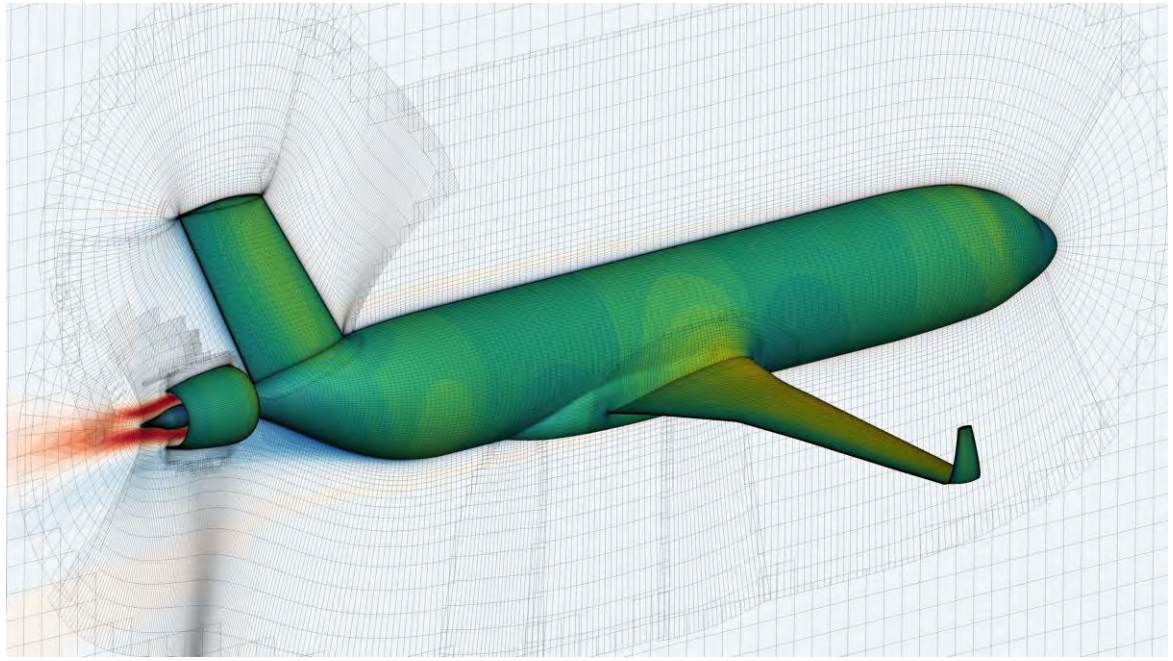
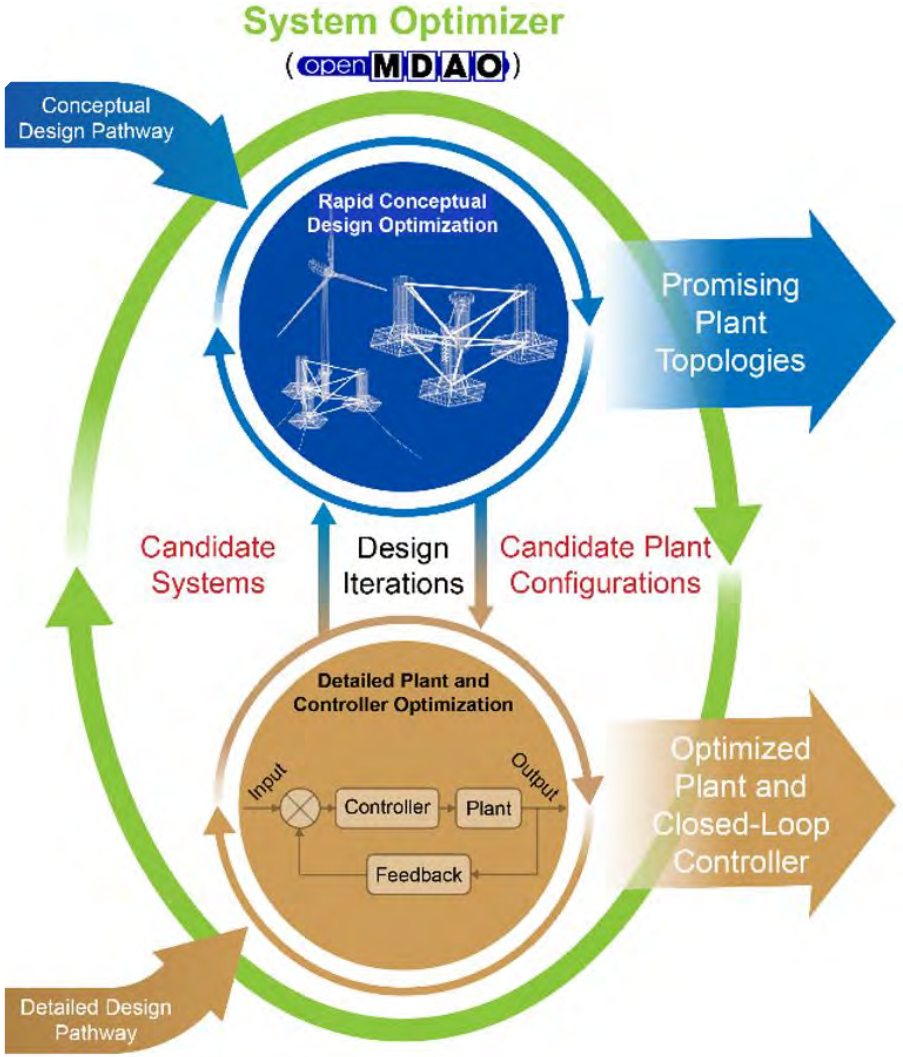
Performing multidisciplinary optimization using OpenMDAO



John Jasa
john.jasa@nasa.gov
NASA Glenn Research Center



What is OpenMDAO?

Who’s using OpenMDAO?

Why should I use OpenMDAO?

How can I learn more about OpenMDAO?

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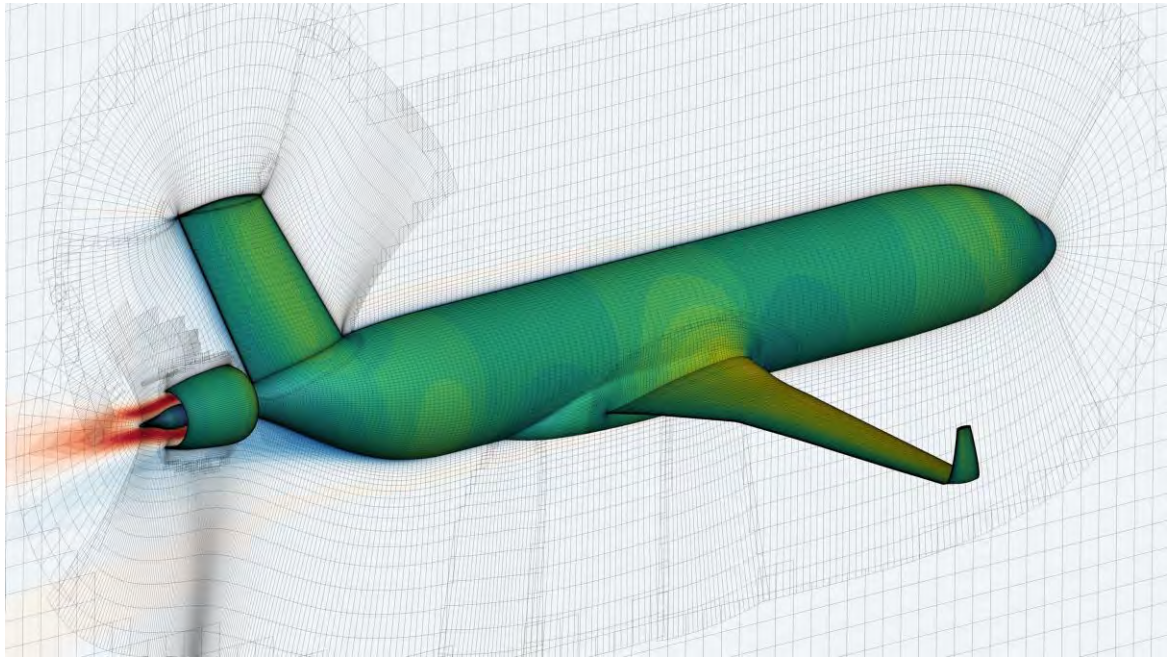
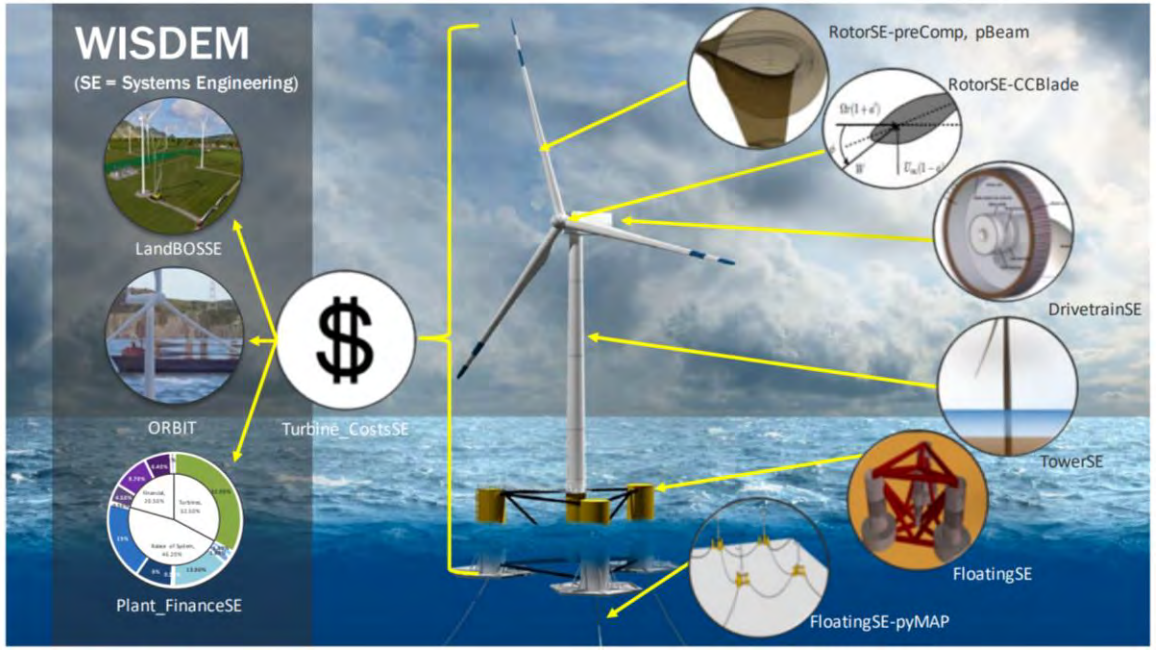
OpenMDAO is a powerful tool for doing gradient-based multidisciplinary optimization

Multidisciplinary **D**esign **A**nalysis and **O**ptimization

OpenMDAO is a powerful tool for doing gradient-based multidisciplinary optimization

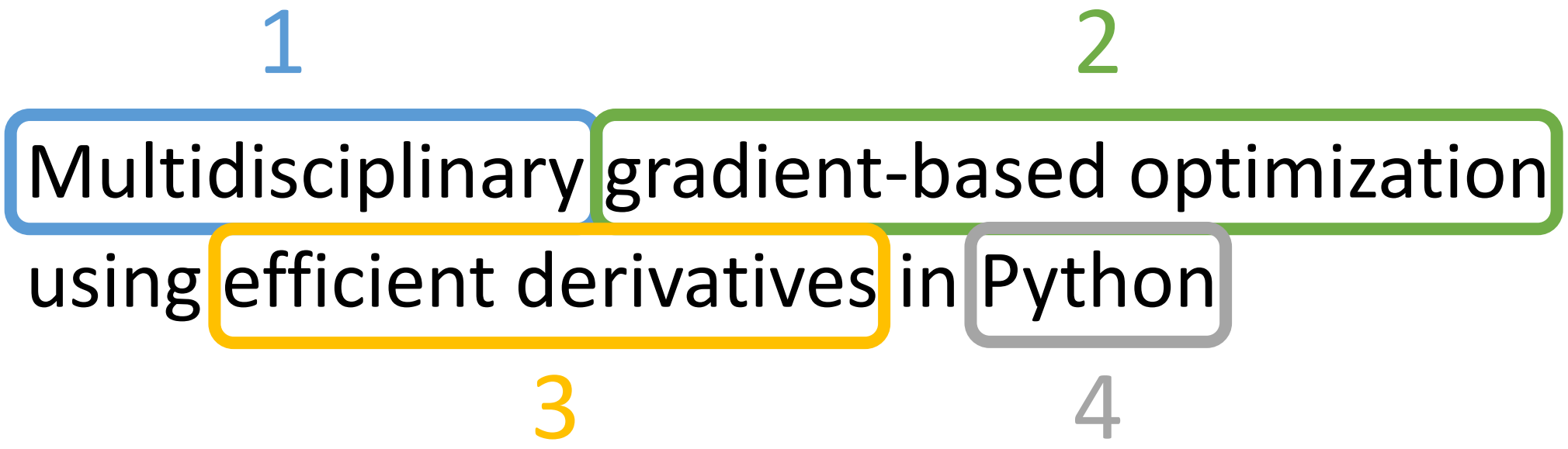


NASA designs complex multidisciplinary systems using OpenMDAO



WISDEM and WEIS are two NREL tools that use the OpenMDAO framework

You should use OpenMDAO if you are doing at least two of these



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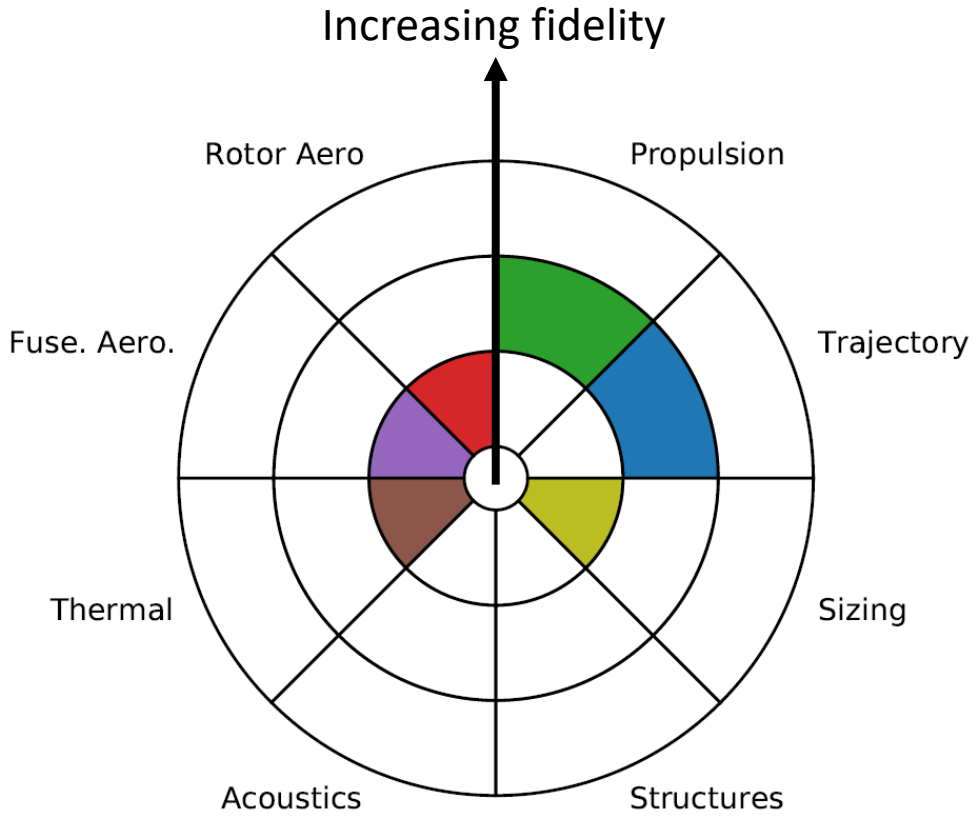
At NASA, we use OpenMDAO to design tightly coupled aircraft



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Multidisciplinary Model					Model
Propeller	Electrical	Turboshaft	Wing	Trajectory	Analysis
OpenBEMT	ZapPy	pyCycle	OpenAeroStruct	Dymos	Library
OpenMDAO					Framework

Other groups have used OpenMDAO for a variety of applications

- NREL, DOE, ARPA-E: WISDEM and WEIS wind turbine design tools
- Air Force Research Lab + Northrup Grumman: Aeropropulsive design optimization
- Aurora Flight Sciences: Aerostructural aircraft wing design
- ONREA: Aircraft and spacecraft design
- Siemens Gamesa
- Uber Elevate: Electric aircraft powertrain design
- Georgia Tech Research Institute, DOD: Model based systems engineering
- Academics: DTU, BYU, UC San Diego, University of Michigan, Georgia Tech, Stanford, MIT, RPI, Purdue, NTNU

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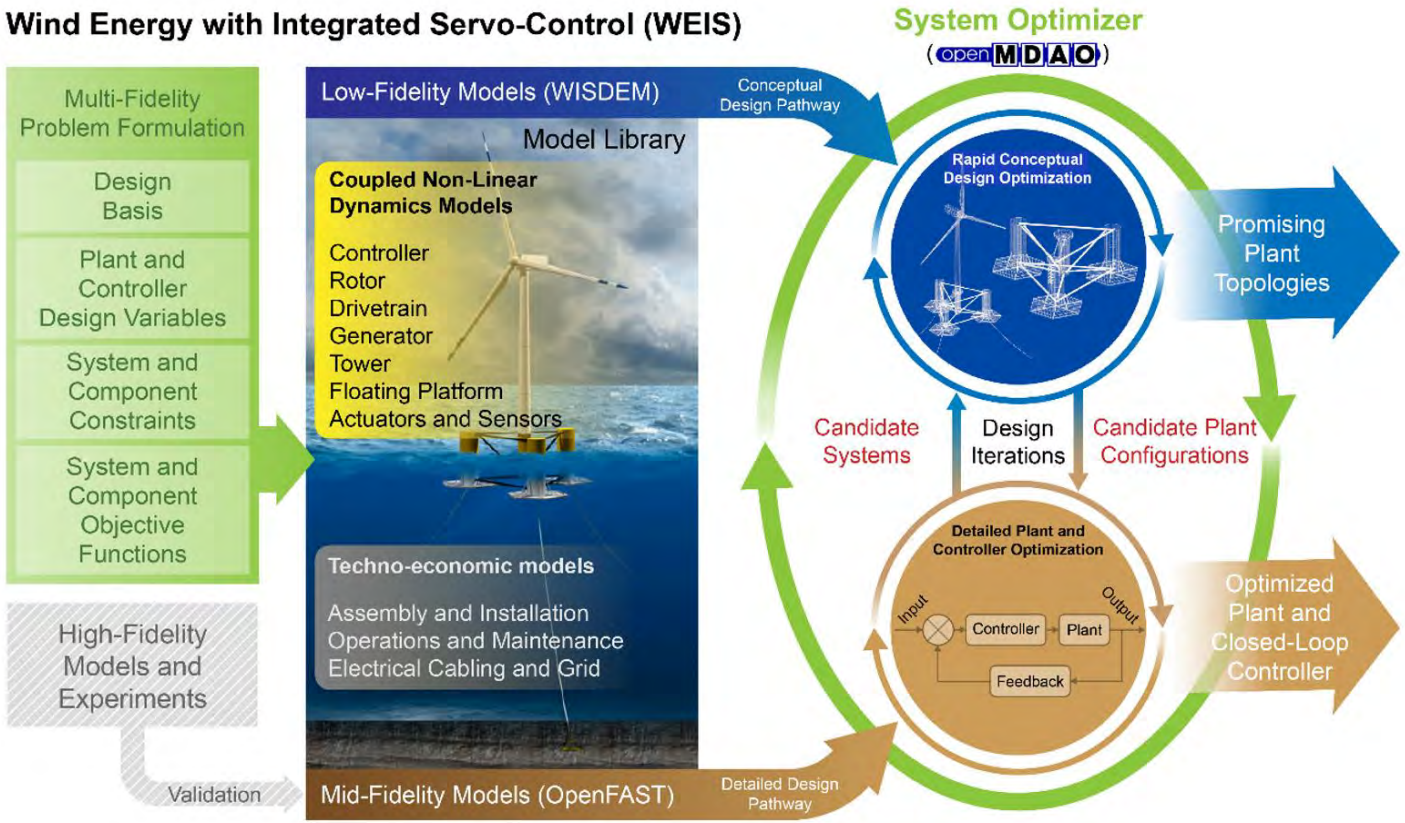

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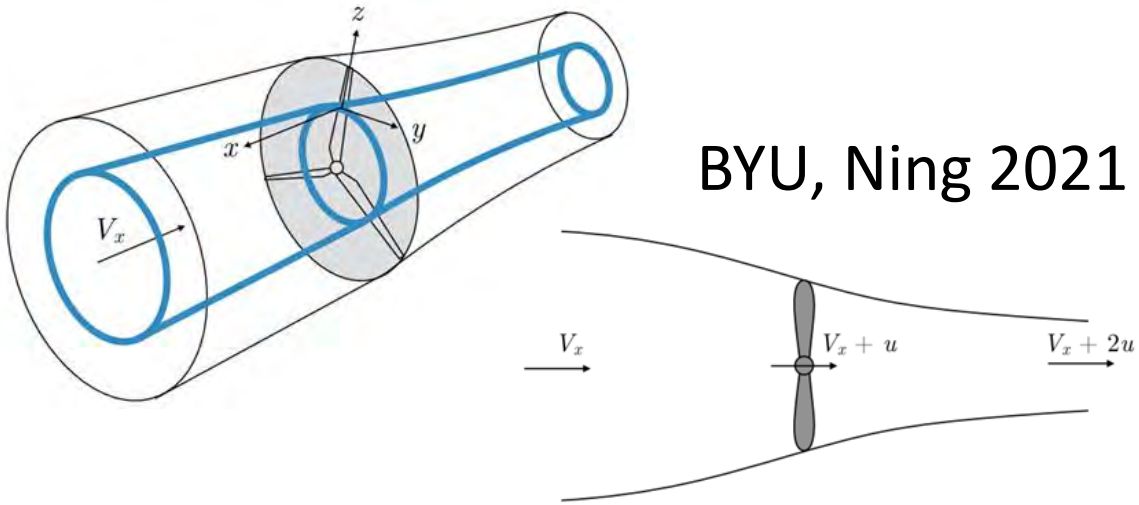
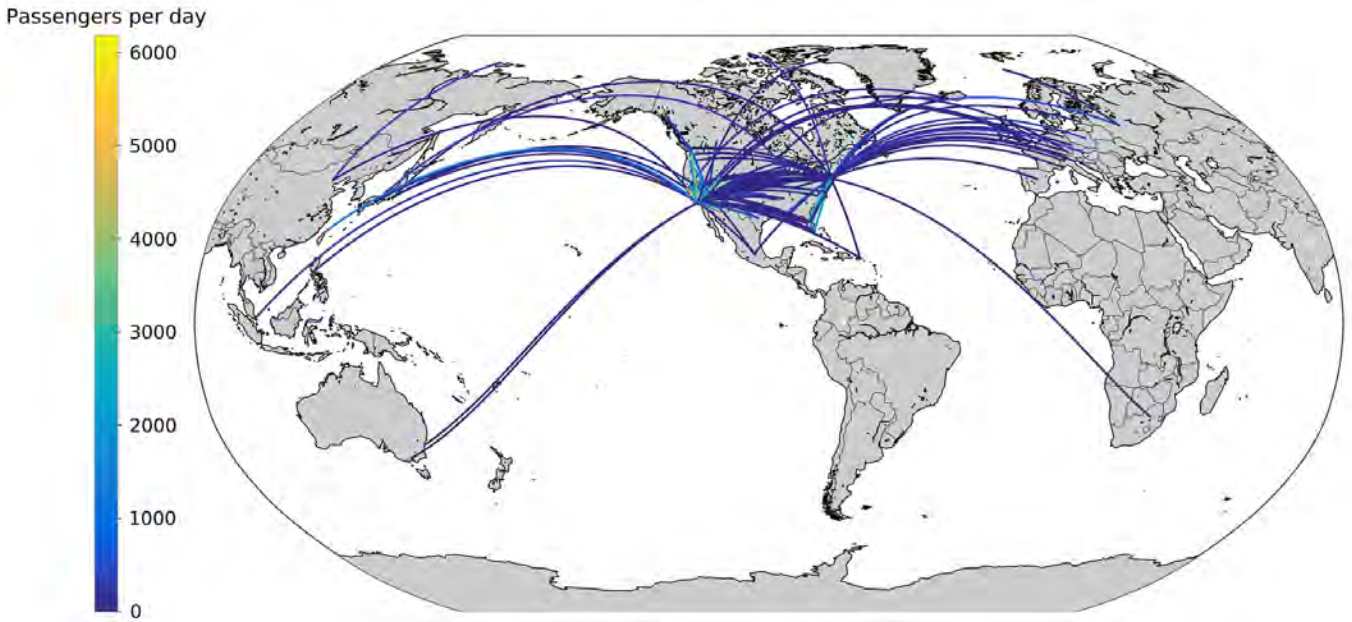
- Aurora Flight Sciences: Aerostructural aircraft wing design
- ONREA: Aircraft and spacecraft design
- Raytheon: Missile design
- Uber Elevate: Electric aircraft powertrain design
- Georgia Tech Research Institute, DOD: Model based systems engineering
- Even more! DTU, BYU, UC San Diego, University of Michigan, Georgia Tech, Stanford, MIT, RPI, Purdue, NTNU

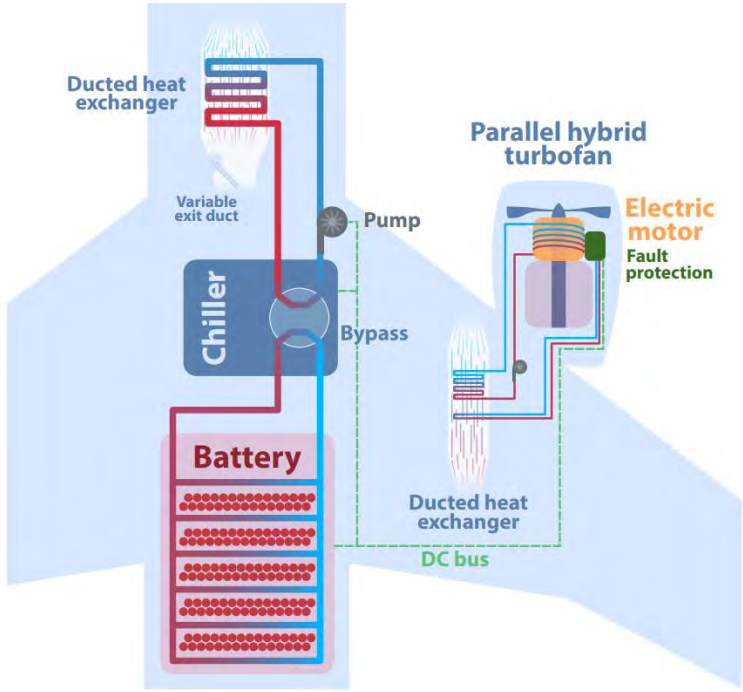
DTU



BYU, Ning 2021



UC San Diego, Hwang et al 2019



U of Michigan, Adler et al 2022

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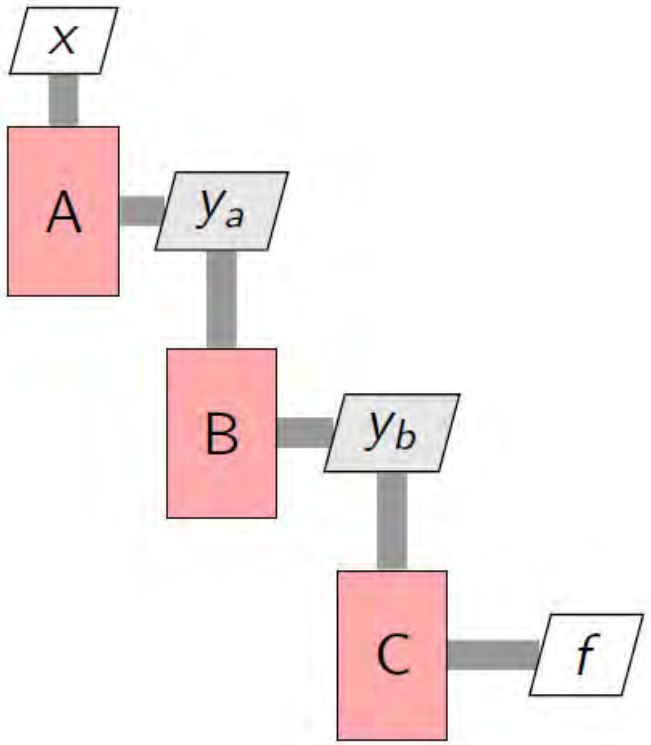
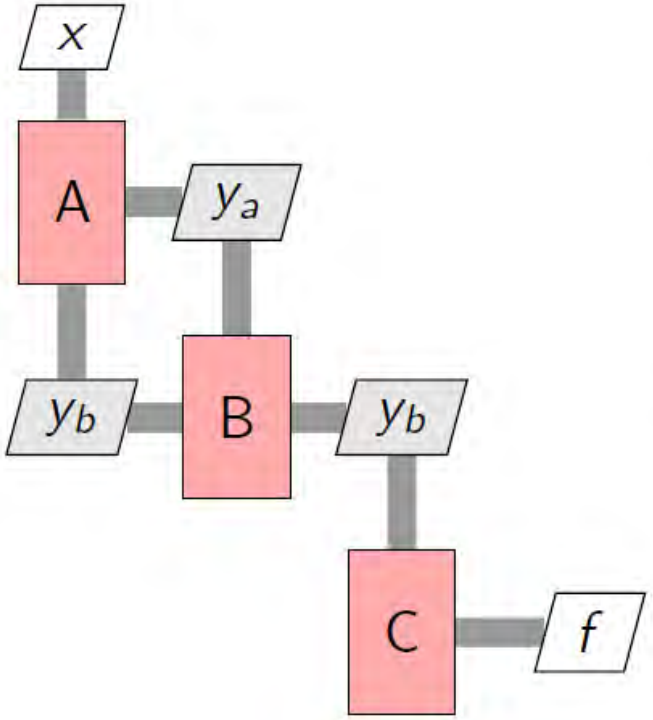
You *could* propagate derivatives through your model by hand



Derivative of f with respect to x:

$$\frac{df}{dx} = \frac{\partial f}{\partial y_b}\frac{\partial y_b}{\partial y_a}\frac{\partial y_a}{\partial x}$$

You *could* propagate derivatives through your model by hand

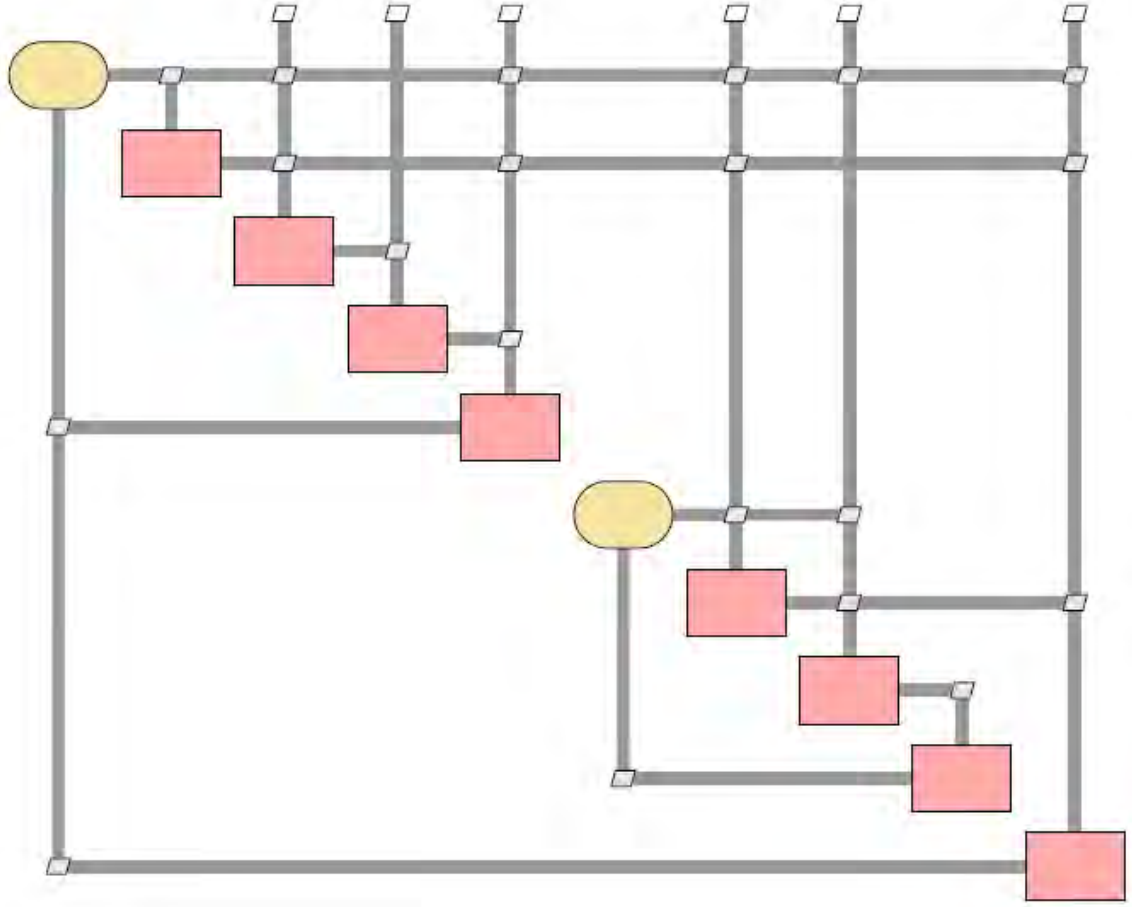


Derivative of f with respect to x:

$$\frac{df}{dx} = \frac{\partial f}{\partial y_b}\frac{\partial y_b}{\partial y_a}\frac{\partial y_a}{\partial x} + \frac{\partial f}{\partial y_b}\frac{dy_b}{dx} + \frac{\partial f}{\partial y_a}\frac{dy_a}{dx}$$

The $\frac{dy_b}{dx}$ and $\frac{dy_a}{dx}$ terms are can be found with an adjoint solve

You *could* propagate derivatives through your model by hand but it gets untenable

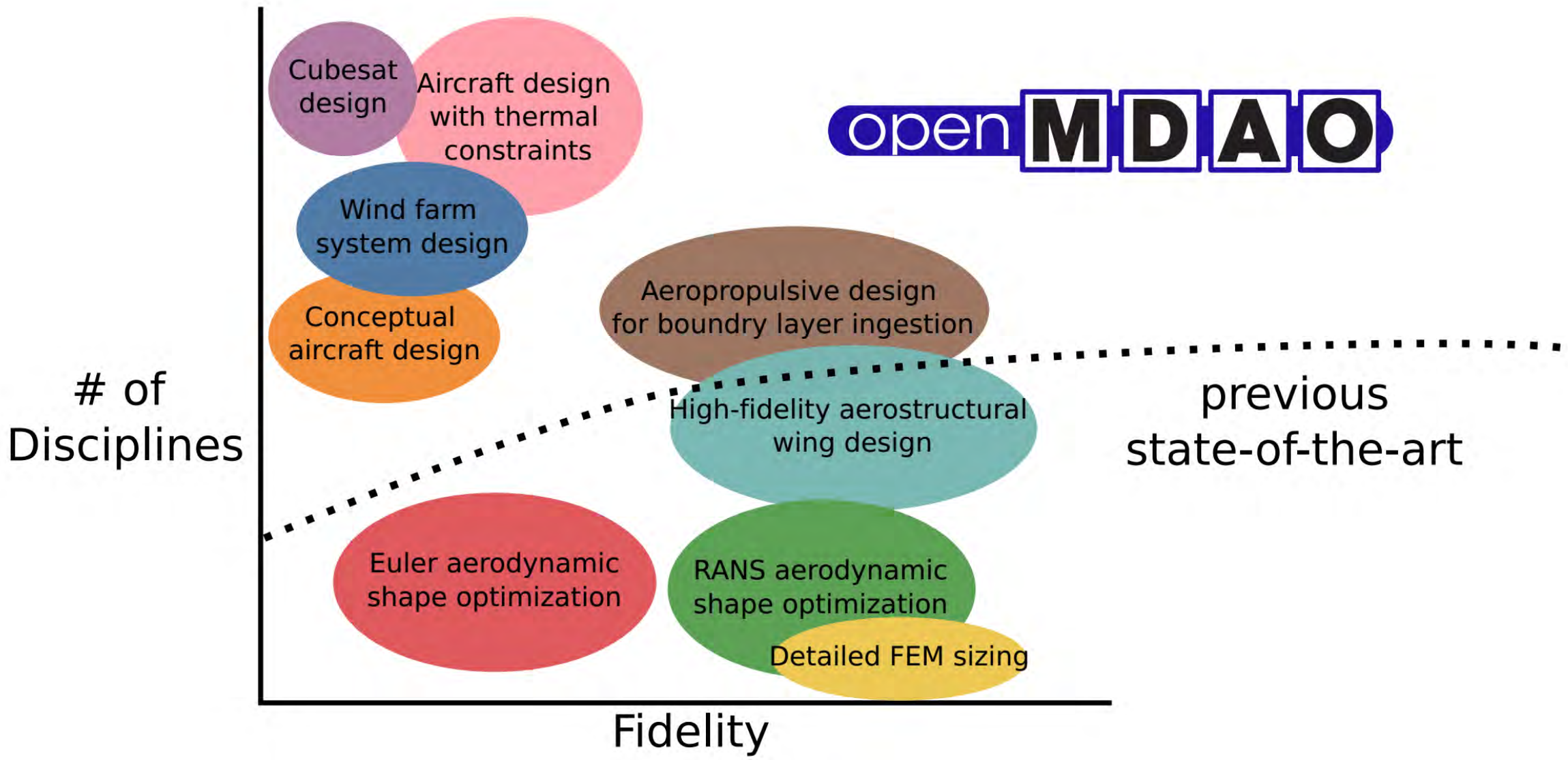


Find $\frac{df}{dx}$:

solvers within solvers??

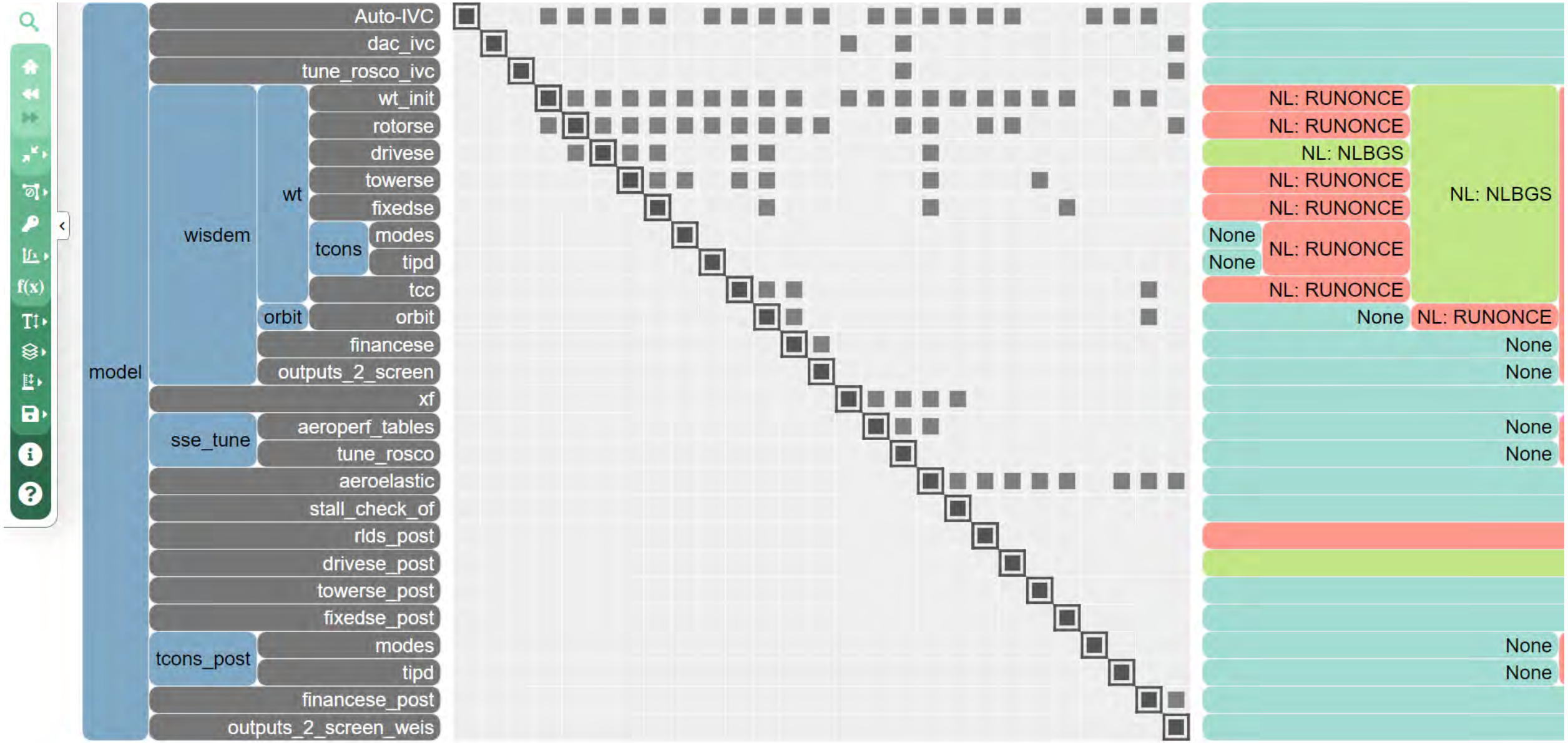
let's be honest,
we're not doing this by hand!

Making the hard easy and the impossible hard



openMDAO

OpenMDAO has built-in tools to help design complicated systems



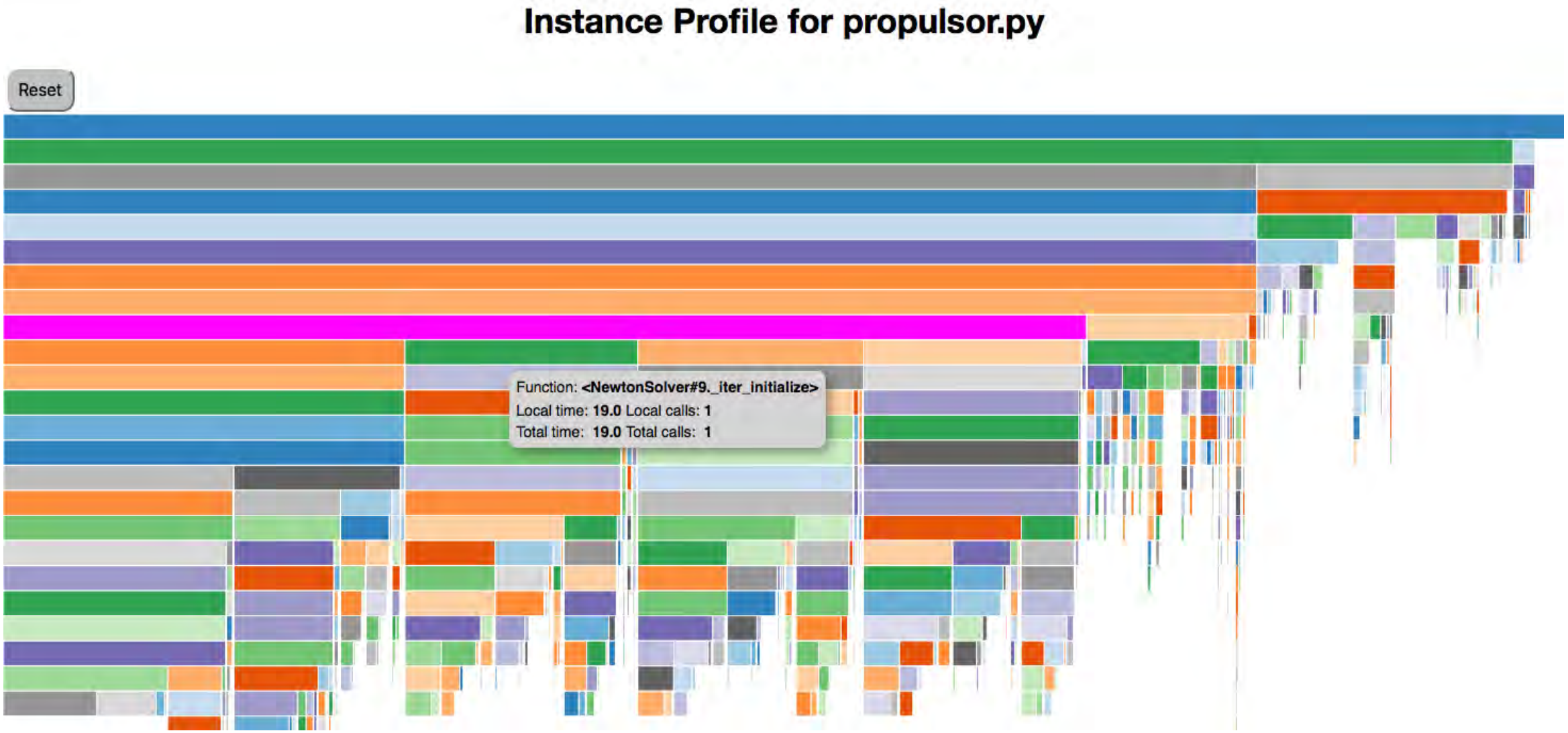
OpenMDAO has built-in tools to help design complicated systems

Connections for propulsor.py

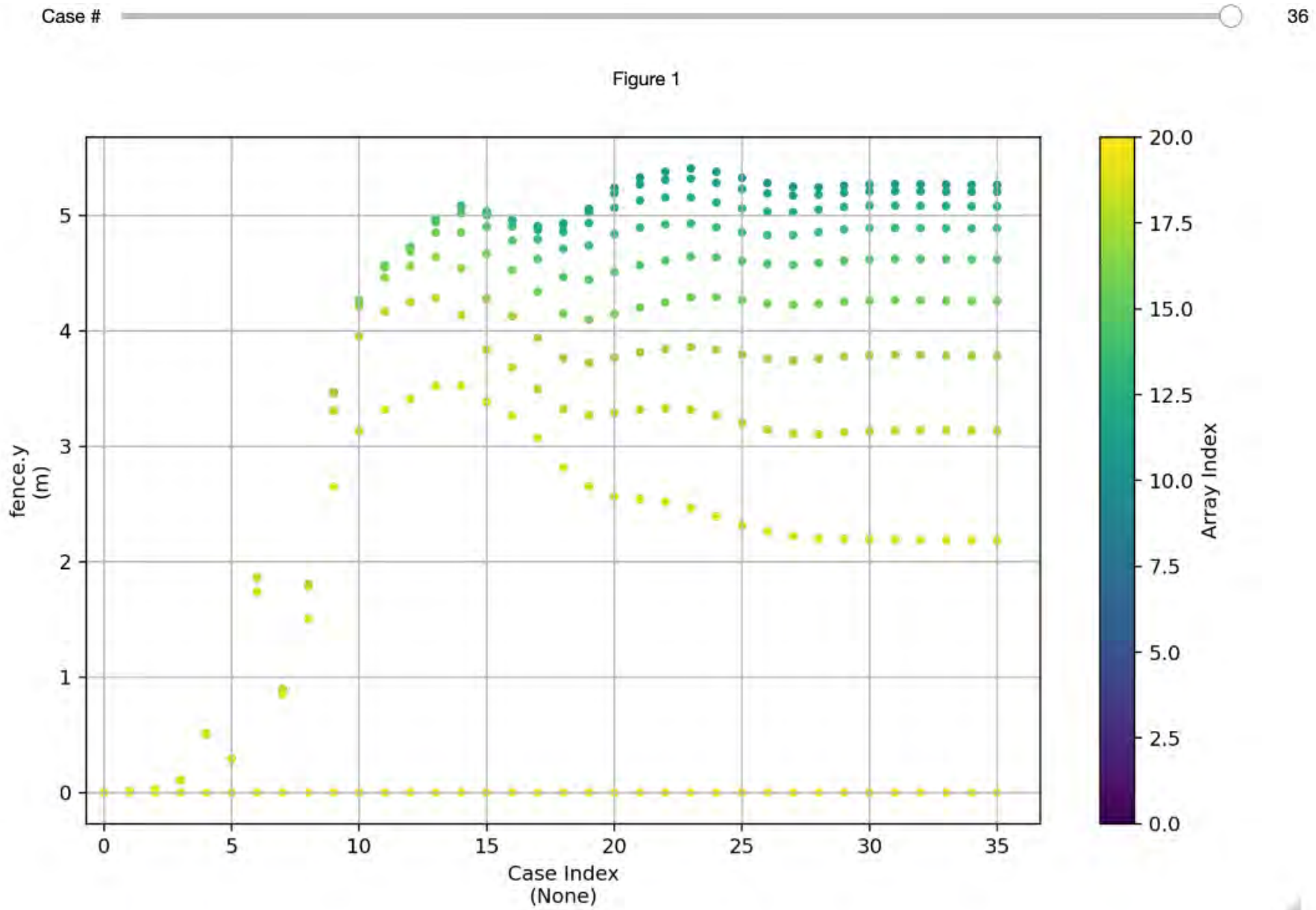
Output (promoted)	Units	Value	Units	Input (promoted)
design.fan.ideal_flow.n		array (10,)		*design.fan.ideal_flow.n*
design.fan.ideal_flow.n_moles		[0.034]		*design.fan.ideal_flow.n_moles*
design.fan.ideal_flow.n_moles		[0.034]		*design.fan.ideal_flow.n_moles*
design.fan.ideal_flow.n_moles		[0.034]		*design.fan.ideal_flow.n_moles*
design.fan.press_rise.Pt_out	**lbf/inch**2**	[0.06895]	**bar**	*design.fan.ideal_flow.P*
design.fan.press_rise.Pt_out	**lbf/inch**2**	[0.06895]	**bar**	*design.fan.ideal_flow.P*
design.fan.press_rise.Pt_out	lbf/inch**2	[1.]	lbf/inch**2	*design.fan.ideal_flow.P*
design.fan.ideal_flow.props.TP2ls.lhs_TP		array (5, 5)		design.fan.ideal_flow.props.ls2p.A
design.fan.ideal_flow.props.TP2ls.rhs_P		[0. 0. 0. 0. 0.]		design.fan.ideal_flow.props.ls2p.b
design.fan.ideal_flow.props.TP2ls.lhs_TP		array (5, 5)		design.fan.ideal_flow.props.ls2t.A
design.fan.ideal_flow.props.TP2ls.rhs_T		[0. 0. 0. 0. 0.]		design.fan.ideal_flow.props.ls2t.b
design.fan.ideal_flow.props.ls2p.x		[0.1 0.1 0.1 0.1 0.1]		design.fan.ideal_flow.props.tp2props.result_P
design.fan.ideal_flow.props.ls2t.x		[0.1 0.1 0.1 0.1 0.1]		design.fan.ideal_flow.props.tp2props.result_T
design.fan.ideal_flow.R	**(N*m)/(kg*degK)**	[0.00024]	**Btu/(lbm*degR)**	*design.fan.ideal_flow.R*
design.fan.ideal_flow.rho	**g/cm**3**	[0.02497]	**lbm/ft**3**	*design.fan.ideal_flow.rho*
design.fan.ideal_flow.T	degK	[400.]	degK	*design.fan.ideal_flow.T*

Absolute Outputs ☐ Promoted Outputs ☑ Output Units ☑ Values ☑ Input Units ☐ Absolute Inputs ☑ Promoted Inputs

OpenMDAO has built-in tools to help design complicated systems



OpenMDAO has built-in tools to help design complicated systems



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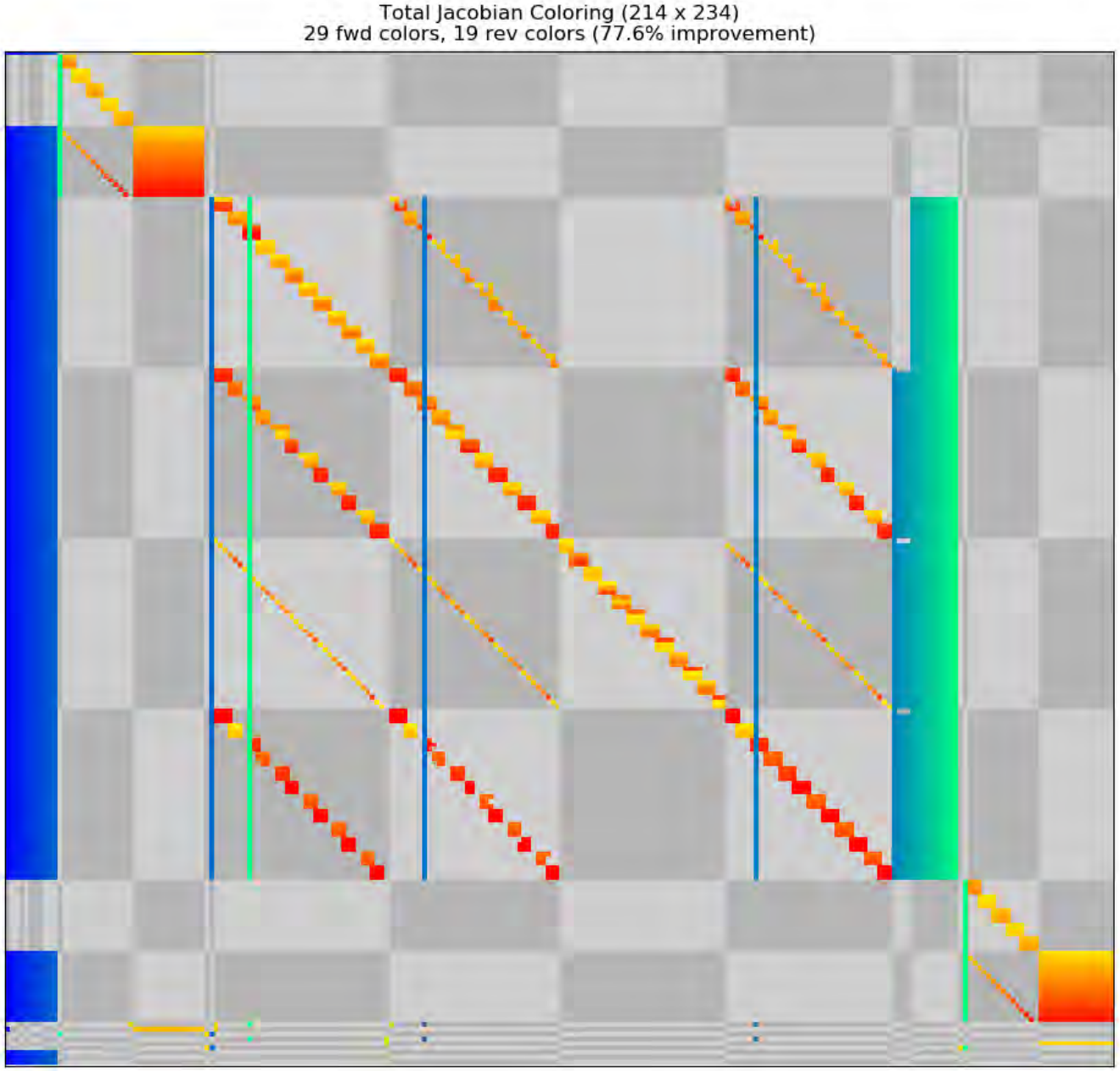

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More details and resources

OpenMDAO: an open-source framework for multidisciplinary design, analysis, and optimization. Gray, Hwang et al, SMO 2019

https://openmdao.org/

Subscribe to the YouTube: OpenMDAO and here's a link to the introductory video: https://youtu.be/P6bFtwf485Q

Join the mailing list: send an email with 'subscribe' in the subject to openmdao-announce-join@lists.nasa.gov

Upcoming OpenMDAO workshop

October 24-25, 2022 in Cleveland, Ohio, USA

An opportunity for users and developers to meet and discuss what they'd like to see from OpenMDAO

Sign up at openmdao.org

Thanks!

john.jasa@nasa.gov