficient from a computational time standpoint and are also very accurate. The problem with hexahedral meshes has been that they are not well-suited to complex geometries, especially in characterizing boundary flows.

Tetrahedral/Wedge Elements

As geometries became more complex, the CFD community shifted to automated unstructured meshes where the boundary layer was captured by layered prism elements and the bulk geometry was filled with tetrahedral elements. Until a decade or so ago, tetrahedral meshes were the most common approach for CFD in industry. Tetrahedral meshes have always been easy to generate automatically, but their accuracy has been questionable. This accuracy limitation has been partially overcome by improved solvers. But achieving accuracy and good convergence in boundary layers and small gaps with tetrahedral elements requires a large number of cells, which increases computing time requirements.

Hexcore Meshing

Even during the period when tetrahedral elements were the most popular meshing solution, analysts still desired the accuracy and efficiency of hexahedral elements as long as they could be achieved without reverting to manual meshing methods. To meet this need, the Hexcore meshing method was advanced around 2005. Hexcore fills the bulk of the flow geometry with octree hex meshes while keeping layered prism elements at the boundary and filling the transition space with tetrahedral elements. The ability of hexahedral elements to handle complex geometries was improved by transitioning from one full-size hexahedral element to eight elements — known as octree 1:8 size reduction — to allow for variation in element size. The interior nodes of the smaller hexahedral elements do not line up with a node in the larger elements, so they are called hanging nodes.

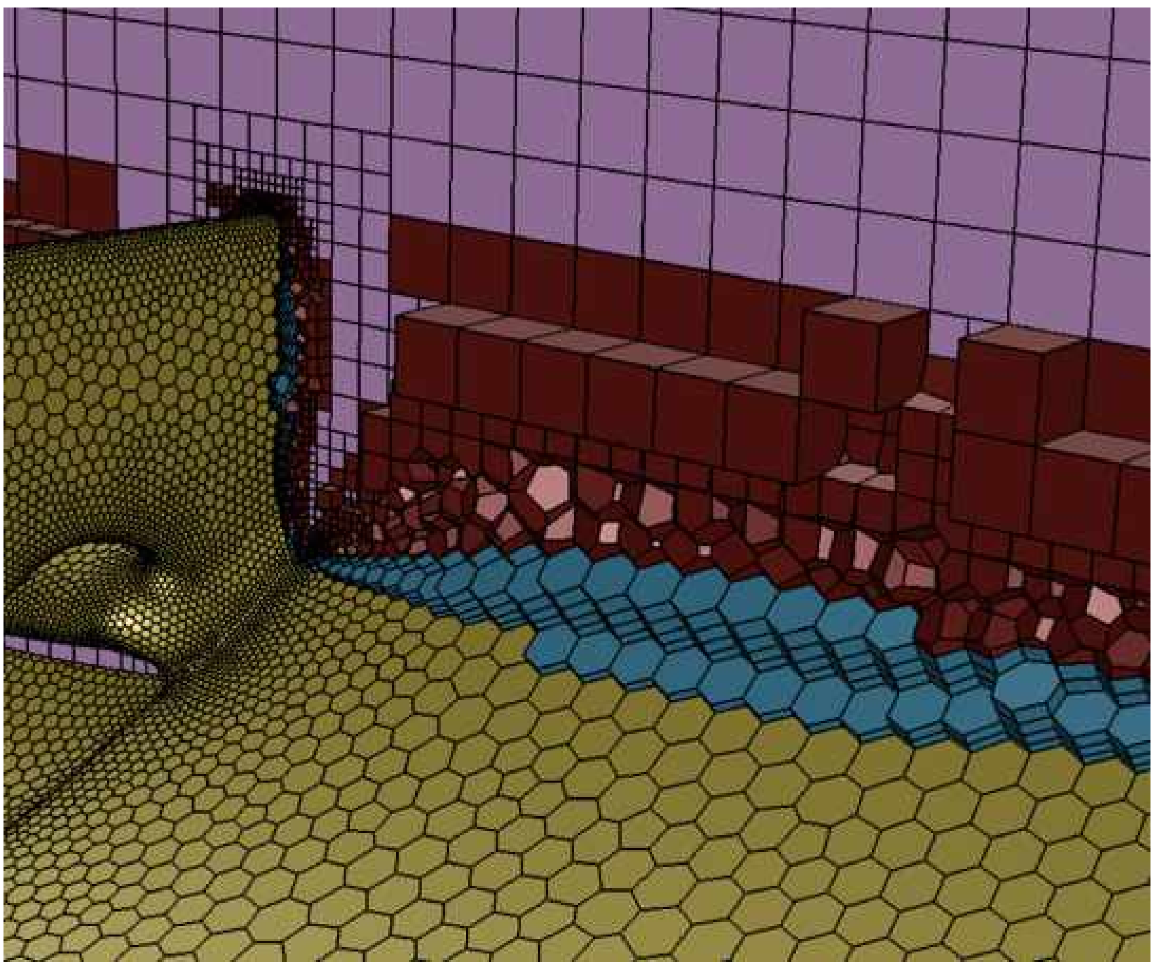
These meshes were quickly accepted for many applications including the external aerodynamics of racing cars. The challenge with Hexcore meshing is that the number of tetrahedral elements is large, and element quality is less than ideal in the small transition region between the layered elements near the boundary and the octreehex elements in the bulk region. The result is longer solution times and greater consumption of both RAM and storage space.

Polyhedral Elements

Around 2010, generalized polyhedral elements began gaining traction in many CFD applications. The initial move towards polyhedral elements was driven by the fact that they require a fraction of the number of cells as tetrahedral elements, so overall they consume less memory and computing time. Polyhedral elements also have many neighbors, so gradients can be better approximated than with tetrahedral elements although the use of gradient algorithms have tended to mitigate this advantage. More neighbors mean more faces that drive more computing operations per cell. Polyhedral elements also offer the same automatic meshing capabilities as tetrahedral elements.

Initially, polyhedral elements created nice-looking but non-ideal elements for CFD. ANSYS developed a native polyhedral mesher that produces very high-quality elements with flat zero-warp interior faces. The cells are orthogonal — the adjacent cell center vector is aligned with the common face normal. These meshes have layered polyhedral prisms on the boundaries to efficiently capture the boundary layer on no-slip walls.

Mosaic Technology



Mosaic meshing technology conformally connects hexahedral elements in the bulk region and isotropic elements in the boundary layer with polyhedral elements.

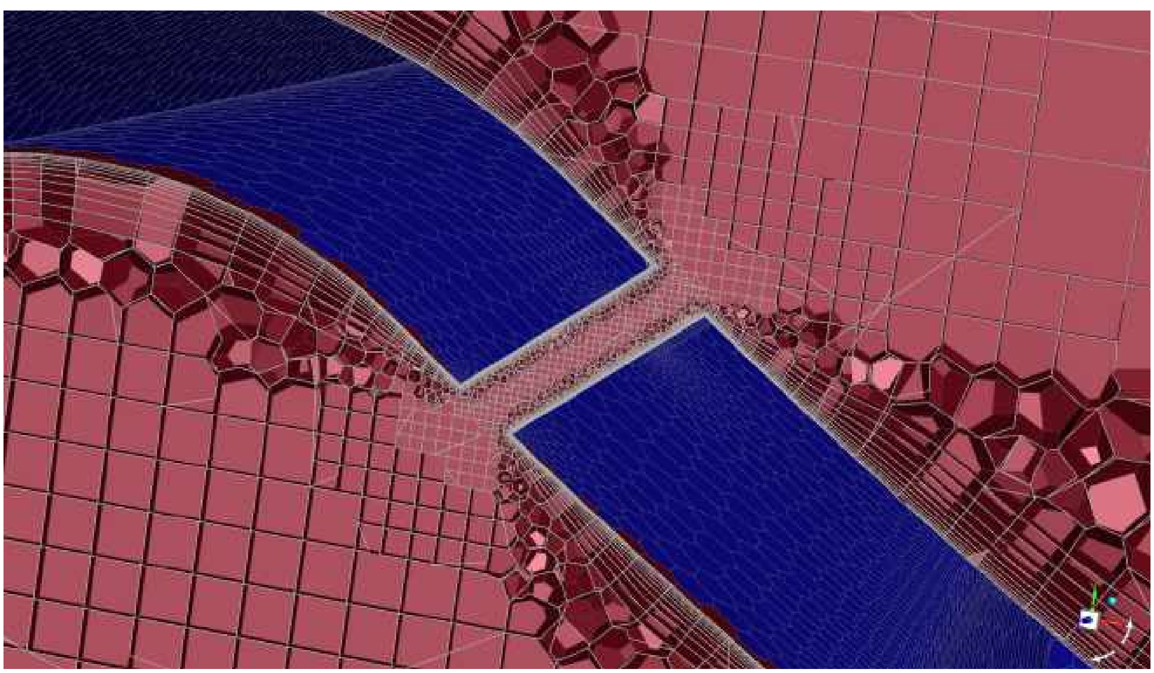
ANSYS Fluent Mosaic Technology Automatically Combines Disparate Meshes with Polyhedral Elements for Fast, Accurate Flow Resolution

ANSYS Fluent developers surveyed the CFD meshing landscape and noted that hexahedral elements are widely desired because of their accuracy and efficiency, while polyhedral elements have the advantage of being well-suited for complex geometries and offer greater efficiency than tetrahedral elements. They asked themselves if it would be possible to give users what they had been asking for by combining both types of elements while maintaining automatic mesh generation.

As a result, ANSYS developed patent-pending Mosaic technology which conformally connects any type of mesh to any other type of mesh, making it possible to build optimal meshes that use the best type of element in every section of the mesh. Mosaic technology allows native polyhedral meshes to connect with the following element types:

- Surface: triangle, quad, polygon.
- Volume: hexahedral, tetrahedral, pyramid, prism.

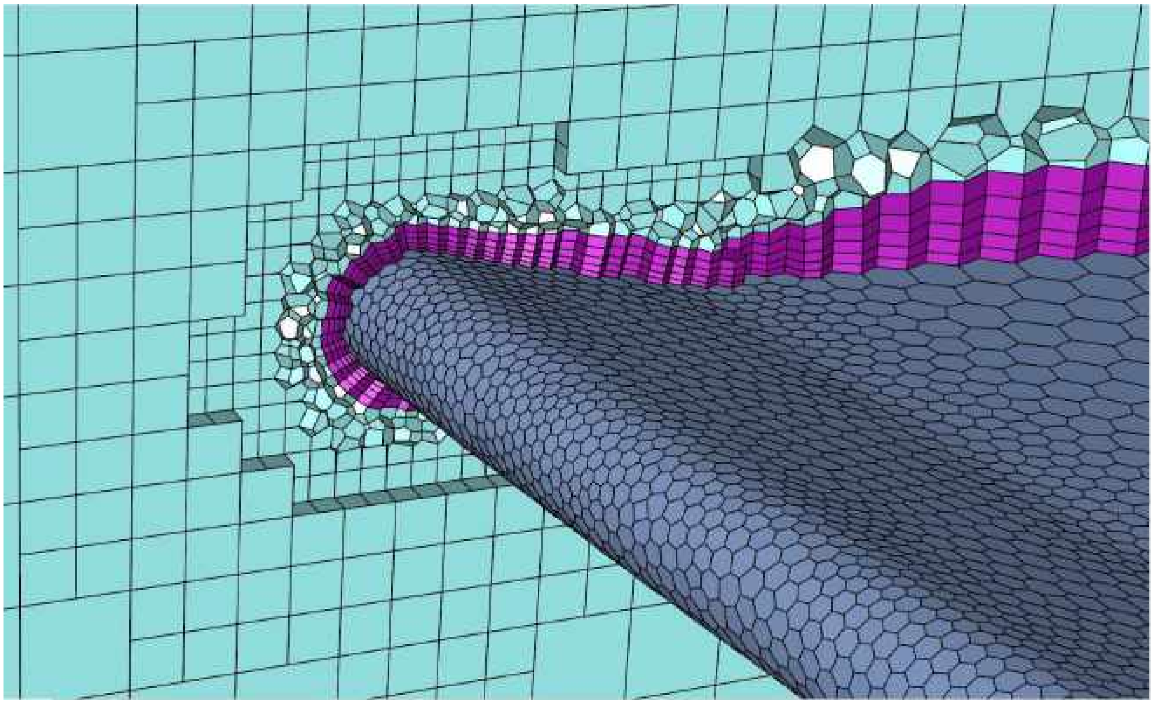
Starting in ANSYS 19.2, Fluent will deliver a completely automated way to get higher quality results at faster speeds with the best combination of mesh quality and memory versus any other meshing technology available today. Poly-Hexcore, the first application of Mosaic technology, fills the bulk region with octree hexes, keeps a high-quality layered poly-prism mesh in the boundary layer and conformally connects these two meshes with general polyhedral elements. On average, hexahedral elements have fewer faces than generalized polyhedral elements, which reduces compute time and memory and disk space requirements. The polyhedral elements used as connectors in Mosaic technology provide a high-quality transition between the meshes of different types, so they maintain the high quality of the previous polyhedral generation.

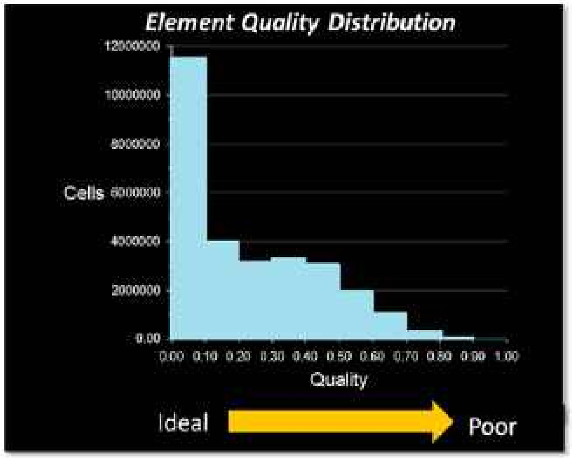


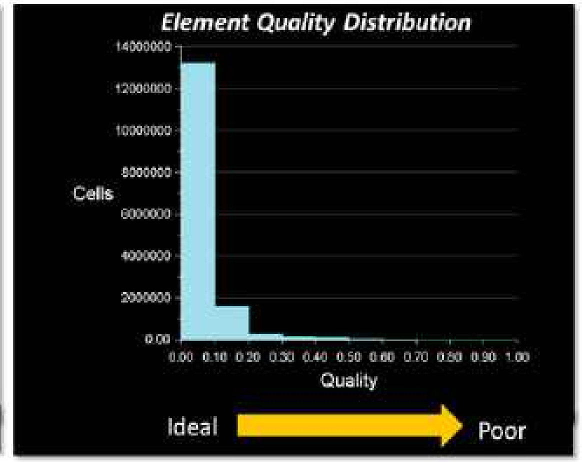
Mosaic technology creates high-quality mesh even in the submillimeter through-holes of this turbine blade.

CFD simulations with meshes created by Poly-Hexcore with Mosaic show a 20 percent to 50 percent speedup in Fluent as compared to Hexcore or generalized polyhedral meshes of the same accuracy. This new approach opens the possibility of further improving solver speed and accuracy by deploying special numerical computation methods on the Cartesian-axis-aligned octree-hexes. Also, mesh generation speed is higher with this method compared to filling the entire volume will generalized polyhedral elements. Finally, Mosaic technology maintains the speed and convenience of fully automated meshing.

Mosaic Example #1: Formula One Wing



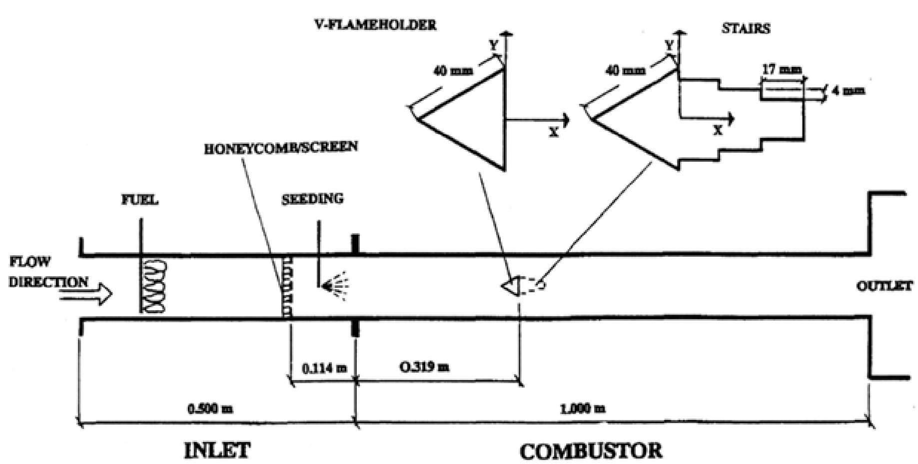




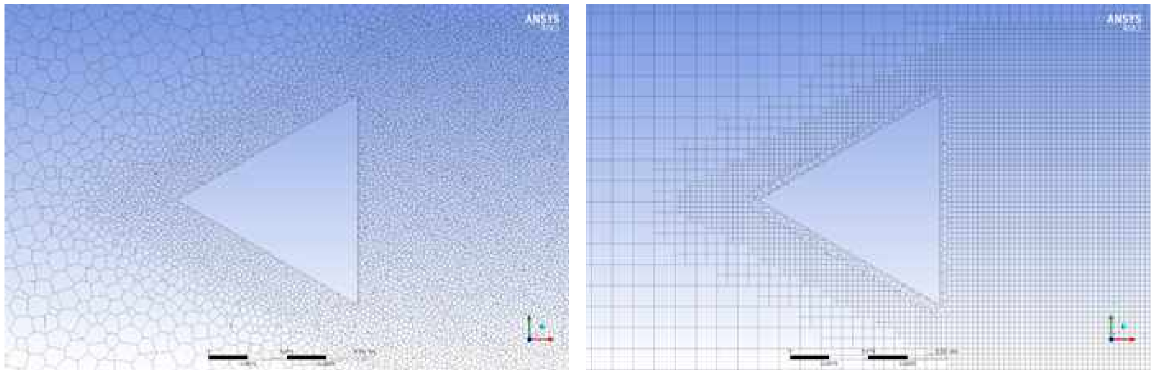
Conventional: Hexcore with Tetrahedral Elements	Poly-Hexcore with Mosaic Technology
6.3 million prism elements	3.2 million poly prism elements
10.1 million cartesian hex elements	8.5 million Cartesian hex elements
11.8 tetrahedral transition elements	3.6 million polyhedral transition elements
Total size: 28.2 million elements	Total size: 15.3 million elements
	46 percent size reduction

Poly-Hexcore Mosaic technology was compared with conventional Tet-Hexcore meshing technology on a generic Formula One wing. In this example, Mosaic technology provides a 46 percent reduction in mesh size as well as a substantial improvement in mesh quality. The result is faster solve times and better solution accuracy.

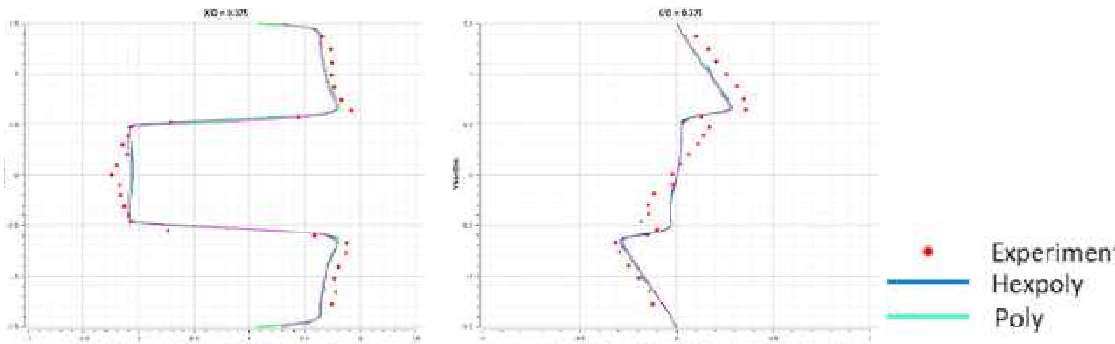
Mosaic Example #2: Bluff Body Flame Holder



Bluff body flame holder



All polyhedral mesh (left) and Poly-Hexcore mesh (right)



Mean X velocity (left) and mean Y velocity (right) for all polyhedral and Poly-Hexcore simulations versus physical experiments

Mesh type	Number of cores	Number of cells	Memory (GB)	Wall clock (s)
All polyhedral	120	7,641,636	63.5668	489,617
Poly-Hexcore	120	6,191,657	41.7829	259,043

The accuracy and performance of all polyhedral and Poly-Hexcore meshes were compared in simulating two reacting cases for a triangular prism bluff body flame holder. The Poly-Hexcore mesh had 19 percent fewer elements than the all polyhedral mesh. The solution time for the Poly-Hexcore mesh on a 120-core high performance computing (HPC) platform was 47.09 percent faster than the all polyhedral mesh. The Poly-Hexcore mesh also used 34 percent less RAM. The solutions for both mesh types generated similar results for statistically averaged flow fields and temperatures. Results for both models correlated well with experimental data.

Further Improvements on the Horizon

Beyond the current Poly-Hexcore that is offered in Fluent 19.2, Mosaic technology has been incorporated into the Fluent product roadmap, where we expect it to enable some innovative solutions to other meshing challenges.

Conclusion

Accuracy and fast solution times are the most critical elements in choosing a CFD meshing technology. Up to now, the only way to achieve the best possible mesh by combining different types of elements has required time-consuming manual meshing. With the introduction of Mosaic technology, ANSYS makes it possible to mix and match meshing technologies as needed to deliver the best possible accuracy and efficiency for every part geometry regardless of its complexity and other characteristics.

ANSYS, Inc.
Southpointe
2600 ANSYS Drive
Canonsburg, PA 15317
U.S.A.
724.746.3304
ansysinfo@ansys.com