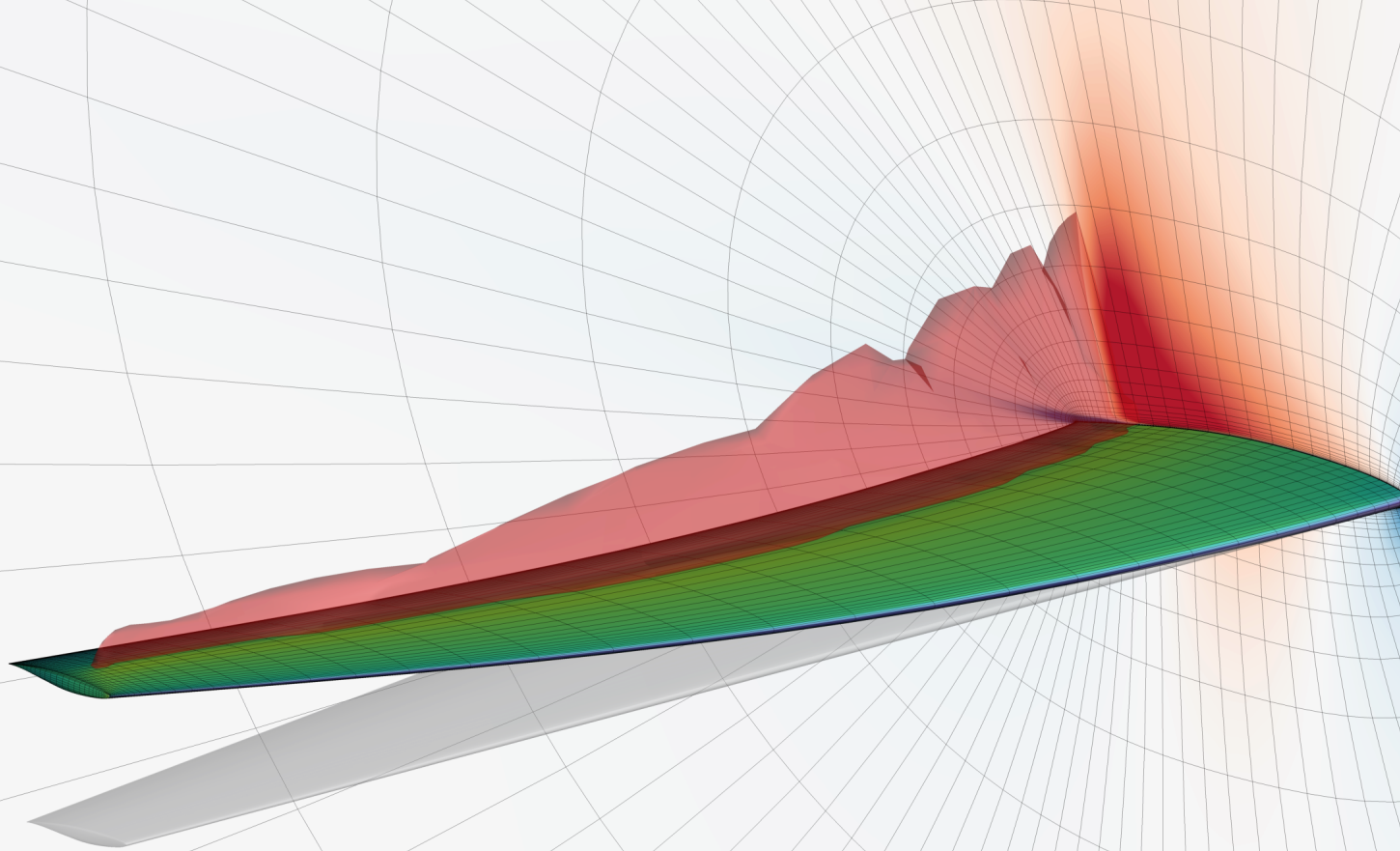


A Modular Multiphysics Simulation Framework



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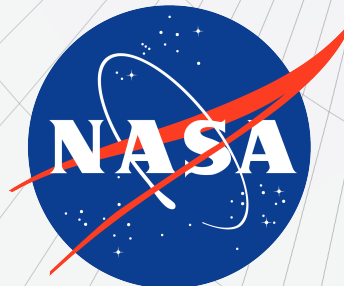
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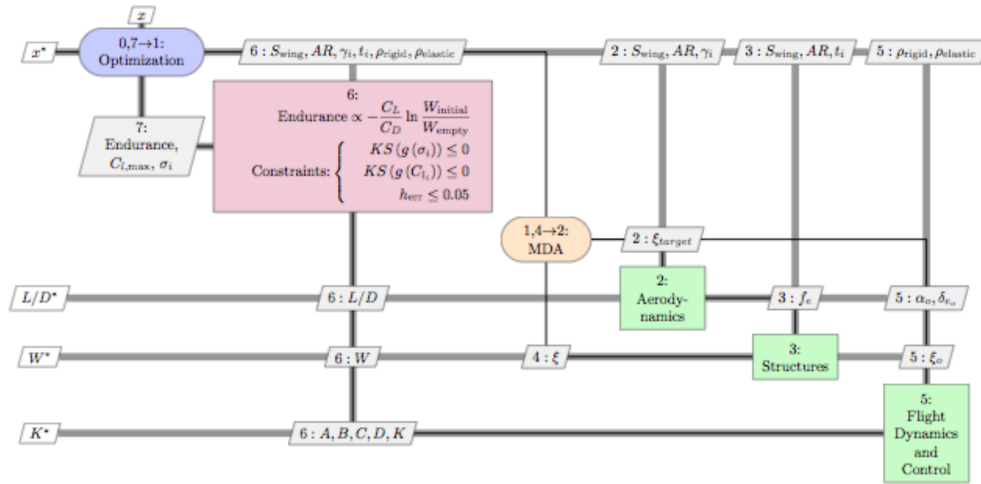
COLLEGE OF ENGINEERING
AEROSPACE ENGINEERING
UNIVERSITY OF MICHIGAN



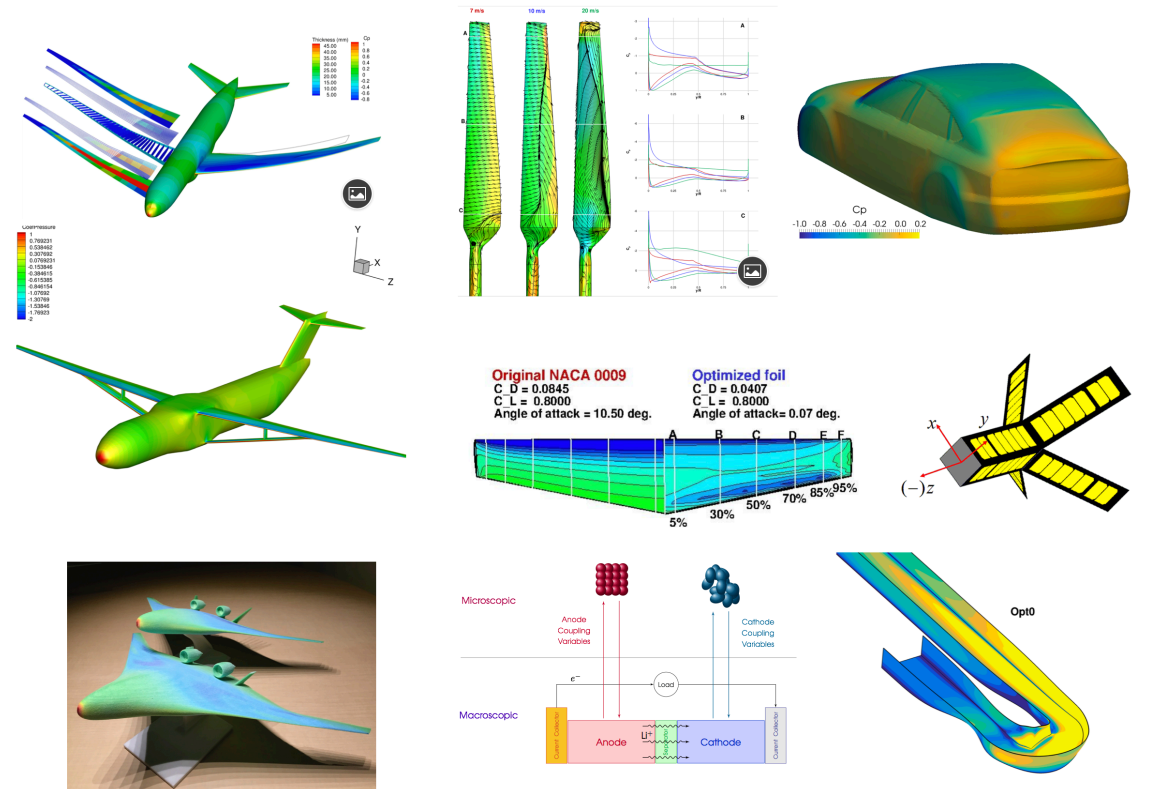
We study multidisciplinary design optimization (MDO)

Research in the MDO Lab is divided into two main thrusts

Fundamental MDO algorithms

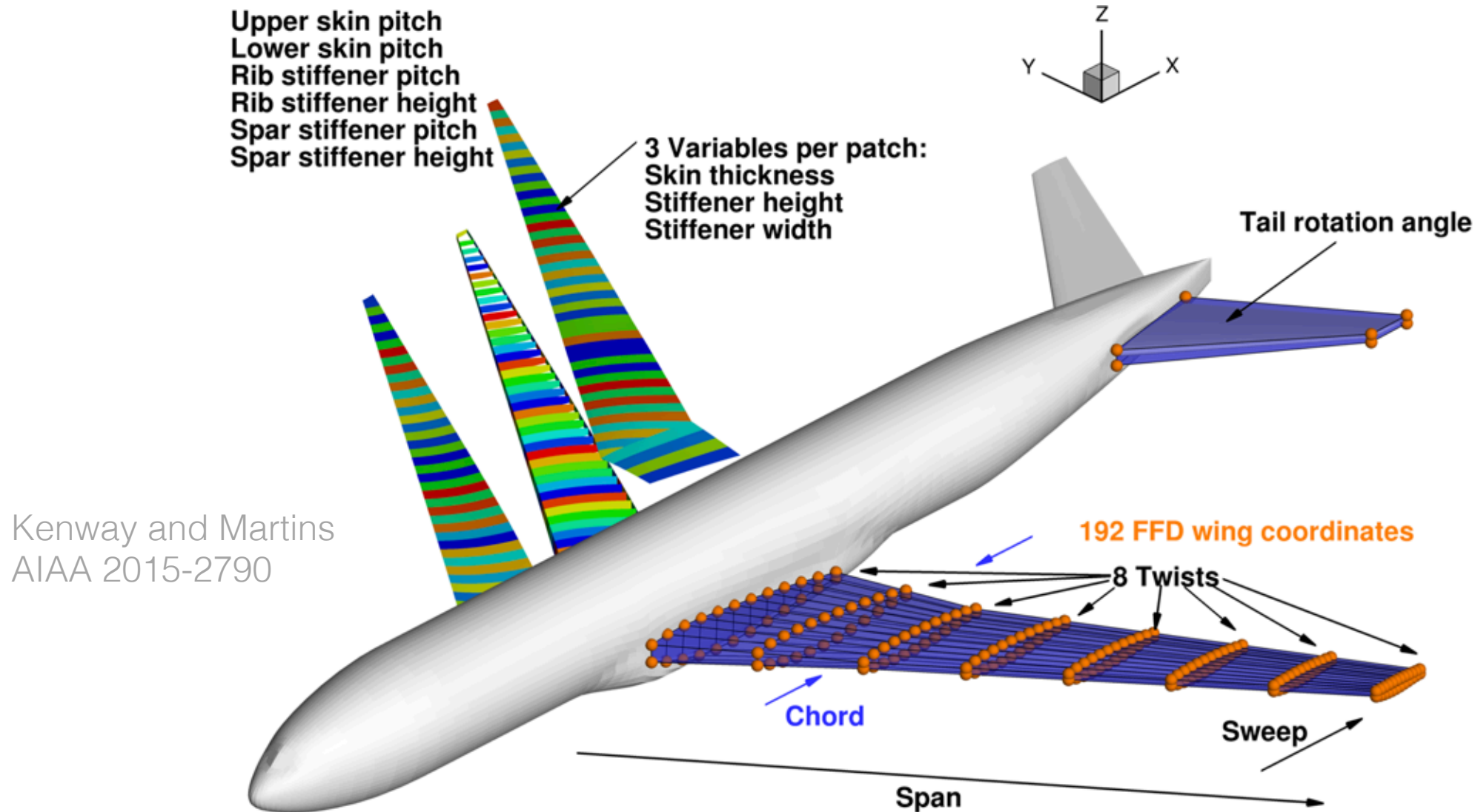


Applications of MDO



$$\frac{\partial R}{\partial u} \frac{du}{dr} = \mathcal{I} = \left[\frac{\partial R}{\partial u} \right]^T \left[\frac{du}{dr} \right]^T$$

Optimized 973 aerodynamic shape and structural sizing design variables



The MACH framework is built for high-fidelity aerostructural optimization

The implementation is ad-hoc, but very efficient

However, it is very difficult to extend to additional disciplines

The complexity of propagating derivatives across the model grows exponentially with each additional discipline

We need a solution for design optimization with aerodynamics + structures + ...

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MPhys

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OpenMDAO Multiphysics (MPhys) is a multidisciplinary simulation package

It provides an OpenMDAO model structure required to build complex models using high-fidelity simulations

Computational performance and parallelism comes built in

While the primary goal is models with high-fidelity simulations, MPhys is also useful for multifidelity models

CFD 2030: MDAO limited by
“one-off laborious, nonstandard interfaces”

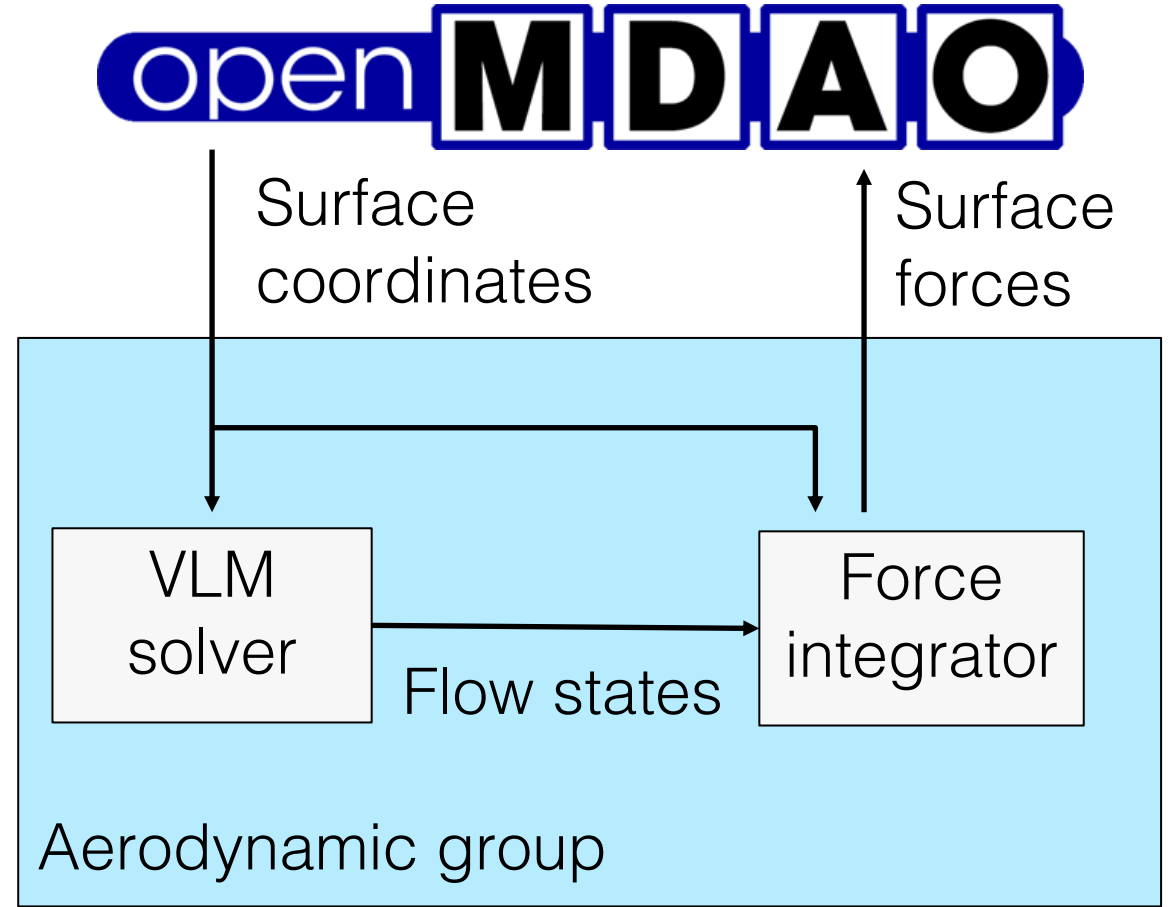
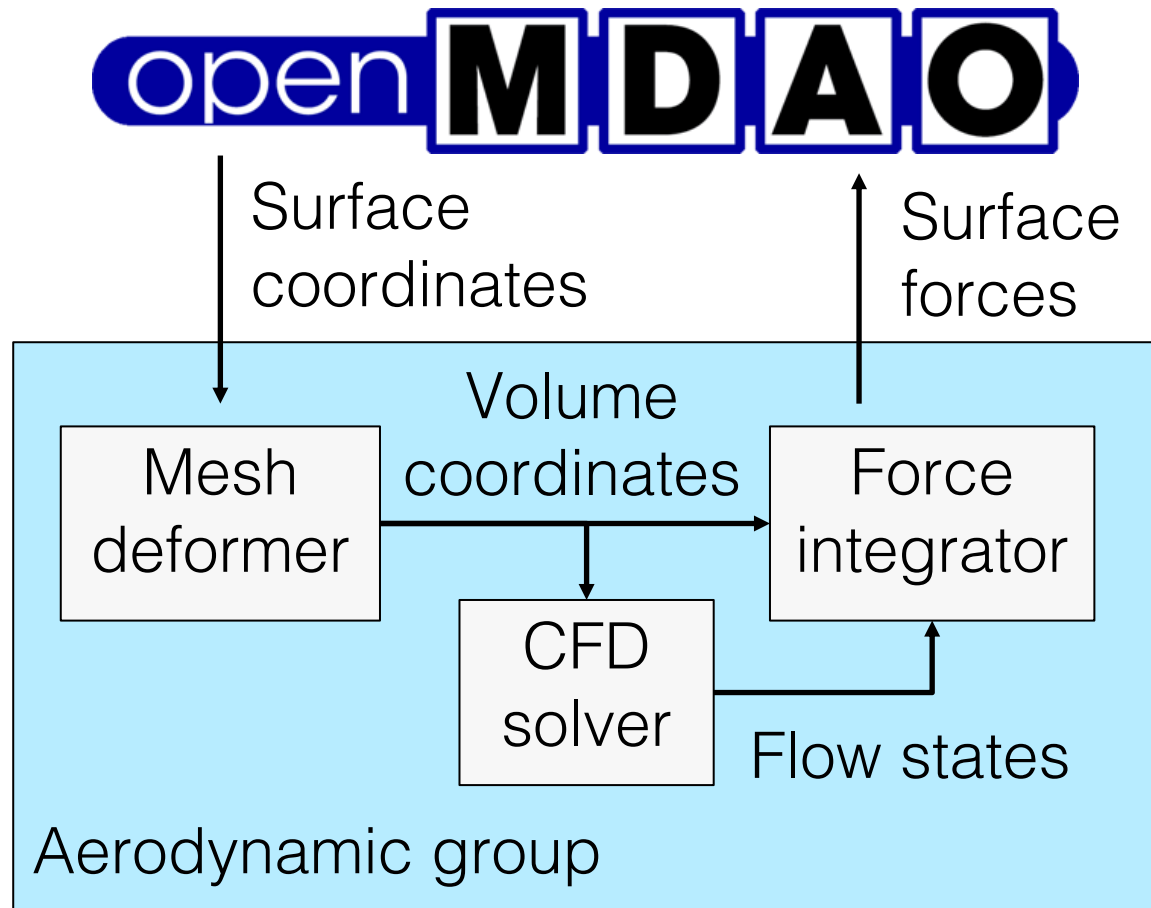
MPhys uses a modular structure

MPhys defines a minimal common API for each solver

Developers can build OpenMDAO wrappers for their solvers that conform with this API

With these common interfaces, MPhys models are plug-and play: the solvers and transfer schemes are interchangeable

Two different aerodynamic solvers can use the same problem interface



We can swap aerodynamic groups

MPhys provides the machinery required for computational efficiency

The allocated memory for the solvers can be reused throughout the model

Multiple flight conditions can be analyzed in serial or in parallel, without incurring an increased computation or memory cost

The abstracted parallelism in MPhys reduces the complexity of each individual runscript

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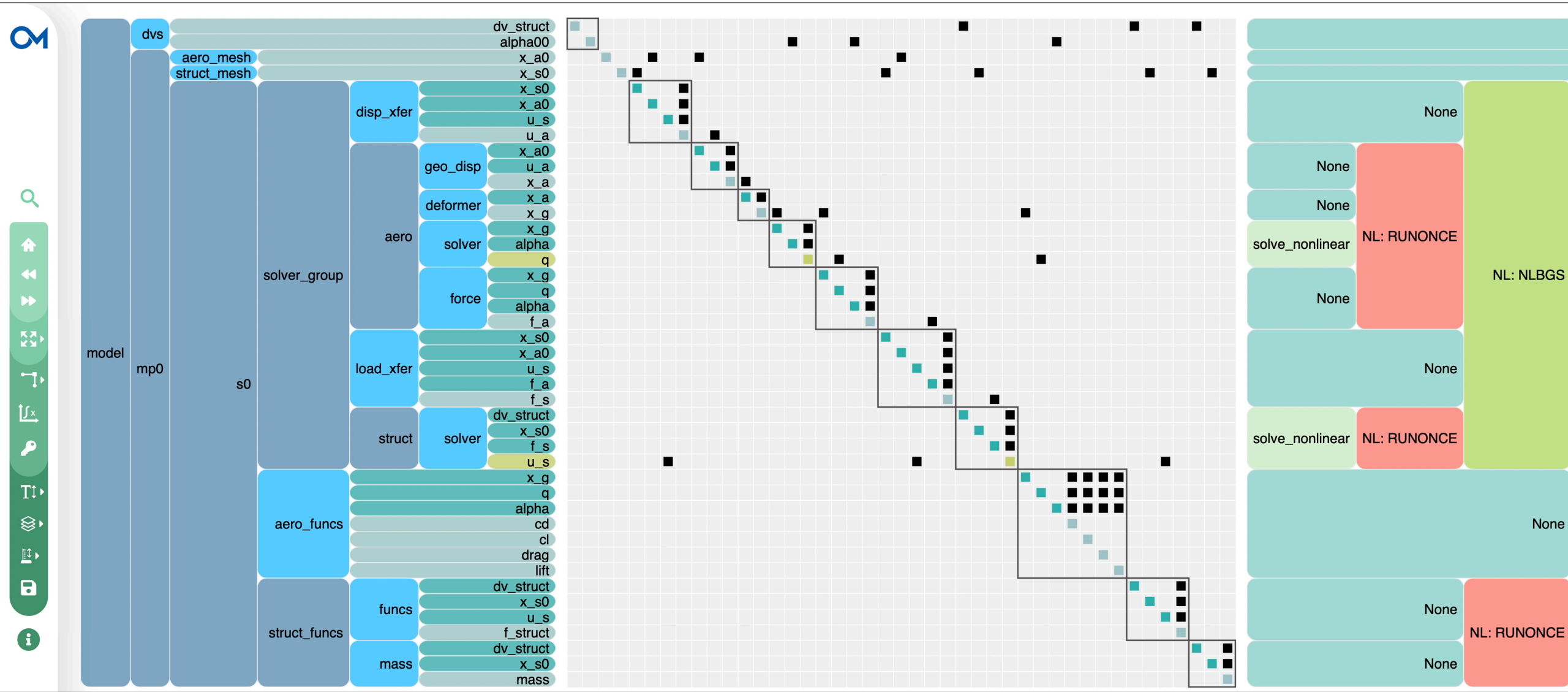
MPhys defines 3 main groups in the OpenMDAO model hierarchy

Multipoint: Contains all scenarios analyzed
with the same combination of solvers and fidelity levels

Scenario: Contains all the groups required for each flight condition,
such as the solver group and the optional functionals groups

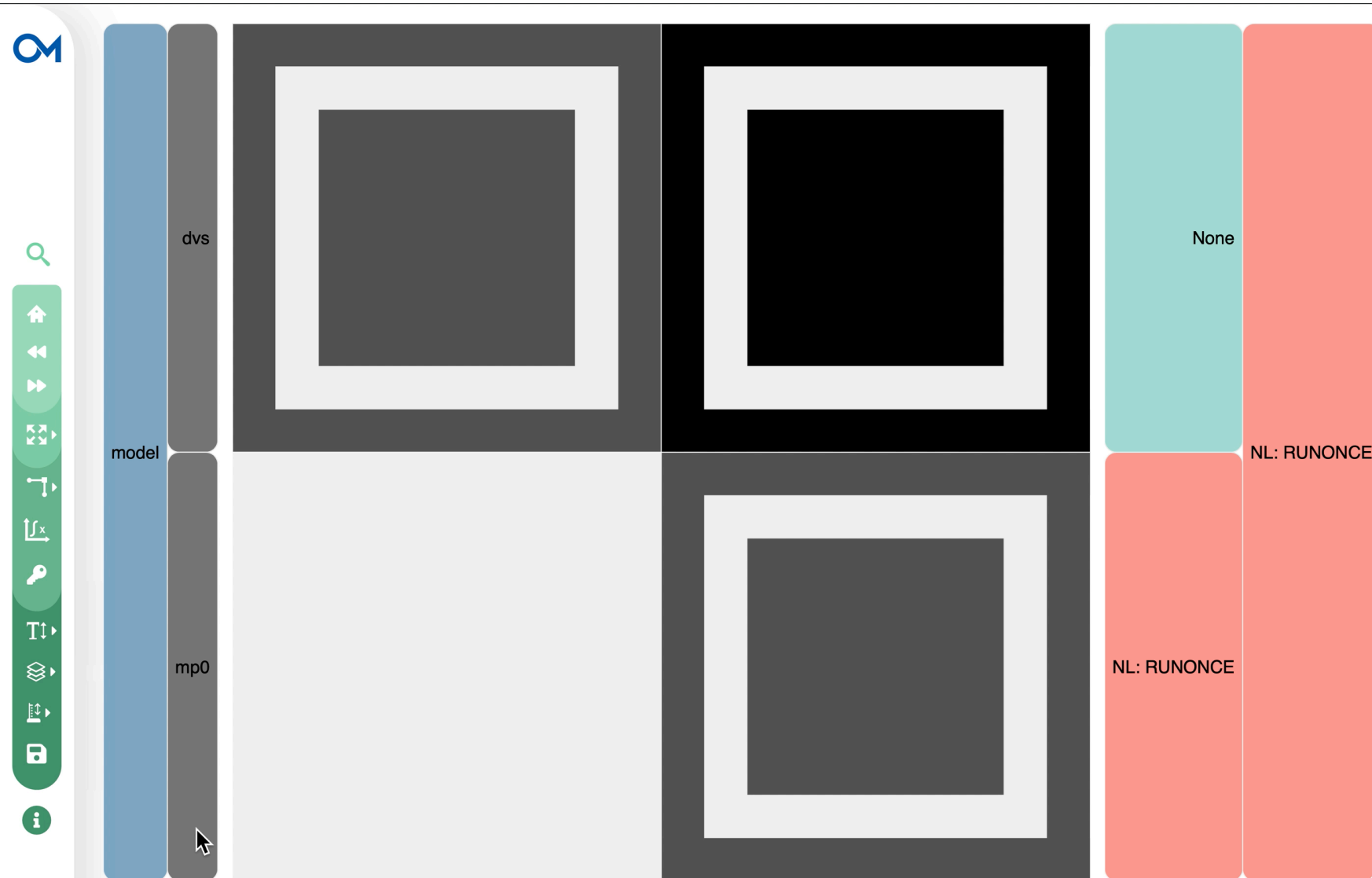
Solver: The non-linear coupled analysis group,
which is the lowest-level group provided by MPHYS

Functionals: Optional group that is run once
after the solver group converges the MDA

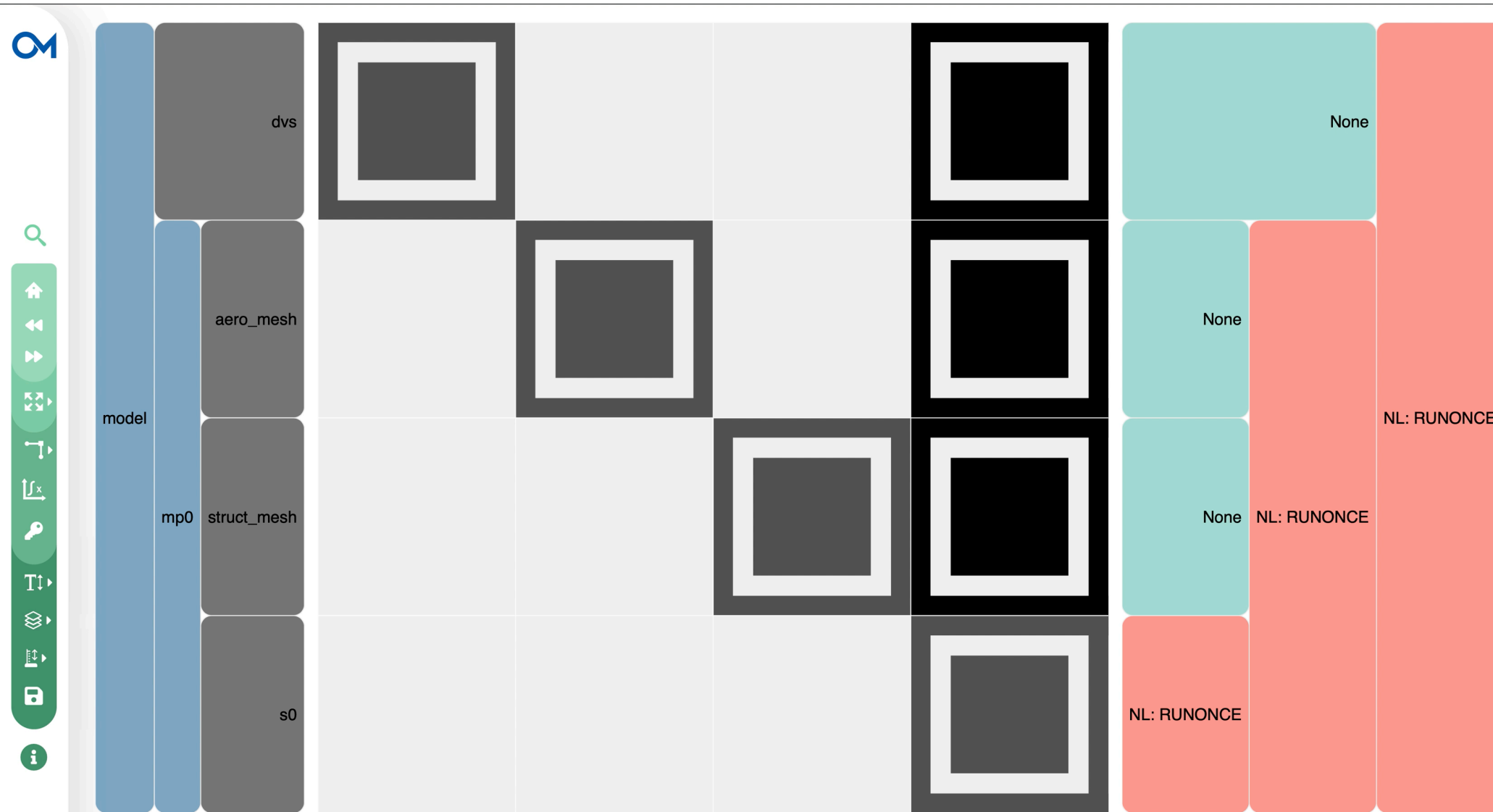




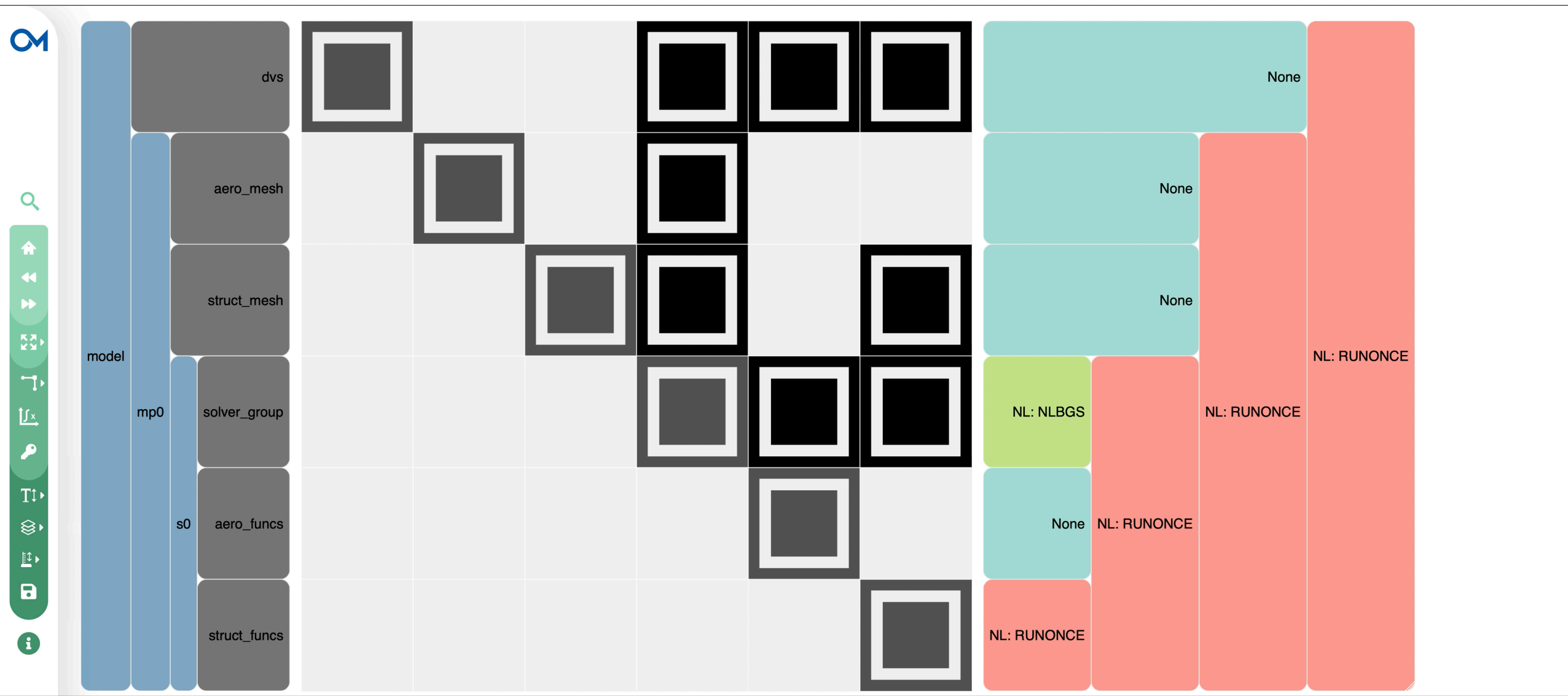
Users add scenarios to the multipoint group



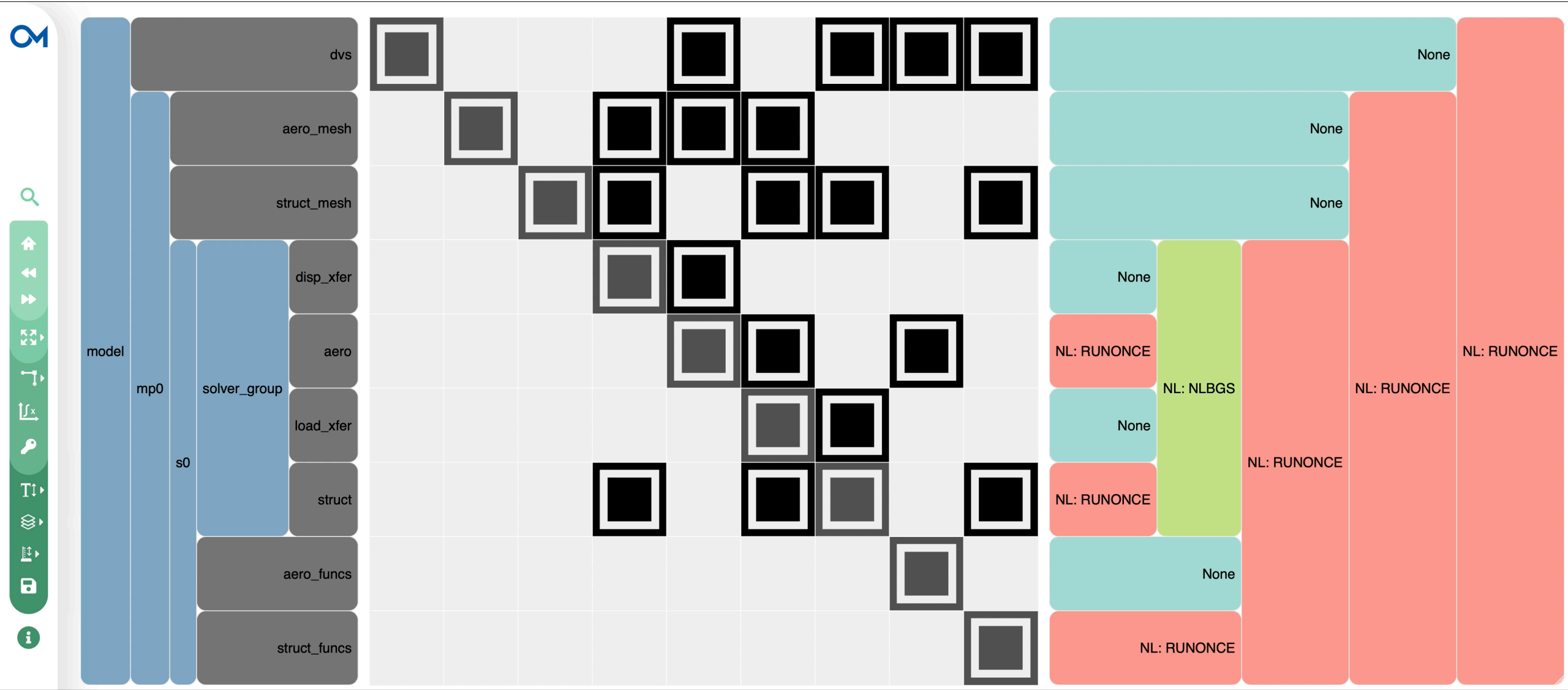
Each scenario group contains a solver loop and optionally functionals



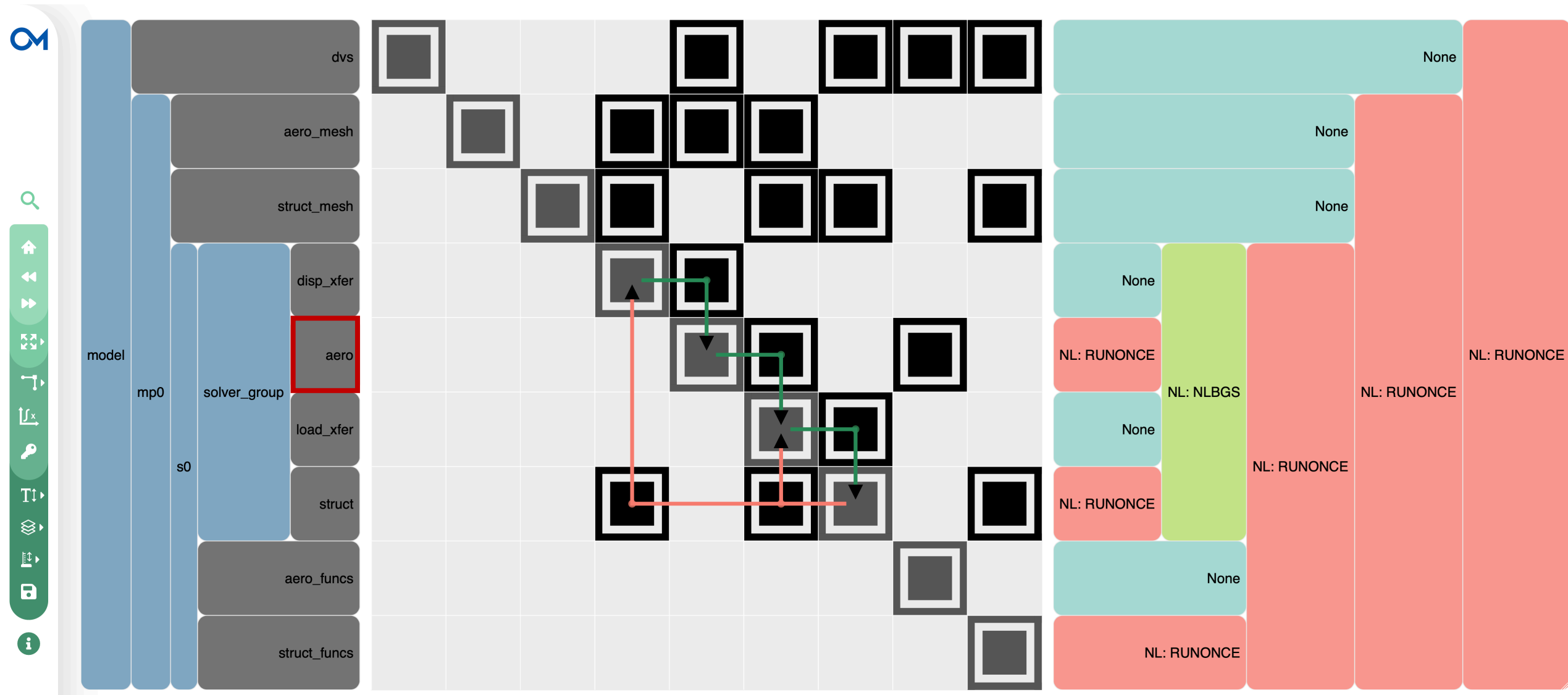
Solver group contains all the discipline solvers and the transfer schemes



MPhys only defines a minimal API that is used to connect disciplines

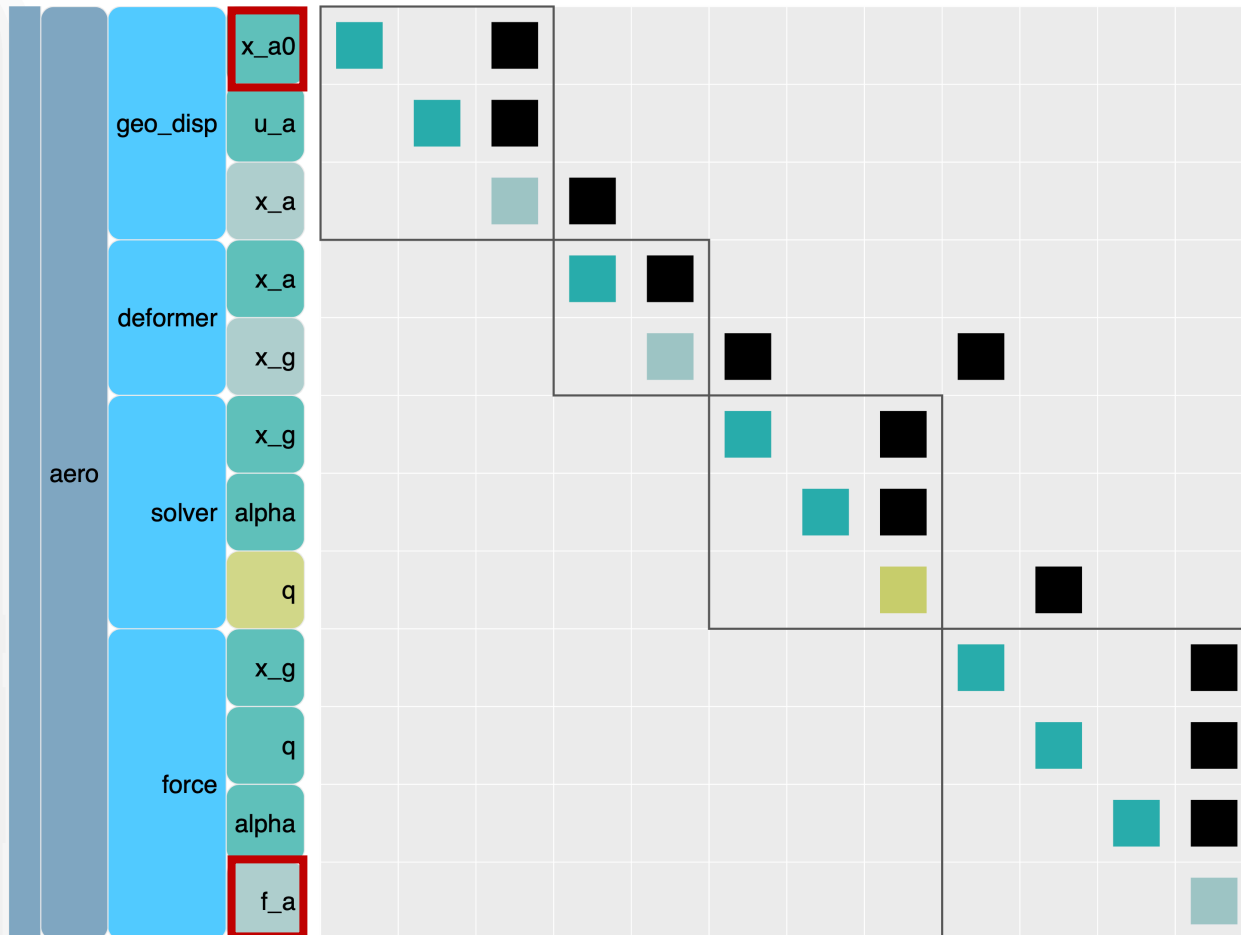


MPhys only defines a minimal API that is used to connect disciplines

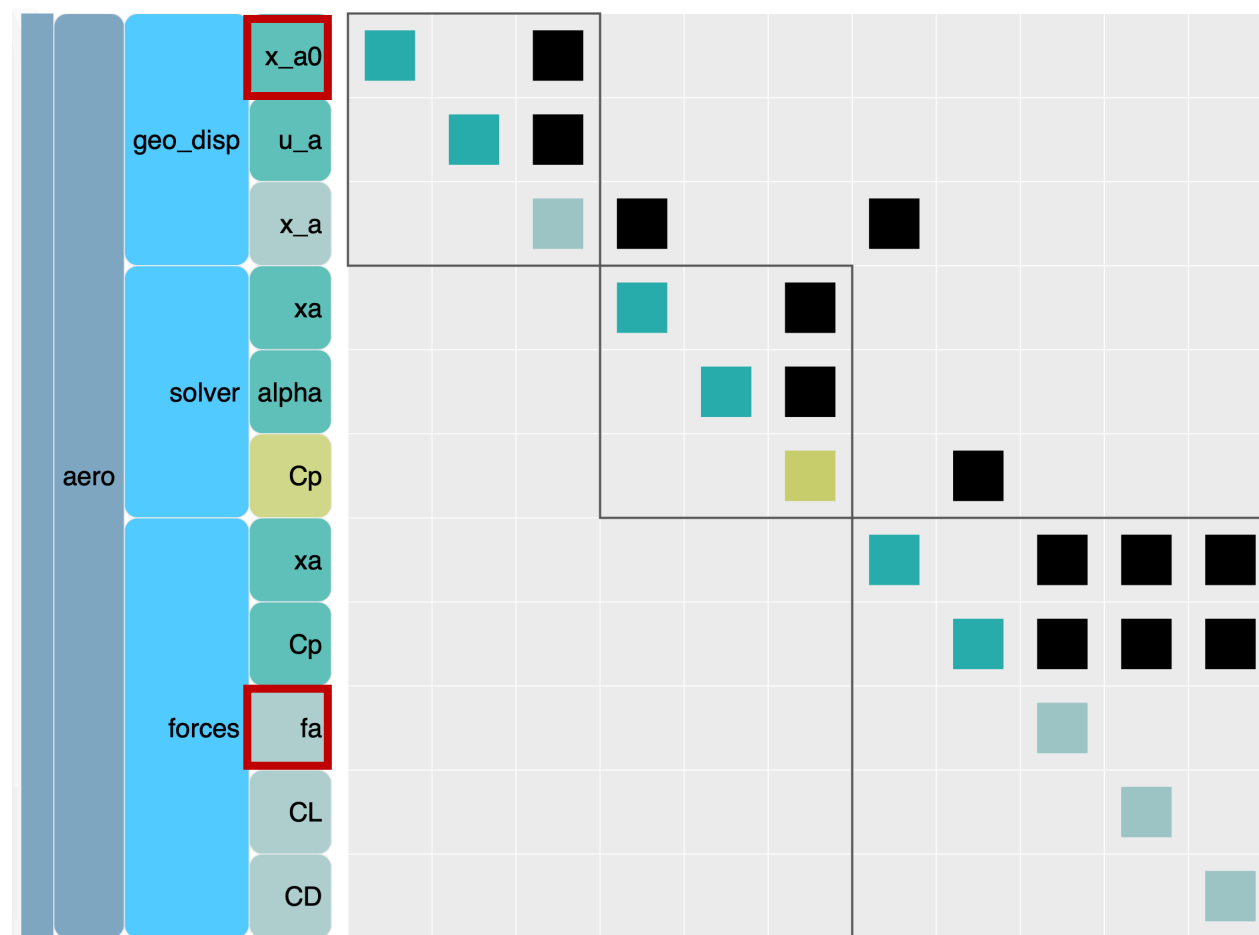


The aerodynamic problem interface is the surface geometry, and the nodal forces

ADflow (RANS CFD)

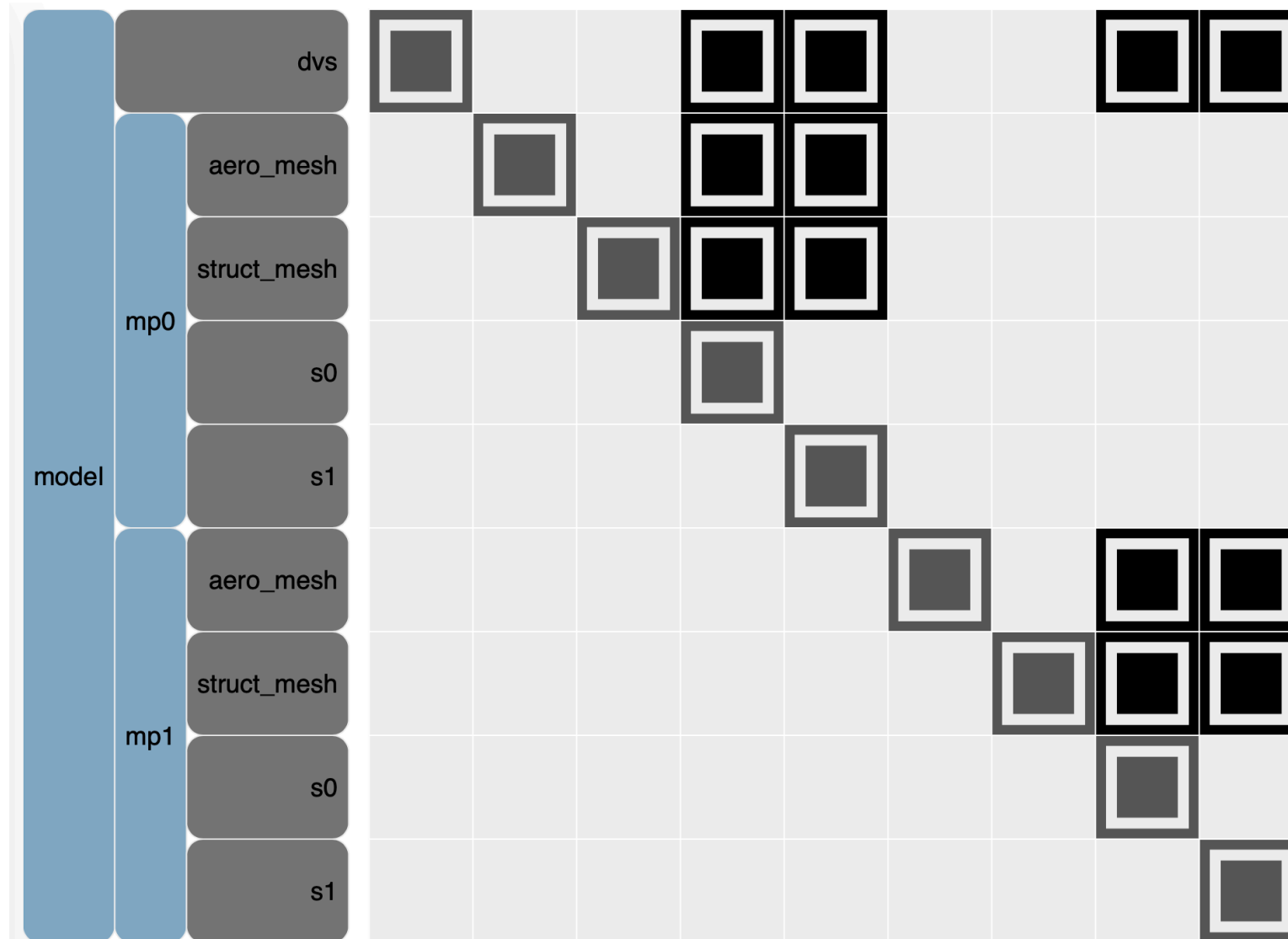


VLM Solver

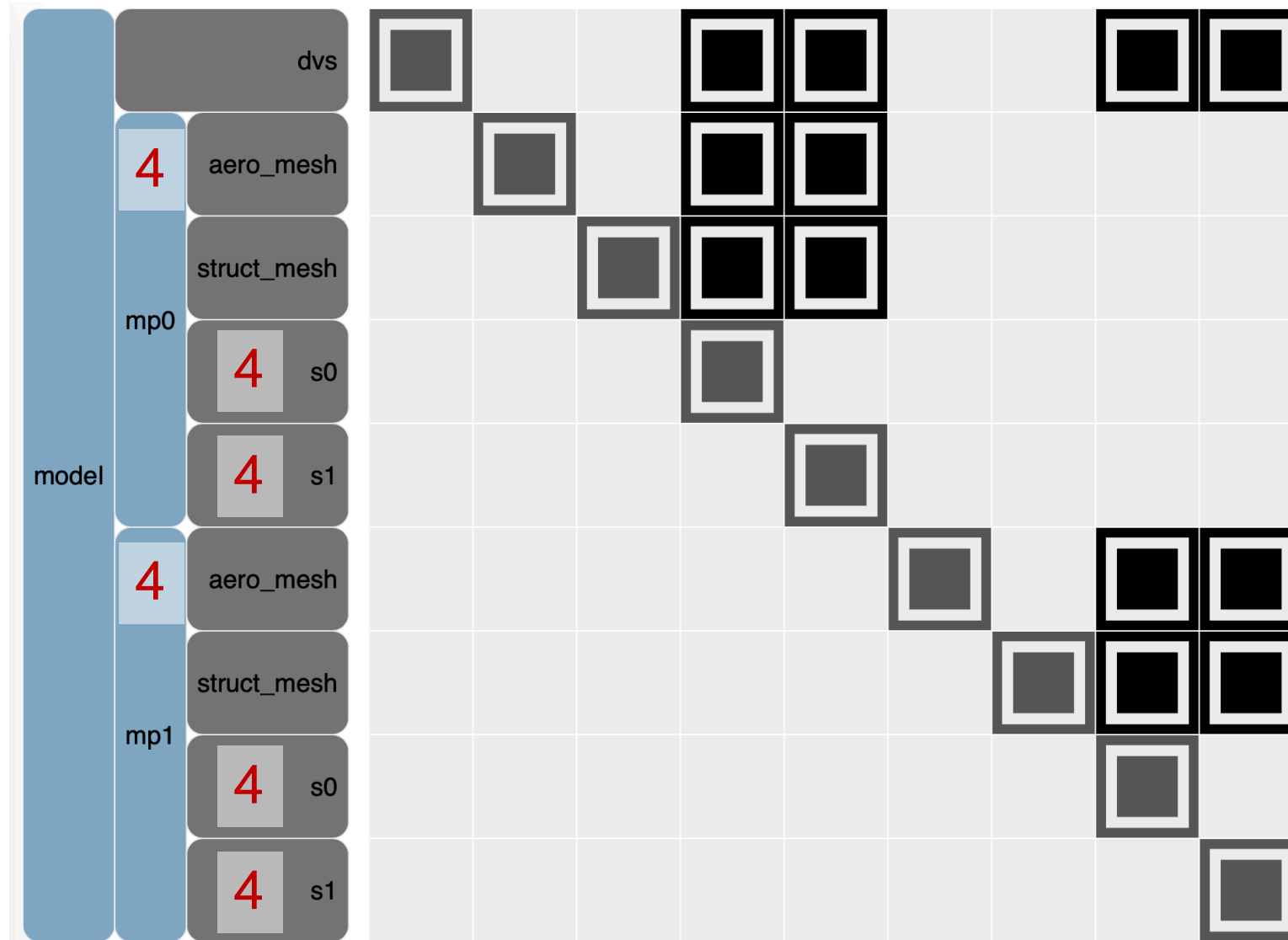




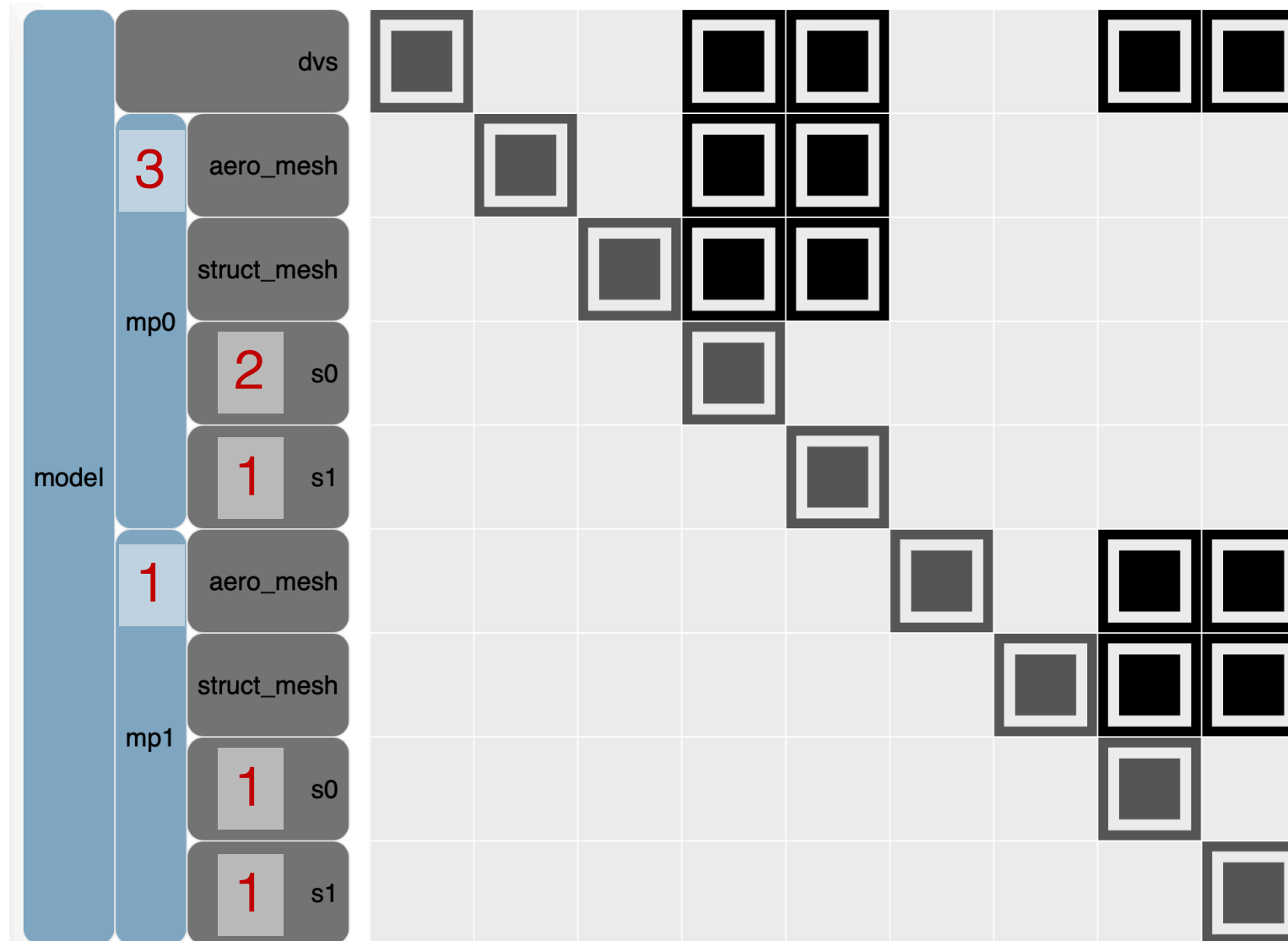
Users can add multiple multipoint groups,
which contain multiple scenarios



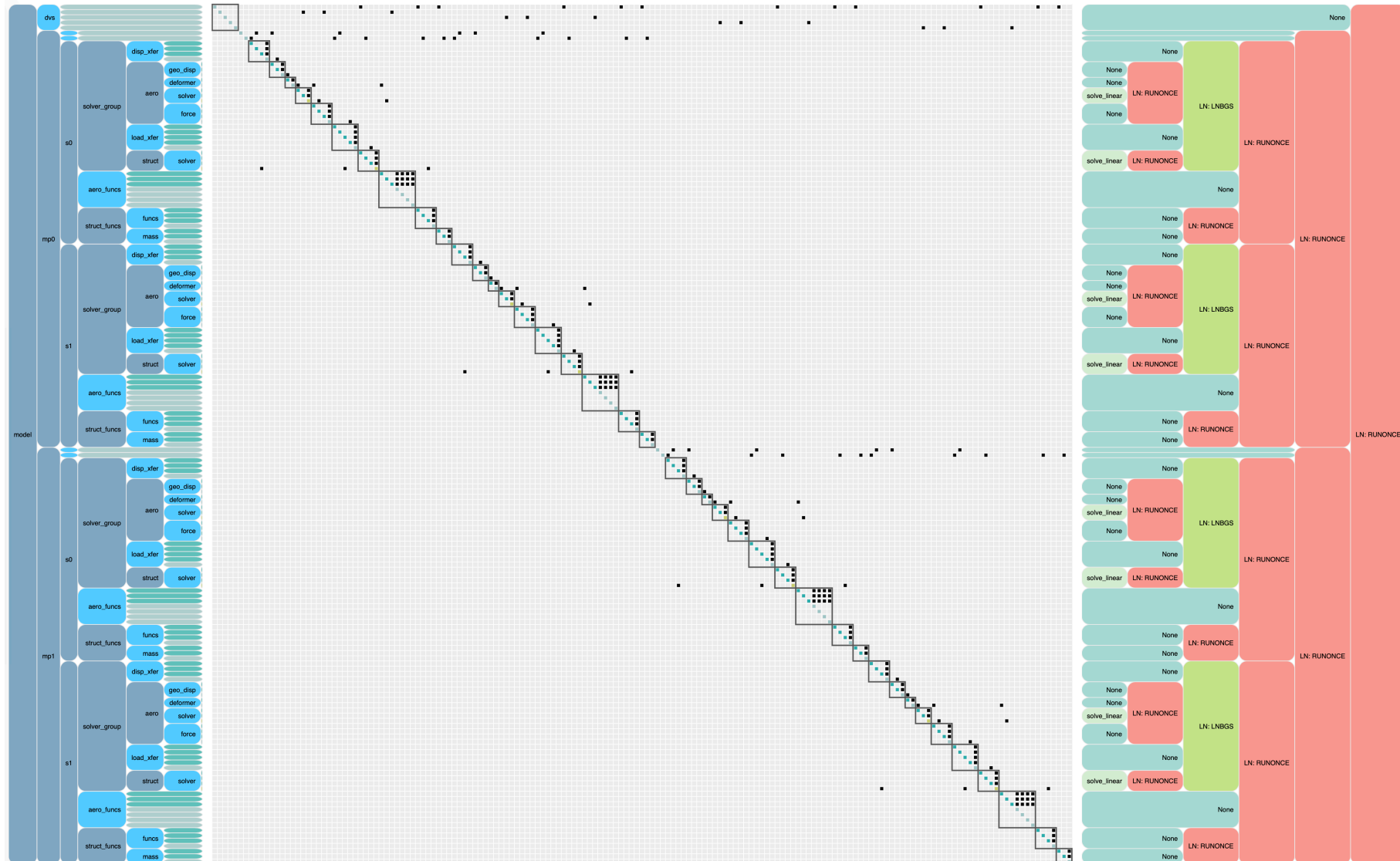
Parallelism can be customized both at the multipoint and scenario level



Parallelism can be customized both at the multipoint and scenario level



These features enable users to build complex models with high-fidelity tools



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MPhys can perform aerostructural simulations using combinations of solvers

Aerodynamics: ADflow (RANS CFD) and a VLM solver developed at LaRC

Structure: TACS (High-fidelity FEM) and a modal solver

Transfer:
Matching-based extrapolation of loads and displacements (MELD) and Rigid Link Transfer (RLT)

We can do aerostructural analyses and basic optimizations with 8 different combinations

Availability of multiple solvers create new possibilities for design optimization

If solvers provide derivatives, they can be included in optimizations

Even without gradients, they can be used to analyze the design, which was optimized using another solver

Different combinations of solvers can be used for each flow condition; e.g., VLM for maneuver loads and RANS CFD for cruise cases

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Work underway to add more solvers and design tools

MPhys wrappers are being developed for FUN3D and SU2

Plans include the addition of NASTRAN, and simple beam and wing-box models

Also working on including geometry parameterization tools:

- Free form deformation (FFD)

- Vehicle Sketch Pad (VSP)

- Engineering Sketch Pad (ESP)

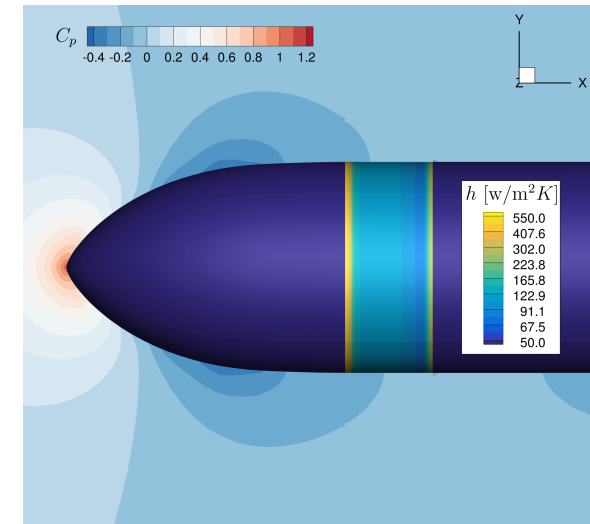
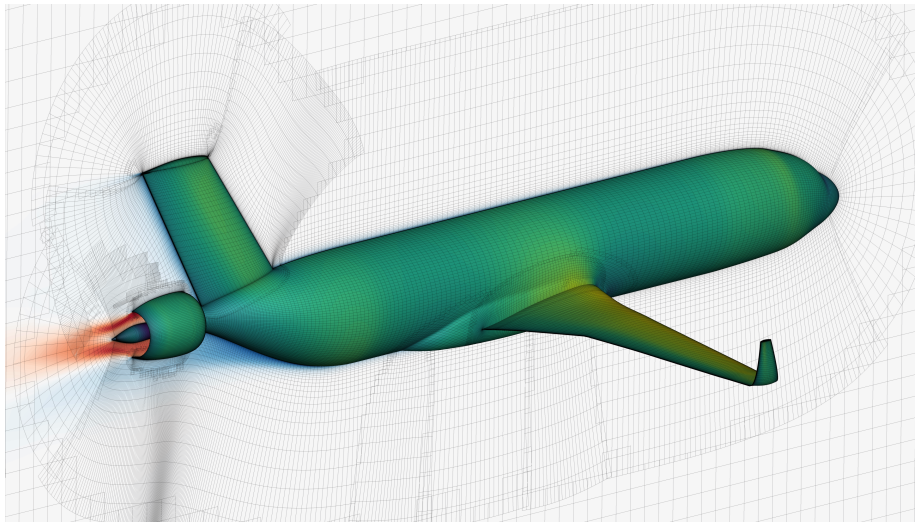
We are also adding more disciplines,
such as propulsion and thermal models

For more details, check out my other presentation at Aviation:

“An Aeropropulsive Test Problem:
Coupling CFD Simulations with a Propulsion Model”

Q&A Session: Community Discussion:
Establishing Shared MDO Test Problems for Research Use

Yildirim et al.
AIAA 2019-3455



Anibal et al.
AIAA 2020-2115

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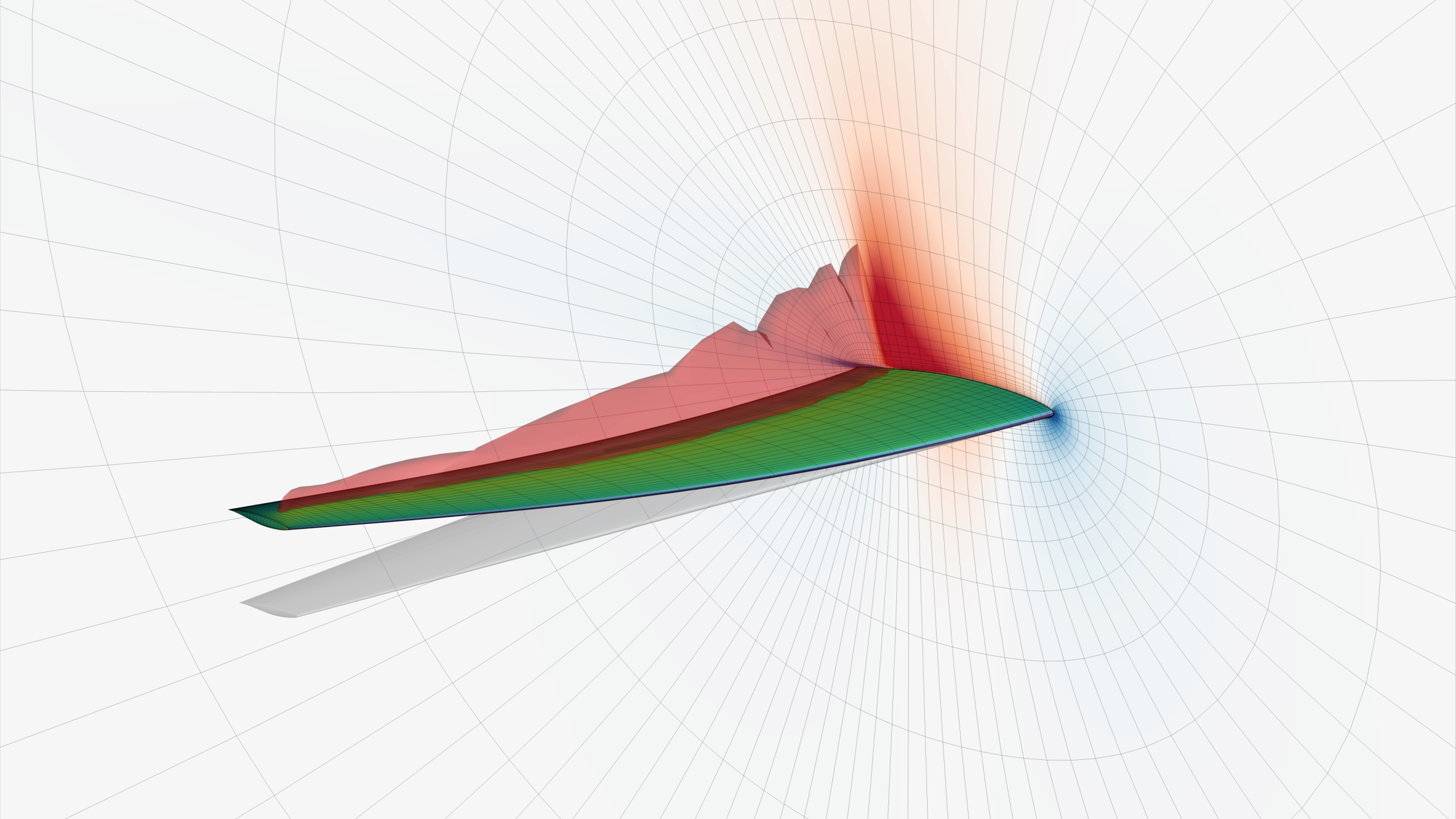
MPhys provides a multiphysics simulation package using OpenMDAO

It streamlines the inclusion of high-fidelity simulations in OpenMDAO models

Users interact with a simplified interface; parallelism is abstracted, and computational performance is optimized by developers

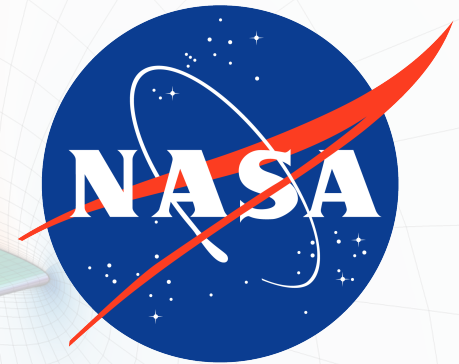
The standard API defined for each discipline enables a plug and play approach, where the solvers are interchangeable

MPhys will be released with an open-source license once we finalize the important details about the API



Thank you!

Q&A Session: MDO-07, Emerging Methods, Algorithms, and Software Development in MDO II



Open-source tools:

<https://github.com/>

mdolab/ADflow

gjkennedy/funtofem

gjkennedy/tacs

OpenMDAO/OpenMDAO

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