Capstone: A platform for geometry, mesh and attribution modeling for physics-based analysis and design

DOD HPC MODERNIZATION PROGRAM

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Outline

- **Motivation, Strategic needs and Challenges**
- **Capstone – the product**
  - Overview
  - Users and Usage Scenarios
- **Current status**
  - Key capabilities
  - Success stories
- **Closing remarks**

Motivation

Goal

Improve efficiency of DoD acquisition engineering by reducing time, cost and risks in research, development and sustainment of weapon systems

Approach

- **Develop Next-Generation Computational Solvers & Optimizers**
- **Insert More (Multi) Physics-Based Analysis Earlier in the Design-Cycle**

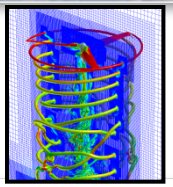
Critical Hurdles

Human Effort & Calendar Time to Produce an Analyzable Representation (Model) of a Design or System

Significantly more time is often spent in 'preparing' the input data needed by solvers than is used by the solvers to solve it.

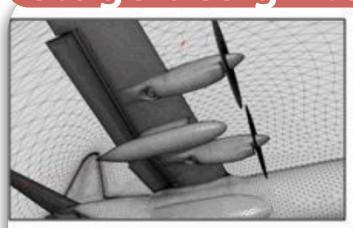
Computational Research and Engineering Tools and Environments (CREATE) Program Focuses on Four Project Areas

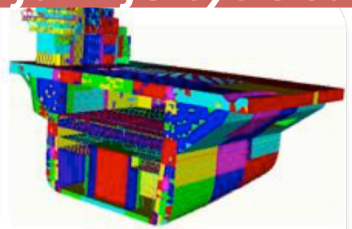
- **Air Vehicles (AV)—Air Force, Army & Navy**
  - Aerodynamics, structural mechanics, propulsion, control, …
- **Ships—Navy**
  - Shock vulnerability, hydrodynamics, concept design
- **Radio Frequency (RF) Antennas—Air Force, Army & Navy**
  - RF Antenna electromagnetics and integration with platforms
- **Mesh and Geometry (MG) Generation**
  - Rapid generation of mesh and geometry representations needed for analysis



Design concept

Seakeeping and resistance





Aircraft and aircraft carrier meshes

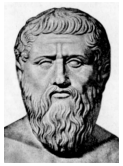
Military platforms with antennas

Shock vulnerability

CREATE tools will support all stages of acquisition from rapid early stage design to full life-cycle sustainment

Geometry and Meshing Needs

"Let no one ignorant of geometry enter" - Plato



Geometry needs to be appropriate for analysis and meshing

- Valid
  - Dimensionally correct (1-,2-,3-D or mixed-dimension, non-manifold)
  - "Water-tight" (no gaps), non-self-intersecting
- Accurate
  - Match a shape to a given tolerance
  - Maintain the accuracy and rate of convergence of the solvers/code

Meshing needs to be appropriate for physics and discretization

What takes time and effort ?

- Geometry repair/clean-up
- De-featuring (geometry good for Physics A is not suitable for Physics B)
- Lack of automation and robustness in meshing (all-hex, complex boundary layers)
- Attribution, multi-component model preparation

CREATE-MG: Mission Summary

Develop Capability and Tools for:

Rapid, Scalable and automated generation of analyzable representations (geometry, mesh, attribution data) for accurate and scalable physics-based solvers

Enabling:

- Multi-physics based analyses earlier in the design process
  - ✓ Rapid turnaround time and automation key to effective design optimization
- Generation and adaptation of meshes for complex and hi-fidelity analyses
  - ✓ Reduce time and human effort needed to prepare complex geometries for meshing that is suitable for given (multi)-physics and accuracy needs

Key Technical Challenges:

- Analysis-suitable geometry-preparation
  - ○ Automation of geometry clean-up, repair and de-featuring
- Automated hexahedral mesh generation
  - ○ Hex-dominant, all-hexahedral (unsolved)
- Automated, high-quality boundary-layer meshing for complex geometries
- Parallel (distributed) mesh representation, generation and geometry-based adaptation
  - ○ Needed for ultra-large meshes for high-fidelity analyses
- Multi-scale geometry and mesh modeling
  - ○ Complex antenna patterns (nm-mm) integrated into large structure O(100)m

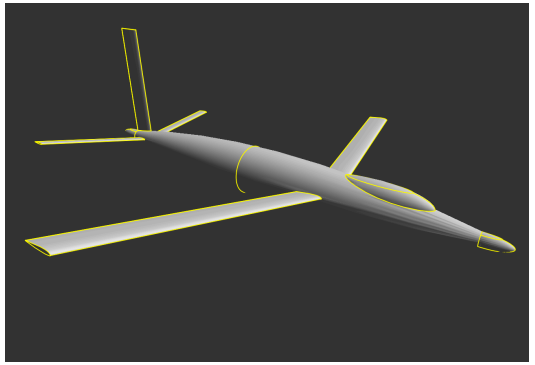
CAPSTONE Critical Requirements

ID	Description
MG-00	Geometry Import (CAD/kernel-native, IGES, STEP)
MG-01	Parameterized Geometry Creation
MG-02	Dependency-based Associative Modeling
MG-03	Geometry Repair
MG-04	Model De-Featuring & Idealization
MG-05	Robust Surface Meshing Algorithms
MG-06	Robust Volume Meshing Algorithms
MG-07	Geometry-based Mesh Generation & Adaptation
MG-08	Multi-Scale Models
MG-09	Legacy Component Integration
MG-10	Analysis Model Attribution
MG-11	Accurate and Scalable Runtime Geometry Access
MG-12	Core framework (MG internal infrastructure requirement to support all of the above)

- Each requirement manifests into one or more ***usecase(s)***
- ***Usecase(s)*** drive development of specific ***capabilities***

Capstone – Overview

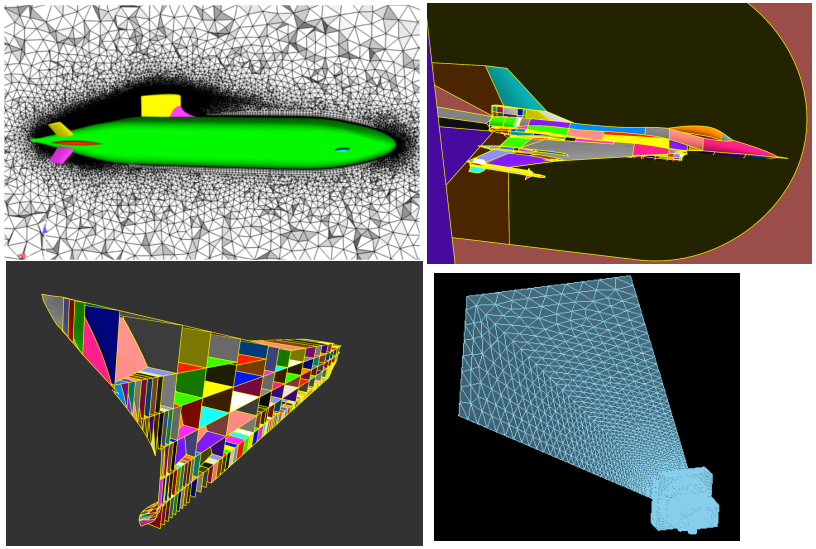
Capstone provides geometry and meshing needs for all phases of acquisition engineering (conceptual-, preliminary-, detailed-design and operational-support)



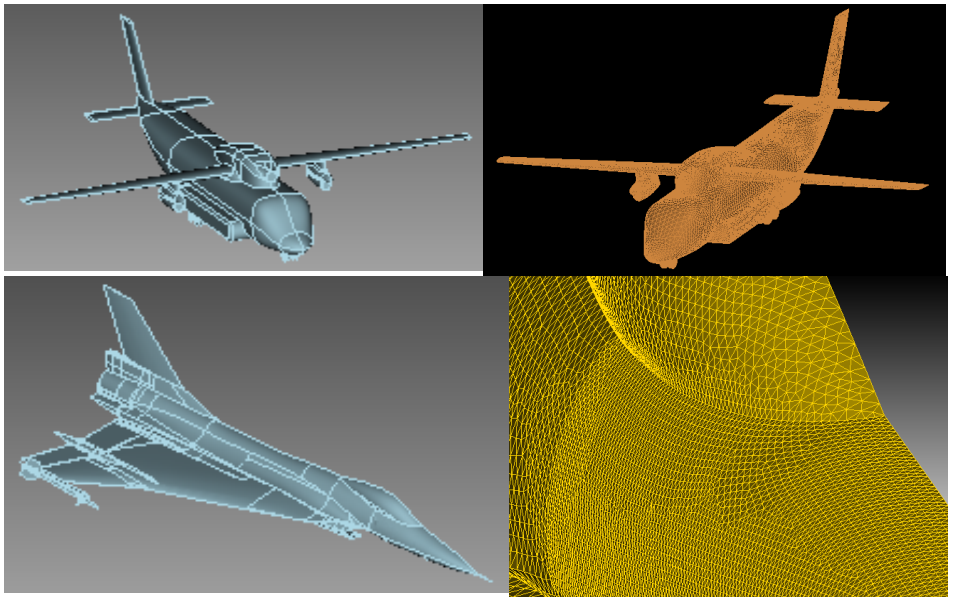
CAPSTONE: SDK

CAPSTONE: GUI

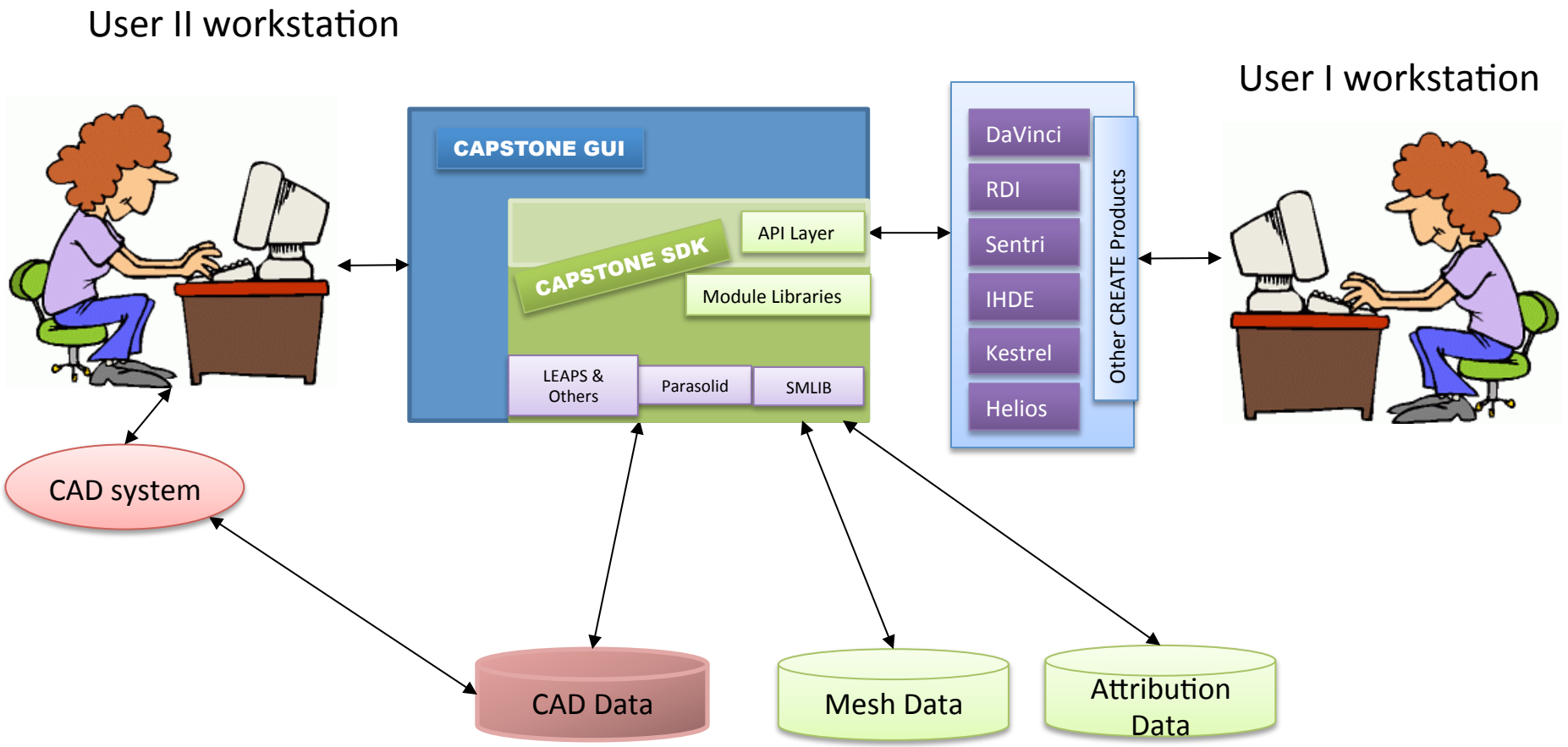
Produce analyzable representations for complex and detailed analysis



Enable parametric, associative geometry and meshes in AV:DaVinci, Ships:RDI; *geometry-based mesh adaptivity*



Capstone Architecture and Usage Notional (High-Level)



CAPSTONE User Types

User Type

- Analysis Data Modeler
  - End-user who creates analysis-suitable mesh from geometry which may be
    - imported from existing (legacy) description
    - created from scratch
  - Not expected to be a developer (programmer)
  - Typical example- bench-engineer (analyst) doing
    - analysis of existing aircrafts for specific maneuvers
    - analysis of shock damage for a ship configuration
    - analysis of complex antenna systems

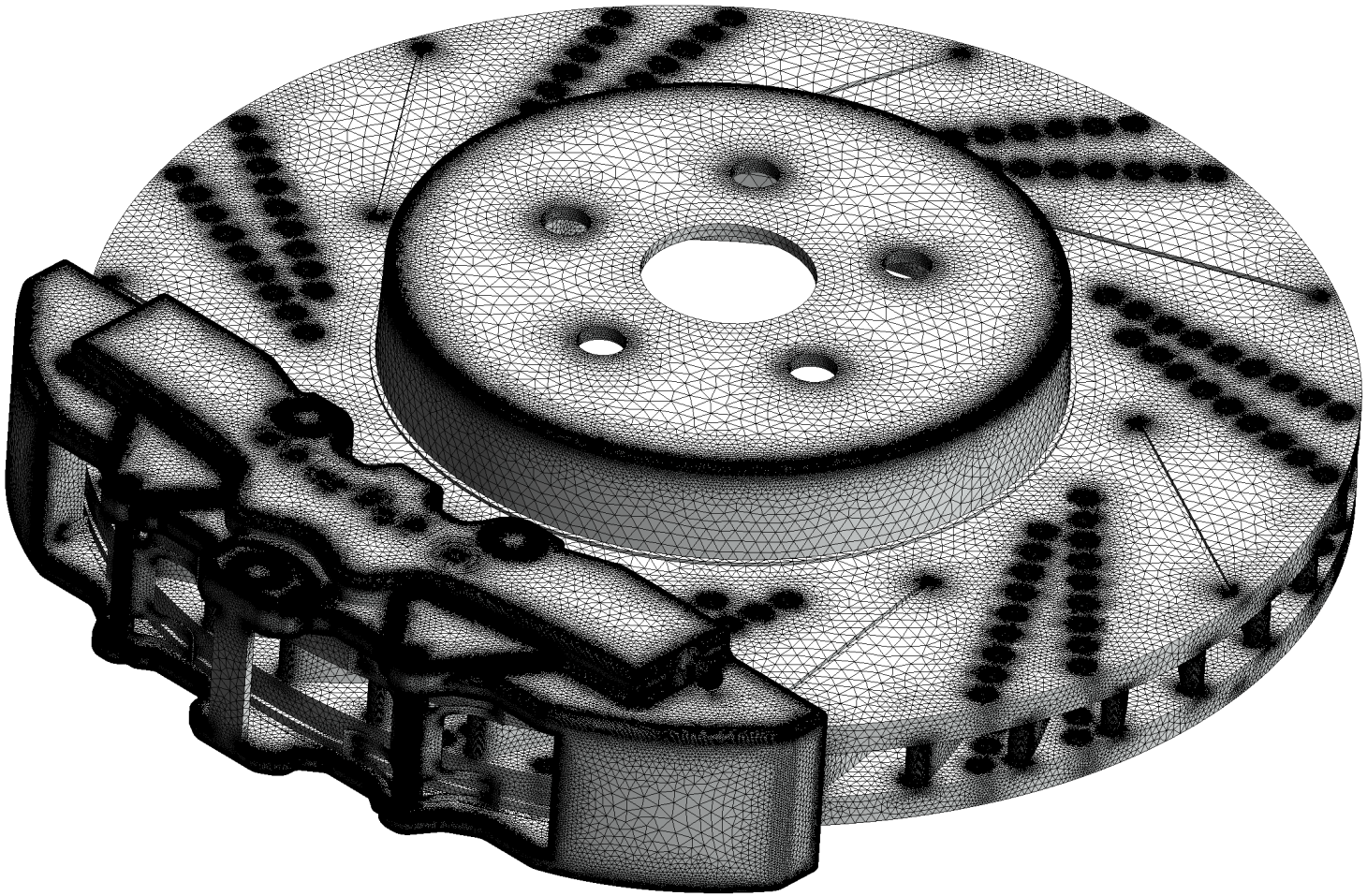
- Design Tool Creator
  - Users (team) producing a tool (environment) for rapid evaluation of conceptual/early designs
  - Expected to be developers (programmers)
  - Typical examples would be AV-DaVinci and Ships-RDI team

- Analysis Code Developer
  - Developers of physics-based CBE analysis tools
  - Expected to be developers (programmers)
  - Typical uses- geometry-based a-posteriori adaptive-analysis

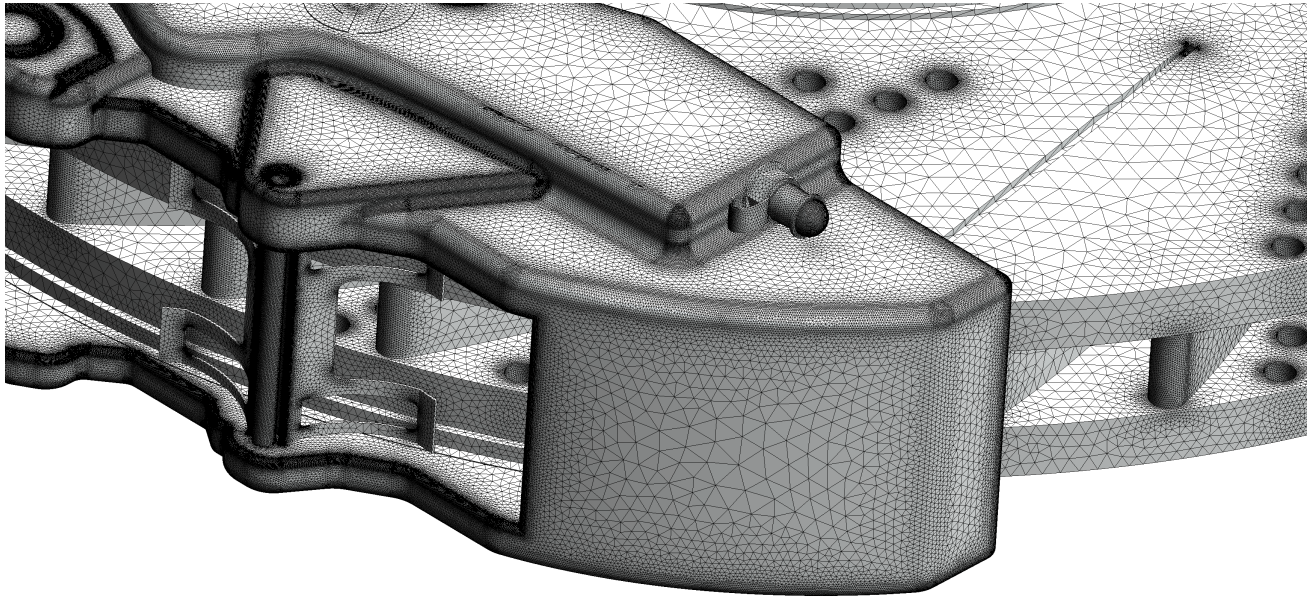
Capstone Architecture and Impact

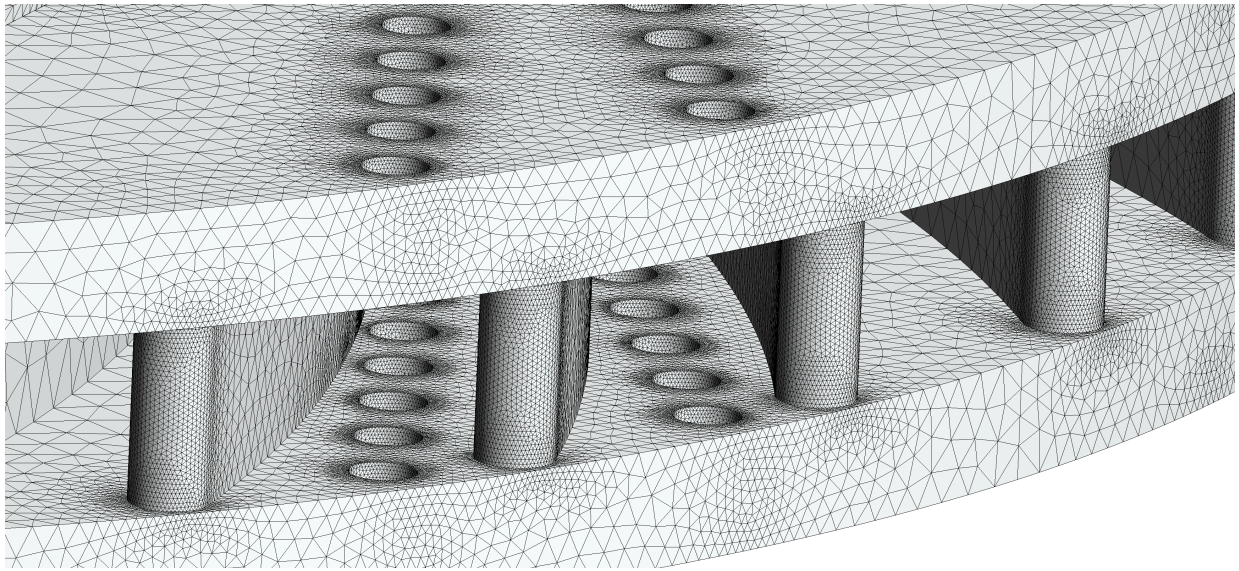
- **Well abstracted reusable functional modules**
  - Three main modules: Geometry, Mesh and Attribution
    - Well defined APIs
  - Reusable Functions built on top of basic module APIs
    - Functions may be reused to build more high-level functionality
- **Extensible using plugins**
- **All the core capabilities can be reused using the SDK**
  - Capstone frontend (GUI) itself uses the SDK
  - DaVinci is built on top of Capstone SDK, RSDE embedding it
  - CREATE solvers plan to reuse the SDK for geometry-based adaptivity
    - Kestrel, Helios, Sentri
  - Army ERDC ITL excited about embedding the SDK in their meshing tools

Surface mesh: Break disk

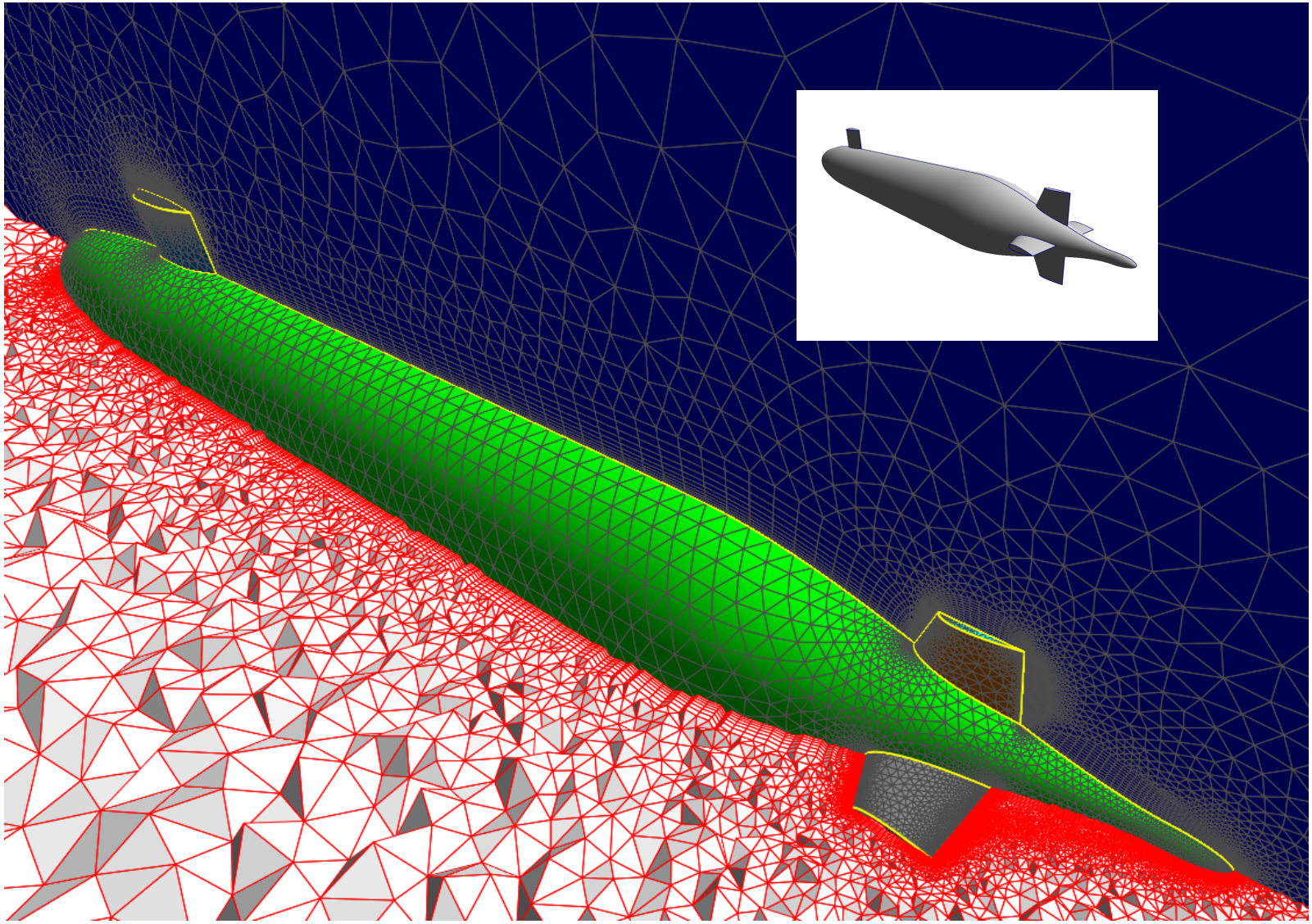


Surface mesh: Break disk



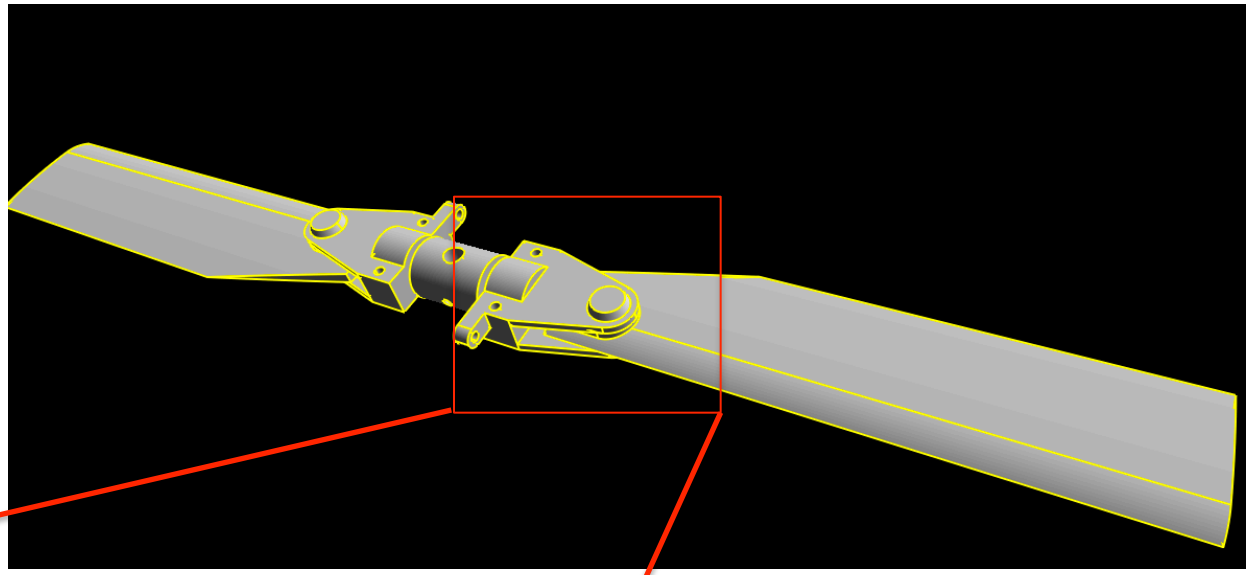


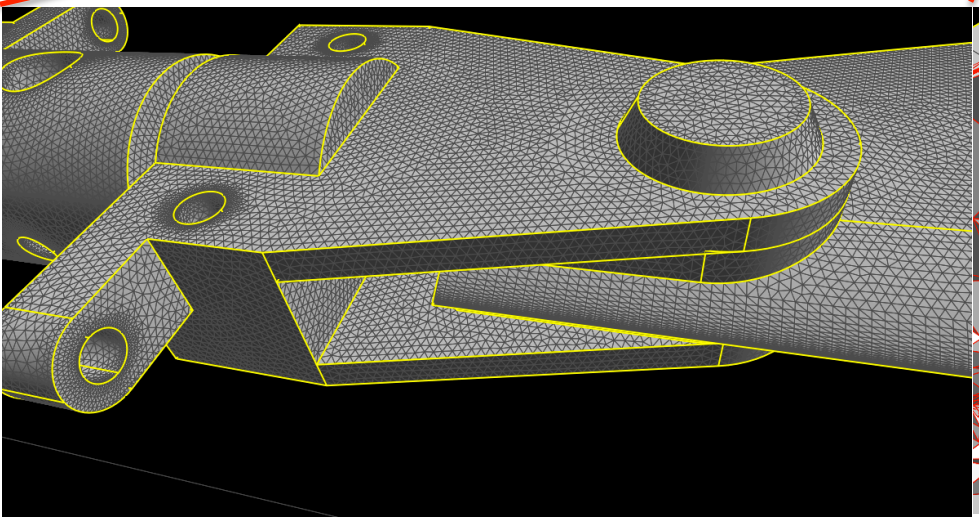
ONR Suboff : Boundary-layer mesh

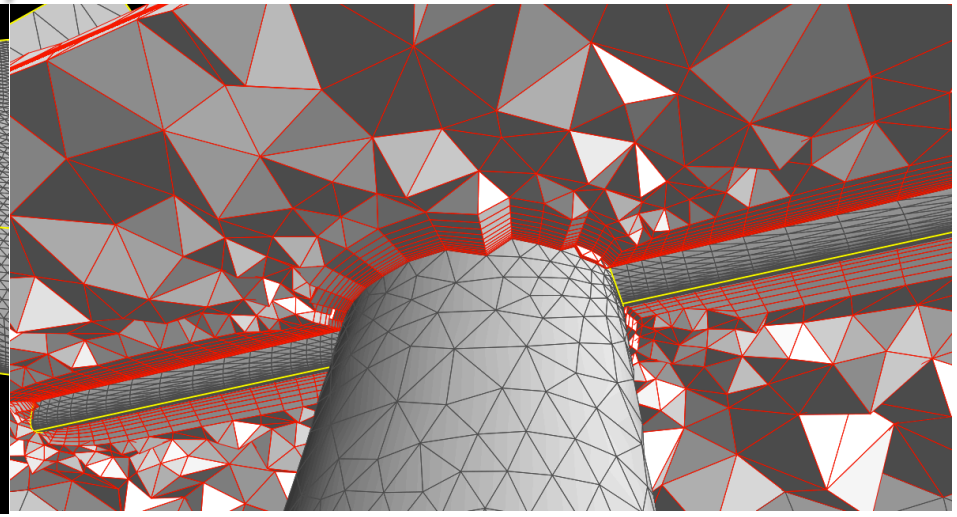


Boundary-Layer mesh for RANS-flow simulations (crinkle-cut)

Anisotropic surface meshing





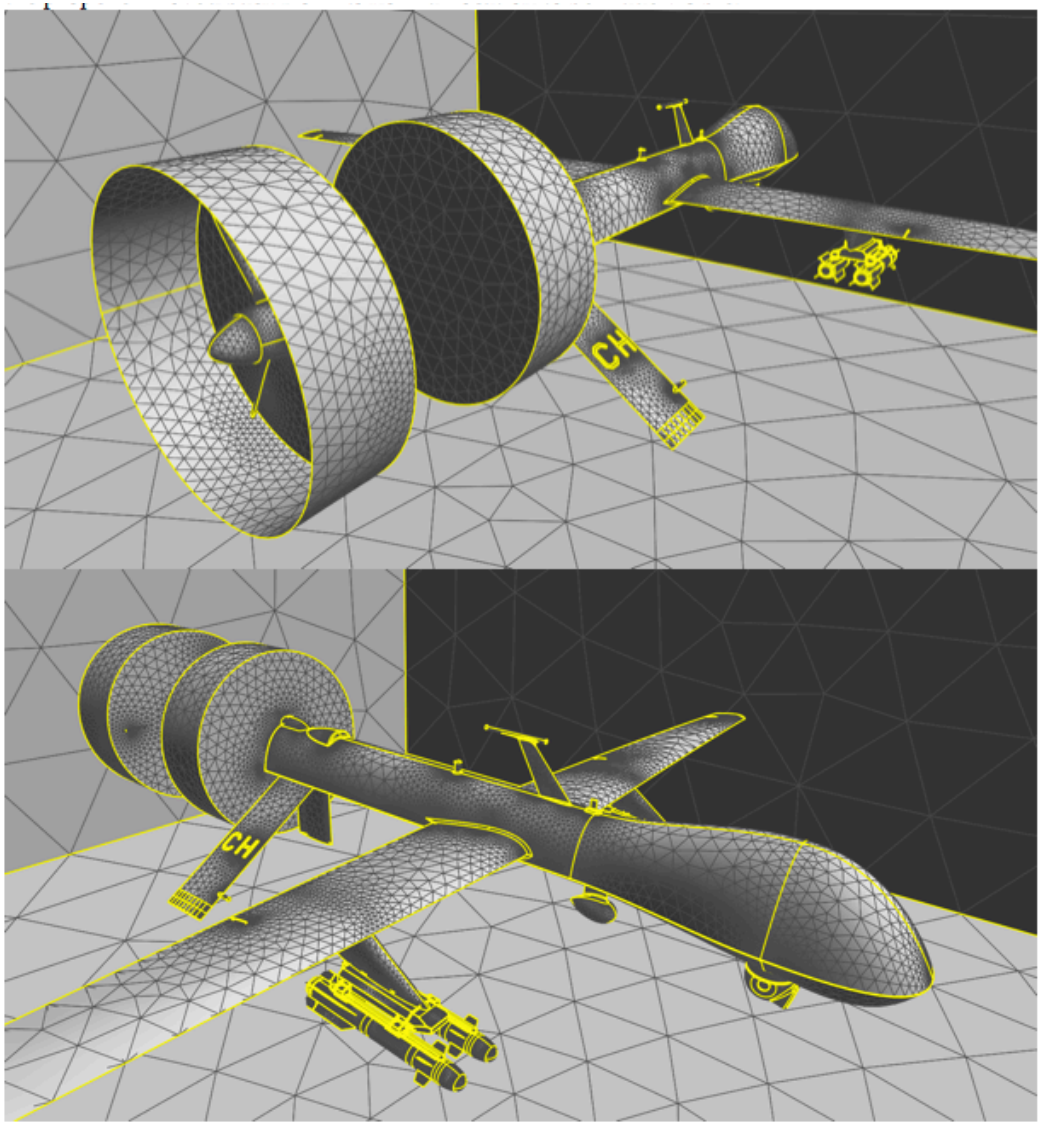


Anisotropic surface meshing

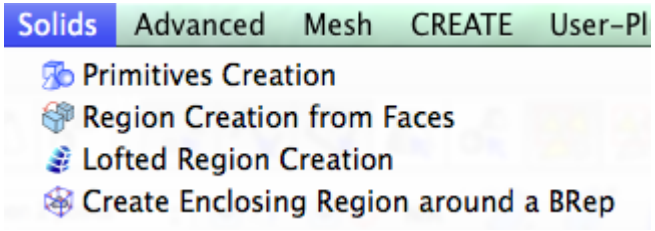
Combined surface and volume BL (crinkle-cut)

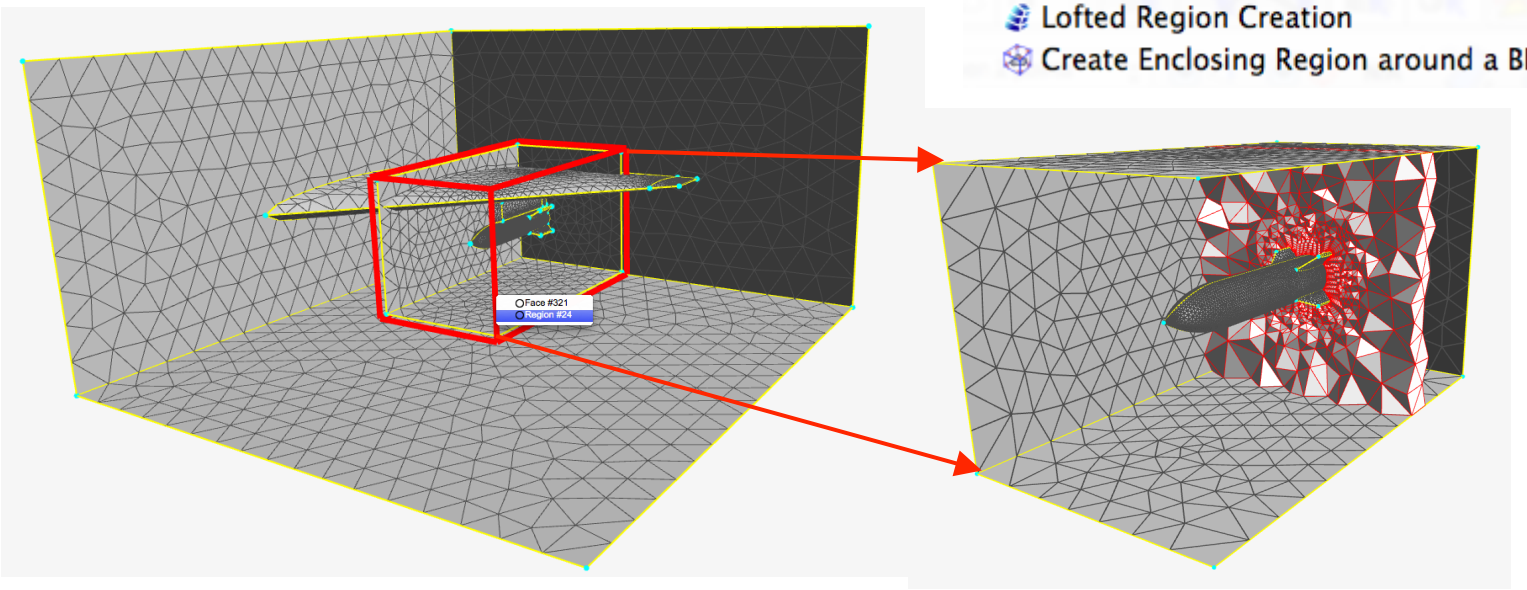
Moving/Rotating parts

Support for meshing suitable for rotating part based on overset approach.

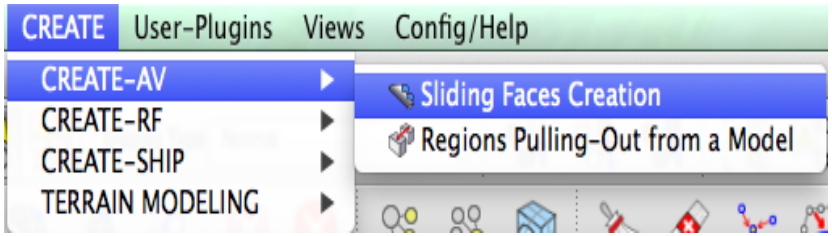


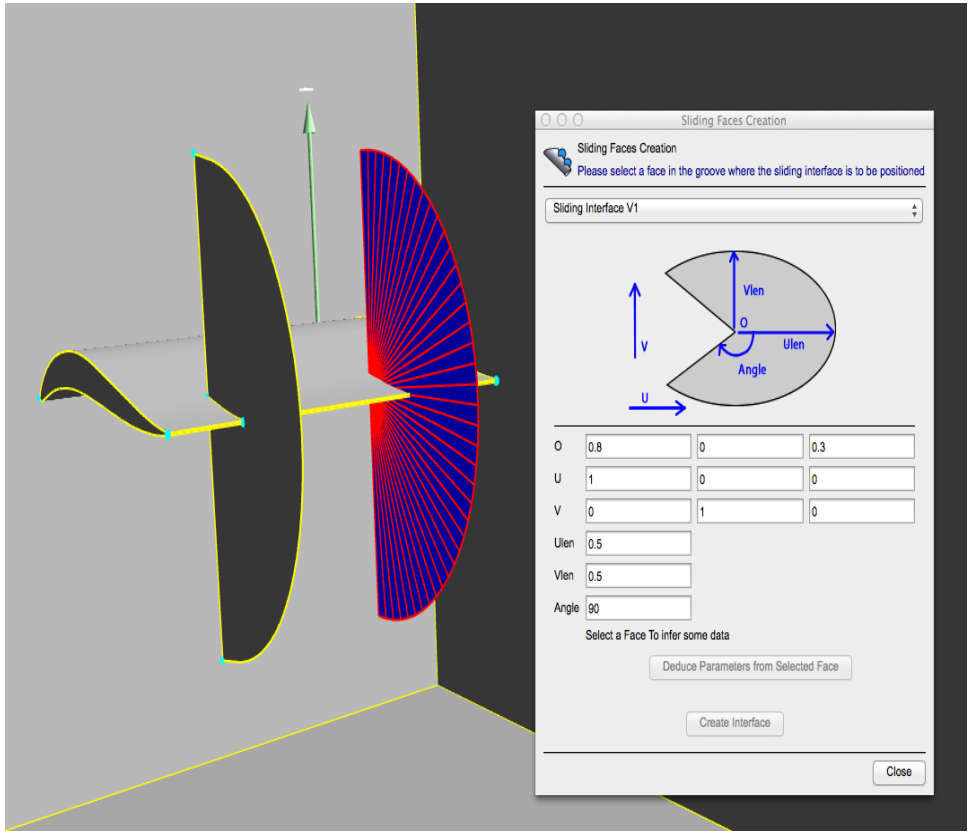
Multi-body meshing for store-separation analyses

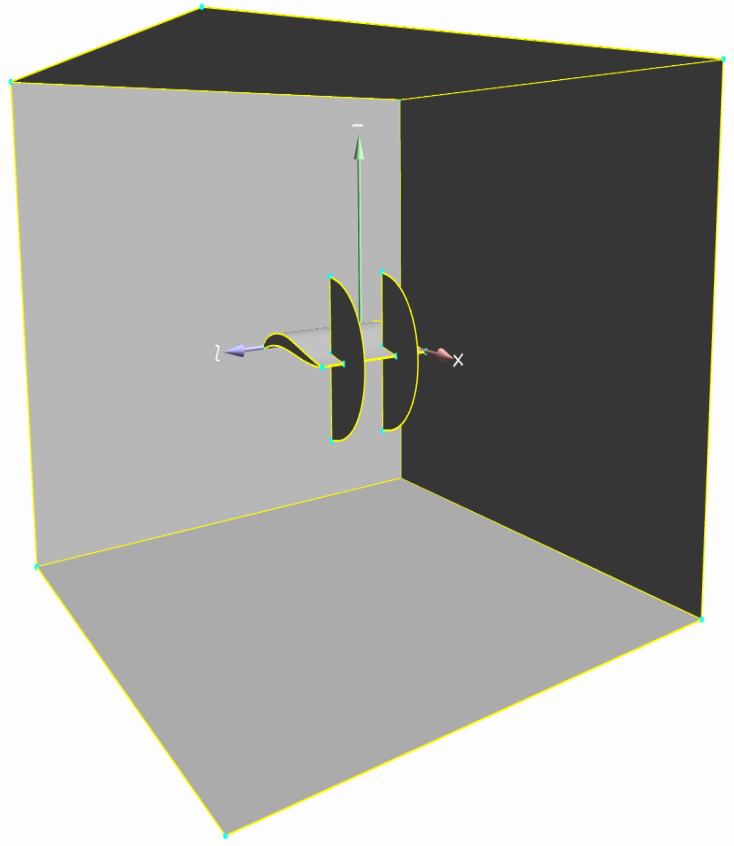




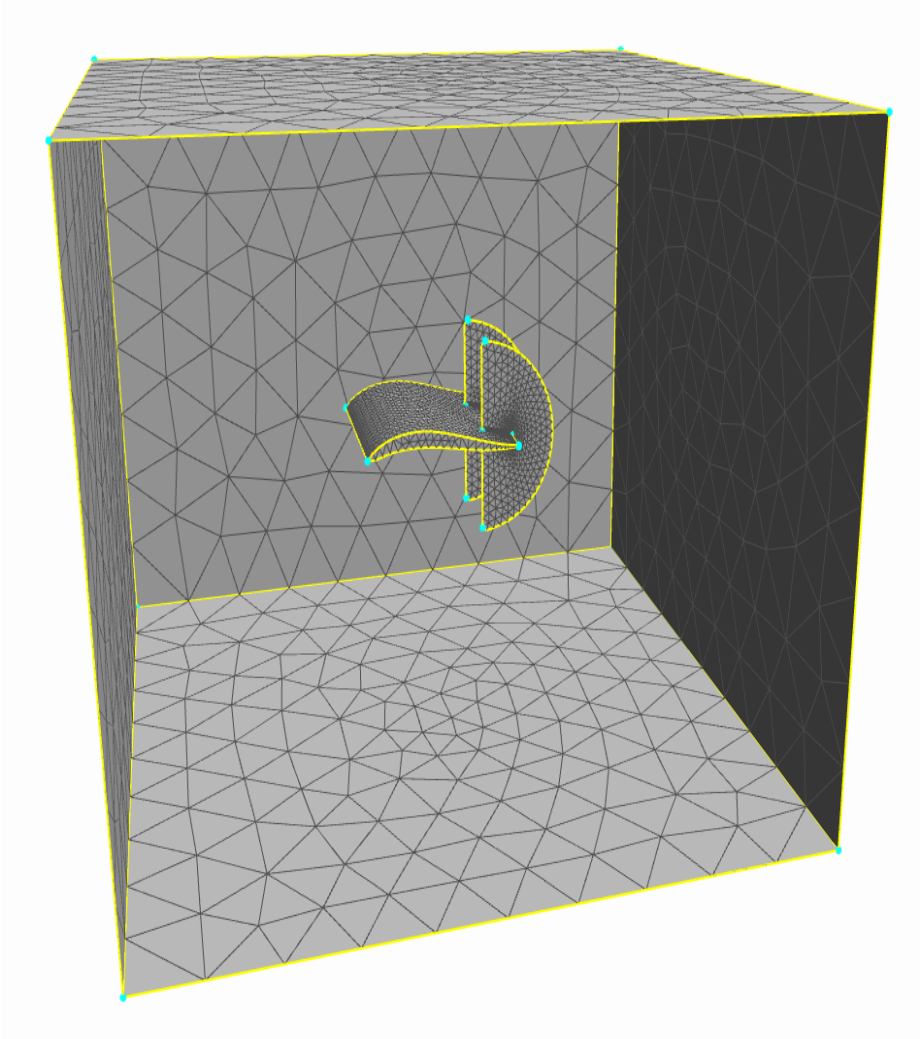
Sliding-Plane Boundary Layer Meshing

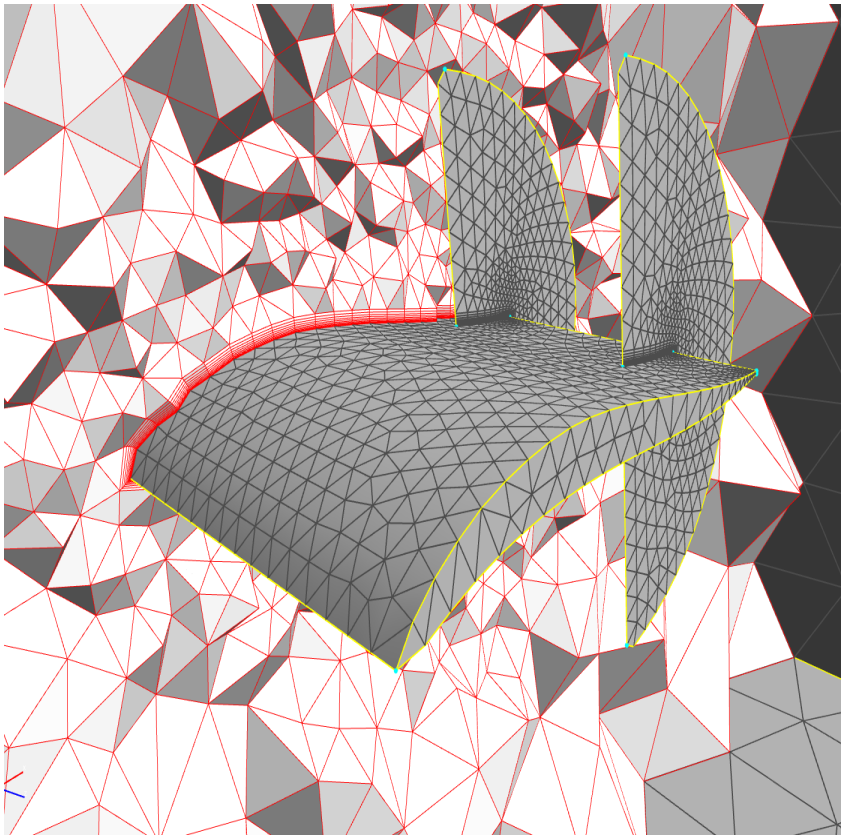




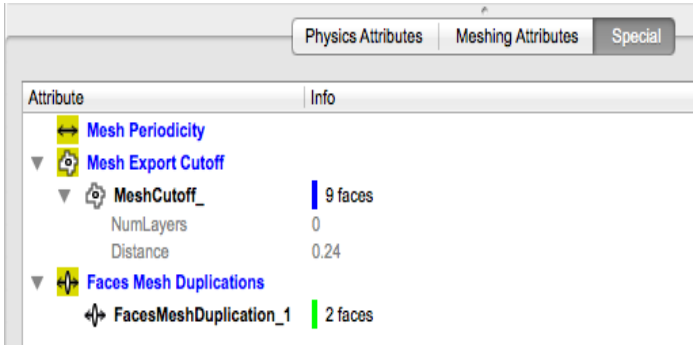


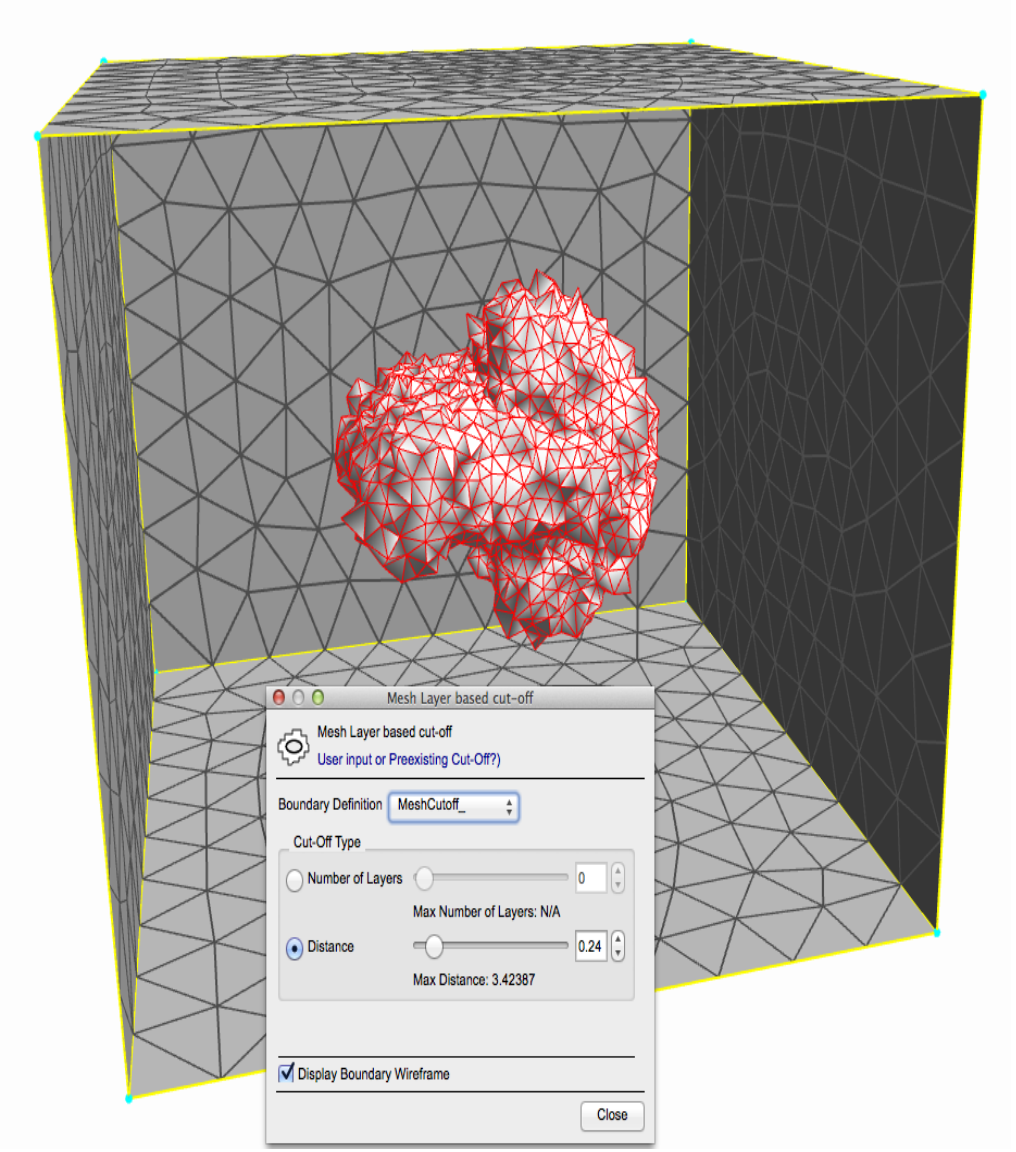
Sliding Plane Boundary Layer Meshing





Near-body mesh cutoff and export



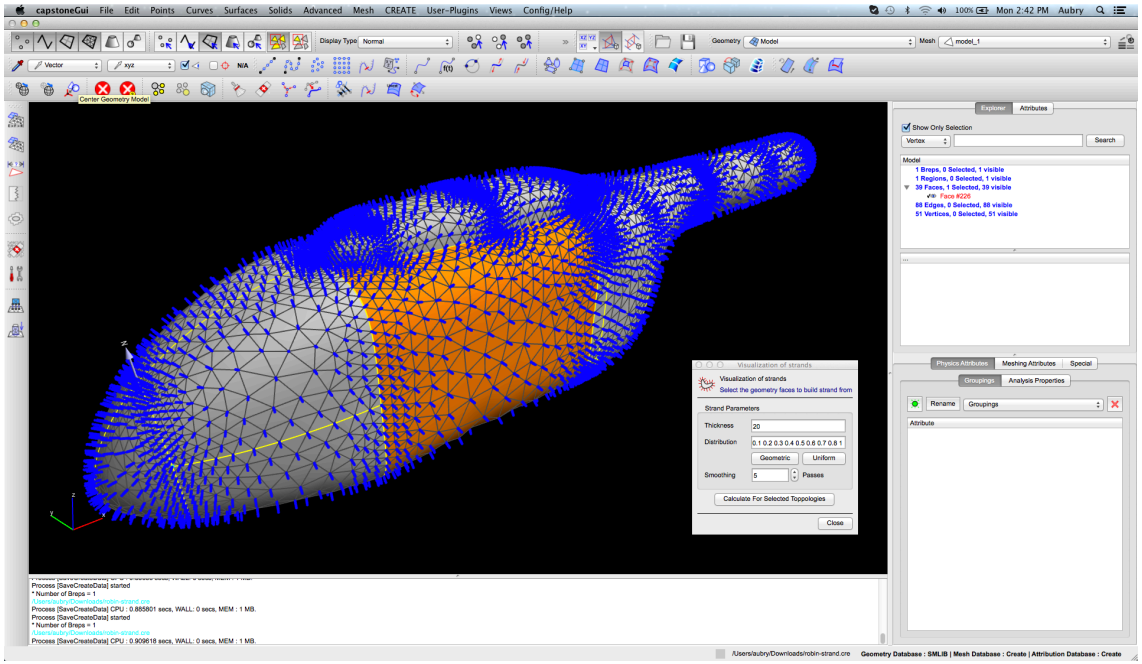


Strand mesher integration

- **Stand-alone API from SDK:**

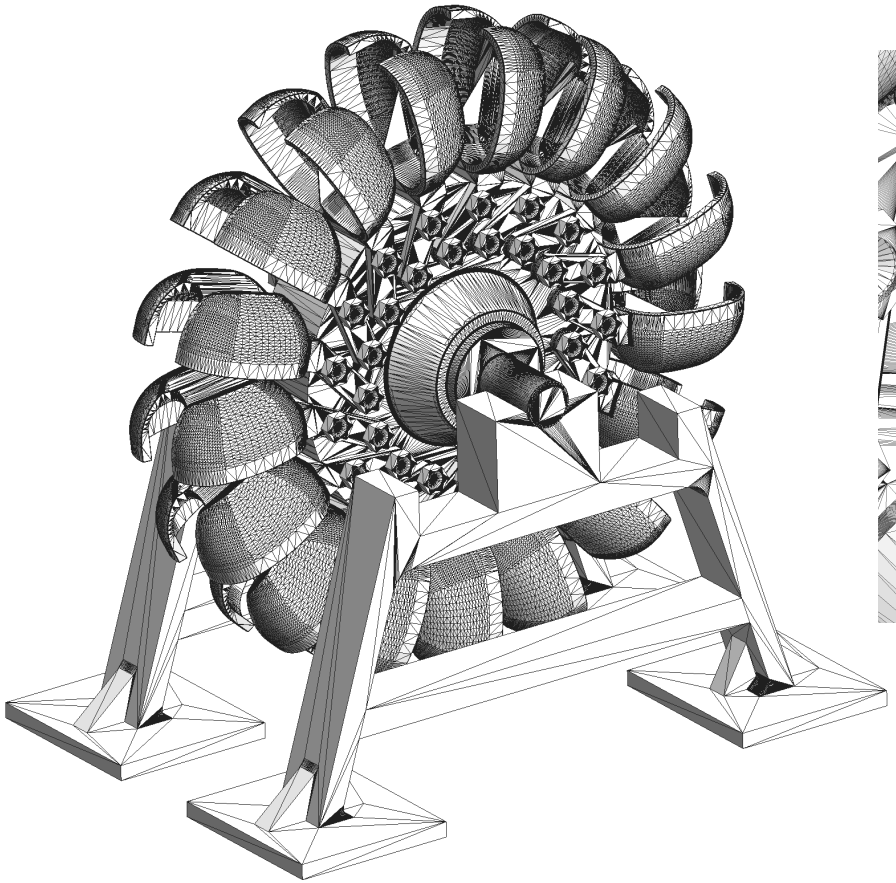
```
capstone_generate_strand(distrib,thickness,smoothingPasses,strands,face);
```

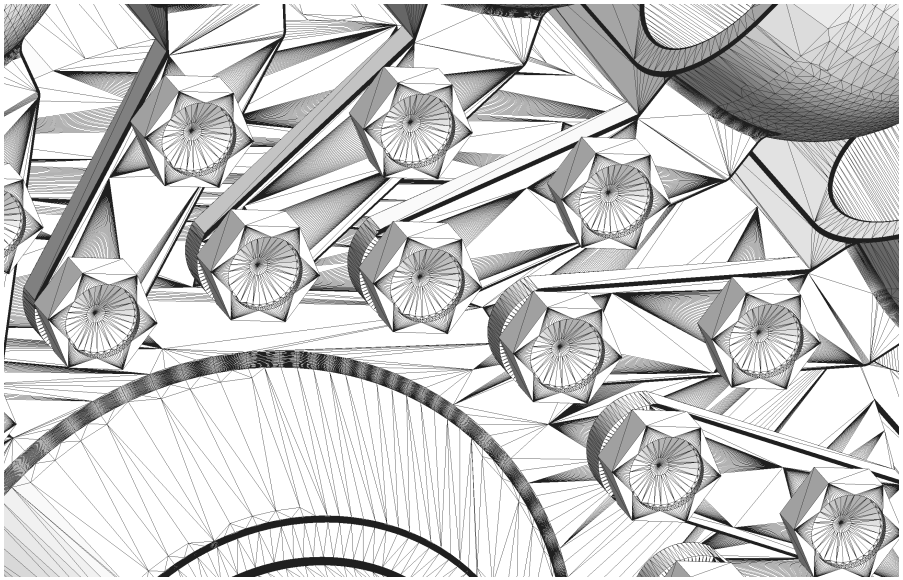
- **Graphic display in Capstone**



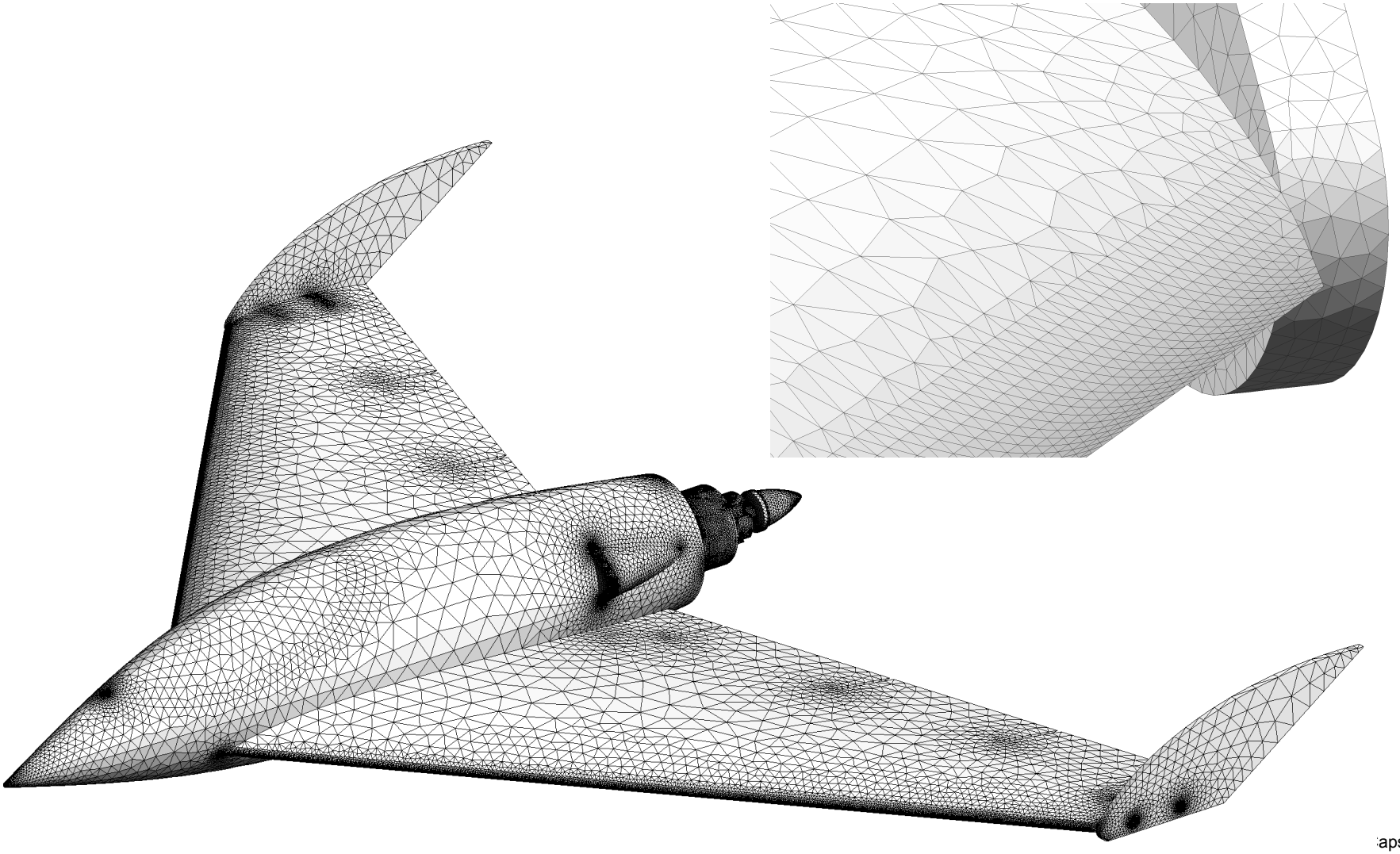
Kernel-independent Tessellation

- Solution for the *kernel's inability to tessellate* its own geometry!
- Also used for LEAPS where it depends on Capstone to provide it

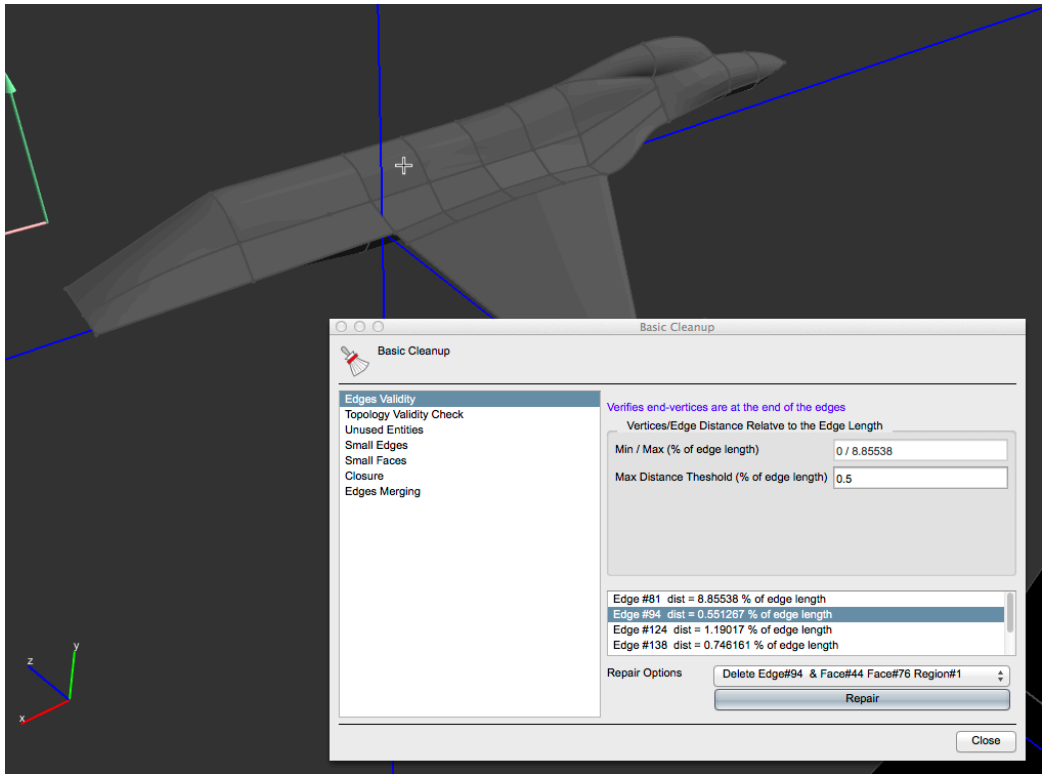




Surface BL



Capstone GUI New Repair Panel

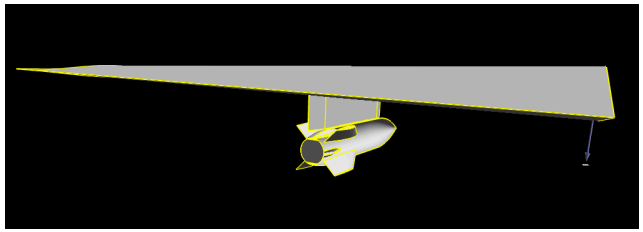


- **Quick analysis of model checking for**
  - IGES/STEP related issues such as topology validity
  - Constraints from small edges & faces
  - Closure check for manifold situations.
- **Visual Location Check**
- **Ability to repair some defects**
- **Repair panel extendable as more complex check will be added**

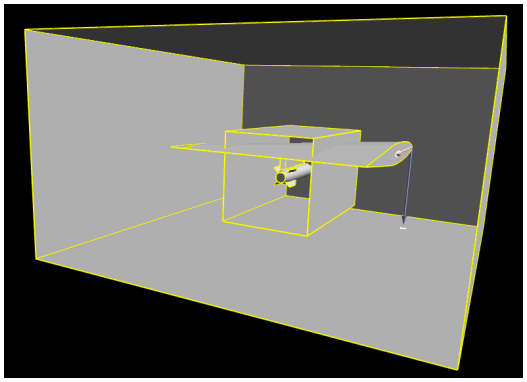
Goal is to improve turnaround time and robustness

Improving turnaround time

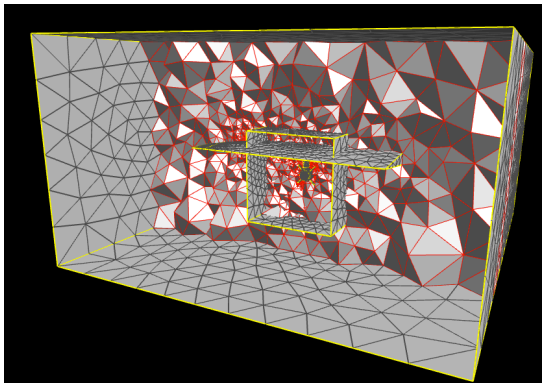
IGES Import (dirty)



Ready to mesh (clean)

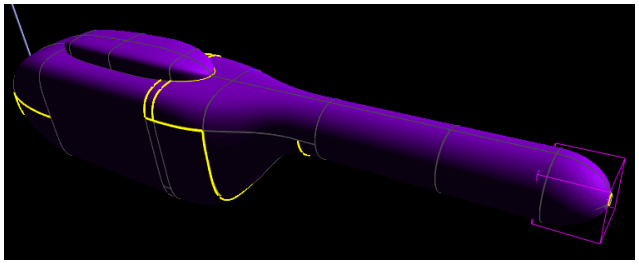


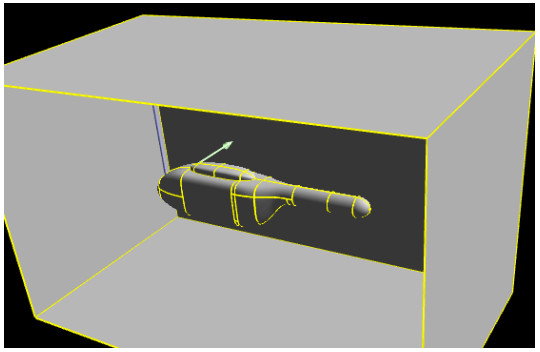
BL Mesh

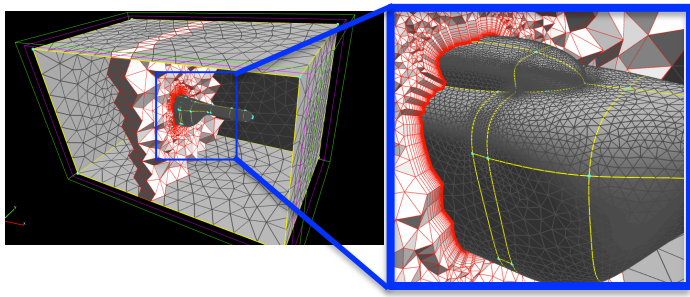


~5 min

~5 min

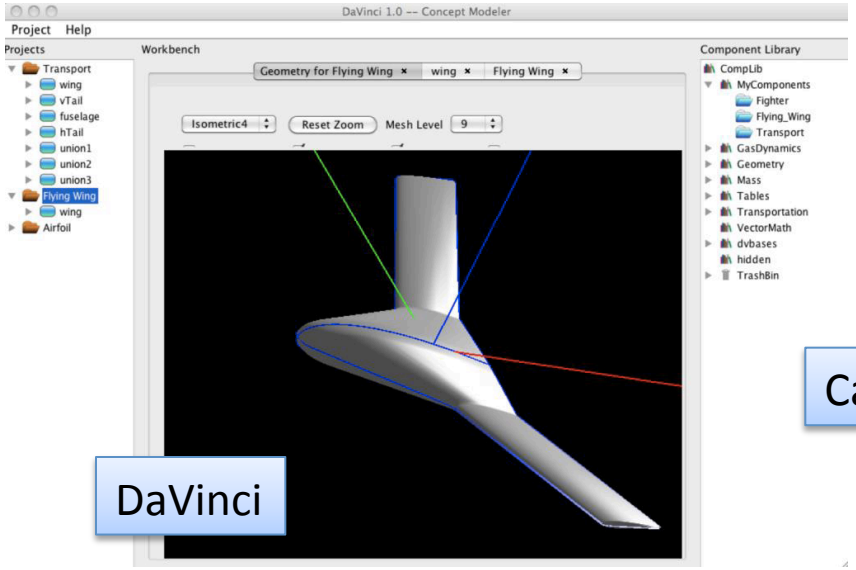


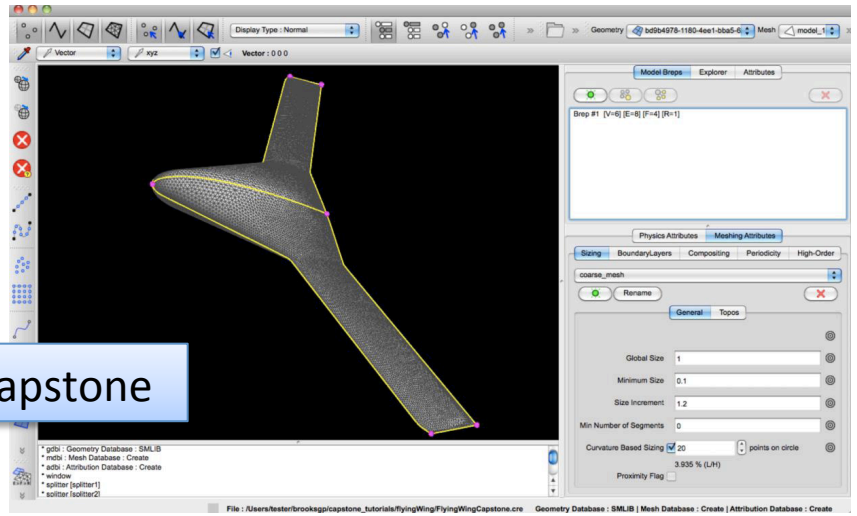


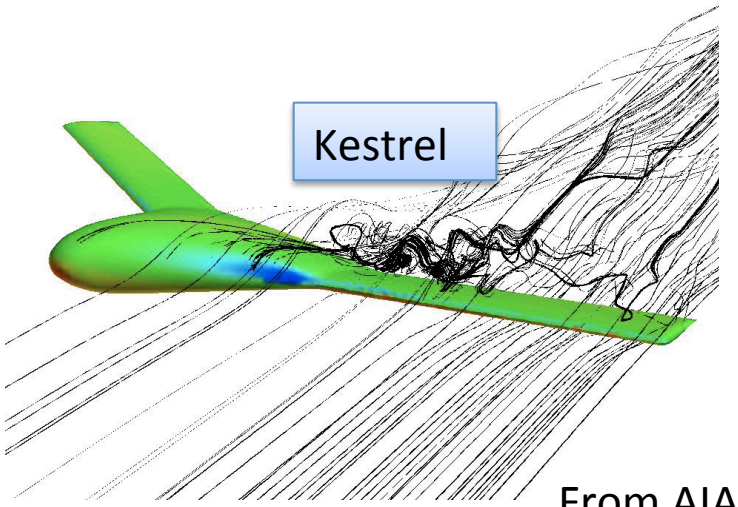


Capstone Impact: Design it better, faster and cheaper!

ASC Pilot Project







Capstone is enabling hi-fidelity physics-based analysis earlier in the design process

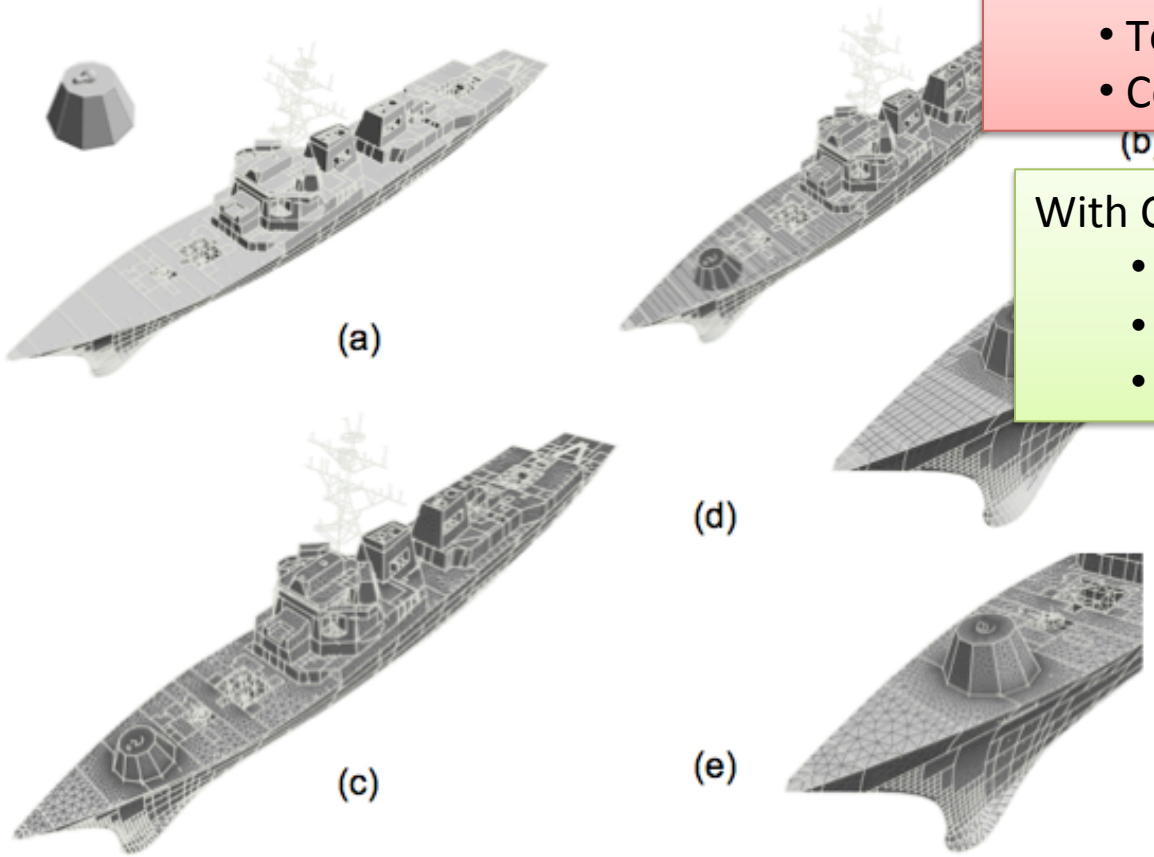
- Huge impact in avoiding cost later
- Recipe-based (kernel/CAD agnostic)

From AIAA paper by Greg Brooks (AV-Shadow Ops)

Capstone Impact: Automated Ship Modeling

Before Capstone:
- Manual
- Took 1 year
- Could produce invalid meshes

With Capstone:
- Automated
- Month or less
- Valid

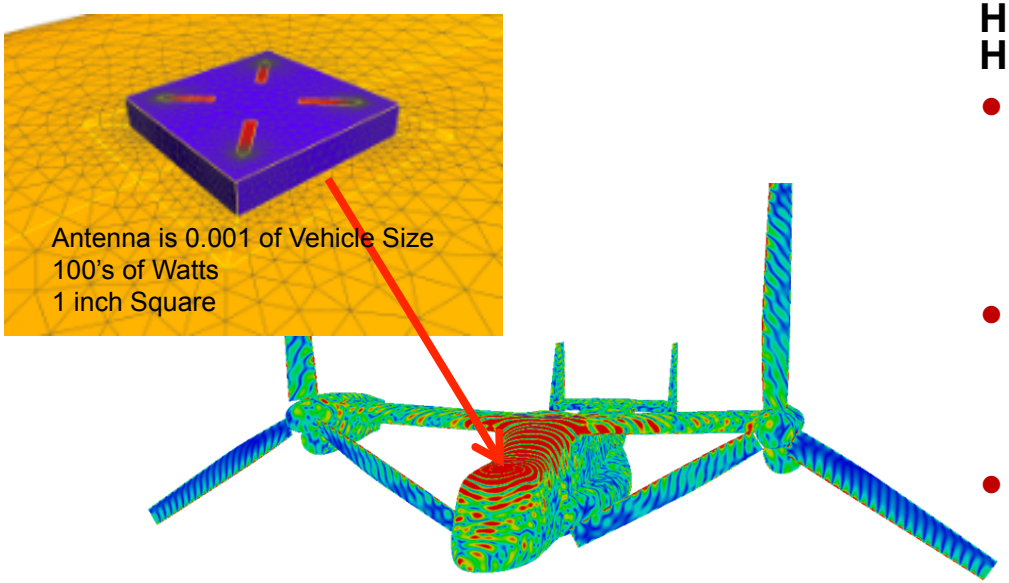


Critical for enabling Computational Full Ship Shock Tests

Huge improvement in turnaround time!

Weapon System Acquisition Kept on Track

In a recent Acquisition Program, the government review board found that, for one critical criterion, the contractor had neither the computational tools nor the skill set to perform the necessary design study. To avoid delay in the delivery of this system, government personnel stepped in and analyzed the device using HPCMP CREATE™ RF SENTRi and Capstone software for multiple design configurations. SENTRi was also used to determine the range of input parameters that met the government's functional requirements. As a result, a design was chosen and the system was fielded on schedule.



Many Antennas per Vehicle
Cause Significant Interference

HPCMP CREATE™ SENTRi software and HPCMP computer resources enabled:

- **Virtual prototyping with SENTRi and Capstone enabled an appreciable reduction in time and expense (parametric physical model construction and testing would otherwise have been required).**
- **Project Chief Engineer stated: "The SENTRi supported study provided user command confidence in the acquisition of the device" allowing it to go to production**
- **The government analyst was nominated for Outstanding Programmatic Achievement.**

HPCMP CREATE™ resources and expertise enabled the antenna to be fielded on schedule and meet its functional requirements.

Closing Remarks

- Effective use of computationally-based tools is a key to improving efficiency of research, development, and sustainment of defense systems
- CAPSTONE is developing geometry, meshing and attribution capabilities that are filling specific gaps
  - Significantly reduced time and effort for geometry preparation and meshing
  - Enable accurate and scalable geometry-based adaptive analysis
  - Provide a common geometry and meshing infrastructure for CREATE-developed solvers and design tools/environment
- Current release 5.0.1 provides significant capabilities that solve several usecases of DoD interest
- Increasing adoption within DoD acquisition community
  - >100 exclusive/unique users of Capstone
  - >500 cumulative users with other CREATE-developed tools
- More information at : https://create.hpc.mil