Penn State Urban Air Mobility (PSUAM)
Hybrid-Electric Propulsion System Executive Summary

Thomas Alfieri, Michael-Paul Awunor, Luke Bowden, Spyro Giannitsanos, Ryan Hoffman, Cole Opalka, David Rigoglioso, Henry Sabine, Jake Sickler, Noah Stoudt

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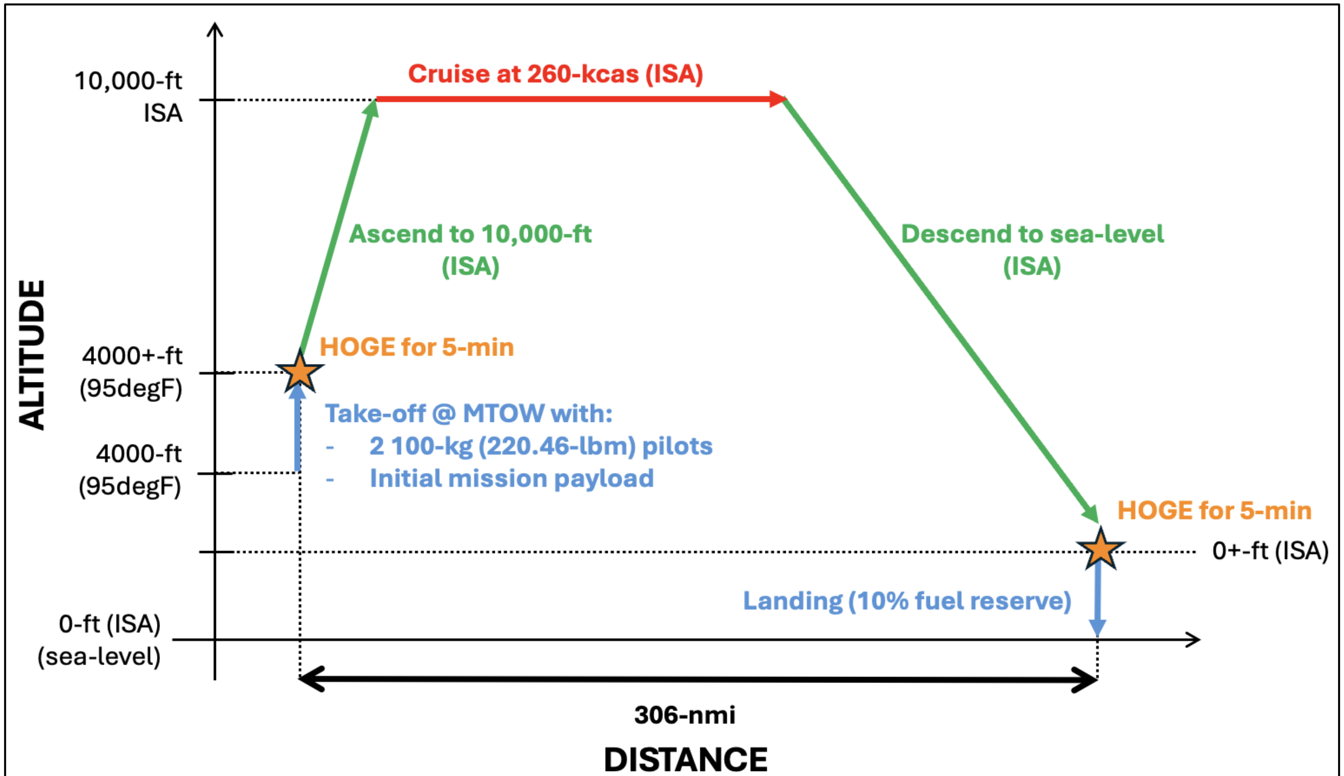
Advised by: Dr. Smith, Prof. Lego

Phase 1: Cygnus Vehicle

Phase 2: Cygnus X Vehicle

Leonardo Requests a Hybrid-Electric Upgrade to NASA's XV-15 Vehicle for Urban Air Mobility [1]



Requested Mission from Leonardo for VFS [1]

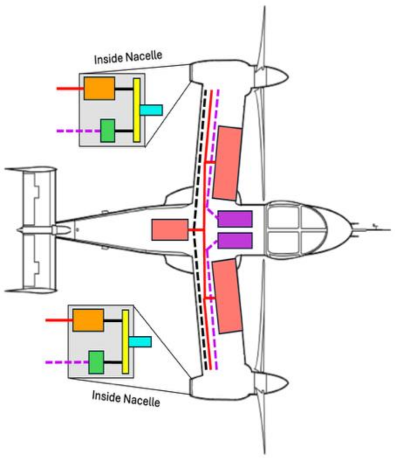
Primary Requirements [1]:

- *Cygnus*:
  - 2 crew (100-kg pilots)
  - same MTOW as baseline (Cygnus carries less fuel than baseline because higher empty weight)
- *Cygnus X*:
  - 1,600-lbf payload (2 crew, 6 passengers)
- *Both*: land with 10% fuel reserves

Phase 1 Vehicle Requirements for the HEPS System from the RFP [1]	
Req. #	**Req. Description**
RFP.1	Assume the same wing, rotor, and blade aerodynamic properties as the NASA XV-15. [1], [2]
RFP.2	Vehicle MTOW shall not exceed that of the NASA XV-15 (13,248 lbf). [1], [2]
RFP.3	Assume the same empty weight as the NASA XV-15 (10,083 lbf), unless modified by hybrid-electric installation. [1], [2]
RFP.4	At least 10% of vehicle power shall be electrically generated. [1]
RFP.5	Vehicle shall use the T-53 turboshaft engine or a scaled variant. [1]
RFP.6	Assume the same specific fuel consumption as the T-53. [1]
RFP.7	Batteries shall meet: 250 Wh/kg, 2500 W/kg, and 600 Wh/l at Pack Level. [1]
RFP.8	Shape changes from the baseline XV-15 permitted only if required for hybrid-electric installation. [1]

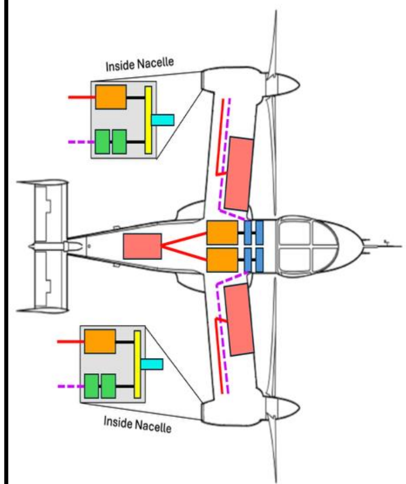
[1] Vertical Flight Society, "43rd Annual Student Design Competition 2025–2026 Request for Proposal (RFP): Hybrid Electric Tiltrotor Sponsored by Leonardo," Mar. 2026.
[2] Maisel, M. D., Giulianetti, D. J., and Dugan, D. C., The History of the XV-15 Tilt Rotor Research Aircraft from Concept to Flight, NASA, 2000.

Phase 1 Propulsion Architectures Considered



Parallel Hybrid
Engines and electric motors are coupled, drawing power from batteries and fuel.

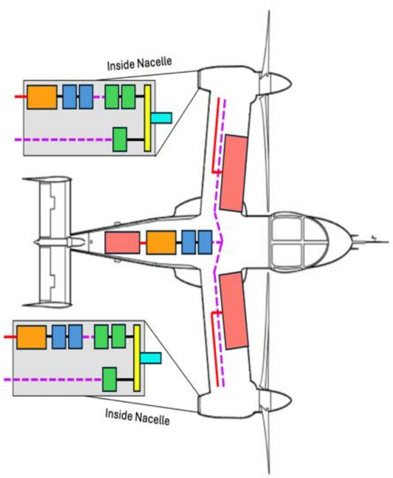
Additions:
- Electric motor (x2)
- Electric wire
- Battery
- Upscaled nacelle gearbox (x2)
- Extra fuel tank (x1)



4 Engine Turboelectric
Two engines operate nominally. Another two transfer power via electric generators. Engine and generator power is combined.

Additions:
- Electric motor (x8)
- Electric wire
- Upscaled nacelle gearbox (x2)
- Fuselage gearbox (x2)
- Extra engine (x2)
- Extra fuel tank (x1)

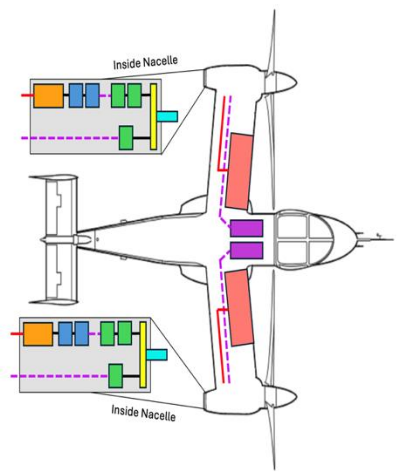
Deletions:
- Cross-shaft system



3 Turboelectric
All three engines transfer power via electric generators. Generator power goes to the rotor.

Additions:
- Electric motor (x12)
- Electric wire
- Upscaled nacelle gearbox (x2)
- Fuselage gearbox (x1)
- Extra engine (x1)
- Extra fuel tank (x1)

Deletions:
- Cross-shaft system



2 Engine Turboelectric
Two engines transfer power via electric generators. Two motors draw power from batteries. The generator and motor power is combined.

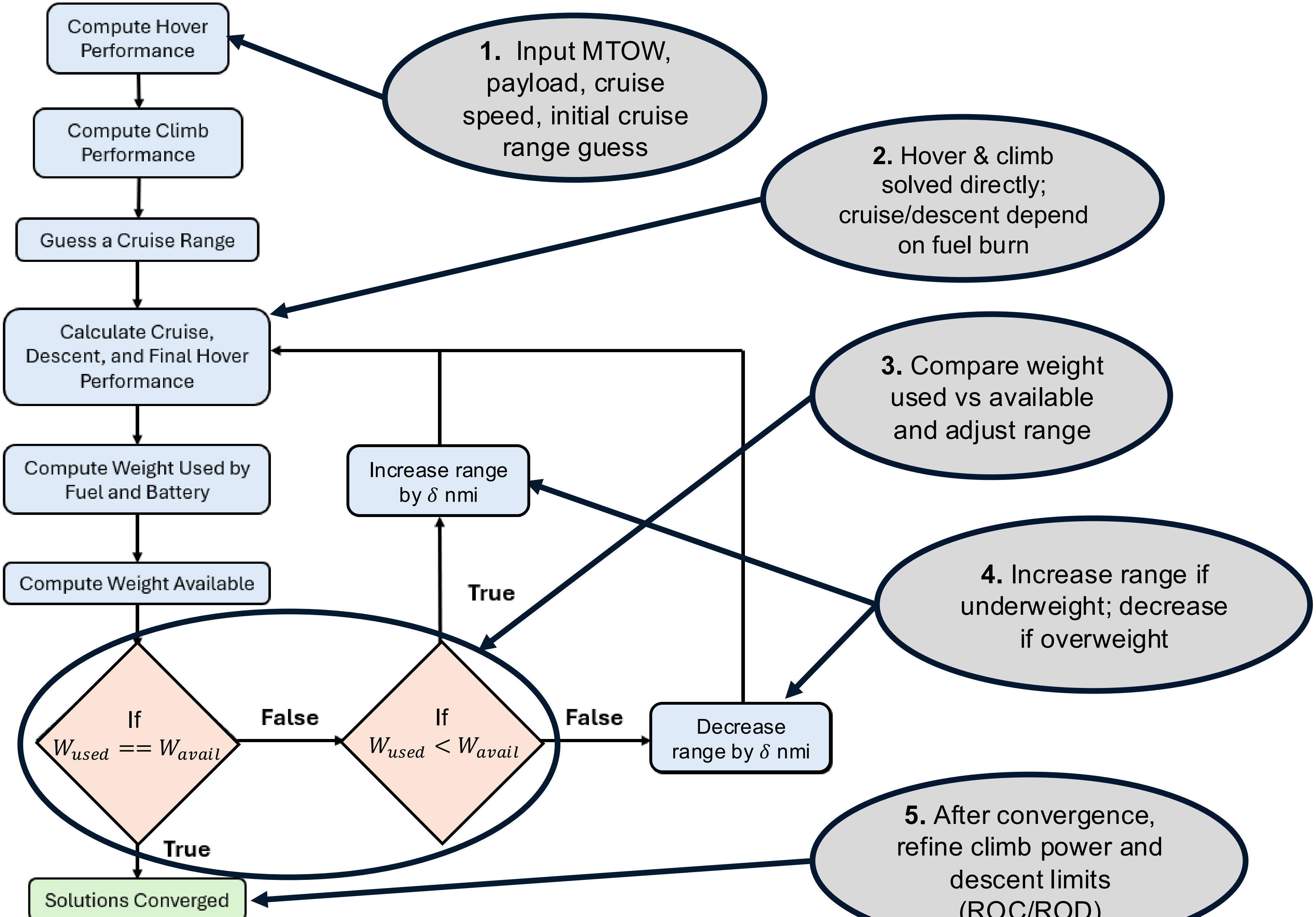
Additions:
- Electric motor (x10)
- Electric wire
- Battery
- Upscale nacelle gearbox (x2)
- Extra fuel tank (x1)

Deletions:
- Cross-shaft system

Legend
- Fuel line
- Electrical line
- Mechanical linkage
- Cross-shaft
- Engine
- Motor
- Gearbox
- Rotor shaft
- Fuel tank
- Battery
- Generator

[1] "A 3-View Line Drawing of a Bell XV-15," Image from NASA posted to Wikipedia, Retrieved 5 October 2025, https://en.wikipedia.org/wiki/Bell_XV-15#/media/File:Bell_XV-15_line_drawing.png.

Same Performance Model Applied Across Phase 1 and Phase 2



$^*W_{used} ==$ fuel + battery weight required for cruise range guess
$^*W_{avail} ==$ weight available for fuel + battery weight storage based on MTOW and empty weight

Propulsion Architecture Downselect, Choosing 3-Turboelectric

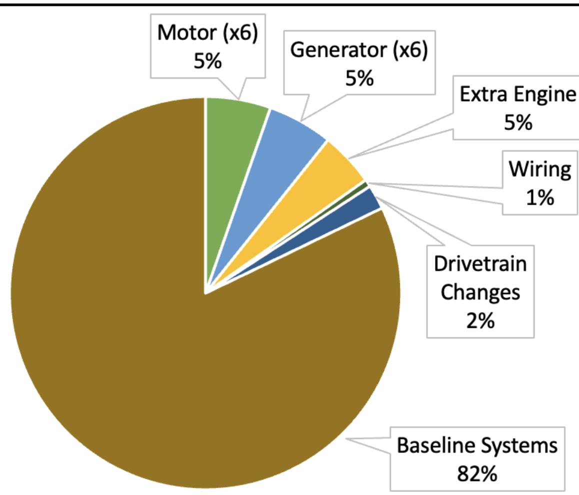
- **Conducted normalized AHP trade study on performance of the 4 architectures**
- **Study driven by Phase 1 range, empty weight, excess power available**
- **3- and 4-engine configurations with highest range, lowest weight**

AHP Trade Study of Propulsion Architectures

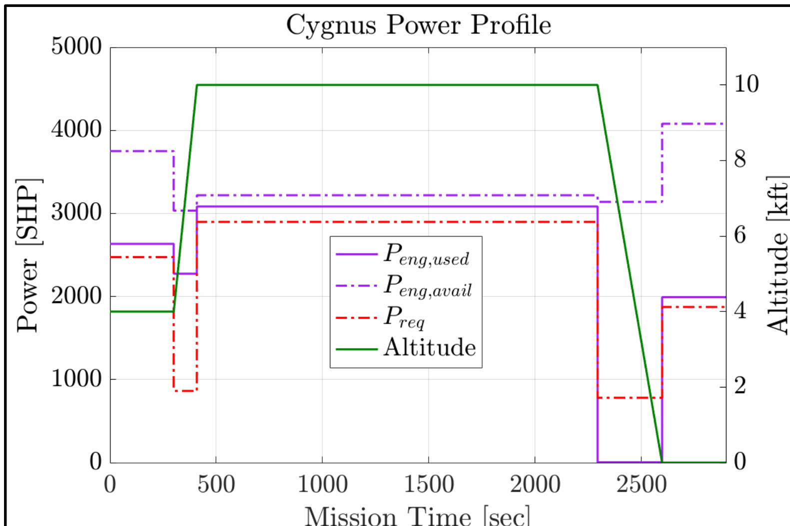
Objective	Parameter	Weight	Parallel Hybrid	3 Turboelectric	4 Engine	2 Turboelectric
	MTOW (lbf)	--	14,248	14,248	14,248	14,248
	Cruise Speed (ktas)	--	300	300	300	300
	Payload (lbf)	--	440	440	440	440
MAXIMIZE	Range (nmi)	47.0%	125.3	175.2	150.5	89.7
MINIMIZE	Empty Weight (lbf)	30.0%	12,981	12,277	12,387	13,134
MAXIMIZE	ROC (ft/s)	2.5%	54.5	55.1	53.2	58.6
MAXIMIZE	ROD (ft/s)	2.5%	-36.7	-34.7	-34.7	-35.3
MAXIMIZE	Excess Cruise Power (SHP)	10.0%	610	321	1,394	609
MAXIMIZE	Excess Hover Power (SHP)	5.0%	1,385.0	1,274.8	2,524.7	1,385.0
MAXIMIZE	Manufacturability (1-10)	3.0%	7	4	2	5
	Total	**100%**	**31.16%**	**77.88%**	**74.57%**	**6.37%**

Phase 1: "Cygnus"

System	Weight (lbf)
Motor (x6)	660
Generator (x6)	660
Extra Engine	550
Wiring	75
Drivetrain Changes	249.2
Baseline Systems	10,083
New Empty	**12,277**



Cygnus Turboelectric Empty Weight Breakdown



Cygnus Turboelectric Power Profile at 14,250-lbf MTOW

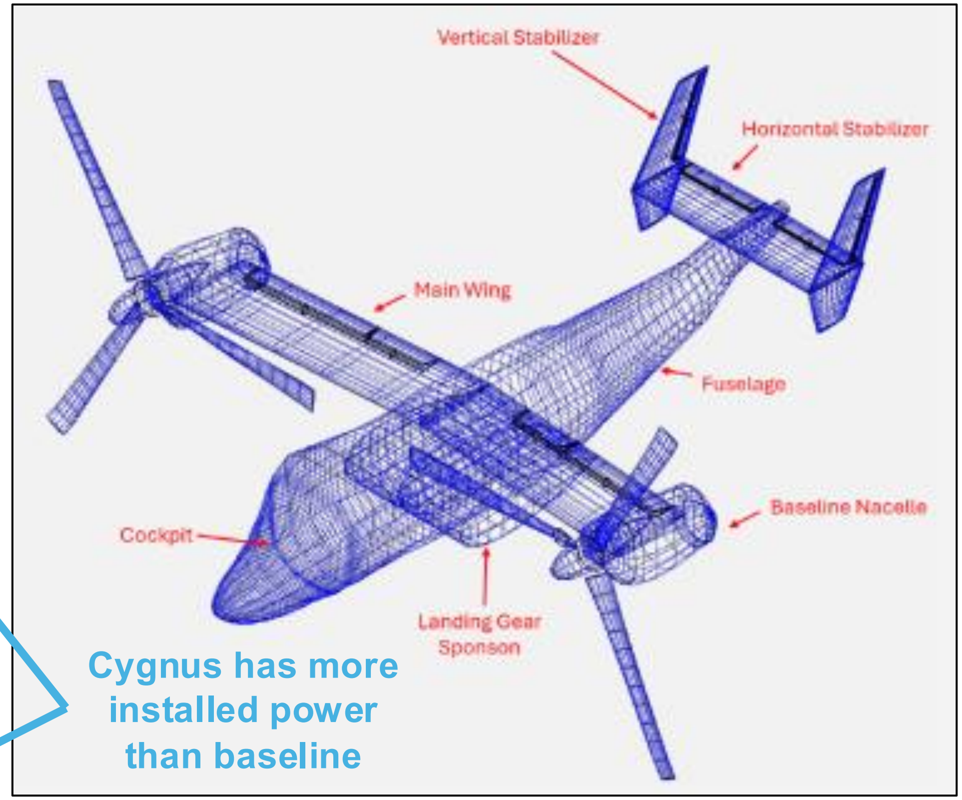
Results based on PSUAM performance models. Full model citations in final report.

[1] Vertical Flight Society, "43rd Annual Student Design Competition 2025–2026 Request for Proposal (RFP): Hybrid Electric Tiltrotor Sponsored by Leonardo," Mar. 2026.
[2] "Tilt Rotor Research Aircraft Familiarization Document," Tech. Rep., NASA and U.S. Army, 1975.

Cygnus Overview: Higher Speed but Lower Range, Payload than Baseline

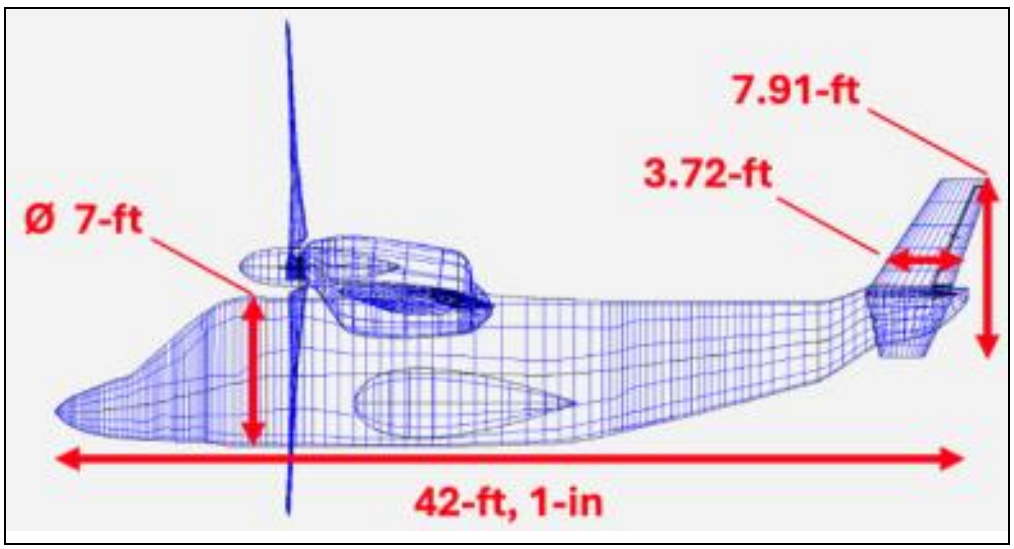
Mission Performance Results for Cygnus Compared to Baseline

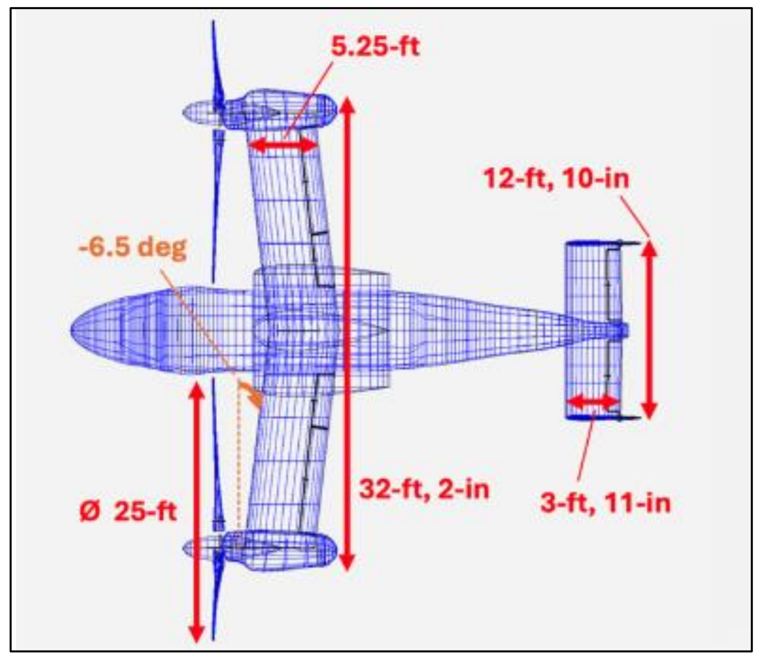
Parameter	Cygnus	Baseline
MTOW (lbf)	13,250	13,250
Cruise Speed (ktas)	300	264
Payload (lbf)	440	1,730
Range (nmi)	43.7	231
Fuel Weight (lbf)	531	1,440
# T-53 Engines	3	2
Empty Weight (lbf)	12,280	10,080
ROC (ft/s)	62.2	30.2
ROD (ft/s)	-32.9	-34.7
CL Max (experienced)	1.08	1.10
Excess Hover Power (SHP)	1,590	341



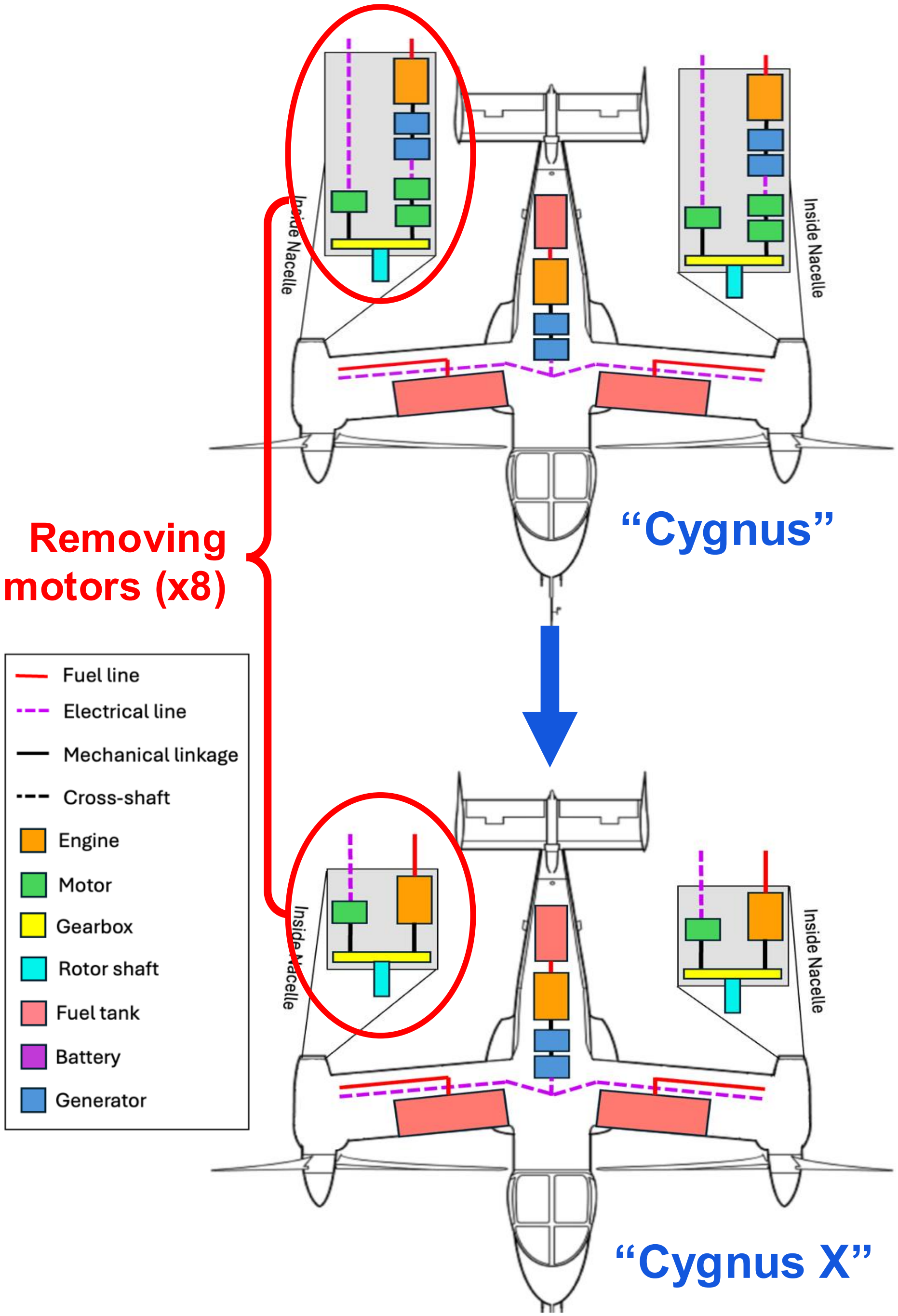
Cygnus has more installed power than baseline

Higher empty weight reduces fuel → lower range, lower payload





Converting from Cygnus to Cygnus X: Removing Nacelle Turboelectric



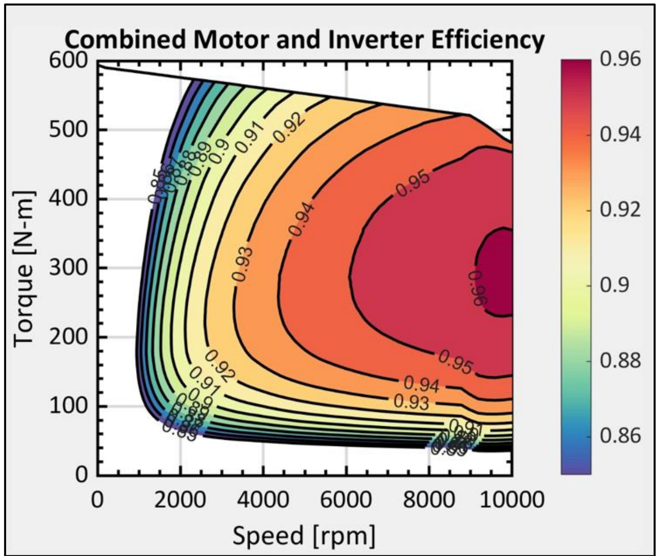
- **Cannot remove gearboxes**
  - High reduction ratio from engine → rotor
  - Torque on motors would be too high
- **Remove the turboelectric systems within the nacelles**
  - **Reduce empty weight** by at least **880-lbf**
  - Same installed power as Cygnus
- **Payload: 440-lbf → 1,600-lbf**
- **Structural loads: 3.5G (airplane), 2G (heli)**

Cygnus X: Fly same mission as Cygnus with these additional requirements.

Req. #	Req. Description
RFP.9	Vehicle payloads shall be 1,600-lbf with 6 passengers and 2 crew at 200-lbf each.
RFP.10	Rotor designs shall be maximum 25-ft in diameter with 3 blades per rotor.
RFP.11	Wing designs shall maintain a span of 32-ft, 2-in.
RFP.12	Vehicle design shall be capable of 300-ktas at 15,000-ft with standard day conditions.
RFP.13	Vehicle designs shall be capable of 350-ktas limit airspeed.
RFP.14	Vehicle designs shall be capable of HOGE with at least 10,000-lbf.
RFP.15	Vehicle designs shall be capable of sustaining 2G structural loads in helicopter/conversion mode and 3.5G structural loads in airplane mode at 95% TOGW.

[1] Vertical Flight Society, "43rd Annual Student Design Competition 2025–2026 Request for Proposal (RFP): Hybrid Electric Tiltrotor Sponsored by Leonardo," Mar. 2026.
[2] Maisel, M. D., Giulianetti, D. J., and Dugan, D. C., The History of the XV-15 Tilt Rotor Research Aircraft from Concept to Flight, NASA, 2000.
[3] "A 3-View Line Drawing of a Bell XV-15," Image from NASA posted to Wikipedia, Retrieved 5 October 2025, https://en.wikipedia.org/wiki/Bell_XV-15#/media/File:Bell_XV-15_line_drawing.png.

Cygnus X Drivetrain Upscaled due to High Torque Requirements at 300-ktas



Using **H3X motors**. Run motors at **10k-rpm** for high efficiency [8]

Rotor Output:
- 498-rpm (airplane)
- 608-rpm (heli)

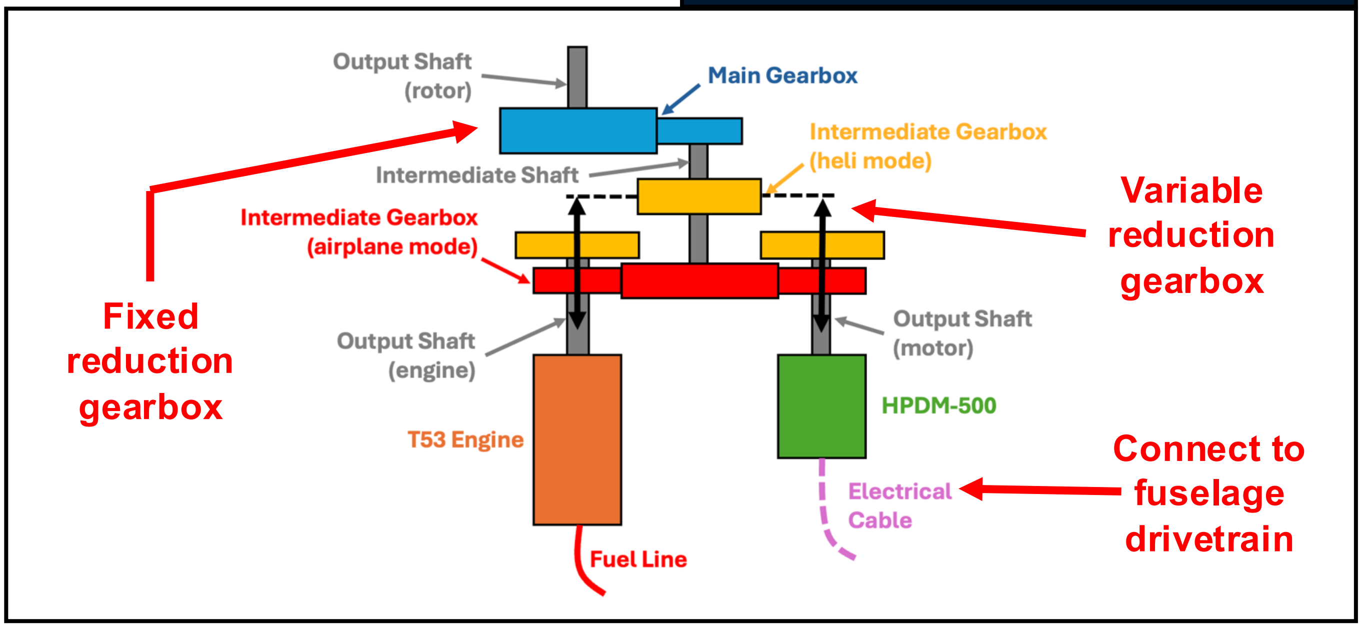
Engine [1]:
- 6,040-rpm (airplane)
- 6,300-rpm (heli)

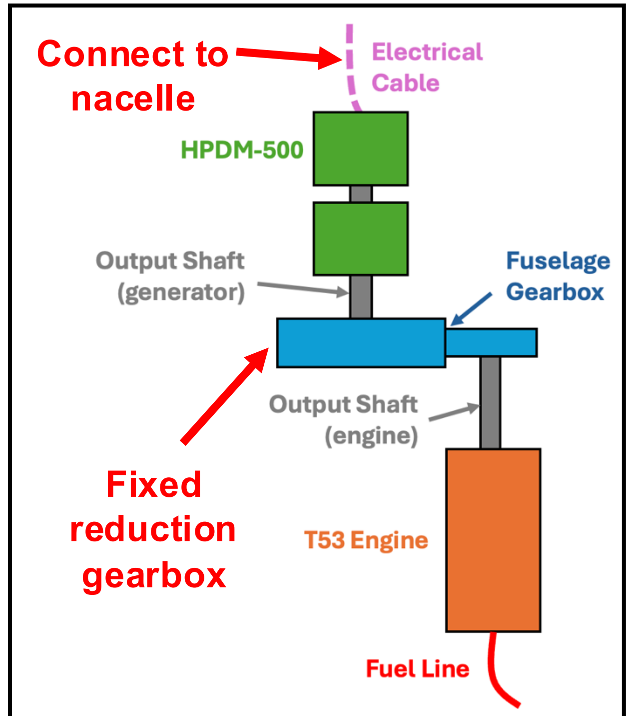
Cygnus X Gear Reduction Ratios

Gearbox	Cygnus X
Main	5.921:1
Intermediate (heli mode, engine)	1.750:1
Intermediate (airplane mode, engine)	2.048:1
Intermediate (heli mode, motor)	2.778:1
Intermediate (airplane mode, motor)	3.391:1
Fuselage	1.587:1

Engine speed fixed by vehicle mode and want constant **10k-rpm for motors** for **maximum efficiency**. Rotor **output speed** set to **maintain same efficiency** as baseline rotor. Requires 2-speed mechanical transmission.

Nacelle Drivetrain





Fuselage Drivetrain

[1] "Type-Certificate Data Sheet for Engine T5313 and T53 17 Series Engines," *EASA*, No. IM.E.250, June 2023.
[2] Maisel, M. D., Giulianetti, D. J., and Dugan, D. C., "The History of the XV-15 Tilt Rotor Research Aircraft from Concept to Flight," NASA, 2000.
[3] "Pyrowear 675," *Carpenter Technology*, Datasheet, https://www.carpentertechnology.com/hubfs/7407324/Material%20Saftey%20Data%20Sheets/Pyrowear%20675.pdf.
[4] Hall, Smith, DeSmidt, "Sizing and Performance of an Electrically-Augmented Gearbox Concept for Electrified Aircraft Propulsion Applications," EATS, 2024.
[5] Kratz, J. L., and Culley, D. E., "Exploration of the Versatile Electrically Augmented Turbine Engine Gearbox Concept," Tech. rep., NASA Glenn Research Center, Cleveland, Ohio, USA, Single Planetary (SP) Variant Analysis.
[6] Magee, J. P., and Alexander, H. R., "A Hingeless Rotor XV-15 Design Integration Feasibility Study," Tech. rep., NASA, 1978. URL https://ntrs.nasa.gov/api/citations/19800009766/downloads/19800009766.pdf.
[7] Vlašićek, D., Miler, D., Mašović, R., Žeželj, D., "Approaches to Reducing Gear Mass and their Effects on Gearing Stresses and Deformations," *Design 2024*, https://doi.org/10.1017/pds.2024.307.
[8] "HPDM-500," H3X Technologies, https://www.h3x.tech/products/hpdm-500.

Cygnus X: Maintain Altitude in OEI & Smaller ROD in Autorotation Compared to Baseline

2 Engines Out Power Parameters

Configuration	P_{req} (SHP)	P_{avail} (SHP)
Baseline XV-15	2,160	0
3 Turboelectric Cygnus X	2,460	1,250

OEI Power Parameters

Configuration	P_{req} (SHP)	P_{avail} (SHP)
Baseline XV-15	2,160	1,250
3 Turboelectric Cygnus X	2,460	2,500

Axial Rate of Descent in Hover at 4K/95degF due to Engine Outage

Configuration	OEI ROD (ft/s)	Autorotation ROD (ft/s)
Baseline XV-15	37.8	89.7
Turboelectric	0.0	46.8

Cygnus X has higher installed power → increased redundancy compared to baseline

Cygnus X eliminates OEI hover descent (0 ft/s) and cuts autorotation ROD ~48% vs. baseline

Results based on PSUAM performance models. Full model citations in final report.

[1] Leishman, J. G., *Principles of Helicopter Aerodynamics*, 2nd ed., Cambridge University Press, New York, 2006.

Cygnus X Structural Material Changed to Reduce Empty Weight and Meet 306-nmi Range

Structural Material AHP Trade Study

Rank	Characteristics	CFRP	GFRP	Aluminum
30%	Density $(\mathrm{kg/m^3})$	1600	1900	2700
30%	Specific Strength $(\frac{\mathrm{N*m}}{\mathrm{kg}})$	1.29	0.16	0.12
20%	Specific Stiffness $(\frac{\mathrm{N*m}}{\mathrm{kg}})$	0.23	0.02	0.026
10%	Manufacturability (0-1)	0	0.5	1
10%	Repairability (0-1)	0.5	1	1
100%	-	0.56	0.23	0.22

- Current structure uses T-6 aluminum; switching to CFRP improves strength-to-weight, stiffness, and reduces density
- Manufacturability and repairability rated based on fabrication difficulty and ease of repair, simpler materials scored higher

Structural Weight Savings Based on Improved Material Selection

Components	Fuselage	Wing	Horizontal Tail	Vertical Tail	Nacelle	Total Saved
Weight (lb)	4,840	950	120	200	300	-
Weight Saved (lb)	3,790	560	70	120	170	1,700 lbs

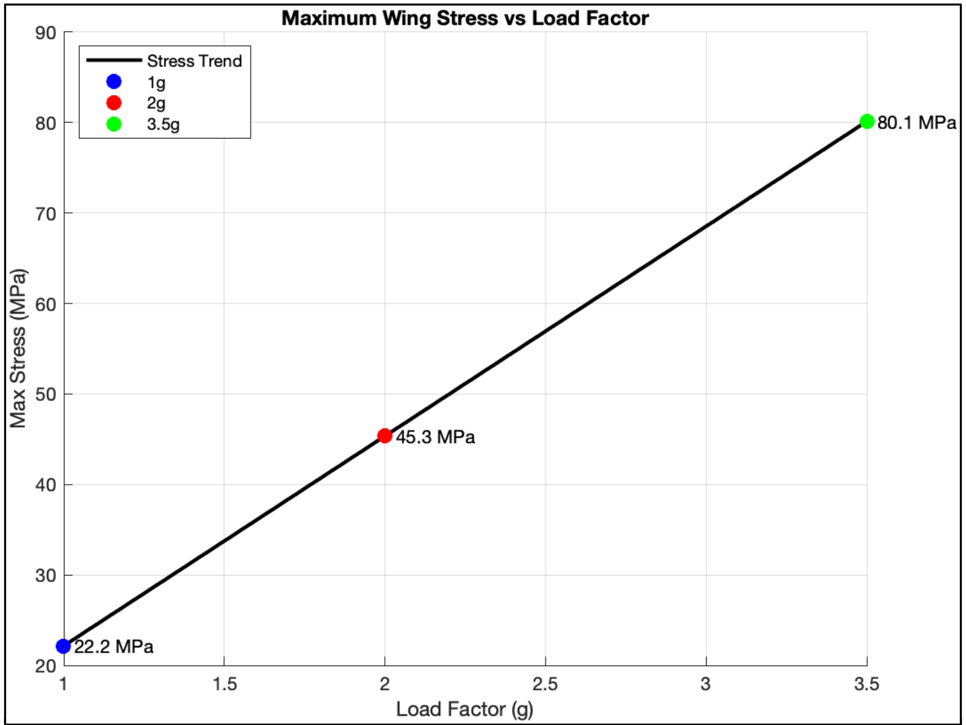
*Prouty and FLOPS equations used to estimate the weights of key components being switched to CFRP

Total general Cygnus X weight reduced by 26-29% by switching to a composite material; fuselage weight reduced by 16.4%

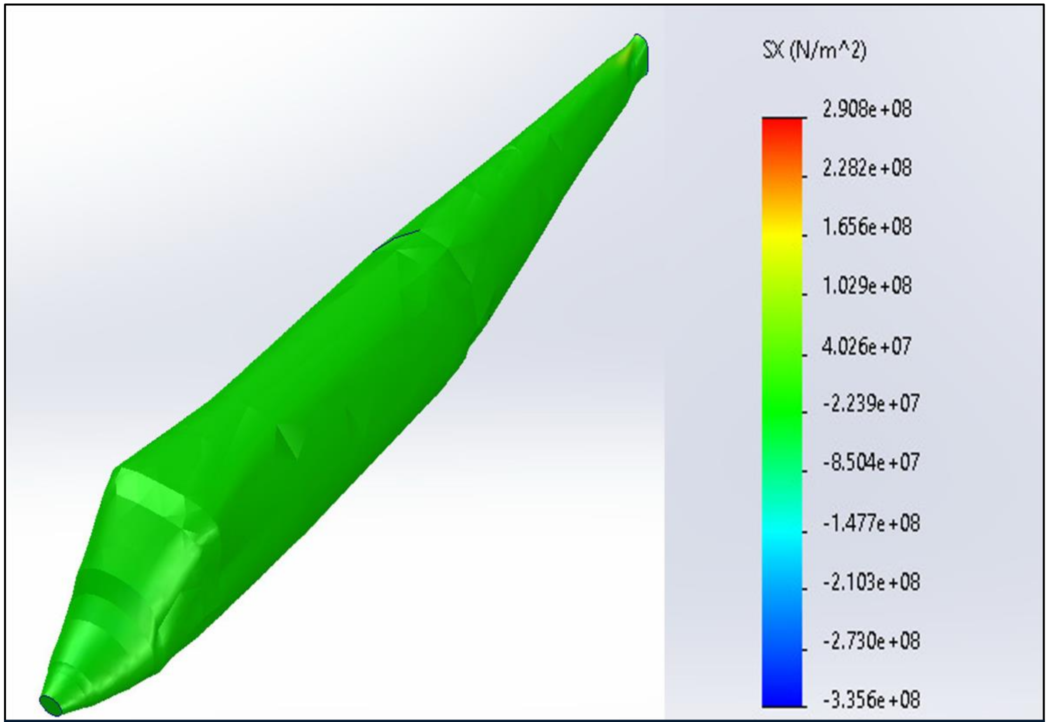
[1] Prouty, R., "Helicopter Performance, Stability, and Control," 2001.
[2] Maisel, M. D., Giulianetti, D. J., Dugan, D. C., "The History of The XV-15 Tilt Rotor Research Aircraft from Concept to Flight", NASA, 2000.
[3] Wells, P. D., Horvath, L. B., McCullers, A. L., "The Flight Optimization System Weights Estimation Method", NASA, 2017.
[4] Marano, D. A., Diodati, G., Paletta, N., Di Palma, L., "Structural Scalability Preliminary Studies for the Next Generation Civil Tiltrotor Composite Wing", 2023.
[5] Jackson, A. C., Campion, M. C., Pei, G., "Study of Utilization of Advanced Composites in Fuselage Structures or Large Transports", NASA, 1984.
[6] Jacoby, M., "Composite Materials," *C&EN*, 30 Aug. 2004, https://cen.acs.org/articles/82/i35/COMPOSITE-MATERIALS.html.

Cygnus X Stress Results Demonstrate Structural Integrity Under Loading

Wing extensions do not compromise the structural integrity or strength of Cygnus X



Wing Stress at Each Required g-loads



Fuselage Stress Analysis

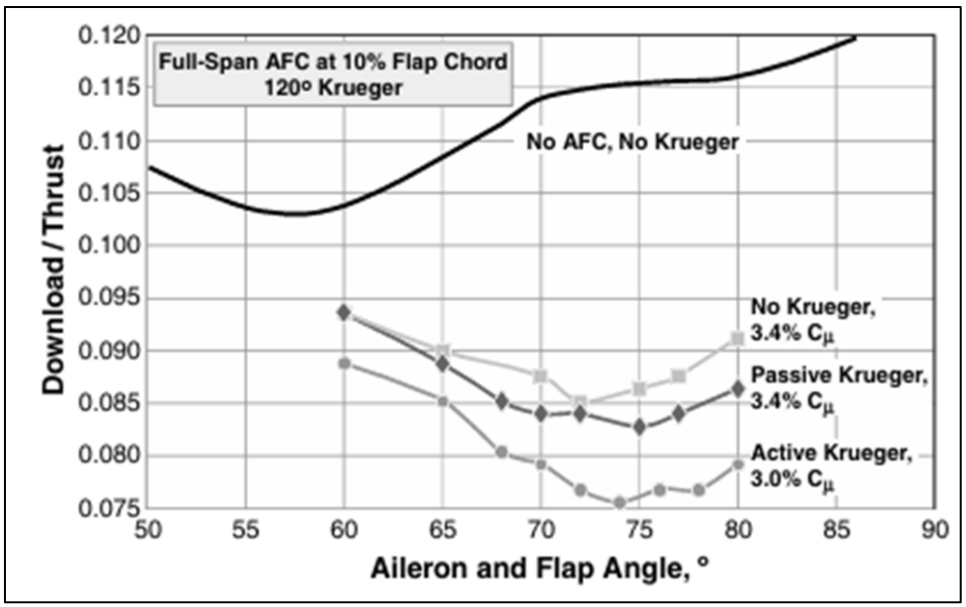
Wing root stress across the required g-levels remains low enough to keep **F.O.S. above 3**

Fuselage experiences a peak stress of ~ 47 **MPa, which stays within allowable limits**

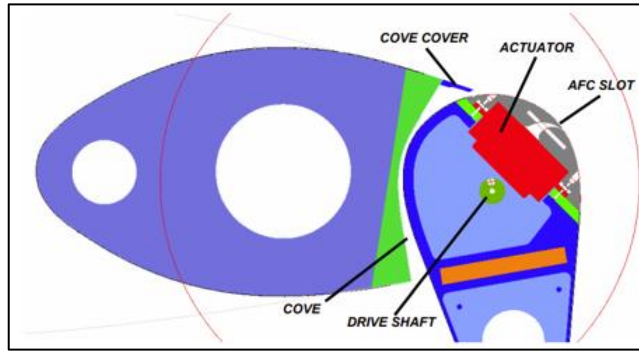
Technologies for Reduced Wing Download: Active Flow Control and Krueger Flap

Active Flow Control (AFC) and Krueger Flap Implementation

- The documentation of NDARC was used to extrapolate the data from [2]
- With AFC and the Krueger flap, the **downloading ratio** dropped from **0.107** [1] on the baseline to as low as **0.075** at some flap angles



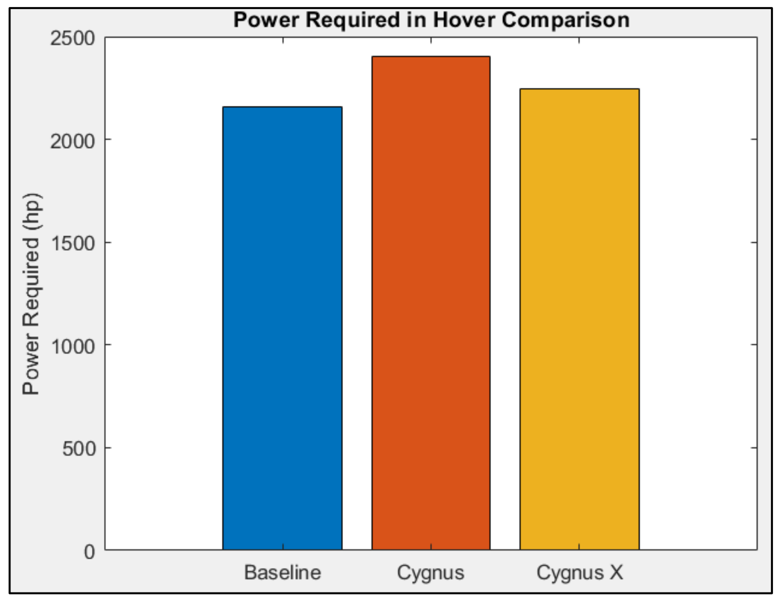
Krueger Flap & AFC Downloading Results



Krueger Flap and AFC [3]

$$\frac{0.107 - 0.075}{0.107} * 100 = 30\ \% = \mathbf{250\ lbs}$$

- **With a 30 % decrease in downloading factor, the thrust required in hover is reduced by 250 lbs**



Power Required in Hover Comparison

[1] Johnson, W., "NDARC — NASA Design and Analysis of Rotorcraft Validation and Demonstration," American Helicopter Society Aeromechanics Specialists Conference, 2010.

[2] McVeigh, M. A., Nagib, H., Wood, T., and Wygnanski, I., *"Full-Scale Flight Tests of Active Flow Control to Reduce Tiltrotor Aircraft Download,"* Journal of Aircraft, Vol. 48, No. 3, May–June 2011, pp. 786–796. https://doi.org/10.2514/1.46956

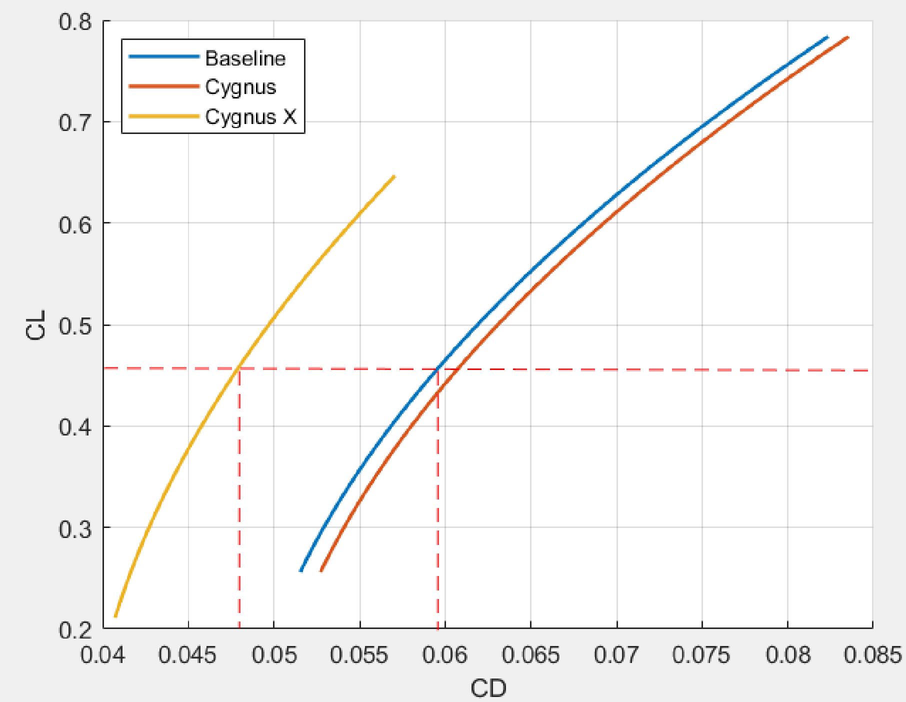
[3] Nagib, H. M., Kiedaisch, J. W., Wygnanski, I. J., Stalker, A. D., Wood, T., and McVeigh, M. A., "First-In-Flight Full-Scale Application of Active Flow Control: The XV-15 Tiltrotor Download Reduction," , 2004. URL: https://publications.sto.nato.int/publications/STO%20Meeting%20Proceedings/RTO-MP-AVT-111/MP-AVT-111-29.pdf.

Cygnus X Cruise Wing Performance Improved with Wing extensions and Decreased Thickness

Wing geometry changes based on [1] and resulting performance improvements					
	$Span\ b\ (ft)$	$S\ (ft^2)$	AR	$\frac{t}{c}$	f_{wing}
Baseline	32.2	169	6.12	0.23	1.86
Cygnus X	41.3	217	7.86	0.20	1.8

Cygnus X Wing Extension

- **Airfoil thinning and Wing extensions**
  - Due to the MTOW of the new configuration increasing and the sizing of the tail increasing to maintain stability, the new design without wing modifications would have higher drag than the baseline.
  - With the airfoil thickness (t/c) reduction from 0.23 [1] to 0.20 and the addition of spanwise wing extensions, the total drag CD experienced in cruise for the same given CL (0.46) produced by the wing will be reduced from 0.060 to 0.048.

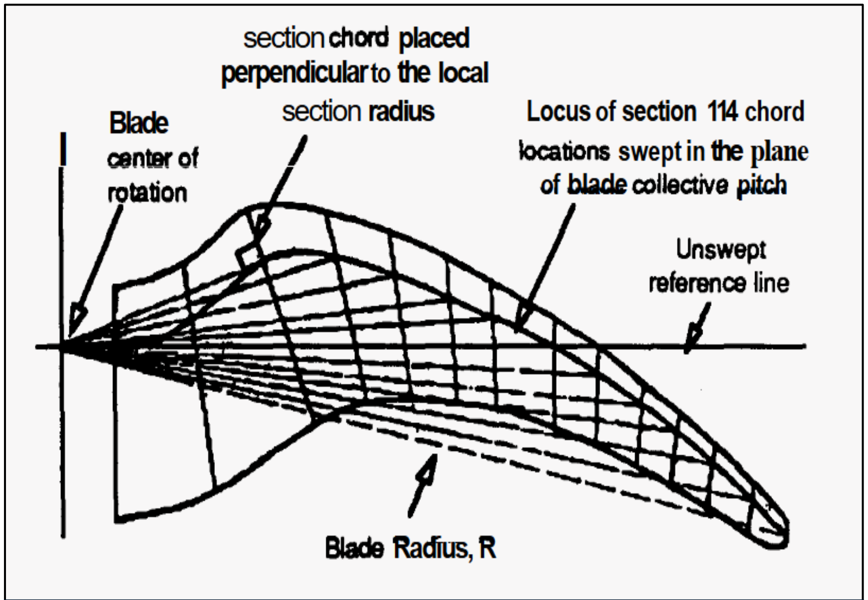


CL vs. CD for All Three Configurations

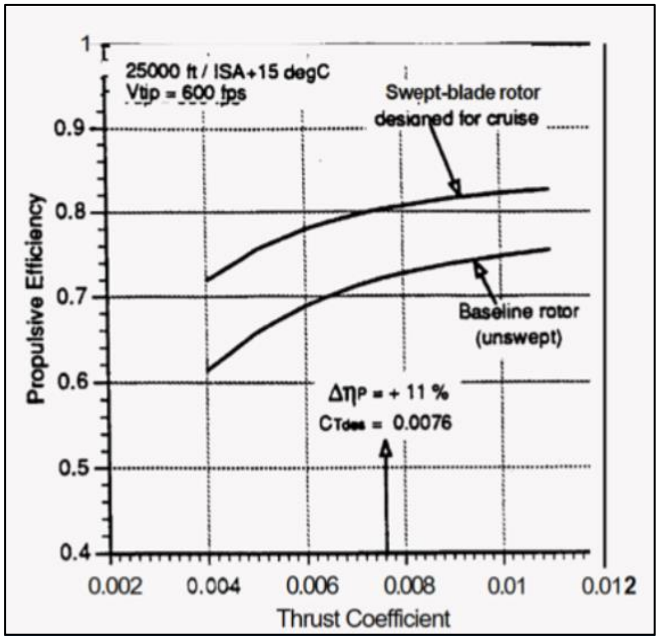
[1] Maisel, M. D., Giulianetti, D. J., and Dugan, D. C., "The History of the XV-15 Tilt Rotor Research Aircraft from Concept to Flight," NASA, 2000.
[2] Kambampati, S., *Optimization of Composite Tiltrotor Wings with Extensions and Winglets*, Ph.D. Dissertation, Dept. of Aerospace Engineering, The Pennsylvania State University, University Park, PA, Aug. 2016. https://etda.libraries.psu.edu/files/final_submissions/12712

Cygnus X Improved Rotor Geometry for Improved Rotor Propulsive Efficiency

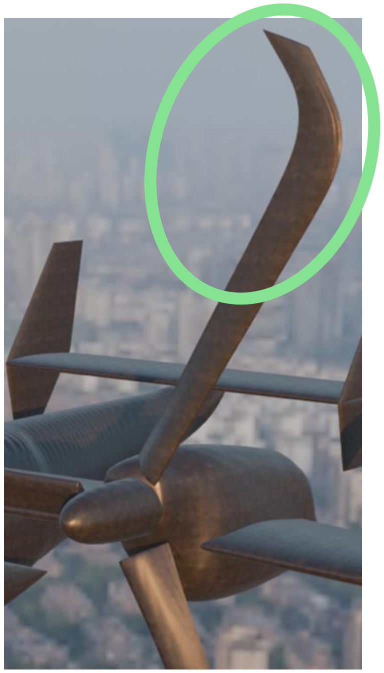
- Improved Rotor Geometry: introduced a geometry of an inboard forward sweep and outboard aft sweep
  - Improved Geometry resulted in **13% Improvement in Rotor Efficiency** changing the $\eta_{rotor} = 0.85 \rightarrow 0.90$



Improved Rotor Design for High-Speed Tiltrotor [1]



Efficiency of Unswept and Optimized Rotor Blade [1]



Swept Cygnus X rotor

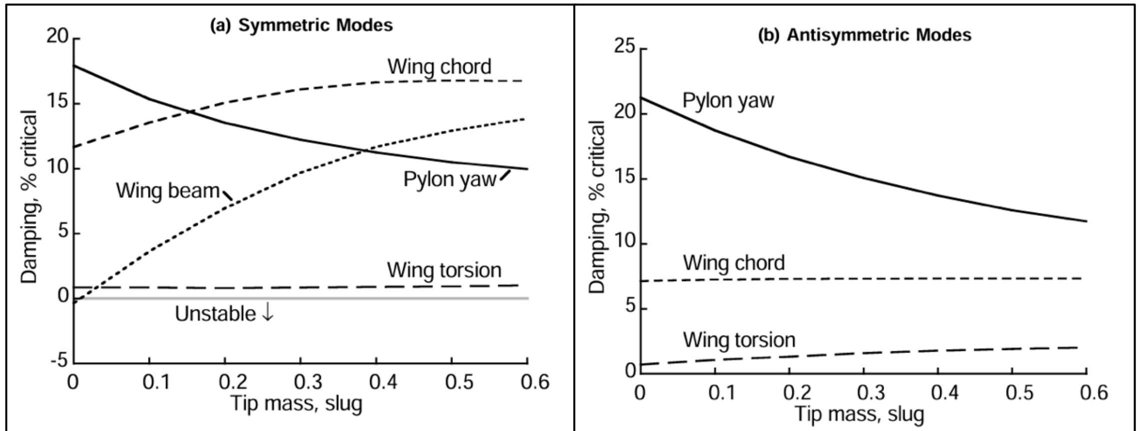
- In cruise, to ensure the rotors $M_{Tip} < 1$, rotor rotational speed was set to **498 RPM**
- In hover, to match the same coefficient of thrust as the baseline XV-15 the rotor rotational speed was set to **608 RPM**

[1] Liu, J., and McVeigh, M., "Design of Swept Blade Rotors for High-Speed Tiltrotor Application," *Aircraft Design and Operations Meeting*, Aug. 1991. https://doi.org/10.2514/6.1991-3147.
[2] Schneider, J., and Wilkerson, J., "Advanced Rotorcraft V/STOL - Technology Needs for High-Speed Rotorcraft," *Aircraft Design, Systems and Operations Conference*, Aug. 1990. https://doi.org/10.2514/6.1990-3298.

Cygnus X Whirl Flutter Effects Reduced by Rotor and Wing Modifications

Rotor Improvements [1]: 10° aft sweep done at 80% of the blade radius

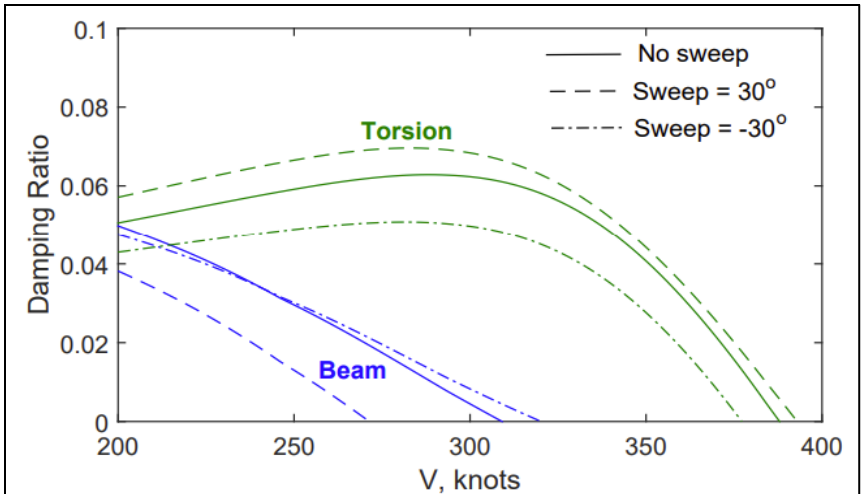
- Resulted in an increase in whirl-flutter stability, each mode's critical damping



Whirl-Flutter Stability Modes of 10° Swept Rotor Blade [1]

Wing Extensions [2]: 4.55 ft extension on each wing implemented based on a PhD dissertation

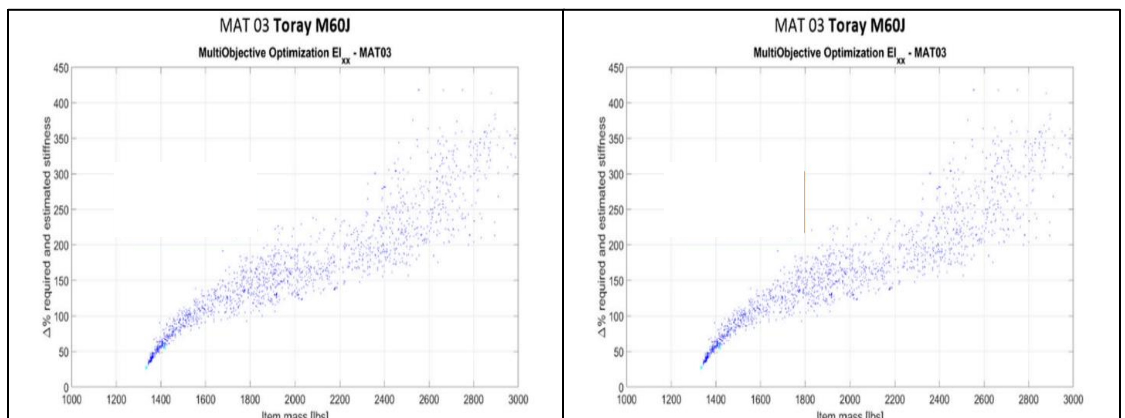
- Resulted in an increase in whirl-flutter stability, especially in the Torsion and Beam modes



Whirl-Flutter Stability Modes of Wing Extensions [2]

Toray M60J [4]: CFRP already possess qualities that ensure bending and stiffness requirement be met

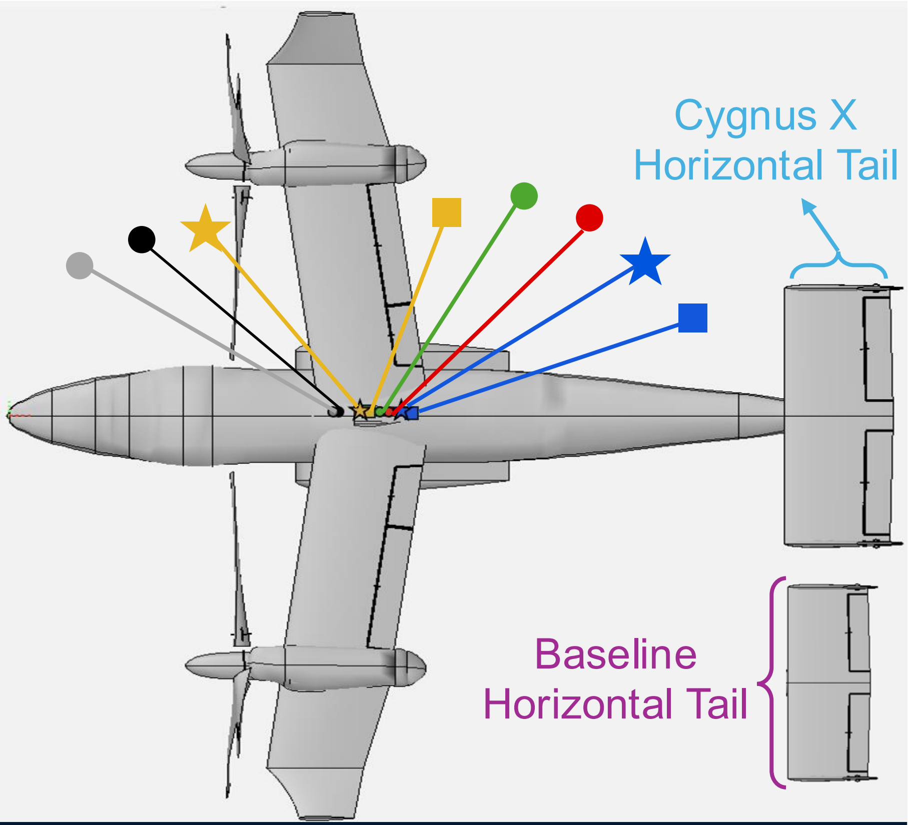
- High torsional rigidity is a key quality that minimizes whirl flutter effects



CFRP Strength and Stiffness Plots [4]

[1] Acree, C. W., Jr., "Effects of Rotor Design Variations on Tiltrotor Whirl-Mode Stability," NASA Technical Report NASA/TM-2003-212265, 2003, https://ntrs.nasa.gov/citations/20030062967.
[2] Kambampati, S., *Optimization of Composite Tiltrotor Wings with Extensions and Winglets*, Ph.D. Dissertation, Dept. of Aerospace Engineering, The Pennsylvania State University, University Park, PA, Aug. 2016. https://etda.libraries.psu.edu/files/final_submissions/12712
[3] Muscarello, V., and Quaranta, G., "Optimization of tiltrotor blade twist to increase whirl-flutter stability," *AIAA Scitech 2019 Forum*, Jan. 2019. https://doi.org/10.2514/6.2019-1366
[4] Marano, D. A., Diodati, G., Paletta, N., Di Palma, L., "Structural Scalability Preliminary Studies for the Next Generation Civil Tiltrotor Composite Wing", 2023. https://www.researchgate.net/publication/370923249_Structural_Scalability_Preliminary_Studies_for_the_Next_Generation_Civil_Tiltrotor_Composite_Wing#pf1c

Cygnus X Stability Overview: SM, MM, and CG within Stable Limits of Aircraft



CG, Neutral Point, and Maneuver Point Positions Relative to The Nose of the XV-15

Legend		
Name	**Value**	**Symbol**
CG Dry Baseline	16.0 ft	● (black)
CG Wet Baseline	15.9 ft	● (gray)
CG Dry 3 Turbo Electric	17.5 ft	● (green)
CG Wet 3 Turbo Electric	18.2 ft	● (red)
Baseline Neutral Point	17.2 ft	■ (gold)
Baseline Maneuver Point	17.0 ft	★ (gold)
3 Turbo Electric Neutral Point	18.8 ft	■ (blue)
3 Turbo Electric Maneuver Point	18.5 ft	★ (blue)

CG shifts aft

- Wet = Fuel Tanks Full
- Dry = Empty Fuel Tanks
- CG ahead of Ntrl. Pt. And Mnvr. Pt. leads to positive SM and MM

- **CG shifts aft** → **Horz. tail resized** to obtain 10% MAC for 3 turboelectric SM shown in above table (**maintain stability and control**)
- Span and chord length chosen to maintain original horz. tail proportions

Stability Parameters for HEPS compared to baseline XV-15.

MM Type	3 Turboelectric	Baseline
Wet MM	4.21% MAC	20.1%
Dry MM	20.0% MAC	19.1%

SM Type	3 Turboelectric	Baseline
Wet SM	10.0% MAC	25.2%
Dry SM	25.0% MAC	24.1%

New Horizontal Tail Parameters

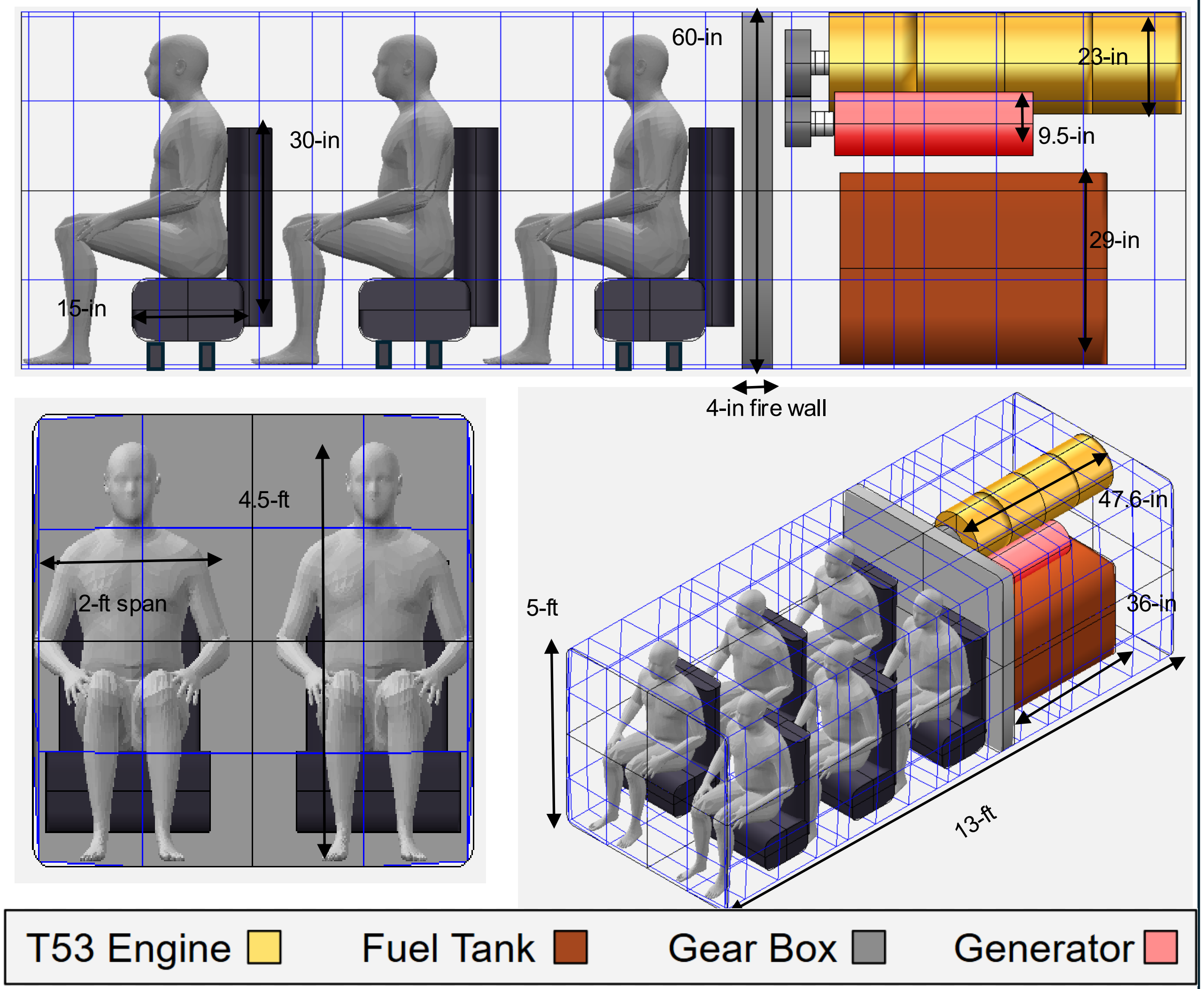
Variable	Horizontal Tail Area	Horizontal Tail Weight	Span Length	Chord Length	Tail Volume Ratio
Symbol	S_t	W_t	b	c	V_H
Cygnus X	83.3 ft^2	212 lbf	16.5 ft	5.05 ft	2.31
Baseline	50.25 ft^2	116 lbf	12.83 ft	3.92 ft	1.40

Results based on PSUAM performance models. Full model citations in final report.

Cygnus X Optimized Interior Layout for 6 Passengers in Urban Air Mobility

Interior Components:

- **Lycoming T53-L-13 (LTC1K-4) Turboshaft Engine**
  - Dimensions: 47.6" x 23"
  - Weight: 549-lb
- **HPDM-500 Generator (x2)**
  - Dimensions: 13.4" x 9.5"
  - Weight: 110-lb
- **Fuel tank**
  - Dimensions: 40" x 36" x 29"
  - Weight: 180-lb (empty), 1350-lb (full)
- **Gear Box**
  - Dimensions:
    - Gear: 3.5" x 10"
    - Pinion: 3.5" x 7.6"
  - Weight: 51.3-lb
- **Sound-proof Fire wall**
  - Dimensions: 4" x 60" x 58"
  - **Require hearing protection** for passengers + crew (loud gearbox and engine in fuselage)
- **Jump Seats [3]**
  - Dimensions: 24" x 15" x 30"
  - Weight: 36.5-lb



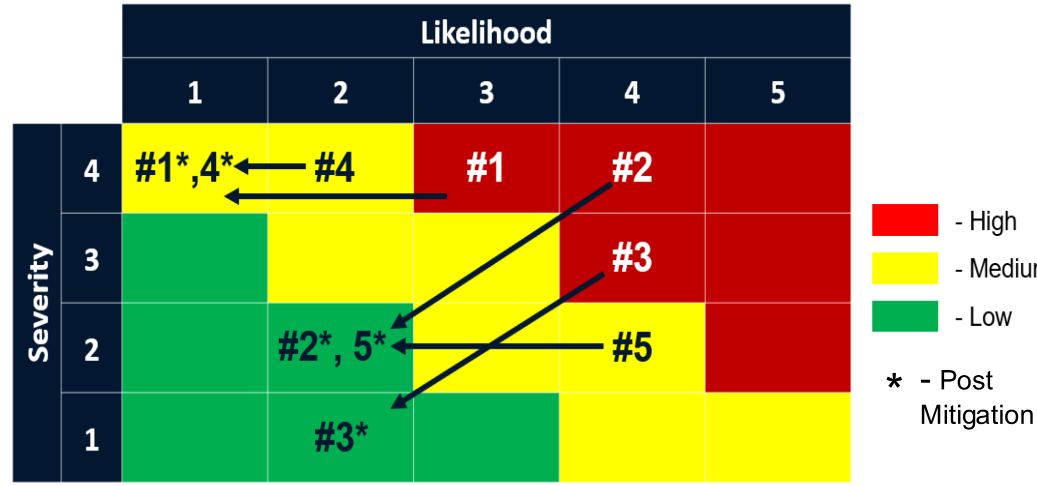
Cygnus X Interior Design Layout

[1] "HDPM-500," H3X Technologies, https://www.h3x.tech/products/hpdm-500.
[2] Smithsonian National Air and Space Museum, "Lycoming T53-L-13/LTC1K-4 Turboshaft Engine," Accessed 2025-12-14.
[3]"JUMP SEAT 09 - floor mounted flip-up seat with 2 point seat belt in gray vinyl," *Suburban Seating & Safety*

Cygnus X Risk & Cost Overview: Low-to-Medium Risk Profile; $33M Flyaway, $81M Development

Risk Table for HEPS

#	Risk	Mitigation
1	Full system failure	Pilot initiates autorotation procedures (see autorotation section).
2	Partial system failure	Failure mode analysis confirms forward flight capability is retained in all single-component failure cases
3	Motor low TRL risk	Continued development and testing; nacelle and fuselage engines remain operational if a motor fails.
4	Fire within the aircraft	Fire suppression system, fire-retardant fuselage materials, and thermal management of the electrical branch.
5	Noise for people in the vehicle	Acoustic bulkhead consistent with modern aviation noise isolation.



Risk Matrix for HEPS

Equation 1. CTM24 Flyaway Cost Equation [1]

$$(1)\quad \hat{c}_{FA} = 1312 \cdot W_E^{0.3481} \cdot P_{inst}^{0.5926} \cdot N_{br}^{0.2827} \cdot H$$

Equation 2. CTM24 Development Cost Equation [1]

$$(2)\quad \hat{c}_{\mathrm{DEV}} = 10.43 \cdot c_{FA}^{0.6923} \cdot W_E^{0.2742} \cdot e^{0.0689 N_{dev}} \cdot (Yr_{MS2} - 1983)^{0.2495}$$

Cost Breakdown for Cygnus X

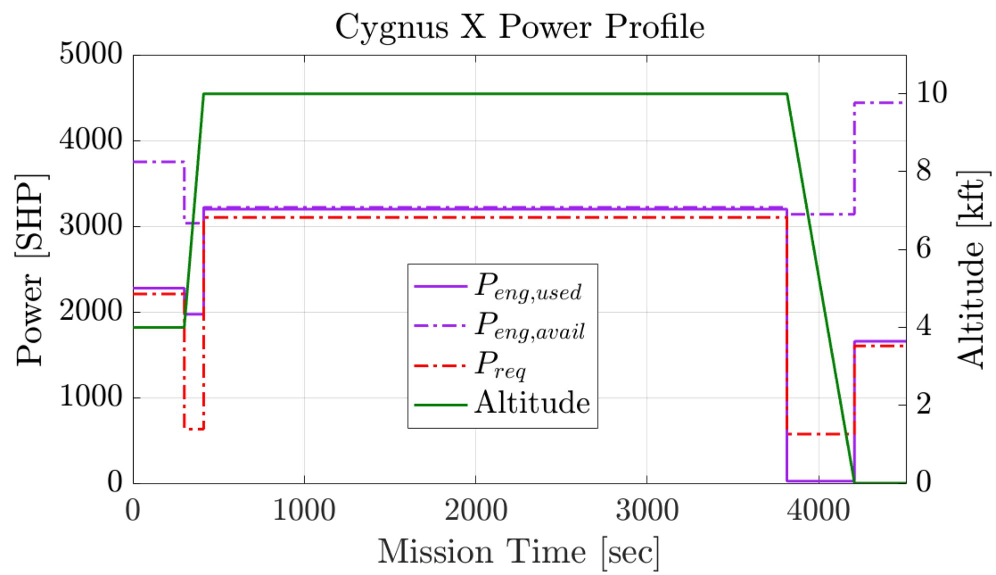
Parameter	Value	Units
Flyaway Cost Buildup		
CPI Adjustment (CTM24)	$21,600,000	FY26 USD
Tiltrotor multiplier	1.5	-
Tiltrotor-adjusted flyaway	$32,500,000	FY26 USD
CFRP material premium	$575,000	FY26 USD
Final flyaway price	**$33,000,000**	**FY26 USD**
Flyaway range (+/-20%)	$26.0M - $39.0M	FY26 USD
Development cost	**$81,300,000**	**FY26 USD**
Development range (+/-20%)	$65.1M - $97.6M	FY26 USD

Flyaway and development costs were estimated using the CTM24 [1] parametric rotorcraft model, with adjustments for tiltrotor complexity, CFRP material cost, and V-22-class program assumptions.

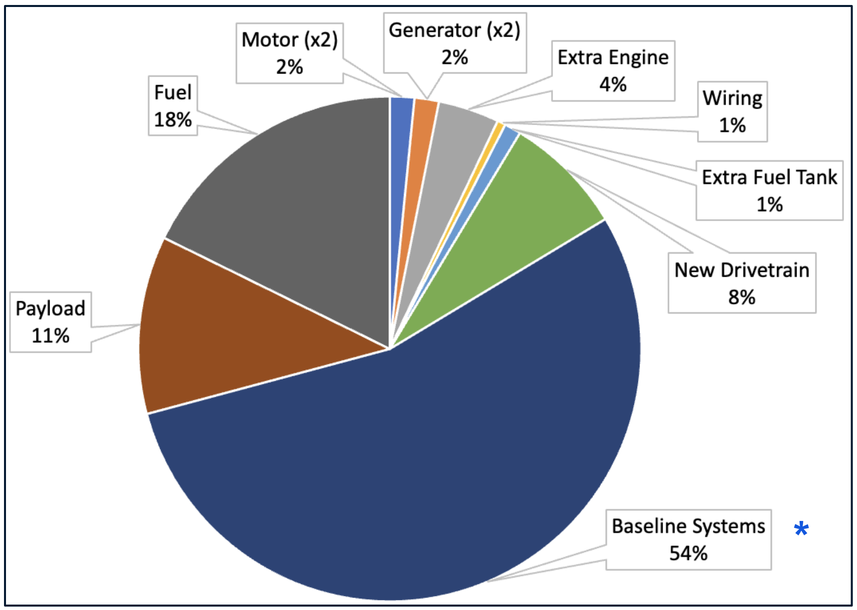
[1] Scott, R., and Nunez, G. F., “Rotorcraft Cost Too Much – Revisited,” Proceedings of the Vertical Flight Society 80th Annual Forum, Vertical FlightSociety, Montreal, Canada, 2024.

Cygnus X Weight & Power Profile: Vehicle Meets the Requested Range, Speed, and Payload

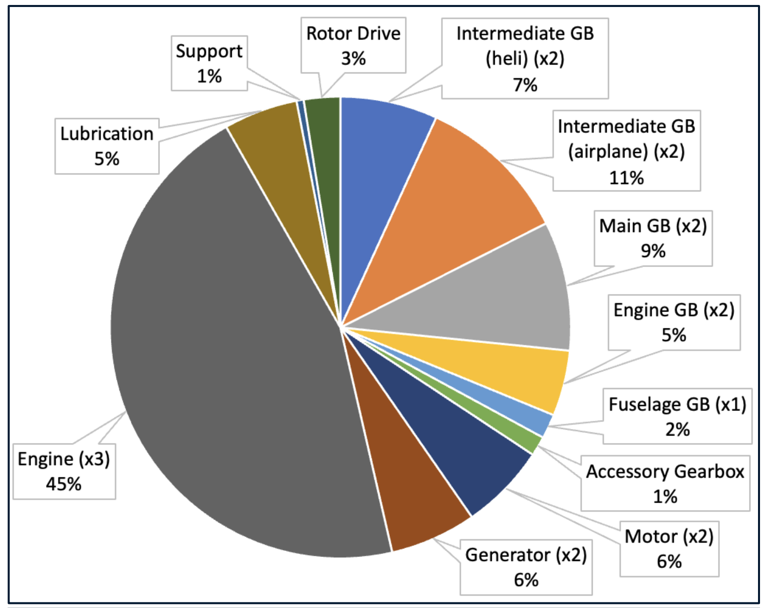
Parameter	Cygnus X	Cygnus	Baseline
MTOW (lbf)	14,030	13,250	13,250
Cruise Speed (ktas)	300	300	264
Payload (lbf)	1,600	440	1,730
Range (nmi)	306	43.7	231
Fuel Weight (lbf)	2,490	531	1,440
# T-53 Engines	3	3	2
Empty Weight (lbf)	9,940	12,280	10,083
ROC (ft/s)	53.1	62.2	30.2
ROD (ft/s)	-25.4	-32.9	-34.7
CL Max (experienced)	0.89	1.08	1.10
Excess Hover Power (SHP)	1,540	1,590	341



Cygnus X has **increased range** and **reduced weight** compared to Cygnus and Baseline.



Cygnus X Full Weight Breakdown

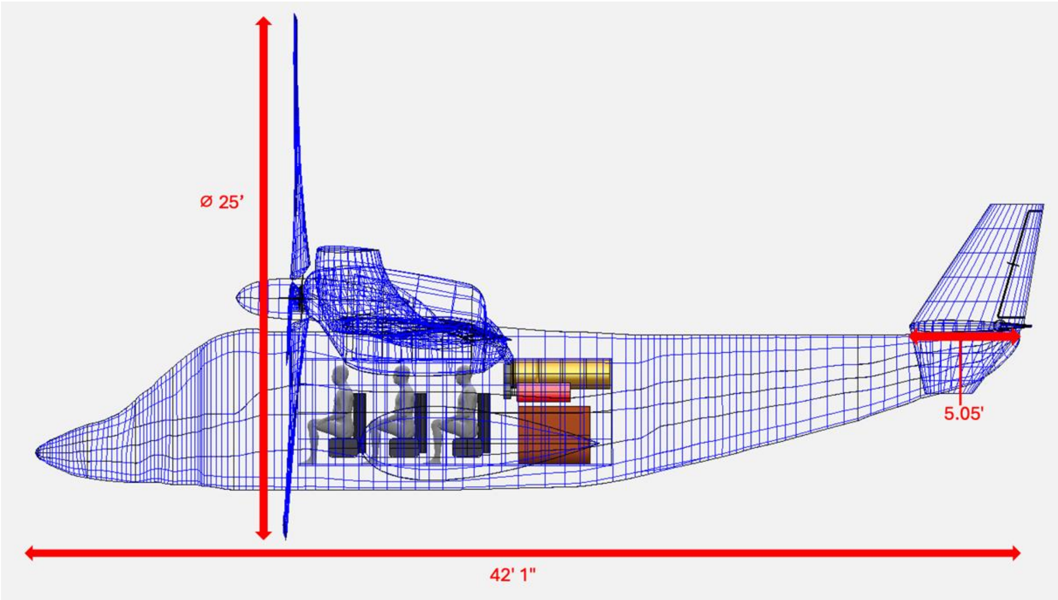


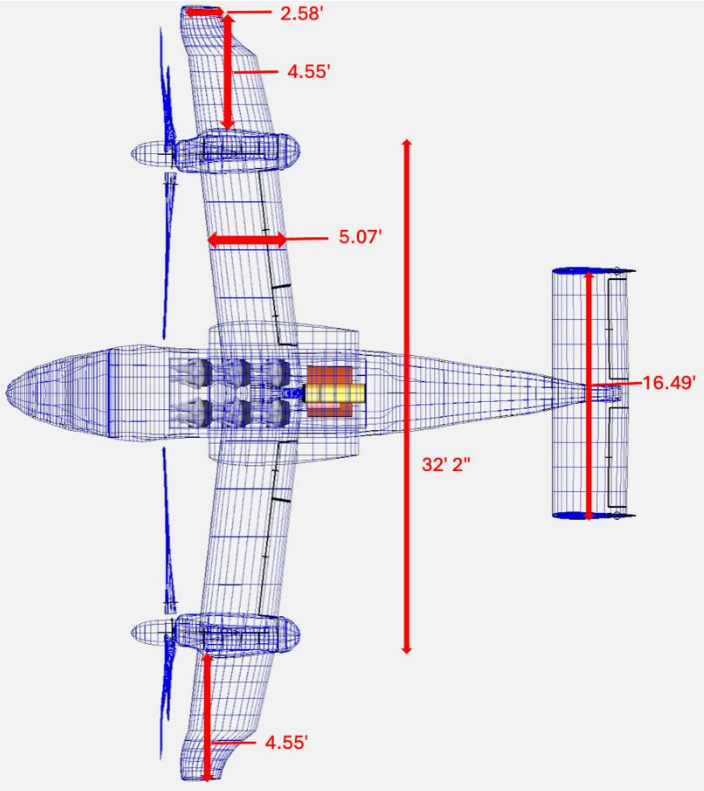
Cygnus X Drivetrain Weight Breakdown

***Baseline systems include baseline engine, fuel tanks, avionics, etc. that were not changed due to HEPS upgrade**

Results based on PSUAM performance models. Full model citations in final report.

Cygnus X Overview: Successfully Met 306-nmi range, 300-ktas Cruise Goals





Design Improvements over the Baseline XV-15:

- **Aerodynamic Improvements (30% Reduced Downloading)**
  - Kreuger Flaps
  - Active Flow Control
  - Wing Extensions
  - Swept Rotor Blades

- **Upgraded HEPS (Meets 306-nmi requirement, up 70-nmi from baseline)**
  - Third T-53 turboshaft engine
  - Four highly efficient HPDM-500 motor/generators
  - Clutch-based gear box to accompany additional components

- **Addition of Composite Materials (1700-lbf payload increase)**

[1] Maisel, M. D., Giulianetti, D. J., Dugan, D. C., "The History of The XV-15 Tilt Rotor Research Aircraft from Concept to Flight", NASA, 2000.