

Multidisciplinary Design Optimization of a Transonic Truss-Braced Wing using Physics-Based Models

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Motivation & Objectives



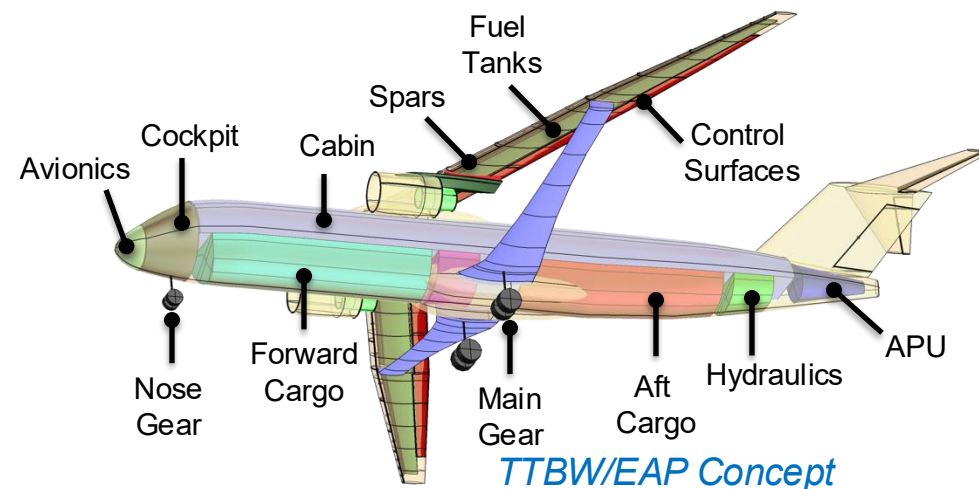
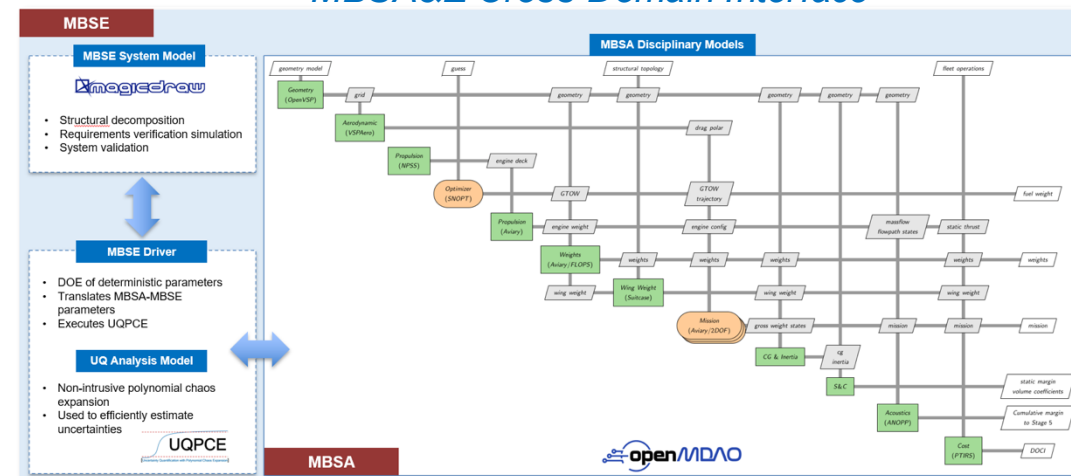
Motivation

- NASA's Model-Based Systems Analysis & Engineering (MBSAE) project is a multi-year effort to tie multiple disciplinary tools together, benchmark a variety of aircraft concepts
- While past work has included physics-based solvers, some aren't differentiated and are impractical to use in optimization
- Advanced concepts such as TTBW offer potential benefits in fuel performance. However, complex coupling inherent with these designs requires physics to be considered in optimization

Goals

- Extend aircraft design capability of framework by solving a fuel burn minimization problem with:
 - Capture of system-level metrics by including physics-based aerodynamic and structural analysis in optimization
 - Considering aircraft geometric design variables and sensitivities to mission optimization problem

MBSA&E Cross-Domain Interface



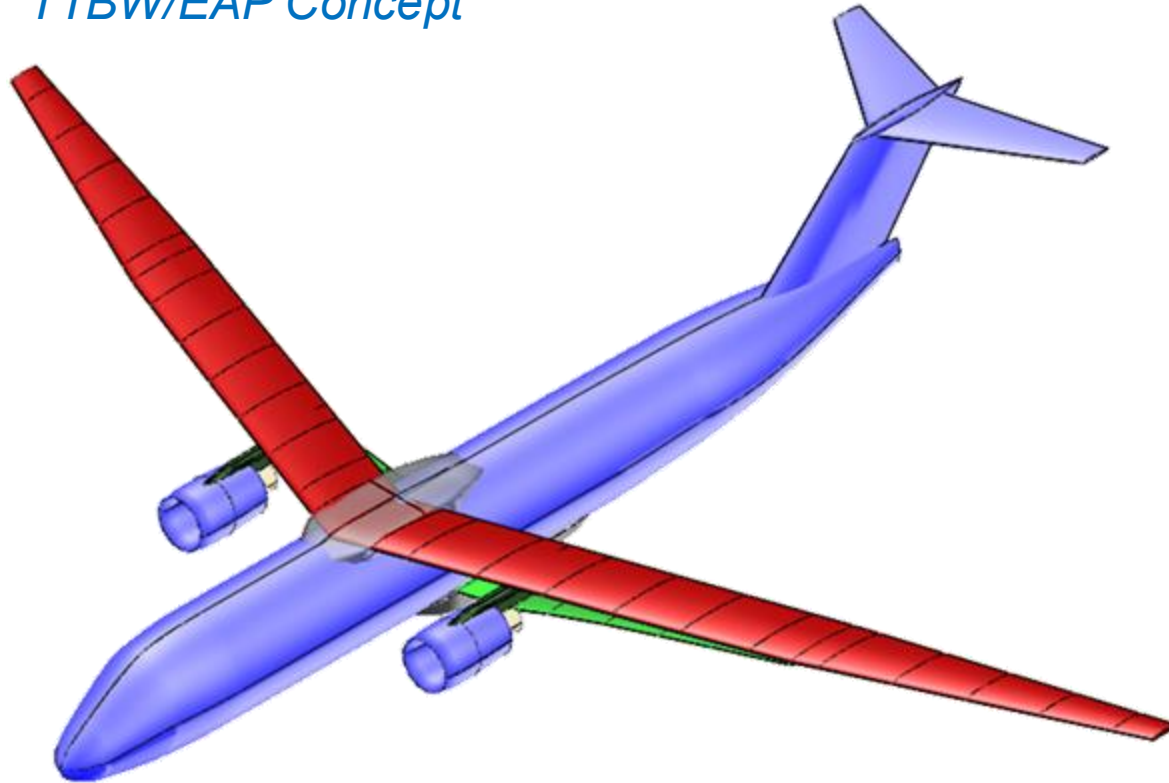
TTBW/EAP Concept

TTBW Reference Model Definition



- Non-proprietary *TTBW Tech Collector* developed by NASA to allow future vehicle technology studies, open publication of results, and easier collaboration with parties outside of NASA.
- gFan+ engine with electric climb assist
- 2035 entry-into-service

TTBW/EAP Concept



Design Specs

TOGW	145,000	lb
OEW	88,000	lb
# of Pax	154	
Design range	3,200	nm
Cruise Mach	0.8	
Cruise altitude	38,000	ft
Aspect ratio	19.7	
Reference area	1,475	ft ²
Span	170	ft
Sweep	21.8	deg

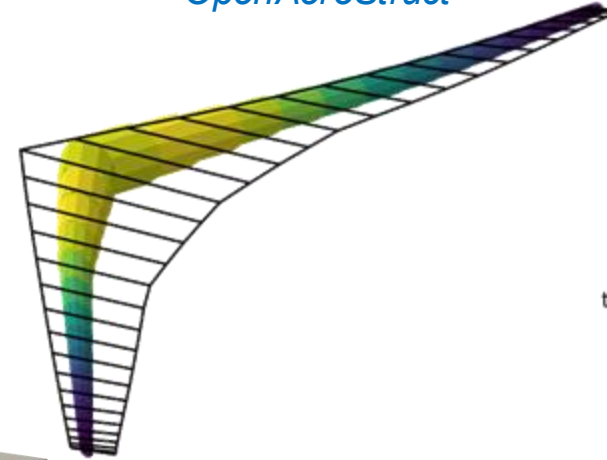
Toolchain Overview



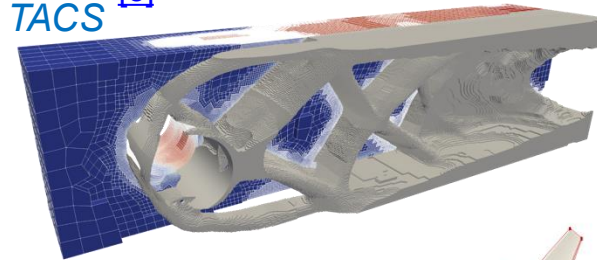
- This work couples together several libraries using OpenMDAO:
 - Aviary: top-level aircraft mission and sizing library
 - OpenAeroStruct: a Vortex Lattice Method (VLM) solver, is used to compute aerodynamic loads
 - TACS: a finite element analysis (FEA) solver, is used to compute the elastic response of the wing structure
 - FunToFEM: an aeroelastic coupling library, is used to handle transferring coupling info across aero/structural models
 - pyGeo: a geometry engine for handling geometric parameterization in optimization
- All models feature analytical gradients/adjoints allowing for efficient gradient-based optimization



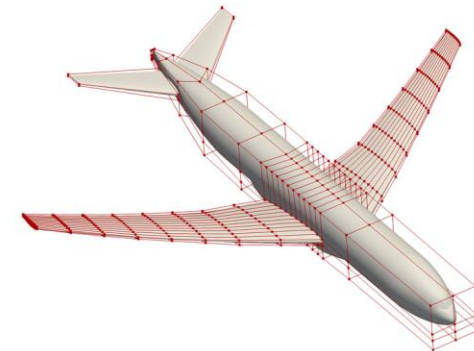
OpenAeroStruct [4]



TACS [8]



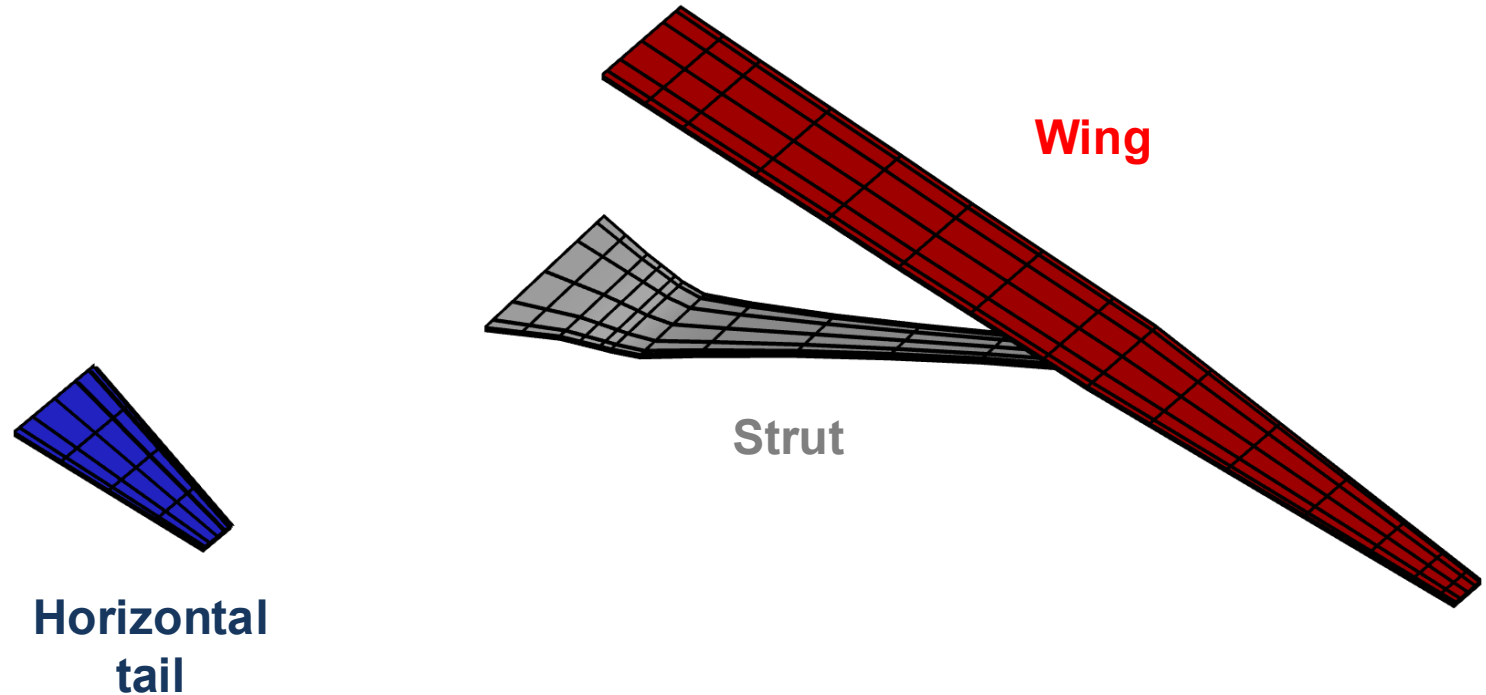
pyGeo [7]



OpenAeroStruct Aerodynamic VLM Model Overview



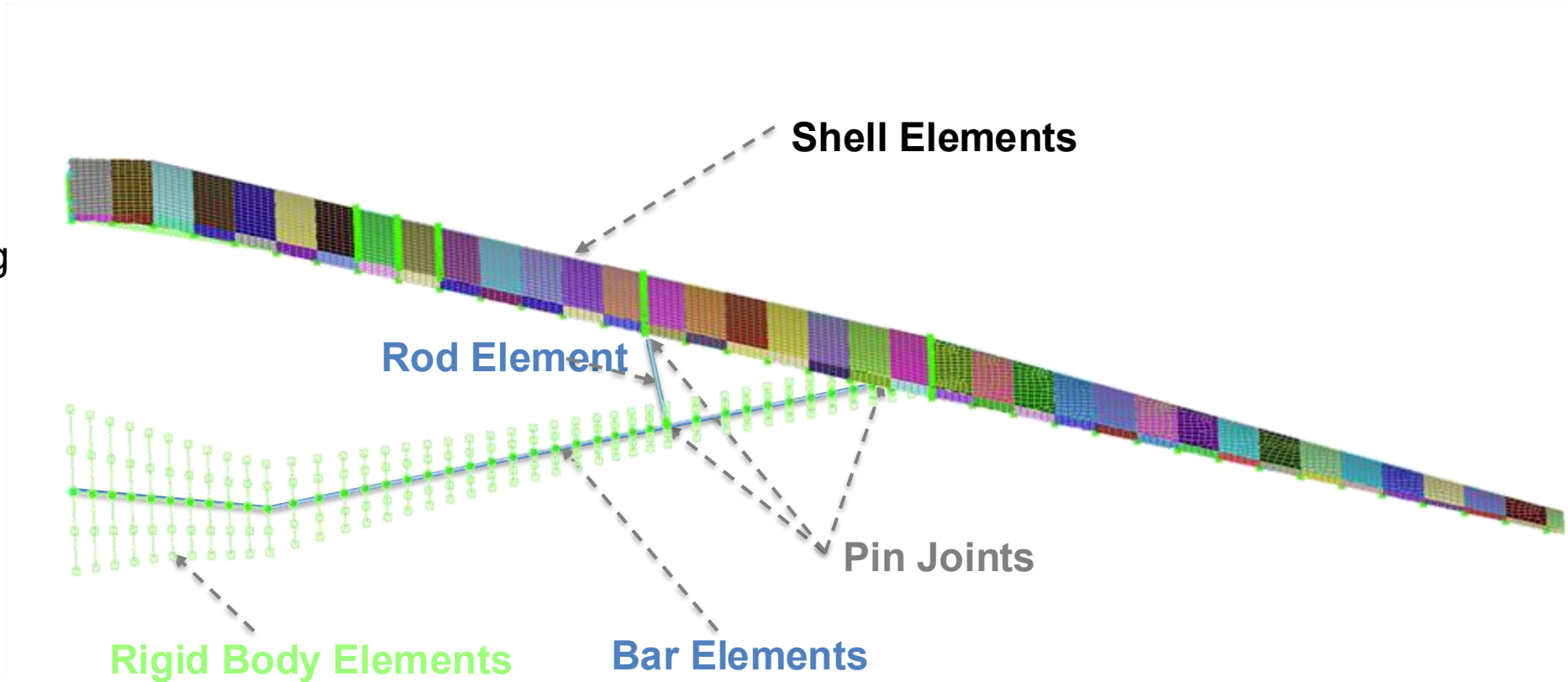
- Wing, strut, and horizontal tail are modeled as independent lifting surfaces
- To take advantage of symmetry all surfaces are half-models
- The aerodynamic effect of other aircraft components (fuselage, vertical tail, etc.) are neglected for wing sizing analysis
- 204 VLM elements in total



TACS Structural FEM Model Overview



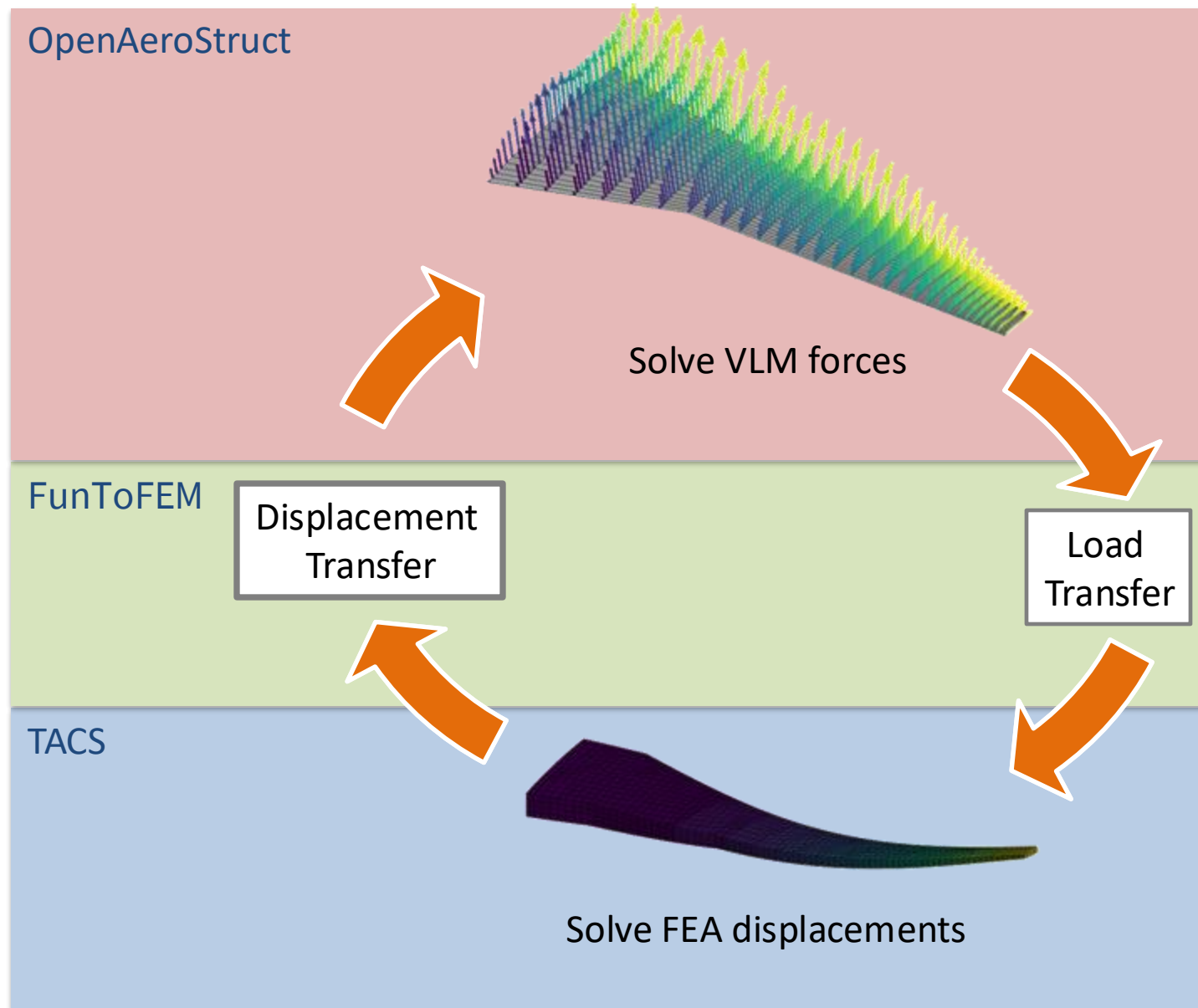
- Only wing is modeled structurally, all other aircraft components are treated as rigid
- Wing skins, ribs, and spars are modeled using shell elements
- Strut and Jury are modeled using bar/rod elements
- Pin joints are modeled using Rigid Body Elements (RBE)
- 9,196 elements, 53,766 DOF in total



Aerostructural Coupling



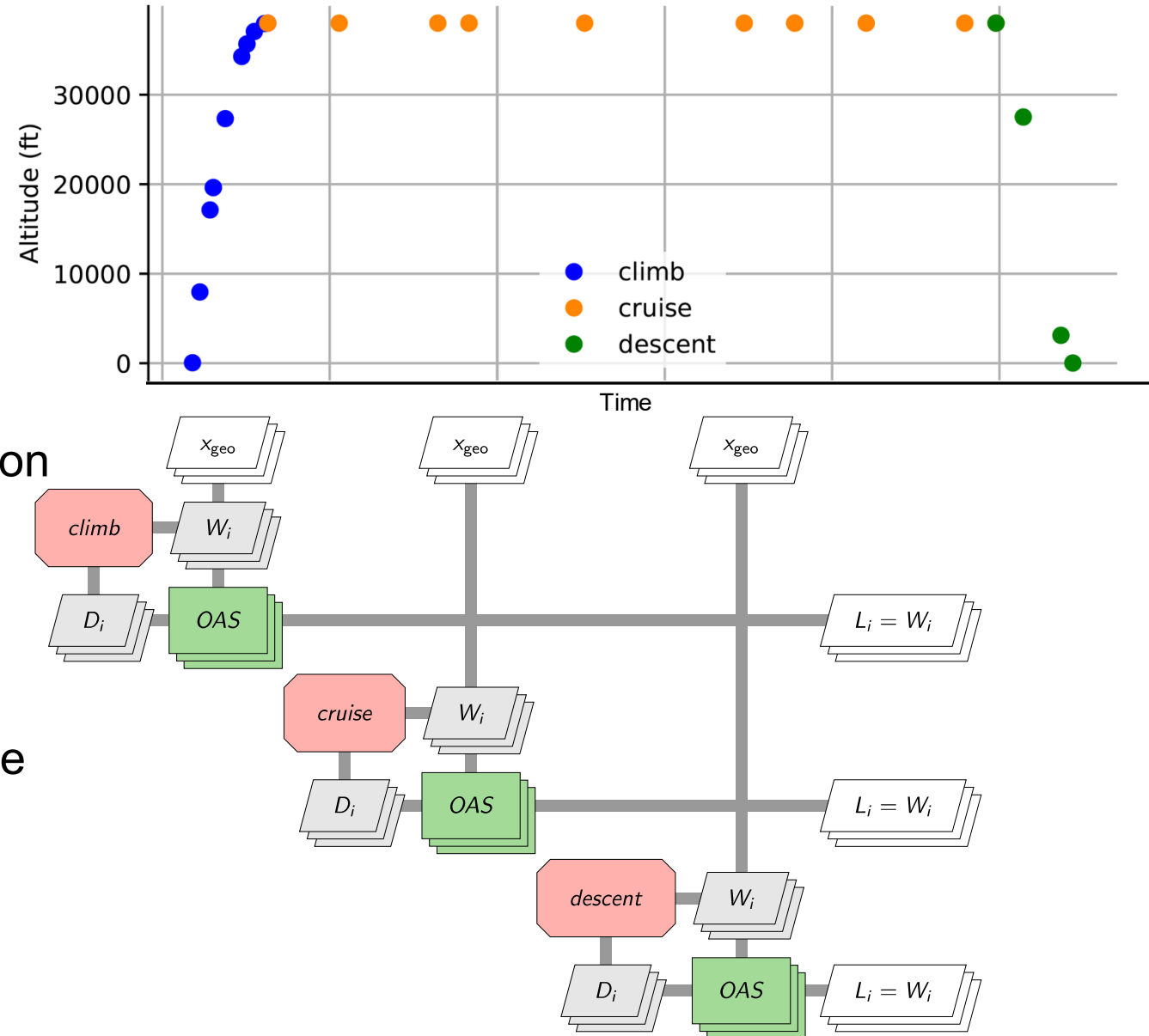
- FunToFEM used to transfer loads and displacements between VLM and FEA model
- Wing is sized using a 2.5g pull up maneuver based on von Mises failure criteria
- Structural wing weight passed to mission analysis component
- All other aircraft weights computed by Aviary



Mission Simulation



- Trajectory broken down in 3 phases: climb, cruise, descent
- Multiple OpenAeroStruct instances are connected to each mission phase
- Each instance computes the instantaneous drag for a given weight at each time integration point, 28 flight points in total
- OpenAeroStruct instances are coordinated using an OpenMDAO **ParallelGroup**, allowing for the aerodynamic calculation to be parallelized



Optimization Problem



Minimize: Fuel burn

With respect to:

- Trajectory (Mach, altitude, etc.) # 209
- Structural thickness # 192
- Twist* # 9
- Span* # 1

Subject to:

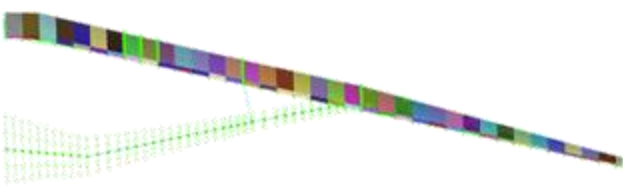
- Trajectory linkage # 87
- Lift/Moment trim # 58
- von Mises stress # 1

Three run cases:

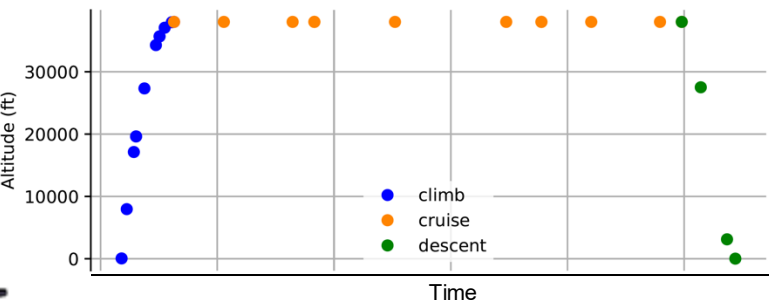
	Twist	Span
Baseline-optimized	✗	✗
Twist-optimized	✓	✗
Fully-optimized	✓	✓

Design variables:

Structural thickness



Trajectory

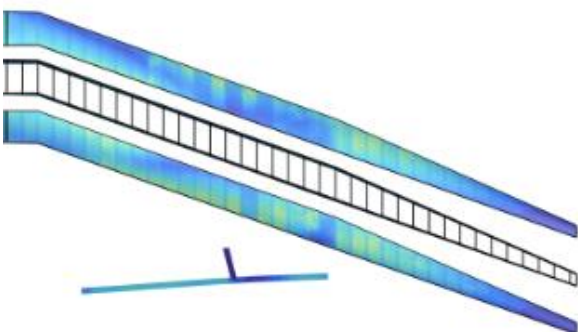


Twist/Span

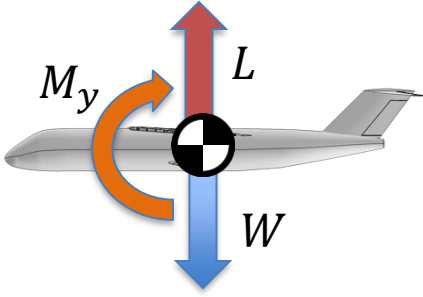


Constraints:

Stress



Lift/Moment trim



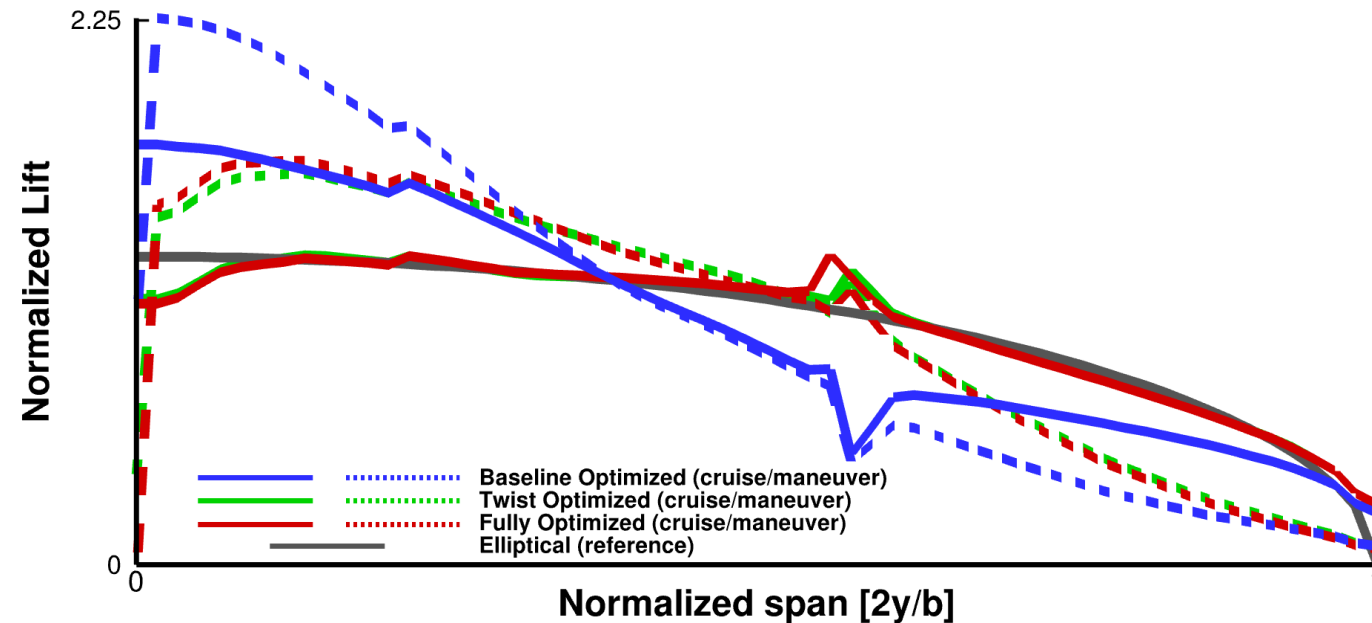
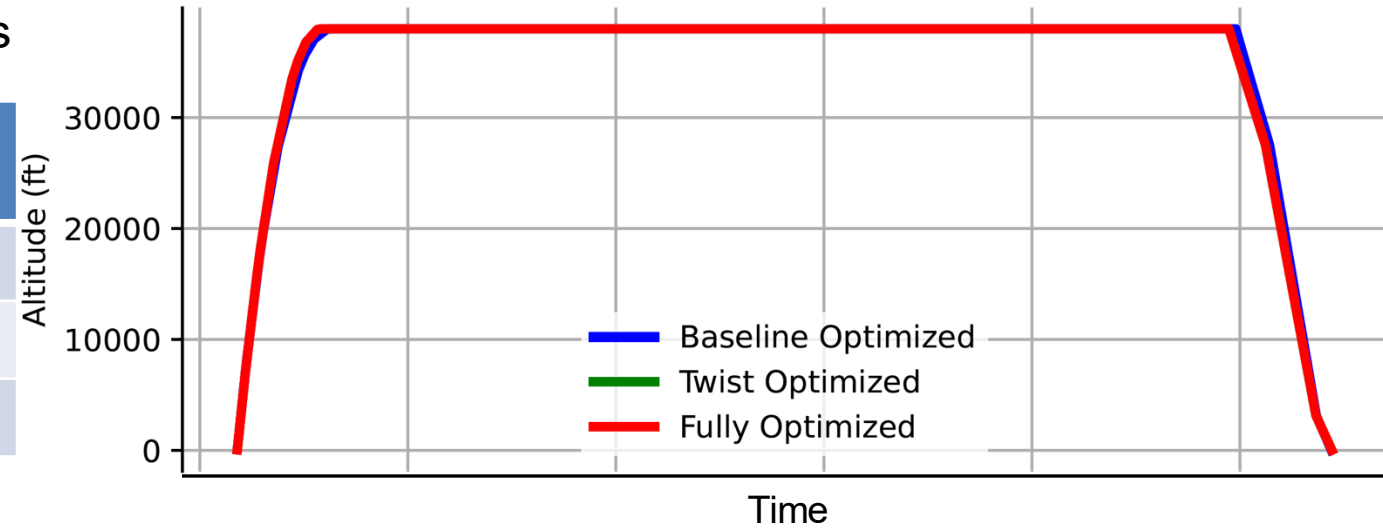
Optimization Results



- All cases run within ≈ 48 hours/run on 12 procs

Design	Fuel burn (lb)	Wing weight (lb)	Span (ft)	L/D_{cruise}
Baseline	20,390	18,410	35.97	25.31
Twist	19,080	20,140	35.97	27.68
Fully	19,070	20,160	37.36	27.72

- Adding twist improves fuel burn by 6%
- Adding span has a negligible impact
- Small trajectory changes across cases
- Higher L/D with twist, but heavier wing
- Twist improves cruise lift distribution (elliptical)
- All designs take advantage of passive load alleviation at maneuver to reduce wing weight



Takeaways & Future Work



- We successfully integrated physics-based aerodynamic, structural analysis, and geometry into an optimization
- Twist proved to be a key design lever for efficiency, while span offered diminishing returns
- Future work:
 - Investigate other geometry dvs: strut placement, airfoil, etc.
 - CFD aero integration
 - Adding structural buckling constraints
- All the tools mentioned today are public and open-source, check them out!

[1] Aviary: <https://github.com/OpenMDAO/Aviary>

[2] FunToFEM: <https://github.com/smdogroup/funtofem>

[3] Mphys: <https://github.com/OpenMDAO/mphys>

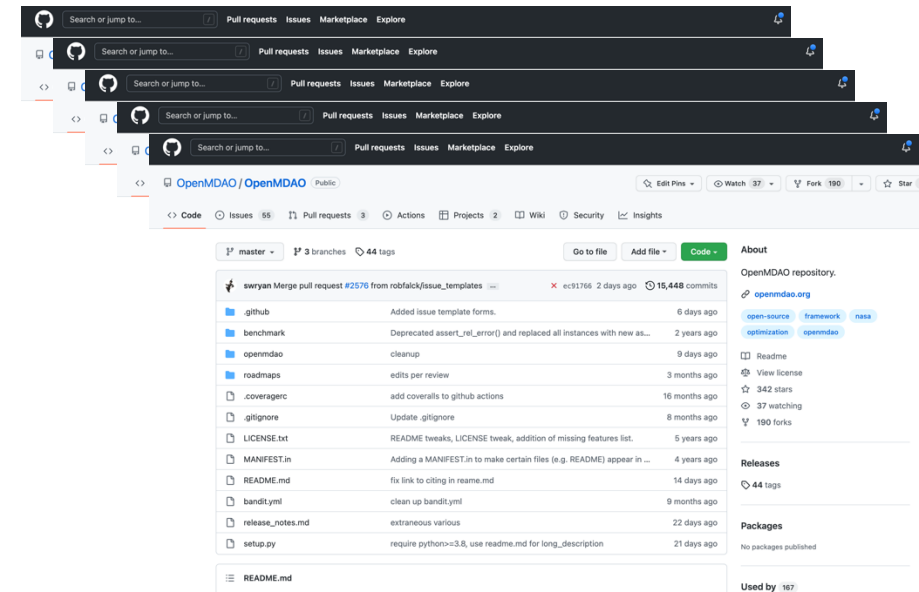
[4] OpenAerostruct: <https://github.com/MDOLab/OpenAeroStruct>

[5] OpenMDAO: <https://github.com/OpenMDAO/OpenMDAO>

[6] OpenVSP: <https://github.com/OpenVSP/OpenVSP>

[7] pyGeo: <https://github.com/MDOLab/pygeo>

[8] TACS: <https://github.com/smdogroup/TACS>





Questions?

