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

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Outline

- **Motivation, Strategic needs and Challenges**

- **Capstone – the product**
  - Overview
  - Users and Usage Scenarios

- **Current status**
  - Key capabilities
  - Applications/Impact

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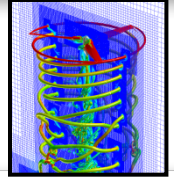o **Insert More (Multi) Physics-Based Analysis Earlier in the Design-Cycle**

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**
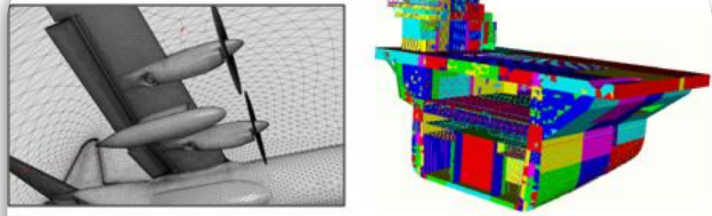 - Rapid generation of mesh and geometry representations needed for analysis

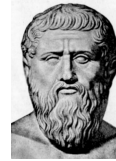*CREATE tools will support all stages of acquisition from rapid early stage design to full life-cycle sustainment*

F-35

Design concept

Seakeeping and resistance

Aircraft and aircraft carrier meshes

Military platforms with antennas

Shock vulnerability

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)
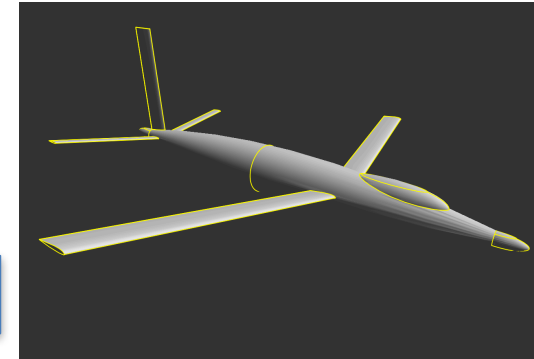
CAPSTONE: SDK

CAPSTONE: GUI

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

Produce analyzable representations for complex and detailed analysis
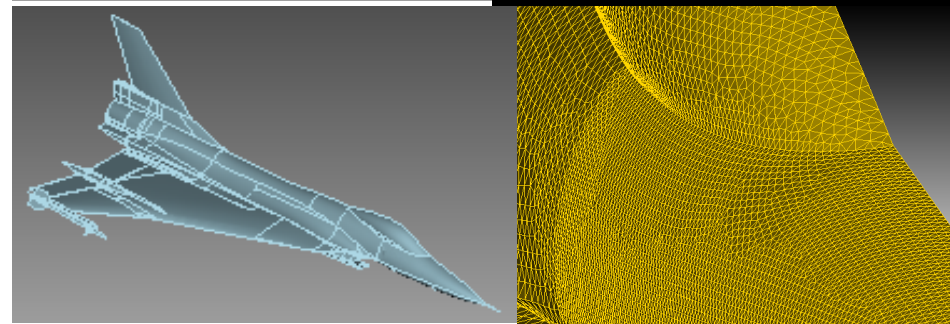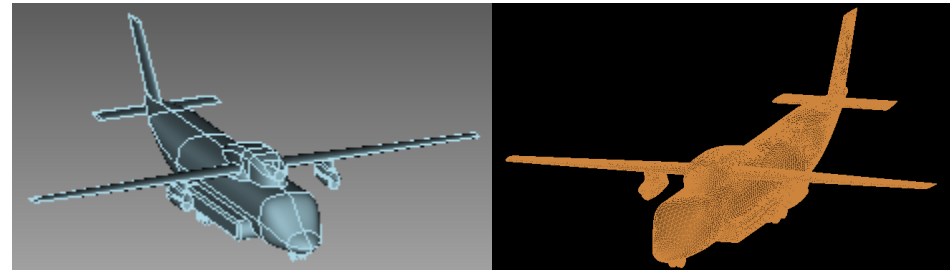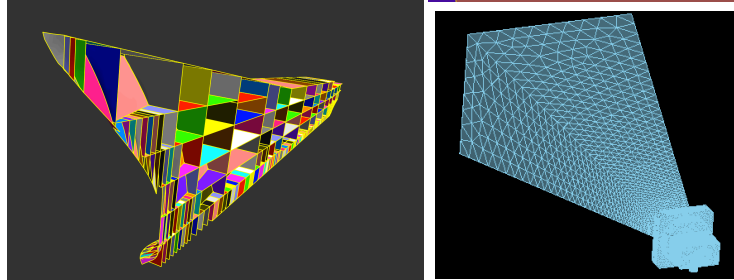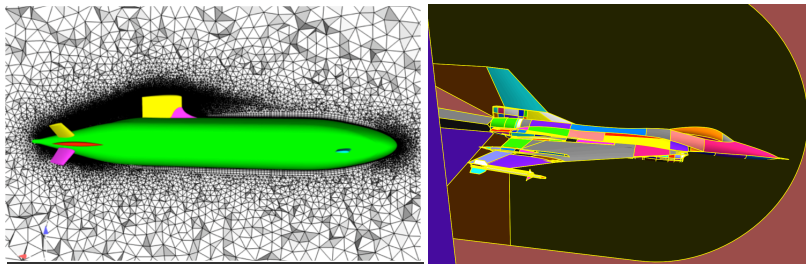
Capstone Architecture and Impact

- **Well <u>abstracted reusable</u> 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
- **<u>Extensible</u> using plugins**
- **All the core capabilities accessed using the SDK**
  - Capstone frontend (GUI) itself uses the SDK
  - Foundation enabling other tools/solvers
    - CREATE-RF Sentri (Gen 2) solver embeds Capstone for geometry-driven analysis capabilities
    - Capstone is a key component of CREATE-Genesis and is the foundation for Genesis-Design component
    - CMB tools from ERDC-ITL embeds the Capstone SDK for geometry and mesh-generation capabilities

Capstone 7.0 Highlights

- ## MG Native Volume Meshing
  - Not required to exclusively use AFLR

AFLR

MG-native

- **BL 'unzipping'**
- **Euler-mesh creeps in**

- **BL mesh grows correctly all the way**
- **Terminates with a smooth lifted surface**
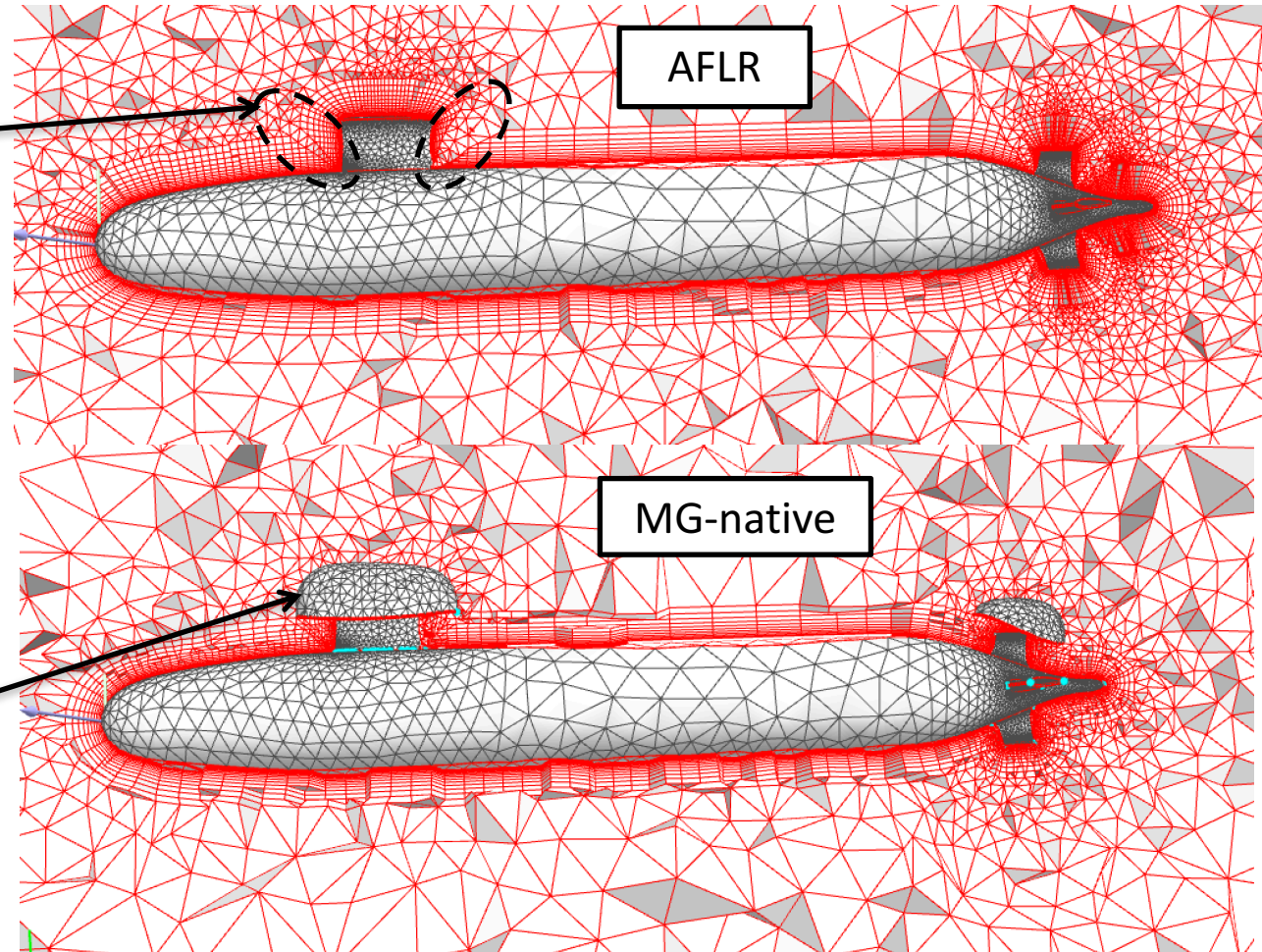
Capstone 7.0 Highlights

- **High-order curvilinear mesh generation**

  – Quadratic and cubic Lagrange mapping
    - successfully used by RF Sentri hp-version
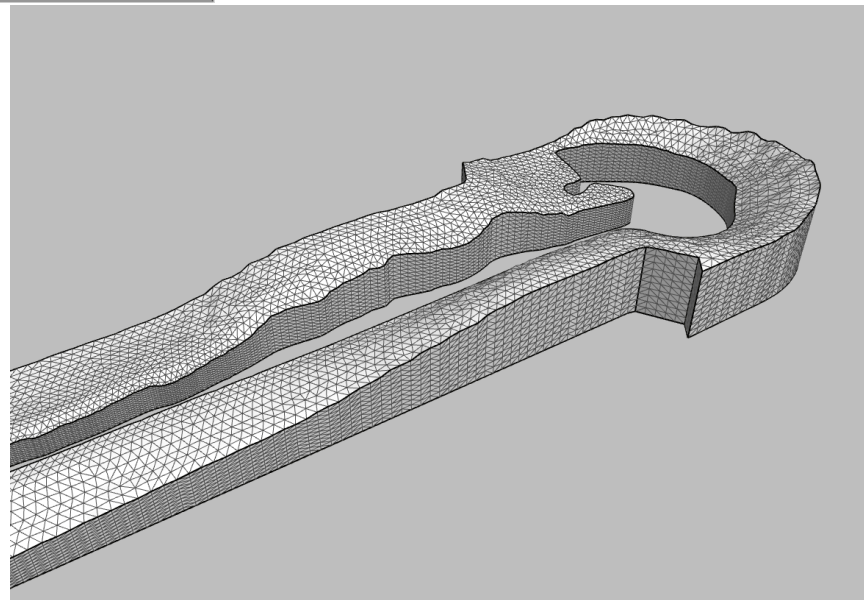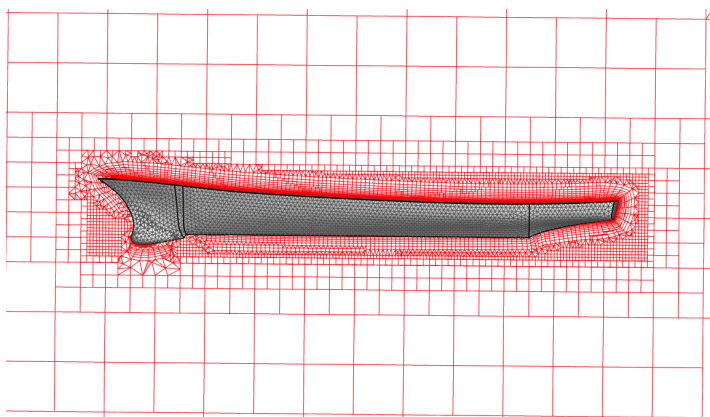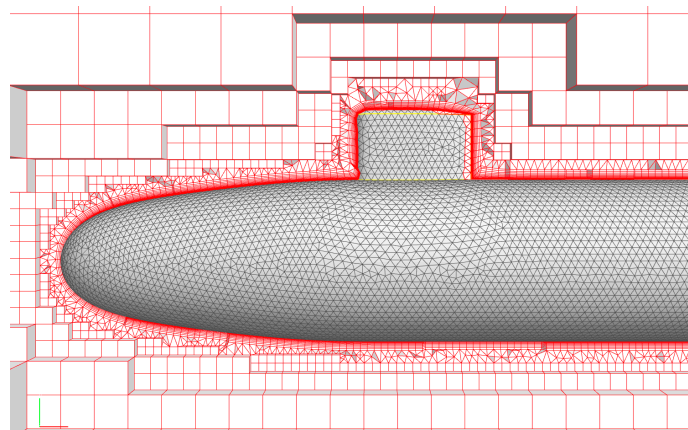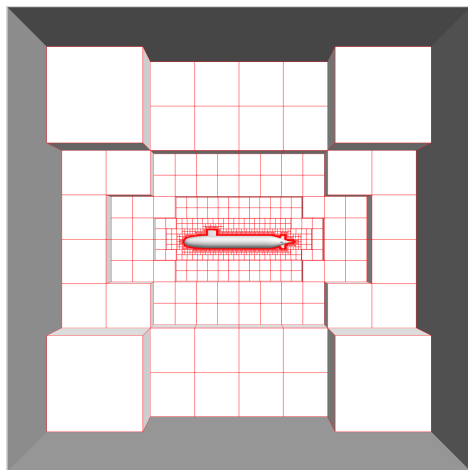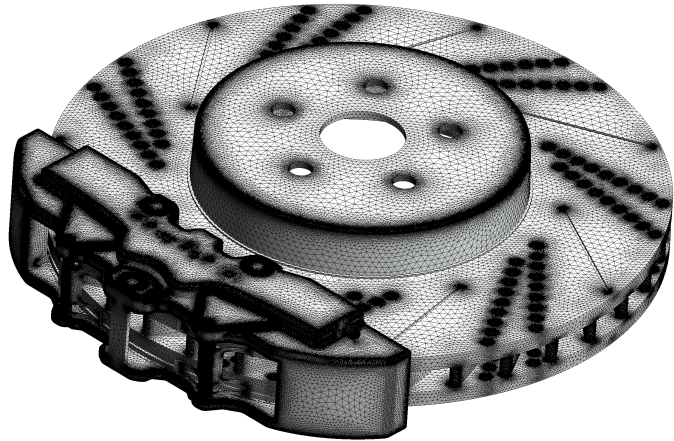 – Conformal to actual CAD geometry
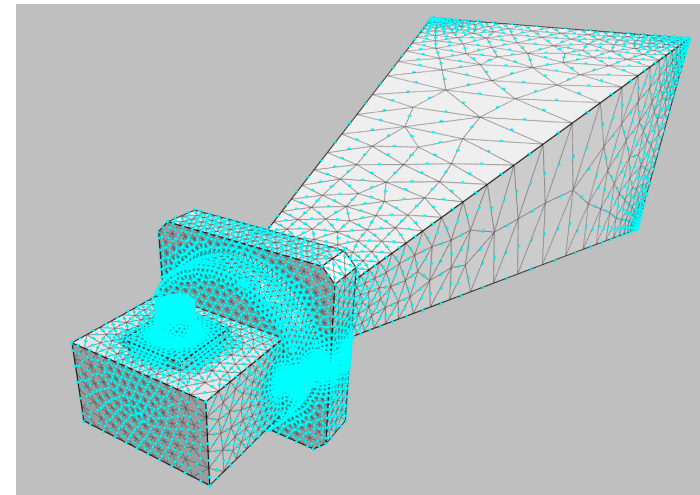
Linear mesh
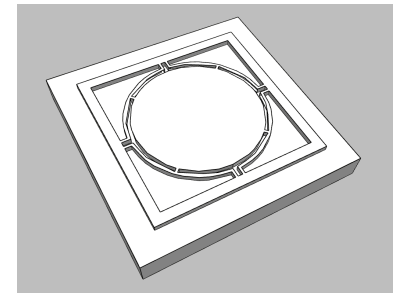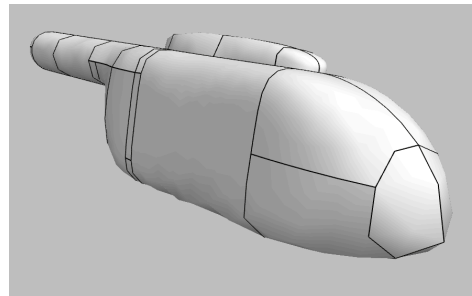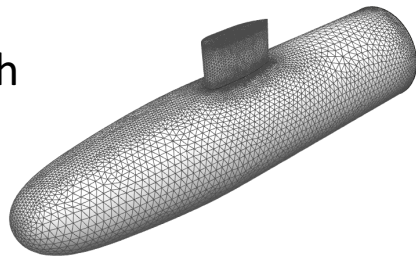
CAD-conforming mesh
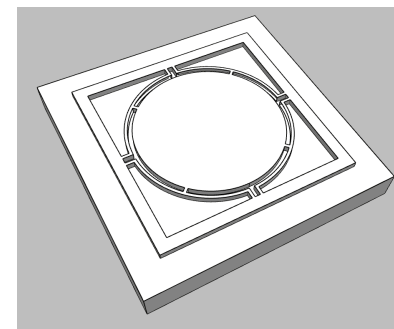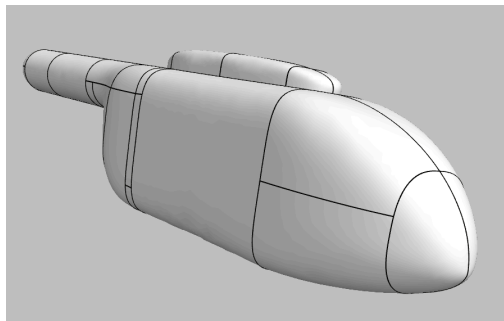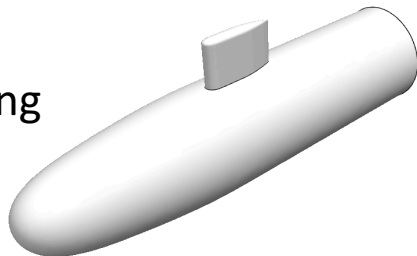
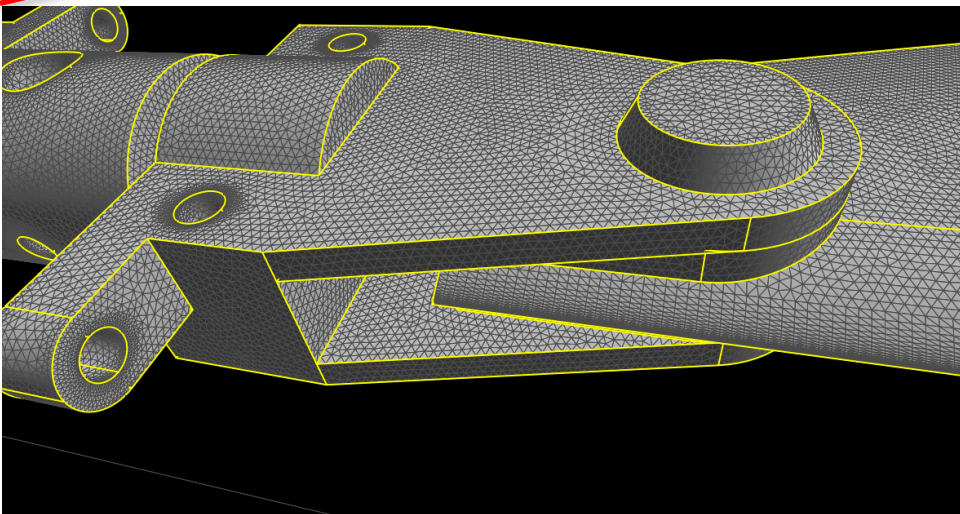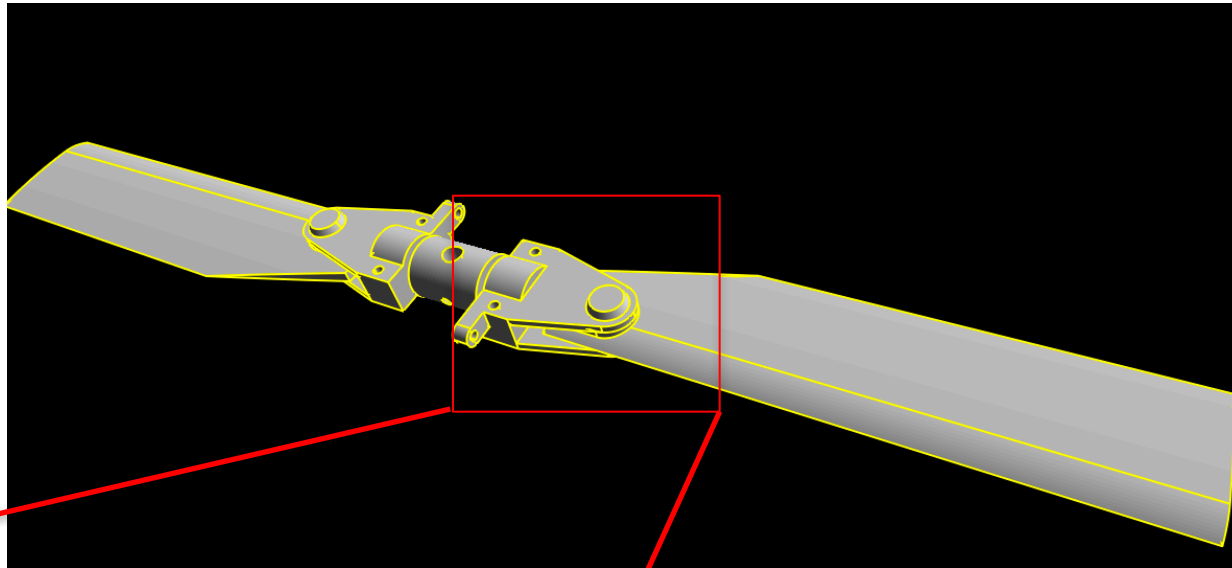# Capstone 7.0 Highlights
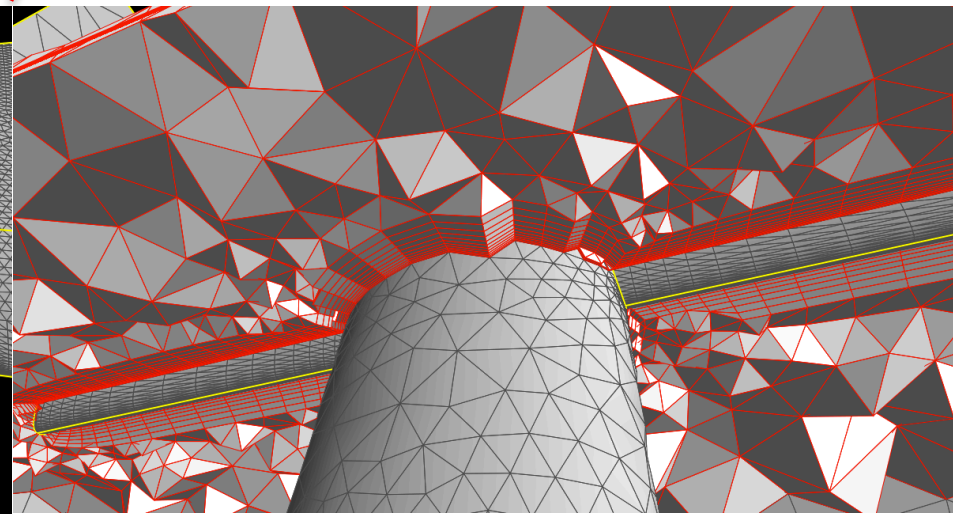
- **Hex-dominant and Extrusion-based Volume Meshing**
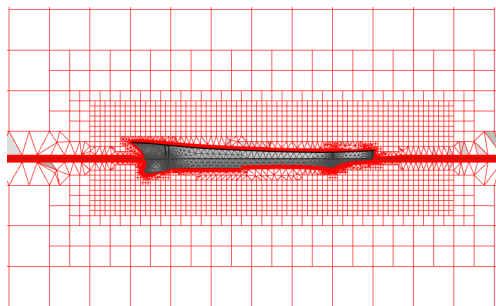
Surface mesh: Break disk
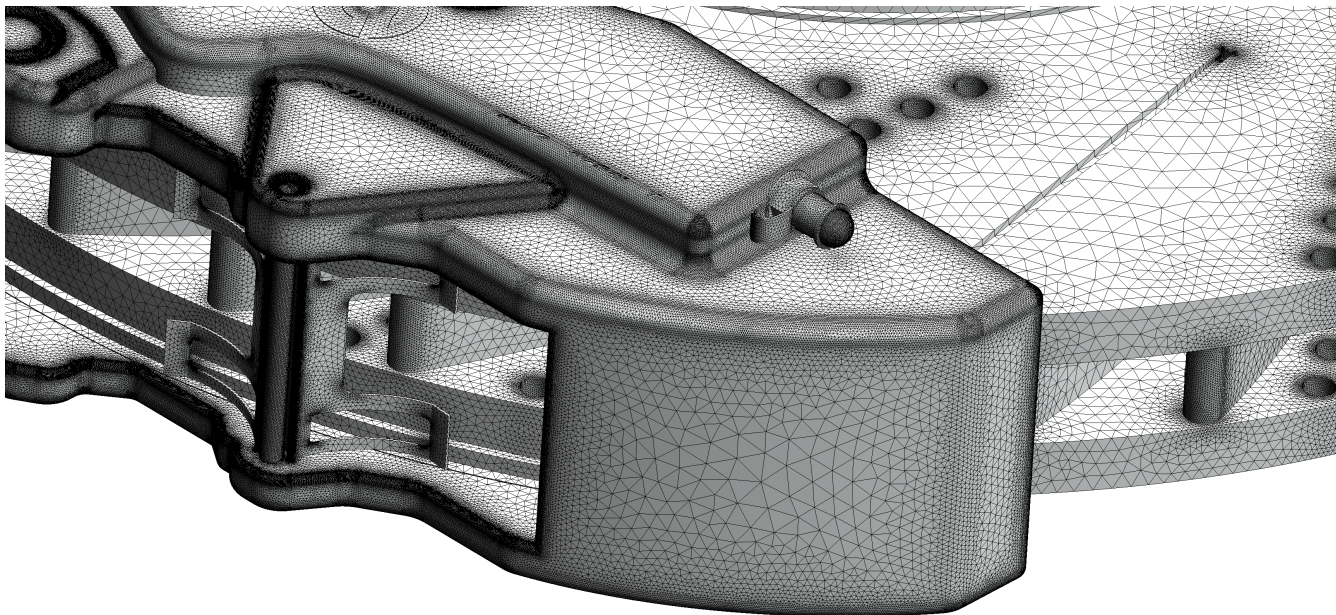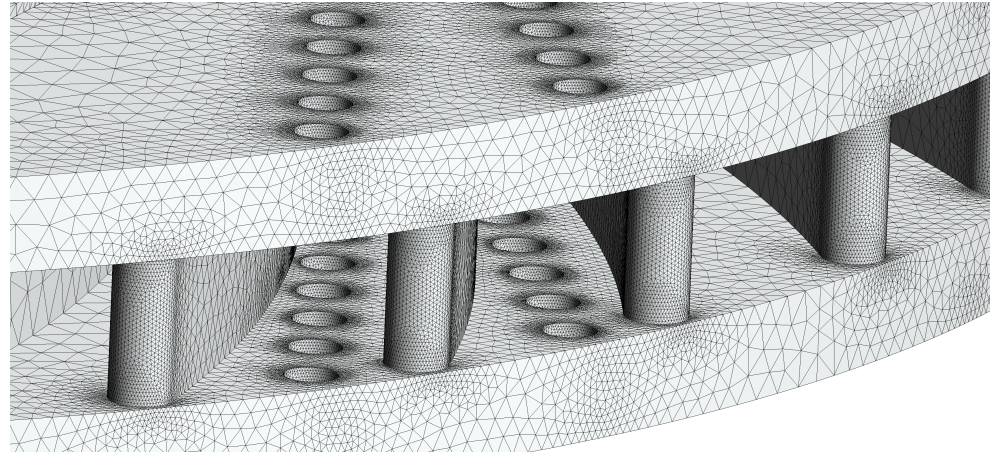
Anisotropic surface meshing

Anisotropic surface meshing   Combined surface and volume BL (crinkle-cut)

MG-Native Volume Meshing

- **AIAA High-Lift Workshop Geometry**

Mesh generation for high-lift aircraft geometry configurations
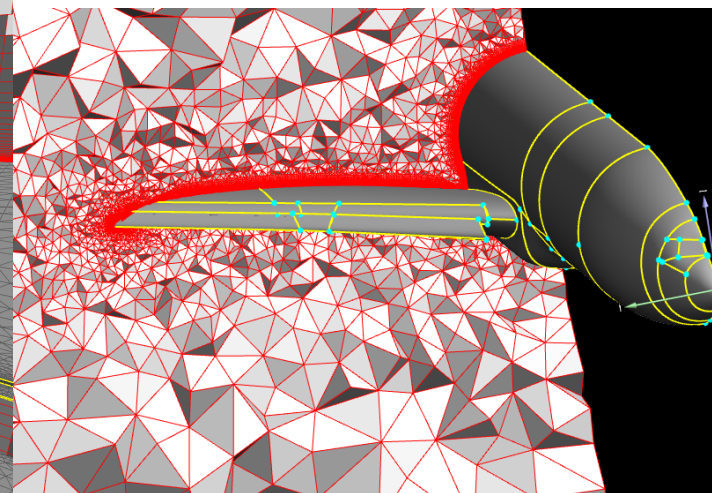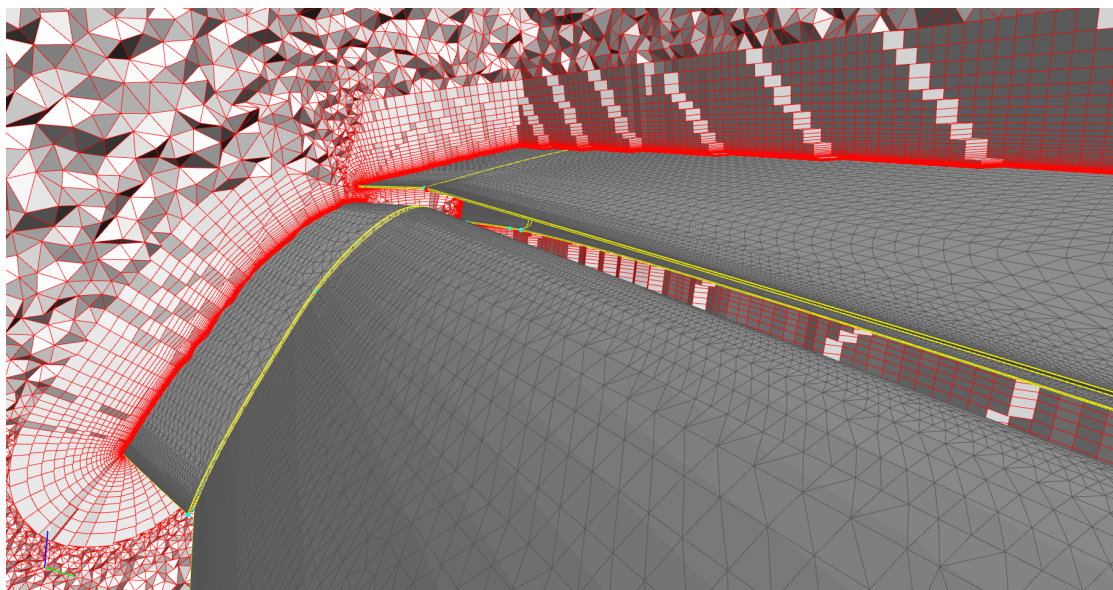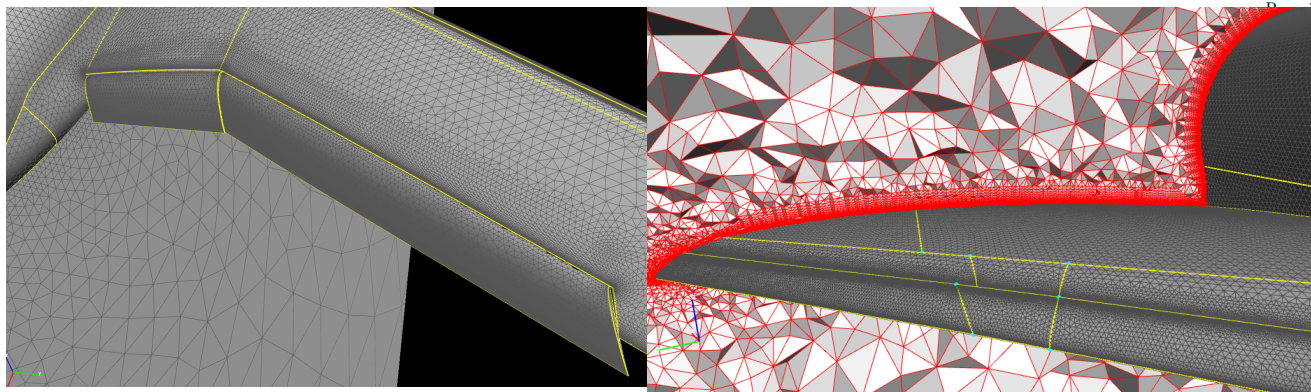
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US Naval Research Laboratory, Washington, DC, 20375, USA

Romain Aubry, B. Kaan Karamete, Eric L. Mestreau and James L. Dean
Sotera Defense Solutions, Herndon, VA, 20171, USA

Mark Richardson
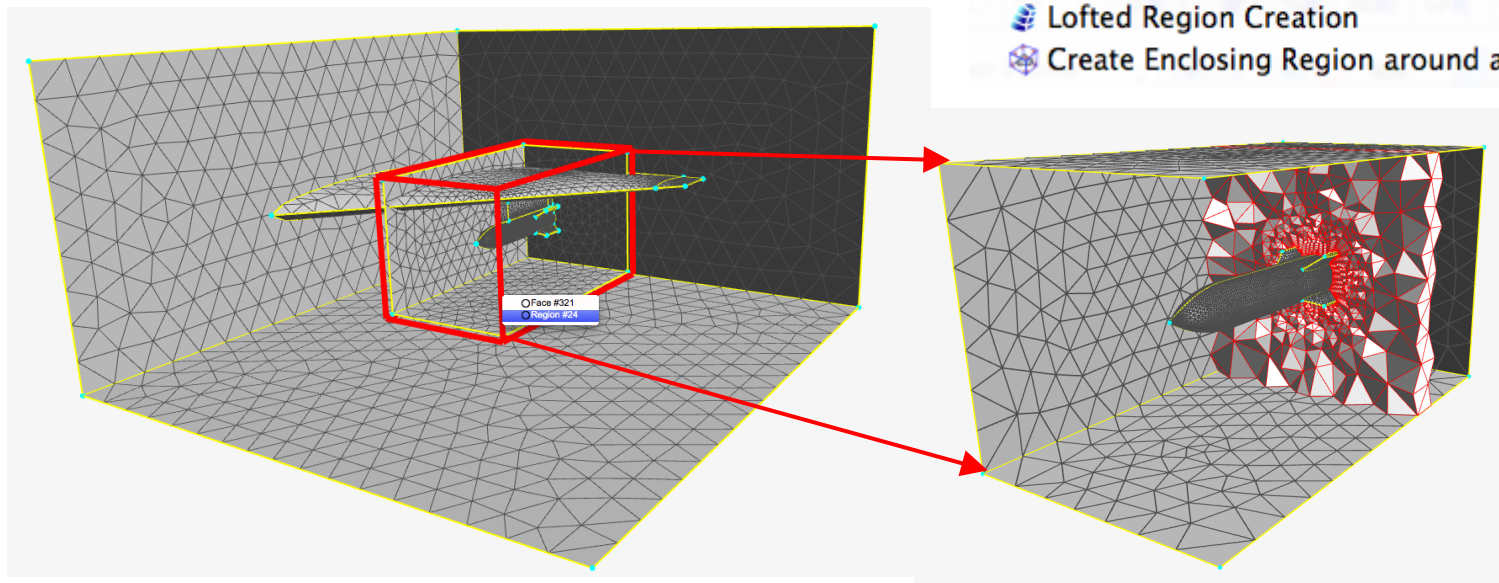Elemental Technologies, American Fork, UT, 84003, USA

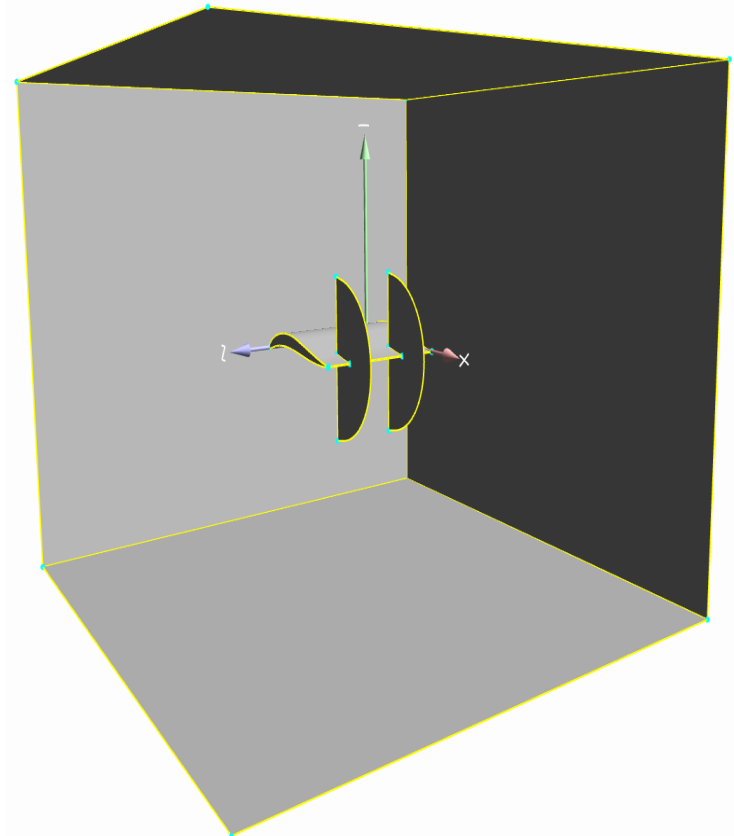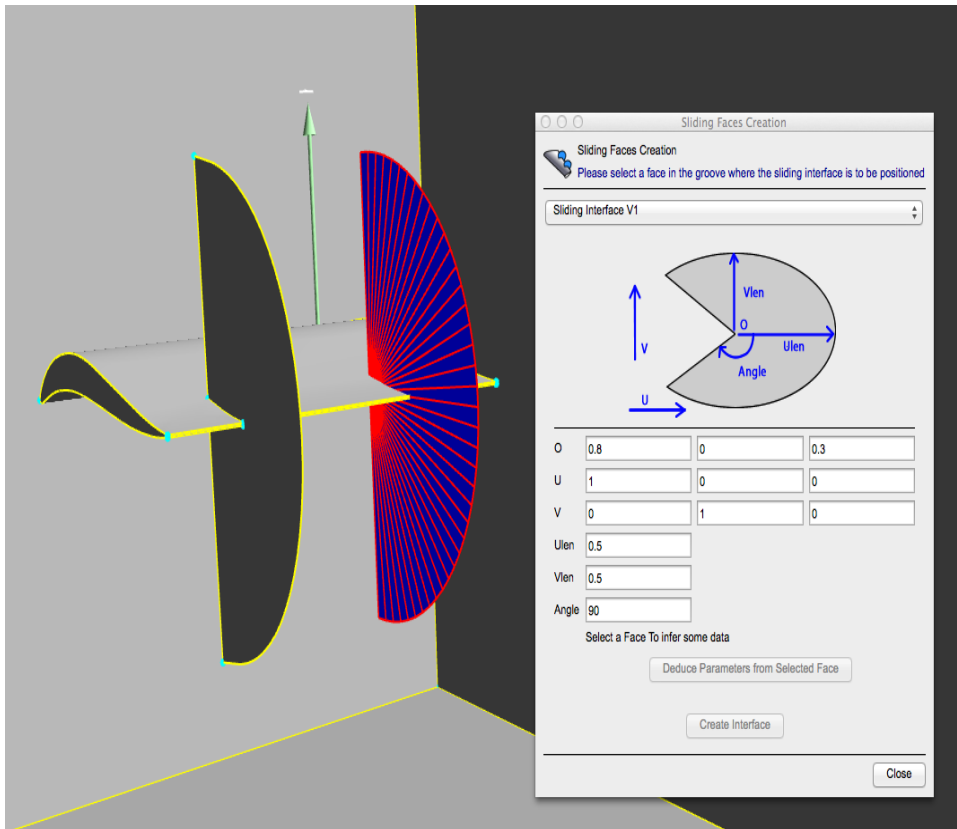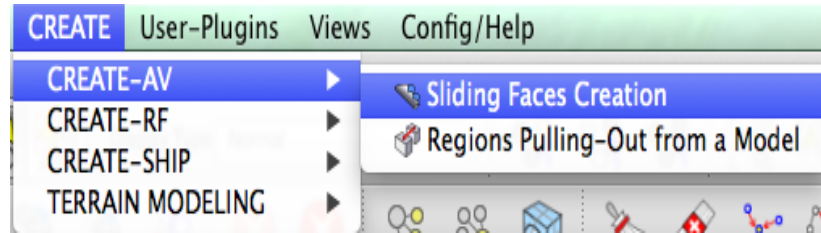AIAA SciTech 2017
Jan 9-13,
Grapevine, TX

Multi-body meshing for store-separation analyses

Sliding-Plane Boundary Layer Meshing

Sliding Plane Boundary Layer Meshing
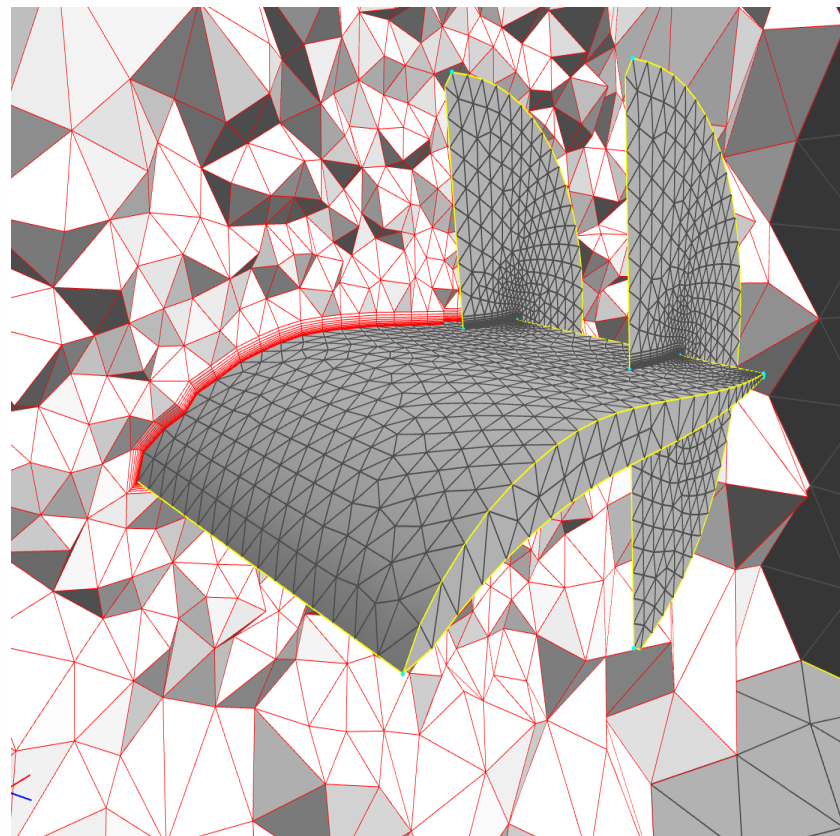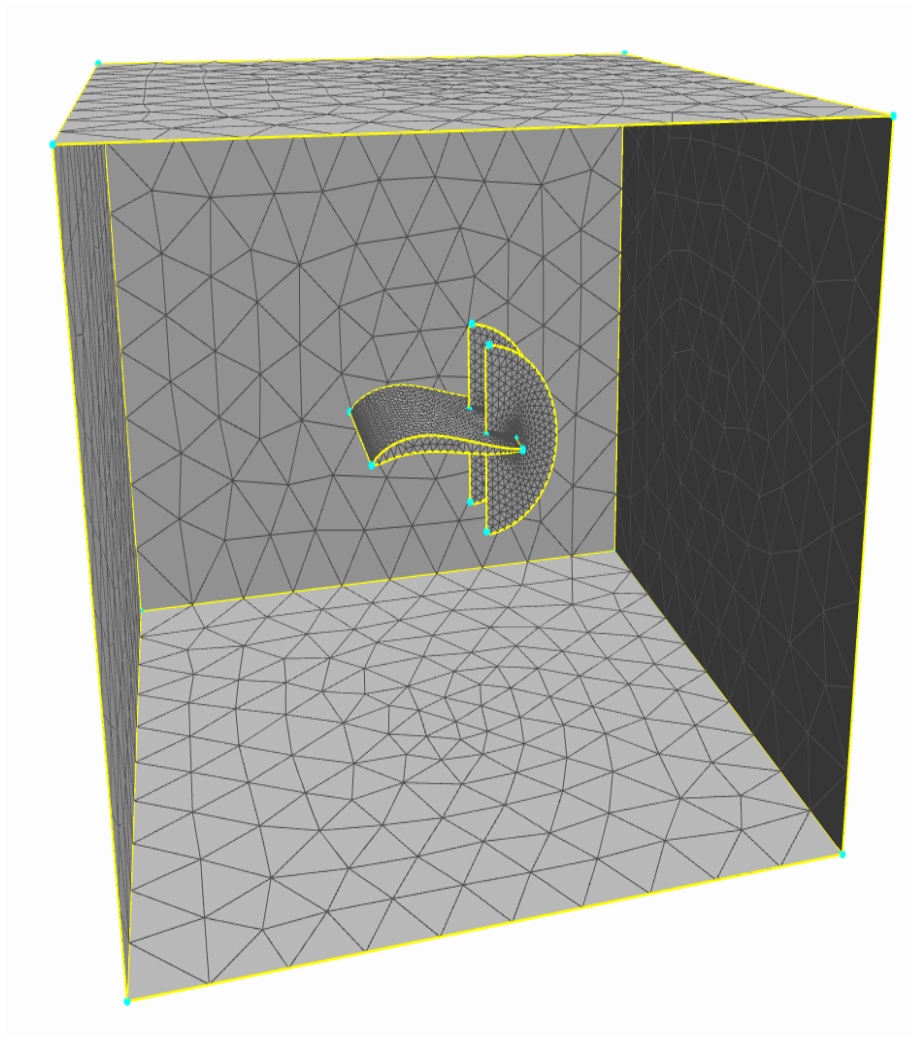
Improving turnaround time

IGES Import (dirty)
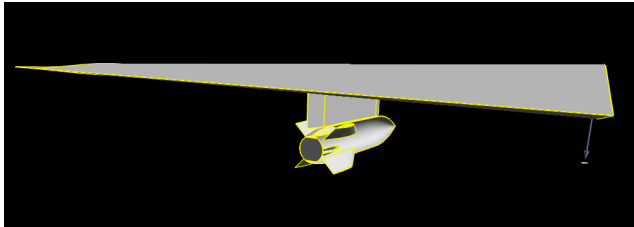
Ready to mesh (clean)
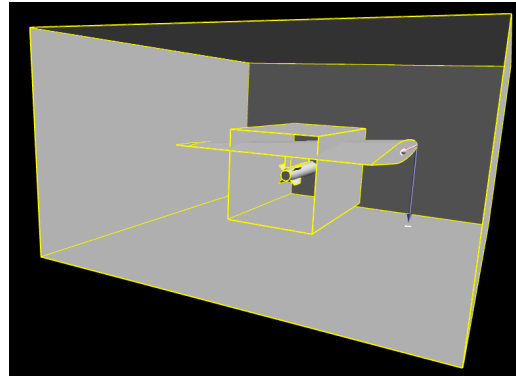
BL Mesh
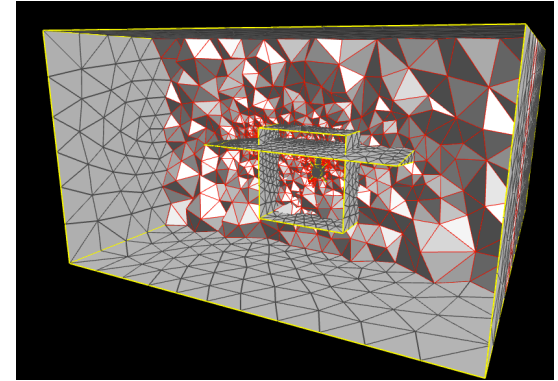
~5 min

~5 min
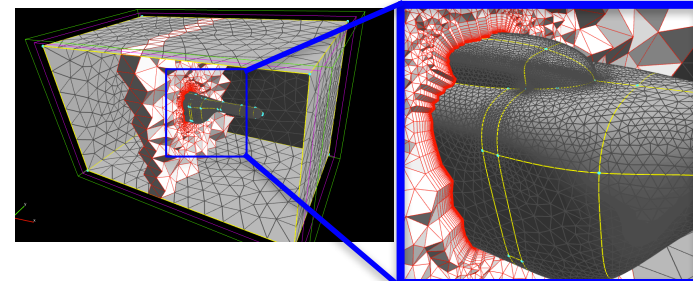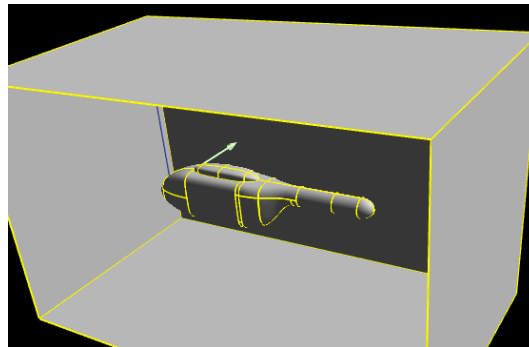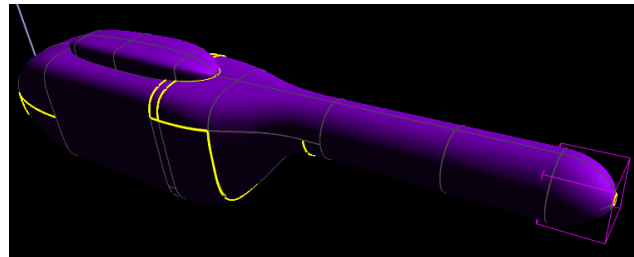
Capstone Impact: **Design it better, faster and cheaper!**   ASC Pilot Project

DaVinci

Capstone

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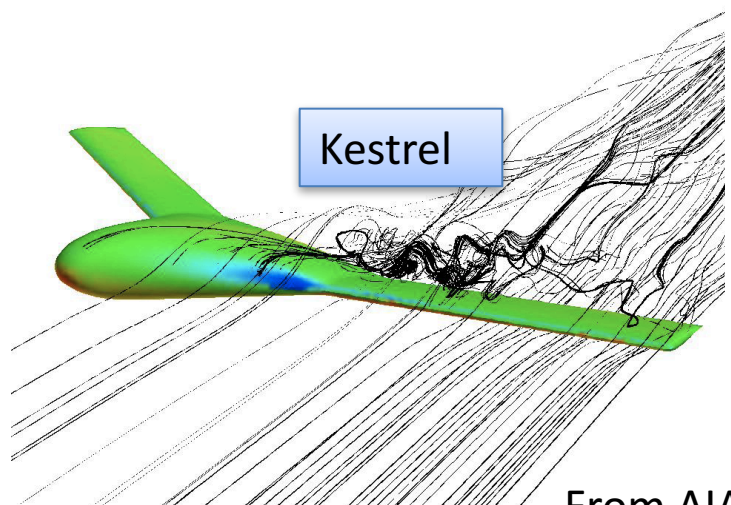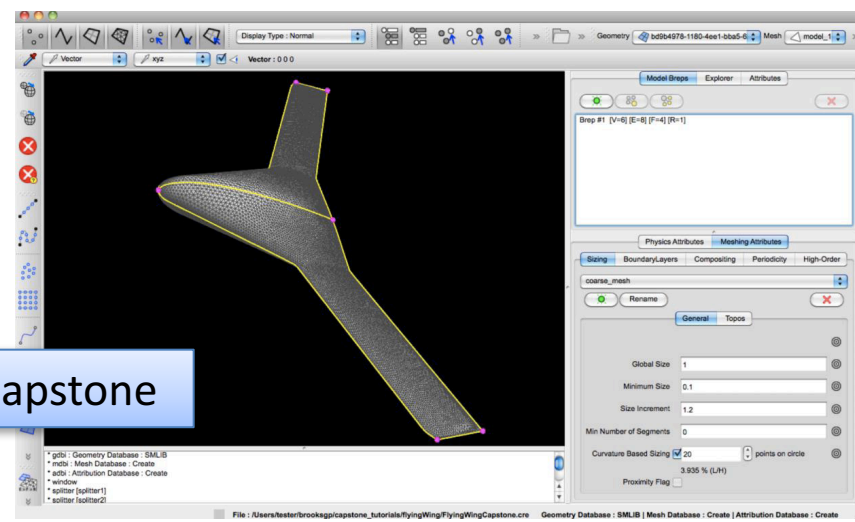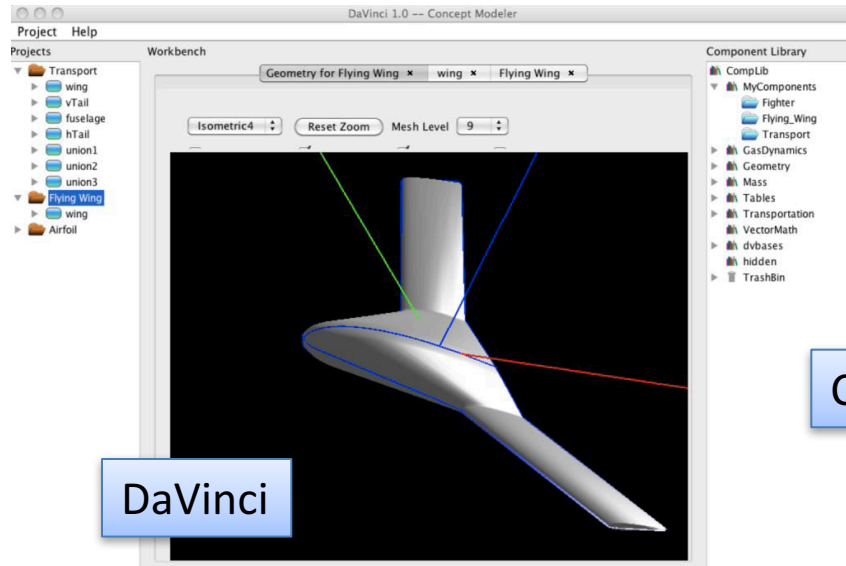
Capstone is enabling hi-fidelity physics-based analysis earlier in the design process

- 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

(a)

(b)

(c)

(d)

(e)

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
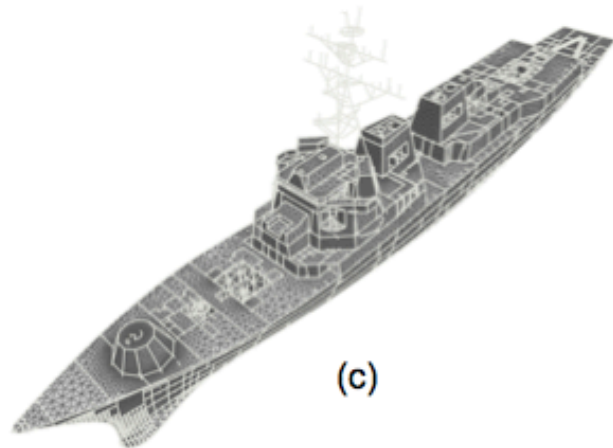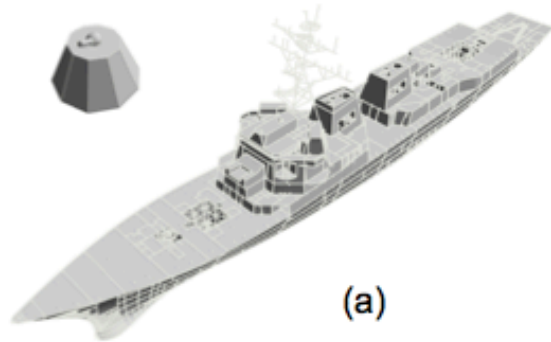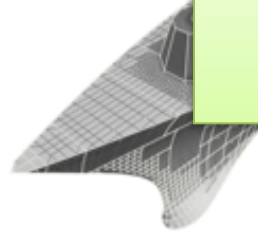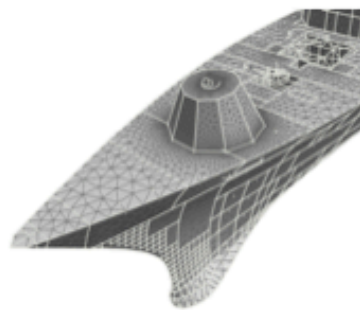
Huge improvement in turnaround time!

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.

Antenna is 0.001 of Vehicle Size
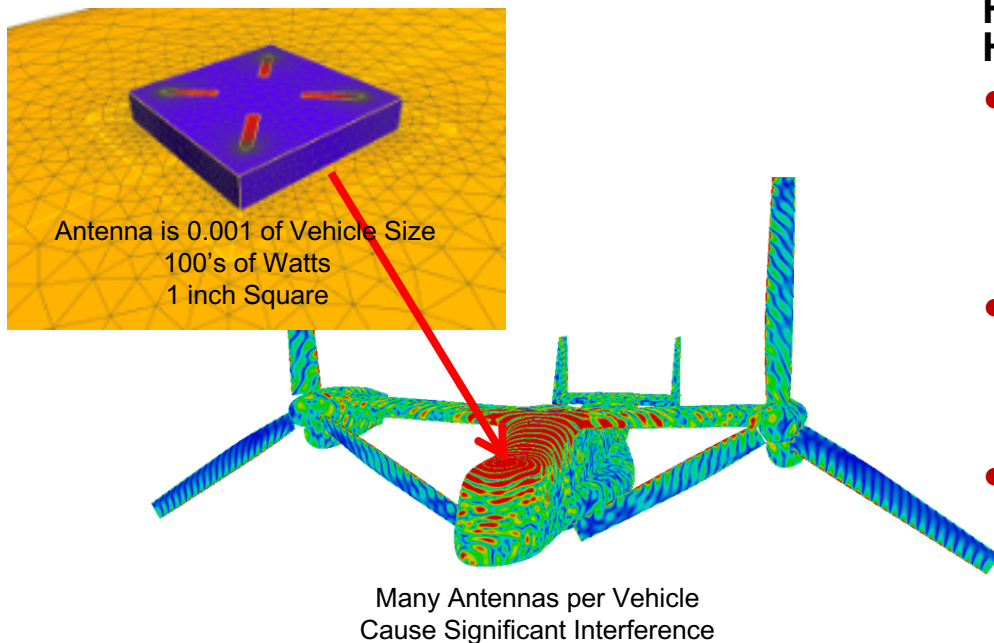100's of Watts
1 inch Square

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.**
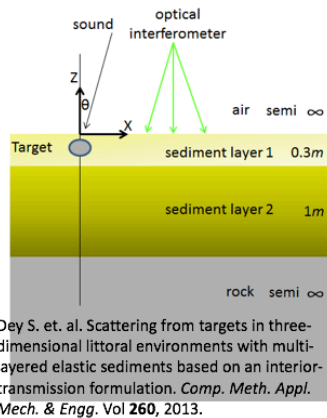
Many Antennas per Vehicle
Cause Significant Interference

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

Distribution Statement A: Approved for Public Release: Distribution is Unlimited
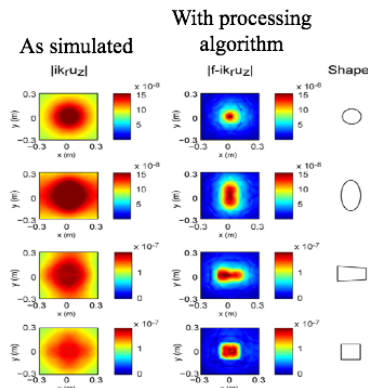
Capstone Impact Beyond CREATE

- ## NRL (Capstone+STARS3D)
  - Low Frequency Broad Band (LFBB) Sonar simulations
    - Transitioned to _Knifefish_ littoral mine-hunting system (part of LCS Mine Counter Measure Mission Package)
  - Unexploded Ordnance detection
    - SERDP program

3D Free-field Scattering Validation: E50

Source

receiver

Numeric — NRL Lab Data

Back scatter — Forward scatter — Back scatter — Degree

Target response and for multi-layered elastic sediments

Full 3D response – do not know of any other tools that do this

Sediment Surface Displacement

As simulated — With processing algorithm — Shape

sound — optical interferometer

Target — air semi ∞ — sediment layer 1 0.3m — sediment layer 2 1m — rock semi ∞

Dey S. et. al. Scattering from targets in three-dimensional littoral environments with multi-layered elastic sediments based on an interior-transmission formulation. _Comp. Meth. Appl. Mech. & Engg._ Vol **260**, 2013.

Robust validation: complex target, littoral setting

Experiment — STARS3D

Proud

Half-buried

Steel 0.52 — Steel 0.16 — Epoxy Resin Filler — Air — Aluminum 0.16
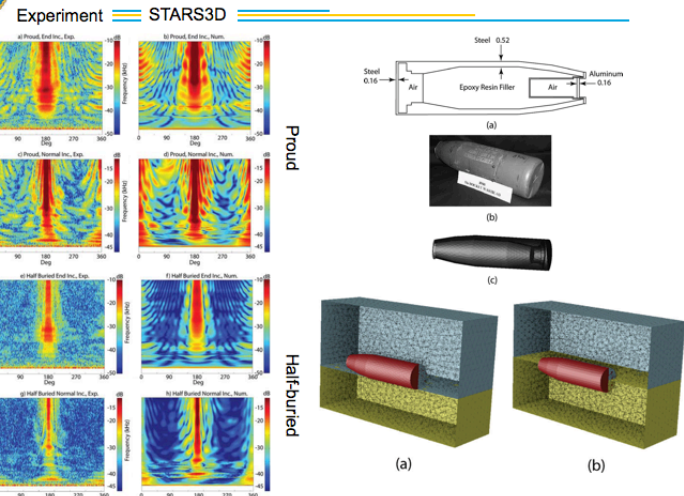
Capstone used to generated numerical models of targets in exterior environments

Closing Remarks

- Effective use of computationally-based tools is a key to improving efficiency of research, development, and sustainment of defense systems
- Capstone provides 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 7.1 provides significant capabilities that solve several use-cases of DoD interest
- Increasing adoption within DoD acquisition community
  - >350 exclusive/unique users of Capstone
  - >600 cumulative users with other CREATE-developed tools
- More information at : https://create.hpc.mil