Overview of NASA GRC Elecrified Aircraft Propulsion Systems Analysis Methods

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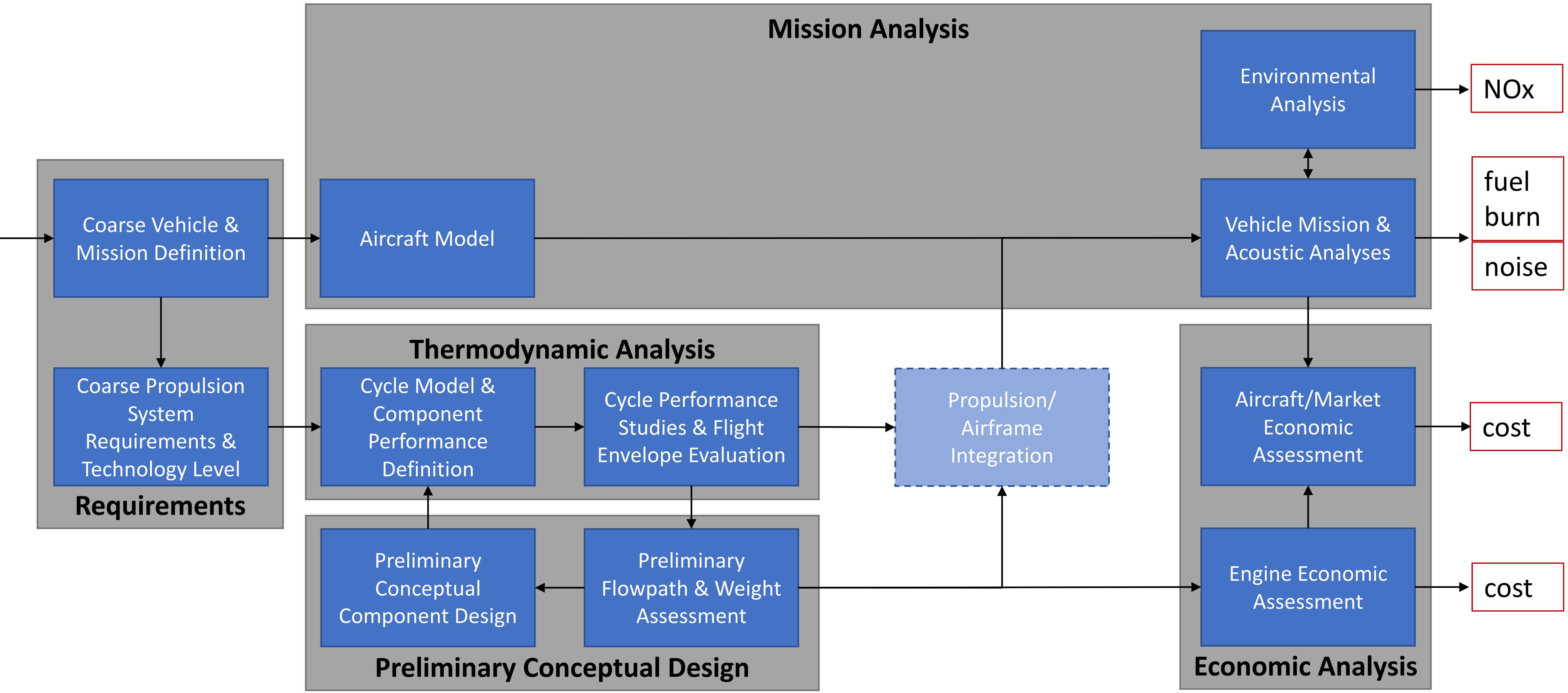
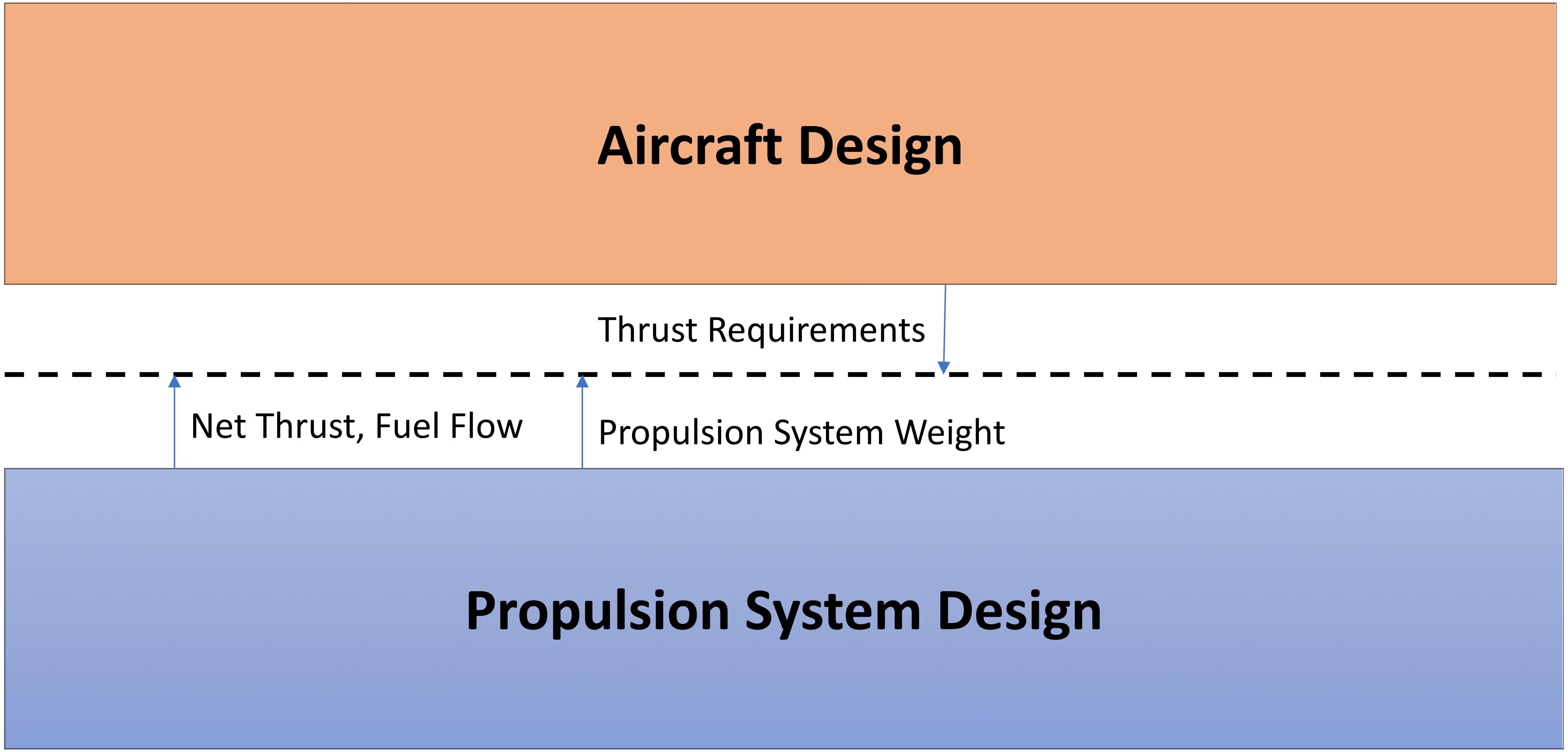
EnergyTech 2017
Cleveland, OH
October 31, 2017

Electrified aircraft propulsion requires a higher level of system level coupling than analyses of traditional subsonic gas turbine engine aircraft concepts.



*From 1998 PSAO Benchmark Peer Review

Traditionally, system level studies of advanced aircraft concepts are split into airframe and propulsion analyses



Typical Outputs:
- Engine size/weights
- Aircraft size/weights
- Vehicle range
- Fuel burn
- Emissions
- Noise

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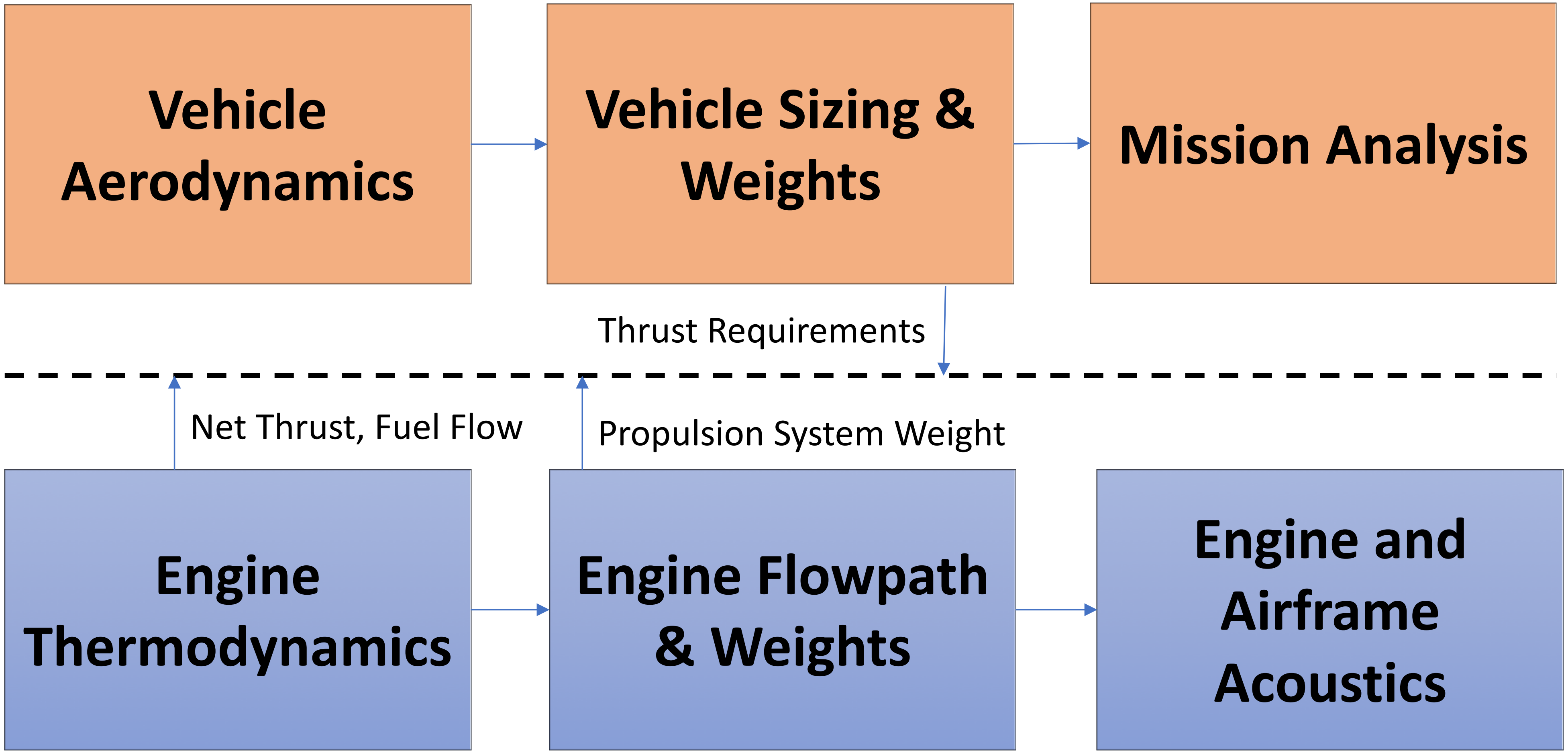

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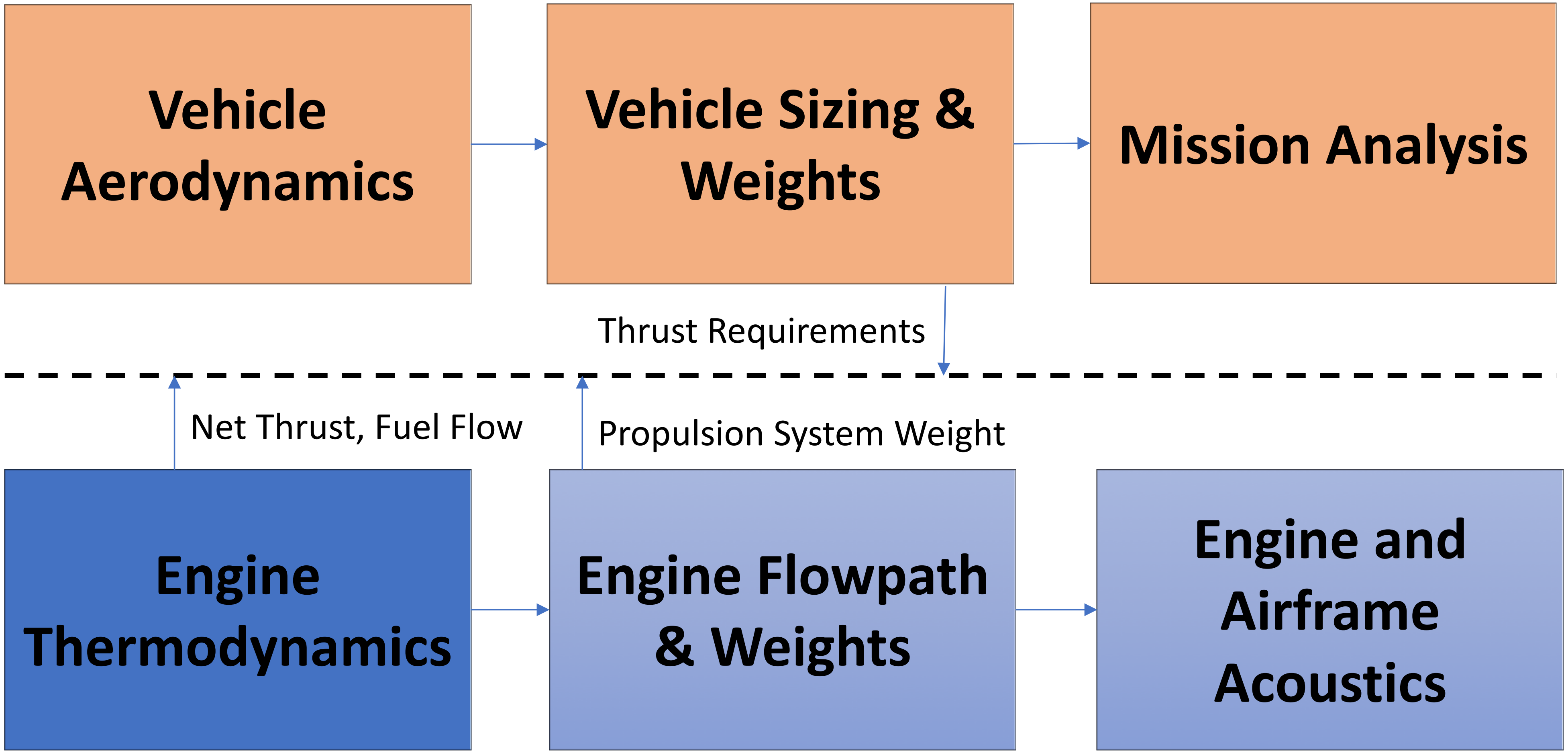

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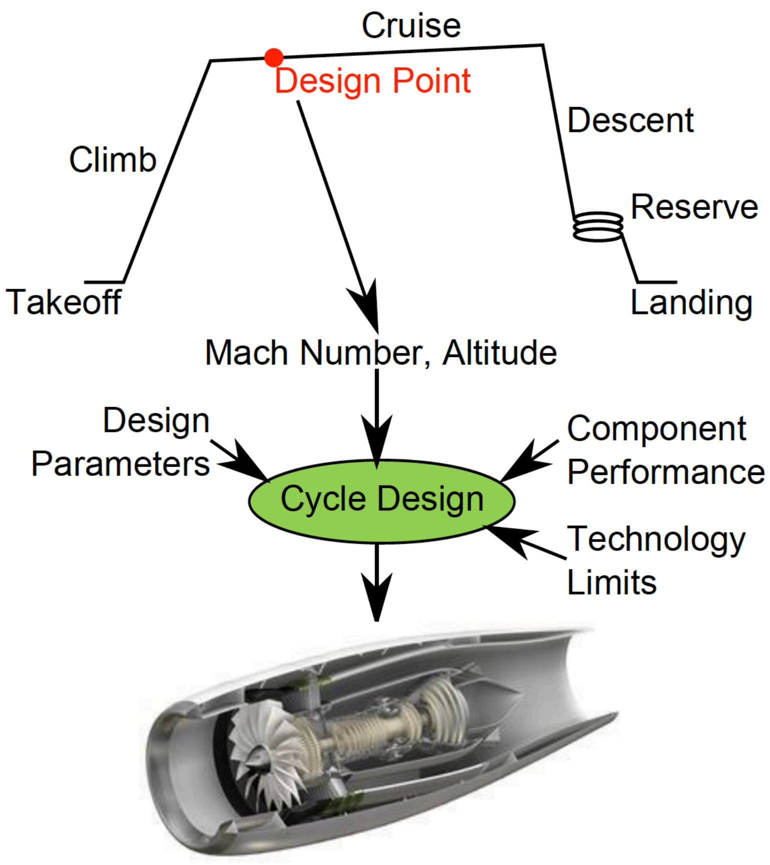
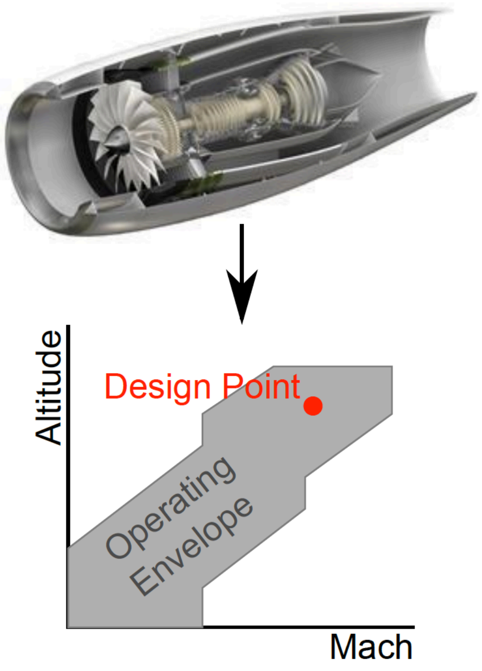
On-Design and Off-Design Phases of Cycle Analysis

On-Design Phase

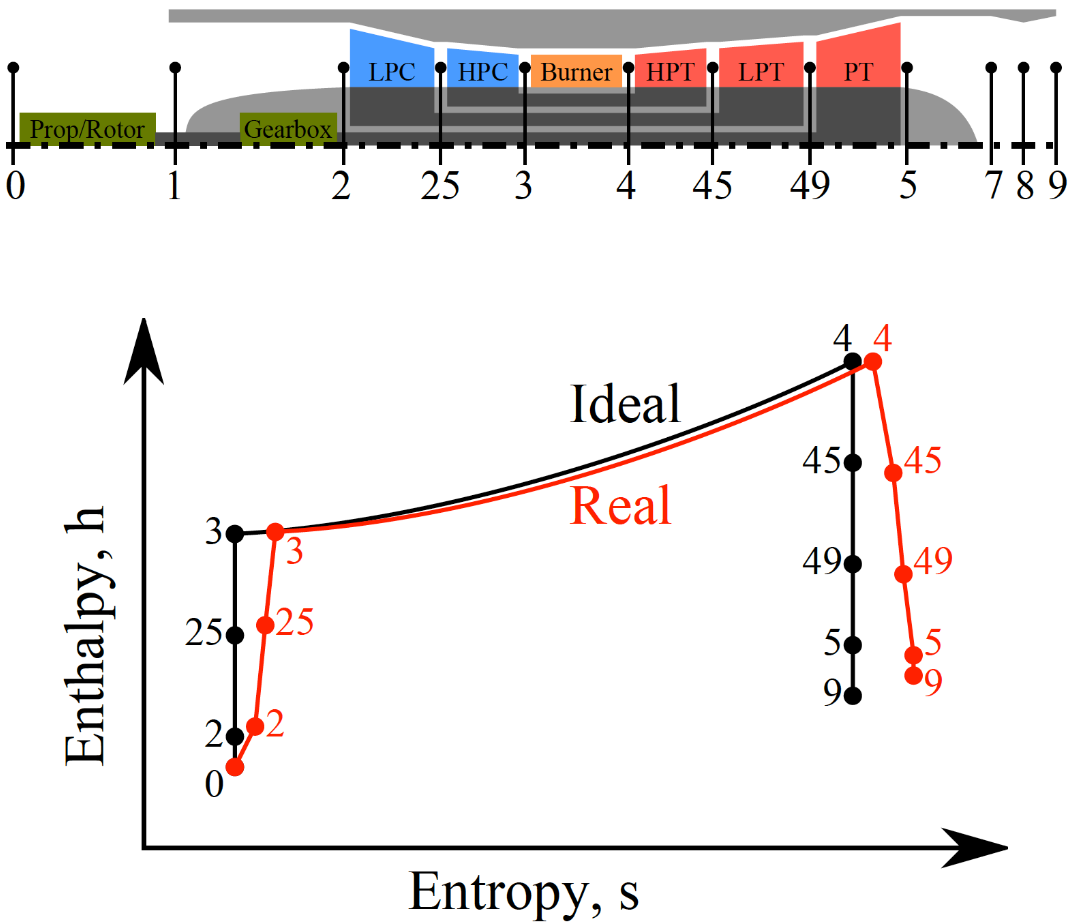


Off-Design Phase



Quality assessment of engine in off-design phase requires component performance maps

Thermodynamic Cycle Analysis



Shaft Power

$$\dot{W}_{out,shaft} = \dot{m}_{45}\left(h_{t,45} - h_{t,5}\right)$$

Thrust

$$T = \frac{1}{g}\left(\dot{m}_9 V_9 - \dot{m}_0 V_0\right) + A_9\left(P_9 - P_0\right)$$

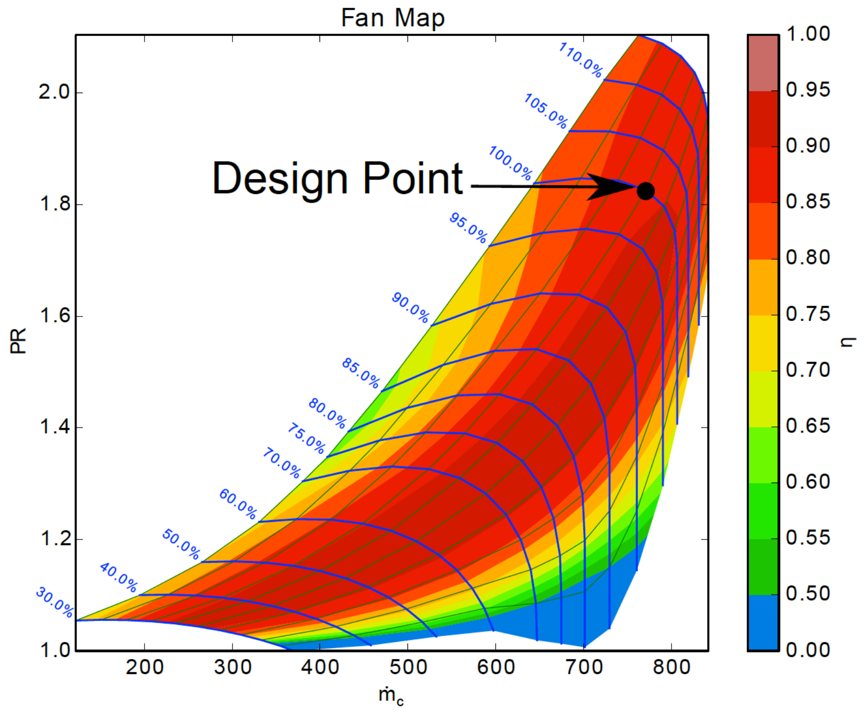
Power Specific Fuel Consumption

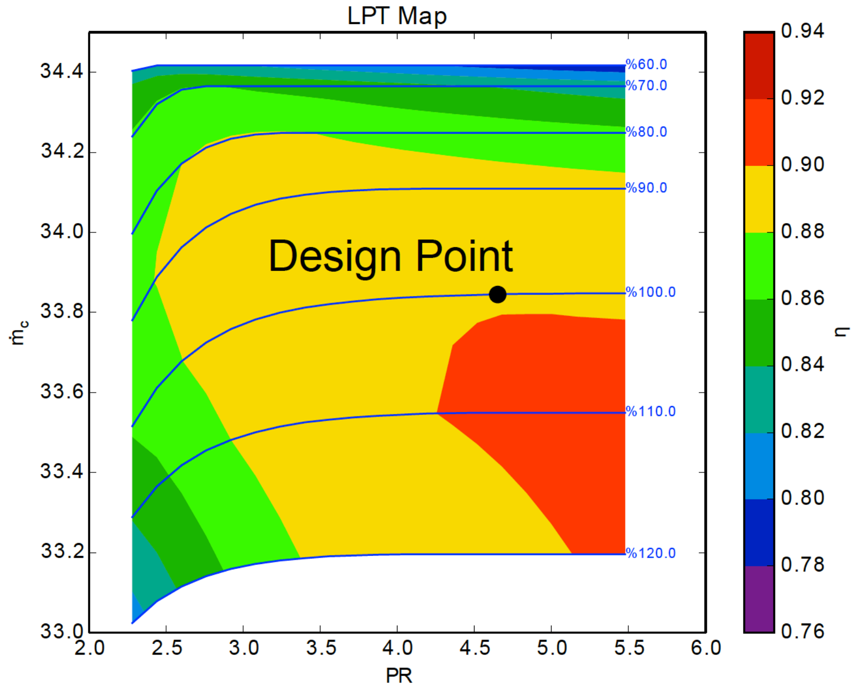
$$PSFC = \frac{\dot{m}_f}{\dot{W}_{out}} = \frac{f}{\dot{W}_{out} / \dot{m}_0}$$

Thrust Specific Fuel Consumption

$$TSFC = \frac{\dot{m}_f}{T} = \frac{f}{T / \dot{m}_0}$$

Turbomachinery Performance Maps and Scaling Equations for Cycle Analysis





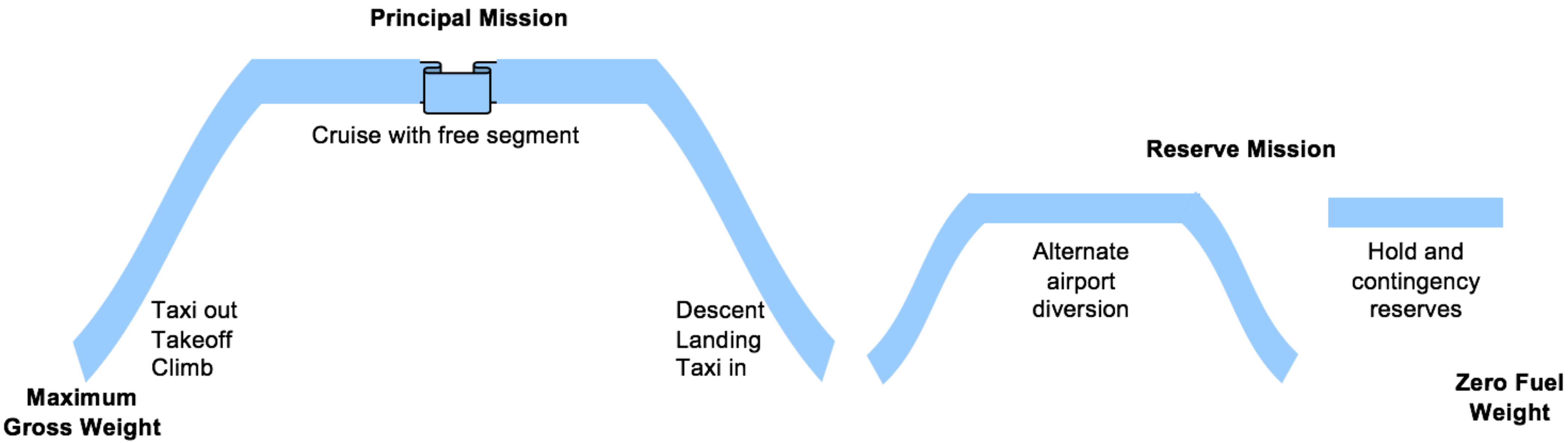
Map Scaling Equations[55]

$$S_{N_{c,design}} = \frac{N_{c,design}}{N_{c,mapdesign}} \qquad S_{\eta_{design}} = \frac{\eta_{design}}{\eta_{mapdesign}} \qquad S_{PR_{design}} = \frac{PR_{design}-1}{PR_{mapdesign}-1} \qquad S_{\dot{m}_{c,design}} = \frac{\dot{m}_{c,design}}{\dot{m}_{c,mapdesign}}$$

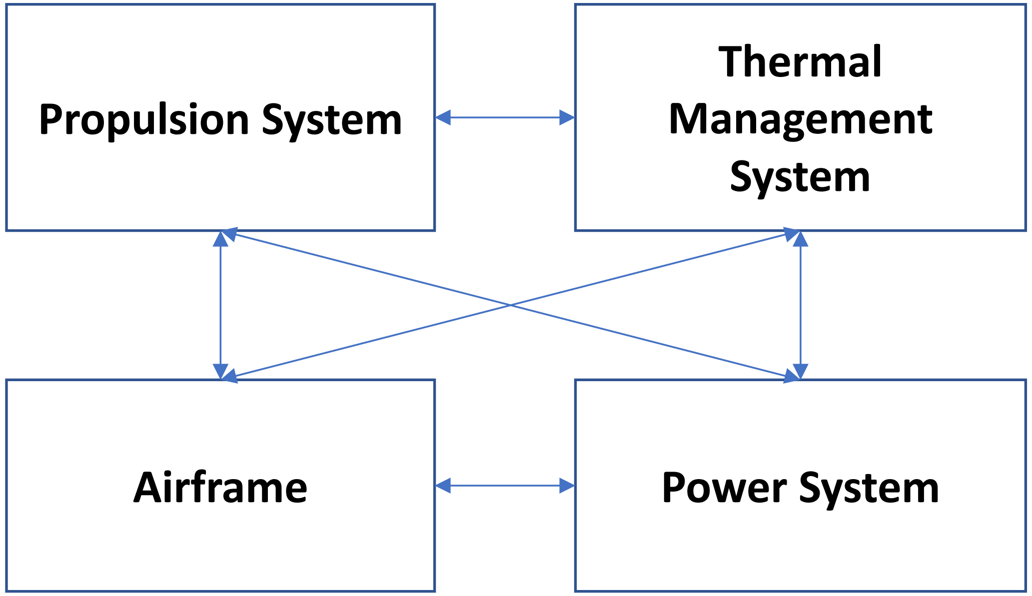
The data is passed from propulsion cycle analysis to mission analysis in the form of an engine deck

MN	Altitude	Throttle	Gross Thrust	Ram Drag	Fuel Flow	TSFC
0.80	35000.0	50	8041.8	4537.0	2493.1	0.71182
0.80	35000.0	48	7721.3	4448.5	2301.9	0.70419
0.80	35000.0	46	7396.0	4355.5	2120.2	0.69846
0.80	35000.0	42	6737.2	4161.3	1777.0	0.69188
0.80	35000.0	38	6067.2	3956.3	1458.3	0.69396
0.80	35000.0	34	5387.5	3741.7	1162.3	0.71110
0.80	35000.0	30	4695.8	3514.9	883.7	0.75697
0.80	35000.0	26	3968.3	3251.3	623.3	0.88977
0.80	35000.0	24	3619.3	3110.7	511.1	1.04238
0.80	35000.0	22	3250.8	2950.5	403.0	1.43840
0.80	35000.0	21	3056.6	2860.5	349.6	1.99627

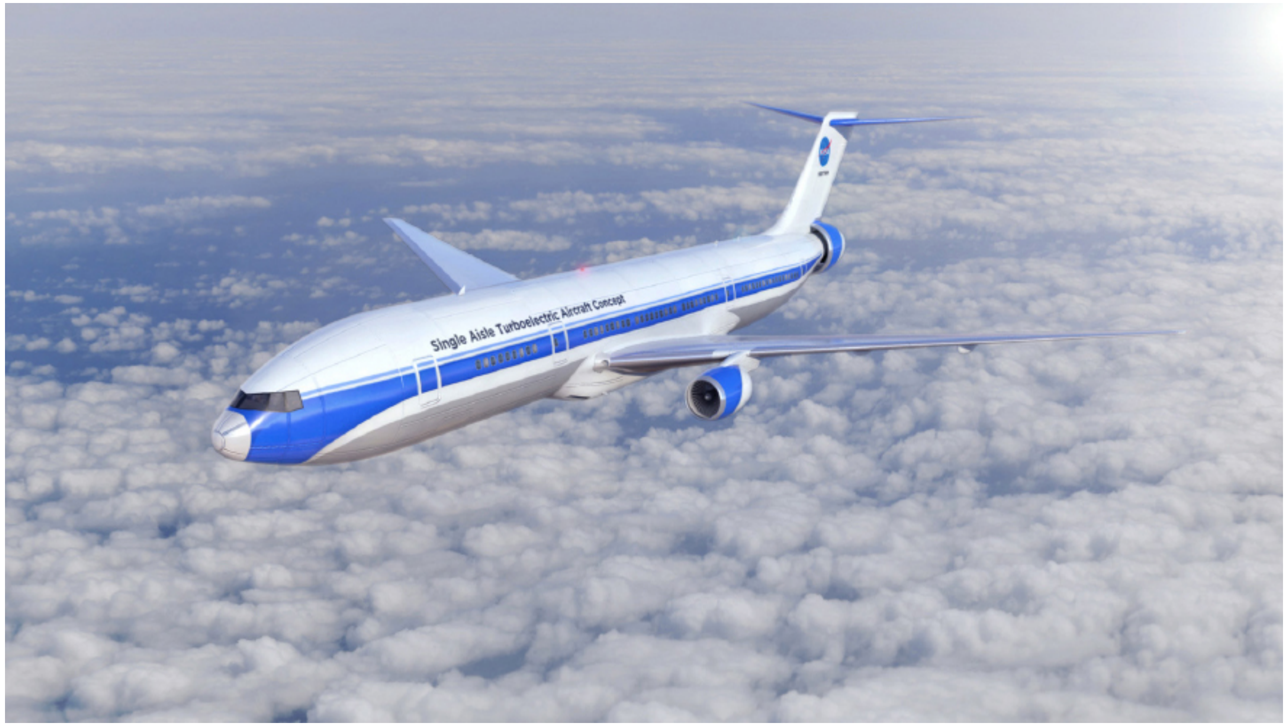
Mission analysis yields the block fuel burn.



Hybrid-electric and Turbo-electric concepts are highly coupled



Turbo-electric systems modeling: STARC-ABL



- **S**ingle aisle **T**urboelectric **AiRC**raft with **A**ft **B**oundary **L**ayer ingestion
- Conventional tube and wing airframe
- Two underwing turbofans electrically power a tailcone propulsor while also generating thrust
- Welstead, J. and Felder, J., “Conceptual Design of a Single-Aisle Turboelectric Commercial Transport with Fuselage Boundary Layer Ingestion”, 2016

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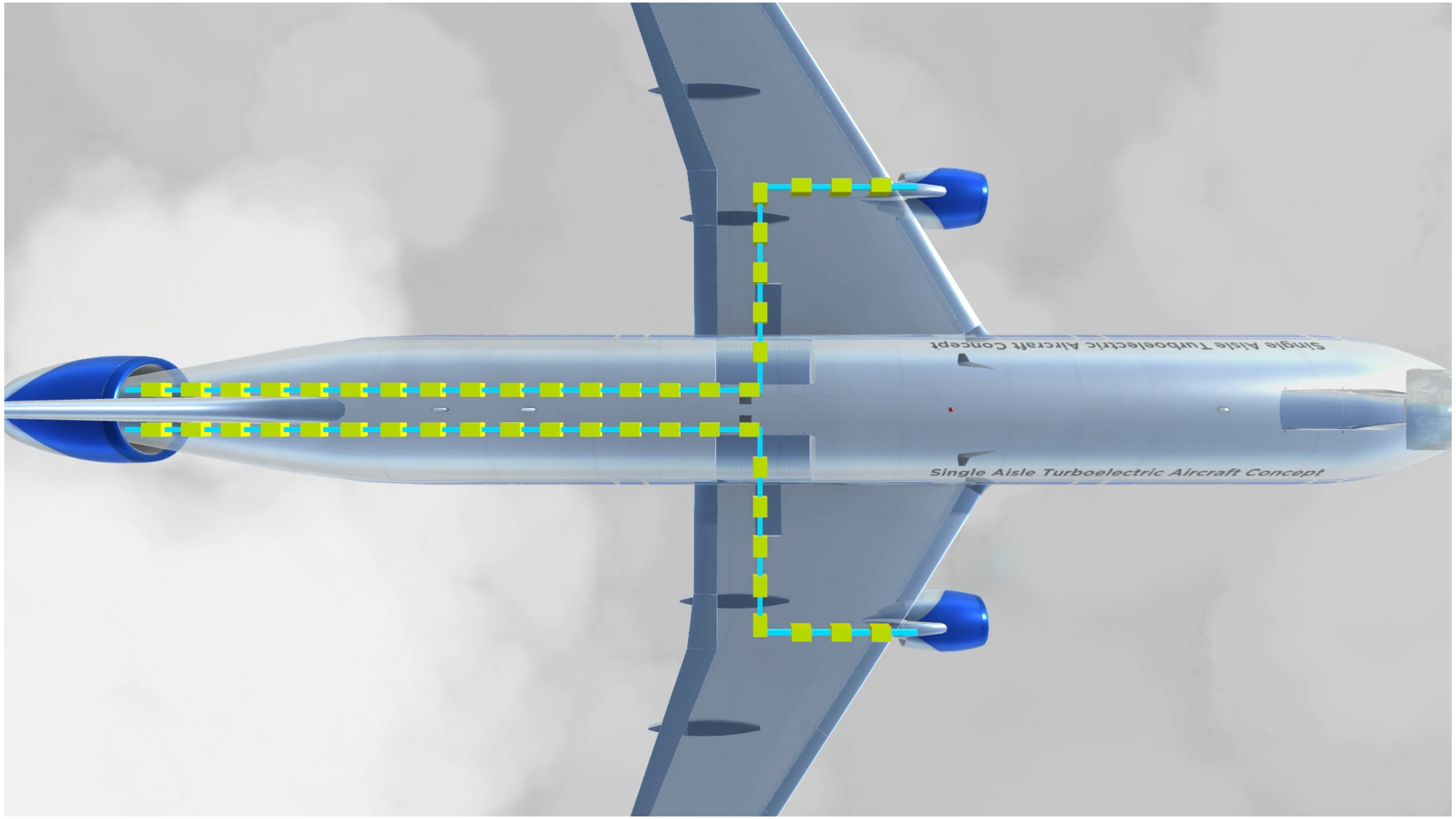

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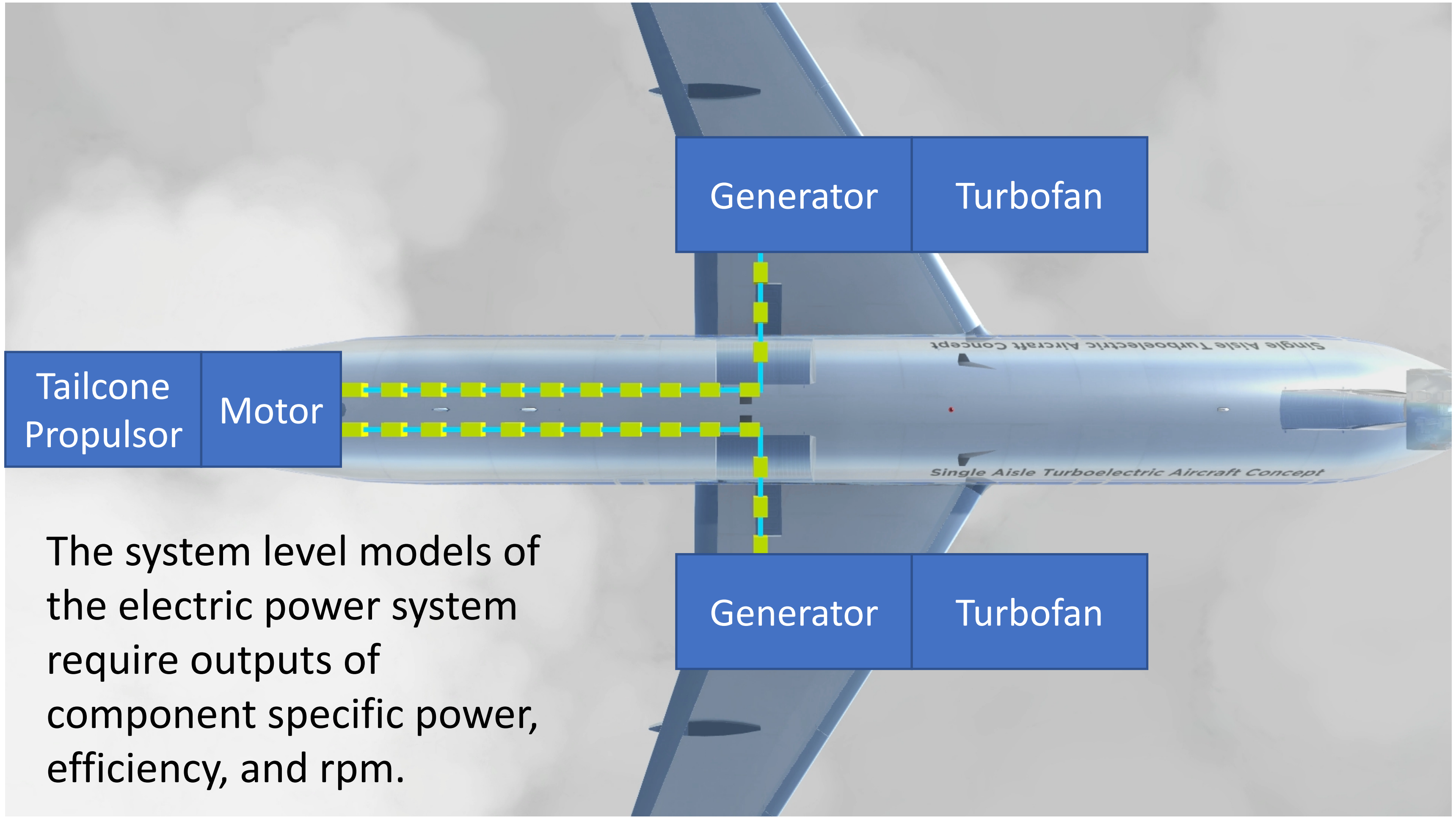
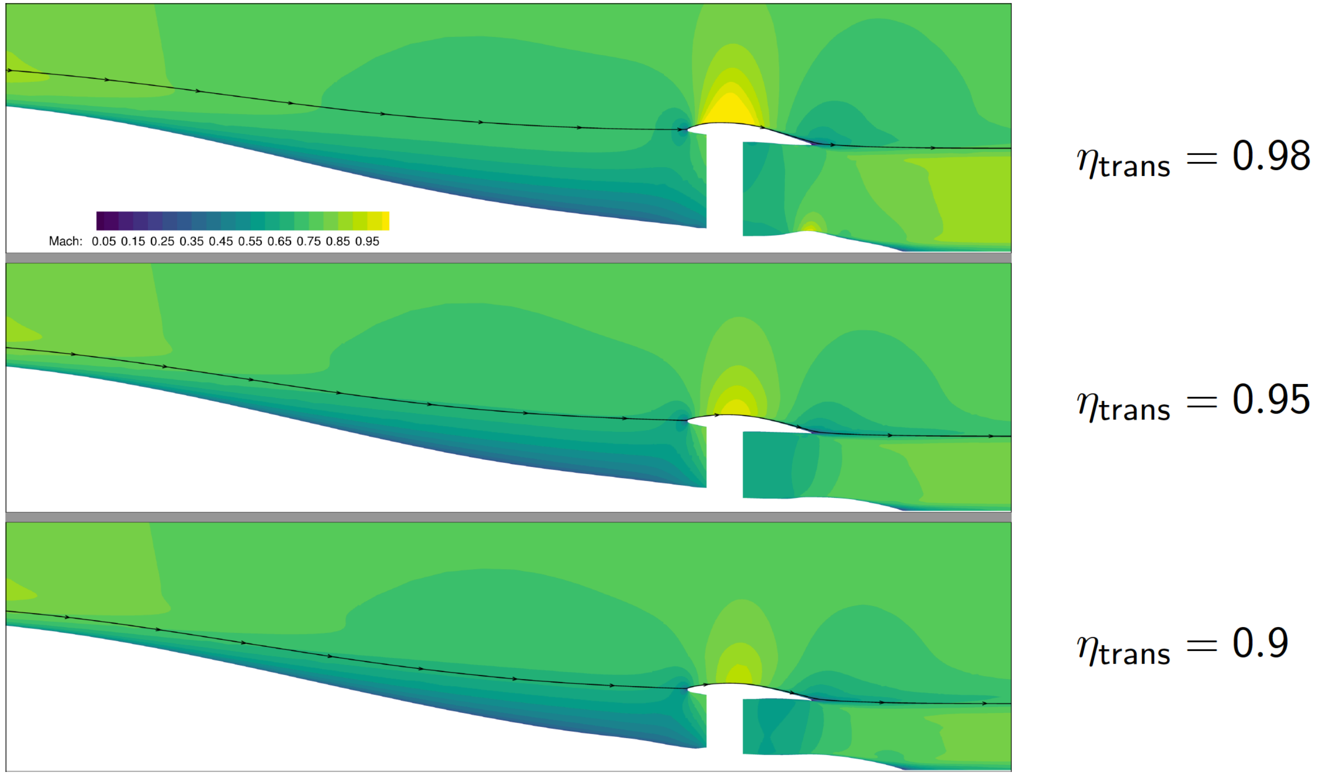


The system level models of the electric power system require outputs of component specific power, efficiency, and rpm.

Turbo-electric systems modeling: STARC-ABL

Further analyses continue to refine the STARC-ABL concept by optimizing the coupling of the systems. [Gray 2017]

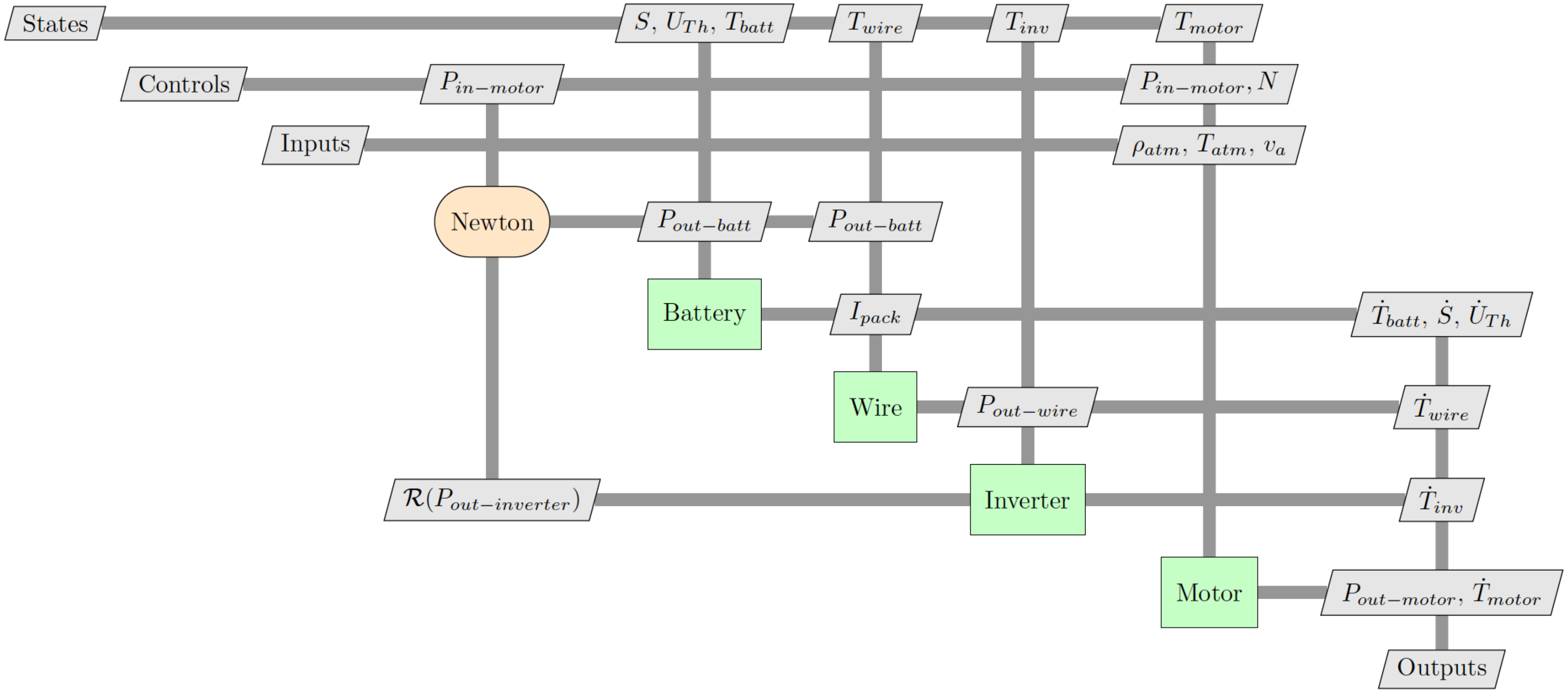


Fully electric system modeling: X-57 Maxwell

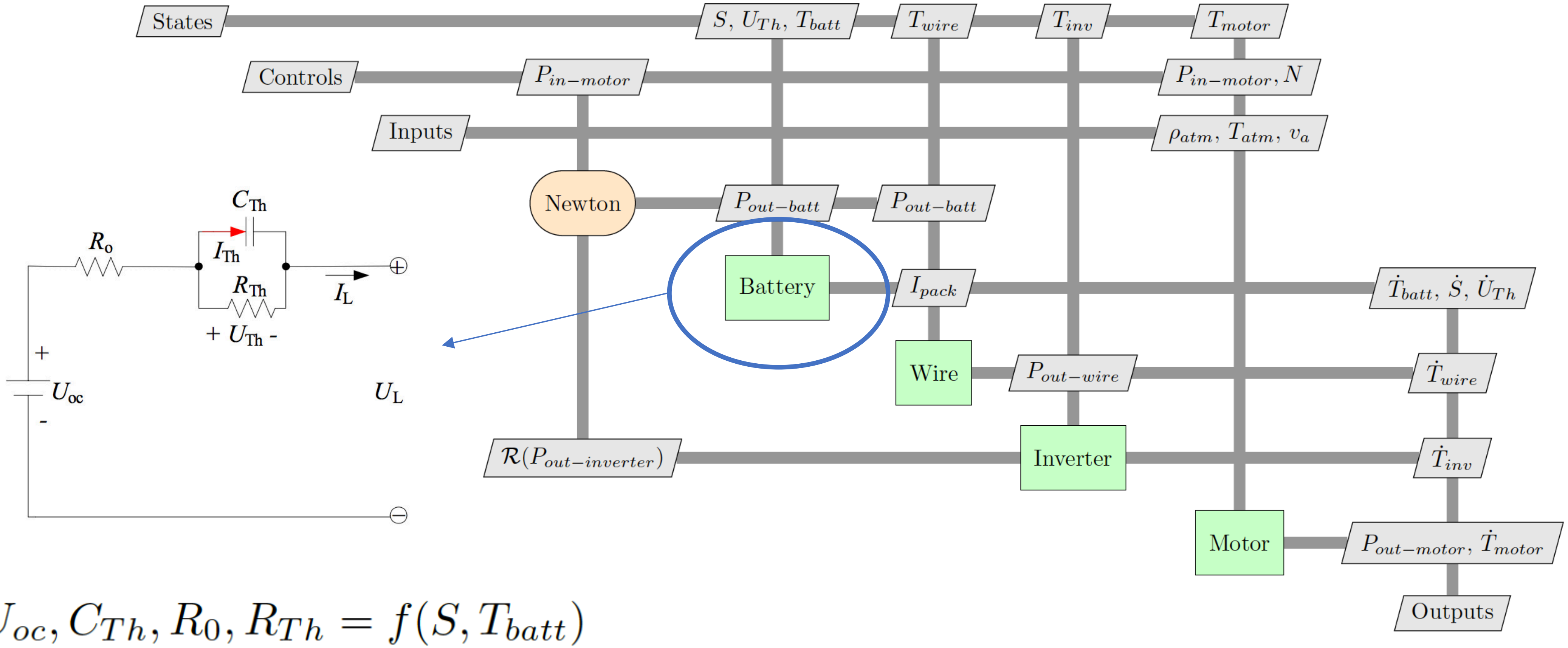
- **S**calable **C**onvergent **E**lectric **P**ropulsion **T**echnology and **O**perations **R**esearch (SCEPTOR)
- Fully electric experimental aircraft to demonstrate a 5 times reduction in energy use at cruise using distributed electric propulsion

Borer, N. K., Patterson, M. D., Viken, J. K., Moore, M. D., Bevirt, J., Stoll, A. M., and Gibson, A. R., "Design and Performance of the NASA SCEPTOR Distributed Electric Propulsion Flight Demonstrator," Jun 2016.

Electric System Model



Electric System Model: Battery Modeling

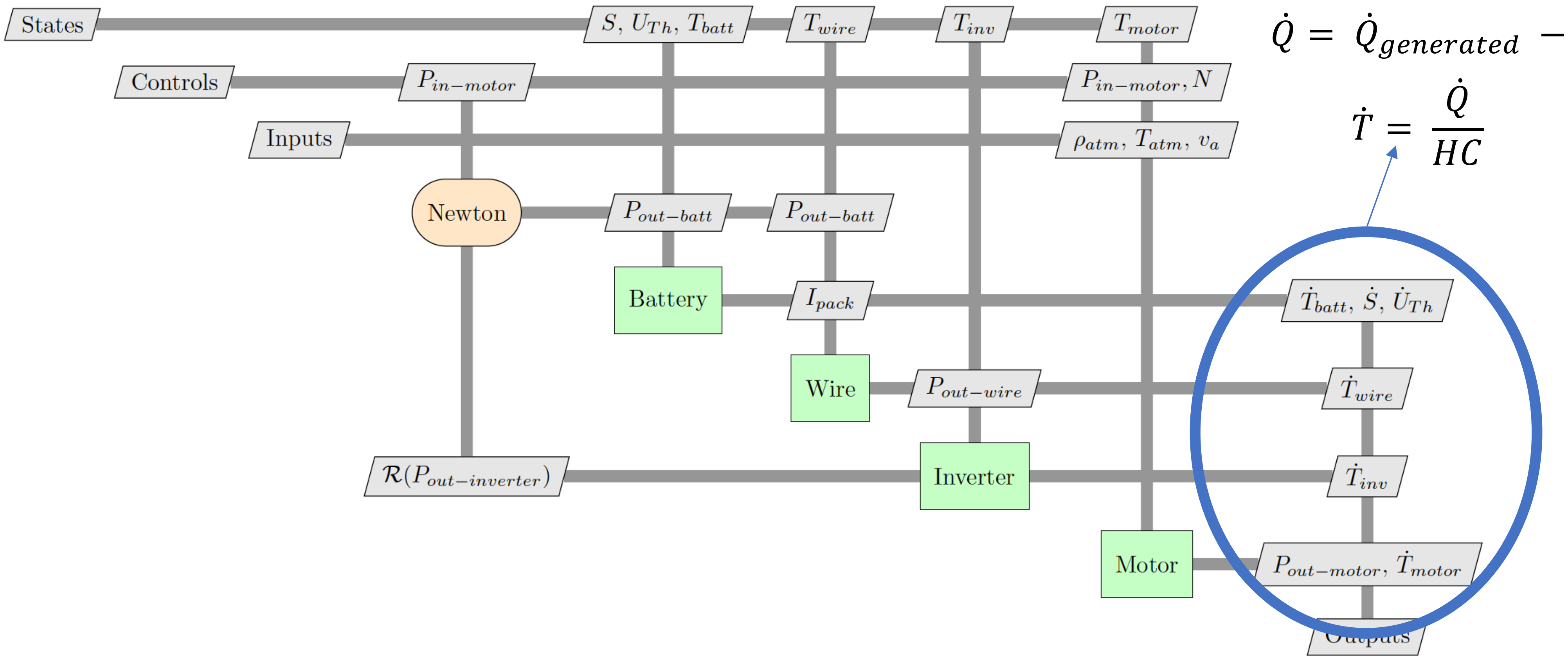


$$U_{oc}, C_{Th}, R_0, R_{Th} = f(S, T_{batt})$$

Electric System Model

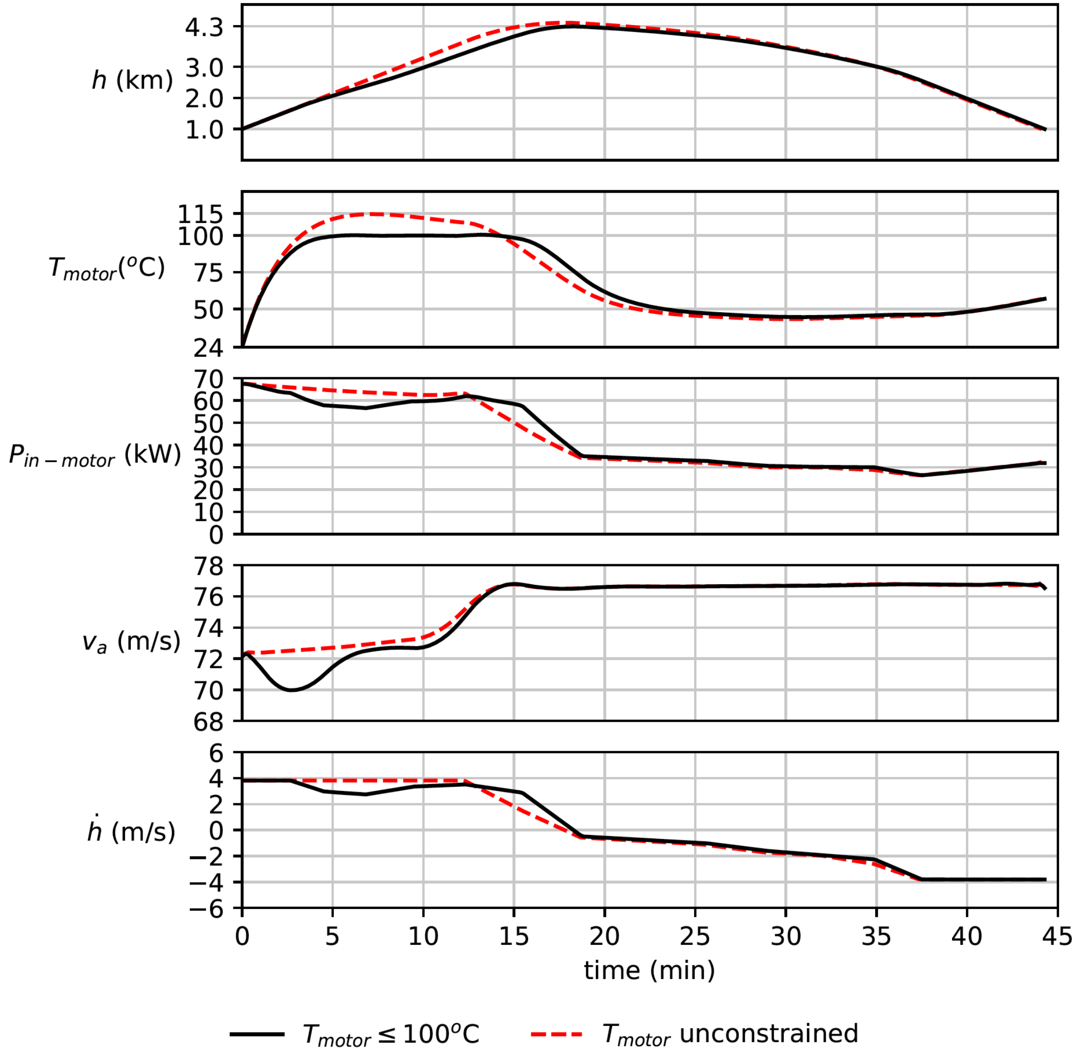
$$\dot{Q} = \dot{Q}_{generated} - \dot{Q}_{cool}$$

$$\dot{T} = \frac{\dot{Q}}{HC}$$



Results of Coupled Analysis

- Successfully determined an optimal trajectory subject to thermal constraints of electric components.
- Modeled the interaction of the propulsion system, airframe, thermal management, and power system.
- Falck, R., Chin, J., Schnulo, S., Burt, J., and Gray, J., “Trajectory Optimization of Electric Aircraft Subject to Subsystem Thermal Constraints," 2016.



Conclusions

- The accurate modeling and analysis of electrified aircraft propulsion concepts require intricate subsystem component coupling.
- **The major challenge in electrified aircraft propulsion concept modeling lies in understanding how the subsystems “talk” to each other and the dependencies they have on one another.**

Thank you.

Questions?