



More / All Electric Vertical Take-Off and Landing (VTOL) Vehicle Sensitivities to Propulsion and Power Performance

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Aircraft Design I / Technical Session B / Paper 68
76th Annual Forum and Technology Display (Virtual)
October 7, 2020



Purpose / Process

High interest in Urban Air Mobility (UAM) / vertical-lift vehicles; Revolutionary Vertical Lift Technology (RVLT) Project released a set of reference vehicles using preliminary assumptions to support tools, operations and technology development within and outside NASA.

Additional research has occurred for the electric propulsion and power systems (additional system definitions, component performance, etc.), suggesting time to update our estimates and better understand which components and respective performance metrics are most important (and how important).

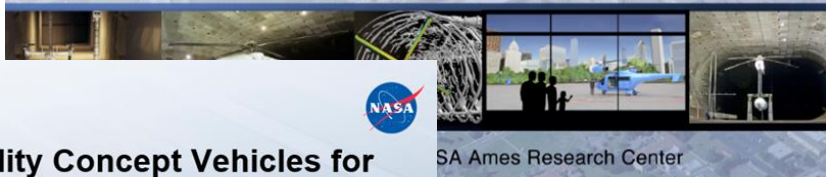
- Review missions, vehicles and study matrix
- Update electric propulsion and power configurations, as well as component performance assumptions
- Discuss results, summarize and suggest future efforts

Missions Evolved Based on Feedback

Concept Vehicles for VTOL Air Taxi Operations

Wayne Johnson
Christopher Silva
Eduardo Solis

American Helicopter Society
Technical Conference on Aeromechanics Design for
Transformative Vertical Flight
San Francisco, California
January 16-18, 2018

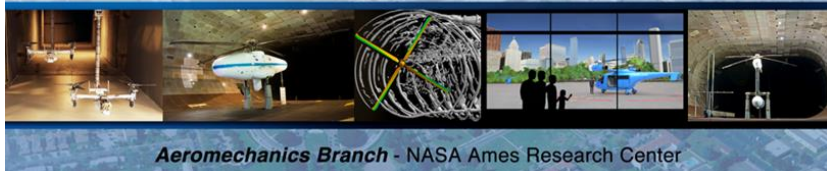


VTOL Urban Air Mobility Concept Vehicles for Technology Development

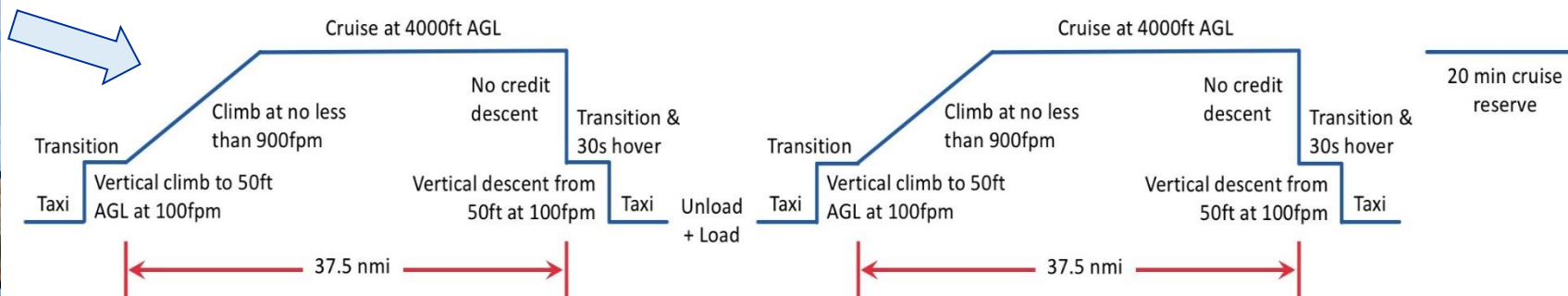
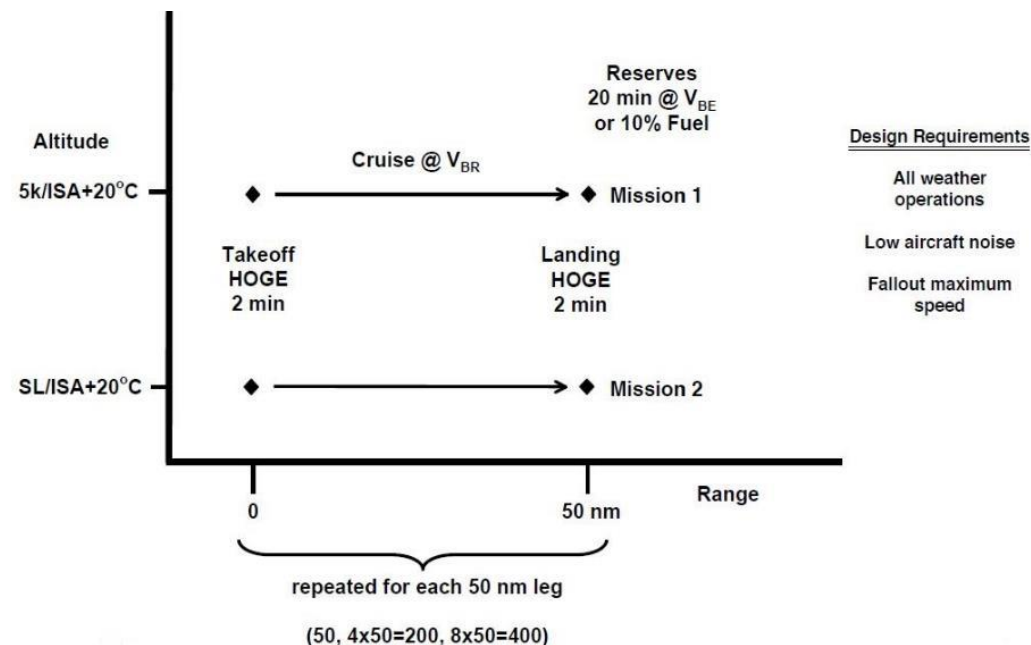
Christopher Silva, Wayne Johnson
NASA Ames Research Center

Kevin Antcliff, Michael Patterson
NASA Langley Research Center

AIAA AVIATION 2018
Atlanta, Georgia
June 28, 2018



Aeromechanics Branch - NASA Ames Research Center



4 Vehicle Concepts Studied (more details on next slide)

Tiltwing
15 pax
8 x 50 nm

Quadrotor
1 pax/
1 x 50 nm
or 6 pax/
2 x 37.5 nm



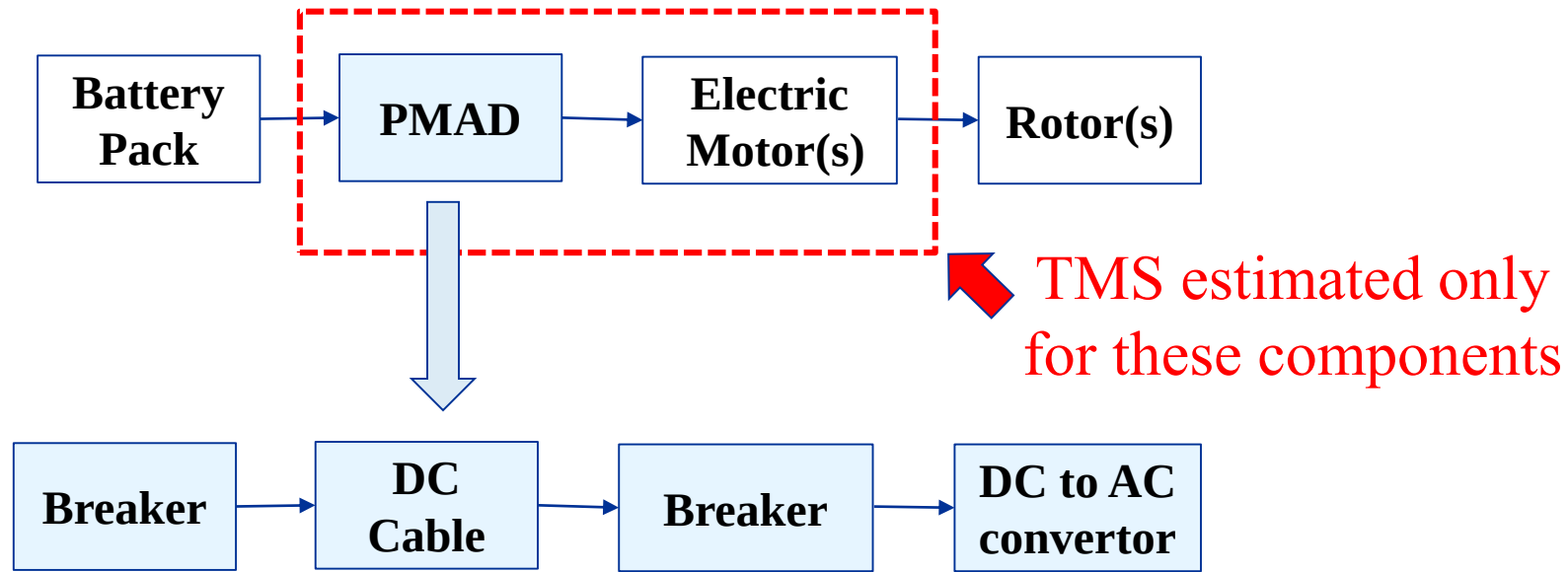
Lift+Cruise
6 pax
2 x 37.5 nm

Side by Side
6 pax
2 x 50 nm
and
2 x 37.5 nm

Study matrix used a variety of vehicles, missions, and propulsion/power (P&P)

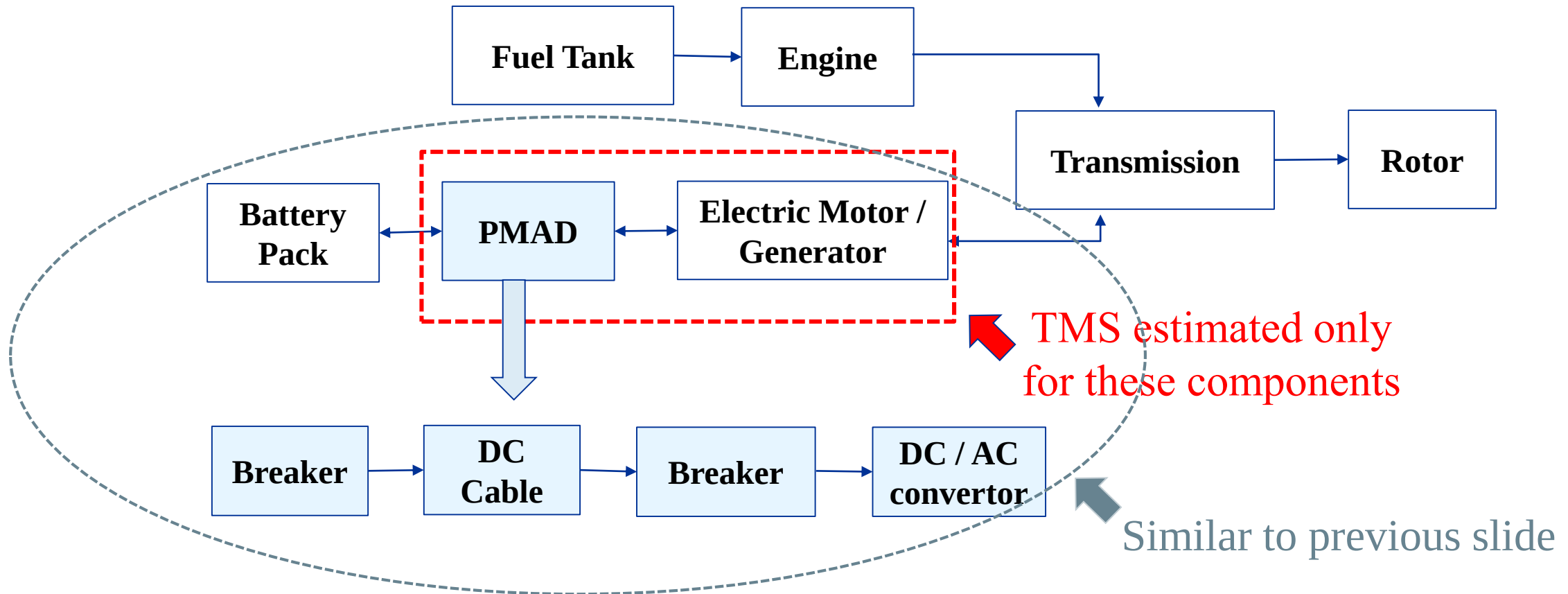
From January 2018 (Reference 2, simple mission profile, 50 nm legs)					
Vehicle type	# pax/ lbm	Mission	DGW, lbm	Disk loading, psf	P&P
Quadrotor	1 / 250	1 x 50 nm	1,325	2.5	BAE
Side-by-side	6 / 1,200	2 x 50 nm	5,590	3.5	BAE
		4 x 50 nm *	3,950	4.5	Hybrid
Tiltwing	15 / 3,000	8 x 50 nm	14,040	30	TE
From June 2018 (Reference 3, “real” mission profile, 2 x 37.5 nm legs)					
Vehicle type	# pax/ lbm	Mission	DGW, lbm	Disk loading, psf	P&P
Quadrotor	6 / 1,200	2 x 37.5 nm	6,480	3.0	BAE
Side-by-side	6 / 1,200	2 x 37.5 nm	4,900	3.5	BAE
Lift+Cruise	6 / 1,200	2 x 37.5 nm	7,480	12	BAE & TE
* For this study, the side-by-side hybrid was sized using the 2 x 50 nm mission (Reference 2 used 4 x 50 nm) BAE = battery, all-electric, DGW = Design Gross Weight, TE = turboelectric					

Propulsion and power models 1) Battery, all electric (BAE)



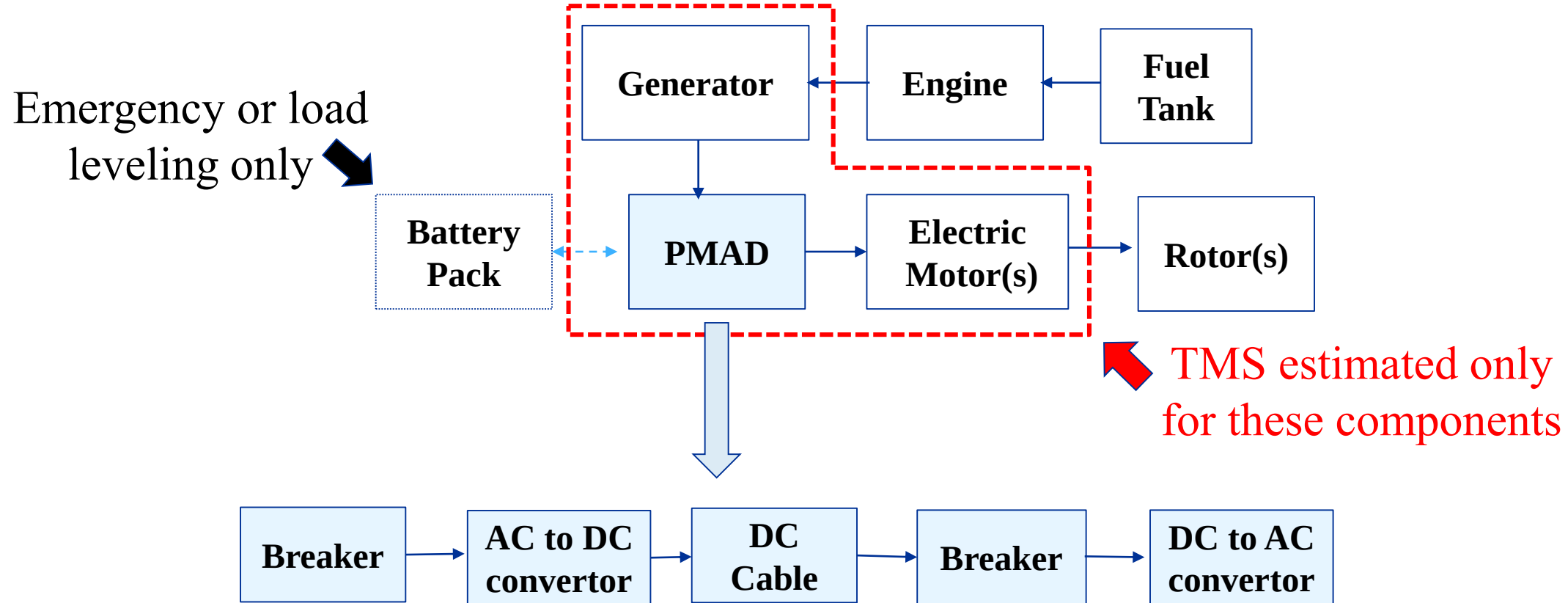
AC = Alternating current DC = Direct current
PMAD = Power Management and Distribution TMS = Thermal Management System

Propulsion and power models 2) Hybrid (similar to BAE)



AC = Alternating current DC = Direct current
PMAD = Power Management and Distribution TMS = Thermal Management System

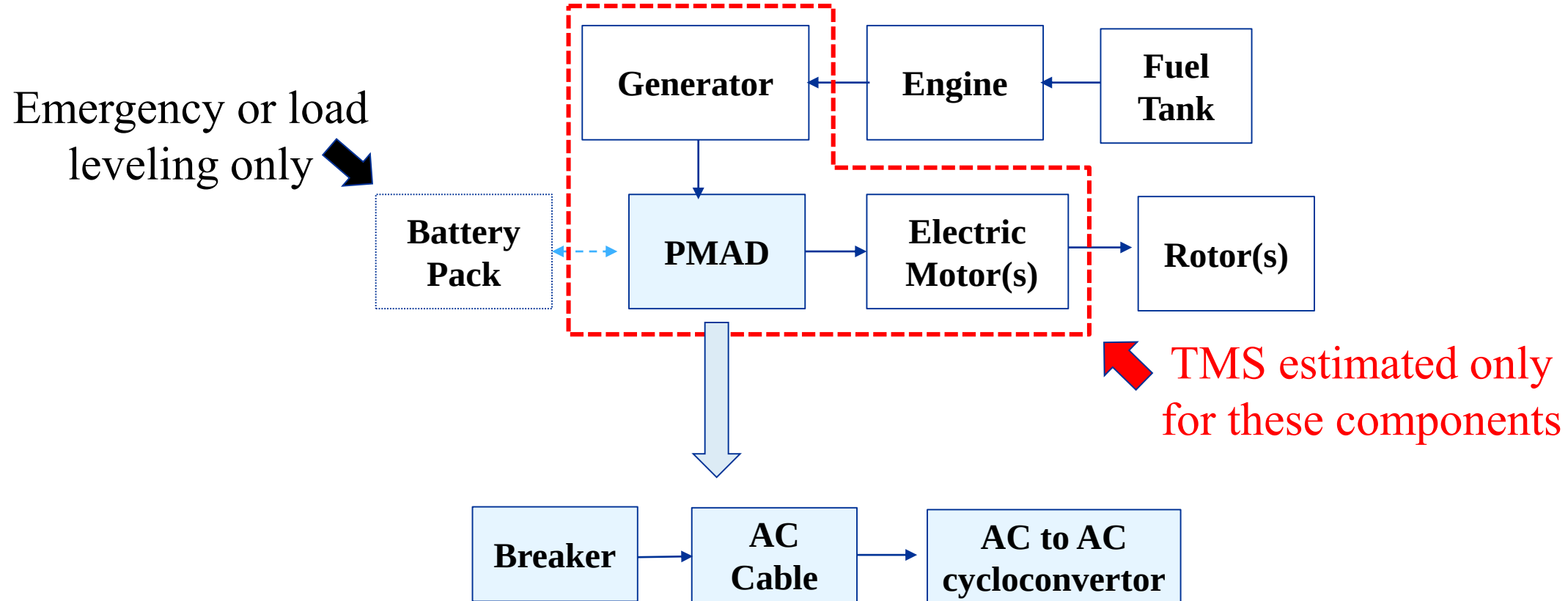
Propulsion and power models 3) Turboelectric (TE), state of art (SOA)



AC = Alternating current DC = Direct current

PMAD = Power Management and Distribution TMS = Thermal Management System

Propulsion and power models 3) Turboelectric (TE), Advanced



AC = Alternating current DC = Direct current
PMAD = Power Management and Distribution TMS = Thermal Management System

Advanced electrical components have higher efficiency, less weight

Component	Baseline (<i>Original</i>)		SOA		Advanced	
	η	Power-to-weight, kW/kg	η	Power-to-weight, kW/kg	η	Power-to-weight, kW/kg
Electric motors/ generators †	95% (total)	-	95%	-	97.5%	-
Converters *		Ψ	95%	9.0	99%	20
† Electric motor and generator weights: $W = 0.5382 \cdot Q^{0.8129}$ (W in lbm, peak torque, Q in ft-lb, Reference 2/3). Used for all electric motor and generator weight calculations. • Converters include AC to DC rectifiers, DC to AC inverters and AC to AC cycloconverters. (breaker weight included in converters) Ψ Baseline PMAD weight = $0.63 \cdot \text{weight}$ (of respective electric motor or generator).						

Other terms for SOA and Advanced systems:

Cable mass = 0.35 kg/kW motor power * relative length (Aretskin-Hariton - Tiltwing)

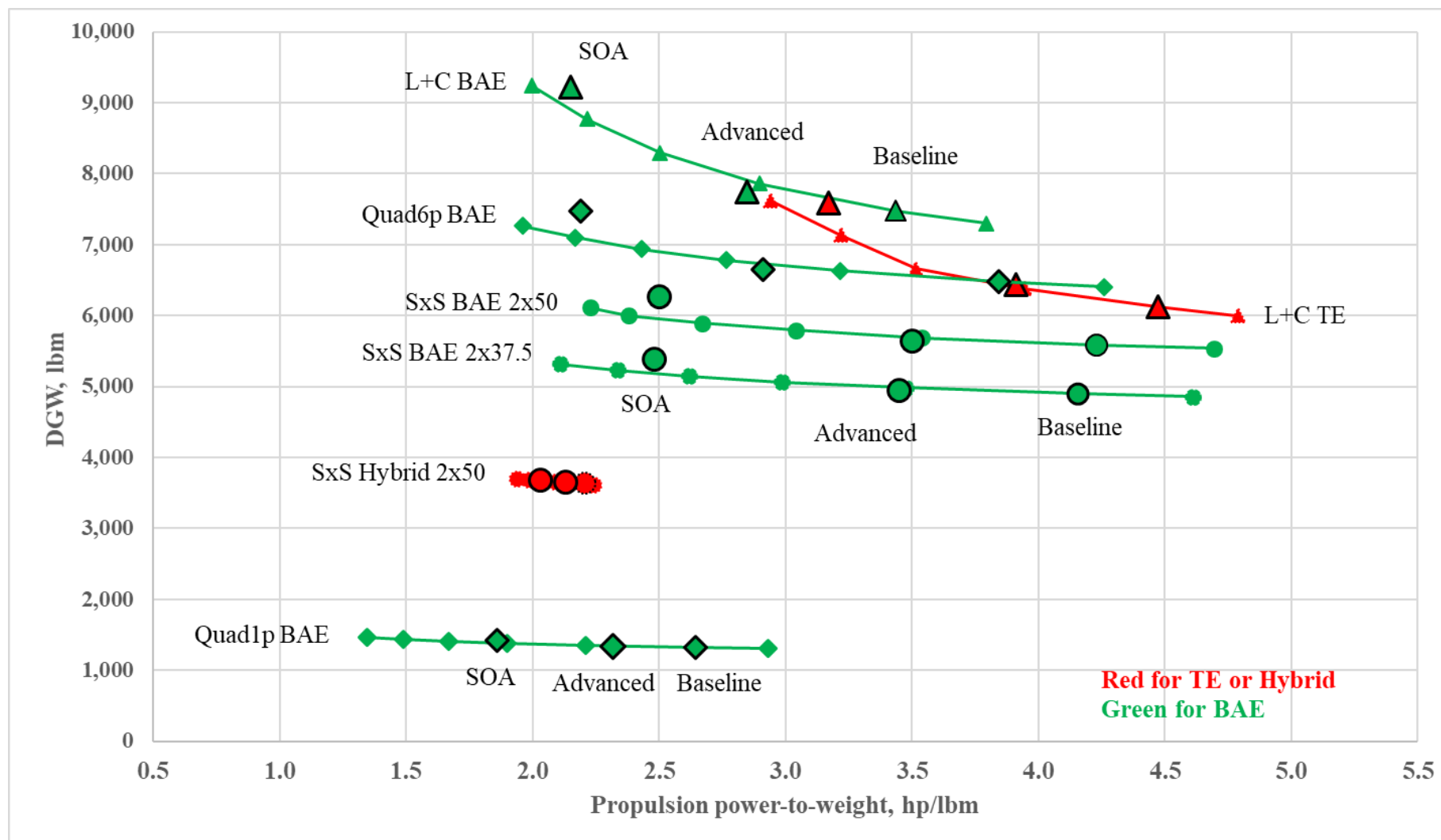
TMS: Weight $\approx$ 0.16 to 0.19 kg/kW heat; Power required $\approx$ 3-4% heat load, (Chapman -Tiltwing)

Electric P&P overhead and Mission Energy Results

Vehicle	P&P	Overhead*			Mission Energy, MJ		
		Baseline	SOA	Adv.	Baseline	SOA	Adv.
Quadrotor 1 pax	BAE	0.63	1.32	0.86	186	208	185
Quadrotor 6 pax	BAE	0.63	1.87	1.15	1,331	1,597	1,348
Side by side 6 pax	BAE	0.63					
2 x 37.5 nm			1.73	0.96	847	969	501
2 x 50 nm			1.76	0.97	1,084	1,263	1,082
2 x 50 nm	Hybrid	0.63	1.66	1.05	3,282	3,325	3,296
Lift + Cruise 6 pax	BAE	0.63	1.61	0.96	1,227	1,580	1,251
	TE	0.63	1.15	0.60	4,346	5,831	4,476
Tiltwing 15 pax 8x50 nm	TE	0.63	1.42	0.65	36,717	49,597	35,677
* additional fraction to account for PMAD and TMS weight, based on electric motor and generator weight							

- Baseline was assuming advanced technologies for overhead (today's weight, but "aviation safe")
- SOA system overheads 2-3 times higher, with significant increase in mission energy
- Advanced systems generally resulted in results very close to baseline for mission energy

Design gross weight versus propulsion power-to-weight trend as expected

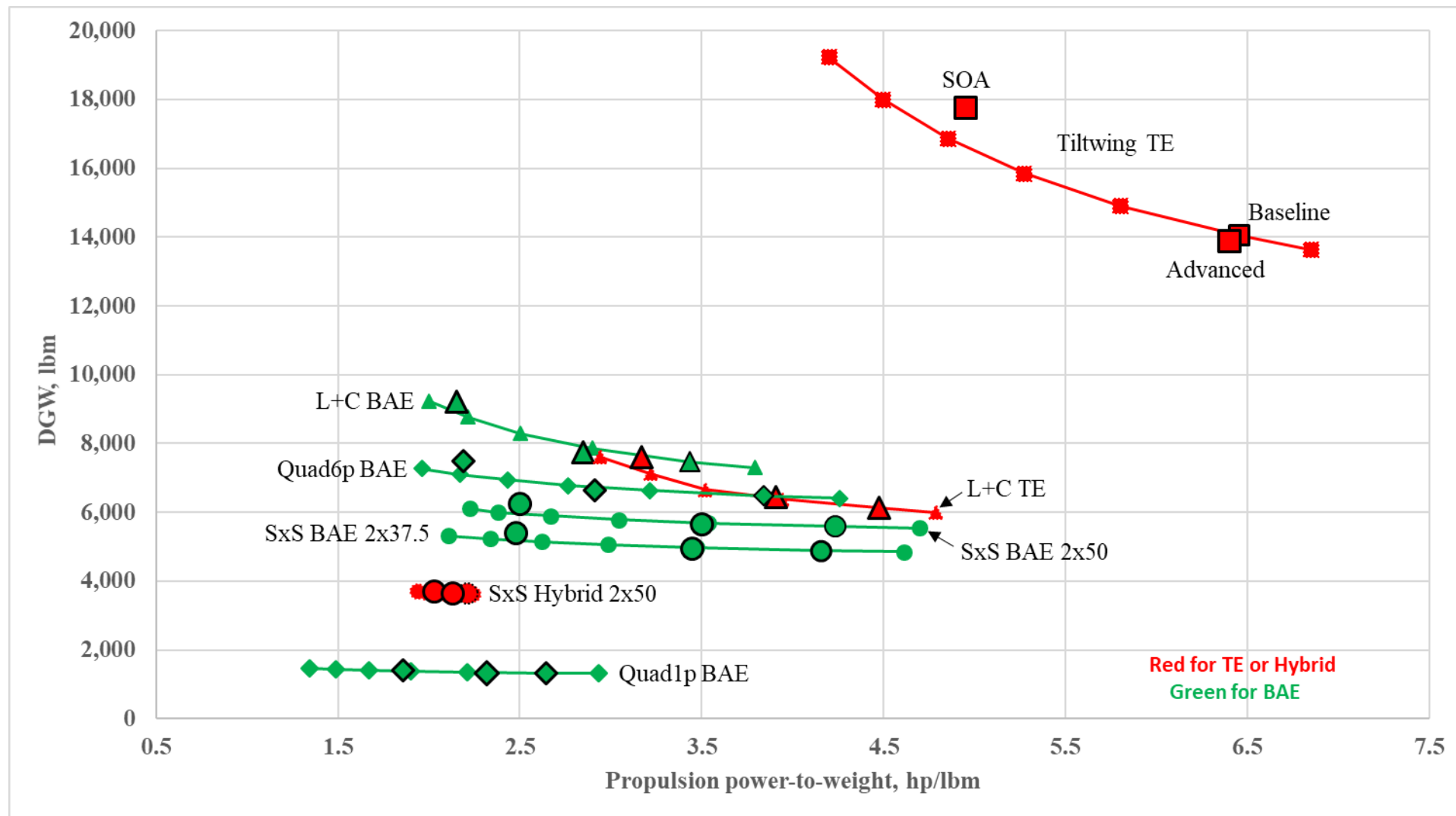


Trendlines use baseline overhead performance (weight & efficiency)

Advanced systems weight more, but higher efficiency (shifted left of baseline, below trendline)

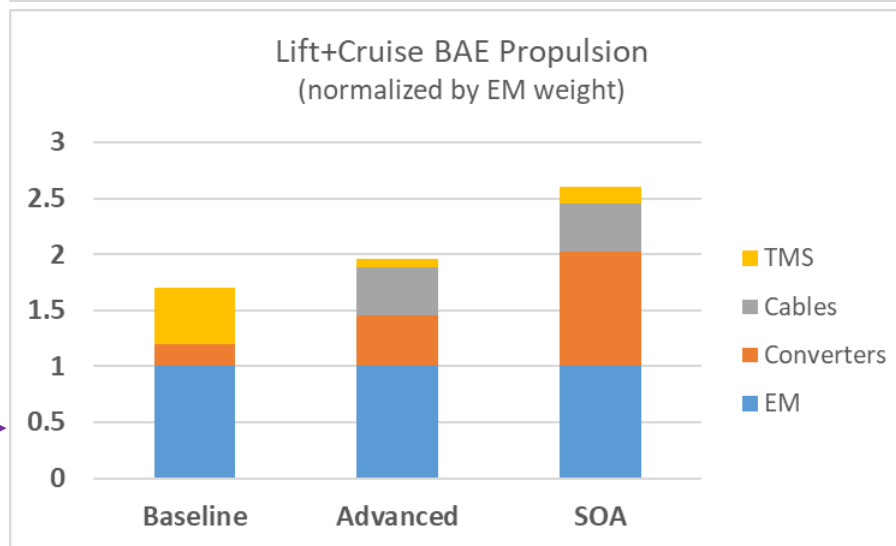
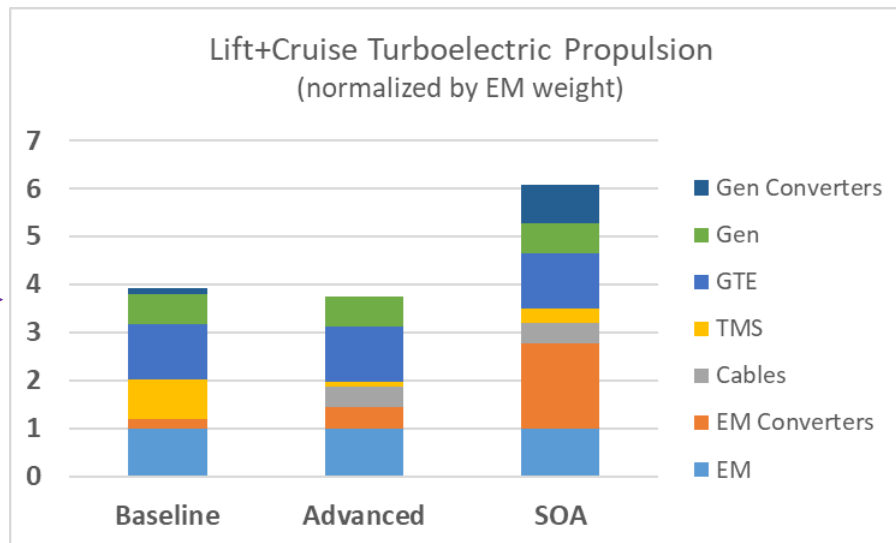
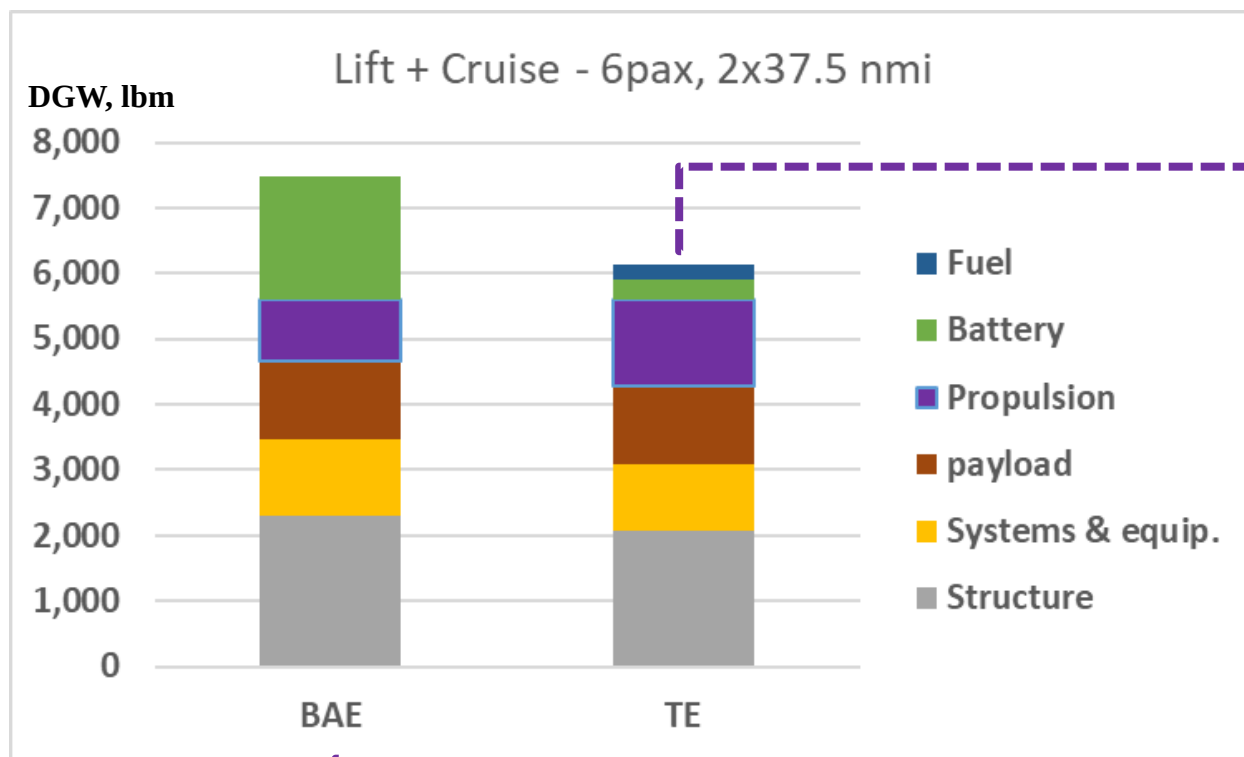
SOA heavier and higher losses (shifted even further left and above trendline)

Turboelectric systems show higher sensitivity to propulsion power-to-weight and component efficiencies than battery, all-electric and hybrid, as expected

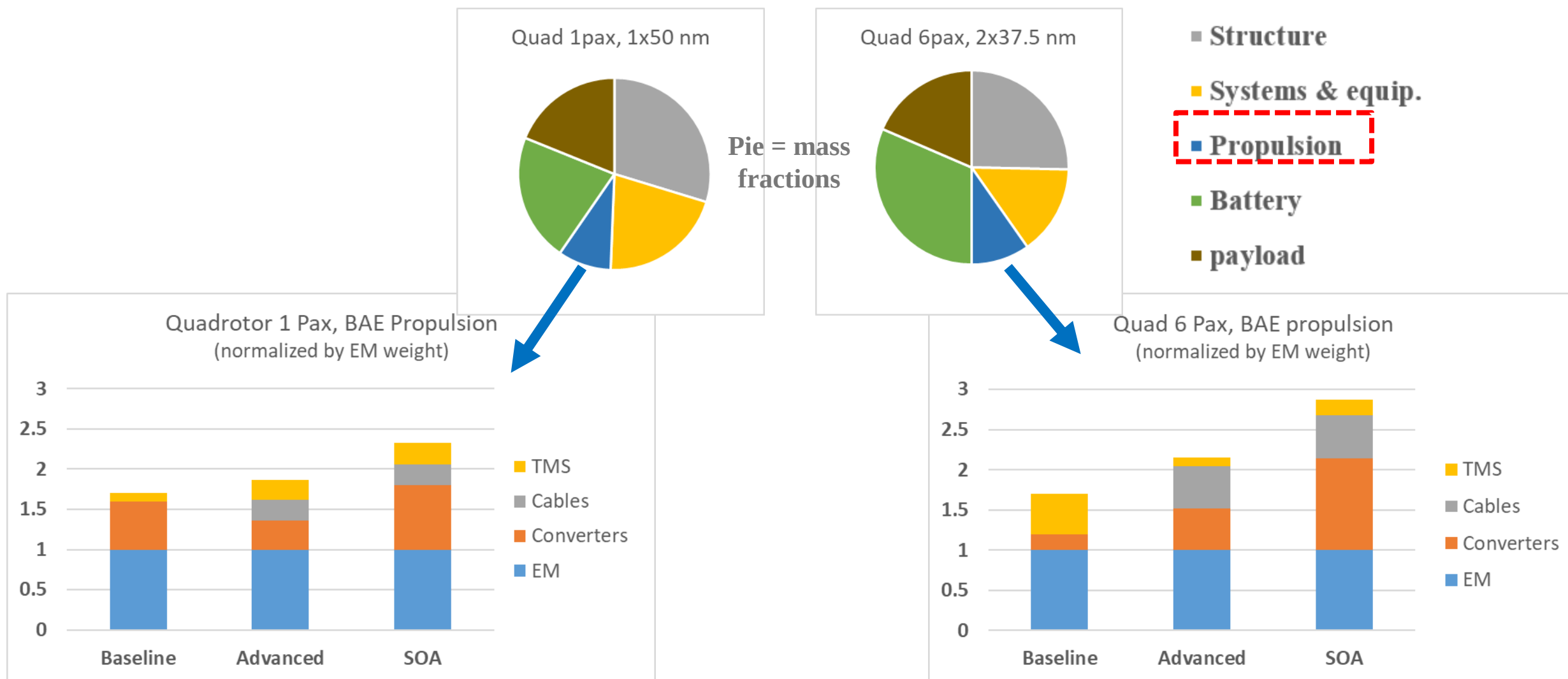


BAE: Significant battery mass reduces vehicle sensitivity to propulsion power/weight

TE: Propulsion weight more significant, cables and converter dominate components (Lift+Cruise)



Be careful scaling electric system components. 6 pax Quad shows higher overhead values vs 1 pax because electric motor weight improves as power increases



Summary

- Sensitivity study performed using the RVLT UAM reference vehicles with updated performance estimates for power management and distribution (PMAD), including a thermal management system (TMS).
- Cables and power converters (rectifiers, inverters, etc.) are significant weight items. Reduce # of conversions to reduce weight and losses (loss = heat to remove).
- Advanced electrical systems with updated PMAD have about 1/3 the thermal losses as SOA systems. Referenced studies suggest TMS weight and power penalties are small compared to other factors, but needs to be included (especially for MDO)
- Vehicles with higher disk loading and turboelectric systems show higher sensitivity to electric system weight, as they tend to have higher power requirements versus design gross weight. High battery mass fraction can mask propulsion weight changes
- Previous, baseline results for design gross weight and energy use were generally very similar to results assuming advanced electrical systems. Using state of the art (SOA) electrical component performance resulted in significant increases in weight and energy use.



Future efforts

- Additional component development needed:
 - Verify performance estimates with further development of these systems at relevant scale and “ilities” (reliability, maintainability, etc.).
 - Other configurations will be developed; can we include them in our assessments?
- Help integrate these more detailed component models or their performance attributes into subsystem and overall vehicle and mission models.
 - Multi-disciplinary analysis and optimization (MDAO) studies: Use the full models or simplified surrogate (or something in-between?)
 - Can we use these models for dynamic effects and transients?



Acknowledgments

This work was supported by the Aeronautics Research Mission Directorate (ARMD)
Advanced Air Vehicle Program (AAVP)
Revolutionary Vertical Lift Technology (RVLT) Project

Transformative Aeronautics Concepts Program (TACP)
Convergent Aeronautics Solutions (CAS) Project
Transformational Tools and Technologies (TTT) Project



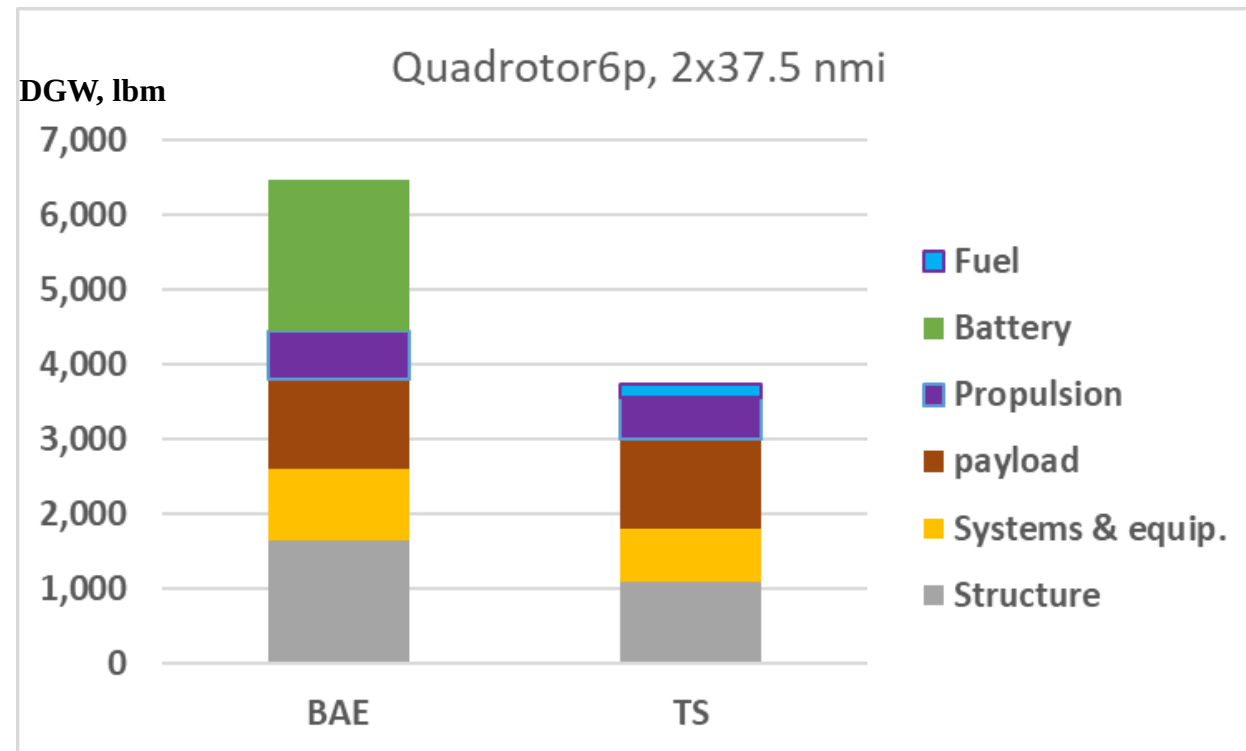
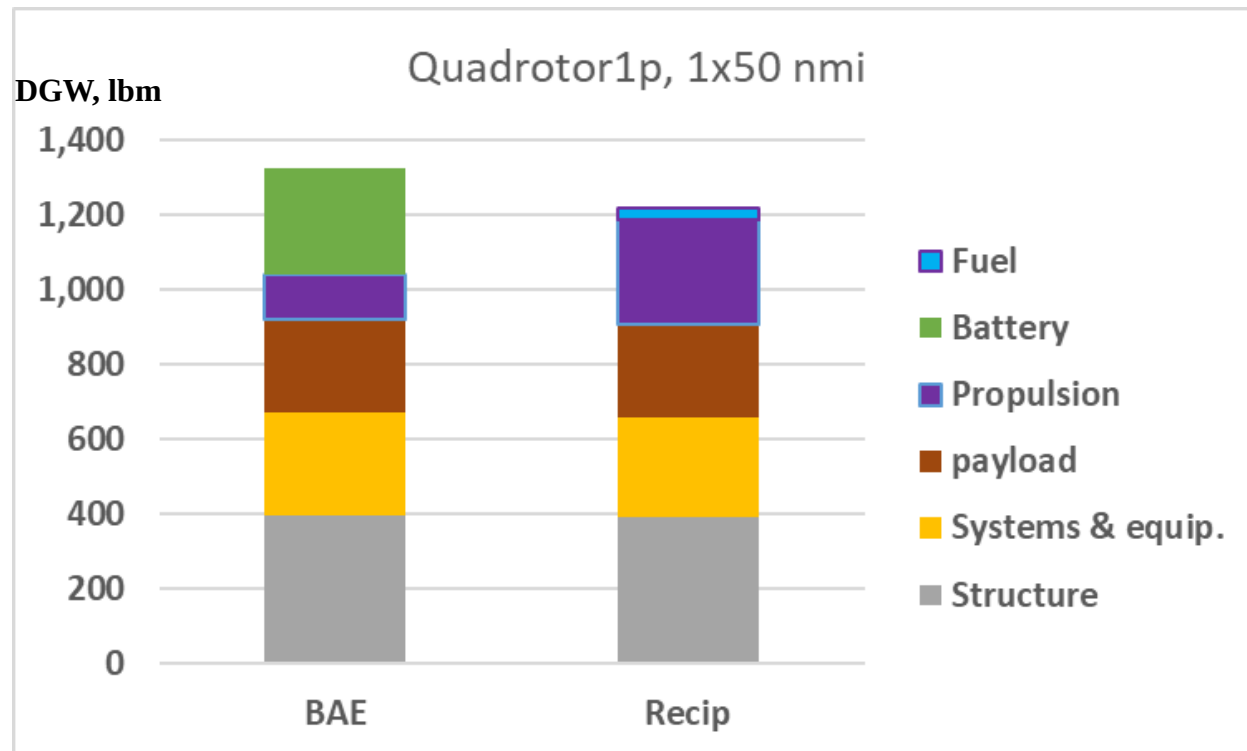
Questions?



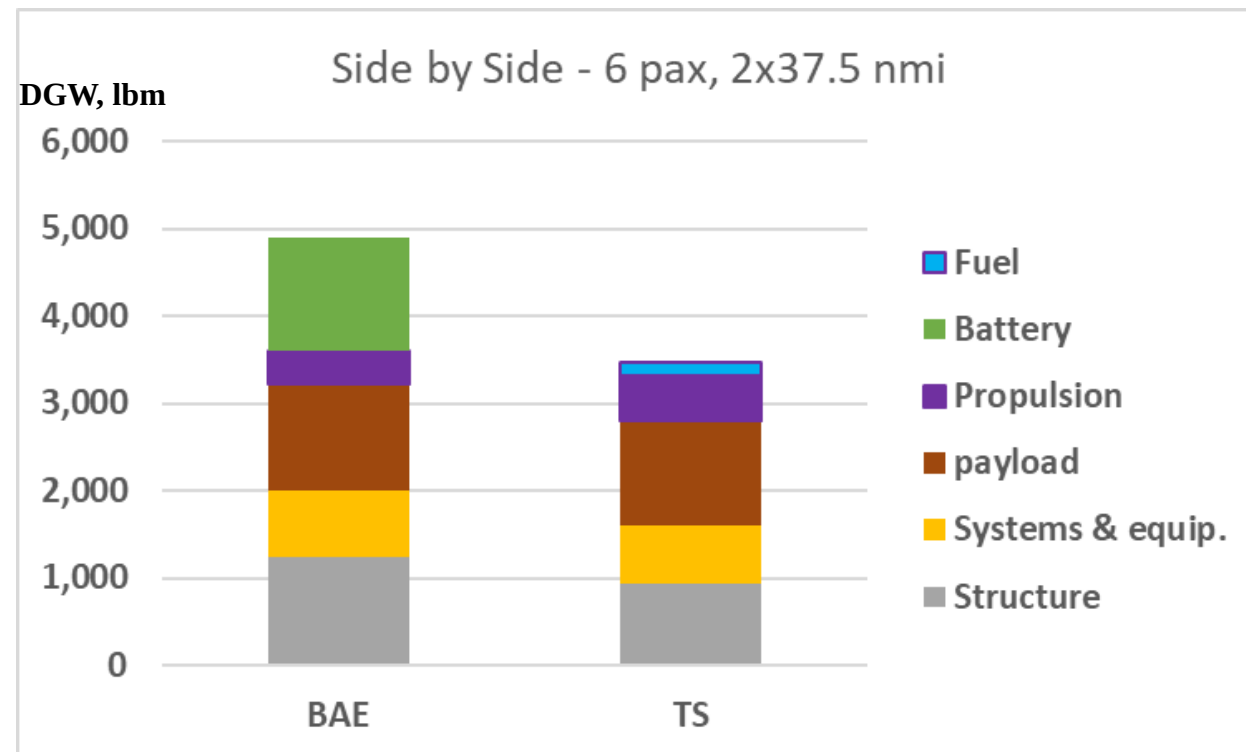
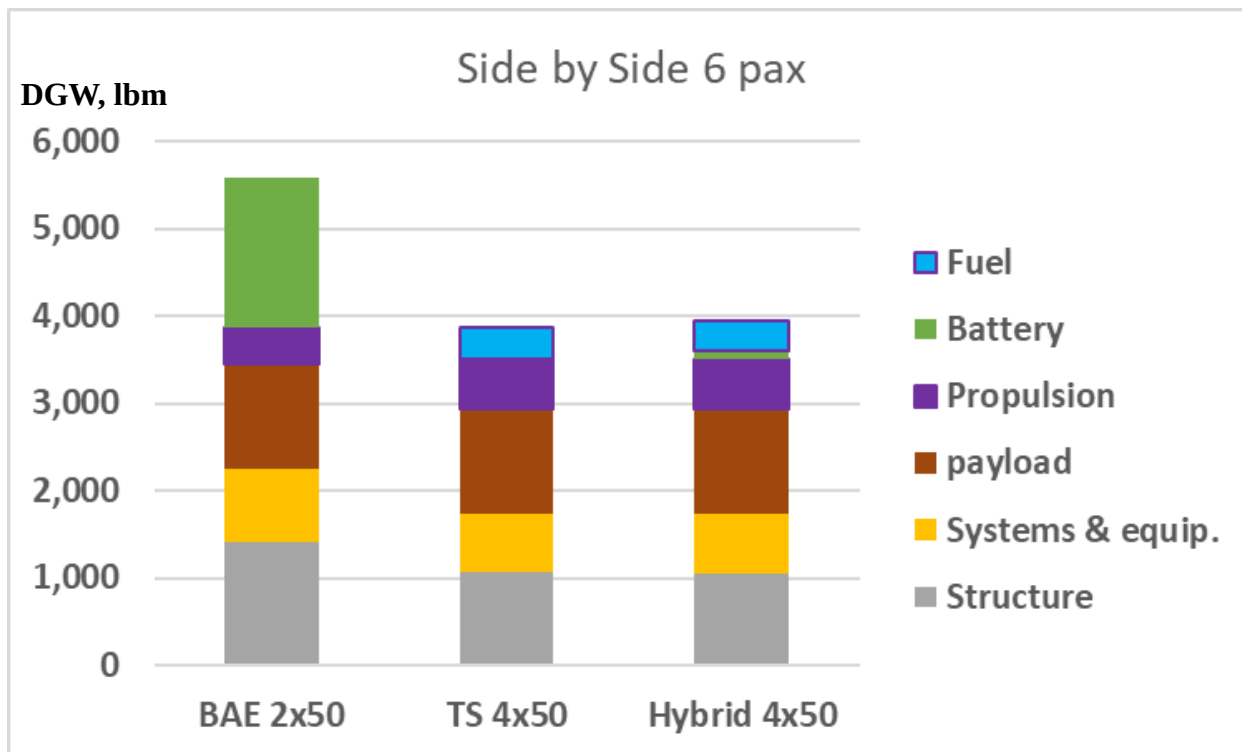


Backup Slides

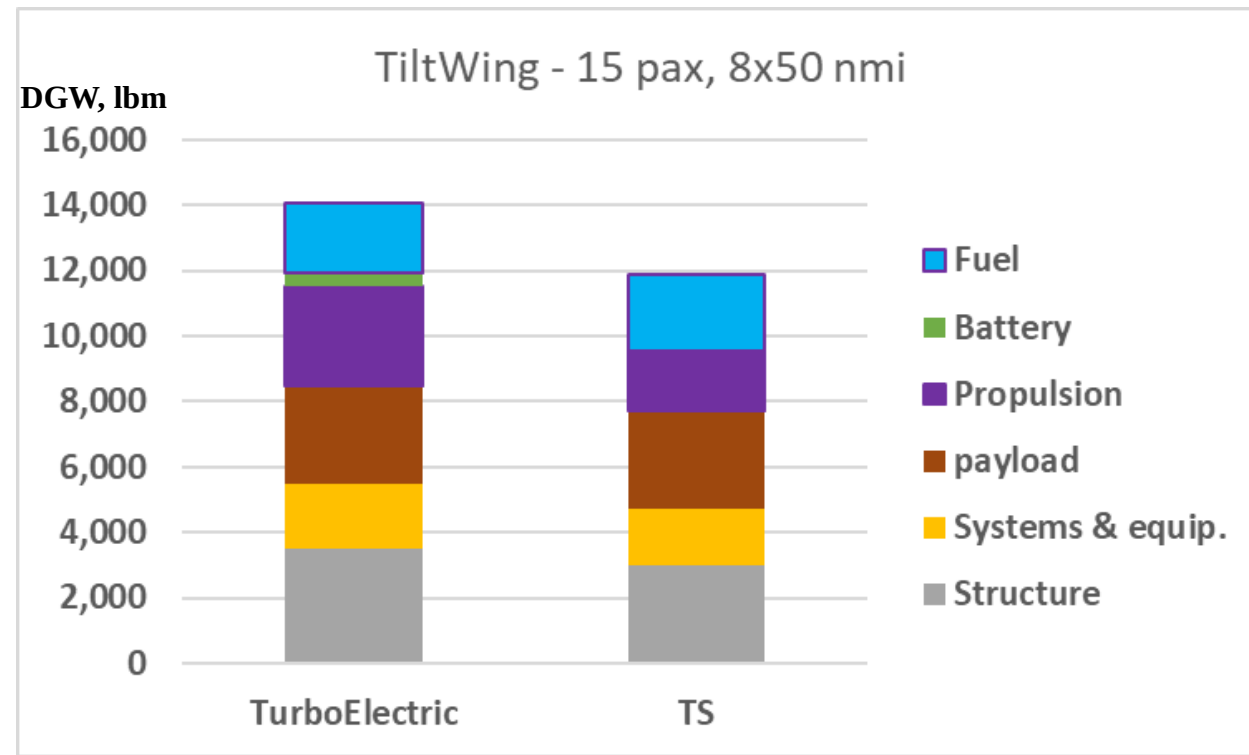
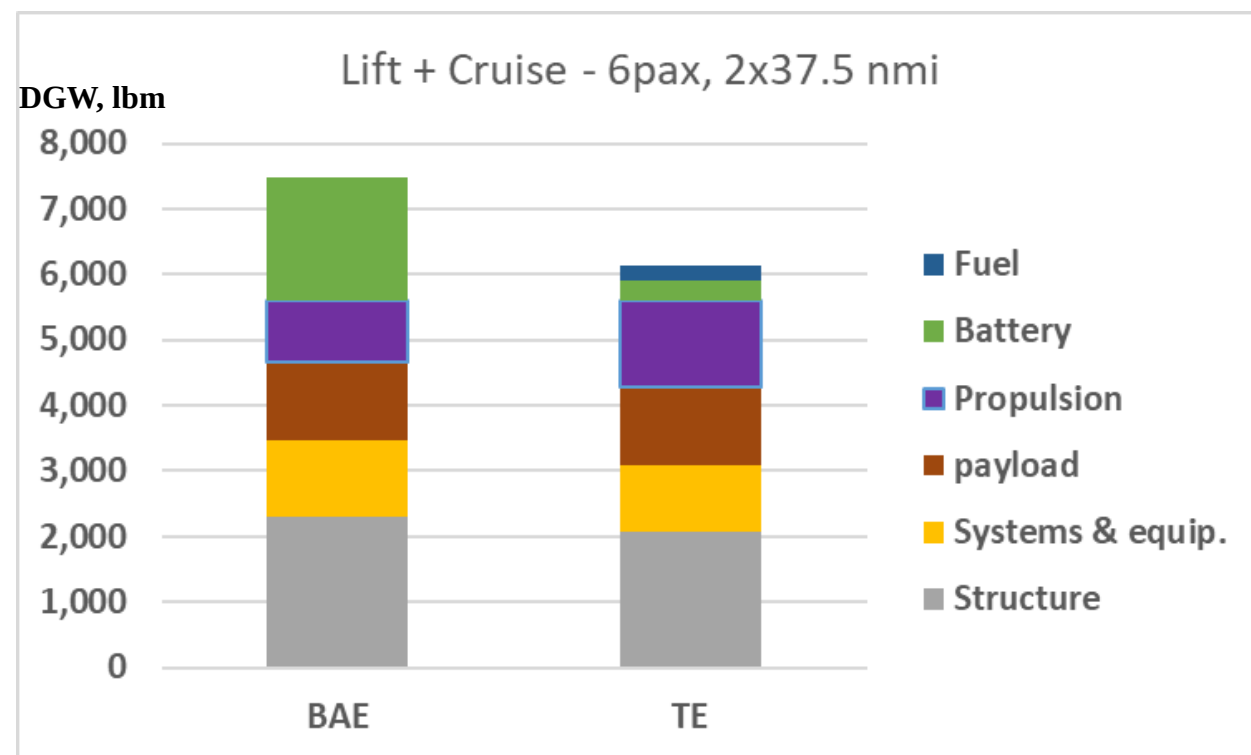
High battery mass fraction reduces vehicle DGW sensitivity to electric propulsion power-to-weight (Quadrotor)



High battery mass fraction reduces vehicle DGW sensitivity to electric propulsion power-to-weight (Side by Side)



High battery mass fraction of BAE reduces vehicle DGW sensitivity to electric propulsion power-to-weight vs TE system (Lift+Cruise and Tiltwing)



ABSTRACT

Battery power and energy density are important parameters for emerging concepts for more / all-electric vehicles. Electric propulsion and power system performance is also important. To better understand how electric propulsion and power systems component performance influences overall vehicle design, a sensitivity assessment was performed noting changes in vehicle gross weight and energy usage. Updated versions of the Revolutionary Vertical lift Technology (RVLT) Project vertical take-off and landing (VTOL) urban air mobility (UAM) reference vehicles and missions were used. NASA electric vehicle studies are discussed which were used to help select the range of electric propulsion and power system performance parameters used in this assessment. Thermal management systems (TMS) considerations are also important; new and innovative power management and distribution (PMAD) systems can reduce electric system weight and losses, reducing thermal management constraints often imposed by electric systems modest maximum use temperatures. Vehicles with higher disk loadings require higher power levels per unit weight for VTOL operations, which make them more sensitive to electric system weights and efficiencies. Battery, all-electric vehicles show different sensitivities to component performance than turboelectric or hybrids systems. Battery, all-electric propulsion systems may increase vehicle weight and size, but still results in lower mission energy usage than their hydrocarbon-fueled versions. Significant vehicle weight growth to electric propulsion and power system power-to-weight reductions also occurs at different levels among the various concepts. From these results, one can more readily identify required component performance levels, potential component choices, or research and development paths.



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