

Cart3D-Mphys Integration

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Outline

Cart3D Introduction

Design Framework

Historical Examples

Mphys Integration

Development Outlook

Summary

Cart3D Overview

Fully-automated Cartesian cut-cell grid generation for complex geometries

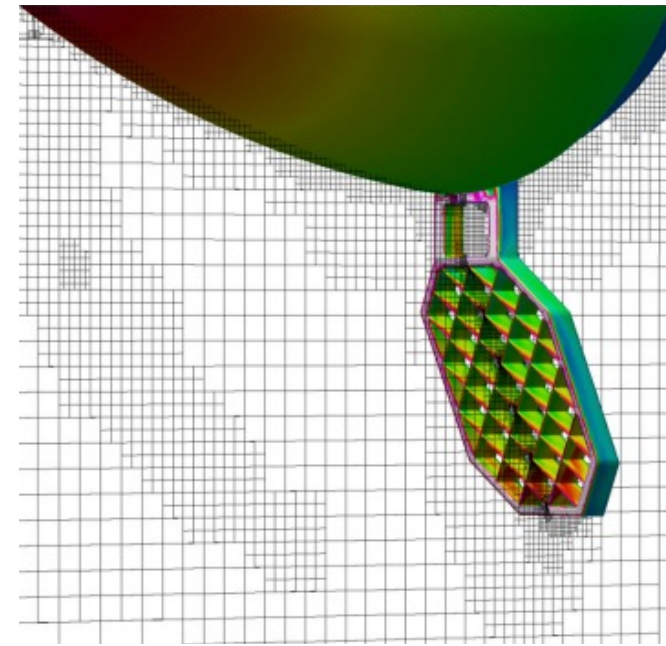
2nd order accurate finite-volume method

Multi-grid 3D Euler solver with RK smoother

Dual time-stepping for unsteady simulations

Output-based adaptive mesh refinement

Nearly 1000 users across government, industry, and academia



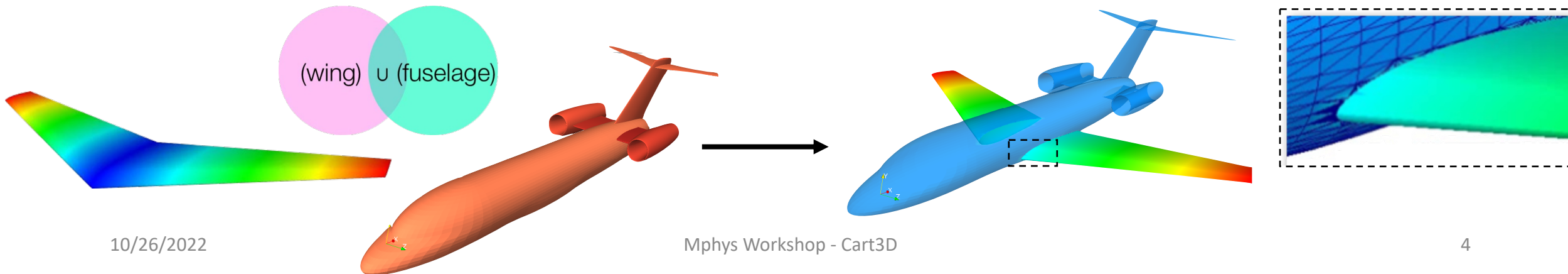
Cart3D Design Framework

Discrete adjoint approach for design gradients

Extensible Design Description Markup problem specification

- Symbolic objectives and constraints with error tracking
- General multipoint design: operating conditions with independent geometry instances and multidisciplinary analysis
- Agnostic of geometry modelers, analysis solvers, and optimizers
- C-library using XML syntax (open-source release Dec 2022)

Component-based geometry for automated modeling

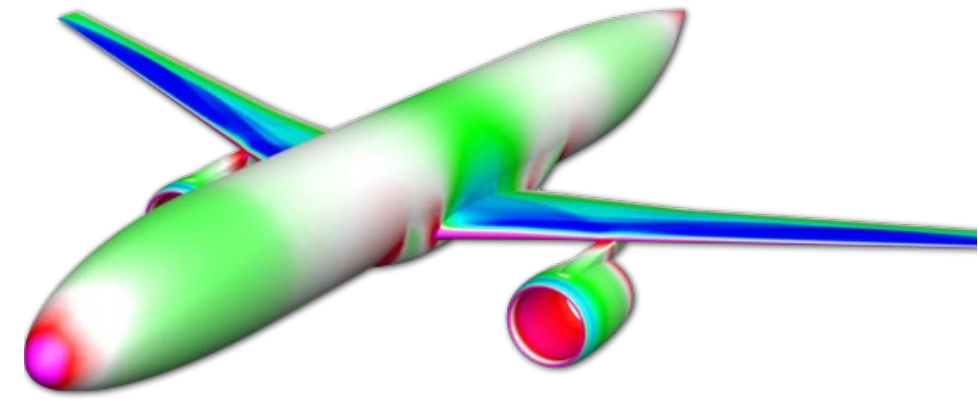
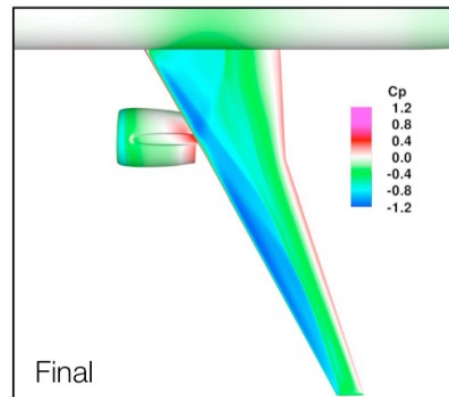
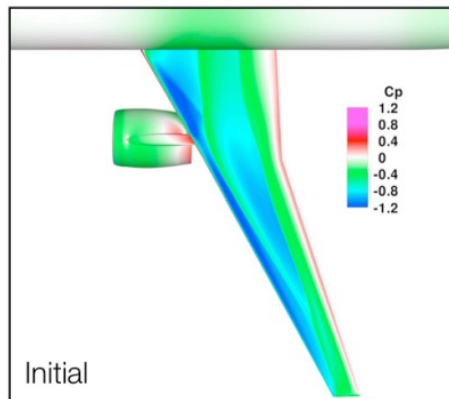


Design Ex. 1: Wing-Body-Nacelle (AIAA 2013-0543)

Aerodynamic shape optimization of integrated wing-body-pylon-nacelle configuration

Drag minimization at multiple freestream conditions with lift, rolling moment, and thickness constraints

Component-based parametric geometry: fixed fuselage triangulation, customer-developed nacelle-pylon modeler, and separate in-house wing modeler



Design Ex. 2: Trailing Edge Flaps (AIAA 2015-1409)

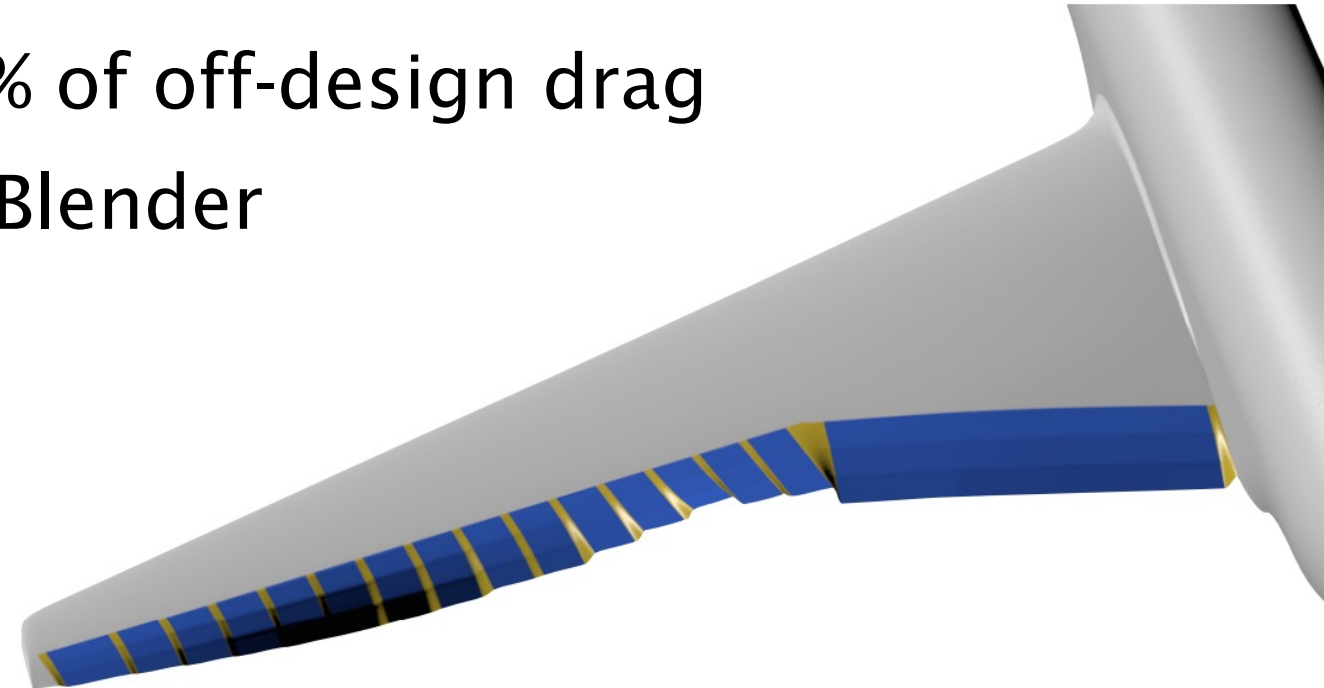
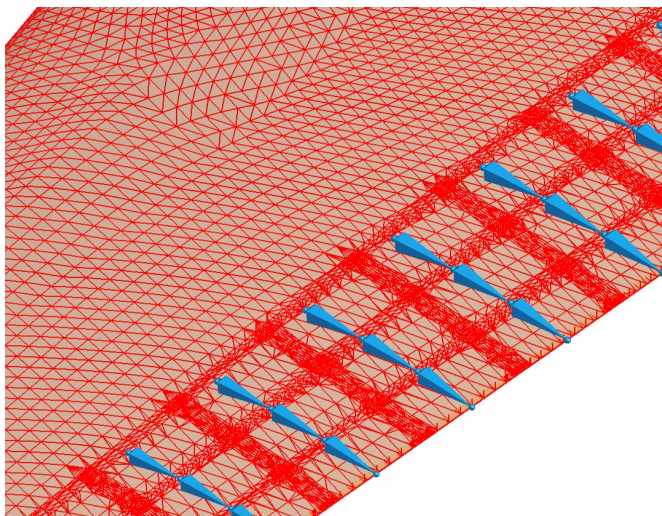
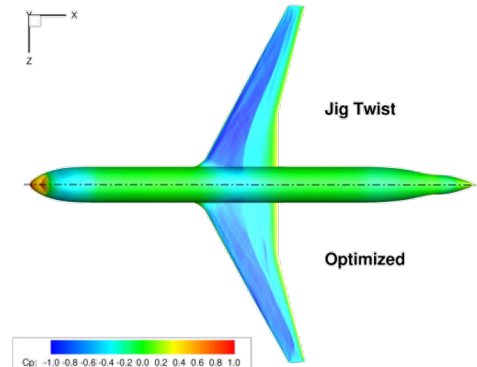
Optimization of wing and trailing edge flap system

- Drag minimization with lift constraint
- Individual flap deflection and wing twist DVs

Aeroelastic analysis with in-house 1D BEAM code

Optimized flaps reduce ~90% of off-design drag

Geometry deformation with Blender



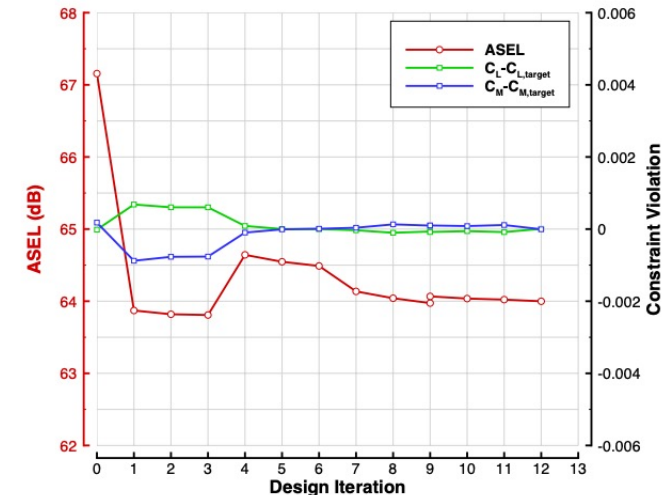
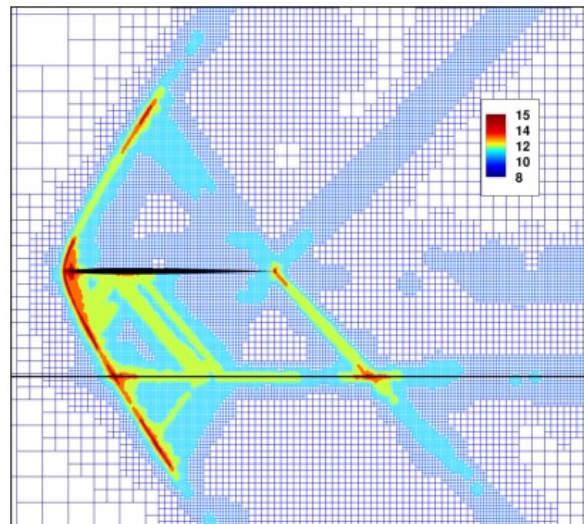
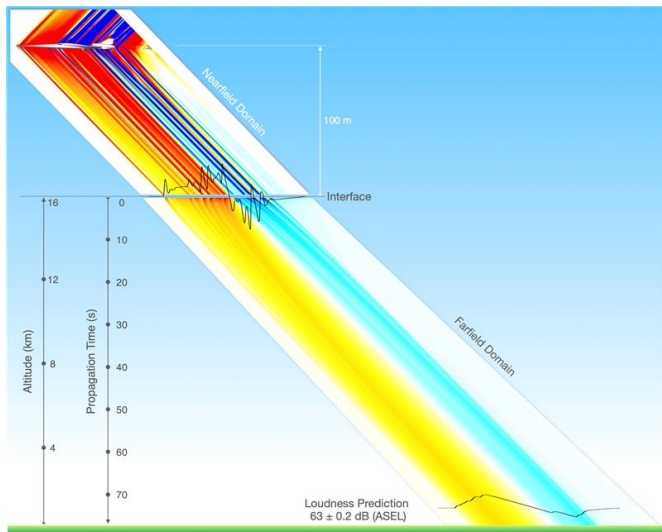
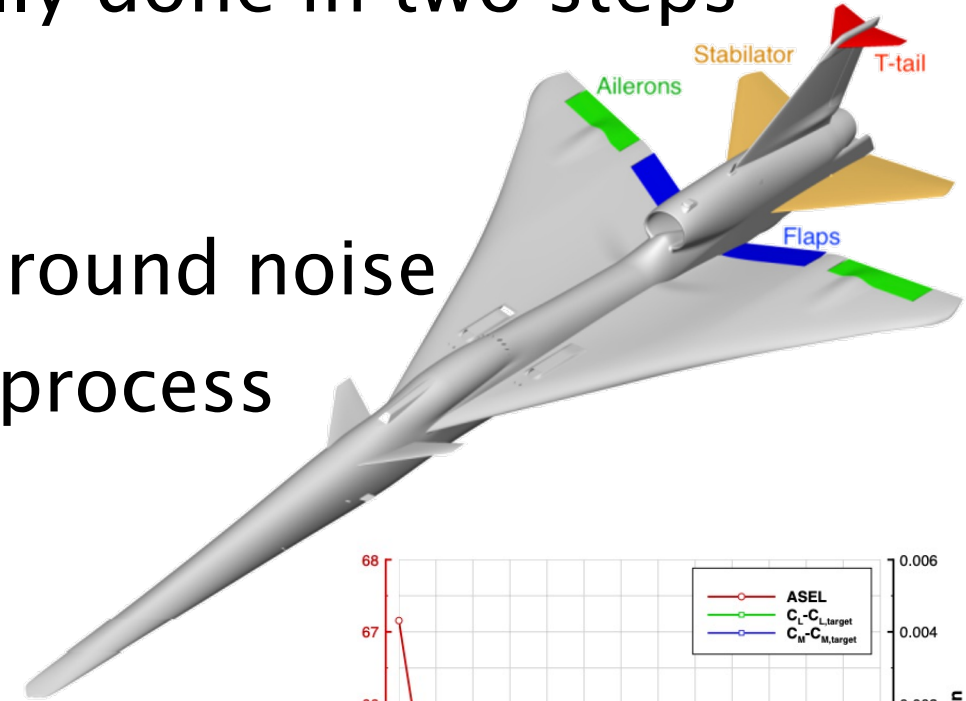
Design Ex. 3: Coupled Adjoints (AIAA 2022-4085)

Sonic boom noise prediction is typically done in two steps

- Nearfield CFD pressure signature
- Farfield propagation for ground noise

Optimization of control surfaces for ground noise

Sequential, coupled adjoint solution process





Cart3D/Mphys Integration

Significant internal & external interest in designing aircraft with highly flexible or low aspect ratio wings

Requires **fully-coupled** aeroelastic design gradients

Leverage the Mphys package for coupling multiple physics disciplines - also interested in other scenarios beyond aerostructural

Integration effort funded by NASA ARMD Transformational Tools & Technologies (T³) MDAO Project

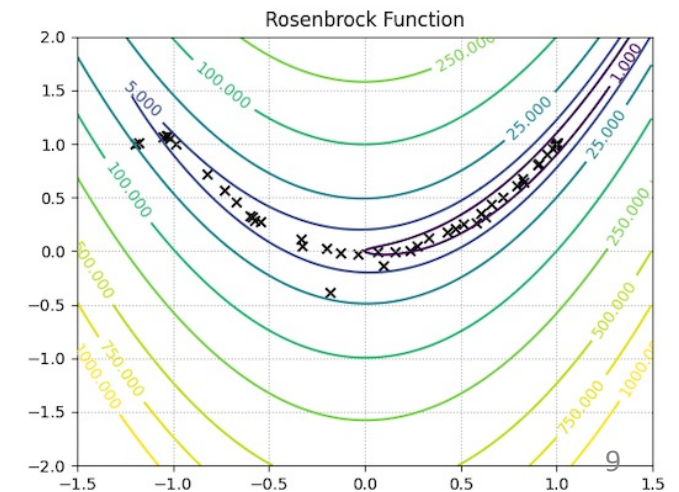
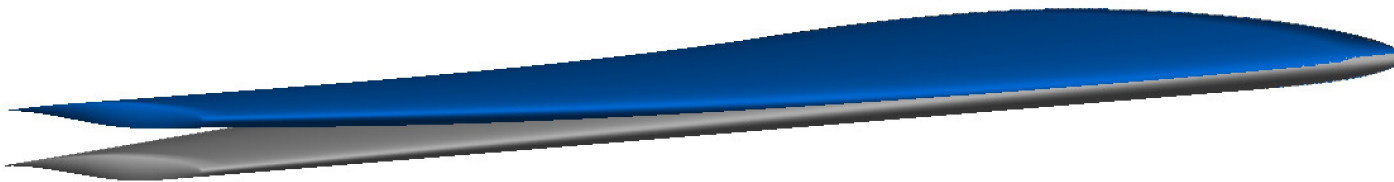
Cart3D/Mphys Integration

Coupled **aerostructural analysis** with MELD-TACS

Drive **XDDM** optimization problem with OpenMDAO optimizers, verified with canonical problems and 2-D aero, **easing transition** for existing design framework users

Supporting Advanced Air Transport Technology (AATT) project's Model Based Systems Analysis & Engineering effort (MBSA&E) with Cart3D Python package and OpenMDAO components

$M = 0.25$, Cart3D aero-structural deflection





Development Outlook

Mphys uses **surface coordinates** for displacement and load transfer scheme

Utilizing the **triangulation** instead of volume mesh cut-cells for structural displacements works for some cases

Cart3D's component-based design paradigm has **variable # nodes** per design iteration (e.g. fuselage-wing junction varying root twist)

Possibility for state vectors of **variable size** in OpenMDAO and Mphys builder paradigm?

Structural modeling with multiple components?



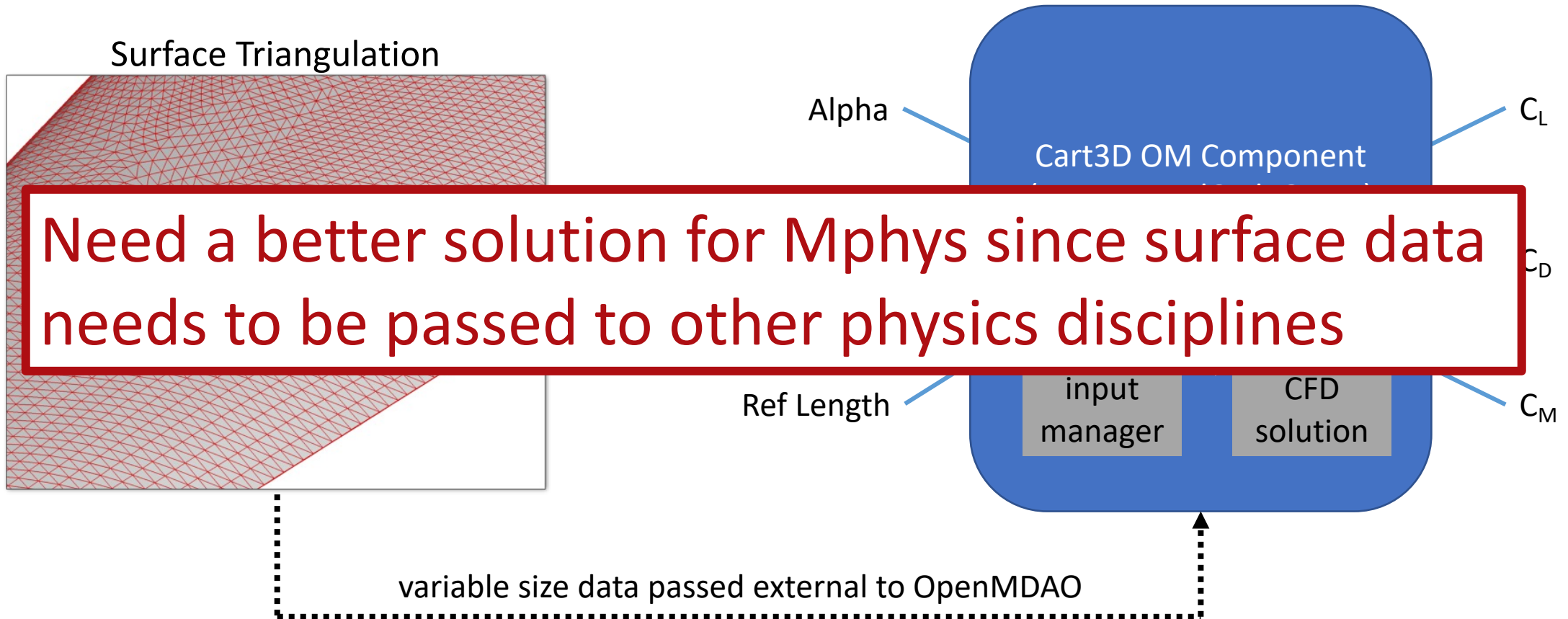
Development Outlook

Exposing partial derivatives of the Cart3D mesh with respect to the **triangulation** (“mesh sensitivities”) requires **significant code refactorization** and I/O changes

Assess best path forward with **lower-dimensional** model problem (pure Python) **before** diving into full code refactor

Continue development and support of Cart3D Python package with pure OpenMDAO components for AATT MBSA&E milestones

Cart3D Python Package



Need a better solution for Mphys since surface data needs to be passed to other physics disciplines



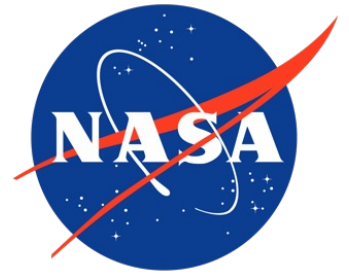
Summary

Continuing **historical efforts** to enable **aerostructural** design and optimization

Sizable interest from internal and external customers for **multi-physics analysis and design** via OpenMDAO

Potential limitations with **fixed length** state vectors? Mphys scenario as a sub-problem?

Significant code refactorization effort to integrate **sensitivities** over the next two years



Questions?

