Fully Integrated Overset Mesh Treatment in CFD++

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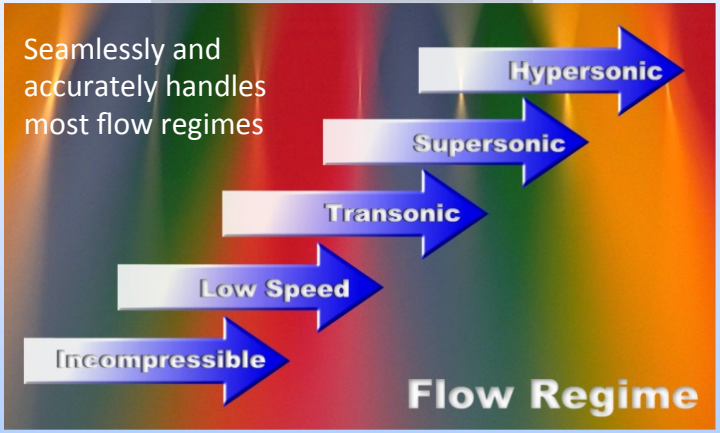
Metacomp Technologies

CFD++ Design Principles

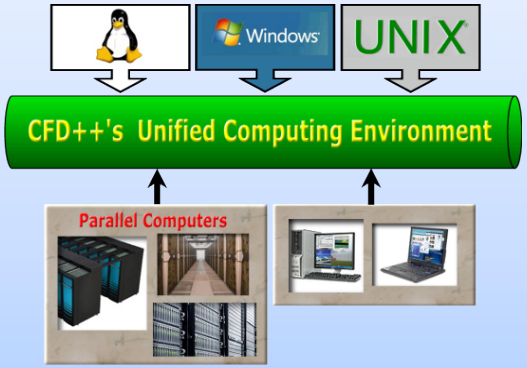
Unified Physics



Unified Grid

- *Ability to handle all cell types*
  Hexahedral, Tetrahedral, Prism, Pyramid, Quadrilateral, Triangle, Line
- *Ability to handle all grids*
  Structured, Unstructured, Hybrid, Patched Non Aligned, Overset, Meshes with Gaps

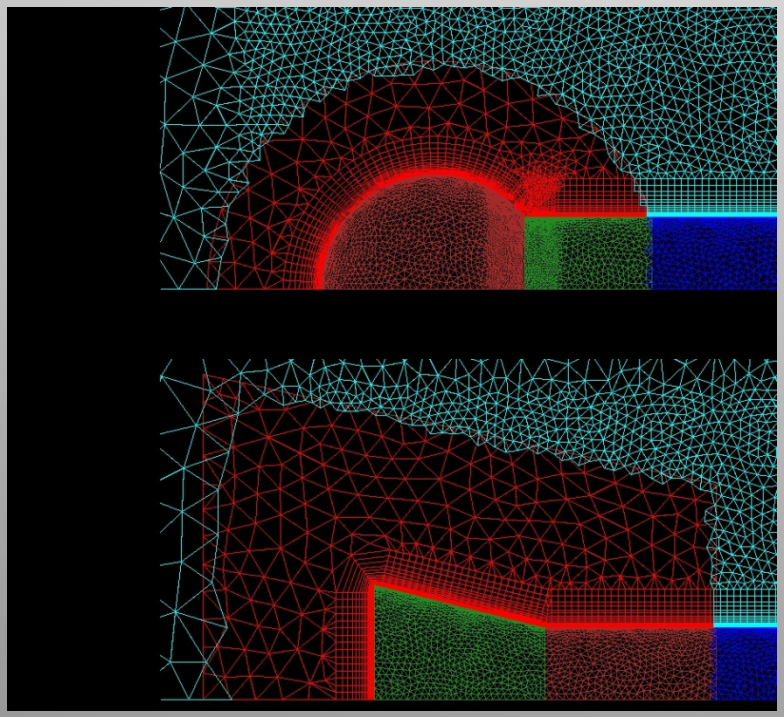
Unified Computing

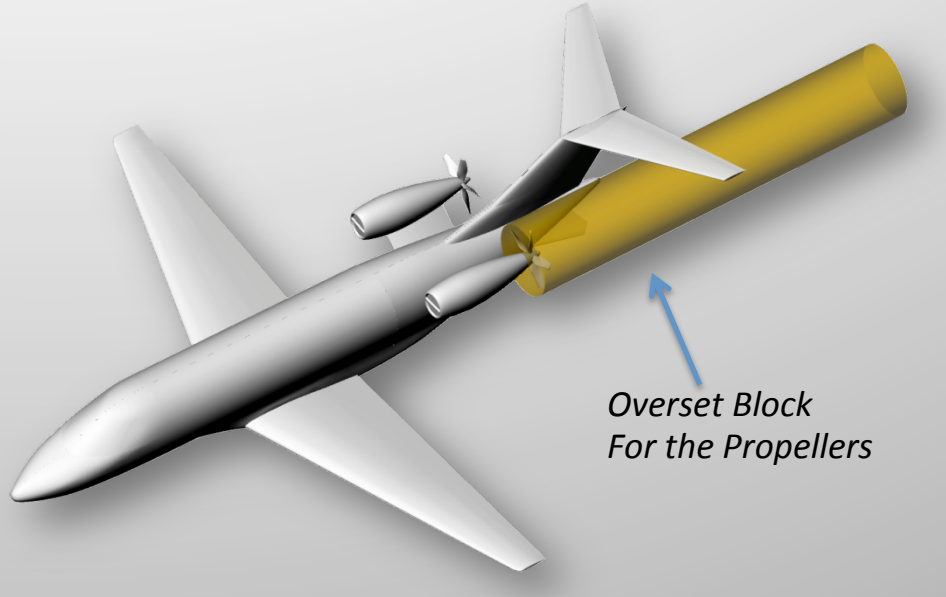


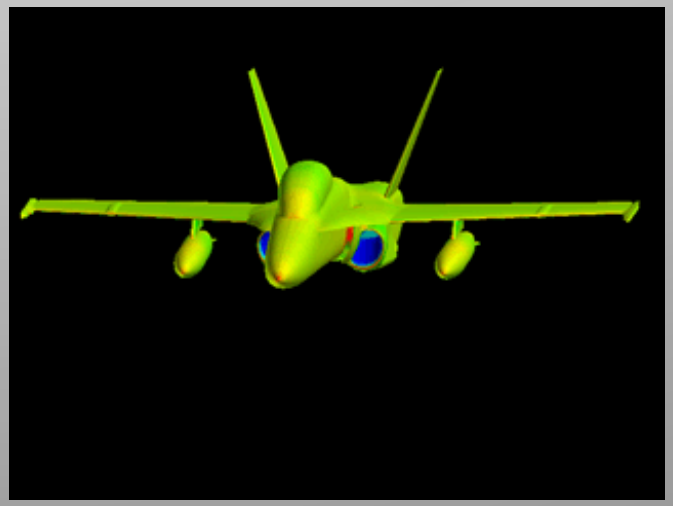
Binary files compatible across all platforms

The Need For Overset

- *Complex geometries*
- *Relative motion*
- *Design optimization*

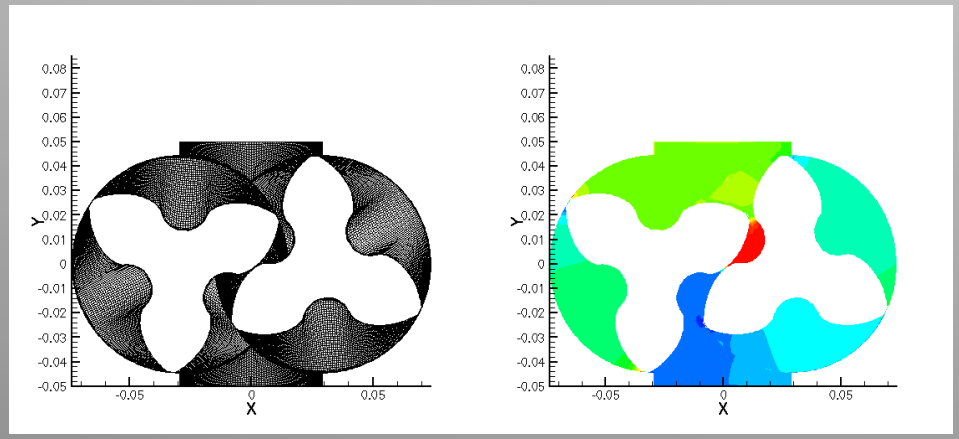


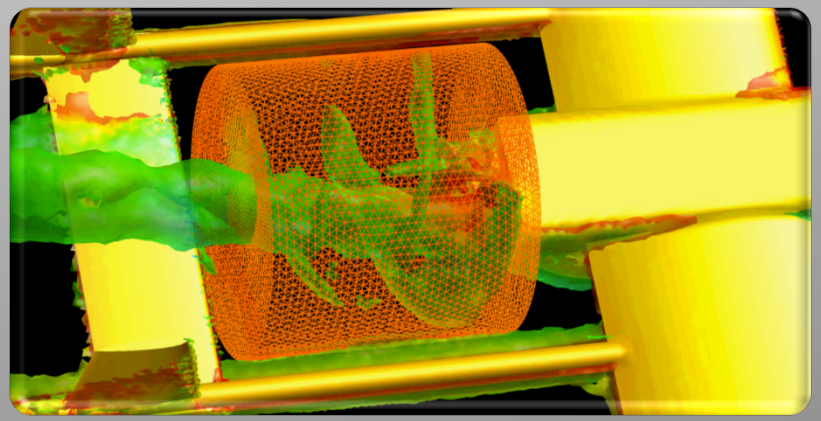


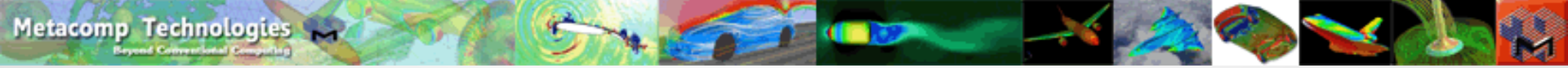


Metacomp's Overset Philosophy

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







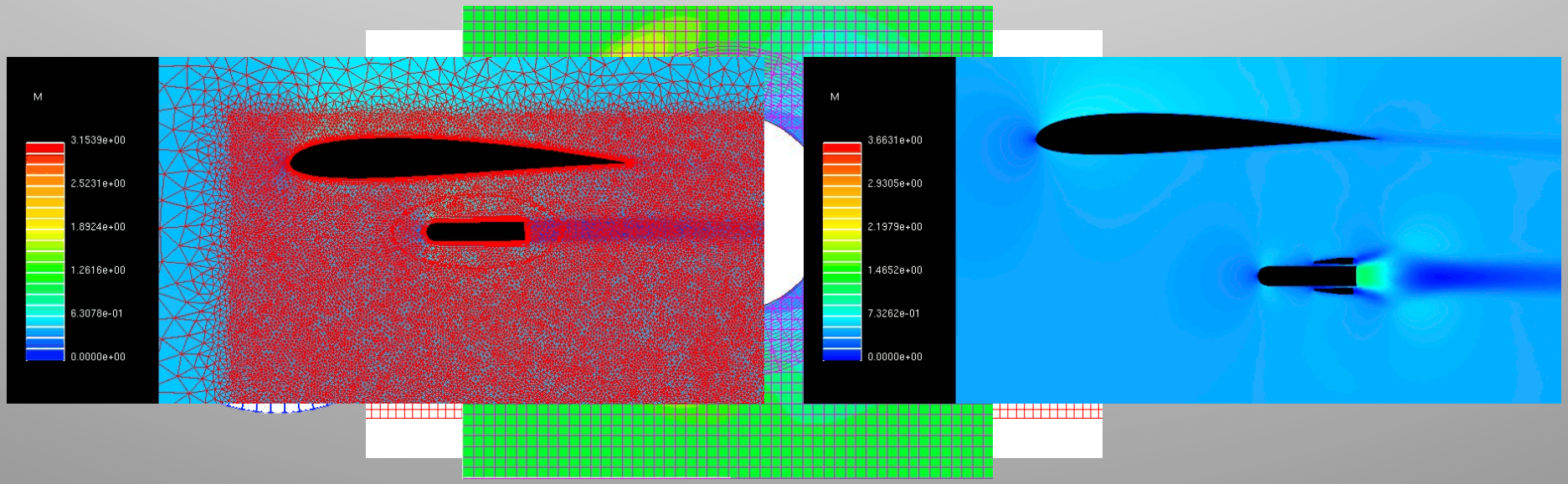
CFD++ Key Attributes

- ✓ ***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***

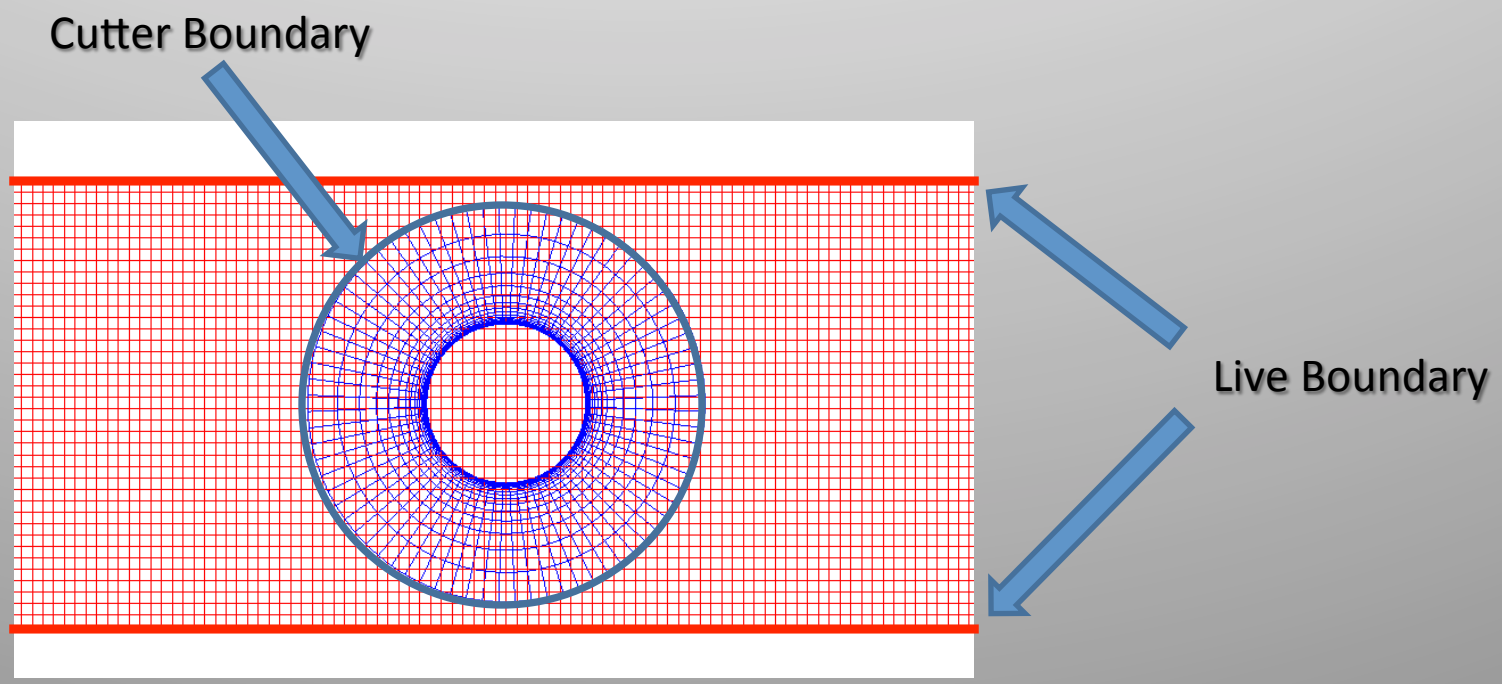
Overset Process in CFD++

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



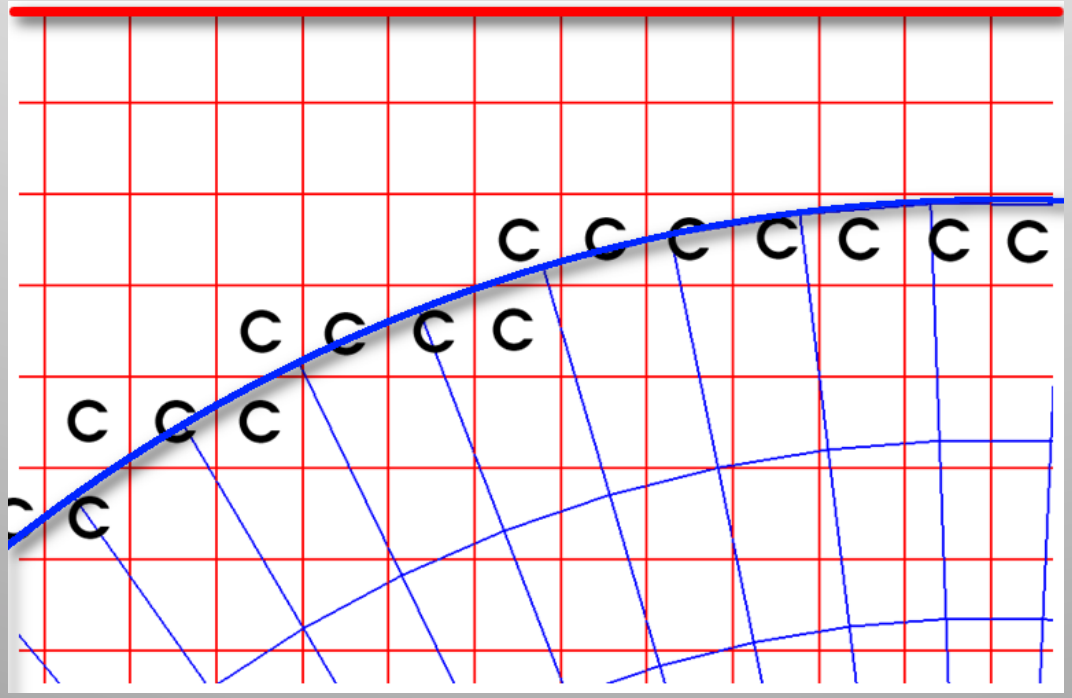
Overset Blanking Procedure

- ✓ *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"*



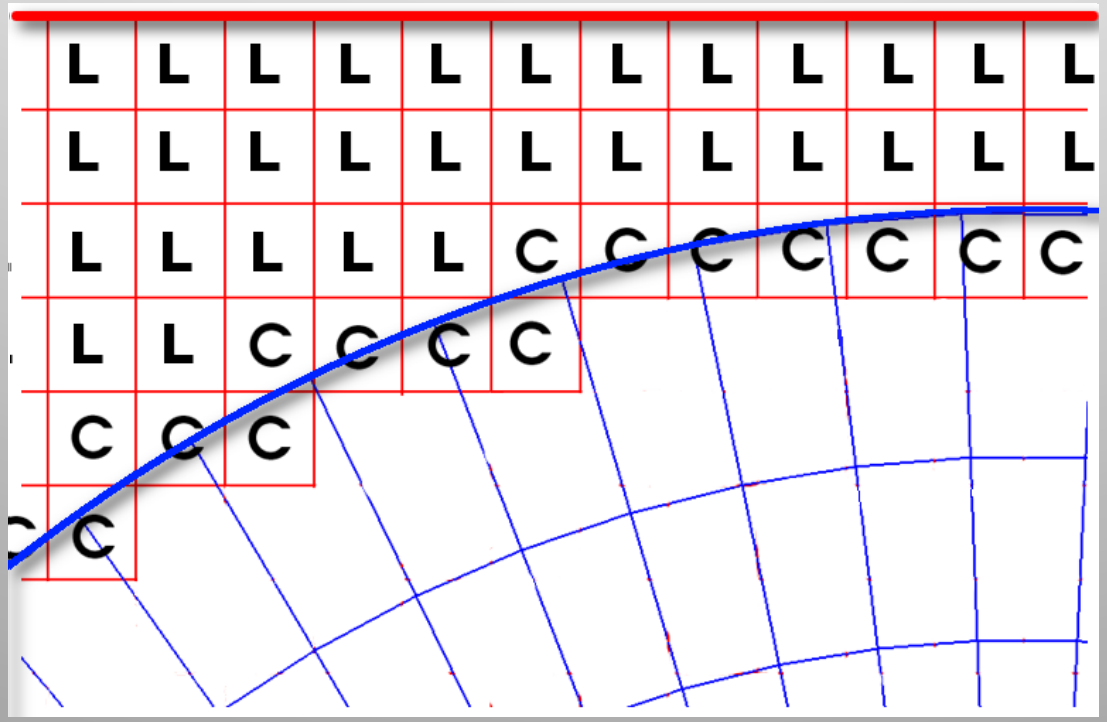
Overset Blanking Procedure

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



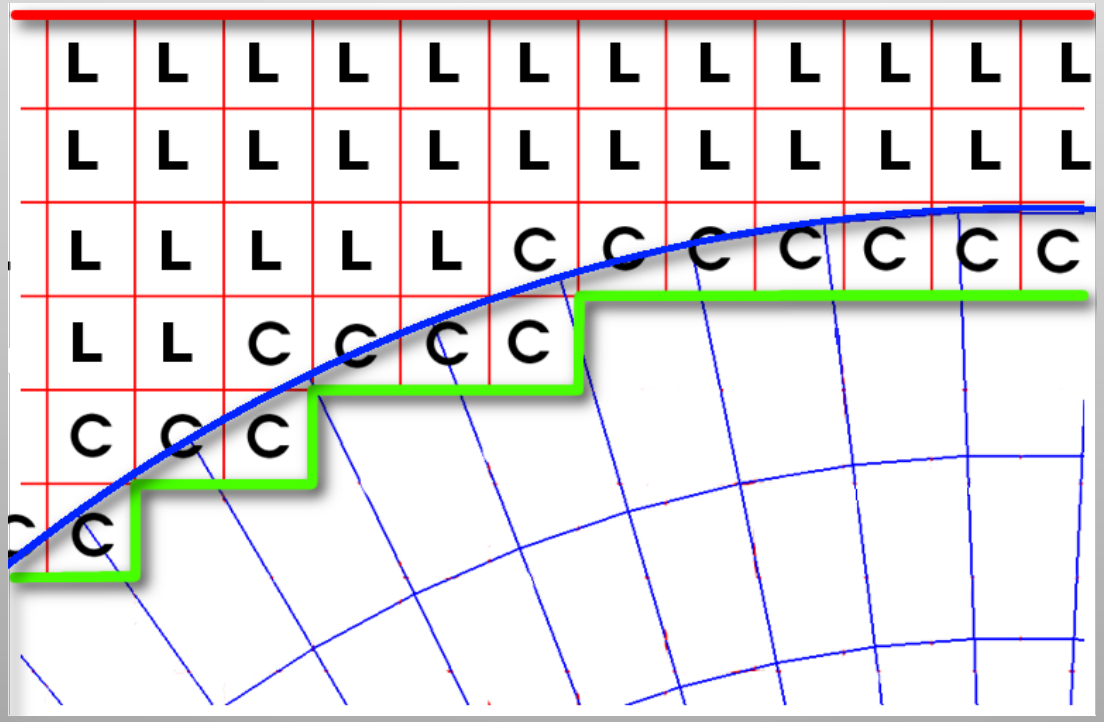
Overset Blanking Procedure

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

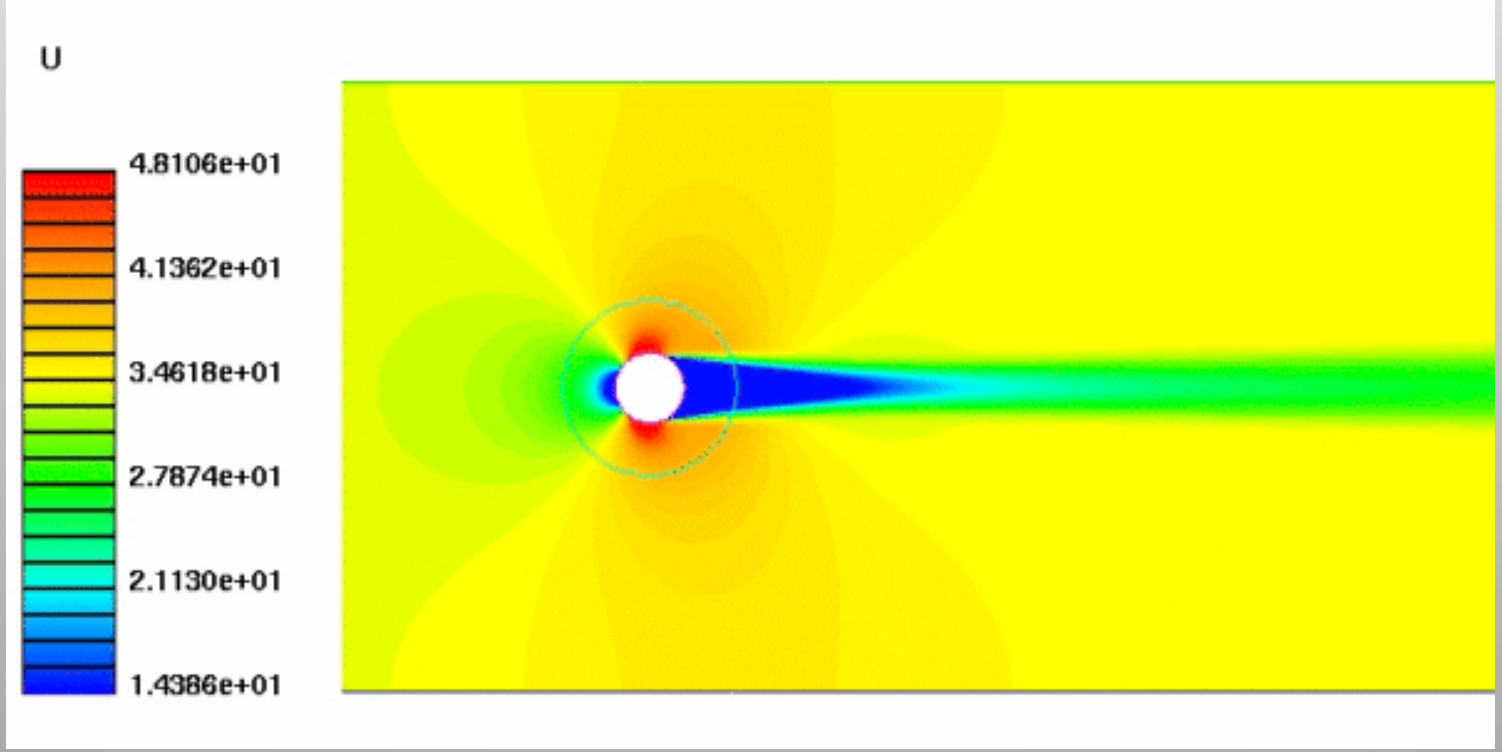


Overset Blanking Procedure

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



Moving Cylinder Training Example



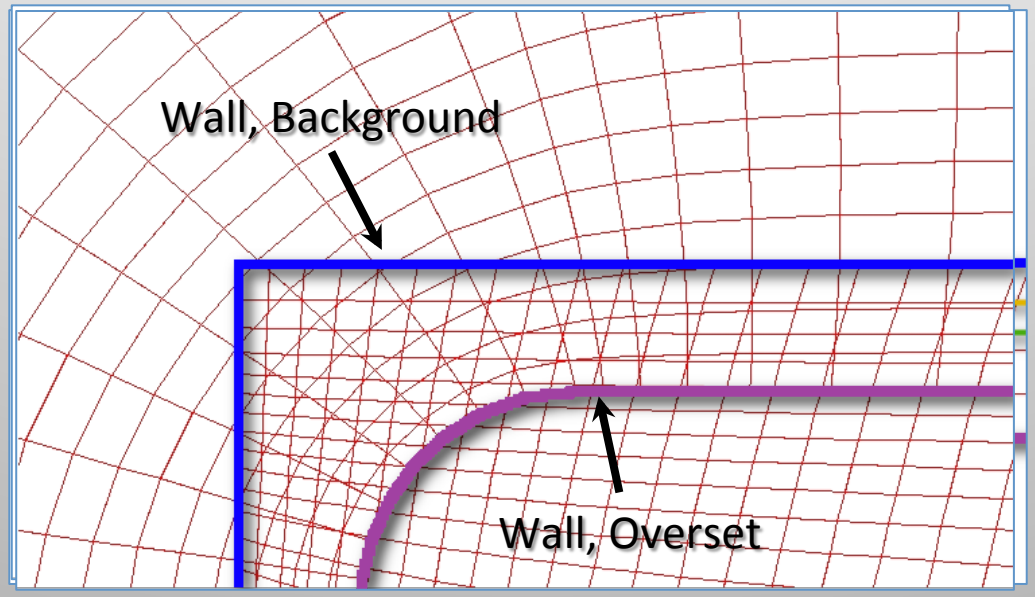
Sequential Cutting

- ✓ *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

Original Grid

Bank 1



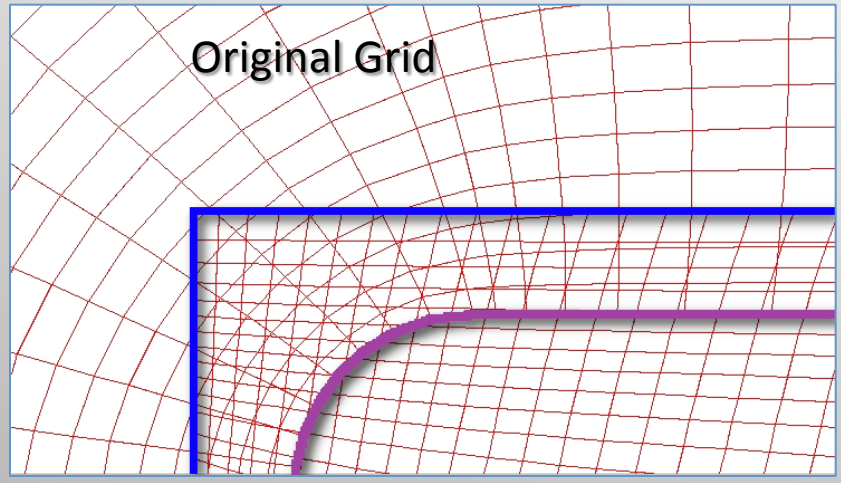
Boundary Cut, Do Not Retain Cells

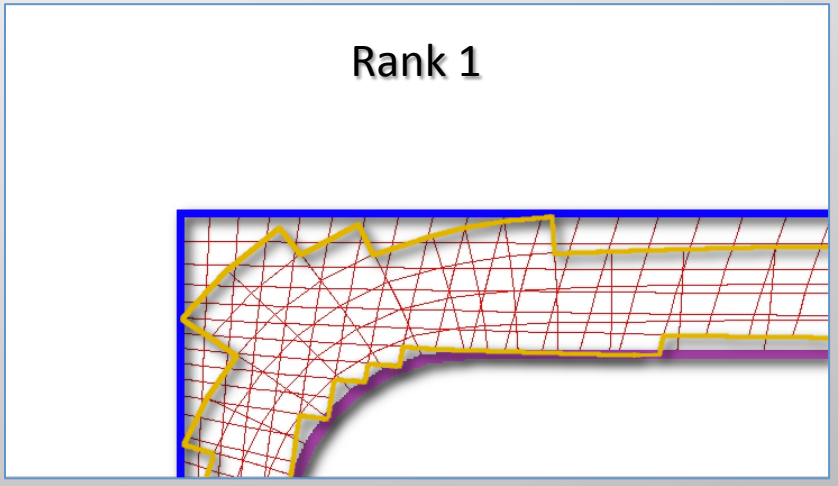
Wall Cut, Do Not Retain Cells

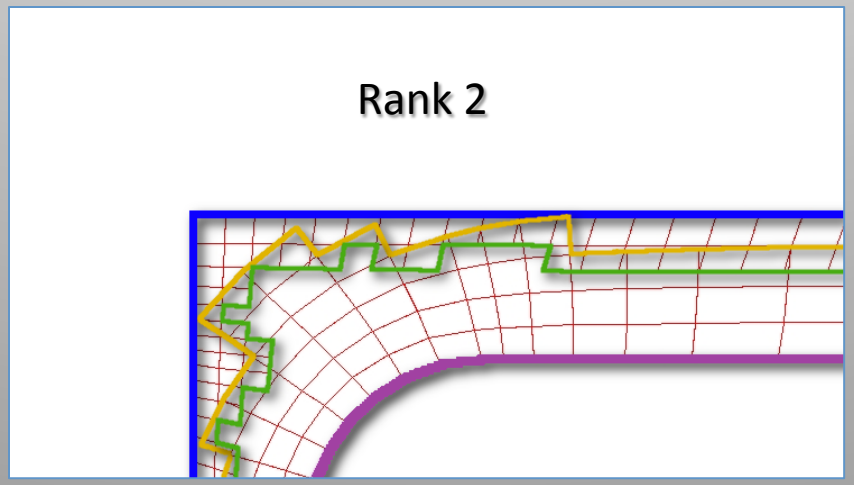
Bank 2

Create, Do Not Retain Cells

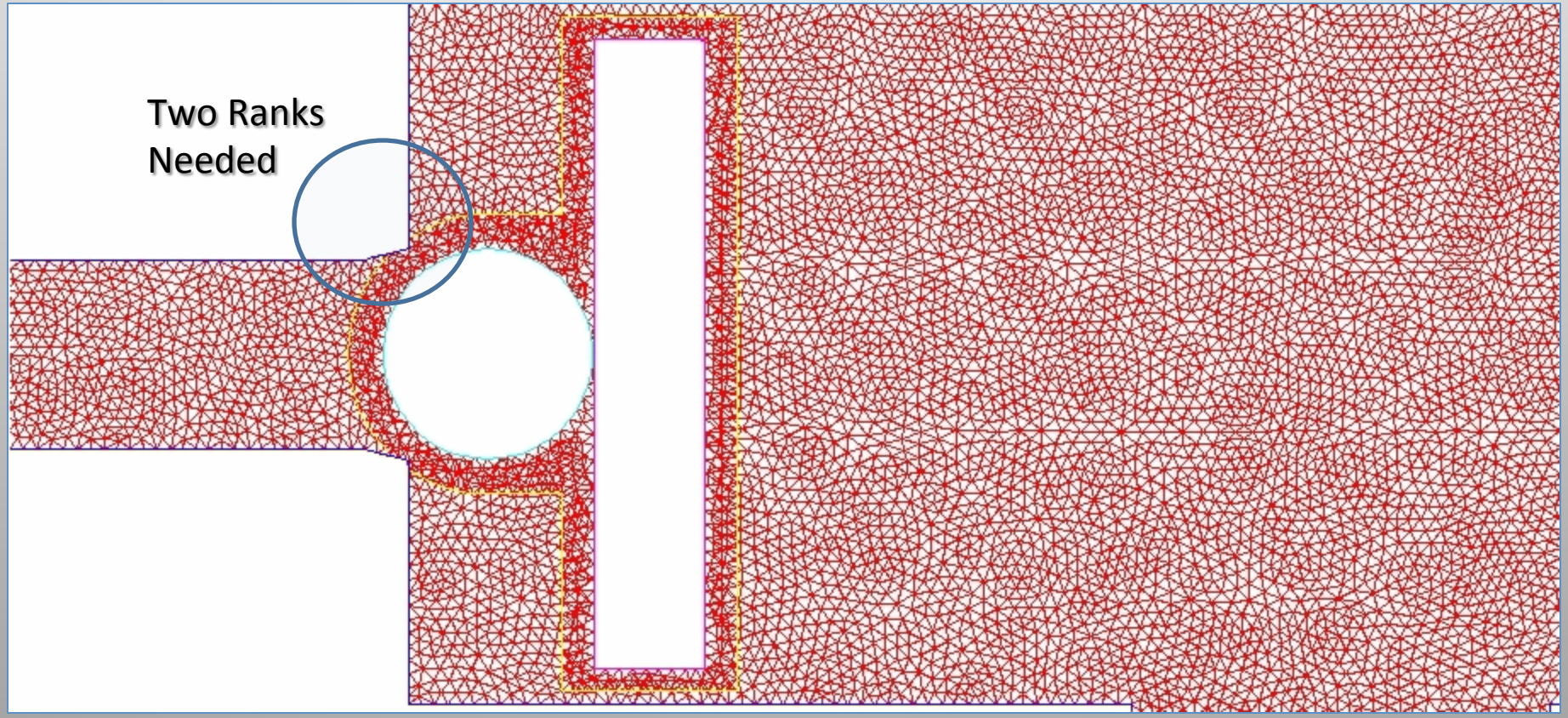
Sequential Cutting





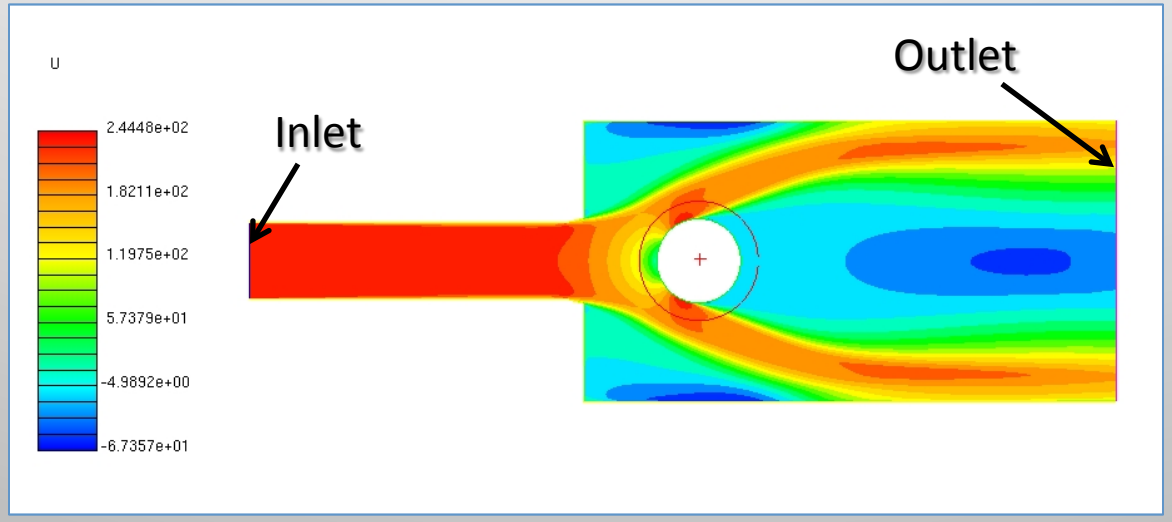


Sequential Cutting



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

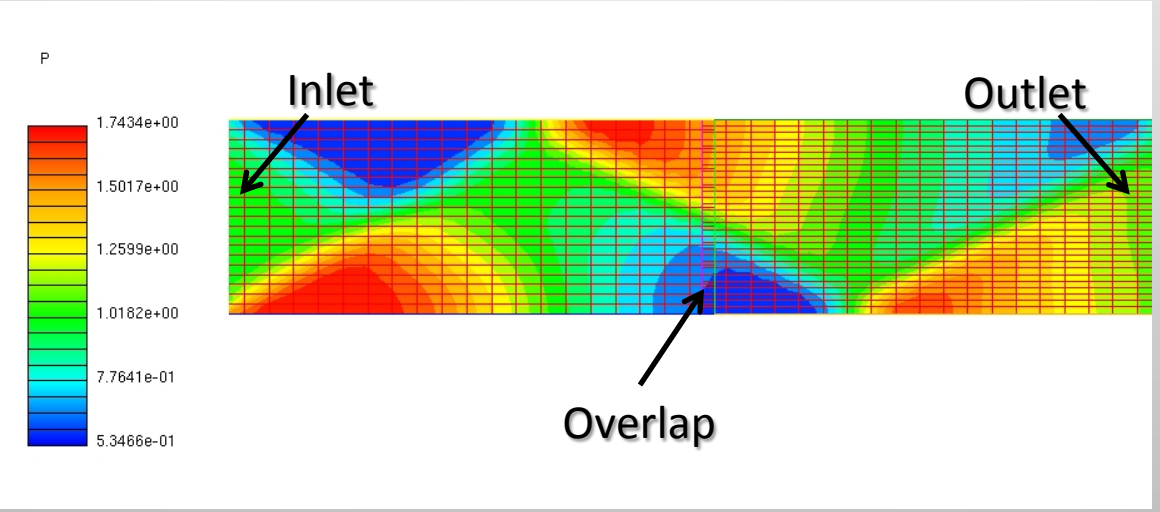
Flux Stitching



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

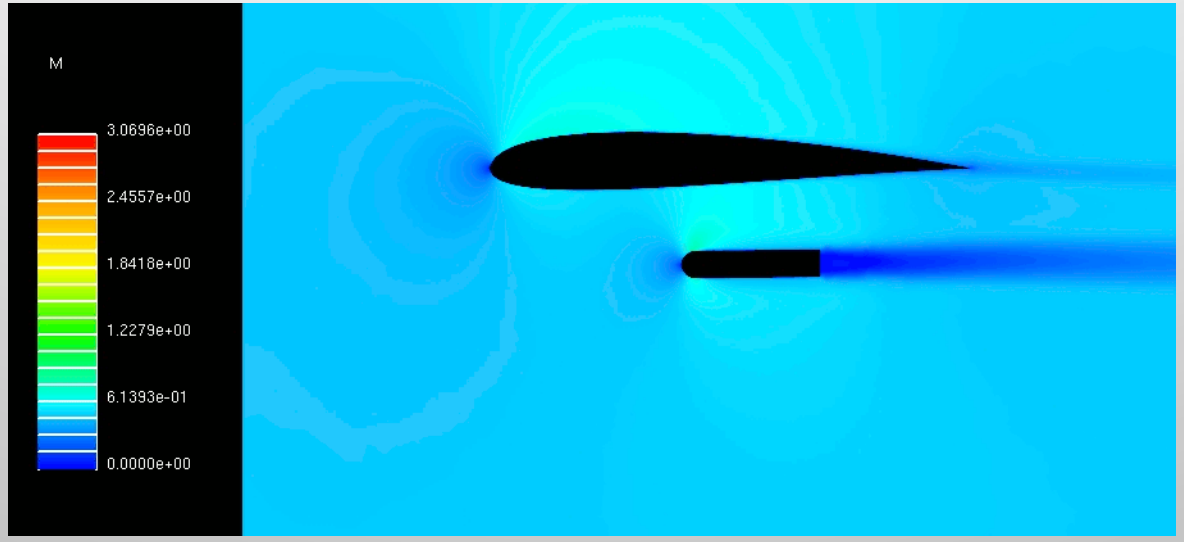
Mass Flux Error % w/o FS	**0.04 %**
Mass Flux Error % with FS	**< 0.001%**

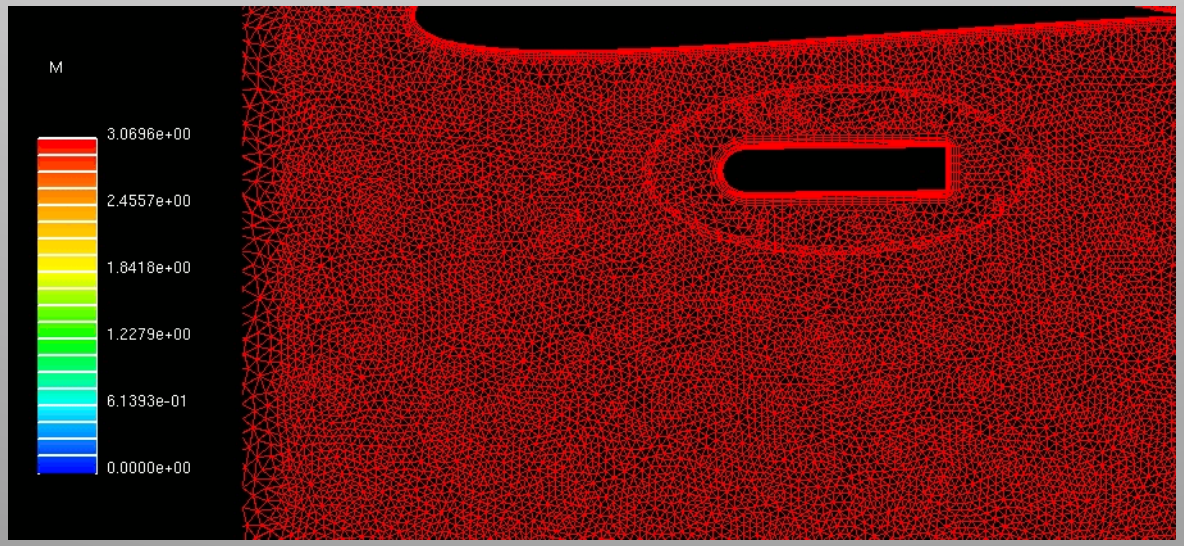
Where Are We Headed?

- ✓ *Automation*
  - ✓ *Adapting grid during course of computation to match overset and background grids*
  - ✓ *Necessary for 6DOF type cases*
  - ✓ *Automatic selection of cutting/blanking controls for super-sequential cutting*

Demonstrative Examples

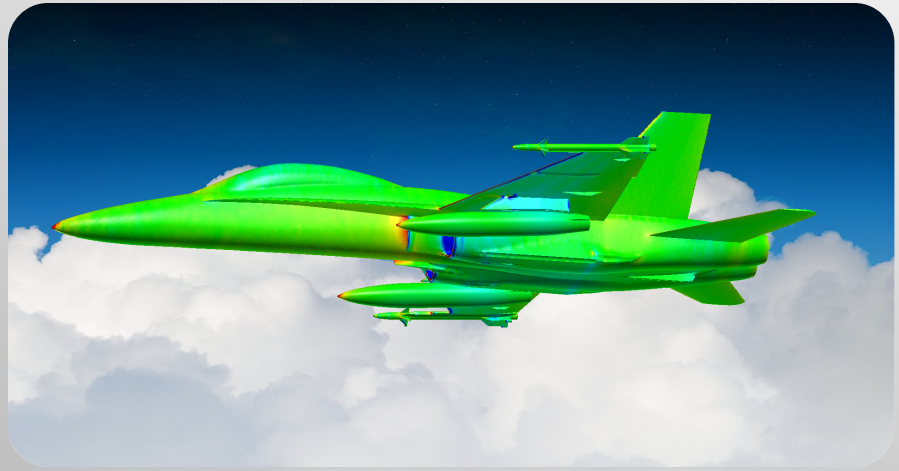
Store Separation Training Example

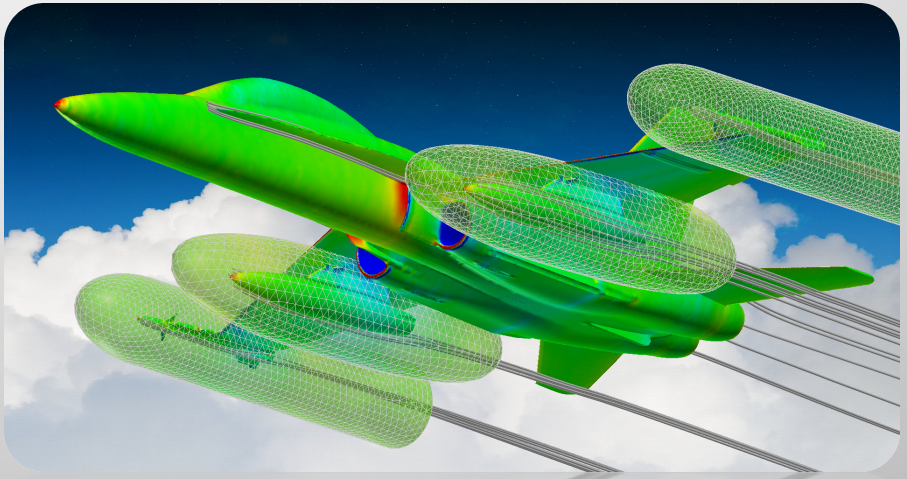


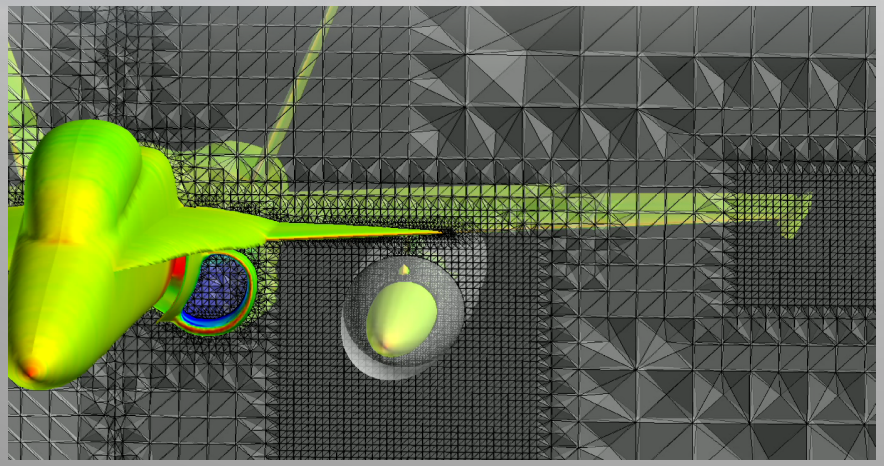


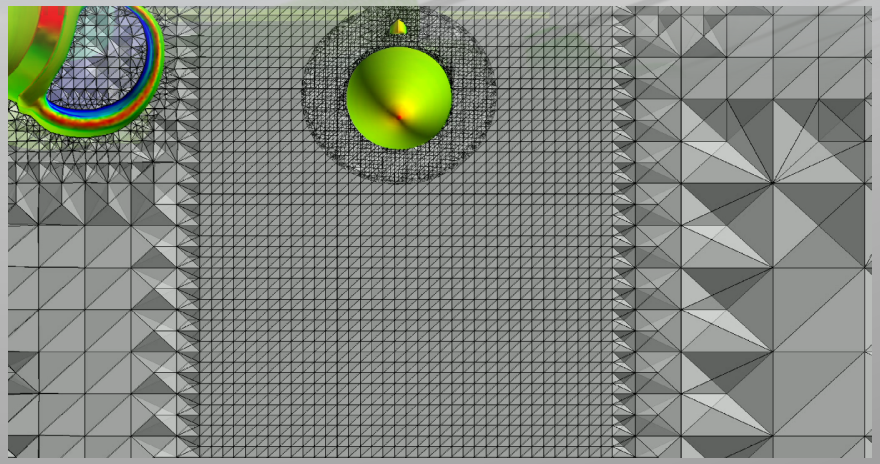
OVERSET MESH APPLICATIONS

Store Separation



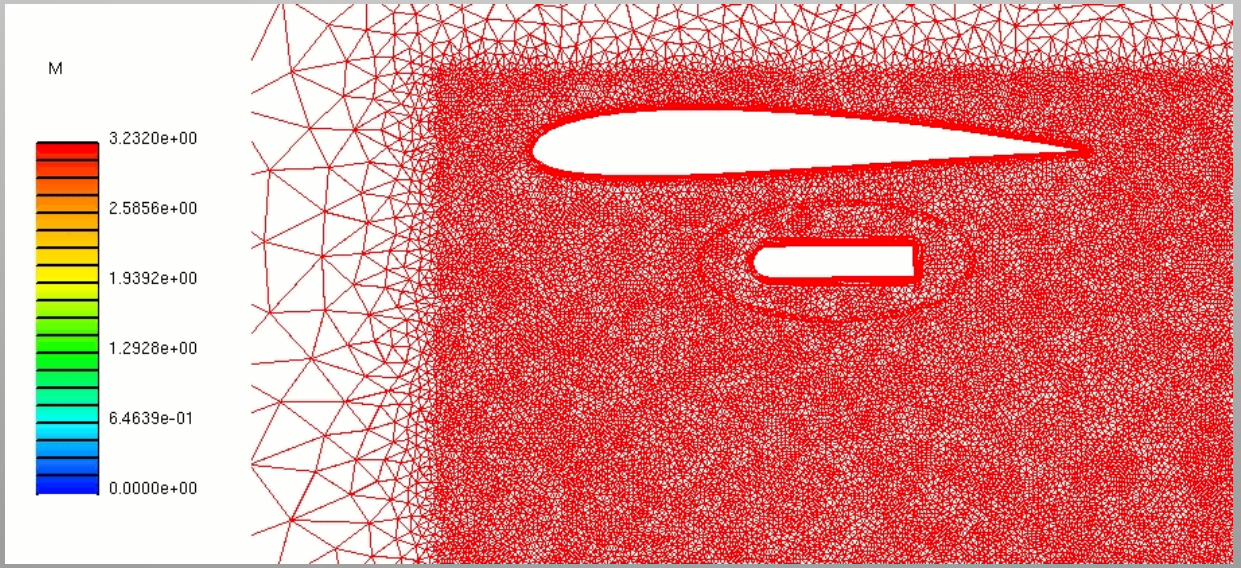




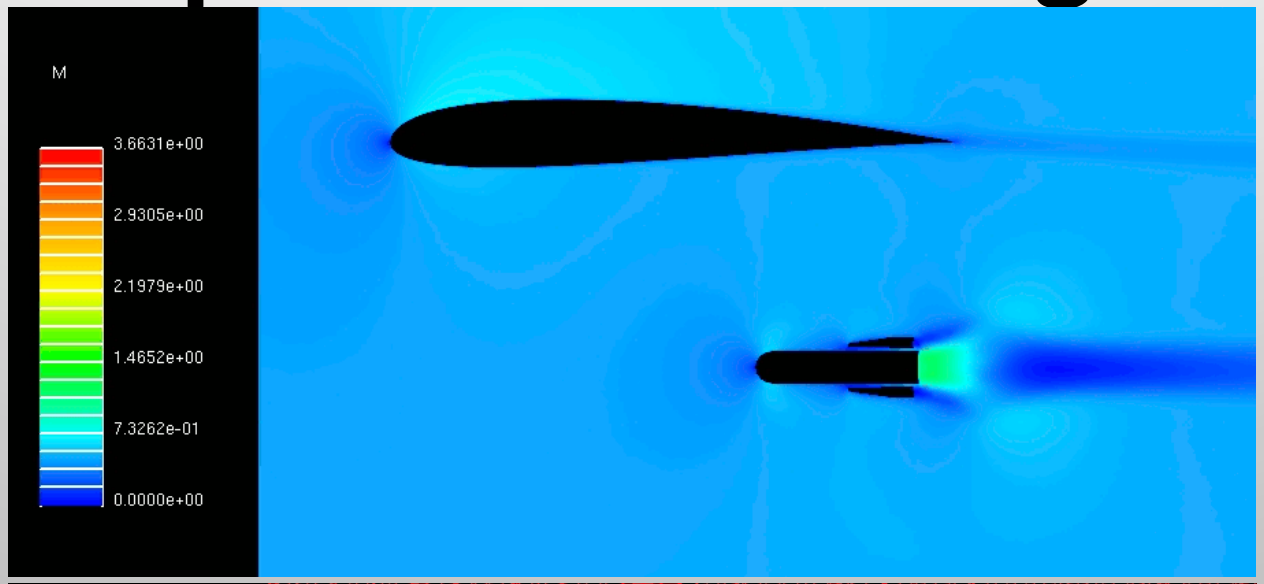


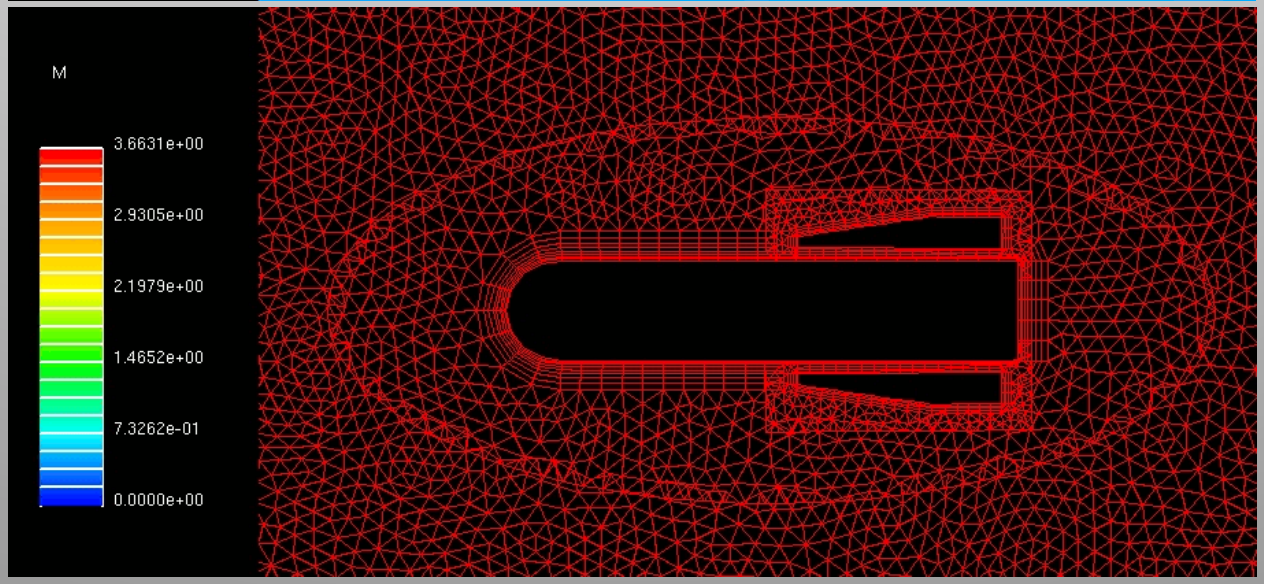
F-18

Fin Deployment Training Example



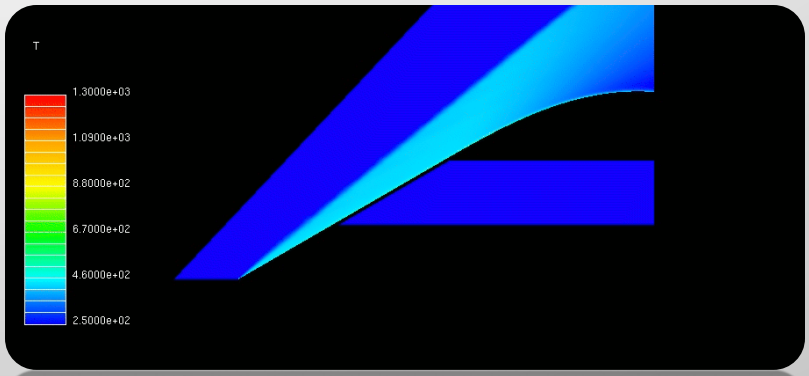
Sabot Separation Training Example

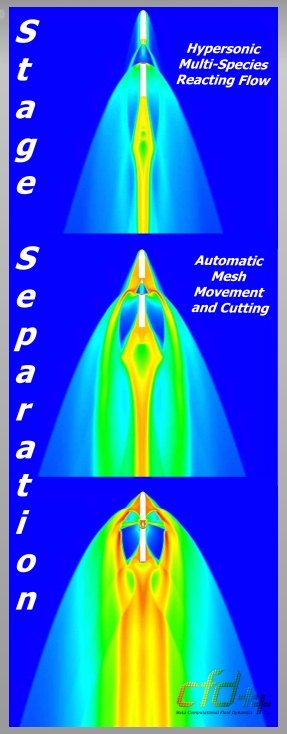




AEROSPACE APPLICATIONS

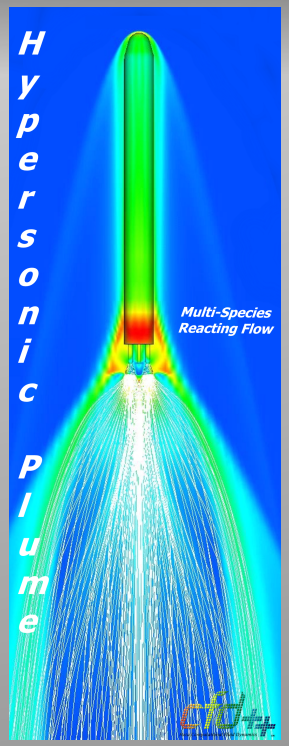
Scramjet Inlet Door Example





Hypersonic Plume

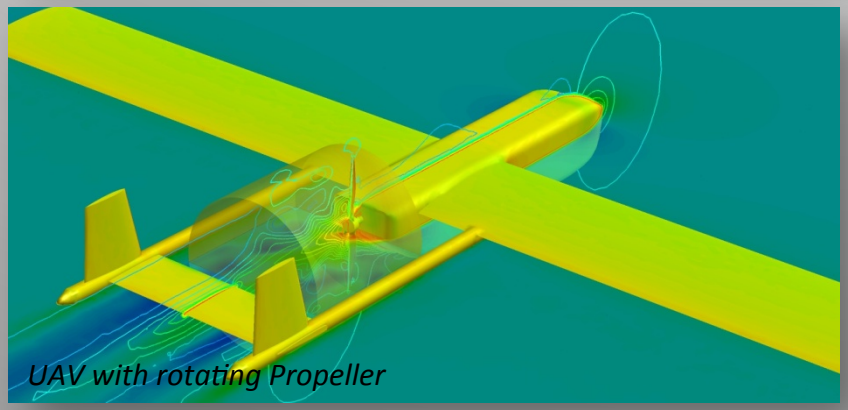
- *Free Stream Mach number is 5.9*
- *Plume expands to Mach 12.0*
- *15 Species, 18 Reactions*
- *Total of 21 equations used*
- *Solution captured the re-compression point successfully*
- *Species generation matched experimental data very well*



OVERSET MESH APPLICATIONS

Overset Meshes

F18 with wing-tip store and under wing store



UAV with rotating Propeller

Unique capabilities

- *In simulating steady and unsteady flows over complex geometries including bodies in relative motion*

Automatically performed operations

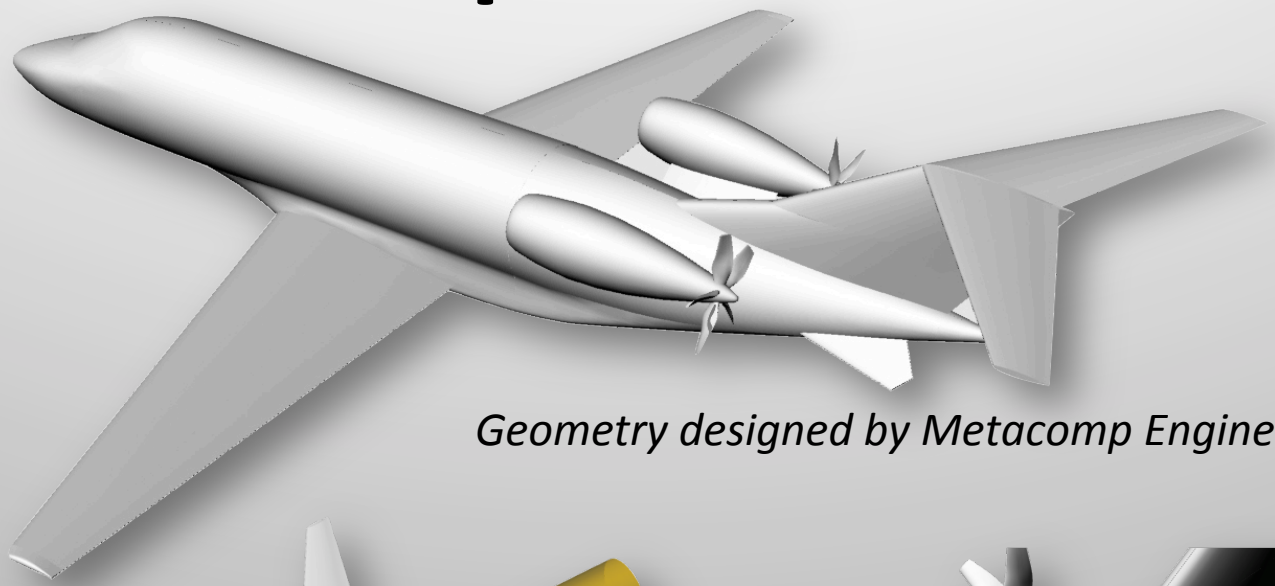
- *Cutting/blanking operations and the interpolation operations are all performed within CFD++ and can be performed every time step for transient simulations.*

RBD and 6DOF

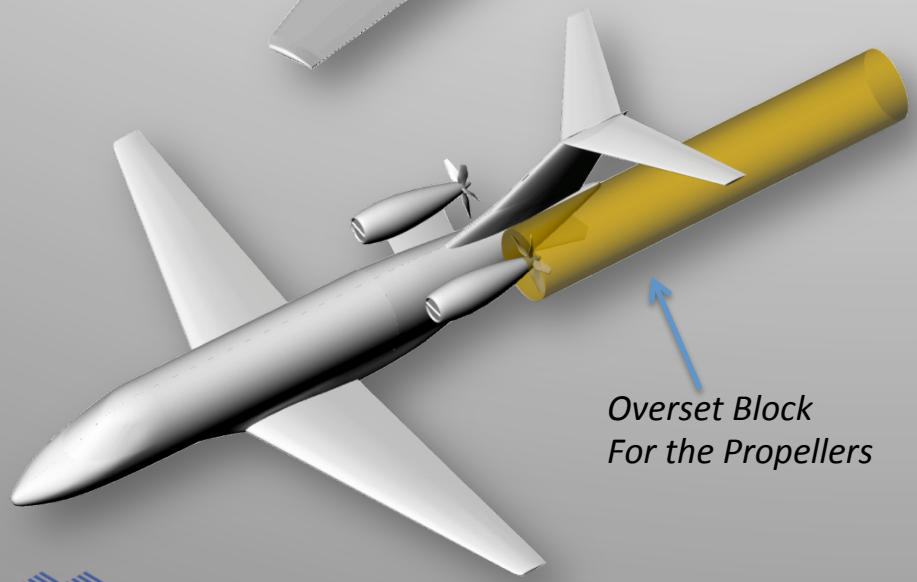
- *Includes an integrated rigid body dynamics (RBD) capability with a six-degree-of-freedom (6DOF) module.*

OVERSET MESH APPLICATIONS

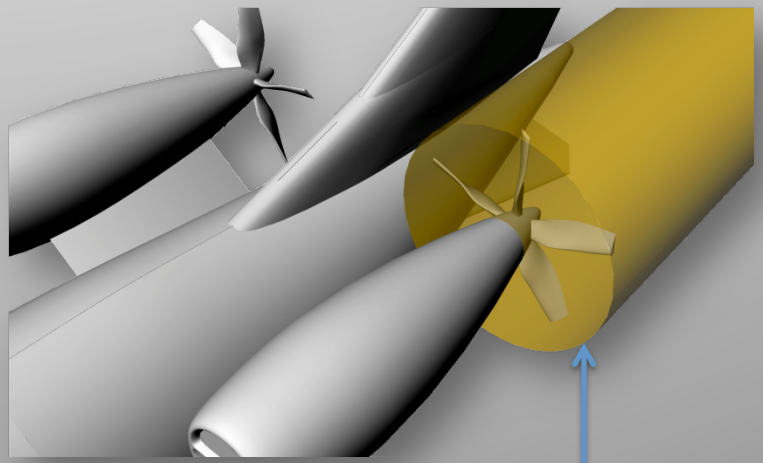
Prop Plane Geometry



Geometry designed by Metacomp Engineers

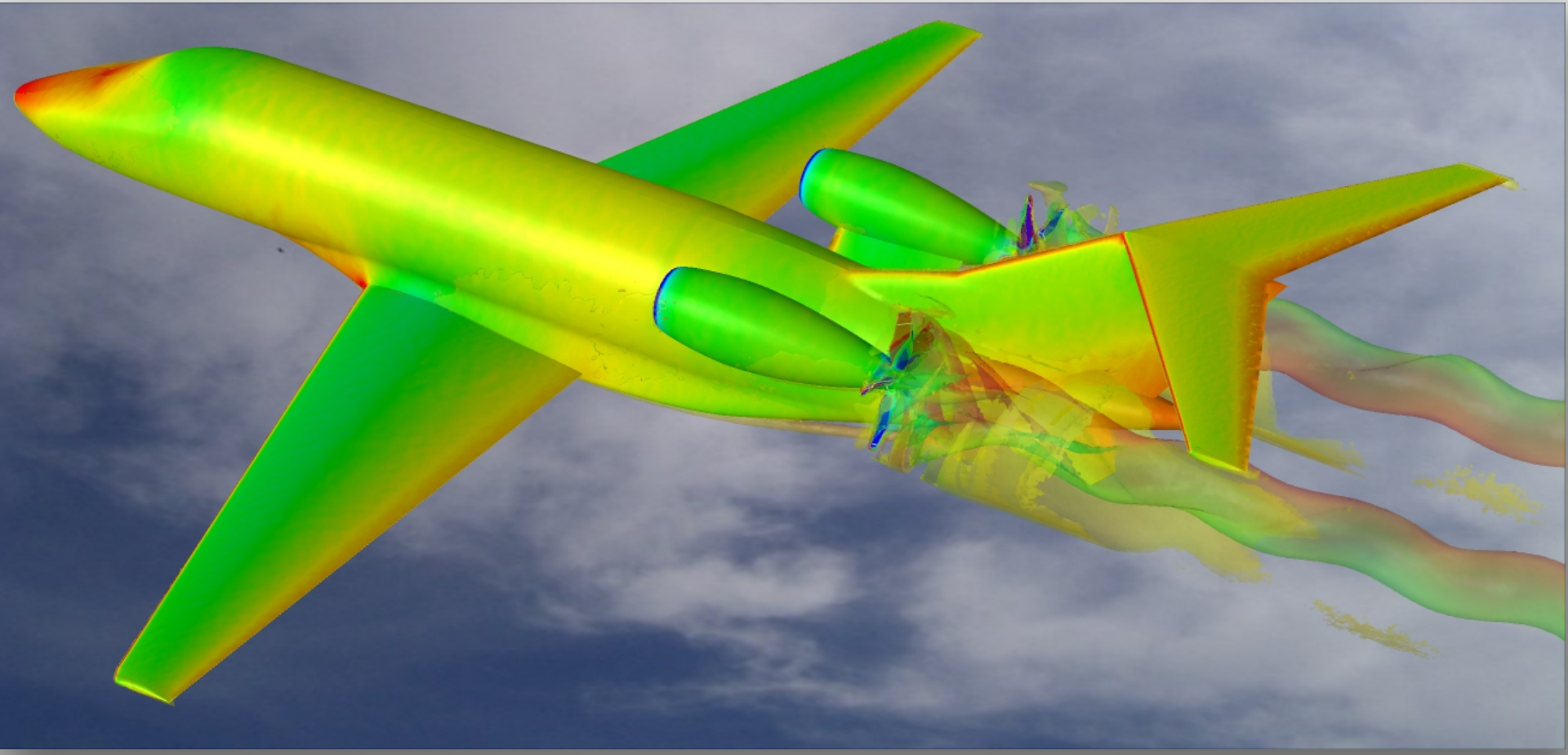


Overset Block
For the Propellers



Overset Block
For the Propellers

Prop Plane Solution

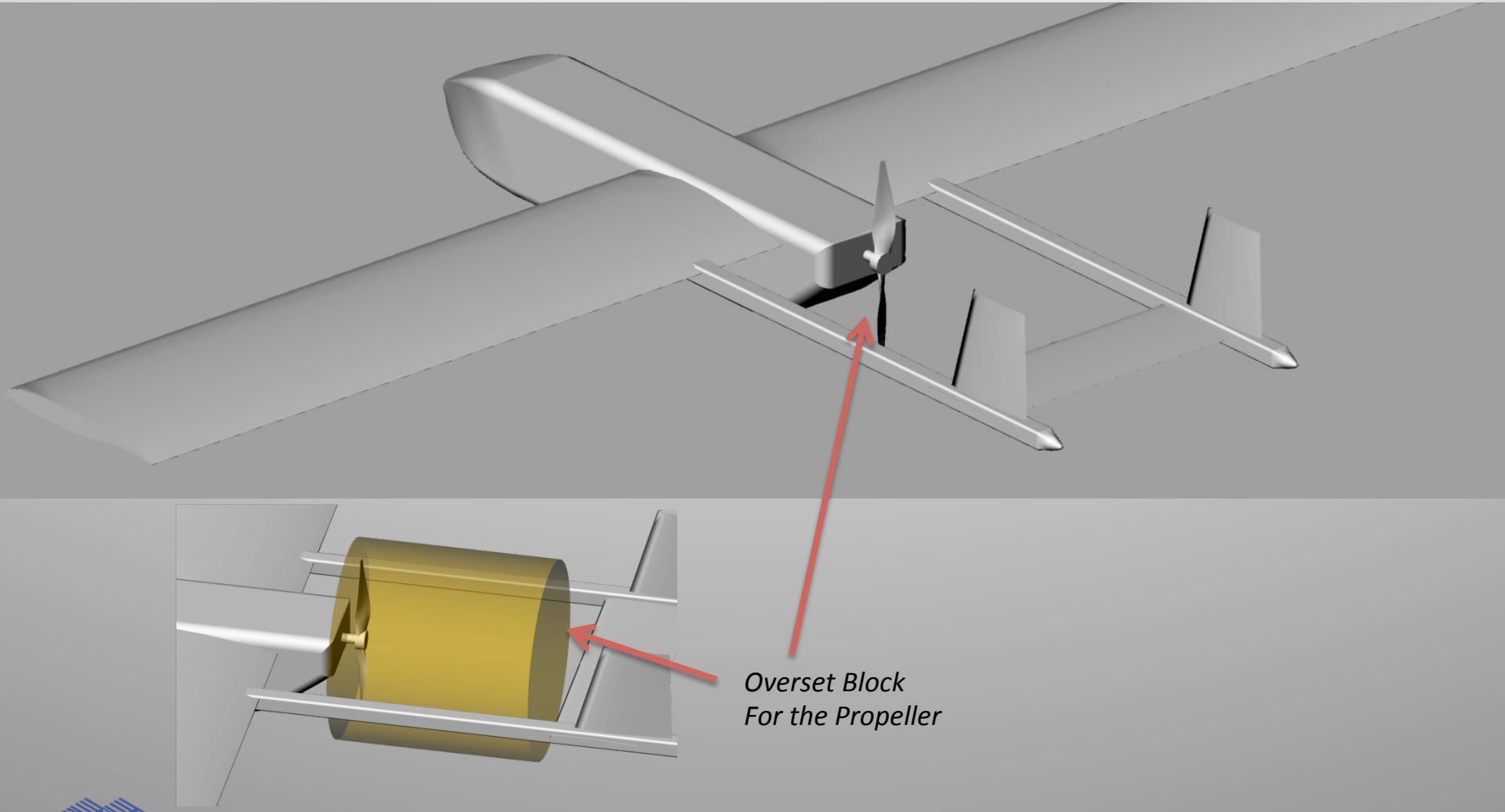


Surface Pressure Contours and Vorticity Iso-surfaces

OVERSET MESH APPLICATIONS

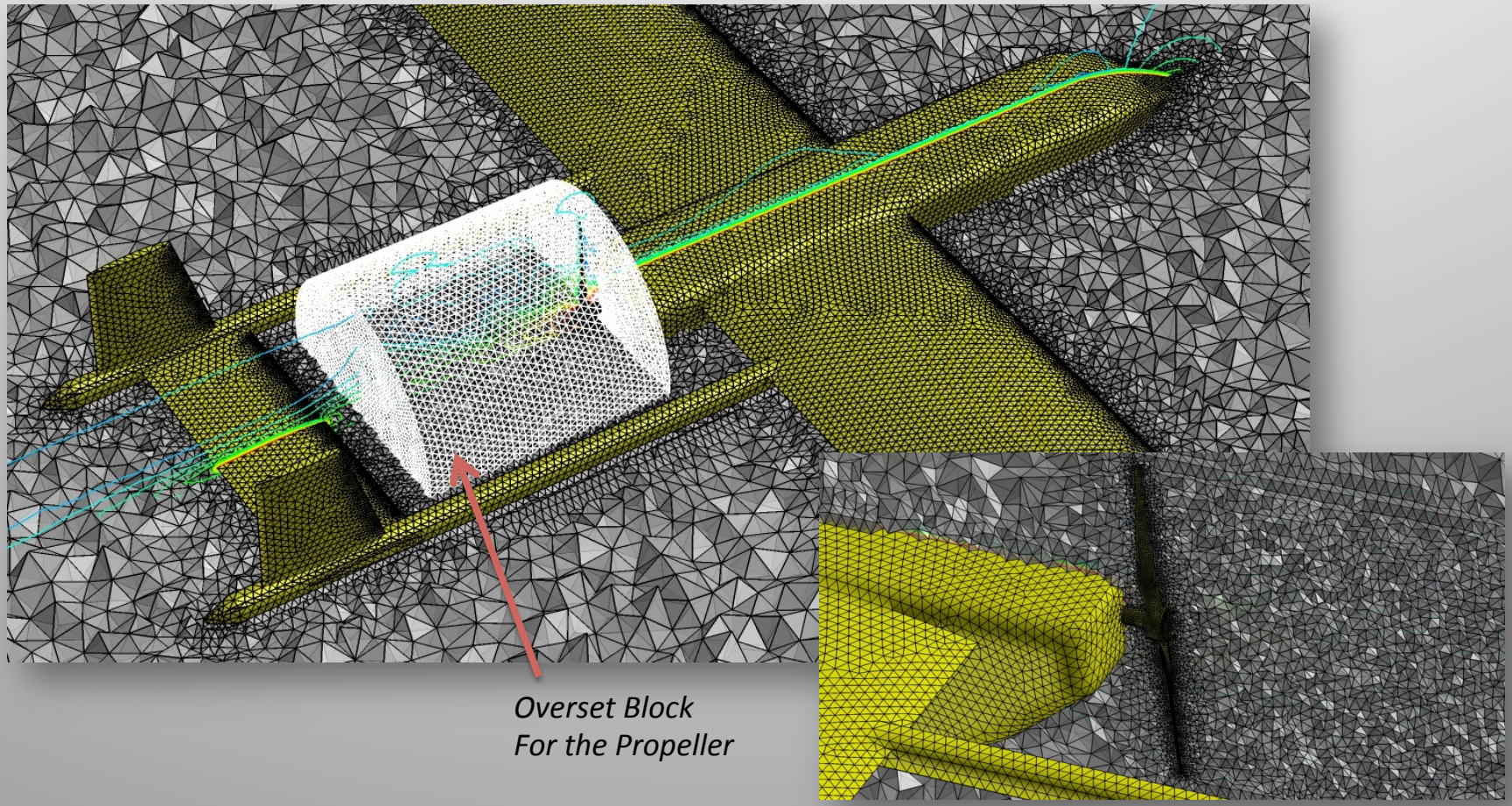
UAV

Geometry designed by Metacomp Engineers



OVERSET MESH APPLICATIONS

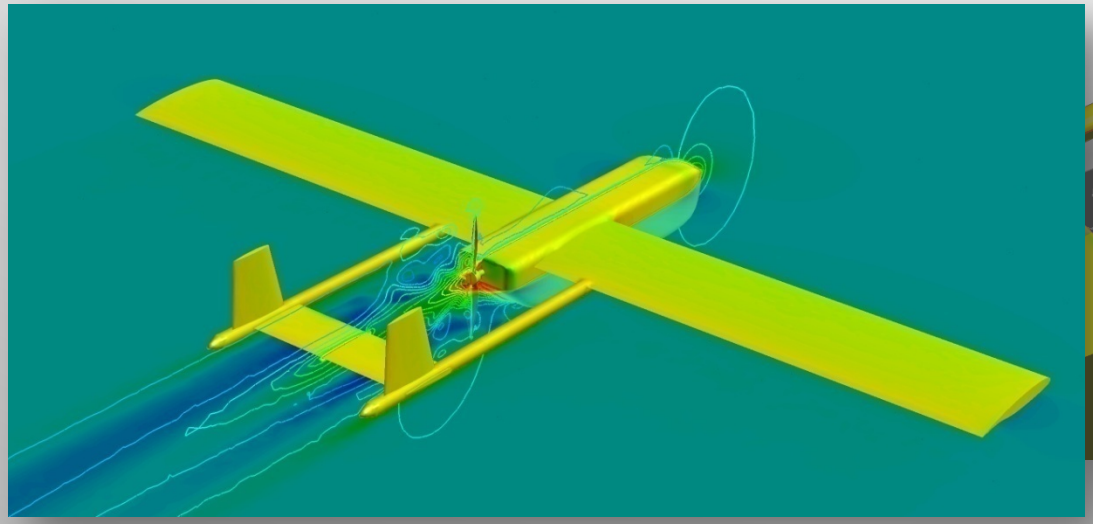
UAV Mesh

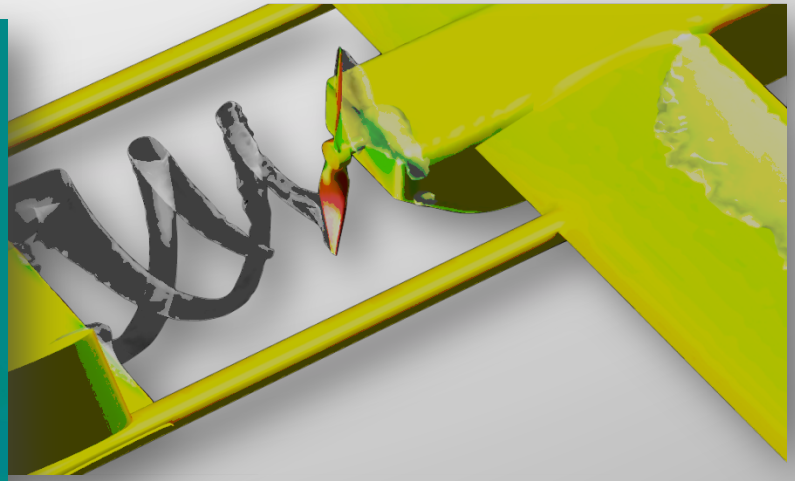


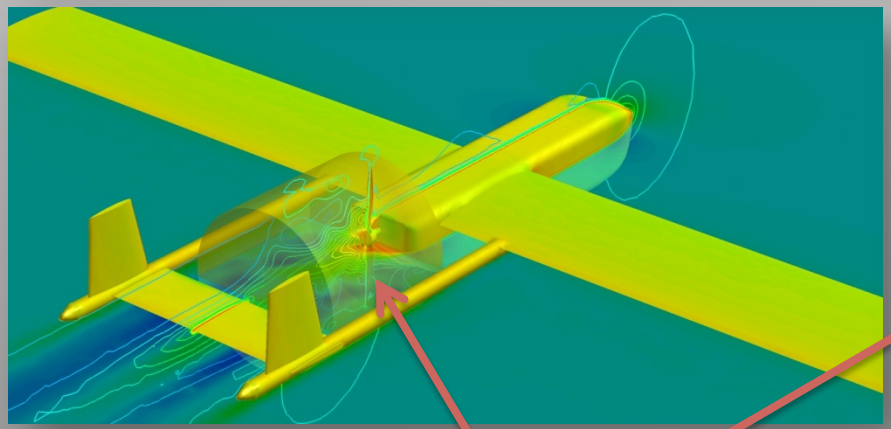
- *Full tetrahedral mesh (3 million including Prop mesh)*
- *UAV Mesh and the Prop Mesh later combined in CFD++*

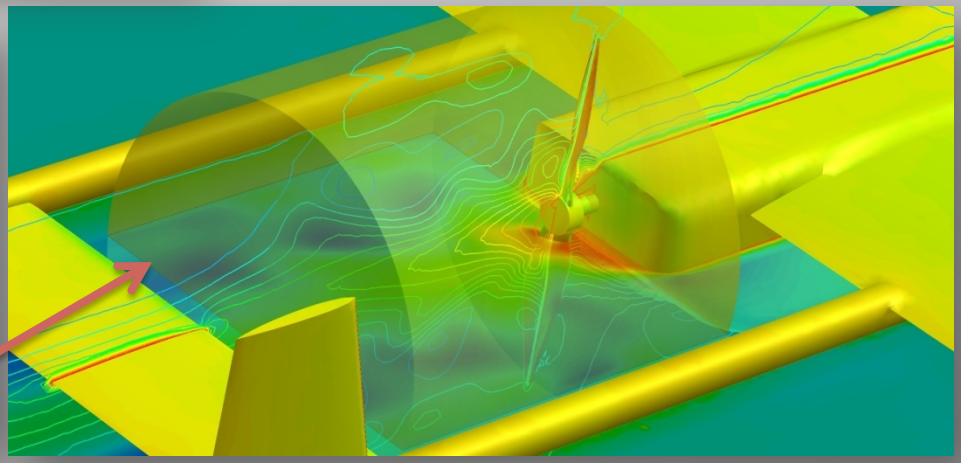
OVERSET MESH APPLICATIONS

Multiple Reference Frame





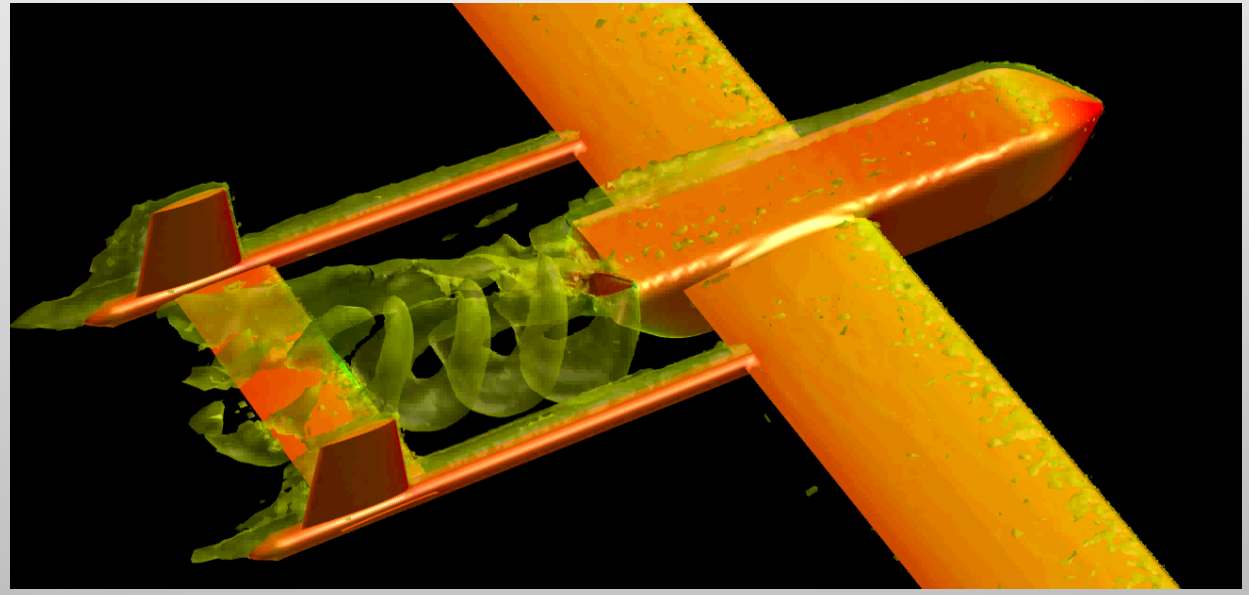


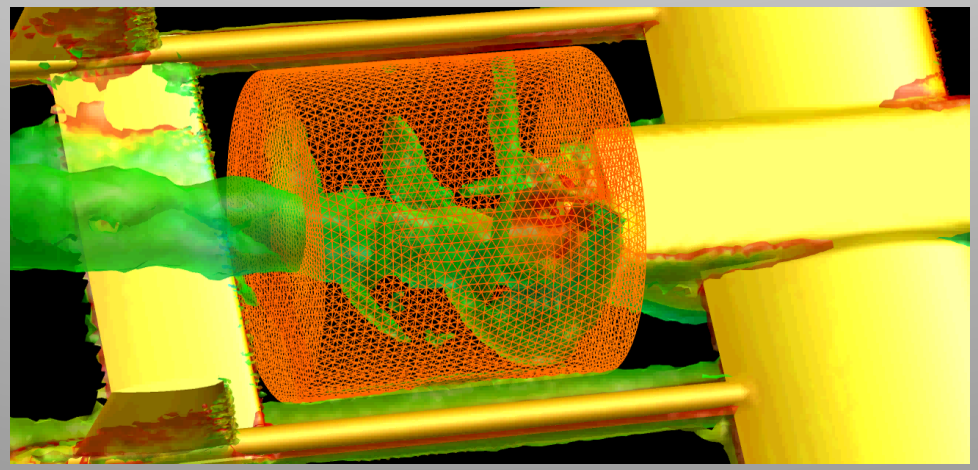


Overset Block
For the Propeller

OVERSET MESH APPLICATIONS

UAV Transient Solution

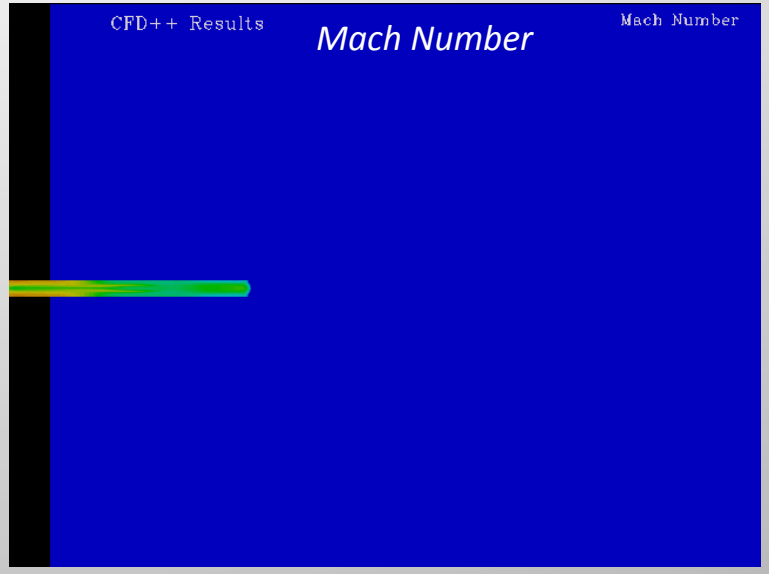


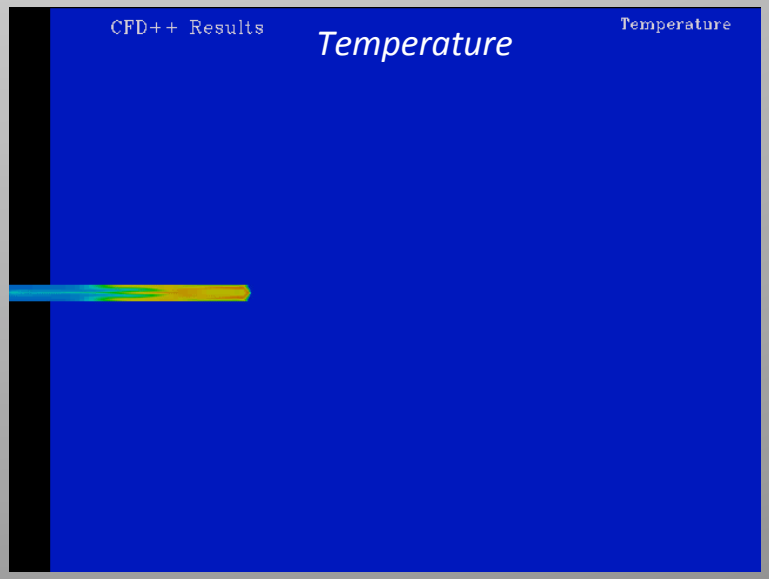


OVERSET MESH APPLICATIONS

Bullet Leaving Gun Barrel

- *To simulate the detonated propellant a region of very high temperature, very high pressure air behind the bullet was used.*
- *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*

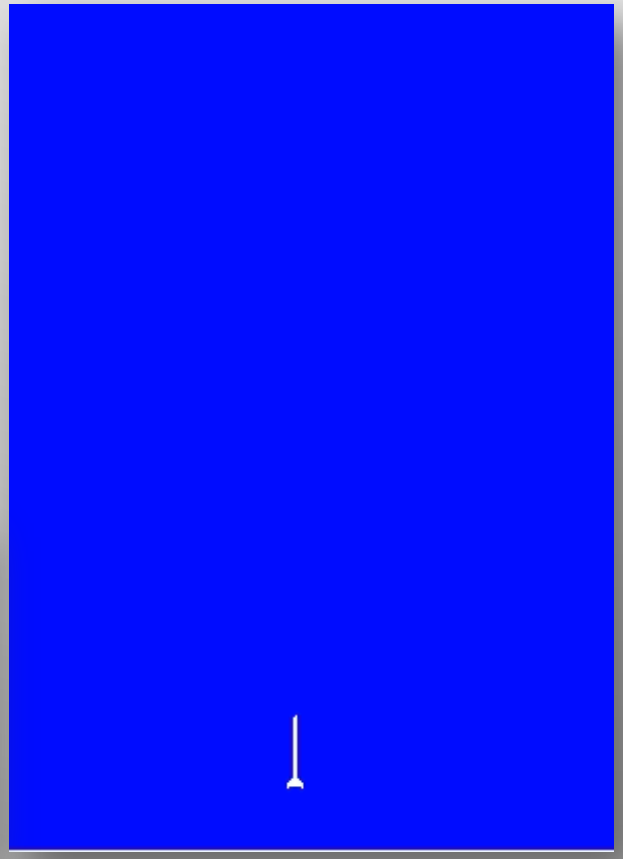




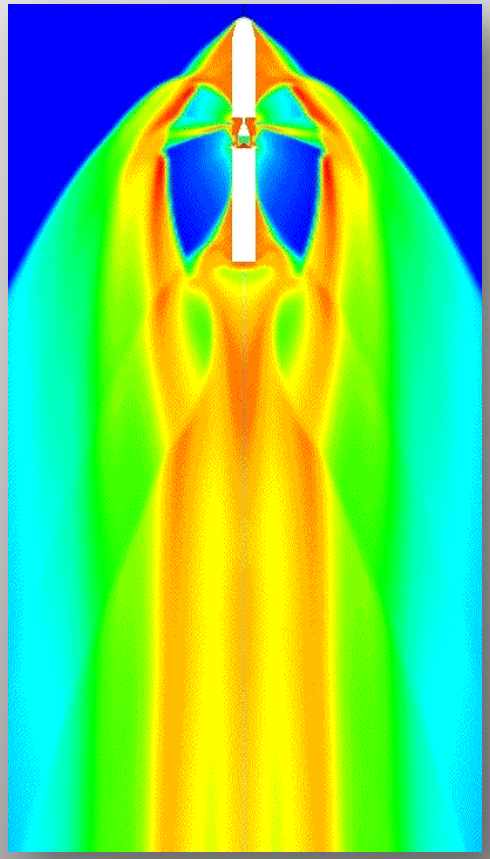
Missile Guidance and Stage Separation

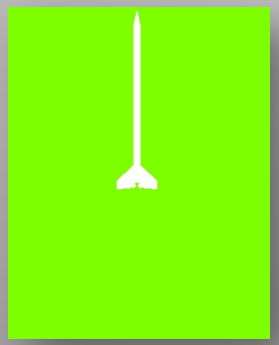
OVERSET MESH APPLICATIONS

Missile guidance with side jets firing



Missile Stage Separation

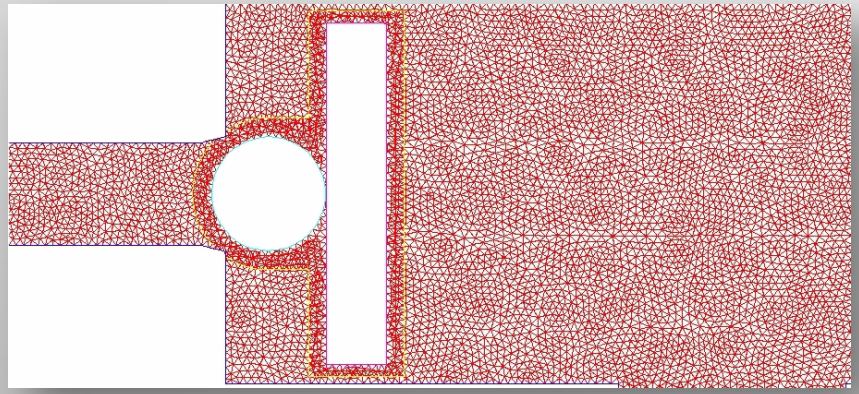


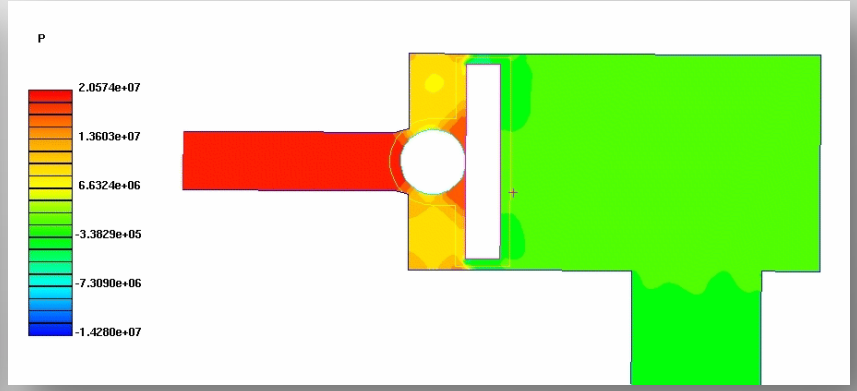


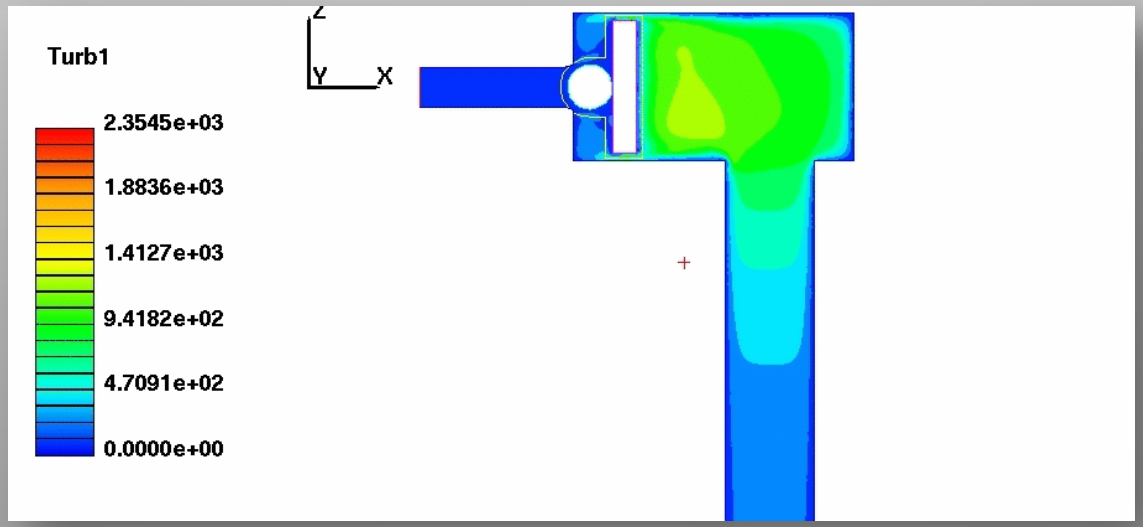
Launch Start-Up

OVERSET MESH APPLICATIONS

Ball/Spring Valve

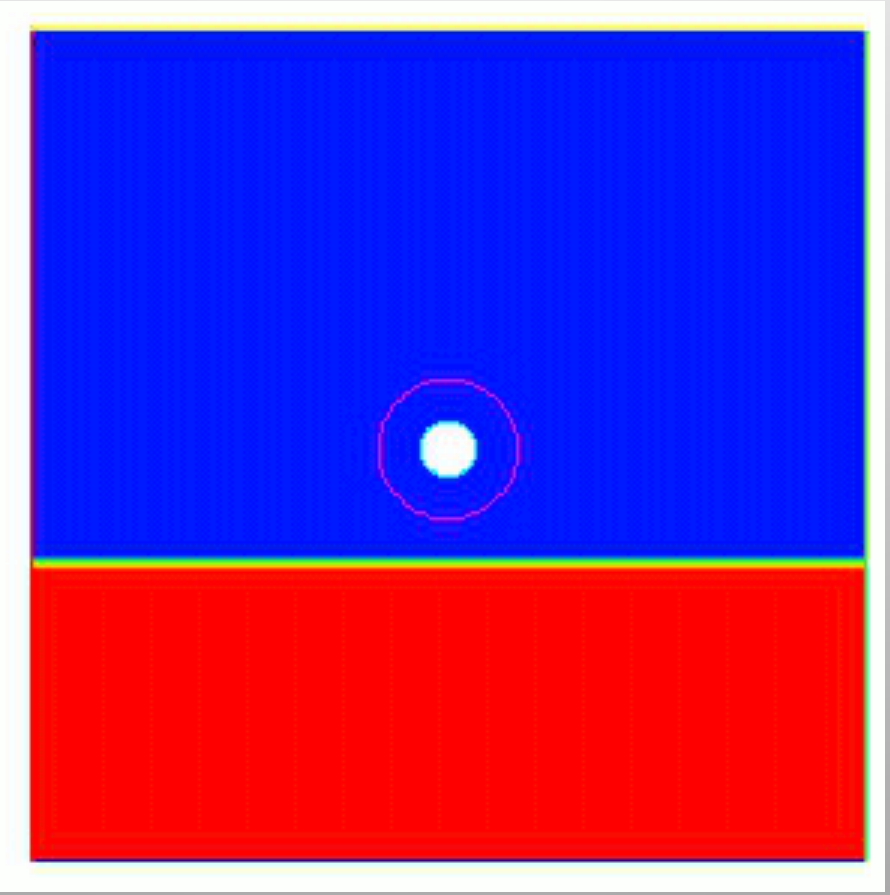






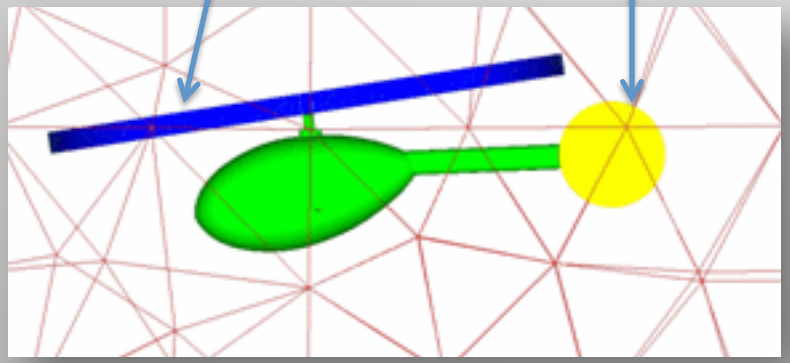
OVERSET MESH APPLICATIONS

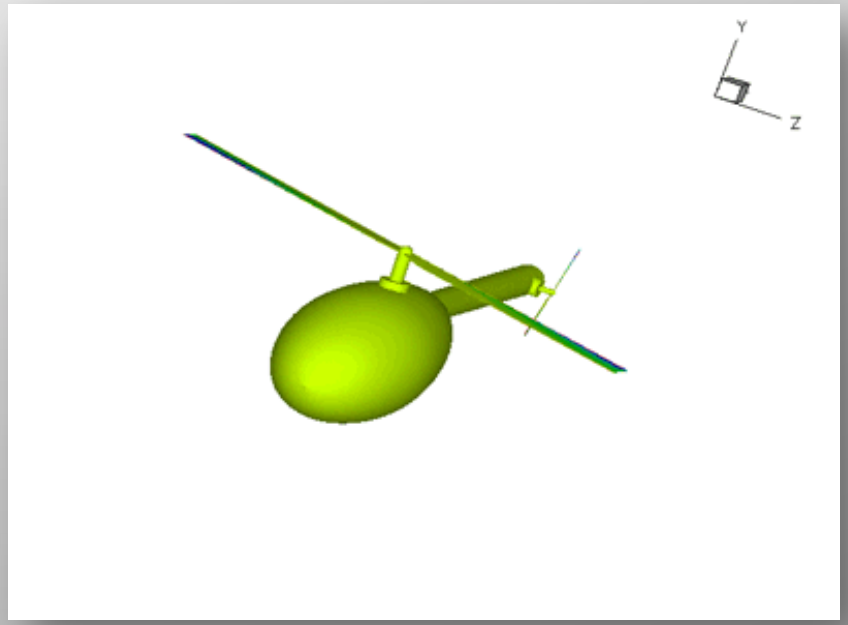
Ball Falling into Water



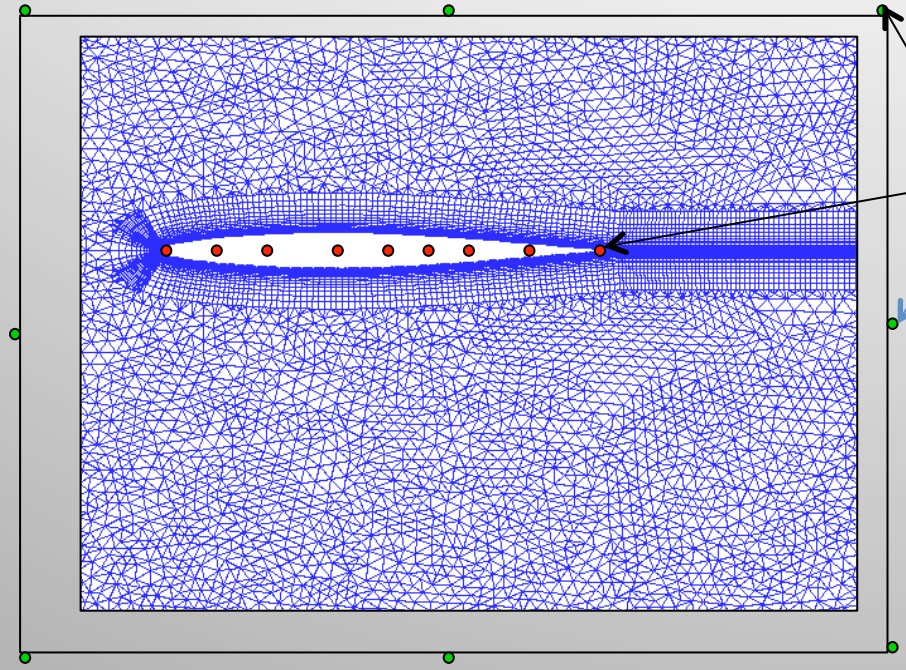
Helicopter Applications

Disks rotating in background mesh





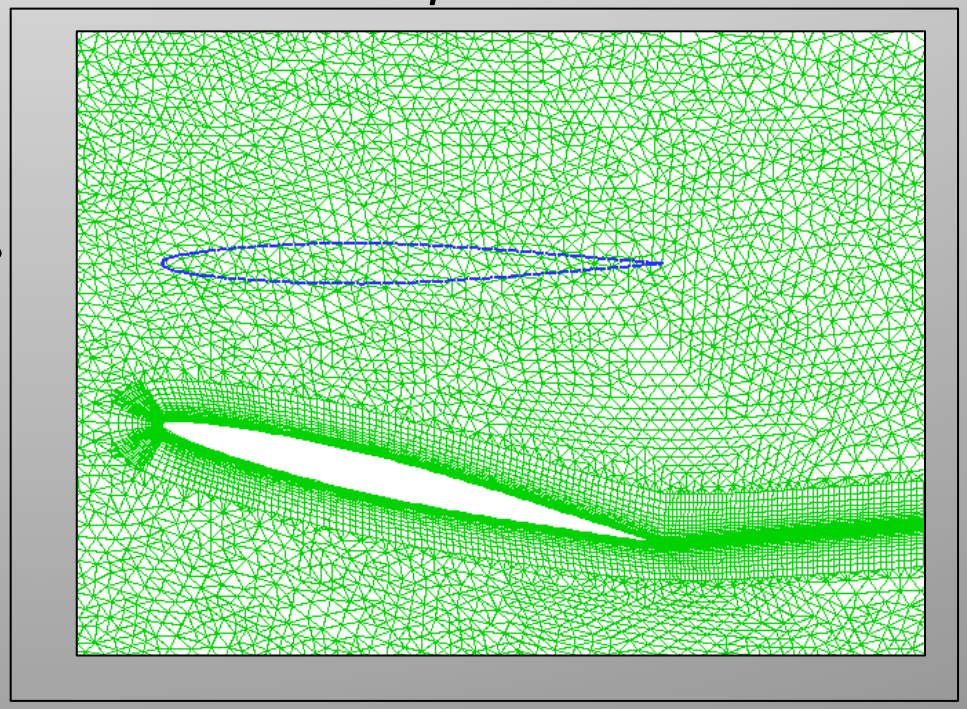
Grid Morphing



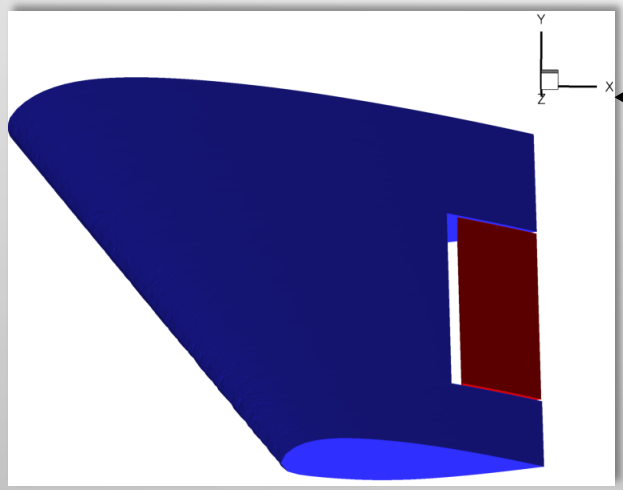
Control Points

Original Grid

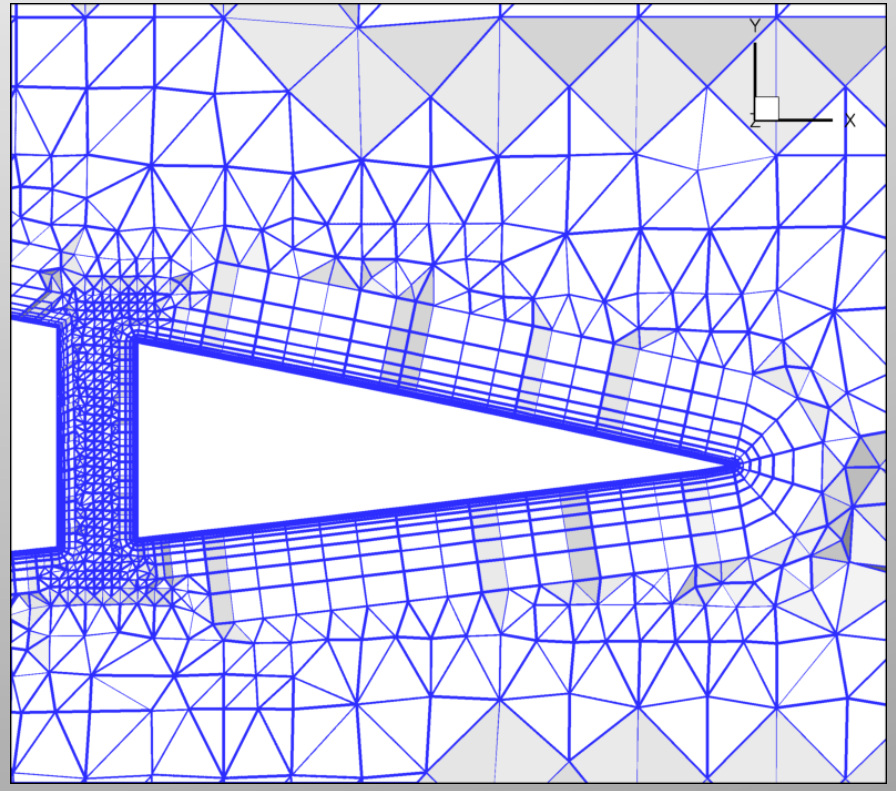
Morphed Grid

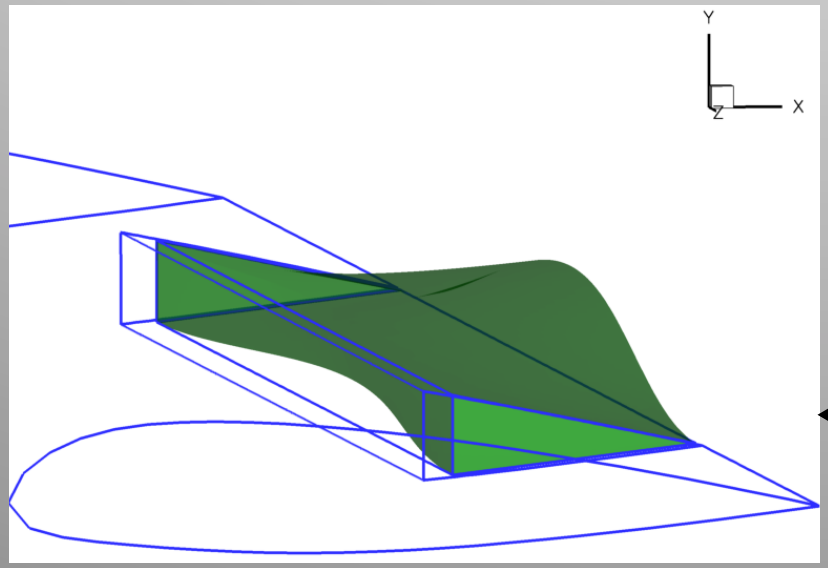


Grid Morphing (3D)



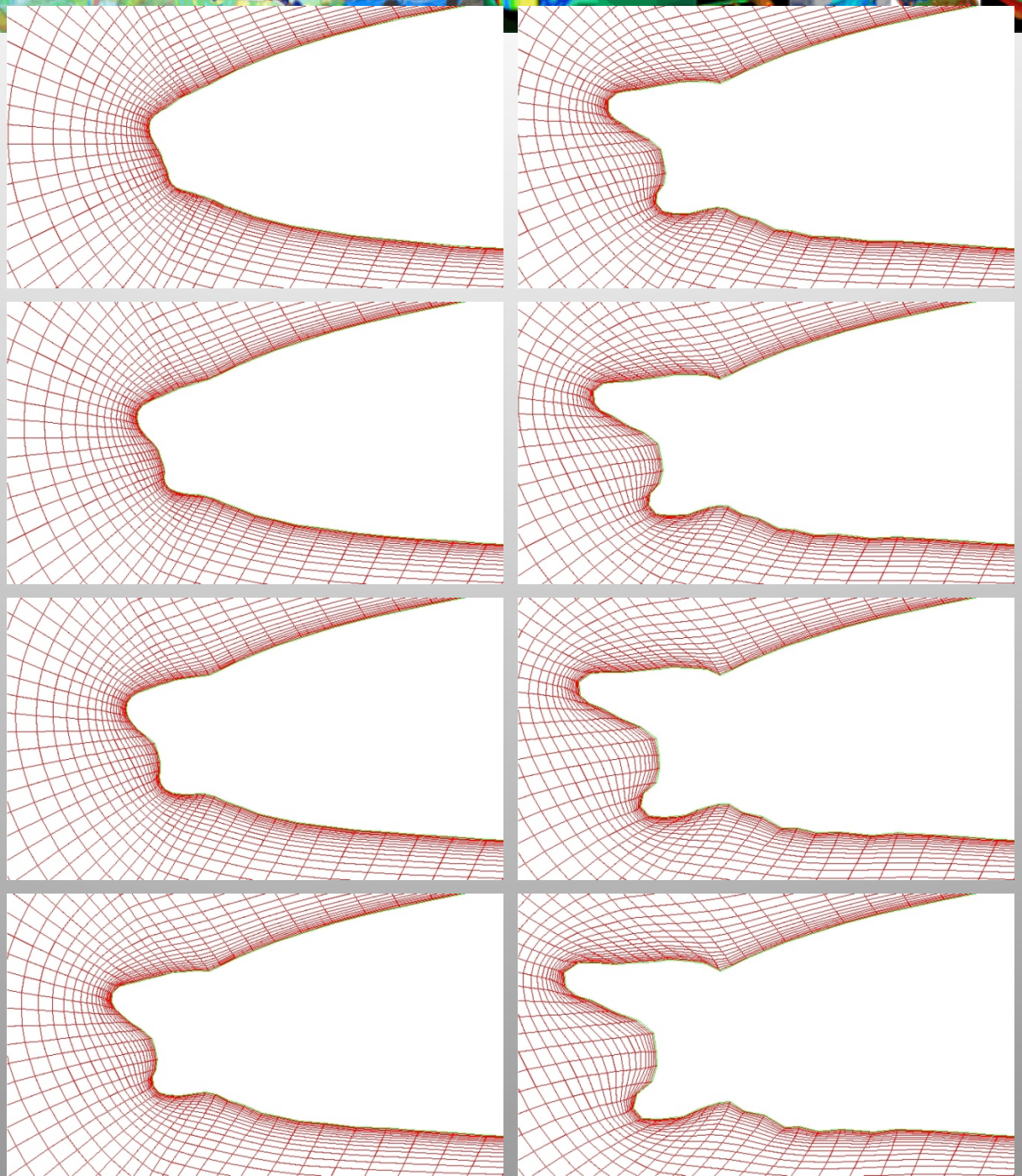
Wing and Flap





Maximum Applied Deformation

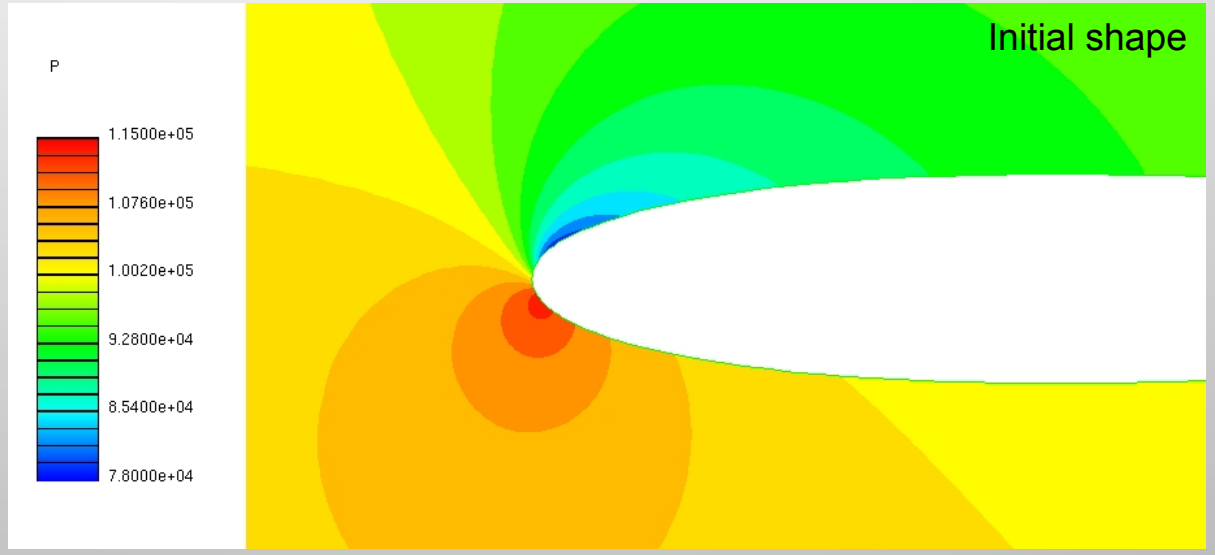
Morphing stages
for
Icing Application

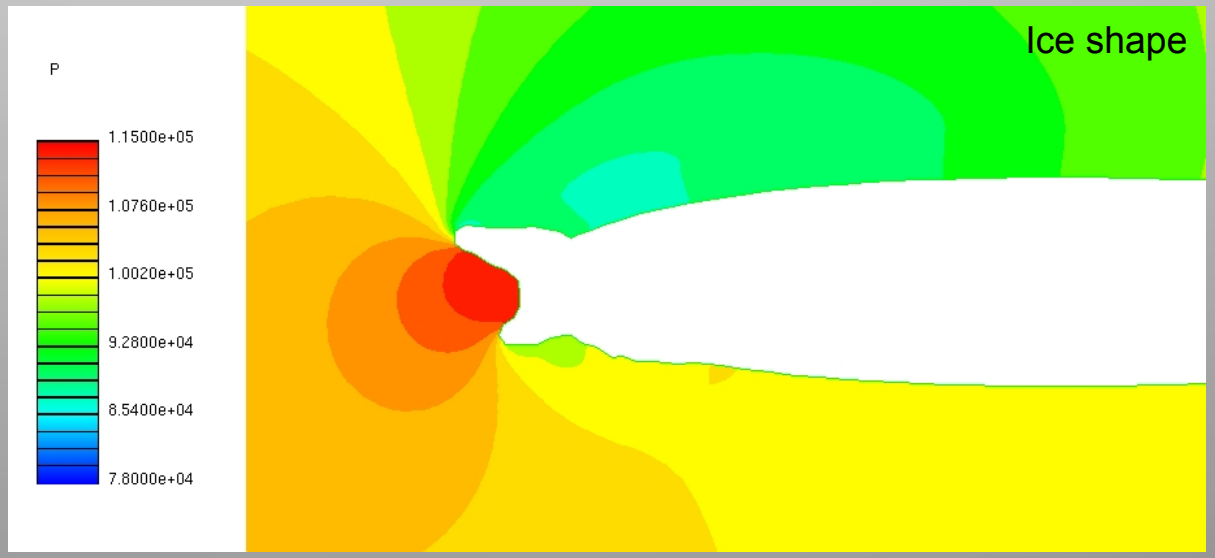


Icing effects: Horn ice (CFD)

Run conditions

alpha = 5 degrees
P = 101325 Pa
T = 288 K
U = 136.15 m/s

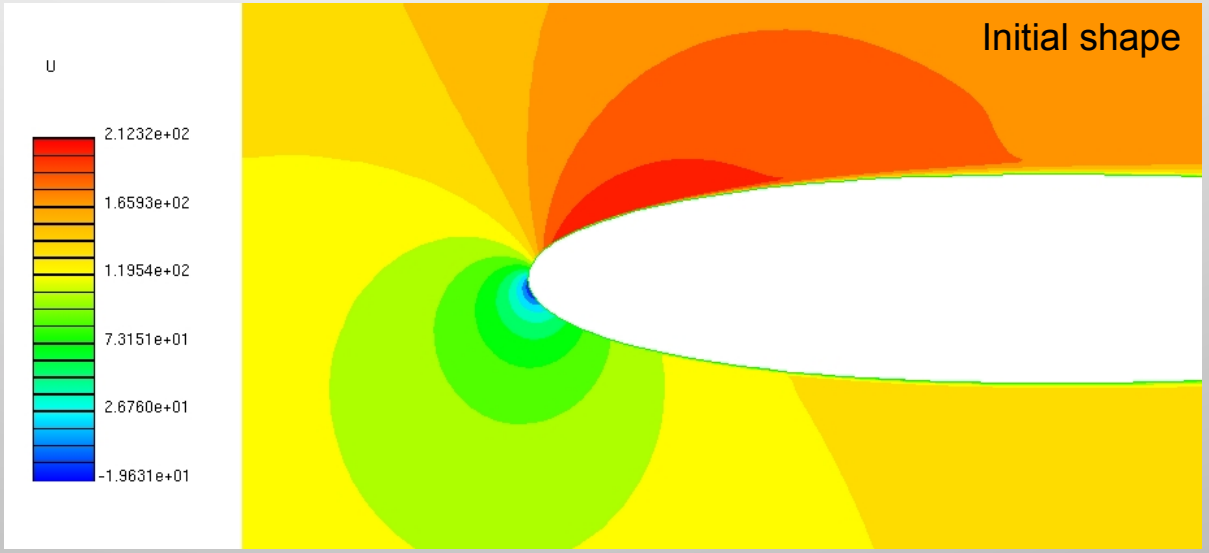




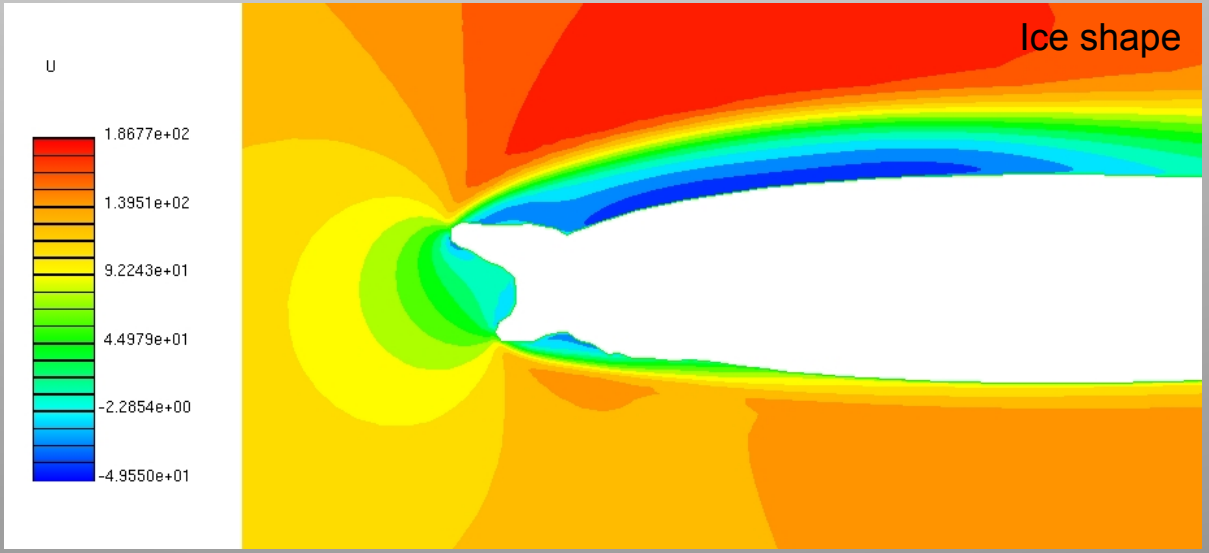
Pressure contours

Icing effects: Horn ice (CFD)

CL = 0.60995
CD = 0.03804

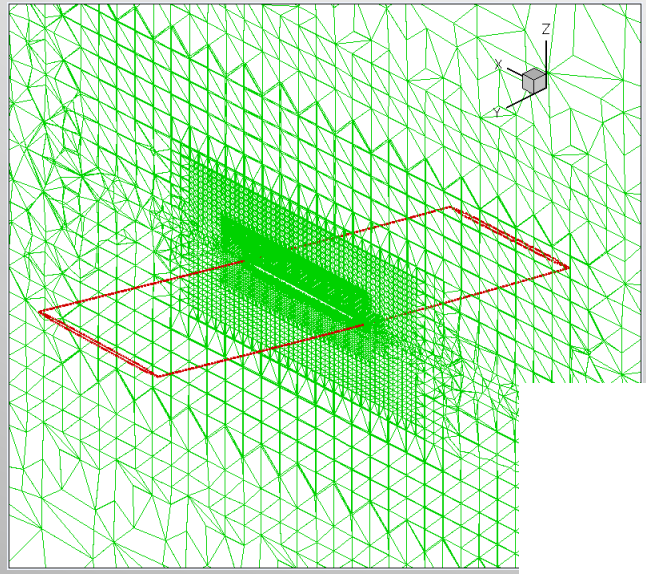


CL = 0.23078
CD = 0.11438

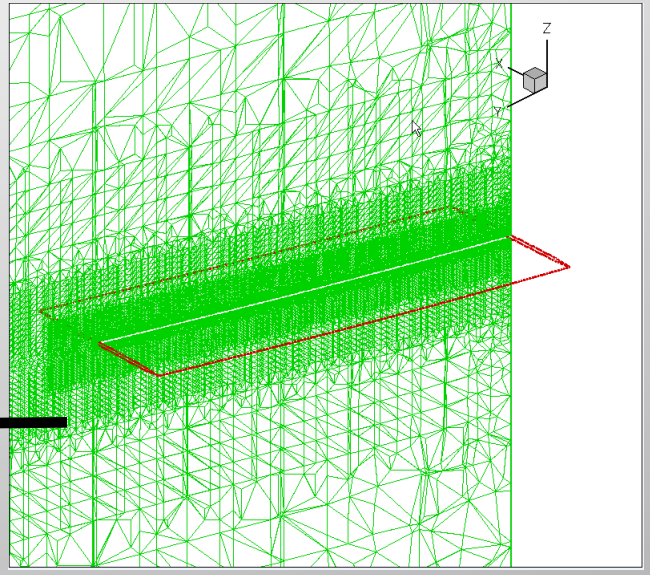


U-velocity contours

Aeroelastic Example (FSI, Mesh Morphing)

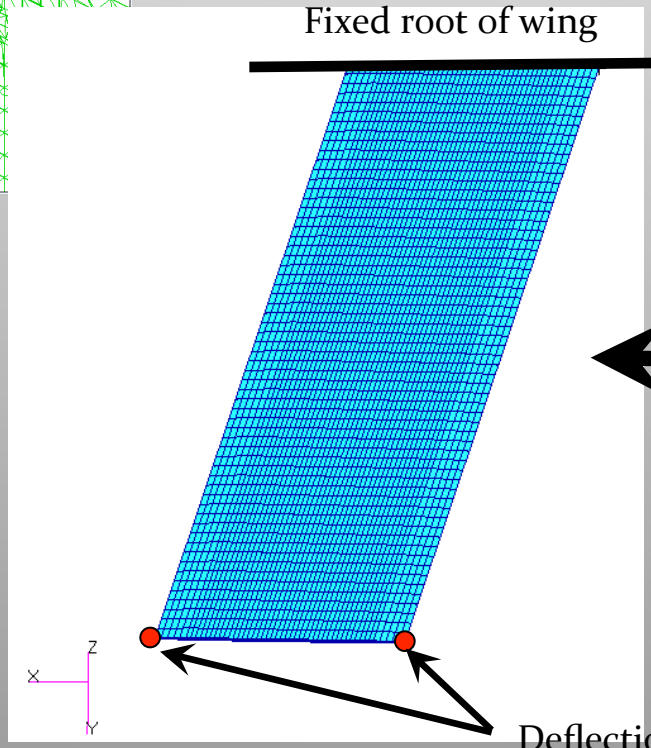


4.0 million cells

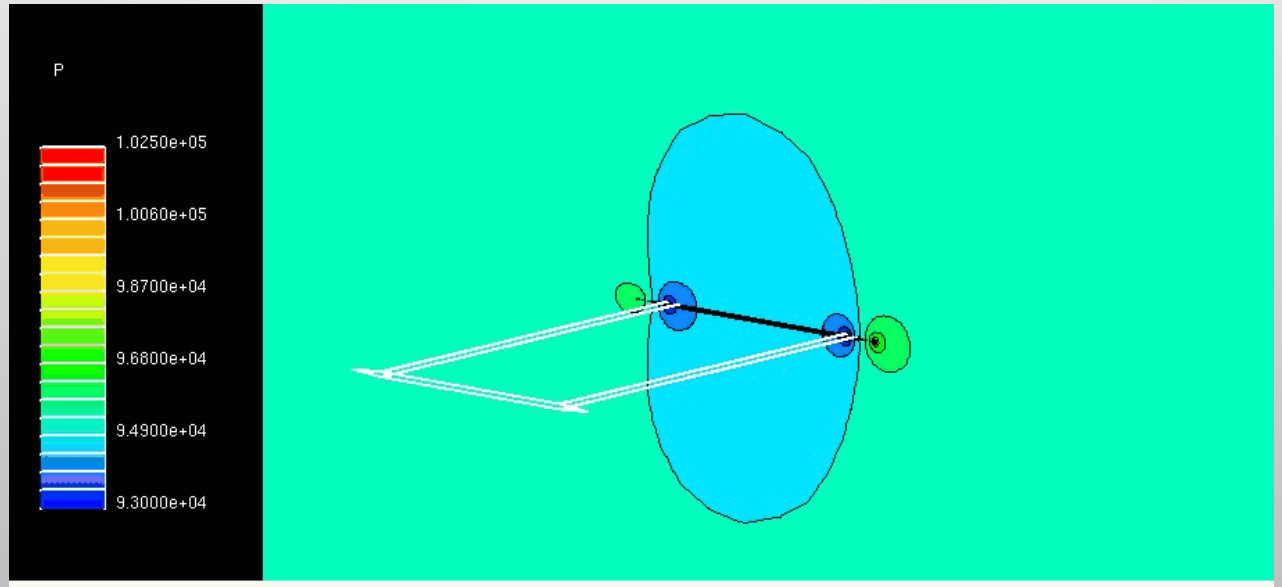


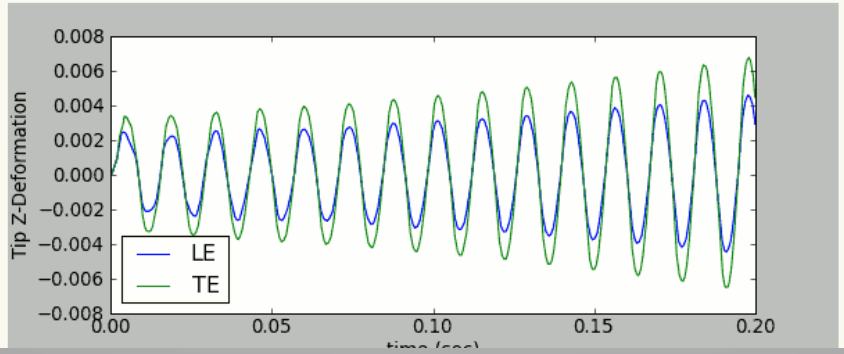
Chordwise section

Spanwise section



Mach 0.48 High Perturbation

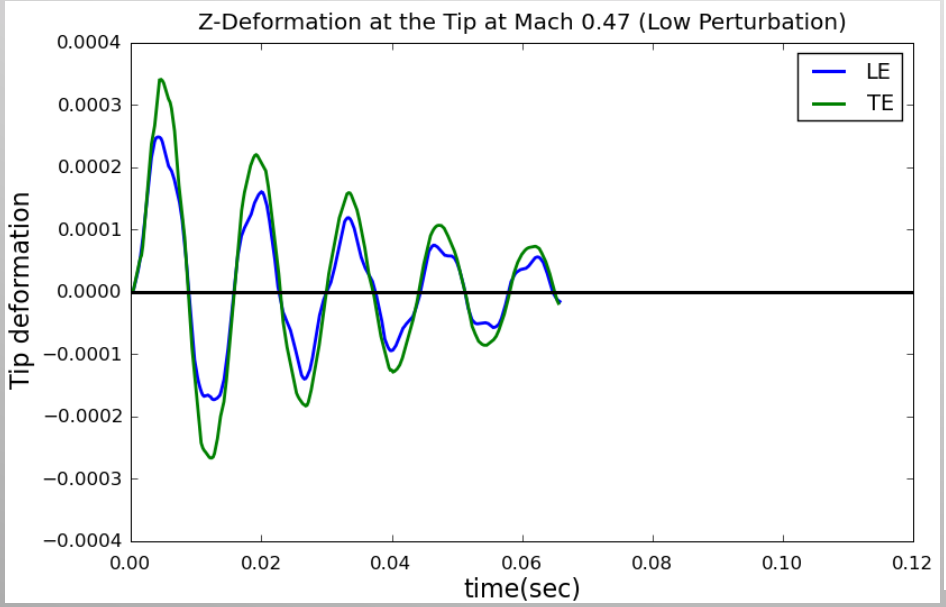




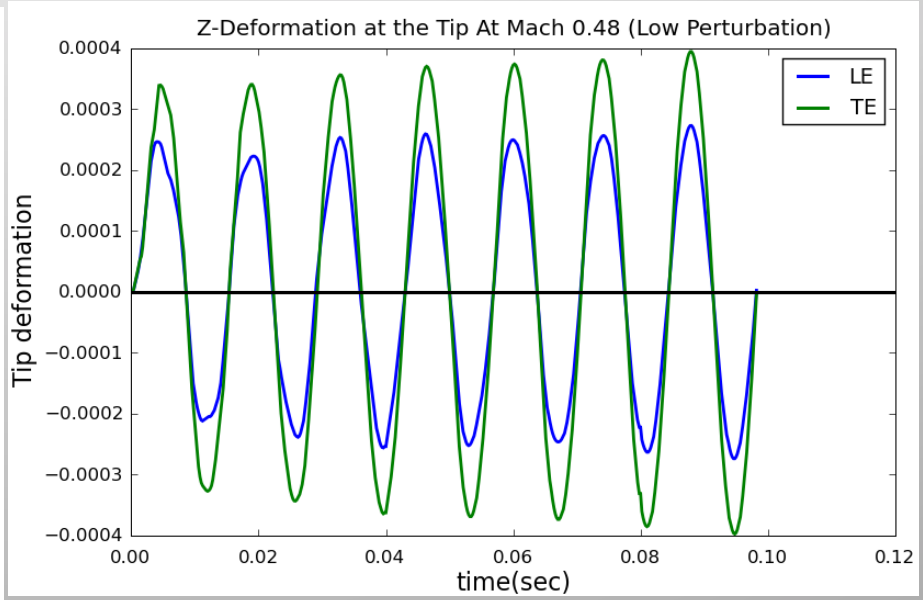
Pressure contours on slice at 50% span

Coupled Response (Low Perturbation)

Mach 0.47

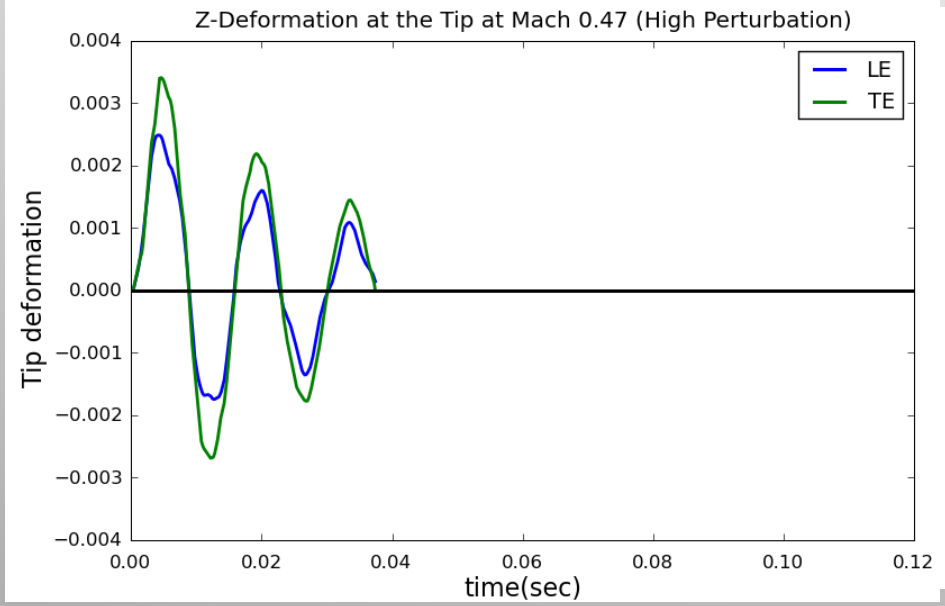


Mach 0.48

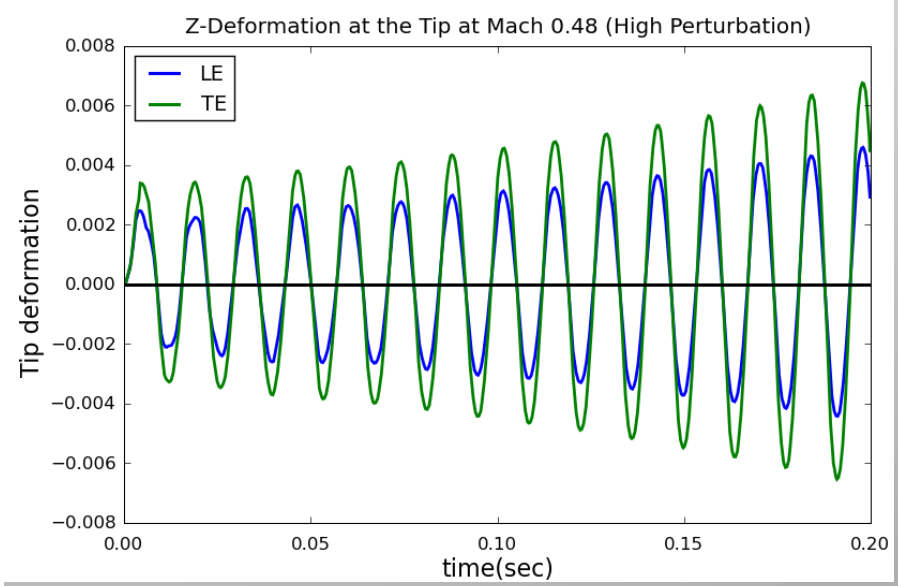


Coupled Response (High Perturbation)

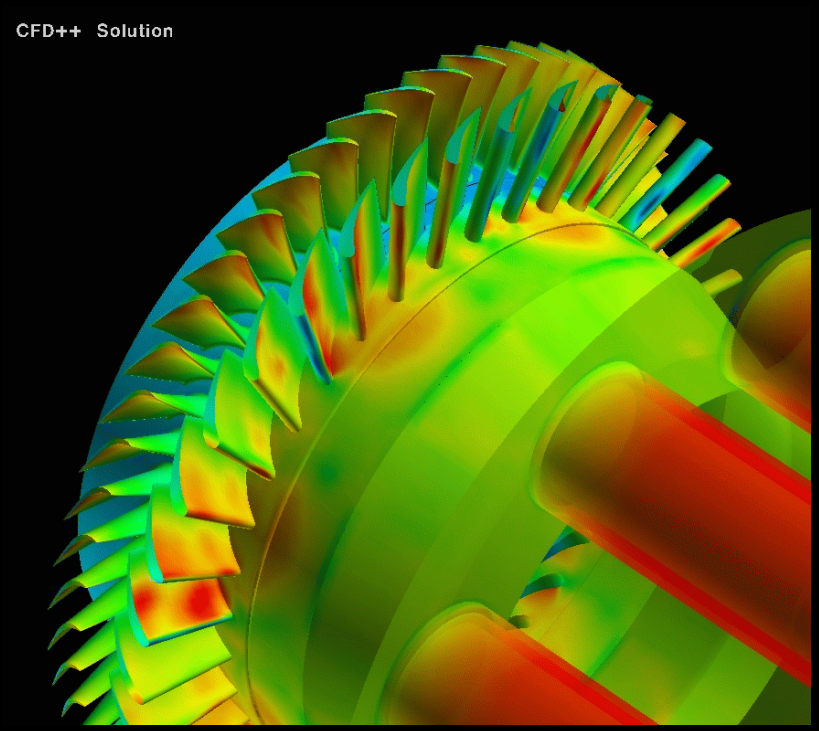
Mach 0.47



Mach 0.48

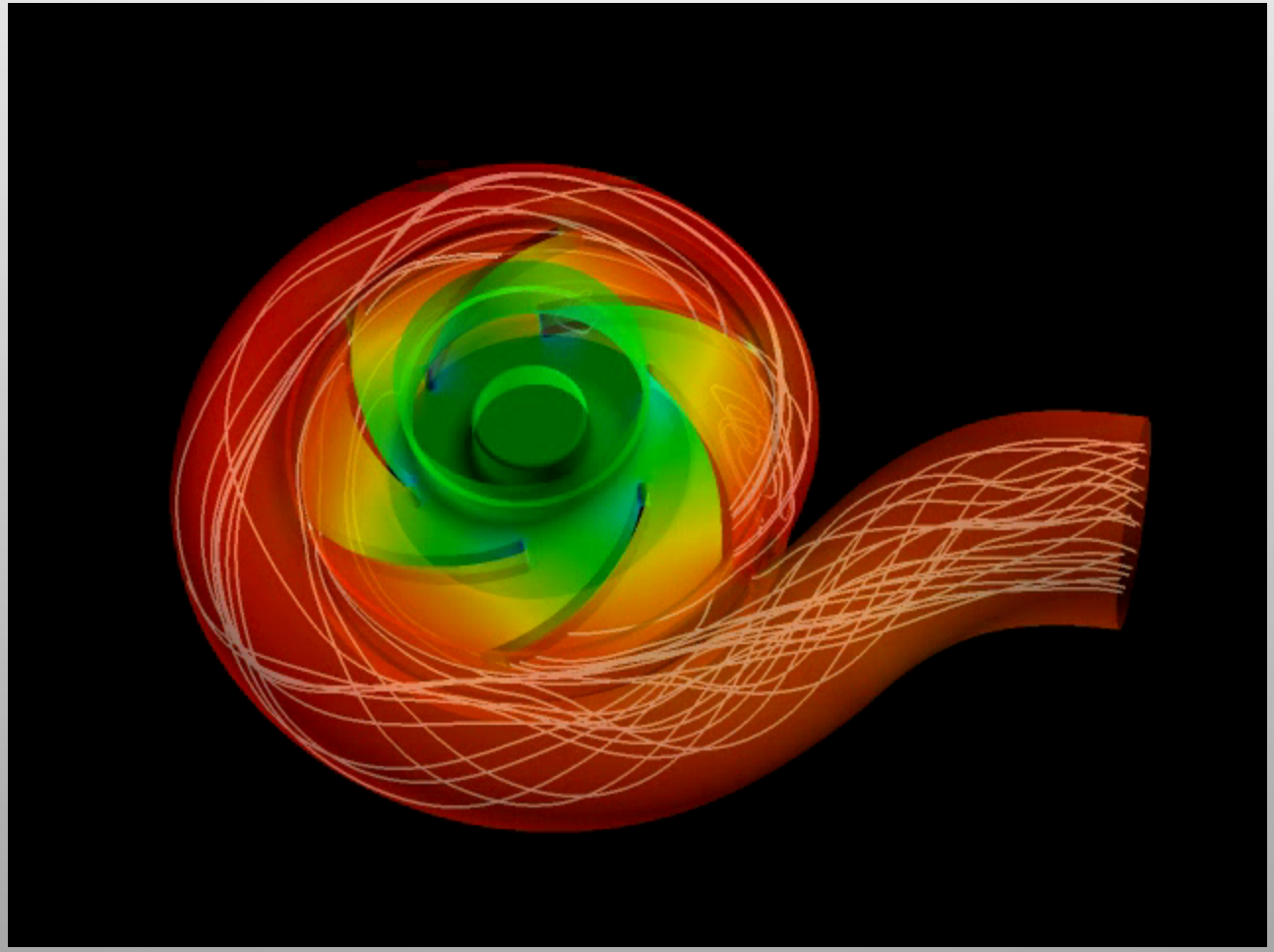


CFD++ CFD for all regimes

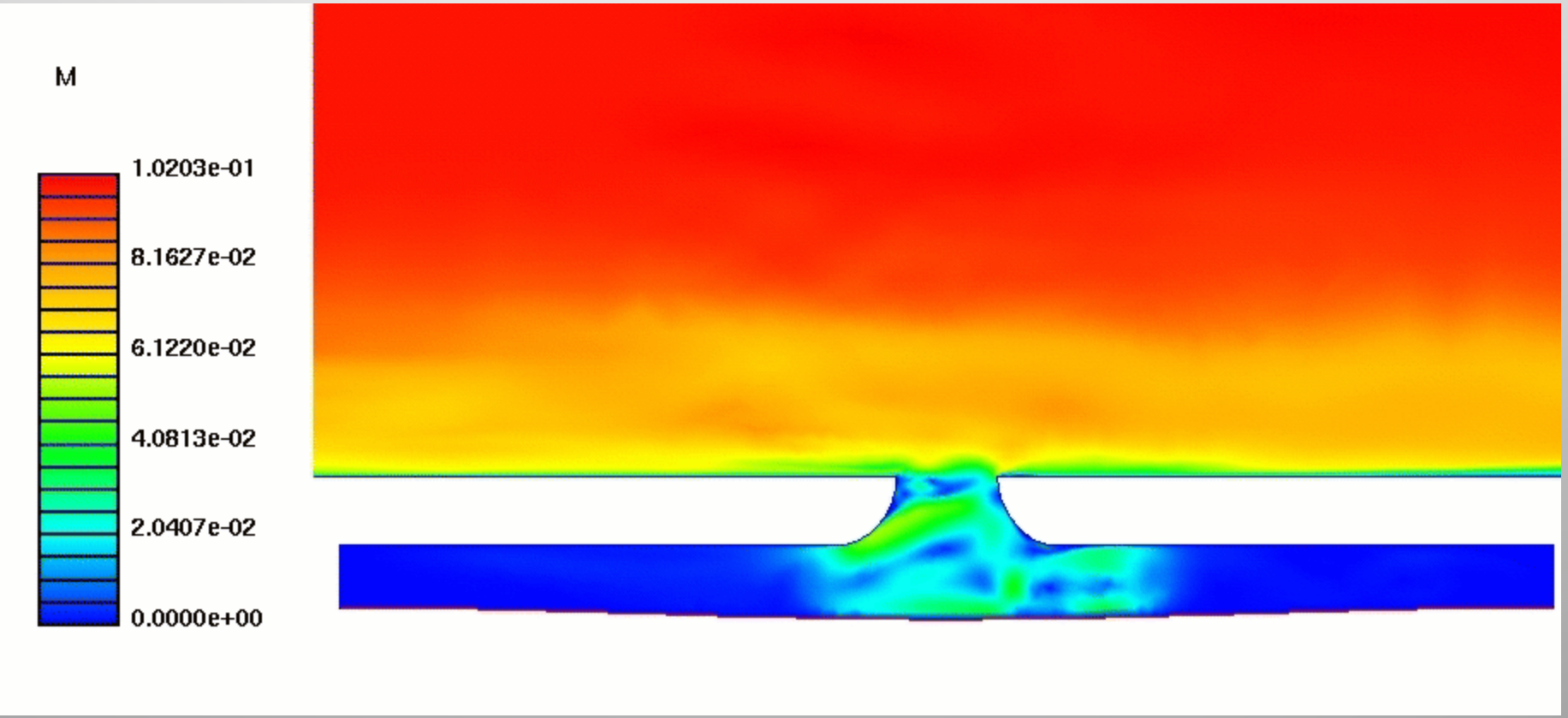


Turbomachinery stages +
Pulse Detonation Engine

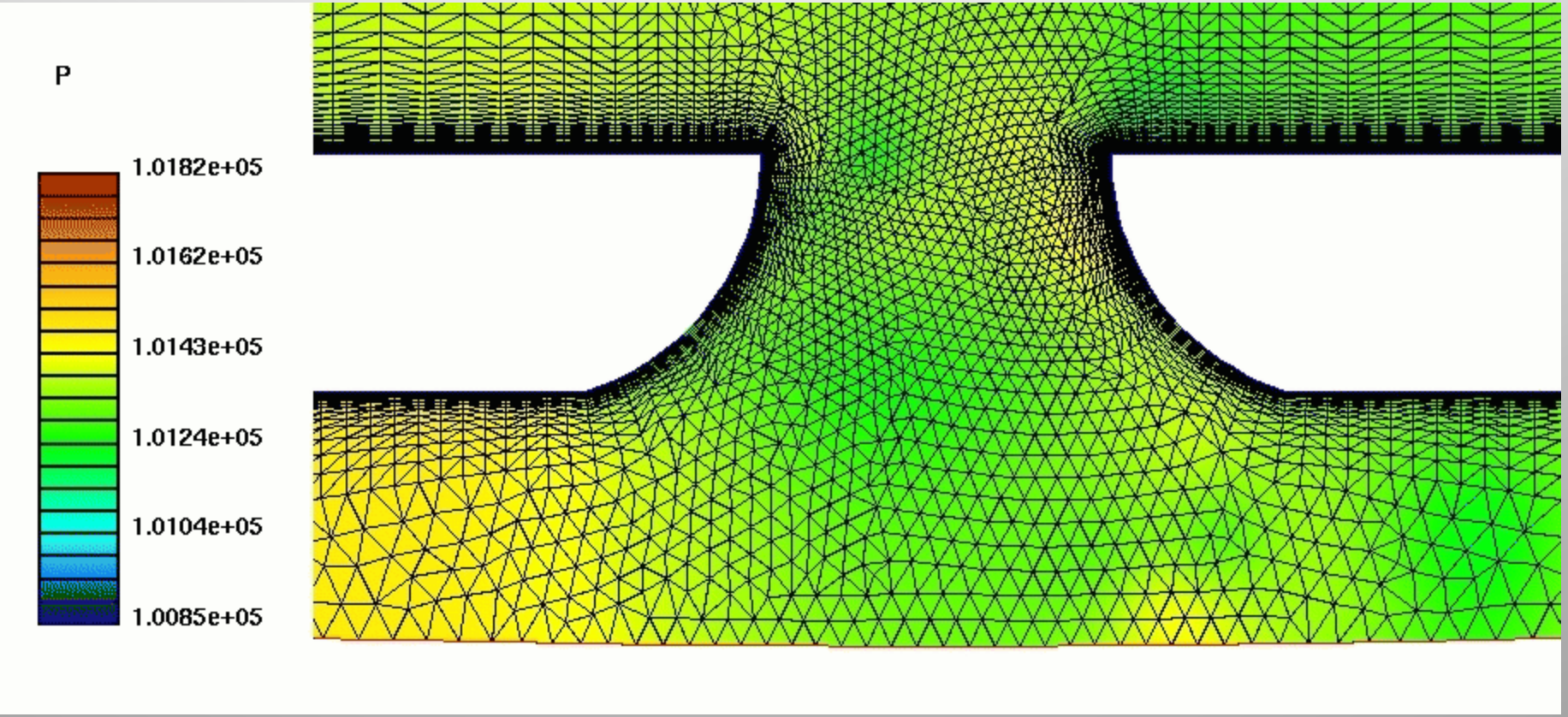
Turbomachinery



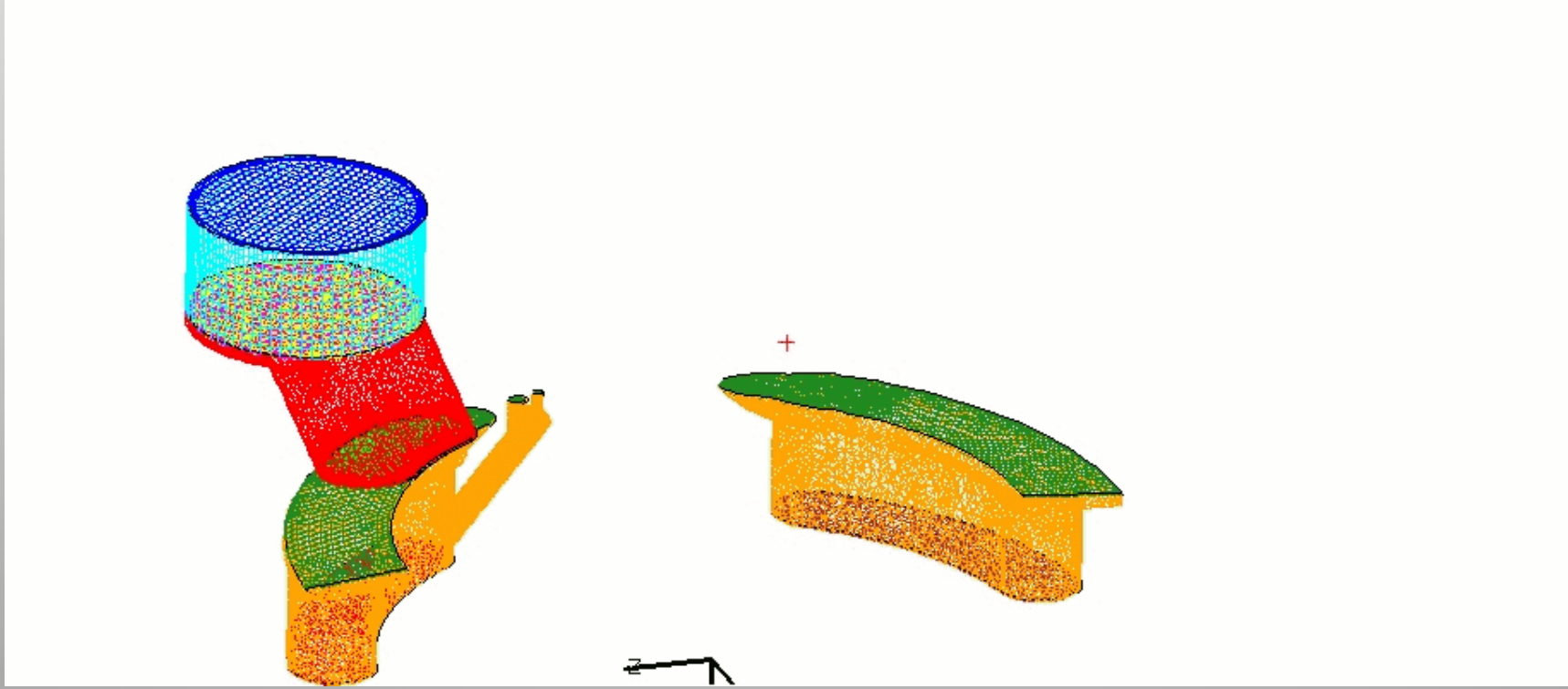
Synthetic Jet Flow Field

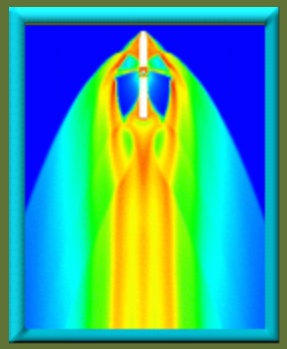


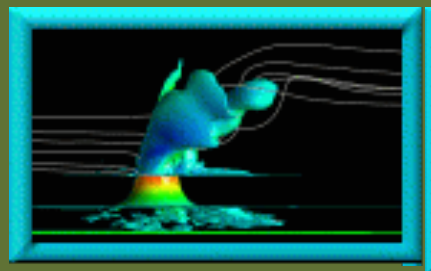
Synthetic Jet Illustration of Moving Mesh

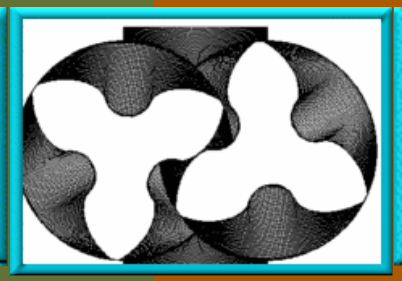


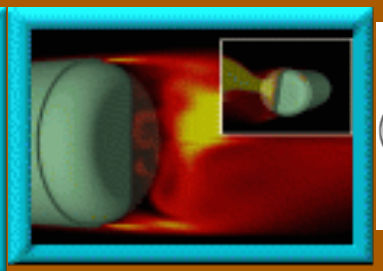
Pump with multiple axis motion

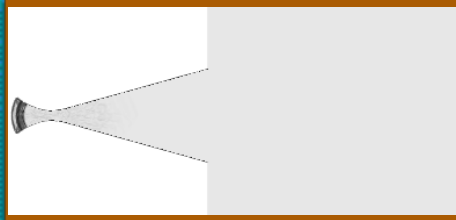










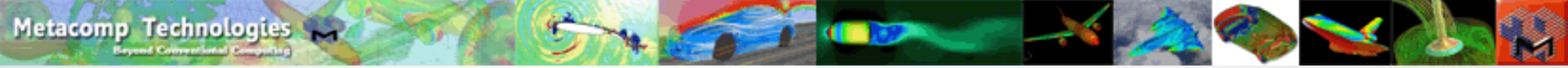


CFD++ Numerical Features

- *Coupled density or pressure-based solver*
- *Realizable physical, mathematical & numerical models*
- *Agglomeration (algebraic) multi-grid accelerated solver*
- *Multi-dimensional TVD framework*
- *Up to fourth order accuracy (temporal) in explicit mode*
- *Second order accuracy in time in implicit mode*
- *Fast convergence to steady state*
- *Fast computation of unsteady flows*
- *Specialized low-diffusion schemes for transient phenomena and acoustics*

CFD++ Efficient Solution Methods

- *Low or high speed, reacting or non-reacting*
- *Multiple incompressible and compressible liquids*
- *Conjugate heat transfer*
- *Supercritical fluids*
- *Multiphase flows*
- *Free-surface and front-tracking*
- *Sliding and overset meshes*
- *6-DOF Applications*
- *Thermal equilibrium & non-equilibrium*
- *Plasmas*
- *Radiation*



Thank you!

Questions?