Aerostructural Optimization of a Flexible-Winged Aircraft Using OpenVSP

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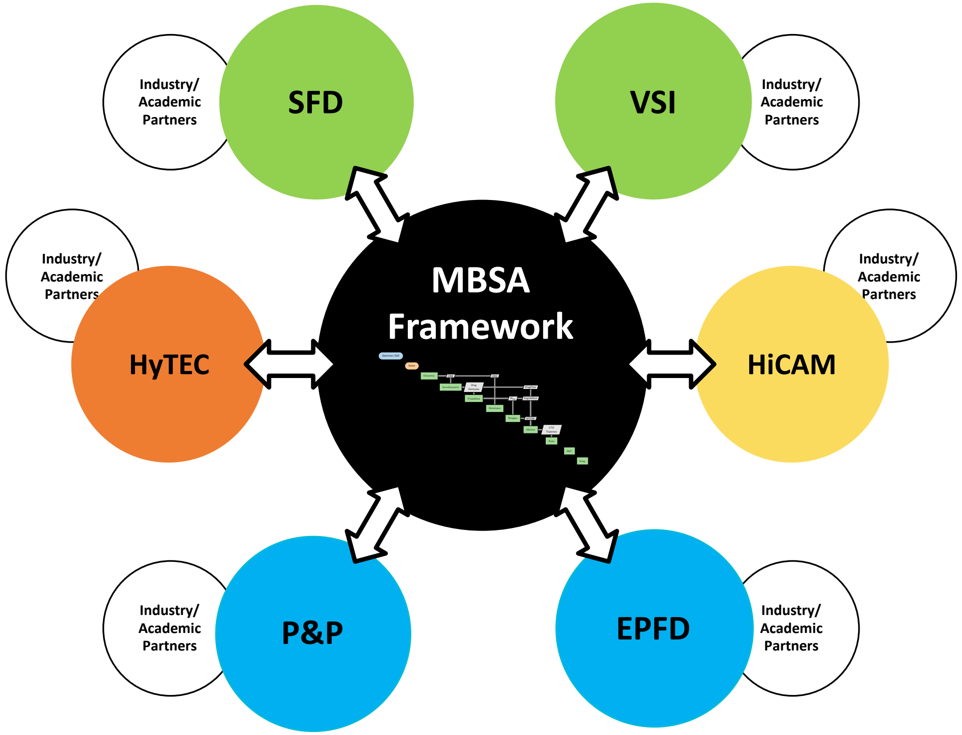
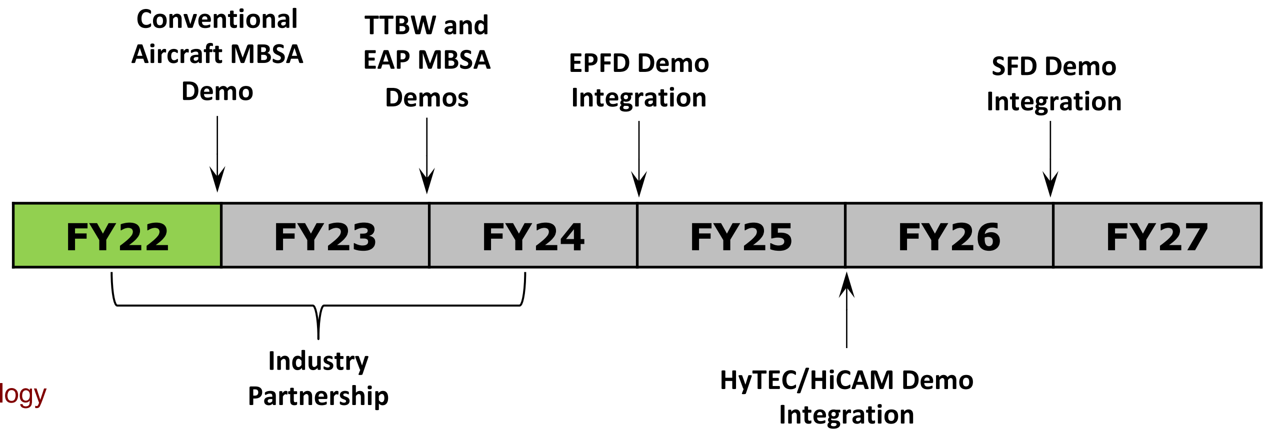
Model-Based System Analysis Engineering (MBSAE) project goals

- Overall goal: Enable the design of unconventional aircraft configurations using a coupled multi-disciplinary toolset
- The project is broken down into multiple year-long phases
- The first two years focus on tool development and validation:
  - Year 1: Create a general aircraft analysis/optimization tool by coupling multiple disciplinary toolsets (aerodynamics, structures, S&C, etc.) into a single framework, benchmark against conventional aircraft concept
  - Year 2: Extend study to unconventional truss-braced wing design





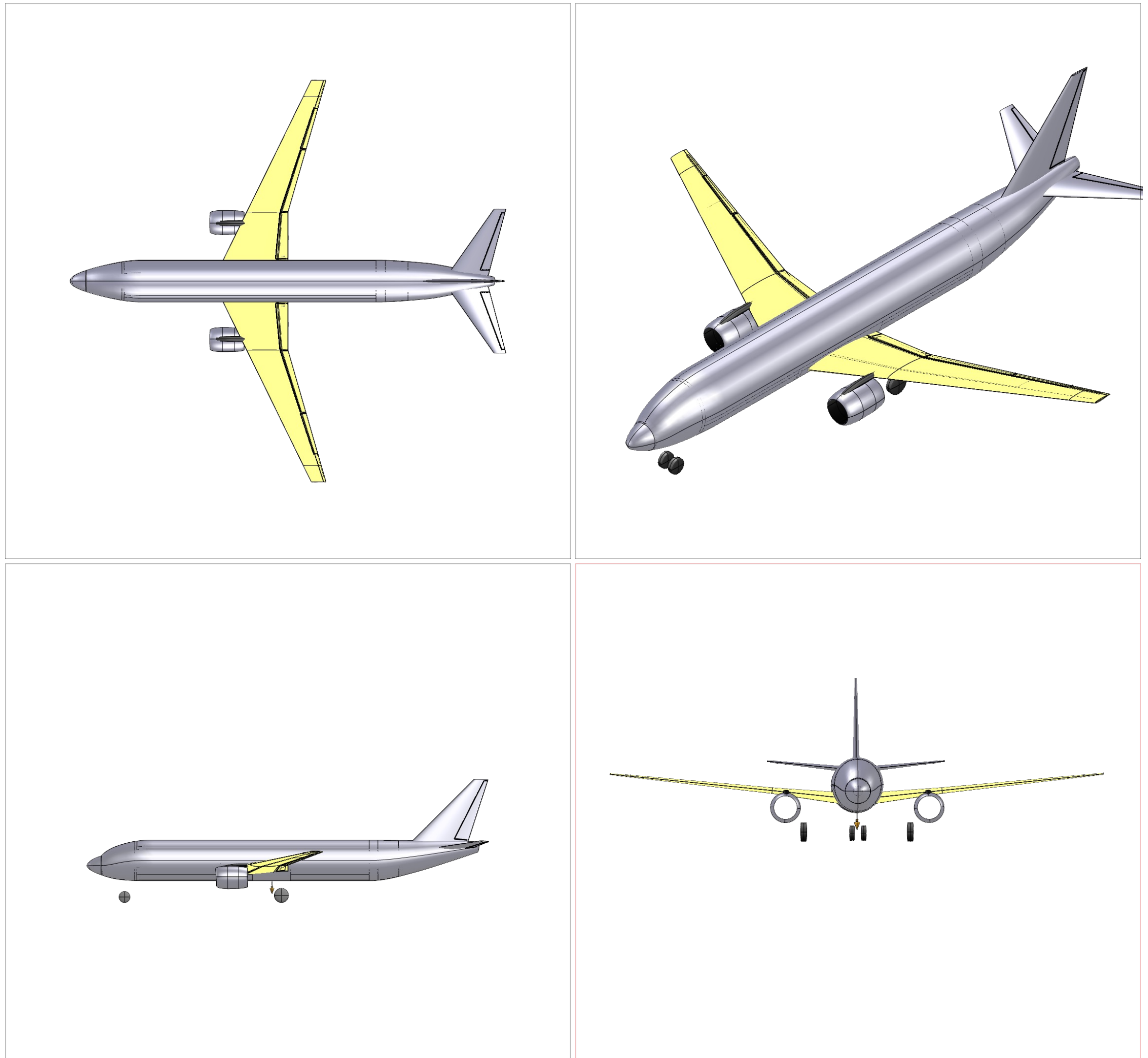
Work based on N3CC Gfan model

- The conventional aircraft design is based off the NASA N+3 Conventional Configuration (N3CC)

- This concept is a single-aisle tube-and-wing transonic transport aircraft

Design Specs

TOGW	51 000	kg
OEW	33 000	kg
# of Pax	154	
Max range	3 500	nm
Cruise Mach	0.8	
Aspect Ratio	11.0	
Reference Area	113.3	m^2
Span	36.2	m
Sweep	26.0	deg



Bradley, M. K., Droney, C. K., and Allen, T. J. 2015

This work uses Mphys: An OpenMDAO library for high-fidelity multi-physics

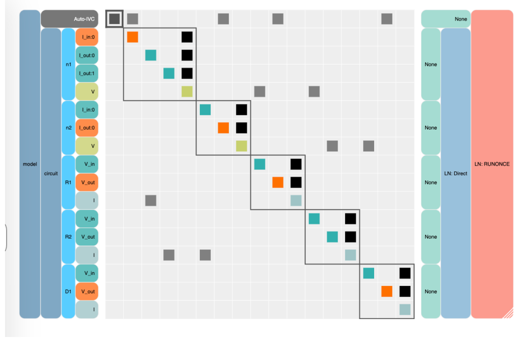
Aero Solvers:
- FUN3D
- CART3D
- ADFlow
- DAFoam
- VLM
- SU2
- OpenAeroStruct

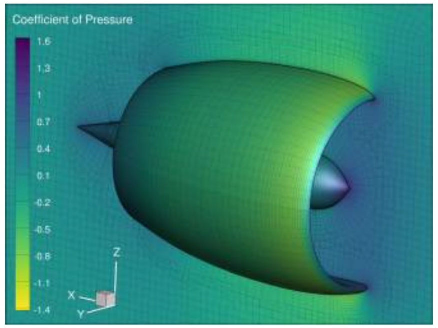
Structural Solvers:
- TACS
- Modal Solver
- NASTRAN

Load & Displacement Transfer:
- MELD
- Rigid Link Transfer

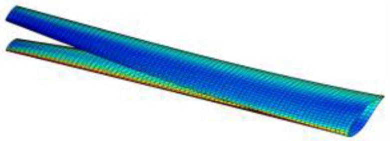
Propulsion:
- pyCycle

Geometry:
- pyGeo (wraps OpenVSP, ESP, FFD)

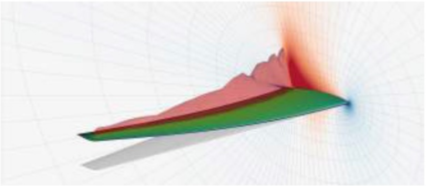

OpenMDAO (NASA GRC)

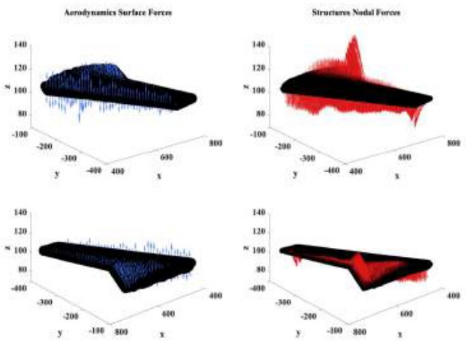


ADflow+pyCycle (Michigan)

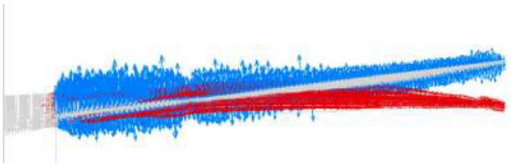

VLM+MELD+TACS


FUN3D+MELD+TACS


ADflow+RLT+TACS (Michigan)



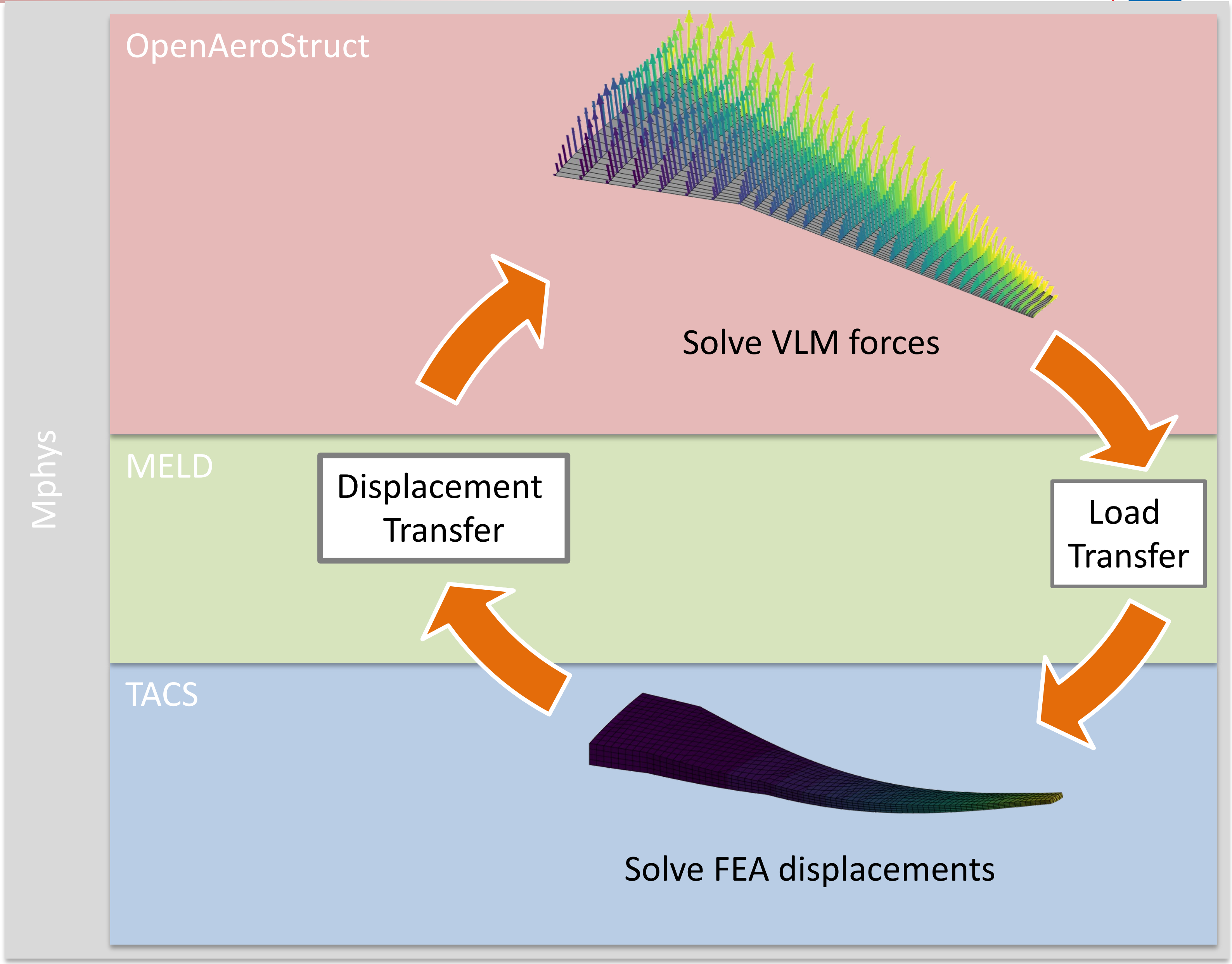
SU2+MELD+NASTRAN (Stanford)


SU2+MELD+TACS (Stanford)

Aerostructural framework breakdown

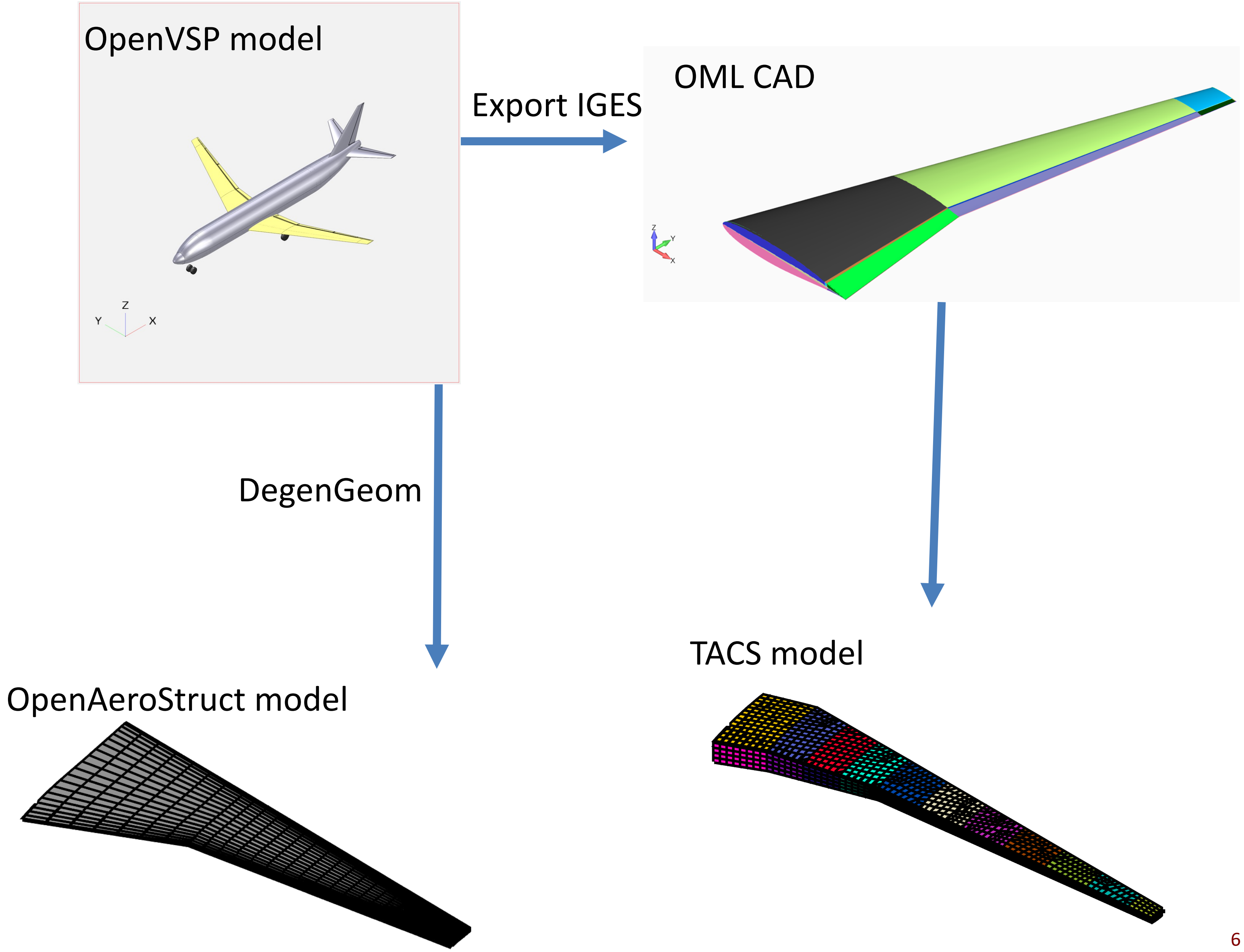
VLM solver	OpenAerostruct: coupled vortex-lattice method (VLM) and a 6 DOF beam model [Jasa et al. 2018]
FEA solver	TACS: Parallelized structural finite element analysis (FEA) solver [Kennedy et al. 2014]
Load/ Displacement transfer	MELD: aerostructural load and displacement coupling scheme available in FunToFEM aeroelastic library [Kiviaho and Kennedy 2019]

Note: Since all tools are wrapped into OpenMDAO through Mphys, we have access to coupled sensitivities by design



Aerostructural model generation centers around OpenVSP

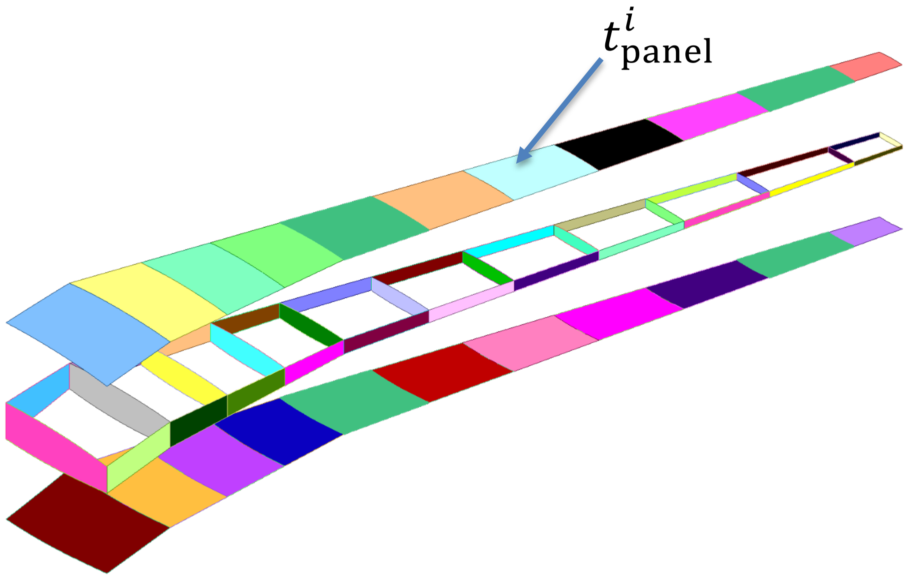
- Model centers around OML defined by OpenVSP geometry
- VLM mesh is generated automatically from VSP using DegenGeom representation
- Internal wingbox FEM is generated manually from IGES of wing OML
- Wing VLM/FEM model serve as inputs to aerostructural analysis



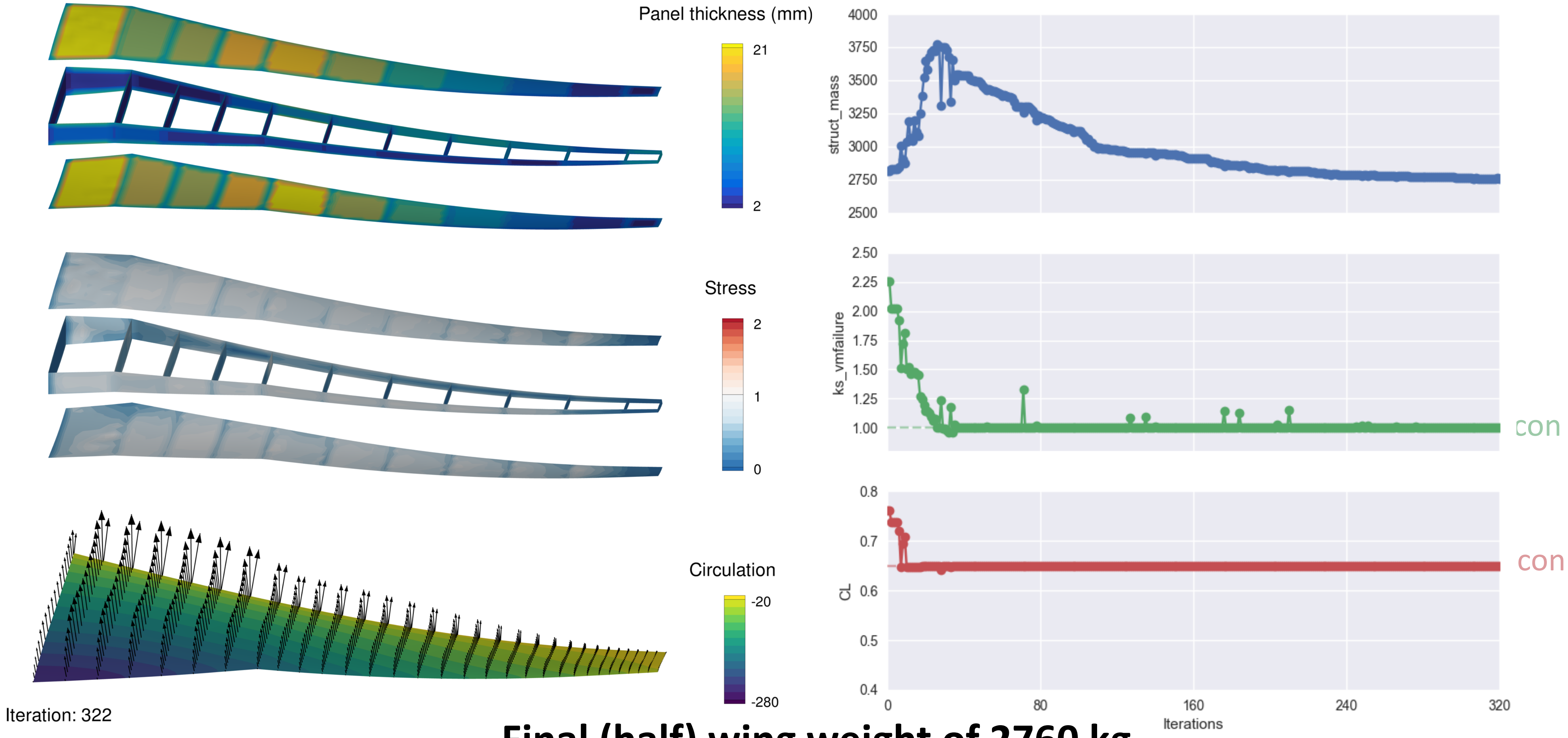
Aerostructural sizing optimization example: Definition

Description: Minimize the weight of the wing structure under a 2.5g maneuver loading

minimize	M_{wing}		
with respect to			
	α	Angle of attack	1
	t^i_{panel}	Panel thicknesses	56
subject to			
	$C_L = 0.65$	Lift constraint	1
	$KS(\lambda_{vm}) \leq 1.0$	Max stress constraint	1



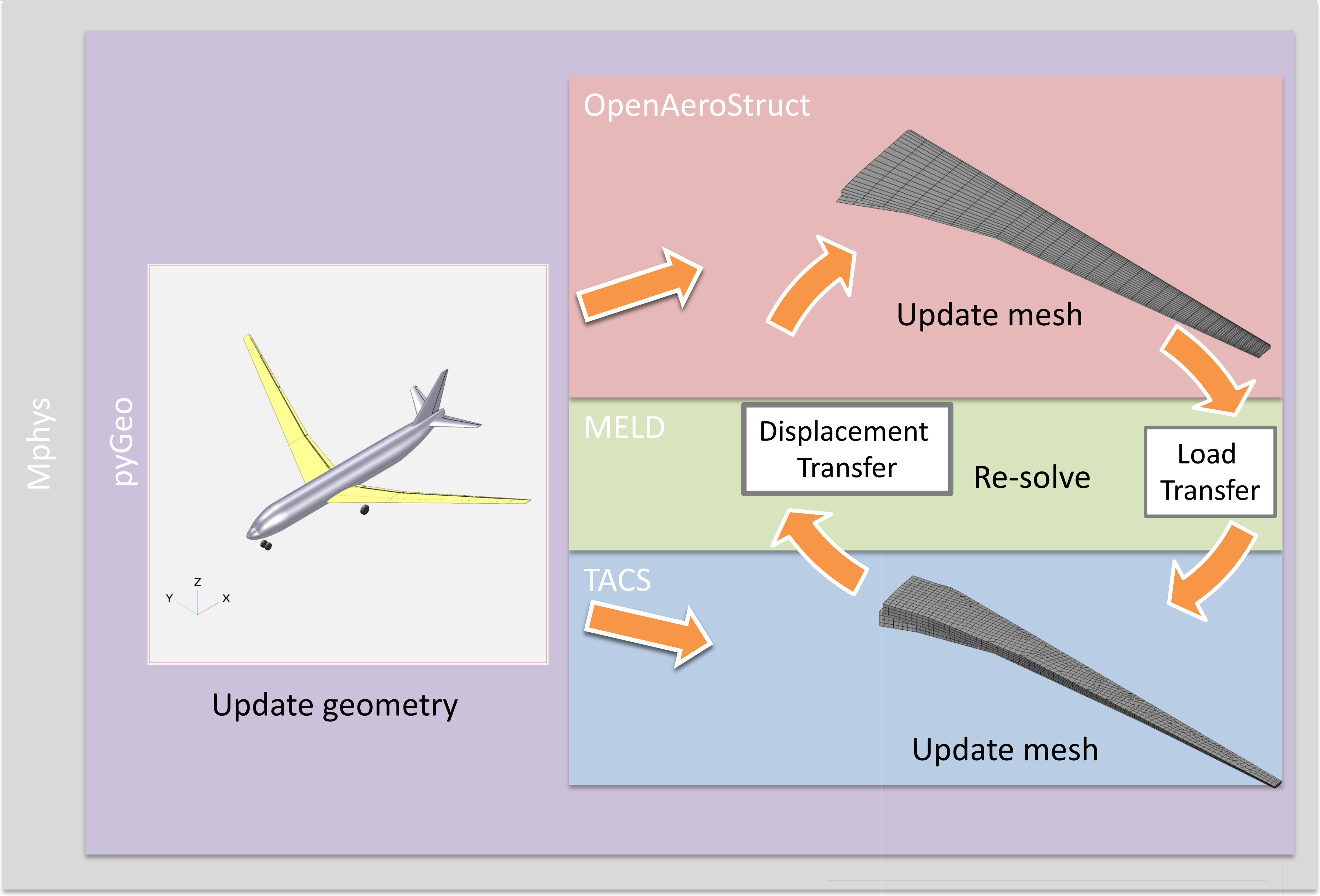
Aerostructural sizing optimization example: Results



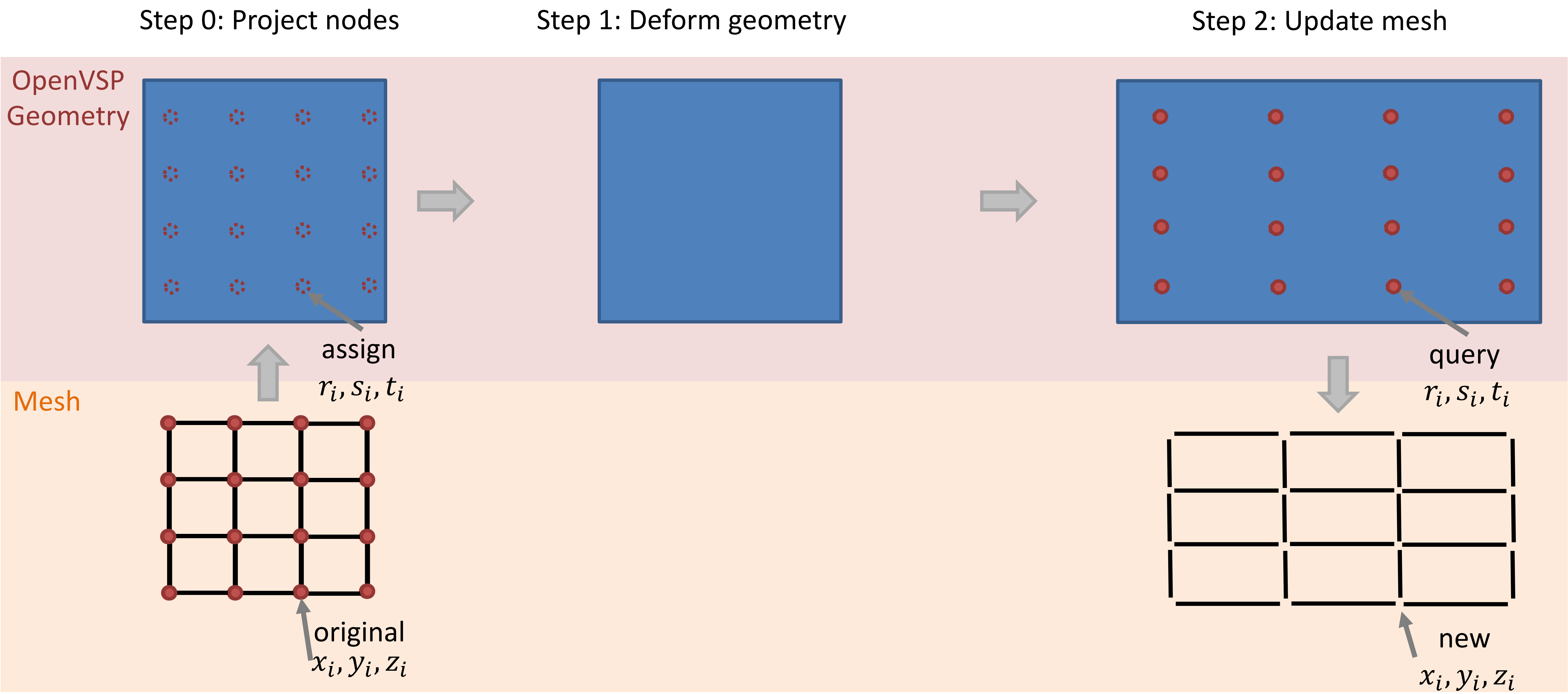
Final (half) wing weight of 2760 kg

Adding in geometry to the optimization

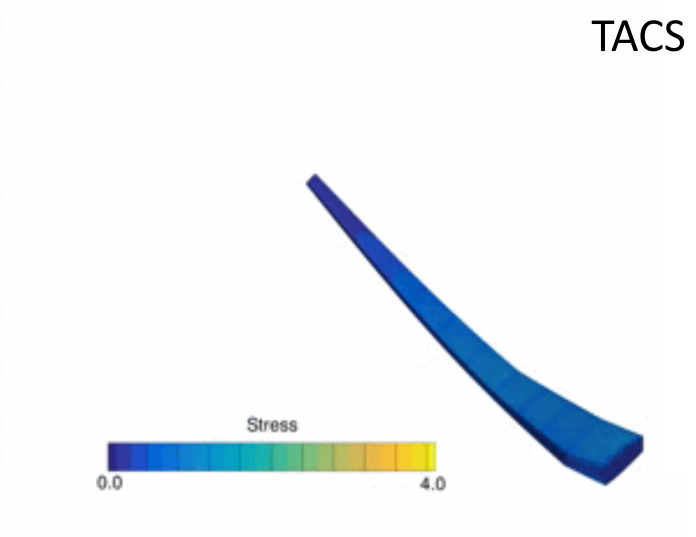
- Next, we'd like to add geometry (span, sweep, etc.) into the optimization
- Re-meshing in-the-loop is too expensive (and not differentiable)
- Instead, we wish to update mesh node locations within optimization
- This was made possible by OpenVSP's new RST coordinate feature
- The pyGeo library is used to wrap OpenVSP into Mphys/OpenMDAO

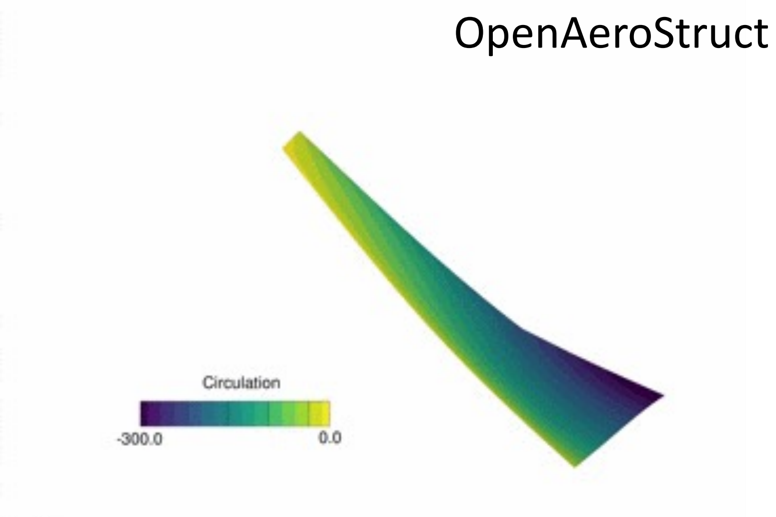


pyGeo: OpenVSP geometry update procedure



With OpenVSP we can now parameterize the geometry of our model

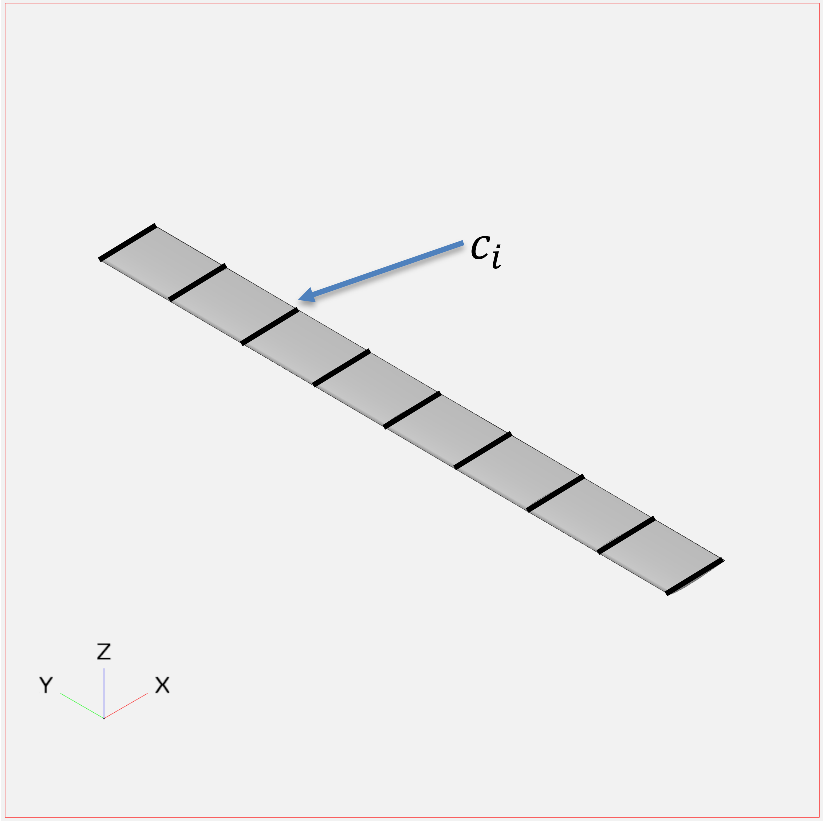




Aerodynamic planform optimization example: Definition

Description: Minimize the drag of an initially rectangular wing ($c = 1, b = 10$)

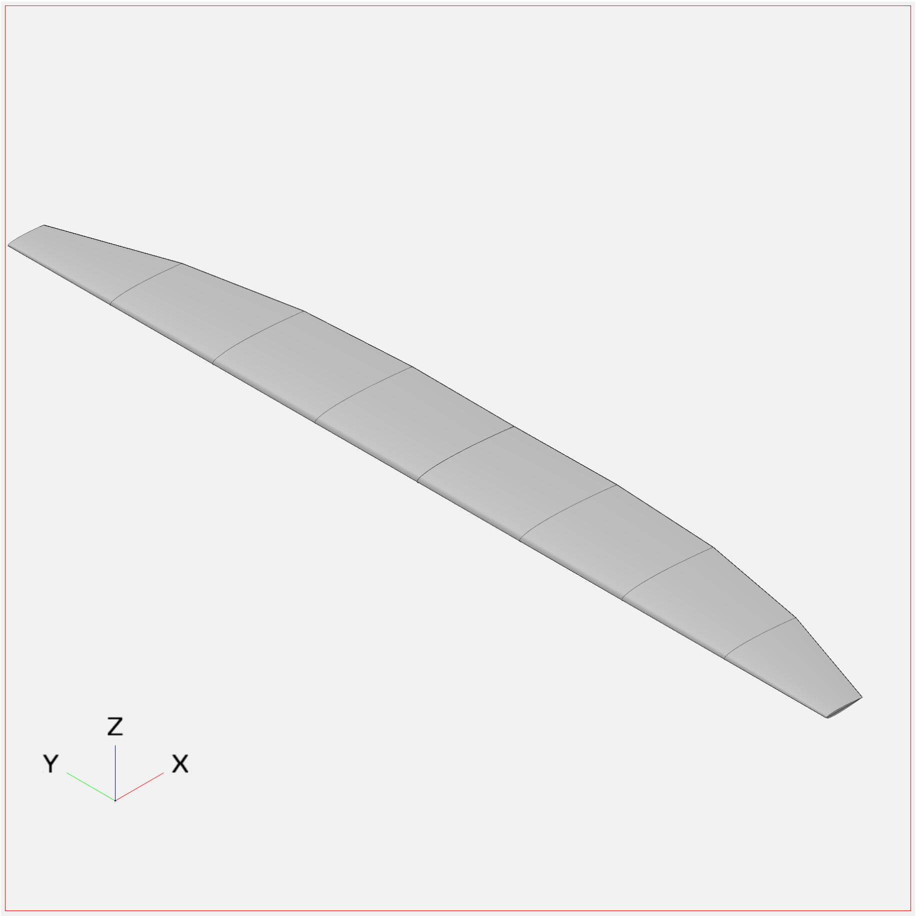
minimize	C_D		
with respect to			
	α	Angle of attack	1
	c_i	chord	5
subject to			
	$C_L = 0.5$	Lift constraint	1
	$S_{\text{ref}} = 10.0$	Area constraint	1

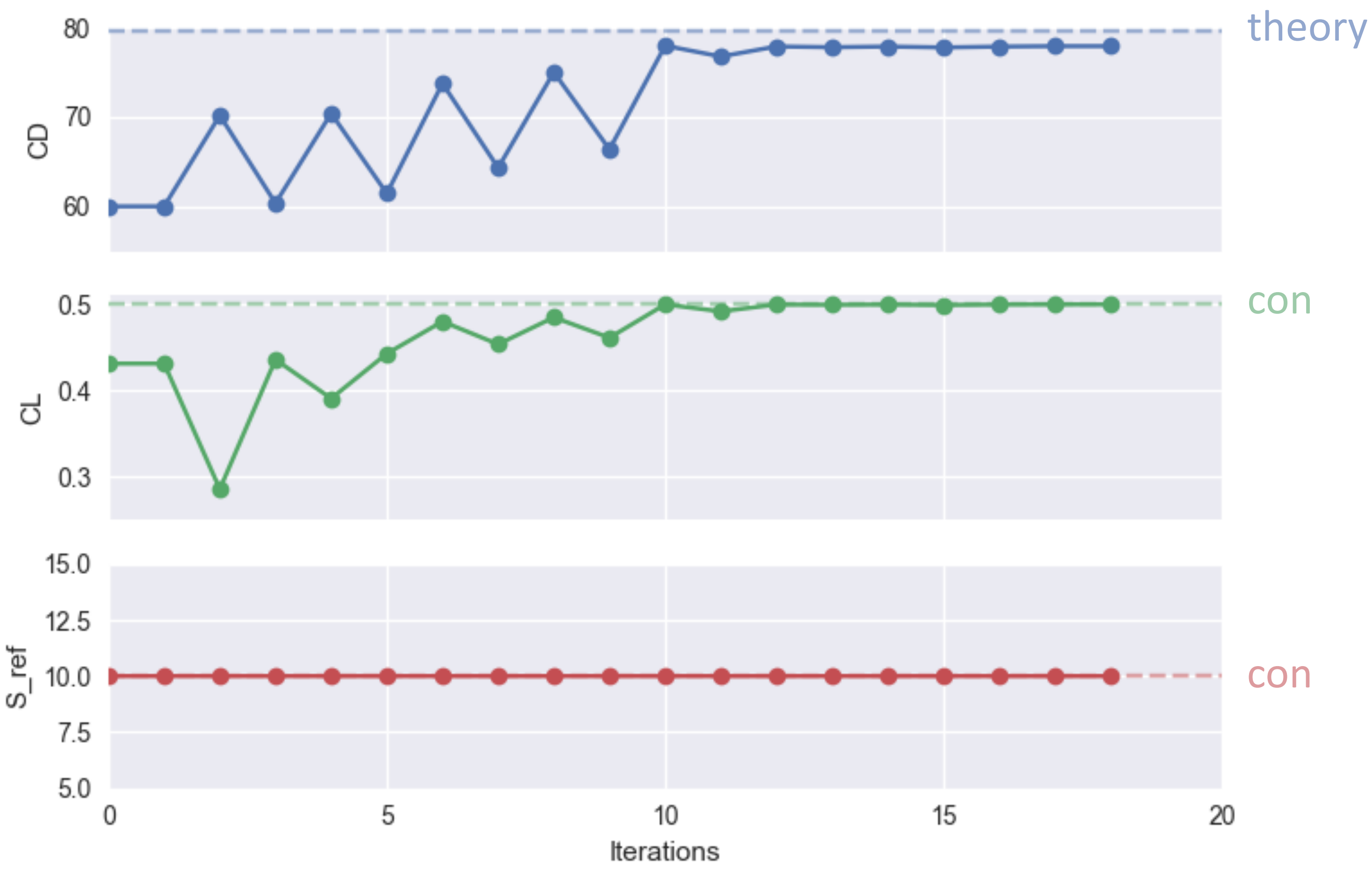


Theoretical minimum given by Lifting Line Theory:

$$C_{D,min} = \frac{C_L^2}{\pi AR}$$

Aerodynamic planform optimization example: Results

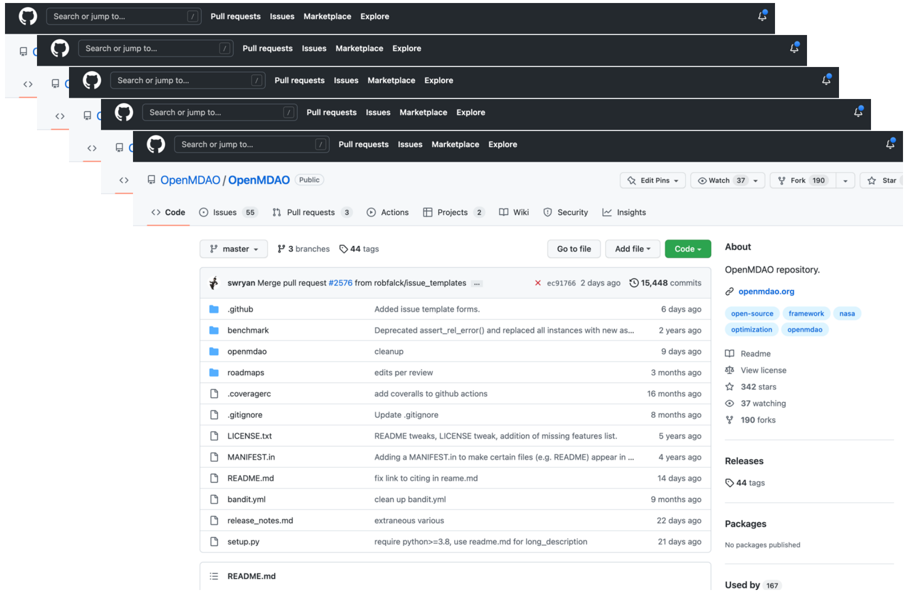




Optimal value within 2% of theory

Future work & Takeaways

- Development avenues for building on this work:
  - Adding geometry variables to aerostructural case to explore planform design space
  - Additional structural sizing considerations (buckling)
  - Adding more aircraft components:
    - Tail (model trim drag/authority)
    - Fuselage (cg tracking, cabin pressurization)
- All the tools mentioned today are public and open-source, check them out!
  - OpenVSP: https://github.com/OpenVSP/OpenVSP
  - OpenMDAO: https://github.com/OpenMDAO/OpenMDAO
  - Mphys: https://github.com/OpenMDAO/mphys
  - TACS: https://github.com/smdogroup/tacs
  - OpenAerostruct: https://github.com/MDOLab/OpenAeroStruct
  - pyGeo: https://github.com/MDOLab/pygeo



Thank you

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