National Aeronautics and Space Administration

NASA's Aviary Takes Flight:

A Public Software for Aircraft Design

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www.nasa.gov

Today's Roadmap

This presentation covers:

- An introduction to NASA Aeronautics
- Historic and future aircraft modeling needs
- Aviary meets these needs
- How Aviary works
  - The structure of Aviary
  - The user's interaction with Aviary
- How Aviary has been used at NASA
  - Transonic Truss Braced Wing
  - Hybrid Electric Turbofans
  - Hybrid Electric Turboprops
- How YOU can get involved

NASA Aeronautics, Looking at Aircraft of the Future

"Building on a legacy of aeronautical research that can trace its origins to the earliest days of powered, heavier-than-air flight, NASA remains committed to transforming aviation by dramatically reducing its environmental impact, improving efficiency while maintaining safety in more crowded skies, and paving the way to revolutionary aircraft shapes and propulsion systems that will open new possibilities for commercial air travel."

- NASA Aeronautics Research Mission Directorate


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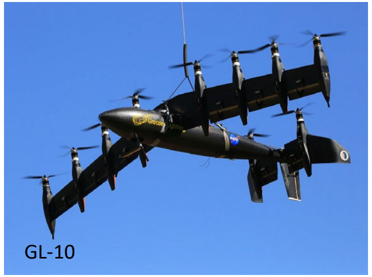
HWB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EPFD


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Where does Aviary fit in?

Aviary's Two Main Areas of Innovative Transformation

Two "Bins" of Transformation

Revolutionary

- Enables coupling of disciplines and trajectories previously unrealizable
- Consolidation and modernization of multiple legacy aircraft design tools
- BYOS: "Bring Your Own Subsystem"

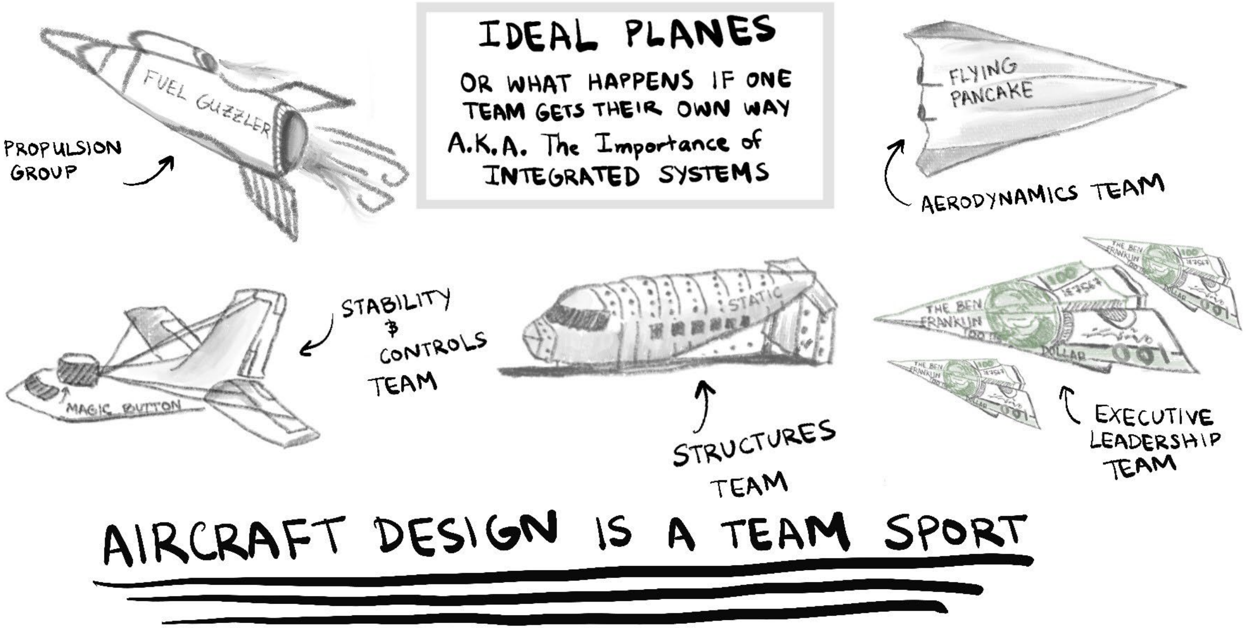
Inspires innovation

- Open source
- Early Career Led
- Outreach/Tech Transfer
- Documentation/ Examples/ Video Tutorials

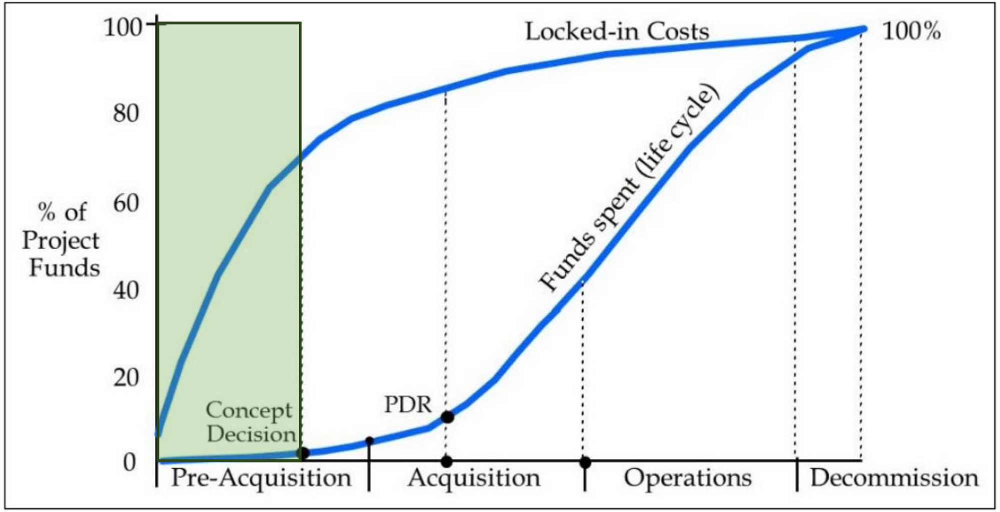
AVIARY

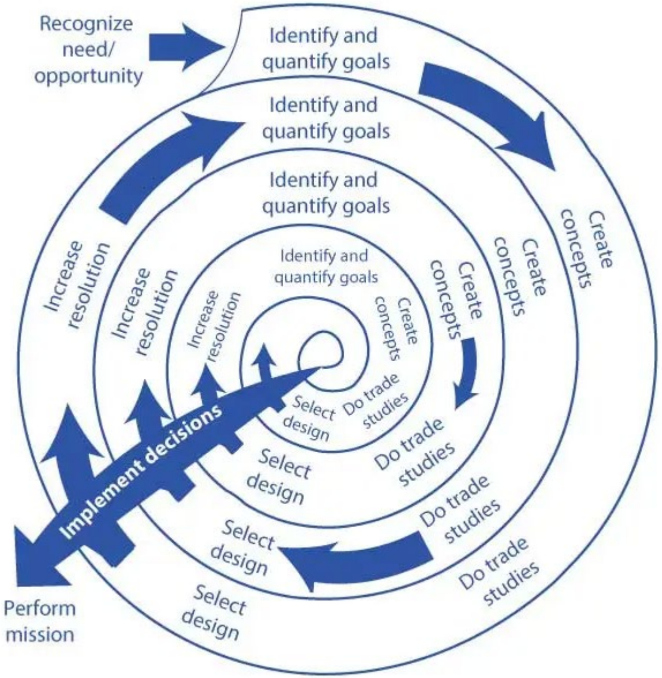
Aircraft Design

- Always a compromise between competing disciplines
  - Structures
  - Aerodynamics
  - Propulsion
  - Controls
  - etc...



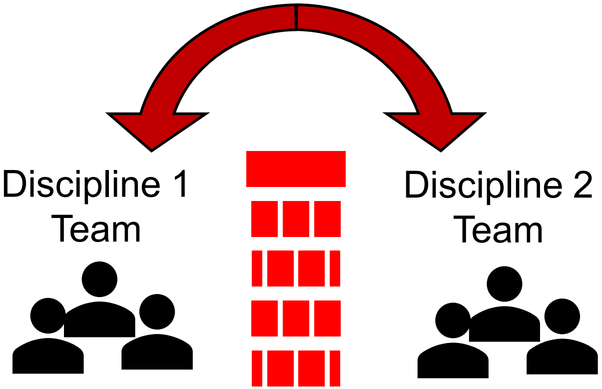
Conceptual Design is an Iterative Process





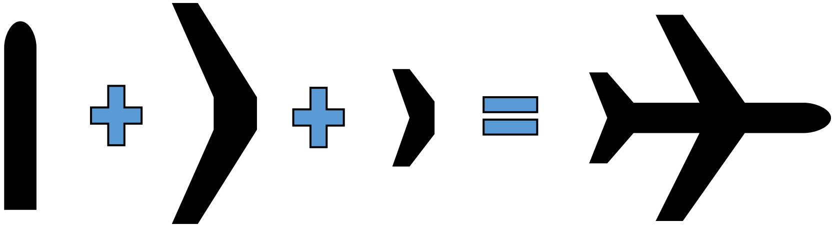
Historic Aircraft Modeling and the Need for a New Tool

Traditional Design Method



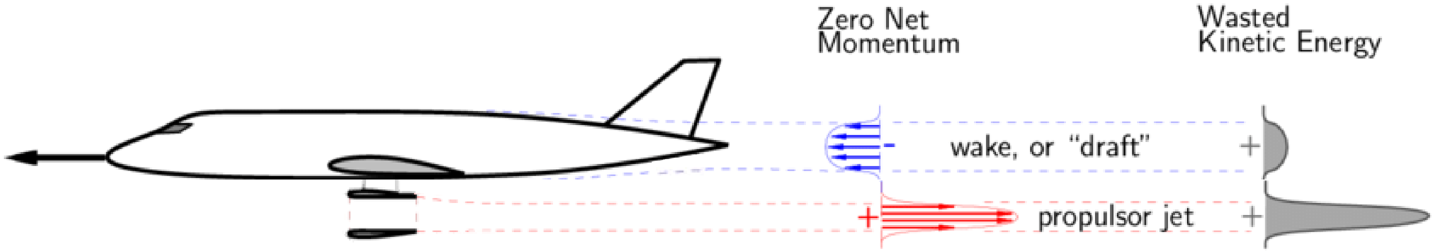
- Teams conduct analysis independently
- Data thrown “over-the-wall”
- Manual iteration required

Aircraft is treated as the sum of its parts

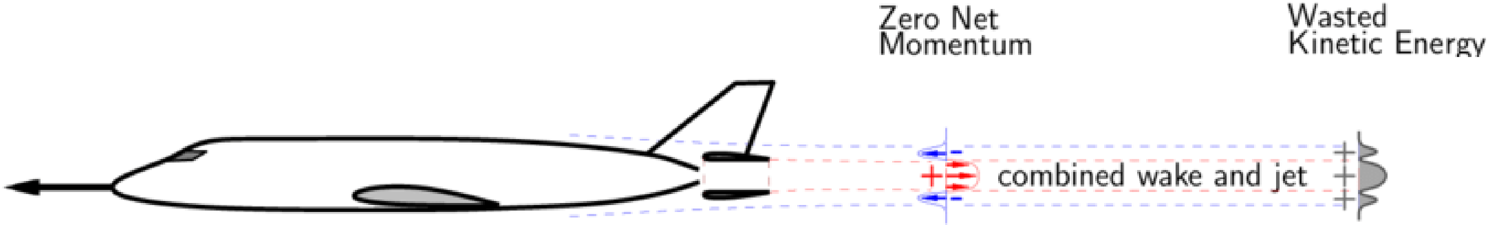


Next-Generation Aircraft Have Connected Systems

Traditional propulsion and aerodynamic systems are not directly coupled:



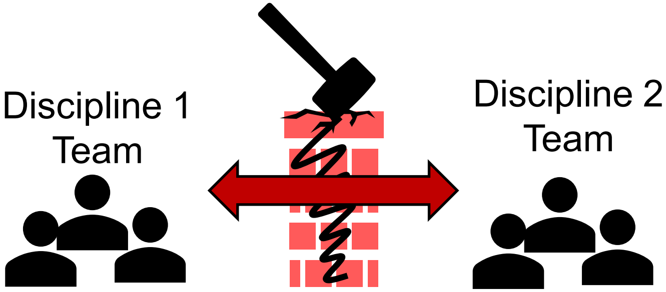
Future aircraft can have increased efficiency by coupling these systems:



But at the cost of increased complexity

Historic Aircraft Modeling and the Need for a New Tool

New Advanced Digital Design Method



- Teams connect analysis through software
- No “wall”, teams work on the same aircraft level model
- No manual iteration needed

Complex interactions require that the aircraft be designed holistically

Aviary is NASA's Open-Source Aircraft Design Tool

- Aviary, the next-generation aircraft design tool supported by multiple NASA centers, is available for public use

- Aviary allows aircraft designers to:
  - include physics-based tools to model new technologies accurately
  - share models and results freely
  - optimize complex aircraft designs for high-level objectives, such as minimum emissions

AVIARY

Aviary Builds on Legacy Tools and Meets this Need

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FF          LL        OO        OO  PP                     SS
FF          LL        OO        OO  PP                     SS
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FF          LLLLLLLLLL   OOOOOO     PP             SSSSSSSS
```

(Flight Optimization System)

General Aviation Synthesis Program

(GASP)

openMDAO

dymos

(SimuPy)

AVIARY

Combine Legacy Tools

Modular for Modification and Substitution

Coupled Optimizations

Analyze Advanced Concepts

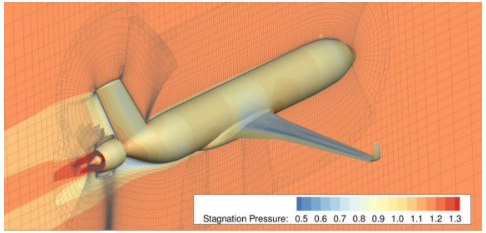
Open-Source Software

When Existing Tools Fall Short

- Most existing design tools have some limitations:
  - Primarily only study conventional aircraft designs
  - Not publicly available or open-source
  - Written in older programming languages such as Fortran
  - Do not allow for user-created subsystems

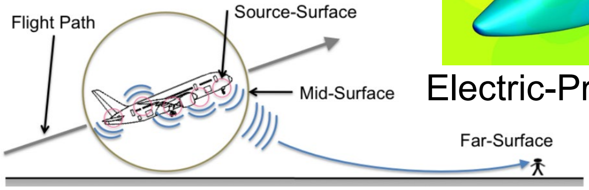
Aviary differs by being an open-source design tool written in Python that is fully user-customizable for the next generation of aircraft designs

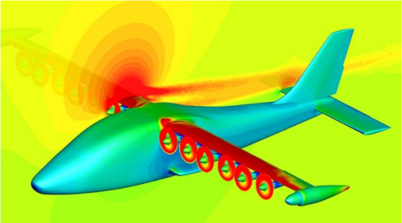
Complex Coupling Between Disciplines



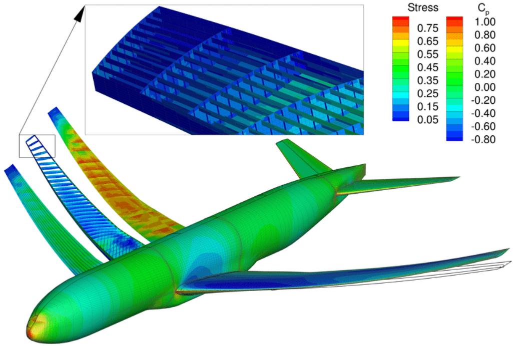
Aero-Propulsive Couplings

Aero-Acoustic Couplings

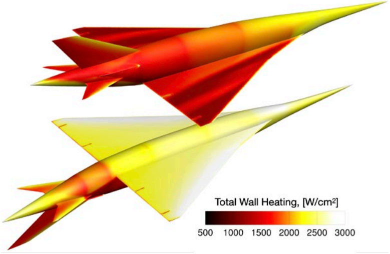




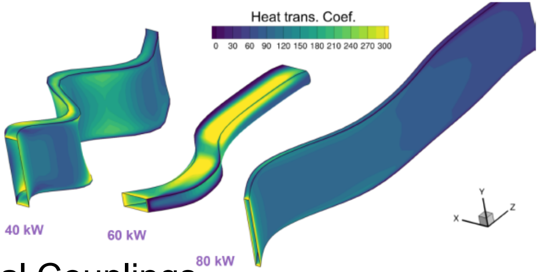
Electric-Propulsion Couplings



Aero-Structural Couplings

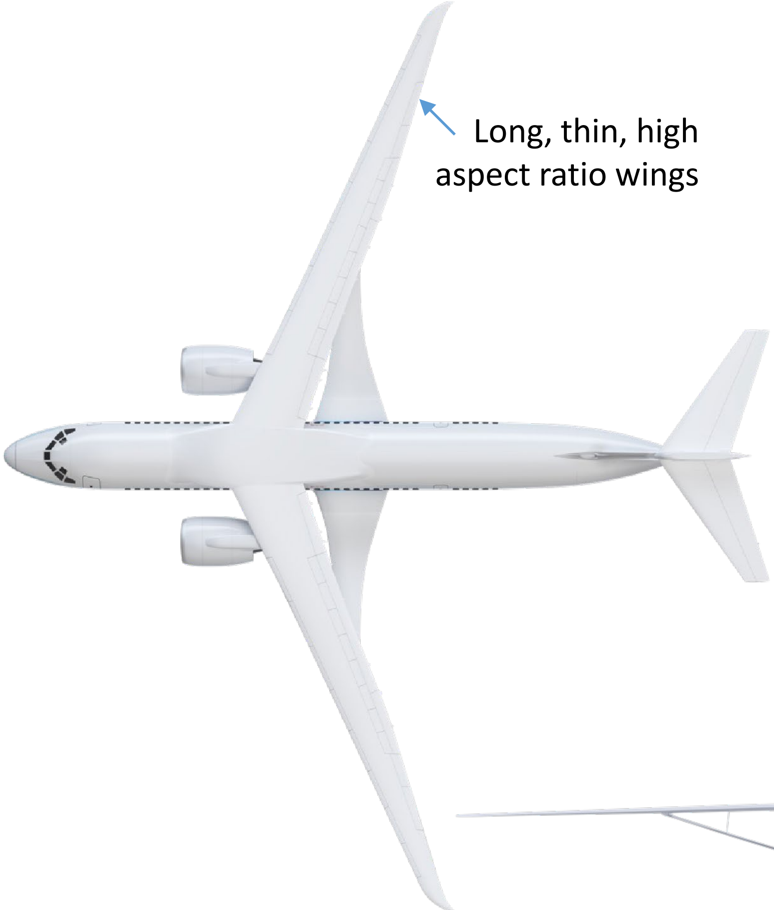


Aerothermal design of heat exchanger passages



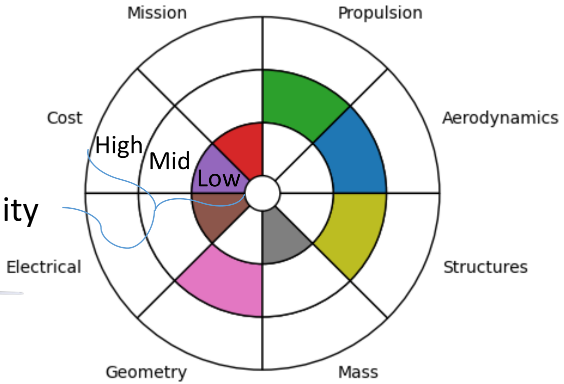
Aero-Thermal Couplings

Concept: Transonic Truss-Braced Wing



Interactions between aerodynamics, structures, propulsion, and mission

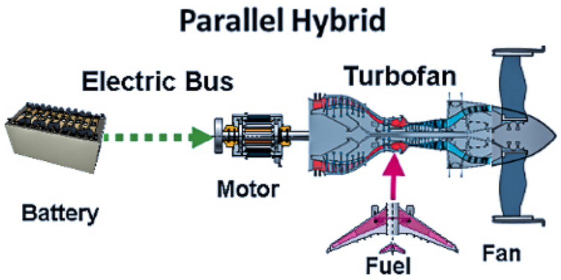
- Wing truss adds weight and drag, but enables higher aspect-ratio wing
- Wing position allows for larger engines with higher bypass ratio
- Larger engines allow higher cruise altitude, required for peak efficiency of new wing shape

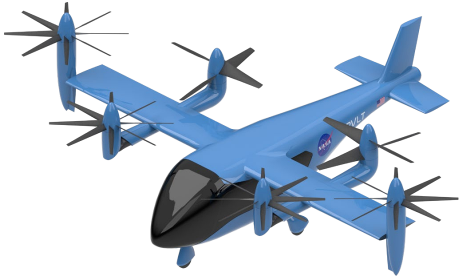


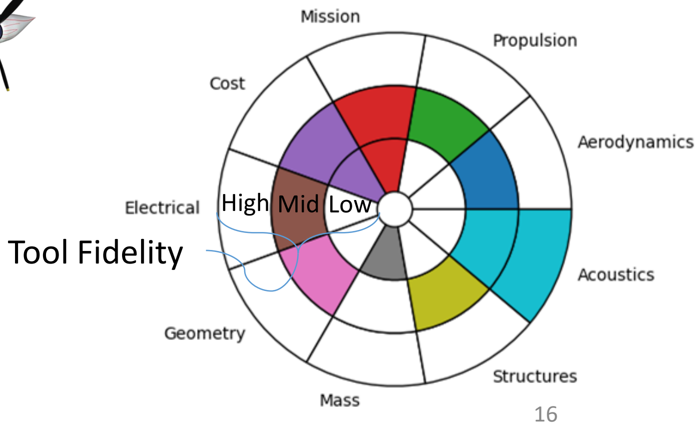
Technology: Electrified Propulsion

Interactions between propulsion and mission (and often others)

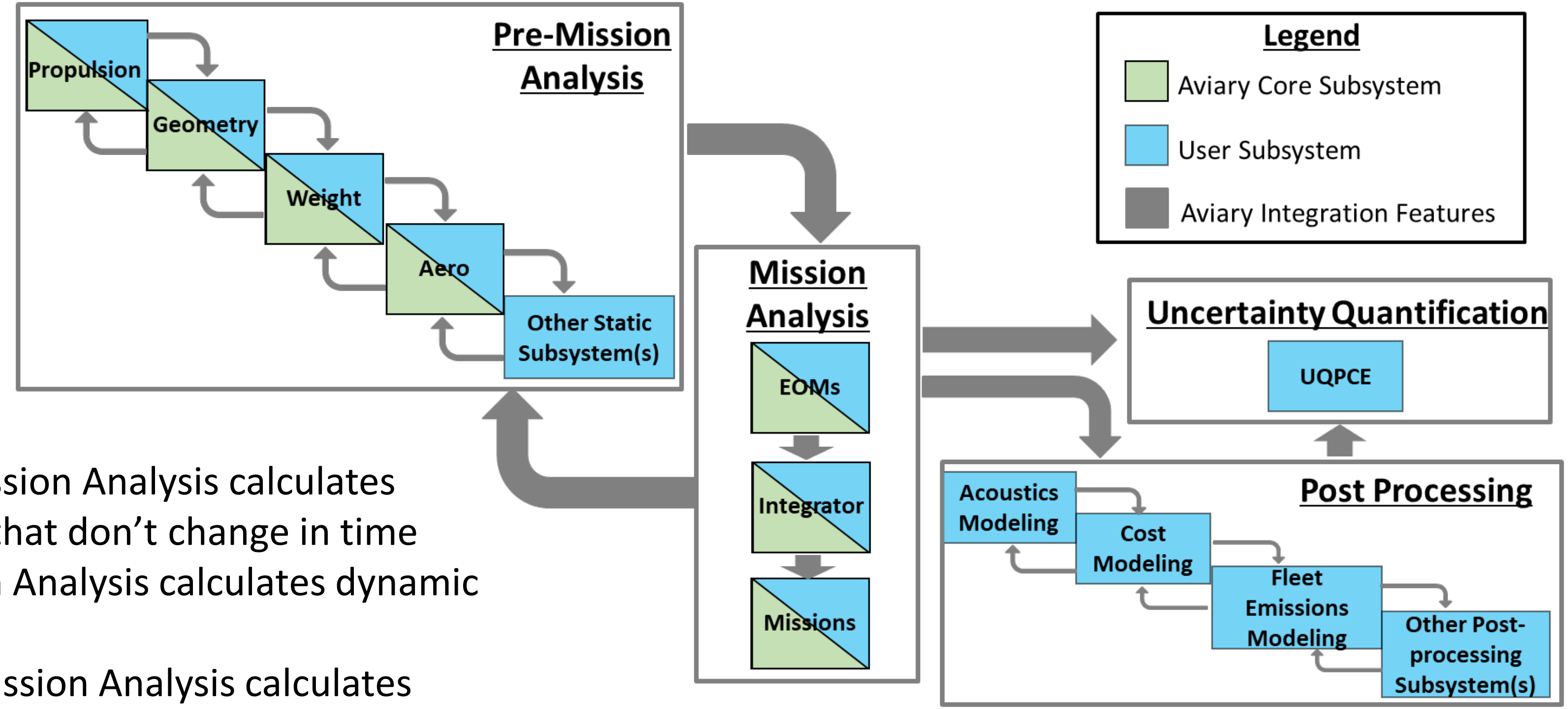
- Batteries don’t get lighter as energy is consumed
- Need to optimize the thrust split or power insertion
- Batteries have a lower energy density than fuel - trade-off between minimizing fuel burn and minimizing total energy





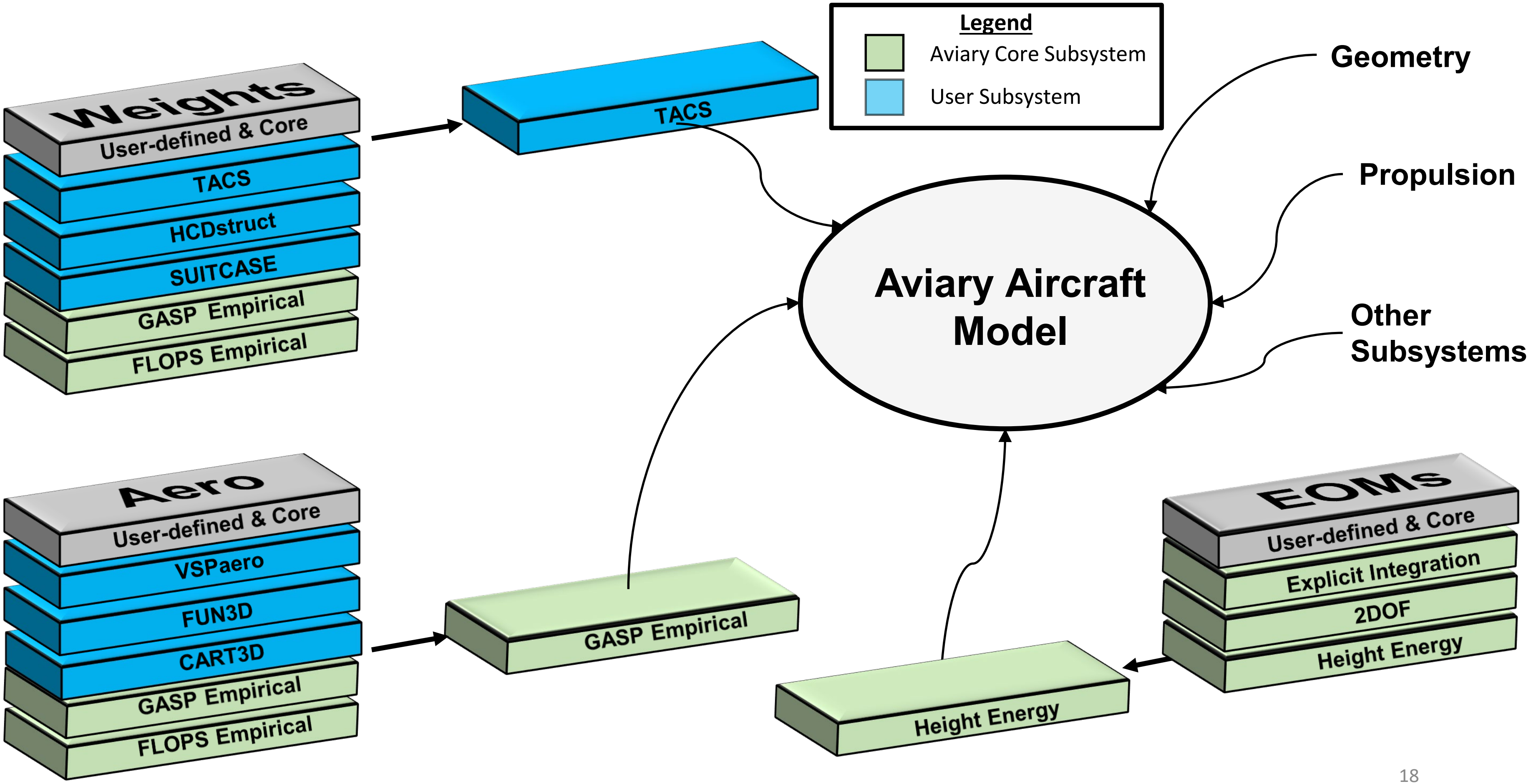


The Structure of Aviary

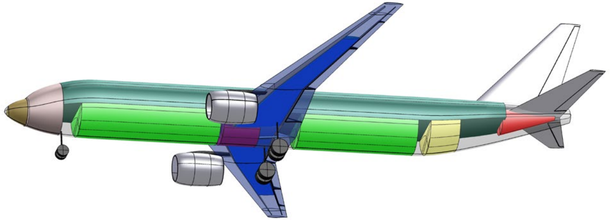


- Pre-Mission Analysis calculates values that don't change in time
- Mission Analysis calculates dynamic values
- Post-Mission Analysis calculates values that depend on the mission analysis

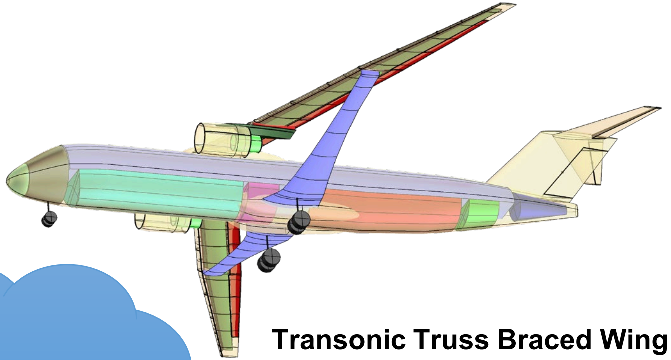
Users can Select Disciplines and Fidelities as Needed



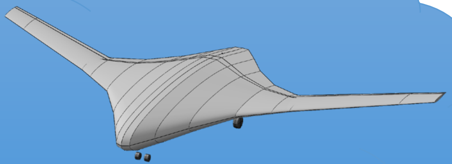
Aviary Usage Within NASA



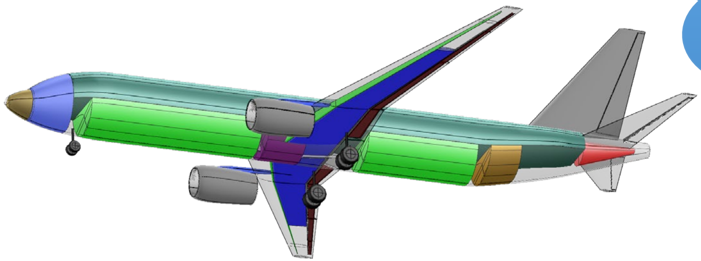
Advanced Tube & Wing Concept
- 2035 entry-into-service
- gFan+ engine



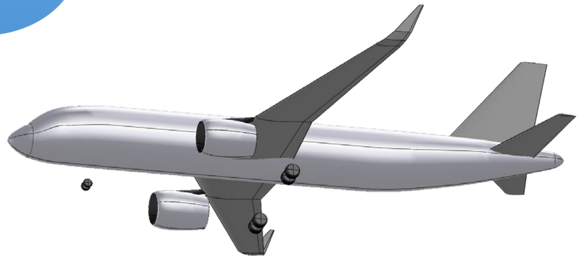
Transonic Truss Braced Wing Concept
- 2035 entry-into-service
- Electrified aircraft propulsion (EAP)
- gFan+ engine



Future Advanced Concepts and Digital Flight Tests (HyTEC, AATT, SFD)



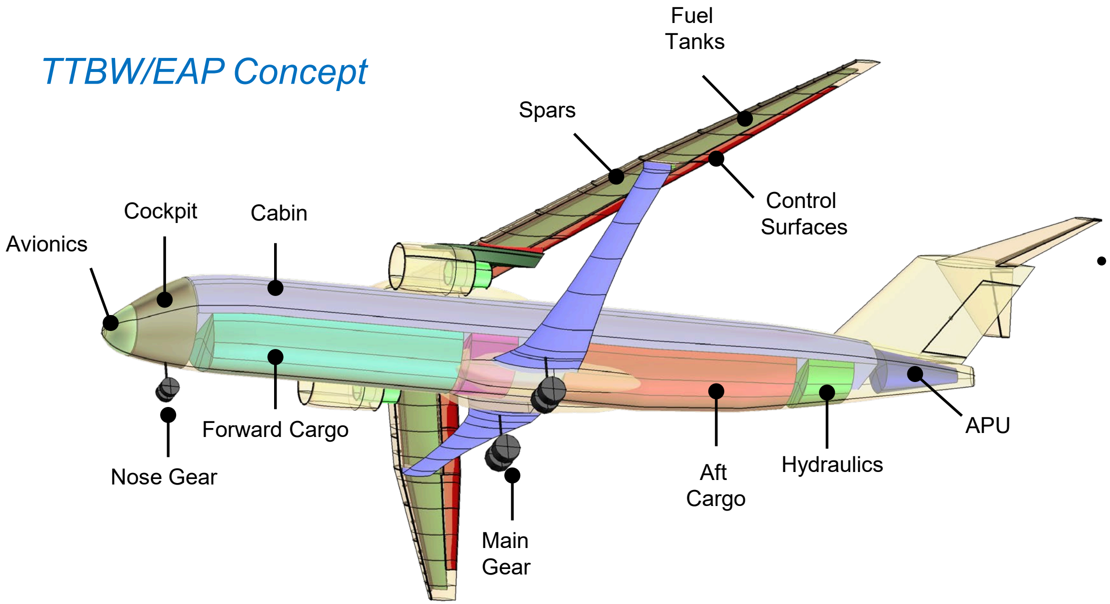
Boeing 737 MAX 8
- Present day technology
- LEAP-1B engine



Airbus A320 Neo
- Present day technology
- PW1100 GTF / LEAP-1A engine

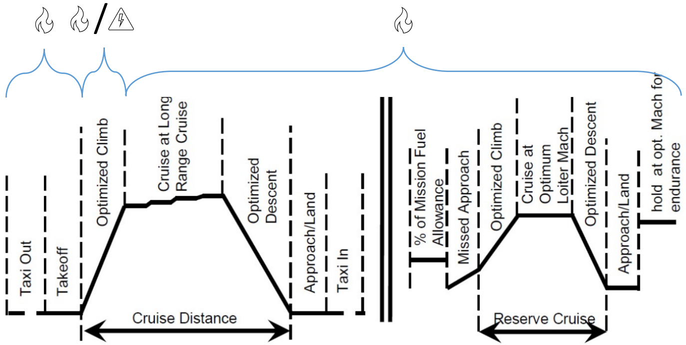
TTBW Tech Collector, a Next-Gen Aircraft

TTBW/EAP Concept

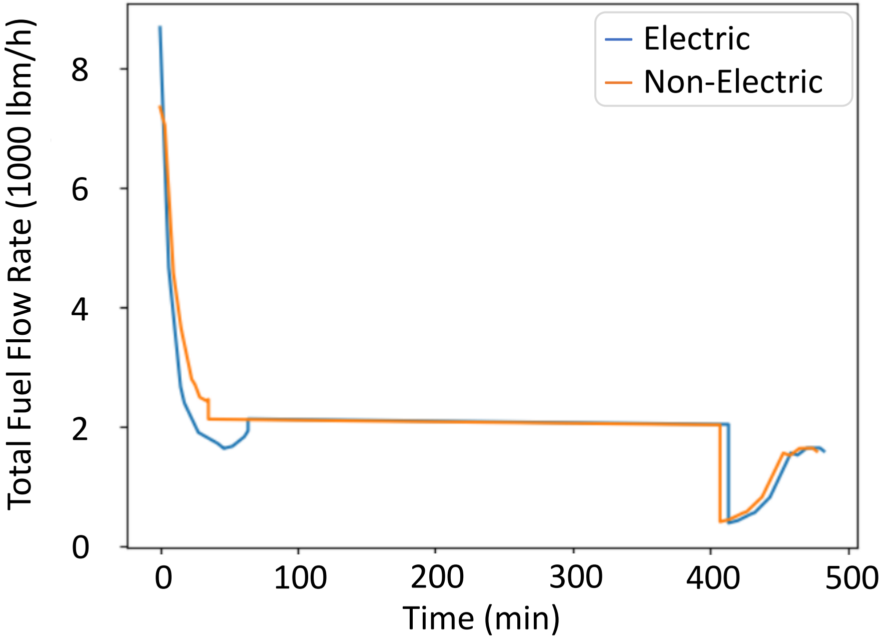


- Cruise Mach: 0.8
- Cruise altitude: 38,000 ft
- Design range: 3,205 nm
- Reserve mission range: 200 nm

- 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.
- EAP technology demonstration for 2023 includes an electric climb assist



Hybrid Propulsion Decreases the Fuel Burn of the TTBW

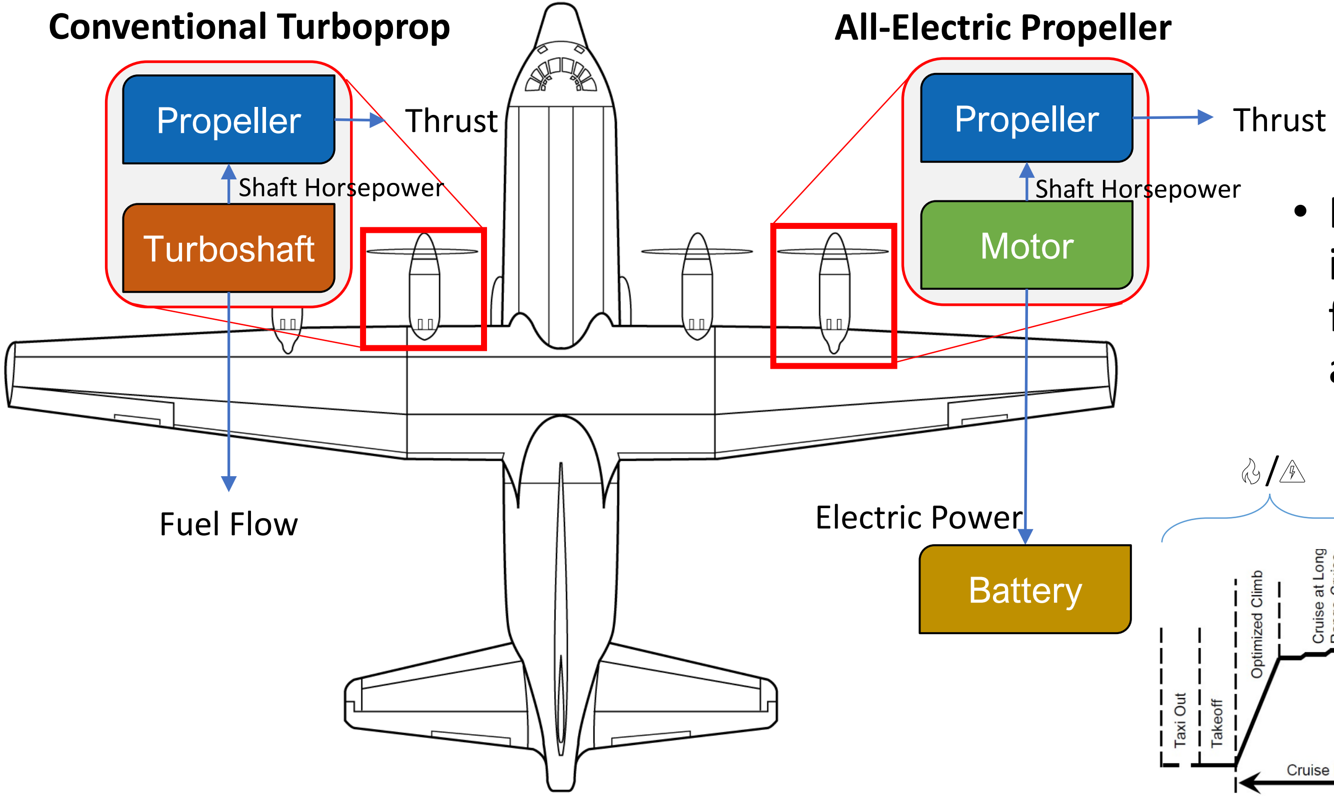


Optimization	Fuel Burn (kg)	GTOW (kg)	Battery Mass (kg)	Battery Enrgy (kWh)	Battery Energy Density (Wh/kg)	Motor Max Power (kWh)
Non-Electric	7542	61941	0	0	N/A	0
Electrified	7350	62692	1221	611	2000	746

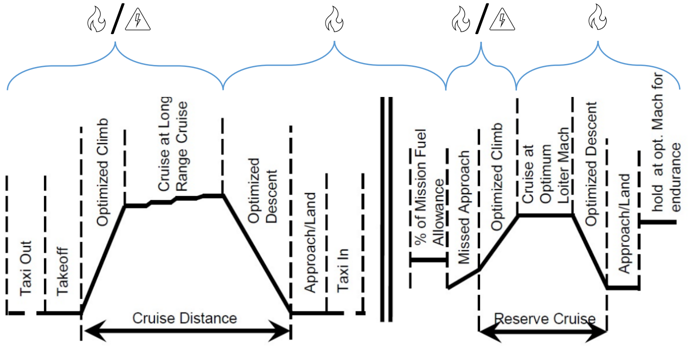
Using Aviary to Model a Hybrid-Electric Turboprop

- Conceptual Electrified Freighter
  - Hybrid-electric C-130
  - Outer pair of turboprops are replaced with all-electric driven propellers
    - Throttle split between fuel/electric propulsors must be optimized
- Aviary can model this vehicle out-of-the-box
  - Structural weight and aerodynamic performance calibrated to publicly available data
  - Multiple unique engine models
    - Conventional turboshaft
    - All-electric propeller
  - Simple motor and battery models available with public release

Using Aviary to Model a Hybrid-Electric Turboprop

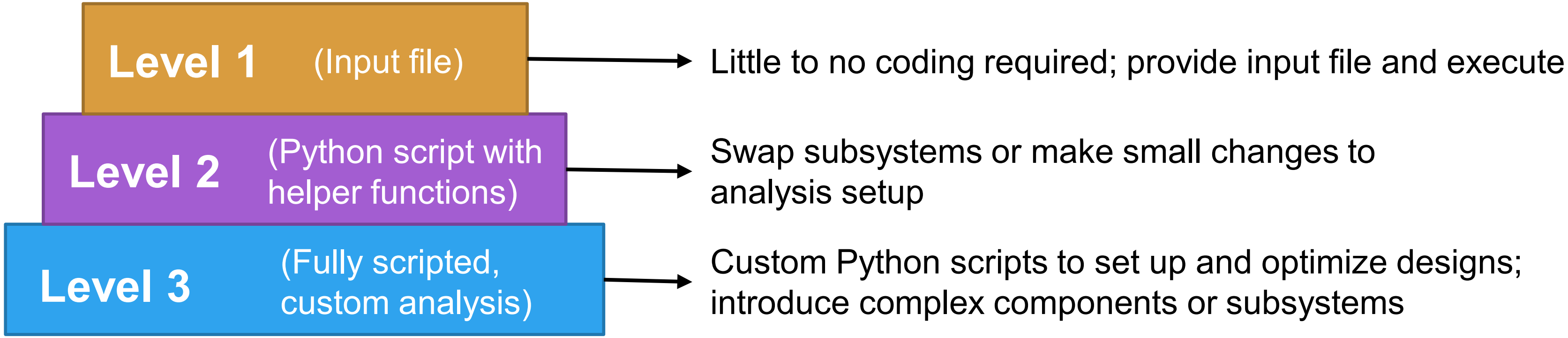


- Reserve mission implementation with flexible definition (fuel and/or electric power use)

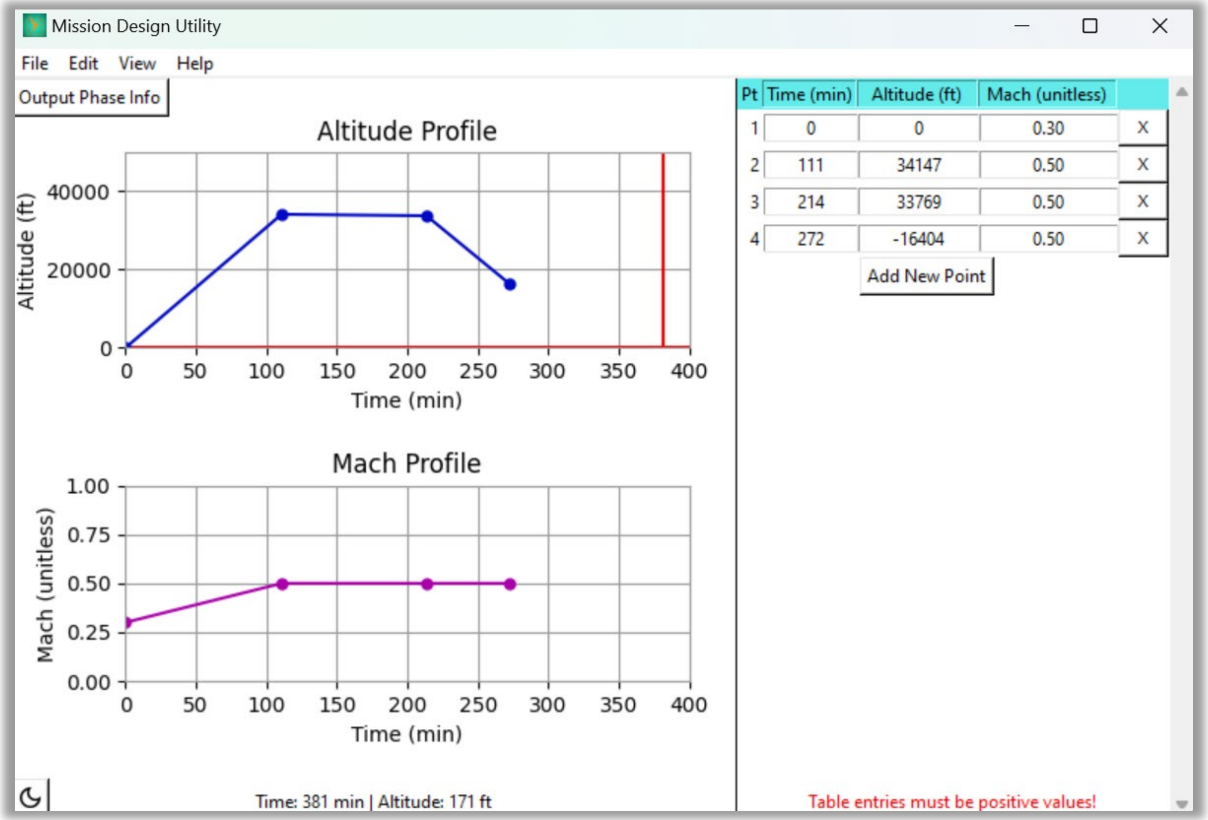


How the User Interacts with Aviary

- Aviary’s user interface is designed as a series of “layers” that build on each other
- Each additional layer becomes more complex and provides more capability & flexibility
- Accommodates users of all experience levels

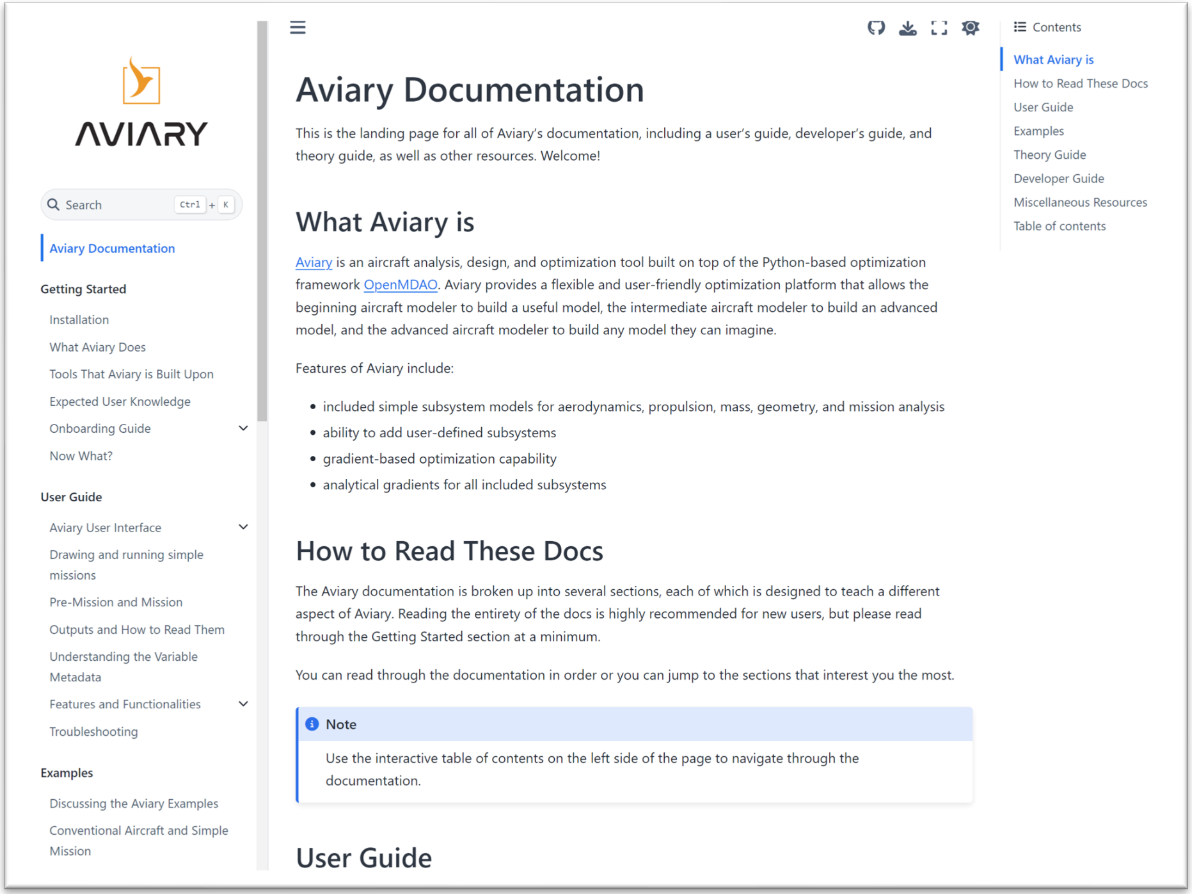


Users can Draw Missions for Aviary



- Used to generate input files
- Allows for visualization of the mission profile
- Validation to ensure that the trajectory is physically valid
- Processing of the points to reduce the risk of numerical problems

Aviary has Detailed Documentation Available



AVIARY

Search Ctrl + K

Aviary Documentation

This is the landing page for all of Aviary's documentation, including a user's guide, developer's guide, and theory guide, as well as other resources. Welcome!

What Aviary is

Aviary is an aircraft analysis, design, and optimization tool built on top of the Python-based optimization framework OpenMDAO. Aviary provides a flexible and user-friendly optimization platform that allows the beginning aircraft modeler to build a useful model, the intermediate aircraft modeler to build an advanced model, and the advanced aircraft modeler to build any model they can imagine.

Features of Aviary include:

- included simple subsystem models for aerodynamics, propulsion, mass, geometry, and mission analysis
- ability to add user-defined subsystems
- gradient-based optimization capability
- analytical gradients for all included subsystems

How to Read These Docs

The Aviary documentation is broken up into several sections, each of which is designed to teach a different aspect of Aviary. Reading the entirety of the docs is highly recommended for new users, but please read through the Getting Started section at a minimum.

You can read through the documentation in order or you can jump to the sections that interest you the most.

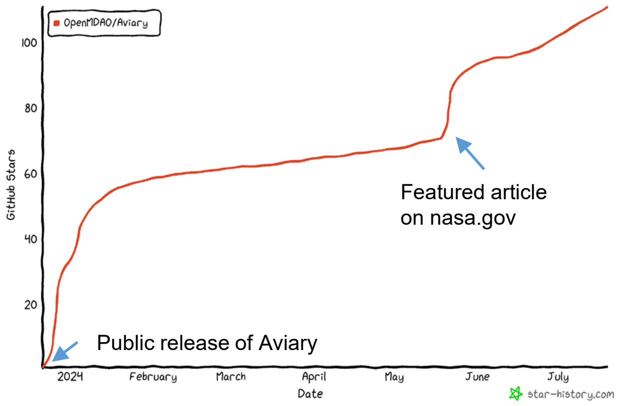
> **Note**
>
> Use the interactive table of contents on the left side of the page to navigate through the documentation.

User Guide

Contents

Aviary Usage Outside of NASA

- Aviary was released open-source at end of 2023
- Aviary has gathered widespread interest with partners in industry, government, and academia using the tool and providing feedback



“Stars” on Aviary GitHub Repository

- **Academia**
  - Georgia Tech
  - University of Michigan
- **Industry**
  - Boeing
  - Northrup Grumman
- **Other Govt.**
  - DoD

- NASA is collaborating with a variety of partners on multiple research projects using Aviary

What's Next

Upcoming internal NASA projects

- Model-Based Systems Analysis & Engineering effort
  - Using Aviary as the backbone to connect large numbers of tools together to further study concepts like the TTBW
- Active flow control integration
  - Using Aviary to predict benefits of advanced technologies for future aircraft
- Aircraft as Energy Nodes
  - Infrastructure planning project across multiple government agencies to utilize small regional airports for local power generation and storage
  - Using Aviary to estimate potential energy demand of electrified aircraft

External projects

- Ongoing research activities with industry and academic partners
- Public outreach, student design teams at universities

Summary

This presentation covered:

- An introduction to NASA Aeronautics
- Historic and future aircraft modeling needs
- Aviary meets these needs
- How Aviary works
  - The structure of Aviary
  - The user's interaction with Aviary
- How Aviary has been used at NASA
  - Transonic Truss Braced Wing
  - Hybrid Electric Turbofans
  - Hybrid Electric Turboprops
- How YOU can get involved

Try Out Aviary Today!

SCAN HERE

Email agency-aviary@mail.nasa.gov to connect with the Aviary team

Aviary can also be installed through GitHub:
https://github.com/OpenMDAO/Aviary
Or the Python package manager:
“pip install om-aviary”

Aviary activities are co-funded by the T³, AATT, and EPFD projects

Acknowledgments: The Aviary Team

Current Members

- Eliot Aretskin-Hariton (GRC)
- John Jasa (GRC)
- Xun Jiang (LaRC)
- Jason Kirk (LaRC)
- Kenneth (Ken) Moore (GRC)
- Carl Recine (ARC)
- Herb Schilling (GRC)
- Chris Bennett (LaRC)
- Kaushik Ponnapalli (GRC)

Past Members

- Darrell (DJ) Caldwell (LaRC)
- Jeff Chapman (GRC)
- Jennifer Gratz (GRC)
- Kenneth (Kenny) Lyons (ARC)
- Ben Margolis (ARC)
- Samara Murri (formerly LaRC)
- Erik Olson (formerly LaRC)
- Dahlia Pham (ARC)
- Janet Ross (LaRC)
- Sydney Schnulo (formerly GRC)
- Greg Wrenn (LaRC)

Current and Past Advisors

- Rob Falck (GRC)
- Bret Naylor (GRC)
- Joseph Garcia (ARC)
- Justin Gray (formerly GRC)
- Eric Hendricks (GRC)
- Ben Phillips (LaRC)

Related Works

Papers Using Aviary:

- “Multidisciplinary Optimization of a Transonic Truss-Braced Wing Aircraft using Aviary” by Eliot Aretskin-Hariton et al. Published at AIAA SciTech 2024.
- “Noise Reduction Trajectory Analysis of a Supersonic Business Jet using Novel Optimization Tools” by Jeshurun Horton et al. Published at AIAA Aviation 2024.
- “Impacts of Hybrid-Electric Propulsion on a Transonic Truss-Braced Wing Aircraft” by Mark Leader et al. Published at AIAA Aviation 2024.
- “Studying the Usability of an Open-source Aircraft Design Tool” by John Jasa et al. Abstract submitted to AIAA SciTech 2025.
- “Optimization of a Multi-Mission Hybrid-Electric Propeller Regional Aircraft using Aviary” by Jason Kirk et al. Abstract submitted to AIAA SciTech 2025.

Additional examples and studies exist on the Aviary GitHub repository.

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