STAR-CCM+ overset mesh

Providing increased modeling accuracy, reduced simulation time and improved designs

Benefits

- Improves modeling accuracy with realistic motions
- Reduces design time through automated parametric studies
- Improves designs with accurate physics modeling
- Accurately handles complex motions with robust algorithms

Features

- Enables automated design exploration studies
- Two-step implementation
- Ability to handle small gaps and contact
- Compatible with most physics models in STAR-CCM+
- Easy to swap CAD parts
- Implicit coupling of background and overset grids

Summary

Since the advent of computational fluid dynamics (CFD), numerical simulation has been constantly evolving. In order to represent the real-world behavior of a design as closely as possible, the motion of components and the complexity of geometries need to be accurately represented. There have been tremendous improvements in tackling these two challenges over the years, but the key solution to both problems lies in a technology developed by the aerospace industry: the overset-mesh (also known as Chimera or the overlapping grids) approach.

Adopting this technology for industrial use has been hindered by the complexity of implementing general-purpose commercial CFD codes and limited compatibility with various physics solvers. Implementing overset mesh in STAR-CCM+ software has transitioned this technology from the confines of research-oriented tools to general-purpose, commercial CFD codes. In this fact sheet, we will discuss the capabilities of overset mesh in STAR-CCM+ and how it can readily be used to increase modeling accuracy, reduce simulation time and improve designs.

Implementation

The implementation of overset mesh in STAR-CCM+ is the first-ever introduction of this technology directly integrated in an industrial-strength commercial CFD code. Overset meshes typically involve a background mesh adapted to the environment and one or more overset grids attached to bodies, overlapping with the background mesh. Multiple overlapping overset regions are also possible, expanding the potential applications of this technology. Data interpolation

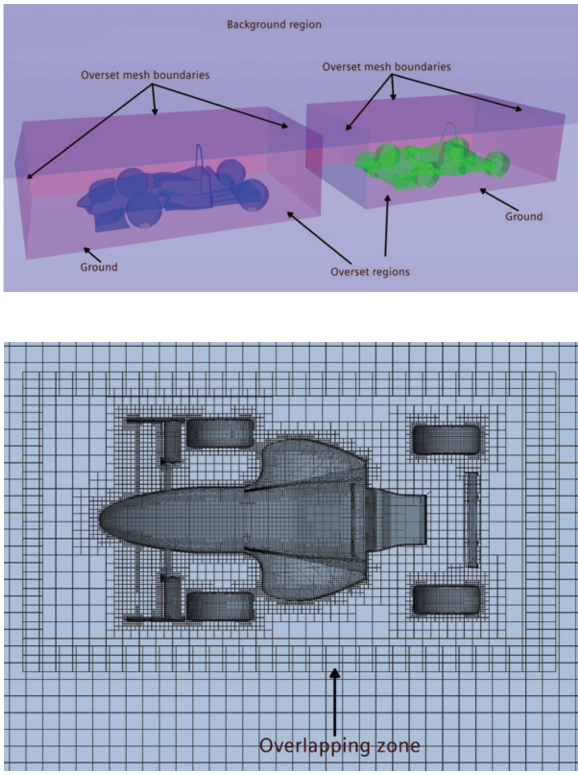

Figure 1: Overset regions for two cars inside the background computational region (top); overlapping zone between overset and background mesh (bottom).

STAR-CCM+ overset mesh

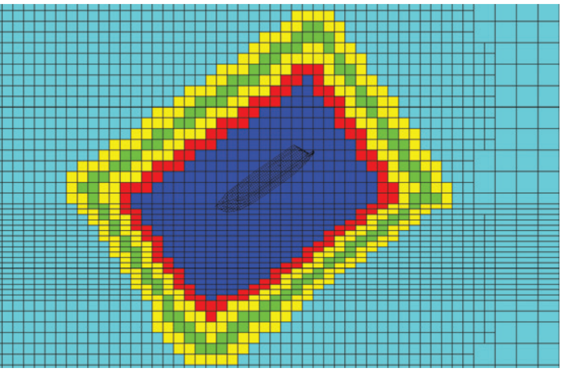

Figure 2: The four types of cells created from the hole-cutting process are shown around a lifeboat.

occurs between the grids, which can move with respect to one another. They are most useful in simulating multiple or moving bodies, as well as parametric studies and optimization analyses. By allowing the overset body to move and also be replaced as many times as needed with different geometry, this technology truly brings multidisciplinary design exploration (MDX) to the fingertips of engineers and designers.

STAR-CCM+ includes geometry tools, preprocessing, solvers, postprocessing and optimization delivered from a single integrated user interface. The individual grids are prepared using the standard meshing process in STAR-CCM+, and you can implement the overset mesh between grids in a few simple and automated steps:

1. Two or more individual regions are created: a region with the background geometry (background region) and separate regions surrounding the bodies of interest (overset regions)
2. The regions are meshed separately: There will be a zone where computational cells overlap between regions
3. The outer boundary of the overset body is set to overset mesh boundary condition; the regions are selected together and an overset interface is created between them

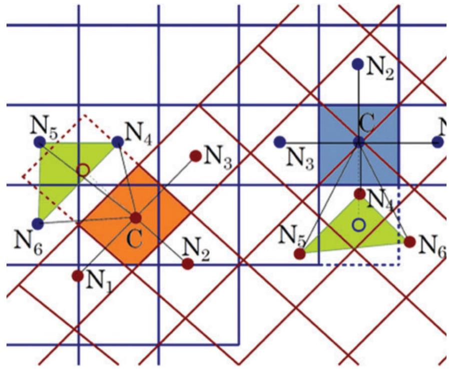

Figure 3: Data transfer between overset mesh (red) and background mesh (blue). Acceptor cells (dotted line) provide information for the calculation of active cell center values (orange and blue).

4. As the overset body moves within the background region, the overlapping zone will change
5. Information is exchanged between the regions through the overlapping cells

Figure 1 shows the classification of regions as overset and background in STAR-CCM+.

Once the overset mesh is created, the hole-cutting process in STAR-CCM+ automatically couples the overset region with the background region through the overset interface. A successful coupling results in a hole being cut out in the background mesh where the overset mesh resides. Cells are marked as active and passive in the coupled simulation. The hole-cutting process follows one of the two approaches:

- Layered approach: A layer of cells along the overset boundary is identified as the donor layer. The immediate cells next to the donors in the background region become acceptors. The cells in the background that are completely covered by the cells in the overset region become inactive
- Global approach: For each cell in the background region, the algorithm verifies whether the cell centroid is inside or outside the overset region. If it is inside the overset region, the cell becomes inactive

Based on the hole-cutting process, four types of cells are identified as shown in figure 2.

- Active cells (cyan and yellow): Discretizing governing equations are solved here
- Passive cells (dark blue): No equations are solved here
- Donor cells (green): These provide interpolation information to the mesh acceptor cells
- Acceptor cells (red): The boundary cells that receive information from the donor cells

Data transfer

The data transfer between the meshes is implicitly coupled, with a solution being computed on all grids simultaneously, leading to improved robustness and convergence. Triangular (2D) or tetrahedral (3D) interpolation elements

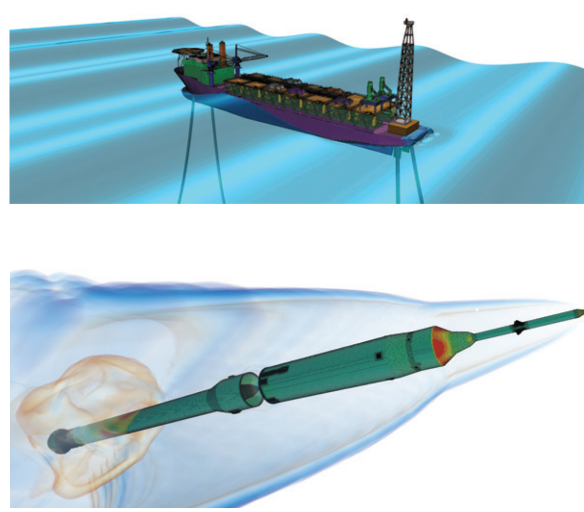

Figure 4: Applications of overset mesh with DFBI: moored floating production storage and offloading on heavy seas (top) and stage separation of the Ares launch vehicle (bottom).

are used with either distance-weighted, linear, linear quasi-2D, or least-square interpolation functions. Figure 3 shows a representation of data transfer between overset mesh (red) and background mesh (blue). For each active cell at the edge of either mesh (C in Figure 3), an adjacent acceptor (or ghost) cell exists (dotted line). These acceptor cells provide information to allow the calculation of cell center values in active cells C and face fluxes between the cell C and the acceptor cell. For each acceptor cell, a number of donor cells in the other mesh are used to determine the contribution of the acceptor cell. The exact relationship between the two types of cells depends on the interpolation scheme.

Key technology 1: Prescribed motion and dynamic fluid body interaction
Whether the motion is known beforehand or needs to be calculated based on external forces, STAR-CCM+ can be used to handle both scenarios.

- Prescribed motion: In many applications, the motion of the object(s) is known. For such simulations, any one of the motion modeling options in STAR-CCM+ can be used with overset mesh. Moving reference frames (MRF) in STAR-CCM+ allow users to model motion (rotating, translating) in steady state. The rigid body motion (RBM) option allows us to prescribe rotation/translation motion in six degrees-of-freedom (DOF) with respect to time. The overset region will undergo the motion prescribed and motion is imparted to fluids in contact with the body. In addition, the overset mesh works well with the mesh morpher for cases in which the overset object is in motion and in contact with a stationary object

  Applications: Mixing vessels, cyclone separators, casting, rotating machinery (propellers, wind turbines, pumps, fans), windshield wipers, marine control surfaces, automotive dipping and spraying, gears/valves/dampers, excavation, landing gears, overtaking maneuvers.

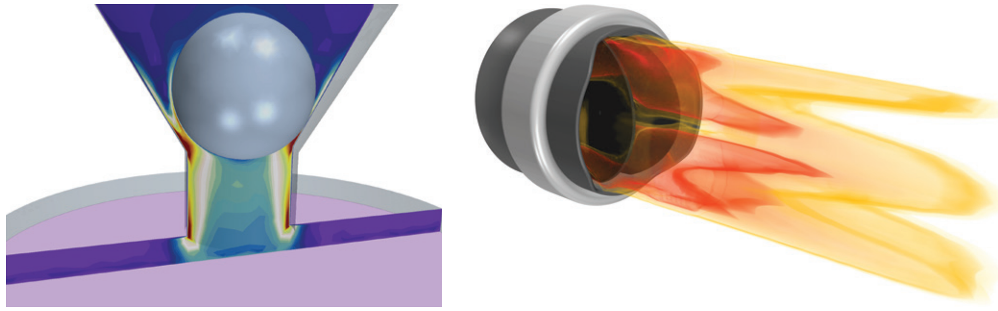

Figure 5: Simulation of a ball valve in motion (left) and an artificial heart valve (right) using the zero gap overset feature.

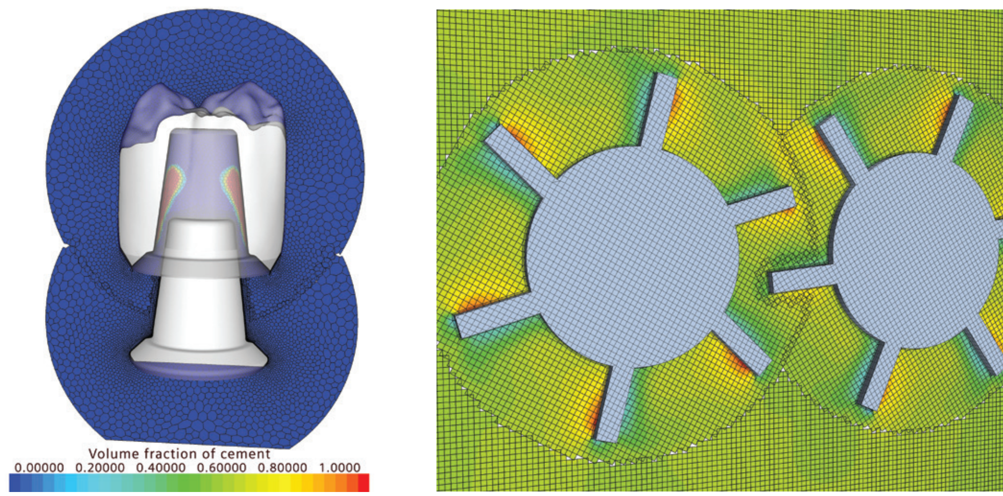

Figure 6: Simulation of a dental crown and implant without background mesh (left) and two counter-rotating objects embedded in two overset regions with background mesh (right).

- Dynamic fluid body interaction (DFBI): The DFBI model enables the analysis of objects when their motion is not known a-priori. The motion of the object, which is due to the action of fluids and other forces, is imparted through the overset mesh. The major advantage of this feature in the design process is that it allows you to determine the motion of the objects using simulation, rather than expensive physical testing. The DFBI contact coupling model allows bodies to collide and rebound from contact, which is modeled as a repulsive force.

  Applications: Boats on free surfaces (tow tank testing, moored/anchored boats), lifeboats, offshore platforms, store/stage separation, ball valves, pigging and drilling, and water entry.

Key technology 2: Handling small gaps
One of the more powerful features of the overset mesh in STAR-CCM+ is the ability to handle small gaps between objects, opening up new possibilities in modeling bodies in motion and contact. Traditionally, mesh morphing was required to perform motion analysis but this approach was challenging

Figure 7: Overset topology options: piston (left) and direction (right).

because it was extremely difficult to preserve cell quality in small gaps during morphing. In overset mesh, there are three ways to handle small gaps:

1. Resolve physical gap: With the overset mesh interface, it is necessary to maintain a two-to-four cell minimum in the gap between objects, depending on the interpolation method, cutting algorithm, etc. This works well when the motion of the objects is known but can lead to excessive cell counts and unrealistically large gaps in the simulation
2. Close proximity option: With this option, the gap refinement requirement comes down to just two cells. There is a tradeoff of some local accuracy for stability and lower mesh size
3. Zero gap overset: When the motion results in small gaps or contact, it is difficult to meet the two-to-four cell criteria. With the overset zero gap interface in STAR-CCM+, it is now possible to easily handle small gaps or contact between bodies, bringing your simulation one step closer to reality. With this interface option, smaller gaps are closed on-the-fly by deactivating cells and surrounding them with temporary walls.

Figure 5 shows a ball valve in motion and an artificial heart valve simulated using the zero gap interface feature. In association with DFBI contact coupling, this feature allows contacts and collisions to be modeled with fewer cells and mesh constraints.

Applications: Gear/positive displacement pumps, valves and pistons, aerospace control surfaces, drill bits.

Key technology 3: Dynamic overset behavior

In some applications, the boundary of the overset body can switch between a wall boundary type to an overset boundary type and vice versa depending on the motion. In addition, a background mesh may or may not be necessary depending on the motion. There are also applications in which a background mesh is needed only for a certain part of the motion. Such dynamic overset behavior can be modeled with or without the background mesh. The boundary type is set to wall when the dynamic overset behavior option is activated. This eliminates the need for background regions when they are not necessary, reducing the cell count and the time required for interpolation. Figure 6 shows two rotating, interlocking geometries with and without a background mesh using the dynamic overset wall boundary option. The boundary remains as a wall type until it comes in contact with the other region, switching to an overset boundary type when this happens.

Applications: Closely counter-rotating objects, such as screw pumps and internal combustion (IC) engine piston motion with a variable radius cylinder.

Key technology 4: Overset topology options

Overset topology describes how the regions in an overset mesh simulation are related to each other, determining the background and overset regions. Although this will be detected automatically in most cases, there are certain applications, such as a piston within a cylinder, in which a more detailed specification is necessary. In such cases, the overset region only partially

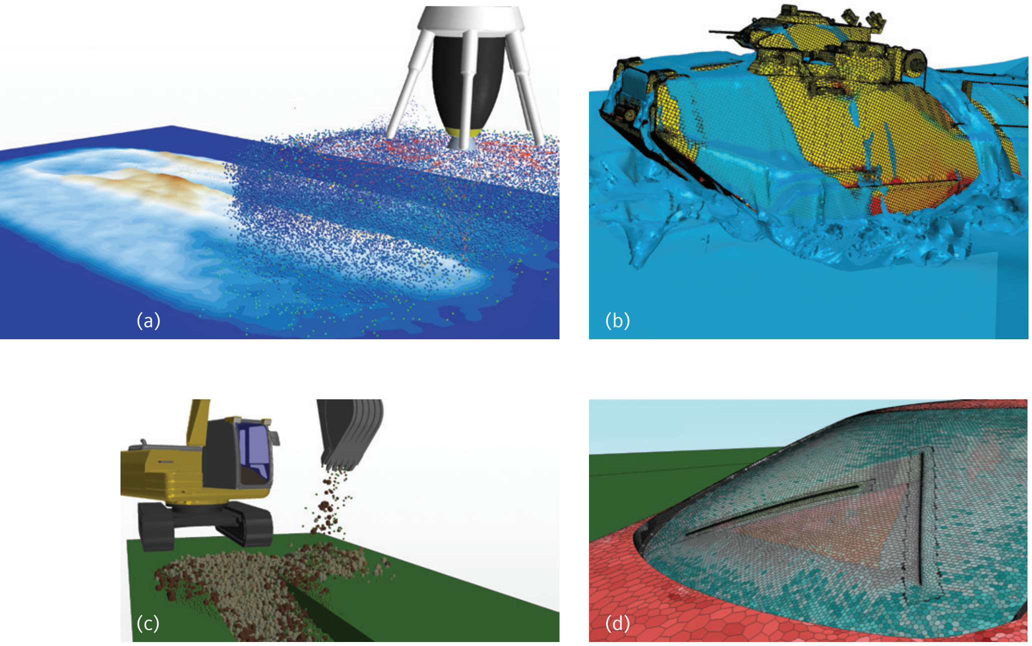

Figure 8: Overset mesh for (a) spray painting, Lagrangian Multiphase module; (b) water entry, VOF; (c) excavator, DEM; (d) windshield wiper, fluid film.

overlaps the background, or not all regions are required. In cases in which the automatic topology option cannot be used, additional overset topologies are available:

- Piston: To simulate a piston within a cylinder configuration
- Direction: To simulate sliding on curved surfaces when the overset boundary does not completely enclose the overset region
- Bounded: To simulate a situation in which a meshless space exists within an overset region that is bounded by a wall of the background region

Applications: Piston within a cylinder, moving control surfaces.

Physics compatibility

The overset mesh capability is compatible with most of the physics models in STAR-CCM+, extending its use to many industrial applications. Some of the major physics models compatible with this technology are:

- Segregated/coupled flow
- DFBI
- Discrete element method (DEM)
- Motion models, reference frames
- Single phase
- Multiphase: Volume of fluid (VOF), Lagrangian, Eulerian, dispersed
- Fluid film
- Combustion
- Passive scalar

Figure 8 shows some varied applications of the overset mesh technology in conjunction with different physics models. The feature is currently not supported for defogging, harmonic balance, grid sequencing, radiation and batteries.

Conclusion

The overset mesh implementation in STAR-CCM+ is the first known implementation of this technology in a commercial CFD code, opening up a vast array of new applications. Whether you are modeling a complicated motion for objects or performing parametric studies involving multiple geometries, the overset mesh technology in STAR-CCM+ offers a streamlined, intuitive two-click process that increases your modeling accuracy, reduces simulation time, improves designs and enables you to virtually tackle complicated problems. With the ability to easily analyze multiple designs, take on complicated motion problems, improve accuracy and reduce simulation time, the overset mesh technology in STAR-CCM+ helps you discover better designs, faster.

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