AEROSPACE ENGINEERING
UNIVERSITY OF MICHIGAN

IDEAS
Integrated Design of Efficient Aerospace Systems Laboratory

# Systems Design and Optimization in Electrified Aviation

## Models, Methods, and Emerging Insights

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Assistant Professor, Aerospace Engineering, University of Michigan
http://gokcincinar.com

Institute for Sustainable Aviation Webinar | 21 October 2025

with contributions from Paul Mokotoff, Maxfield Arnson, Emma Cassidy, Miranda Stockhausen, Yi-Chih Wang, Triet Ho, Dillon Agrawal, and Conan Lee.

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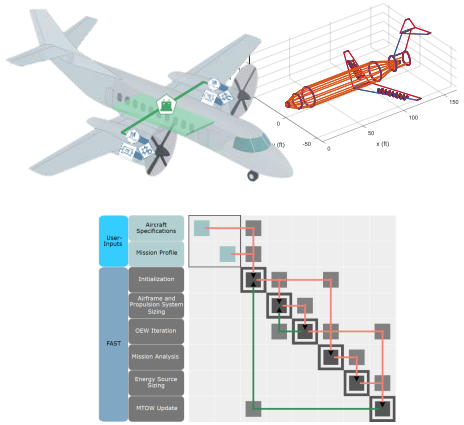
# IDEAS

Integrated Design of Efficient Aerospace Systems Laboratory

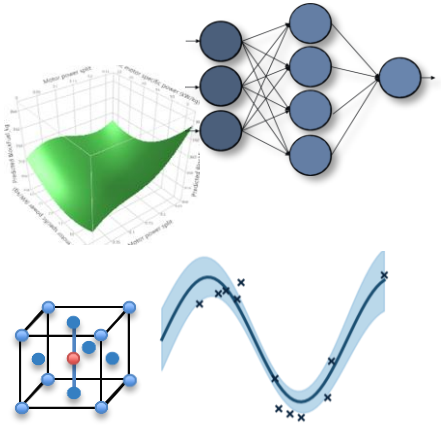
## Advancing computational methods for the design, analysis, and optimization of future aerospace systems.

### Multi-fidelity Modeling & Simulation



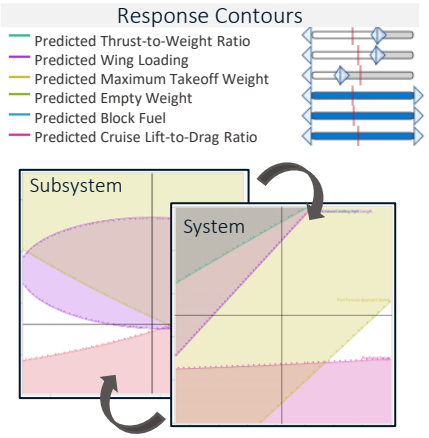

Physics-based models across fidelities, integrated with MBSE/MDAO for end-to-end analyses.

### Data-driven Methods & Machine Learning

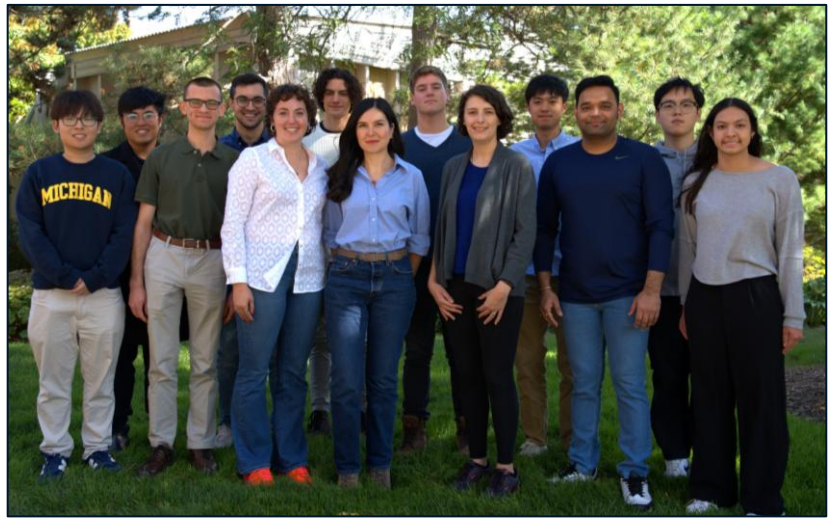


Statistical learning, probabilistic design, and surrogate modeling for robust decisions.

### Design Space Exploration & Optimization




Surrogate-assisted, multi-objective trades from component to system-of-systems.



6 PhD students • 1 Research Associate • 6 Master's • 3 Undergraduate Researchers

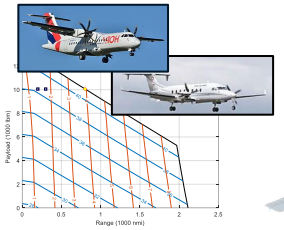
Gökçin Çınar | cinar@umich.edu | www.gokcincinar.com

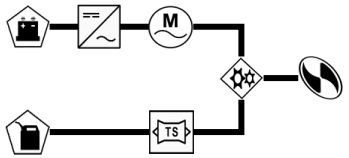
# Agenda

## I. Introduction to Electrification

**Why Electrify:** Opportunities and Challenges

**Case Study:** Systems Design and Analysis for NASA EPFD Project



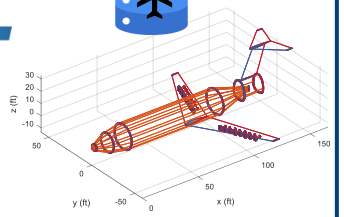


| | | | | | |
|---|---|---|---|---|---|
| S.I | TX | TKO | CLB (full) | CRZ | DSC |
| S.II | TX | TKO | CLB (lo-alt) | CRZ ↑ | DSC ↑ |

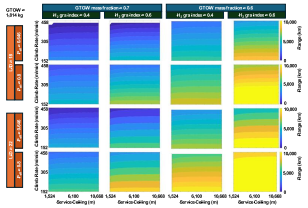
## II. Advanced Concepts

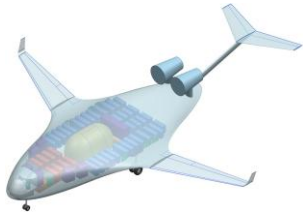
Turning Legacy into Leverage

FAST

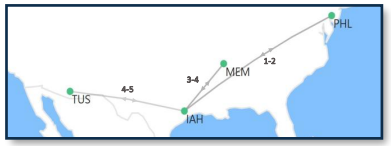


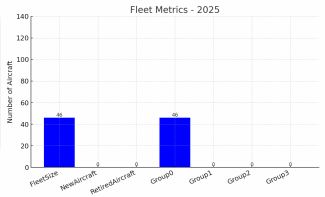
Hydrogen Fuel Cells





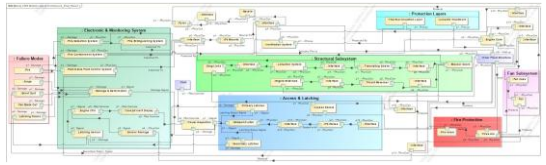
**System-of-Systems**: Fleet operations



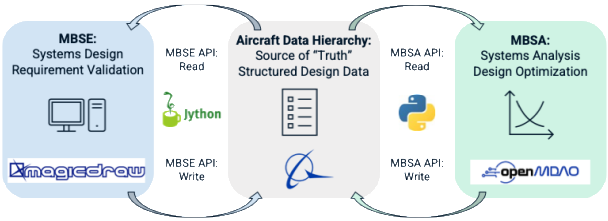




## III. Digital Transformation

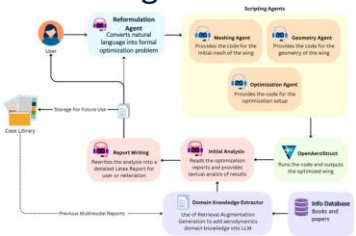
Digital Thread for Sustainable Propulsion System Design



Model-based Systems Analysis & Engineering




AI-Enabled Digital Transformation



# Electrified Aircraft Propulsion

**The Light Side of Electrification**

True zero emissions *(in flight)*

Quieter

Propulsive flexibility

High efficiency

Reliability and maintainability

Cost of electricity

A simple fuel-to-battery swap is not feasible — the physics just don't close for most aircraft classes.

**The Dark Side of Electrification**

Jet A:
**11.9 kWh/kg**

Lithium-Ion Battery:
**0.2 kWh/kg**
**~60 times heavier**

Thermal issues

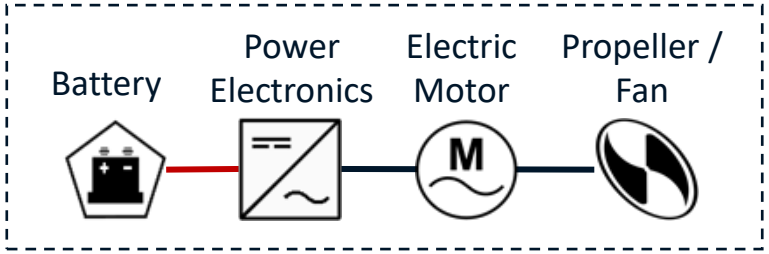
Safety and certification

Battery life and degradation

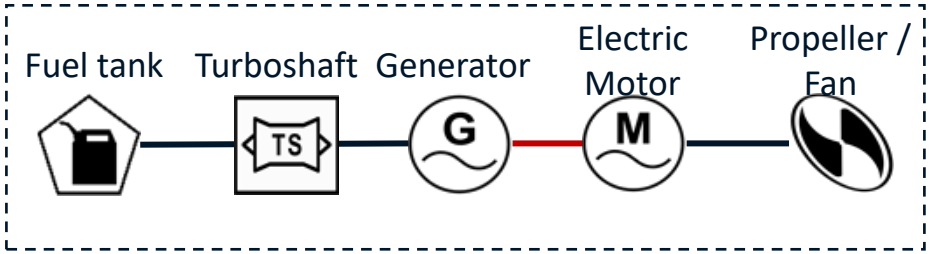
Lifecycle cost of $CO_2$

# (Some) Electrified Propulsion Architectures

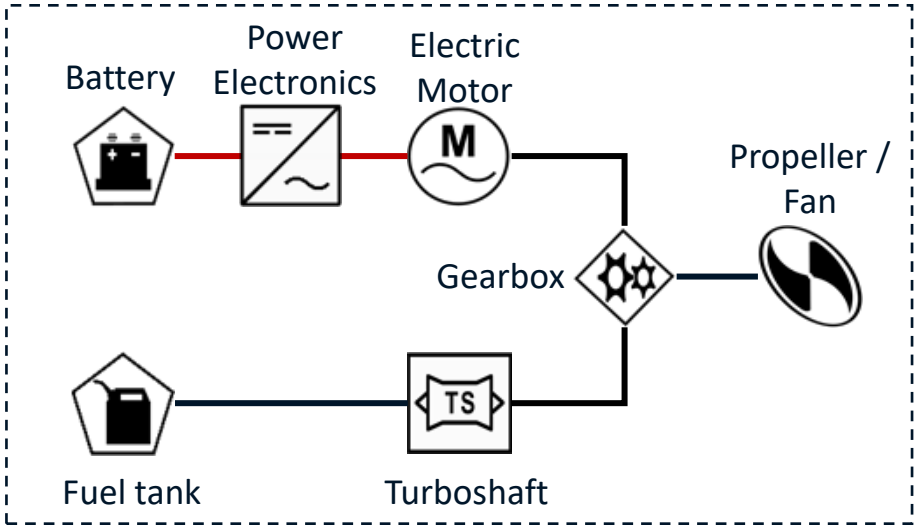
## Fully Electric



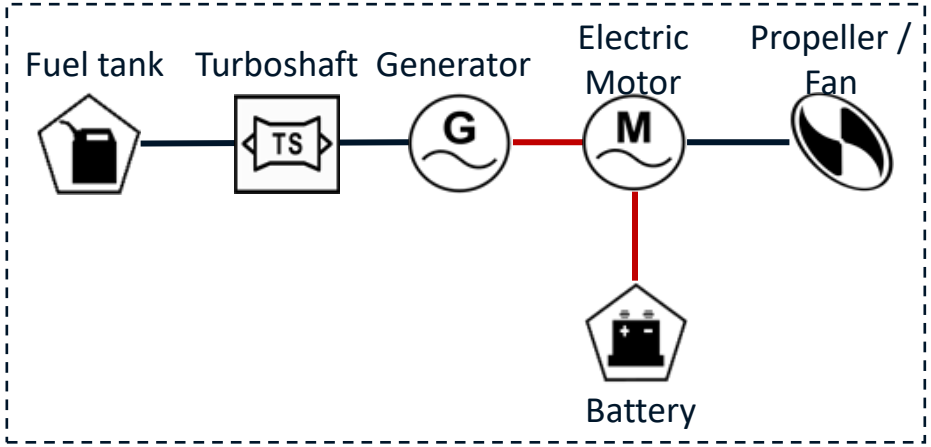

## Turboelectric




## Parallel Hybrid Electric




## Series Hybrid (aka Hybrid Turboelectric)




*...and many more architectures!*

"Hybrid": when there is more than one energy source for primary power & propulsion

# Electrified Aircraft: A Diverse Design Space

Joby Aviation S4 2.0
Urban Air Mobility
Image Credit: jobyaviation.com

Pipistrel Alpha Electro
Electric Propulsion
Image Credit: pipistrel.si

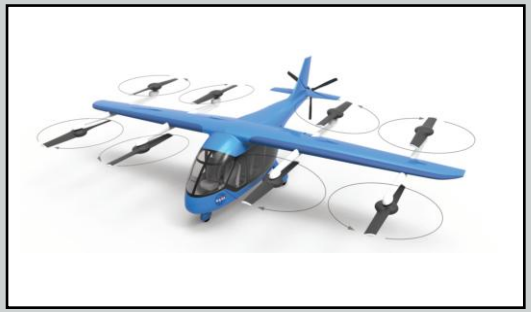
UTC Hybrid-Electric Vehicle
Parallel Hybrid Electric Propulsion
Image Credit: tech.utc.com

NASA SuSAN
Partially Turboelectric Distributed Propulsion
Image Credit: nasa.gov

***Electric***

***Hybrid***

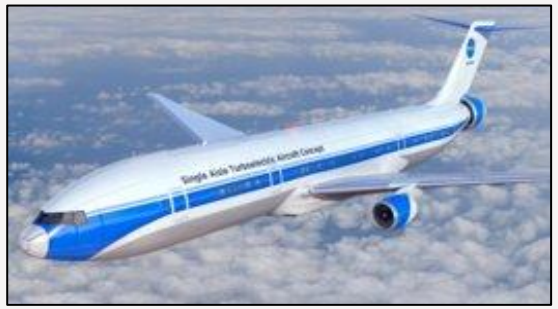
***Turboelectric***



NASA Lift + Cruise eVTOL
Turboelectric Propulsion
Image Credit: nasa.gov

NASA X-57 Mod IV
Distributed Electric Propulsion
Image Credit: nasa.gov

Electra.aero Ultra Short
Hybrid Turboelectric Propulsion
Image Credit: electra.aero



NASA STARC-ABL
Partially Turboelectric Propulsion
Image Credit: nasa.gov

More range and payload

100% Less dependence on battery 0%

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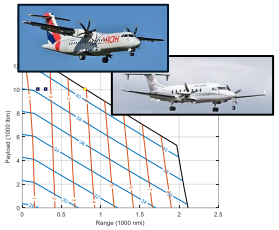
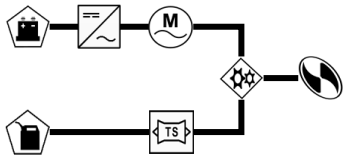





## II. Advanced Concepts

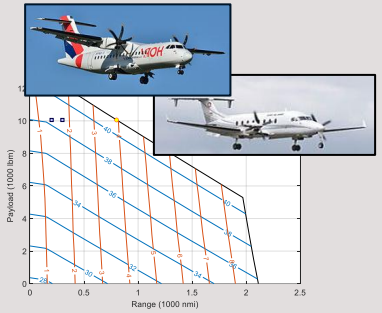
## III. Digital Transformation

# System Design and Analysis for NASA Electrified Powertrain Flight Demonstration (EPFD) Project

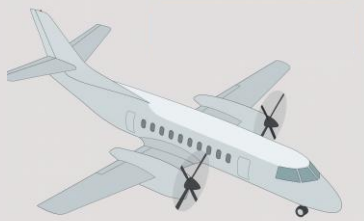
**Objective:** Explore the design space for the thin-haul and regional vision systems with parallel hybrid electric propulsion system architectures for the NASA EPFD project (2019—2025).

- Cinar et al., 2023, Journal of Aircraft
- Cinar et al., 2022, IEEE/AIAA Transportation Electrification Conference ***(Best Paper Award)***
- Cai et al., 2022, IEEE/AIAA Transportation Electrification Conference
- Pastra et al., 2022, IEEE/AIAA Transportation Electrification Conference

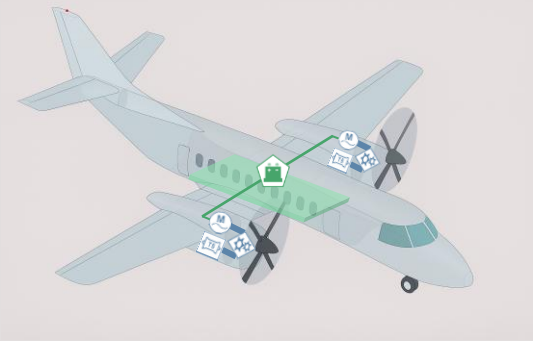
Reference Aircraft Modeling



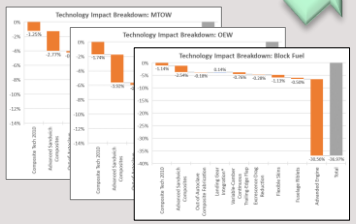

Advanced Technology Aircraft Sizing

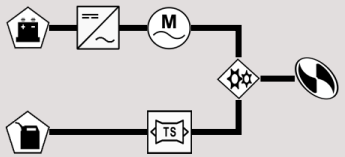


Hybrid Electric Aircraft Sizing



Advanced Technology Modeling & Integration



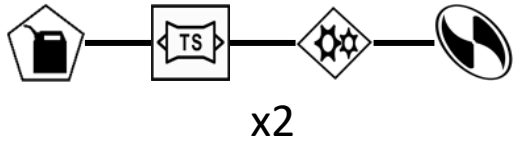

Physics-based Electrified Propulsion Modeling & Integration

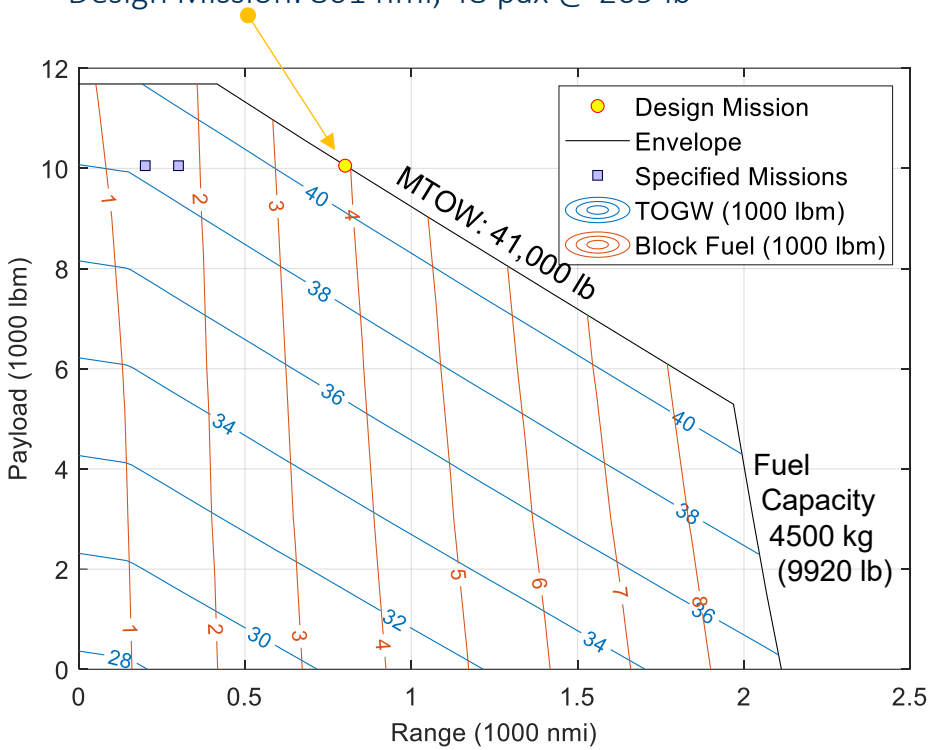
# Baseline Aircraft Modeling and Mission Performance

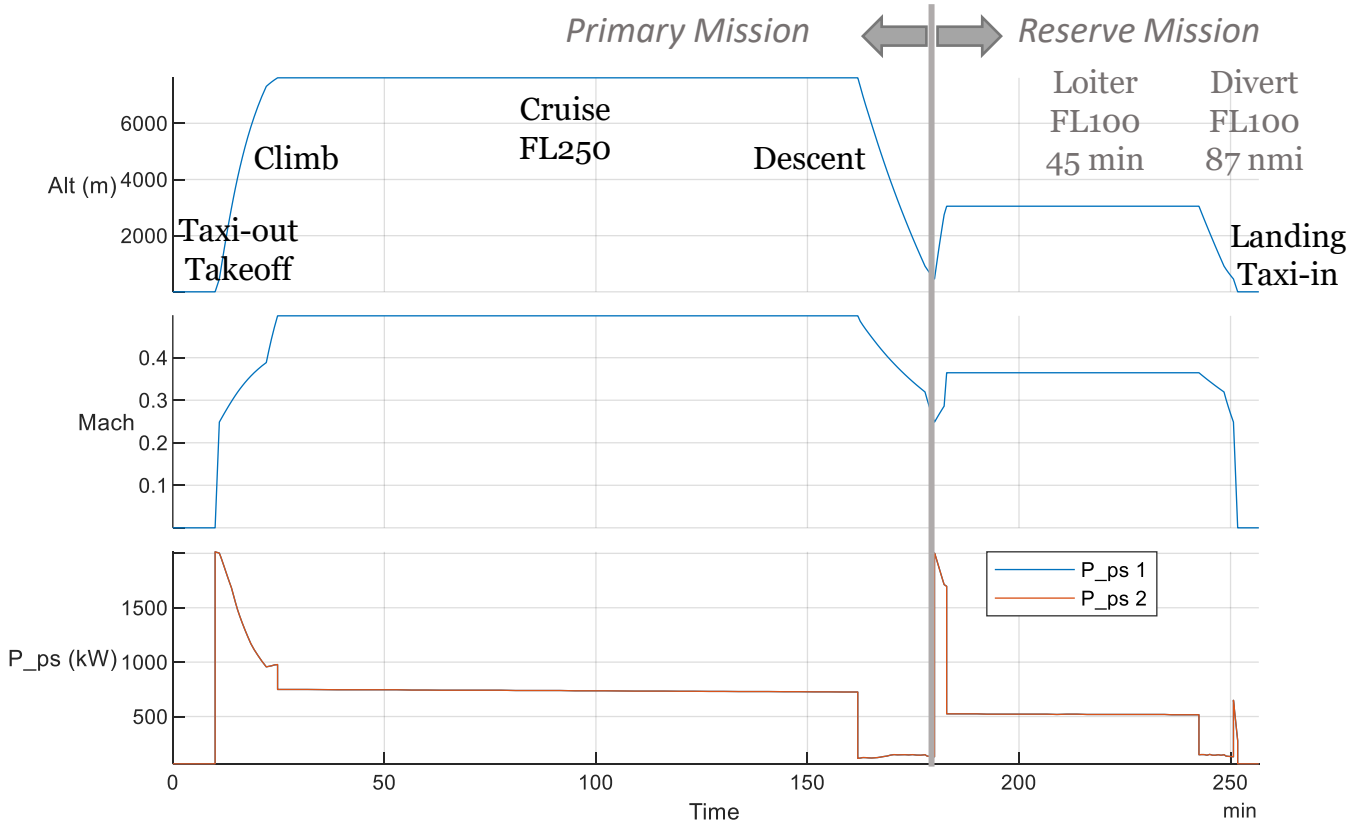
## Baseline Aircraft

Power: 2 x 1610 kW
MTOW: 41,000 lb
Design Mission: 801 nmi, 48 pax @ 209 lb

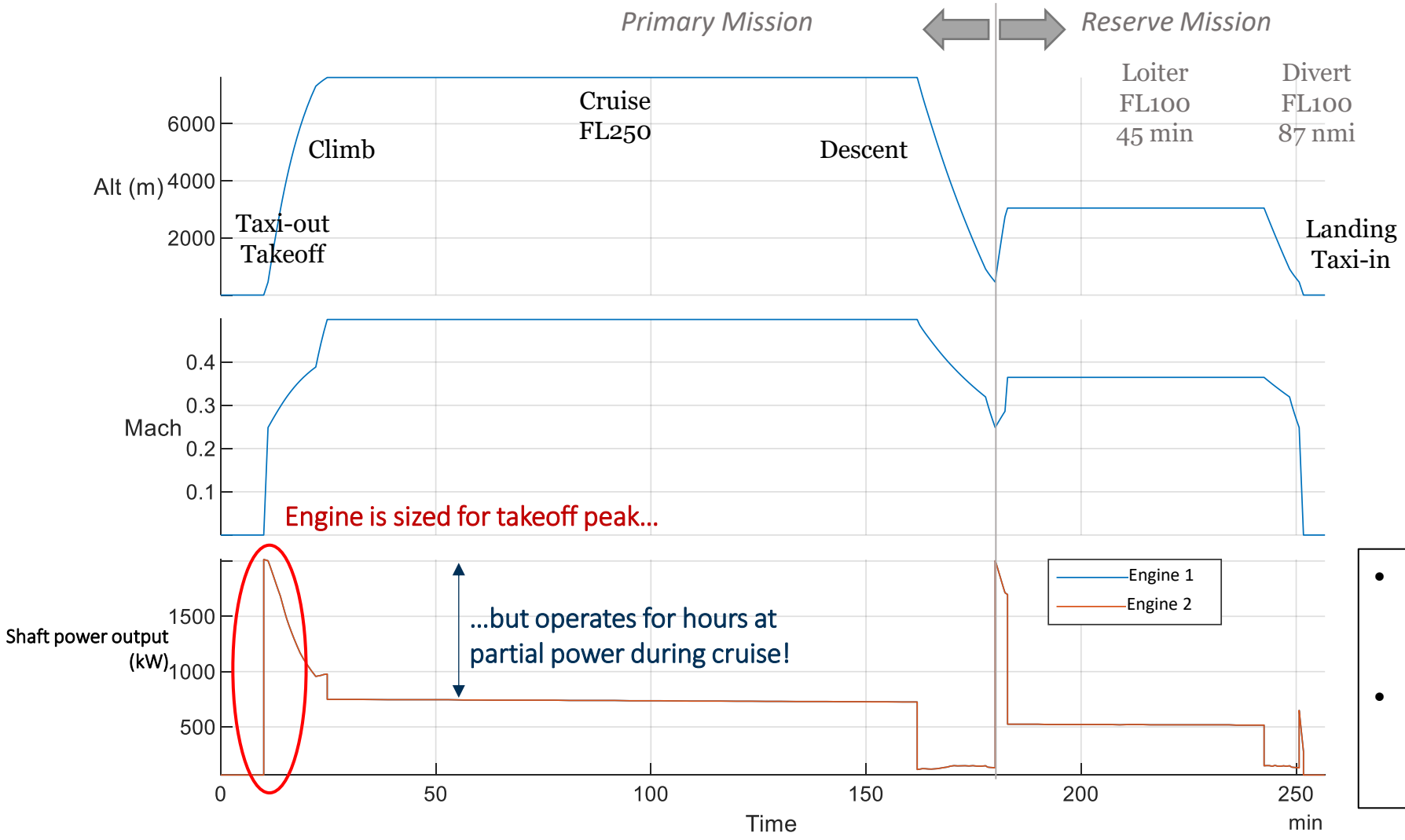
## Baseline Architecture

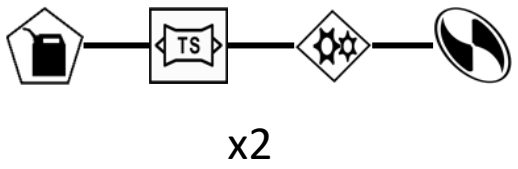


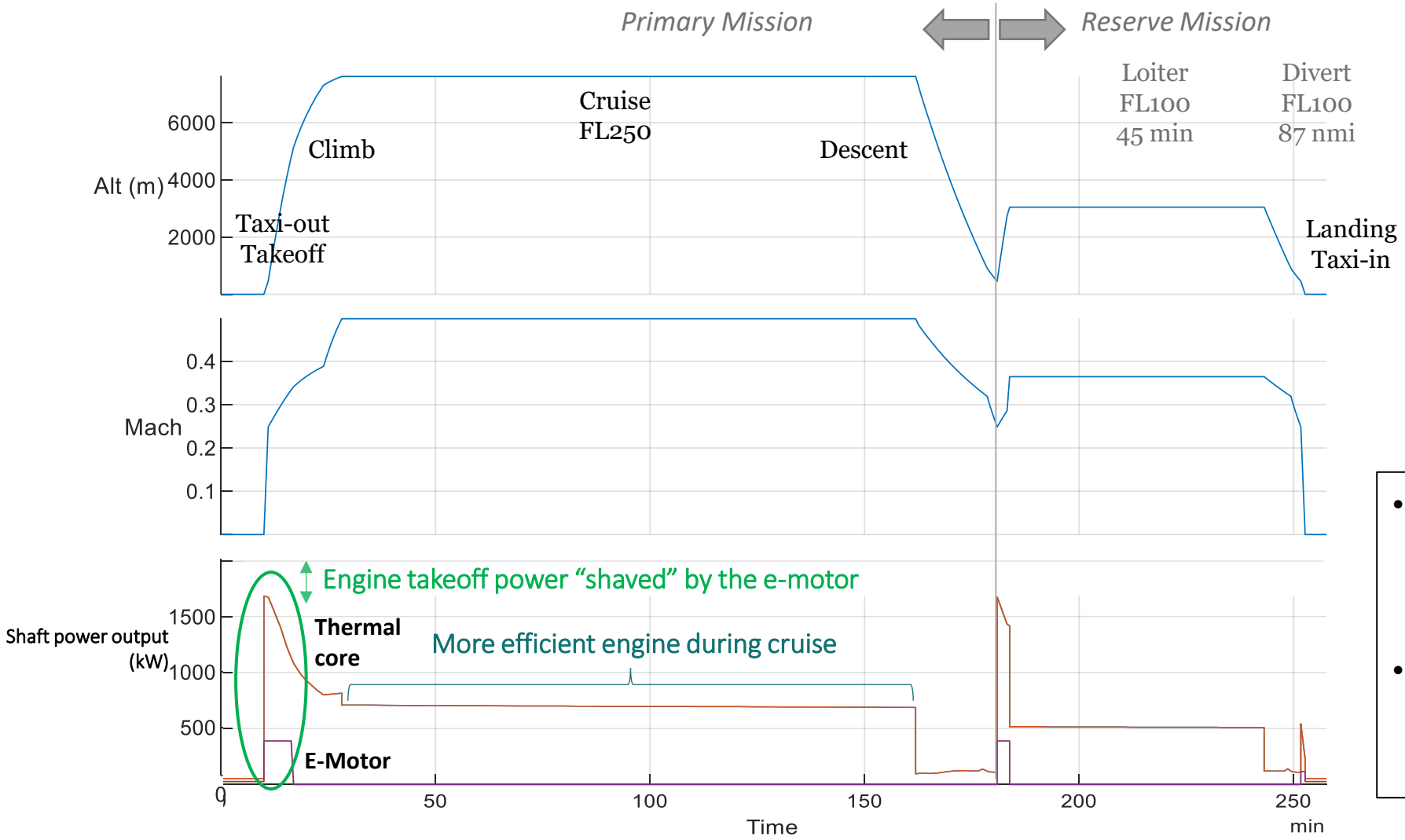
# Flight Mission Performance of a Conventional Aircraft

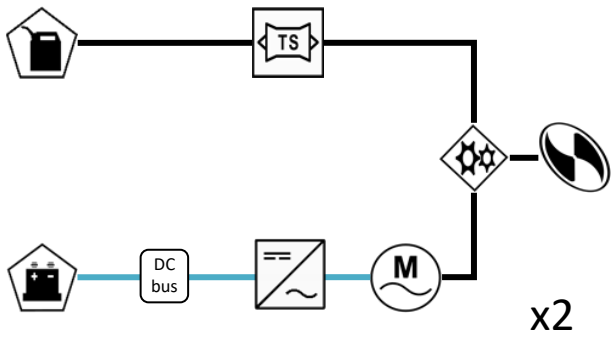



- Engine is sized for short-duration takeoff peaks ➔ oversized core, off-design cruise, higher TSFC.
- Takeoff power requirement dominates a system whose efficiency is determined by cruise.

# Electrification Enables Higher Propulsive Efficiency

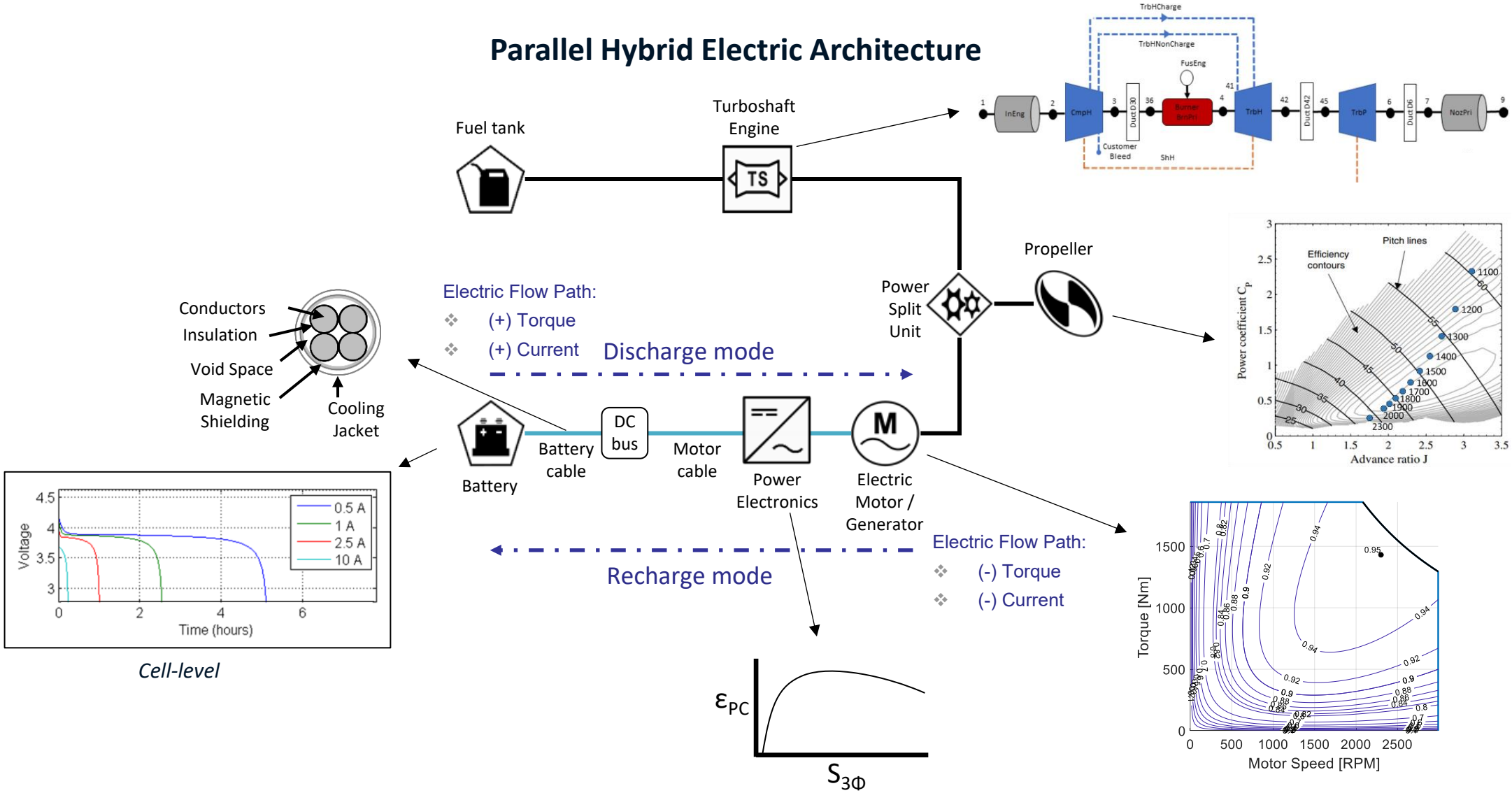



- Electric assist covers the short takeoff peak ➔ smaller core tuned closer to cruise power.
- Even though cruise remains non-hybrid, its efficiency improves — **a clear example of systems thinking.**

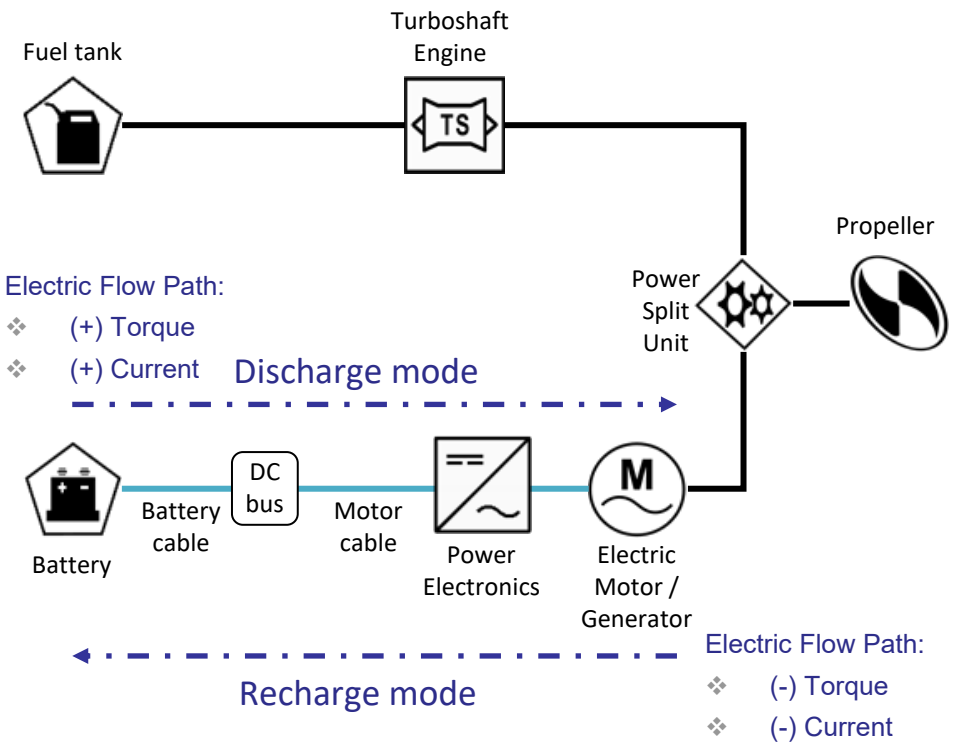
# Electrified Propulsion Modeling: Components

## Parallel Hybrid Electric Architecture

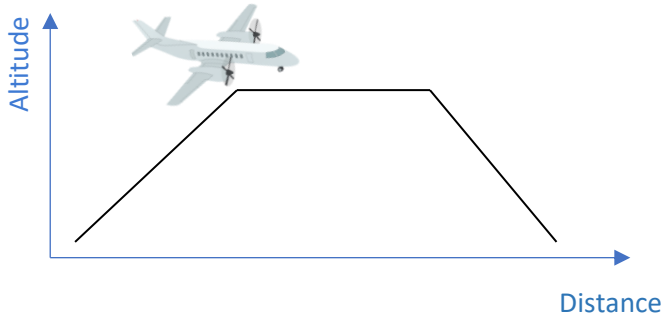


# Electrified Propulsion Modeling: Components

## Parallel Hybrid Electric Architecture



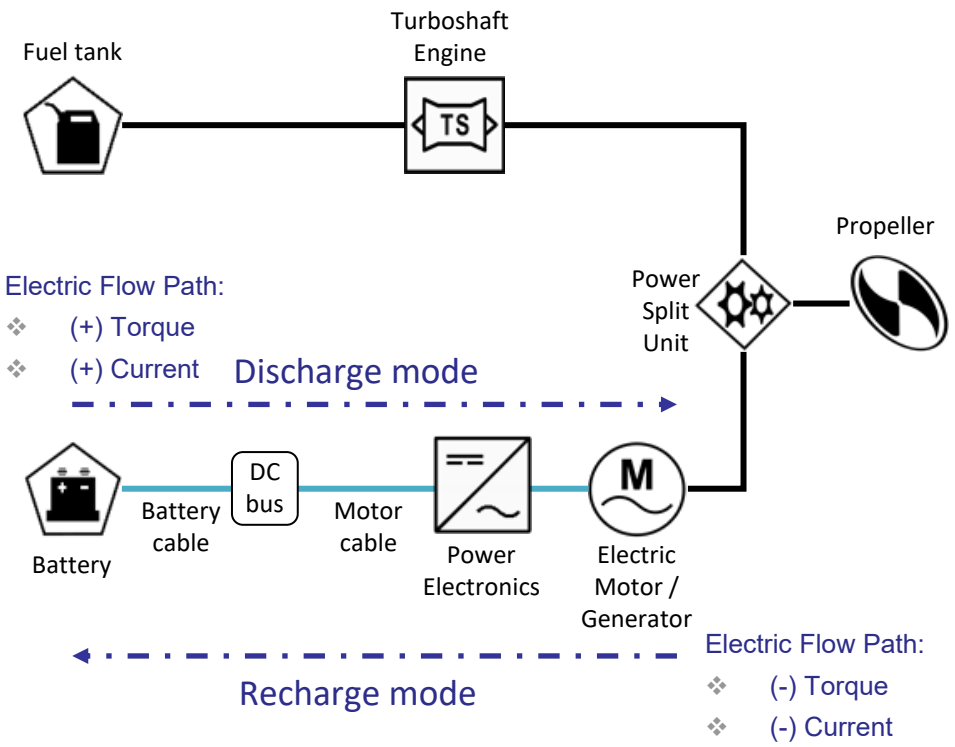

Notional mission profile




- **How much** electric power?
- **When** to electrify?
- **How long** to electrify?

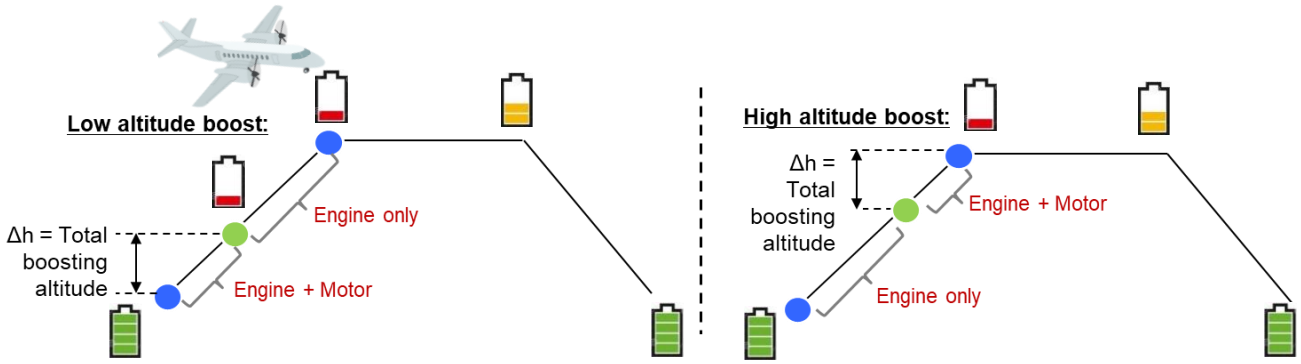
# Electrified Propulsion Modeling: Components & *Power Management*

## Parallel Hybrid Electric Architecture




## Modes of Operation

- Takeoff power shaving
- Climb e-boost
- Electric taxi
- In-flight battery recharge




- **How much** electric power?
- **When** to electrify?
- **How long** to electrify?

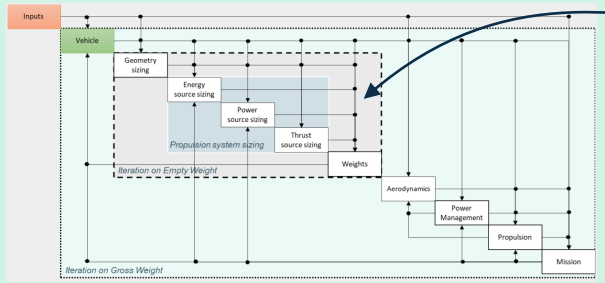
*Power Management Strategy*

**Need advanced computational methods for the co-design and optimization of aircraft configuration, propulsion system architecture *and* hybrid operation.**

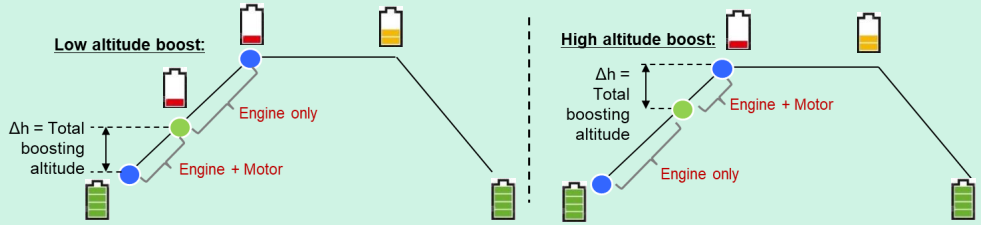
# System Design and Analysis for Advanced Concepts

Methods

Multidisciplinary Analysis

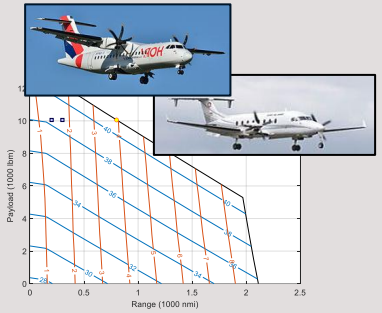



Adaptive Power Control

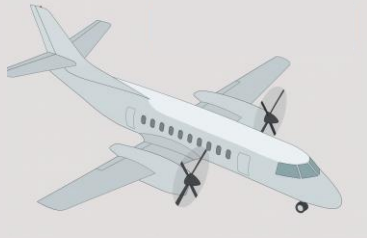



Applications

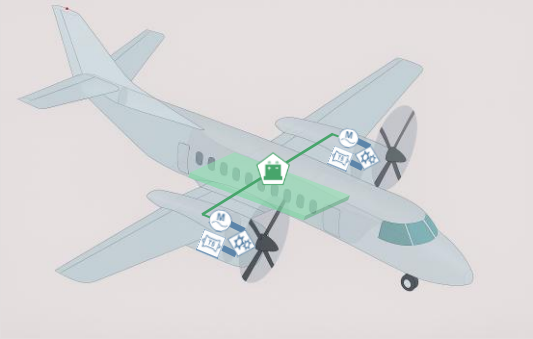
Reference Aircraft Modeling



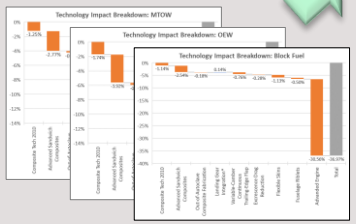

Advanced Technology Aircraft Sizing

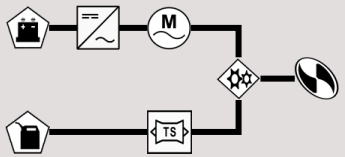


Hybrid Electric Aircraft Sizing

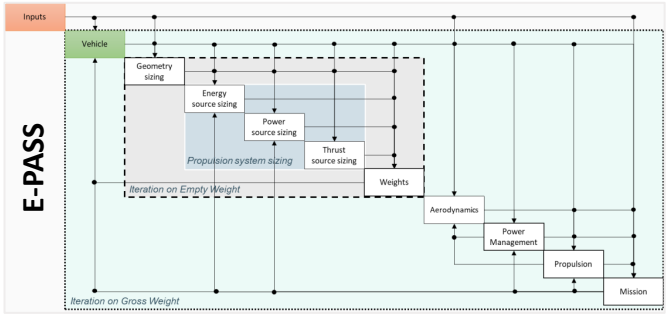


Advanced Technology Modeling & Integration



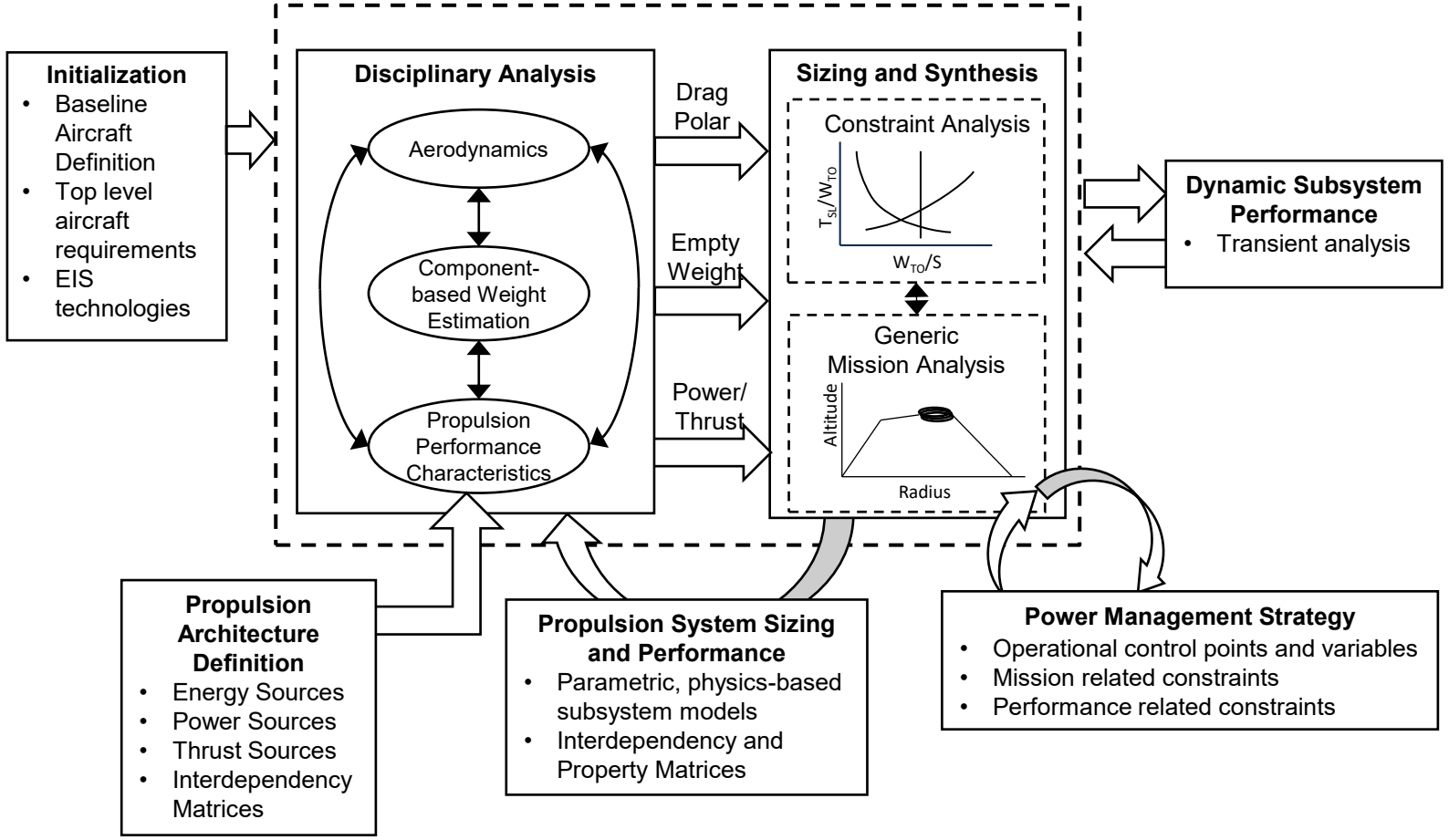




Physics-based Electrified Propulsion Modeling & Integration



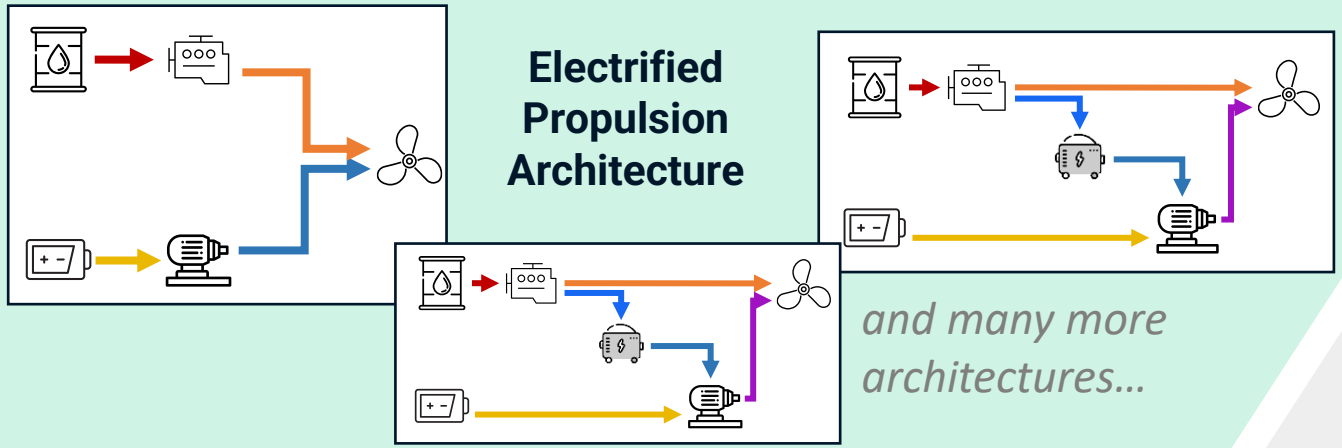

# E-PASS: Electrified Propulsion Architecture Sizing and Synthesis

- **Energy-based** aircraft sizing and synthesis
- **Graph-based propulsion system** framework enables design and performance evaluation of advanced aircraft concepts with ***any*** type of propulsion system
- Allows for rapid comparisons between diverse architectures ***and*** flight operations




Cinar, G. (2018). *A methodology for dynamic sizing of electric power generation and distribution architectures* (Doctoral dissertation, Georgia Institute of Technology).

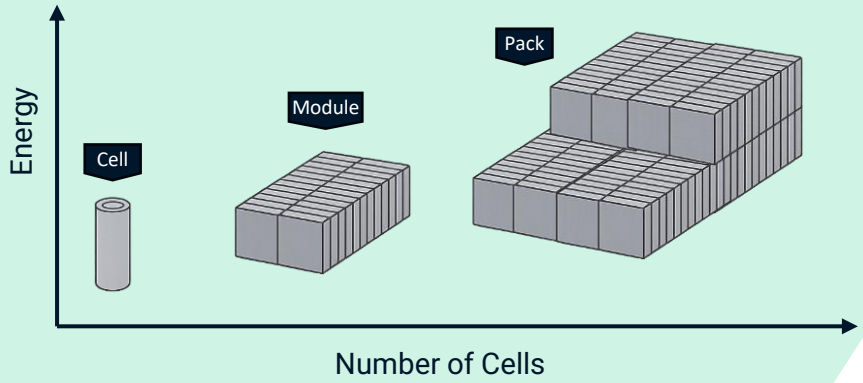
# Aircraft design is (for the most part) a continuous optimization. Hybrid-electric changes that.



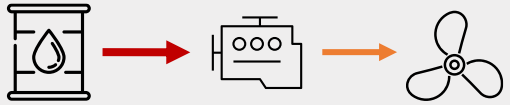
**Electrified Propulsion Architecture**

*and many more architectures…*

*Many design variables, discrete + continuous*



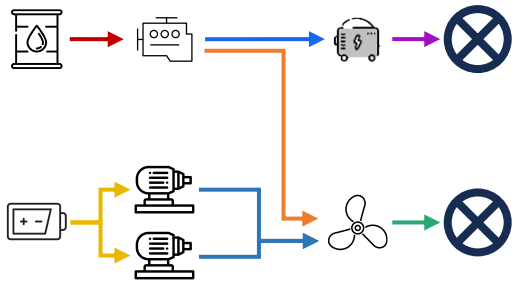

**Conventional Propulsion Architecture**



*Fewer, continuous design variables*

## Graph-based Propulsion System Analysis

for systems-level architecture exploration, operation, and evaluation.



*Machine-readable Propulsion Architecture Encoding*

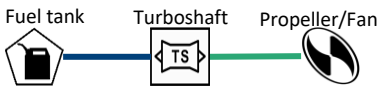
$$A = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Method evolution: Cinar, 2018 – *Original formulation* | Cinar. et al., 2020, Aircraft Engineering and Aerospace Technology – *Refined method* | Mokotoff. et al., 2025, Aerospace Science and Technology – *Most advanced formulation.*

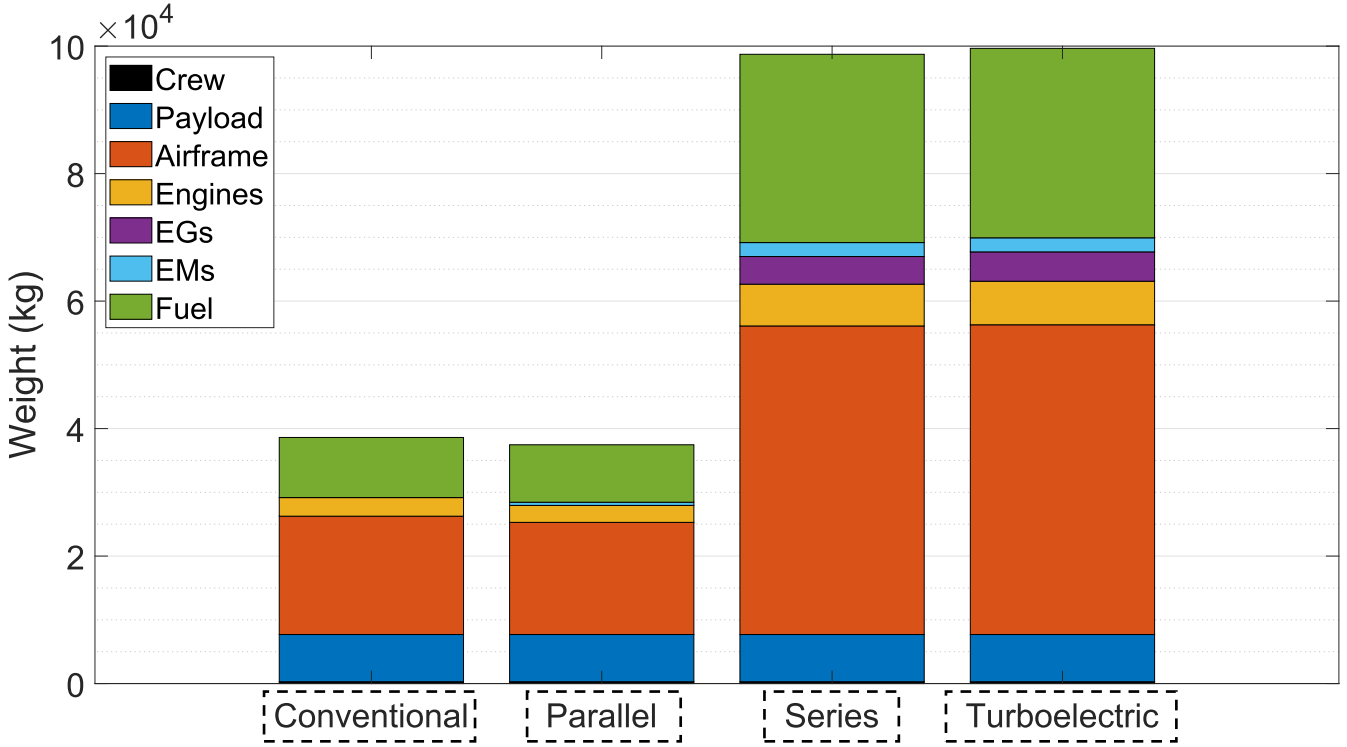
# Graph-based Propulsion System Analysis

## for systems-level architecture exploration, operation, and evaluation.

### Conventional



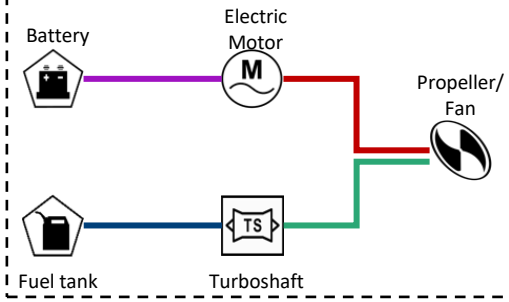

$$A = \begin{array}{c} \\ (F) \\ (B) \\ (TS) \\ (EG) \\ (EM) \\ (P/F) \end{array} \begin{array}{c} \begin{array}{cccccc} (F) & (B) & (TS) & (EG) & (EM) & (P/F) \end{array} \\ \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \end{array}$$




### Turboelectric

$$A = \begin{array}{c} \\ (F) \\ (B) \\ (TS) \\ (EG) \\ (EM) \\ (P/F) \end{array} \begin{array}{c} \begin{array}{cccccc} (F) & (B) & (TS) & (EG) & (EM) & (P/F) \end{array} \\ \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \end{array}$$

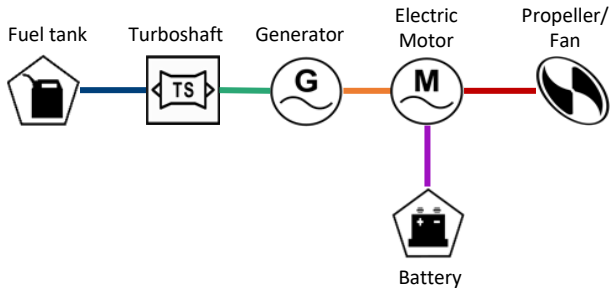
### Parallel Hybrid




$$A = \begin{array}{c} \\ (F) \\ (B) \\ (TS) \\ (EG) \\ (EM) \\ (P/F) \end{array} \begin{array}{c} \begin{array}{cccccc} (F) & (B) & (TS) & (EG) & (EM) & (P/F) \end{array} \\ \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \end{array}$$

### Series Hybrid

$$A = \begin{array}{c} \\ (F) \\ (B) \\ (TS) \\ (EG) \\ (EM) \\ (P/F) \end{array} \begin{array}{c} \begin{array}{cccccc} (F) & (B) & (TS) & (EG) & (EM) & (P/F) \end{array} \\ \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \end{array}$$

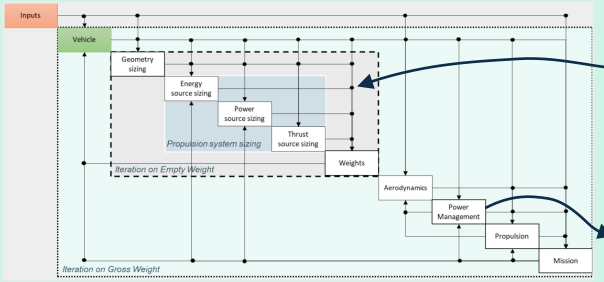



Mokotoff. et al., 2025, Aerospace Science and Technology

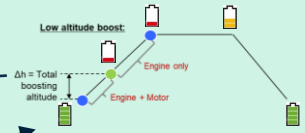
# System Design and Analysis for Advanced Concepts

Methods

Multidisciplinary Analysis




Adaptive Power Control

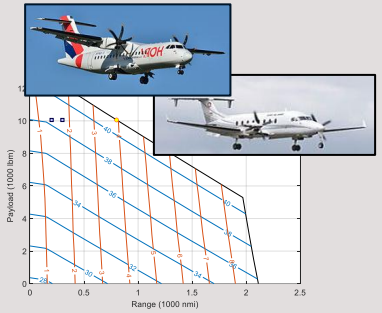



$$A = \begin{bmatrix} 0 & \lambda_{1,2} & 0 \\ 0 & 0 & \lambda_{2,3} \\ 0 & 0 & \lambda_{3,3} \end{bmatrix}$$

Graph-based Framework

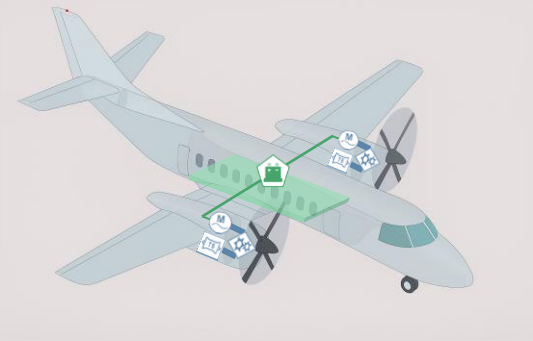
Applications

Reference Aircraft Modeling

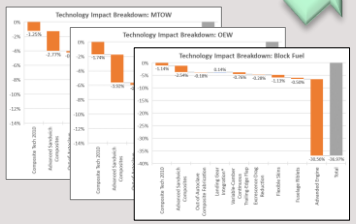


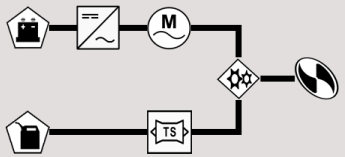

Advanced Technology Aircraft Sizing

Hybrid Electric Aircraft Sizing



Advanced Technology Modeling & Integration



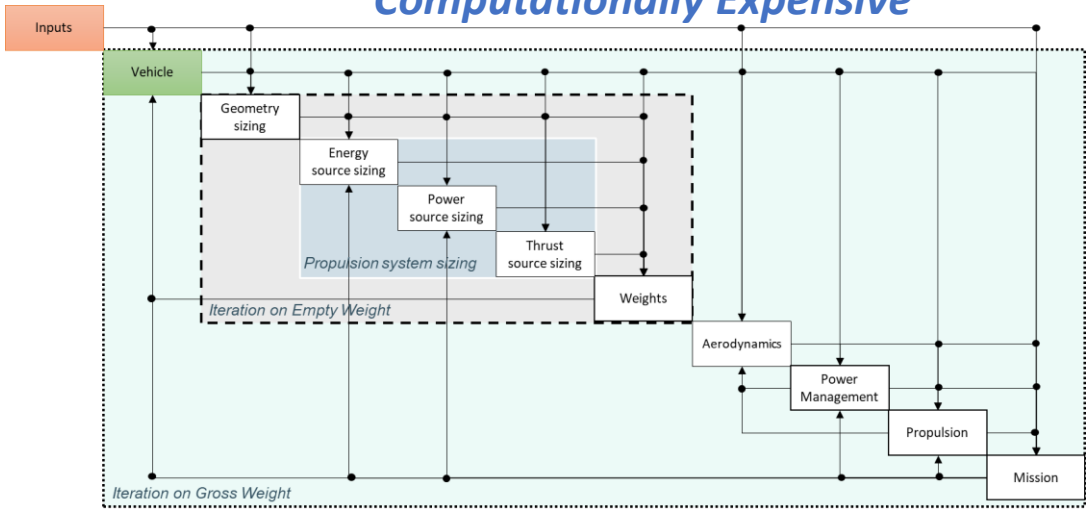




Physics-based Electrified Propulsion Modeling & Integration

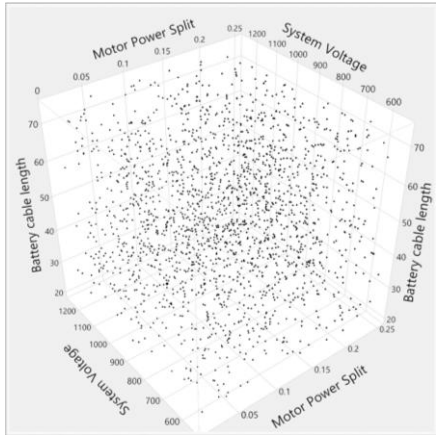
# Design Space Exploration Powered by Machine Learning

**Physics-based Code**

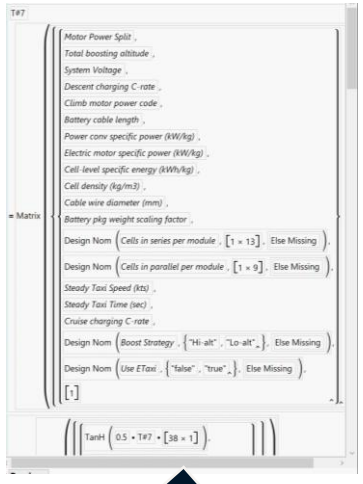
***Computationally Expensive***



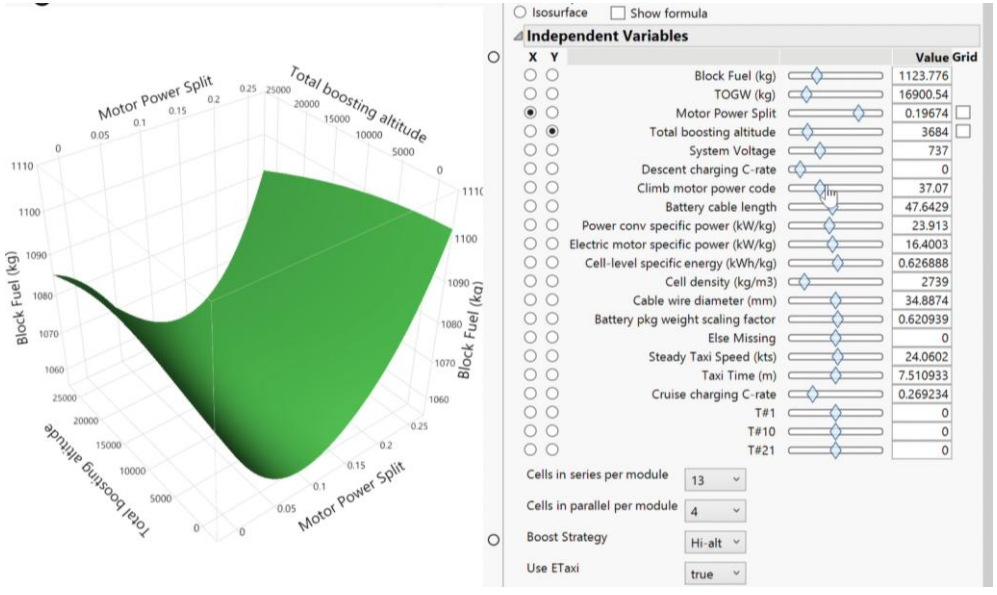

**Design of Experiments**




**Artificial Neural Networks**



Need to sweep through the **combinatorial** design space to explore system level impact of variations in technology, operation, modeling assumptions…

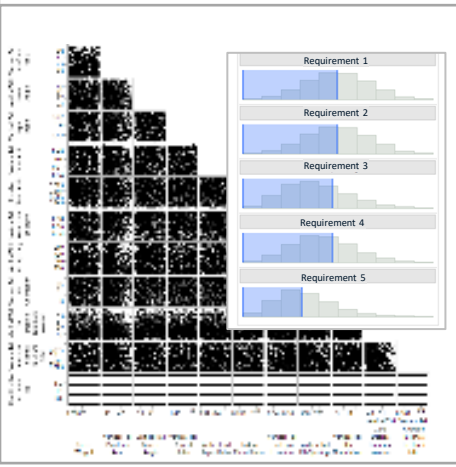


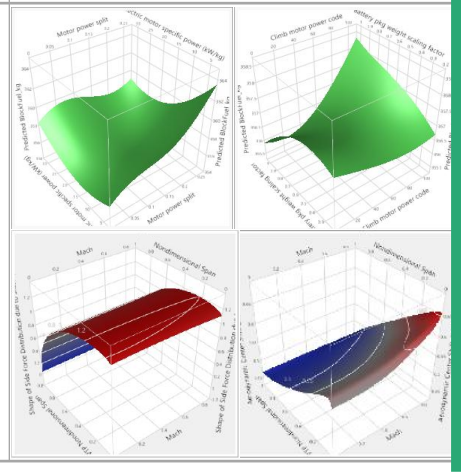

**Rapid Design Space Exploration powered by surrogate models**

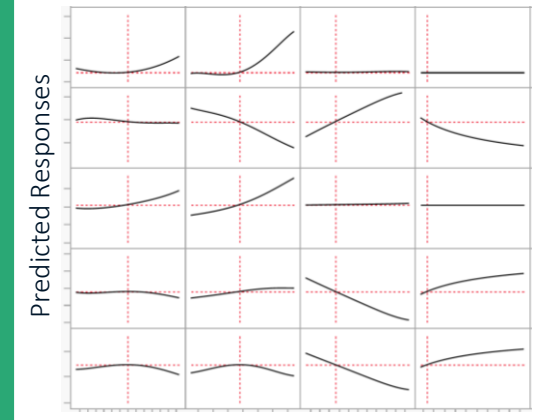
# ML-Assisted Multidisciplinary Design Exploration & Optimization

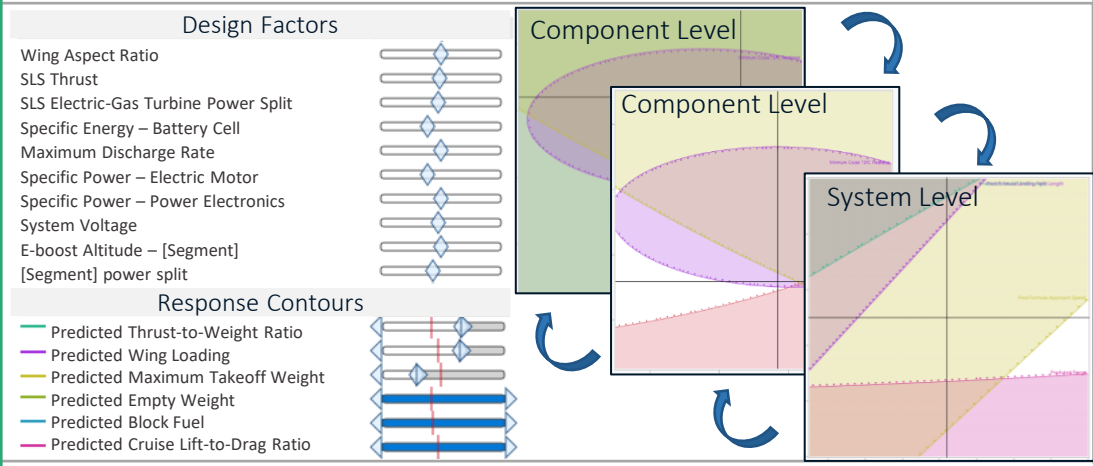
Neural-network surrogate of the feasible MDA enables fast exploration and robustness analysis.

| Requirements analysis and robust design | Disciplinary analysis impact visualization and surrogates | Dynamic sensitivity analysis | Real-time constraint analysis and cascading impacts at different design levels |
|---|---|---|---|





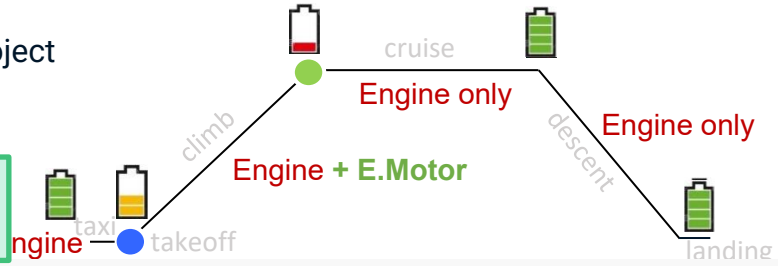



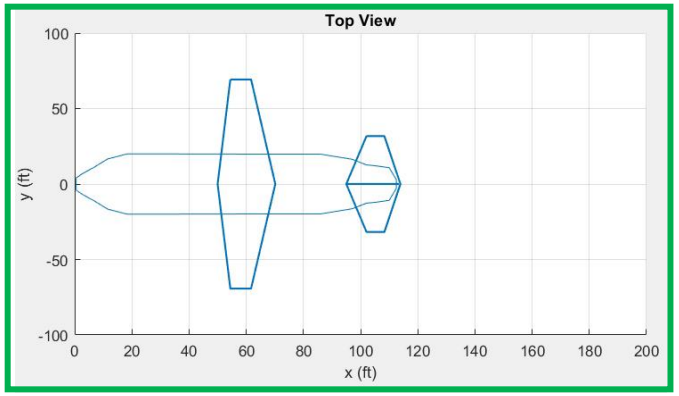

Surrogate model trained on converged MDA results → continuous mapping between design variables and feasible aircraft outcomes.

Electrified Powertrain Flight Demonstration Project

Cinar et al., 2023, Journal of Aircraft

Predicted aircraft-level metrics update with every feasible design.




Predicted Design

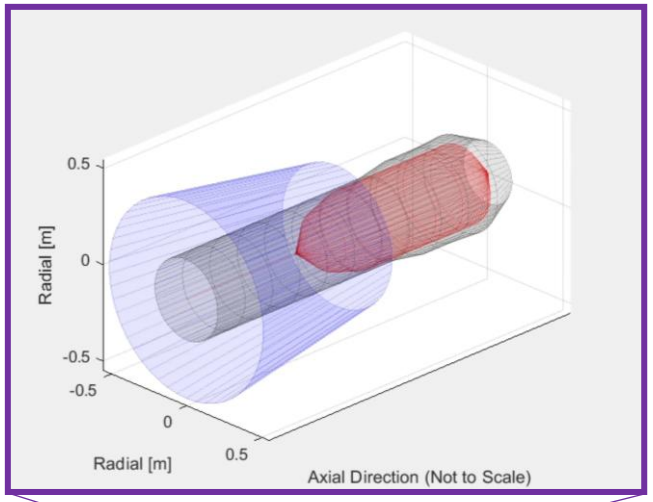
| | |
|---|---|
| Battery SoC TOD | 0.2737 24 |
| Battery SoC BOD | 0.4138 4 |
| Tot Fuel Weight (kg) | 1522.2 2 |
| Pack Level Spec Energy (kWh/kg) | 0.4193 08 |
| OEW (kg) | 10395. 76 |
| TOGW (kg) | 16669. 53 |
| Elec Motor Rated Power | 83.405 78 |
| Engine SLS Rated Power | 1571.5 29 |
| Crz Avg BSFC (lb/hr/hp) | 0.3675 21 |
| Block Fuel (kg) | 1110.8 29 |
| Success Neural | Other true 4e-5 1 |

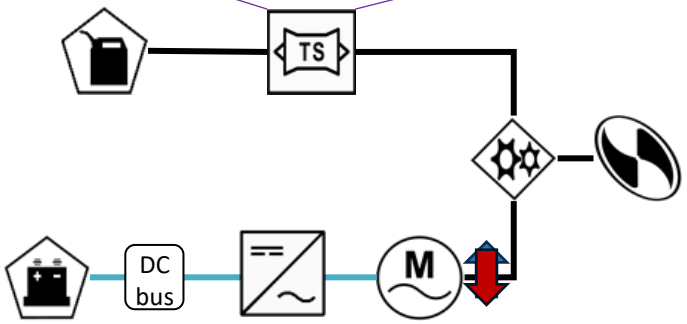
Each black trace represents a continuous sweep through the design space — **every point is a feasible, converged aircraft design** predicted by the surrogate model.

Changing a design variable triggers a new surrogate evaluation → a new aircraft design prediction.

Design Variables

| Motor Power Split | Use ETaxi | Boost Strategy | Total boosting altitude | Climb motor power code | Cruise charging C-rate | Descent charging C-rate | System Voltage | Cell-level specific energy (kWh/kg) | Electric motor specific power (kW/kg) | Power conv specific power (kW/kg) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.05 | false | Hi-alt | 23500 | 100 | 0 | 0 | 1250 | 0.5 | 13 | 16.4 |



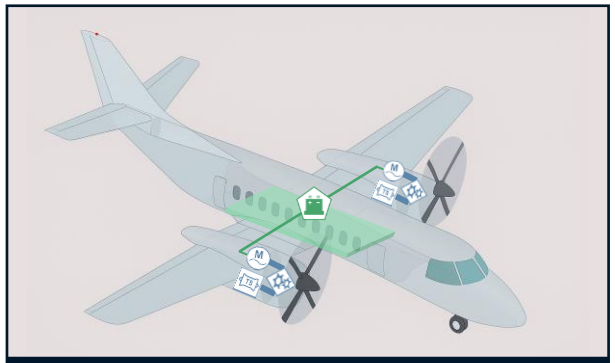



# Benefit Assessments of a 50 pax 2030 EIS Hybrid Electric Aircraft

| Scenario | Block fuel (kg) | Cruise avg BSFC (lb/hr/hp) | Engine SLS rated power (kW) | Electric motor rated power (kW) | Battery capacity (kWh) | OEW (kg) | TOGW (kg) |
|---|---|---|---|---|---|---|---|
| S.0 - Advanced Conventional | 1165 | 0.3679 | 1657 | N/A | N/A | 10419 | 16539 |
| S.I - EAP no e-taxi; no charging | 1151 | 0.3684 | 1598 | 84 | 75 | 10494 | 16778 |
| *comparison over S.0* | *-1.17%* | *+0.13%* | *-3.61%* | - | - | *+0.72%* | *+1.45%* |
| S.II - EAP no e-taxi; battery charged | 1150 | 0.3687 | 1586 | 83.4 | 37.8 | 10463 | 16657 |
| *comparison over S.0* | *-1.29%* | *+0.22%* | *-4.28%* | - | - | *+0.42%* | *+0.71%* |
| S.III - EAP with e-taxi; battery charged | 1074 | 0.3697 | 1456 | 237.0 | 133.2 | 10542 | 16895 |
| *comparison over S.0* | *-7.81%* | *+0.49%* | *-12.13%* | - | - | *+1.18%* | *+2.15%* |
| S.IV - EAP with e-taxi; no charging | 1055 | 0.3700 | 1476 | 240.3 | 205.2 | 10612 | 17127 |
| *comparison over S.0* | *-9.37%* | *+0.58%* | *-10.92%* | - | - | *+1.86%* | *+3.55%* |

Surrogate-assisted mixed-variable search identifies Scenario IV as the fuel-best design, even with slightly higher cruise BSFC—because engine down-rating and system-level allocation dominate.

BSFC: Brake Specific Fuel Consumption OEW: Operating Empty Weight
TKO: Takeoff TOGW: Takeoff Gross Weight



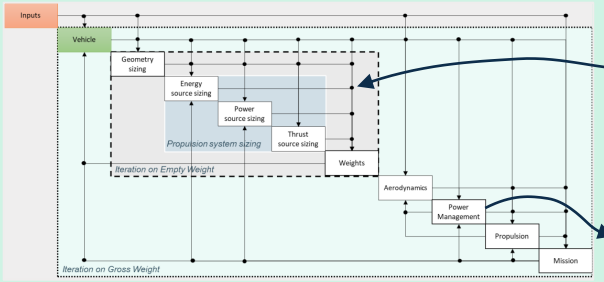
**Power Management Strategy:**

- S.I: 5% motor power split, full power at takeoff, full climb e-boost at full power
- S.II: 5% motor power split, full power at takeoff, low alt. climb e-boost at 25% motor power for 2500 ft
- S.III: 14% motor power split, full power at takeoff, low altitude climb e-boost at full motor power for 12000 ft
- S.IV: 14% motor power split, full power at takeoff, full climb e-boost at full power

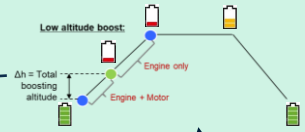
# System Design and Analysis for Advanced Concepts

## Methods

### Multidisciplinary Analysis



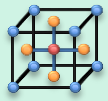

### Adaptive Power Control



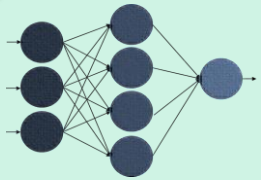

$$A = \begin{bmatrix} 0 & \lambda_{1,2} & 0 \\ 0 & 0 & \lambda_{2,3} \\ 0 & 0 & \lambda_{3,3} \end{bmatrix}$$

Graph-based Framework

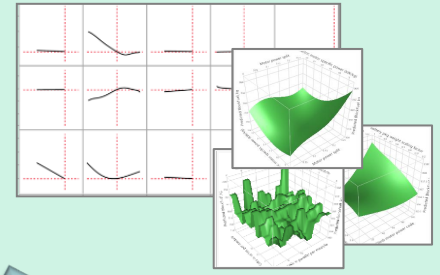
### Surrogate Modeling



$$f(x) \approx \hat{f}(x) + \varepsilon$$

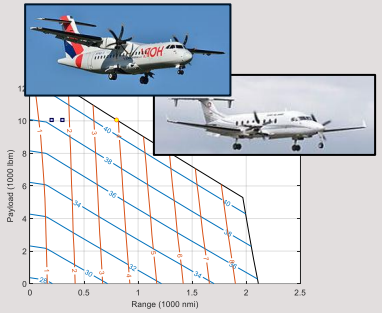


### Design Space Exploration & Optimization

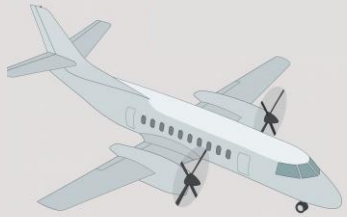


## Applications

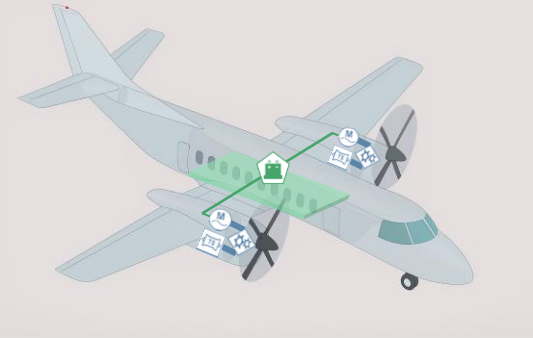
### Reference Aircraft Modeling




### Advanced Technology Aircraft Sizing



### Hybrid Electric Aircraft Sizing



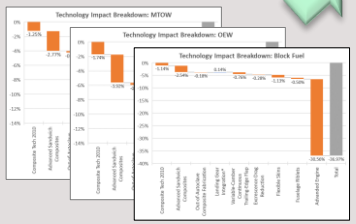
### Robust Design with Best Power Management Strategy

| | | | | | |
|---|---|---|---|---|---|
| S.0 | TX | TKO | CLB | CRZ | DSC |
| S.I | TX | TKO | CLB (full) | CRZ | DSC |
| S.II | TX | TKO | CLB (lo-alt) | CRZ 🔋↑ | DSC 🔋↑ |
| S.III | TX | TKO | CLB (lo-alt) | CRZ 🔋↑ | DSC 🔋↑ |
| S.IV | TX | TKO | CLB (full) | CRZ | DSC |

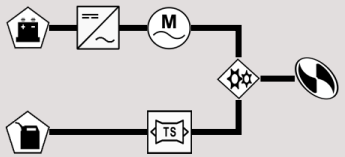
Engine only | Low assist | Moderate assist | Full electric

🔋↑ Battery charging

### 2030 Technology Modeling & Integration




### Physics-based Electrified Propulsion Modeling & Integration

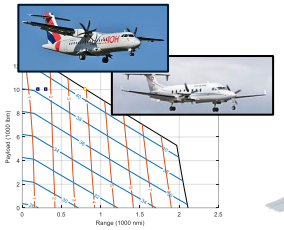


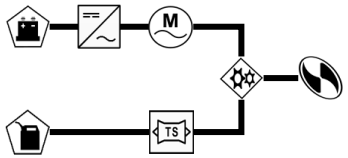
# Agenda

## I. Introduction to Electrification

**Why Electrify:** Opportunities and Challenges

**Case Study:** Systems Design and Analysis for NASA EPFD Project



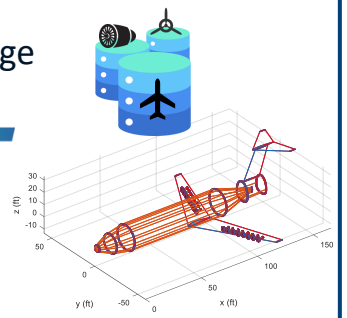


| | | | | | |
|---|---|---|---|---|---|
| S.I | TX | TKO | CLB (full) | CRZ | DSC |
| S.II | TX | TKO | CLB (lo-alt) | CRZ ↑ | DSC ↑ |

## II. Advanced Concepts

Turning Legacy into Leverage

FAST



## III. Digital Transformation

Available on GitHub

# FAST AEROBASE

**A**ircraft and **E**ngine **R**egistry **O**pen-Source Data**base**

Over **400 turbofan aircraft**, 70 turboprop aircraft, and **200 gas turbine engines**.

EASA European Aviation Safety Agency

Federal Aviation Administration

AIRBUS

BOEING

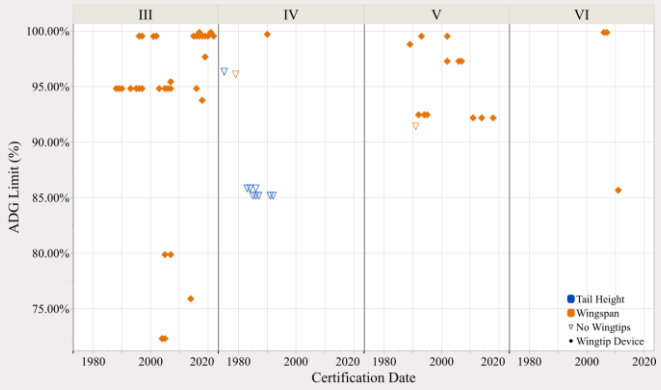
| Aircraft | Airbus A319-131 |
|---|---|
| EIS | 1997 |
| PAX | 145 |
| Range | 6,667 [km] |
| MTOW | 75,900 [kg] |
| OEW | 40,800 [kg] |
| Engine | IAE V522-A5 |
| Sources | FAA A28NM, A319 APM |

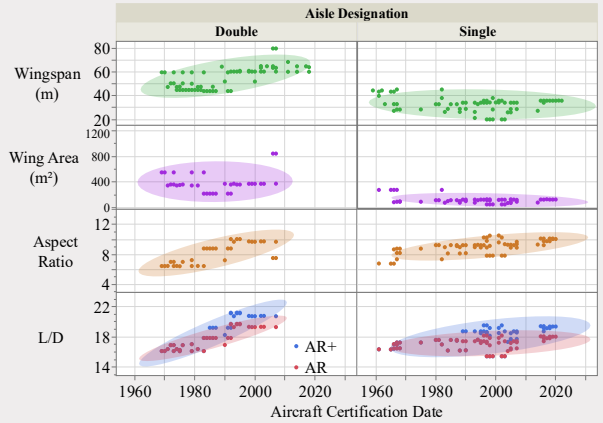
| Engine | IAE V522-A5 |
|---|---|
| EIS | 1996 |
| SLS Thrust | 102,000 (N) |
| BPR | 4.9 |
| TSFC at SLS | 0.34 (1/hr) |
| TSFC at Crs | 0.57 (1/hr) |
| # Shafts | 2 |
| Sources | P&W Manufacturer Catalog, EASA E069 |

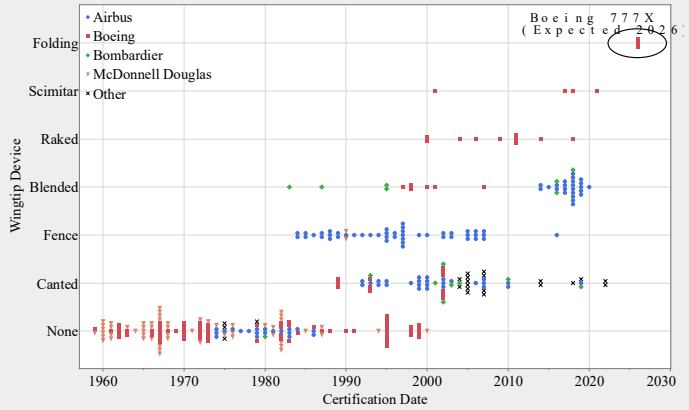

- Acar, et al. 2025, *Journal of Aircraft*, DOI: 10.2514/1.C038340
- Arnson, et al., 2025, *Journal of Aircraft*, in press. (preprint available on lab website)

Acar, et al. 2025,
*Journal of Aircraft*,
DOI: 10.2514/1.C038340

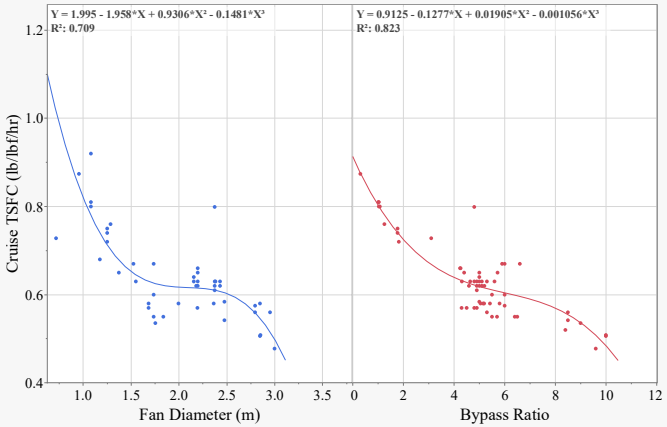
# Historical Trends in Key Performance Parameters

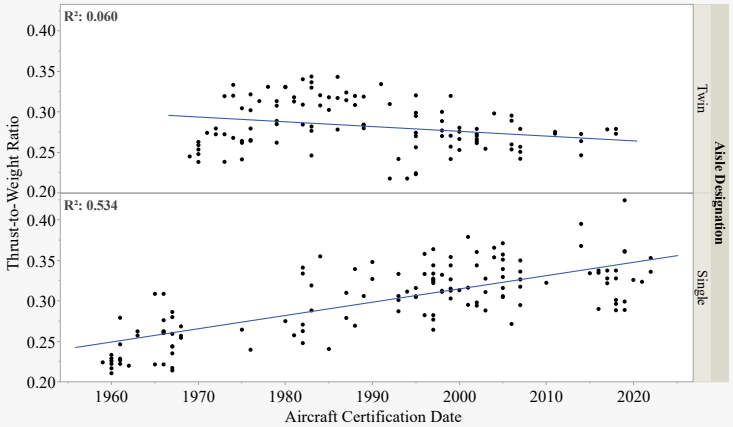


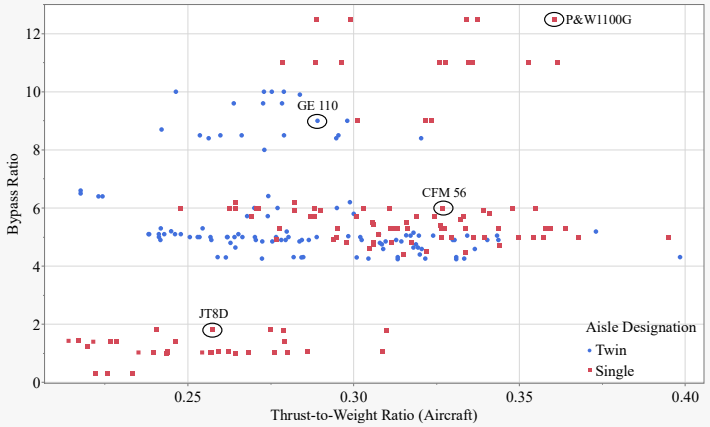




## Historical Data Unlocks the Drivers of Performance Evolution



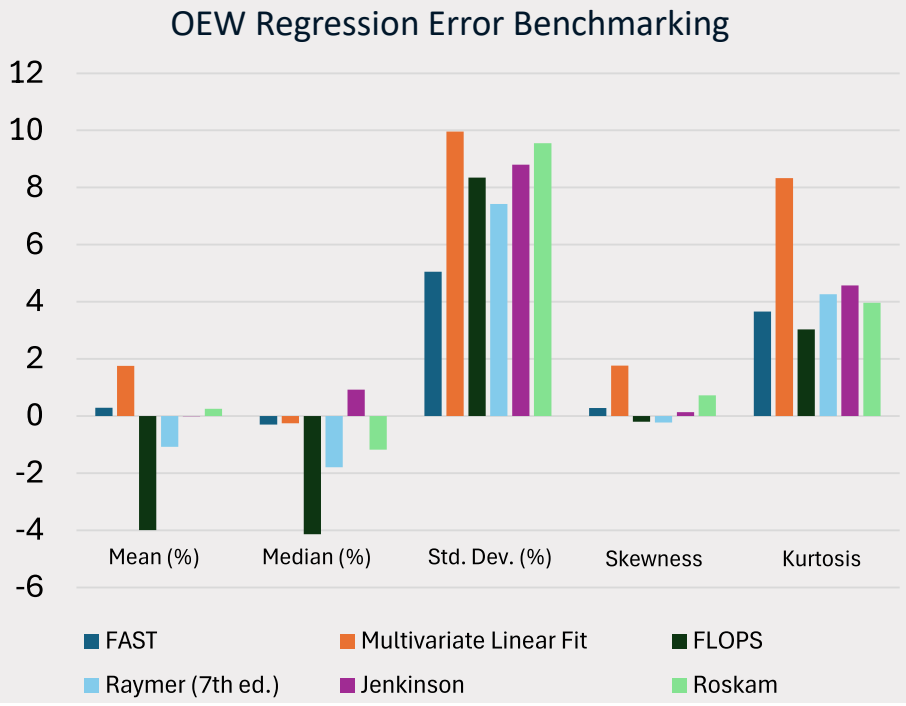

## *and Informs Electrified Aircraft Design*

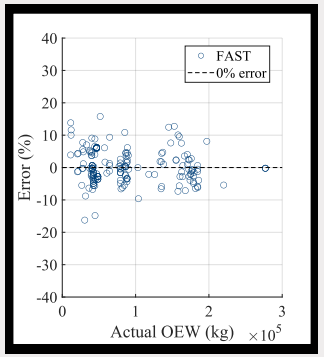
Gökçin Çınar | cinar@umich.edu | www.gokcincinar.com

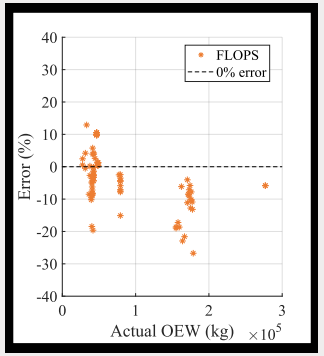
# Probabilistic Regressions on Aircraft Performance Parameters

Gaussian-process regressions reduce sizing uncertainty and extend historical methods to electrified aircraft.

## Leading Data-Driven Method Development




Arnson, et al., 2025, *Journal of Aircraft*, in press. (preprint available on lab website)

## Tool Agnostic

FAST

AVIARY

## Adaptable to Electrified Concepts

**A**irframe + **S**tructures + **O**perations

$$W_{ASO} = W_{MTO} - W_{Payload} - W_{Energy} - W_{Propulsion}$$

| Aircraft | Predicted ASO (kg) | True ASO (kg) | Difference (%) |
|---|---|---|---|
| SUSAN | 39,310 | 39,800 | -1.231 |
| SUGAR Volt: Balanced | 33,530 | 36,070 | -7.042 |
| SUGAR Volt: Core-Shutdown | 40,820 | 38,290 | +6.607 |

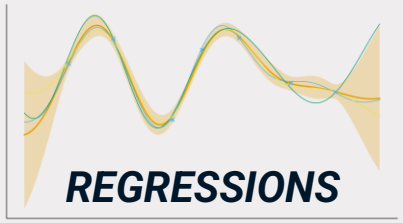
# Future Aircraft Sizing Tool

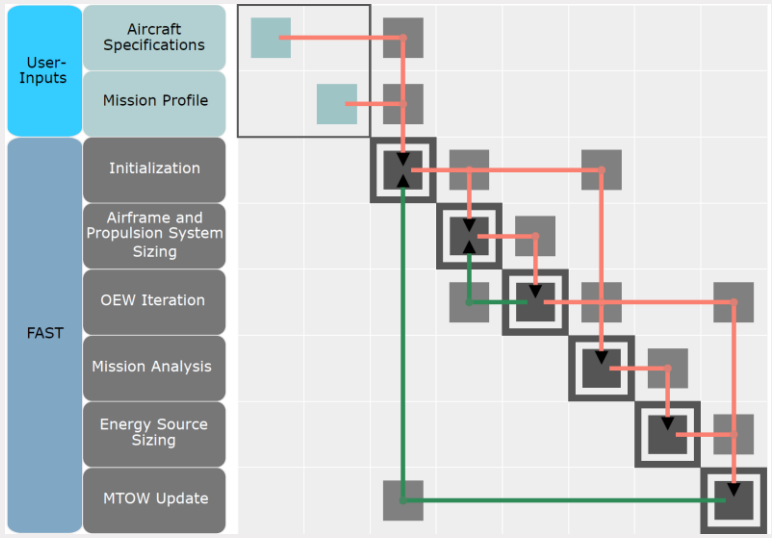
*Open Source on GitHub*

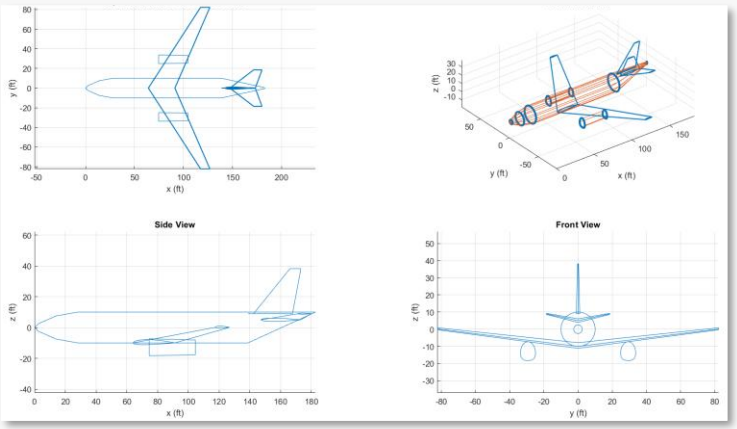
## Adaptive, Multi-Fidelity Aircraft Design via Integrated Data- and Physics-Based Modeling

Over 400 turbofan aircraft, 70 turboprop aircraft, and 200 gas turbine engines.

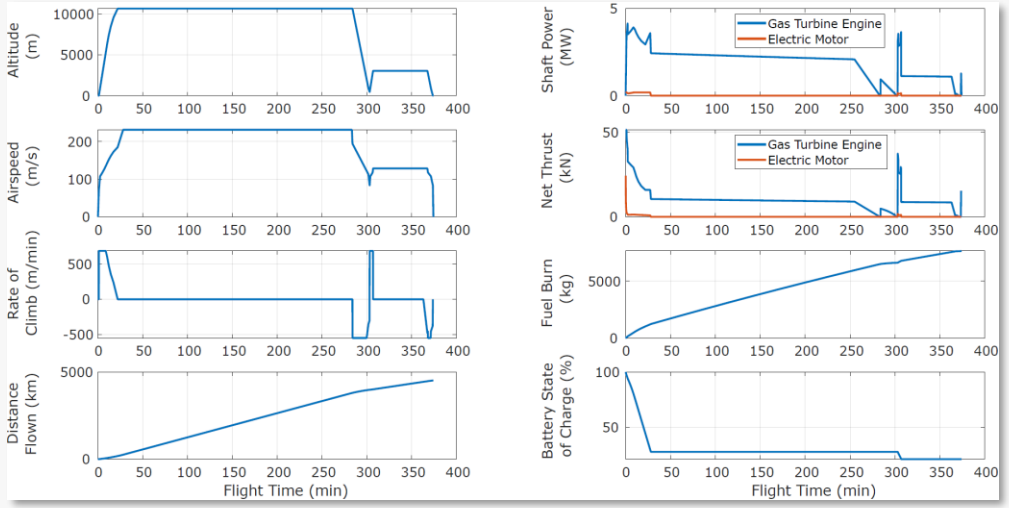
***AEROBASE***



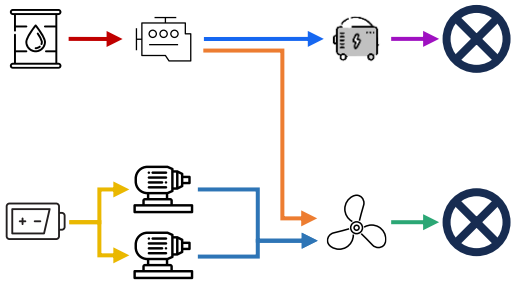




## Rapid mixed-variable design space exploration




## Novel Graph-based Propulsion System Analysis Framework



*Machine-readable Propulsion Architecture Encoding*

$$A = \begin{bmatrix} 0&0&1&0&0&0&0&0&0 \\ 0&0&0&0&1&1&0&0&0 \\ 0&0&0&1&0&0&1&0&0 \\ 0&0&0&0&0&0&0&0&1 \\ 0&0&0&0&0&0&1&0&0 \\ 0&0&0&0&0&0&1&0&0 \\ 0&0&0&0&0&0&0&1&0 \\ 0&0&0&0&0&0&0&0&0 \\ 0&0&0&0&0&0&0&0&0 \end{bmatrix}$$



Mokotoff et al., 2025, *Journal of Aircraft*, DOI:10.2514/1.C038452

# NASA SUbsonic Single Aft eNgine (SUSAN) Concept

Image credit: nasa.gov

# SUSAN’s Turboelectric Distributed Propulsion

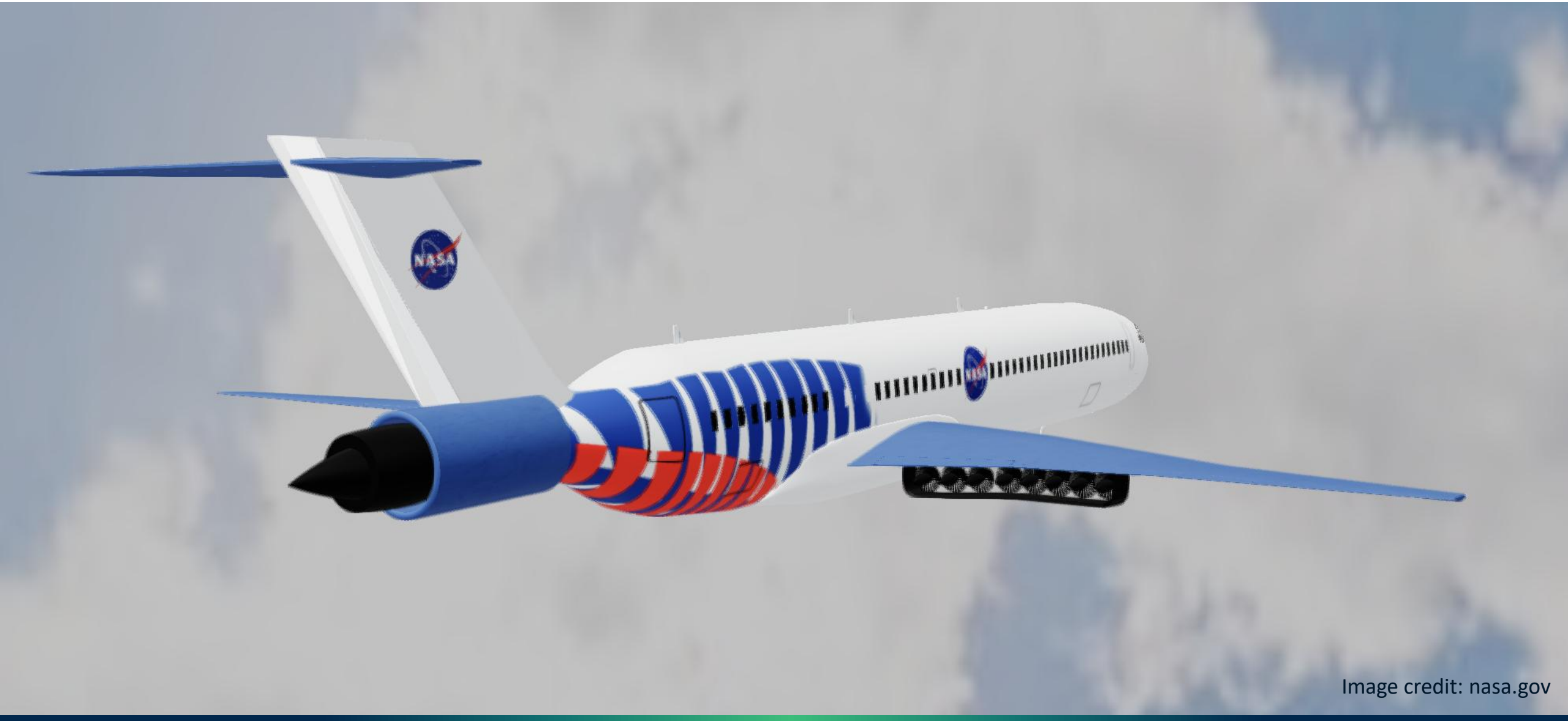
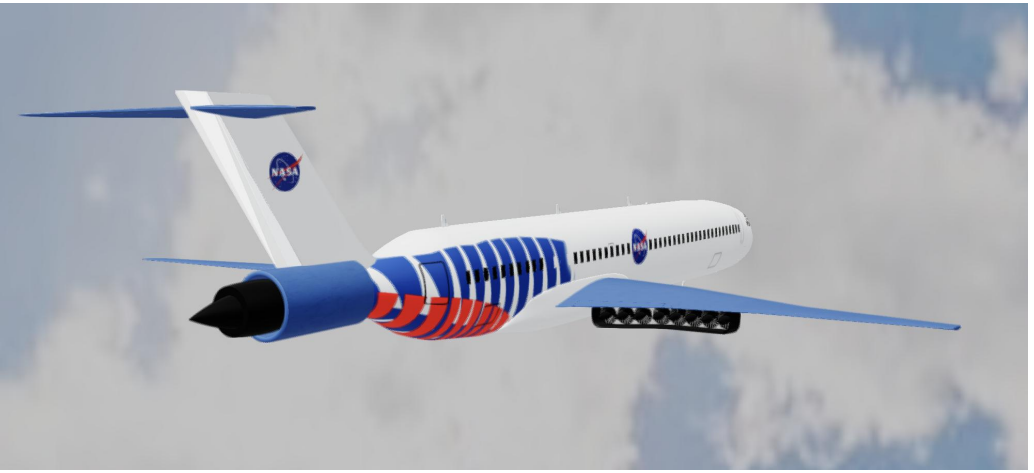
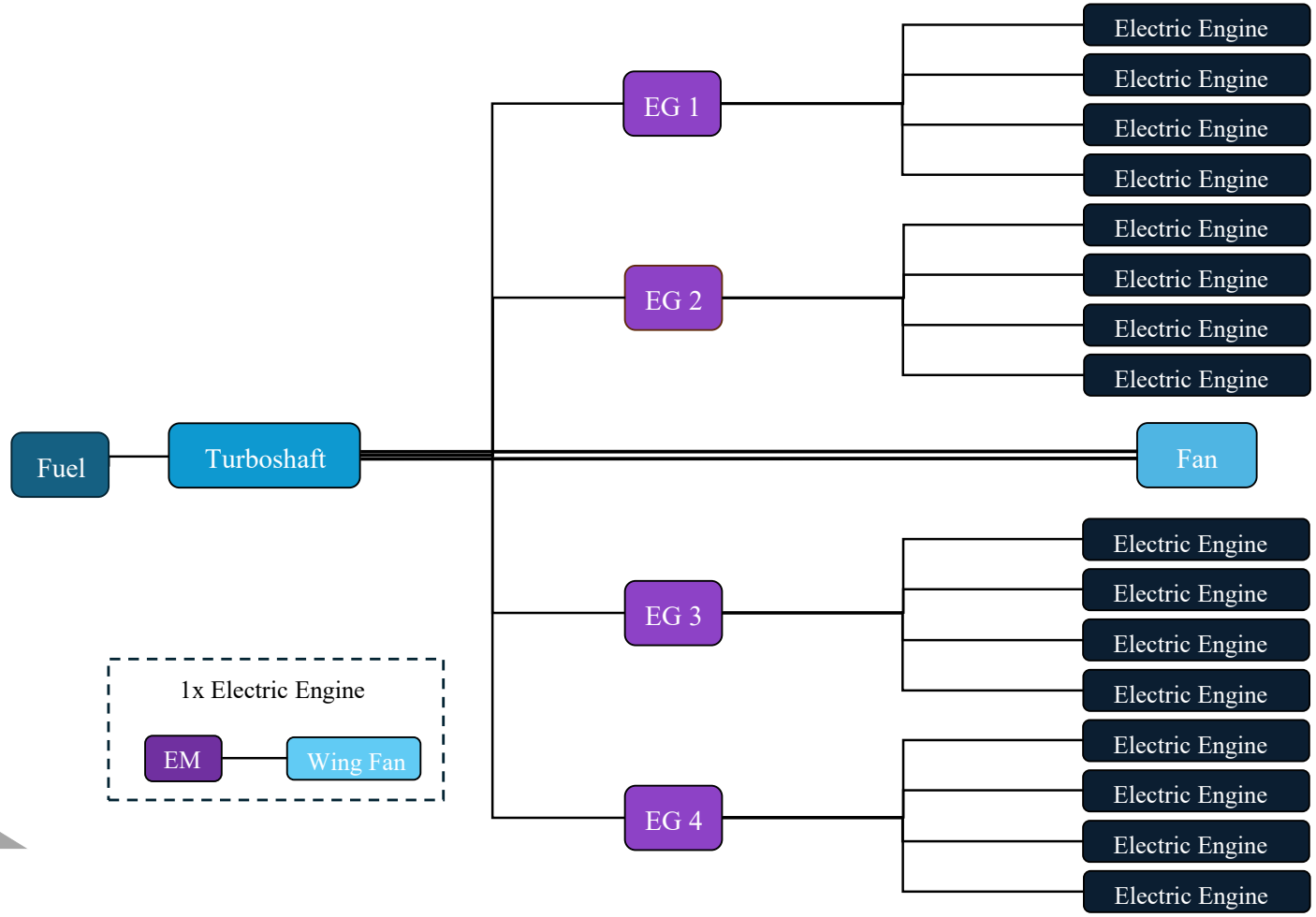



Image credit: nasa.gov

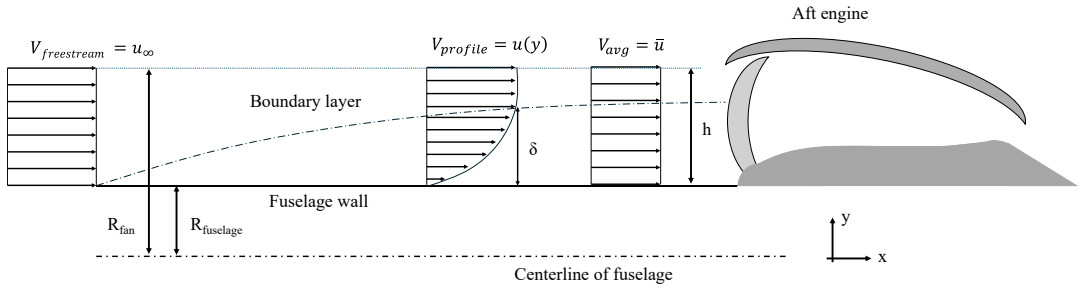
# SUSAN Propulsion System Model in FAST






## Boundary Layer Ingestion

*TSFC reduced by 1.6%*

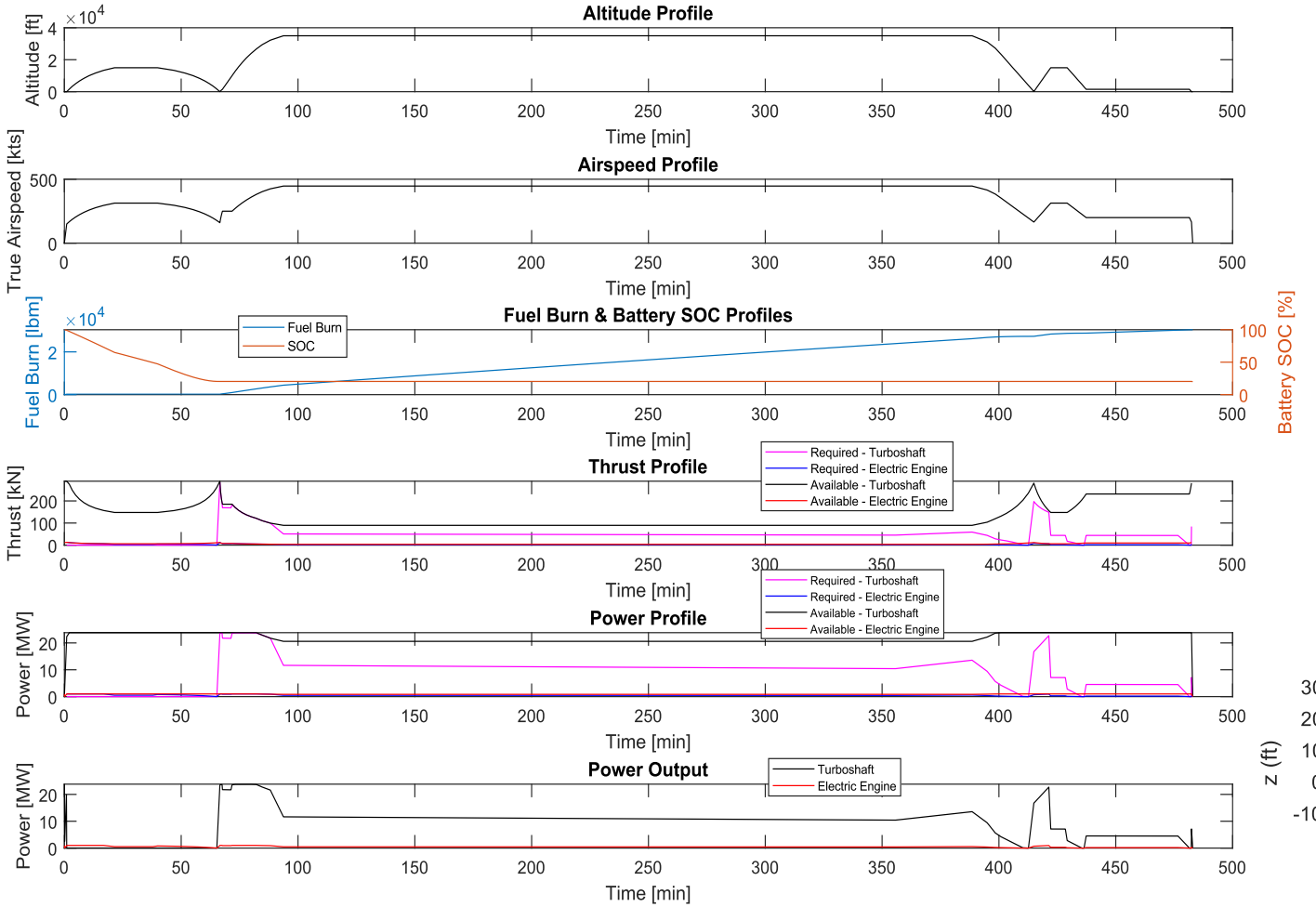


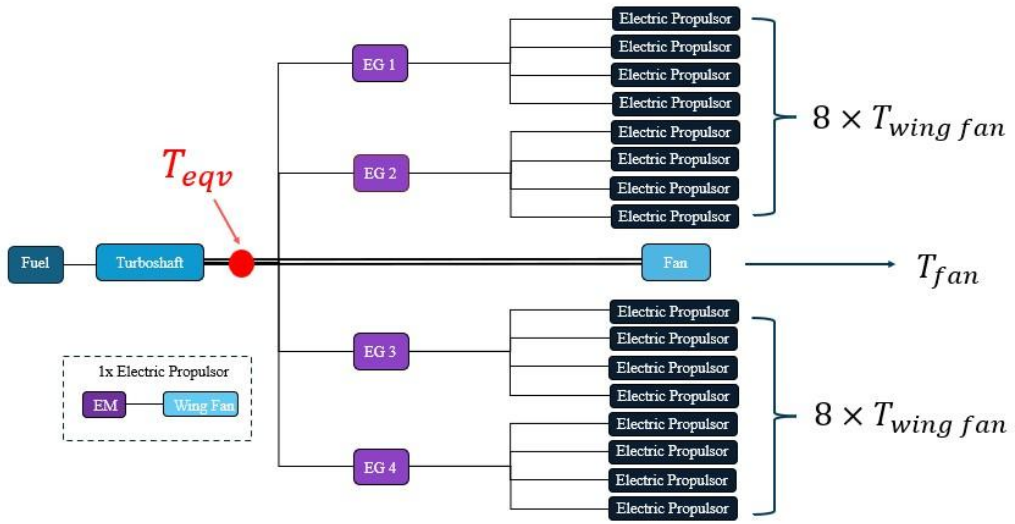

Wang, et al., 2025, AIAA SCITECH Forum, DOI: 10.2514/6.2025-2376

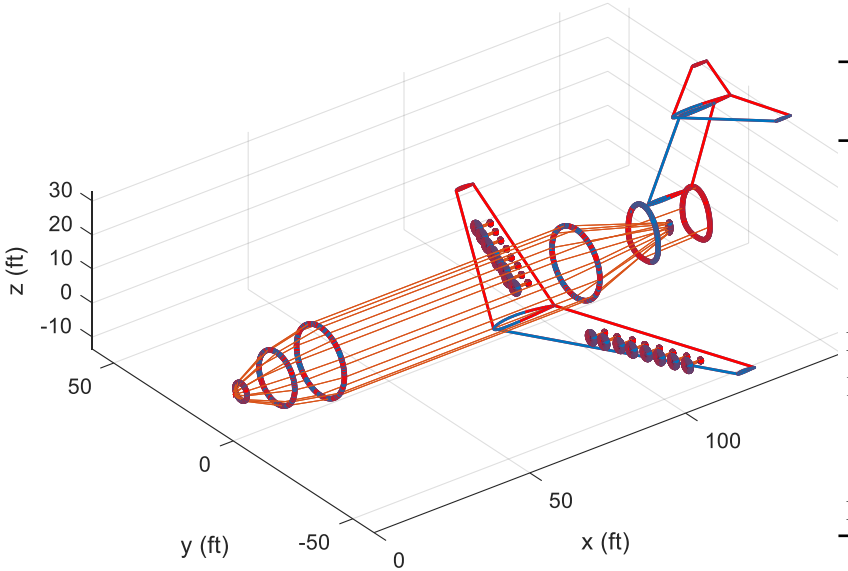
# SuSAN in FAST

**Novel Equivalent Thrust Method for Accurate Hybrid-Electric Fuel Flow**

$$\dot{m}_f = a \times \left( C_{ff3}\left(\frac{T_{eqv}}{T_{eqv,max}}\right)^3 + C_{ff2}\left(\frac{T_{eqv}}{T_{eqv,max}}\right)^2 + C_{ff1}\left(\frac{T_{eqv}}{T_{eqv,max}}\right)\right) + C_{ff,ch} \times T_{eqv} \times h$$




| Weight Group | FAST Results (lbs) |
|---|---|
| MTOW | 188302 |
| OEW | 108447 |
| Airframe | 79365 |
| Payload | 39710 |
| Block Fuel | 30305 |
| Propulsion System | 15087 |
| Battery | 8319 |
| Block Fuel | 30305 |

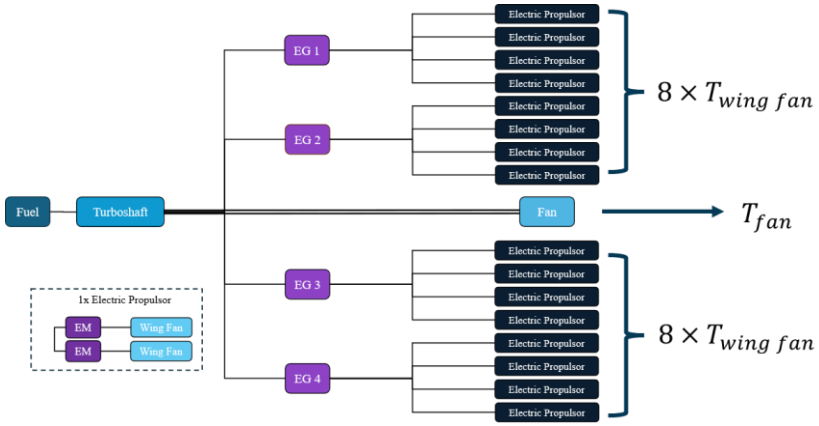
11,000 lbs less fuel than Boeing 737-8Max

Wang, et al., 2025, AIAA SCITECH Forum, DOI: 10.2514/6.2025-2376

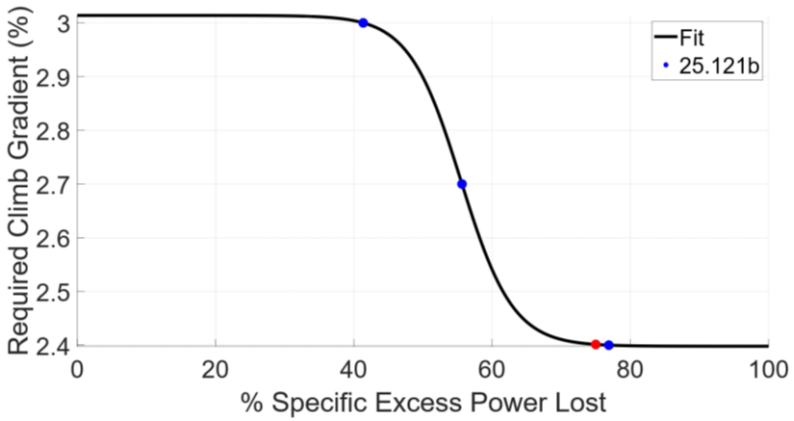
# Electrified Powertrain Flight Demonstration Project

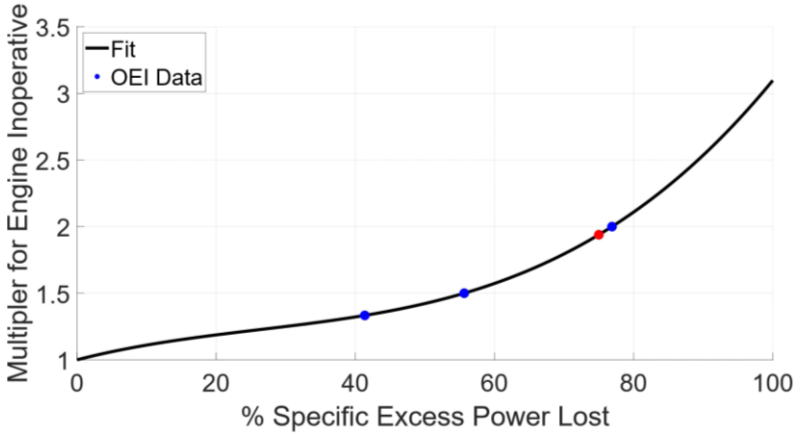
## Novel Performance Requirements for Advanced Propulsion Concepts and Operational Scenarios

*Select Configuration and Engine Inoperative Scenario*

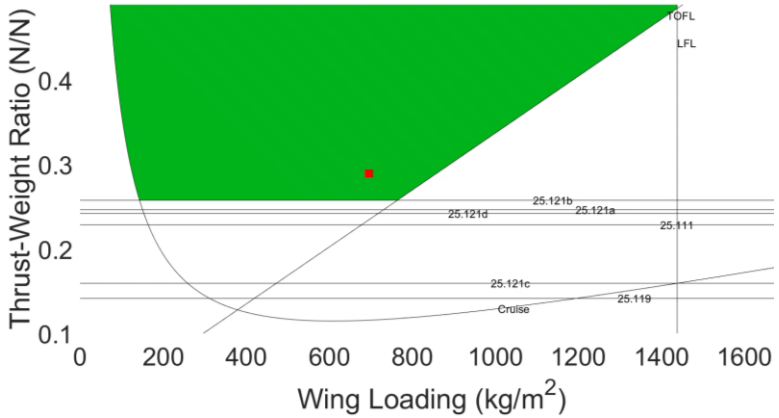


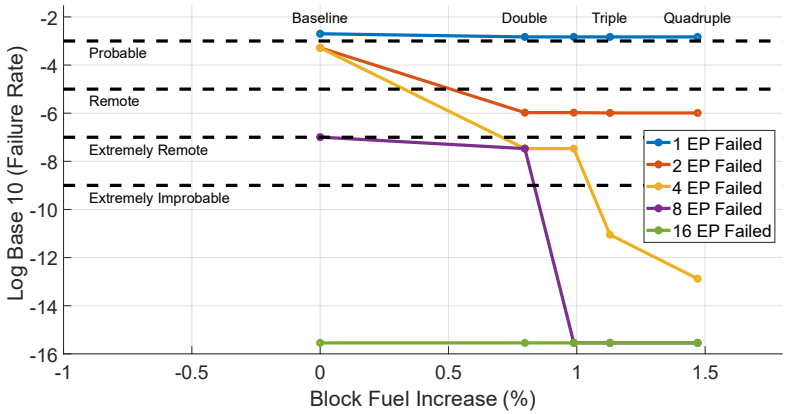

*Continuous Performance Requirements Applicable to All Aircraft Concepts*




*Propulsion System Performance and Safety from Operational Conditions*



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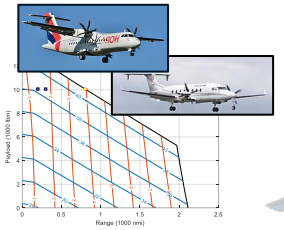
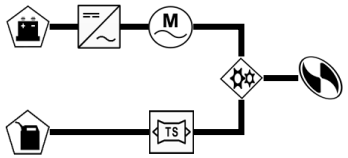


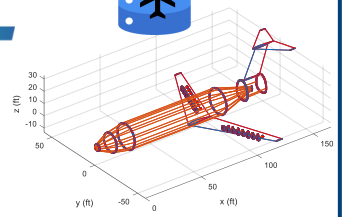


| | | | | | |
|---|---|---|---|---|---|
| S.I | TX | TKO | CLB (full) | CRZ | DSC |
| S.II | TX | TKO | CLB (lo-alt) | CRZ ↑ | DSC ↑ |

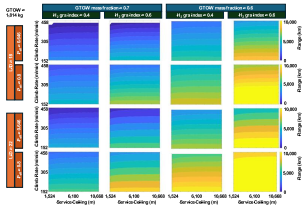
## II. Advanced Concepts

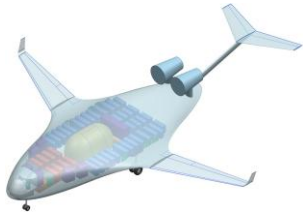
Turning Legacy into Leverage

FAST



Hydrogen Fuel Cells

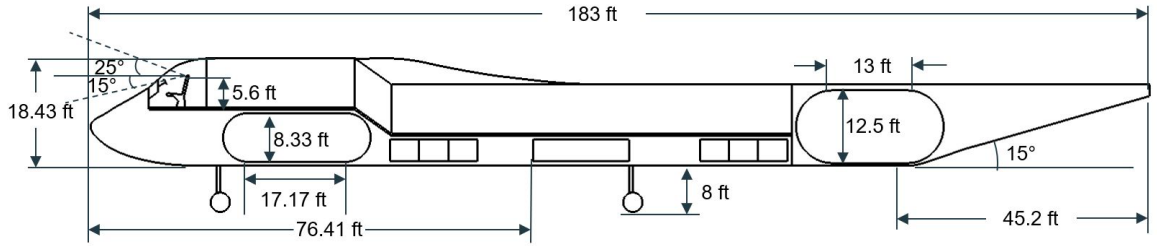


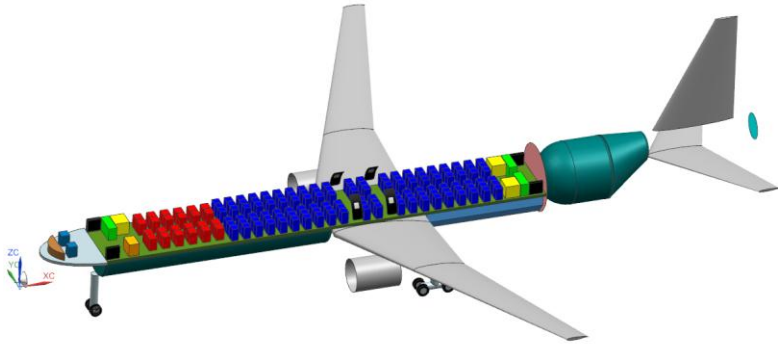


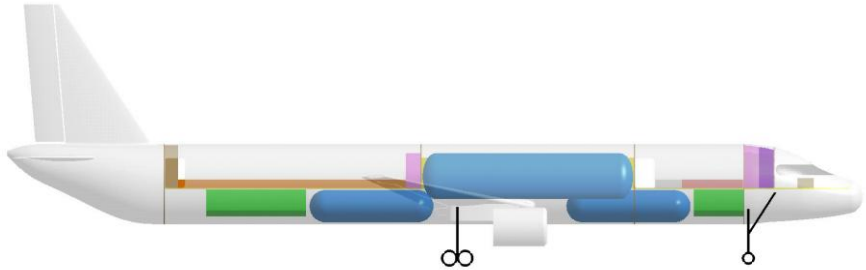
## III. Digital Transformation

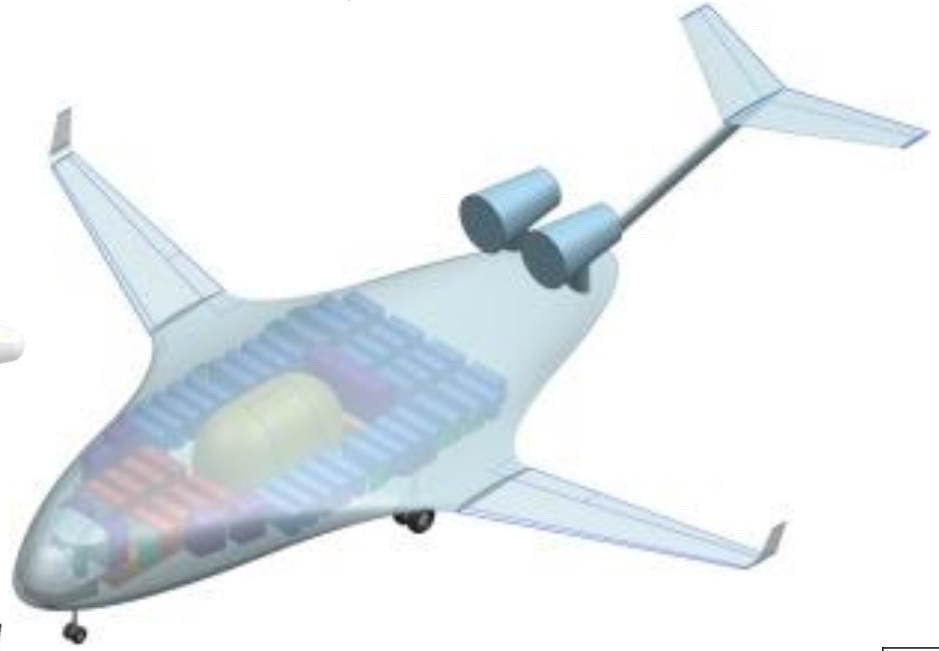
# $H_2$ Tank Integration: Student designs

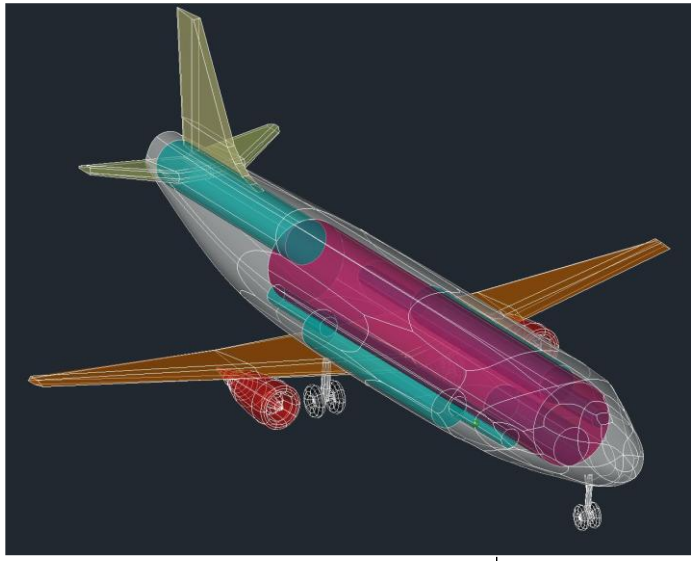
U-M Aerospace Engineering
Senior Capstone Design
Projects, Fall 2023

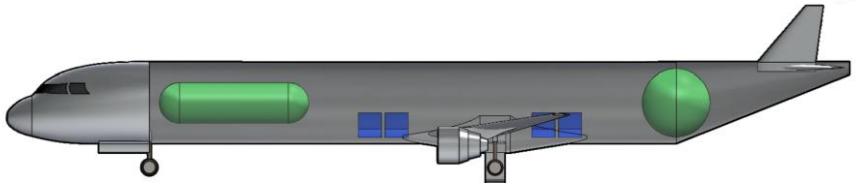


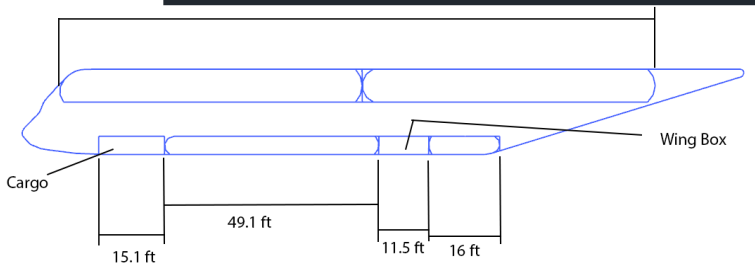







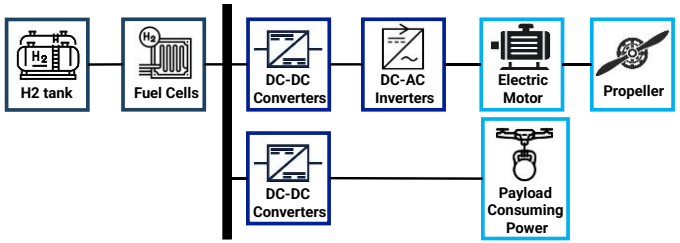


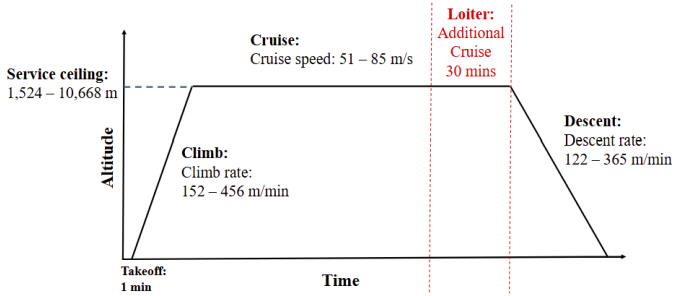


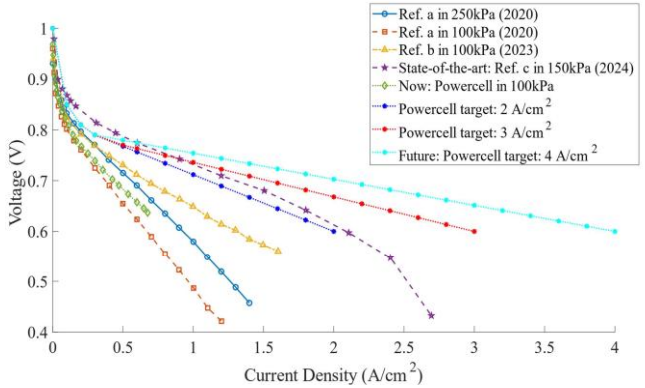


# Design Space Exploration and Performance Analysis of Fuel Cell Propulsion Aircraft

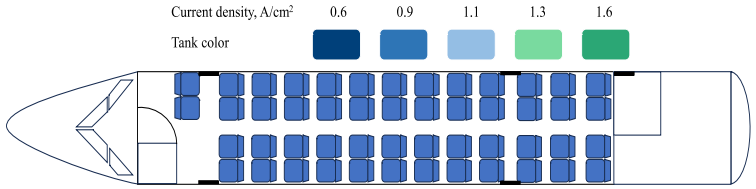
## Fuel Cell Propulsion System and Operation Modeling



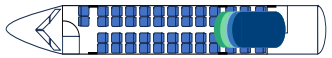




## Tank Integration – Retrofitting

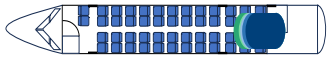



(a) Original seat map of Dash 8 Q300.

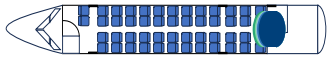
(b) 100% power split



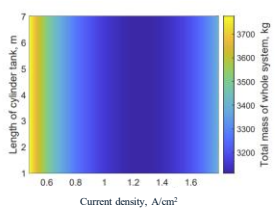
(c) 75% power split.



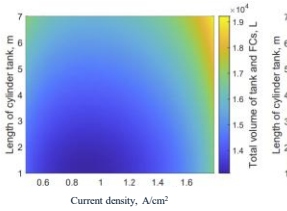
(d) 50% power split.



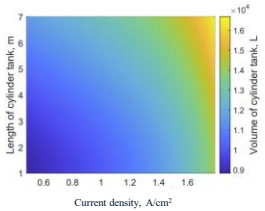
(e) 25% power split.



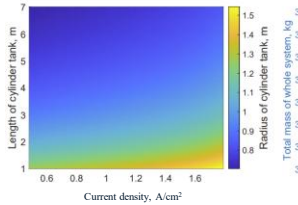

(a) The change of the total mass of the whole system.



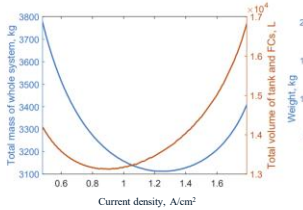

(b) The change of the total volume of tank and FCs.



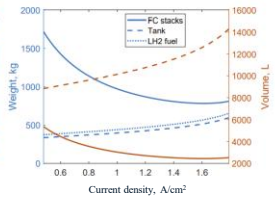

(c) The change of the volume of hydrogen tank.




(d) The change of the shape of hydrogen tank.

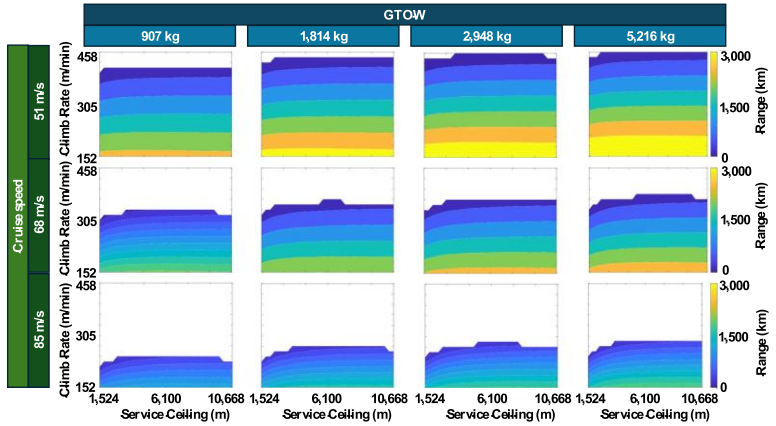


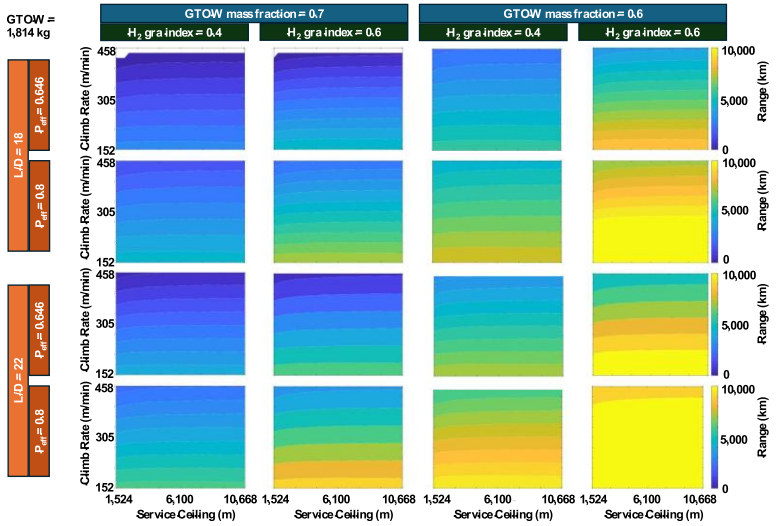

(e) The comparison of total mass volume of the system.




(f) The change of the weight of FCs, tank and LH2 fuel.

## Clean Sheet Design





- Wang, & Cinar, 2024, *AIAA AVIATION FORUM AND ASCEND*, DOI: 10.2514/6.2024-3829 (Best Paper Award)
- Wang, et al., 2025, *IEEE/AIAA Transportation Electrification Conference and Electric Aircraft Technologies Symposium,* DOI: 10.1109/ITEC63604.2025.11098128

# Agenda

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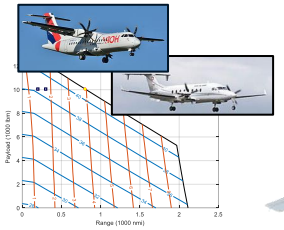
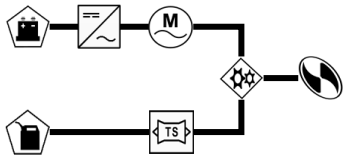
**Why Electrify:** Opportunities and Challenges

**Case Study:** Systems Design and Analysis for NASA EPFD Project





| | | | | | |
|---|---|---|---|---|---|
| S.I | TX | TKO | CLB (full) | CRZ | DSC |
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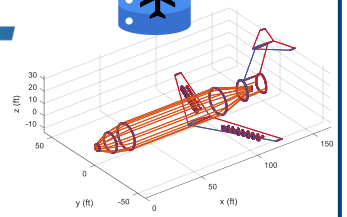
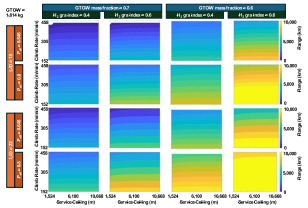
## II. Advanced Concepts

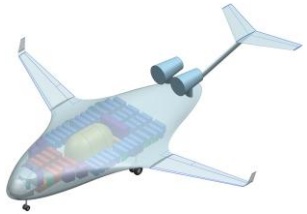
Turning Legacy into Leverage

FAST

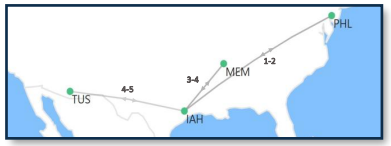


Hydrogen Fuel Cells



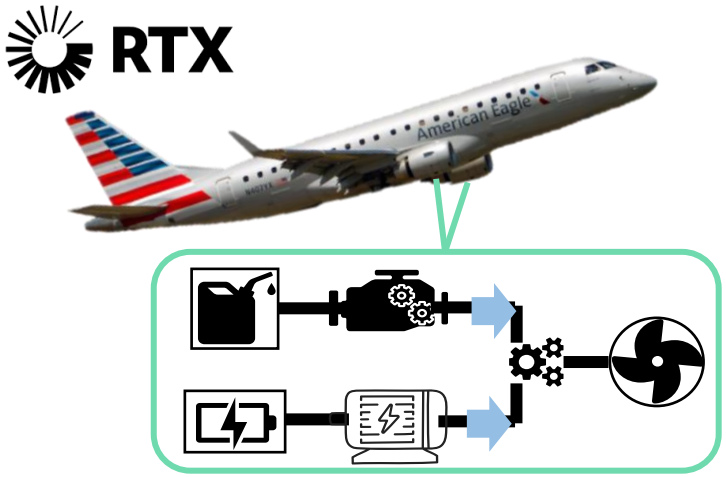


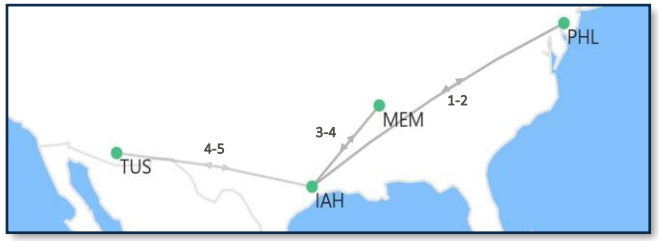
**System-of-Systems**: Fleet operations

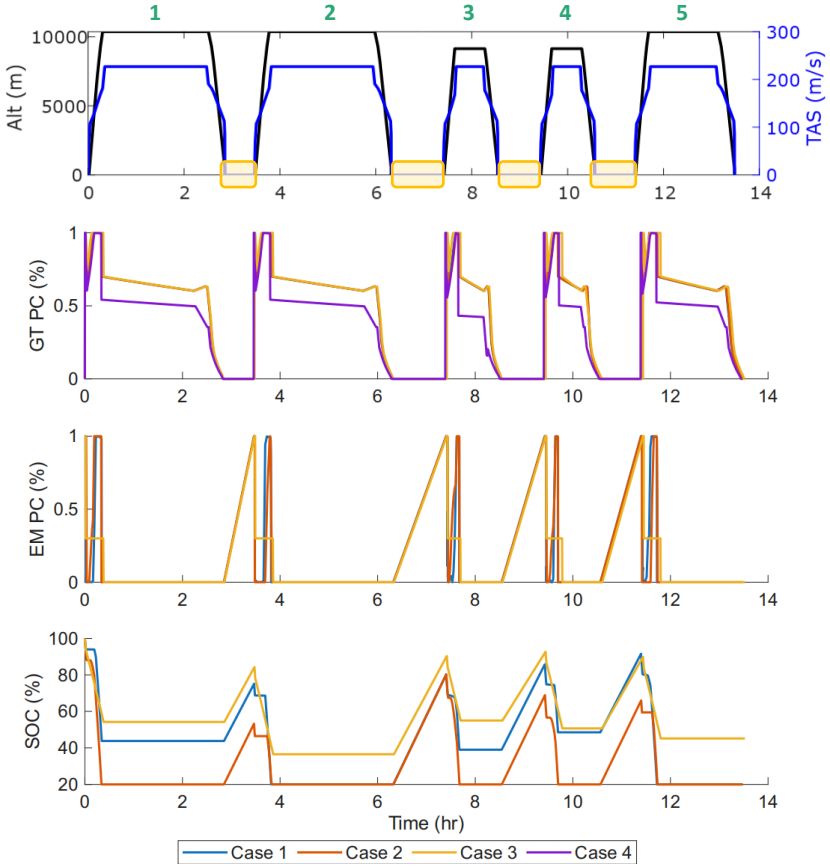



## III. Digital Transformation

# Power Management Optimization for Hybrid Electric Regional Aircraft on Sequential Missions




## Beyond the Design Mission: Optimizing Power Management Across *Real-World* Airline Operations

*Minimize fuel burn for all flights in a daily sequence*

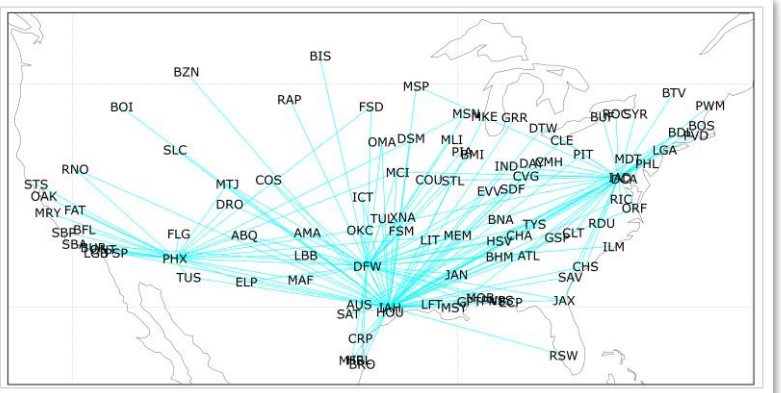
$$\text{minimize} \quad \sum_{k=1}^{n} W_{f,k}$$

*Controlling the power usage in each flight separately*

$$\text{by varying} \quad PC_{\mathrm{EM},k,i},\ PC_{\mathrm{GT},k,i},$$

$$\begin{aligned} \text{subject to} \quad & 0\% \le PC_{\mathrm{EM},k,i} \le 100\%, \quad 0\% \le PC_{\mathrm{GT},k,i} \le 100\%, \\ & 20\% \le SOC_k \le 100\%, \quad TOGW_k \le MTOW, \\ & P_{\mathrm{req},k,i} \le P_{\mathrm{av},k,i}, \quad RC_{k,i} \le RC_{\max}. \end{aligned}$$

*Accounting for the existing airline schedule (time at the gate), charging infrastructure, and battery & flight performance*



## Expanded to Full Network *Cost* Optimization

| Compared 4 aircraft cases on test sequence | Fuel Savings |
|---|---|
| *Case 1.* HEA – power codes optimized across the entire sequence | %3.02 |
| *Case 2.* HEA – power codes optimized for each individual mission | %2.84 |
| *Case 3.* HEA – original design power codes | %1.04 |
| *Case 4.* Conventional baseline model | -- |


- Cassidy. et al. 2025, *Aerospace, DOI:* 10.3390/aerospace12070598
- Cassidy. et al. 2025, *IEEE/AIAA Transportation Electrification Conference and Electric Aircraft Technologies Symposium.* DOI: 10.1109/ITEC63604.2025.11098014
- Kamat, et al. 2025, *IEEE/AIAA Transportation Electrification Conference and Electric Aircraft Technologies Symposium,* DOI: 10.1109/ITEC63604.2025.11098001

# Fleet Level Operations and Technology Integration Environment

Integrate technology into platform

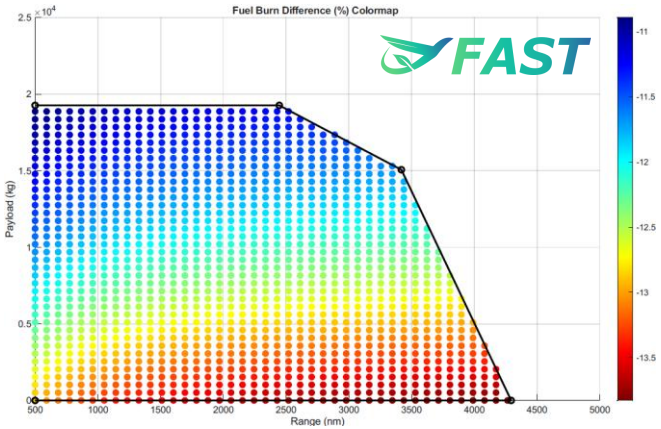
**Goal:** Analyze advanced aircraft technology impacts on future fleets

Group1 Technology

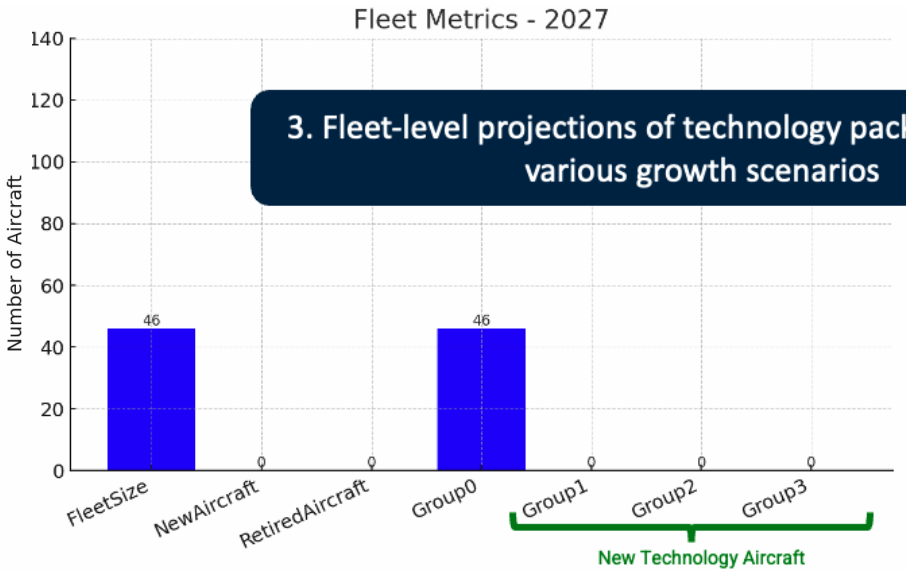
| Categories | Technologies | Weight | L_D | Power | Fuel |
|---|---|---|---|---|---|
| Airframe | Composite Wings | -5% | NA | NA | NA |
| | Composite Fuselage | -5% | NA | NA | NA |
| | Composite Tail | -1% | NA | NA | NA |
| | Folding Wingtips | NA | 3% | NA | NA |
| | Thin Wings | 1% | 5% | NA | NA |
| | BLI | NA | NA | NA | -9% |
| Landing Gear | full electric landing gear | -2% | NA | 1% | NA |
| Power Distribution | High voltage electric power lines | -2% | NA | -1% | NA |
| | Electric actuators | -1% | NA | NA | NA |
| Flight Control | Thin profile actuators | NA | -1% | NA | NA |
| | Elevators (electric) | NA | NA | 1% | NA |
| | Rudder (electric) | NA | NA | 1% | NA |
| | Fly-by-Wireless | 2% | NA | NA | NA |
| | Fly-by-Light | 1% | NA | NA | NA |
| | Wireless Avionics Networks | 0.5% | NA | NA | NA |
| | Active Flow Control | 2% | NA | NA | NA |
| Propulsion | Ultra High Bypass Turbofan | NA | NA | NA | -5% |
| | Geared Turbofan | NA | NA | NA | -10% |
| | Series Hybrid Electric | NA | NA | NA | NA |
| | Parallel Hybrid Electric | NA | NA | NA | NA |
| | Advanced Materials Propeller | NA | 5% | NA | NA |
| | Aeroefficient Propellers | NA | NA | NA | -5 |
| Cabin | Lightweight Seats | -5% | NA | NA | NA |
| | BYOD Cabins | NA | NA | NA | NA |

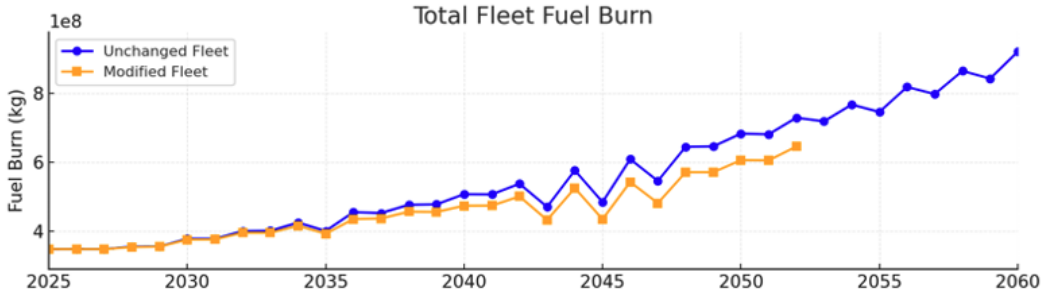
1. Component-level technology impacts

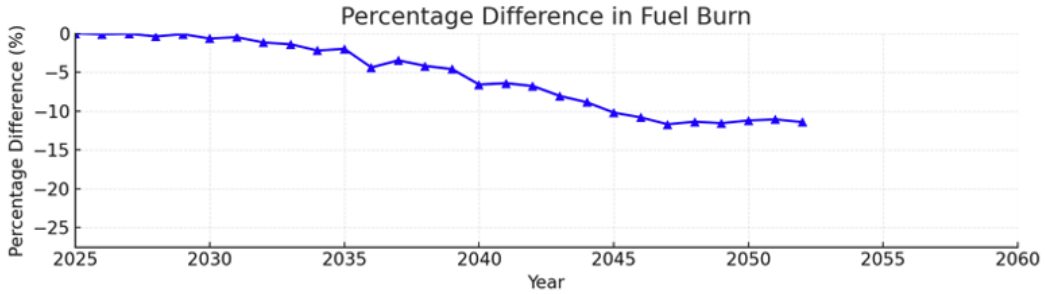
2. Aircraft-level performance




3. Fleet-level projections of technology packages based on various growth scenarios



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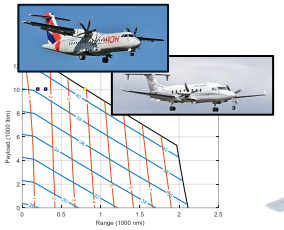

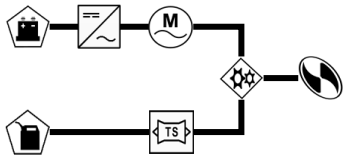

| | | | | | |
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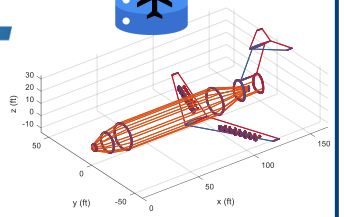

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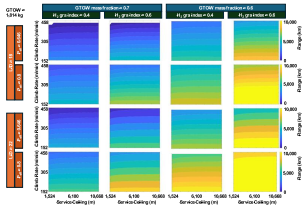

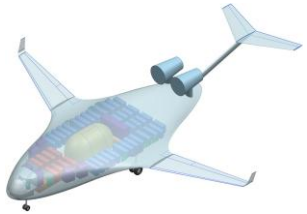

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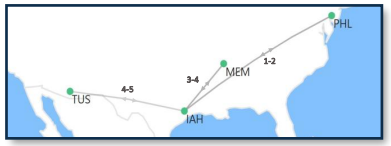
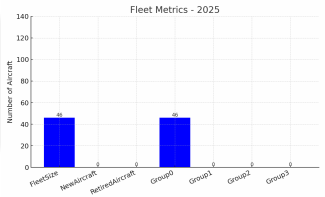
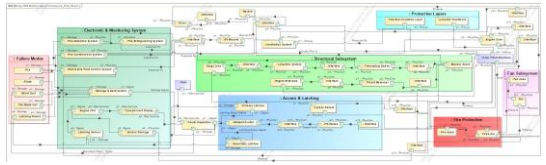


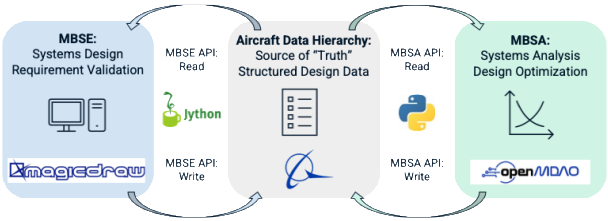




## III. Digital Transformation

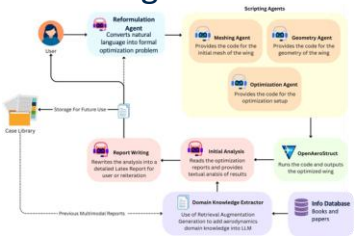
Digital Thread for Sustainable Propulsion System Design



Model-based Systems Analysis & Engineering



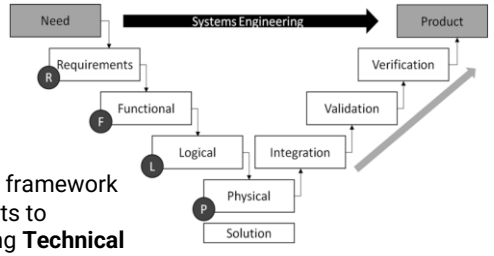

AI-Enabled Digital Transformation



# Digital Thread for Sustainable Propulsion System Design

## Model-Based Systems Engineering (MBSE) Framework

MBSE provides a structured digital approach to aircraft design using SysML.

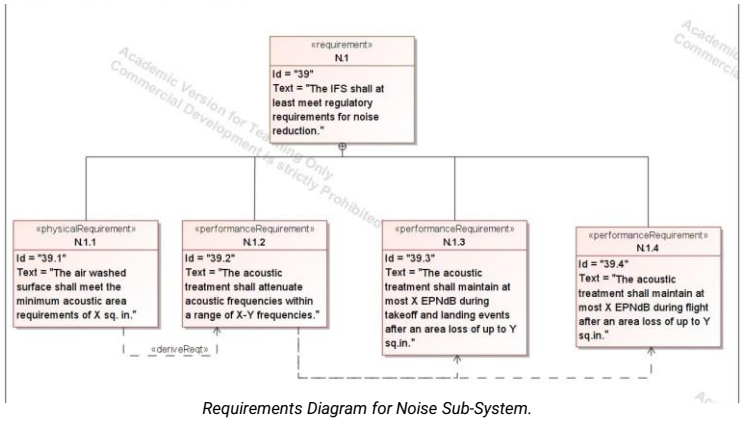



**Research Goal:** Develop an MBSE framework that connects system requirements to component-level design, advancing **Technical Design Documentation** (TDD) for integrated decision-making.

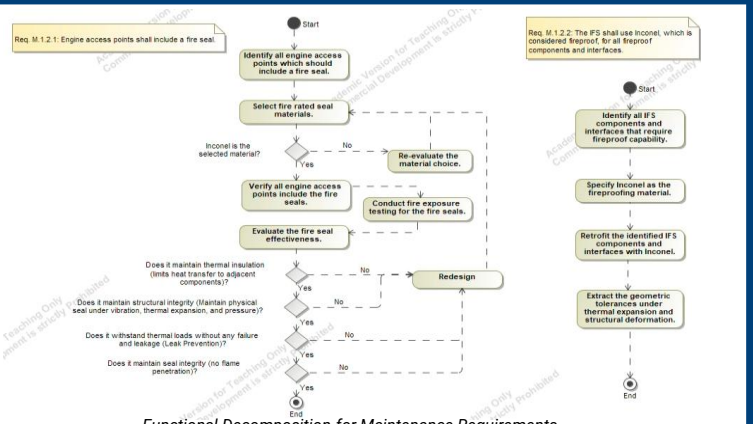
**Demonstration:** Implemented a SysML-based digital thread capturing requirement-to-component traceability in an engine-inlet subsystem. [Jagtap et al., 2025]

## Iterative Modeling for Next-Gen Engine Inlet Design

Extending MBSE to hybridized propulsion architectures via a two-phase iterative approach in SysML/MagicDraw.



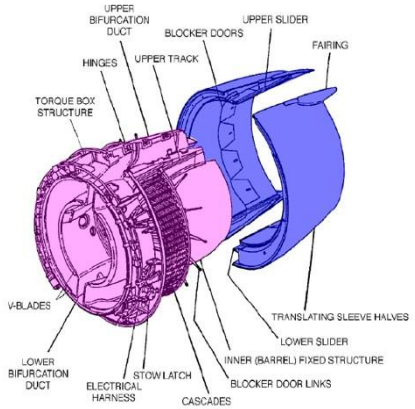

*Requirements Diagram for Noise Sub-System.*



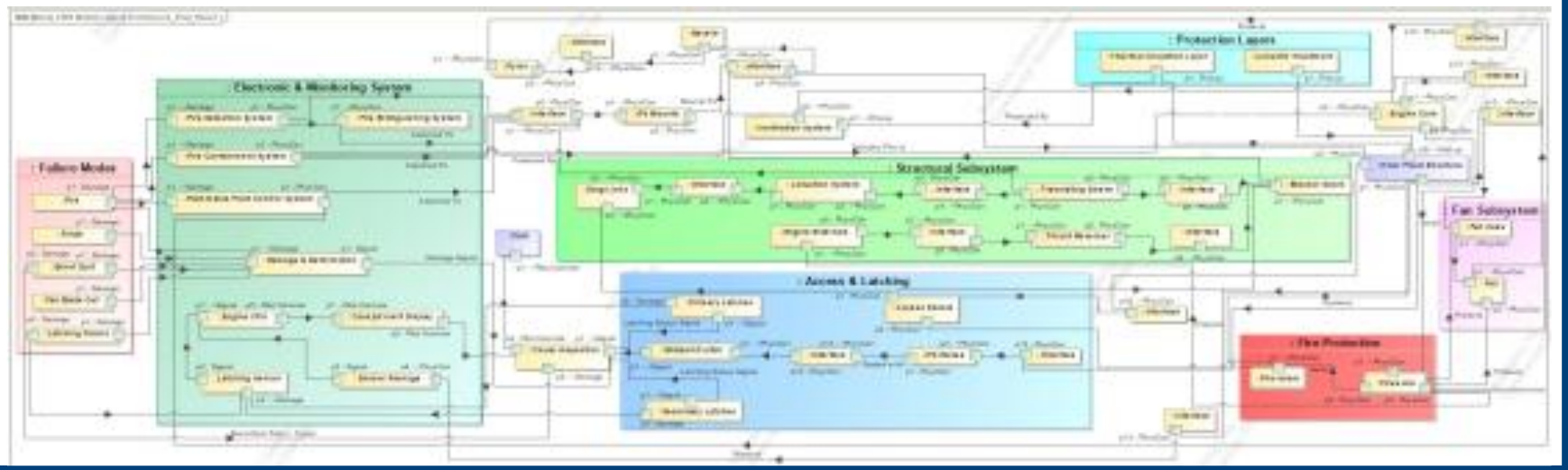

*Functional Decomposition for Maintenance Requirements.*

## From Conventional to Hybridized Design Representation

**Inner Fixed Structure (IFS)**: the inner casing of a turbofan nacelle, the outer shell of the engine "core" compartment.




*Inner Fixed Structure and adjacent components*




***Baseline Logical & Physical Design of the IFS (Phase 1 model)***

**Phase 2:** Integrate a >3MW hydrogen-based superconducting machine to evaluate system-level implications within the IFS design.

**Key Takeaway:** SysML-based digital design models enable interactive traceability, allowing engineers to refine subsystem interactions and evaluate system-level impacts.

# Model-Based Systems Analysis/Engineering

How can MBSA and MBSE capabilities be integrated together during design?

**Coupling Framework Permits Bi-Directional Data Transfer**

**Open-Source API:** https://github.com/ideas-um/MBSAE-API

**MBSE:**
Systems Design
Requirement Validation

MBSE API:
Read

Jython

MBSE API:
Write

magicdraw

**Aircraft Data Hierarchy:**
Source of "Truth"
Structured Design Data

MBSA API:
Read

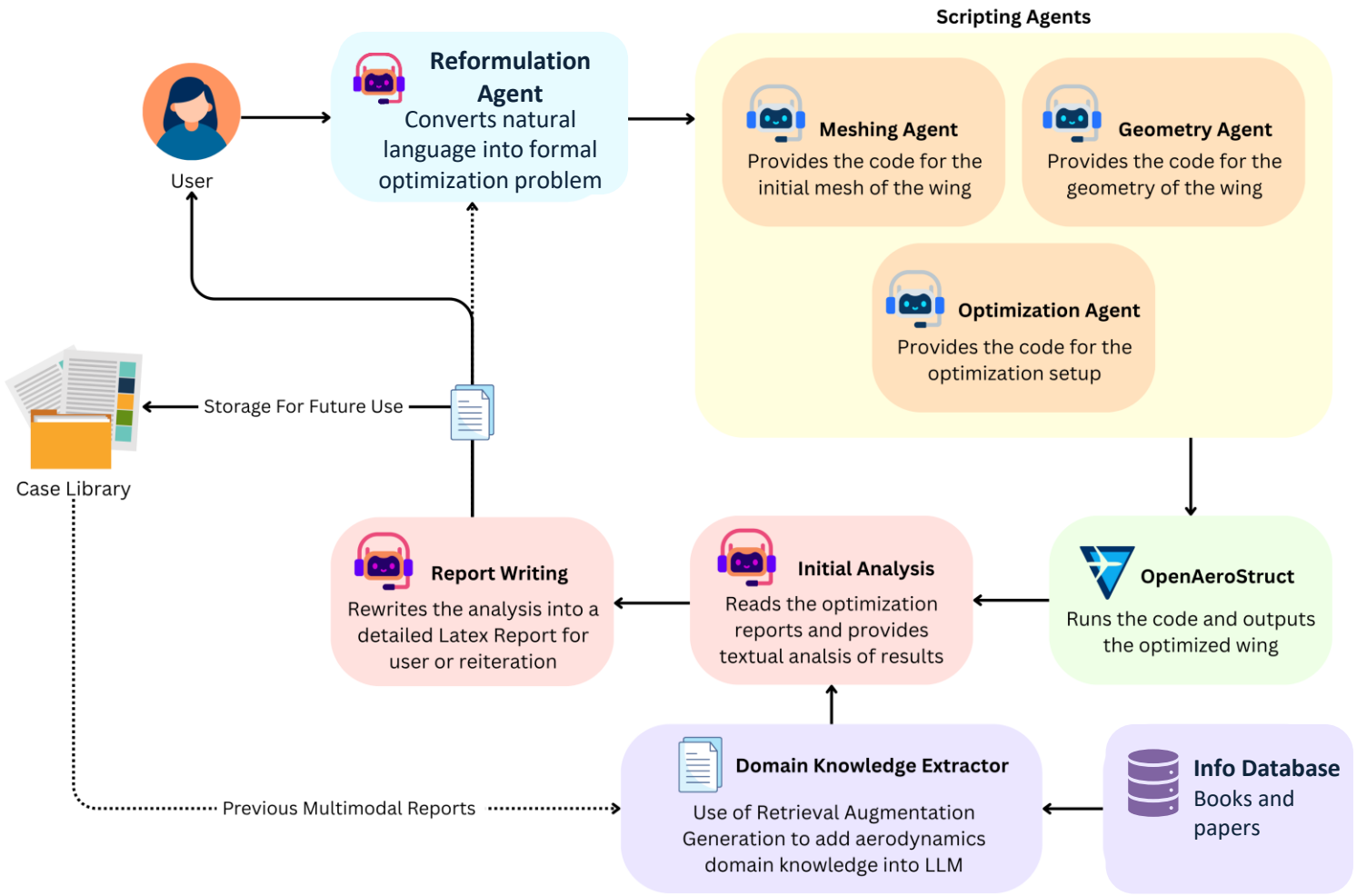
MBSA API:
Write

**MBSA:**
Systems Analysis
Design Optimization

openMDAO

Mokotoff, et al., 2026, Coupling Model-Based Systems Analysis and Engineering Tools for Design Workflows. In *AIAA SciTech 2026 Forum* (accepted).

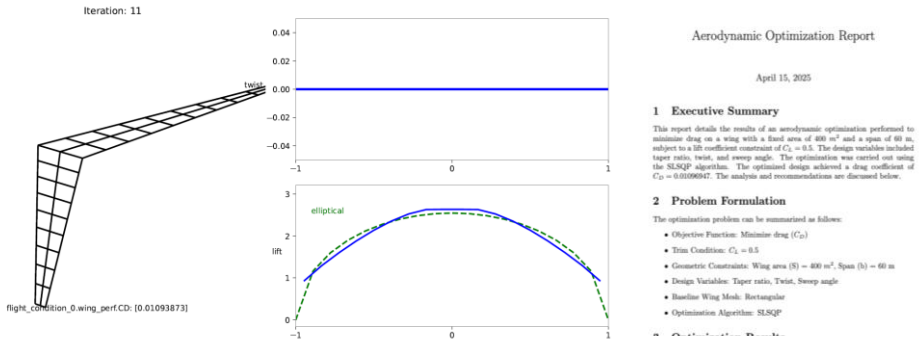
# AI-Enabled Digital Transformation




**User Input 1**

For this design, we will keep the area constant at S = 400 $m^2$. The span is b = 60 m. The cruise condition corresponds to $C_L = 0.5$. Your job is to minimize drag at the condition of $C_L = 0.5$ and you have complete freedom in the taper and sweep of the wing. Make a plot of the elliptical lift distribution.

$$
\begin{aligned}
\min_{\mathbf{x}} \quad & C_D(\lambda, \gamma, \theta, \Lambda) && \text{(Minimize Coefficient of Drag)} \\
\text{subject to} \quad & C_L = 0.5 && \text{(Cruise Trim Condition)} \\
& S = 400\,\text{m}^2 && \text{(Wing Area Constraint)} \\
& b = 60\,\text{m} && \text{(Wing Span Constraint)} \\
\text{where } \mathbf{x} = & \{\lambda, \gamma, \theta, \Lambda\} \in \mathbb{R}^4 && \text{(Design Variables: Taper ratio, Dihedral, Twist, Sweep)}
\end{aligned}
$$




**Open-Source API:**
https://github.com/ideas-um/openaerostruct-llm-agent

Lee, et al., 2025 (preprint)

# Charting the Future of Flight: What It Will Take

- Portfolio of technologies
- High risk, high reward innovations
- Advanced computational methods
- Integration and infrastructure
- Collaboration is the key!

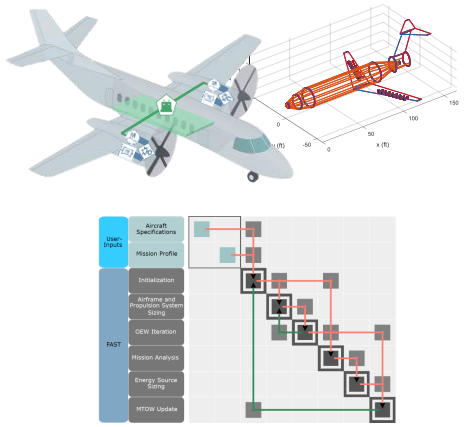
AEROSPACE ENGINEERING
UNIVERSITY OF MICHIGAN

# IDEAS

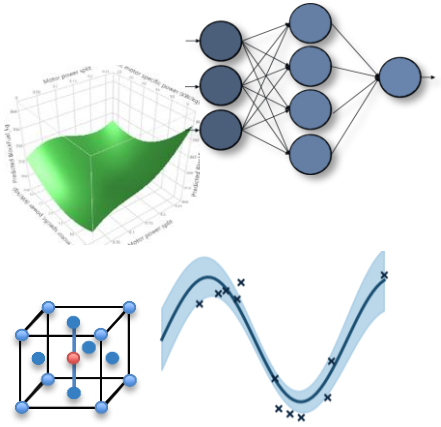
Integrated Design of Efficient Aerospace Systems Laboratory

## Thank you for your attention!
## Our papers and open-source software are available on our website:
## gokcincinar.com | github.com/ideas-um

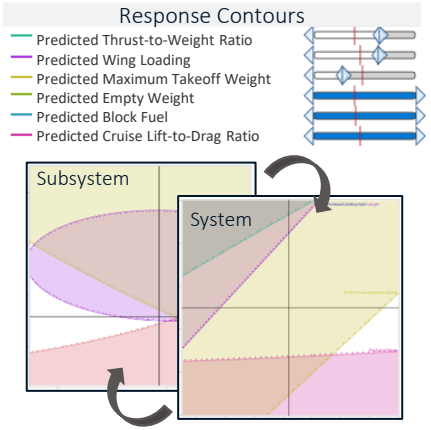
### Multi-fidelity Modeling & Simulation

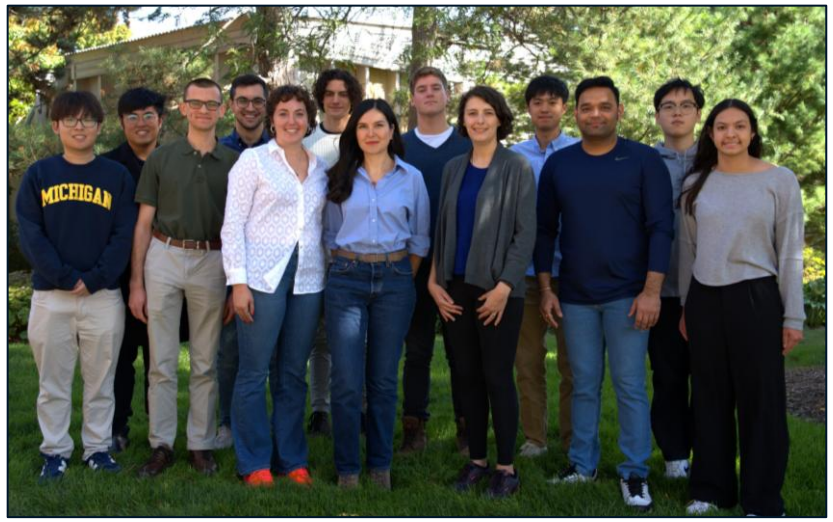


### Data-driven Methods & Machine Learning



### Design Space Exploration & Optimization



Advancing computational methods for the design, analysis, and optimization of future aerospace systems.

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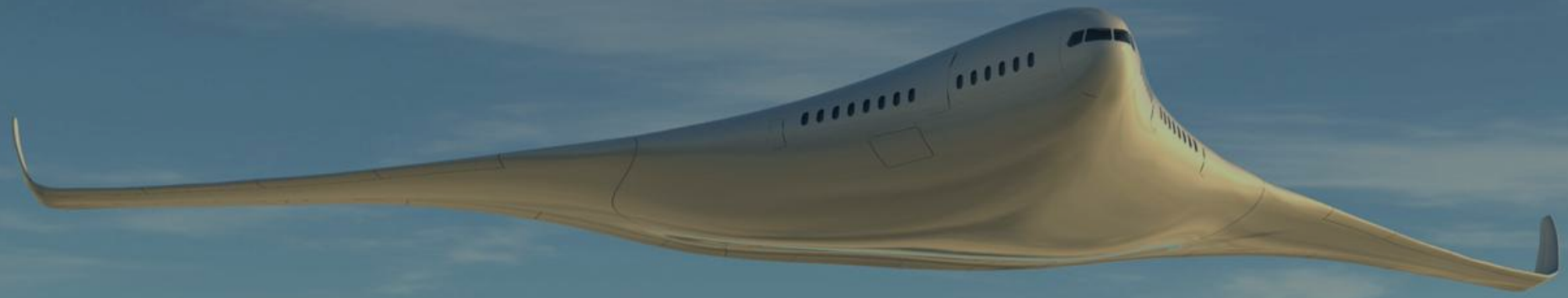
# Michigan Initiative for Sustainable Aviation (MISA)

We aim to **reduce the harmful impact of aviation on the environment** through new practices and radical innovation. Sustainable Aviation has broad implications across disciplines from **engineering to environmental and climate sciences, public policy, business and law**. University and industry partners across disciplines can converge under MISA to bring a **holistic approach that considers the full life-cycle impact of design, development, and operation of aircraft systems on the environment and society.**



**Our research focus addresses:**

- High efficiency airframes
- Propulsion technologies
- Sustainability-driven system design and integration
- Energy generation, storage, and management on- and off-ground
- Thermal and power management
- Advanced multi-functional materials and ecomaterials
- Next-gen air traffic management and operational improvements
- Environmental, economical, and societal impacts

**Get involved with our efforts**

To join our affiliate list and working groups, join our interest list at **myumi.ch/Ek1r7** or scan the QR code