



# Overset and Mesh Morphing Capabilities in CFD++: Multiple Physics, Multiple Applications, One Solver

## Overset Grid Symposium 2014

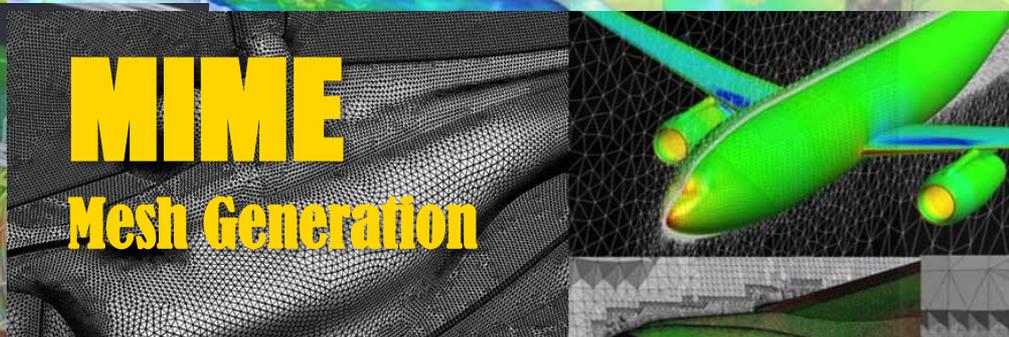
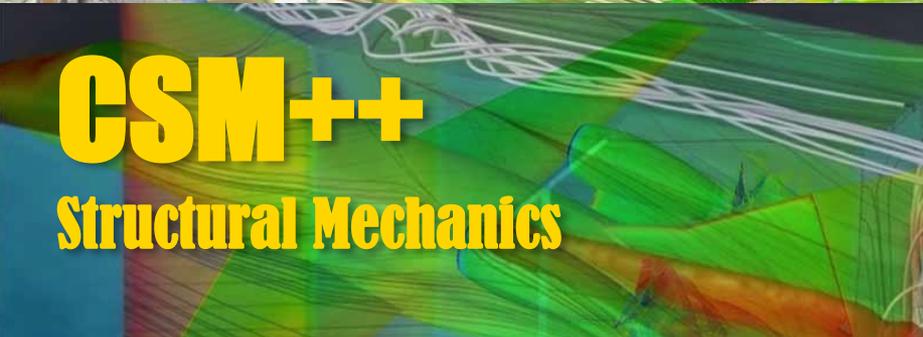
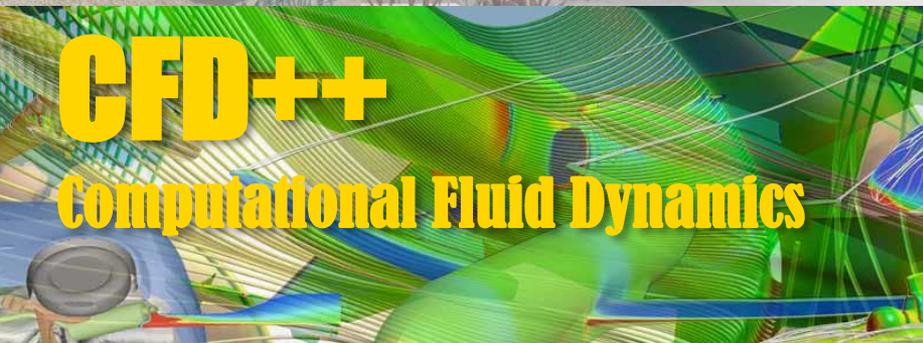


Metacomp Technologies

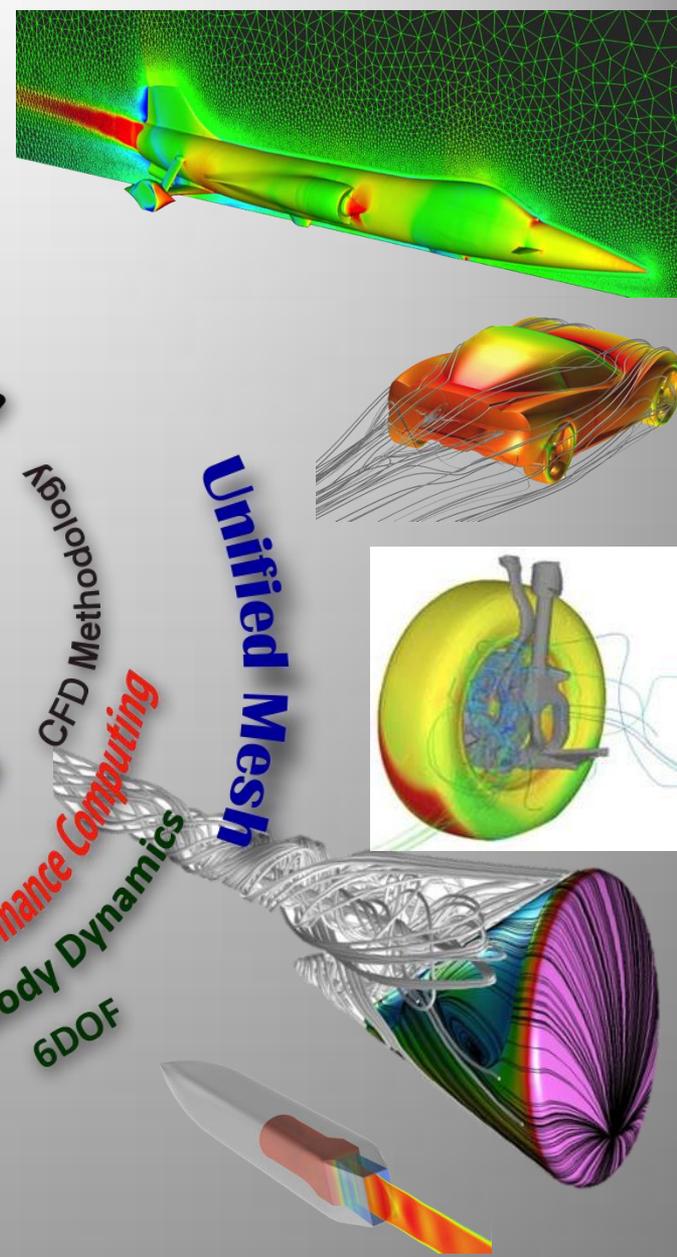
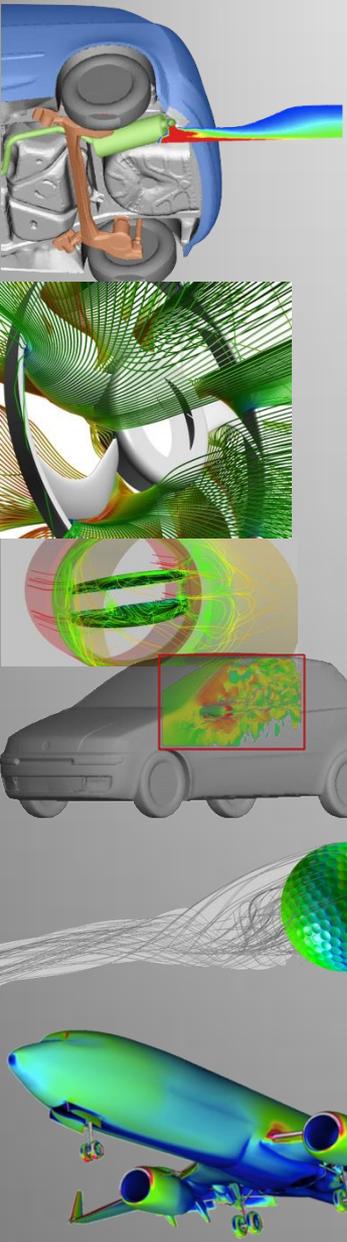


# Background : Metacomp Technologies

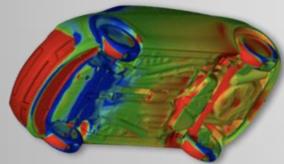
- Founded in 1994
- Key staff members are pioneers in CFD research
- CFD++ is 7th generation CFD software by founder, each one state-of-the-art when introduced
- Strong algorithm to applications experience
- Provides complete CAE solutions for its customers



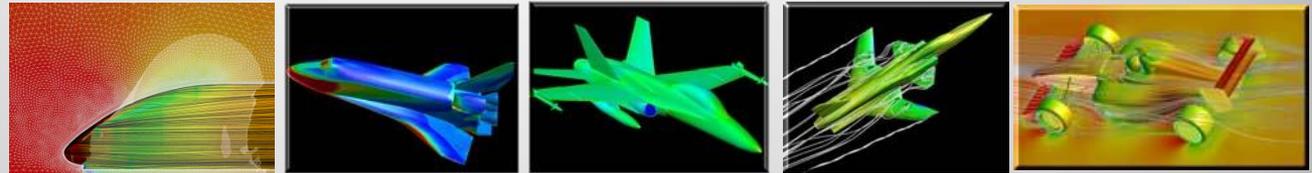
# Company Focus



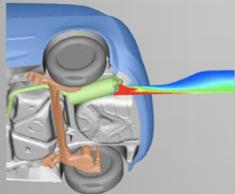
# CFD++ Capabilities



Under-hood flows

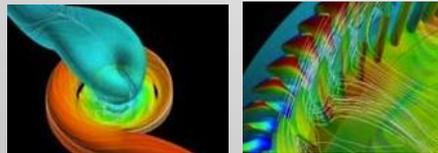


External Aerodynamics

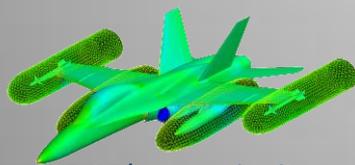


Exhaust gas infiltration

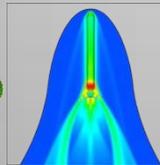
Turbomachinery



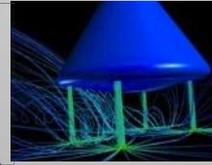
**CFD++ is a comprehensive software suite that includes a rich collection of tools to help increase the end users' effectiveness.**



6DOF/moving bodies



Propulsion

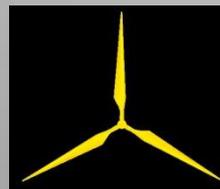


High- and low-Speed combustion

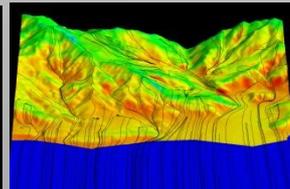
- External and Internal flows
- Sliding/Moving/Overset Meshes
- Rotating Machinery
- 6DOF/Moving Bodies
- Conjugate Heat Transfer
- Porous Media Modeling
- High-Speed and Low-Speed Reacting flows
- Multi-Speed Problems
- Supercritical Fluids
- Dispersed Phase Models (particles and droplets)
- Multiphase Mixture Models
- Phase Change Modeling (evaporation/condensation)
- Free Surfaces and Fronts (flames, shocks, etc.)
- Radiation Heat Transfer
- Unique Propeller and Helicopter Blade Model



Unsteady flow with Hybrid RANS/LES

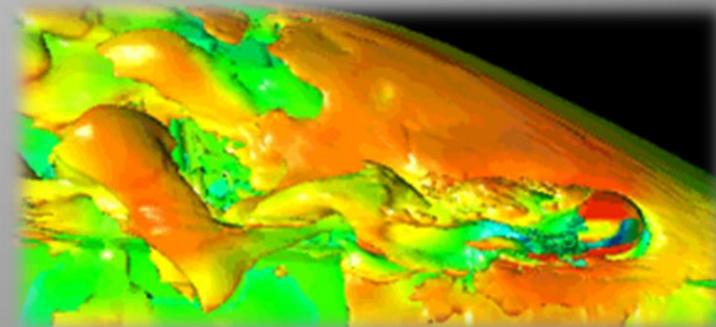
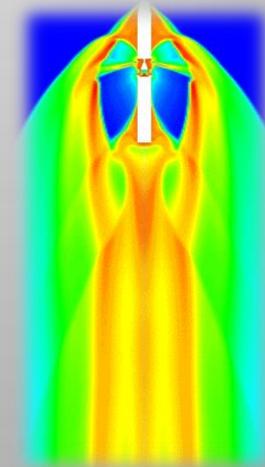
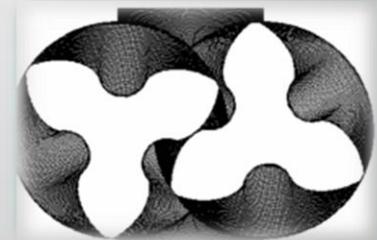


Wind energy – terrain verification



# CFD++ Numerical Features

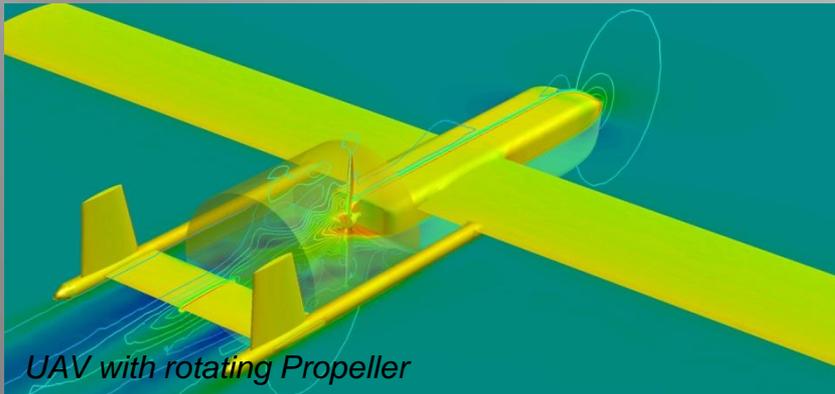
- ❑ Coupled density or pressure-based solvers
- ❑ Realizable physical, mathematical & numerical models
- ❑ Agglomeration (algebraic) multi-grid accelerated solver for fast convergence to steady state
- ❑ Multi-dimensional TVD framework for truly 2<sup>nd</sup> order accuracy on all meshes
- ❑ Up to fourth order accuracy (temporal) in explicit mode
- ❑ Second order accuracy in time in implicit mode
- ❑ Specialized low-diffusion schemes for transient phenomena



# CFD++ Overset Meshes



F18 with wing-tip store and under wing store



UAV with rotating Propeller

## Unique capabilities

- Simulation of steady and unsteady flows over complex geometries including bodies in relative motion

## Automatically-performed operations

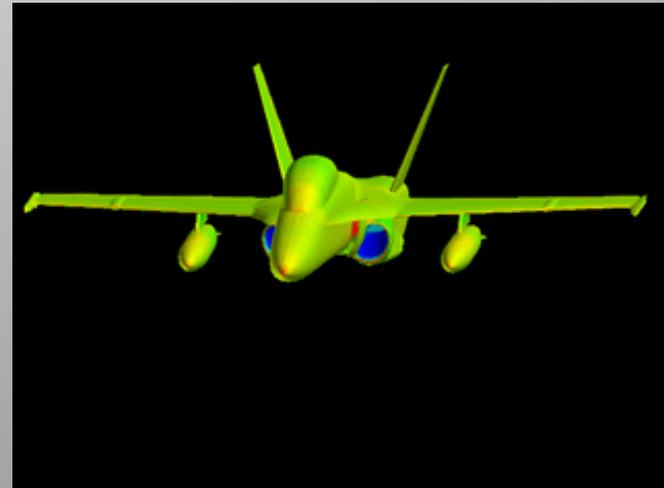
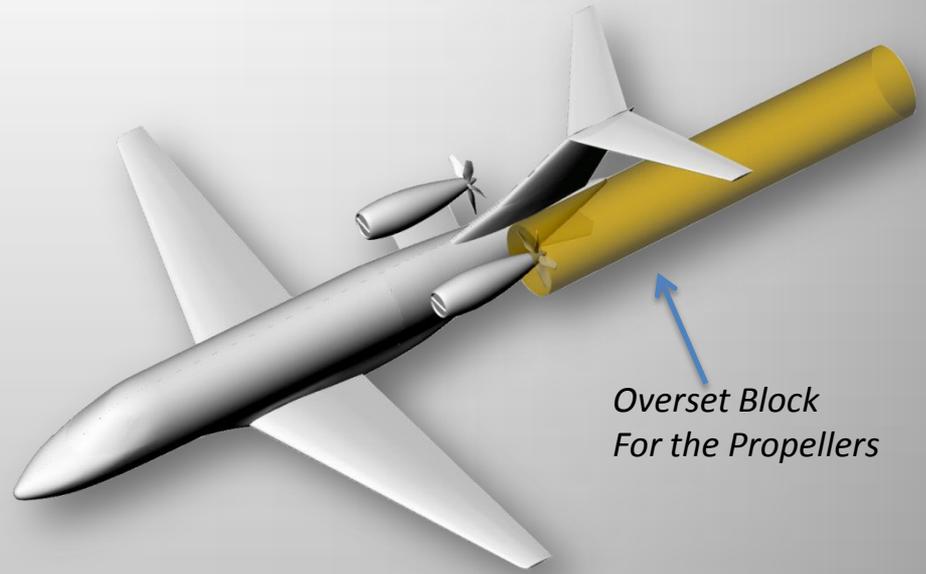
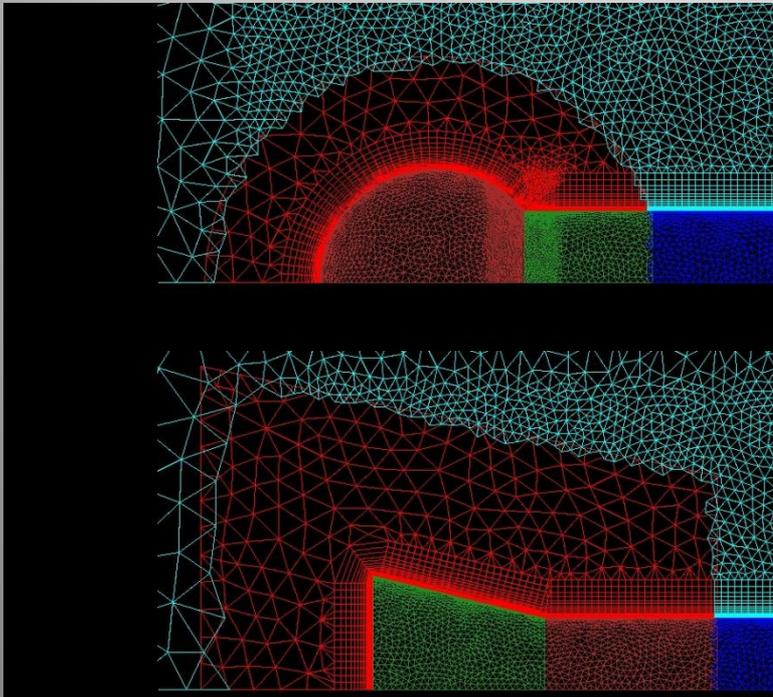
- For transient simulations, cutting, blanking and interpolation operations can all be performed within CFD++ at every time step

## RBD and 6DOF

- Includes an integrated rigid-body dynamics (RBD) capability with a six-degree-of-freedom (6DOF) module

# Why Overset?

- *Complex geometries*
- *Relative motion*
- *Design Optimization*

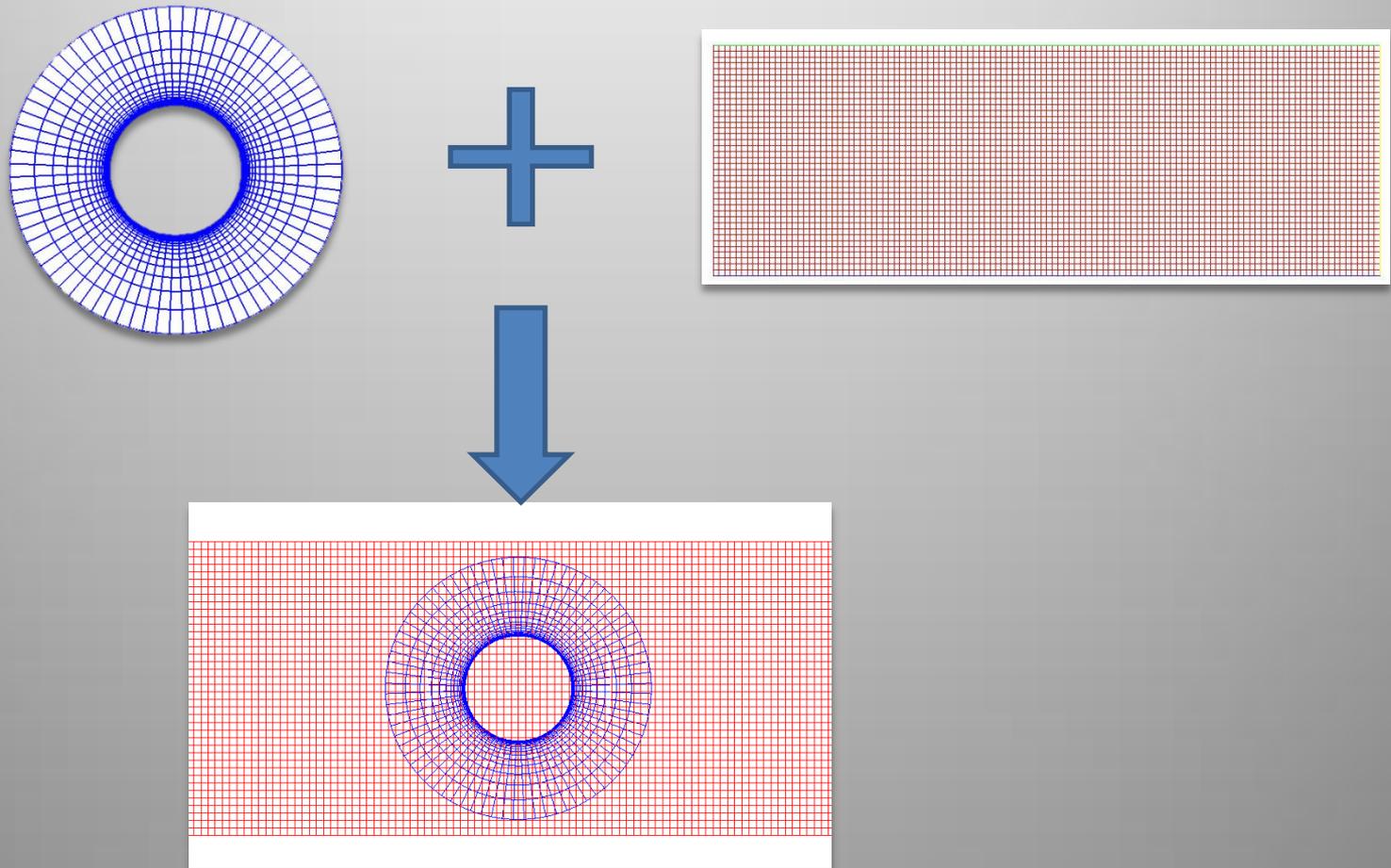


# CFD++ Key Attributes

- ✓ *Internal unstructured book-keeping*
  - ✓ *Allows for all cell types within same grid*
  - ✓ *Multiple blocks OK (structured and unstructured)*
- ✓ *Wall distance free turbulence models*
  - ✓ *Allows for transient computation with grid blanking*

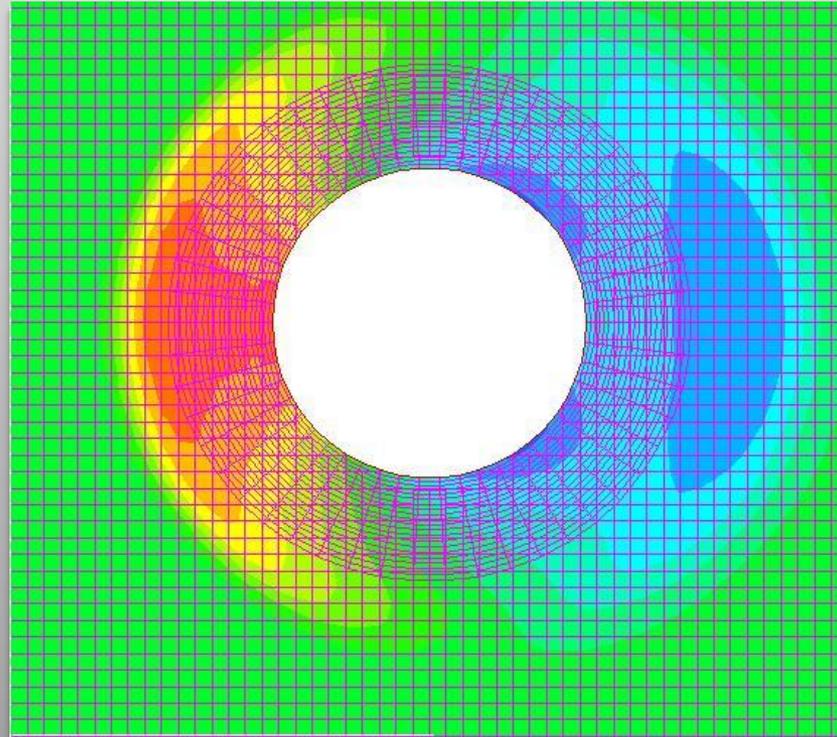
# Overset Process in CFD++

✓ *Concatenation of grids*



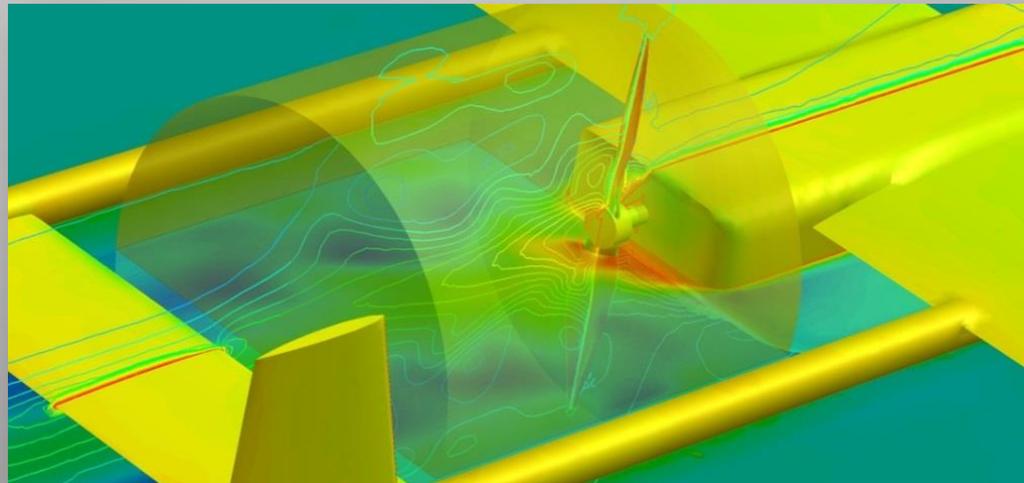
# Overset Process in CFD++

- ✓ *Concatenation of grids*
- ✓ *Cutting and Blanking*



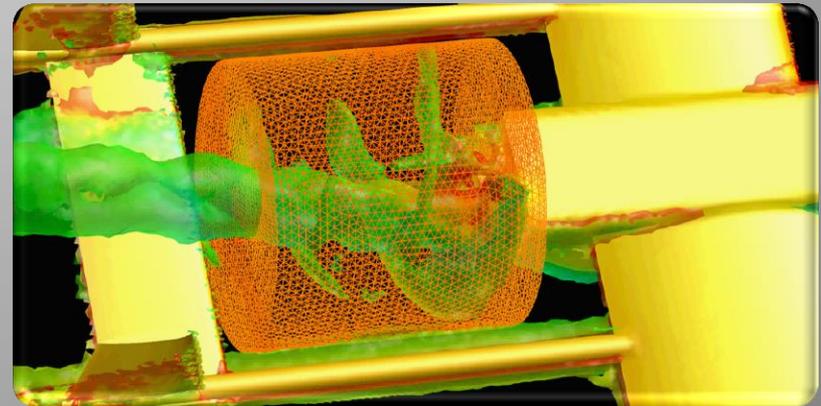
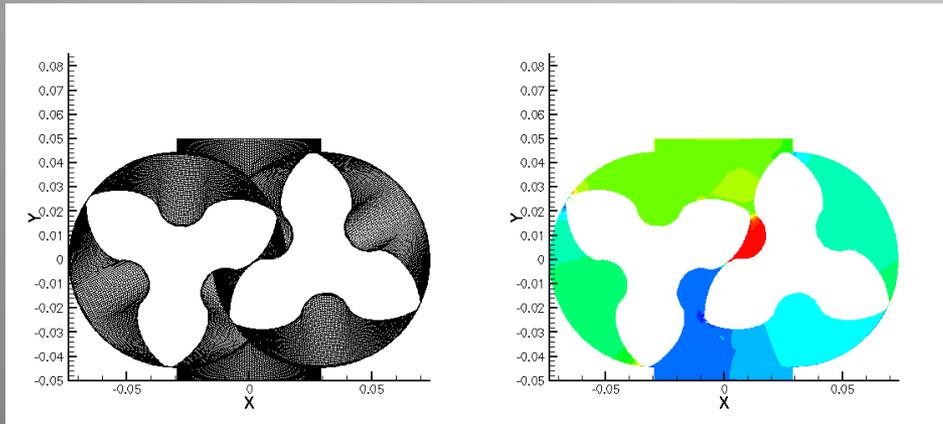
# Overset Process in CFD++

- ✓ *Concatenation of grids*
- ✓ *Cutting and Blanking*
- ✓ *Application of Boundary Conditions and Grid Motion*



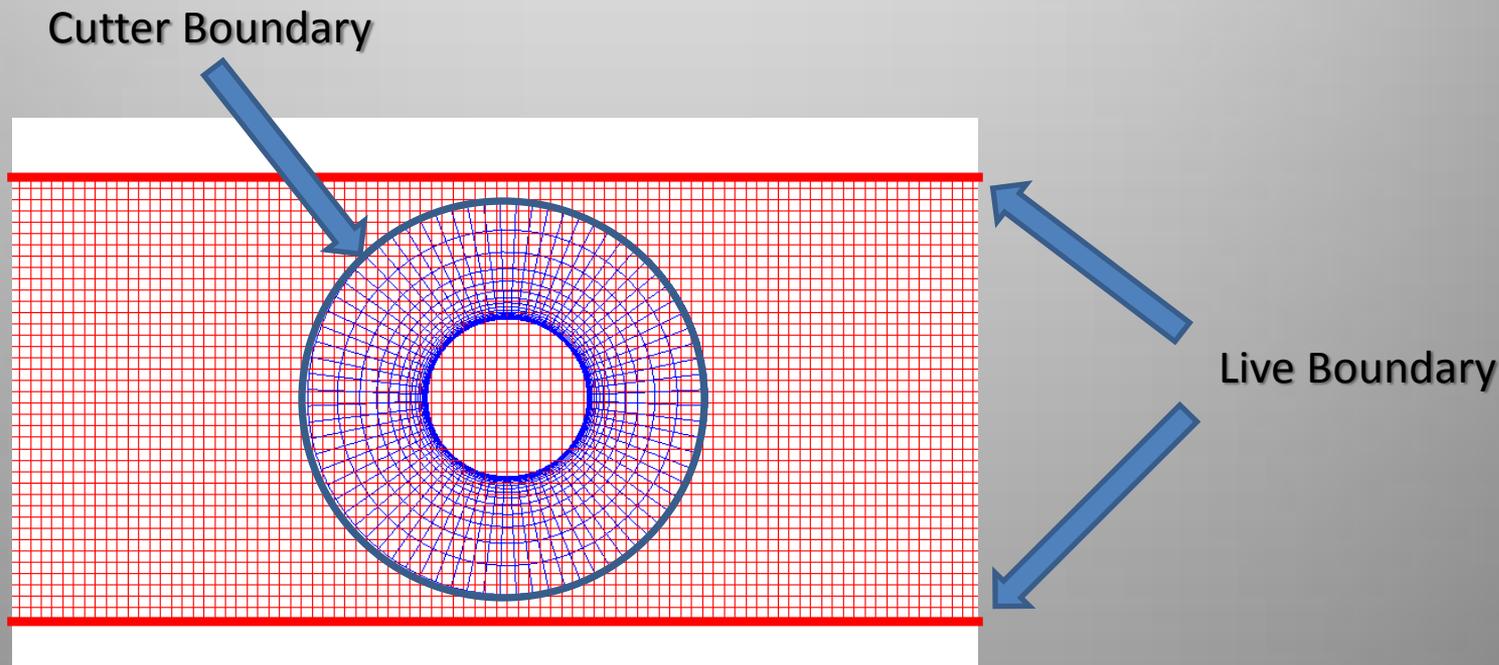
# Metacomp's Overset Philosophy

- ✓ *Same multidimensional least squares interpolation everywhere*
- ✓ *Very intuitive geometric approach*
  - ✓ *Flexibility via sequential cutting (reduces number of overlap cells)*
- ✓ *Fully integrated*
  - ✓ *Cutting can be performed (if necessary) completely within the run*
  - ✓ *Coupled with Rigid Body Motion and 6DOF computation*
- ✓ *Perfect conservation via flux-stitching*



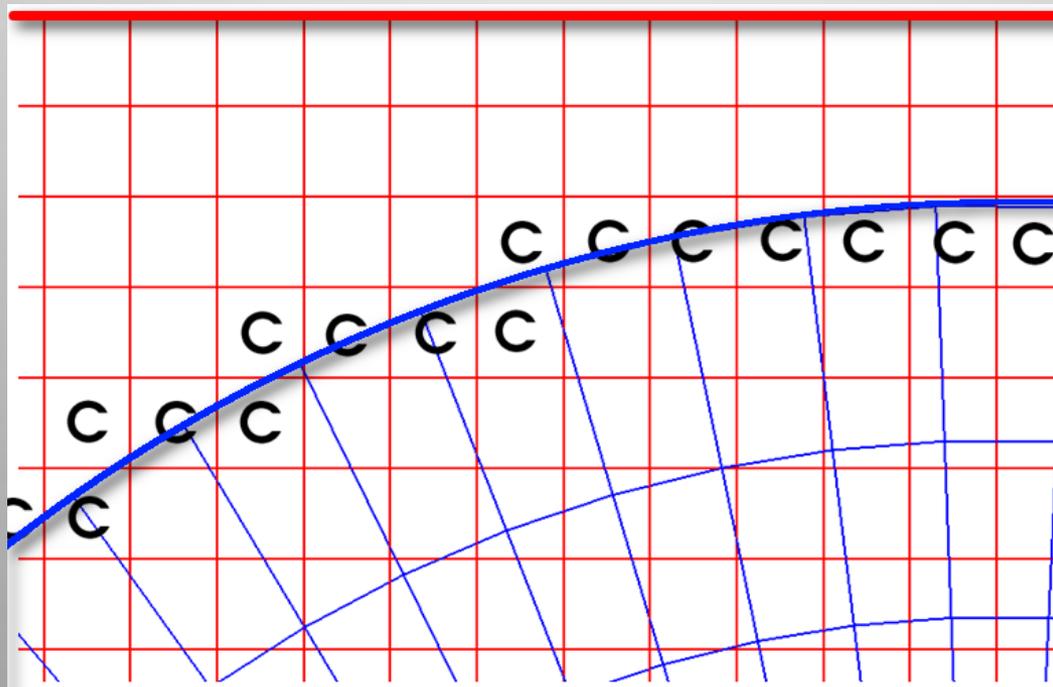
# Overset Blanking Procedure

- ✓ *Marking cells intersecting the cutter surface (“cut cells”)*
- ✓ *Blanking cells enclosed by the layer of “cut cells” and non-live boundaries*
- ✓ *Retain or not retain “cut cells”*



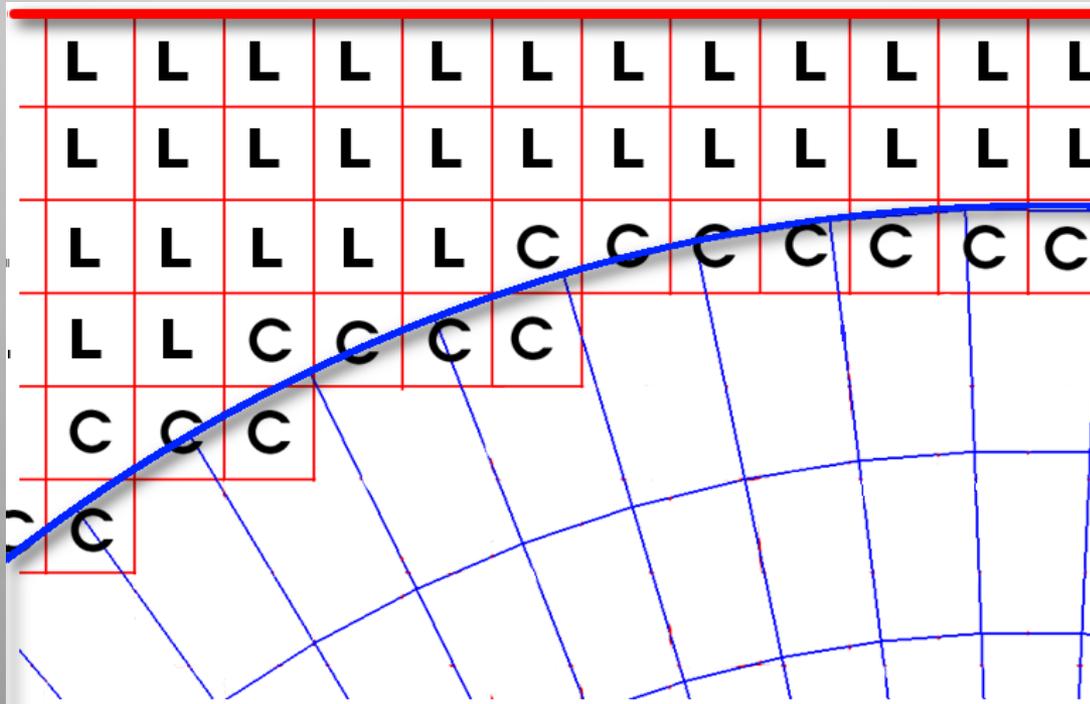
# Overset Blanking Procedure

- ✓ *Marking cells intersecting the cutter surface ("cut cells")*



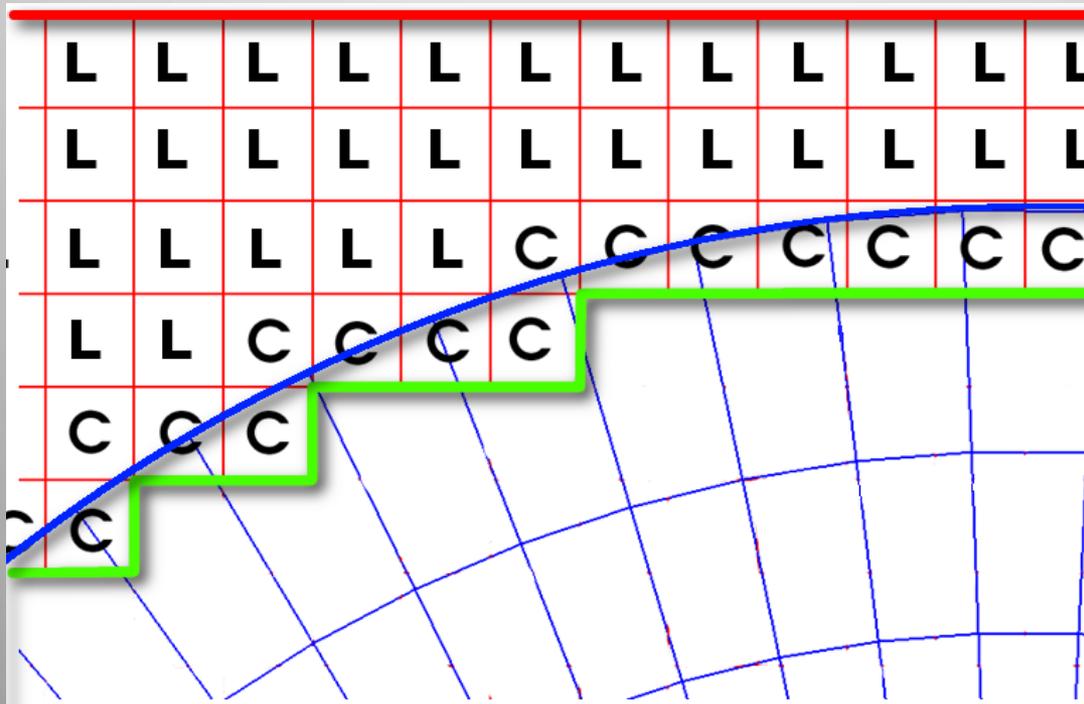
# Overset Blanking Procedure

- ✓ *Marking “live” cells – recursively marching to adjacent cells until “cut” cell or non-live boundary is encountered*



# Overset Blanking Procedure

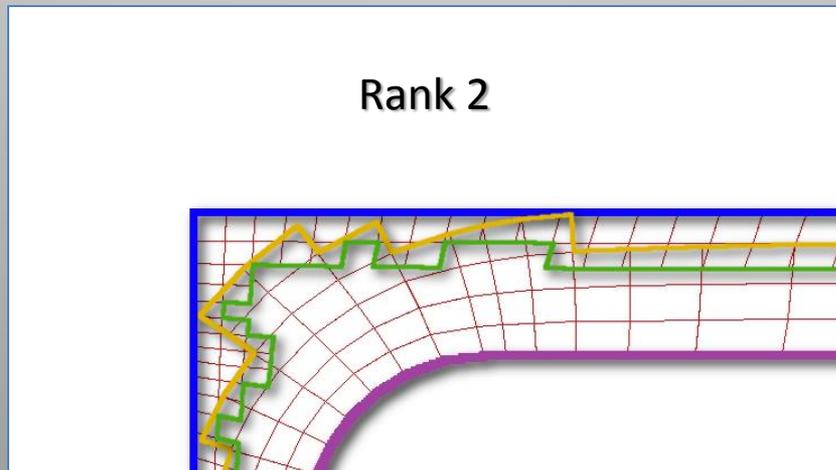
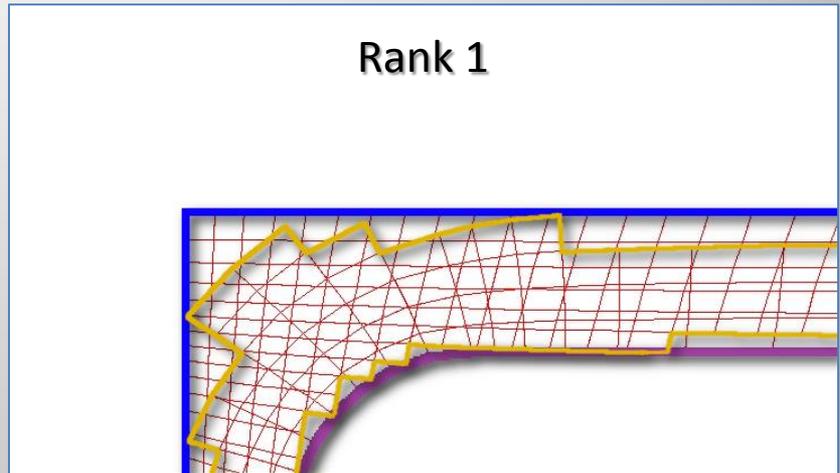
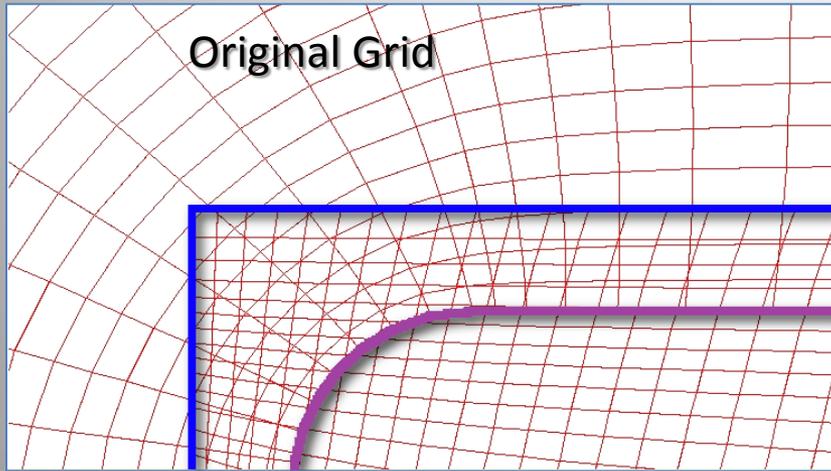
- ✓ Retain/Blank “cut” cells – additional boundary created after cutting (overset/patched)



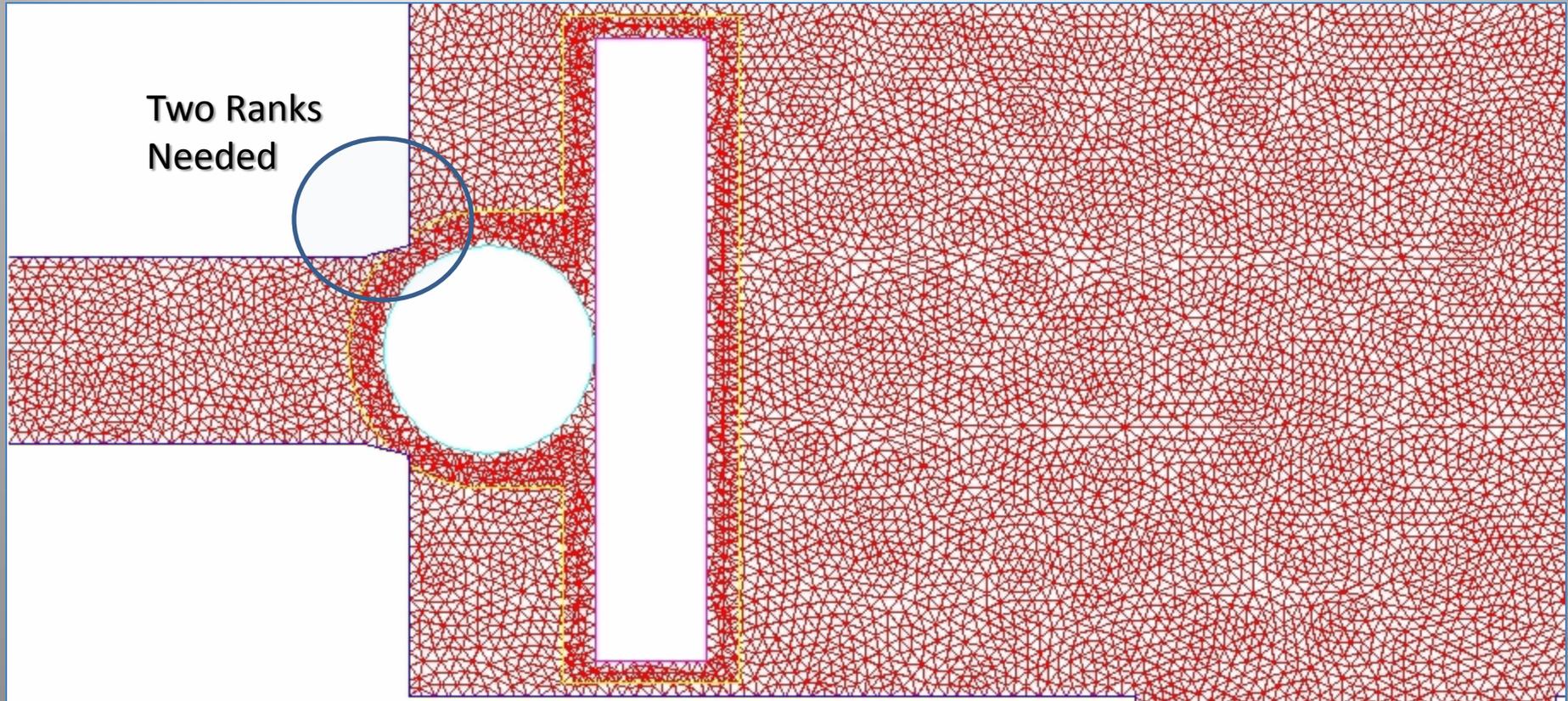
# Sequential Cutting

- ✓ *Allows multiple sequential cuts of varying types, retain options, live BC/cell designations*
- ✓ *Multiple “Ranks”(each utilizes regular cutting procedure)*
- ✓ *Allows “BC created by cutting” to subsequently act as cutter*
- ✓ *Useful for complex overlapping geometries, robust cutting procedures for evolving transient solutions, 3+ overlapping bodies*

# Sequential Cutting



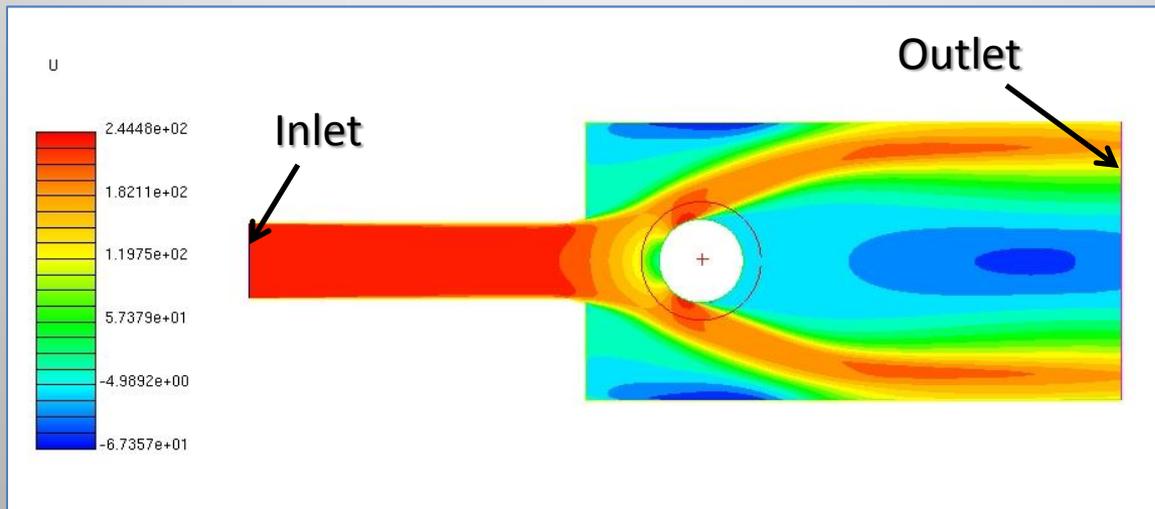
# Sequential Cutting



Rank 1: Use wall, do not retain cut cells

Rank 2: Use BC created by rank 1 and zonal, retain cut cells

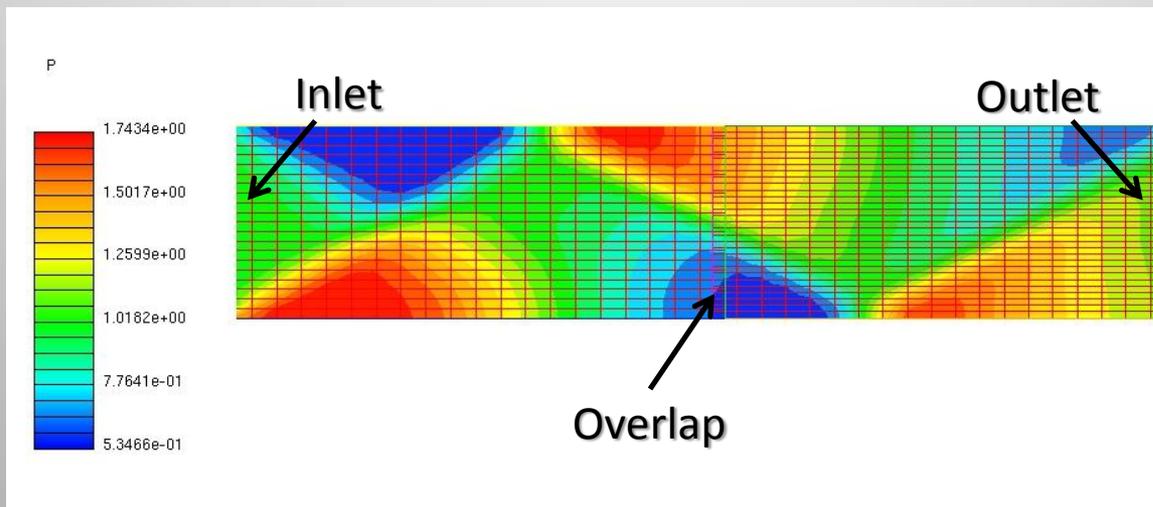
# Flux Stitching



2D Incompressible, Steady Ball Valve

<b>Mass Flux Error % w/o FS</b>	<b>0.1%</b>
<b>Mass Flux Error % with FS</b>	<b>&lt; 0.001%</b>

# Flux Stitching

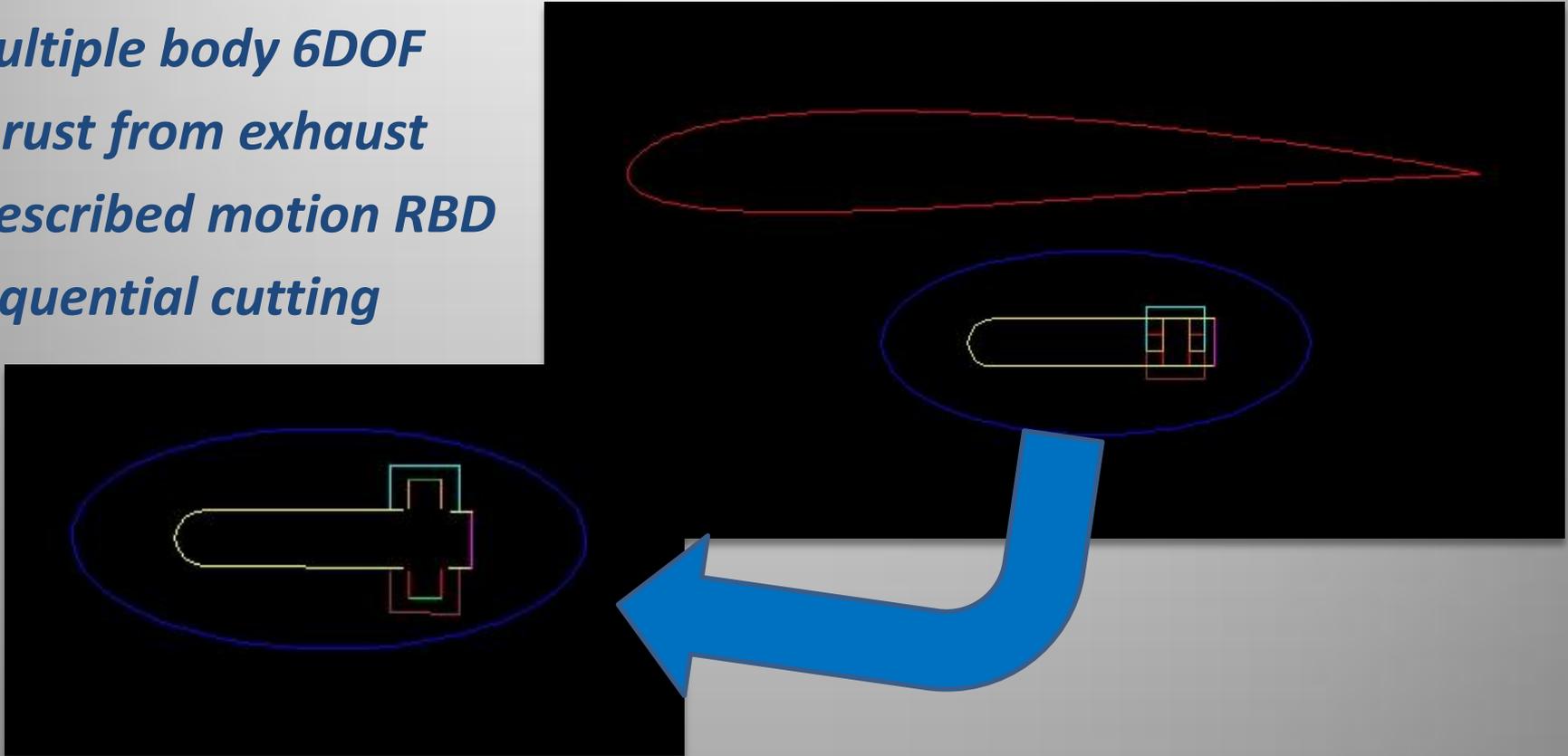


3D Supersonic Flow in Channel

<b>Mass Flux Error % w/o FS</b>	<b>0.04 %</b>
<b>Mass Flux Error % with FS</b>	<b>&lt; 0.001%</b>

# Case 1: Store Separation with Fin Deployment

- ✓ *Multiple body 6DOF*
- ✓ *Thrust from exhaust*
- ✓ *Prescribed motion RBD*
- ✓ *Sequential cutting*





# Case 1: Steps

## Steady State:

- 1. Concatenate Grids**
- 2. Cutting/Blanking**
- 3. Flow Specifications**

## Transient:

- 1. Grid Motion /6DOF**
- 2. Flow Specifications**

# Case 1: Concatenate Grids

File Grid Wizards Edit Setup Topology Numerics Physics **Tools** Execute Help

GRID INFO REF Q dt

**Concatenate using Sub-directories**

**Background/Airfoil**

**Store**

**Fins**

Modes of Graphics Operation:  Rotate  Translate  Zoom  Axis  Outlines  Hiding  Cross

Press F9 to toggle between rot/tran/zoom and pick modes --- Current mode is: rot/tran/zoom X = -2.5793e-01 Y = 7.8013e-01

Viewpoint Controls Lock View Turn off BCs Print to File Toggle Background Boundary Manager Lighting Control

# Case 1: Cutting/Blanking

The screenshot shows a software interface with a menu bar (File, Grid, Wizards, Edit, Setup, **Topology**, Numerical, Help) and a toolbar. A yellow box labeled "Sequential Cutting" is positioned over the "Topology" menu item. The main workspace displays a red wireframe grid of a mechanical part. Three blue callout boxes with yellow arrows point to specific areas: "Remove Background Grid" points to the outer boundary, "Remove Store Grid" points to a central rectangular feature, and "Remove Fin Grids" points to a fin-like structure. Below the grid, the text "Original Grid" is written in yellow. At the bottom, there is a control bar with "Modes of Graphics Operation" (Rotate, Translate, Zoom, Axis, Outlines, Hiding, Cross) and a status bar showing "Press F9 to toggle between rot/tran/zoom and pick modes --- Current mode is: rot/tran/zoom" and coordinates "X = -2.5793e-01 Y = 7.8013e-01". A row of buttons includes Viewpoint, Controls, Lock View, Turn off BCs, Print to File, Toggle Background, Boundary Manager, and Lighting Control.

# Case 1: Cutting/Blanking

The screenshot shows a software interface for 'Sequential Cutting'. The main window displays a red grid with a blue cutter path. A yellow circle highlights a specific area of the grid. A yellow arrow points to a 'Live: Airfoil' label. A blue box labeled 'Overlap: Retain' shows a zoomed-in view of the grid and cutter path. A blue box labeled 'Cutter: Store Zonal' is at the bottom right. A blue box labeled 'Blank: Background Group' is at the bottom left. The interface includes a menu bar with 'File', 'Grid', 'Wizards', 'Edit', 'Setup', 'Topology', 'Numerics', and 'Help'. The 'Topology' menu is circled in red. The status bar shows 'Modes of Graphics Operation: Rotate Translate Zoom Axis Outlines Hiding Cross' and 'Press F9 to toggle between rot/tran/zoom and pick modes --- Current mode is: rot/tran/zoom'. The coordinates 'X = -2.5793e-01 Y = 7.8013e-01' are displayed. A 'Rank 1 Grid' label is at the bottom center.

# Case 1: Cutting/Blanking

The screenshot displays a software interface for a cutting/blanking process. At the top, the menu bar includes 'File', 'Grid', 'Wizards', 'Edit', 'Setup', 'Topology' (circled in red), and 'Numerics'. A yellow box labeled 'Sequential Cutting' is positioned over the 'Topology' menu. Below the menu is a toolbar with various icons, including 'GRID INFO', 'REF', 'IC', 'BC', 'COMN', 'OPTS', and 'K8'. The main workspace shows a 'Rank 2 Grid' (a red mesh) with a central black cutout. Annotations with arrows point to specific areas: 'Cutter: All Walls' points to the inner boundary of the cutout; 'Blank: Store and Fin Groups' points to the outer boundary; 'Overlap: Don't Retain' points to a circular area of overlapping mesh; and 'Live: Exhaust and Fin Tops' points to the top-right corner of the cutout. At the bottom, there is a status bar with 'Modes of Graphics Operation' (Rotate, Translate, Zoom, Axis, Outlines, Hiding, Cross) and 'Press F9 to toggle between rot/tran/zoom and pick modes --- Current mode is: rot/tran/zoom'. Below the status bar are several control buttons: 'Viewpoint', 'Controls', 'Lock View', 'Turn off BCs', 'Print to File', 'Toggle Background', 'Boundary Manager', and 'Lighting Control'. The coordinates 'X = -2.5793e-01 Y = 7.8013e-01' are displayed on the right side of the status bar.

# Case 1: Flow Specifications

File Grid **Wizards** Edit Setup Topology **Numerics** Physics Tools Execute Help

GRID INFO REF Q IC BC SYS COM PLOT OPTS dt

**Aerodynamic Wizard**

**Boundary Conditions**

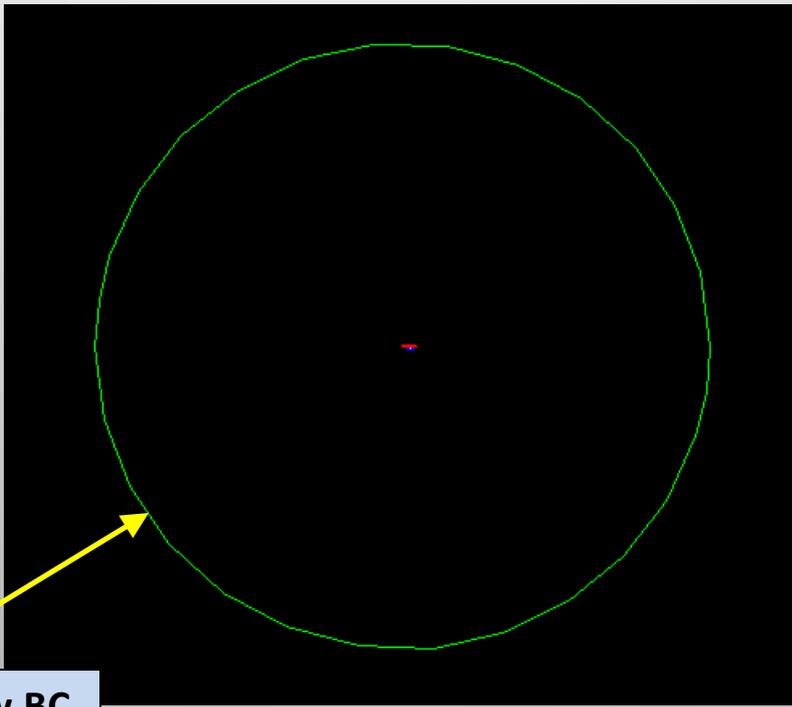
**Steady State Setup**

Modes of Graphics Operation:  Rotate  Translate  Zoom  Axis  Outlines  Hiding  Cross

Press F9 to toggle between rot/tran/zoom and pick modes --- Current mode is: rot/tran/zoom X = -2.5793e-01 Y = 7.8013e-01

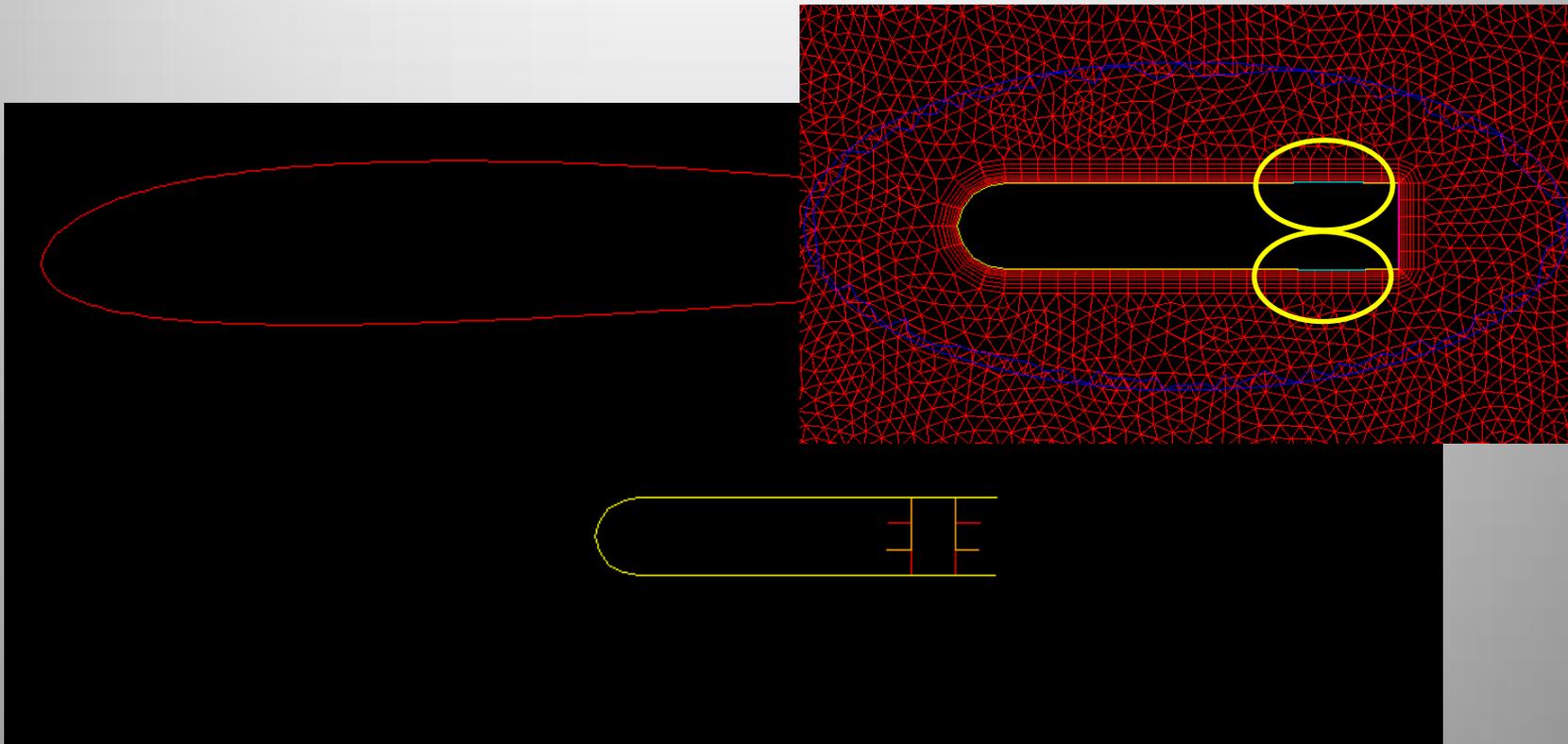
Viewpoint Controls Lock View Turn off BCs Print to File Toggle Background Boundary Manager Lighting Control

# Case 1: Boundary Conditions



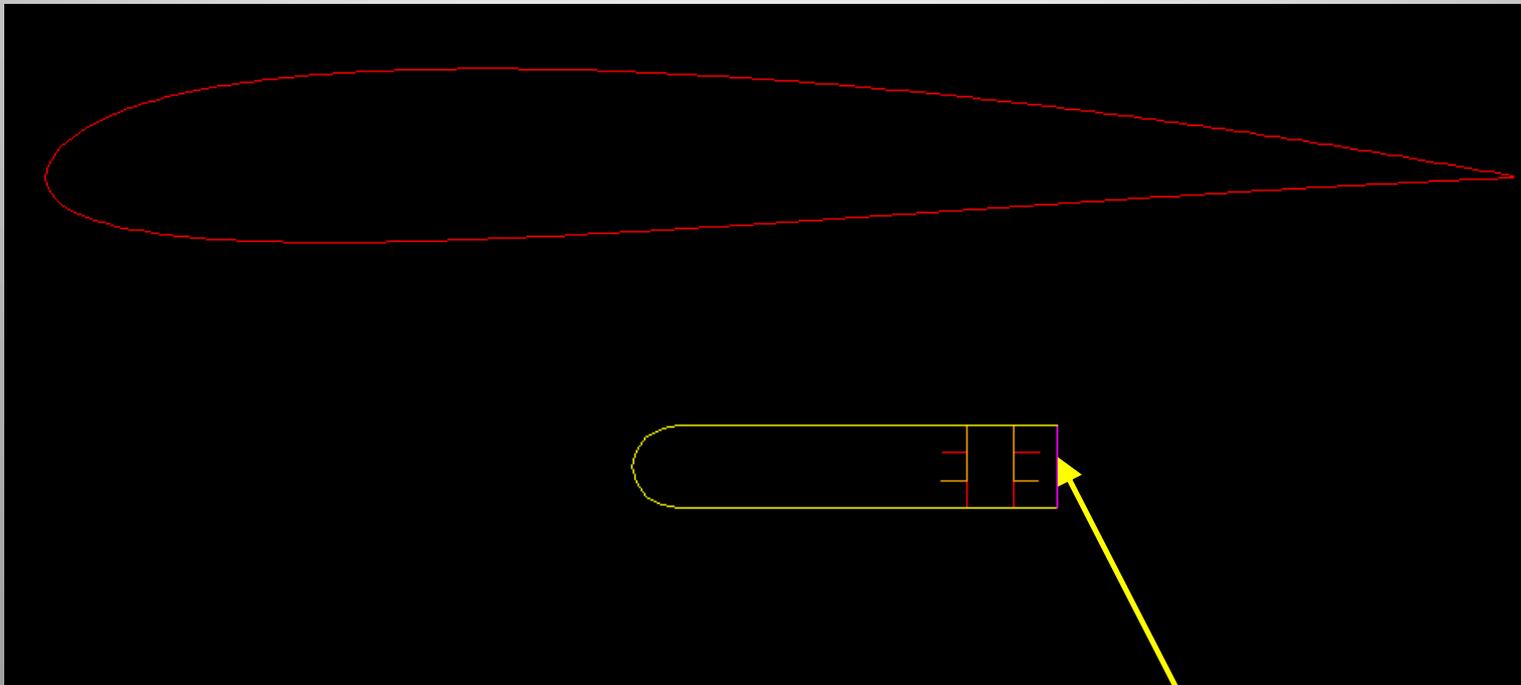
Far-field: Inflow/Outflow BC

# Case 1: Boundary Conditions



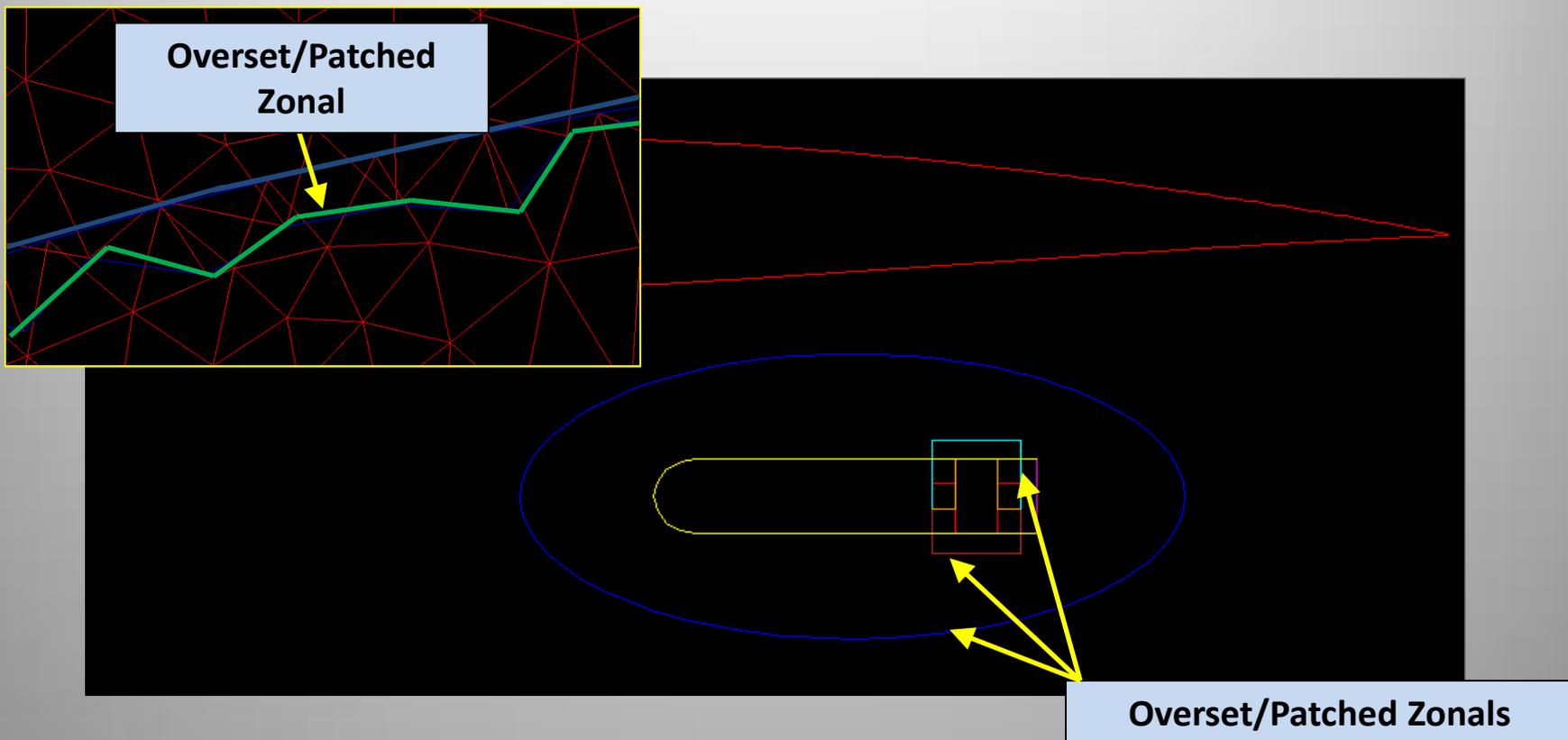
**Adiabatic, Viscous Wall  
Functions**

# Case 1: Boundary Conditions



**Exhaust: Time dependent  
Mass Flow Rate, Temp.**

# Case 1: Boundary Conditions



# Case 1: Flow Specifications

File Grid **Wizards** Edit Setup Topology **Numerics** Physics Tools Execute Help

GRID INFO REF Q IC BC SYS COM PLOT OPTS dt

**Aerodynamic Wizard**

**Boundary Conditions**

**RUN**

**Steady State Setup**

Modes of Graphics Operation:  Rotate  Translate  Zoom  Axis  Outlines  Hiding  Cross

Press F9 to toggle between rot/tran/zoom and pick modes --- Current mode is: rot/tran/zoom X = -2.5793e-01 Y = 7.8013e-01

Viewpoint Controls Lock View Turn off BCs Print to File Toggle Background Boundary Manager Lighting Control

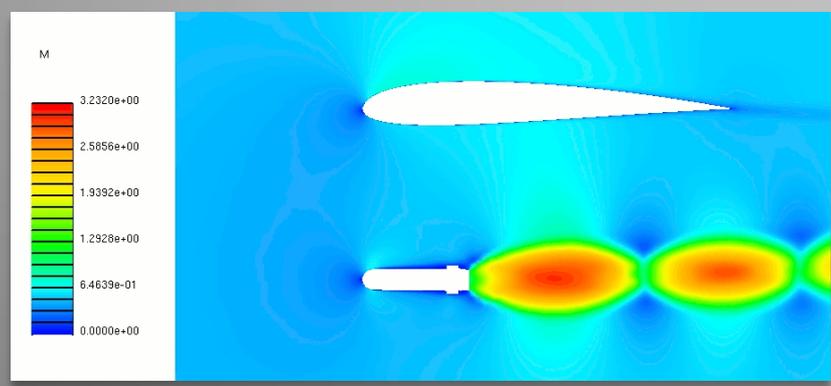
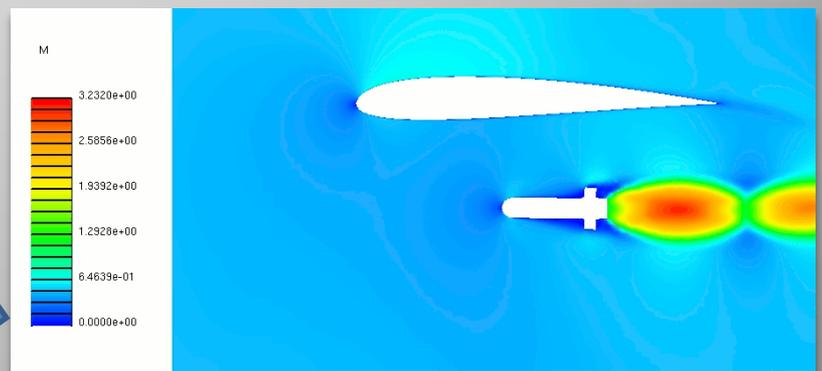
# Case 1: Flow Specifications

The screenshot shows a software interface with a menu bar (File, Grid, Wizards, Edit, Setup, Topology, Numerics, Physics, Tools, Execute, Help) and a toolbar with various icons. The main workspace is black and contains a yellow teardrop-shaped object. A red circle highlights the 'Topology' menu item, with a red line pointing to a yellow box labeled 'Rigid Body Motion'. A blue oval encloses the yellow teardrop object, with a blue arrow pointing to a light blue box labeled '6DOF: Store + Fins'. A yellow circle highlights a detail of the teardrop's internal structure, with a yellow arrow pointing to a light blue box labeled 'File-based Translation: Fins'. The text 'Transient Setup' is written in yellow at the bottom of the workspace. Below the workspace is a control bar with 'Modes of Graphics Operation' (Rotate, Translate, Zoom, Axis, Outlines, Hiding, Cross) and a status line: 'Press F9 to toggle between rot/tran/zoom and pick modes --- Current mode is: rot/tran/zoom X = -2.5793e-01 Y = 7.8013e-01'. At the bottom are buttons for 'Viewpoint', 'Controls', 'Lock View', 'Turn off BCs', 'Print to File', 'Toggle Background', 'Boundary Manager', and 'Lighting Control'.

# Case 1: Flow Specifications

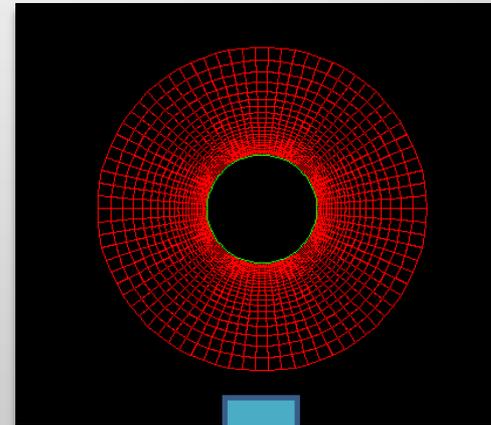
The screenshot shows a software interface with a menu bar (File, Grid, Wizards, Edit, Setup, Topology, Numerics, Physics, Tools, Execute, Help) and a toolbar. Three red circles highlight the 'Wizards' menu, the 'Topology' menu, and a 'RUN' button. Below the toolbar, three yellow boxes are labeled 'Transient Wizard', 'Rigid Body Motion', and 'Numerics Wizard'. A blue arrow labeled 'RUN' points to the right. A blue oval encloses a 3D model of a wing-like structure with a grid. The text 'Transient Setup' is displayed in yellow at the bottom of the main window. At the very bottom, there is a status bar with 'Modes of Graphics Operation' (Rotate, Translate, Zoom, Axis, Outlines, Hiding, Cross) and a coordinate display 'X = -2.5793e-01 Y = 7.8013e-01'. A row of buttons includes 'Viewpoint', 'Controls', 'Lock View', 'Turn off BCs', 'Print to File', 'Toggle Background', 'Boundary Manager', and 'Lighting Control'.

# Case 1: Store Separation with Fin Deployment



# Case 2: 2D Ball Drop

- ✓ *6DOF*
- ✓ *Volume of Fluid*
- ✓ *Buoyancy*
- ✓ *Cutting and Blanking*





# Case 2: Steps

## Ball Drop:

- 1. Concatenate Grids**
- 2. Cutting/Blanking**
- 3. Grid Motion (6DOF)**
- 4. Flow Specifications**

# Case 2: Concatenate Grids

The screenshot displays a software application window with the following components:

- Menu Bar:** File, Grid, Wizards, Edit, Setup, Topology, Numerics, Physics, **Tools** (circled in red), Execute, Help.
- Toolbar:** Contains various icons for grid operations. A yellow callout box points to the 'Concatenate using Sub-directories' icon.
- Main Viewport:** Shows two red wireframe grids: a rectangular 'Background' grid on the left and a circular 'Ball' grid on the right, separated by a plus sign (+).
- Status Bar:** Displays 'Modes of Graphics Operation:  Rotate  Translate  Zoom  Axis  Outlines  Hiding  Cross'. Below this, it says 'Press F9 to toggle between rot/tran/zoom and pick modes --- Current mode is: rot/tran/zoom' and 'X = -2.5793e-01 Y = 7.8013e-01'.
- Control Panel:** A row of buttons at the bottom: Viewpoint, Controls, Lock View, Turn off BCs, Print to File, Toggle Background, Boundary Manager, Lighting Control.

# Case 2: Cutting/Blanking

The screenshot shows a software window titled "Sequential Cutting". The menu bar includes "File", "Grid", "Wizards", "Edit", "Setup", "Topology", "Numer", and "Help". The "Topology" menu is circled in red. The toolbar contains various icons for grid operations, including "GRID INFO", "REF", "IC", "BC", "COMN", "OPTS", and "K8". The main workspace displays a red grid with a circular hole in the center, labeled "Original Grid". A yellow arrow points from a button labeled "Remove Background Grid" to the grid. Below the workspace, there are checkboxes for "Modes of Graphics Operation": Rotate, Translate, Zoom, Axis, Outlines, Hiding, and Cross. A status bar indicates "Press F9 to toggle between rot/tran/zoom and pick modes --- Current mode is: rot/tran/zoom" and coordinates "X = -2.5793e-01 Y = 7.8013e-01". At the bottom, there are buttons for "Viewpoint", "Controls", "Lock View", "Turn off BCs", "Print to File", "Toggle Background", "Boundary Manager", and "Lighting Control".

# Case 2: Cutting/Blanking

The screenshot shows a software interface for 'Sequential Cutting'. The main window displays a 'Rank 1 Grid' with a circular hole. A yellow box at the top center contains the text 'Sequential Cutting'. The 'Topology' menu item is circled in red. A yellow arrow points from the 'Live: Top' label to the top of the grid. A yellow circle highlights a portion of the grid's boundary, with a yellow arrow pointing to a blue box labeled 'Overlap: Retain' which shows a magnified view of the grid's stepped edge. A yellow arrow points from the 'Blank: Background Group' label to the grid. Another yellow arrow points from the 'Cutter: Zonal' label to the grid. The interface includes a menu bar (File, Grid, Wizards, Edit, Setup, Topology, Numerics, Help), a toolbar with various icons, and a status bar at the bottom with buttons for 'Viewpoint', 'Controls', 'Lock View', 'Turn off BCs', 'Print to File', 'Toggle Background', 'Boundary Manager', and 'Lighting Control'. The status bar also displays 'Modes of Graphics Operation: Rotate Translate Zoom Axis Outlines Hiding Cross' and 'Press F9 to toggle between rot/tran/zoom and pick modes --- Current mode is: rot/tran/zoom X = -2.5793e-01 Y = 7.8013e-01'.

# Case 2: Grid Motion

File Grid Wizards Edit Setup **Topology** Numerics Physics Tools Execute Help

GRID INFO REF Q IC BC SYS COMM PLOT OPTS dt

**6DOF Flux-stitching**

**Ball Group**

**2D Ball Setup**

Modes of Graphics Operation:  Rotate  Translate  Zoom  Axis  Outlines  Hiding  Cross

Press F9 to toggle between rot/tran/zoom and pick modes --- Current mode is: rot/tran/zoom X = -2.5793e-01 Y = 7.8013e-01

Viewpoint Controls Lock View Turn off BCs Print to File Toggle Background Boundary Manager Lighting Control

# Case 2: Flow Specifications



File Grid Wizards Edit Setup Topology Numerics Physics Tools Execute Help

GRID INFO = REF [Water Drop] [Grid] IC BC SYS COMM PLOT OPTS dt [Triangle] [Arrow] [U\_t] [K\_E] [Check] [Home] [Run] [Warning] [Plot]

Equation Set Definition

Fluid Properties

Initial Conditions

Air

Water

2D Ball Setup

Modes of Graphics Operation:  Rotate  Translate  Zoom  Axis  Outlines  Hiding  Cross

Press F9 to toggle between rot/tran/zoom and pick modes --- Current mode is: rot/tran/zoom X = -2.5793e-01 Y = 7.8013e-01

Viewpoint Controls Lock View Turn off BCs Print to File Toggle Background Boundary Manager Lighting Control

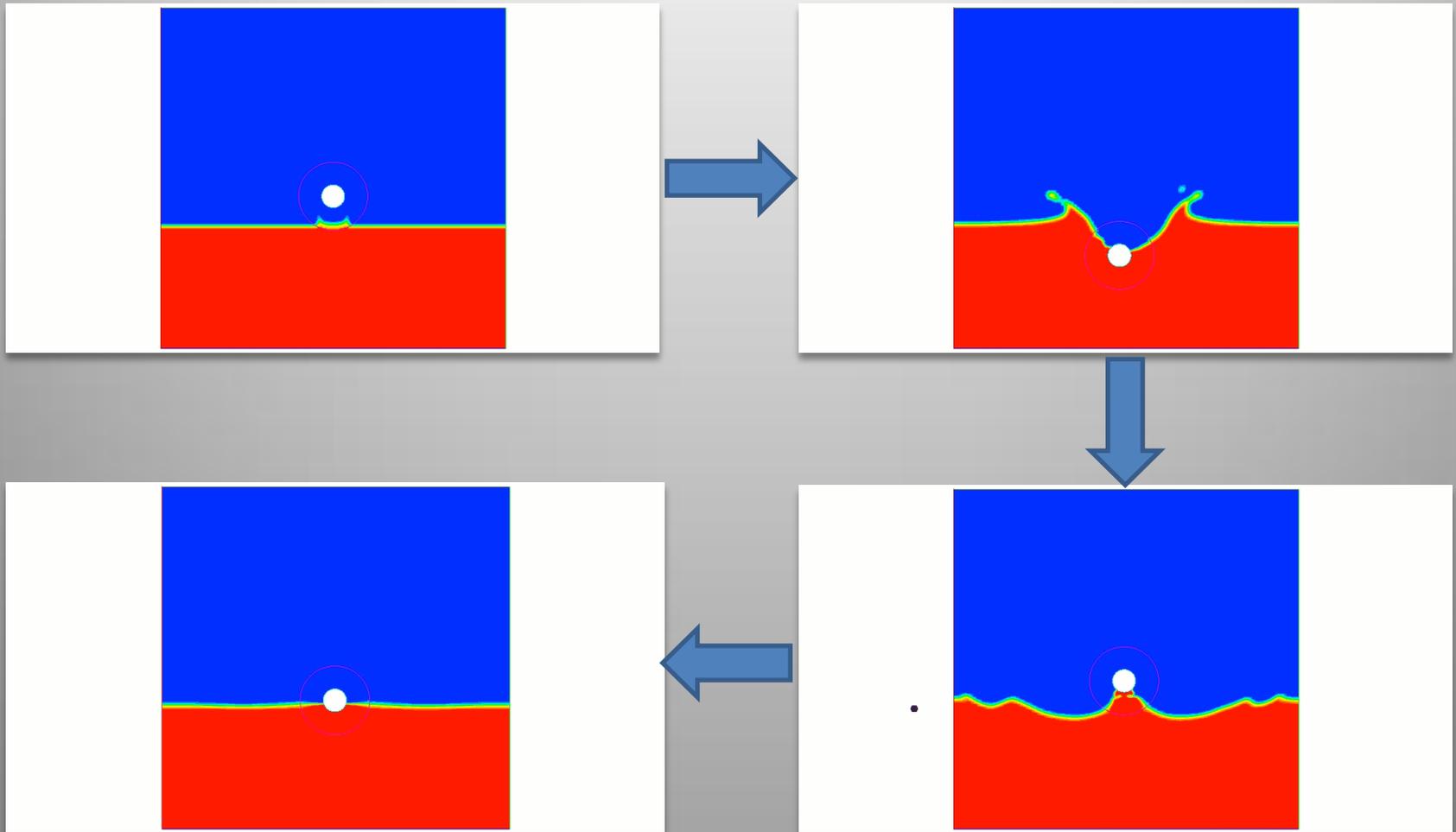
# Case 2: Flow Specifications

Short-cut Button Path

The screenshot shows a software interface with a menu bar (File, Grid, Wizards, Edit, Setup, Topology, Numerics, Physics, Tools, Events, Help) and a toolbar. A red arrow labeled "Short-cut Button Path" points from the title to the toolbar. The toolbar contains several icons, with three circled in red: a yellow box with an equals sign, a blue box with a water drop, and a blue box with a grid. Red lines connect these icons to yellow boxes on the left: "Equation Set Definition", "Fluid Properties", and "Initial Conditions". A red line also connects the "IC" icon to a yellow box labeled "Boundary Conditions". The main window displays a 3D grid with a blue line and a purple line. A blue box labeled "Overset/Patched Zonal" points to the grid. A blue box labeled "Adiabatic, Visc. Walls" points to a small circle on the grid. A blue box labeled "Inflow/Outflow" points to a yellow arrow on the grid. Another blue box labeled "Overset/Patched Zonal" points to a yellow arrow on the grid. The bottom of the interface has a status bar with "Modes of Graphics Operation" (Rotate, Translate, Zoom, Axis, Outlines, Hiding, Cross) and "Press F9 to toggle between rot/tran/zoom and pick modes --- Current mode is: rot/tran/zoom". Below the status bar are buttons for "Viewpoint", "Controls", "Lock View", "Turn off BCs", "Print to File", "Toggle Background", "Boundary Manager", and "Lighting Control".



# Case 2: 2D Ball Drop

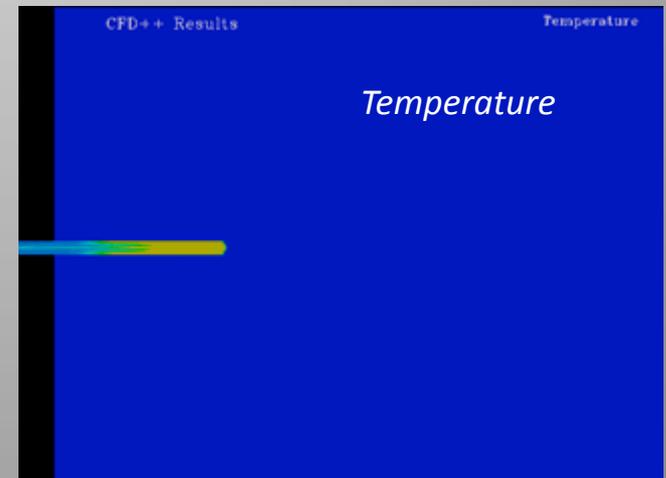
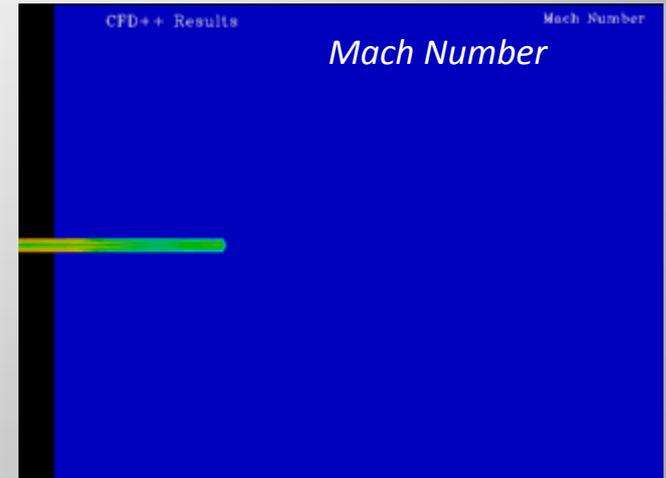




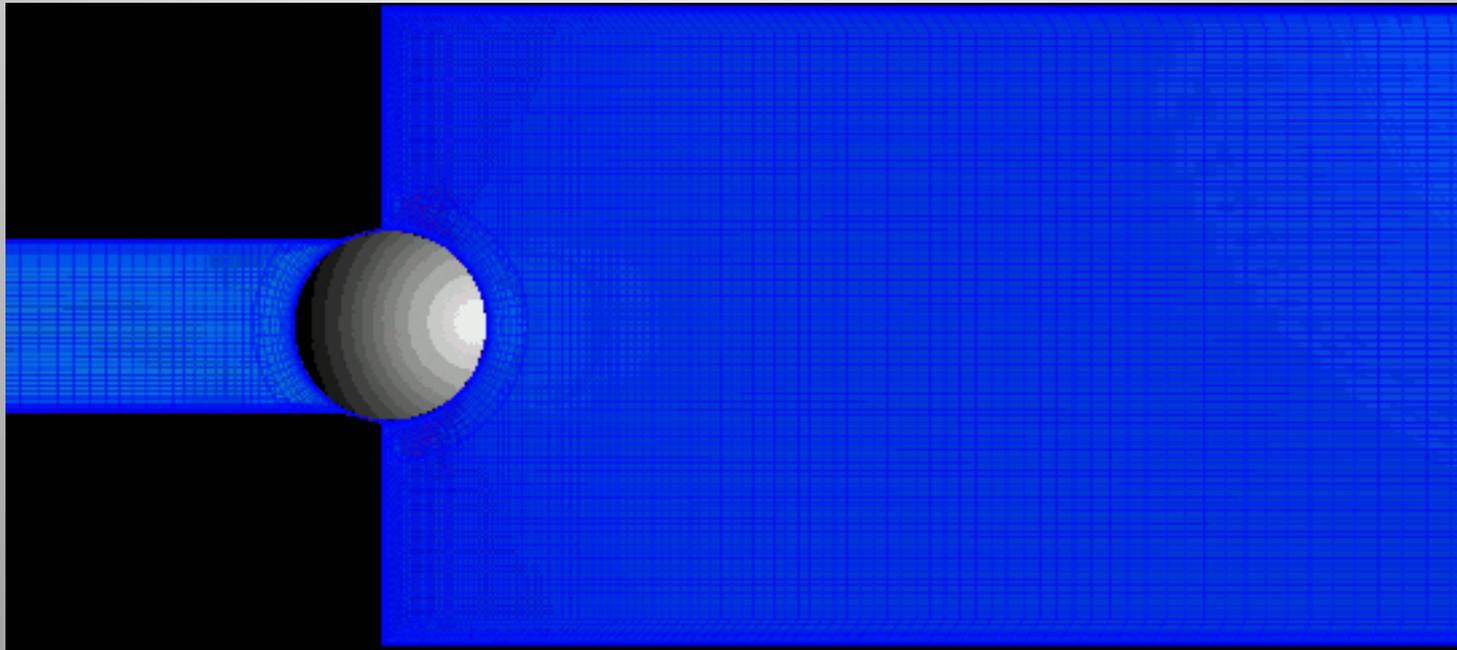
# More Examples

# Bullet Leaving a Gun Barrel

- ❑ *To simulate the detonated propellant a region of very high temperature and pressure air was imposed behind the bullet*
- ❑ *2-D axisymmetric computation simulates about  $2.5e-4$  s (when bullet reaches end of domain, about 0.1 m from barrel exit) - grid was 81,000 cells*
- ❑ *Propellant races ahead of bullet and exits barrel at about  $6.25e-5$  s*
- ❑ *1.5 hours on 2 CPUs, required 2500 global time-steps with 9900 total iterations*
- ❑ *Each animation frame is  $2.5e-6$  s*



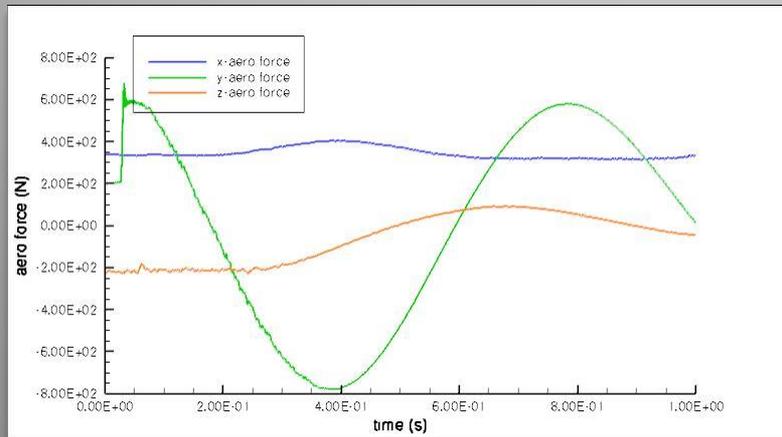
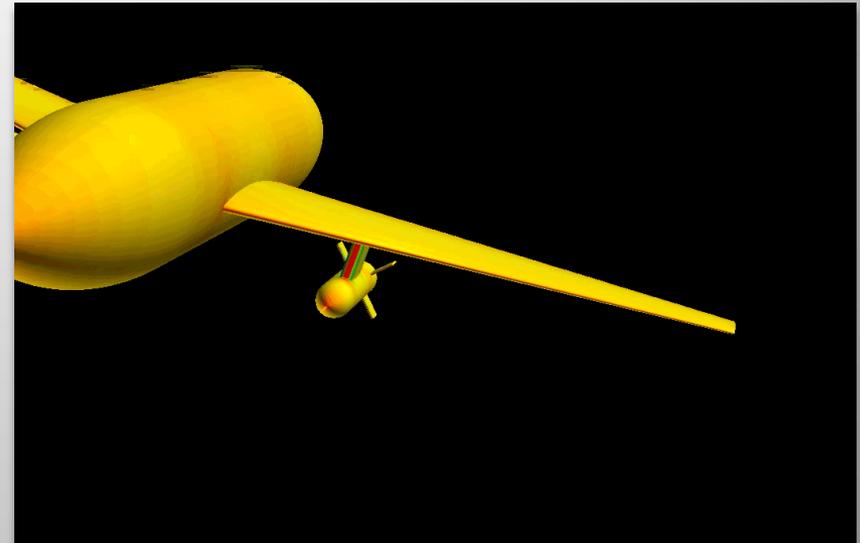
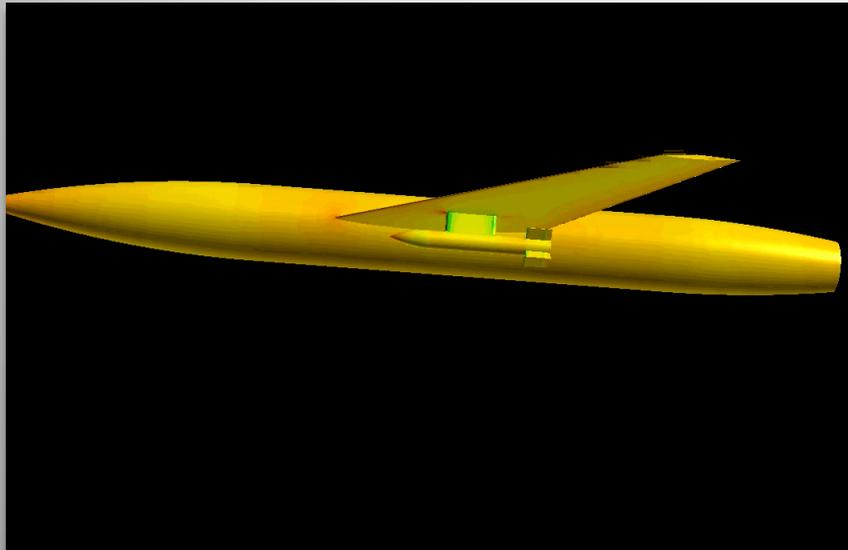
# Mesh Movement



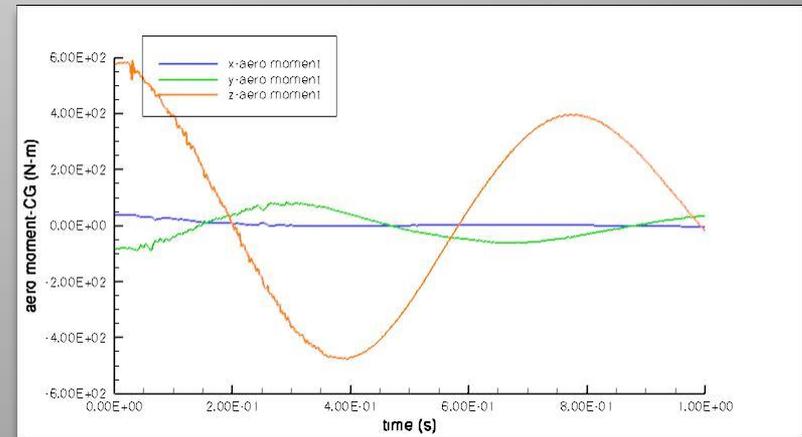
**Ball-valve example: mesh cutting with zonal connections**

**Flux stitching guarantees perfect conservation at zonal boundaries!**

# Store Separation using CFD++

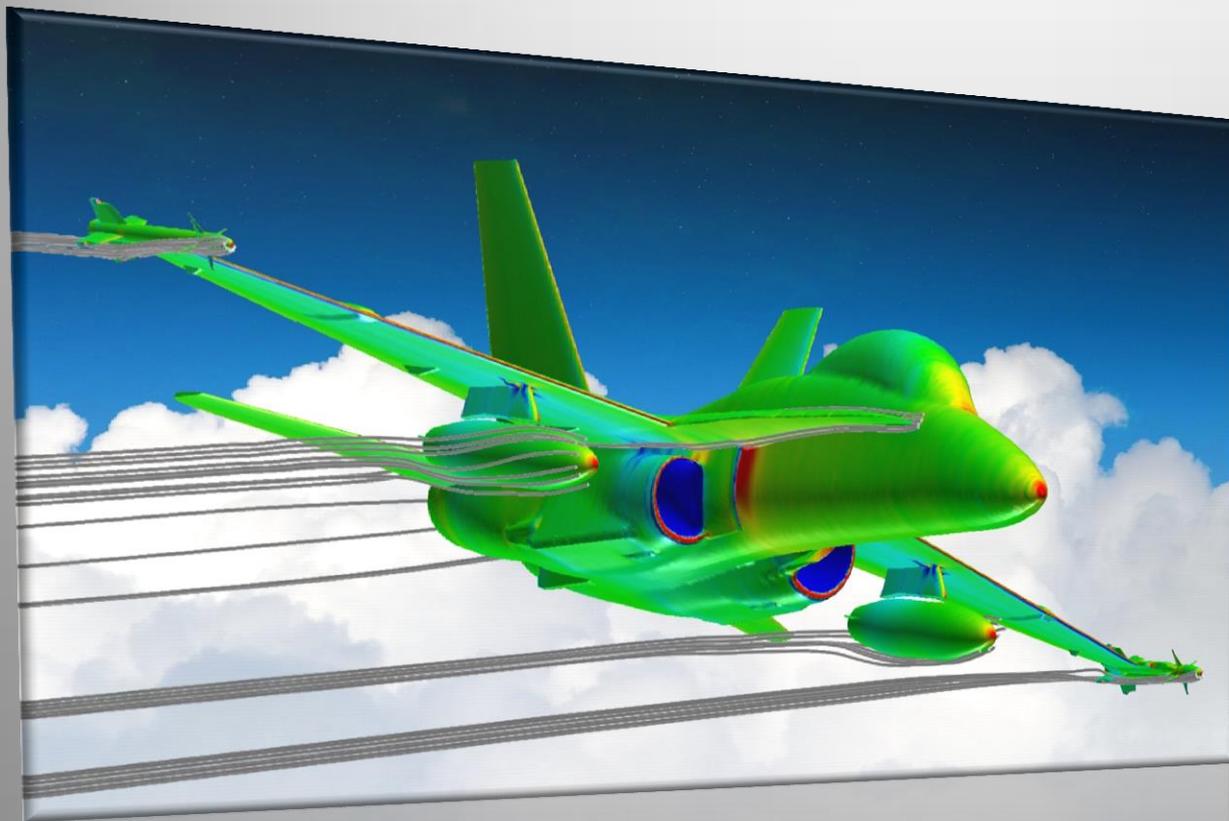


*Aerodynamic forces on store*

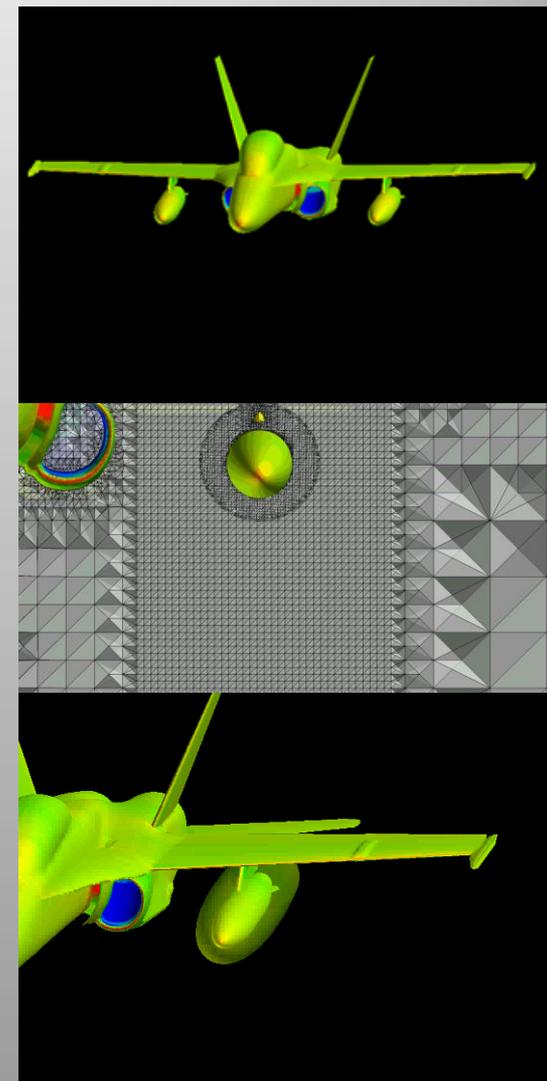


*Aerodynamic moments on store*

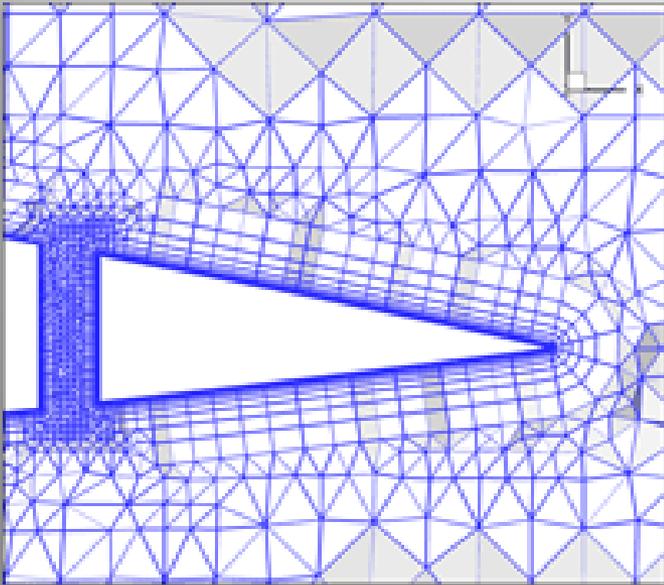
# F18 Fuel Tank Separation



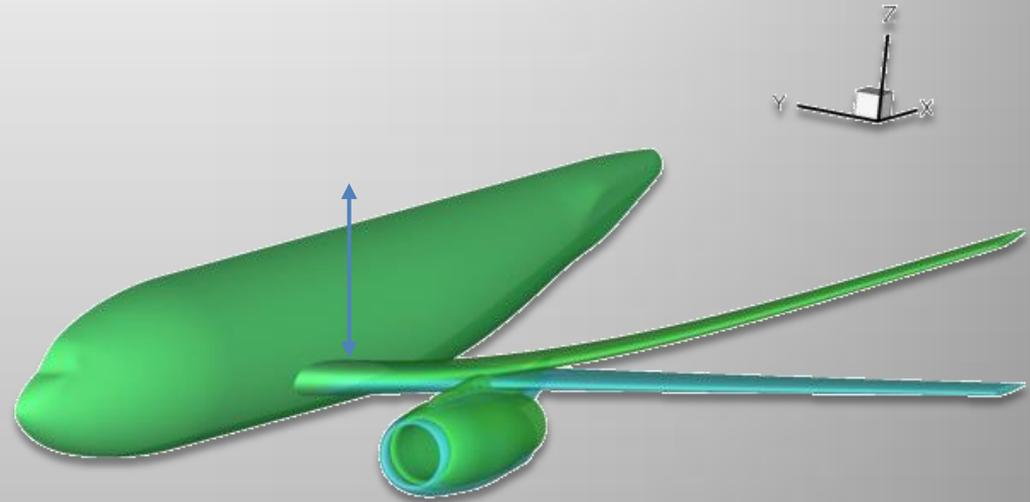
- ❑ Localized cutting, zonal connection, force integration and localized 6DOF



# Grid Morphing

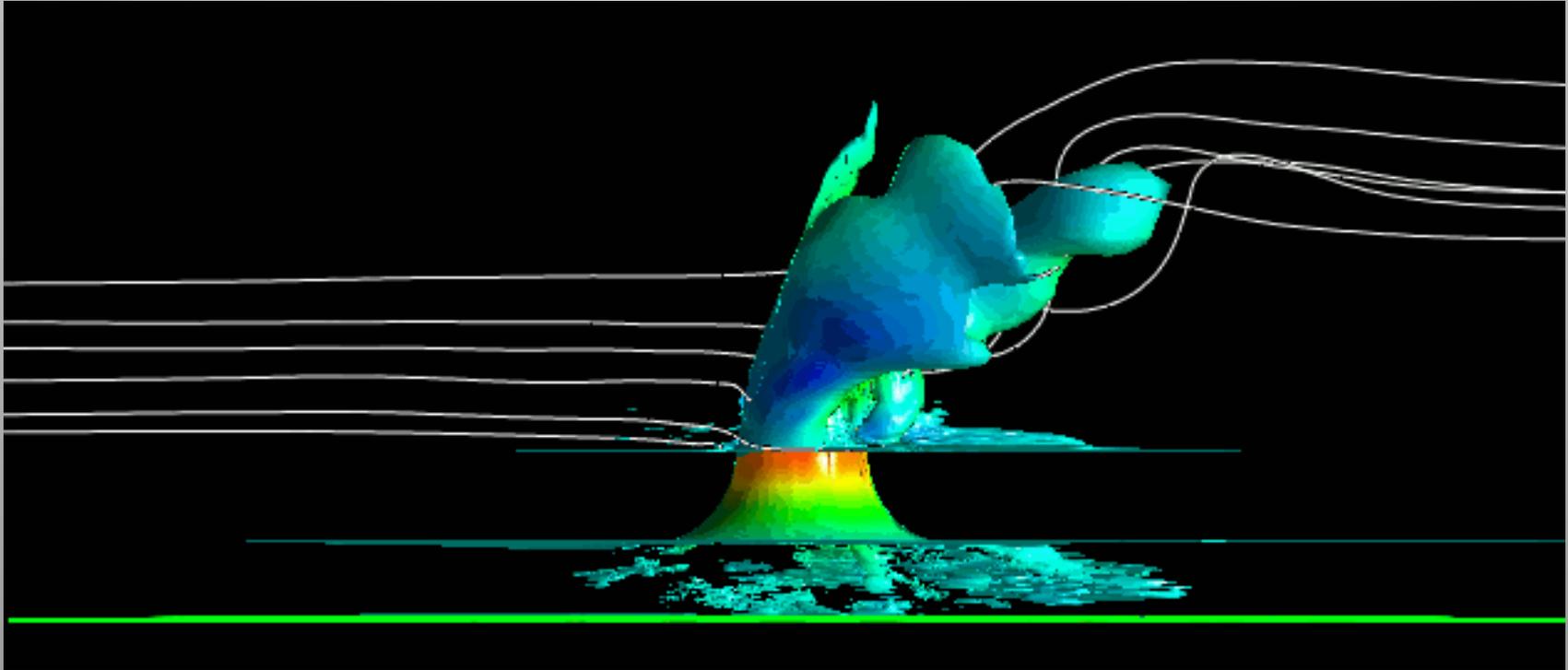


**Generic flap-deflection  
Controlled by local radial  
basis function  
interpolation**



**Drag Prediction Workshop  
Mesh  
33.8 million cells  
13.8 million nodes  
Localized deformation**

# Active Flow Control



- **Boundary-motion with local mesh morphing**
- **Sinusoidal time- (and space-) varying BC simulates membrane motion**
- **Ejection of fluid through BL on upstroke**
- **Suction on downstroke => thinned downstream BL**

# GLC-305 with 944 ice shape



*22.5 min glaze ice / 944 ice shape*