Executive Summary

Carleton University, Ottawa

Undergraduate Team

43rd Annual Student Design Competition

Student Design Competition

Hybrid Electric Tiltrotor

Sponsored by LEONARDO

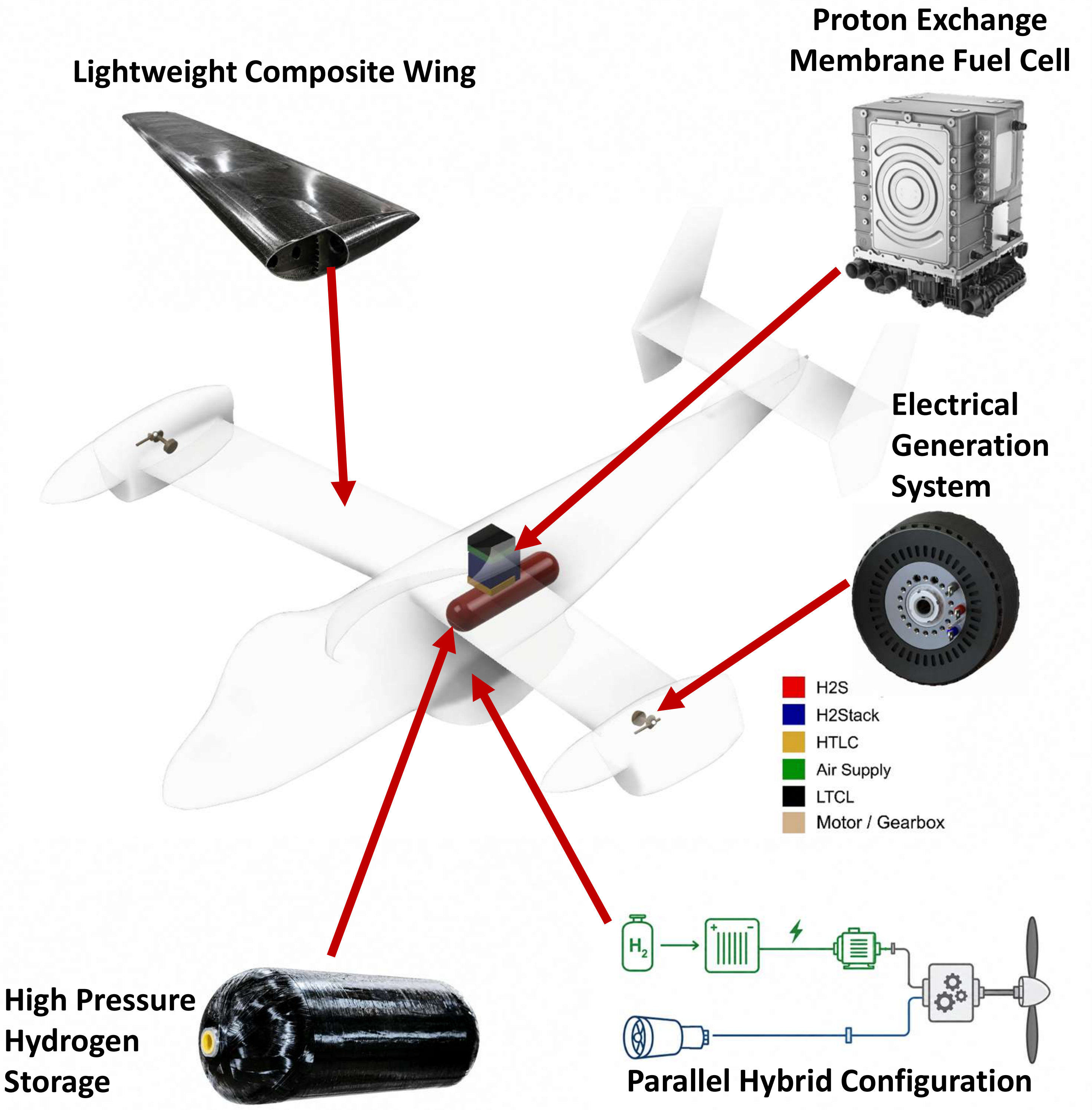
RAVENS

Carleton University – Team Ravens

Department of Mechanical and Aerospace Engineering

Ottawa, Ontario, 1125 Colonel by Drive, K1S 5B6, Canada

Key Features



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Ravens

The name **Ravens** was selected to represent both the identity of Carleton University and the design philosophy behind this hybrid-electric tiltrotor concept. As Carleton University's mascot, the raven reflects the team's academic origin and collective identity. At the same time, ravens are known for intelligent, adaptable, and highly capable flight, which aligns closely with the operational character of a tiltrotor aircraft. Like a raven, a tiltrotor is not limited to one flight mode; it can rise vertically, transition efficiently, and cruise freely across different flight regimes.

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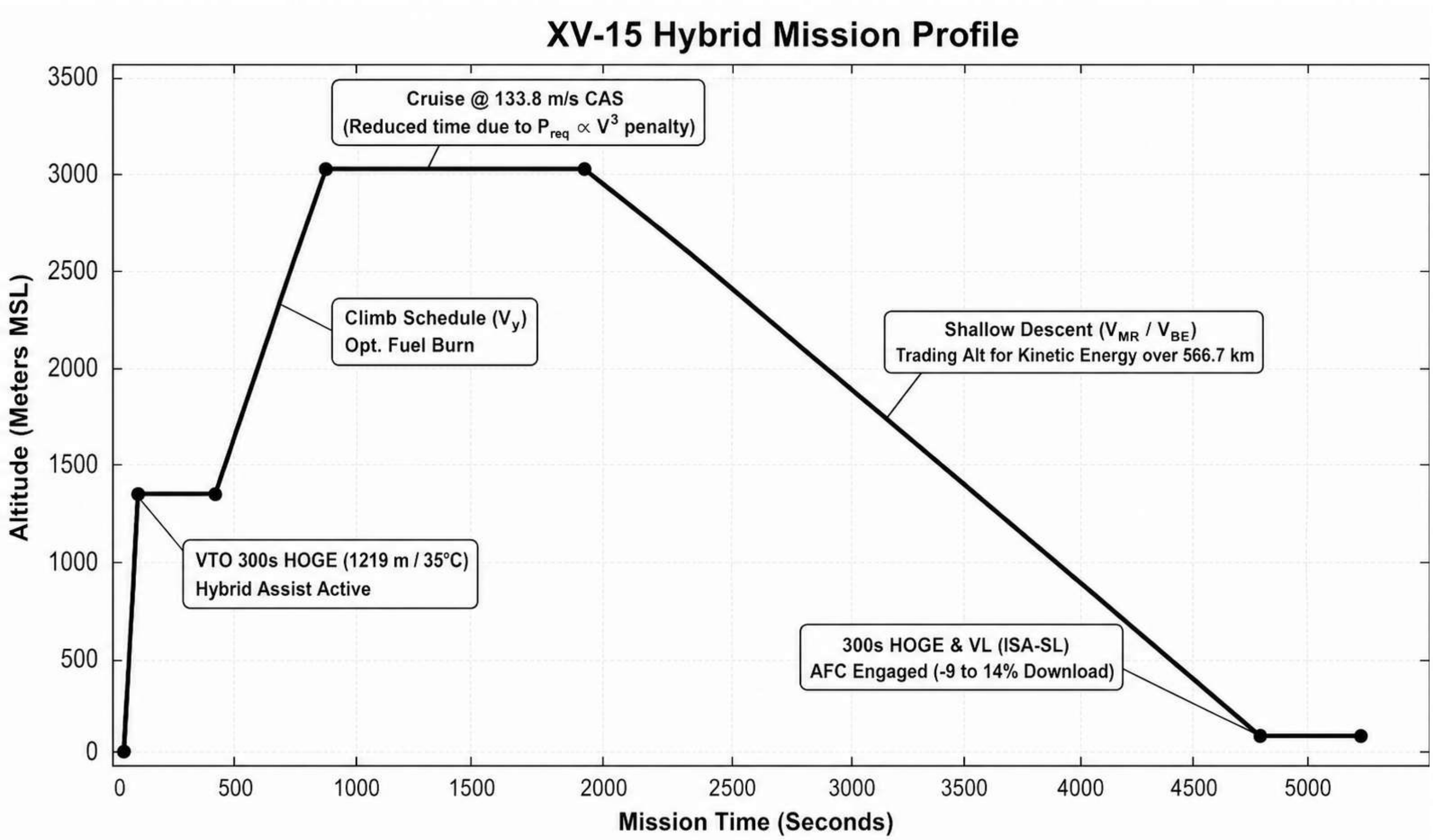
Design Challenge

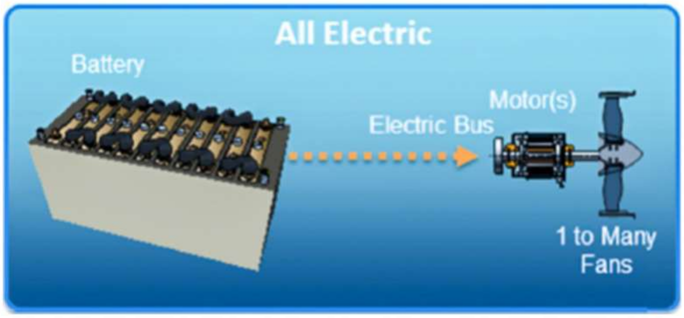
- **Phase I:** Install a hybrid-electric system while maintaining the primary XV-15 configuration.
- **Phase II:** Perform aircraft-level optimization while maintaining critical constraints.
- At least 10% mission must come from electrically generated sources
- One Engine Operation, autorotation, translation from helicopter to airplane mode

Mission Profile

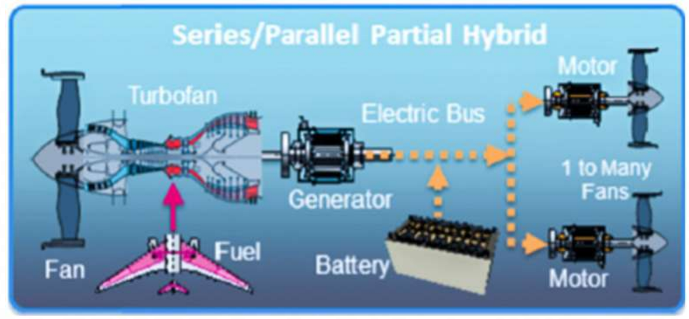
- 5 min Hover Out of Ground Effect, MTOW, 4K/95ºF
- Change altitude to 10,000 ft
- Cruise, 260 KCAS
- Descend and land for a total distance of 306 nm
- 10% fuel reserve
- 5 min HOGE, landing, ISA-Sea Level
- 2 pilots @ 100kg



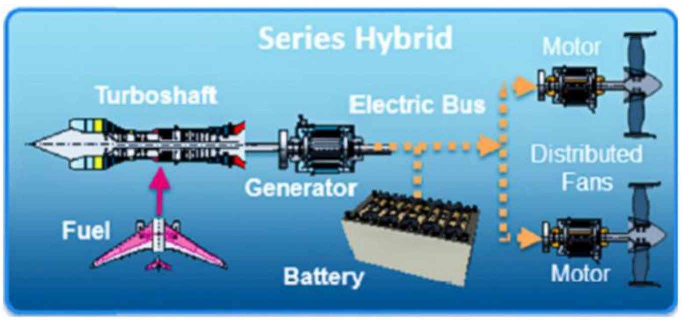
Hybrid System Selection



Requires high-power motors, **excessive mass** and integration risk for this design.



Requires multiple energy-conversion stages, **increasing efficiency losses**



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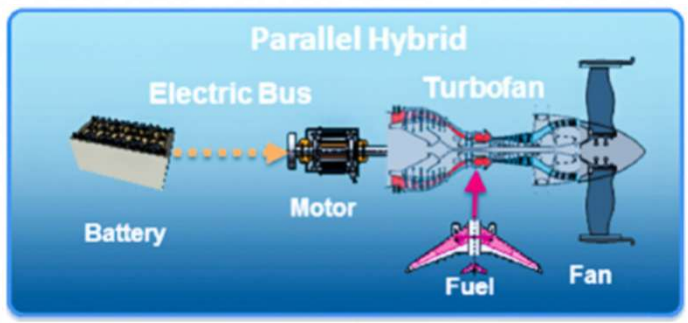

Best balance between RFP compliance, low modification risk, and system simplicity.

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Electrical Power Generated Source

Proton Exchange Membrane Fuel Cell

- **Highest power density** among the fuel-cell options considered.
- **Lower mass penalty** than battery-based solutions.
- Greater aviation maturity than hydrogen-combustion and SOFC technologies.
- Well suited to an **auxiliary hybrid-electric** propulsion role.
- Provides the **best balance** of performance, feasibility, integration risk, and technology readiness.

Eliminated Choice

Solar Power

Solid Oxide Fuel Cell

Battery

Thermal Engine Generation

Hydrogen Combustion Engine

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PEMFC

Calculated Weight*

PEMFC System	364.5	Kg
PEMFC Fuel Stack	44.55	Kg
H2	12	Kg
H2 Storage Tank	202.8	Kg
Electrical	8	Kg
Compressor	30	Kg
Humidifier	1.65	Kg
Filter	0.33	Kg
Regulator	0.33	Kg
Power	1.65	Kg
HT Cooling Weight	53.84	Kg
LT Cooling Weight	10.35	Kg

PEMFC Component Selection

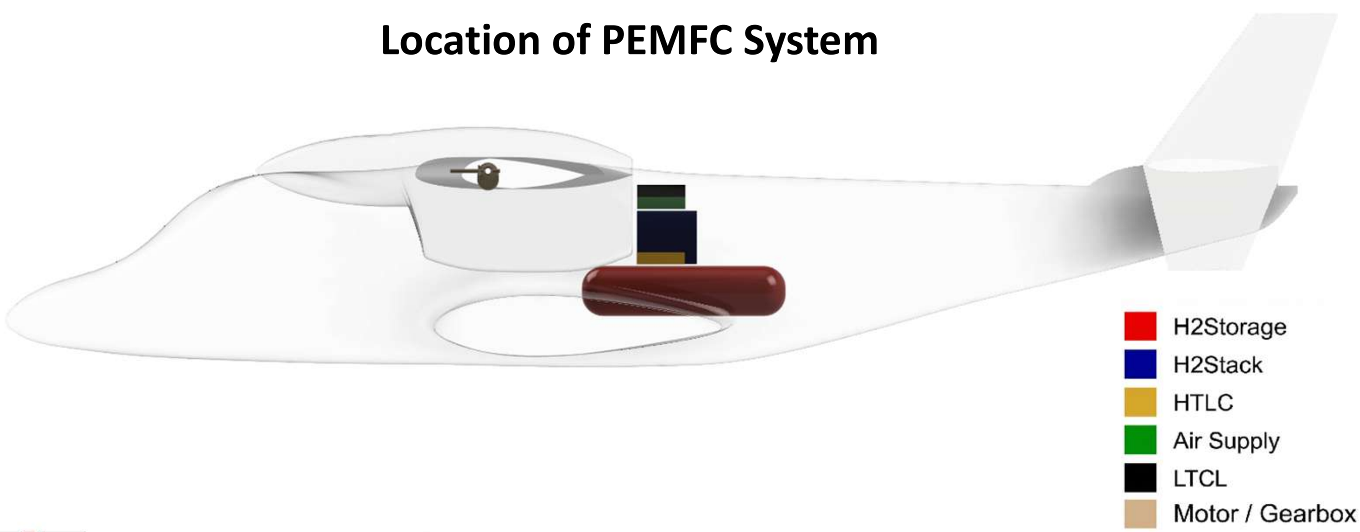
EKPO NM12 Twin PEM Fuel Cell Stack

Hexagon Purus H2-70-610X2060

NeoAir CEV45 Fuel Cell Compressor

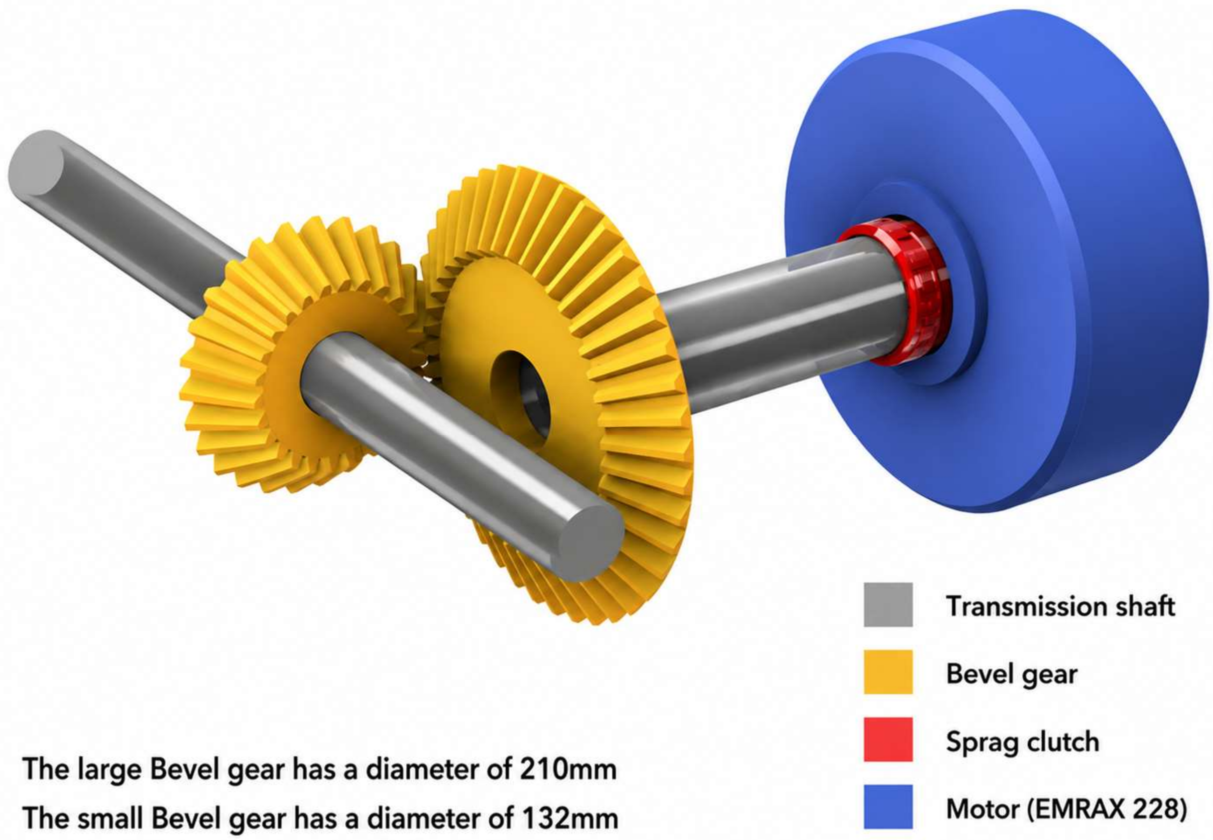
Note*: Aircraft-level mass sizing uses NASA code estimates; real-world components are shown to demonstrate engineering availability and feasibility.

Location of PEMFC System



Mechanical Coupling System

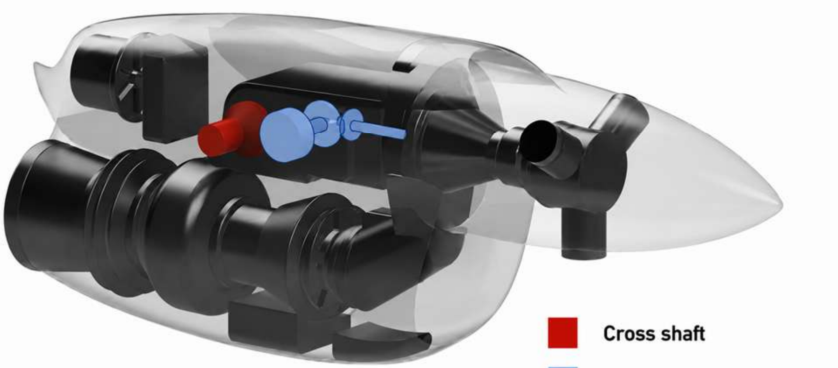
- Preserves the original XV-15 drivetrain architecture.
- Avoids the efficiency losses associated with fully electric power-conversion architectures.
- Maintains OEI capability and propulsion redundancy.



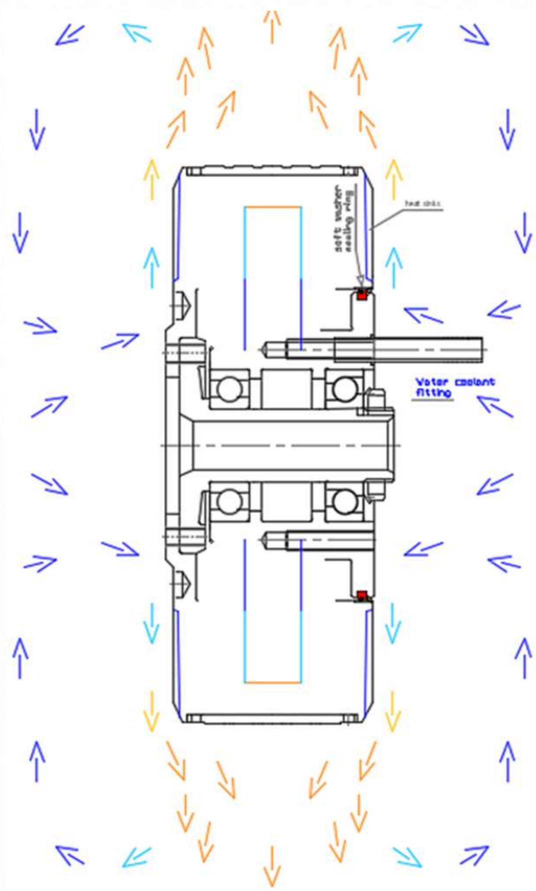
Motor

- Enables compliance with the RFP electrical-energy contribution requirement while minimizing fuel consumption.
- Delivers near-instant torque response.

Motor: EMRAX 228



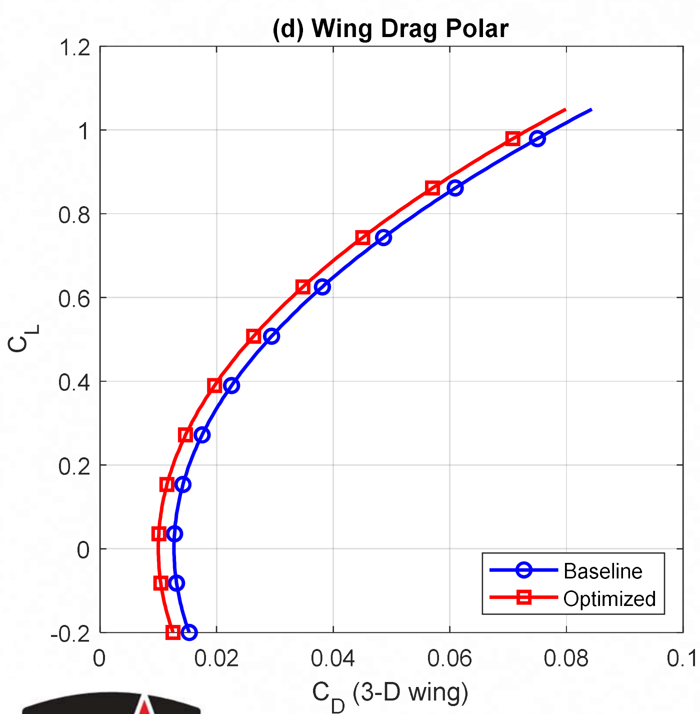
Location of motor

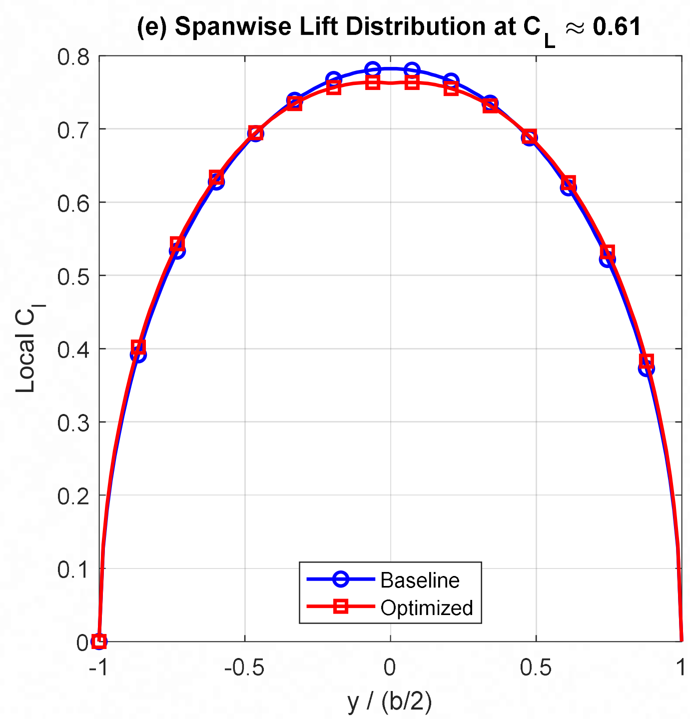


Combined Cooling Illustration

Wing Aerodynamic Improvement

- Thinner 18% composite wing for reduced cruise drag.
- ~16.5% reduction in cruise drag and energy consumption.
- Wing lift-to-drag ratio improved from 16.5 to 19.8.
- Optional nacelle sails retained for future drag reduction.
- Active flow control reduces hover download and VTOL power demand.





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Weight Reduction

- High-modulus CFRP wing structure replaces selected metallic components.
- ~83 kg wing structural weight reduction.
- Improved stiffness-to-weight ratio and whirl-flutter resistance.
- Electromechanical actuators reduce hydraulic-system mass.
- Simplified flap/flaperon architecture provides additional weight savings.

Item	Estimated saving
CFRP/composite wing replacement	83 kg
Selected electromechanical actuator (EMA) replacement	23–68 kg
Flap/flaperon simplification and sealing	9–27 kg
Total direct empty-weight reduction	115–178 kg

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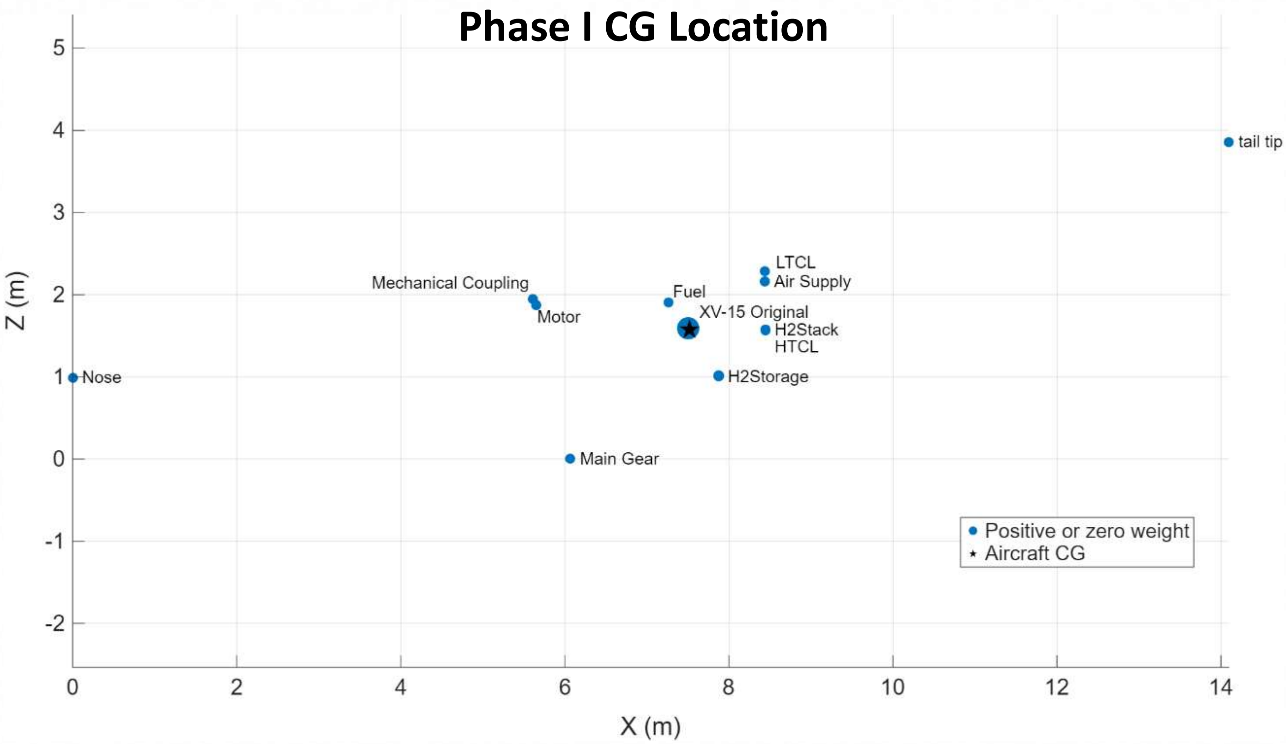
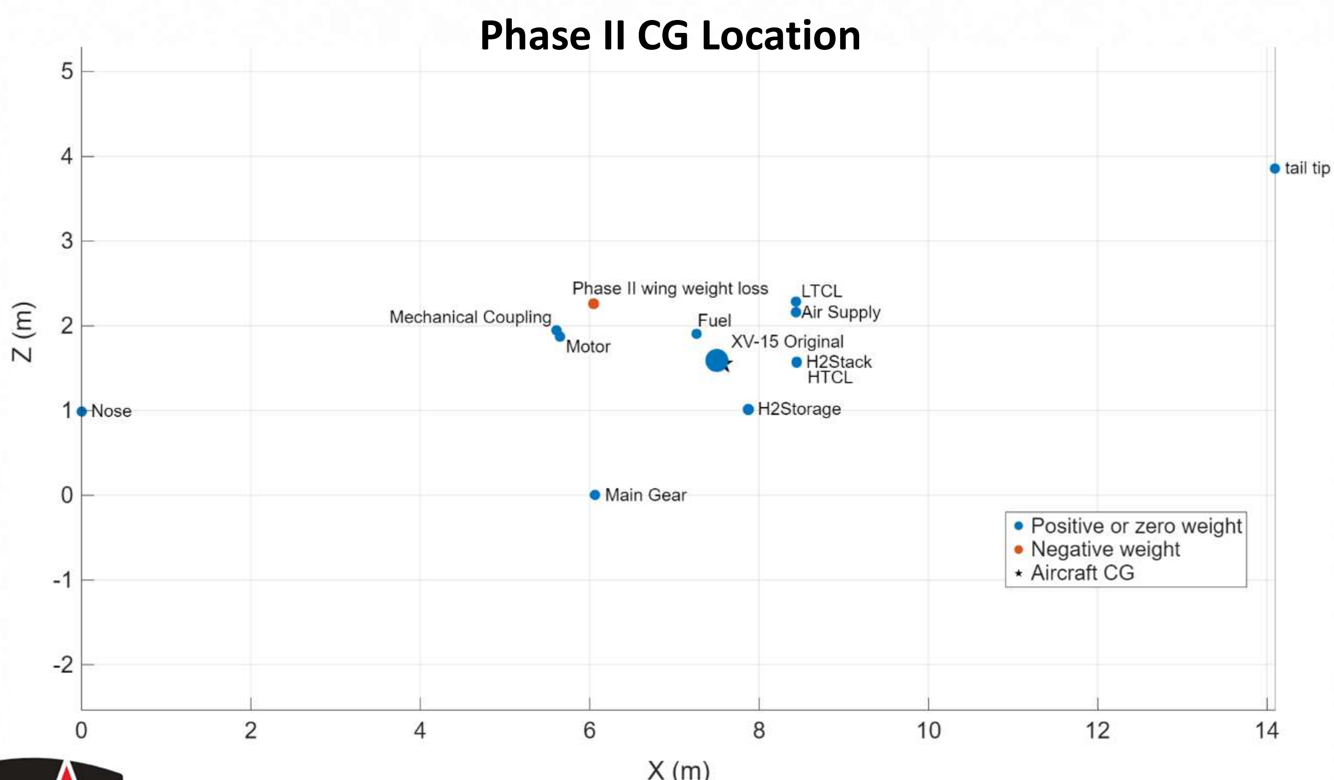
CG Analysis


Phase I CG Location
Z (m)
X (m)
tail tip
LTCL
Air Supply
Mechanical Coupling
Fuel
XV-15 Original
Motor
H2Stack
HTCL
Nose
H2Storage
Main Gear
Positive or zero weight
Aircraft CG


Phase II CG Location
Z (m)
X (m)
tail tip
Phase II wing weight loss
LTCL
Air Supply
Mechanical Coupling
Fuel
XV-15 Original
Motor
H2Stack
HTCL
Nose
H2Storage
Main Gear
Positive or zero weight
Negative weight
Aircraft CG

Mission Achievement

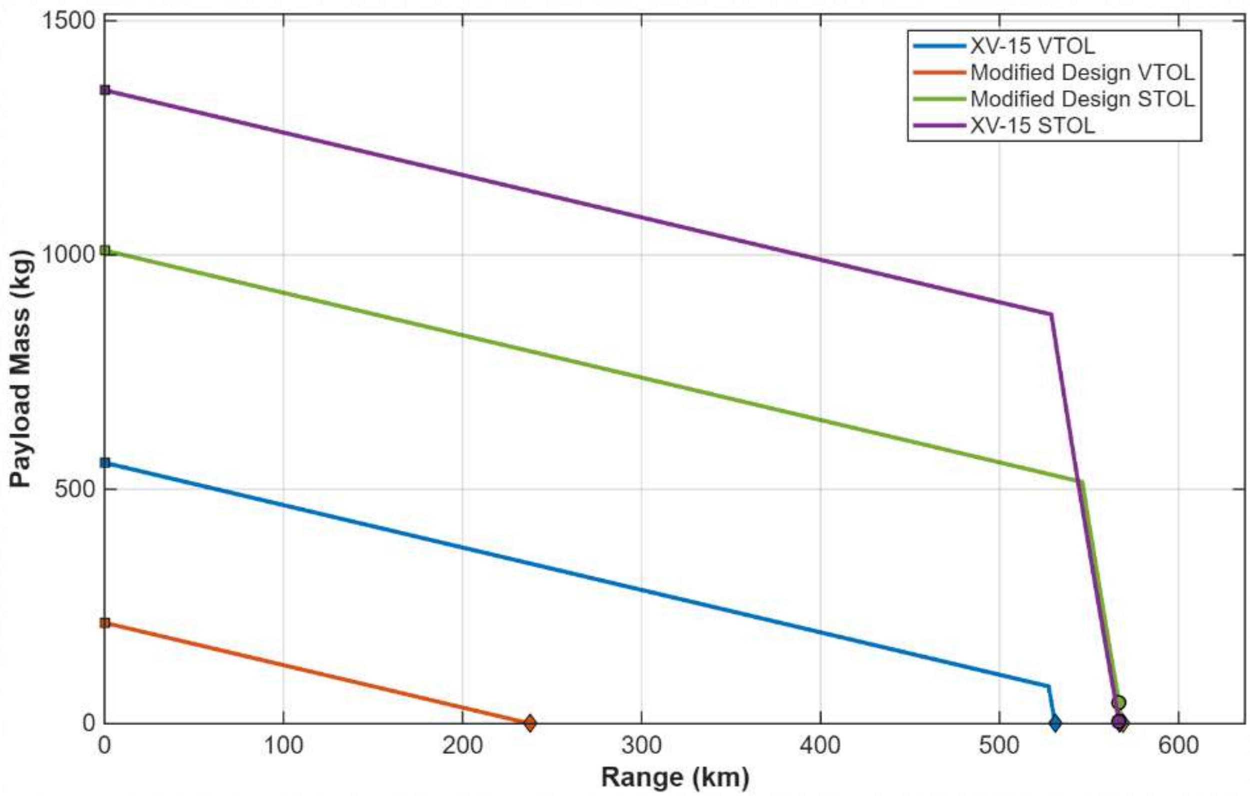
- Thermal-only VTOL strategy preserves baseline XV-15 safety during low-altitude hover segments.
- Emergency electric torque assist retained for OEI transient recovery and rotor-speed protection.
- Electric propulsion activated after climb entry for hybrid mission-energy contribution.
- Both Phase I and Phase II satisfy the RFP minimum electrical-energy requirement.

Result Summary

Item	Phase I	Phase II
Electrical energy percentage, VTOL	10.20%	10.70%
Electrical energy percentage, STOL	10.10%	10.60%
VTOL fuel usage	505 kg	469 kg
STOL fuel usage	507 kg	472 kg
PEMFC system mass	364.5 kg	same as Phase I
Phase II empty-weight reduction	—	115–178 kg
OEI capability	retained	retained
Autorotation capability	retained	retained
Electrical energy percentage, VTOL	10.20%	10.70%

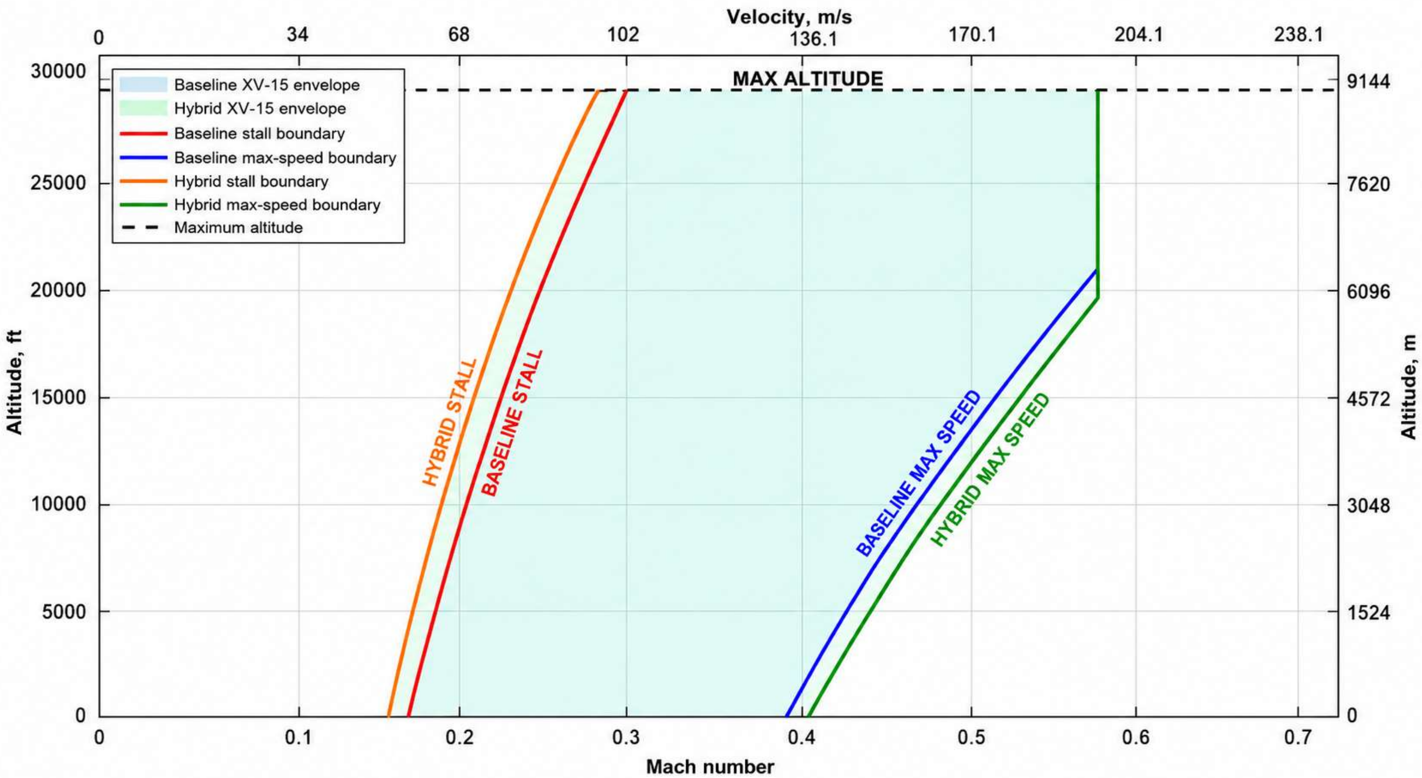
Payload Range

- Payload–range analysis compares the baseline XV-15 and modified design under both VTOL and STOL takeoff modes.
- The modified VTOL design has reduced payload capability due to the added mass of the hybrid-electric system.
- The modified STOL configuration preserves useful payload capacity while still supporting the required mission range.



Flight Envelope

- Stall boundary improved through aerodynamic optimization.
- Maximum-speed capability increased relative to the baseline XV-15.
- 260 KCAS cruise at 10,000 ft **remains** comfortably within the envelope.
- Phase II satisfies all RFP flight-envelope speed requirements.



Risk Management

Transition

- Lift transfers from rotors to wings during conversion.
- Control shifts from rotor pitch control to aerodynamic surfaces.
- Electric propulsion improves flexibility but requires advanced control allocation.

Autorotation

- Baseline XV-15 rotor geometry is retained to preserve autorotation capability.
- One-way clutch isolates the motor and prevents drag during rotor freewheeling.

Phase II Technical Risk

- Thinner composite wing improves cruise efficiency but requires flutter validation.
- Active flow control and nacelle sails add system complexity.
- Further structural, aerodynamic, and control validation is required.

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Recommendation

Future Research

- Obtain higher-fidelity PEMFC and BOP data to improve power, efficiency, and mission-level performance predictions.
- Acquire more detailed XV-15 flight-test and configuration data to strengthen performance, envelope, and safety analyses.
- Further validate thermal management, mass distribution, and flight-dynamics models.

Future Design Improvements (Without RFP Constraints)

- Replace the T53 with a modern turboshaft engine to improve fuel efficiency and power density.
- Investigate a fixed-engine / rotating-proprotor architecture to reduce tilting mass and drivetrain complexity.
- Re-optimize the wing and rotor system for improved aerodynamic performance.
- Adopt a fully digital fly-by-wire control system to enhance handling qualities, OEI response, and overall safety.

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