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
- **Capability Development Roadmap**
- **Current status, use-cases and testing**
- **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**

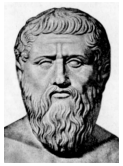
Critical Hurdles

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.

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 all-hexahedral mesh generation
  - ○ Currently no known algorithm works robustly for complex geometries
- 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

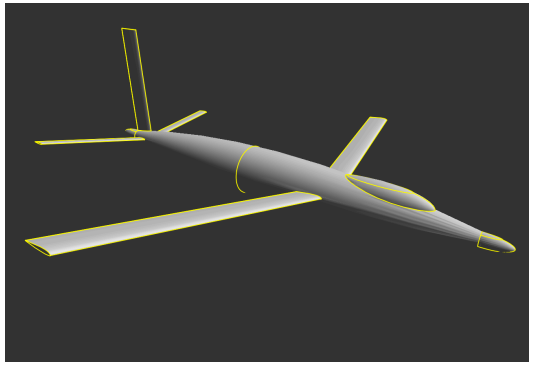
CAPSTONE Critical Requirements

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

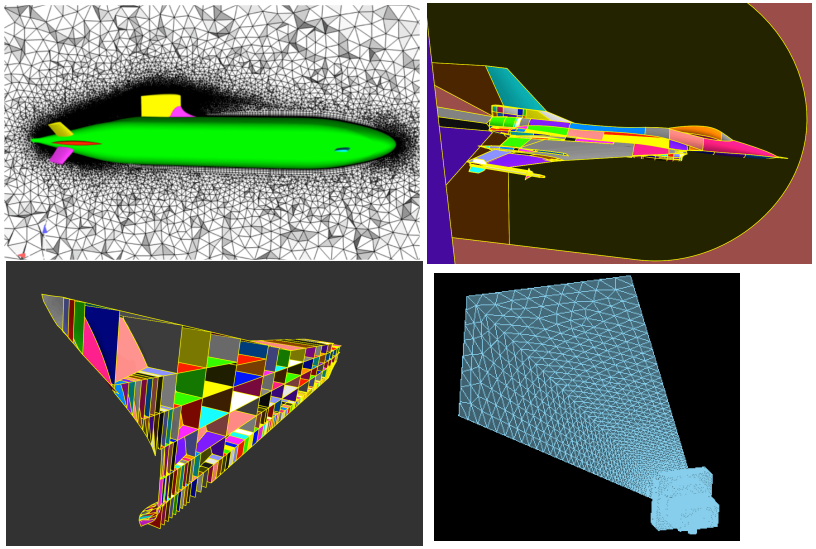
Capstone provides geometry and meshing needs for all phases of acquisition engineering (conceptual-, preliminary-, detailed-design and operational-support)



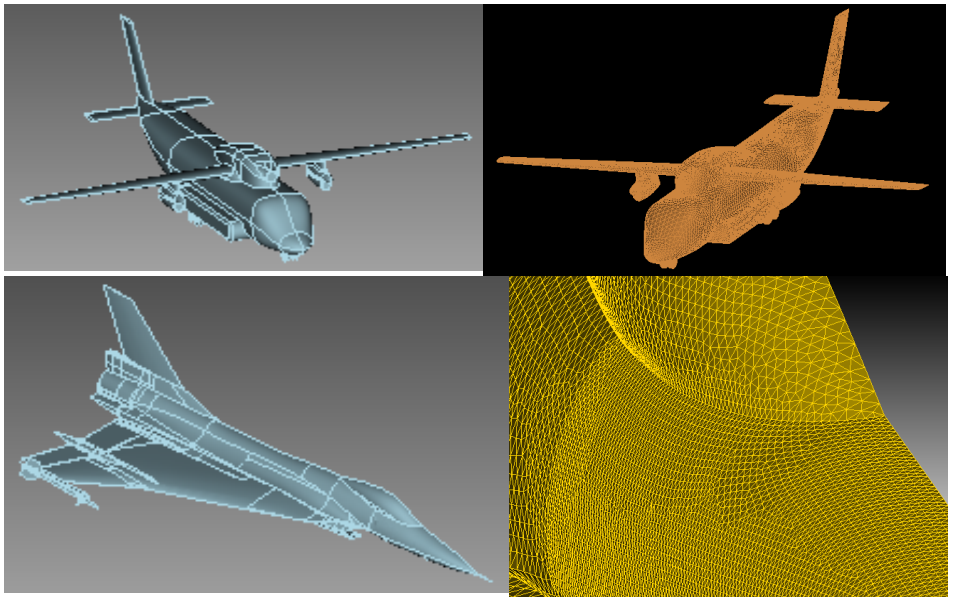
CAPSTONE: SDK

CAPSTONE: GUI

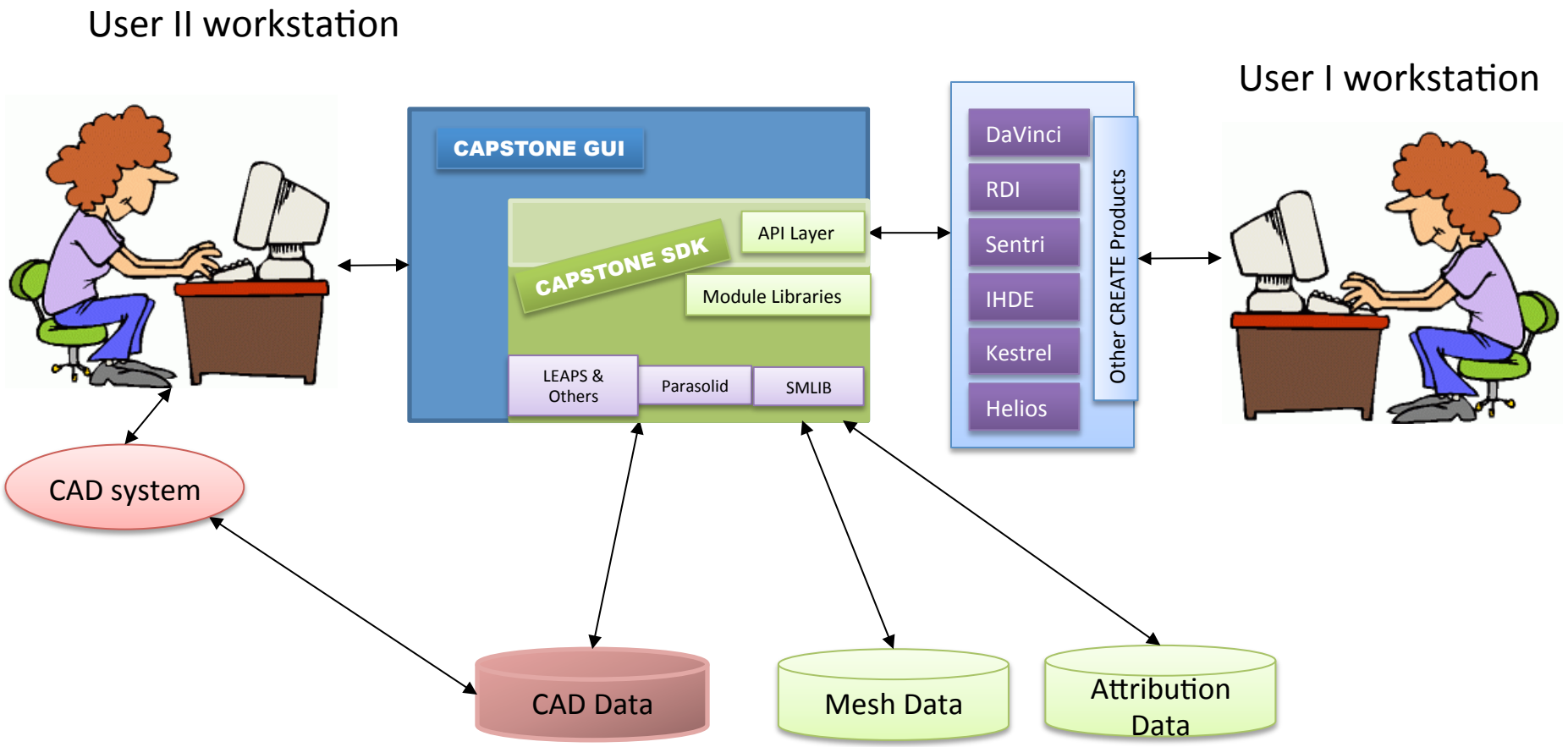
Produce analyzable representations for complex and detailed analysis



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

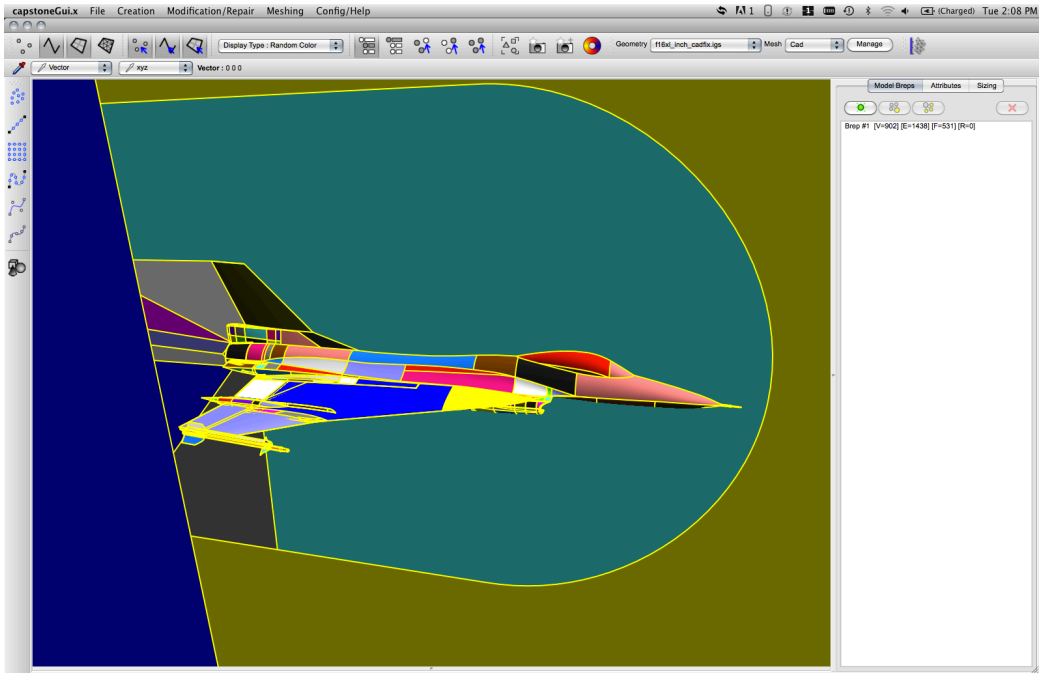
- Analysis Data Modeler
  - End-user who creates analysis-suitable mesh from geometry which may be
    - imported from existing (legacy) description
    - created from scratch
  - Not expected to be a developer (programmer)
  - Typical example- bench-engineer (analyst) doing
    - analysis of existing 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

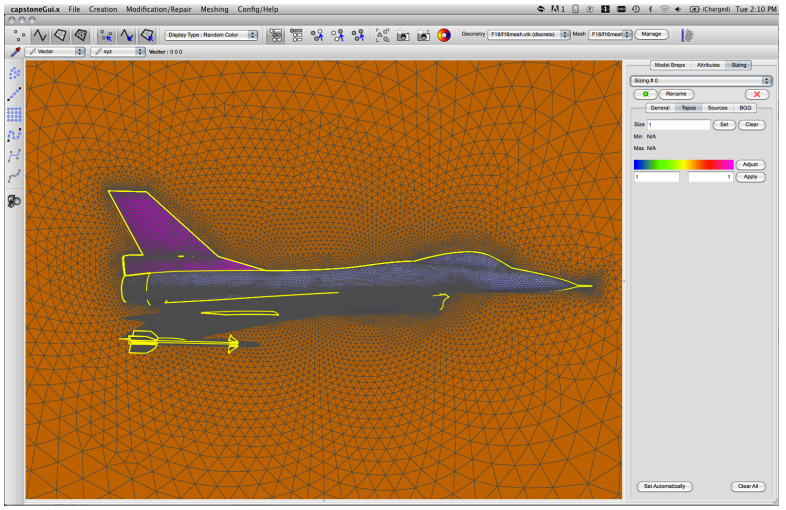
- Analysis Code Developer
  - Developers of physics-based CBE analysis tools
  - Expected to be developers (programmers)
  - Typical uses- geometry-based a-posteriori adaptive-analysis

Capstone: GUI Application and Usage

Product: Component	Expected Users	Gaps Addresses
CAPSTONE : Frontend	Analysis Data Modelers • interactive (GUI, CLI, scripting) • background/batch mode	MG-03-06, 08-10



GUI: Graphical User Interface
CLI: Command Line Interface

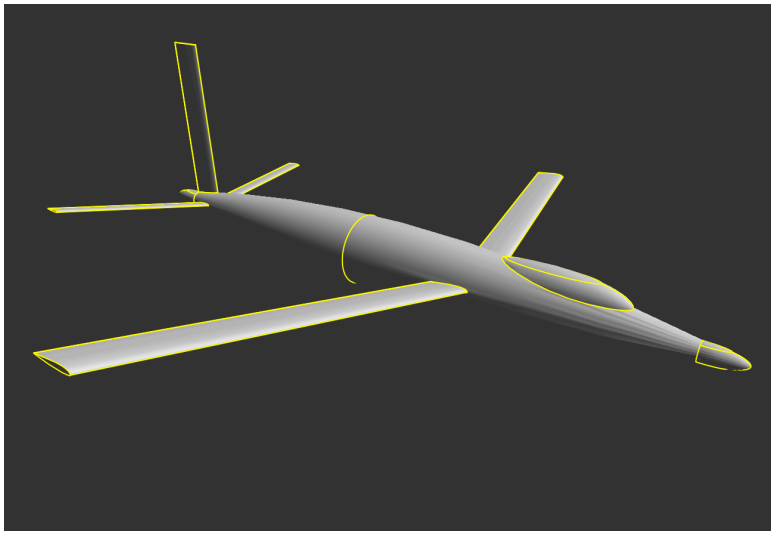


Capstone: SDK Application and Usage

Product: Component	Expected Users	Gaps Addresses
CAPSTONE : Core	CBE Tools Developers; Design Tools Developers • tight (compiled or runtime) integration • access to mesh, geometry and attribution data	MG-00, 07-08, 10-11

Uses of CAPSTONE: Core APIs for

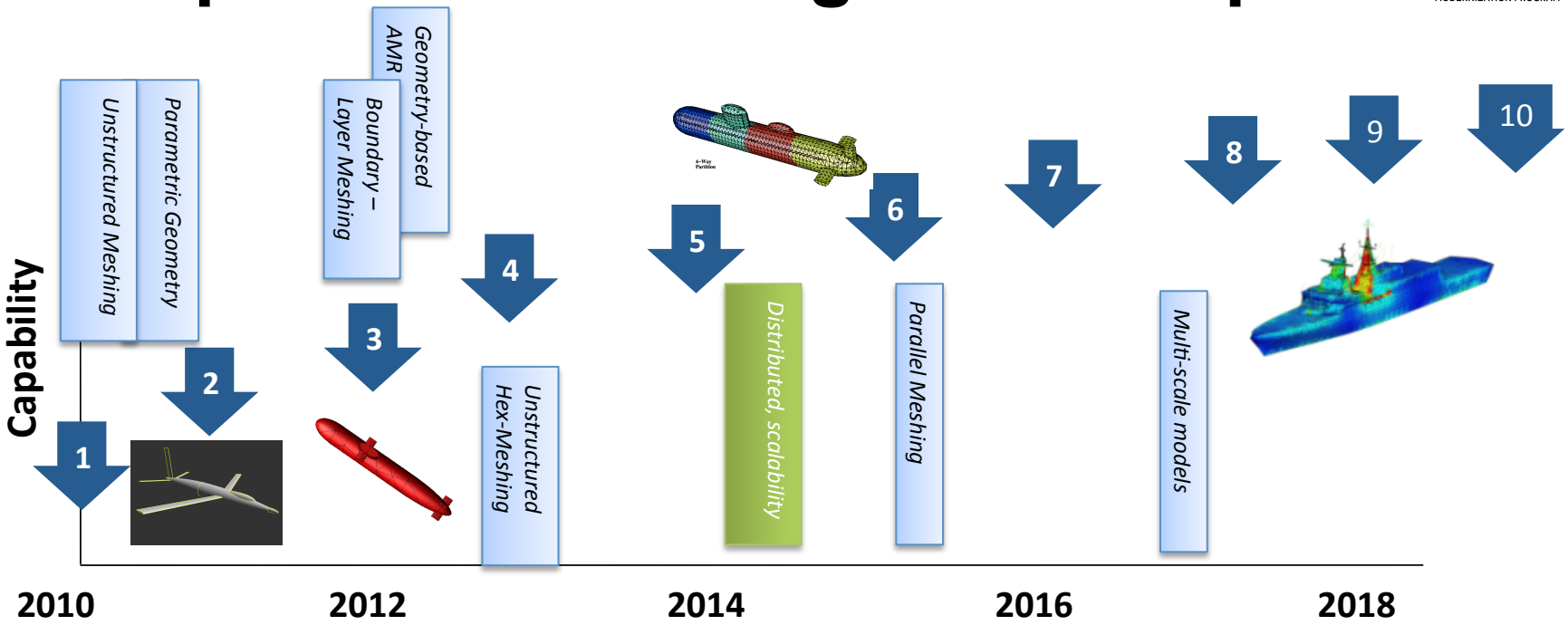
- Recipe-based parametric, associative model building with tools like DaVinci
- Scalable geometry-based AMR for physics-based solver



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
  - ERDC ITL excited about embedding the SDK in their meshing tools

Capstone: Four Stage Roadmap



Start up

FY08 – ICD, planning, team formation

FY09 – Evaluate legacy tools; early prototype

Initial Capability For AV, RF and Ships

FY10 – v1.0; Foundational capabilities, mesh implant

FY11 – v2.0; BL meshing, repair, complex parametric geometry

FY12 – v3.0; geometry-based AMR, advanced repair, complex BL, Improved rendering

FY13 – v4.0; ultra-large distributed mesh representation, hex meshing; scripting interface

Scaling Improvement

FY14 – v5.0; Re-factor/optimize for distributed scalability

FY15 – v6.0; Parallel meshing

FY16 – v7.0; Multi-scale representations

Full-scale Deployment

FY17 – v8.0; Improved robustness for large-scale problems

FY18 – v9.0; Support multi-physics, multi-disciplinary models

FY19 – v10.0; Improve robustness

Capstone: End-state and Impact

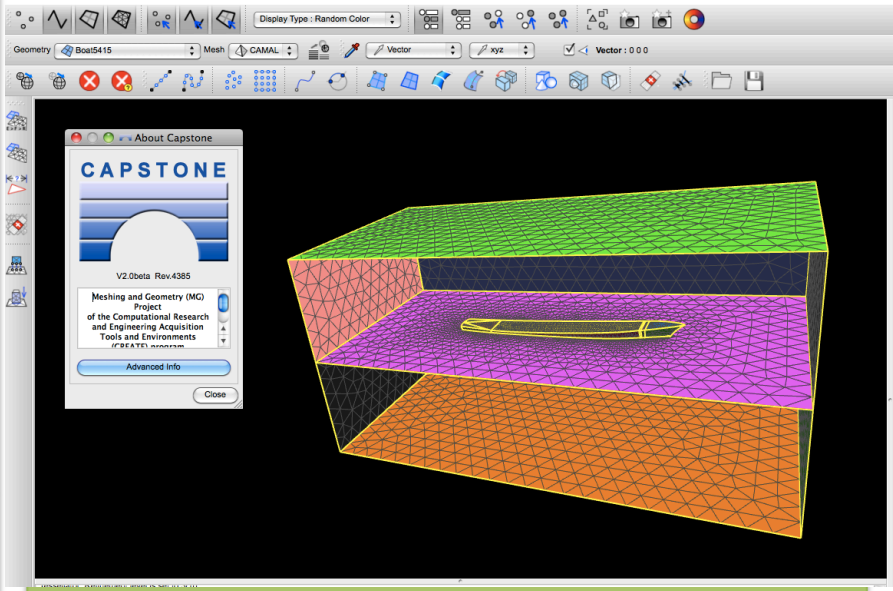
- Significant improvement in automation and turn-around time to produce analyzable representation
- Provides an integrated environment for multi-disciplinary parametric design & optimization workflow (AV-DaVinci, Ships-RDI)
- Provides ability to handle multi-scale ultra large models (billions of elements with sizes ranging from inches to miles)
- Provides ability to fully take advantages of large distributed multi-core computer systems to provide very accurate physics based analysis (CFD/CEM/CSD)
- Provides a state-of-the-art framework to accelerate research & development of new geometry & meshing algorithms
- Reduce the acquisition cost and time for new systems by bringing physics earlier in the design process

CAPSTONE Current (v2.3) Capabilities

CAD-agnostic Geometry Module
- **Native support for Parasolid, SMLib kernels**
- **IGES/STEP import (SMLib)**
- **Improved geometry repair and clean-up**

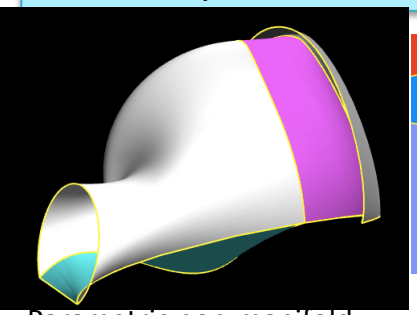
Mesh Module
- Automated boundary layer meshing
- Periodic and curvilinear meshes
- Local mesh optimizations
- Automated implant of components

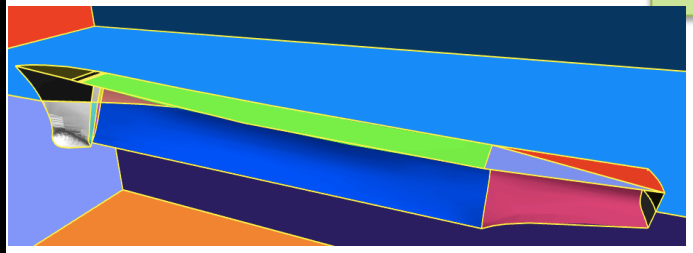
Attribution Module
- Mesh sizing based on sources, curvature, topology and proximity
- Geometry-associative attribution of analysis properties
- Export to CREATE AV, RF and Ships solvers

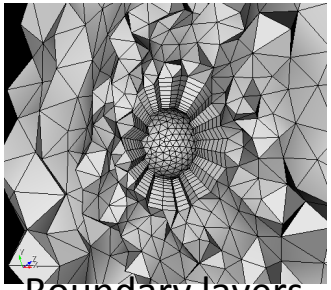


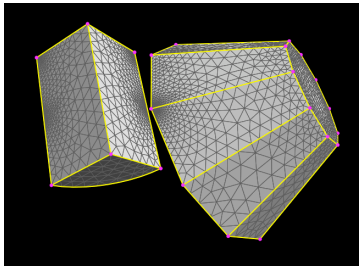
CAPSTONE 2.3 released Aug 1, 2012

https://portal.create.hpc.mil/mg/index.php


Parametric non-manifold geometry


Improved repair and cleanup


Boundary layers


Periodic Meshing

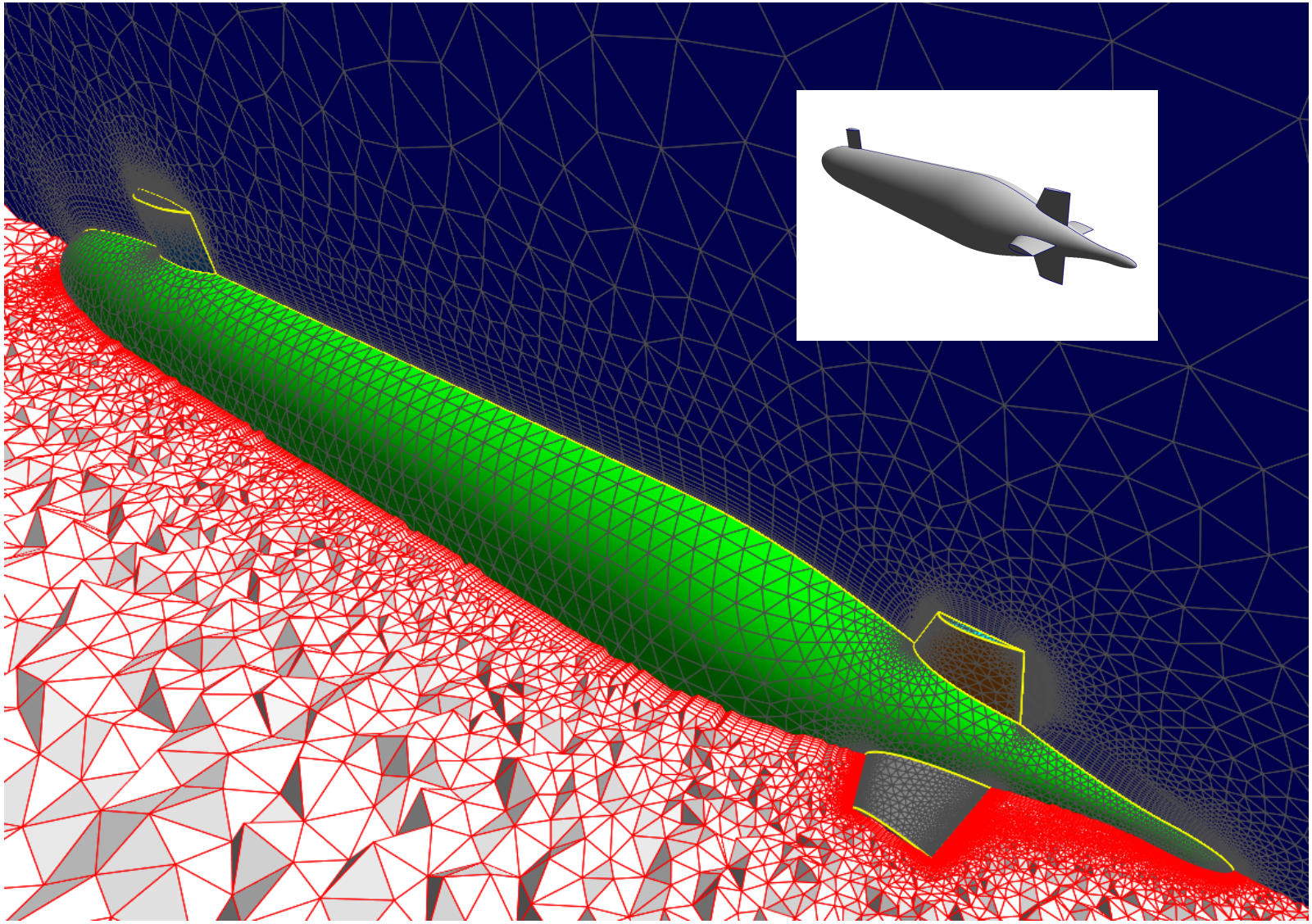
CAPSTONE V3.0 Preview

- **Release Goals**
  - Demonstrate impact within user community
    - Via Pilot-projects
  - One-stop-shop for analyzable representations
    - Make Capstone the only tools needed for most usecases
  - Improve user experience, stabilize existing features
    - Increased robustness, better documentation/ tutorials

- **Key (new) Features**
  - Simply SDK and expose core capabilities
  - Improved geometry repair/cleanup
  - Automated Mesh Quality optimization
  - Automated near-body meshing for viscous-flow applications
  - BL meshing for complex geometries
  - Modeling slip-planes for moving/rotating parts
  - Volume mesh rendering
    - Crinkle-cuts
  - Surface meshing improvements
    - BL-like anisotropy on surface meshes

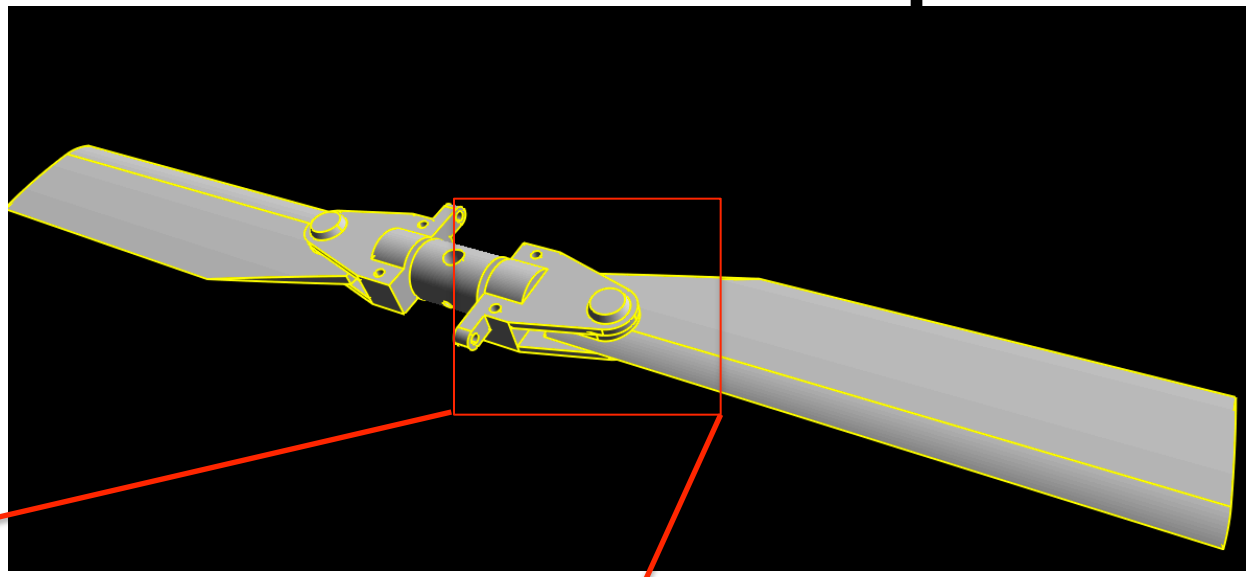
V3.0 Release : Nov 30, 2012

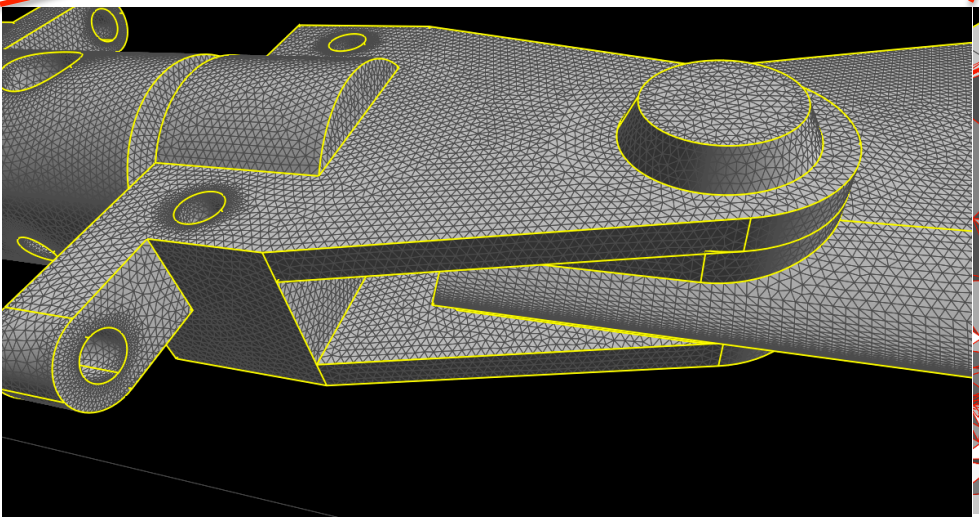
Current Status and Examples

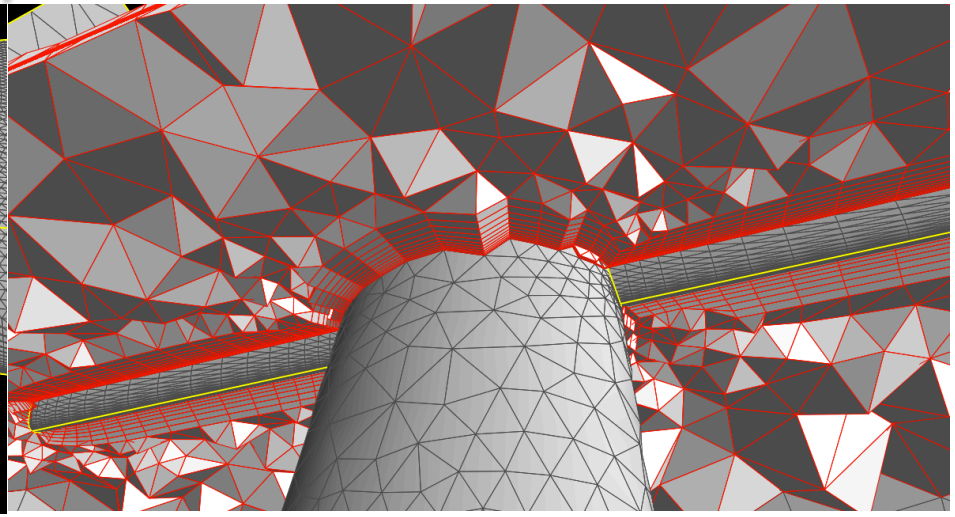


Boundary-Layer mesh for RANS-flow simulations (crinkle-cut)

Current Status and Examples



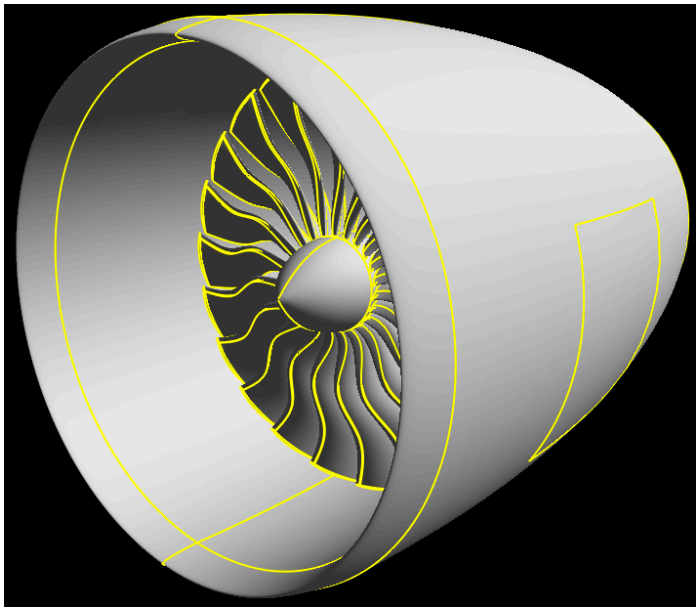


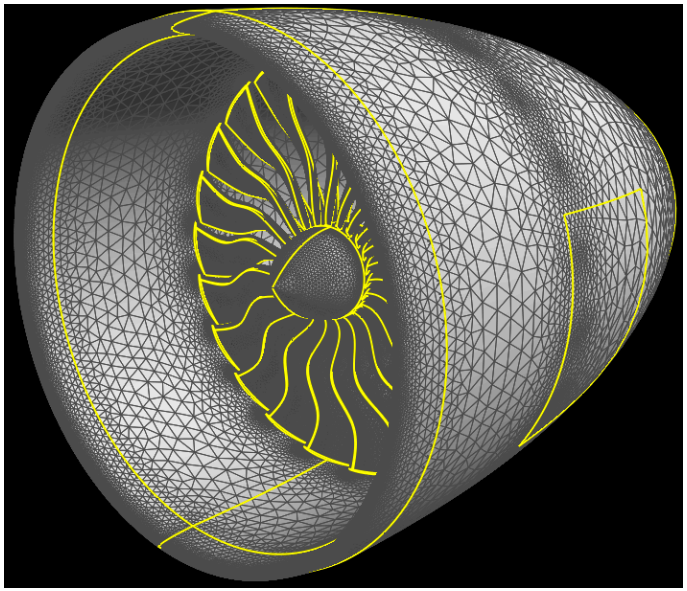


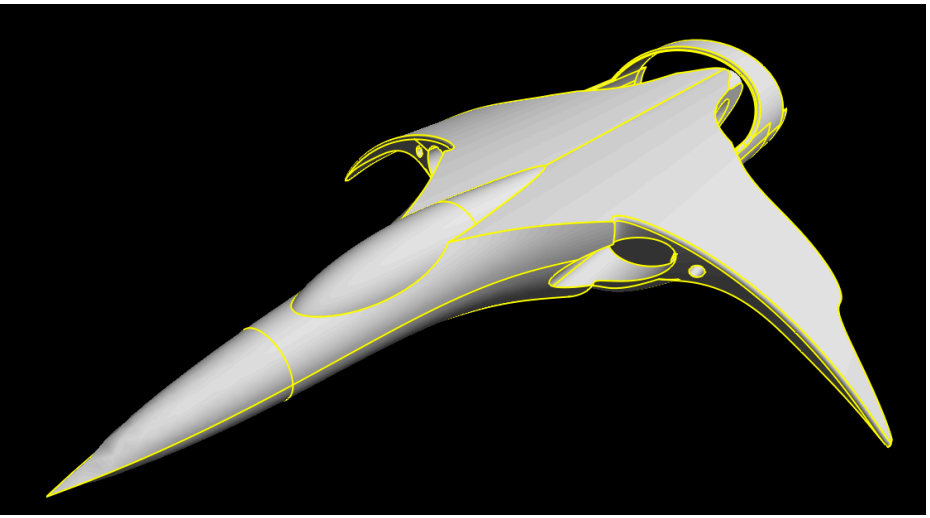
Anisotropic surface meshing

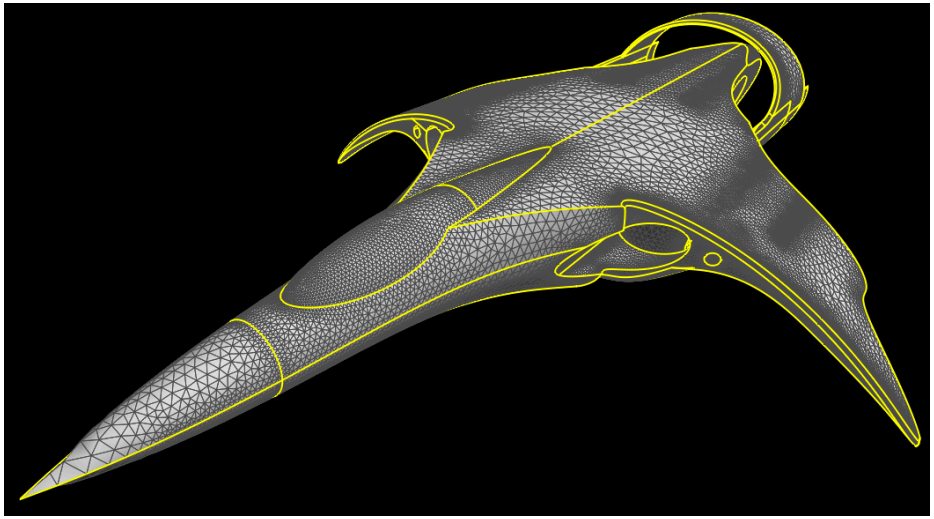
Combined surface and volume BL (crinkle-cut)

Current Status and Examples



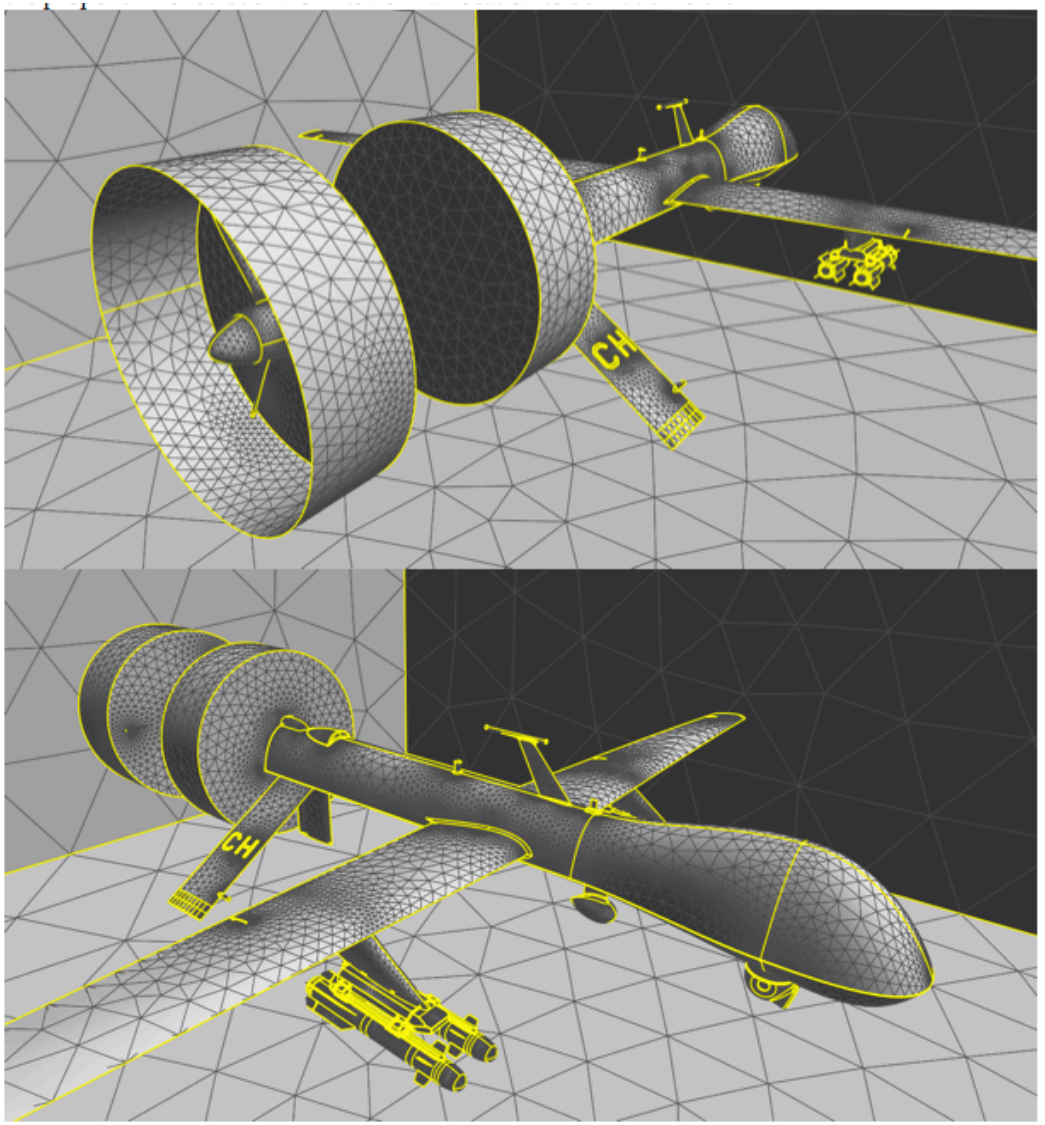






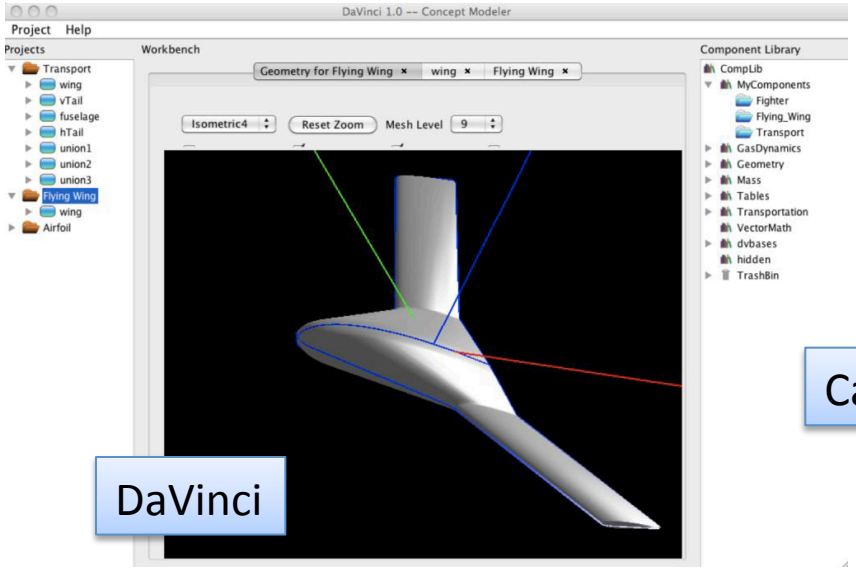
Current Status and Examples

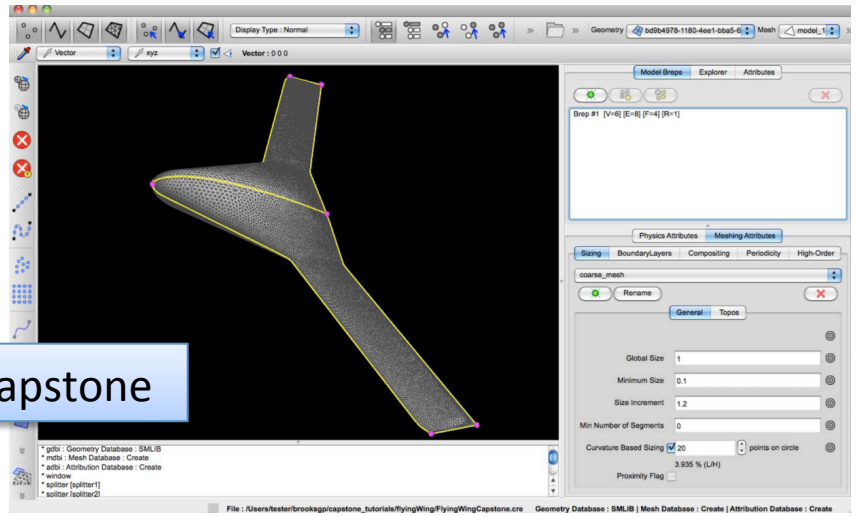
Support for meshing suitable for rotating part based on overset approach.

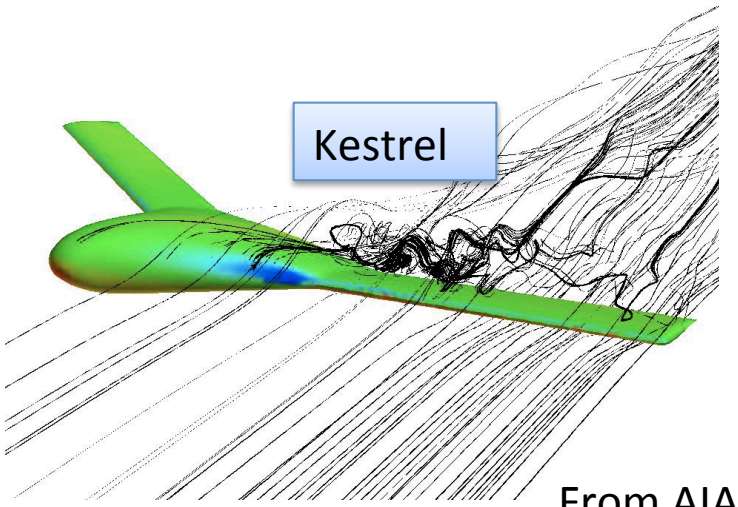


Capstone Impact: Design it better, faster and cheaper!

ASC Pilot Project





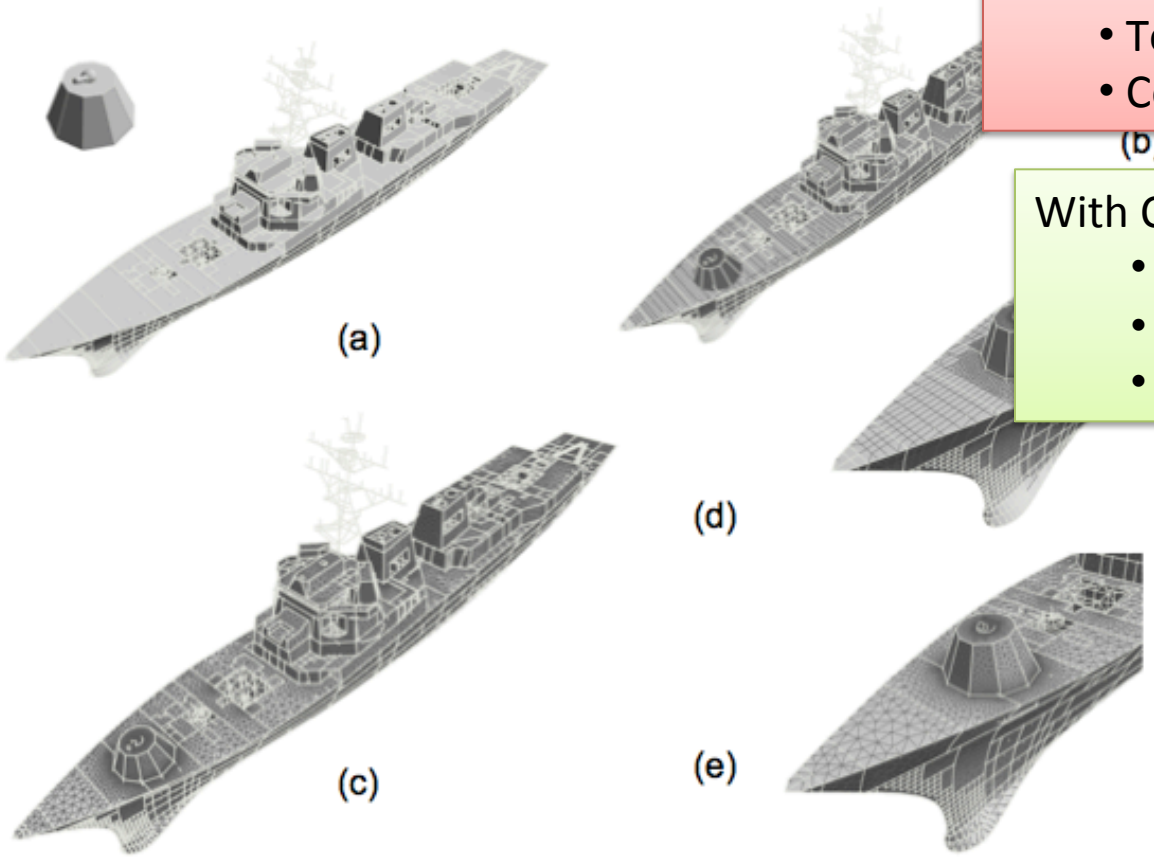


Capstone is enabling hi-fidelity physics-based analysis earlier in the design process

- 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!

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 2.3 provides significant capabilities that solve several usecases of DoD interest
- Upcoming release 3.0 will increase usability and robustness.