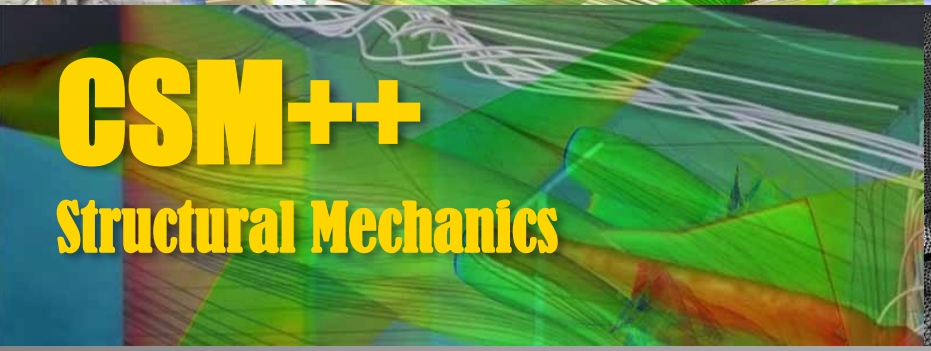
Overset and Mesh Morphing Capabilities in CFD++: Multiple Physics, Multiple Applications, One Solver

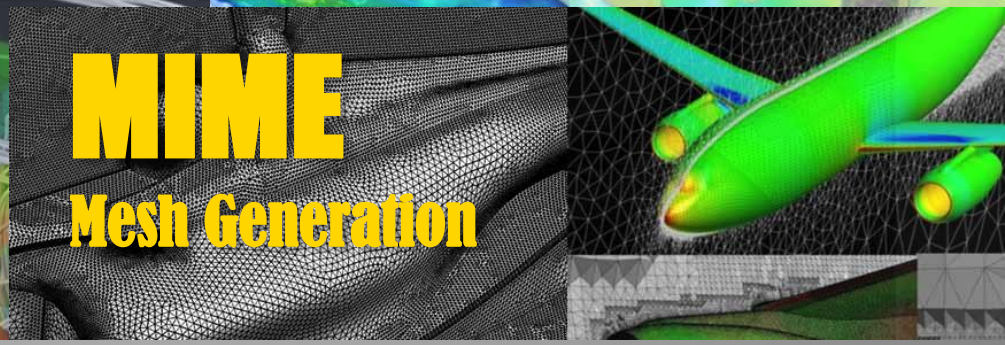
Overset Grid Symposium 2014

Metacomp Technologies

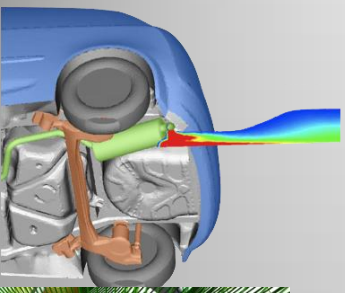
Background : Metacomp Technologies

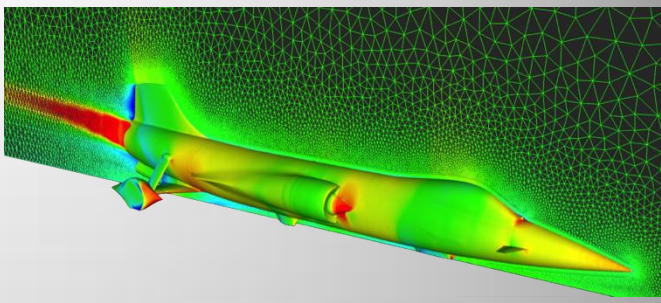
- Founded in 1994
- Key staff members are pioneers in CFD research
- CFD++ is 7th generation CFD software by founder, each one state-of-the-art when introduced
- Strong algorithm to applications experience
- Provides complete CAE solutions for its customers

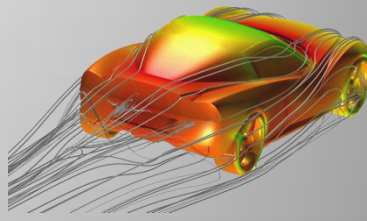


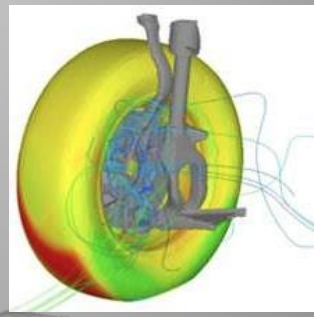


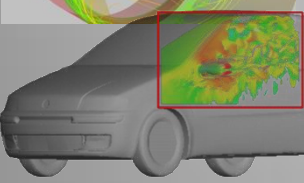
Company Focus

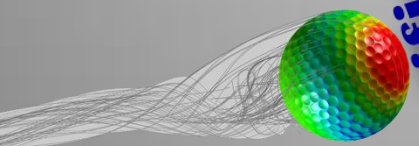


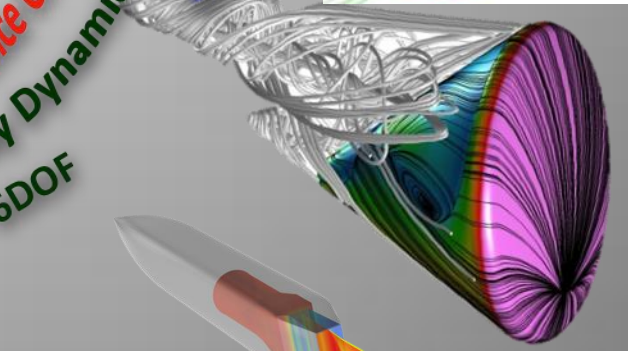


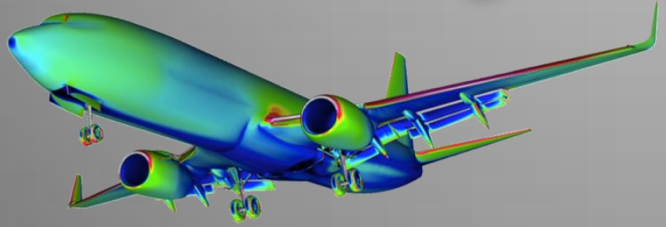


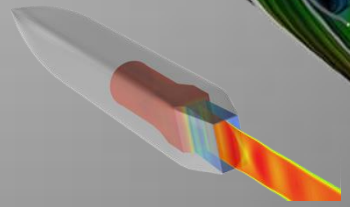






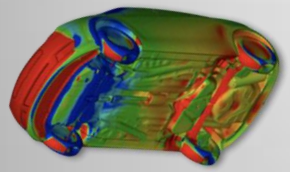






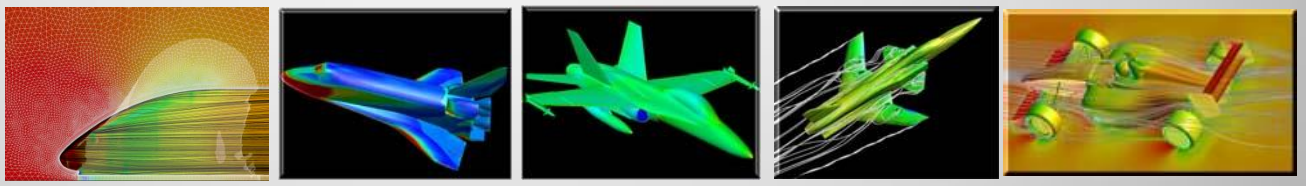
Unified Physics
Mesh Generation
Turbulence Modeling
Unified Computing
CFD
FSI
Acoustics
CFD Methodology
Unified Mesh
STRUCTURAL ANALYSIS
VOF
Overset Mesh
Radiation
Dispersed Phase
High Performance Computing
Rigid Body Dynamics
6DOF

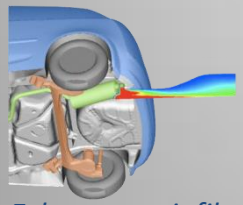
CFD++ Capabilities



Under-hood flows

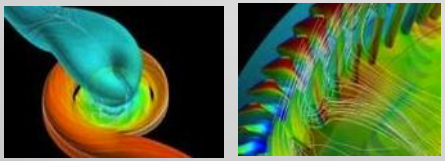
External Aerodynamics



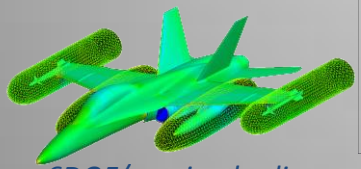


Exhaust gas infiltration

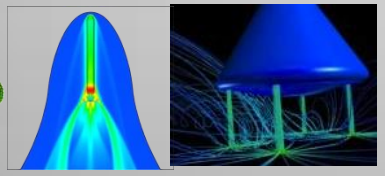
Turbomachinery



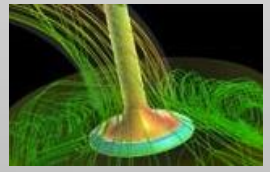
CFD++ is a comprehensive software suite that includes a rich collection of tools to help increase the end users' effectiveness.



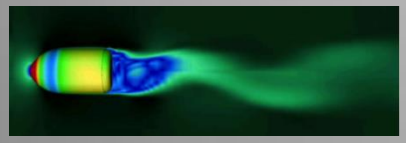
6DOF/moving bodies



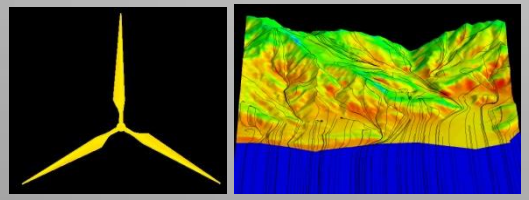
Propulsion



High- and low-Speed combustion



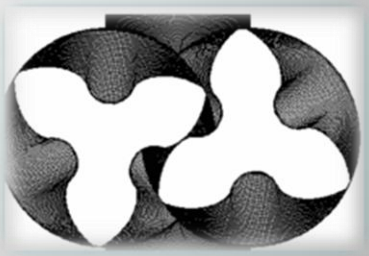
Unsteady flow with Hybrid RANS/LES



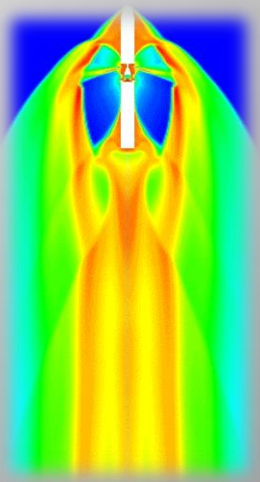
Wind energy – terrain verification

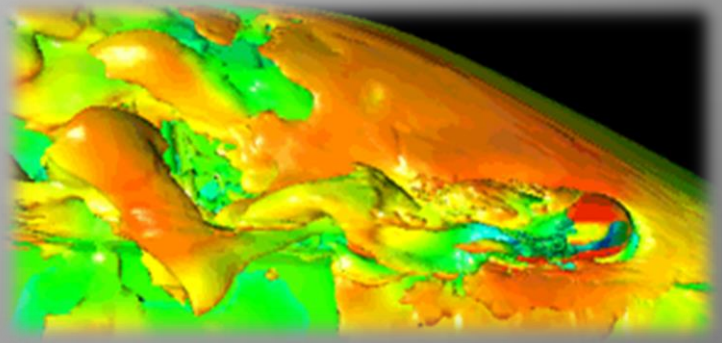
- *External and Internal flows*
- *Sliding/Moving/Overset Meshes*
- *Rotating Machinery*
- *6DOF/Moving Bodies*
- *Conjugate Heat Transfer*
- *Porous Media Modeling*
- *High-Speed and Low-Speed Reacting flows*
- *Multi-Speed Problems*
- *Supercritical Fluids*
- *Dispersed Phase Models (particles and 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



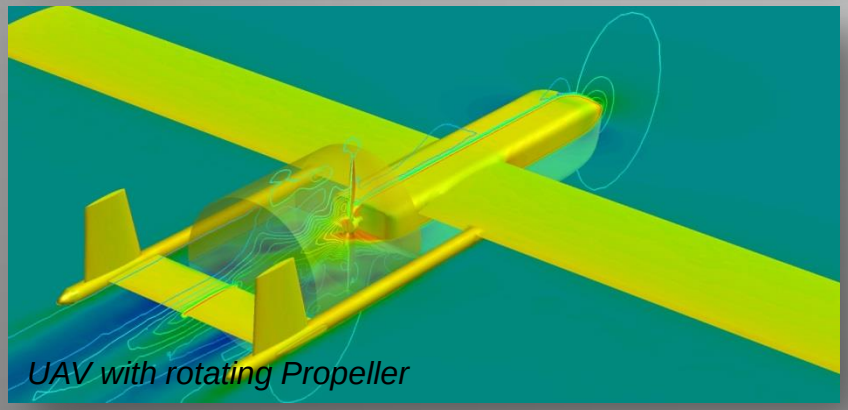
- Coupled density or pressure-based solvers
- Realizable physical, mathematical & numerical models
- Agglomeration (algebraic) multi-grid accelerated solver for fast convergence to steady state
- Multi-dimensional TVD framework for truly 2nd order accuracy on all meshes
- Up to fourth order accuracy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

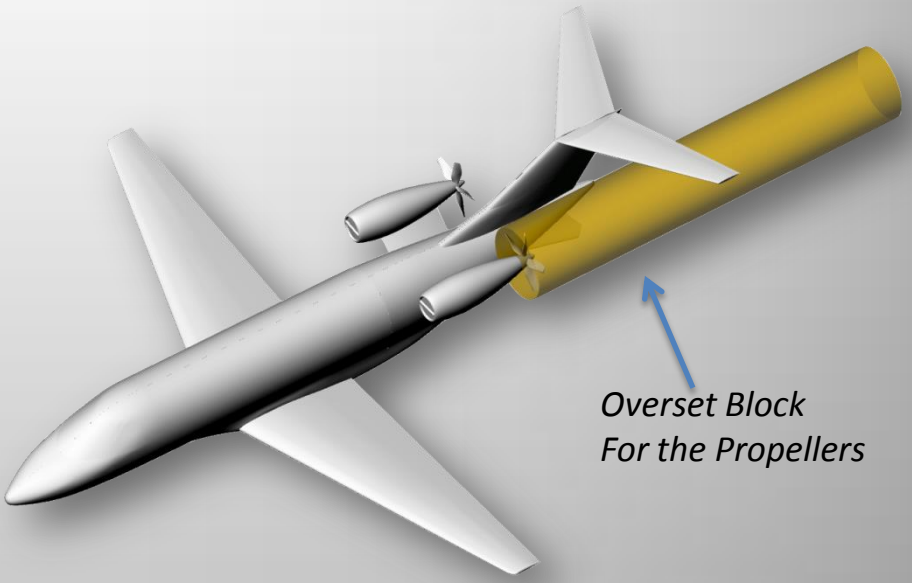
- *For transient simulations, cutting, blanking and interpolation operations can all be performed within CFD++ at every time step*

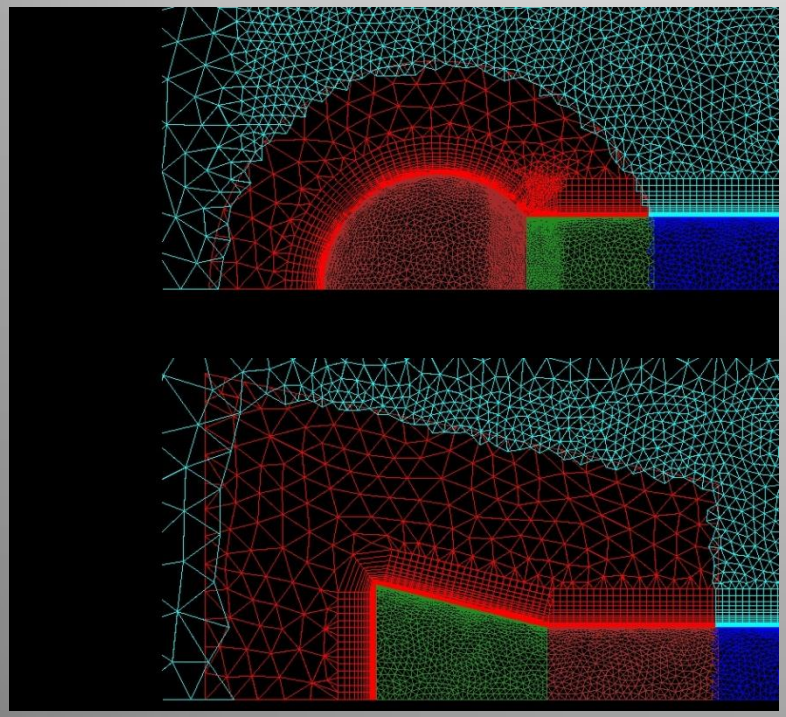
RBD and 6DOF

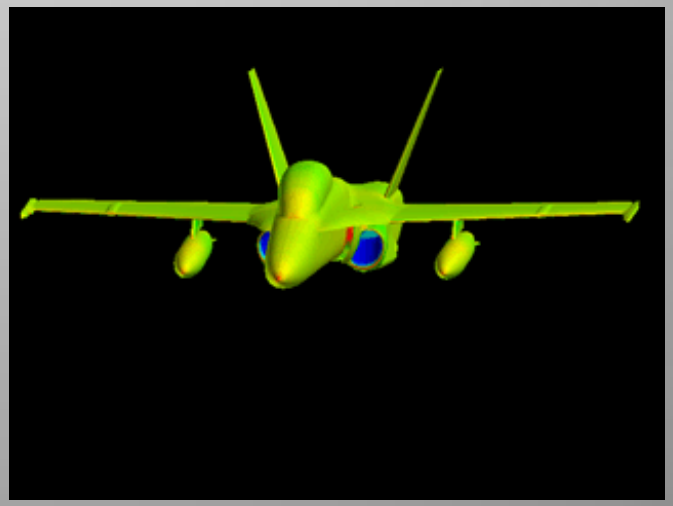
- *Includes an integrated rigid-body dynamics (RBD) capability with a six-degree-of-freedom (6DOF) module*

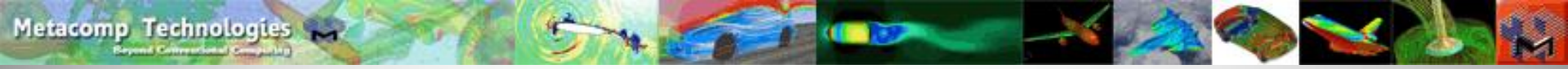
Why Overset?

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







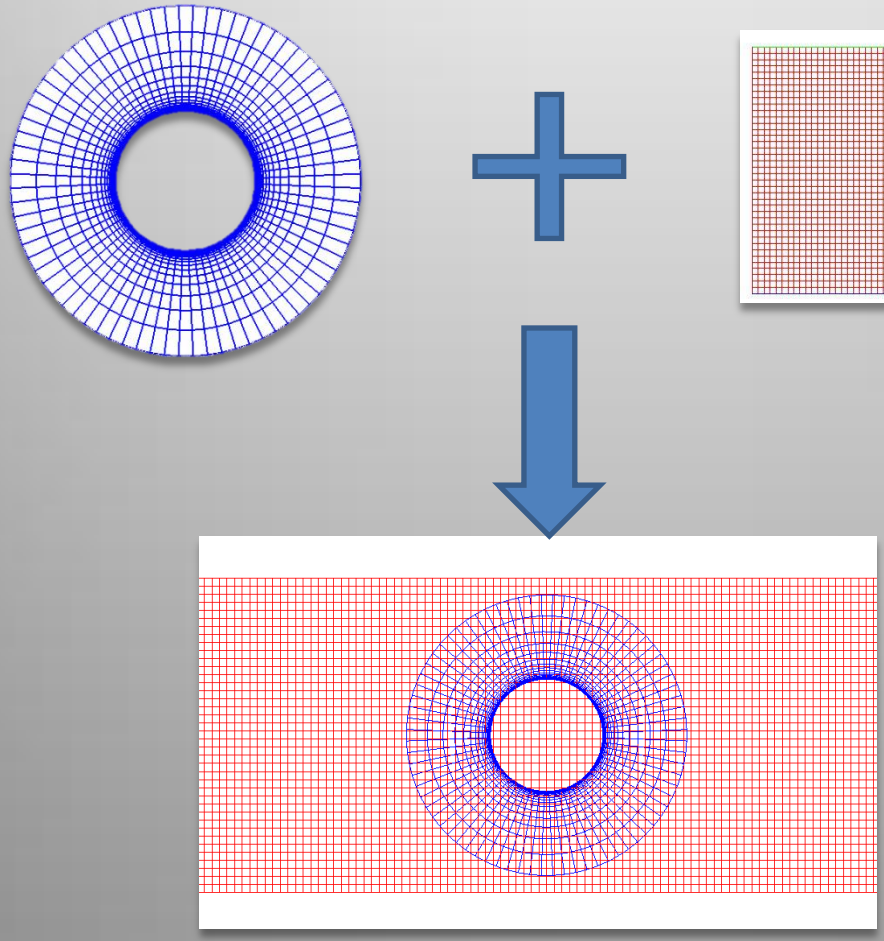


CFD++ Key Attributes

- ✓ *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*

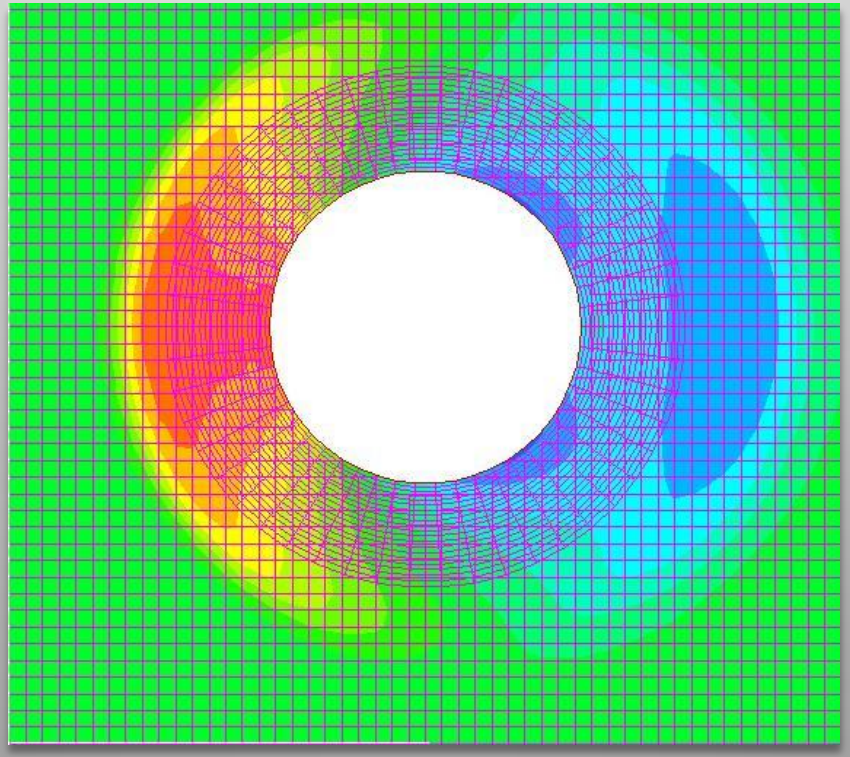
Overset Process in CFD++

- ✓ *Concatenation of grids*



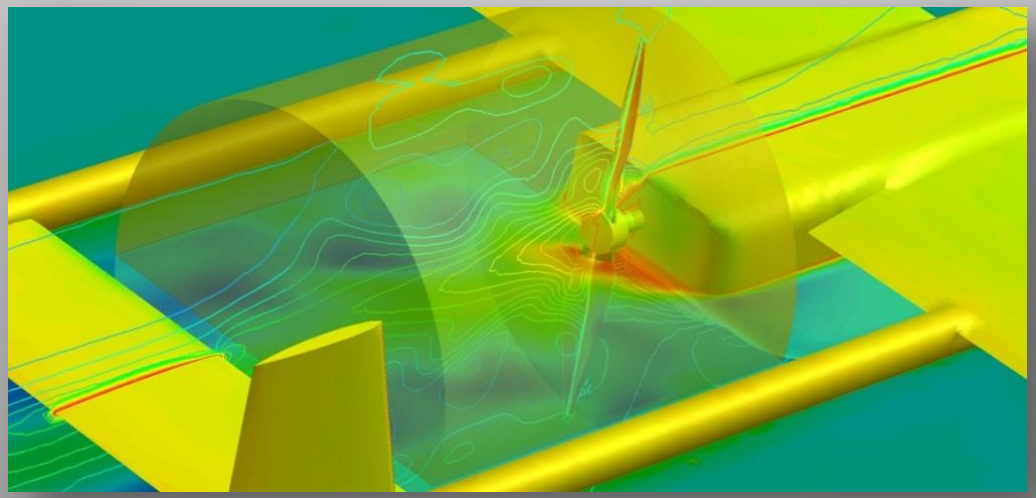
Overset Process in CFD++

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



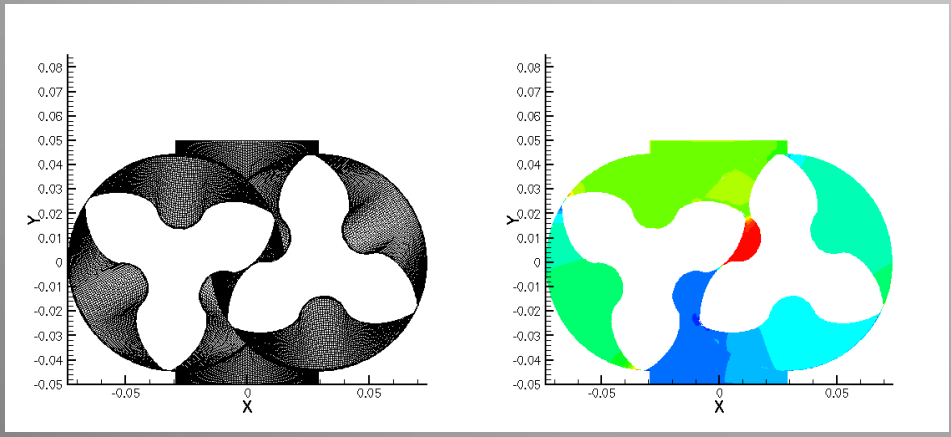
Overset Process in CFD++

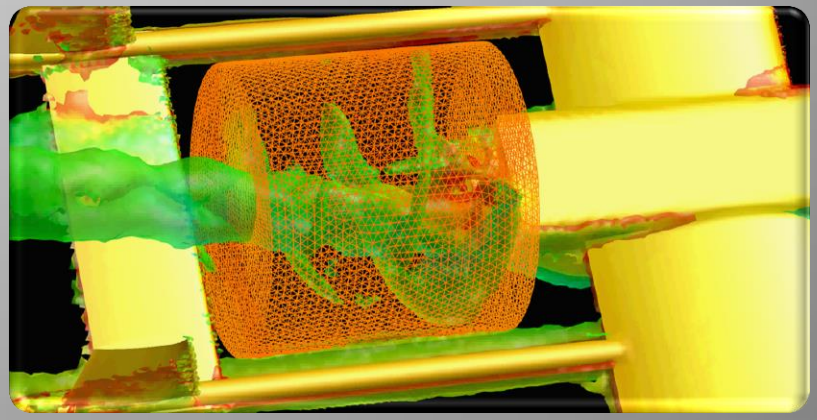
- ✓ *Concatenation of grids*
- ✓ *Cutting and Blanking*
- ✓ *Application of Boundary Conditions and Grid Motion*



Metacomp's Overset Philosophy

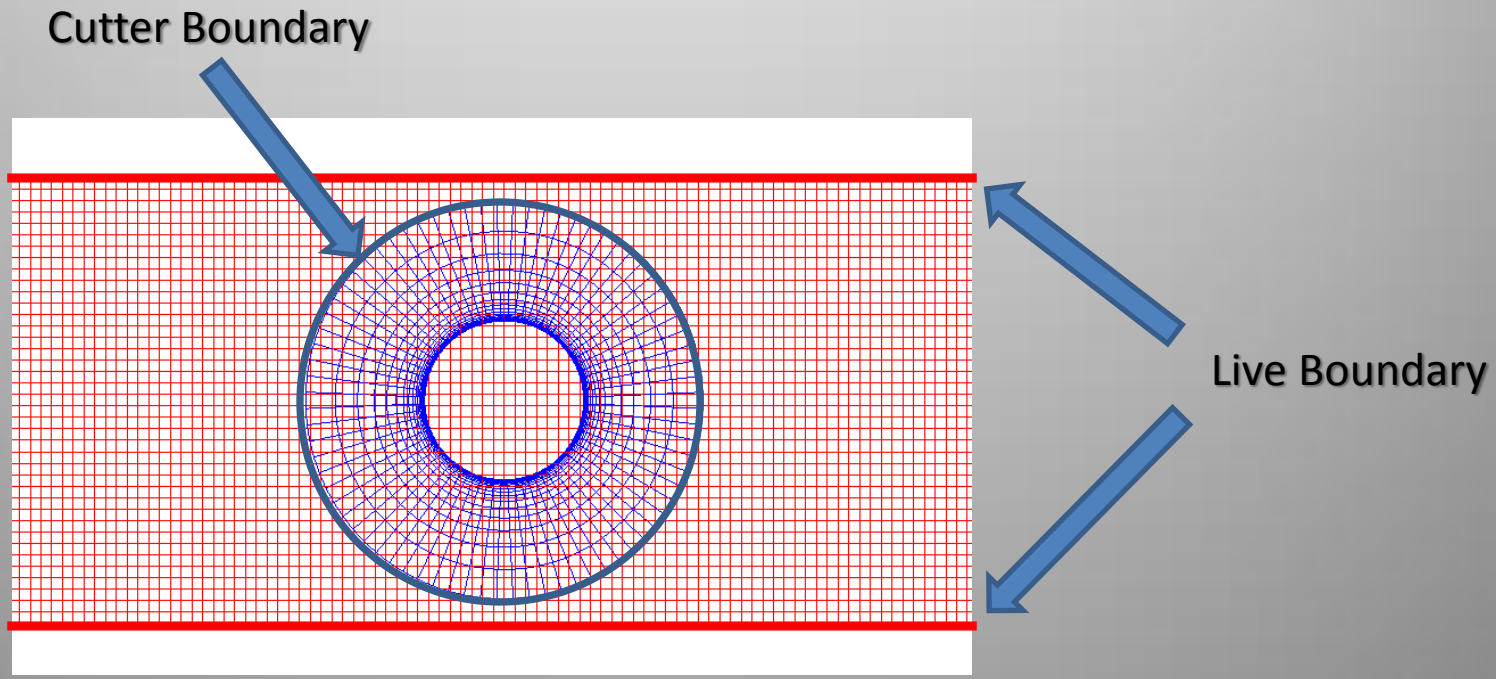
- ✓ *Same multidimensional least squares interpolation everywhere*
- ✓ *Very intuitive geometric approach*
  - ✓ *Flexibility via sequential cutting (reduces number of overlap cells)*
- ✓ *Fully integrated*
  - ✓ *Cutting can be performed (if necessary) completely within the run*
  - ✓ *Coupled with 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

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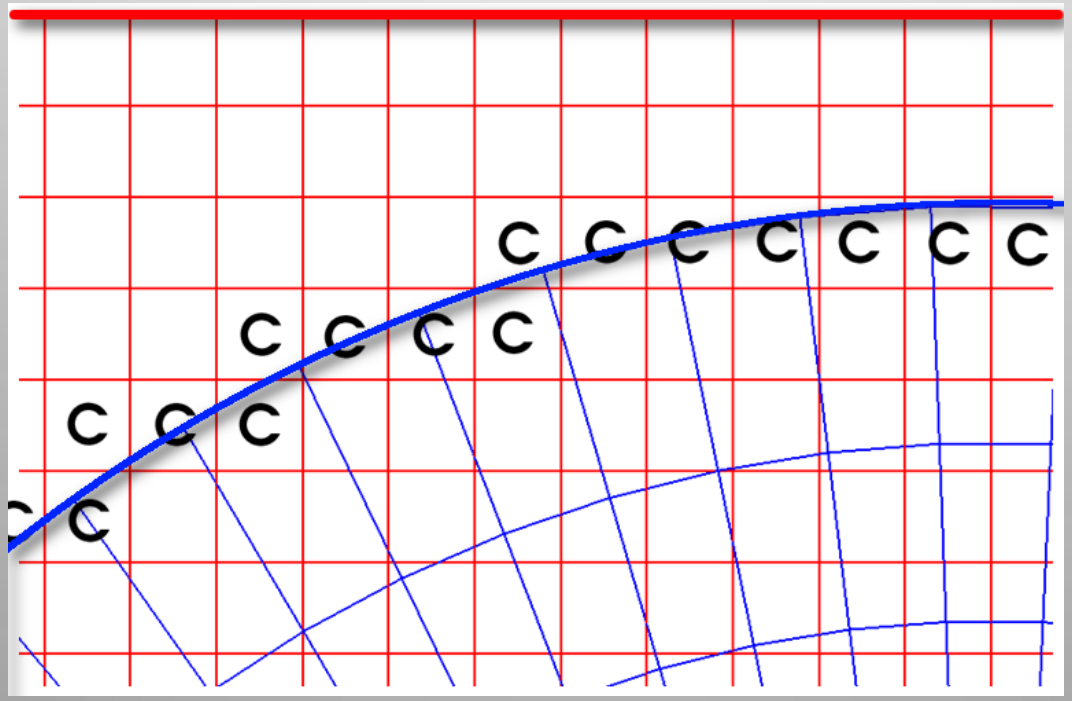
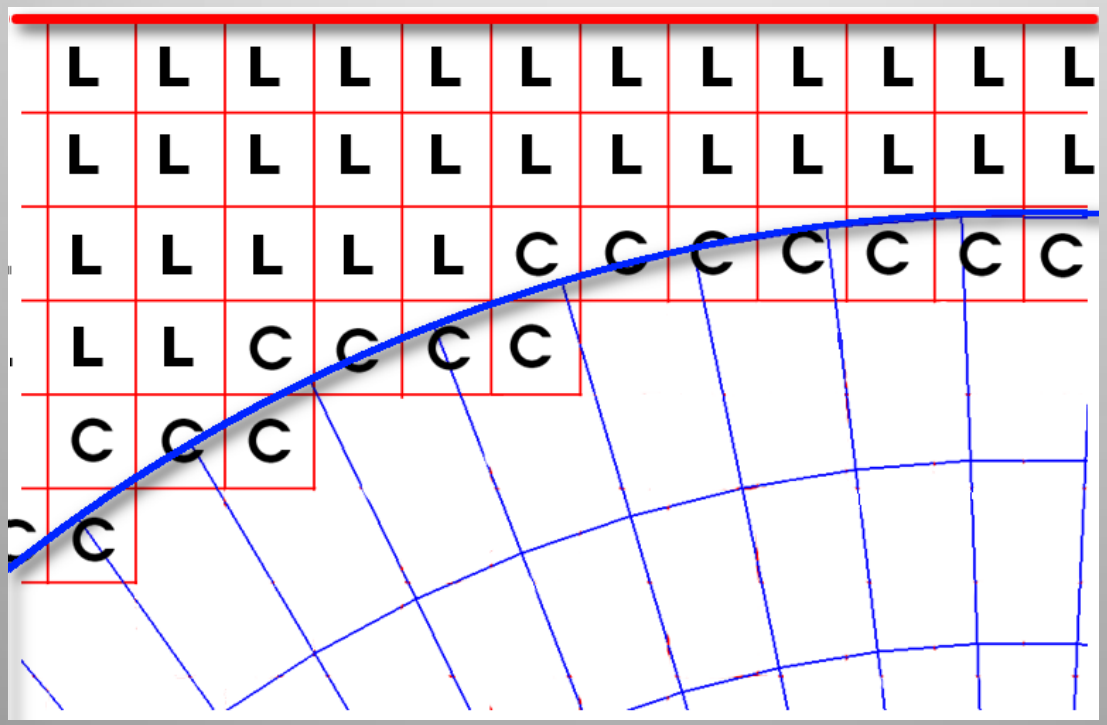


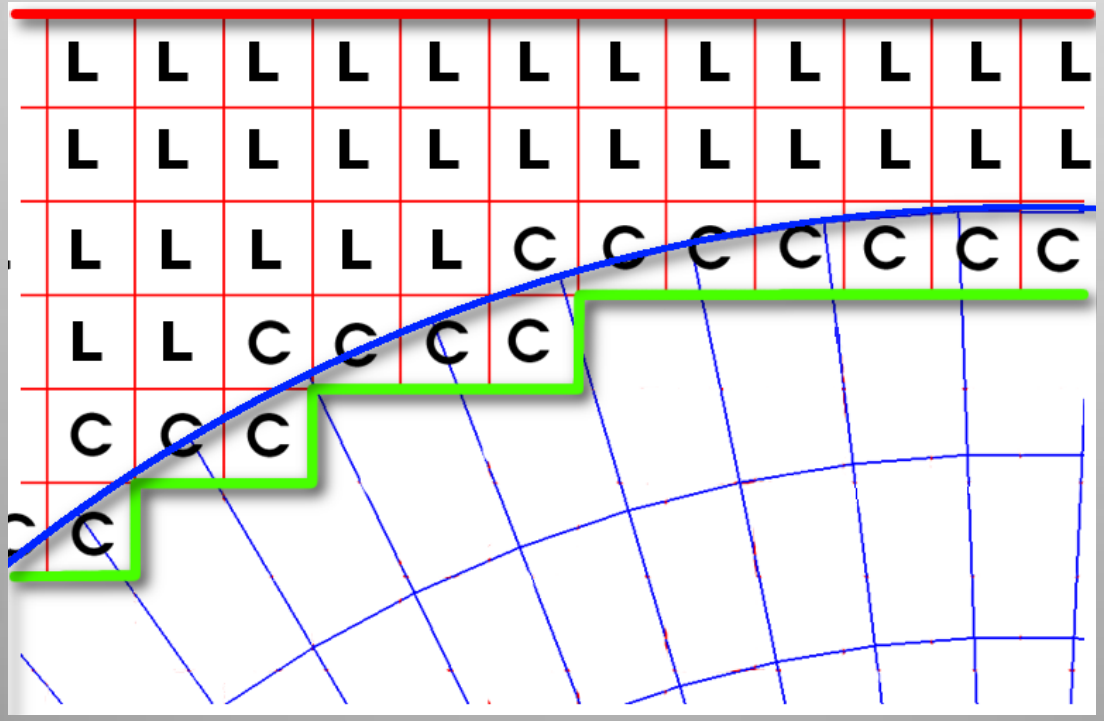
Overset Blanking Procedure

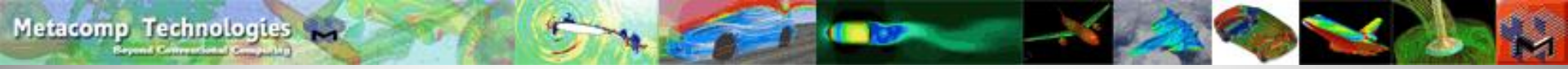
- ✓ *Marking "live" cells – recursively marching to adjacent cells until "cut" cell or non-live boundary is encountered*



Overset Blanking Procedure

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

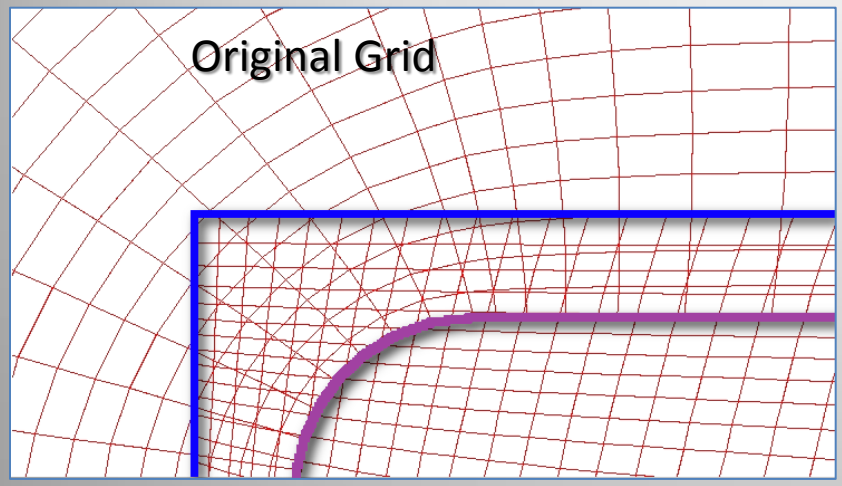


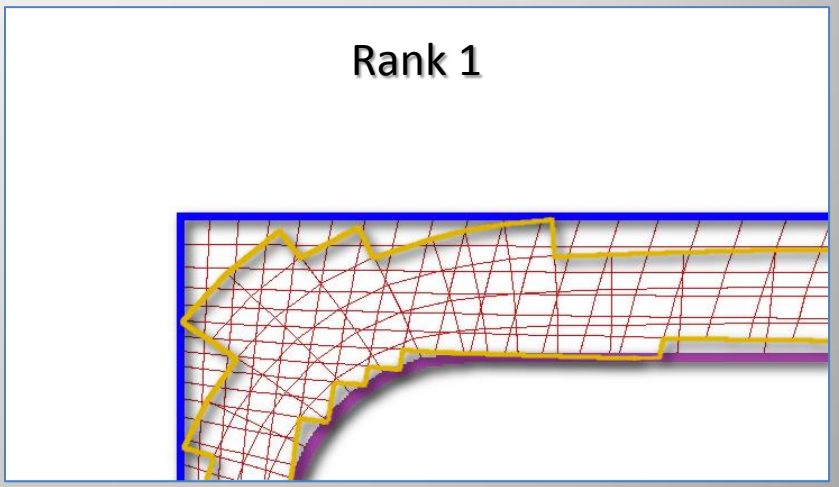


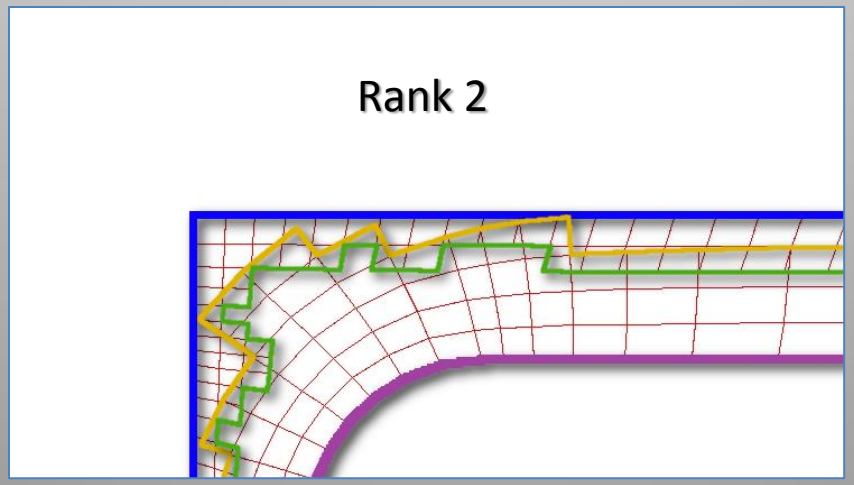
Sequential Cutting

- ✓ *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*

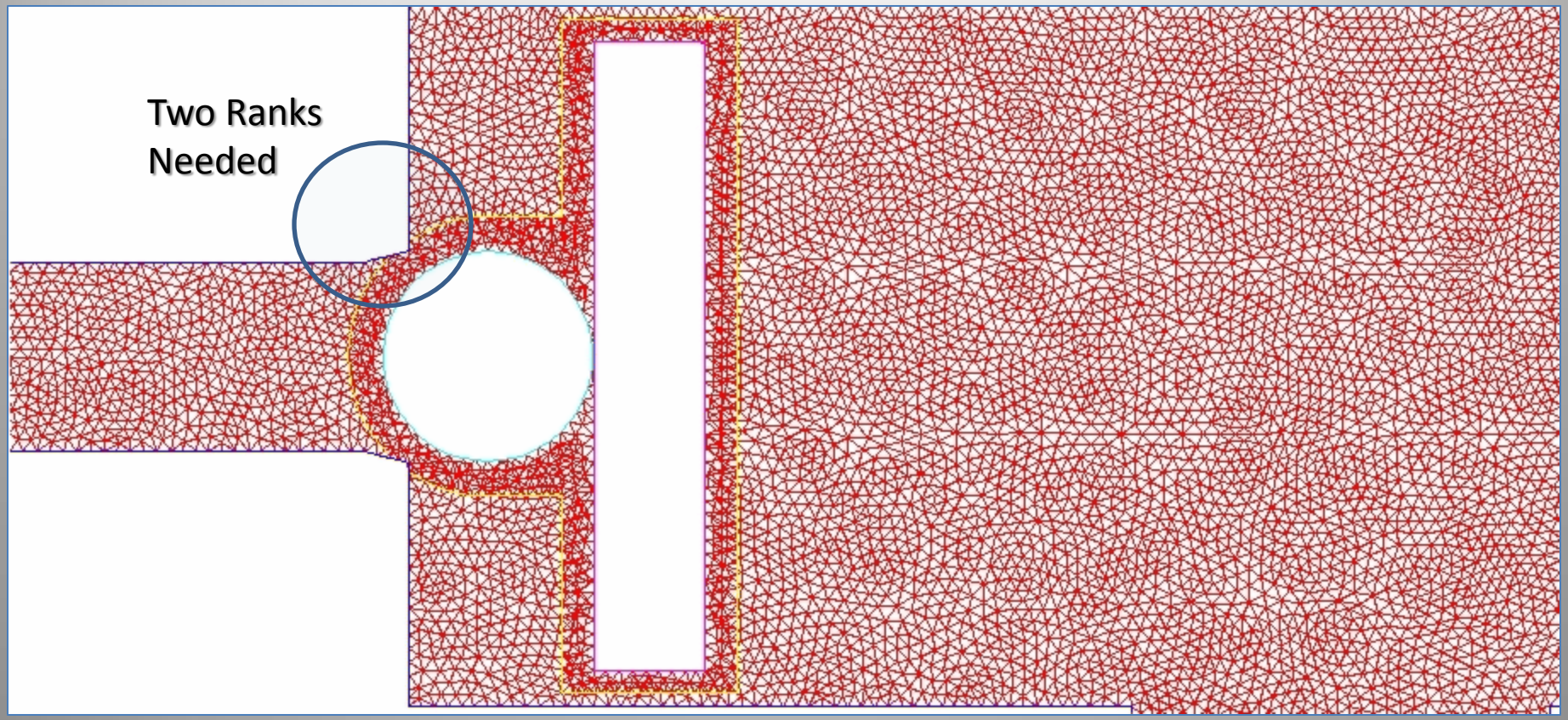
Sequential Cutting





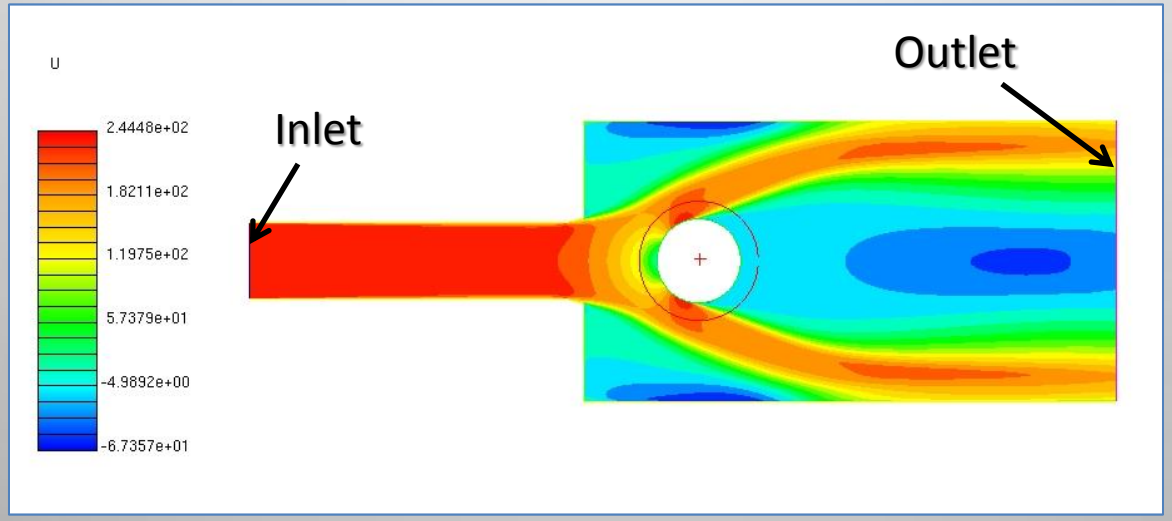


Sequential Cutting



Rank 1: Use wall, do not retain cut cells
Rank 2: Use BC created by rank 1 and zonal, retain cut cells

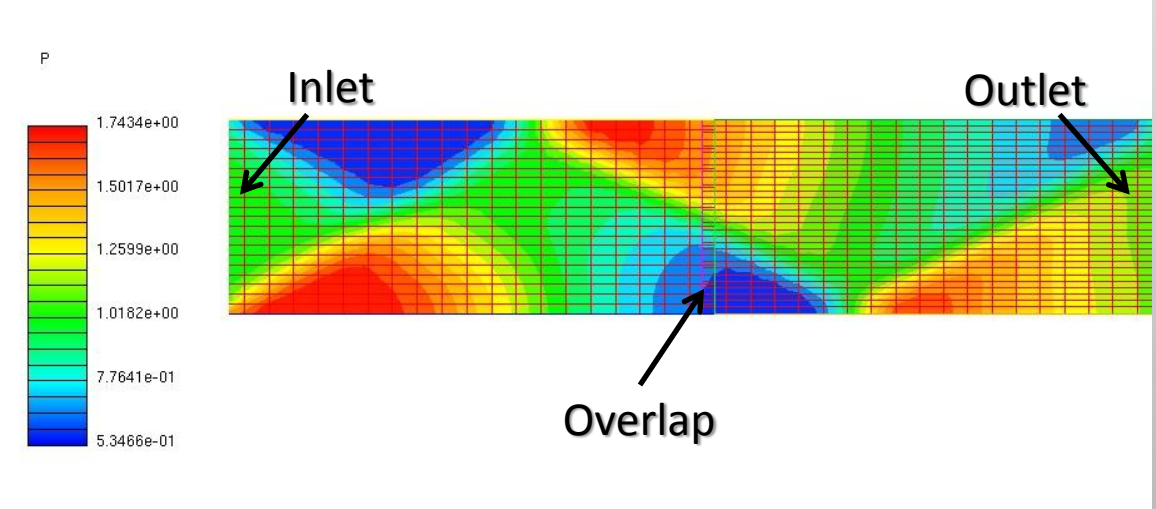
Flux Stitching



2D Incompressible, Steady Ball Valve

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

Flux Stitching

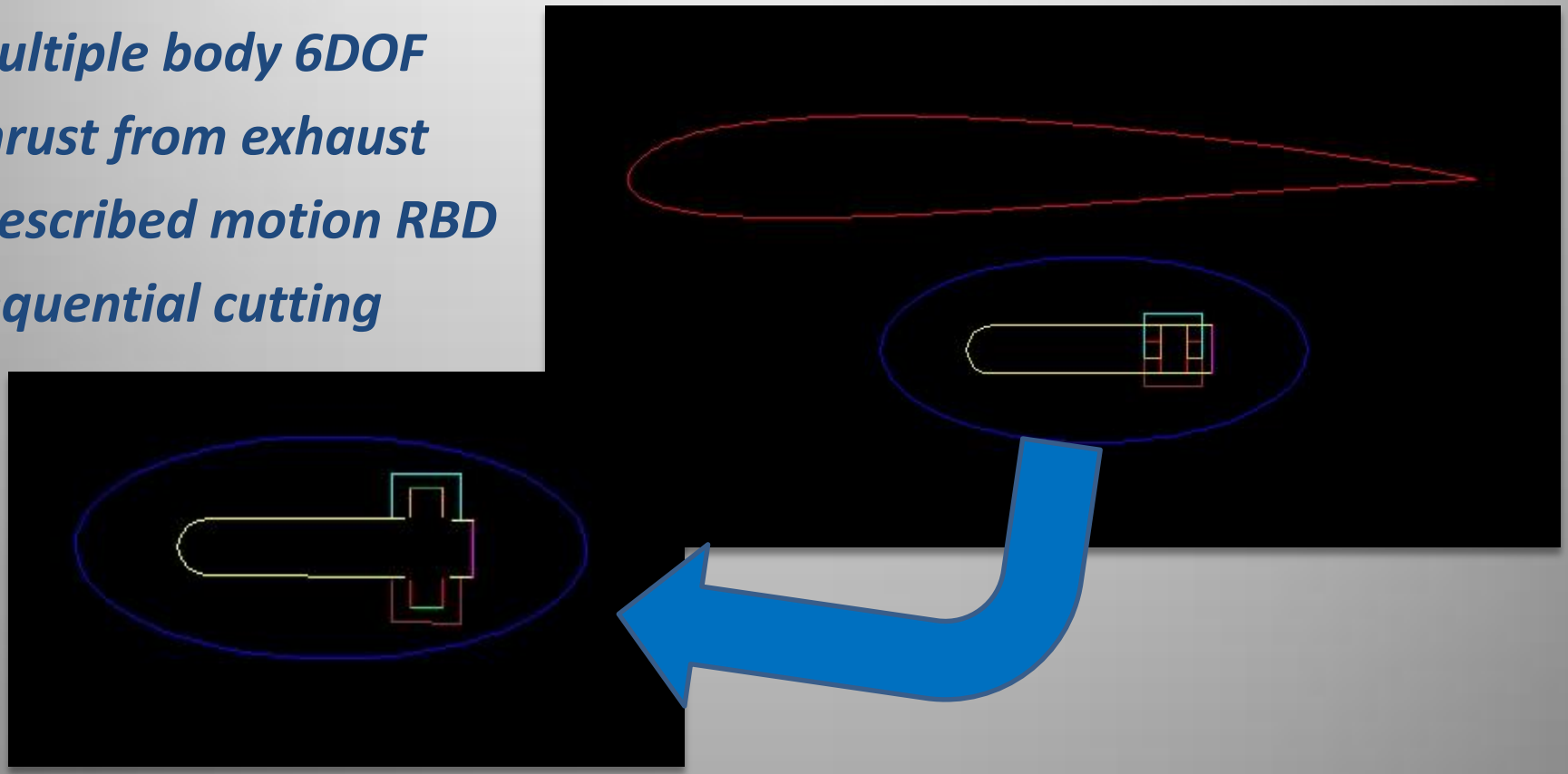


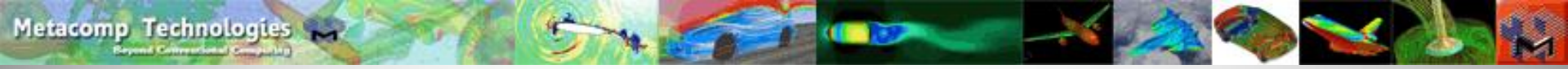
3D Supersonic Flow in Channel

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

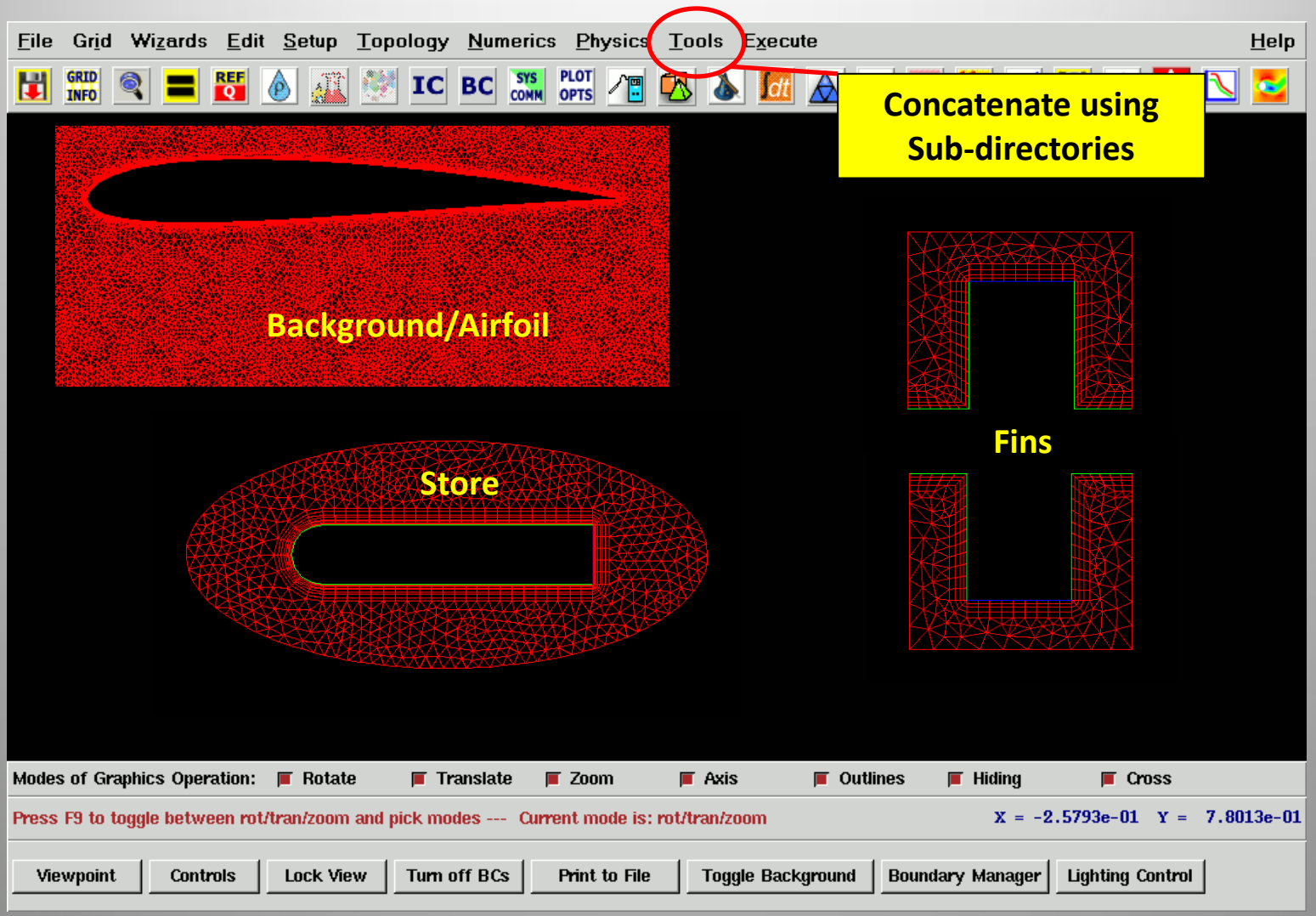
Steady State:

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

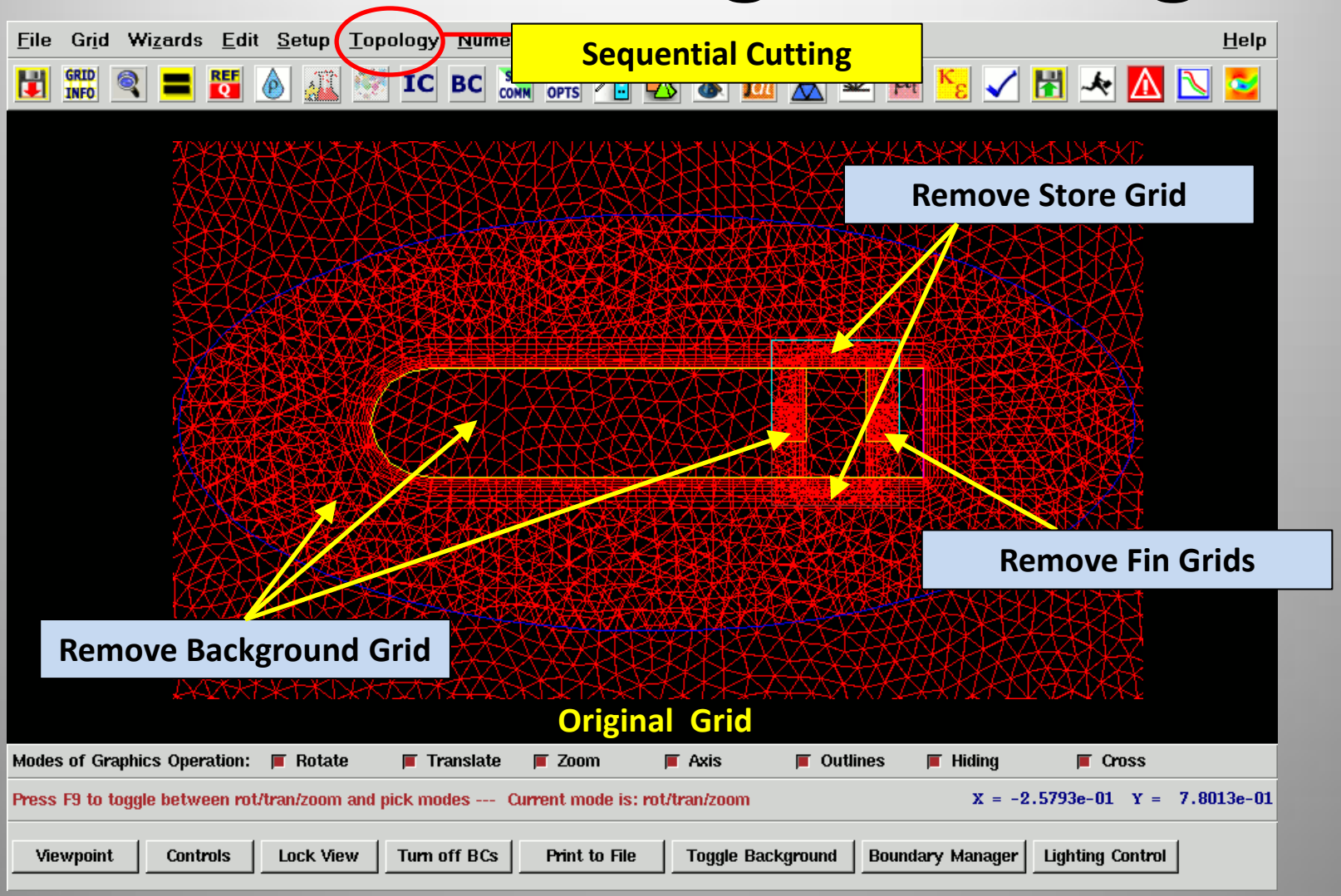
Transient:

1. Grid Motion /6DOF
2. Flow Specifications

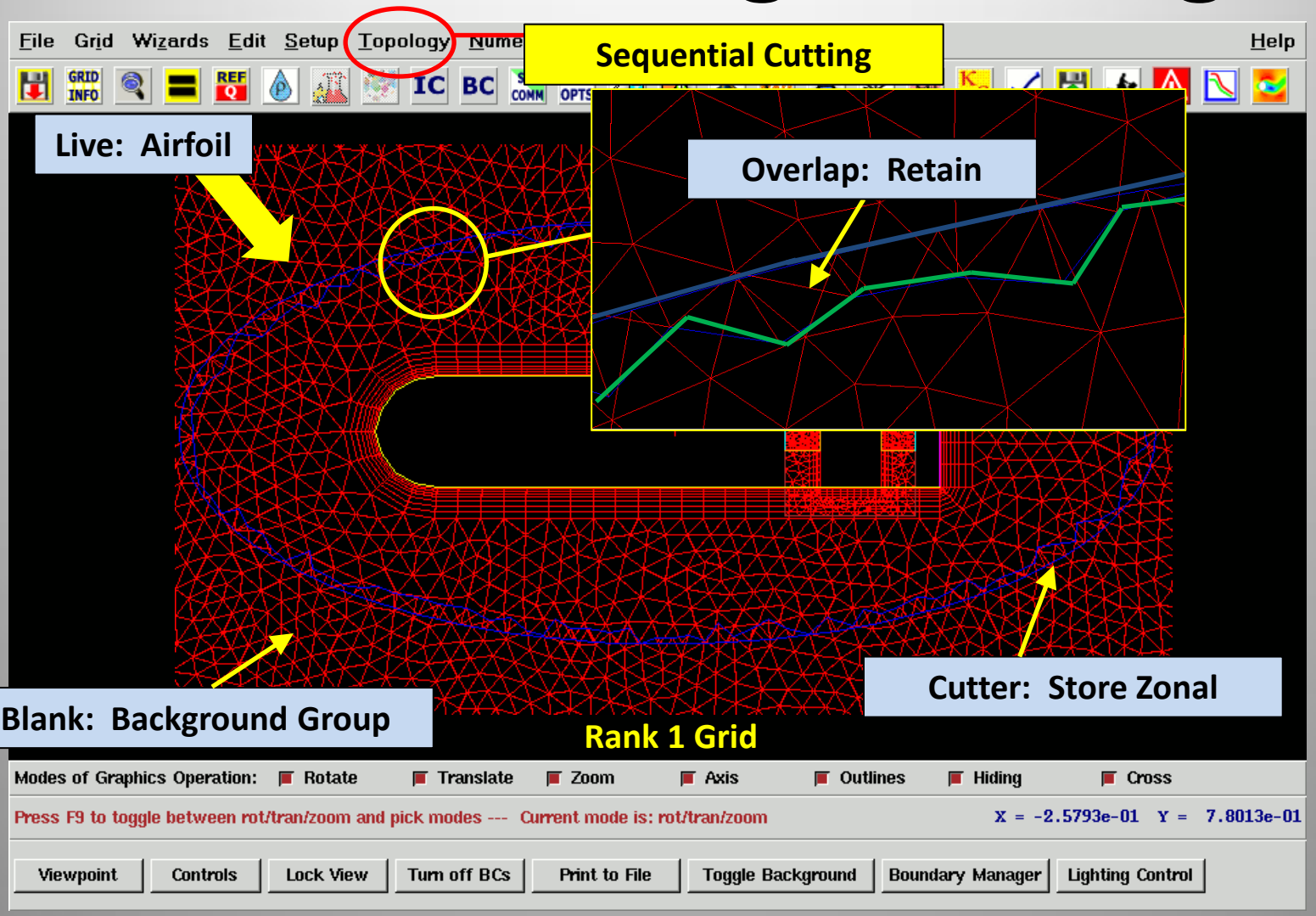
Case 1: Concatenate Grids



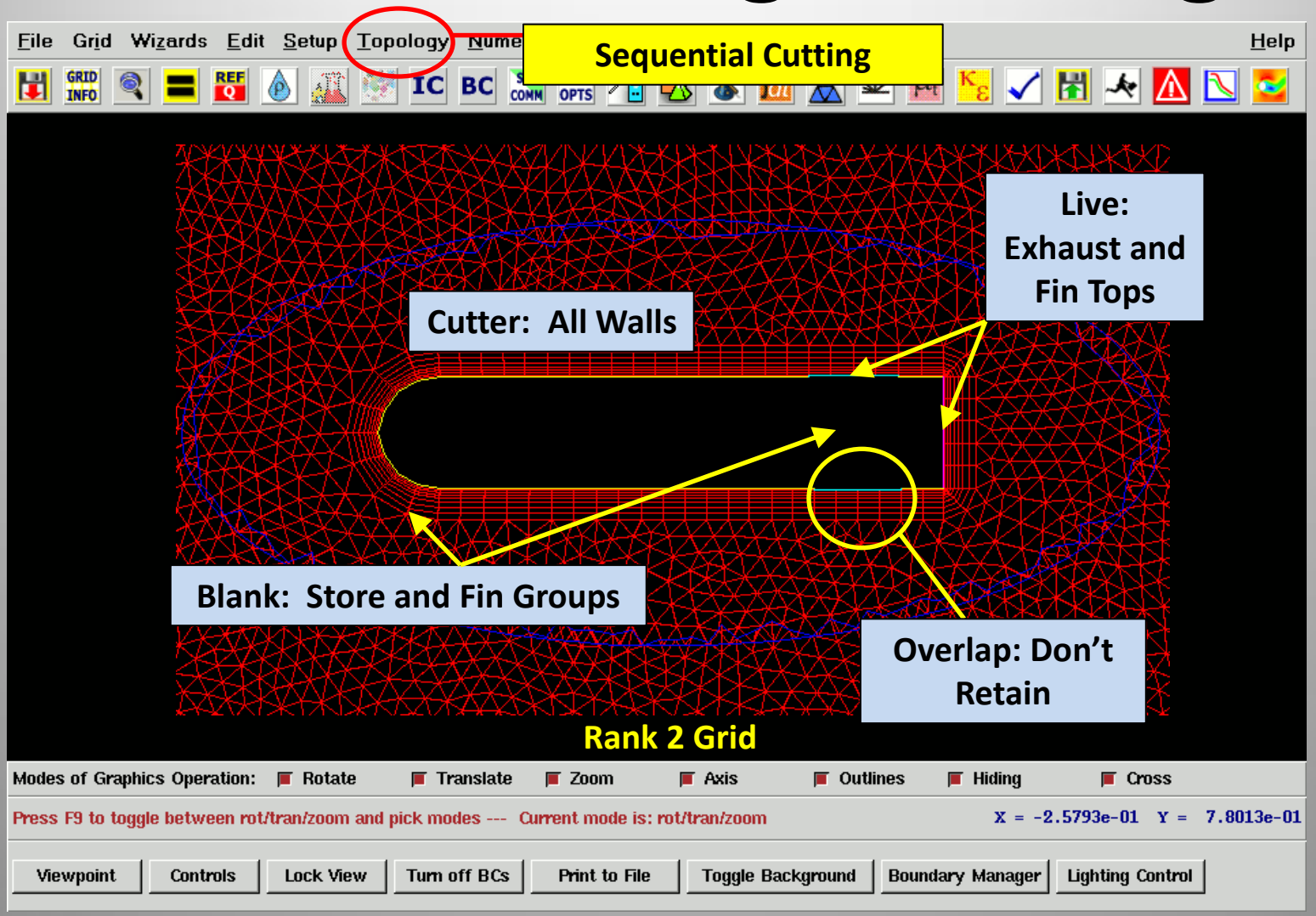
Case 1: Cutting/Blanking



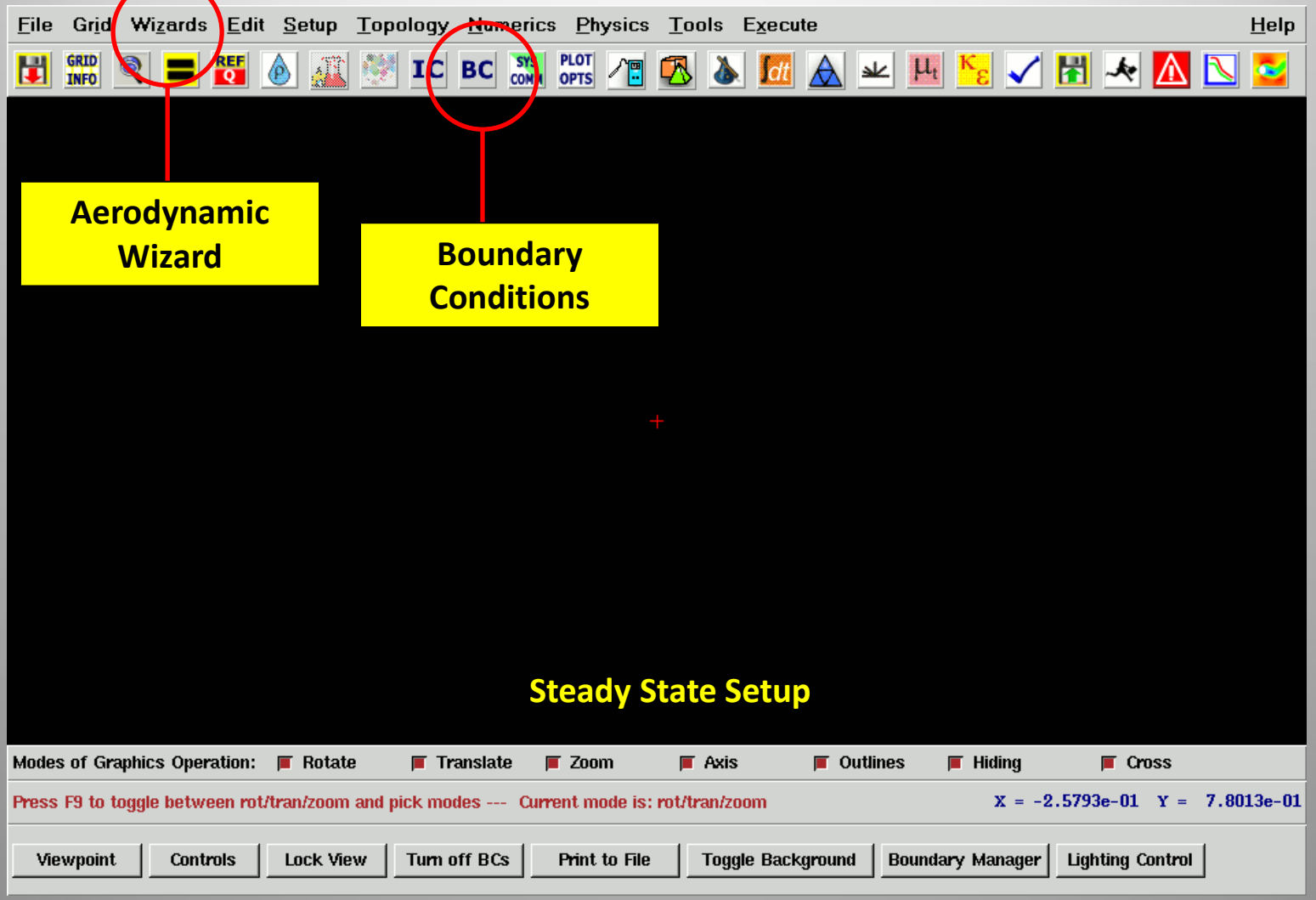
Case 1: Cutting/Blanking



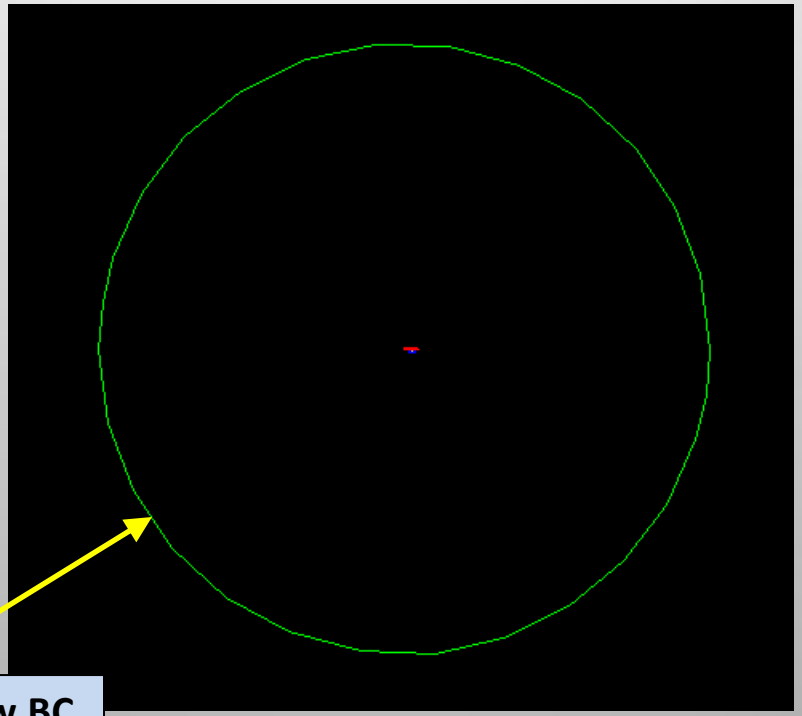
Case 1: Cutting/Blanking



Case 1: Flow Specifications

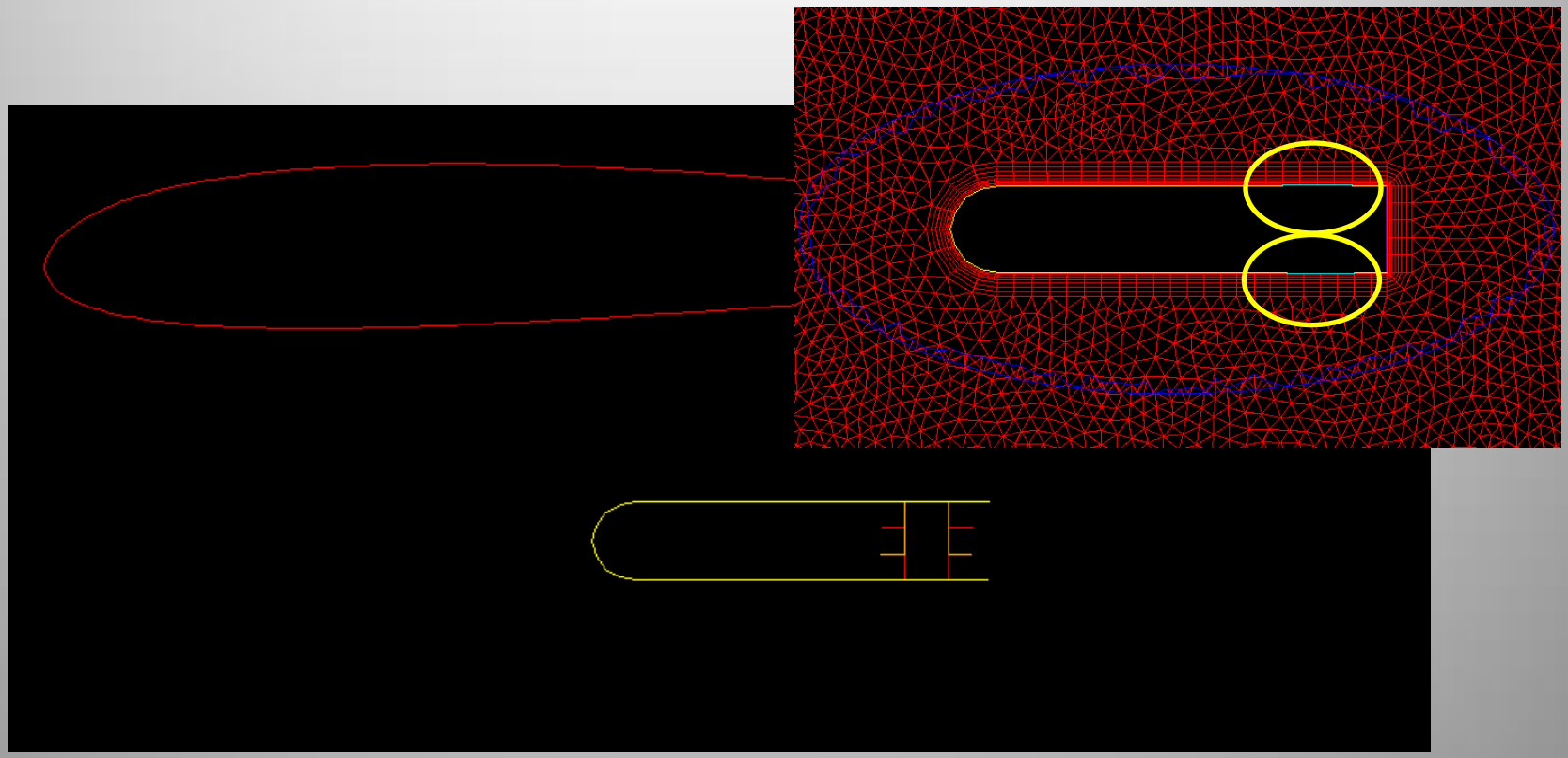


Case 1: Boundary Conditions



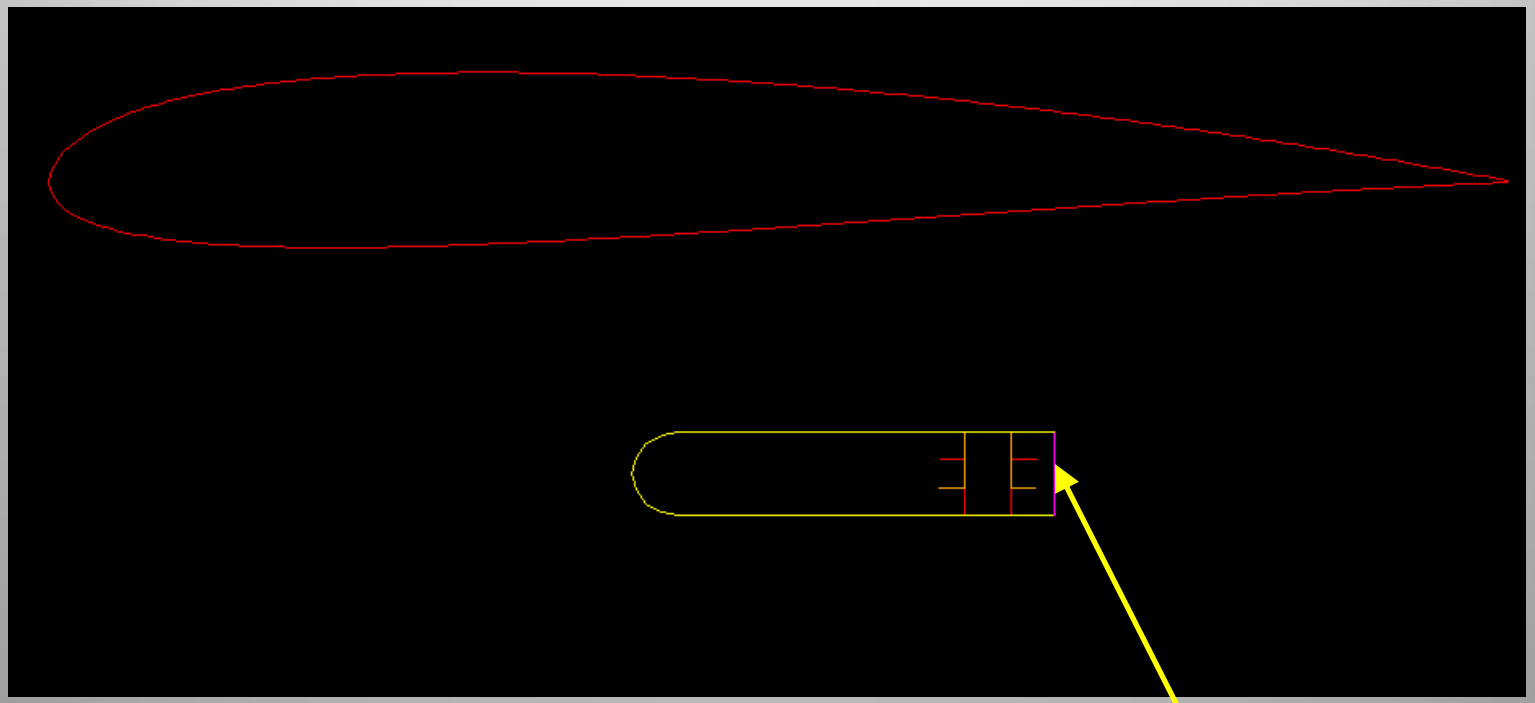
Far-field: Inflow/Outflow BC

Case 1: Boundary Conditions

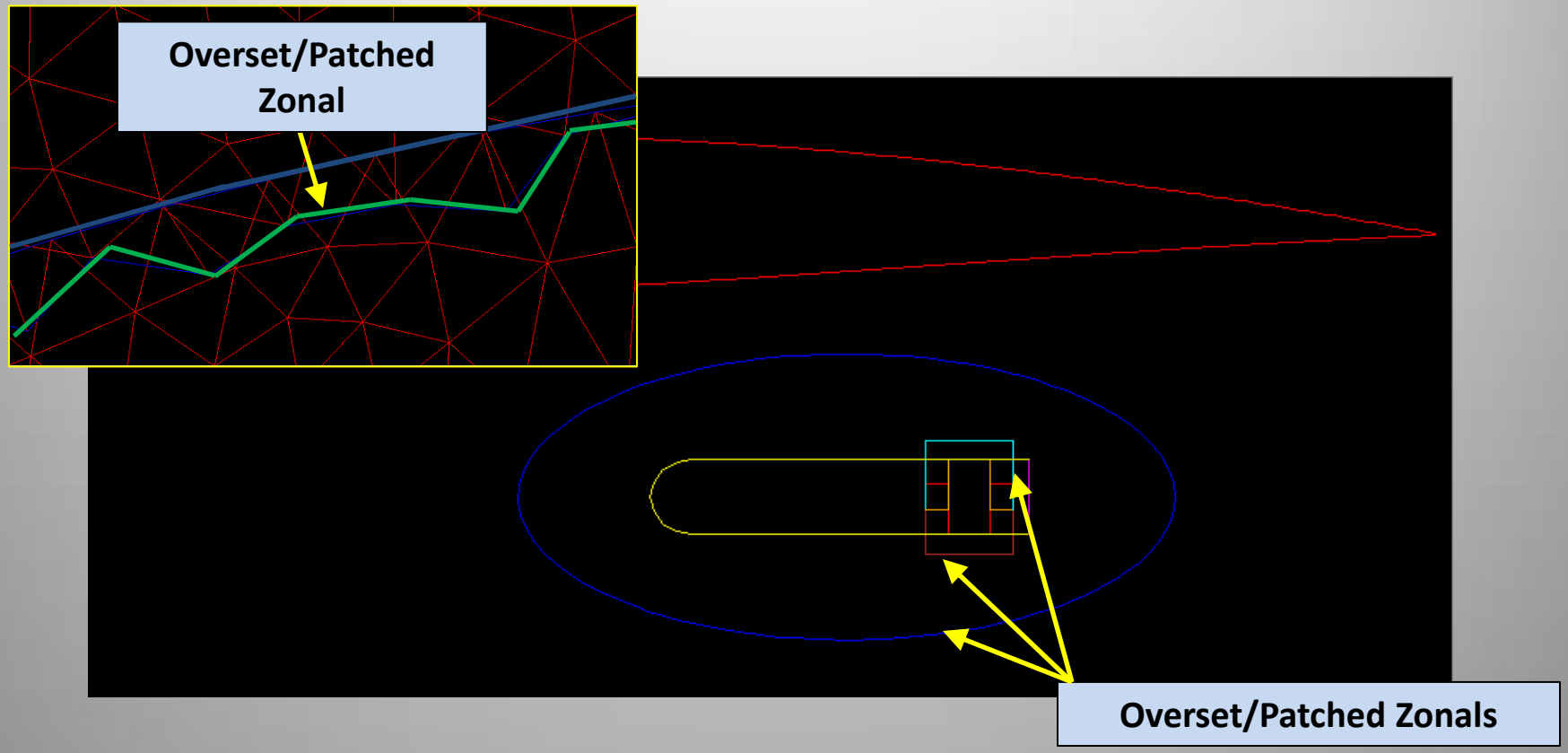


Adiabatic, Viscous Wall Functions

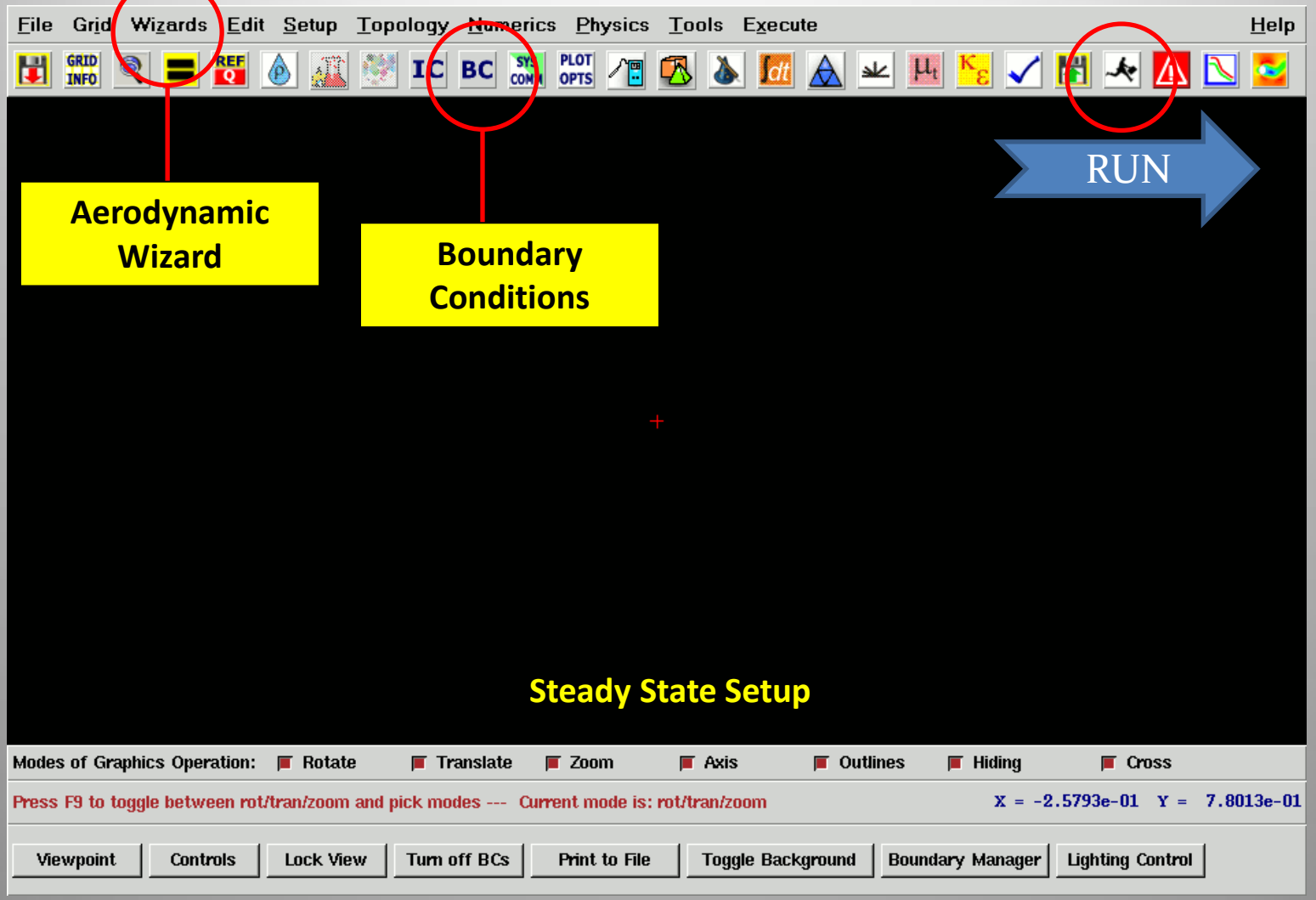
Case 1: Boundary Conditions



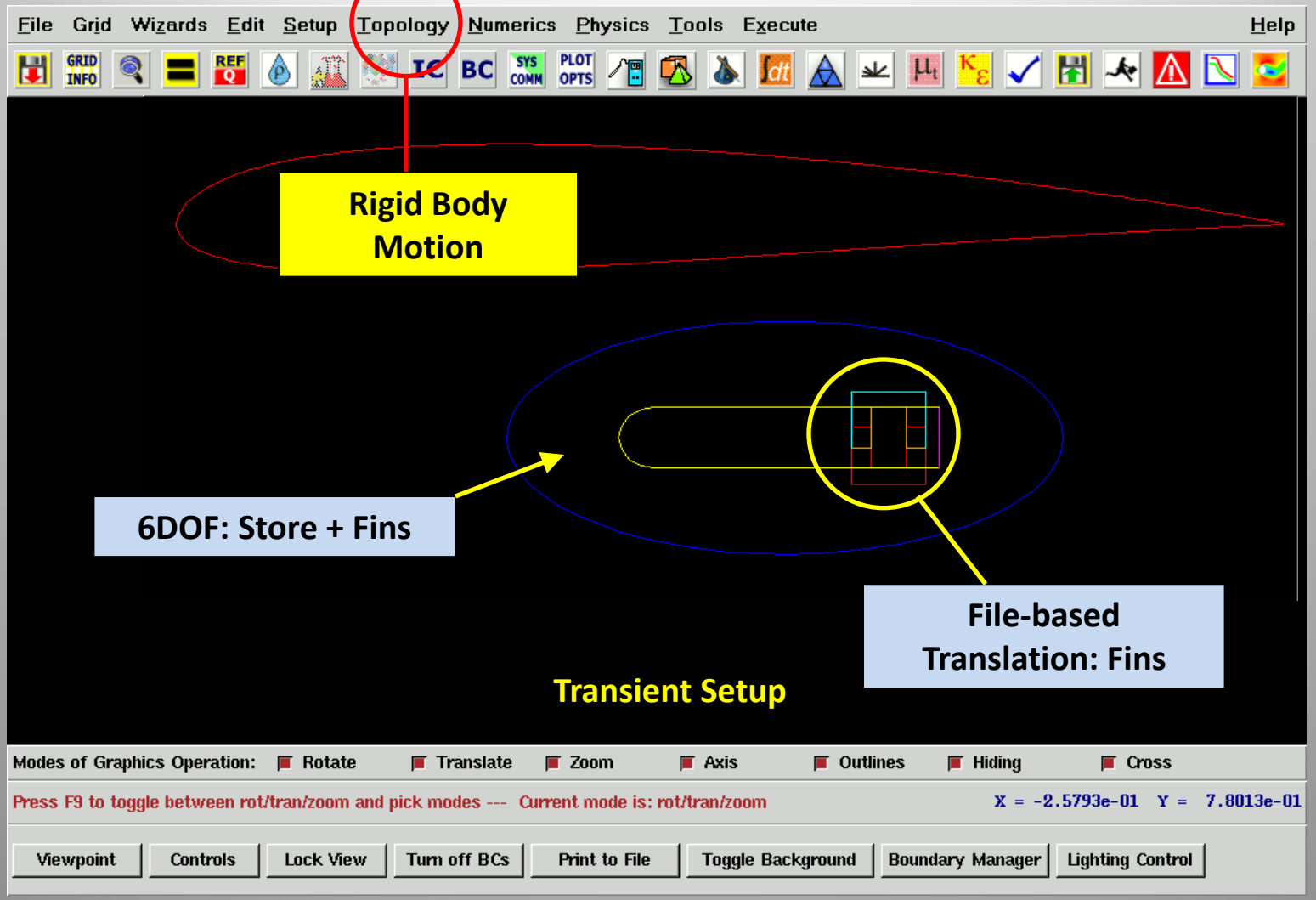
Case 1: Boundary Conditions



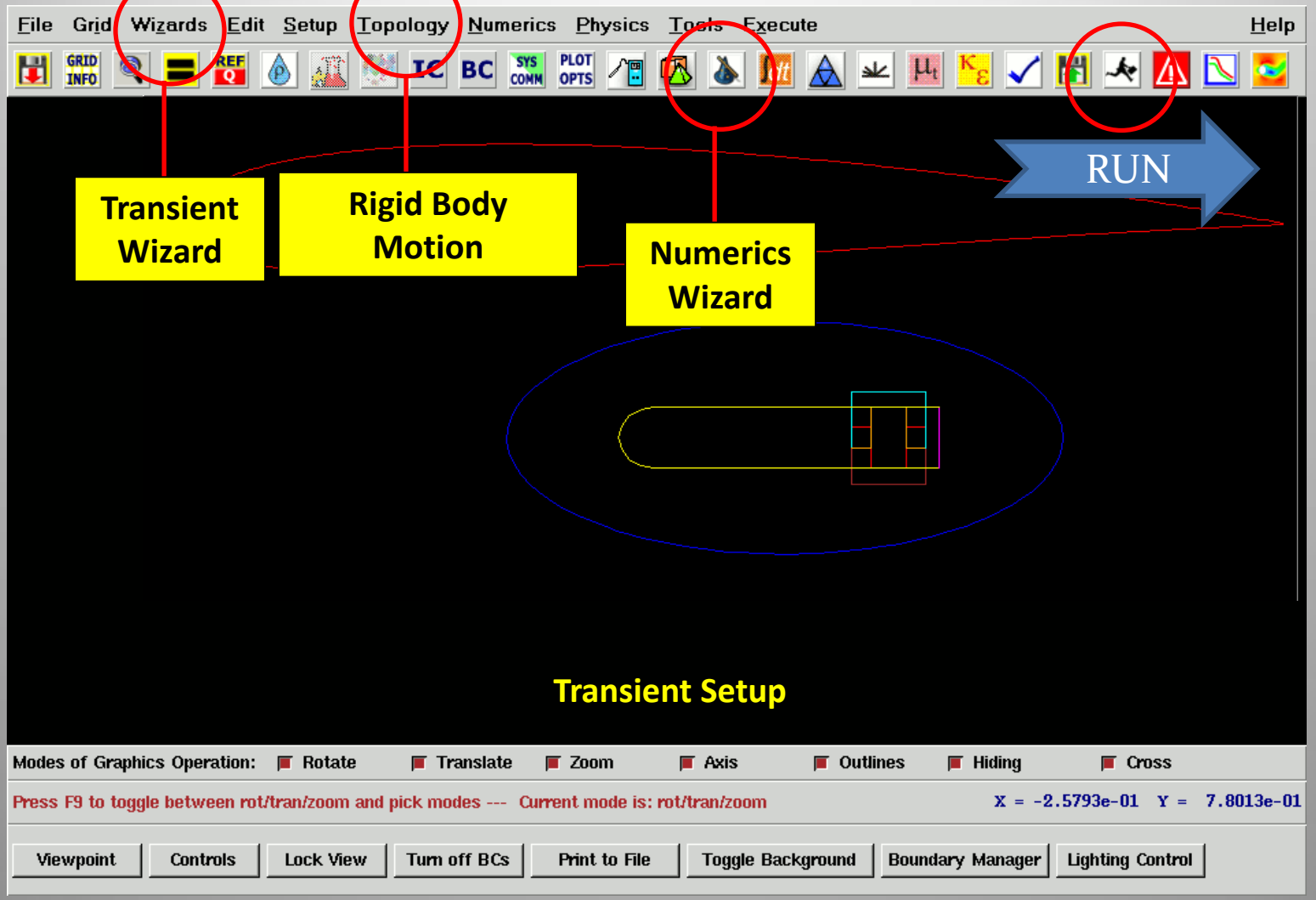
Case 1: Flow Specifications



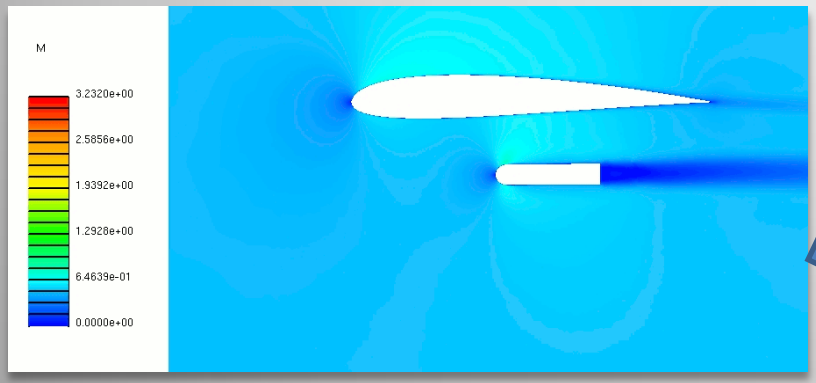
Case 1: Flow Specifications

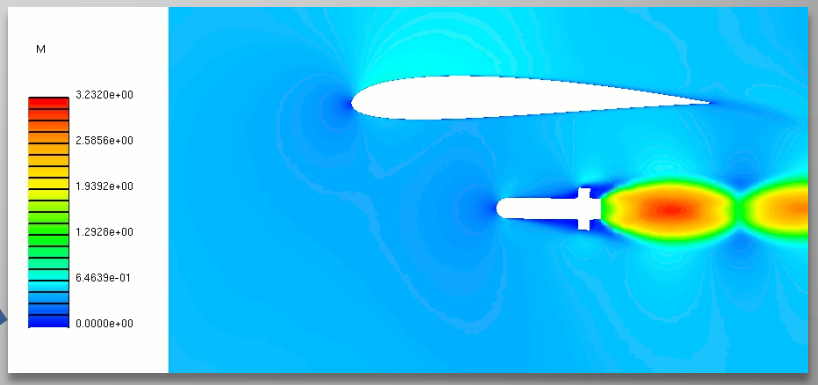


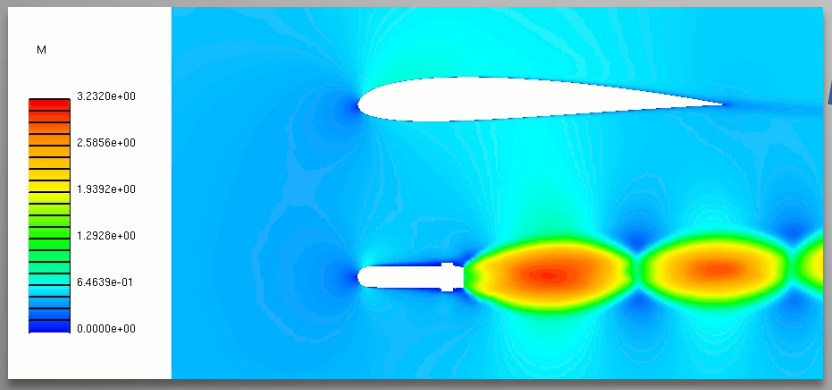
Case 1: Flow Specifications



Case 1: Store Separation with Fin Deployment

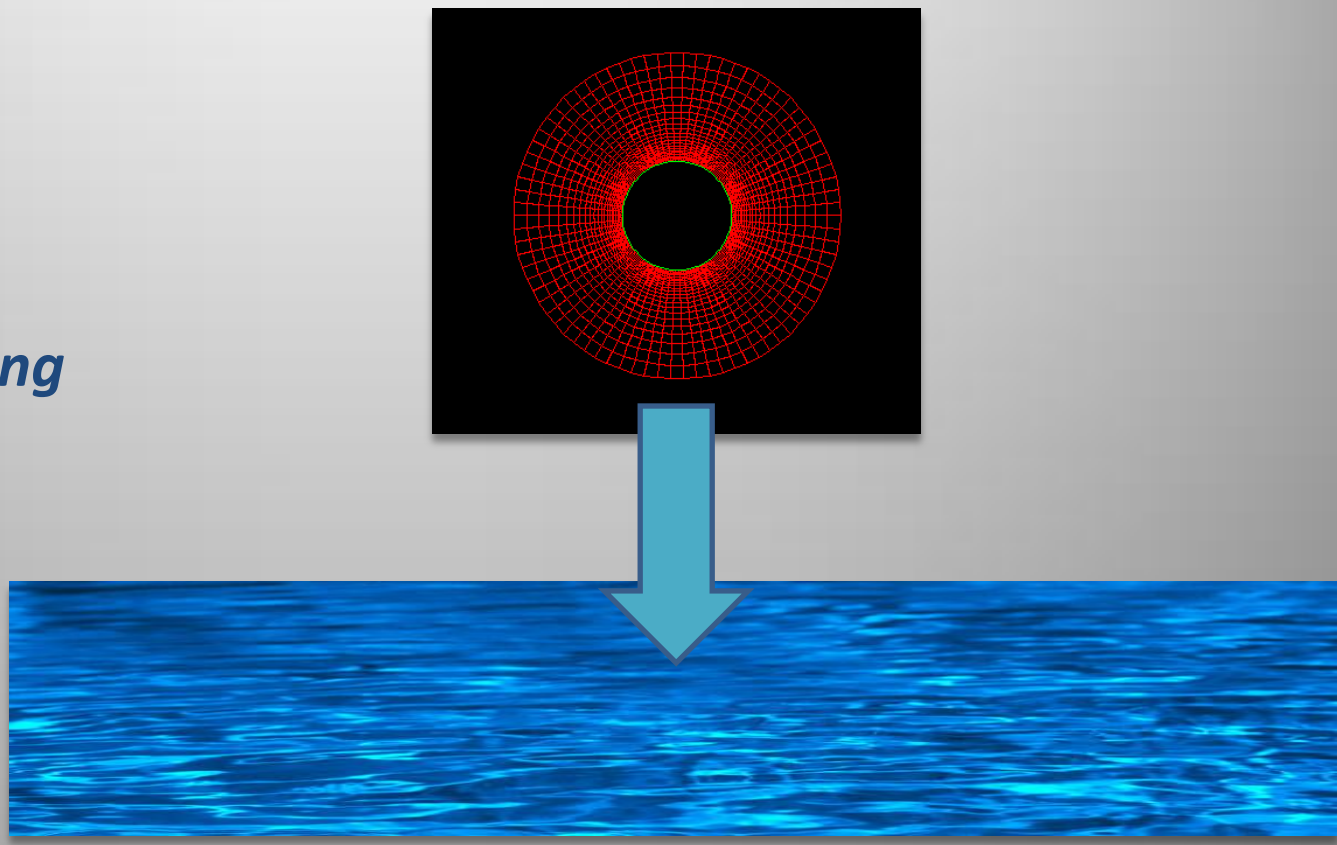






Case 2: 2D Ball Drop

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

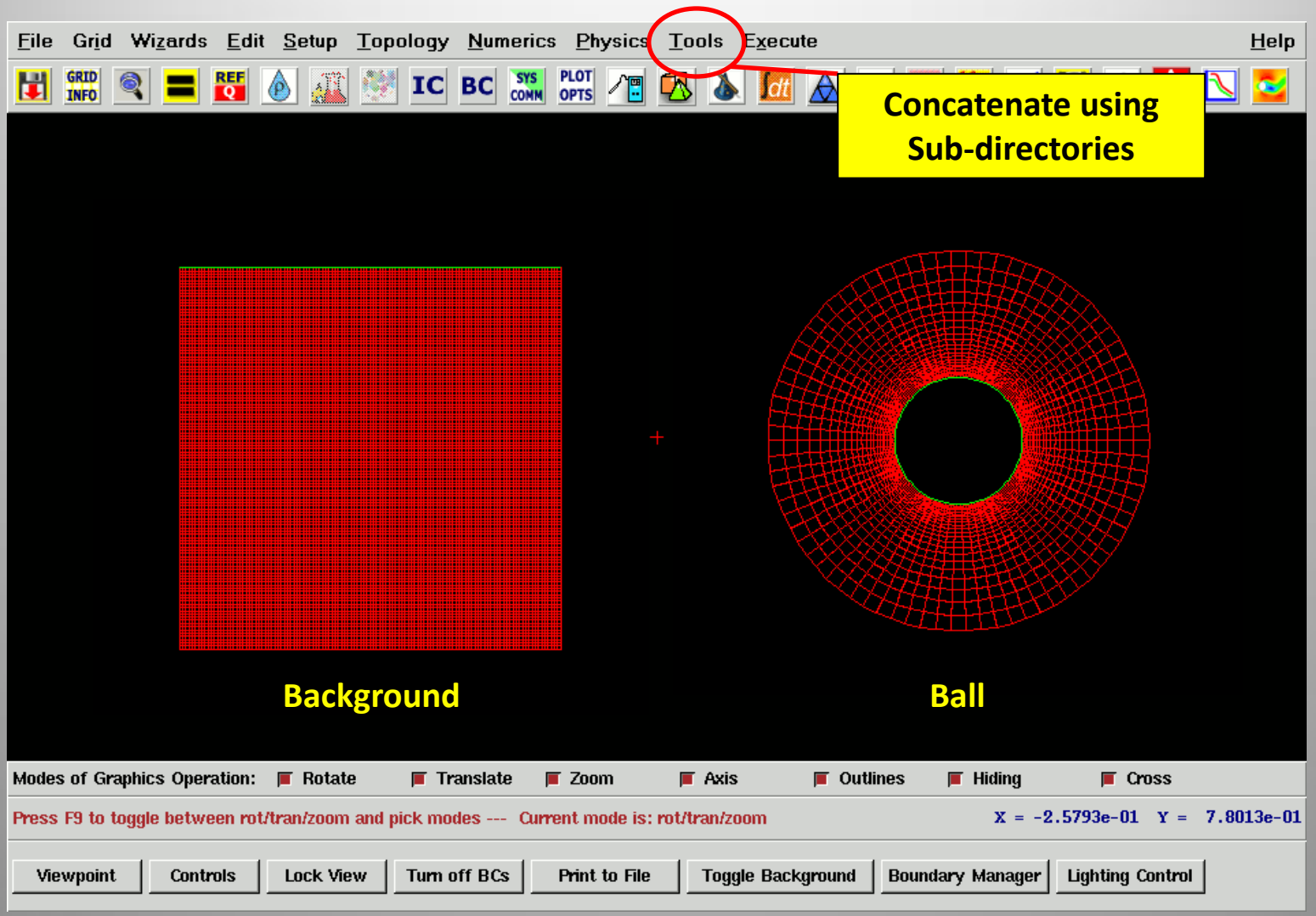


Case 2: Steps

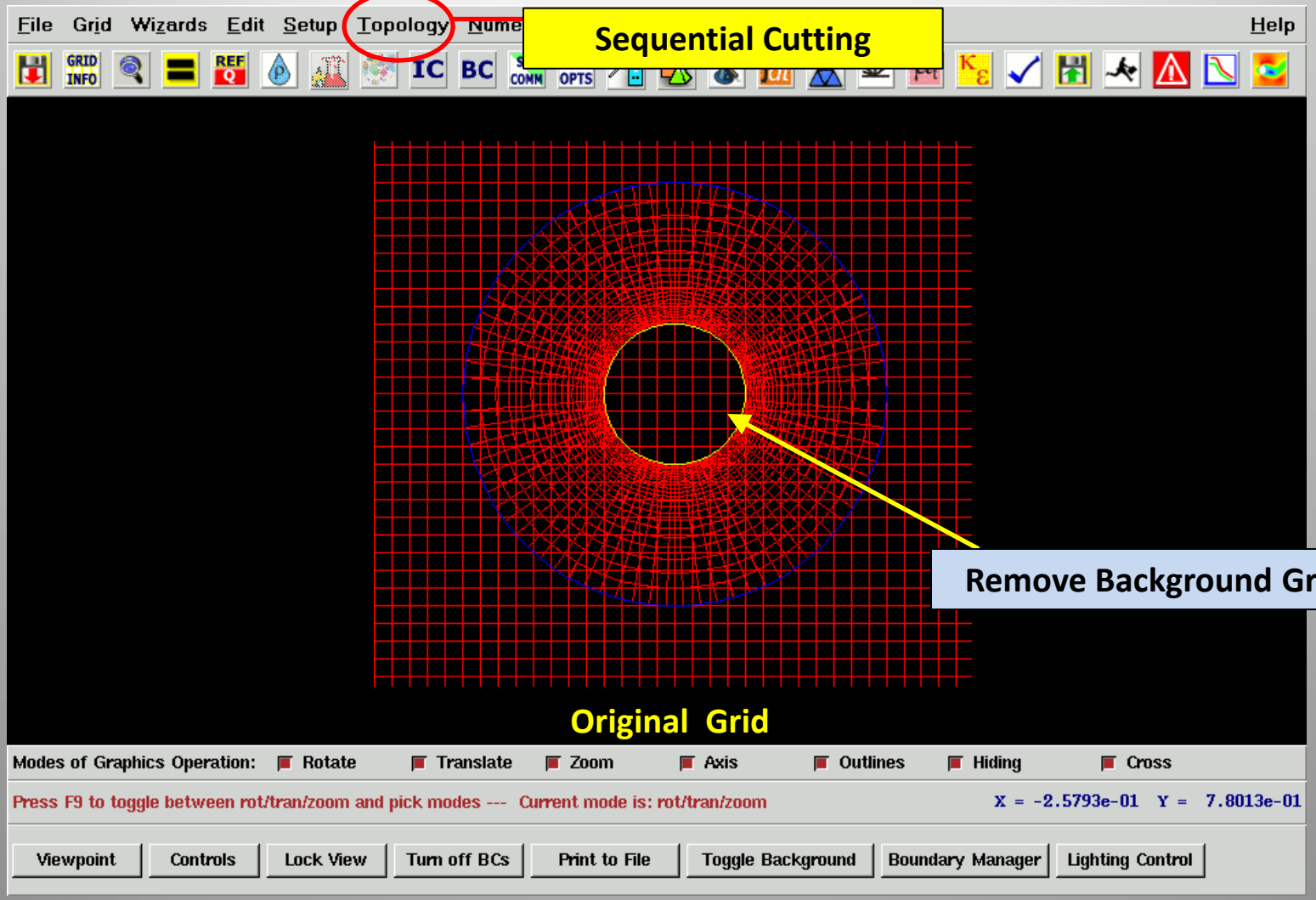
Ball Drop:

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

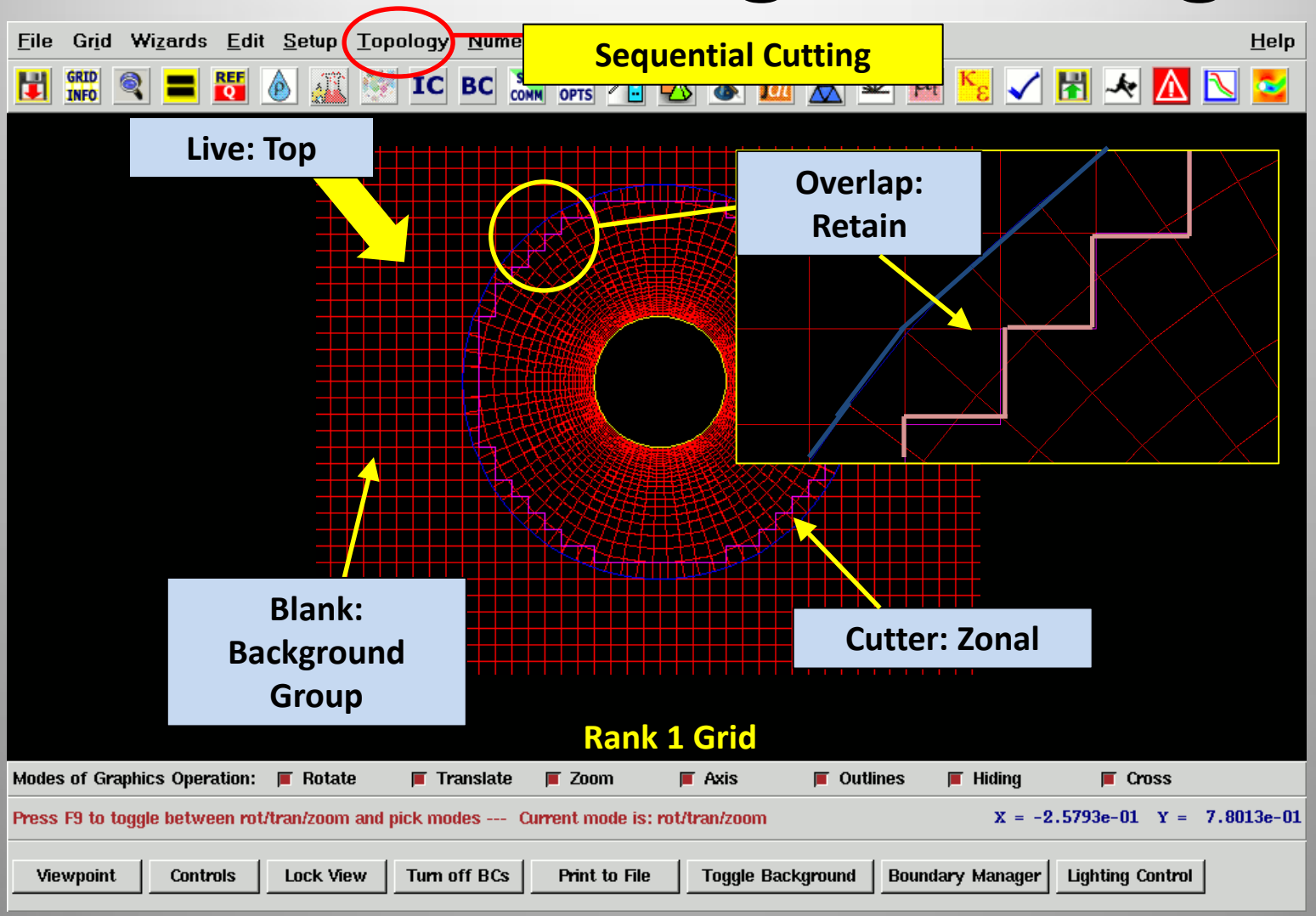
Case 2: Concatenate Grids



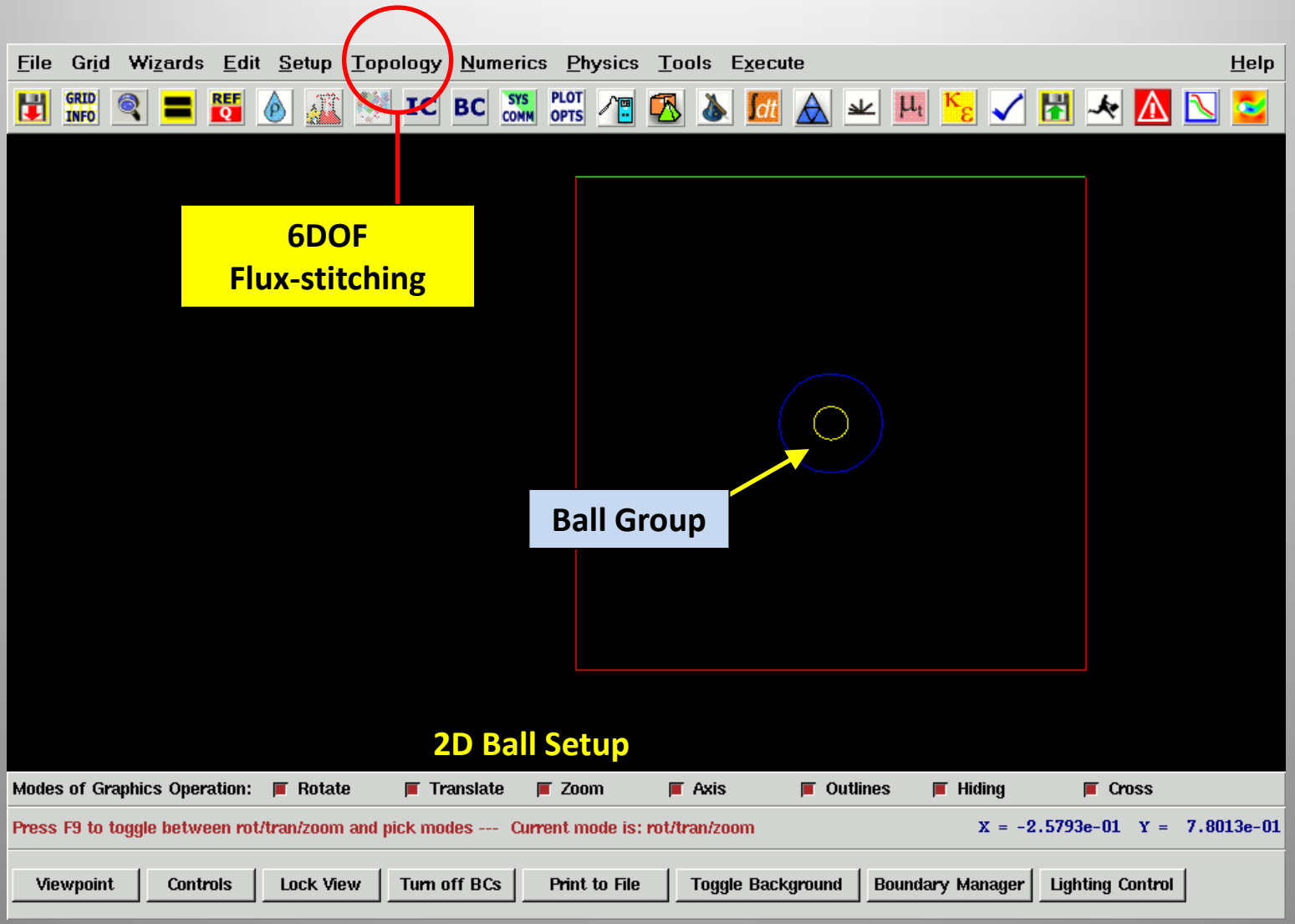
Case 2: Cutting/Blanking



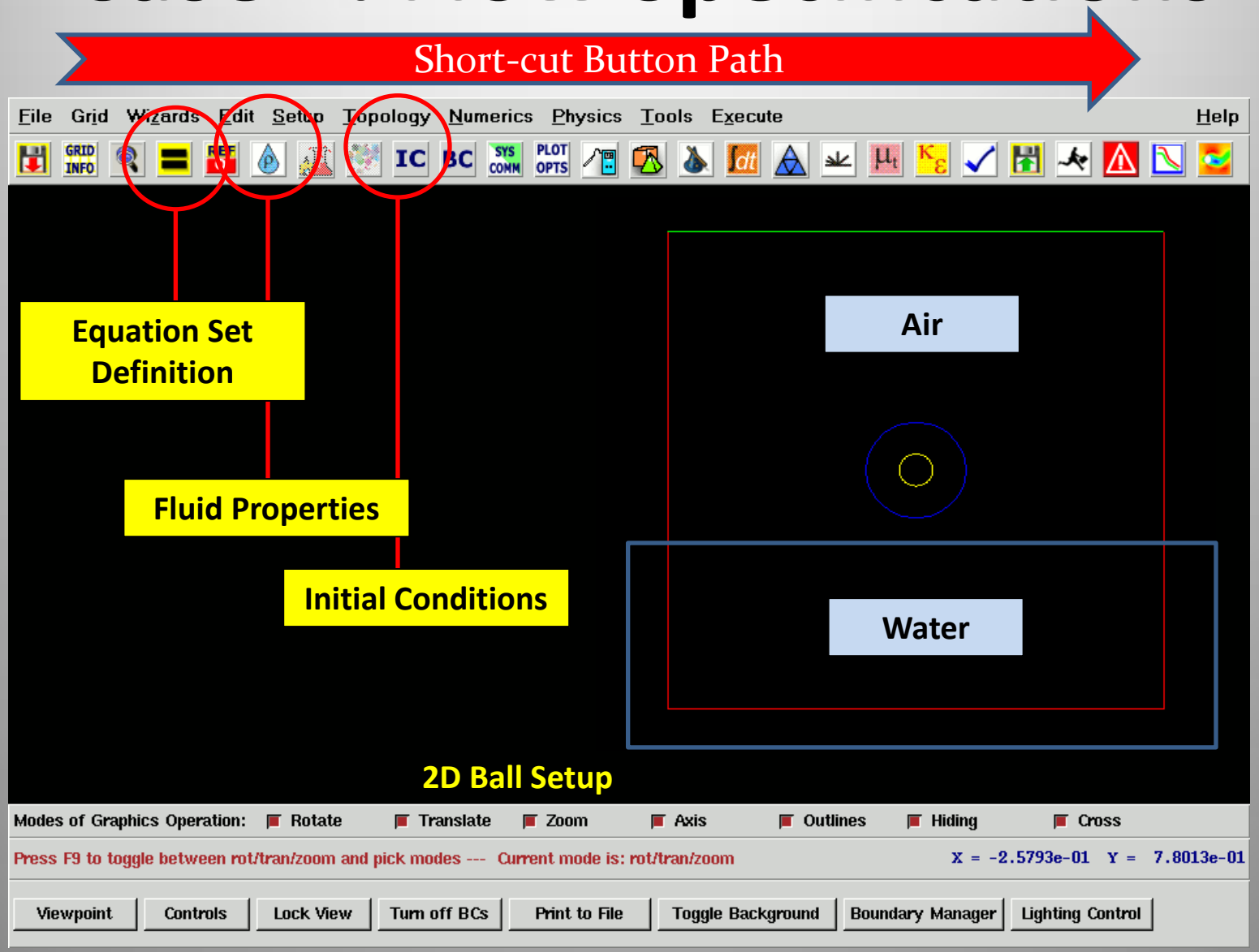
Case 2: Cutting/Blanking



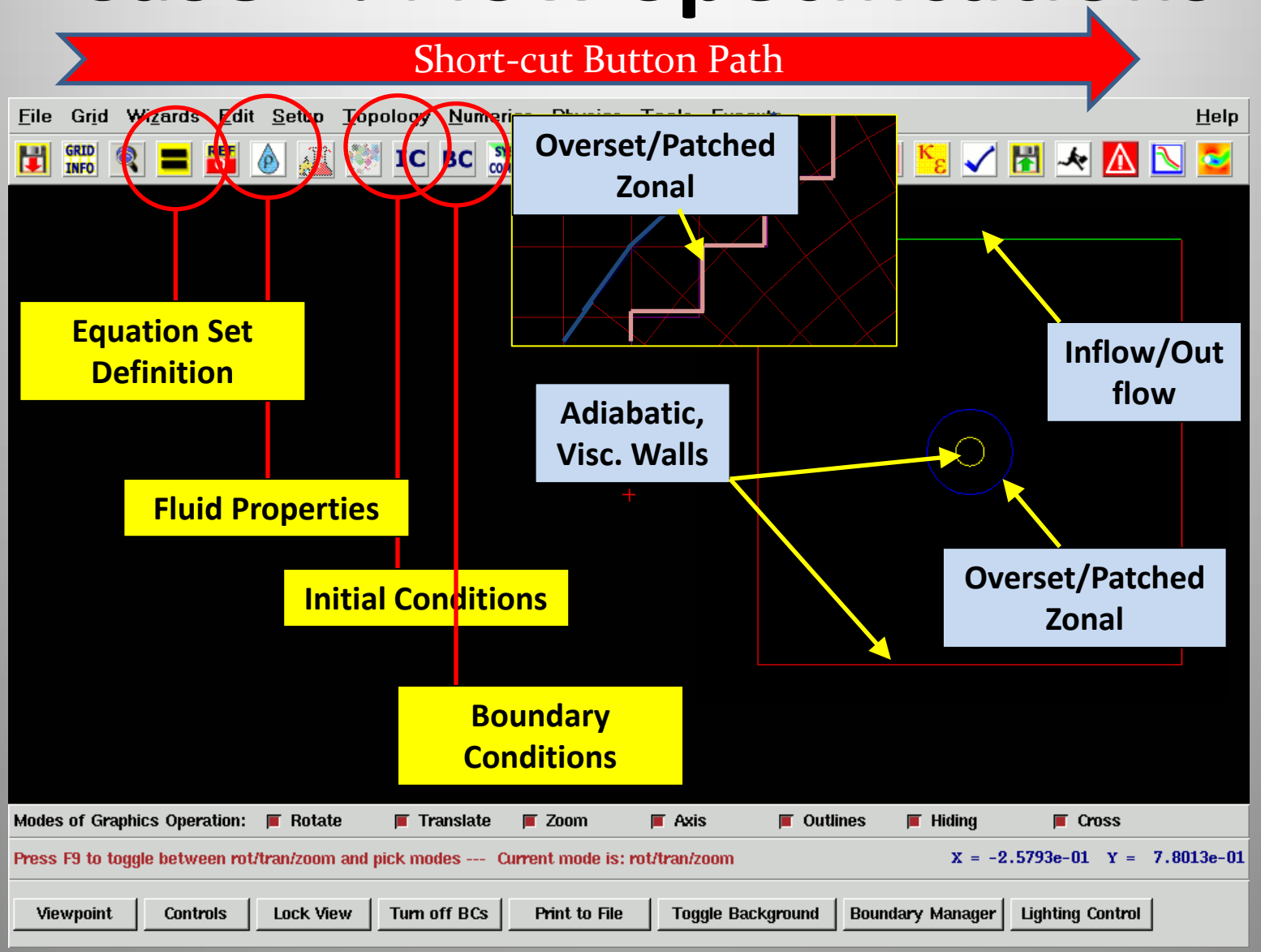
Case 2: Grid Motion



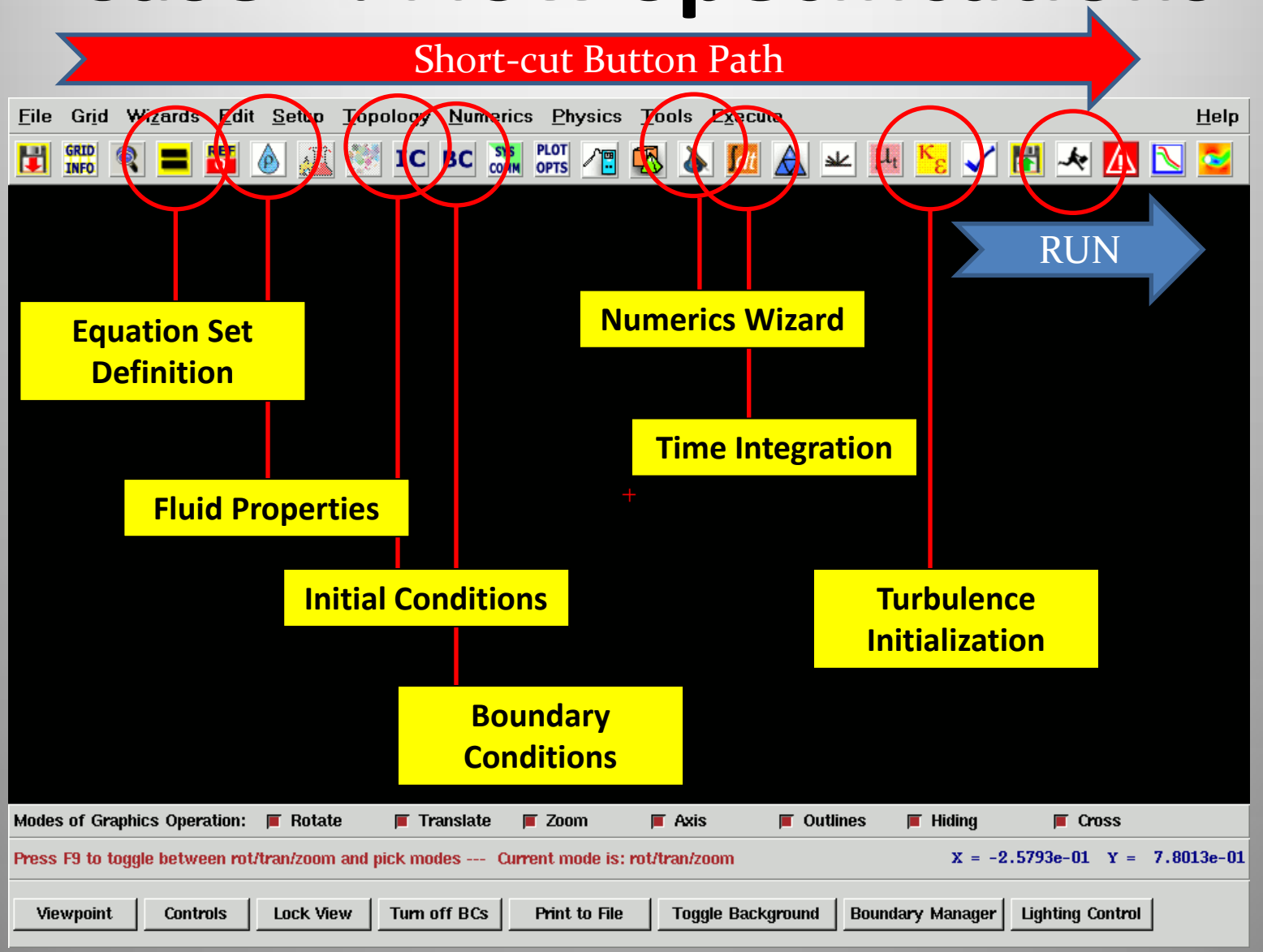
Case 2: Flow Specifications



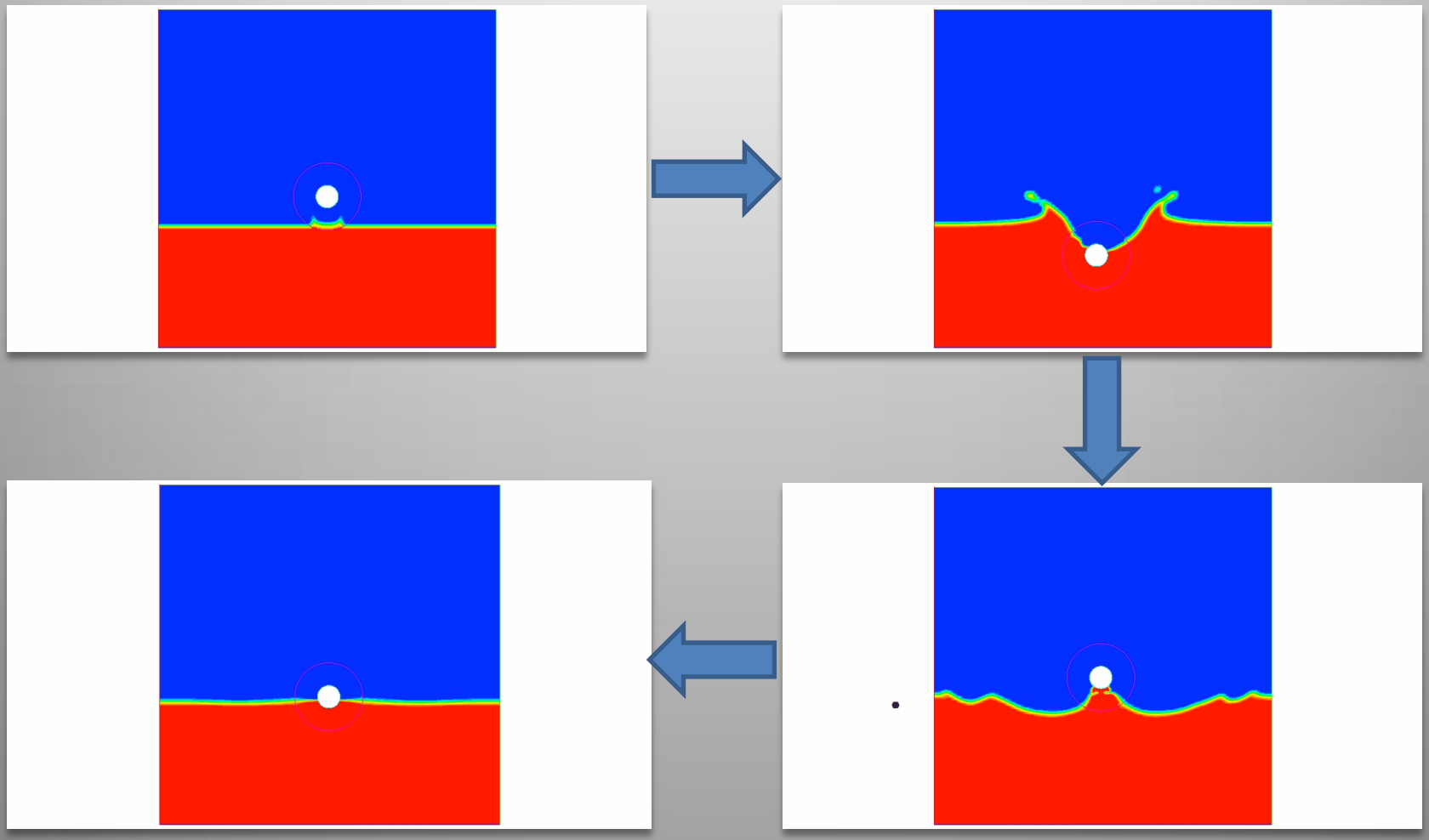
Case 2: Flow Specifications

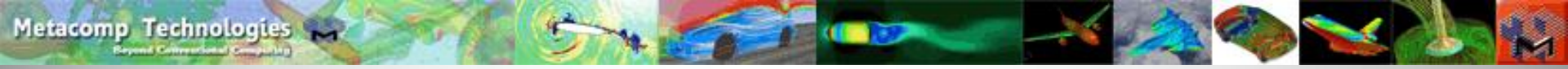


Case 2: Flow Specifications



Case 2: 2D Ball Drop

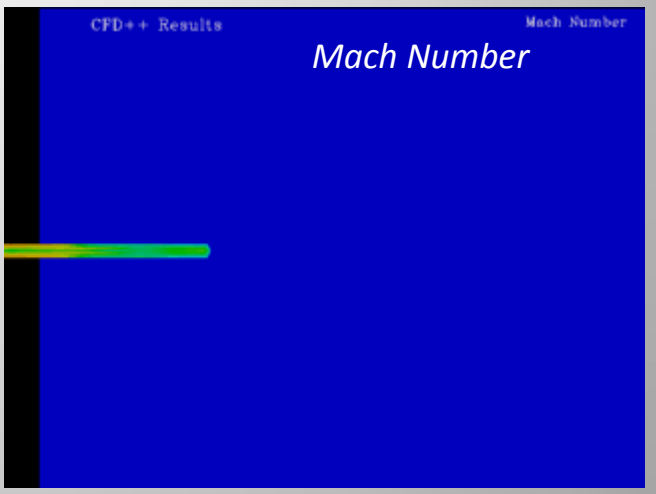


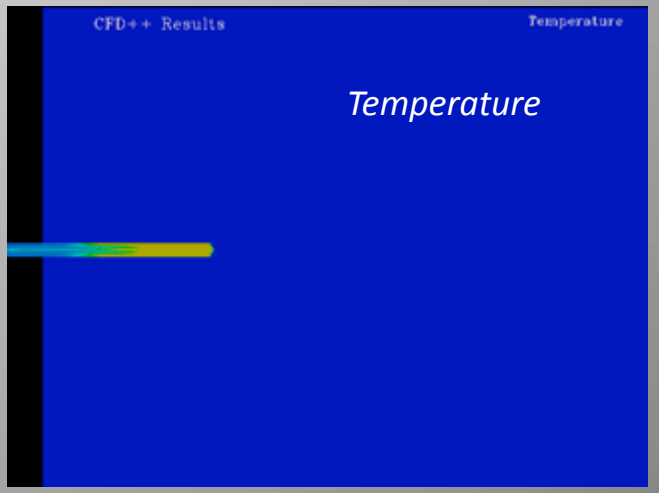


More Examples

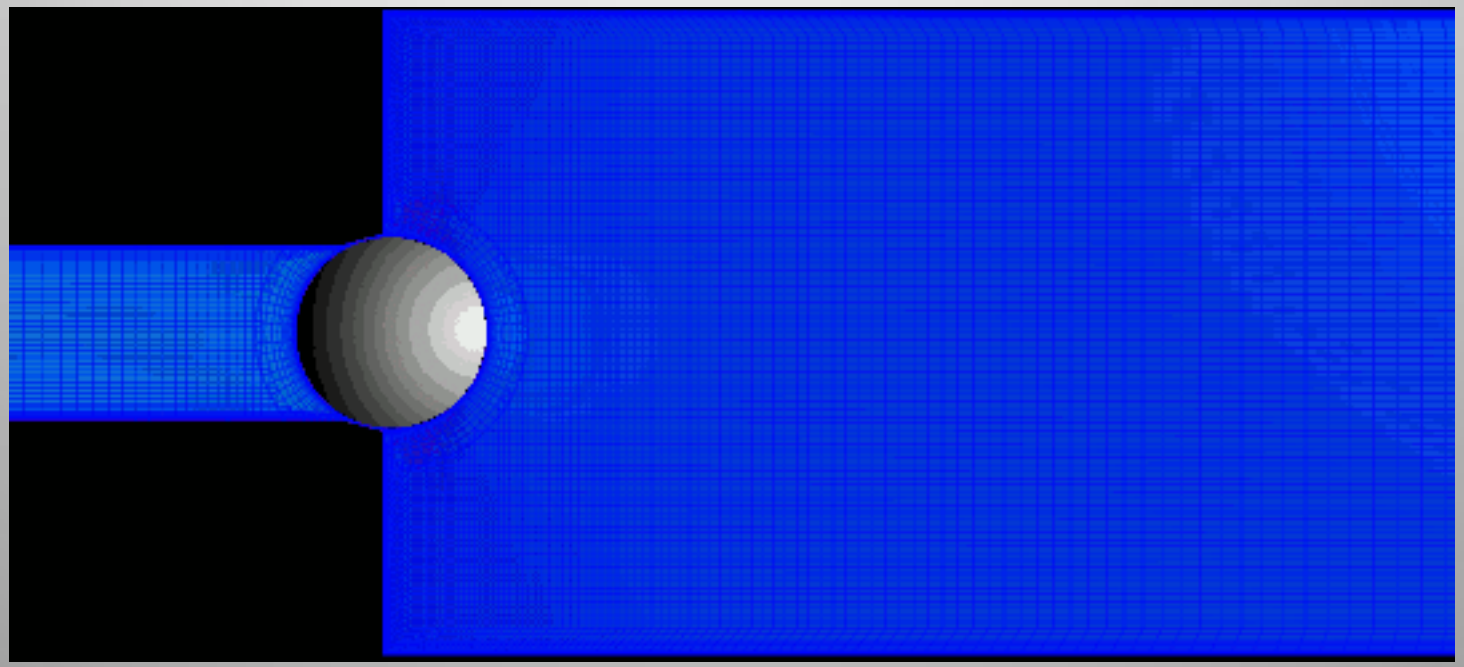
Bullet Leaving a Gun Barrel

- *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*





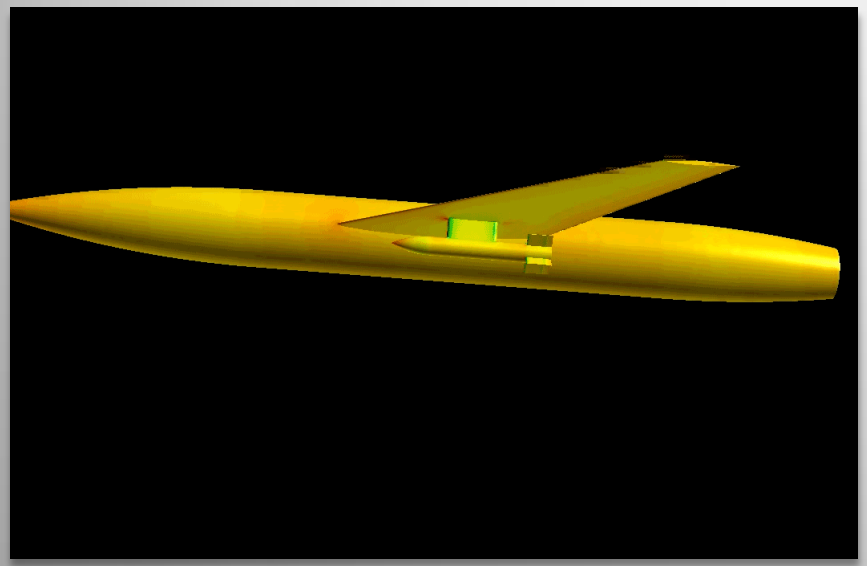
Mesh Movement

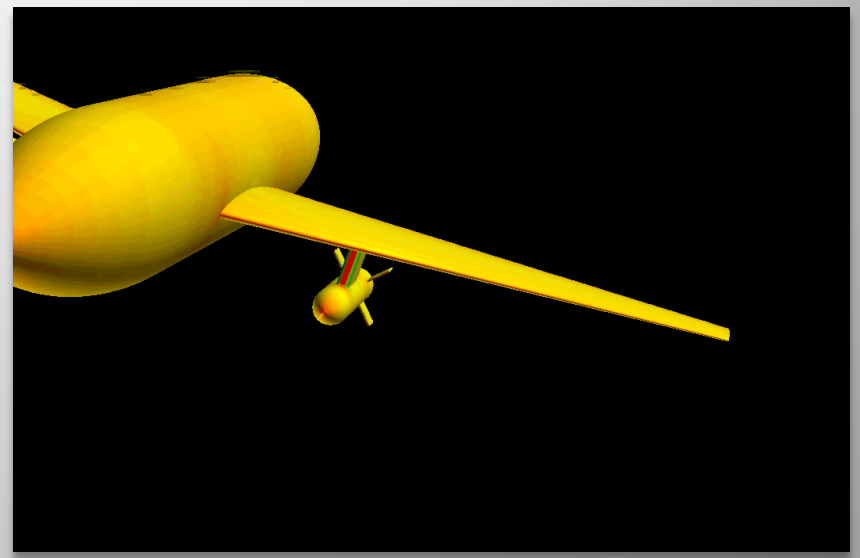


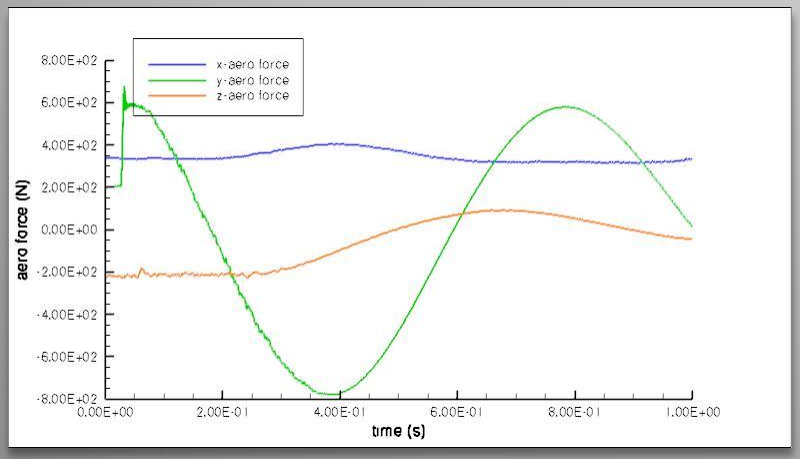
Ball-valve example: mesh cutting with zonal connections

Flux stitching guarantees perfect conservation at zonal boundaries!

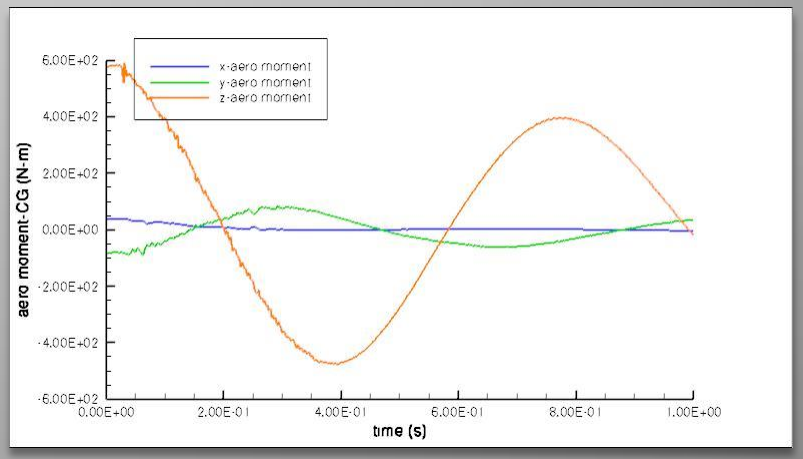
Store Separation using CFD++





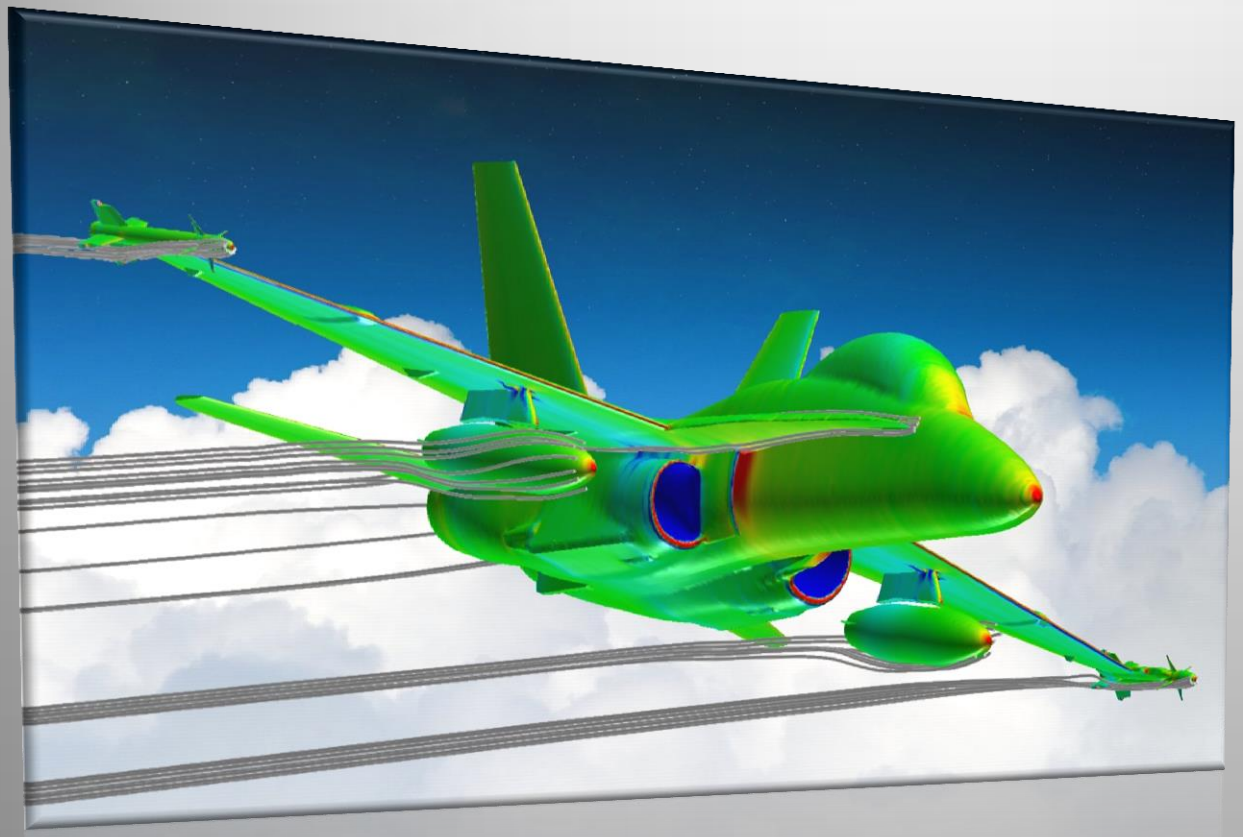


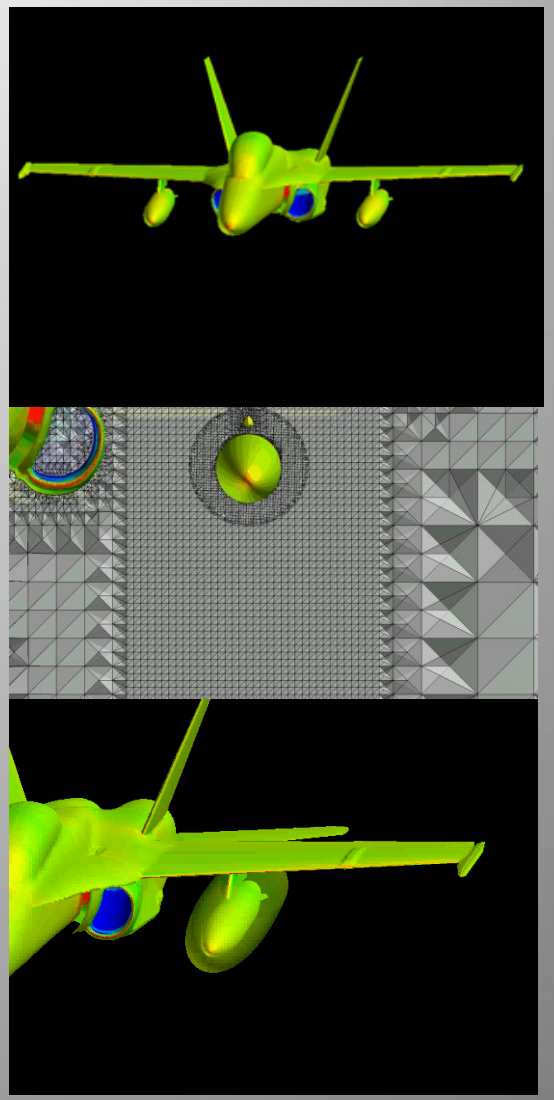
Aerodynamic forces on store



Aerodynamic moments on store

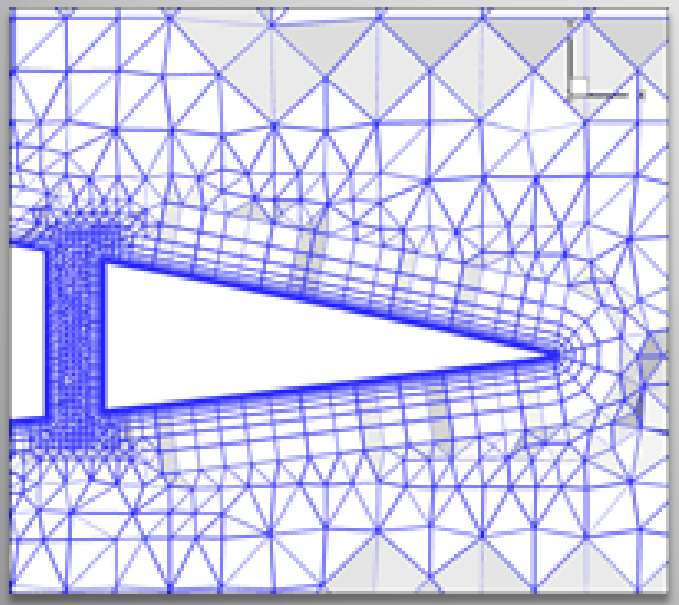
F18 Fuel Tank Separation



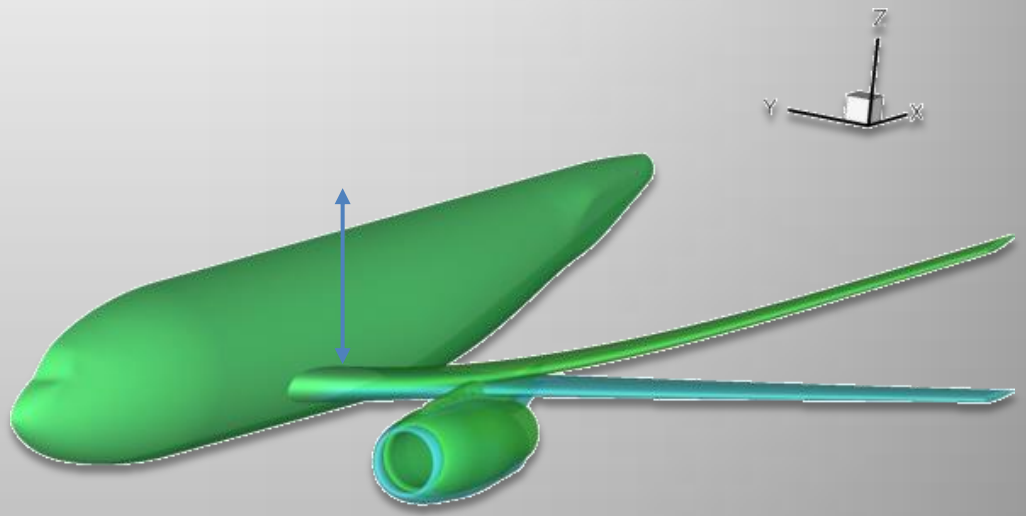


- Localized cutting, zonal connection, force integration and localized 6DOF

Grid Morphing

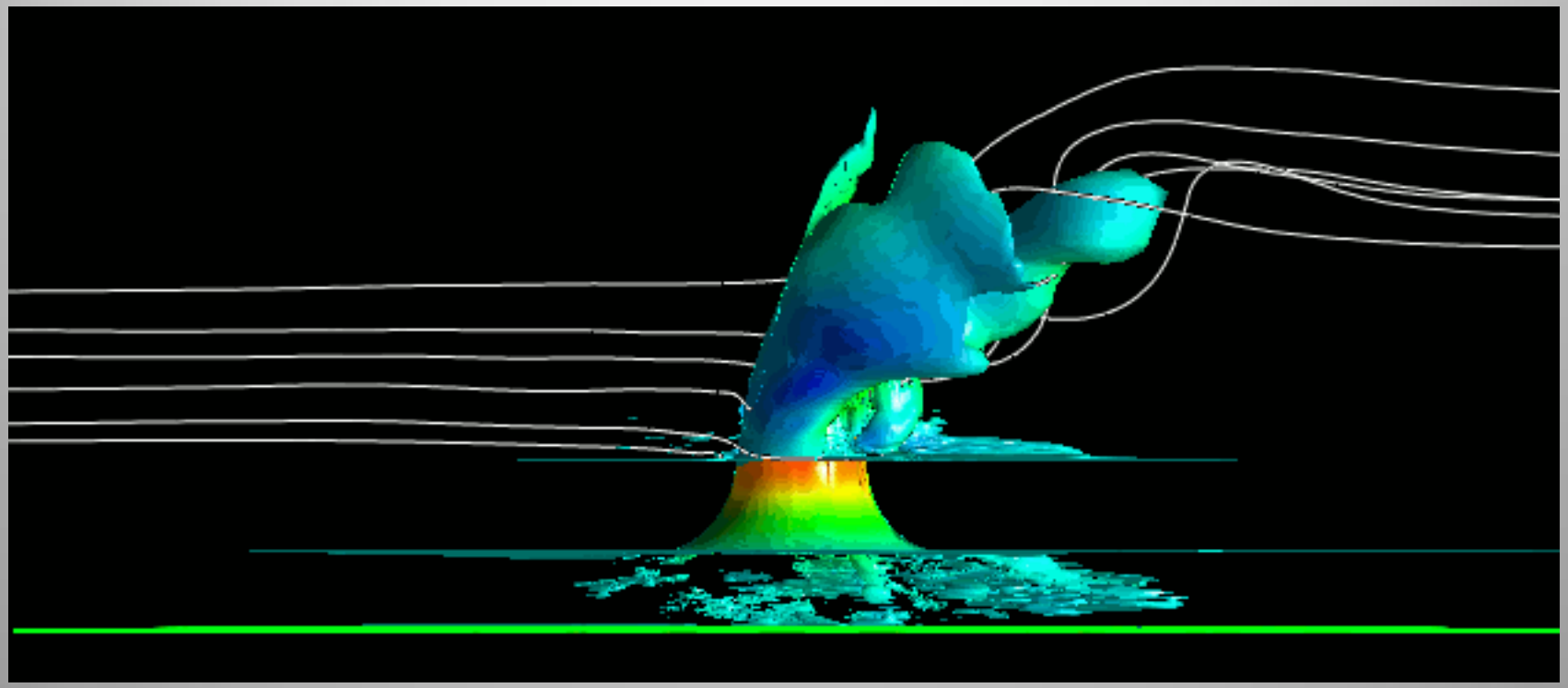


Generic flap-deflection
Controlled by local radial basis function interpolation



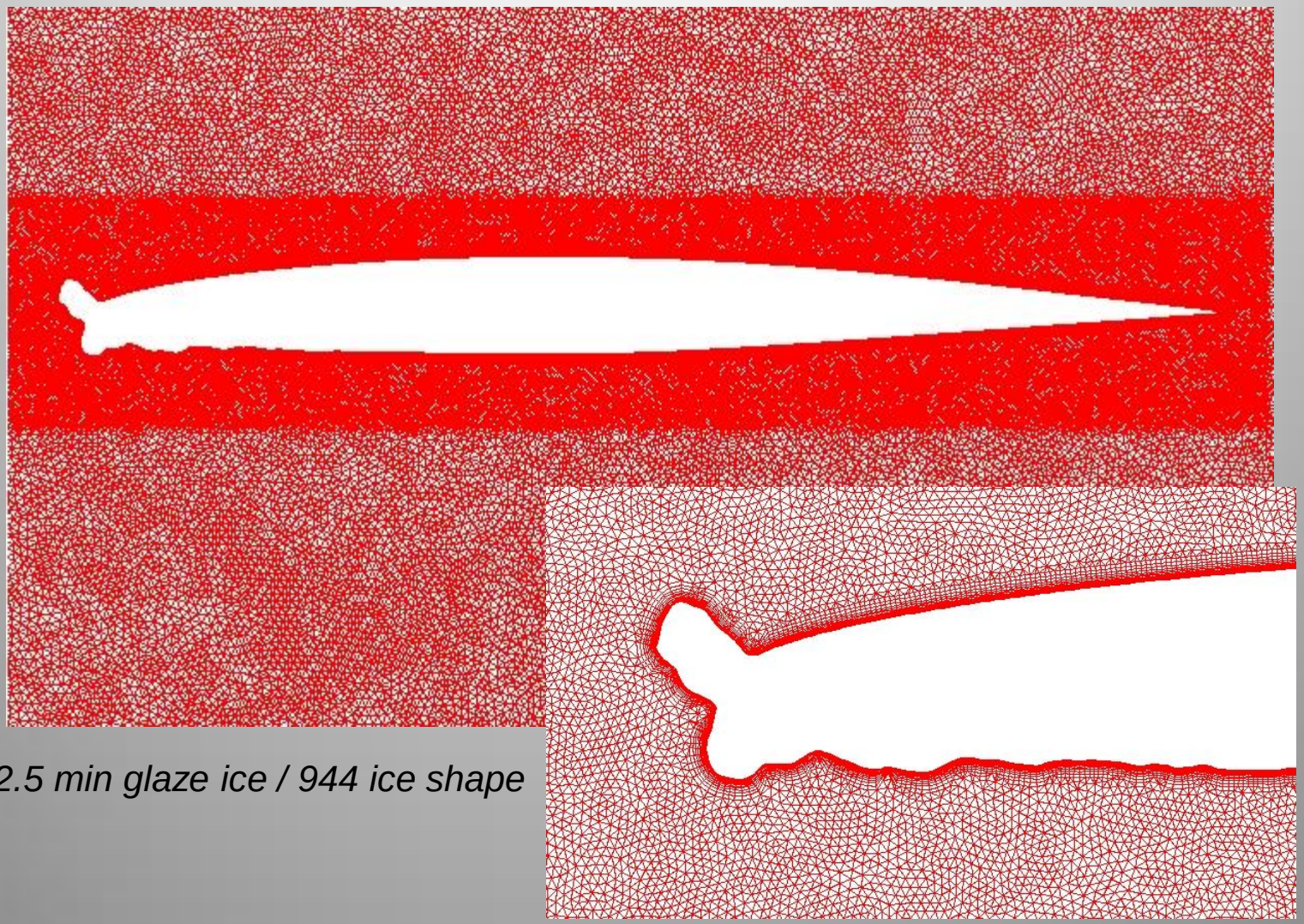
Drag Prediction Workshop Mesh
33.8 million cells
13.8 million nodes
Localized deformation

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