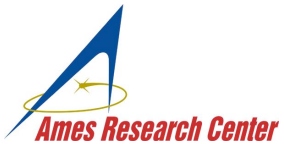


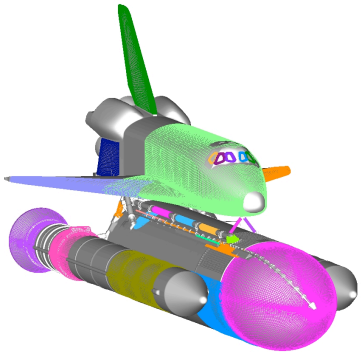
RECENT DEVELOPMENTS IN CHIMERA GRID TOOLS

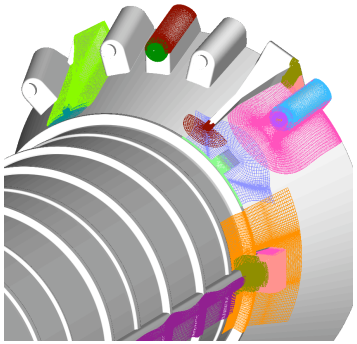
William M. Chan

NASA Ames Research Center

10th Symposium on Overset Composite Grids and Solution Technology,
Moffett Field, California, September 20-23, 2010

BOTTLENECKS IN CFD PROCESS USING STRUCTURED OVERSET GRID TECHNOLOGY





Level of Difficulty ↑

Surface grid generation

- Decisions in surface domain decomposition
- Decisions in grid point distribution

Volume grids domain connectivity

- Lack of software that is robust, automatic, fast, modular, and has low memory usage

Post-processing

- Difficult to determine solution convergence on large number of grids and geometric components (10^3 – 10^4)
- Difficult to do accurate surface loads computation
- Lack of robust and fast line loads analysis tool

OVERVIEW

Chimera Grid Tools Version 2.1 Enhancements (8/2007 – 3/2010)

- Software management and individual tools
- OVERGRID GUI
- Post-processing tools
- Grid generation strategy and tools
- Recent applications

Chimera Components Connectivity Library (4/2010 -)

- A domain connectivity library for overset grids with new algorithms for various operations (work in progress)

CHIMERA GRID TOOLS (CGT) VERSION 2.1

A software package of pre-processing and post-processing tools for overset grid computations

Authors - William Chan, Stuart Rogers, Shishir Pandya, David Kao, Pieter Buning, (Robert Meakin, David Boger, Steve Nash)

Availability - U.S. citizens/permanent residents under U.S. org. within the U.S.
- Source for Linux, Unix, Mac OS-X
- Executables for Mac 10.5, Windows-XP

ENHANCEMENTS IN SOFTWARE MANAGEMENT AND INDIVIDUAL TOOLS

General software management and operation

- New configure.in script and Makefiles

- Single *make* command to create single precision, double precision, OVERGRID and OVERSMART executables

- More automatic handling of big/little endian files in OVERGRID

- Conversion to Fortran 90 for most main modules

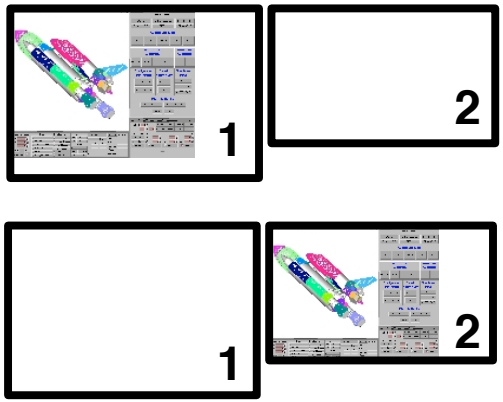
Individual tools

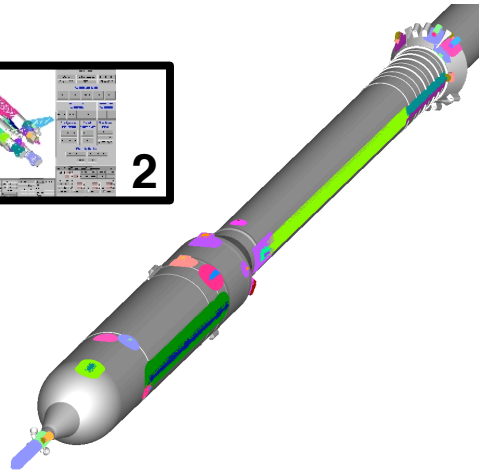
- Hyperbolic volume grid generator HYPGEN (added OpenMP option)

- Triangulation editor TRIGED (added functions for adding/deleting verts/triangles, detecting zero area and other logical degeneracies, fixing inconsistent normals, etc.)

OVERGRID NEW FEATURES

Dual screen mode





Individual CAD Volumes Inputs Control

CAD Volumes Info 1

CAD Volumes Information and Tesselation 1

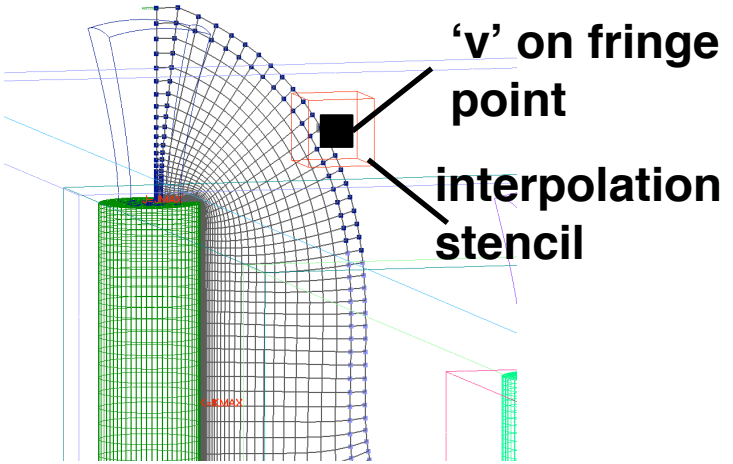
Number of volumes = 35 Global scale factor = 96.24332

No.	Name from CAD file	Orig. Scale	Mod. Scale	MaxAngle	MaxEdge	MaxChord	Tesselate
1	CLV_A106_LAS_SM	217.0	156.6217	14.0	0.1	0.05	☑
2	CLV_A106_US	252.1204	174.1819	14.0	0.1	0.05	☐
3	CLV_A106_IS_CYL	252.1204	174.1819	14.0	0.1	0.05	☐
4	CLV_A106_IS_FRUSTRUM	252.1204	174.1819	14.0	0.1	0.05	☐
5	CLV_A106_SRB	252.1204	174.1819	14.0	0.1	0.05	☐
6	CLV_A106_LASTUN_LAS	56.05231	76.14782	14.0	0.1	0.05	☐
7	CLV_A106_HARD_PNT_US	95.48853	95.86592	14.0	0.1	0.05	☐
8	CLV_A106_UHT_US	7.0	51.62166	14.0	0.1	0.05	☐
9	CLV_A106_UHT_US	4.377441	50.31038	14.0	0.1	0.05	☐
10	CLV_A106_CAM_US	8.938236	52.59078	14.0	0.1	0.05	☐
11	CLV_A106_CAM_US	0.6764297	48.45987	14.0	0.1	0.05	☐
12	CLV_A106_CAM_US	10.90268	53.573	14.0	0.1	0.05	☐
13	CLV_A106_USSTUN_US	31.19292	63.71812	14.0	0.1	0.05	☐
14	CLV_A106_PRESSTUN_US	71.08081	83.66207	14.0	0.1	0.05	☐
15	CLV_A106_ULLAGE_US	17.72524	56.98428	14.0	0.1	0.05	☐
16	CLV_A106_ULLAGE_US	17.72524	56.98428	14.0	0.1	0.05	☐
17	CLV_A106_ULLAGE_US	17.72524	56.98428	14.0	0.1	0.05	☐
18	CLV_A106_ULLAGE_US	17.72524	56.98428	14.0	0.1	0.05	☐
19	CLV_A106_RCS_US	29.7648	63.00406	14.0	0.1	0.05	☐
20	CLV_A106_RCS_US	12.45275	54.34804	14.0	0.1	0.05	☐

SELECT ALL | UNSELECT ALL | RE-TESSELATE | QUIT | QUIT ALL

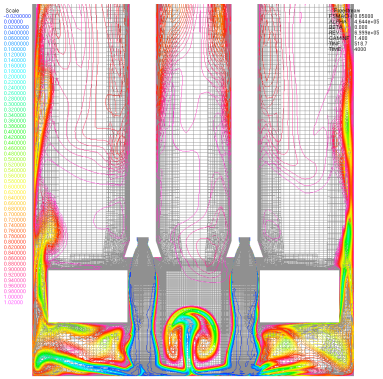
- Tesselation on/off switch
- Triangulation grid attributes
- Useful for large configurations with a big range of geometric scales

Interpolation stencil viewing



New Solution Viewer Functions

- Vorticity magnitude
- Strain rate
- Laminar & kinematic viscosity
- Wall y+
- Wall shear stress
- Q-criterion (unscaled)
- Q-criterion (normalized)

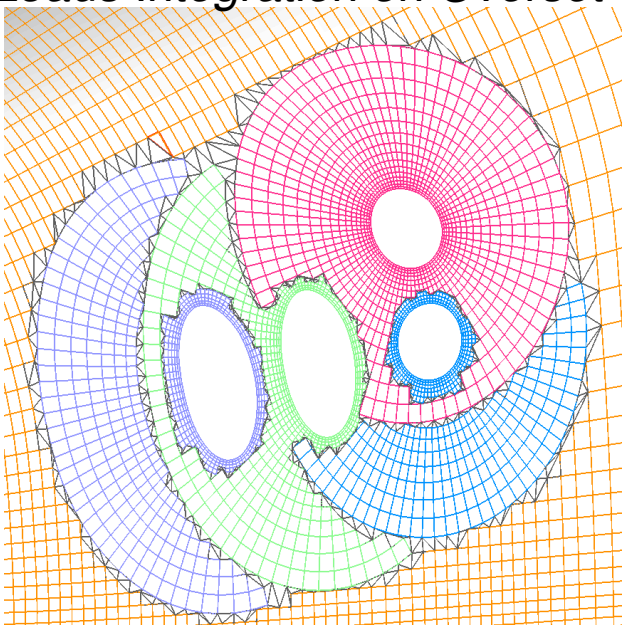


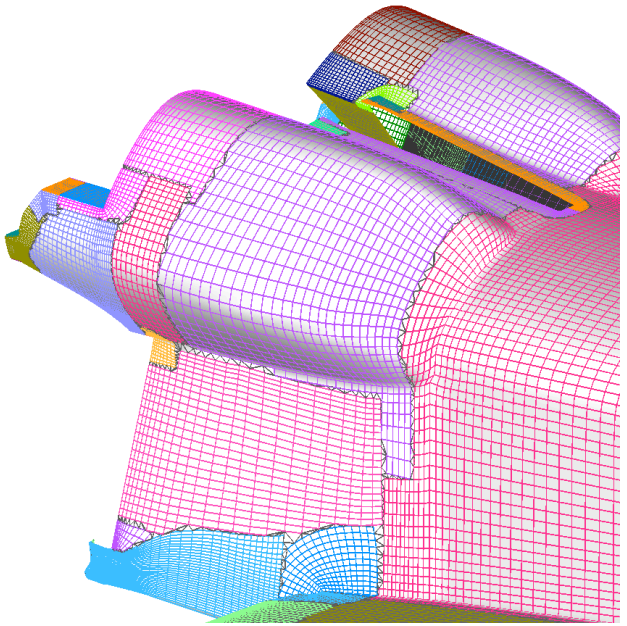
FORCE/MOMENT COMPUTATION

MIXSUR enhancements (hybrid surface mesh generator)

- **New sub-patch bounding box search, new triangulation scheme**
- **Much more robust and a factor of 40+ increase in speed**

Chan, W. M., Enhancements to the Hybrid Mesh Approach to Surface Loads Integration on Overset Grids, AIAA Paper 2009-3990, 2009.





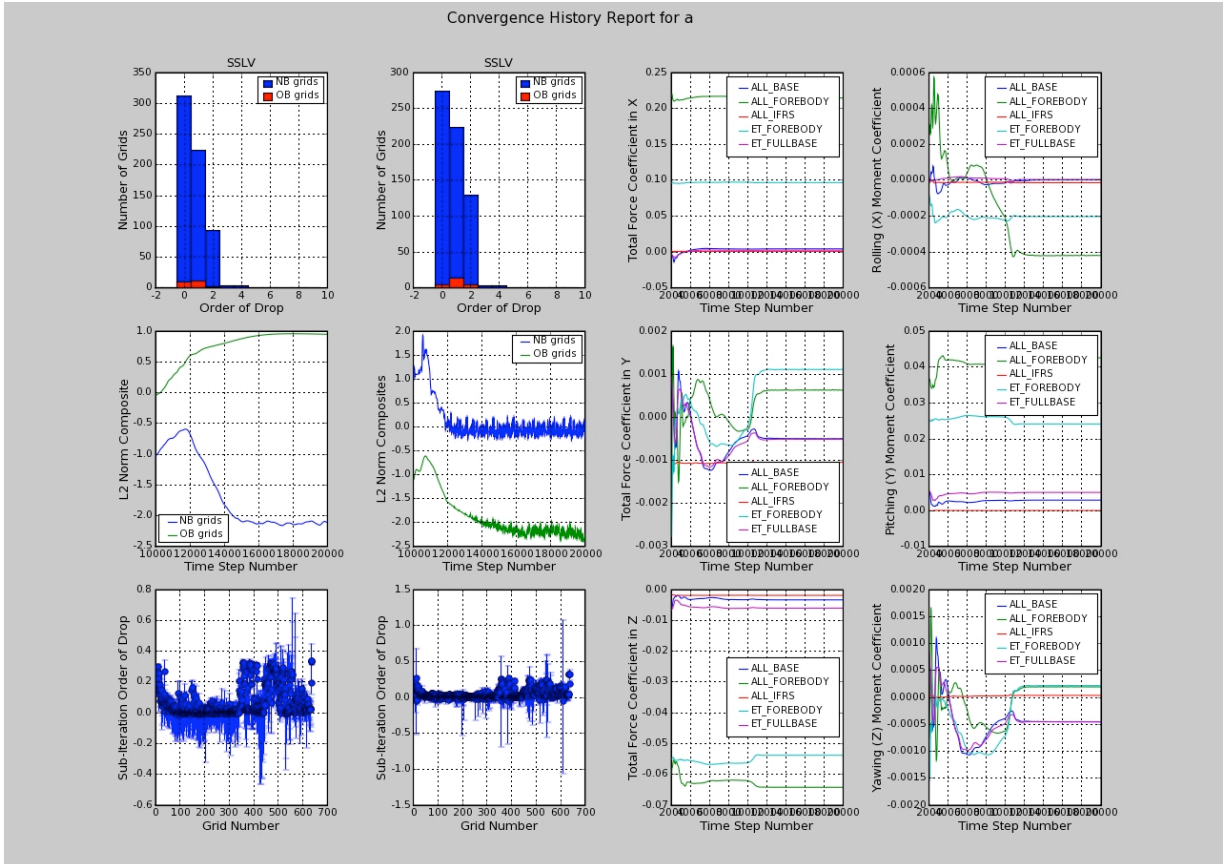
OVERINT enhancements (force/moment integrator)

- **integrate – (p – p_inf) or – p**
- **report forces/moments in non-dimensional or dimensional units**
- **report contributions from quads and triangles**

OVERSMART - SOLUTION CONVERGENCE SUMMARY REPORT

- Generate executive summary of convergence for residuals/sub-iterations of N-S and turbulence model equations for ALL grids, and histories of component forces/moments
- Command-line or GUI mode with python and matplotlib

Just type "oversmart" to generate summary page →



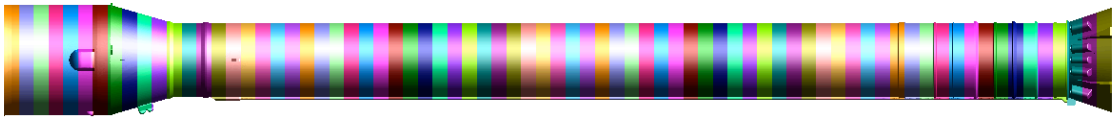
SSLV case: 10,000 time steps, 636 grids, 3 sub-iterations (19 million lines)

Kao, D. L., Chan, W. M., OVERSMART – A Solution Monitoring and Reporting Tool for the OVERFLOW Flow Solver, AIAA Paper 2009-3998, 2009.

LINE LOADS INTEGRATION TOOL – TRILOAD (S. Pandya)

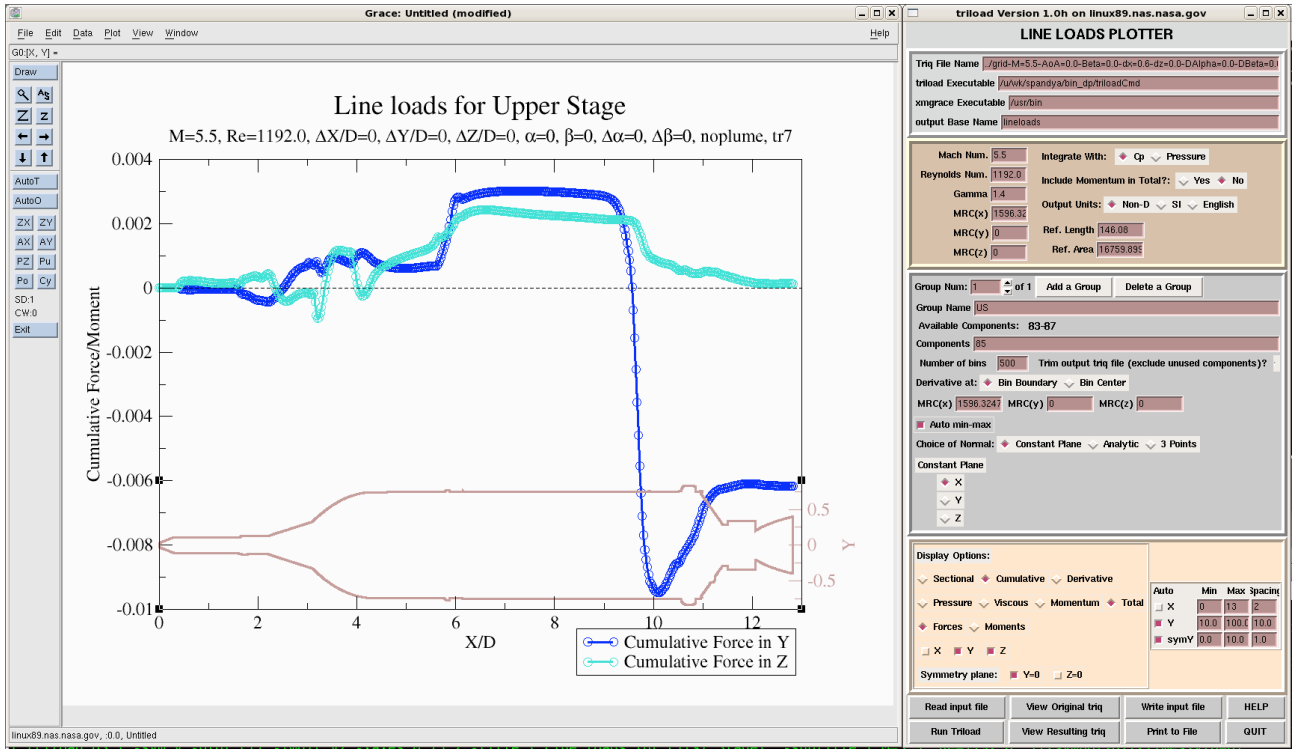
- Slices through a triangulation in a user-specified direction and computes sectional and cumulative loads
- New algorithm is a factor of 36 faster than previous methods (Previous time = 9 min., current time = 15 sec., 501 slices on launch vehicle)

Slice direction →



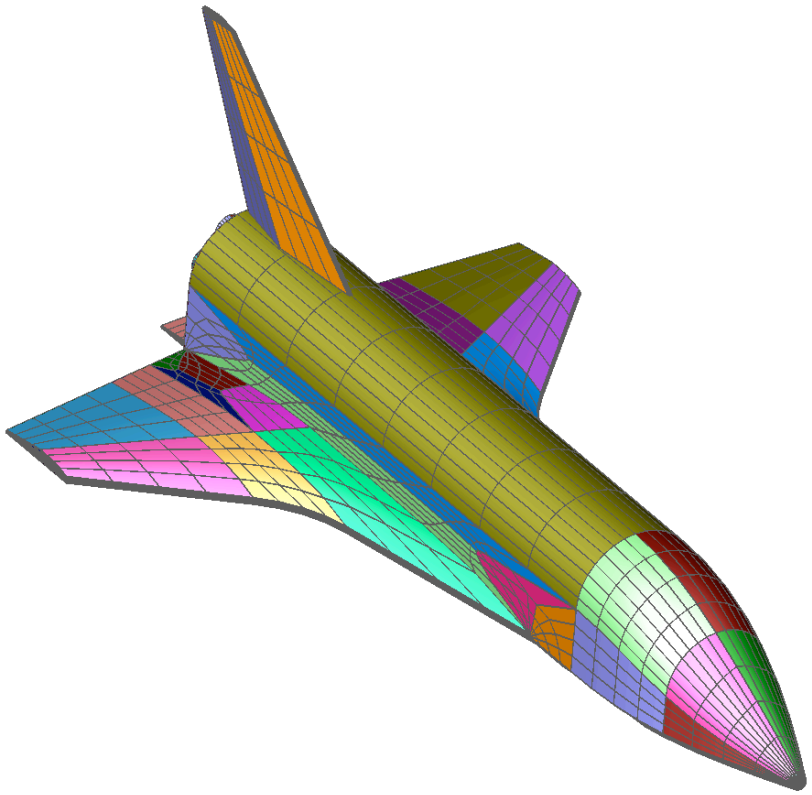
Modes

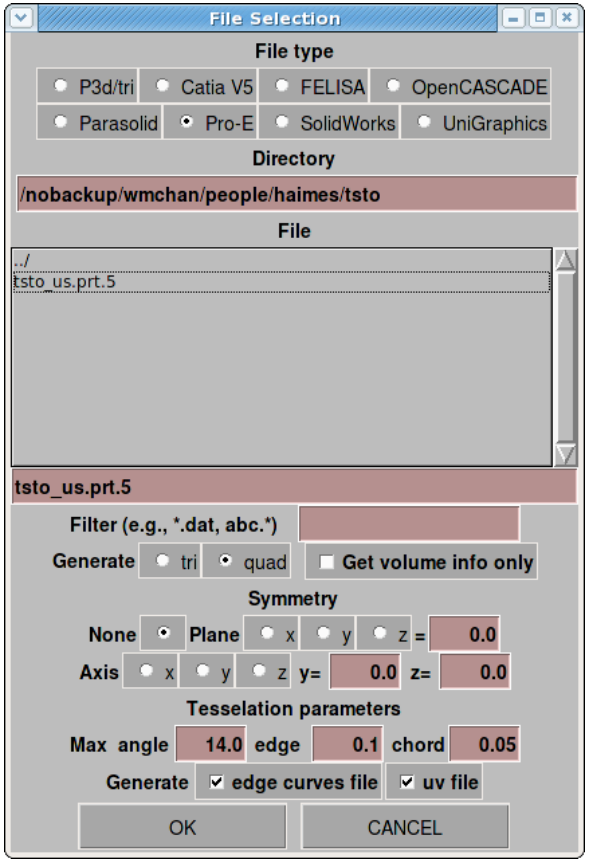
- Command line *(in CGT 2.1)*
- GUI *(in CGT 2.1b)*



SURFACE GRID GENERATION AUTOMATION STRATEGY (PLAN A)
Virtual Topology Editor (VTE) Library Interface

- **Auto creation of structured quadrilateral surface patches from solid CAD parts (*J. Dannenhoffer* ,** Syracuse University, ***R. Haimes,*** MIT**)**
- **Tcl script interface, no compilation needed to interface with OVERGRID**
- **Good potential for general automation**
- **Early development stage, grid cells are of mixed quality**





SURFACE GRID GENERATION AUTOMATION STRATEGY (PLAN B)
CGT Script Library

Library of grid generation script macros

Pros - Automated parameterized grid generation for topologically similar components

Cons - Not general, need to build script the first time, and script modification is required for any change in topology

- Over 50 new macros introduced in CGT 2.1

Level 1: Low level grid operations (2005-2009)

Level 2: Straight forward combination of Level 1 or Level 2 steps (2008 - …)

Level 3: Level 2 plus expert knowledge in gridding decisions (2009 - …)

Level 4: Creation of grid systems for specific component classes e.g., wings, rotors, feedlines, collars, … (1991 - …)

Goal: Reduce grid generation effort by creating more Level >=2 macros

Pandya, S. A., Chan, W. M., Kless, J., Automation of Structured Overset Mesh Generation for Rocket Geometries, AIAA Paper 2009-3993, 2009.

CGT SCRIPT LIBRARY – Level 1 Macros Examples

Grid Operations

Extract	Translate	Swap index	Revolve
Concatenate	Rotate	Reverse index	Split
Redistribute	Mirror	Duplicate	Smooth

Geometry Creation

Cylinder
Frustum
Airfoil

Pre-processing Commands

Boundary conditions
Hole cut instructions
Components specs

Grid Generation

Hyperbolic-surface
Algebraic-surface
Hyperbolic-volume
Cartesian-volume
X-ray creation

Input Files Creation

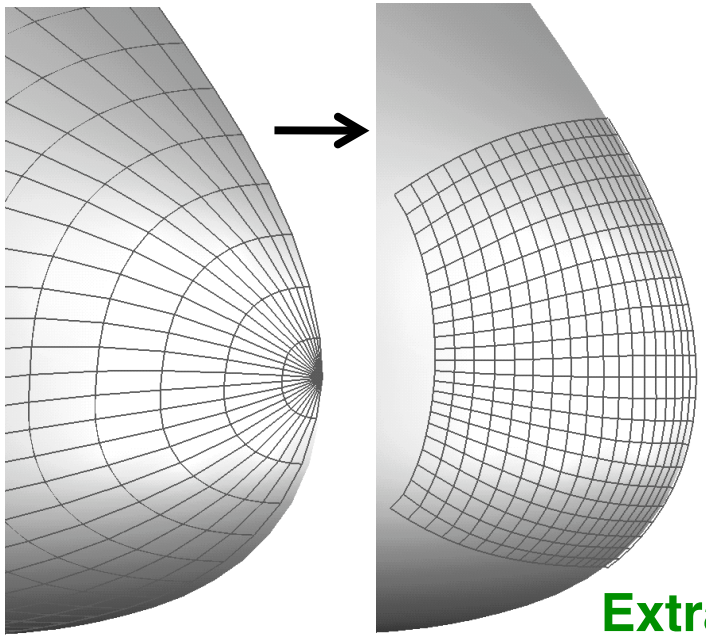
Flow solver
Force/moment integration

File Manipulation

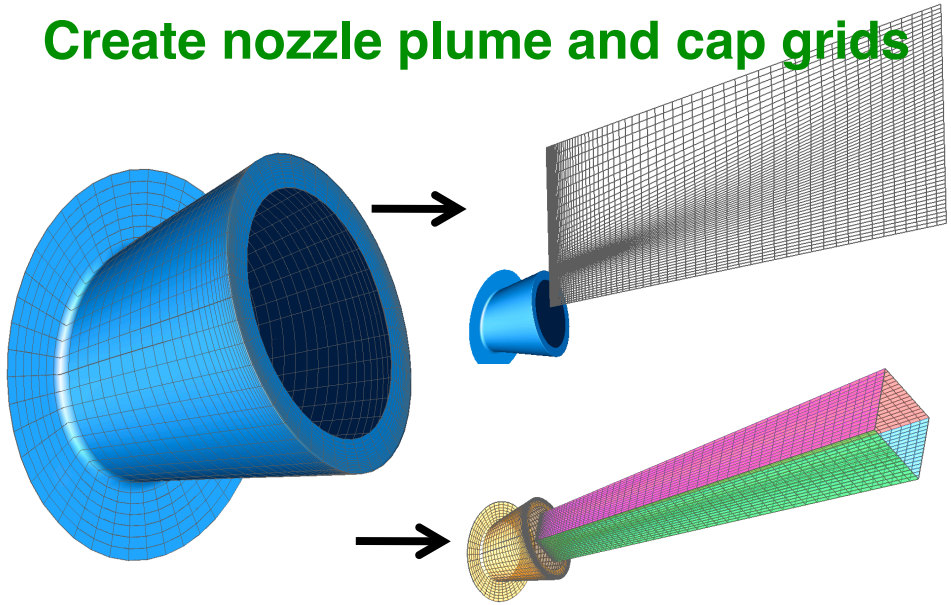
Split, Combine, Clean-up

CGT SCRIPT LIBRARY – Level 2 Macros Examples

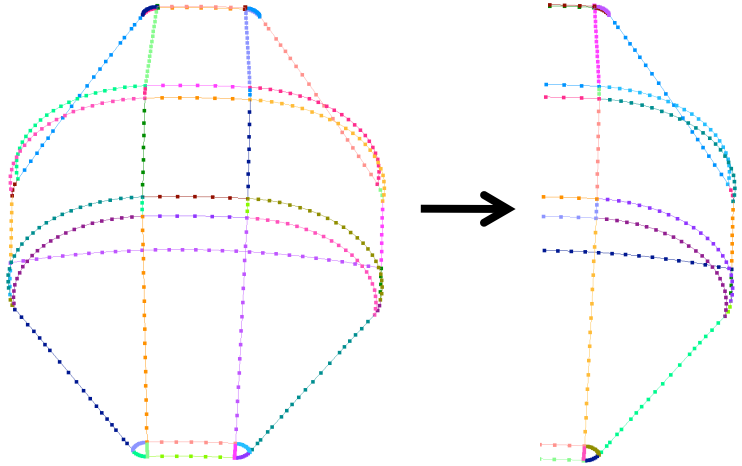
Create axis cap grid



Create nozzle plume and cap grids

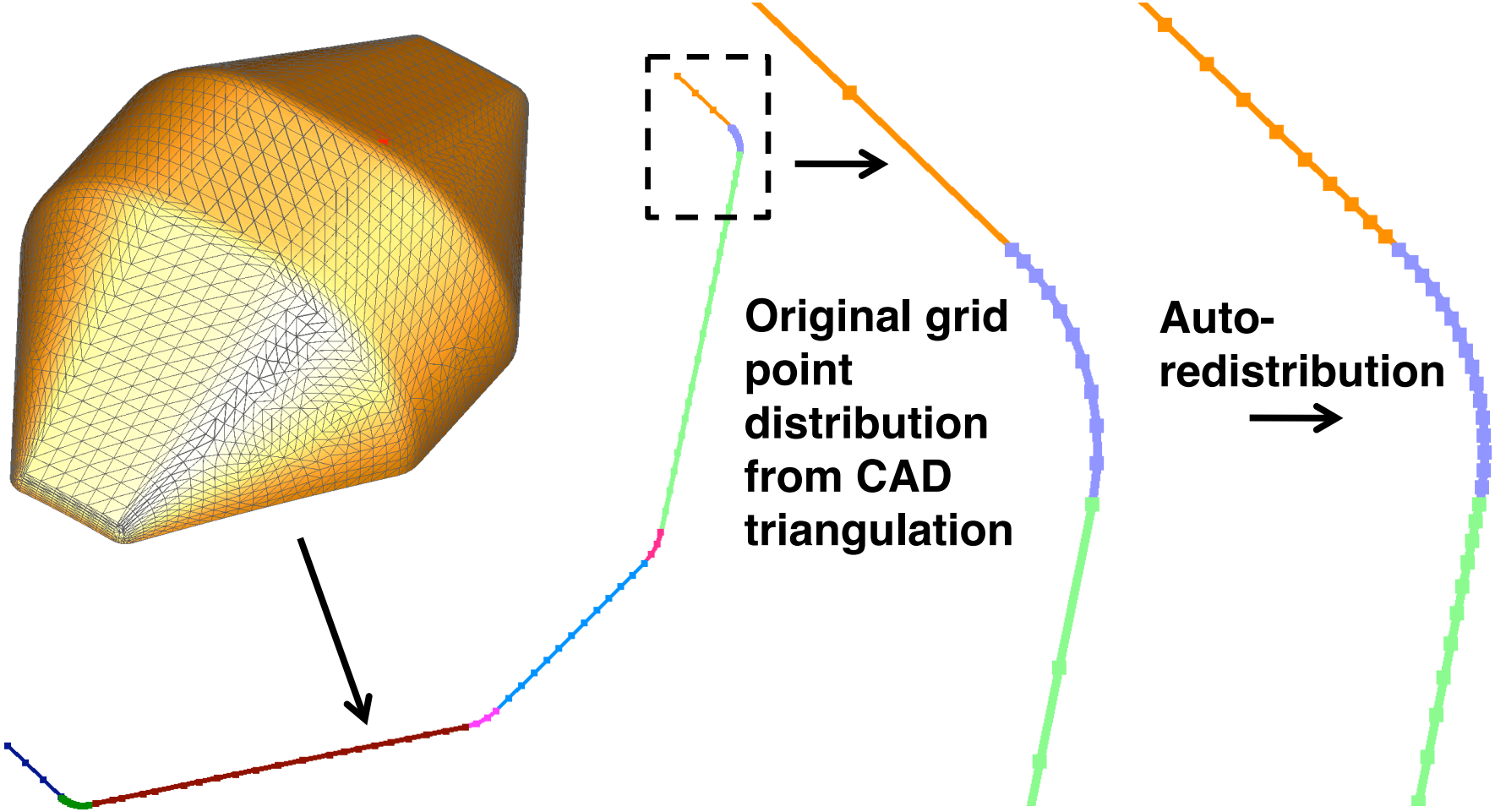


Extract curves in half plane



CGT SCRIPT LIBRARY – Level 3 Macros Example

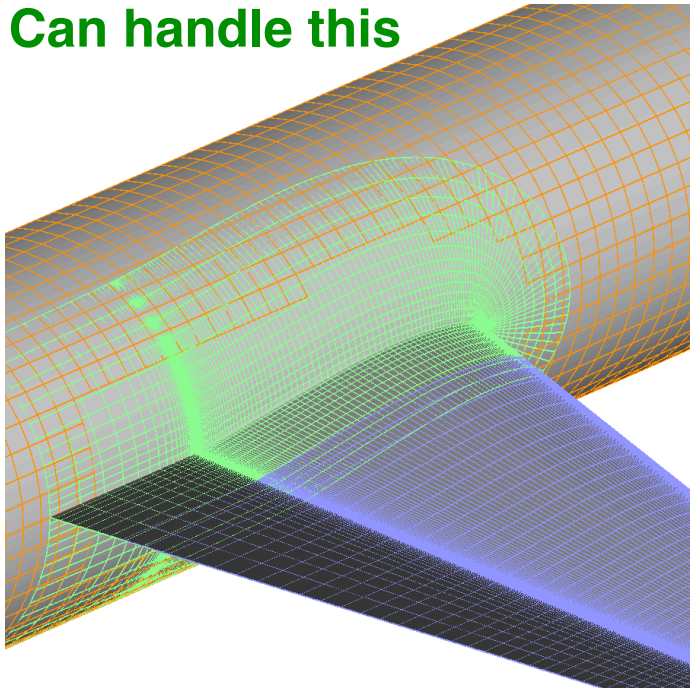
Automatic grid point redistribution on multiple curve segments based on turning angle, concave/convex corner considerations
Inputs: max Δs, end Δs, max stretching, max turning angle, scale factor



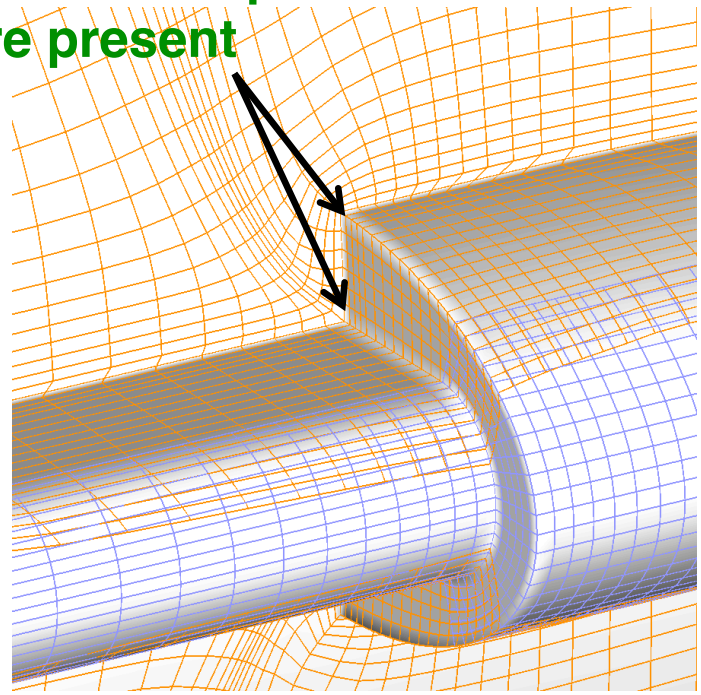
CGT SCRIPT LIBRARY – Early Level 4 Macros

Collar grid script (early 1990's) – creates collar grid connecting two components that are topologically similar to a simple wing/ body system

Can handle this



Fails if sharp features are present



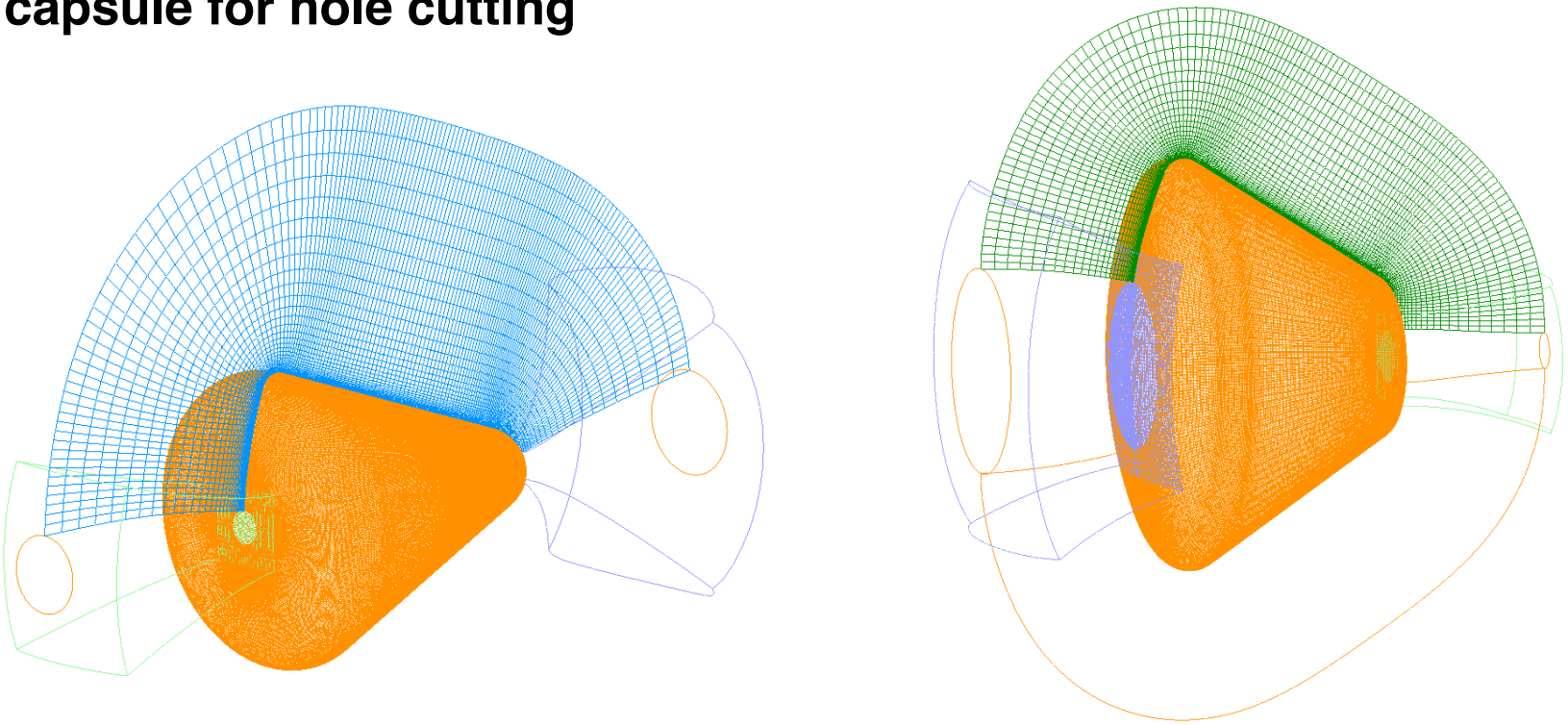
Also fails for low/high wing

Work is planned to generalize the collar technology

RECENT LEVEL 4 MACROS – Capsule Script (2007)

Starting point – 3- or 4-segment axisymmetric curve that defines geometry

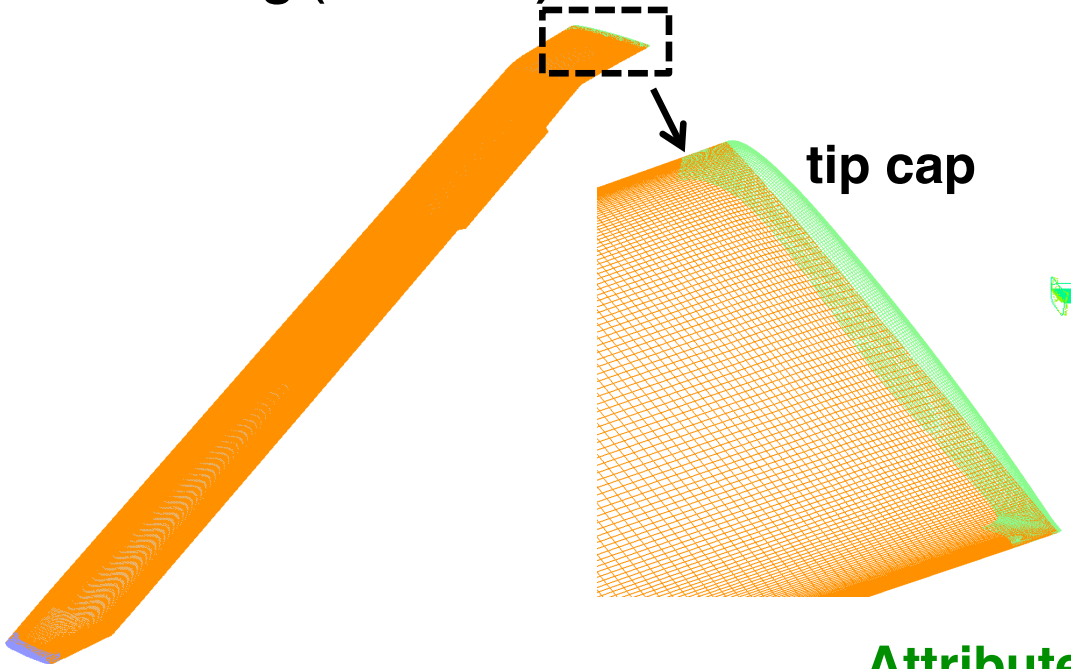
Product - capsule surface and volume grid system with main body plus end caps for capsules with one or two shoulders, X-ray file of capsule for hole cutting

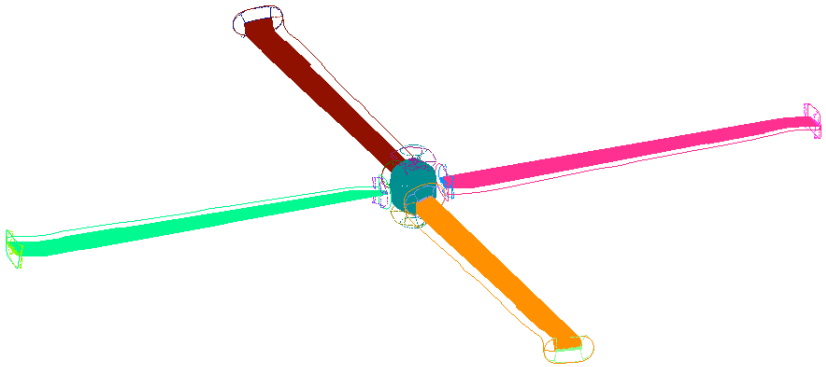


Chaderjian, N. M., Olsen, M. E., Grid Resolution and Turbulence Model Effects on Space Capsule Navier-Stokes Simulations, AIAA Paper 2007-4562, 2007.

RECENT LEVEL 4 MACROS – Rotor Blade Script (2008-2010)

Starting point – blade surface geometry in one or more sections
Product – rotor blades surface and volume grid system with main blade plus root and tip caps for N blades, blade X-ray file for hole cutting (N=3 or 4)





4-bladed volume grid system

Attributes

- **O-mesh**
- **Finite-thickness trailing edge**
- **Truncated or rounded root/tip caps**

Ahmad J., Kao, D., Chaderjian, N. (unpublished)

MACROS FOR OTHER PRE-PROCESSING TASKS

Specification of boundary conditions

SetOvrBCInput $gn $i $bctype $ibdir $args

$gn = grid number, $i = ith boundary condition,
$bctype = boundary condition type, $ibdir = +/- J/K/L
$args = J,K,L index ranges (optional)

Specification of X-ray hole cut instructions

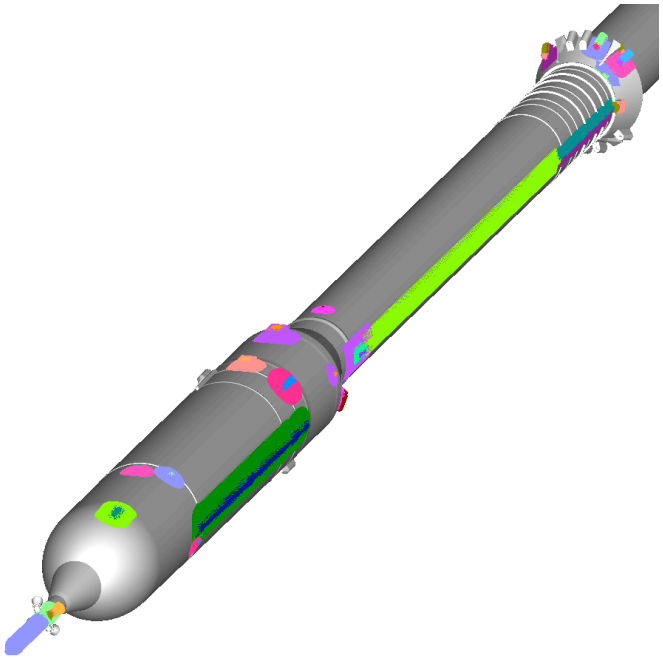
SetOvrHoleCutInstr $j $xid $xdelta 1 $glist
SetOvrHoleCutInstr $j $xid $xdelta 0 $gs $ge

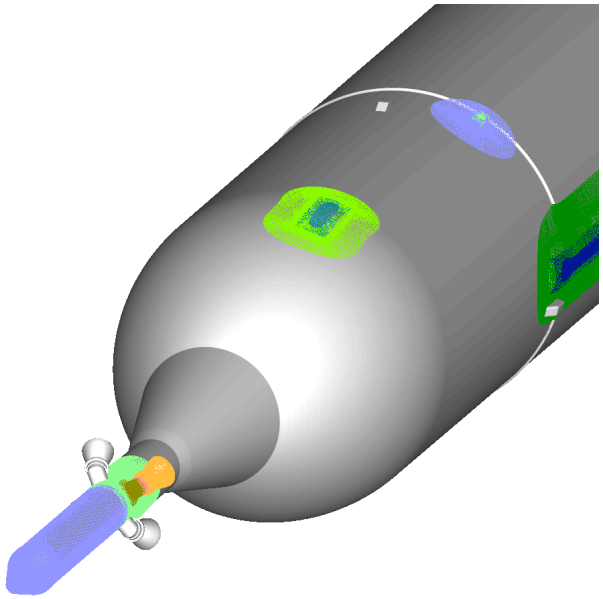
$j = jth hole cut instruction, $xid = X-ray ID,
$xdelta = hole offset distance, $glist = grid list
$gs, $ge = start and end grid numbers

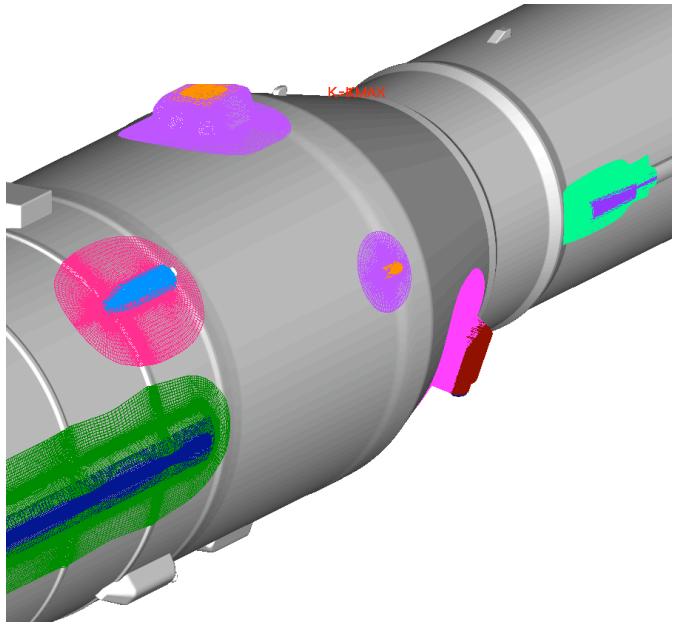
Write Overflow2 flow solver input file with above info

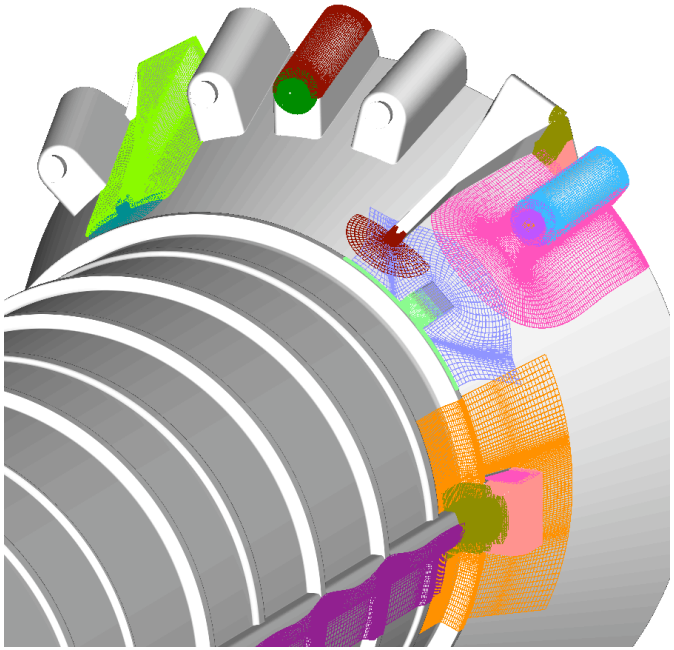
WriteOvr2InpFile $filename

RECENT APPLICATIONS OF CGT SCRIPT LIBRARY
1. Space Launch Vehicle – integrated stack (various designs)







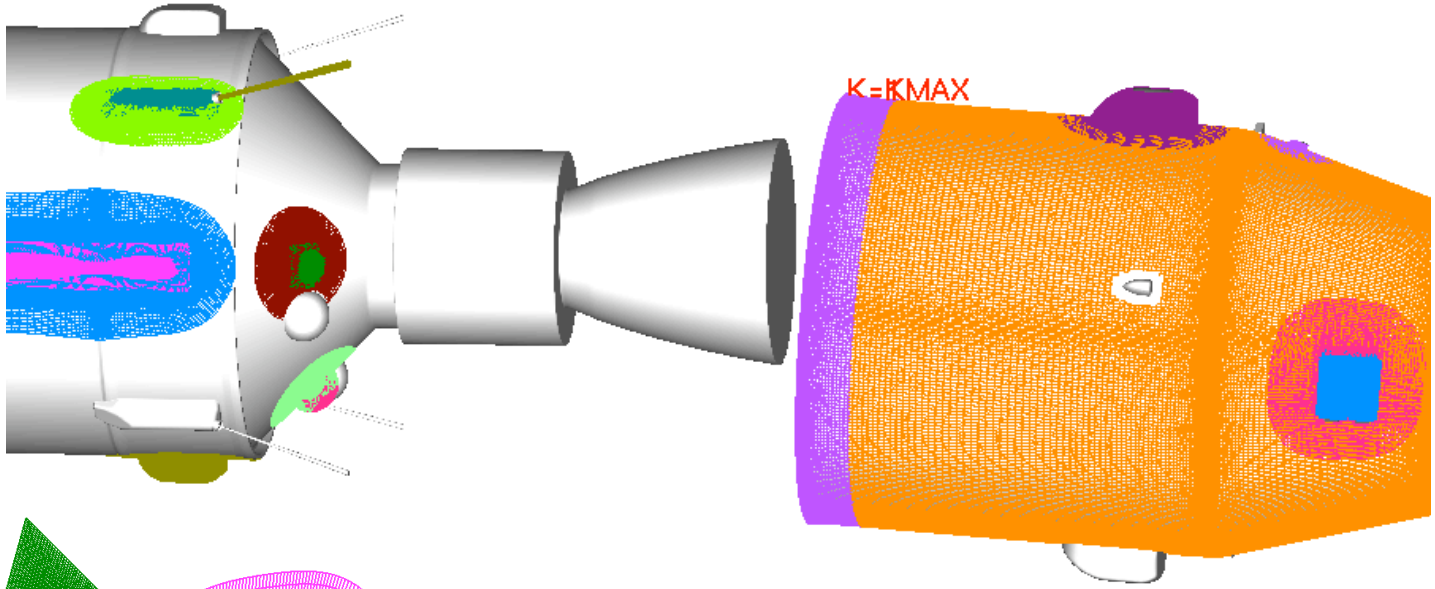


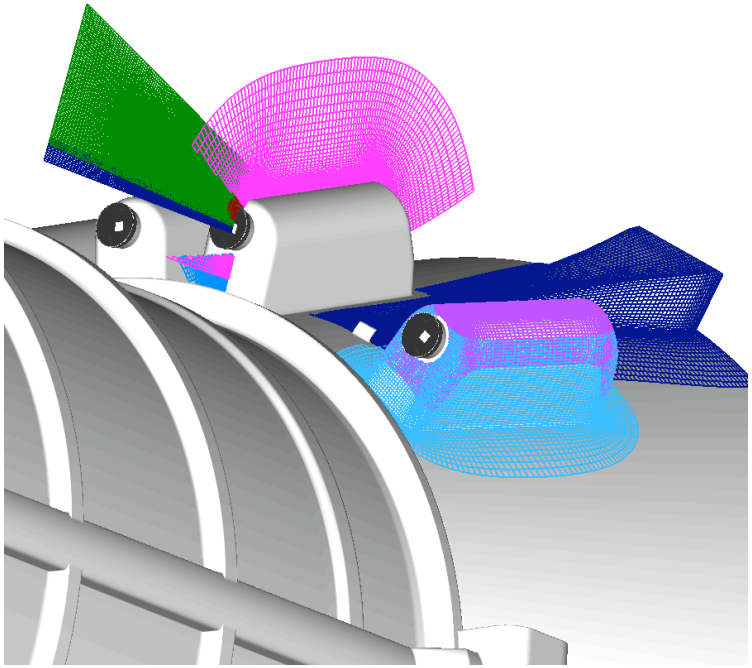
190 volume grids

185 million volume grid points

89 X-rays

RECENT APPLICATIONS OF CGT SCRIPT LIBRARY
2. Space Launch Vehicle – stage separation mode with plumes





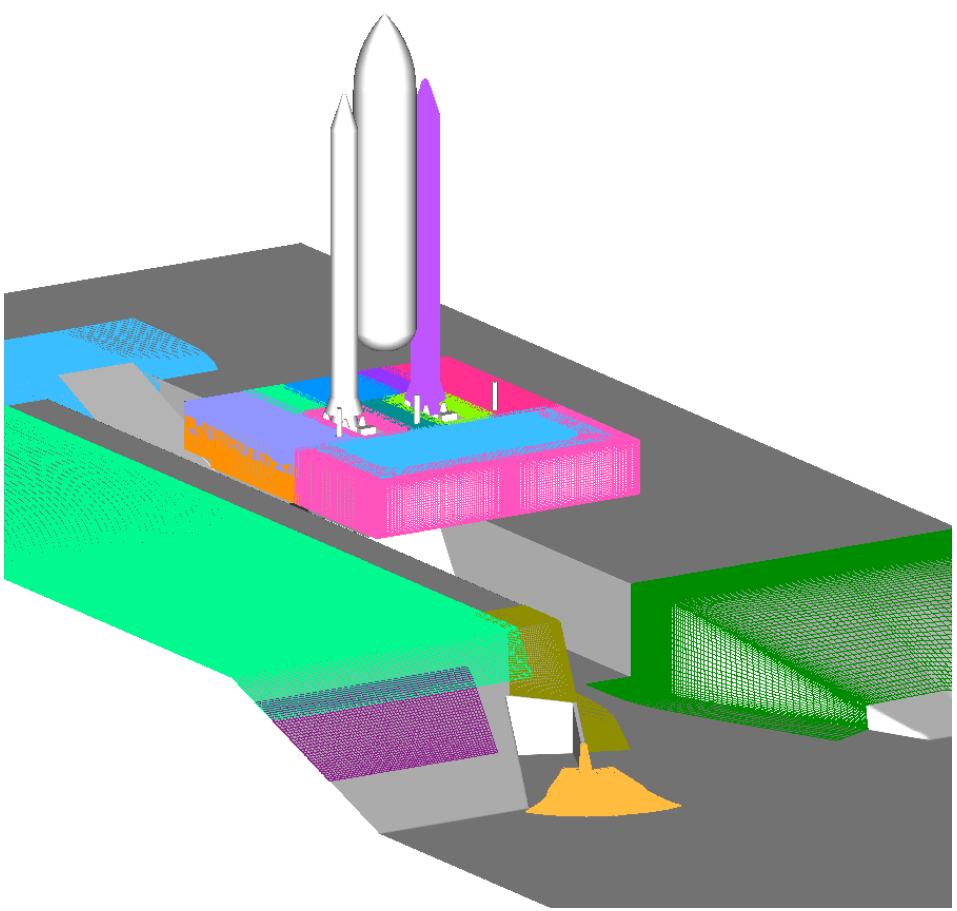
224 volume grids

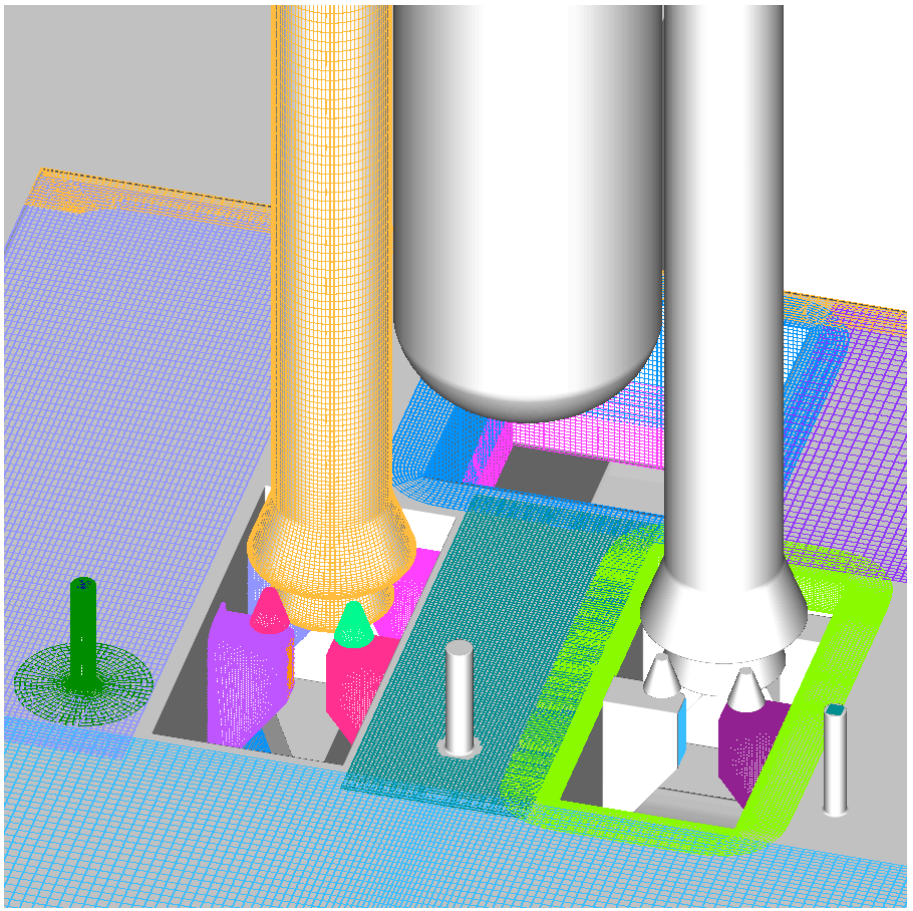
267 million volume grid points

162 X-rays

RECENT APPLICATIONS OF CGT SCRIPT LIBRARY
3. Launch Site Analysis

224 volume grids, 267 million volume grid points, 32 X-rays





CHIMERA COMPONENTS CONNECTIVITY LIBRARY (C3LIB)

Motivation

- Each domain connectivity code has their own pros and cons
- Would like to easily
  - mix and match different algorithms for different parts of the process
  - link to a flow solver in relative motion problems

Objectives

- Create a standard API for various domain connectivity operations
- Library interface for
  - * creating iblank array for minimum hole cut
  - identification of outer and hole boundary fringe points
  - data structure creation for stencil searches
  - * stencil search for point in surface domain (multiple surface grids)
  - * stencil search for point in volume domain (multiple volume grids)
  - * outer/hole boundary connectivity for multiple surface/volume grids
  - * hole/stencil optimization
  - near-wall stencil shifting

* Investigate new algorithms to improve various parts of the process

C3LIB FUNCTIONS

Starting inputs:

- Multiple overset structured volume grids
- User-supplied locations of surface subsets that make up each Chimera component (grid numbers, J,K,L index ranges) (automatable)

Minimum Hole Cut (Noah Kim)

- Automated Oriented On-Demand X-rays (in progress)

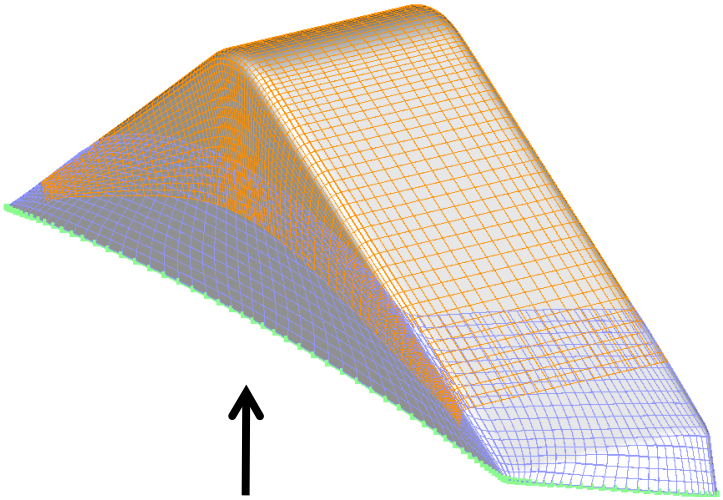
Surface Point Stencil Search

- Bounding box search based on index space subset sub-division (same as algorithm in mixsur)

Fringe Point Stencil Search for Volume Grids

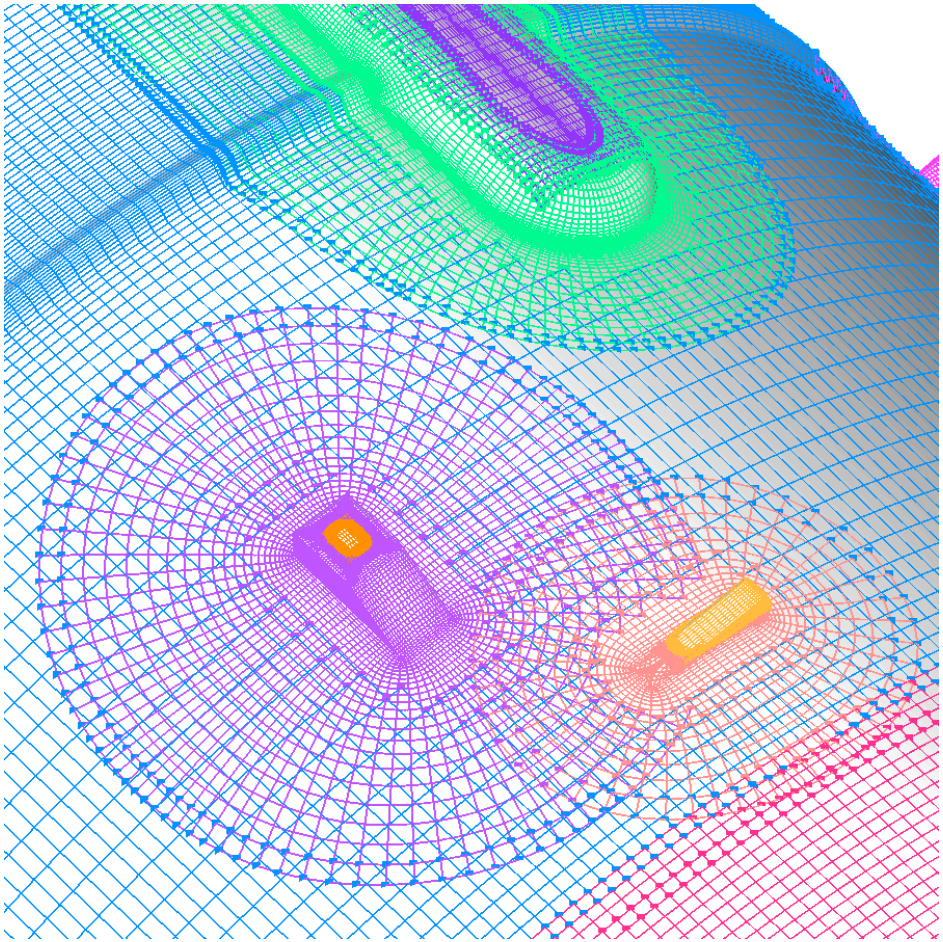
- Similar bounding box search as surface point search but with adjustments for volume grids

SURFACE POINT STENCIL SEARCH



Identification of open boundary points used in building closed hole-cutters for components

Establish surface grids connectivity for stencil shifting at surface fringe points



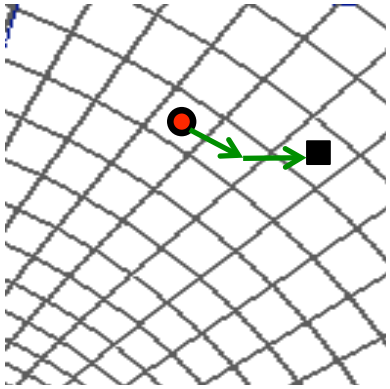
Preliminary test case results

2 million surface grid points, 100000 fringe points, interpolation stencils found in 9 CPU seconds with 1 processor of Intel Core i7

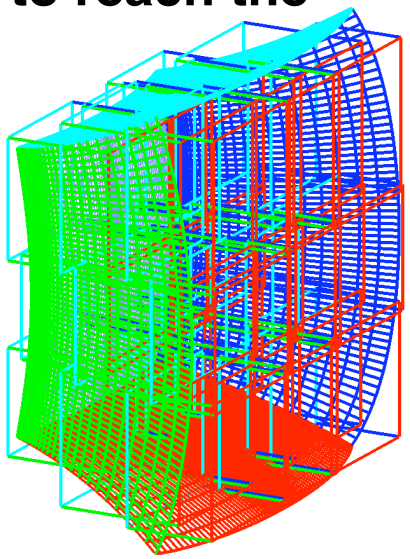
FRINGE POINT STENCIL SEARCH FOR VOLUME GRIDS

Establish volume grids connectivity at outer boundary and hole boundary fringe points

Two ways to begin stencil search for each volume fringe point:



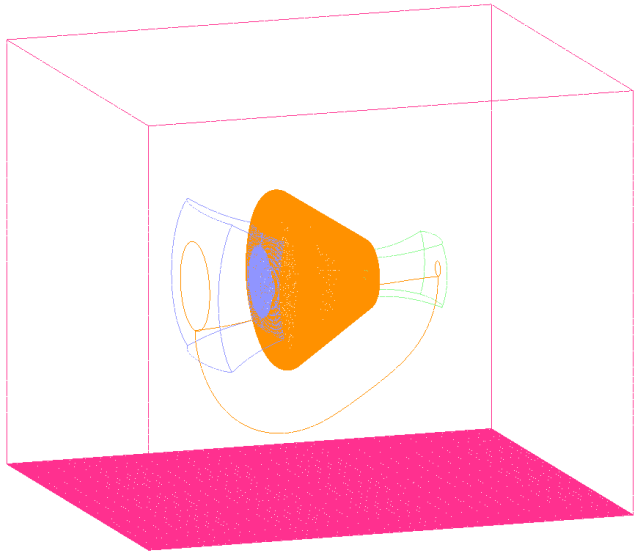
Local search – begin with an initial guess close to the donor stencil, use a small number of stencil walk steps to reach the donor stencil



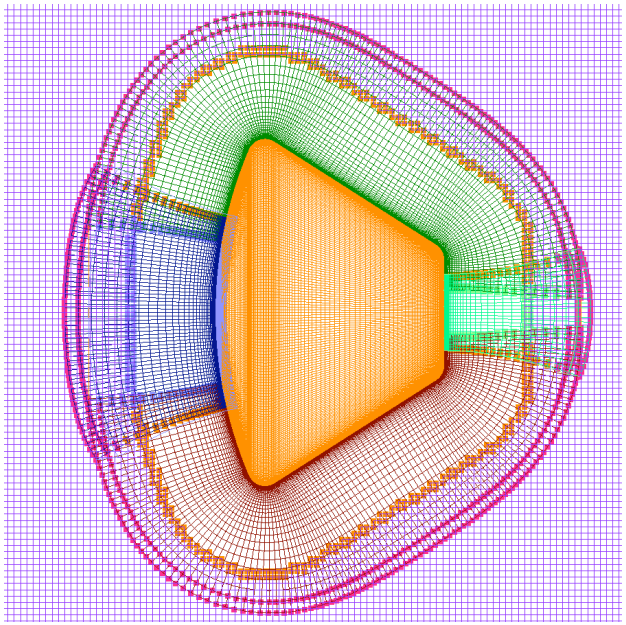
Global search – begin with no initial guess, use ADT, octree, or cascading bounding boxes to get close to the donor stencil, then use local search method

Local search is cheaper => use local search for as many fringe points as possible to achieve faster results

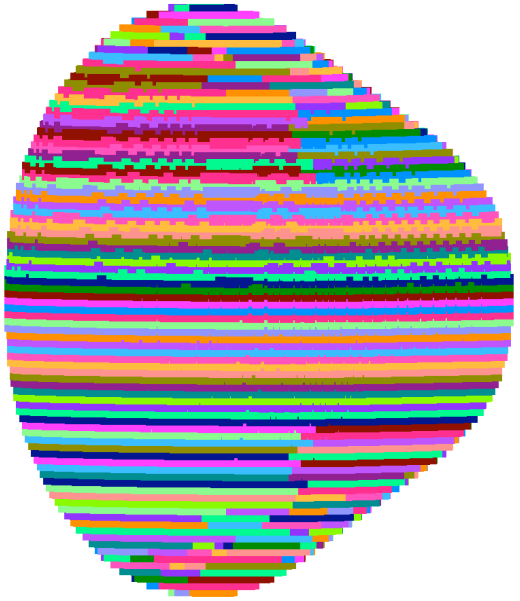
CAPSULE EXAMPLE – FRINGE POINTS



Volume grid system for capsule



Fringe points through symmetry plane slice

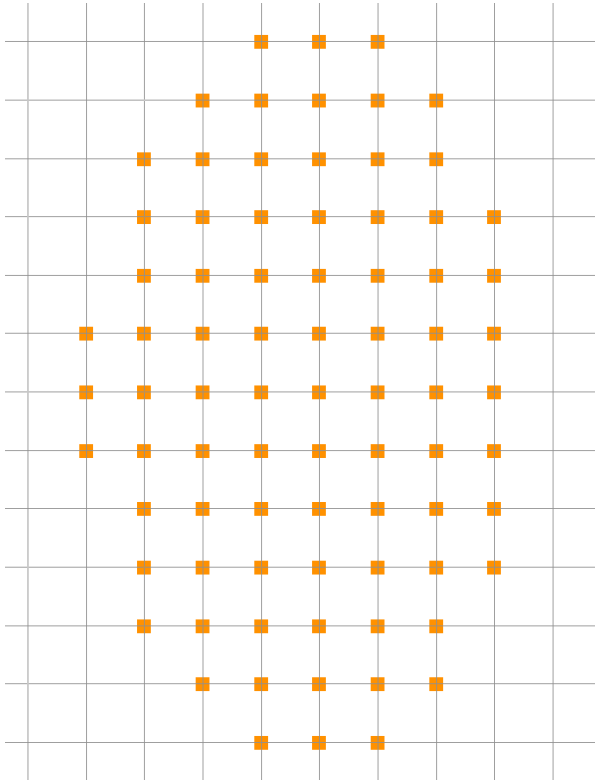


Layers of fringe points in Cartesian grid

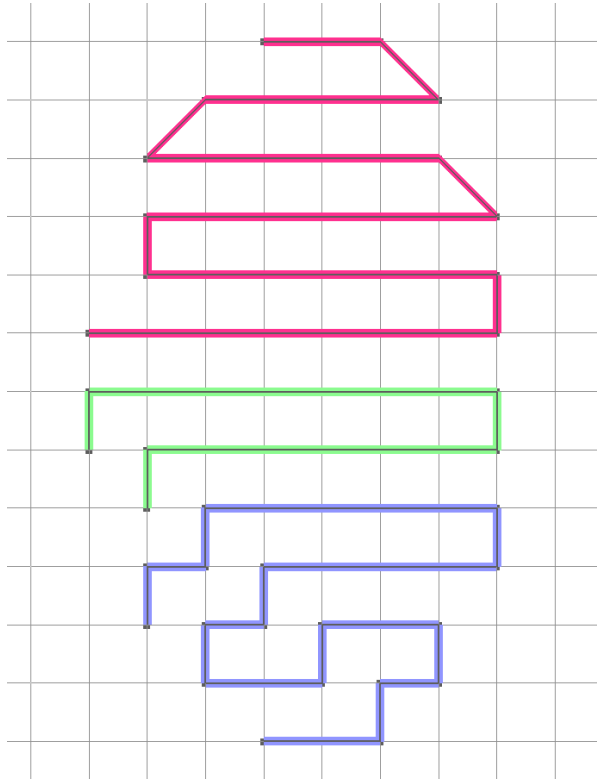
Can we use global search for a few points (or just one point) on a slice, and use local search for the remaining points?

STENCIL SEARCH WITH SPACE FILLING CURVE ON GRID SLICE

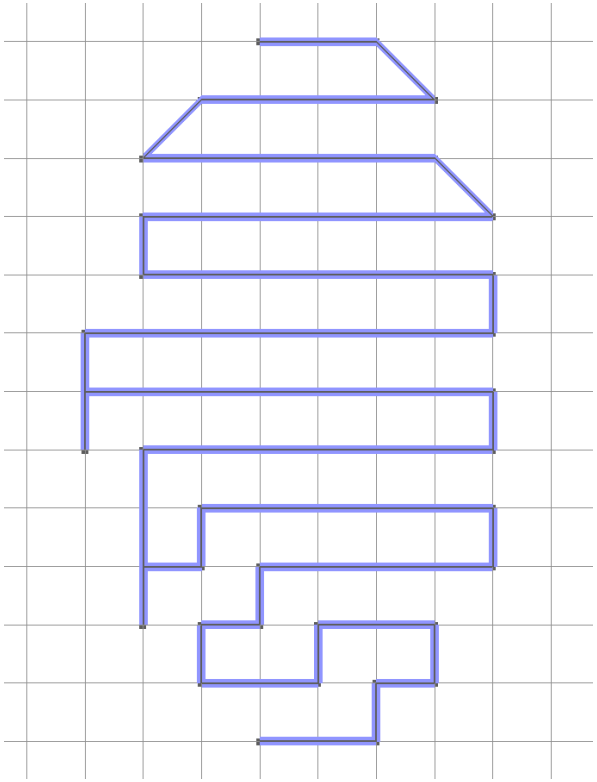
- Pick any un-processed fringe point, walk to neighboring fringe point within one cell away
- Continue until all fringe points are processed
- Between any two consecutive points along path, donor stencils should be reachable with a small number of stencil walks



Fringe points on a slice

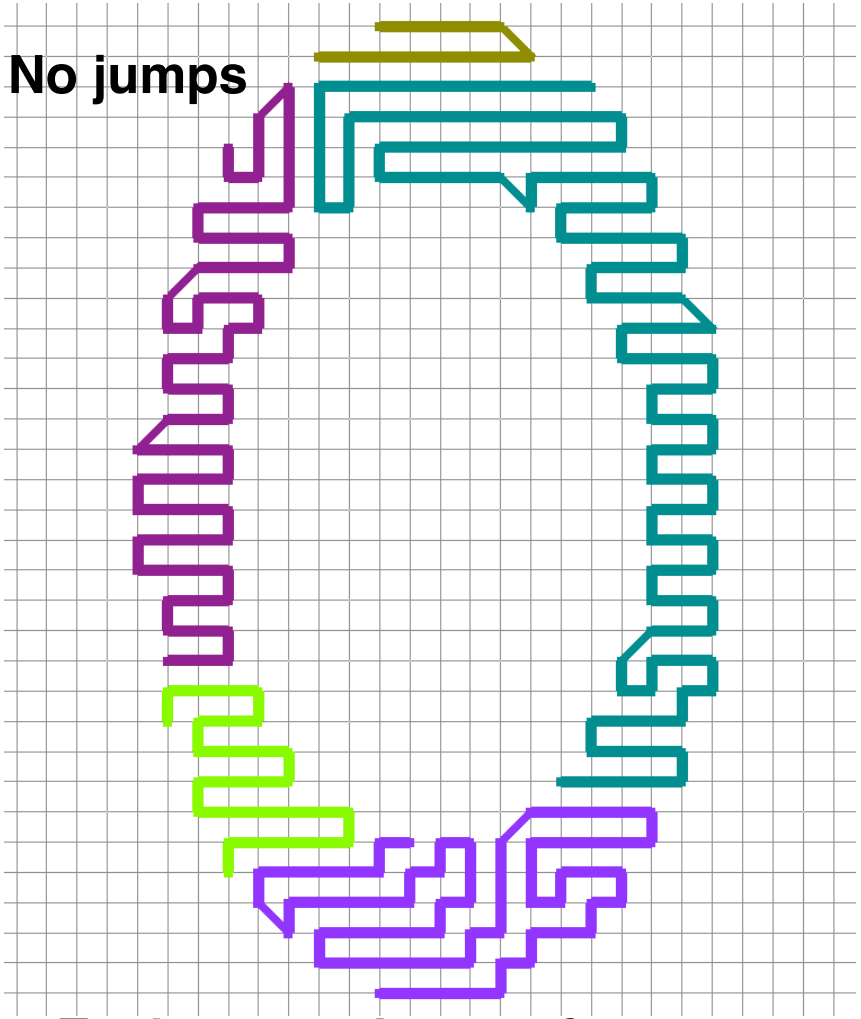


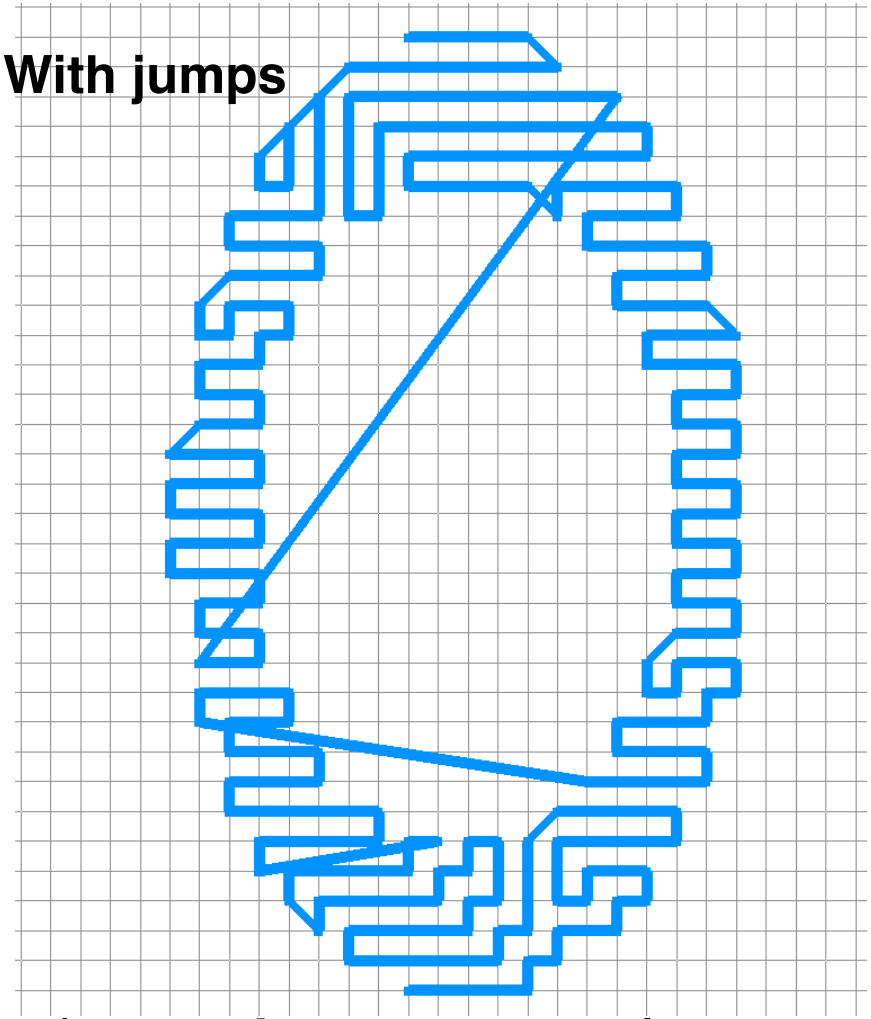
Path (no jumps)



Path (jump allowed)

MORE EXAMPLES ON SPACE FILLING CURVE



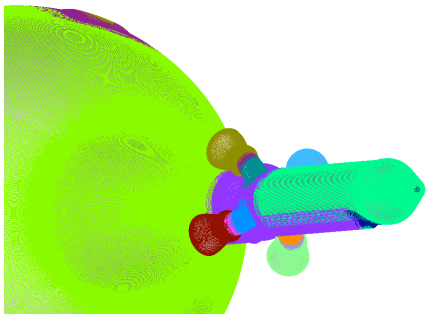


- Each colored curve forms a group (parallelize over groups)
- Do global search for first point in group
- Do local search for subsequent points in group until donor stencil jumps to another grid

STENCIL SEARCH TIMES WITH OPENMP
CPU time in sec. (Intel Dual Quad Core Xeon)
Capsule (4 grids, 6 million volume grid points, 270000 fringe points)

Number of processors	Global search for every point	Space filling curve (no jumps)	Space filling curve (with jumps)
1	73.94	2.53	2.61
2	53.84	2.23	2.22
4	31.52	2.20	2.14
6	23.12	2.09	2.11
8	20.15	2.14	2.10

Rocket (28 grids, 31 million volume grid points, 2 million fringe points)



Number of processors	Space filling curve, no jumps (schedule)	Space filling curve, with jumps (schedule)
4	525 - (default)	462 - (default)
8	393 - (default)	329 - (default)
8		256 - (static,1)
8		213 - (dynamic, 1)

SUMMARY

Chimera Grid Tools 2.1 released in March, 2010

Strategies in automation of overset grid generation

Scripting approach – develop higher level macros

General approach – utilize CAD solid topology in automation for arbitrary geometries (VTE library)

Chimera Components Connectivity Library (C3LIB)

- **Modularize domain connectivity operations**
- **Preliminary enhanced algorithms for each step show good potential for automation, robustness and speed**
- **Future work**
  - **Complete minimum hole cut routines**
  - **Investigate other ways to parallelize stencil search**
  - **Investigate new ways to perform hole boundary optimization**