



Overset and Mesh Morphing Capabilities in CFD++:

Multiple Physics, Multiple
Applications, One Solver

Overset Grid Symposium 2014

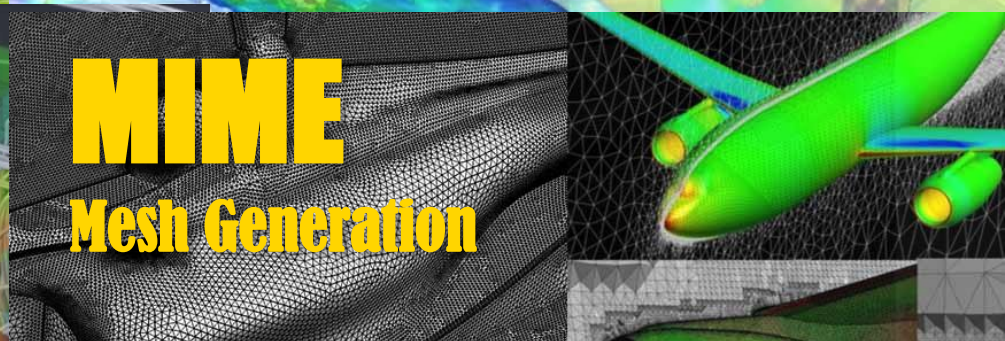
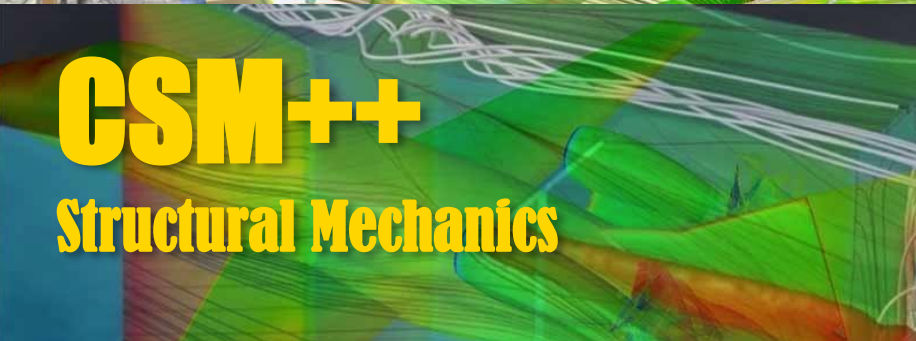


Metacomp Technologies

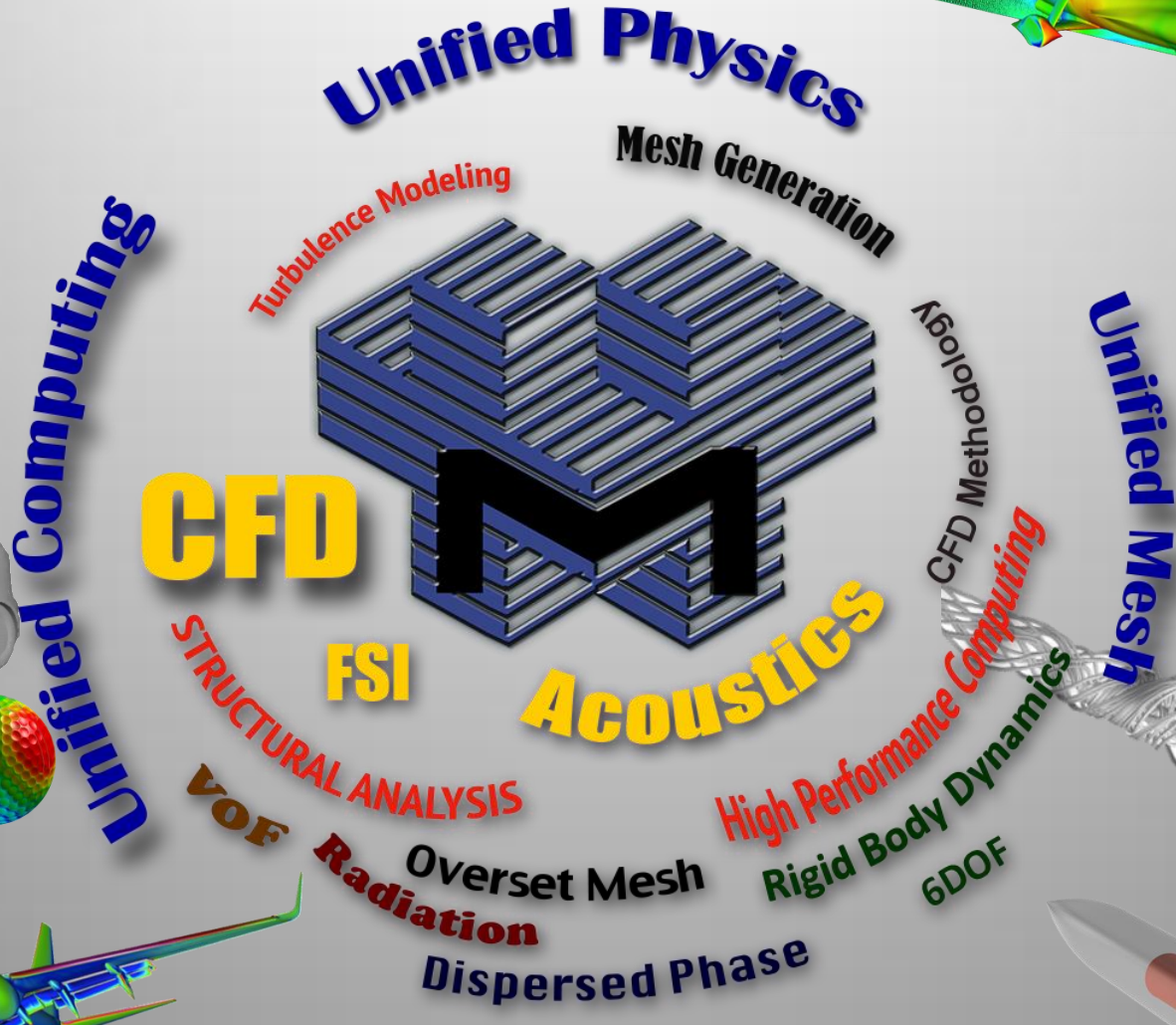
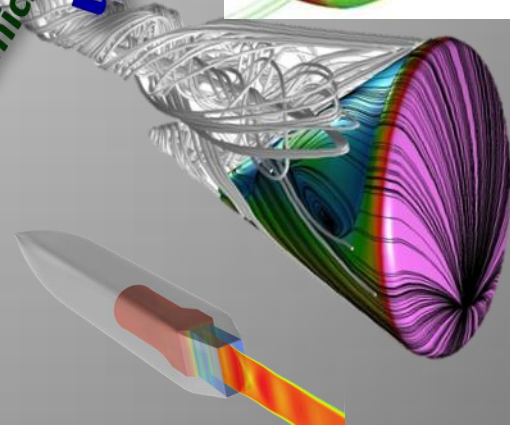
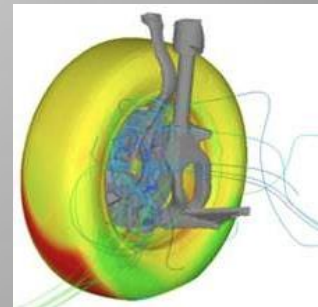
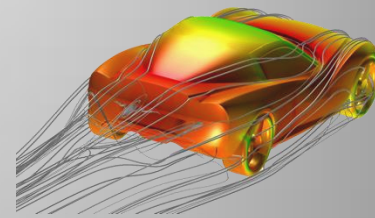
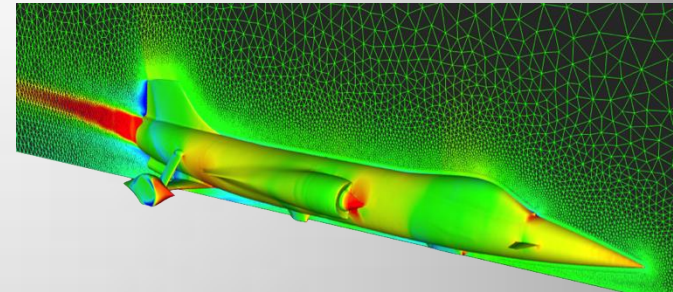
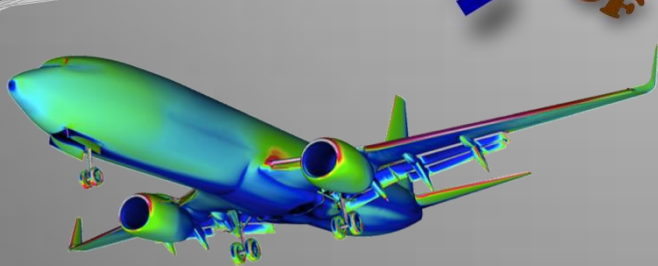
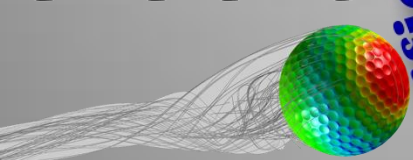
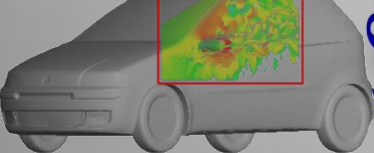
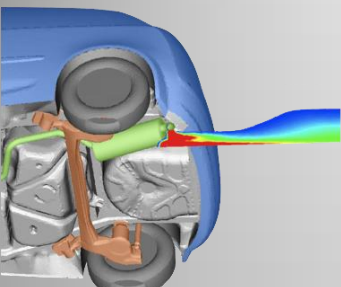


Background : Metacomp Technologies

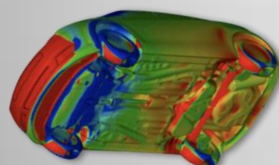
- Founded in 1994
- Key staff members are pioneers in CFD research
- CFD++ is 7th generation CFD software by founder, each one state-of-the-art when introduced
- Strong algorithm to applications experience
- Provides complete CAE solutions for its customers



Company Focus

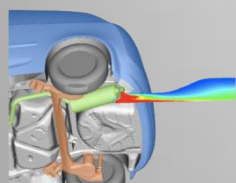
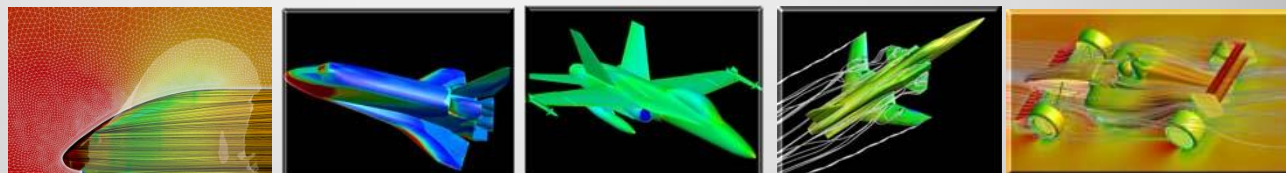


CFD++ Capabilities



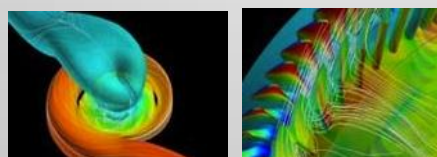
Under-hood flows

External Aerodynamics

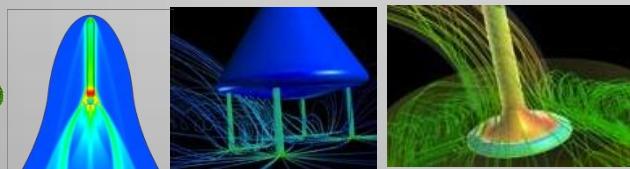


Exhaust gas infiltration

Turbomachinery

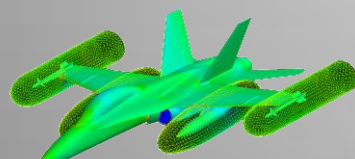


CFD++ is a comprehensive software suite that includes a rich collection of tools to help increase the end users' effectiveness.

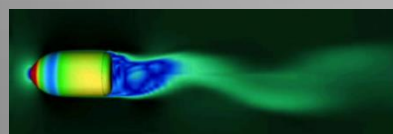


Propulsion

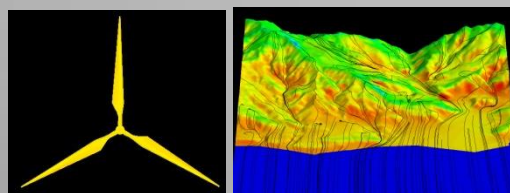
High- and low-Speed combustion



6DOF/moving bodies



Unsteady flow with Hybrid RANS/LES

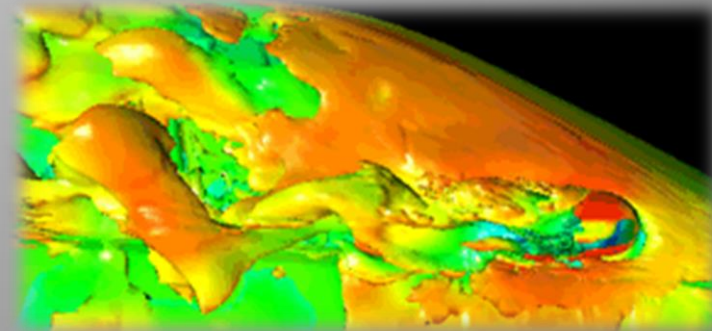
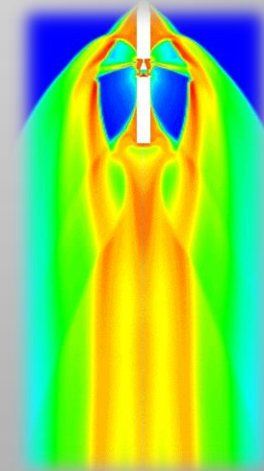
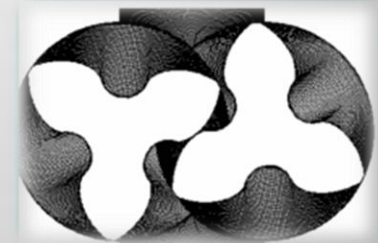


Wind energy – terrain verification

- 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

CFD++ Numerical Features

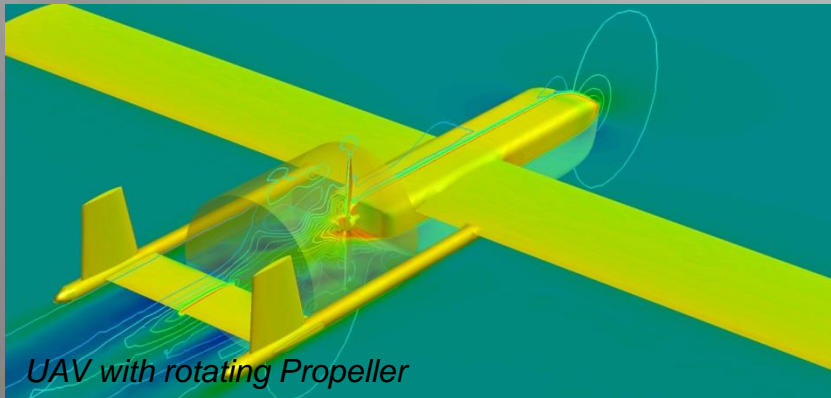
- ❑ Coupled density or pressure-based solvers
- ❑ Realizable physical, mathematical & numerical models
- ❑ Agglomeration (algebraic) multi-grid accelerated solver for fast convergence to steady state
- ❑ Multi-dimensional TVD framework for truly 2nd order accuracy on all meshes
- ❑ Up to fourth order 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

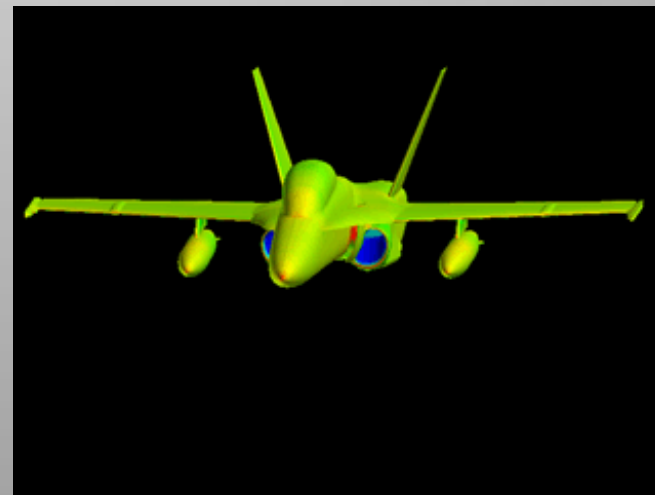
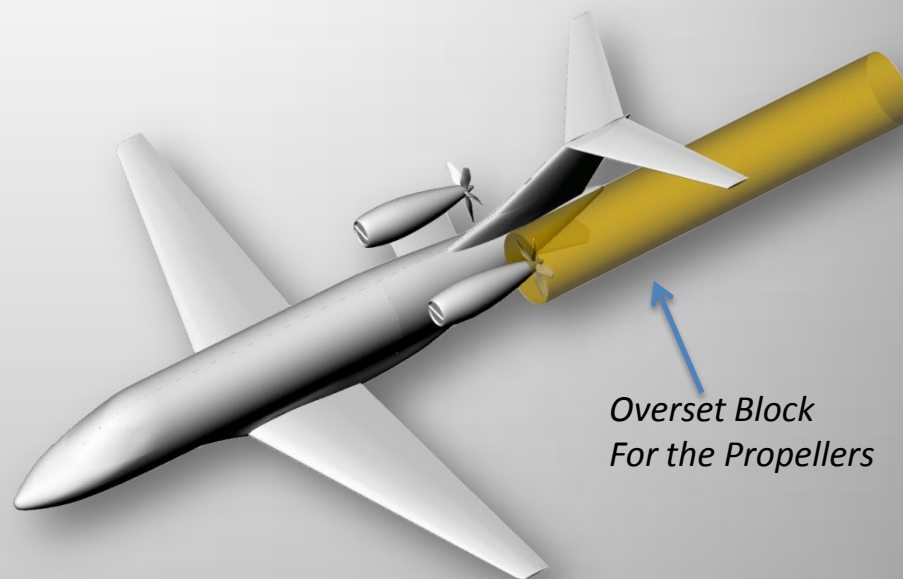
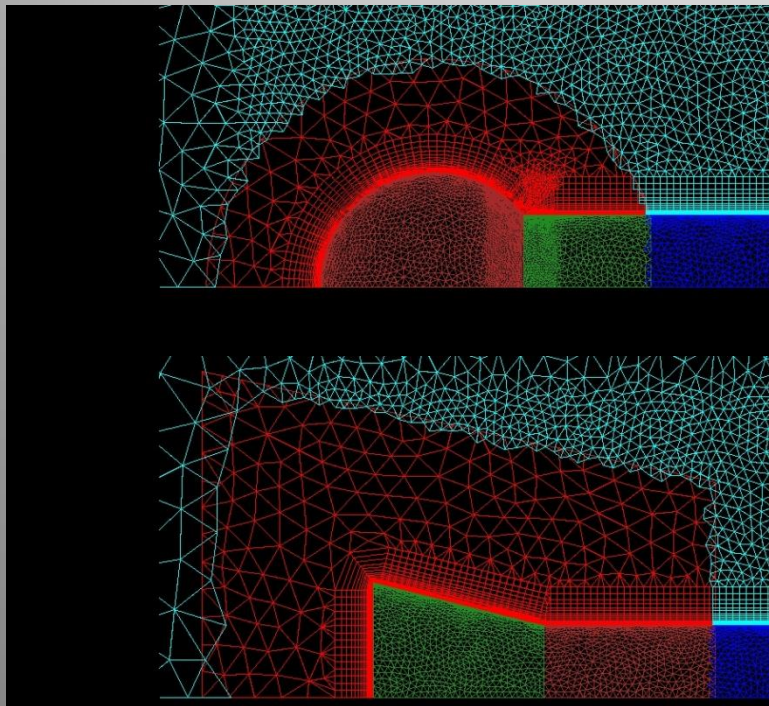
- *For transient simulations, cutting, blanking and interpolation operations can all be performed within CFD++ at every time step*

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*





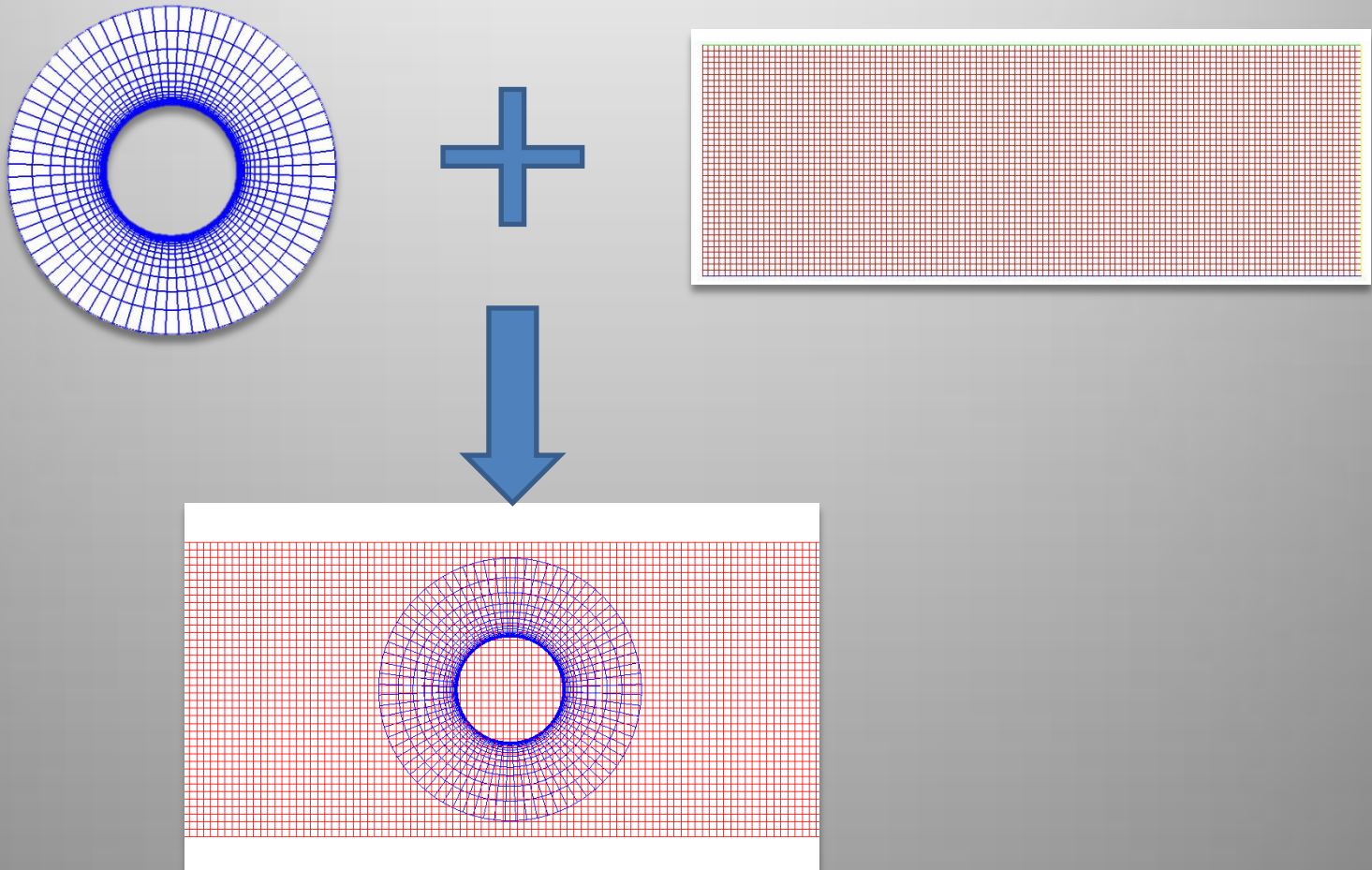
CFD++ Key Attributes

- ✓ *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*

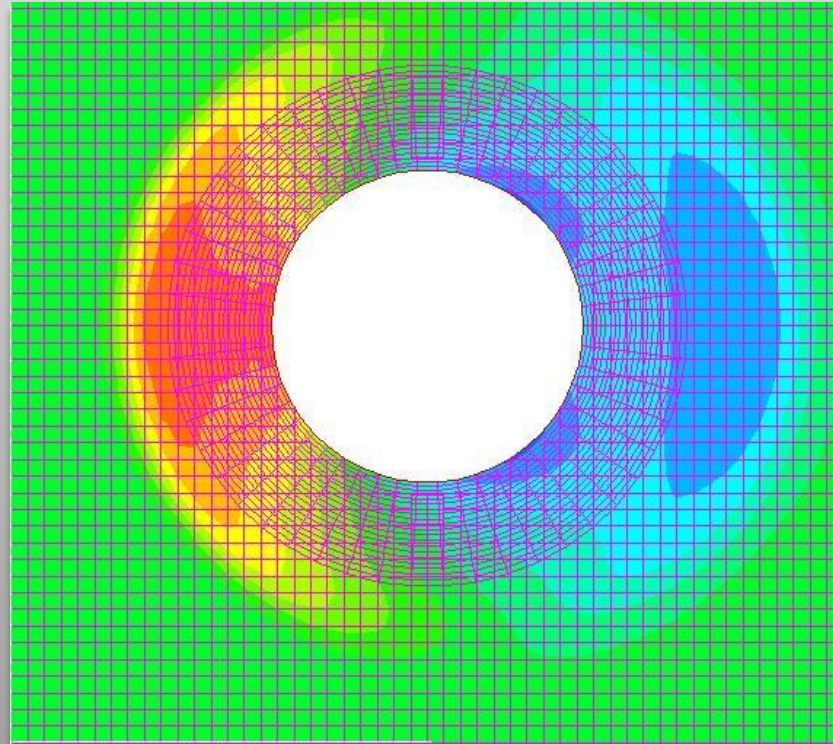
Overset Process in CFD++

✓ *Concatenation of grids*



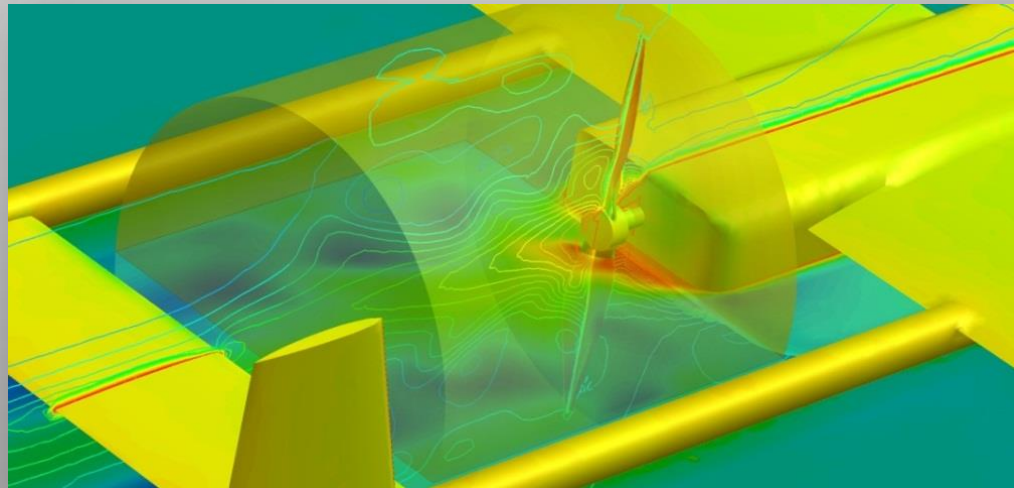
Overset Process in CFD++

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



Overset Process in CFD++

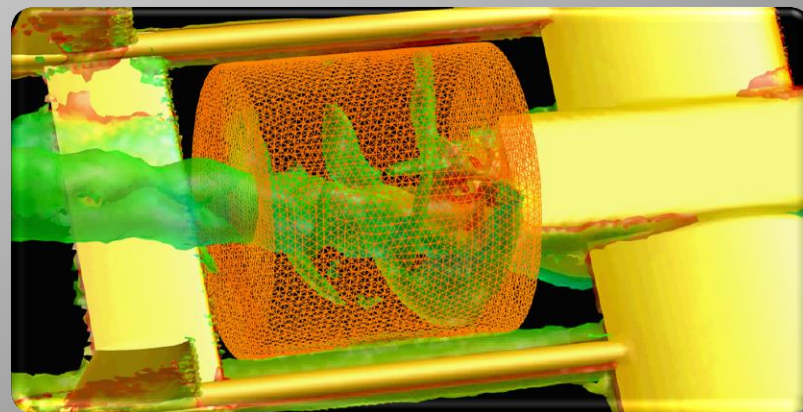
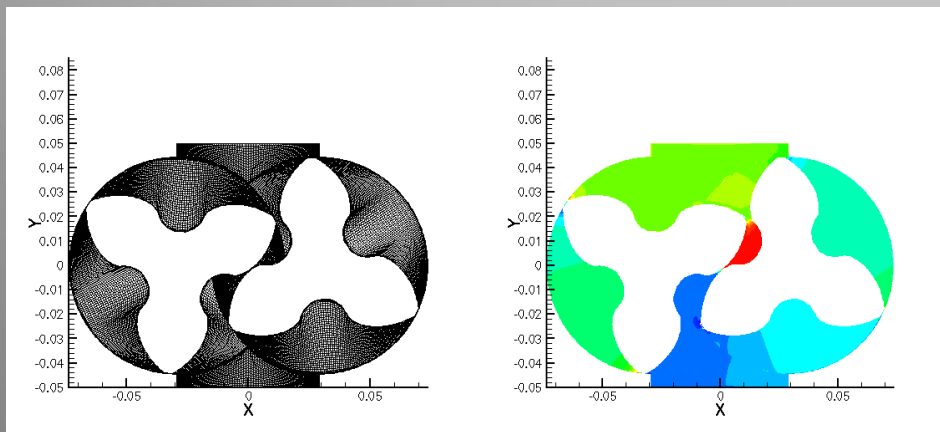
- ✓ *Concatenation of grids*
- ✓ *Cutting and Blanking*
- ✓ *Application of Boundary Conditions and Grid Motion*





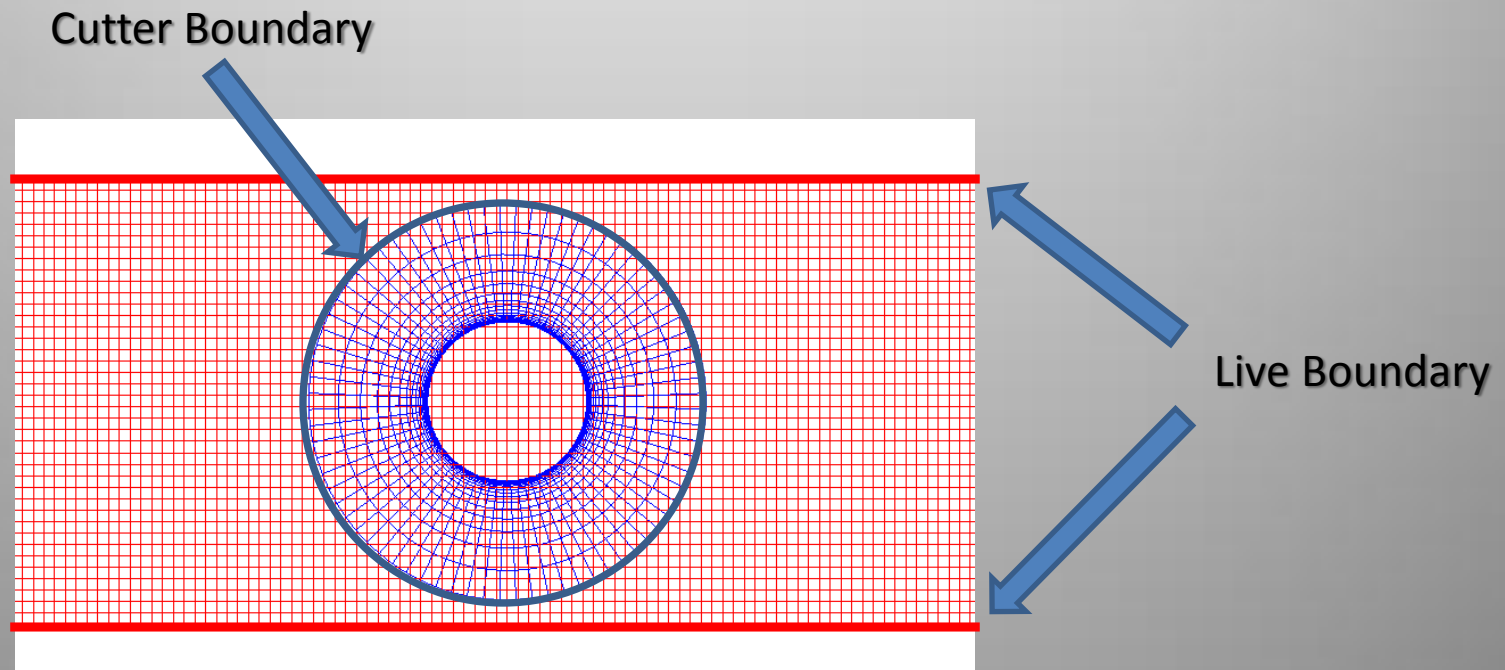
Metacomp's Overset Philosophy

- ✓ *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*



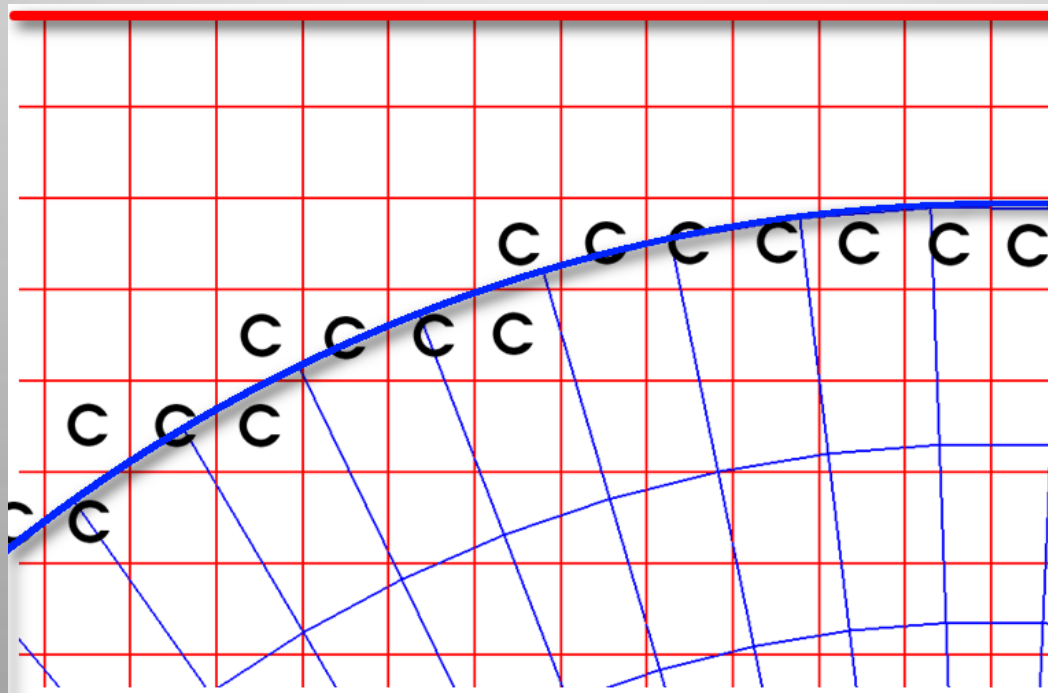
Overset Blanking Procedure

- ✓ *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”*



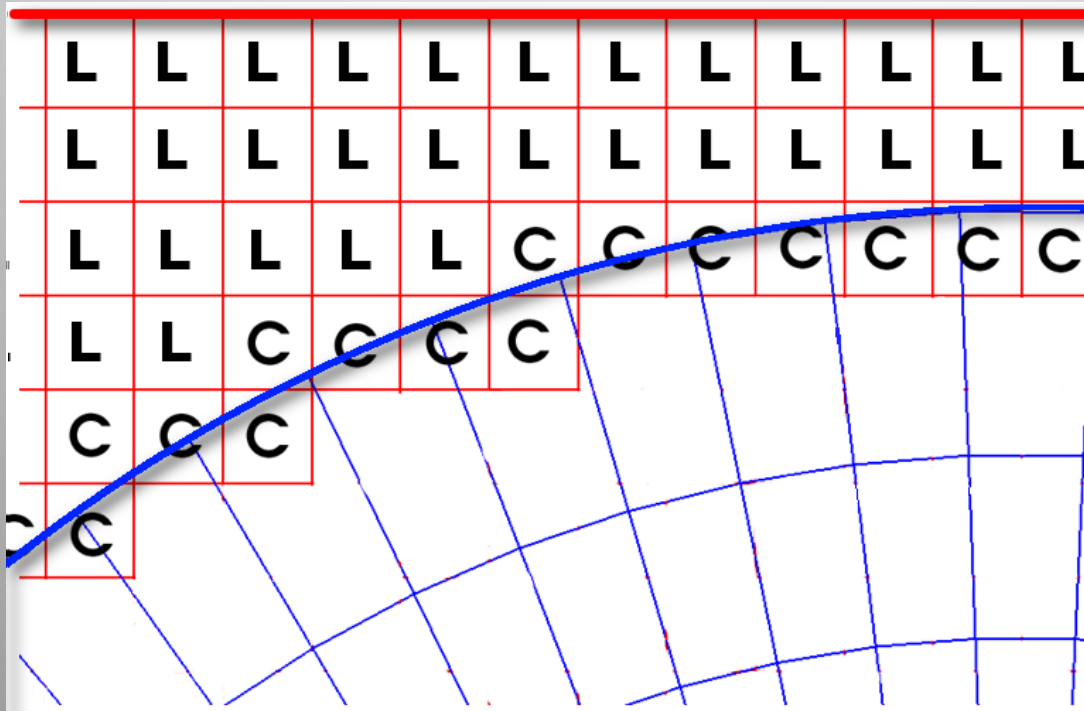
Overset Blanking Procedure

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



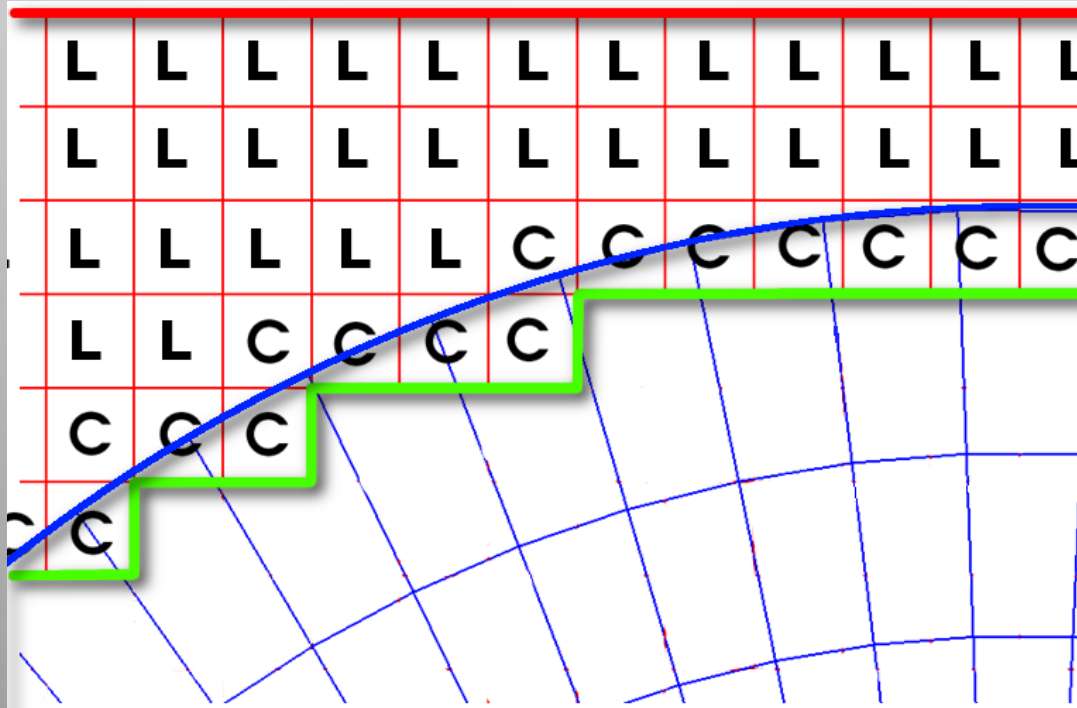
Overset Blanking Procedure

- ✓ *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)

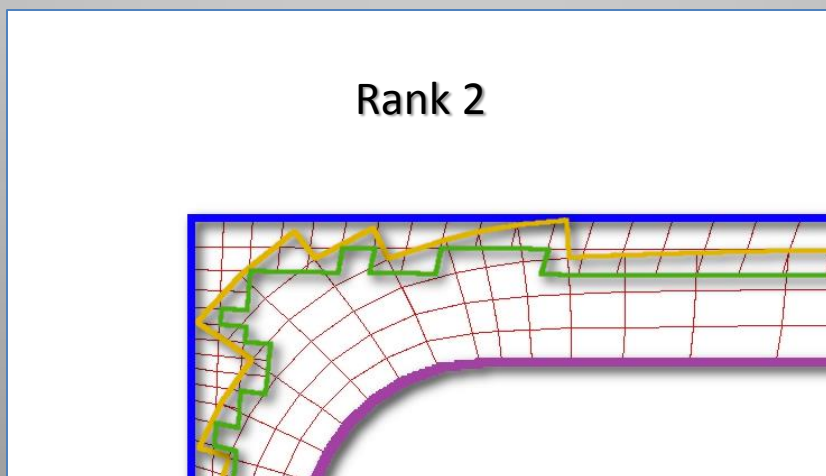
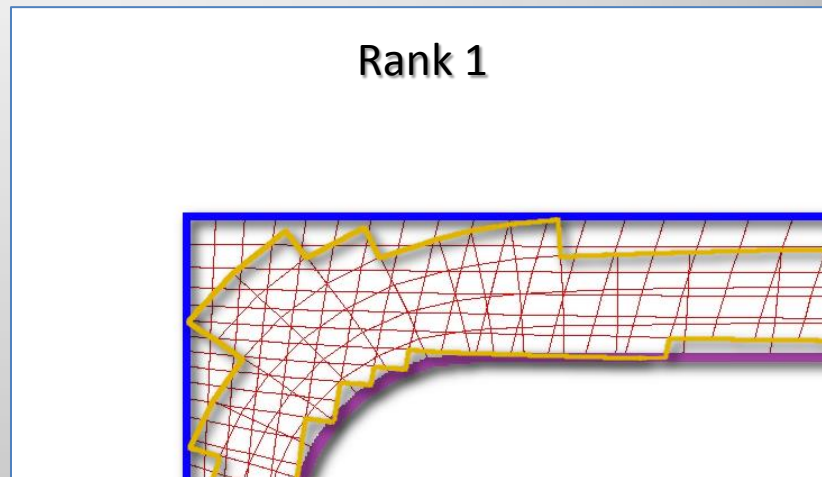
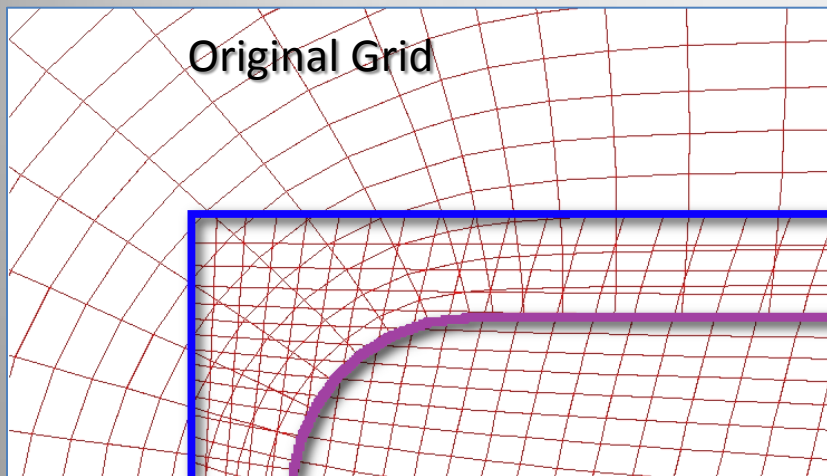




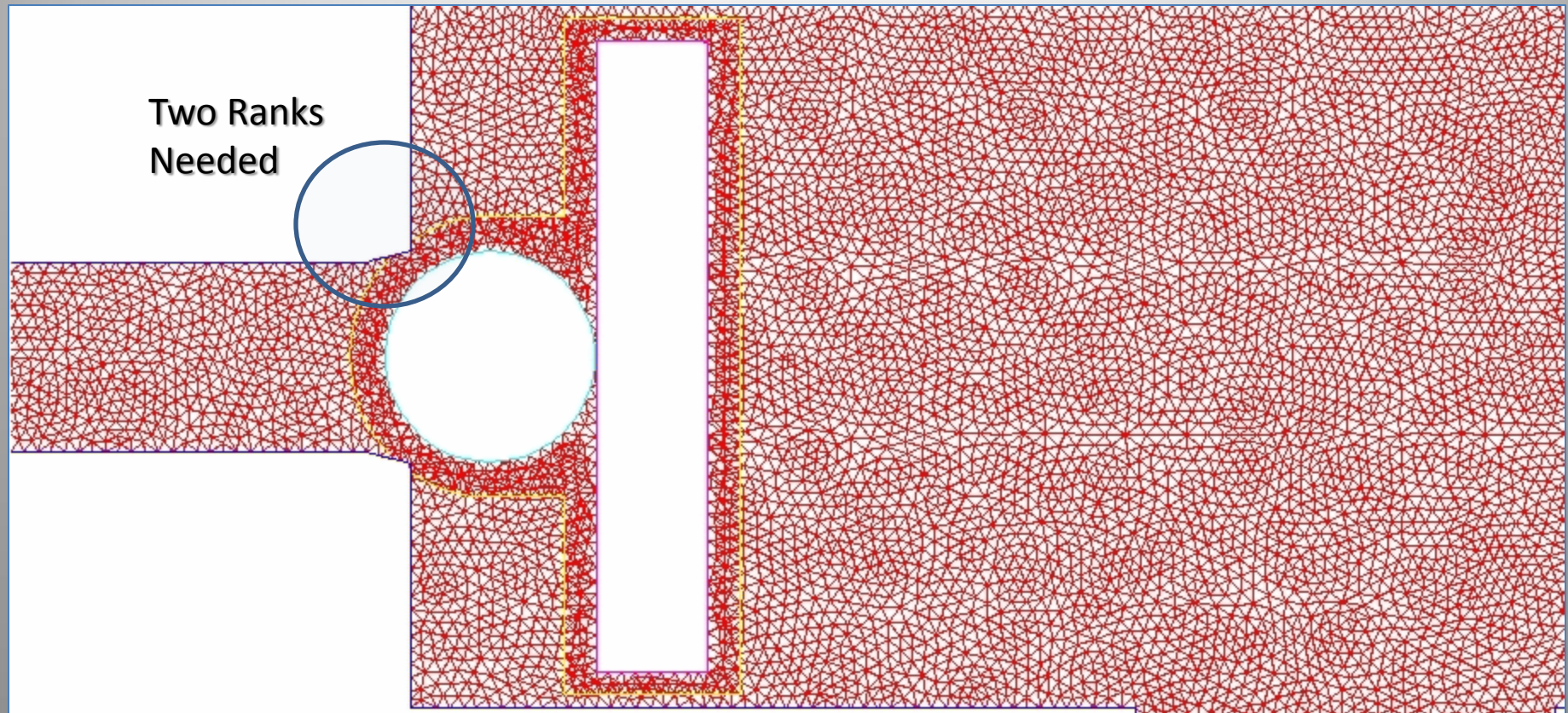
Sequential Cutting

- ✓ *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



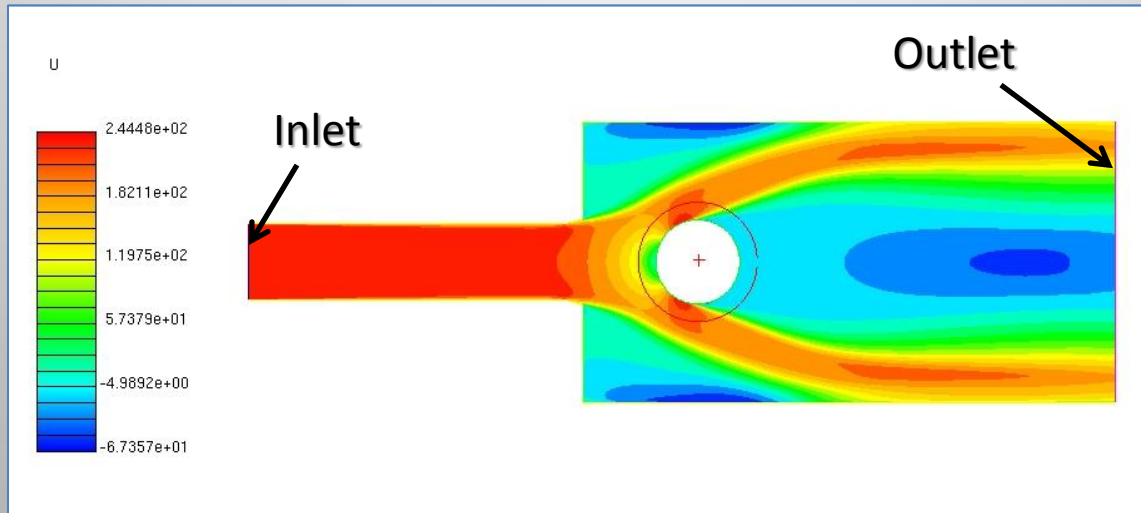
Sequential Cutting



Rank 1: Use wall, do not retain cut cells

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

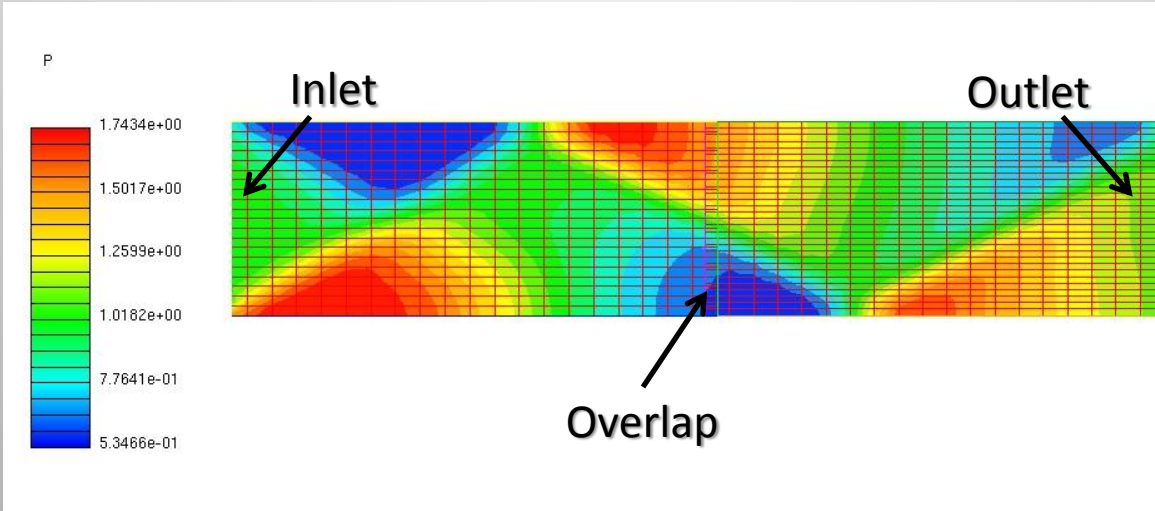
Flux Stitching



2D Incompressible, Steady Ball Valve

Mass Flux Error % w/o FS	0.1%
Mass Flux Error % with FS	< 0.001%

Flux Stitching

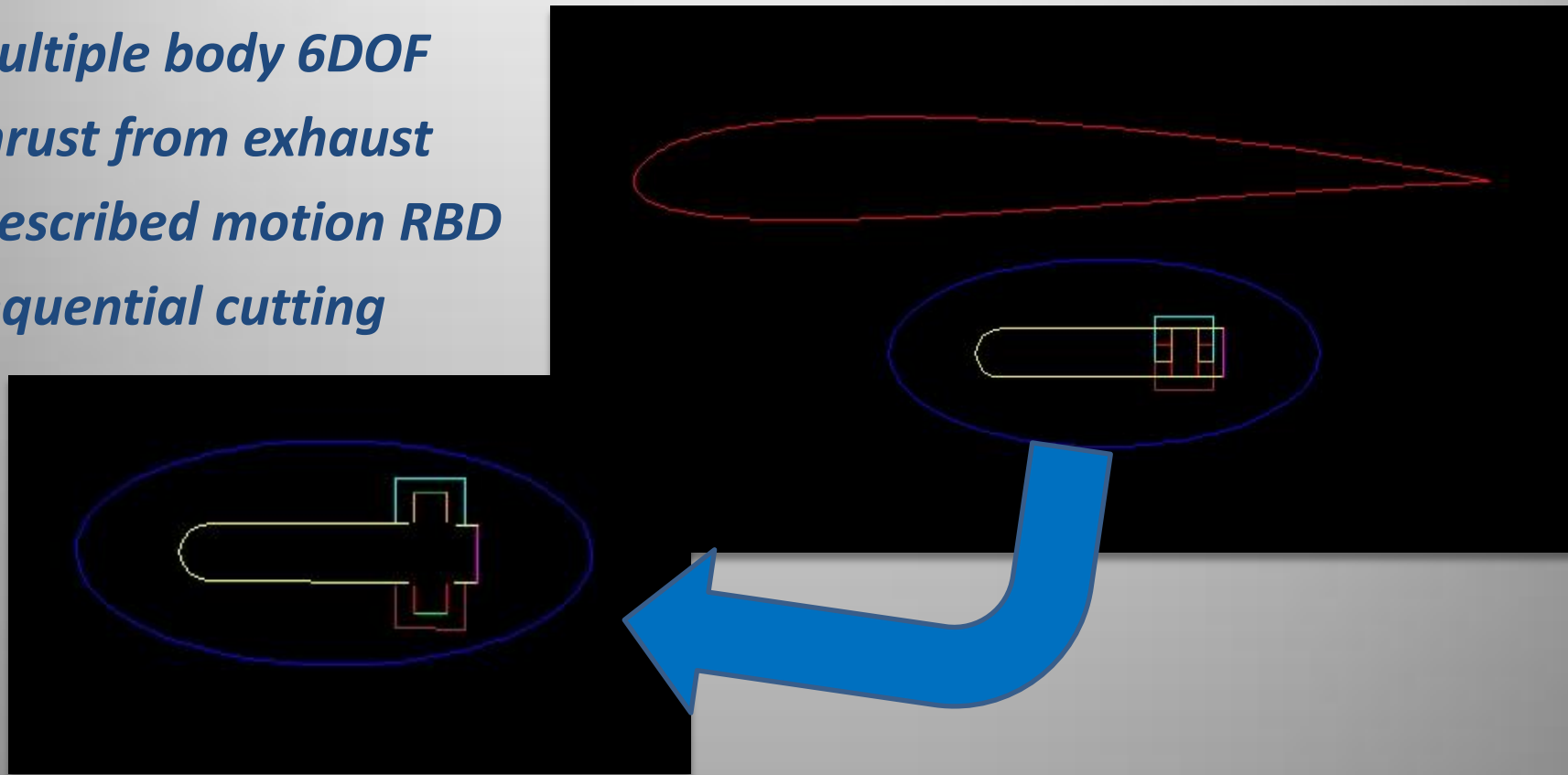


3D Supersonic Flow in Channel

Mass Flux Error % w/o FS	0.04 %
Mass Flux Error % with FS	< 0.001%

Case 1: Store Separation with Fin Deployment

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





Case 1: Steps

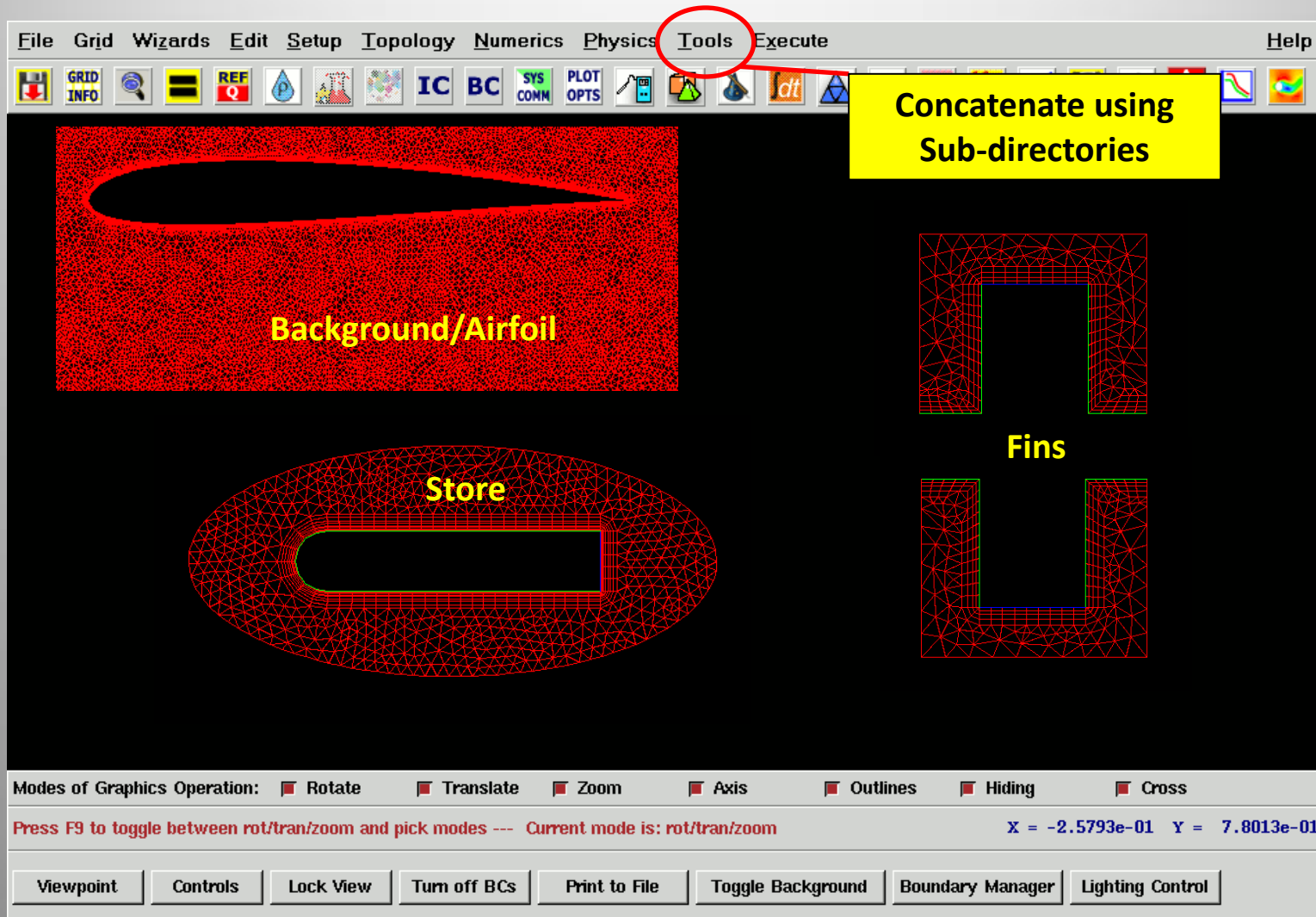
Steady State:

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

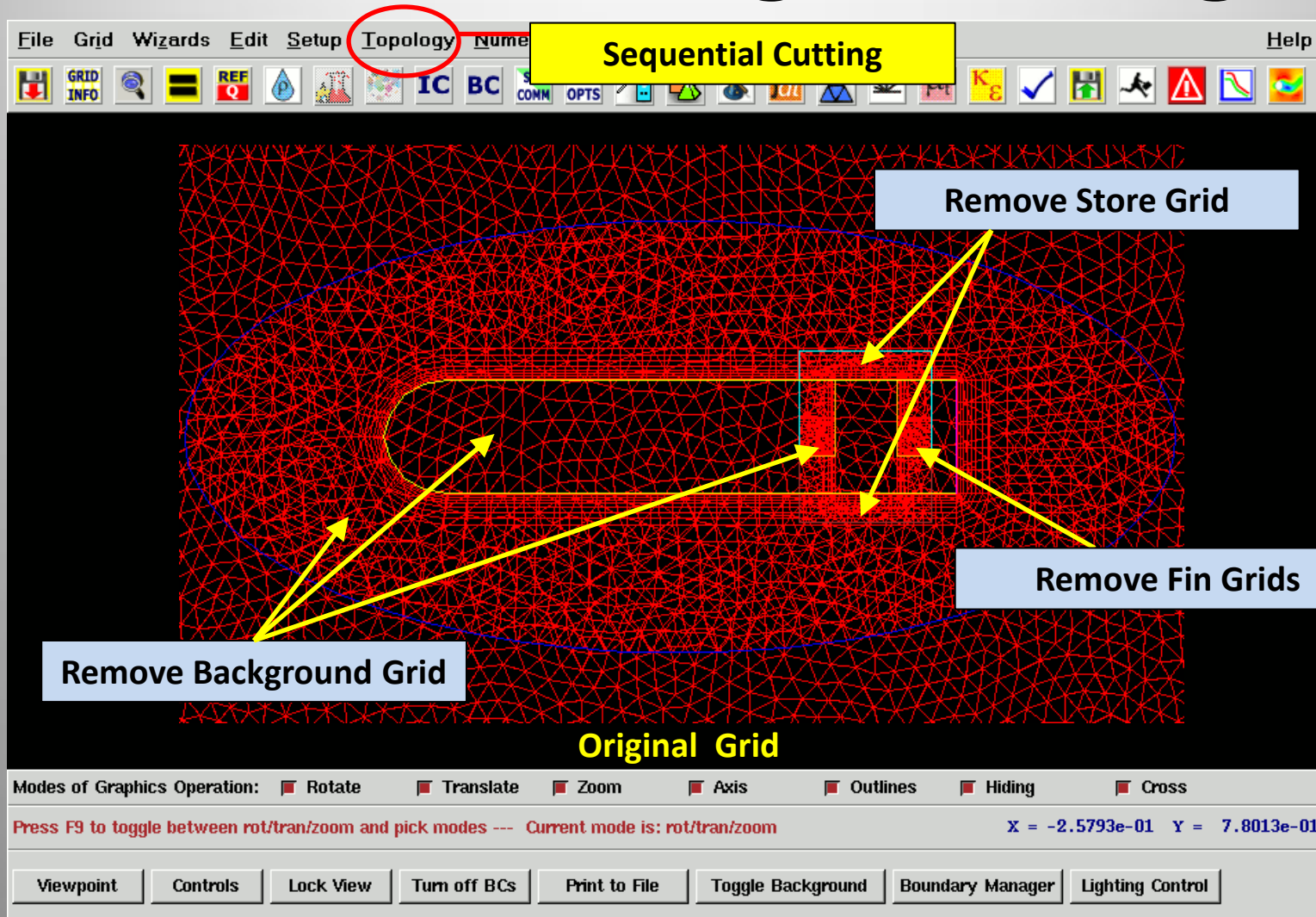
Transient:

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

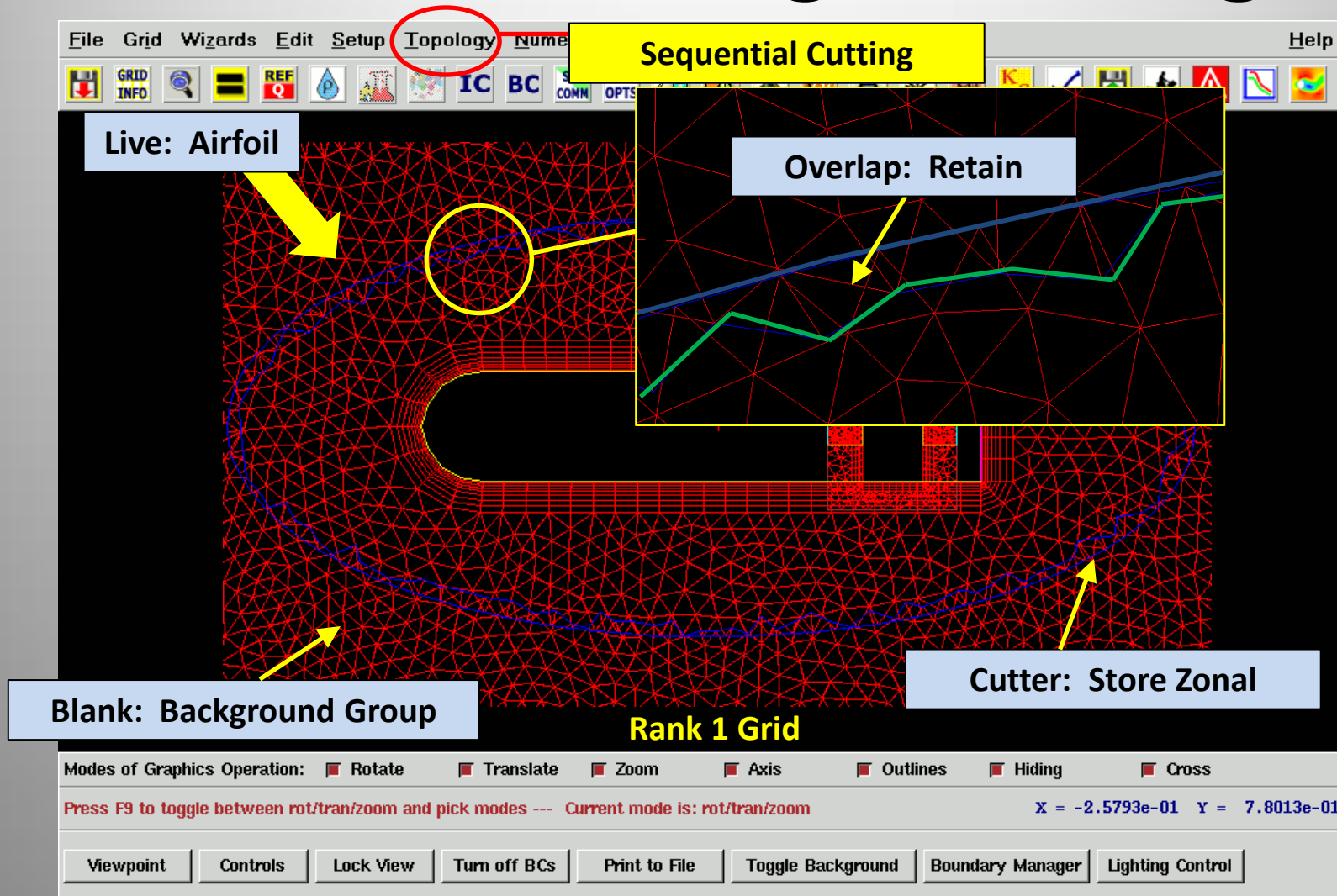
Case 1: Concatenate Grids



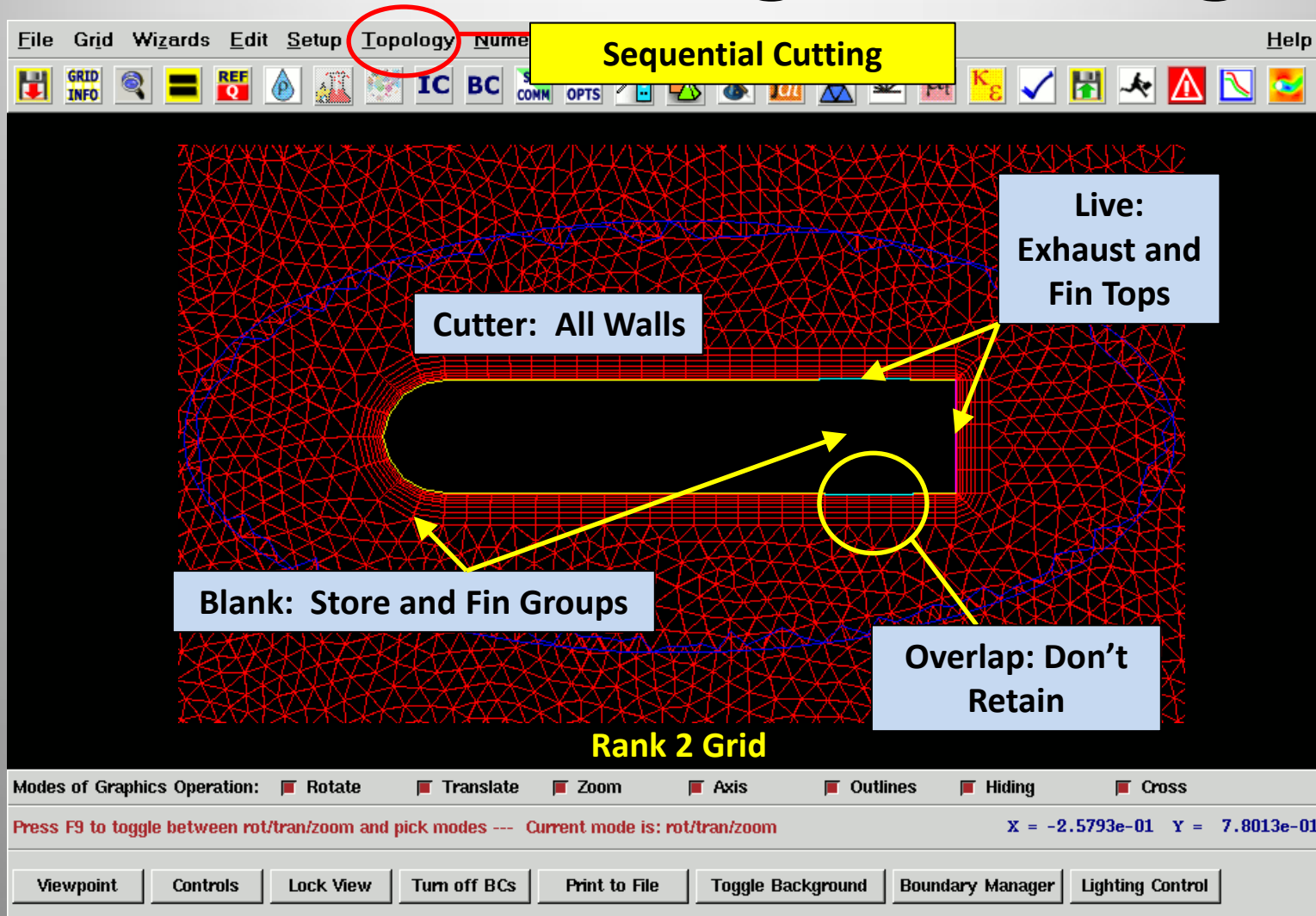
Case 1: Cutting/Blanking



Case 1: Cutting/Blanking

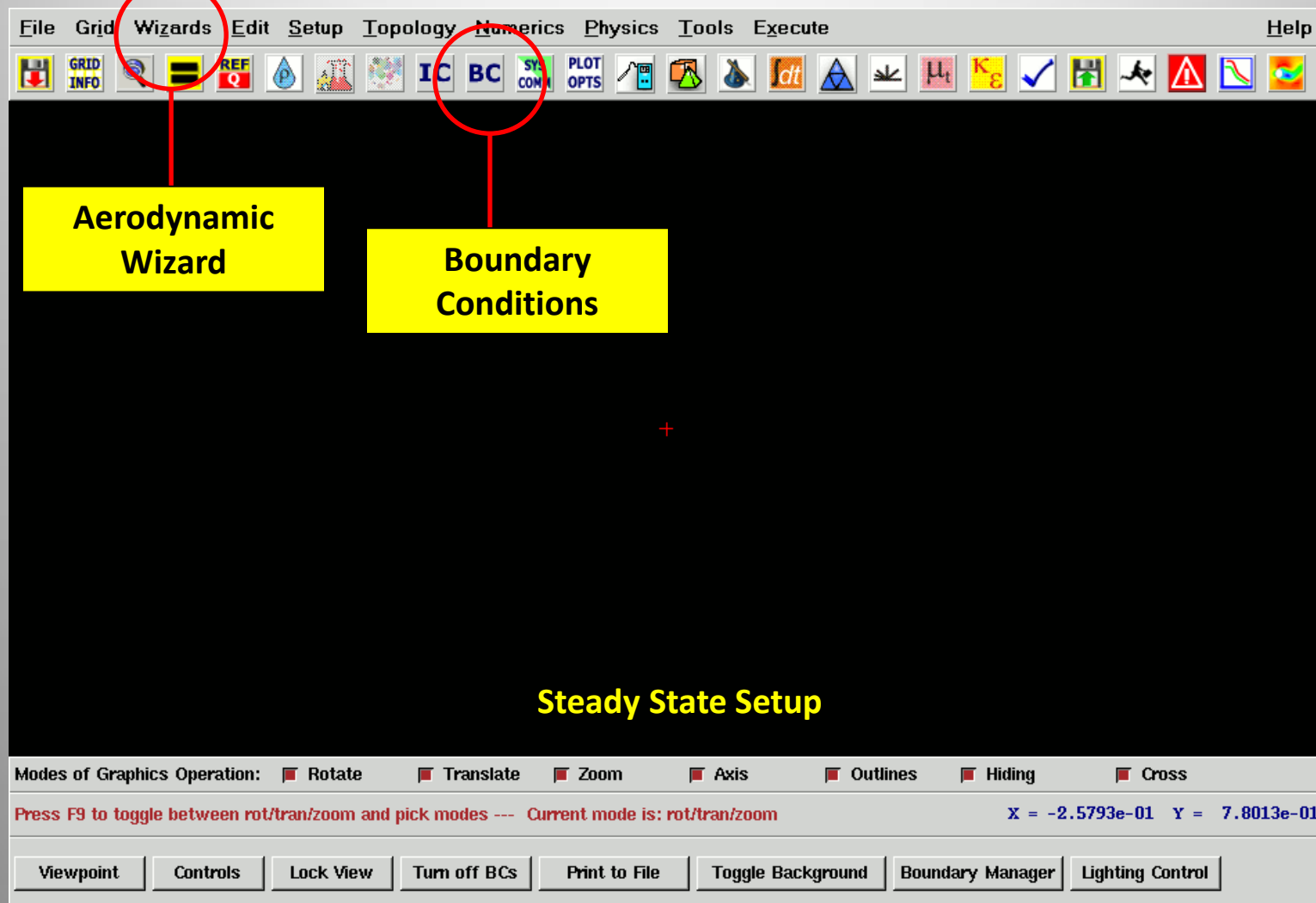


Case 1: Cutting/Blanking

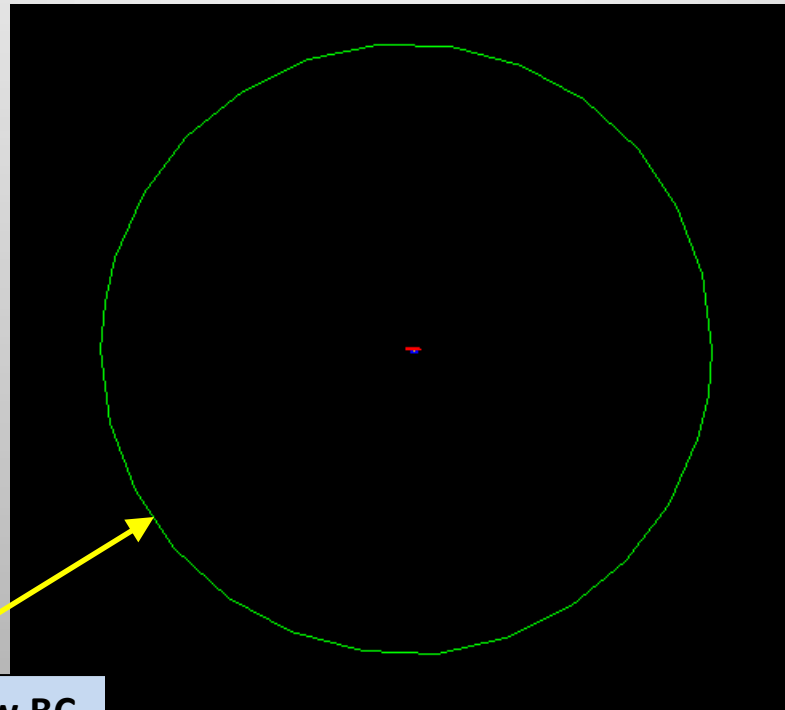




Case 1: Flow Specifications

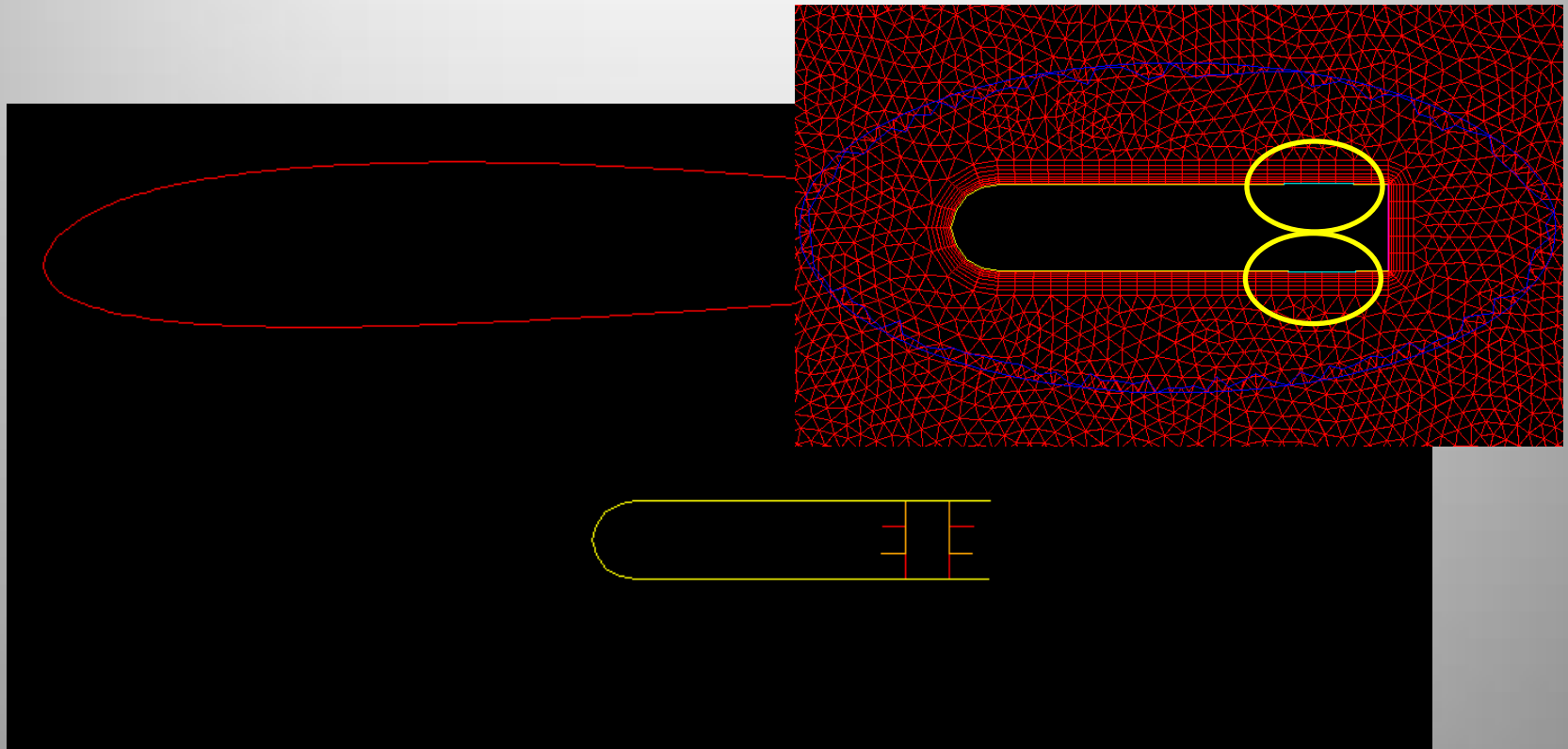


Case 1: Boundary Conditions



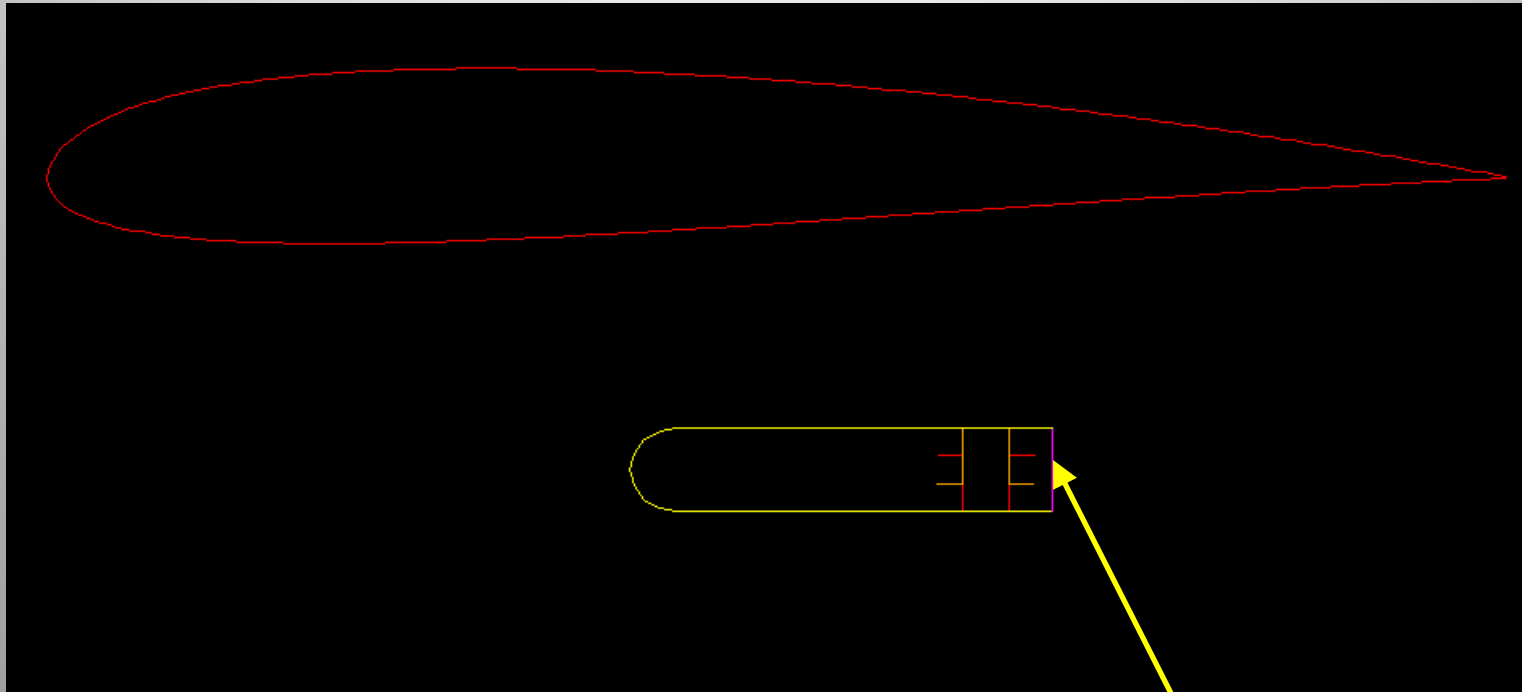
Far-field: Inflow/Outflow BC

Case 1: Boundary Conditions



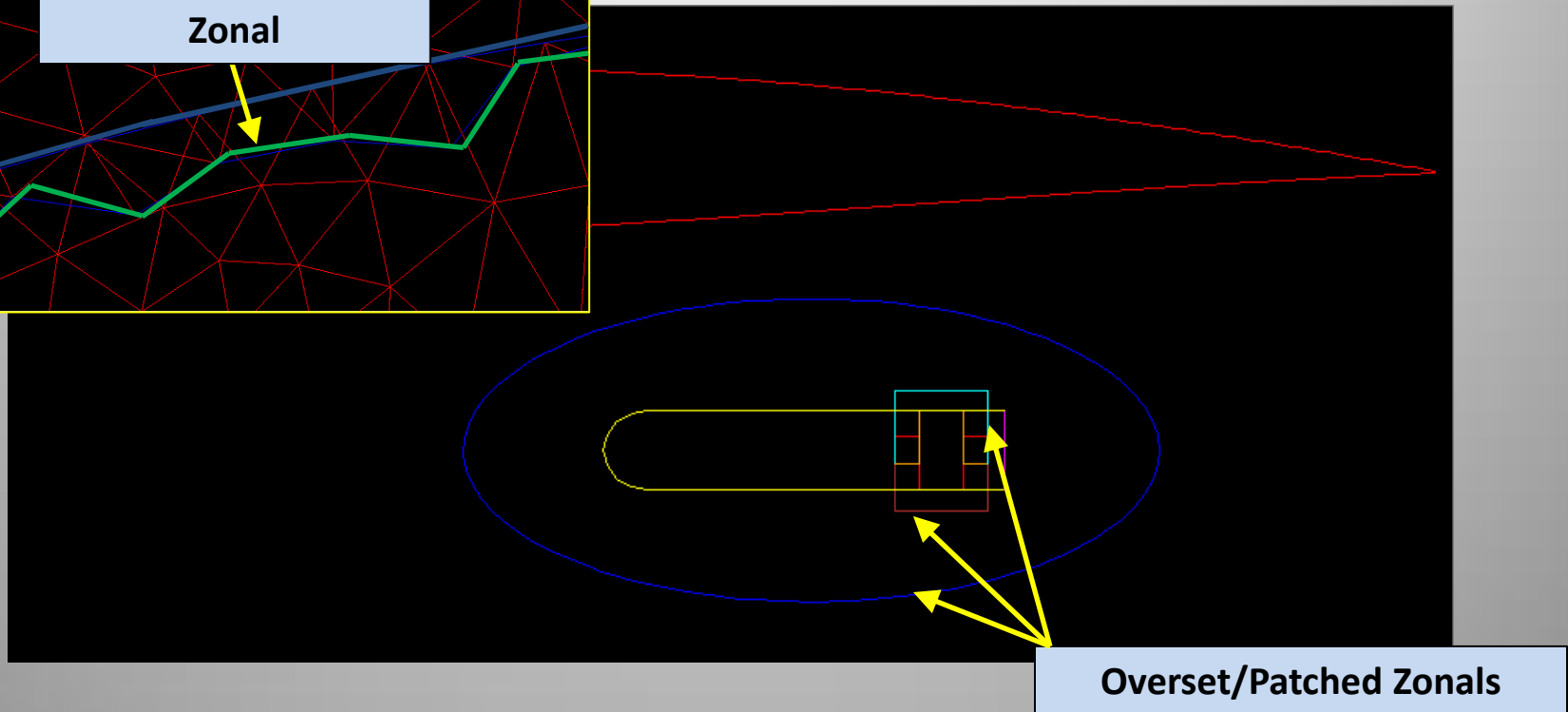
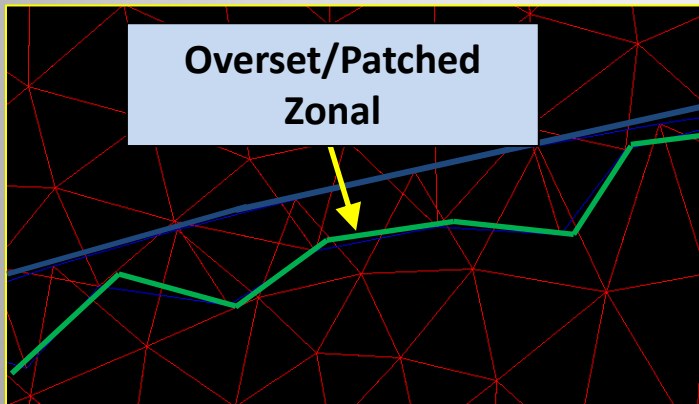
**Adiabatic, Viscous Wall
Functions**

Case 1: Boundary Conditions



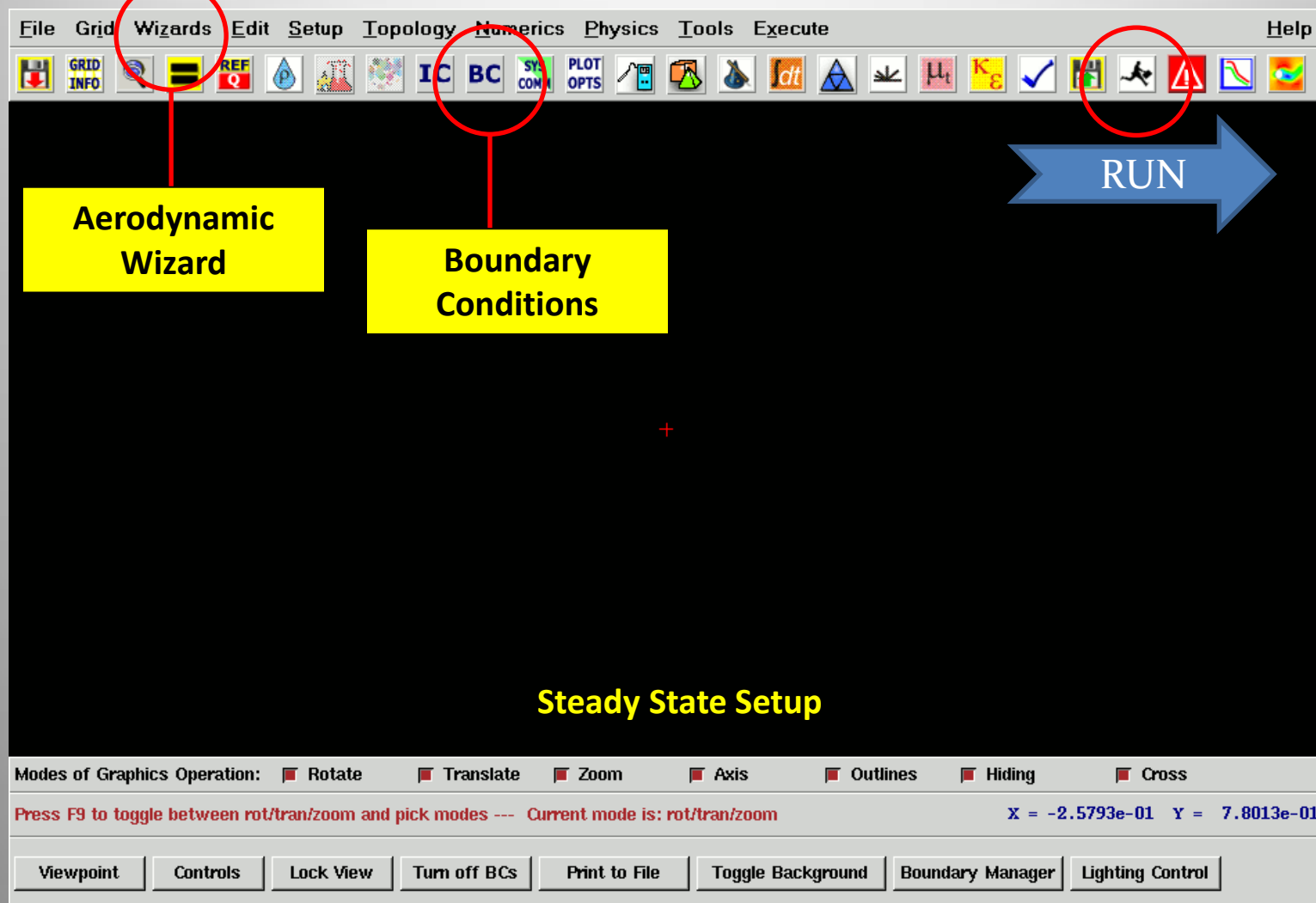
Exhaust: Time dependent
Mass Flow Rate, Temp.

Case 1: Boundary Conditions





Case 1: Flow Specifications





Case 1: Flow Specifications

The screenshot displays the Metacomp Technologies software interface. The top menu bar includes File, Grid, Wizards, Edit, Setup, Topology, Numerics, Physics, Tools, Execute, and Help. Below the menu is a toolbar with various icons. The main workspace shows a 3D model of a flow domain with a yellow box labeled "Rigid Body Motion" and a blue box labeled "6DOF: Store + Fins". A yellow circle highlights a specific region of the model, with a callout box labeled "File-based Translation: Fins". The text "Transient Setup" is visible in the center of the workspace. At the bottom, there is a status bar with "Modes of Graphics Operation" (Rotate, Translate, Zoom, Axis, Outlines, Hiding, Cross) and a message "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 also displayed.

File Grid Wizards Edit Setup Topology Numerics Physics Tools Execute Help

GRID INFO REF Q

Rigid Body Motion

6DOF: Store + Fins

File-based Translation: Fins

Transient 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

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

GRID INFO REF Q PLOT OPTS

Transient Wizard **Rigid Body Motion** **Numerics Wizard** **RUN**

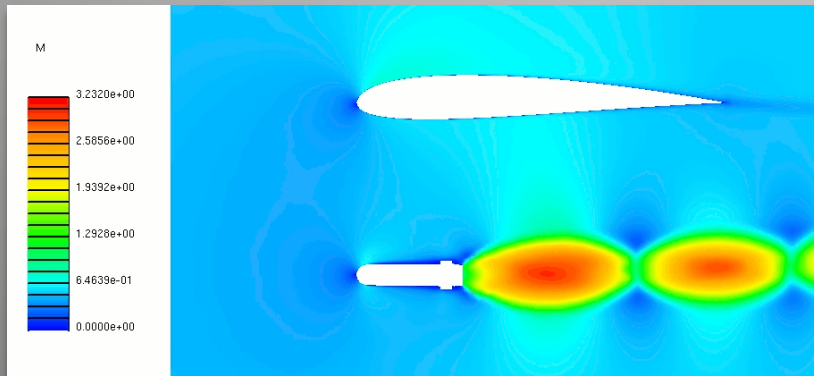
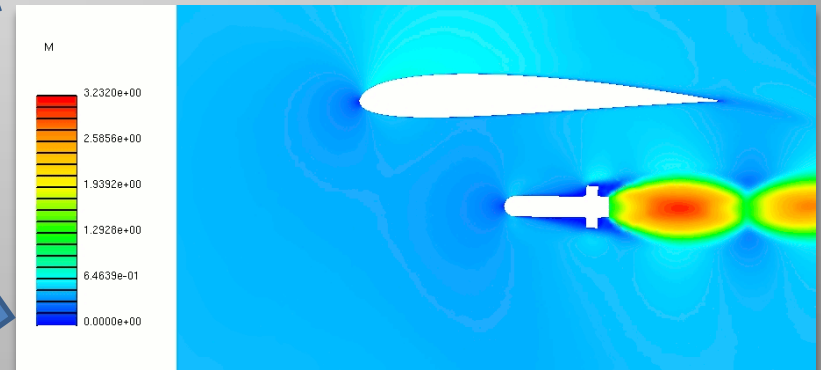
Transient Setup

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

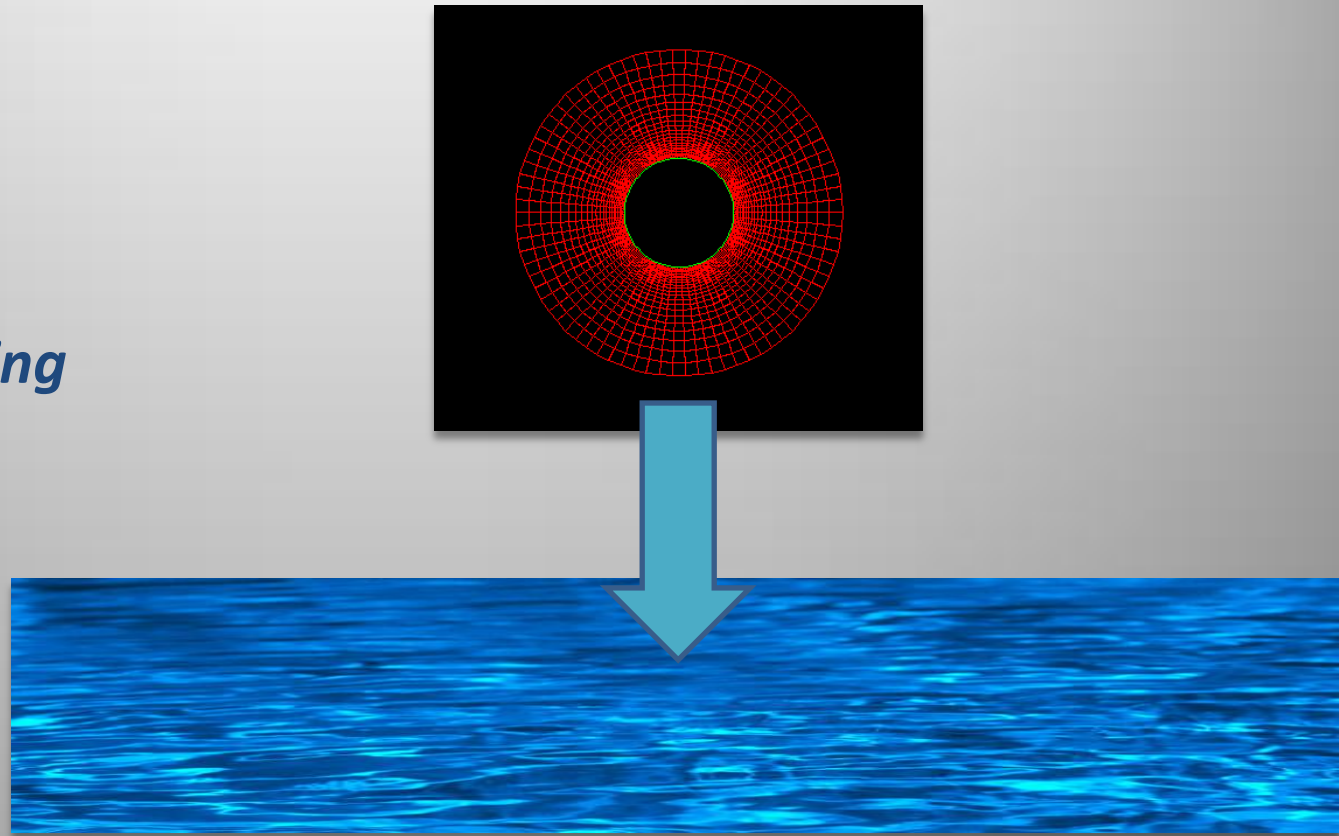
Viewpoint Controls Lock View Turn off BCs Print to File Toggle Background Boundary Manager Lighting Control

Case 1: Store Separation with Fin Deployment



Case 2: 2D Ball Drop

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



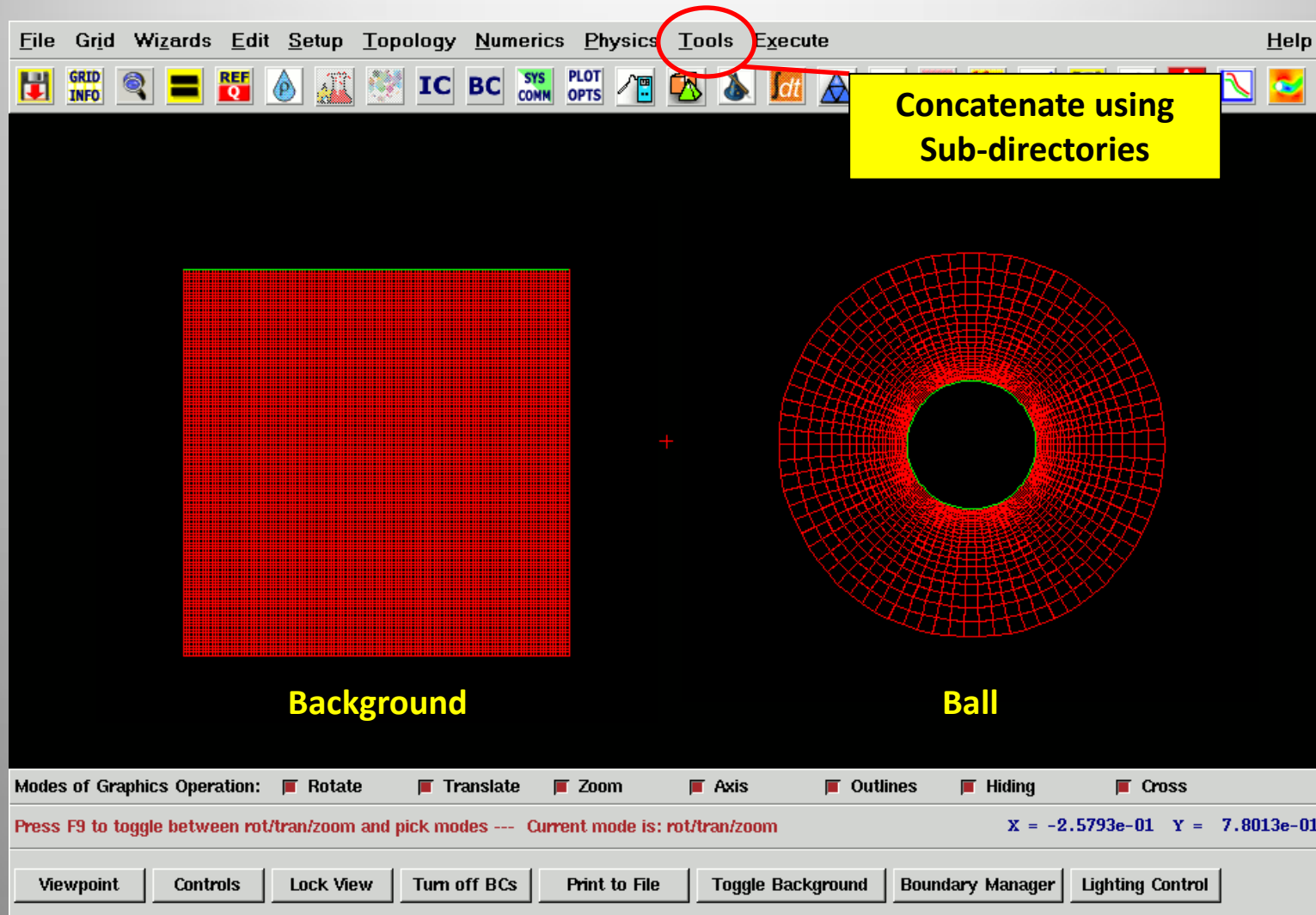


Case 2: Steps

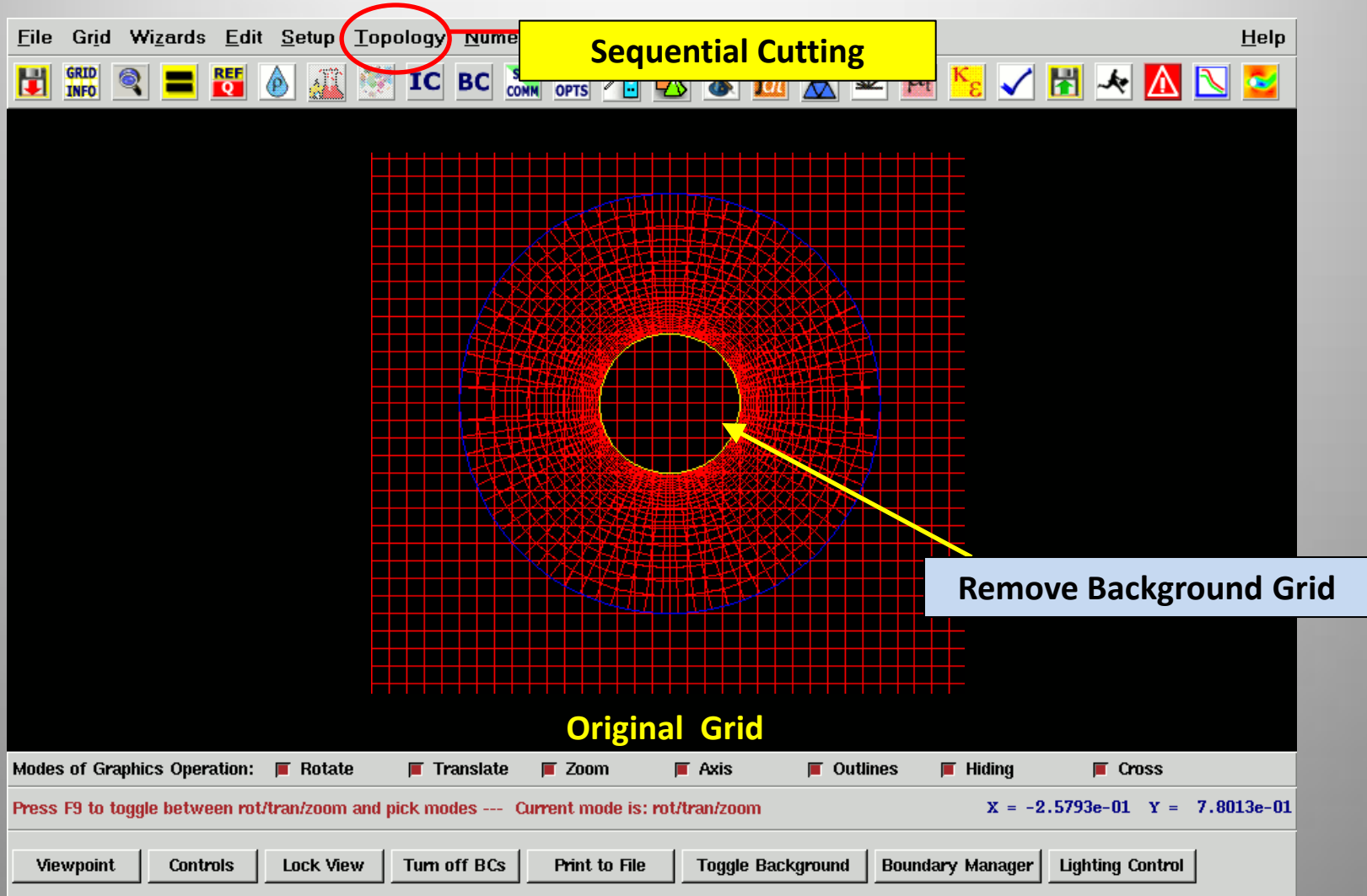
Ball Drop:

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

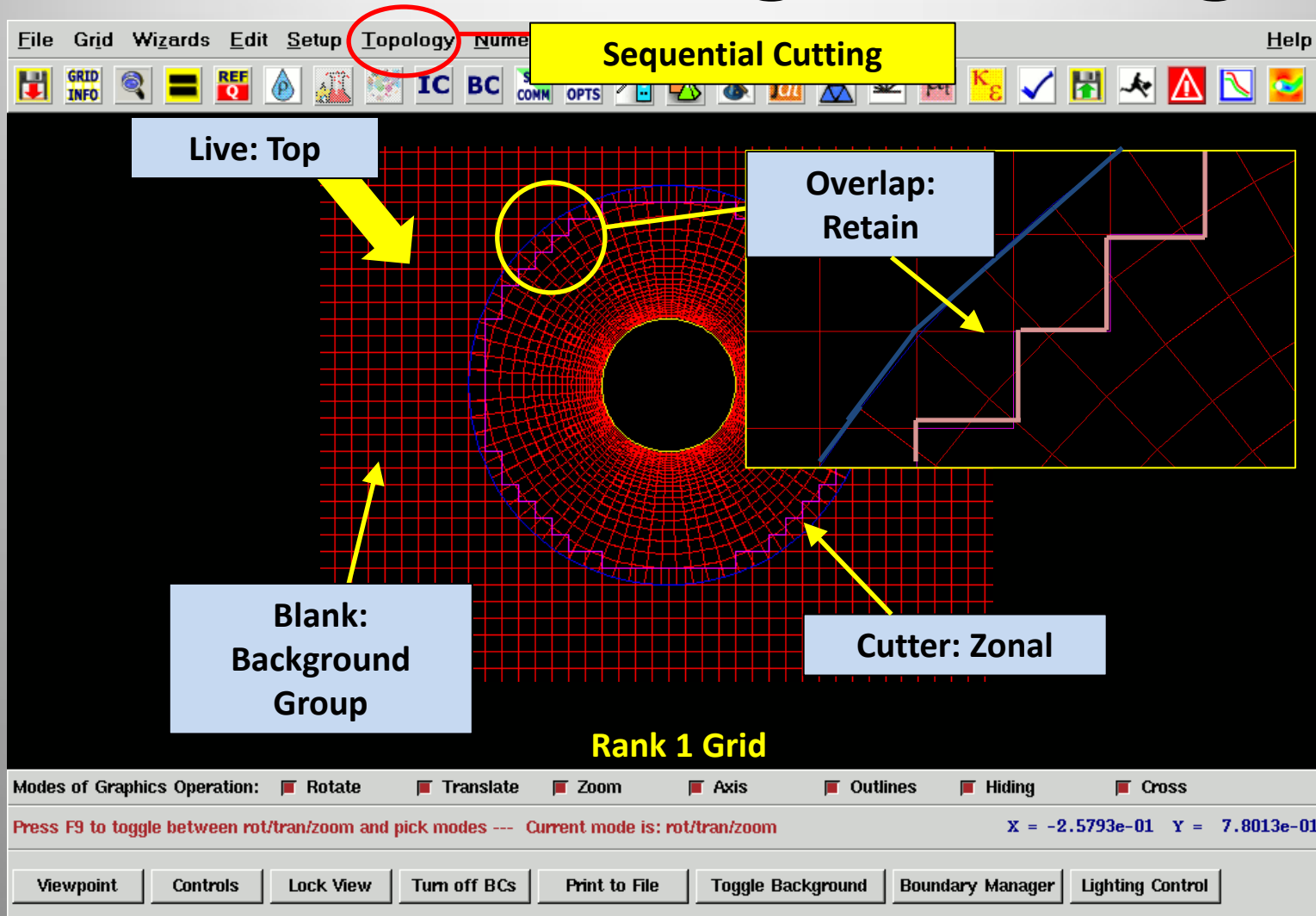
Case 2: Concatenate Grids



Case 2: Cutting/Blanking

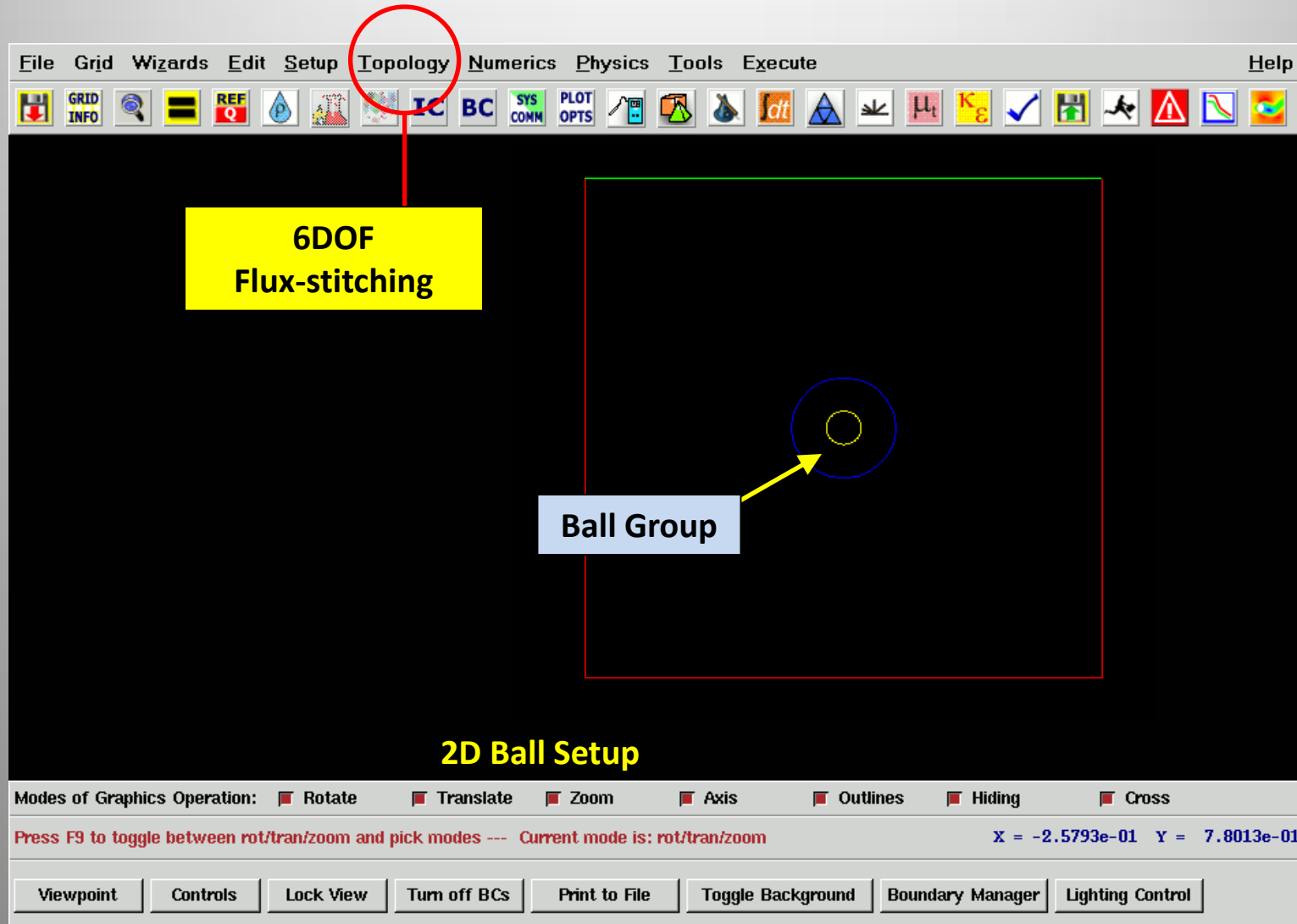


Case 2: Cutting/Blanking





Case 2: Grid Motion





Case 2: Flow Specifications

Short-cut Button Path

File Grid Wizards Edit Setup Topology Numerics Physics Tools Execute Help

GRID INFO **Equation Set Definition** **Fluid Properties** **Initial Conditions** IC BC SYS COMM PLOT OPTS

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

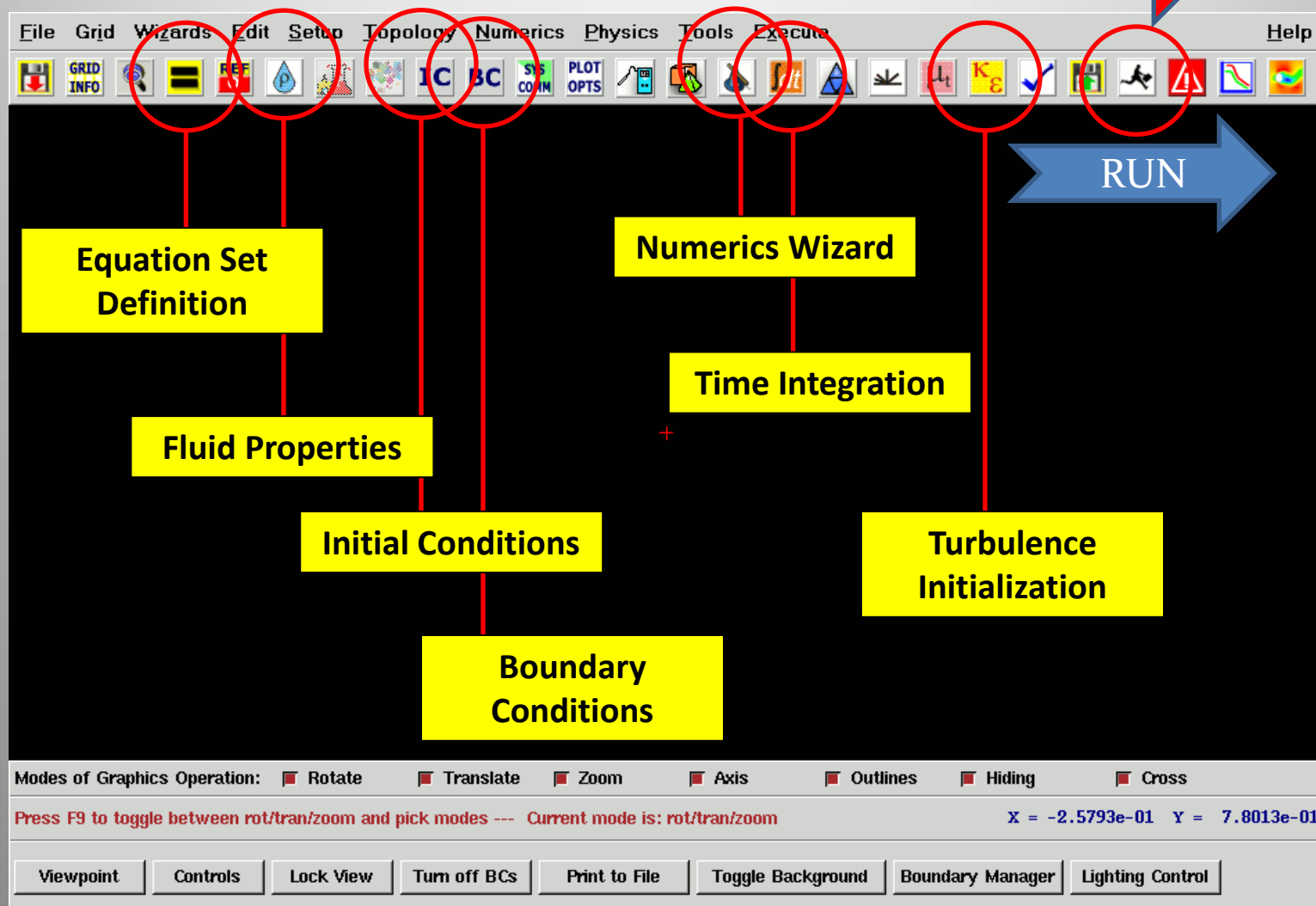
The screenshot shows the Metacomp software interface with various toolbars and a central workspace. Annotations highlight specific features and their relationships:

- Equation Set Definition:** Points to the **EF** button in the top toolbar.
- Fluid Properties:** Points to the **FF** button in the top toolbar.
- Initial Conditions:** Points to the **IC** button in the top toolbar.
- Boundary Conditions:** Points to the **BC** button in the top toolbar.
- Overset/Patched Zonal:** Points to a specific region in the central workspace.
- Adiabatic, Visc. Walls:** Points to a specific region in the central workspace.
- Inflow/Out flow:** Points to a specific region in the central workspace.
- Overset/Patched Zonal:** Points to another specific region in the central workspace.

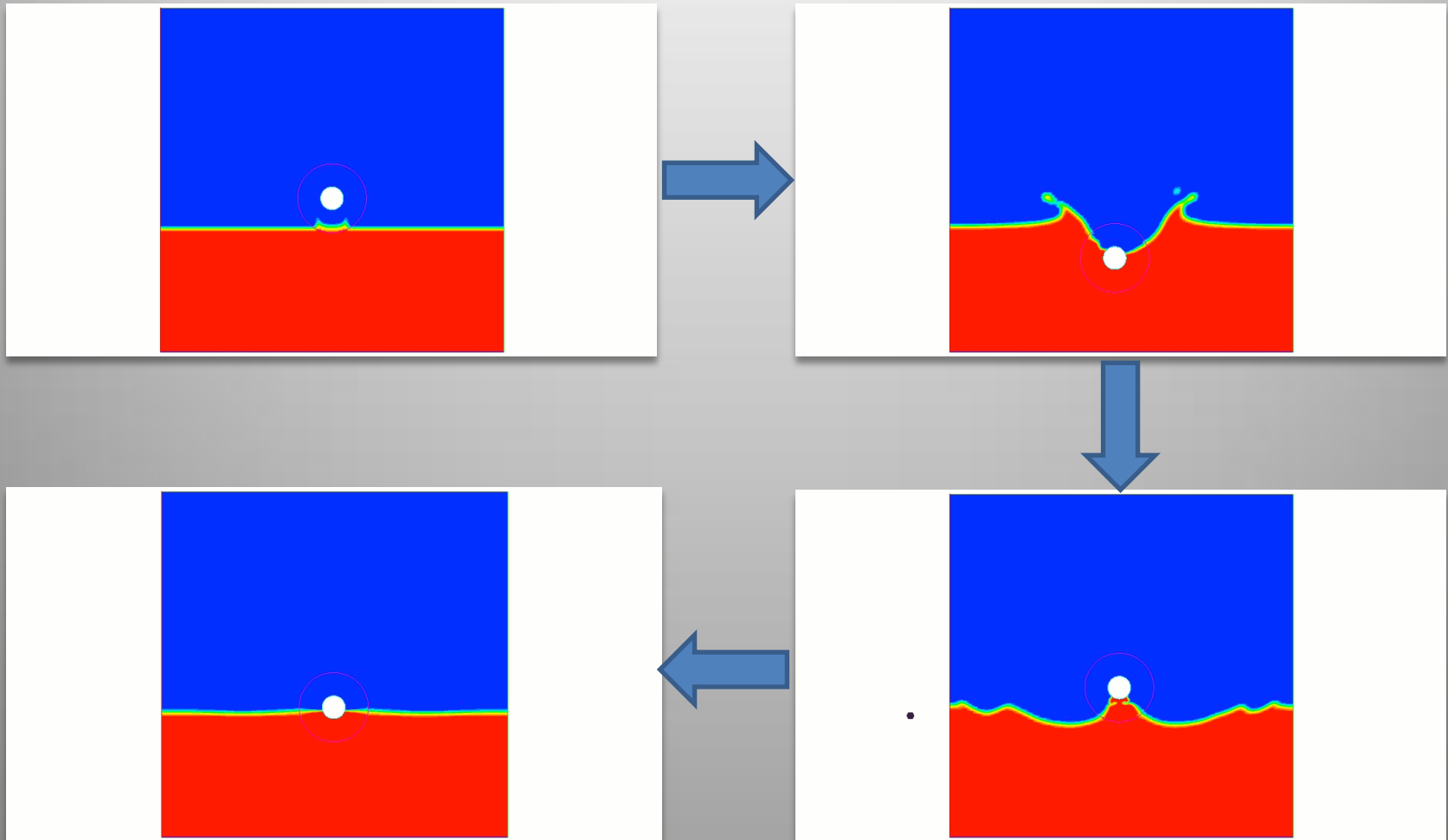
The interface includes a menu bar (File, Grid, Wizards, Edit, Setup, Topology, Numerics, Physics, Tools, Events, Help) and a toolbar with icons for various functions. The bottom status bar shows the current mode as **rot/tran/zoom** and provides coordinates **X = -2.5793e-01 Y = 7.8013e-01**.

Case 2: Flow Specifications

Short-cut Button Path



Case 2: 2D Ball Drop



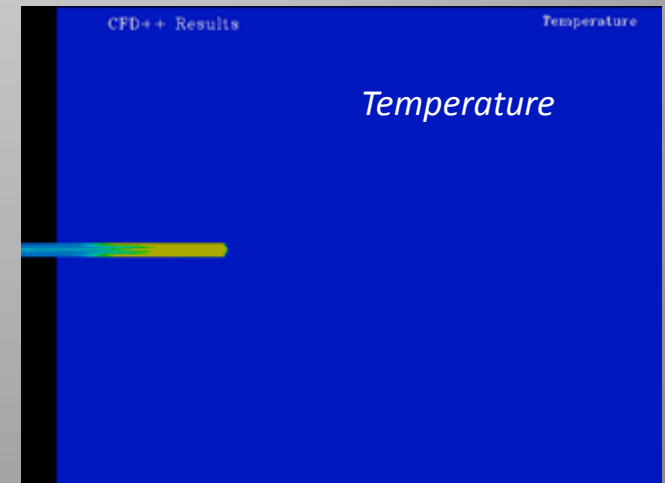
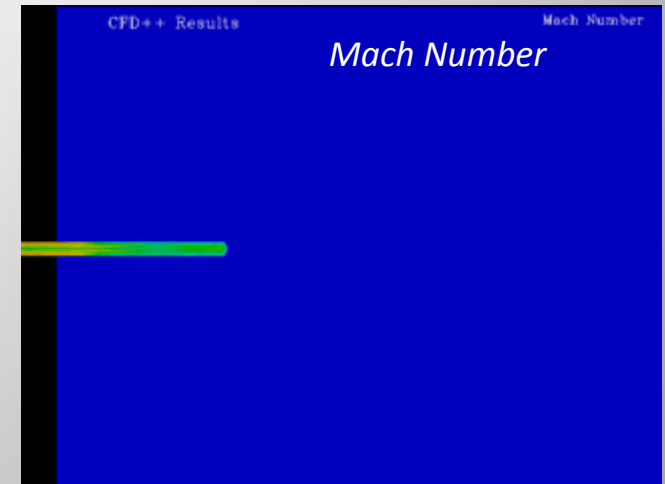


More Examples

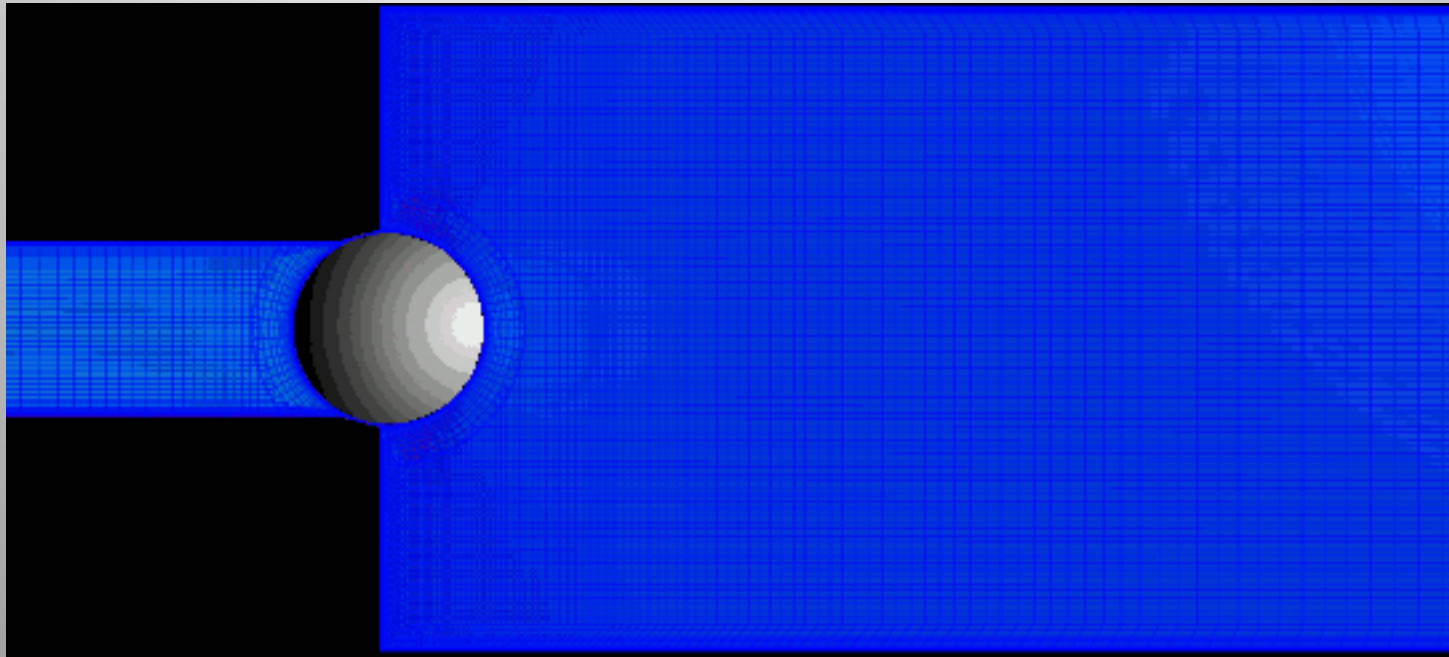


Bullet Leaving a Gun Barrel

- ❑ *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*



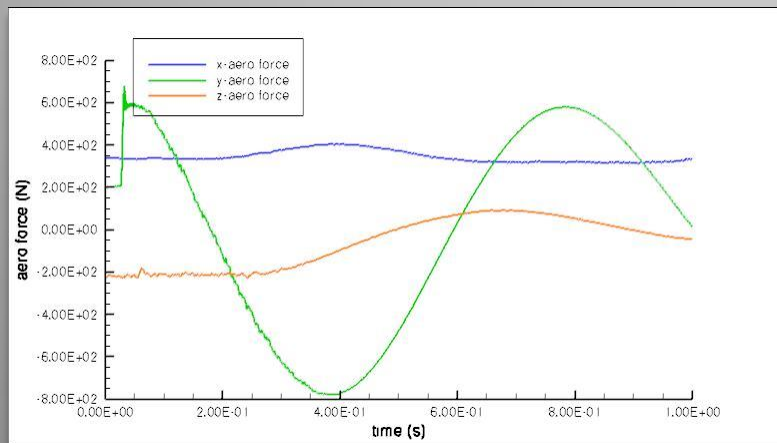
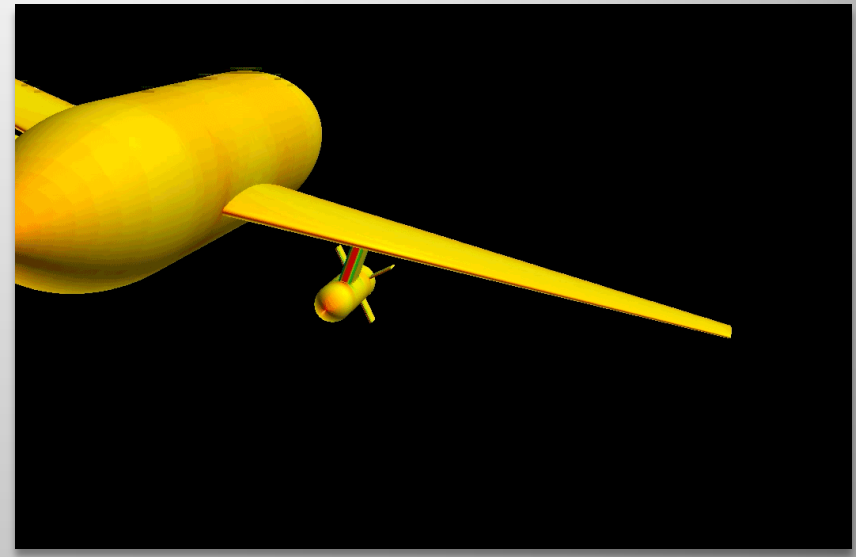
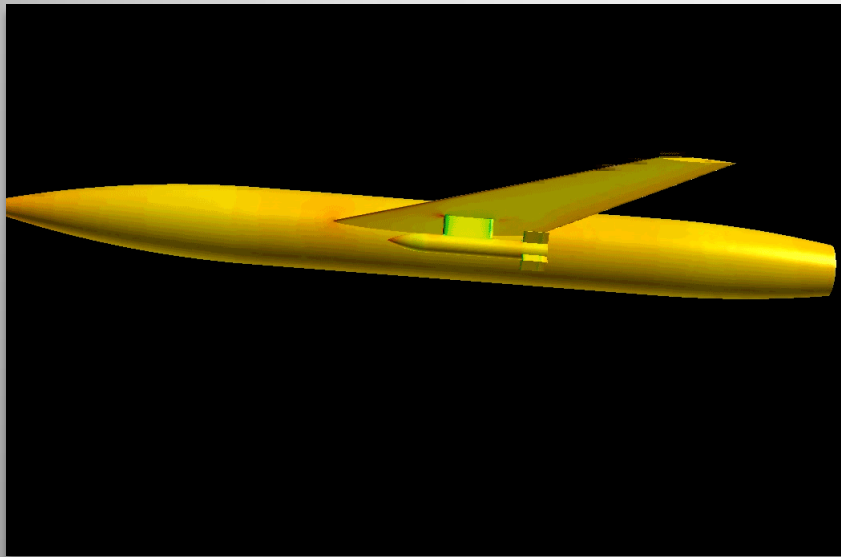
Mesh Movement



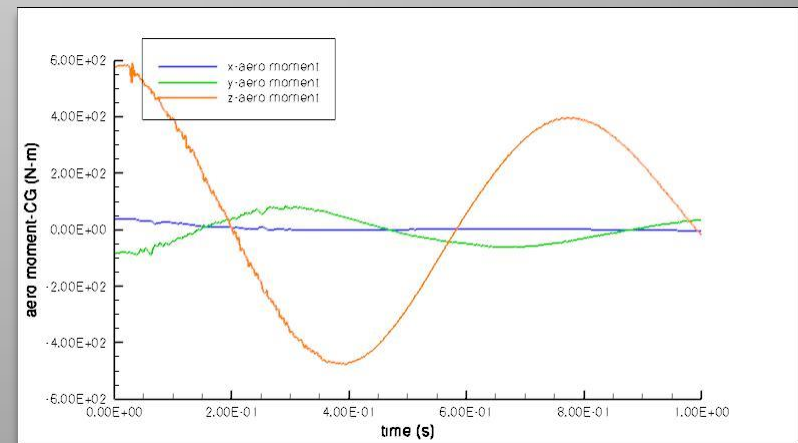
Ball-valve example: mesh cutting with zonal connections

Flux stitching guarantees perfect conservation at zonal boundaries!

Store Separation using CFD++

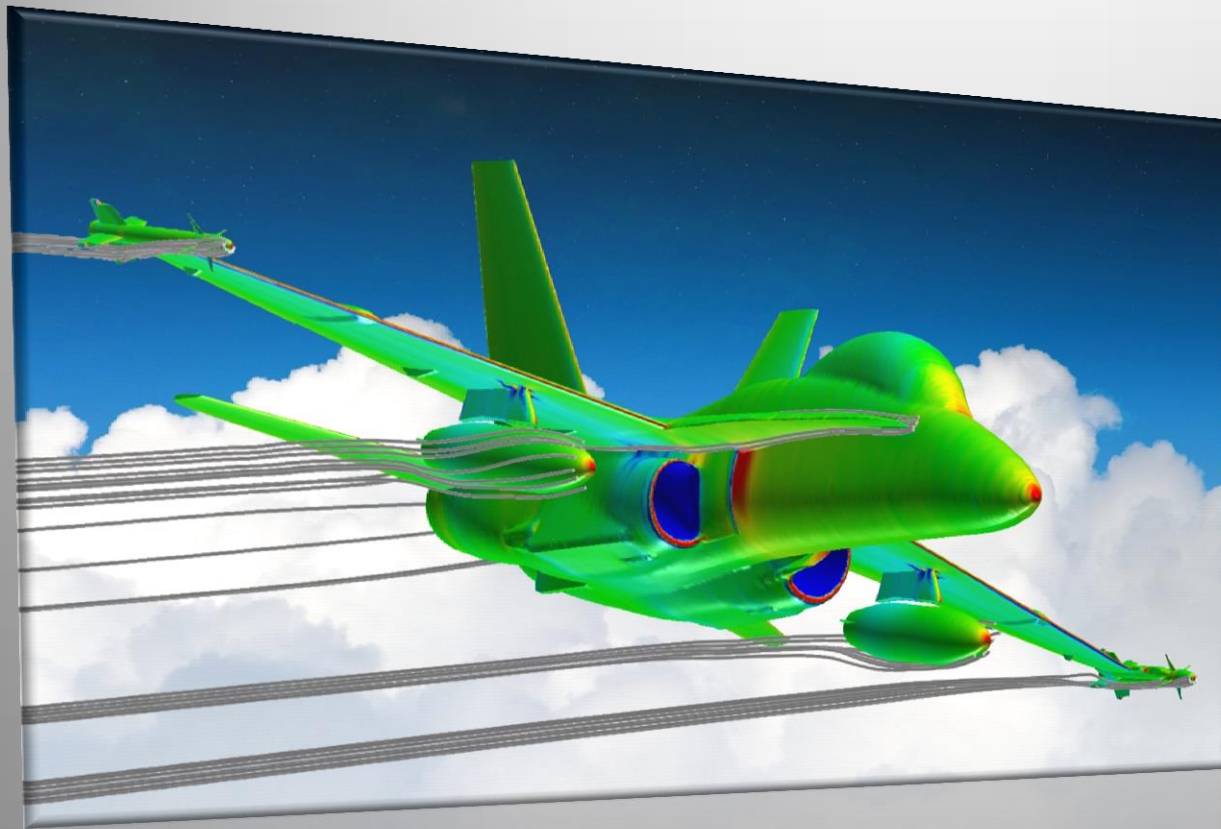


Aerodynamic forces on store

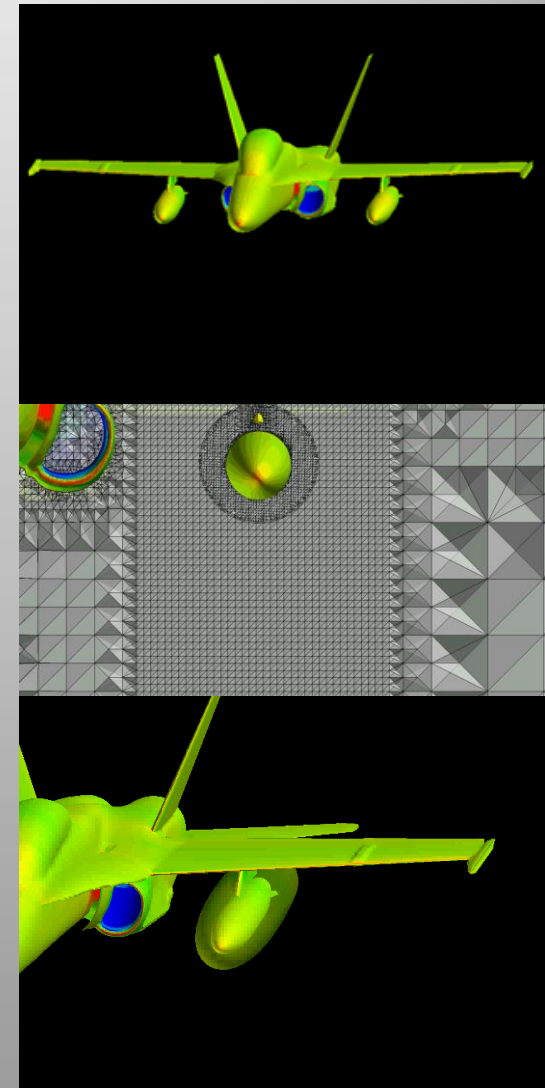


Aerodynamic moments on store

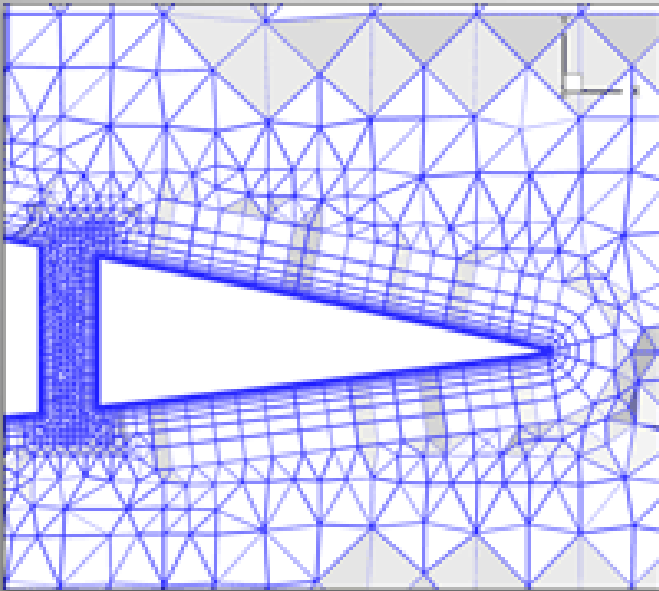
F18 Fuel Tank Separation



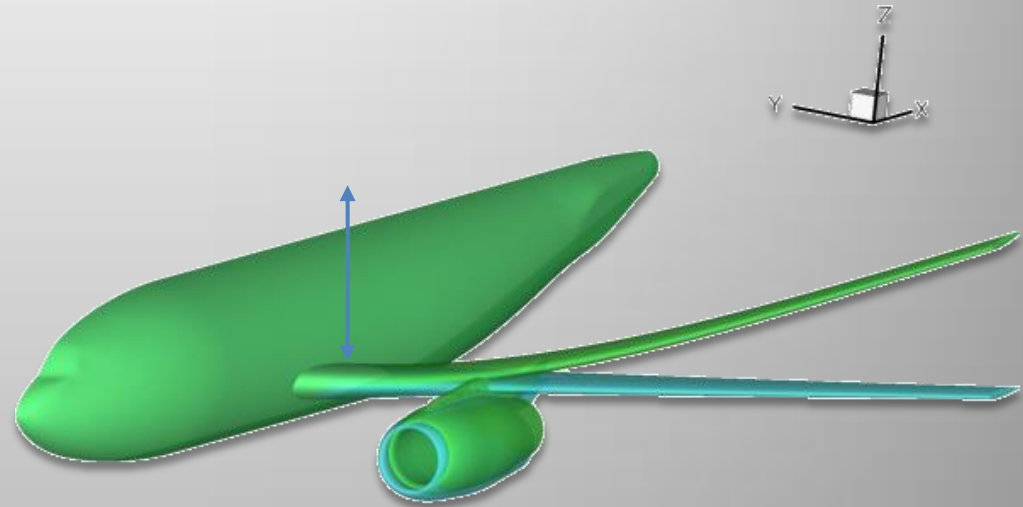
- ❑ Localized cutting, zonal connection, force integration and localized 6DOF



Grid Morphing

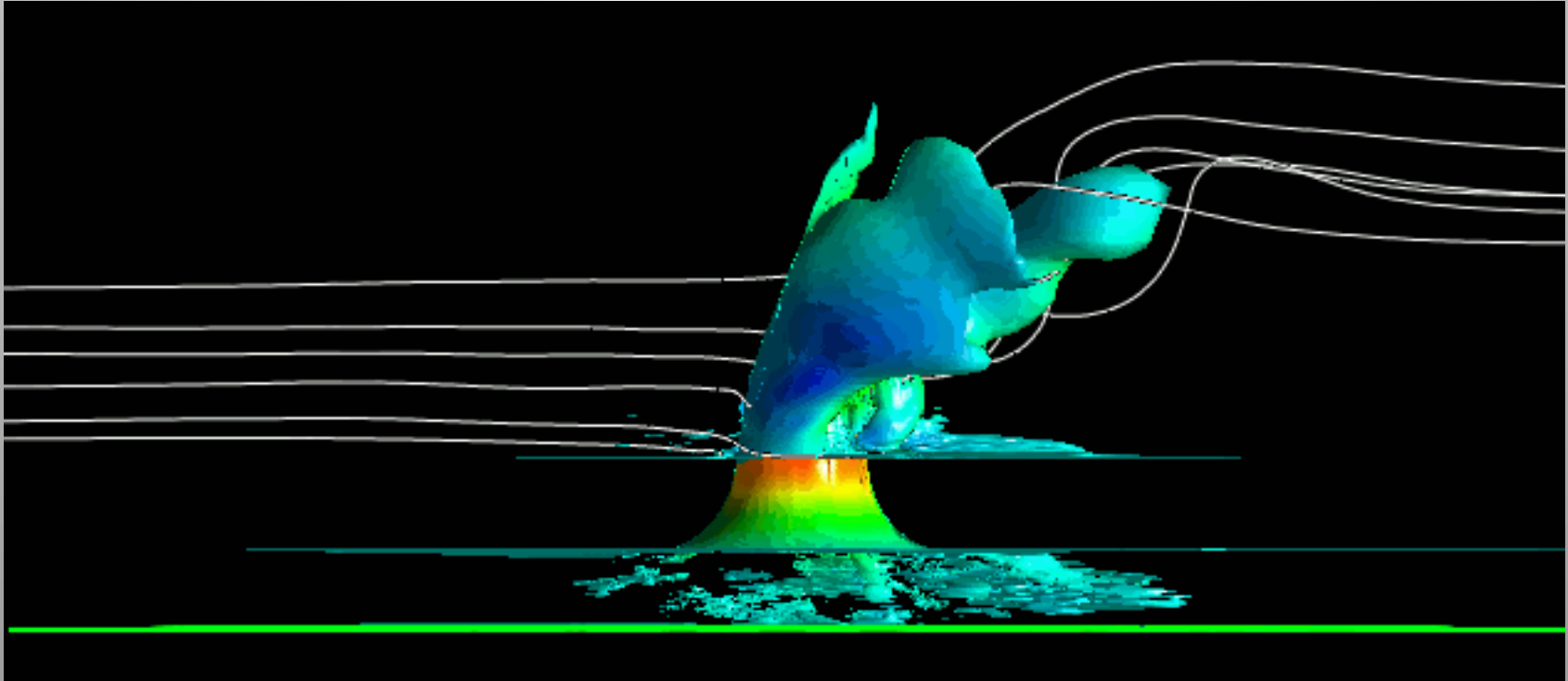


**Generic flap-deflection
Controlled by local radial
basis function
interpolation**



**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