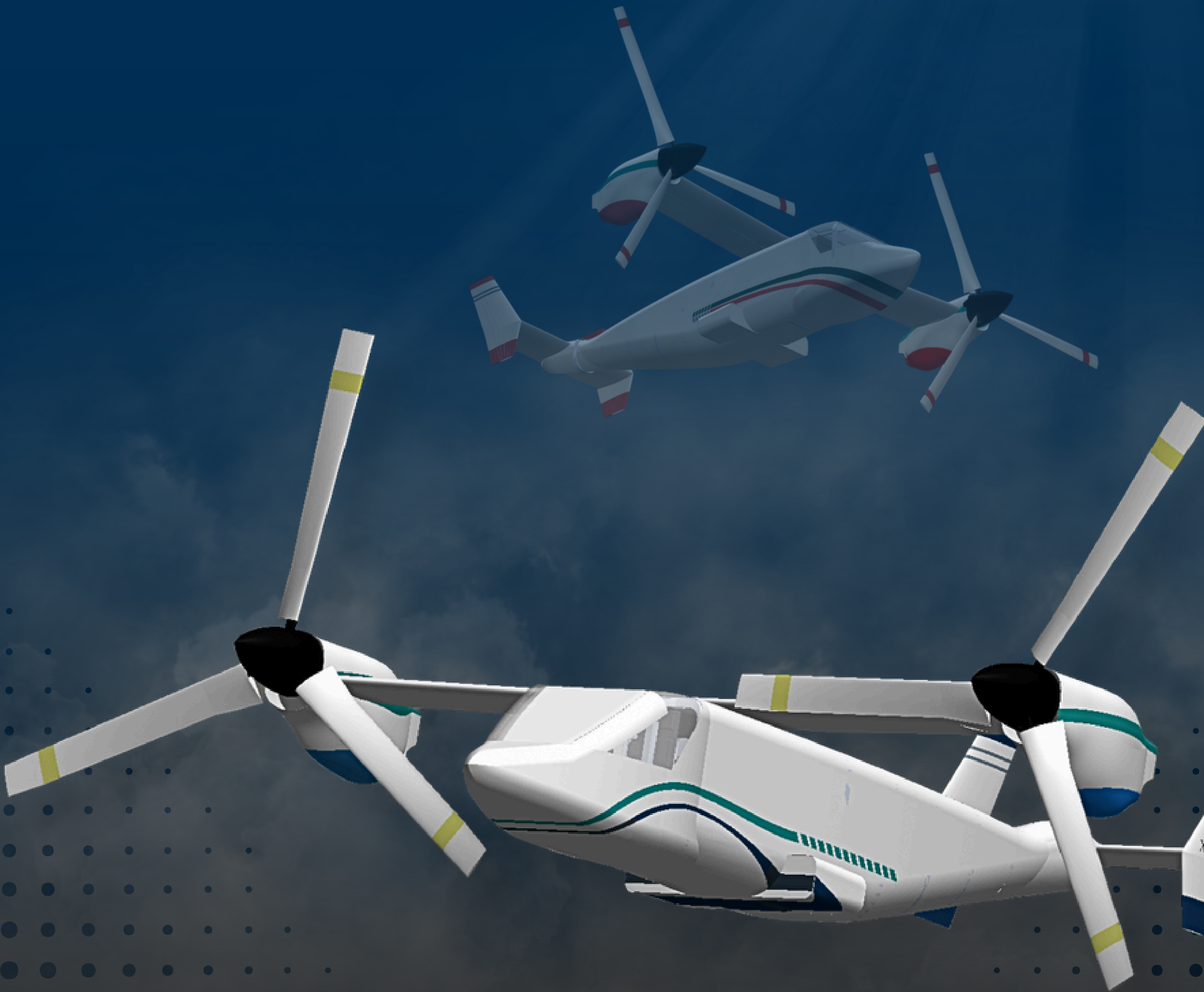


IBRIDO

43rd Annual Student Design Competition

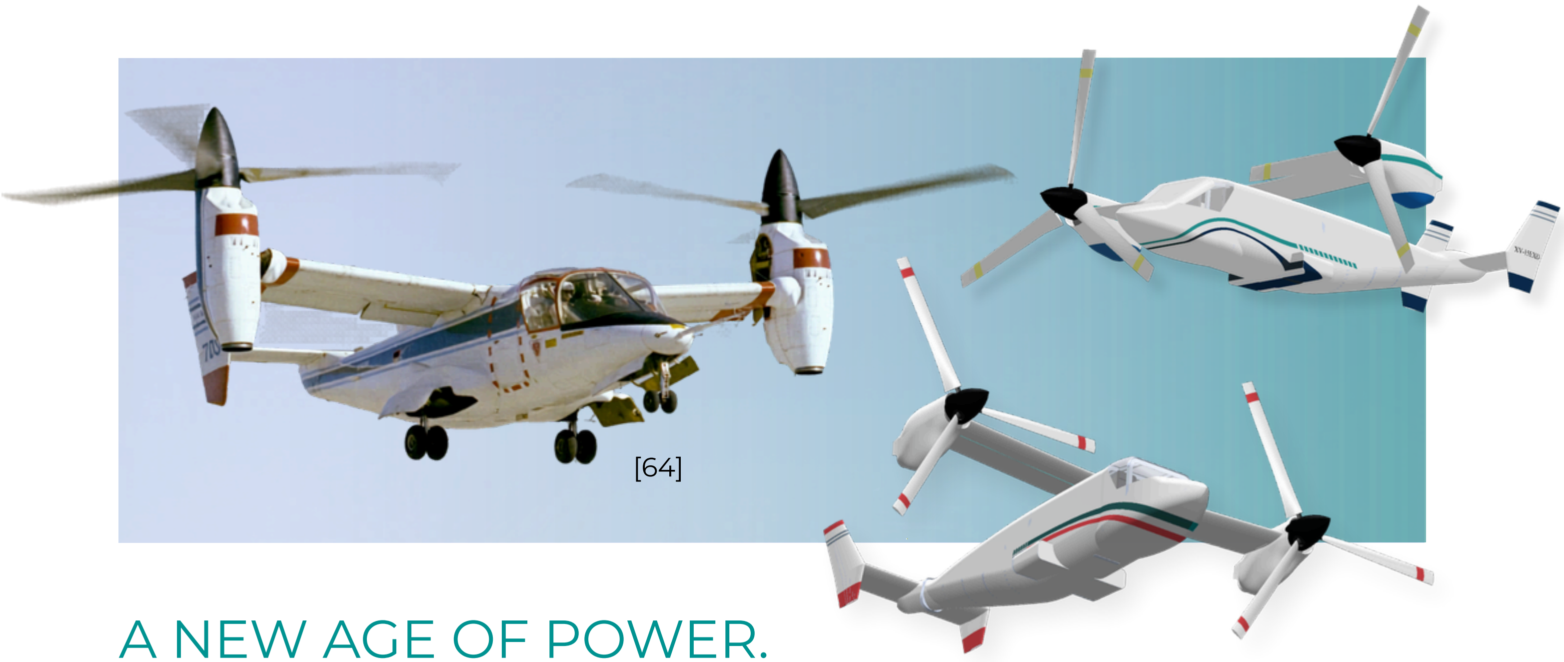
HYBRID ELECTRIC TILTROTOR

sponsored by

LEONARDO

Georgia Institute of Technology

Vertical Flight Society



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A NEW AGE OF POWER.

With the continued development in aviation technologies to meet long-range Vertical Takeoff and Landing (VTOL) air vehicles and sustainable resource goals, the need for a realistic and reliable hybrid electric tilt-rotor aircraft is becoming essential. A major driver of change and innovation within the aerospace industry is the continued increase in fuel costs, which is the only significant air transportation cost that has grown over time. The world is entering a time-frame where technology convergence in sustainable technologies and propulsion innovation are colliding in the aviation industry. The automobile industry has seen significant strides in hybrid-electric and electric technologies. The time is now for aviation.

Hybrid-electric air vehicles play a critical role in the further development and progress in creating sustainable aircraft. The pairing of traditional jet engine technologies and emerging electric propulsion systems allows for a necessary bridge in the development and understanding of these innovations. Taking a current, well-researched tilt-rotor aircraft and implementing deliberate design choices to create an effective and reliable hybrid-electric air vehicle for optimized performance is a critical step in understanding new propulsion architectures.

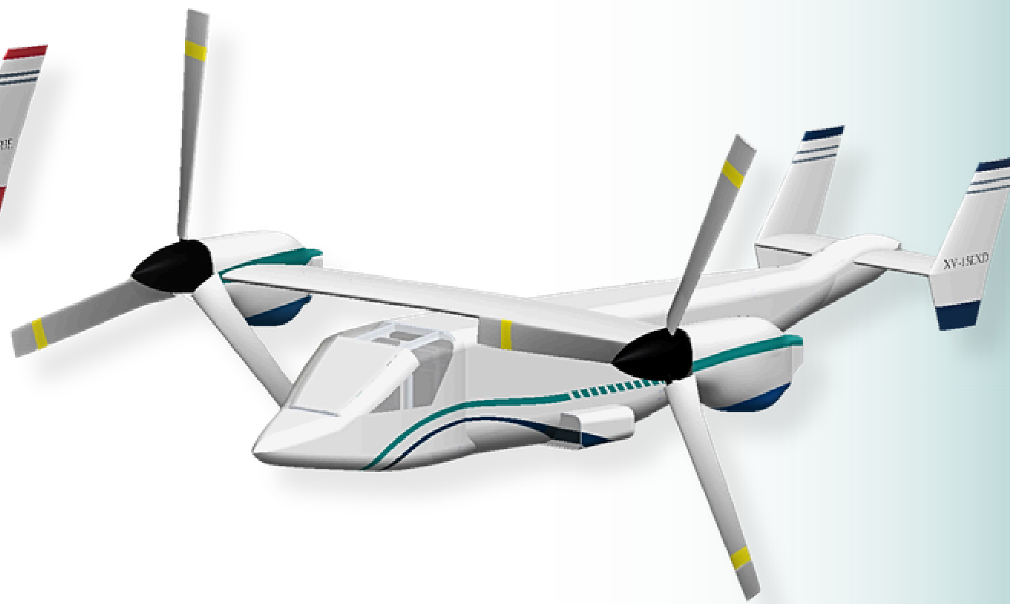
For this Vertical Flight Society (VFS) Student Design Competition (SDC) 2025-2026 Request for Proposal (RFP), Leonardo has challenged the academic community to make realistic and comprehensive design choices to develop a high-performing XV-15 with a hybrid-electric propulsion architecture. The Georgia Institute of Technology (GT) Graduate Design Team designed an effective hybrid-electric propulsion architecture for the XV-15 in Phase I and an improved hybrid-electric tilt-rotor based on the XV-15 in Phase II. The team accomplished these feats through the imperative mix of personal innovation and discussions with subject matter experts who are working at the forefront of these technologies. These designs were aptly named *Ibrido*, meaning hybrid in Italian. The decision to name our designs *Ibrido* stems from our commitment to develop a performance-optimized hybrid-electric propulsion architecture to the highest standard, with a nod to the Italian heritage of Leonardo.

OVERVIEW | **VEHICLE OVERVIEW & KEY FEATURES**

Phase I – Hybrid Retrofit for RFP Compliance

Phase I retrofitted the legacy XV-15 with a **parallel hybrid-electric architecture**, **downsizing the T53 engines** and **integrating twin EMRAX motors** to deliver **10.2% electrically distributed mission power** as required by the RFP. Performance margins were optimized to meet minimum cruise speed, HOGE, and hybridization thresholds while preserving the baseline airframe and CG envelope. *Trade studies included: Hybrid-Electric (TEEM).*

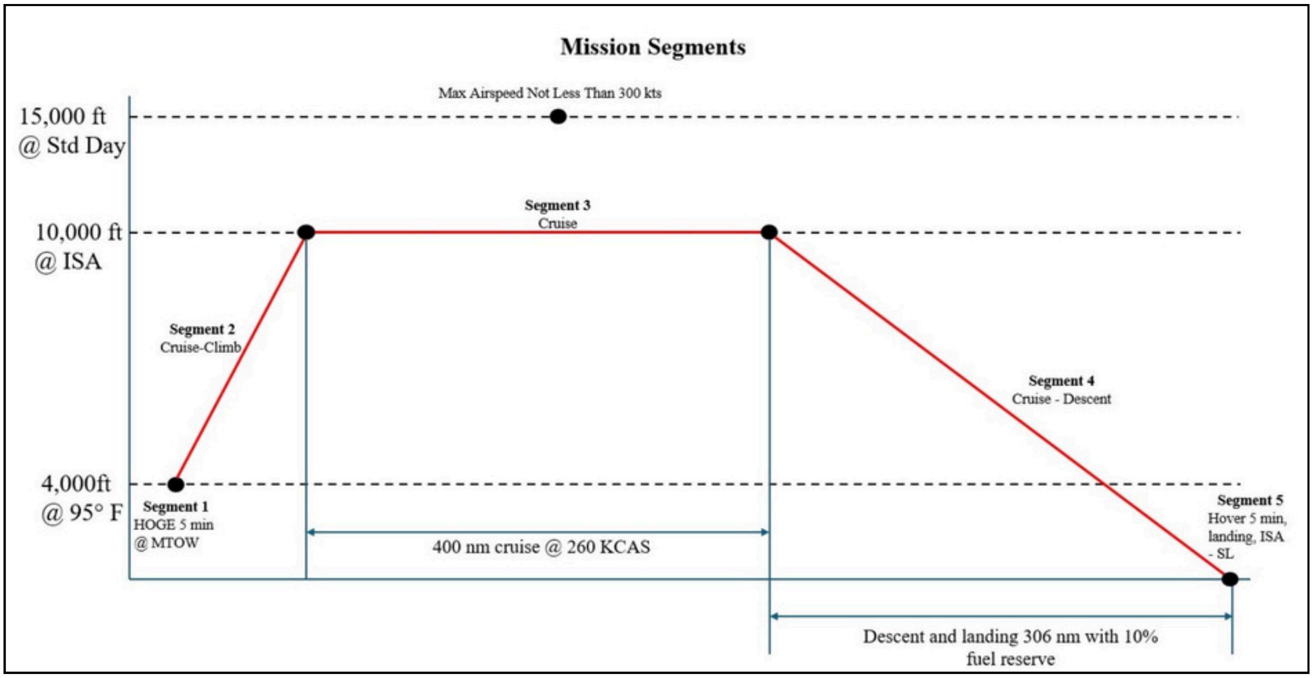
Phase II – Expanded Redesign to Close All RFP Gaps



Phase II expanded the design beyond retrofit, incorporating **aerodynamic refinements**, **structural weight reduction**, **rotor and wing optimization**, and **fly-by-wire controls** to fully meet RFP range, speed (300 KTAS @ 15,000 ft), maneuverability, autorotation, and payload requirements. This phase transformed Ibrido into a fully compliant, performance-optimized hybrid tiltrotor at **10.8% electric**. *Trade studies included: Structural Material, Tail Configuration, Main Rotor Airfoil, and Wing Airfoil.*

OVERVIEW | **PERFORMANCE SNAPSHOT**

Hybrid design improves range capability while preserving payload and mission constraints.



Design Mission (RFP-Compliant)

- 5 min HOGE @ 4,000 ft, 95°F
- 400 nm cruise @ 260 KCAS
- Descent + landing w/ 10% fuel reserve
- Max airspeed ≥ 300 kts

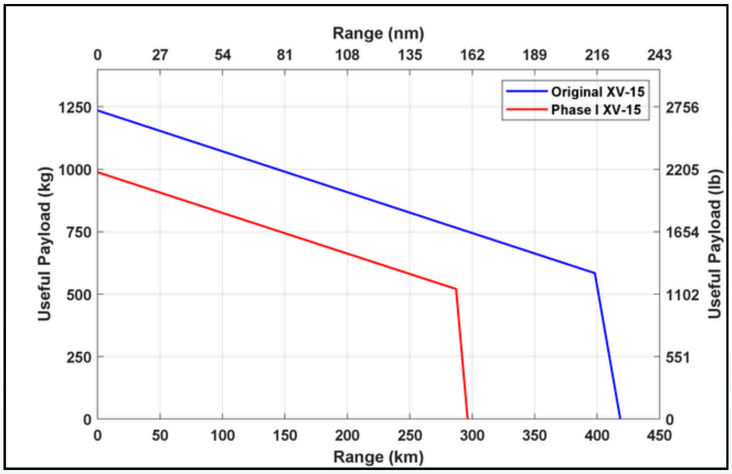
Phase I: Hybridization

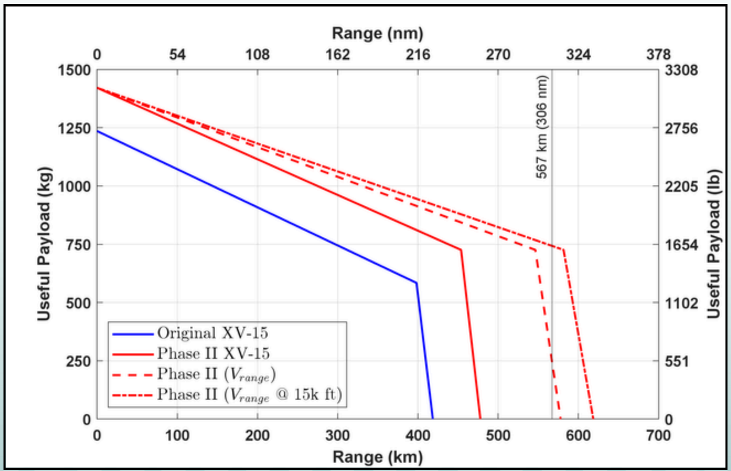
- 10% electric mission power achieved
- Fuel burn reduced through optimized engine scaling (α)

Phase II: Expanded Design

- Rotor RPM and wing refinement improved cruise efficiency
- Structural weight reduction increased payload fraction
- Maximum range extended to ~560 km (306 nm) with reserve

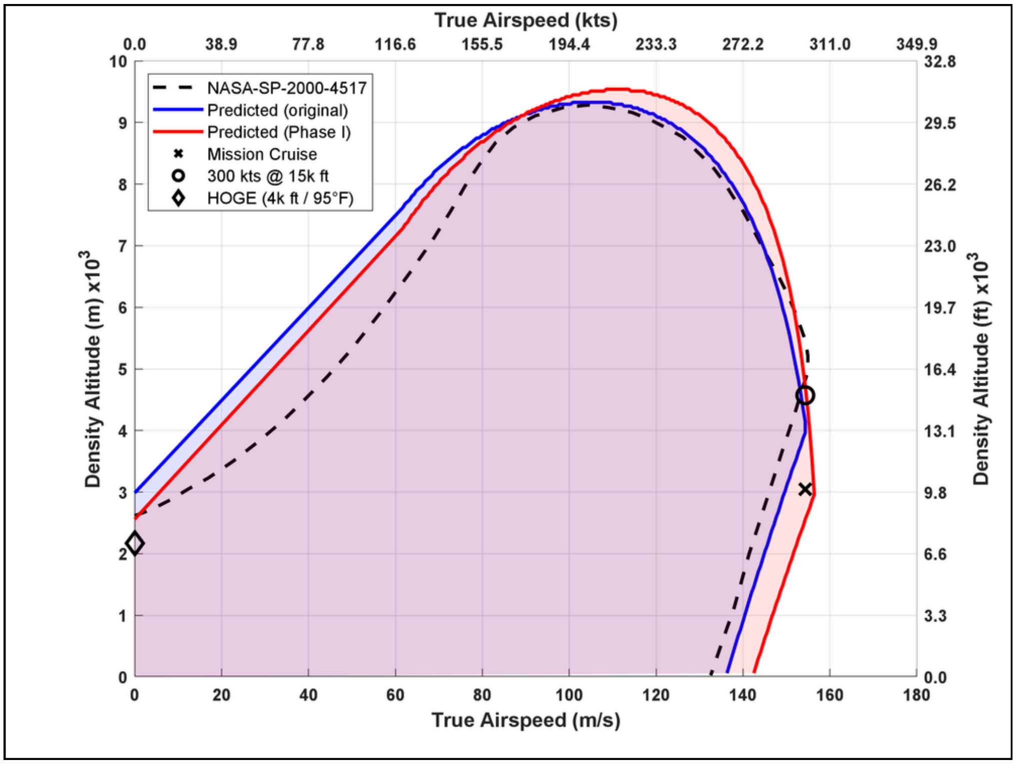
- **10.2/10.8% electric** mission power
- **Cruise efficiency improved** via RPM reduction strategy
- **+18% range improvement** (Phase II vs Original XV-15)
- **No HOGE or autorotation violations**

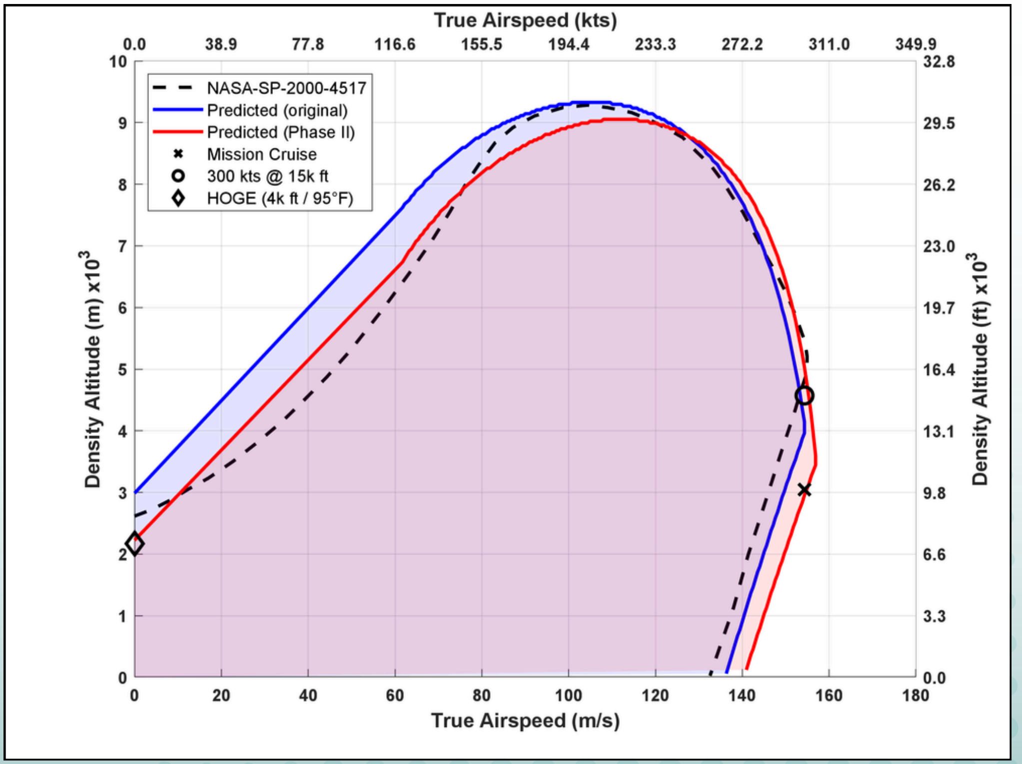




OVERVIEW | **FLIGHT ENVELOPES**

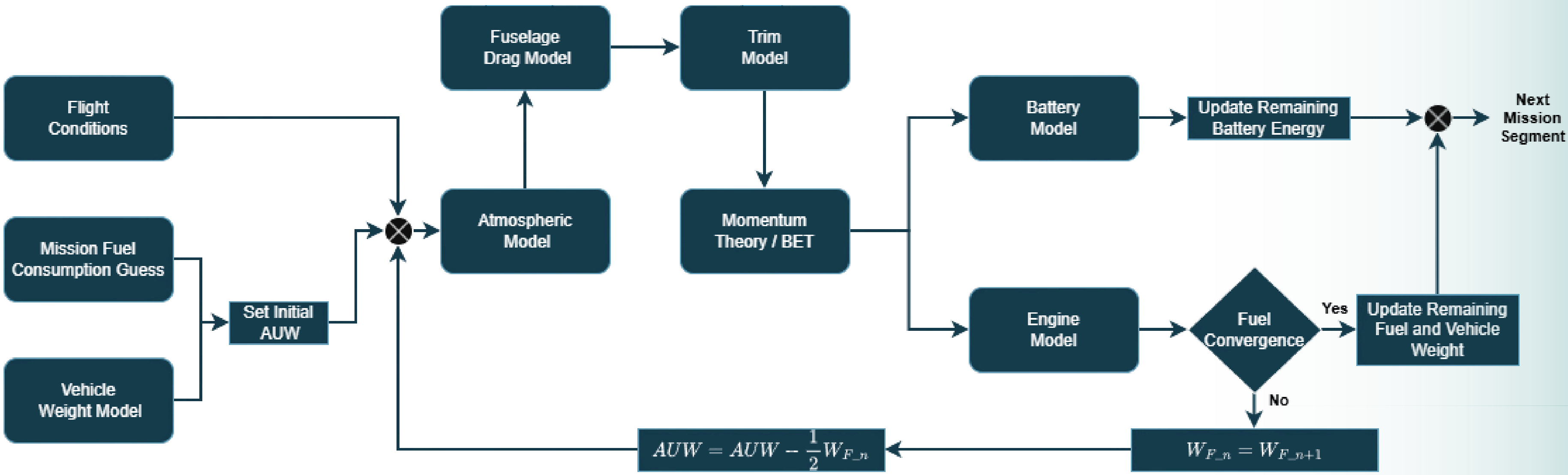
Optimizing for never-seen-before XV-15 ranges, while also incorporating electric power.





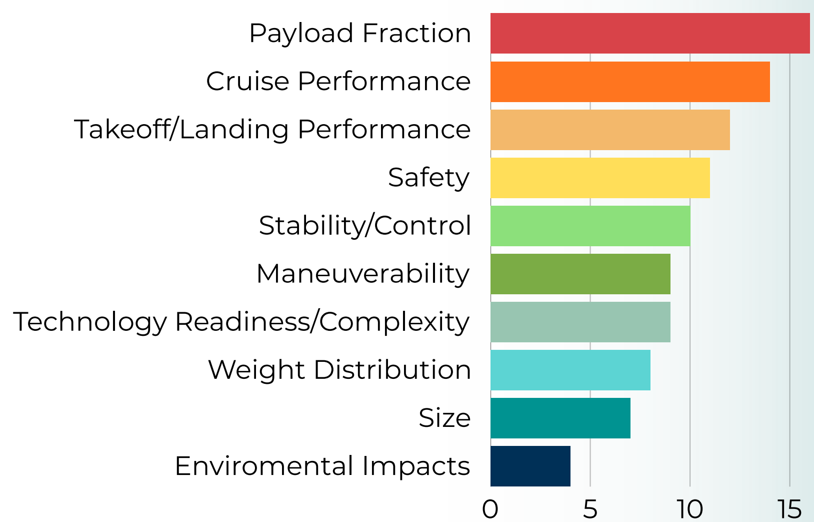
OVERVIEW | **DESIGN METHODOLOGY**

A purpose-built, sizing and mission optimization code was developed specifically for IBRIDO, enabling fully integrated propulsion, aerodynamic, structural, and energy convergence tailored to XV-15 hybridization.



2.8 million configurations evaluated across Phase I & II.

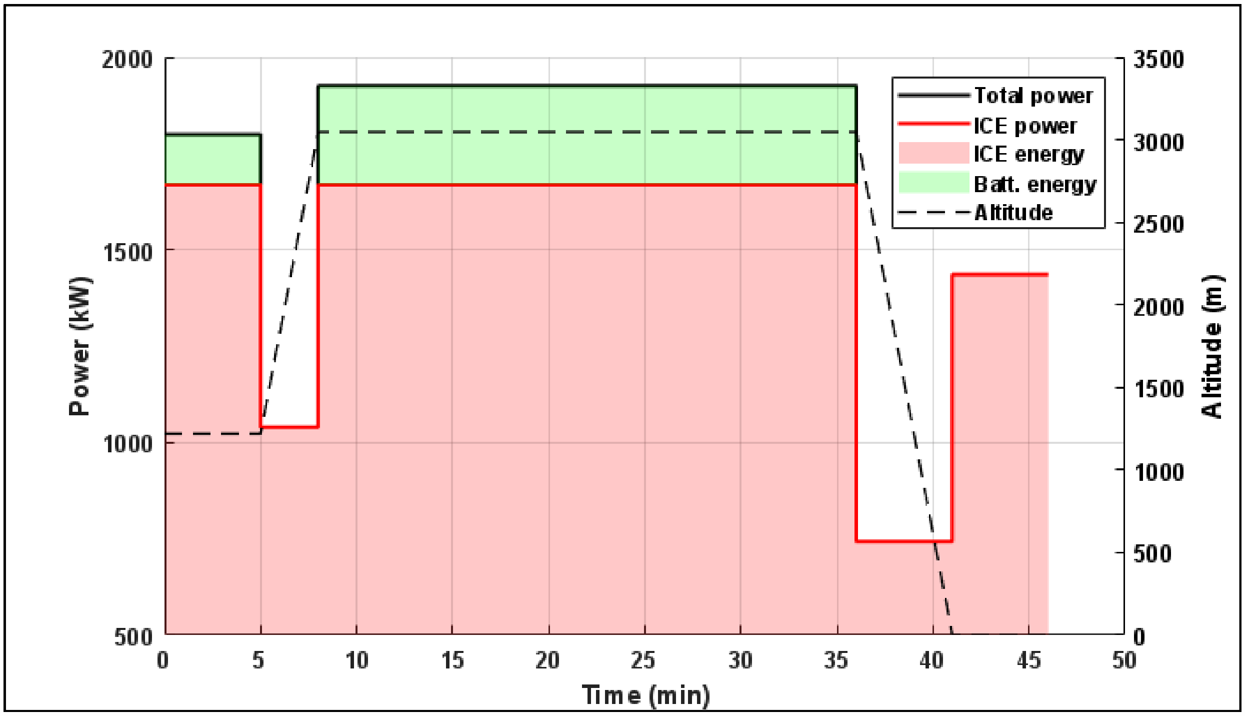
- **AHP-weighted, RFP-driven** multi-objective design environment
- Fully coupled propulsion–aerodynamic–structural–energy convergence
- α–RPM **co-optimized hybrid-electric powertrain architecture**
- Physics-based MT/BEMT rotor modeling across all segments
- Segment-specific rotor speed scheduling for energy minimization
- Peak-SOC deficit battery sizing with regenerative cruise/descent recovery
- **Autorotation and performance margins embedded** within loops
- Constraint-based feasibility filtering (CT/σ, Mtip, HOGE, VNO, reserves)



OVERVIEW | **POWER & ENERGY**

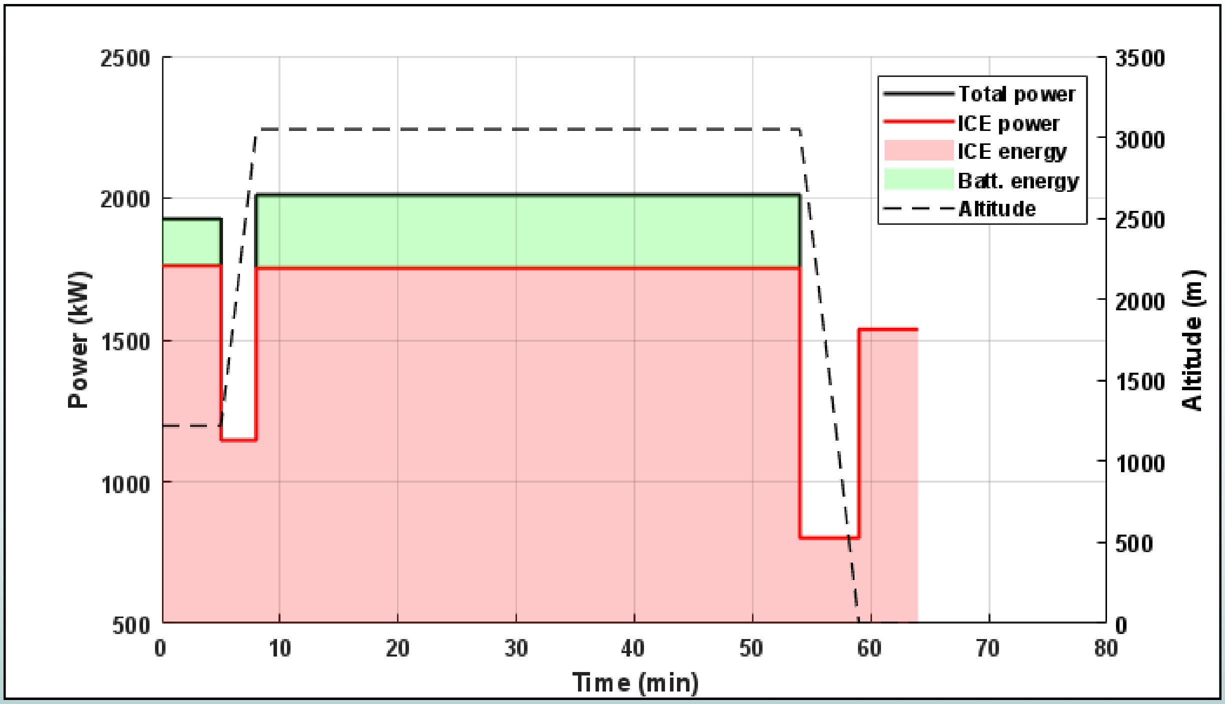
Mission-driven hybrid power management: Segment-level ICE and battery contributions are optimized to minimize fuel while meeting RFP constraints.

PHASE I – BASELINE HYBRID STRATEGY

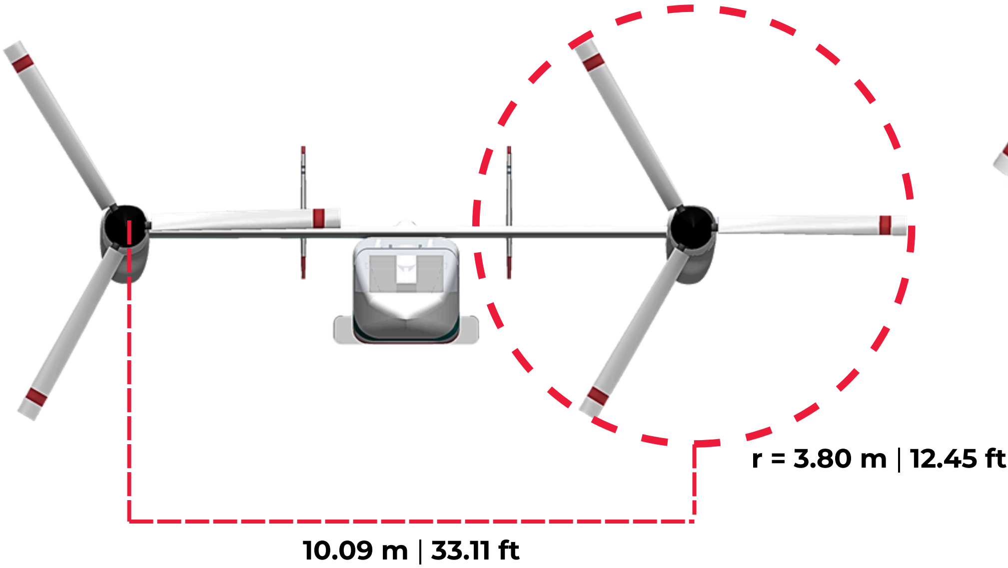


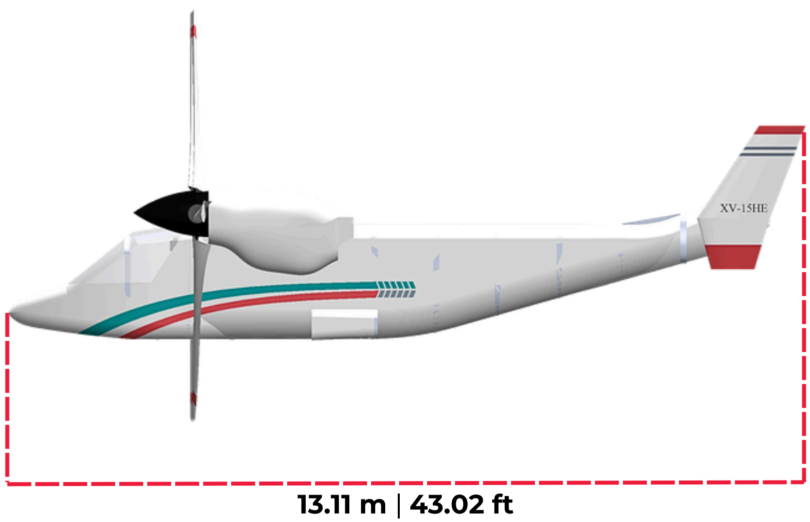
Cruise Hybridization: 28% → 41%
Mission Fuel: 312 kg → 287 kg
Battery Use: 48 kWh → 63 kWh

PHASE II – OPTIMIZED HYBRID STRATEGY



PHASE I | **HYBRID-ELECTRIC XV-15**





Percent Electrification:

10.2%

Payload:

570 KG | 1256 LB

Power Generation (Turboshaft):

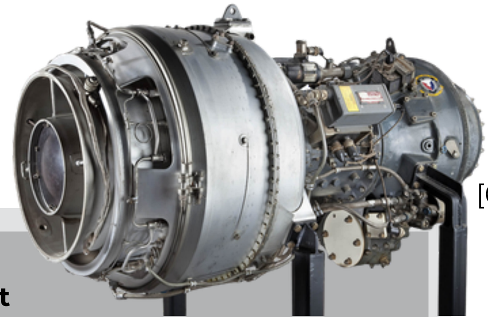
1040 KW | 1395 HP

Power Generation (Electric):

290 KW | 389 HP

PHASE I | **HYBRIDIZATION**

XV-15 Baseline Preserved
(Rotor, Wing, MTOW Fixed per RFP 2.2.1)



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POWER SOURCE

Aviation-Grade Lithium-Ion Battery Pack

- 250 Wh/kg, 2500 W/kg (RFP compliant)
- **10.2% mission shaft energy provided electrically**
- Opportunistic regenerative capture (not mission-credit dependent)

T53-L-13 Turboshaft Engine

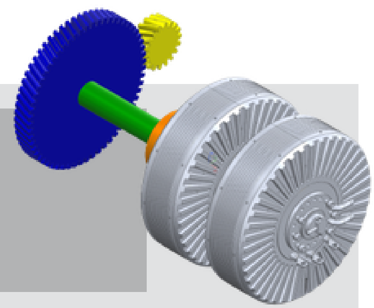
(Scaled α = 0.90/0.95)

- 90–95% rating, same SFC (per RFP)
- Operates nearer SFC sweet spot
- Mechanical OEI shaft power retained

Regenerative charging

Mechanical Shaft Power

HYBRID INJECTION LAYER



Modified Main Gearbox + Cross Shaft

- Parallel torque blending architecture
- Electric + thermal power coupling
- Full OEI compliance preserved

Conversion Assist

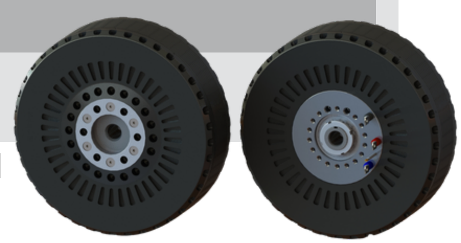
High-Voltage Inverters

- 830 V DC bus
- 96% inverter efficiency
- Dual-loop liquid thermal management

Twin EMRAX 348 Motors

- 140 kW continuous each
- Hover boost & transient assist
- Generator mode during descent

Electrical Power Boost



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TEEMs introduced in Phase II.

Dual parallel liquid cooling circuits

- Motor & inverter liquid cooling (manufacturer specified)
- 2880 L/s total flow capacity
- 500 kPa head pressure margin
- 5.5 L coolant reservoir (3.6 L active volume)
- Pump sized for peak component thermal demand

Parallel Hybrid Architecture

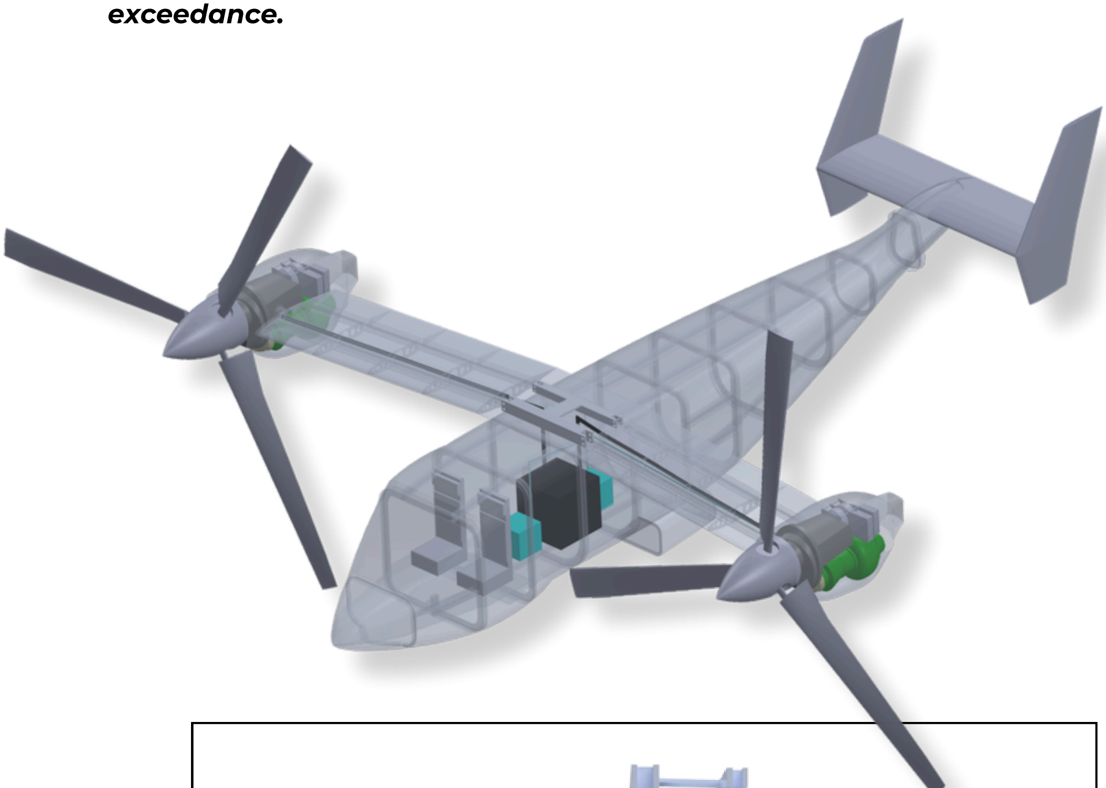
- Enables engine downsizing
- Reduces hover SFC
- Improves transient response
- Maintains mechanical fail-operational capability

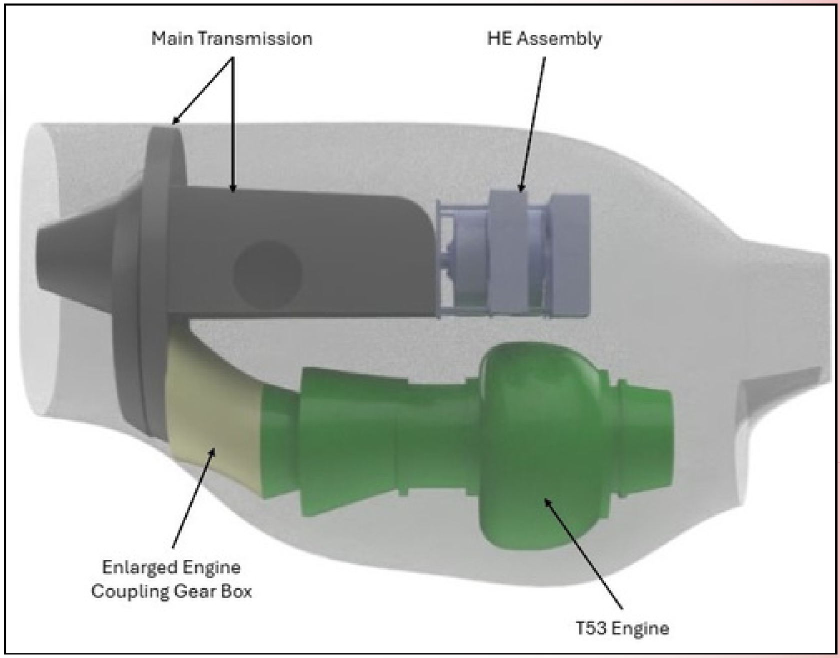
Safety & Compliance

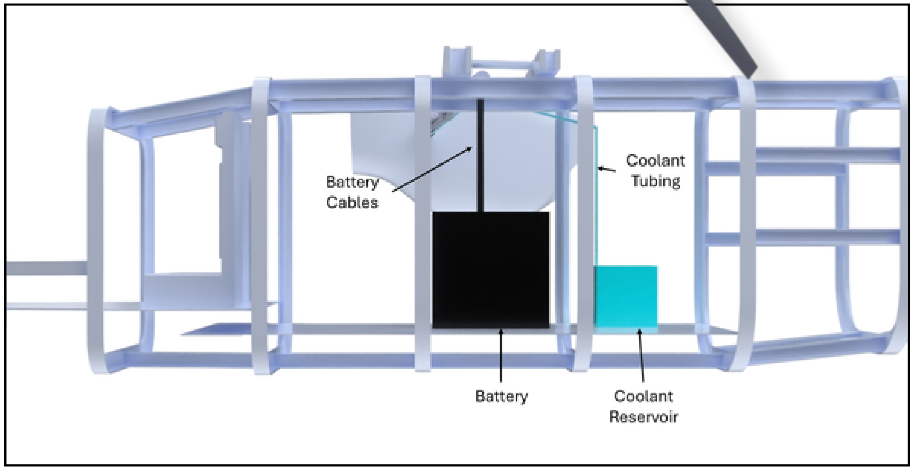
- Autorotation capable
- Powered-lift OEI compliant
- ADS-33 short-period augmented
- HOGE requirement met

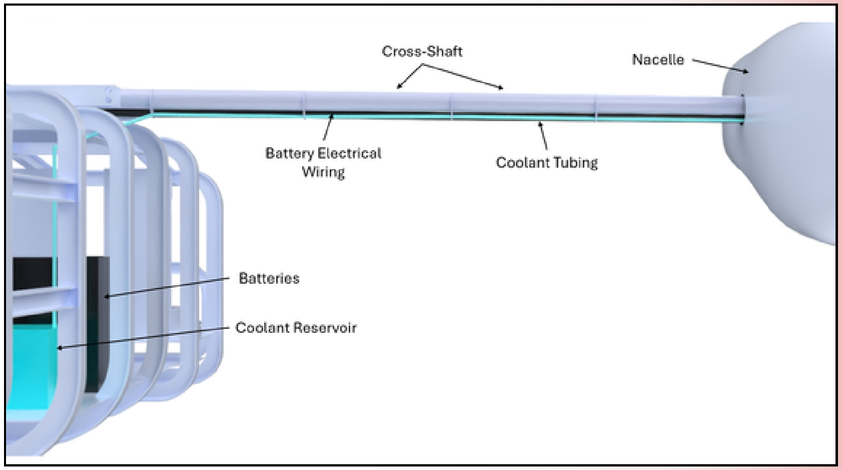
PHASE I | **INTEGRATION ARCHITECTURE**

A parallel hybrid-electric architecture was integrated within the existing XV-15 drivetrain envelope, preserving transmission geometry while incorporating electric torque augmentation, battery modules, and dedicated thermal management without CG exceedance.

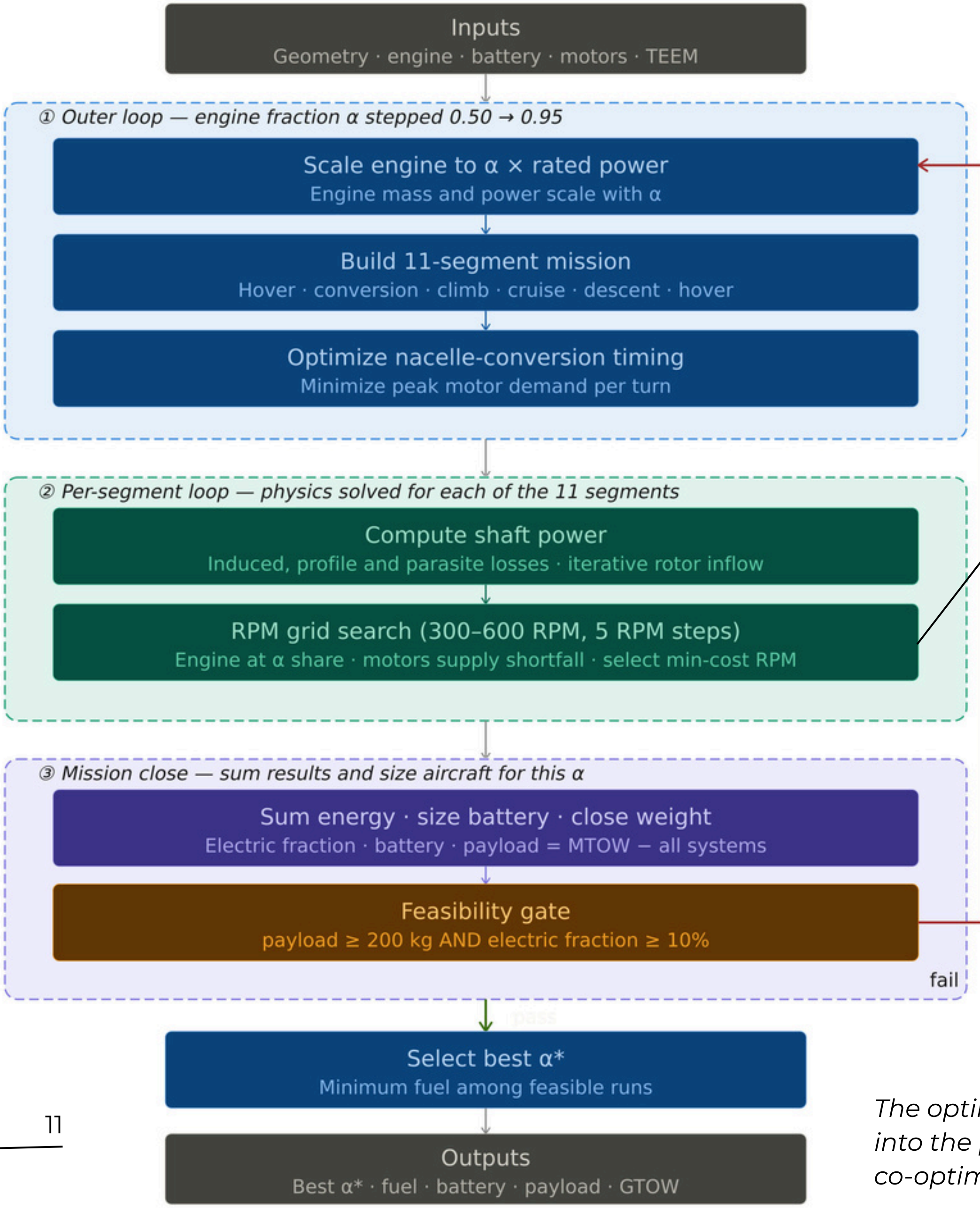


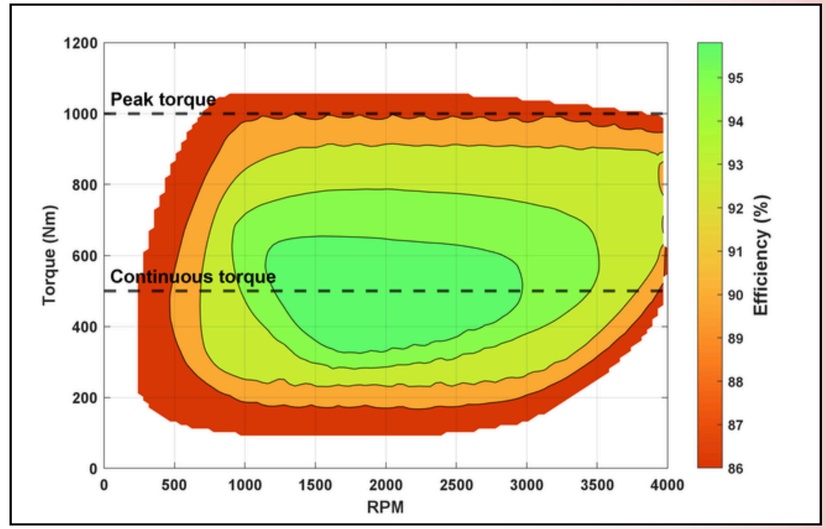






PHASE I | **STRATEGIC RPM DESIGN**



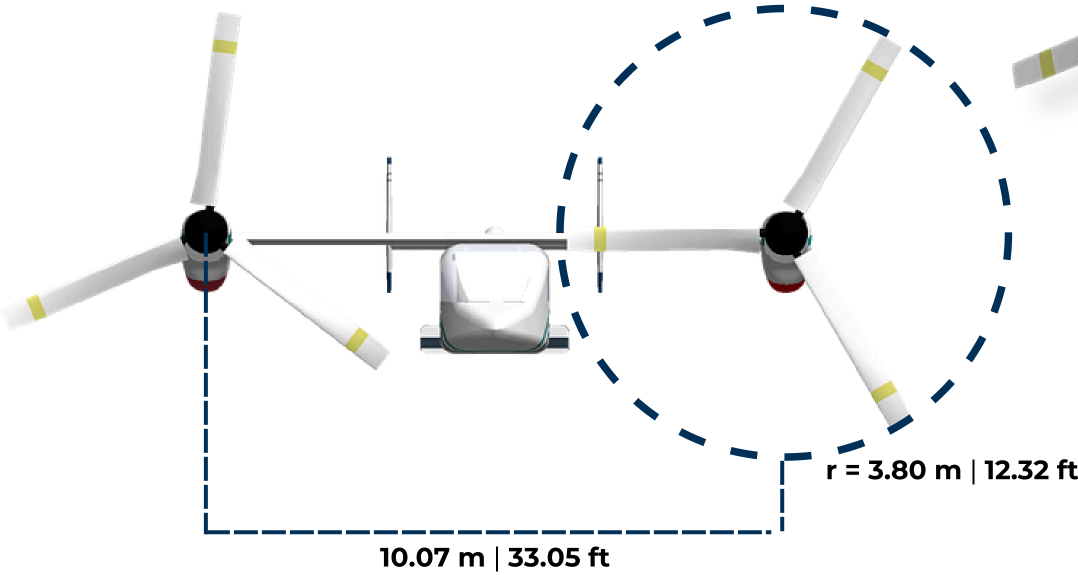


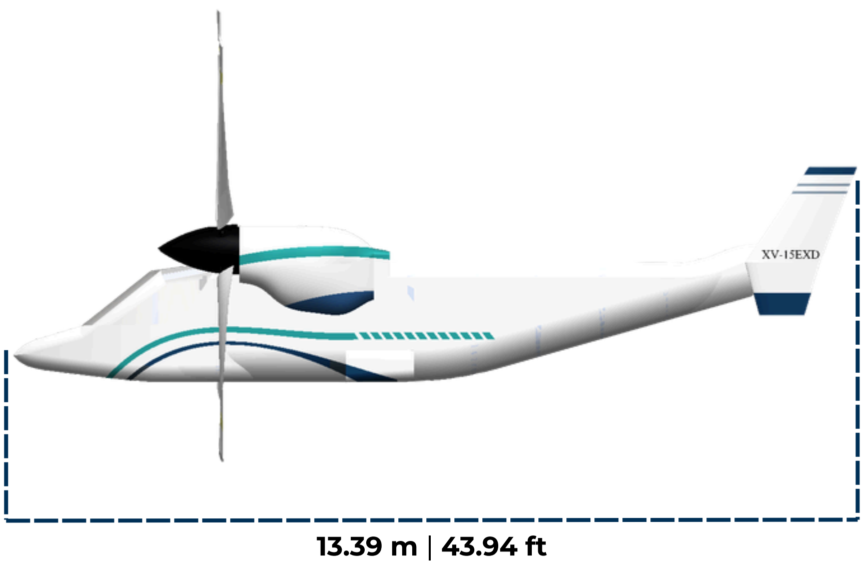
EMRAX 348 Performance Map driving RPM selection within the optimization algorithm to effectively select the optimum RPM for each mission segment.

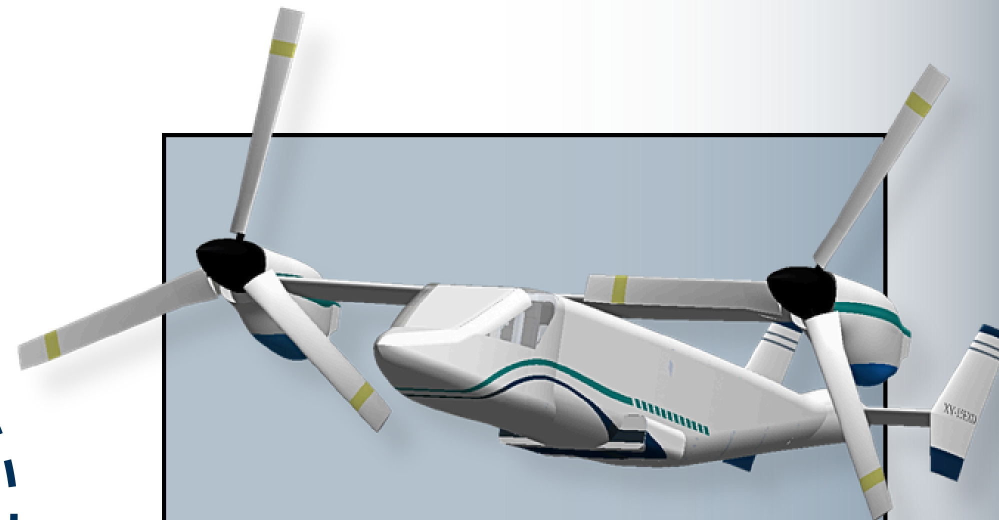
Takeoff Hover (4k / 95°F)	***575 RPM***
Nacelle Conversion (Takeoff)	***575 RPM***
Airplane-Mode Climb	***575 RPM***
Cruise – 154 m/s (260 KCAS)	***325 RPM***
Airplane-Mode Descent	***300 RPM***
Nacelle Conversion (Landing)	***575 RPM***
Landing Hover (SL ISA)	***515 RPM***

The optimal rotor speed schedule was integrated directly into the performance portion of the sizing code and co-optimized during both Phase I and Phase II design loops.

PHASE II | **EXPANDED DESIGN**







Percent Electrification:

10.8%

Payload:

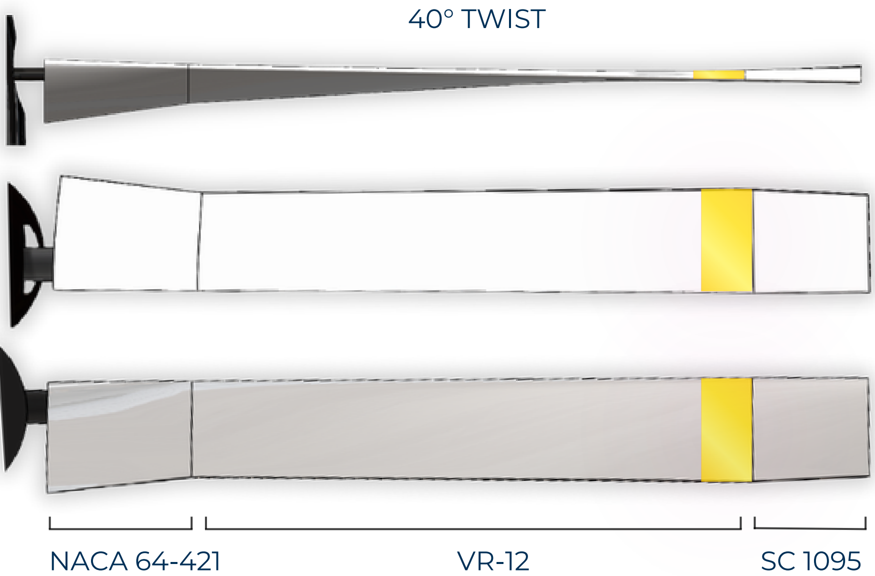
964 KG | 2126 LB

Power Generation (Turboshaft):

1098 KW | 1473 HP

Power Generation (Electric):

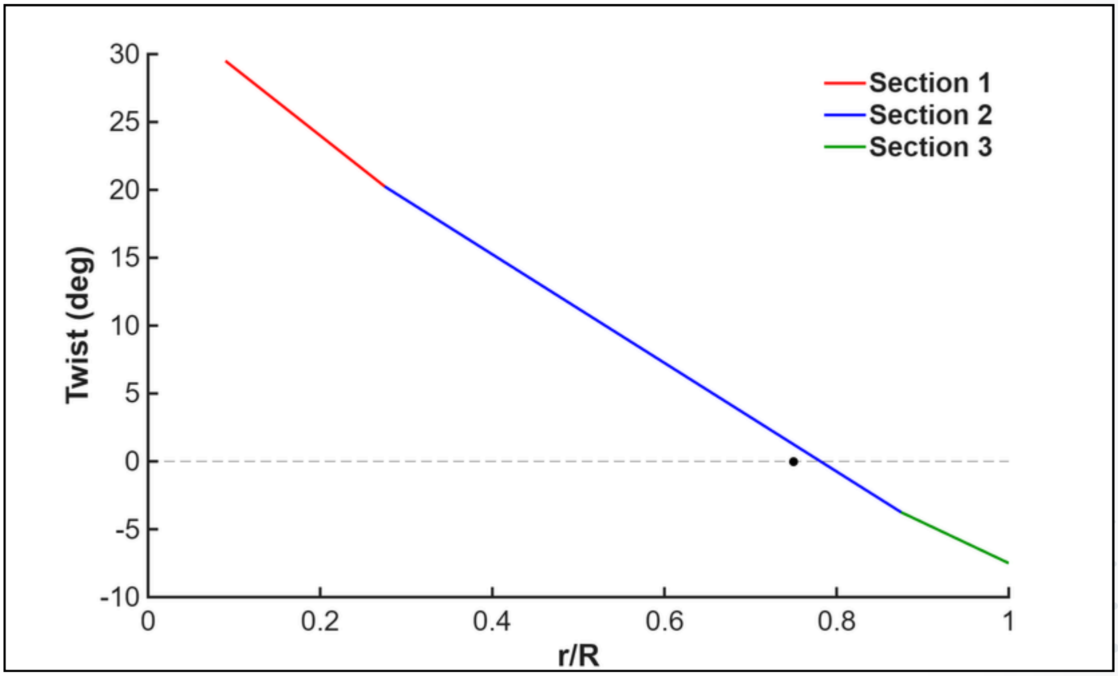
290 KW | 389 HP



- **BEMT-Optimized Design** for hover (4,000 ft) and high-speed cruise (10,000 ft, 300 kts)
- **3-Blade, 3.81 m Radius** (XV-15 baseline) with +20% solidity for hybrid mission demands
- **40° Optimized Twist** balancing cruise efficiency and hover capability
- **0.95 Taper Ratio** preserving autorotation performance at extreme speeds
- **9% Root Cutout** experimentally validated

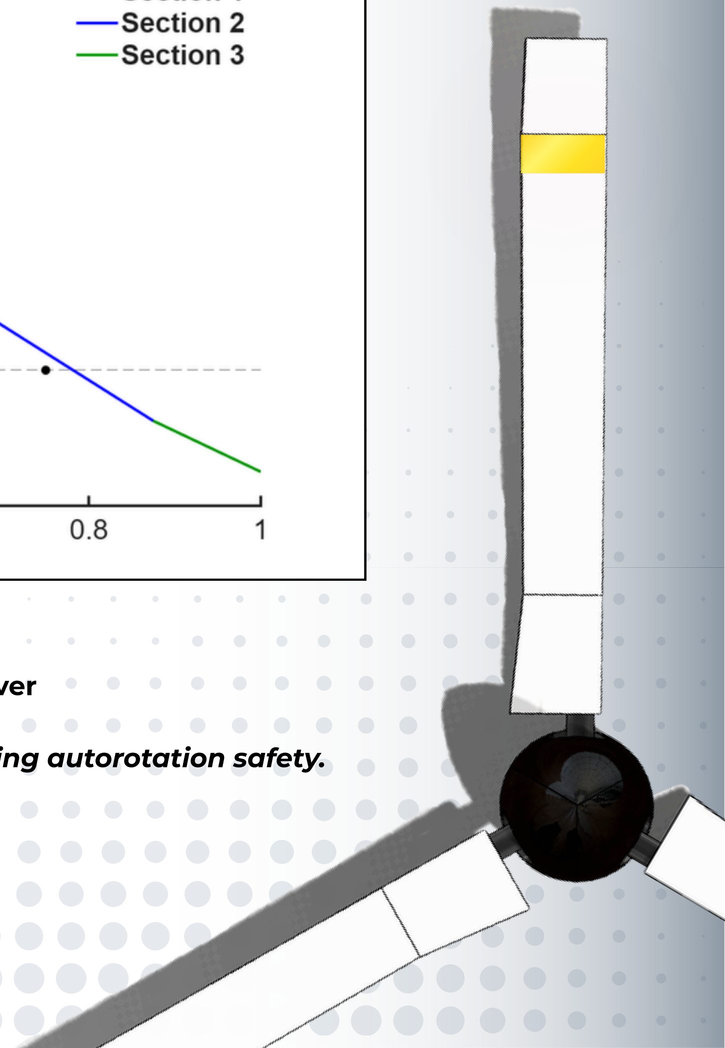
PHASE II | **MODERNIZED MAIN ROTOR**

Mission-Specific Rotor Designed Using a Custom-Built BEMT Optimization Code



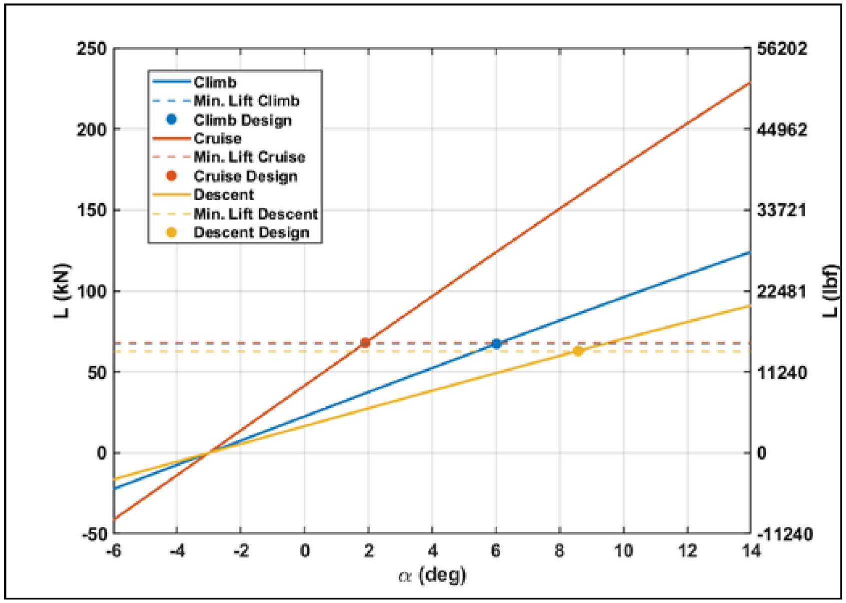
- Figure of Merit (Hover): **0.7234**
- Propeller Efficiency (Cruise): **0.8714**
- Cruise-Weighted Optimization: **75% cruise / 25% hover**

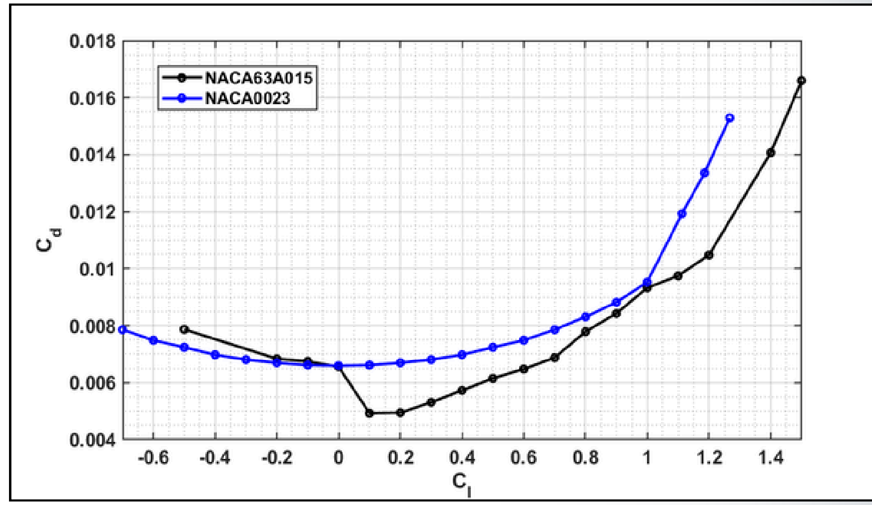
Delivering high-speed efficiency without compromising autorotation safety.

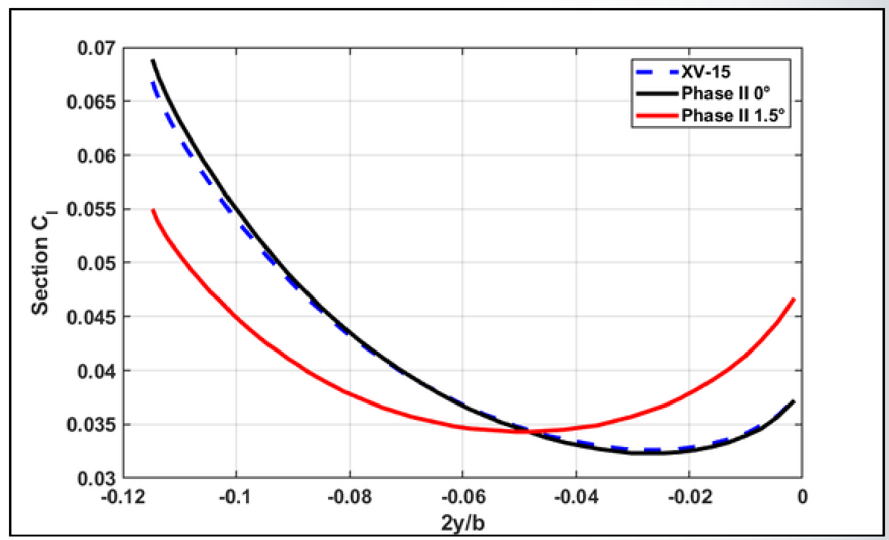


PHASE II | **OPTIMIZED LIFT WING**

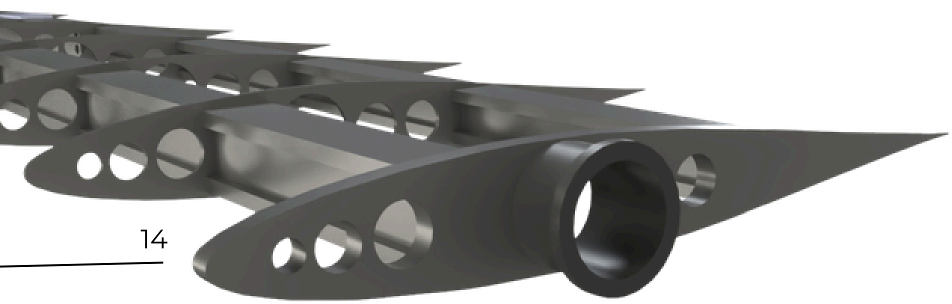
Data-Driven Airfoil Selection and Spanwise Optimization, Validated Through 2D Viscous (XFOIL) and 3D AVL Analysis.







- **+18.4% increase in $C_{L,max}$** (NACA63A015 vs baseline)
- **12.6% average drag reduction** in cruise lift range
- Meets required lift in climb, cruise, and descent
- Cruise **operates near peak $(L/D)_{max}$**



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PHASE II | **REDUCED-DRAG FUSELAGE**

Cruise Drag Reduced via Forward-Fuselage Pressure Gradient Refinement.

Phase II Design

Original XV-15

CFD Results (Cruise, 260 KCAS @ 10,000 ft)

- Phase II: C_D = 0.0828
- Phase I: C_D = 0.1113

26% drag reduction

- Phase II: CL = 0.0899
- Phase I: CL = 0.1081

17% fuselage lift reduction (wing compensates)

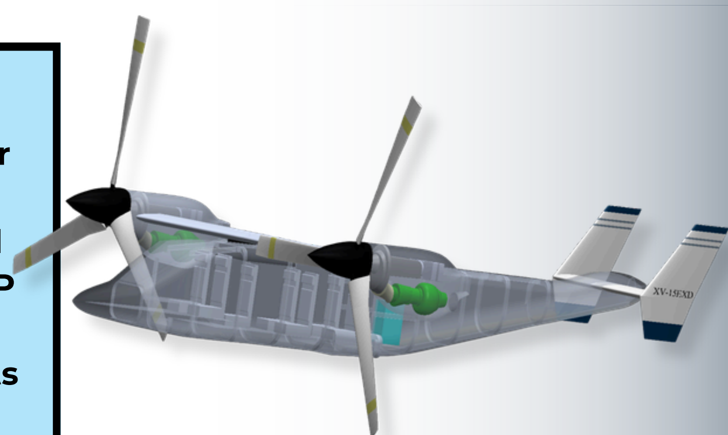
Design Changes

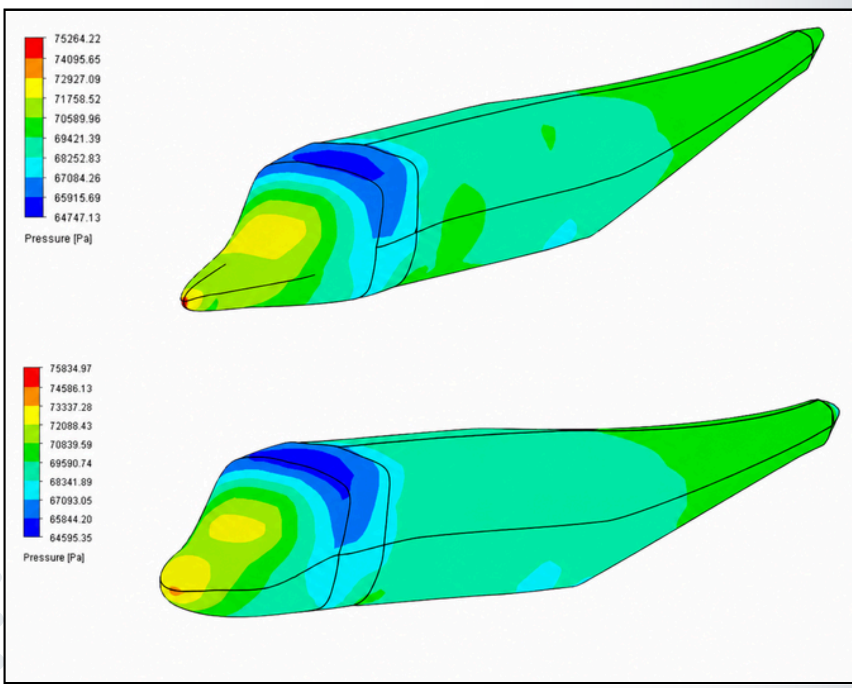
- Smoothed nose geometry
- Reduced windshield pressure spike
- Improved upper-body pressure recovery

Mission Impact

- 20% reduction in cruise fuselage drag force
- Lower parasitic power at 300 KTAS
- Direct contribution to extended payload-range

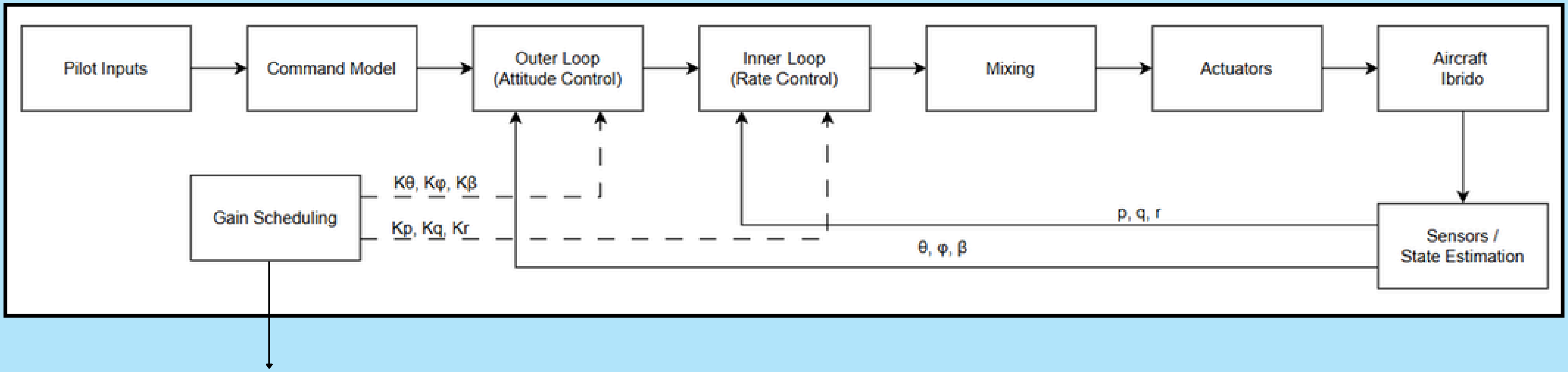
~90 kW Less Cruise Power Required & Additional Room for RFP Passenger Requirements





PHASE II | **FLY-BY-WIRE SYSTEM**

A modern control architecture, shaped by operational flight experience.



Enables the Ibrido achieve consistent stability and desirable handling qualities across all modes and regimes of flight.

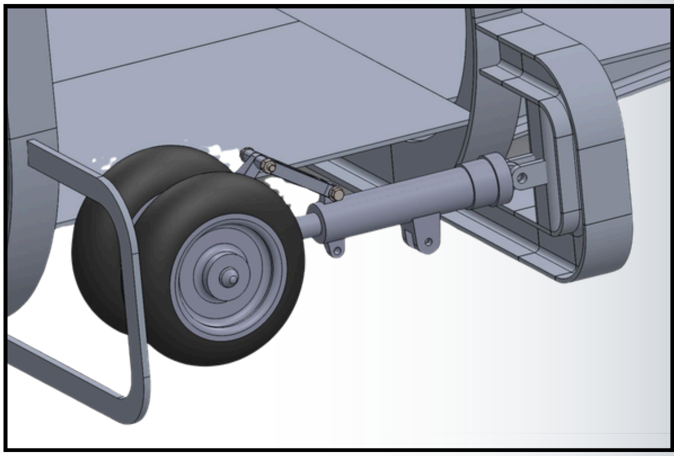
Key Improvements include:

- Enables optimized battery and coolant placement to support a **725 kg (1600 lb) mission payload** and **six-passenger** cabin configuration.
- Gain-scheduled fly-by-wire control achieves **ADS-33E Level 1** short-period damping (**$\zeta \geq 0.35$**) across the **full conversion corridor**.
- Continuous **control blending** between proprotor and fixed-wing surfaces ensures **stable helicopter–airplane transition**.
- Hybrid-electric torque assist slows rotor RPM decay during power-loss events, **improving autorotation safety margins**.
- Retains **cross-shaft OEI protection** with **supplemental electric torque authority**.
- **Reduces control system mass by 85 kg (187 lb)** relative to the legacy mechanical system.

PHASE II | **STRUCTURES & COMPOSITES**

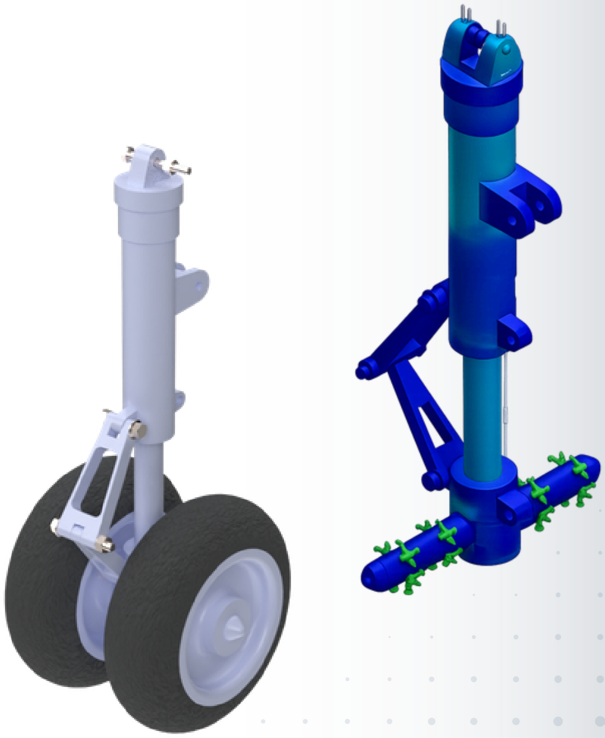
Lighter and stronger to supplement RFP requirements for autorotation & FAA stability margins; ultimately enabling payload increase.

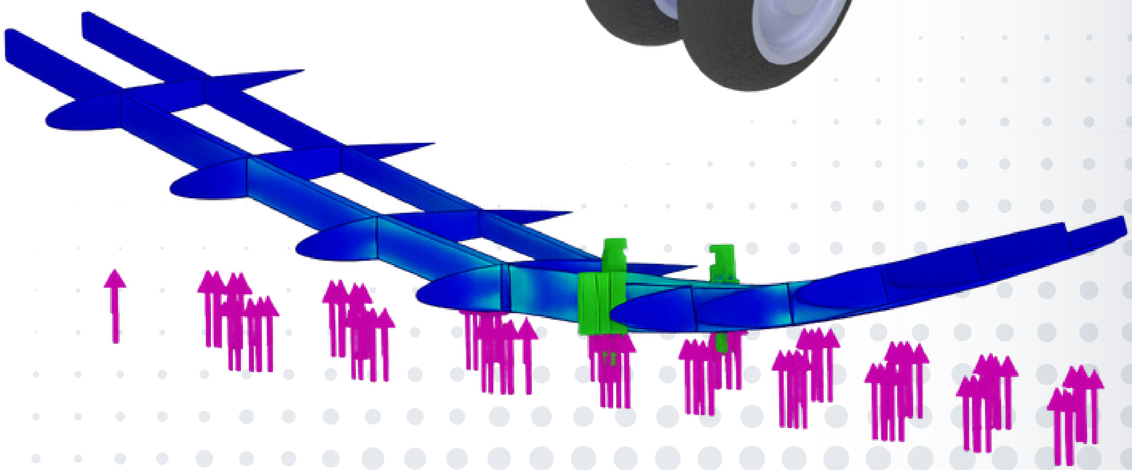
Wing Structural Redesign
CFRP (Carbon Fiber) would be used as skin material due to the relative strength as well as weight savings of 50% compared to the original aluminum. An aluminum matrix composite (Aluminum / GLARE-2) would be used as the material in the wing spars. The specific composite selected was a 5-ply in a 0/45/-45/45/0 degree laminate where 0 is parallel to the span of the wing.



Fuselage Structural Redesign
Designed several aluminum bulkheads that follow the form of a carbon fiber fuselage.

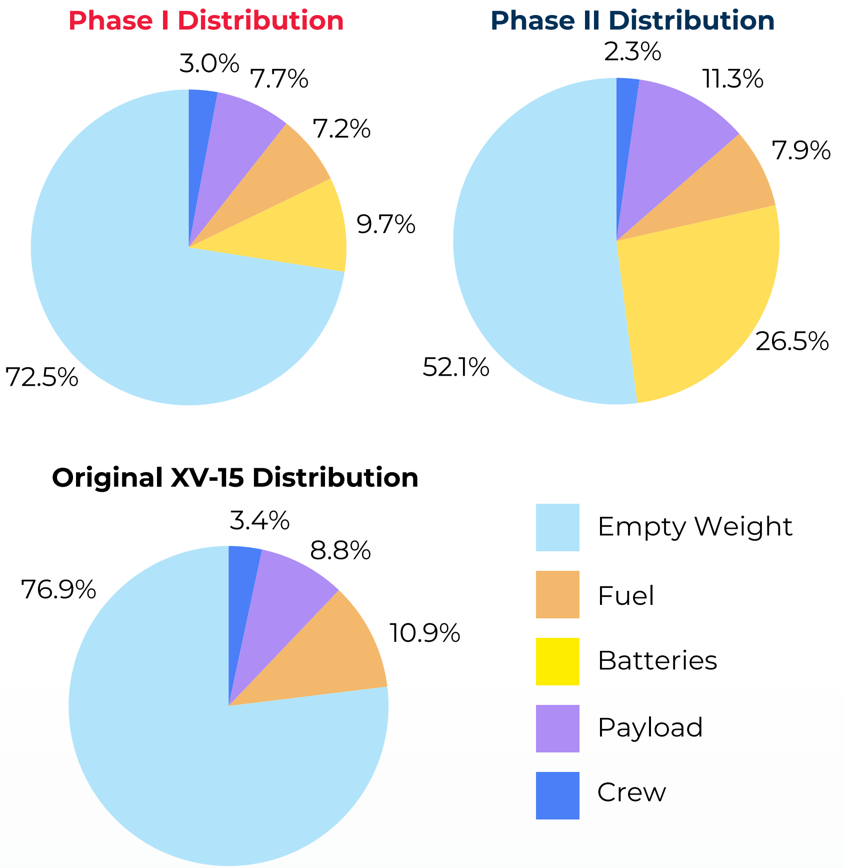
Landing Gear Structural Redesign
Chromoly Steel 4130 was the selected alloy for the landing gear struts due to its ability to handle large loads with higher fatigue cycle life for this specific type of application. The landing gear was designed to handle a 3.5G (1000 fpm descent) landing from an autorotation.

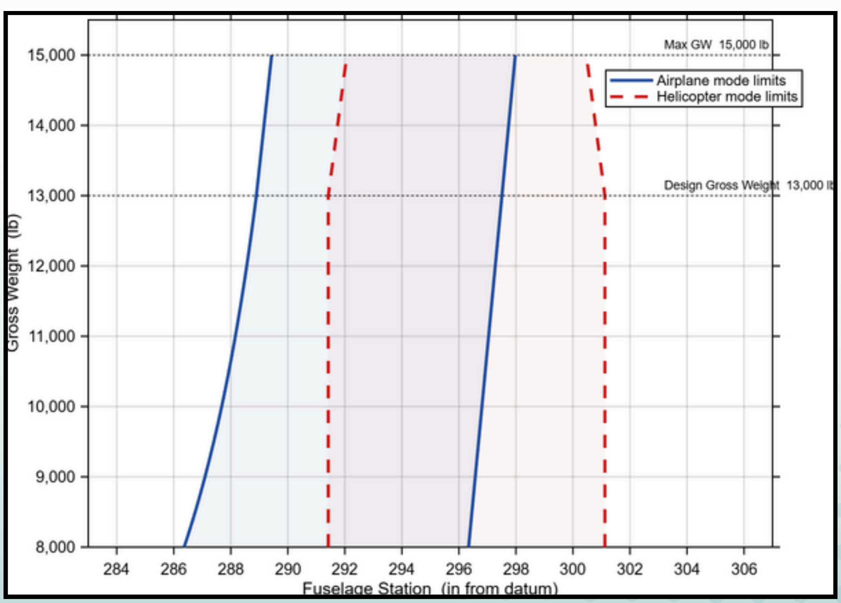




COMPARISON| **WEIGHT & BALANCE**

An accurate account of weight and weight savings via NDARC equations. The product, a superior lightweight, balanced tiltrotor that meets all safety standards.





Compliance Summary

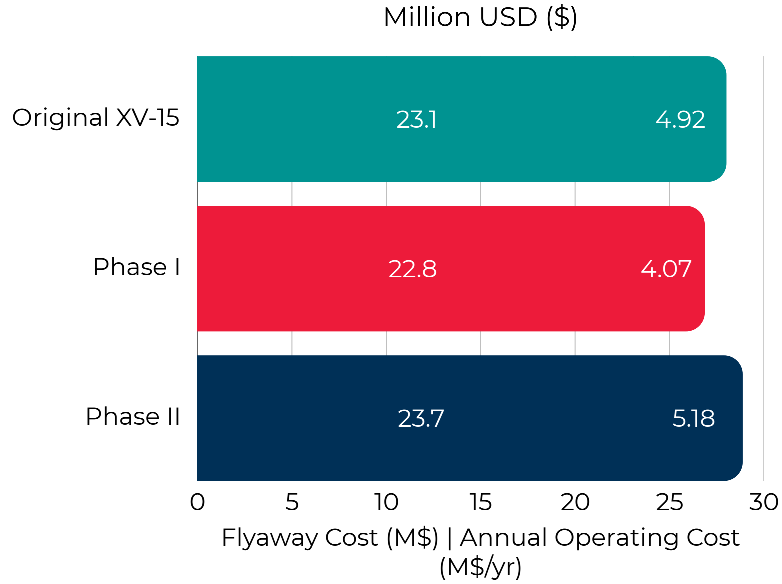
- **Meets 2G structural requirement** in helicopter and conversion modes (Factor of Safety = 2.4) AND **meets 3.5G structural requirement** in airplane mode (Factor of Safety = 4.1).
- **Phase II structural margins remain compliant despite MTOW increase** driven primarily by the 1,059 kg (2,335 lb) battery system.
- Phase II composite wing and fuselage redesign offset structural weight growth, preserving maneuver capability at increased gross weight.
- **CG remains within certified XV-15 longitudinal limits** from minimum gross weight through MTOW, including full fuel, zero fuel, full payload, and all mission fuel states.
- **Hybrid components integrated without CG exceedance** through battery placement near aircraft CG and nacelle motor mass balancing via composite structural reductions.
- **Autorotation capability preserved** in all flight modes, with hybrid system slowing rotor RPM decay and increasing pilot reaction margin.
- **Fly-by-wire and structural redesign improve weight efficiency** while maintaining full regulatory maneuver margins.

Final configurations balance hybrid-electric capability, structural integrity, 2G/3.5G maneuver compliance, and full CG envelope control.

COMPARISON | **COST OF HYBRIDIZATION**

The bottom line of hybridizing the XV-15.

- **Hybridization impact is modest at acquisition level** (±3% flyaway vs baseline).
- **Operating cost is driven primarily by fuel consumption**, not capital cost.
- Phase I achieves the lowest total operating cost of all configurations.
- Phase II cost increase is driven by structural modernization (composites + FBW), not propulsion alone.
- Battery system is the largest new cost driver in both hybrid phases.
- **Hybrid-electric integration remains economically feasible** within conventional rotorcraft cost margins.
- Economic optimum occurs at moderate hybridization (Phase I).
- **Full mission compliance requires cost growth beyond the economic minimum (Phase II).**



With a 10-year total cost of $55.93M per aircraft, Phase I confirms that hybridization is economically viable compared to the original XV-15.

	Phase I	Phase II
Flyaway Cost	↓ 1.3%	↑ 2.6%
Fuel Cost	↓ 28%	↑ vs Phase I
Operating Cost	↓ 17%	↑ 27%
Range	Limited	Meets RFP at optimized cruise
Complexity	Low	Higher (FBW + composites)

Phase I maximizes economic efficiency.
Phase II trades cost growth for mission performance.

SUMMARY | **RFP COMPLIANCE**

Validation. Hybridization. Enhancement.

XV-15 Baseline Parameters					
Maximum Gross Weight, VTOL*		Maximum Gross Weight, STOL†		Installed Power	
6122 kg	13,497 lb	6804 kg	15,000 lb	1156 kW	1550 hp
Payload VTOL		Payload STOL			
697 kg	1537 lb	1379 kg	3040 lb		
Rotor Diameter		N/A			
7.60 m	25 ft				
Turboshaft Engine Weight					
498 kg			1098 lb		
Fuel Weight					
651 kg			1436 lb		

*Maximum gross weight (VTOL) limited by available engine power (assumes operation @ 4k ft, 95°F).
†Maximum gross weight (STOL) limited by certified MTOW = 15k lb limit of original XV-15 (assumes operation @ 4k ft, 95°F).

Final Configuration Parameters: Phase I							
Maximum Gross Weight, VTOL*		Maximum Gross Weight, STOL*		Power Generation / Distribution			
				Turboshaft		Electric	
6804 kg	15,000 lb	6804 kg	15,000 lb	1040 kW	1395 hp	290 kW	389 hp
Payload VTOL		Payload STOL					
570 kg	1256 lb	570 kg	1256 lb				
Battery Weight				Scaled Turboshaft Engine Weight			
653 kg		1441 lb		448 kg		988 lb	
Electrical Power Distribution System Weight				Fuel Weight			
435 kg		960 lb		607 kg		1339 lb	
Electrical Power Generation System Weight							
467 kg		1030 lb					
Other Weight Additions				Other Weight Deletions			
Item		kg	lb	Item		kg	lb
Item		kg	lb	Item		kg	lb
Item		kg	lb	Item		kg	lb
Item		kg	lb	Item		kg	lb

*Maximum gross weight (VTOL and STOL) of the Phase I configuration is limited by the certified MTOW = 15k lb limit of the original XV-15 per RFP Phase I requirements (assumes operation @ 4k ft, 95°F).

Final Configuration Parameters: Phase II							
Maximum Gross Weight, VTOL*		Maximum Gross Weight, STOL*		Power Generation / Distribution			
				Turboshaft		Electric	
7503 kg	16,540 lb	8083 kg	17,820 lb	1098 kW	1473 hp	290 kW	389 hp
Payload VTOL		Payload STOL					
964 kg	2126 lb	1545 kg	3406 lb				
Battery Weight				Scaled Turboshaft Engine Weight			
1059 kg		2335 lb		473 kg		1043 lb	
Electrical Power Distribution System Weight				Fuel Weight			
435 kg		960 lb		695 kg		1533 lb	
Electrical Power Generation System Weight							
494 kg		1089 lb					
Other Weight Additions				Other Weight Deletions			
Fly-By-Wire System		28 kg	62 lb	Mechanical Flight Controls		113 kg	250 lb
N/A		kg	lb	Aluminum Structure		225 kg	496 lb

*Maximum gross weight (VTOL and STOL) limited by available engine and electric motor power (assumes operation @ 4k ft, 95°F).

Through numerous analysis and five unique trade studies, this multi-university team was able to design two viable hybrization of the XV-15 tiltrotor.