APISAT 2019

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ENGINEERS
AUSTRALIA

Electric Systems

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Performance Assessment and Comparison of a Tilt Rotor UAV Using Hybrid-Electric Propulsion Systems

Presentation Topics

- ➢INTRODUCTION
- ➢METHODS
  - ○ Flight Performance Model Development
  - ○ Parallel Hybrid Propulsion System
  - ○ Series Hybrid Propulsion System
- ➢RESULTS
- ➢CONCLUTIONS

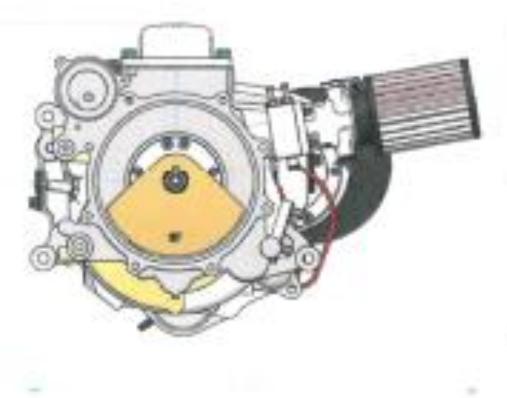
INTRODUCTION

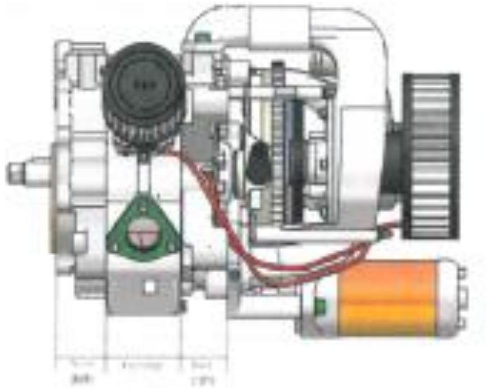
VTOL aircraft, such as tilt rotor aircraft, usually has different power demand between takeoff and cruise flight mode.

	BA609	King Air 350
Take off weight（kg）	7620	6804
Engine Power（kW）	1447*2	783*2
Weight/Power（kg/kW）	2.63	4.345
Cruise speed（km/h）	509	578

INTRODUCTION

For light VTOL UAVs (MTOW≤500kg), which are usually powered by only one internal combustion engine, the engine is usually selected according to the takeoff flight mode power demand, and this engine will has great power surplus and operates inefficiently in cruse flight mode.



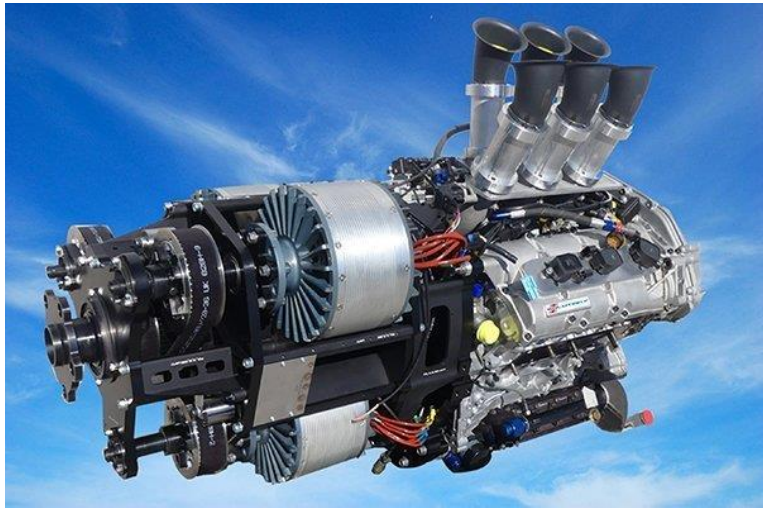


Power	41kW
Weight	27.8kg
Power density	1.47kW/kg

INTRODUCTION

Recently, significant developments have been made in the research of hybrid-electric aircraft propulsion, the applying of which is considered to be capable of disengaging the mismatch between takeoff and cruise power conditions for VTOL UAVs

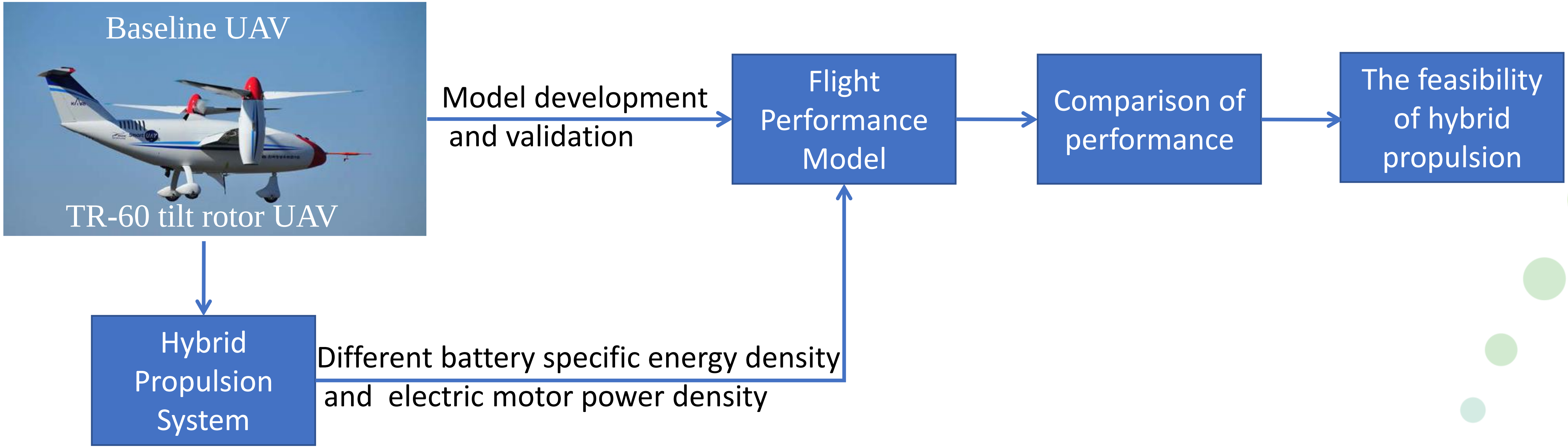
Cassio hybrid prototype



VoltAero hybrid power module

RESEARCH METHOD

The goal of this study is to explore the feasibility of a typical light tilt rotor UAV using parallel and series hybrid-electric propulsion.



RESEARCH METHOD—Flight Performance Model Development

Geometric and performance data of TR-60

Item	Data	Item	Data
MTOW (kg)	200	**Payload (kg)**	20
Power Plant (kW)	41 Rotary	**Overall Length (m)**	3.0
Wing Span (m)	3.0	**Wing Chord (m)**	0.5
Rotor Radius (m)	1.1	**Max Speed (km/h)**	240.0
Loiter Speed (km/h)	160.0	**Operational Altitude (km)**	3.0
Max Altitude (km)	4.0	**Endurance (hrs)**	5.0

RESEARCH METHOD—Flight Performance Model Development

Performance Calculation Formula

$$C_D = C_{D0} + KC_L^2$$

$$V_{Loiter} = \sqrt{\frac{2W}{\rho S}\sqrt{\frac{K}{3C_{D0}}}}$$

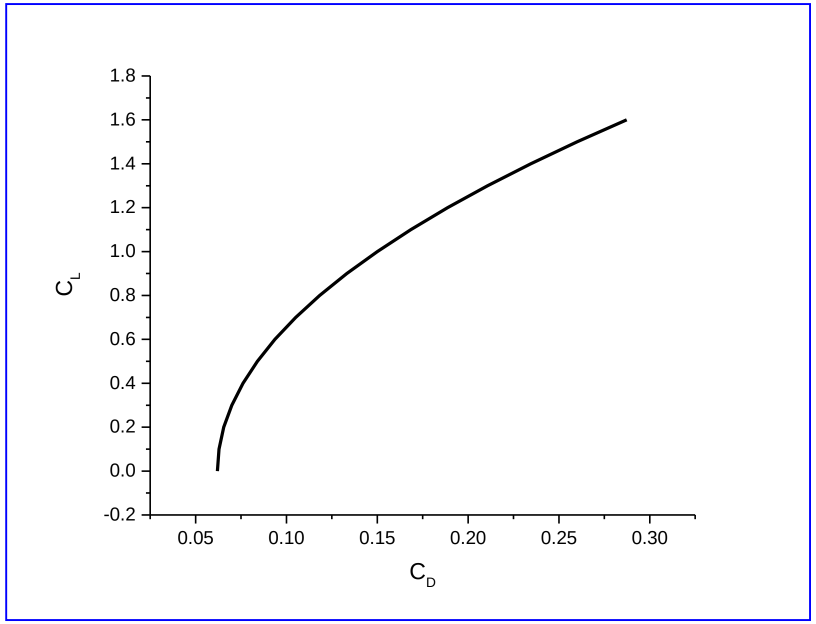
$$P = P_0\left(\frac{\rho}{\rho_0} + \frac{1-\rho/\rho_0}{7.55}\right)$$

Assumptions

Tilt rotor efficiency: 0.82

Engine install loss: 10%

Rotor drive efficiency: 93%



lift-drag aerodynamic performance

Flight Performance of original airframe

Loiter Speed: 160km/h

Max speed: 240km/h

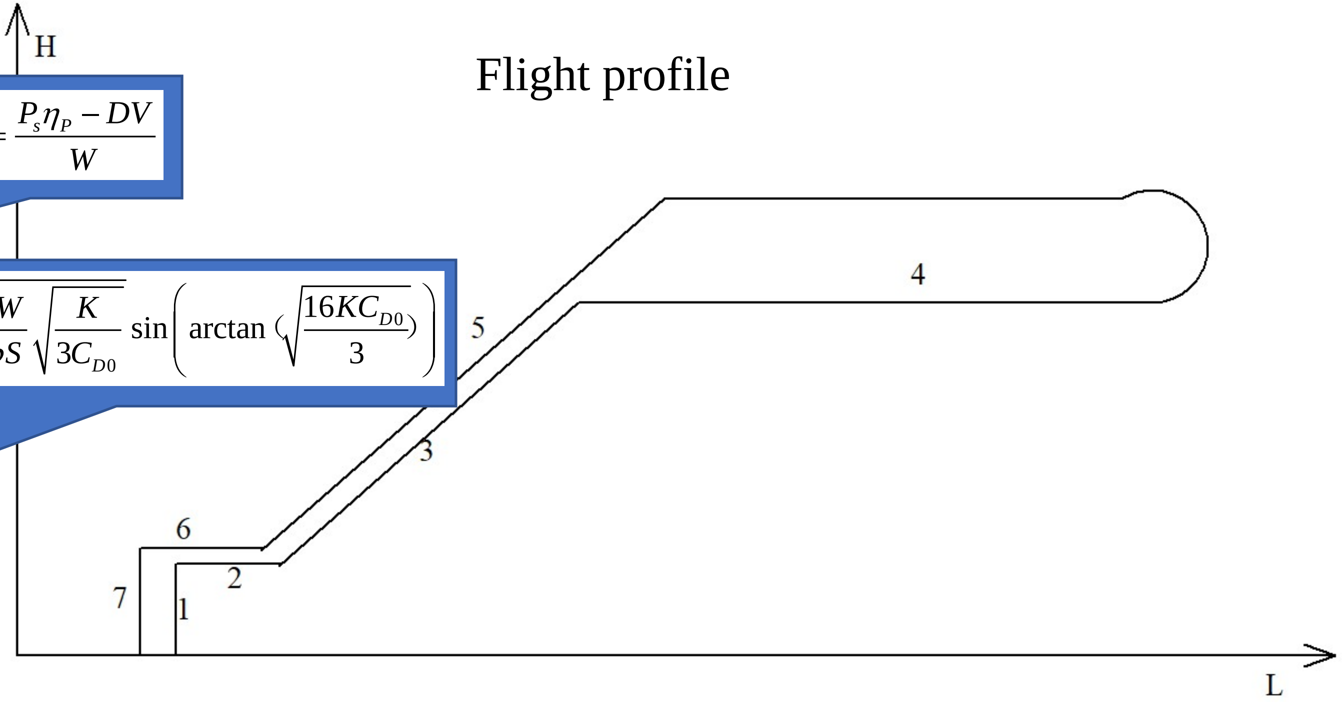
Operational Altitude: 3km

RESEARCH METHOD—Flight Performance Model Development

1. Vertical take-off and climb to 20m height (10s with 2.5m/s climb rate)
2. Conversion to airplane mode（30s）
3. Climb to 3km altitude (best rate of climb)
4. Cruise and loiter (with minimum power demand)
5. Descent to 20m height (minimum sink rate)
6. Conversion to helicopter mode (30s)
7. Vertical landing (30s)

$$V_V = \frac{P_s \eta_P - DV}{W}$$

$$V_V = \sqrt{\frac{2W}{\rho S}\sqrt{\frac{K}{3C_{D0}}}} \sin\left(\arctan\left(\sqrt{\frac{16KC_{D0}}{3}}\right)\right)$$



Flight profile

RESEARCH METHOD—Flight Performance Model Development

After the flight performance simulator is established, the max altitude and flight time are obtained based on 200kg takeoff weight and 35kg fuel weight. With a small overall percent error, the simulation is sufficiently representative of a tilt rotor VTOL UAV for the purposes of this study.

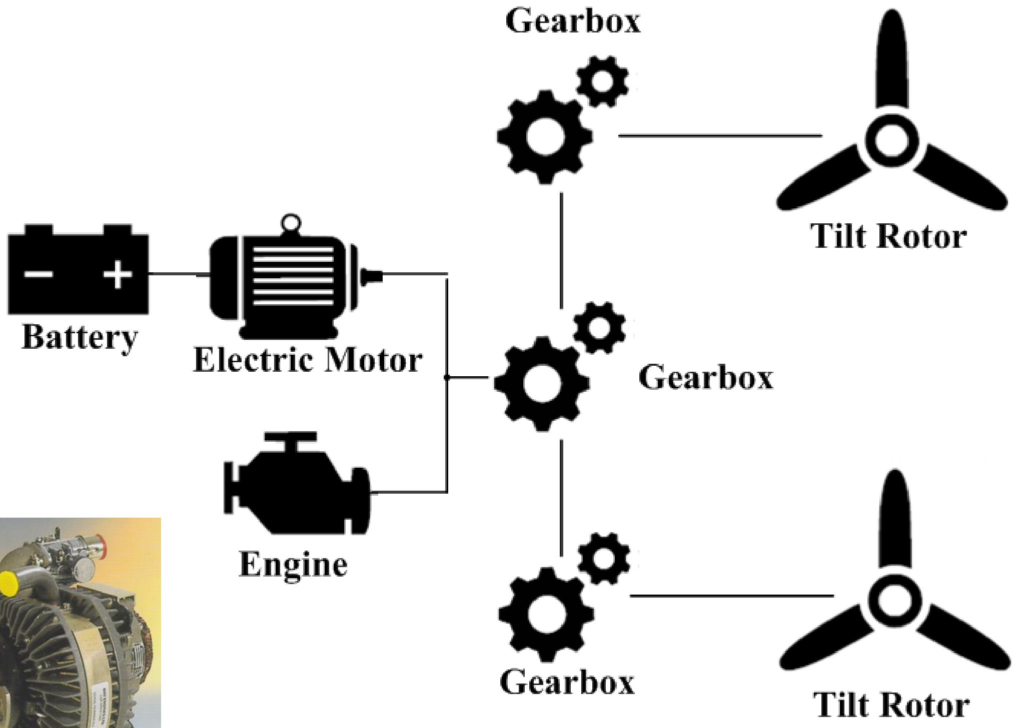
Reported and simulated TR-60 performance comparison

Item	Real	Simulated	Percent difference
Max Altitude (km)	4.0	4.036	0.9%
Endurance (hrs)	5.0	5.24	4.8%
Time to Altitude 3km (s)	/	878	/
Time to Decent (s)	/	473	/

RESEARCH METHOD—Parallel Hybrid Propulsion System

The parallel hybrid propulsion system is developed with a battery-powered electric motor system, coupled to an internal combustion engine system through the center gearbox.

The engine is selected according to the cruise flight power demand, and a parallel electric motor are selected according to the excess power demand for takeoff.



28.3kW AR 741 rotary engine

RESEARCH METHOD—Parallel Hybrid Propulsion System

Some parameters for electric driving system

- Motor power density is 5.26kw/kg
- The weight of motor controller is weigh 30% of the weight of the motor
- The electric motor efficiency is 93%
- Only 80% of the battery energy is used

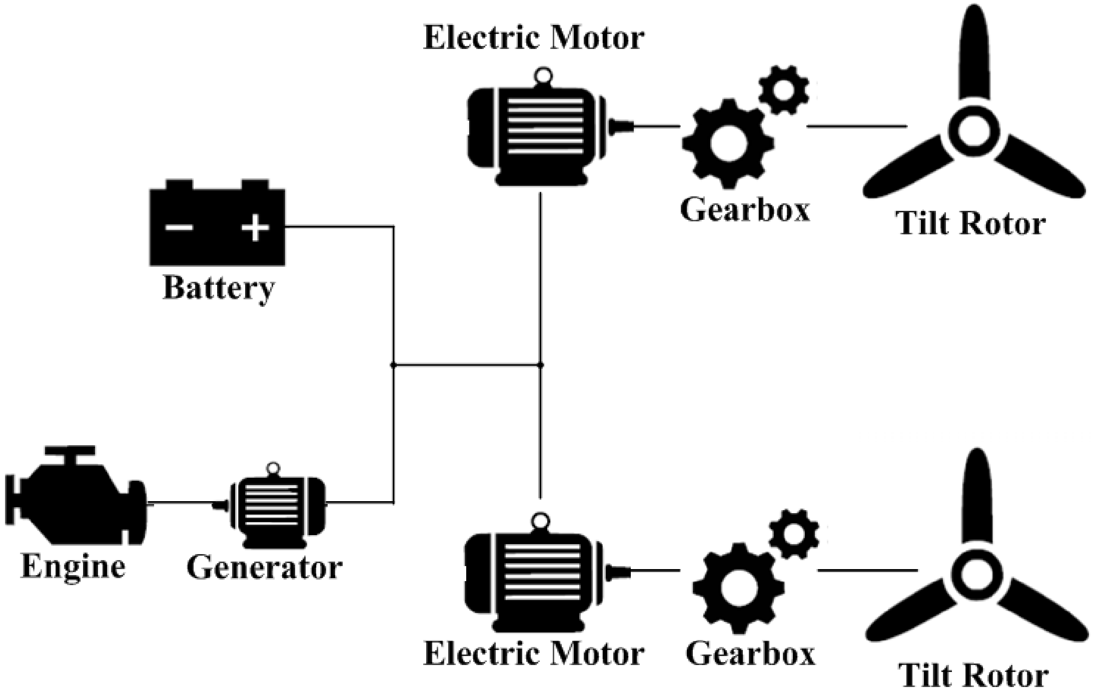
Comparison of propulsion systems

Item	Single engine	Parallel hybrid
Engine Power (kW)	41.0	28.3
Motor Power (kW)	/	12.7
Total Power (kW)	41	41
Engine Weight (kg)	24.5	10.7
Motor Weight (kg)	/	2.4
Motor Controller Weight (kg)	/	0.7
Total propulsion system weight (kg)	24.5	13.8
Fuel and Battery Weight (kg)	35.0	45.7

RESEARCH METHOD— Series Hybrid Propulsion System

The rotor is turned with an electric motor through pylon gear box, which is powered by batteries and a generator connected to an internal combustion engine.

The electric motor is selected according to the takeoff flight mode power demand, and the engine and generator are selected according to the cruise flight mode power demand, battery is selected according to the excess power demand for takeoff.



RESEARCH METHOD— Series Hybrid Propulsion System

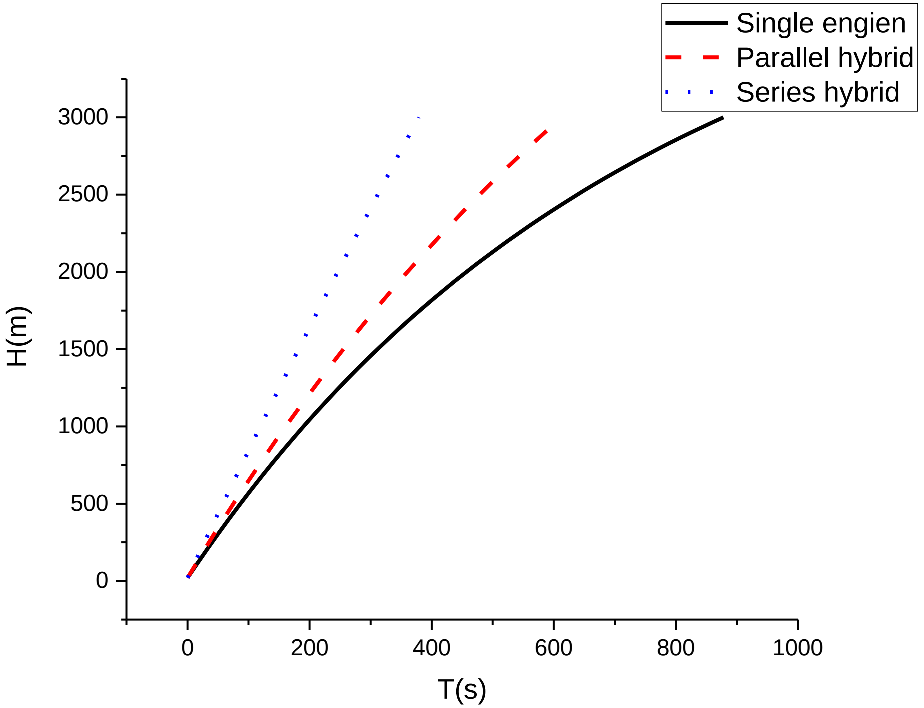
Some parameters for driving system

- Generator efficiency is 95%
- Saving weight for the cancel of center gearbox is 10kg
- Rotor drive efficiency is 95%

Comparison of propulsion systems

Item	Single engine	Paralledl hybrid
Engine Power (kW)	41.0	28.3
Motor Power (kW)	/	20 (Single)
Total Power (kW)	41	40
Engine Weight (kg)	24.5	10.7
Motor Weight (kg)	/	3.8 (Single)
Motor Controller Weight (kg)	/	2.3
Generator Weight (kg)	/	4.9
Fuel and Baterry Weight (kg)	35.0	44.0

RESULTS

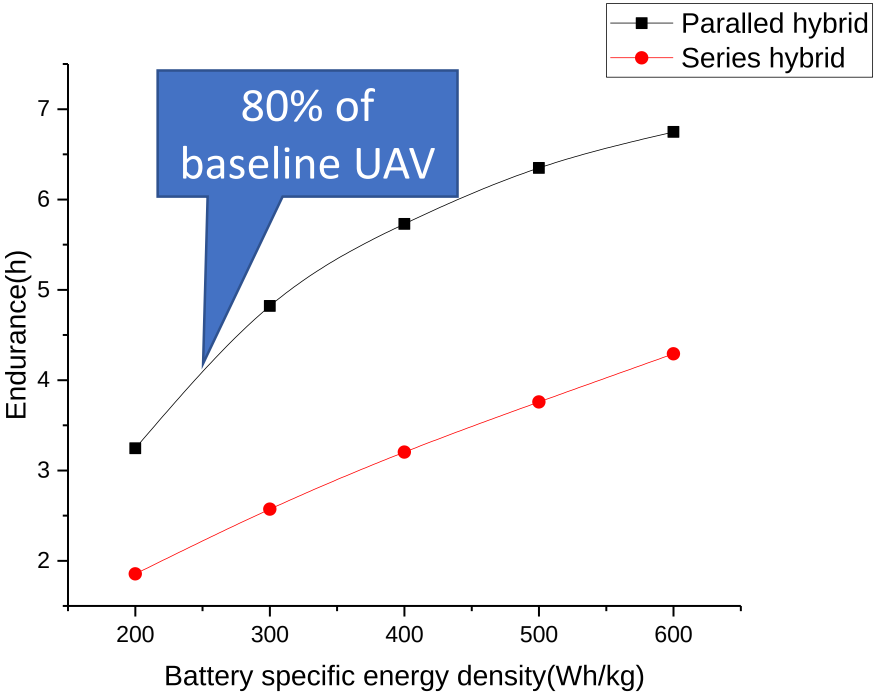


Comparison of altitude to simulated times curve during climb

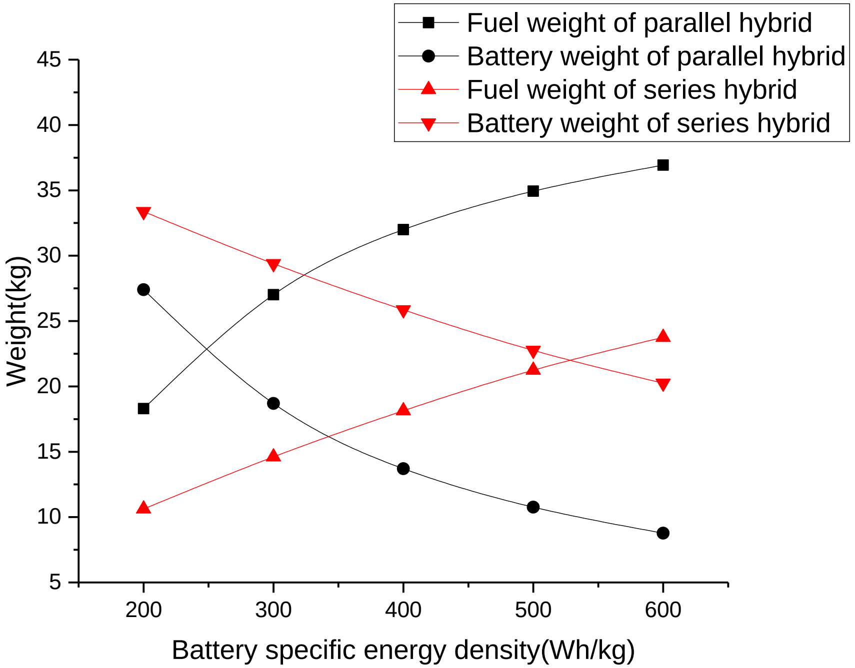
Comparison of max altitude and speed

Item	Single engine	Paralledl hybrid	Series hybrid
Max Altitude (km)	4.0	5.9	13.5
Max Speed (km/h)	240.0	260.3	293.6

RESULTS

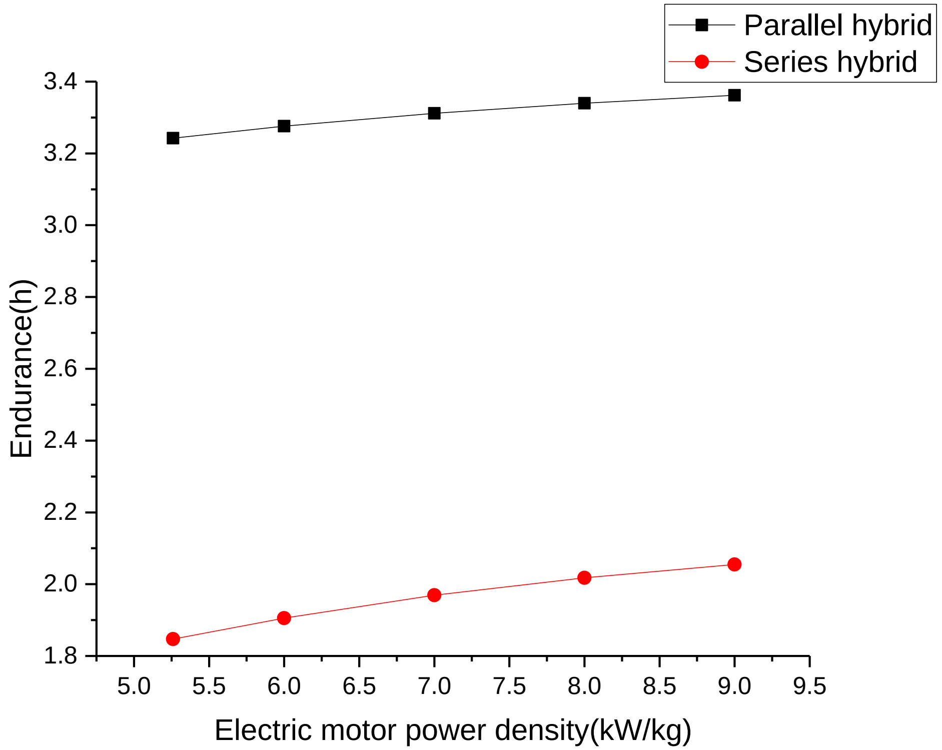


Endurance as a function of battery specific energy density



Fuel and battery weight as a function of battery specific energy density

RESULTS



Endurance as a function of electric motor power density

CONCLUSIONS

- The parallel hybrid power architecture is feasible for VTOL UAV application based on current technology;
- The endurance performance will get largest promotion with the immediate improvements in battery specific energy density;
- The endurance of series hybrid tilt rotor UAV is much less than baseline UAV based on current technology;
- Distributed electric propulsion system, will likely cause the endurance of series hybrids to surpass parallel hybrids at current technology.

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Thank you !

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