Executive Summary
26th Annual AHS Student Design Competition
2009 - Graduate Category

Peregrine

AgustaWestland

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Starting from a current, in-service design:

Requirements:

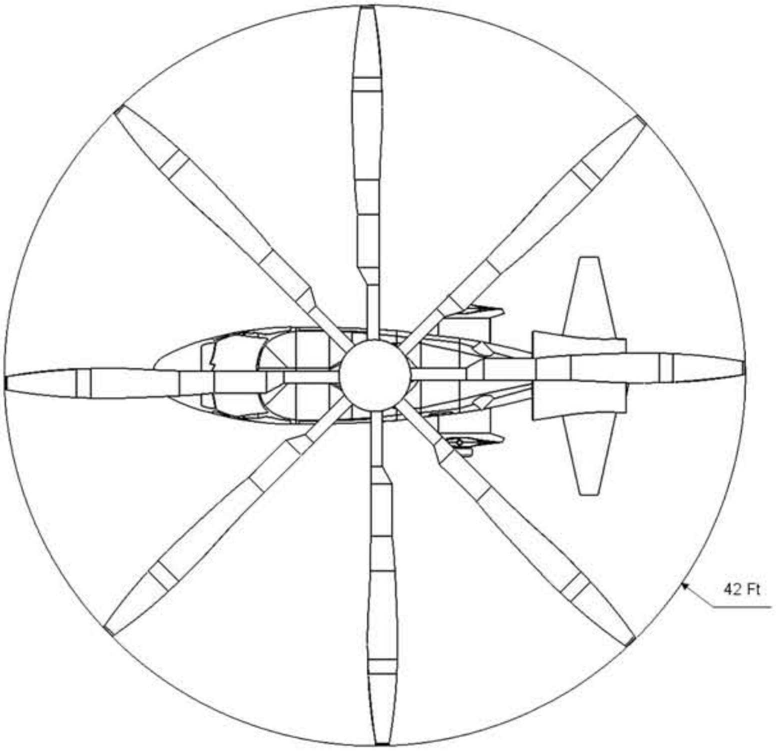
- Develop an alternative, non conventional rotor/drive system, including all necessary subsystems
- Endow the new design with improved performance in terms of speed, range, payload, endurance and noise signature
- Must add to existing technology
- Retain rotorcraft flight characteristics (hover, flight in any direction, power-off autorotations)

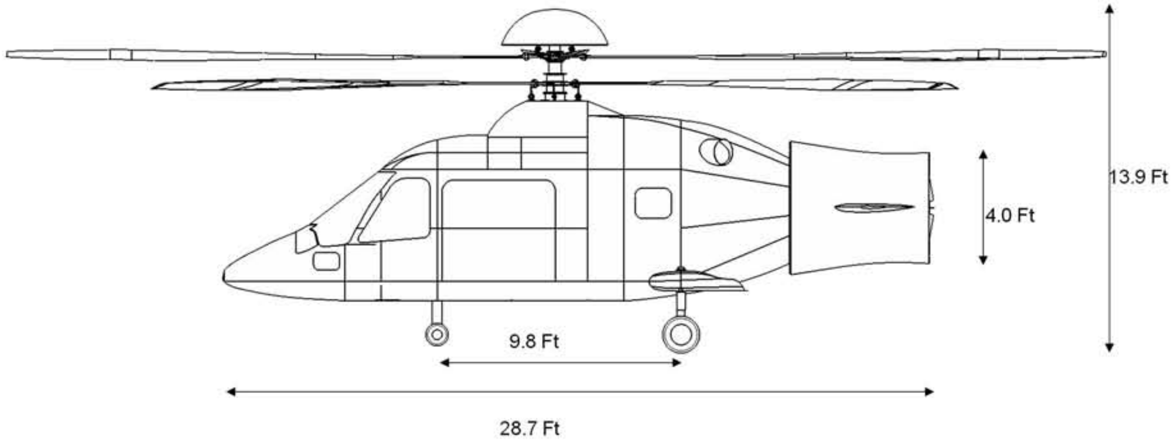
Mission: Military Utility Multi-purpose

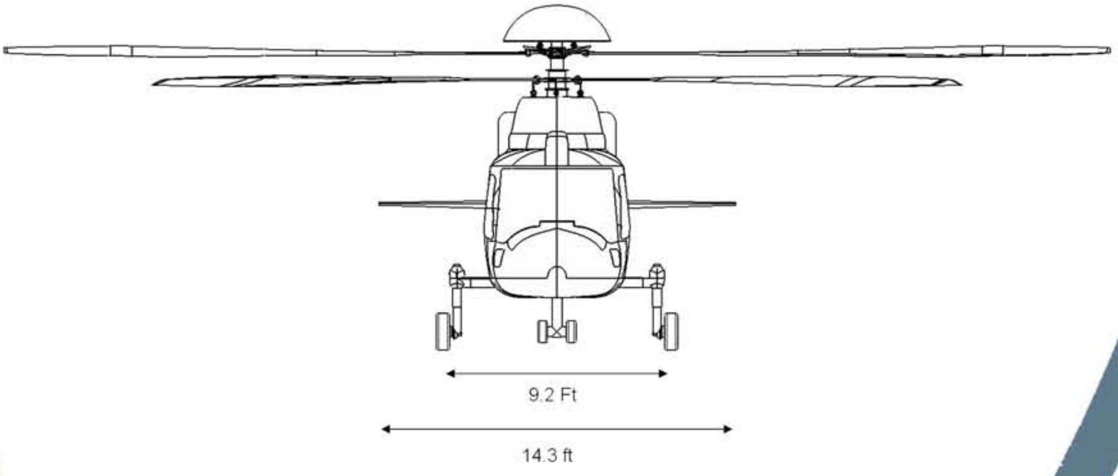
Team Design Goals:

- Increased dash speed 250 knots
- Increased cruise speed 215 knots
- Radius of action 210 nm
- Max Payload 4500 lbs
- Service Ceiling 20,000 ft
- Increased excess power ratio
- Reduced noise in hover, in-flight
- Reduced Production and Operating Costs

Peregrine Specifications







Peregrine

Empty Weight 7572 (3435 kg)
Max GW 14700 lbs (8165 kg)
GTOW 12360 lbs (5606 kg)
Payload 4500 lbs (2041 kg)
Fuel 2272 (1031kg)
Number of Seats: 8

Max Range
420 nm
(581.5 km)
Max Airspeed (IRP)
249.8 knots
(462.6 km/h)
Cruise Speed (MCP)
222.5 knots
(412.1 km/h)
Cruise Speed
Max Rng
120 knots
(222.2 km/h)
Max Endurance
2.53 hours
IRP 3100 shp
MCP 2880 shp

Rotor Radius
21 ft (6.4m)
Flat Plate Area
14.49 sq ft (1.35 sq m)
Tip Speed (Fast)
650 ft/s (198 m/s)
Tip Speed (Slow)
420 ft/s (128 m/s)
Disk Loading
9.07 lb/sq ft (434 N/sq m)
Max Service Ceiling
15,813 ft (4820 m)

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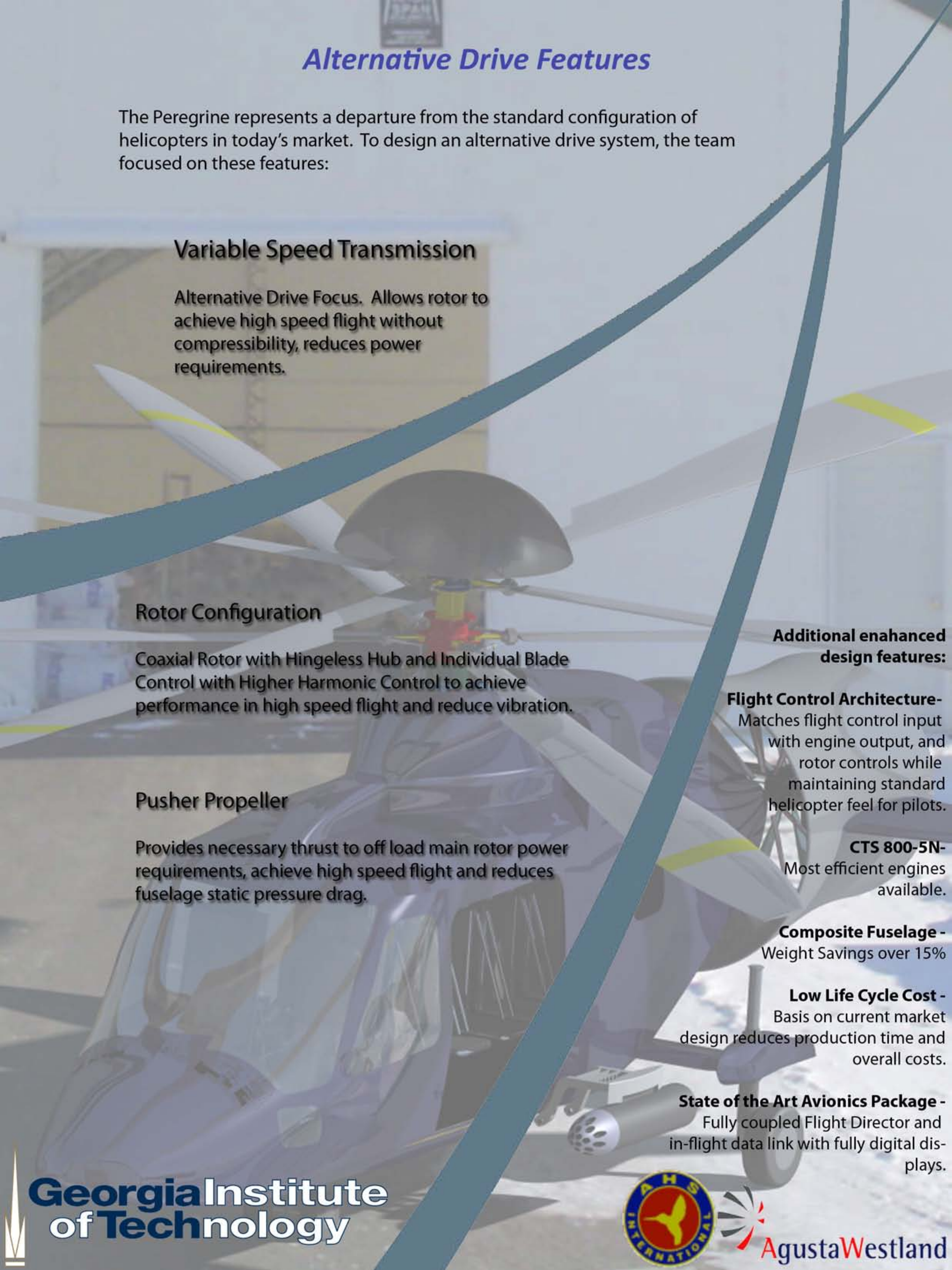

Alternative Drive Features

The Peregrine represents a departure from the standard configuration of helicopters in today's market. To design an alternative drive system, the team focused on these features:

Variable Speed Transmission

Alternative Drive Focus. Allows rotor to achieve high speed flight without compressibility, reduces power requirements.

Rotor Configuration

Coaxial Rotor with Hingeless Hub and Individual Blade Control with Higher Harmonic Control to achieve performance in high speed flight and reduce vibration.

Pusher Propeller

Provides necessary thrust to off load main rotor power requirements, achieve high speed flight and reduces fuselage static pressure drag.

Additional enahanced design features:

Flight Control Architecture- Matches flight control input with engine output, and rotor controls while maintaining standard helicopter feel for pilots.

CTS 800-5N- Most efficient engines available.

Composite Fuselage - Weight Savings over 15%

Low Life Cycle Cost - Basis on current market design reduces production time and overall costs.

State of the Art Avionics Package - Fully coupled Flight Director and in-flight data link with fully digital displays.

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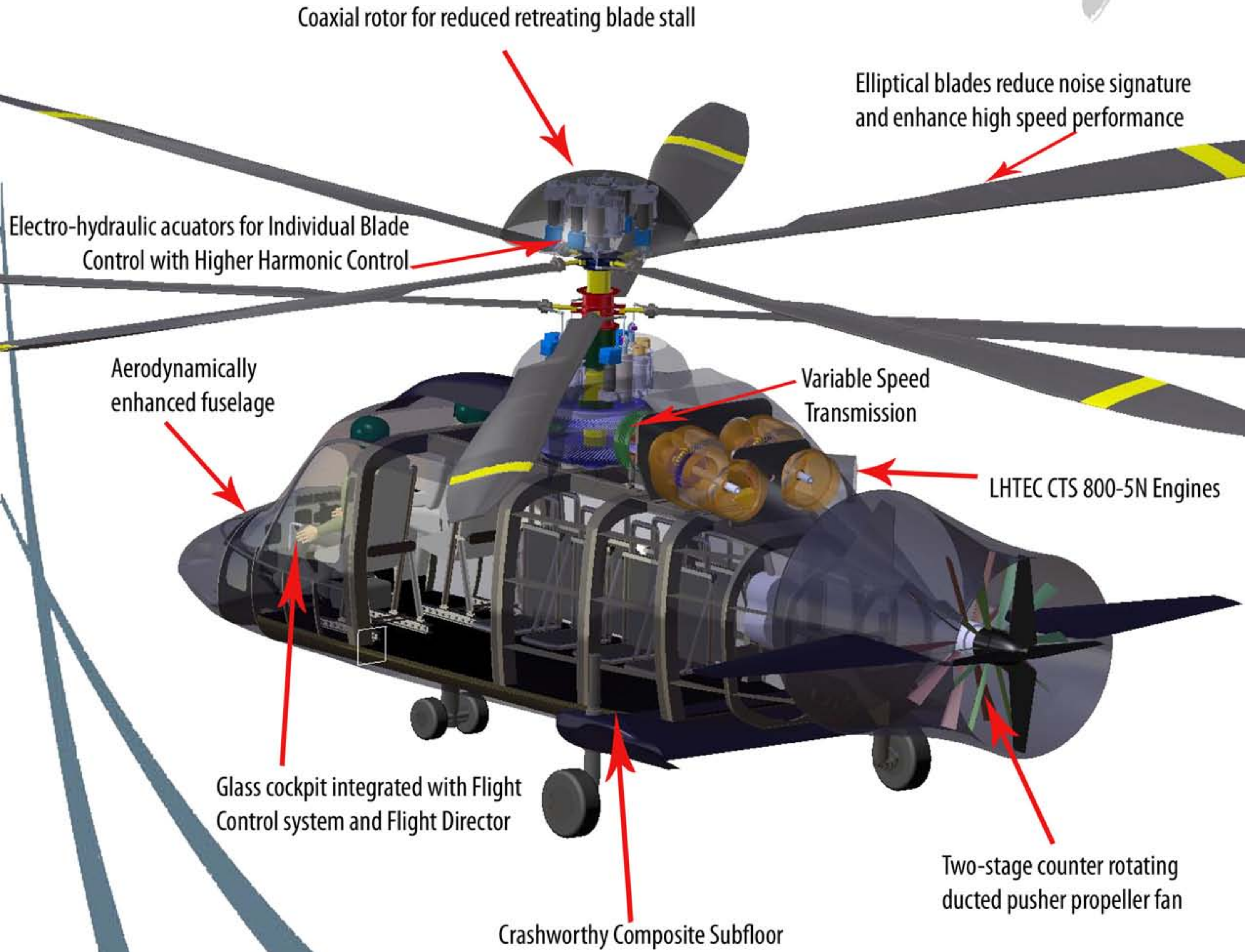
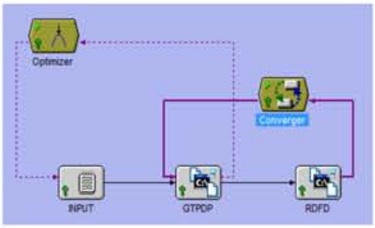
Key Features



Design of Conceptual Model

Baseline Modeling

Build the analysis environment & Validation of Baseline
1. GTPDP: Georgia Tech Preliminary Design Program
2. RDFD: Requirements-Driven Fuselage Design Program



Environment for Coupling Analyzers

Baseline:
Super Lynx 300

Coaxial Derivative

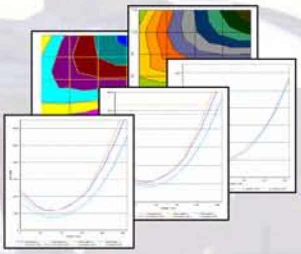
Selection of Candidates

Candidate 1
Baseline
+ Compounding

Candidate 2
Baseline
+ Compounding
+ Slowed Rotor

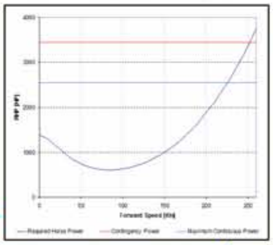
Candidate 3
Coaxial rotorcraft
+ Compounding

Candidate 4
Coaxial rotorcraft
+ Compounding
+ Slowed Rotor



Parametric Study

RHP .vs. Velocity

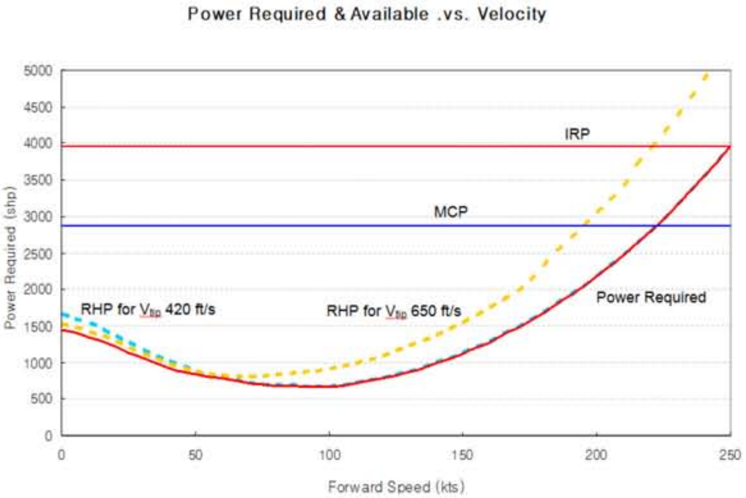


Optimization

Candidate 4:
Coaxial Rotorcraft with Compounding and Slowed Rotor
For Lighter GW, Less RHP and Fuel Consumption, Higher Flight Speed and Maneuverability

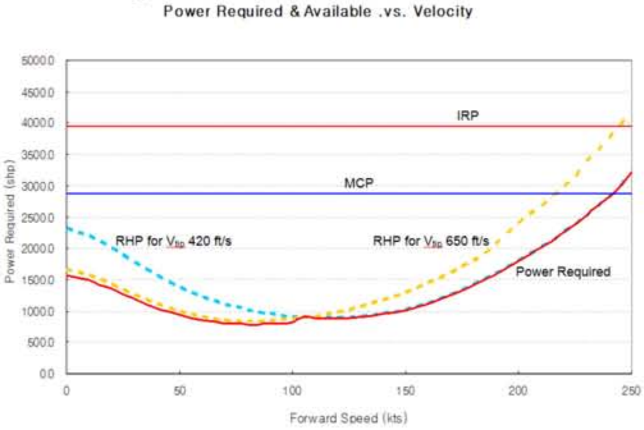
Performance Summary

- Increased performance throughout flight regime from coaxial rotor to two-speed transmission
- Increased payload without sacrificing range or fuel capacity
- AFCS schedules pusher propeller corover and power application



Max Cruise: 249.8 knots; Cruise 222.5 knots
(Flight Cond: SLS)

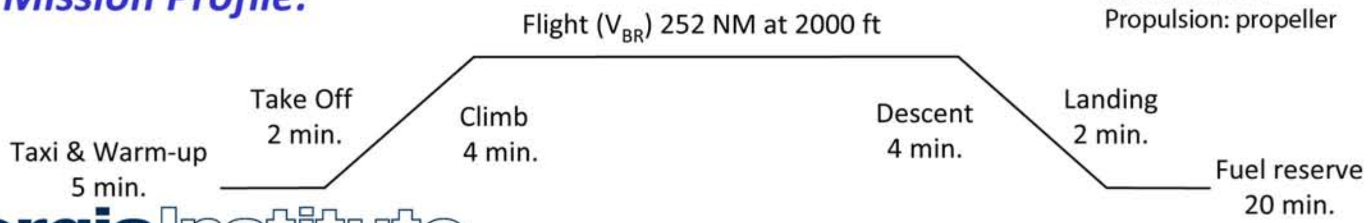
Max Speed: 225.3 knots; Cruise 185.6 knots
(Flight Cond: 5000 ft, 95 deg F)



Vel < max range
Lift: main rotor
Propulsion: main rotor

Vel > max range
Lift: main rotor
Propulsion: propeller

Mission Profile:



Flight (V_{BR}) 252 NM at 2000 ft

Taxi & Warm-up
5 min.

Take Off
2 min.

Climb
4 min.

Descent
4 min.

Landing
2 min.

Fuel reserve
20 min.

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Transmission

Bevel gear differential to ensure each rotor operates at same speed

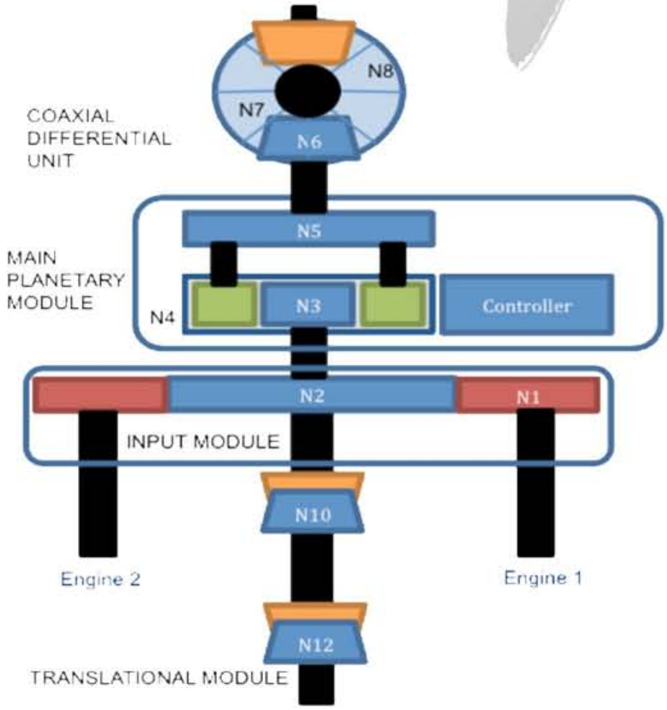
Variable Speed Control through rotation of the ring gear in the planetary gear system

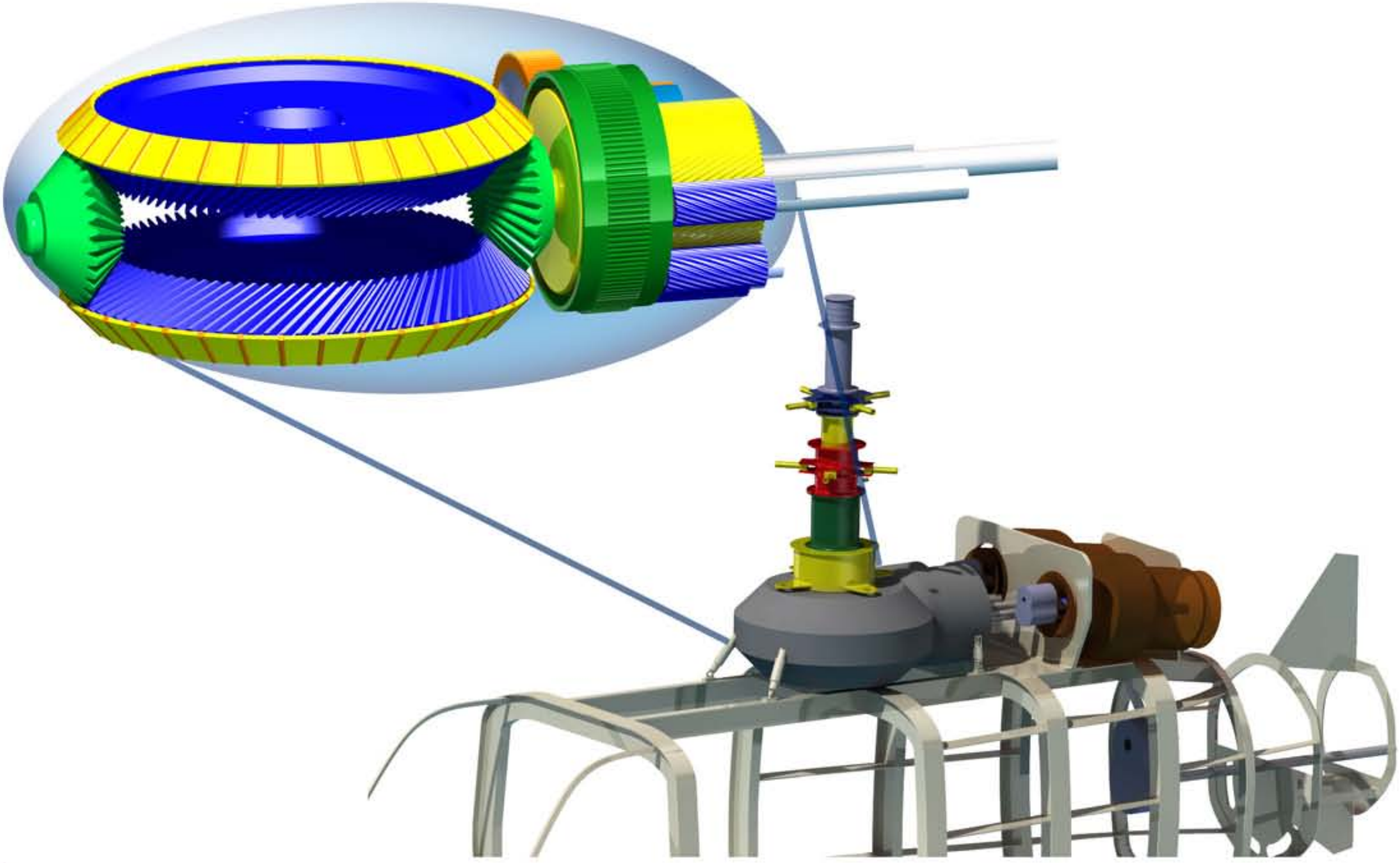
High Speed:

- 650 ft/s tip speed
- Ring gear locked

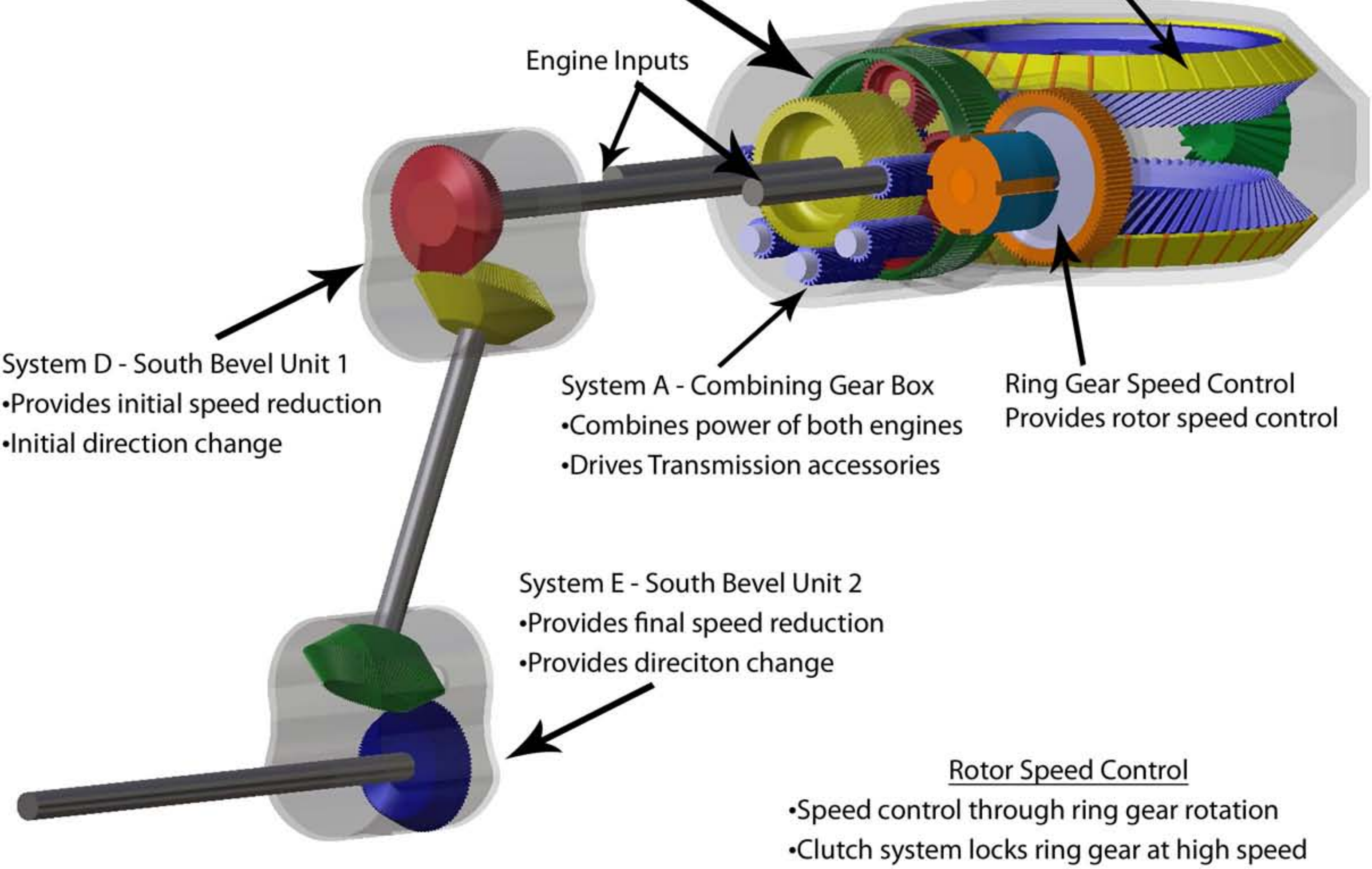
Slow Speed:

- 420 ft.s tip speed
- Ring gear at 341 rpm





Transmission Optimization



System B - Planetary Reduction Gear System
- Provides Primary Engine Reduction
- Rotor Speed controlled through ring gear speed

System C - Coaxial Differential Unit
- Provides counter rotation direction and power split
- Ensures rotor speed matching

Engine Inputs

System D - South Bevel Unit 1
- Provides initial speed reduction
- Initial direction change

System A - Combining Gear Box
- Combines power of both engines
- Drives Transmission accessories

Ring Gear Speed Control
Provides rotor speed control

System E - South Bevel Unit 2
- Provides final speed reduction
- Provides direciton change

Rotor Speed Control

- Speed control through ring gear rotation
- Clutch system locks ring gear at high speed
- AC motor powers speed control gear to spin ring gear at low speed

Gear System Optimization

Optimized with Genetic Algorithm
23 independent variables
4.598 e 34 possible cominations
Increased probability of finding gobal optimum in presennce of many local optimums

Mode	Tip Sped	Input	Output	Ring Gear Speed
High Speed	650 ft/s	Sun Gear	Planet Carrier	0 – Locked
Low Speed	400 ft/s	Sun Gear	Planet Carrier	391 RPM

Transmission Optimized Gear Parameters

System	A – Mixing Spur Gears		B- Planetary Reduction Stage			C- Rotor Drive Bevel System		D- Pusher Prop Intermediate		E- Pusher Prop gear box	
Parameter	Gear 1	Gear 2	Sun	Planets	Ring	Gear 6	Gear 7+8	Gear 9	Gear 10	Gear 11	Gear 12
Diameter (in)	2.625	10.25	4.75	5.00	14.75	10.0	30.0	9.3	10.2	9	11.9
Teeth	21	82	38	40	118	30	90	93	102	90	119
Material	Pyrowear 53	Pyrowear 53	Vasco X2M	Aisi 9310	Vasco X2M	Vasco X2M	Vasco X2M	Vasco X2M	Vasco X2m	Pyrowear 53	Vasco X2M
Face Width (in)	6.8		2.8			3.9		2.7		3.1	
Diametral Pitch (1/in)	8		8			3		10		10	
Helical Angle (deg)	25		25			25		25		25	
Gear Ratio	3.9048 : 1		4.1053 : 1			3.00 : 1		1.0968 : 1		1.3222 : 1	

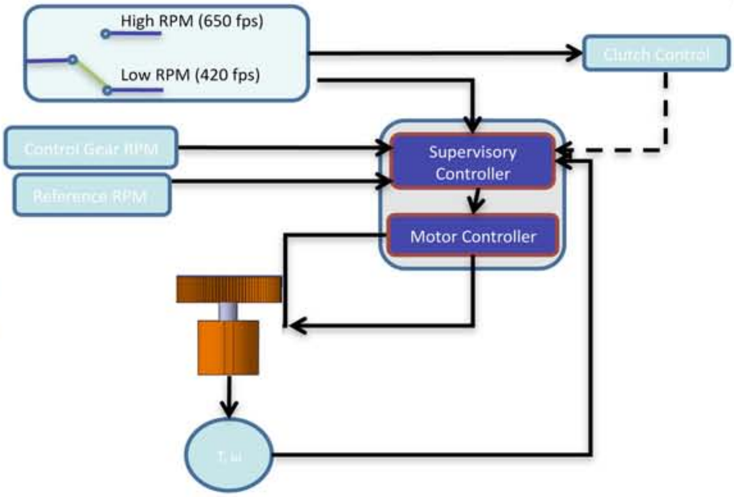
Power Electronics Module

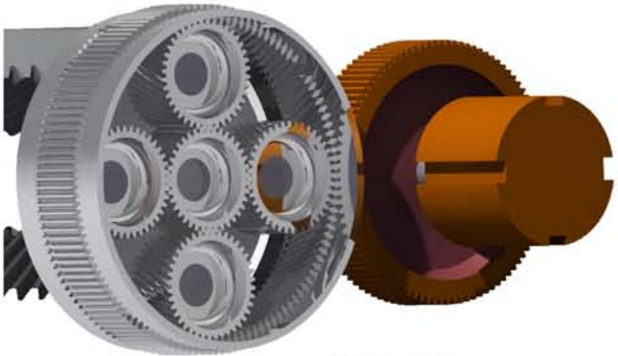
PEM : heart of the transmission control system

Controls the sequence of clutch engagement and gradual slowing of drive shaft rpm

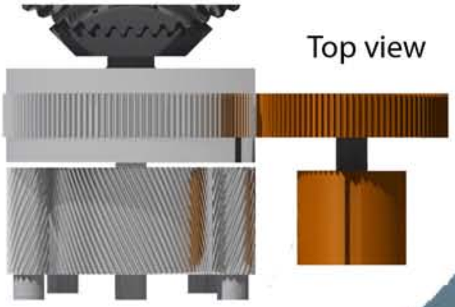
Uses contactless optical speed encoders

Translates signals into precisely timed voltages, telling the motor to respond with the proper speed, direction of rotation and torque





Rear view



Top view

PEM Monitors:
- Helicopter Electrical system voltage
- Motor rotation speed and final drive shaft speed
- Motor temperature and power electronic temperature

Electric Motor:
- 3 phase, 4 pole, 375 volt
- AC induction air cooled
- Variable frequency drive
- Maximum Power: 124 hp
- Maximum RPM: 14,000 rpm
- Weight: 70 lbs

Pusher Propfan Attributes

Ducted, constant-speed, counter-rotating, composite pusher propeller (propfan)

DESIGN METHOD:

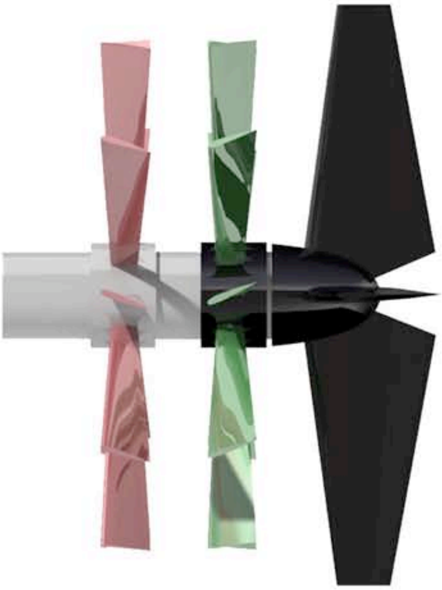
- Blade-Element MATLAB program to calculate thrust and power
- Single propfan design optimized at 215 knots (cruise) for min C_T/C_P
- Diameter constrained based on fuselage width;
- Blade root constrained for strength
- Manufacturing/cost a factor in selection
- Placed closely to fuselage to allow Goldschmied wake regeneration
- Power pulled from main CTS800-5 turbines to save weight

HORIZONTAL - NACA 2419 (Inverted)

STABILIZERS

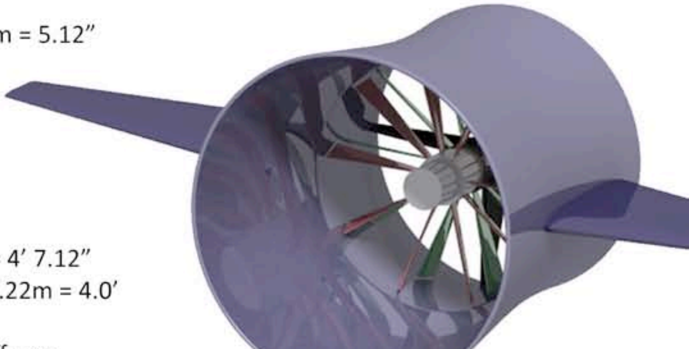
- Stabilizers placed aft of propfans to reduce required surface area and increase moment arm
- Horizontal: 0.32 m^2 stabilizer, inverted NACA 2410
- Vertical: 0.27 m^2 control surface, NACA 64A010
- Duct will have additional stabilizing effect

VERTICAL - NACA 64A010



PHYSICAL ATTRIBUTES:

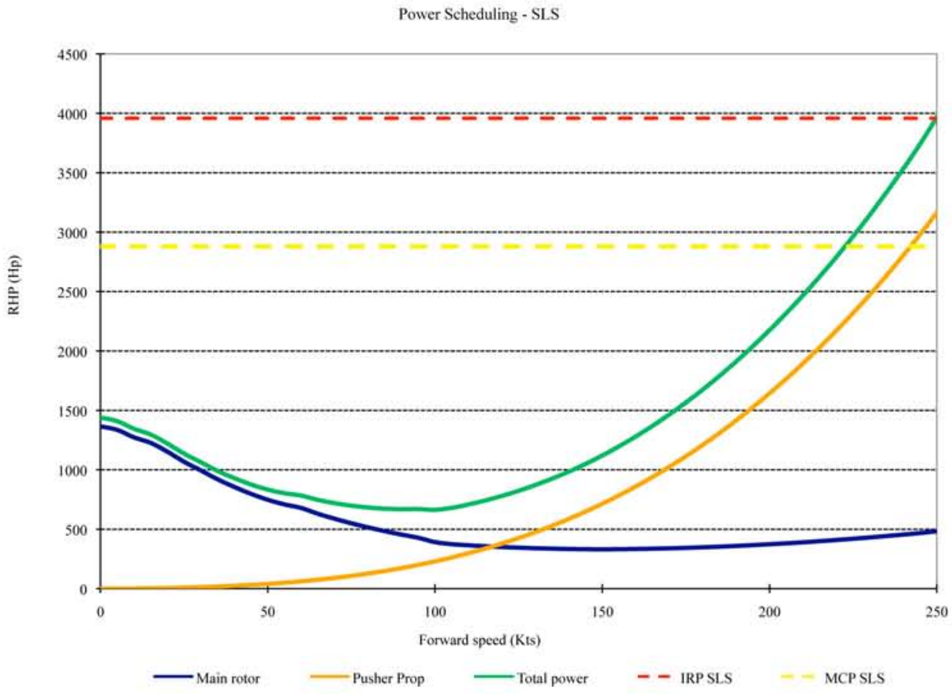
- Two 10-bladed counter-rotating fans
- Airfoil: NACA 4415
- Variable Pitch from -10° to +55°
- Operating speed: 2,500 rpm
- Fan Diameter: 1.2m = 3′ 11.25″
- Hub Diameter: 0.24m = 9.45″
- Max chord (at tip): 0.17m = 6.69″
- Min chord (at root): 0.065m = 2.56″
- Twist: linear 35° from root to tip
- Leading-edge sweep angle: +3.13°
- Solidity: 0.519
- Inter-prop spacing: 0.13m = 5.12″



DUCT ATTRIBUTES

- Outer Diameter: 1.4m = 4′ 7.12″
- Inner Diameter (min): 1.22m = 4.0′
- Length: 0.95m = 3′ 1.4″
- Aft portion serves as diffuser
  (10 degree half-angle)
- Blade tip clearance = 0.01m; 0.8% of inner duct diameter

Pusher Propfan Performance



Max Design Power (200 knots)

Advance Ratio: 2.06
Effective Tip Mach No: 0.567
At 44 degree mechanical pitch (Tip at 11 degree effective angle of attack):

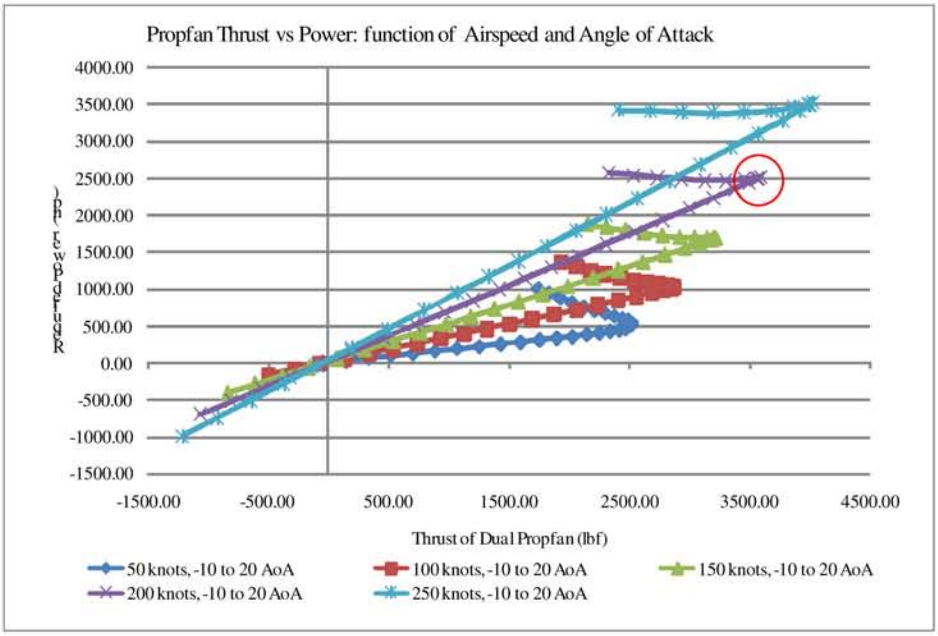
Expected Thrust of system= 3587 lbf

Expected power required= 2504 hp

Disk Loading: 295 lb/sqft

Propfan Maximum Thrust/Power

Airspeed	Advance Ratio	Thrust/Power (maximum)	Tip AoA (effective)
100	1.03	2.86	1° to 4°
150	1.54	1.92	3° to 4°
200	2.06	1.44	1° to 8°
250	2.57	1.15	0° to 11°

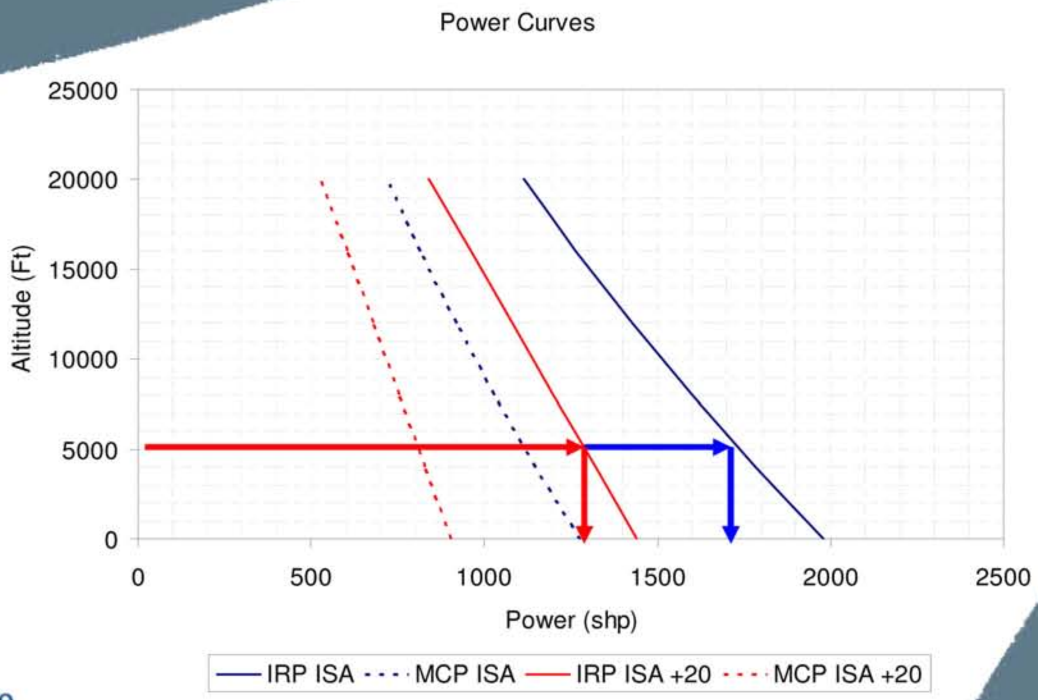


LHTEC CTS 800-5N Engines

Efficient, reliable engine was deteremined to be most resourceful method of power creation over cost of developing an entirely new, unsubstantiated model

Includes FADEC to schedule power through transmission to rotor and pusher propeller

Continued high performance at desired hot day evaluation: 5000' and 95 deg F



Performance

Sea level std., static	Minimum thermodynamic shaft horsepower	Sfc lb/shp-hr (max)
Contingency	1721	0.469
Maximum	1681	0.470
Intermediate	1550	0.473
Max. continuous	1276	0.490
4000 feet, 95°F, static		
Contingency	1269	0.488
Maximum	1232	0.491
Intermediate	1110	0.502
Max. continuous	905	0.523

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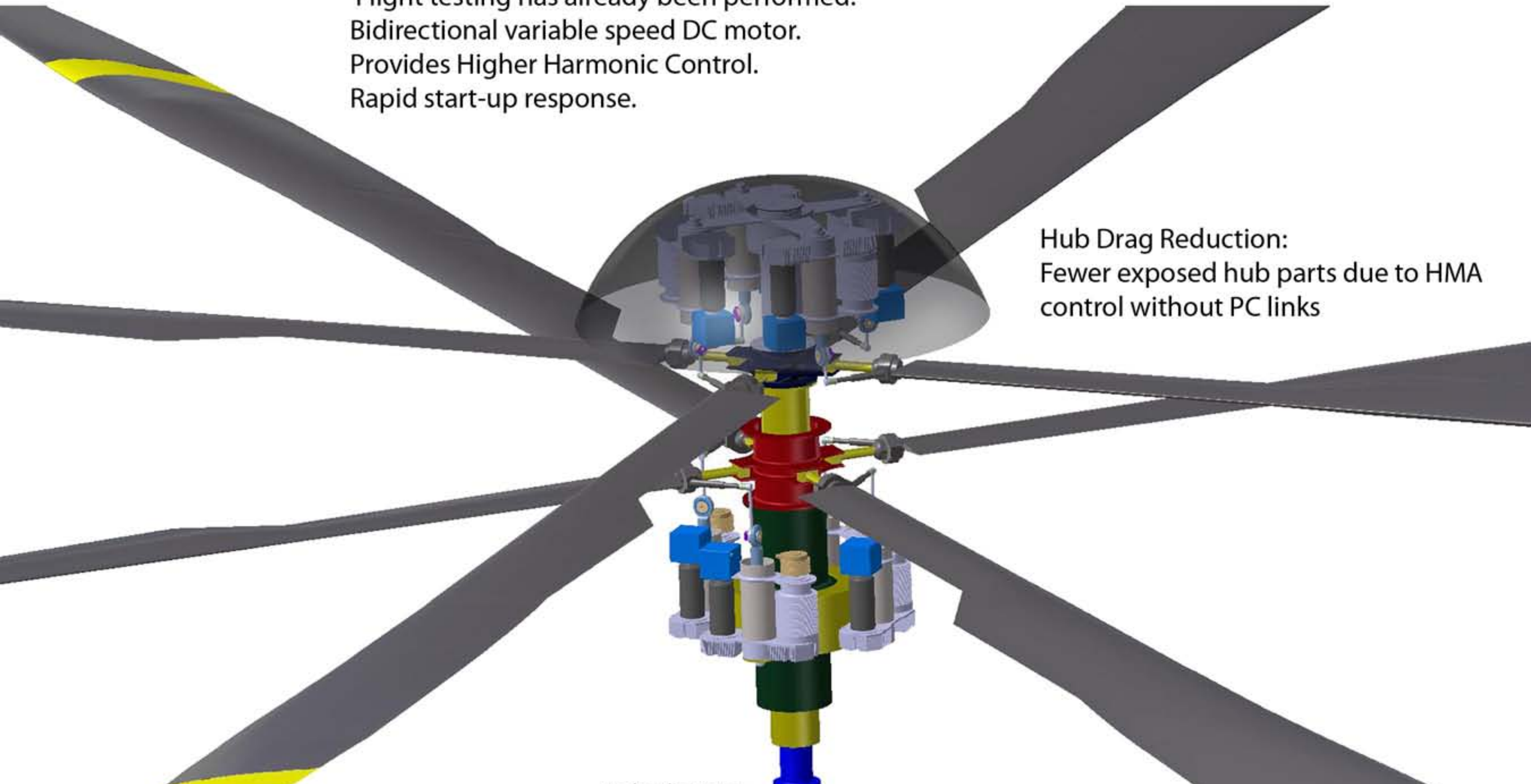
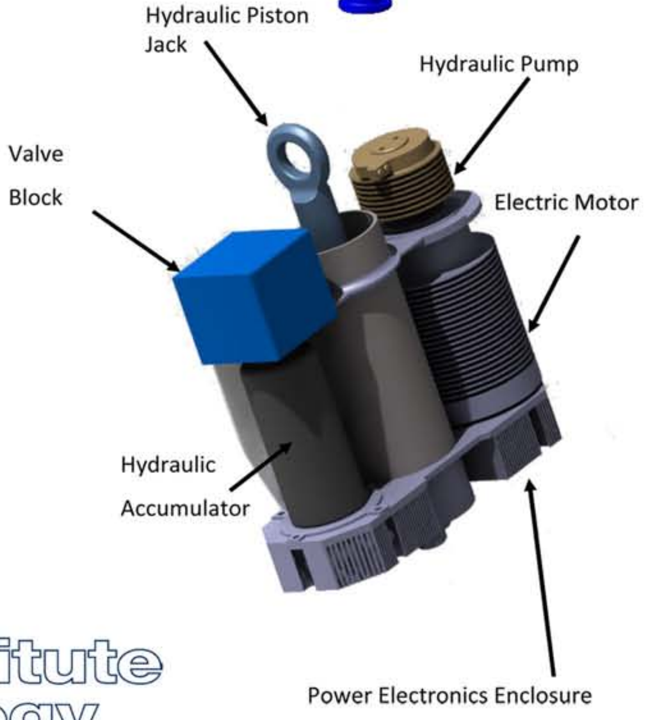
Hub and Rotor Configuration with IBC

Peregrine

Individual Blade Control (IBC) is achieved through Electro-Hydraulic Actuators.
EHA technology is completely self-contained in the actuator assembly.
Active-Standby or Active-Active modes available.
Flight testing has already been performed.
Bidirectional variable speed DC motor.
Provides Higher Harmonic Control.
Rapid start-up response.



Hub Drag Reduction:
Fewer exposed hub parts due to HMA control without PC links



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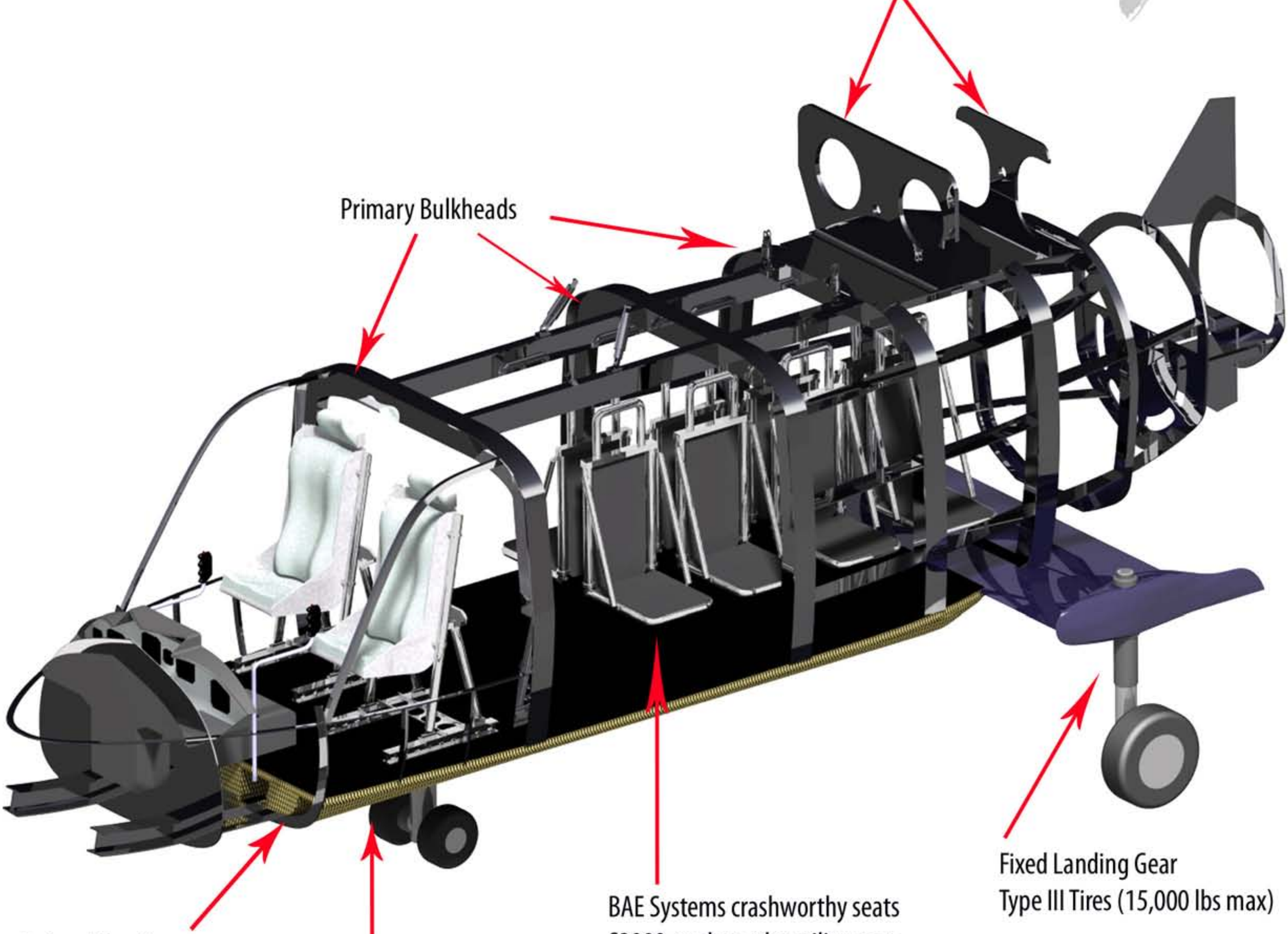
Crashworthy Airframe

Peregrine



Engine Mounts

Primary Bulkheads

Carbon Fiber frames
Carbon Nomex skin and floor
Foam Subfloor

Crashworthy Full
Composite Subfloor

BAE Systems crashworthy seats
S3000 crashworthy utility seats
S7000 energy-abosorbing crew seat
Accommodate 5th-percentile female to 95th-percentile male

Fixed Landing Gear
Type III Tires (15,000 lbs max)

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Fuselage Static Pressure Drag Reduction

Suction near trailing edge of body preserves pressure recovery.

Mitigates flow displacement and separation.

40-50% reduction in propulsive power.

Hub Drag Reduction: Flight at AoA = 0; fewer exposed hub parts due to HMA controlw without PC links

Aerodynamic Static Pressure Thrust Concept (Goldschmied, 1987)

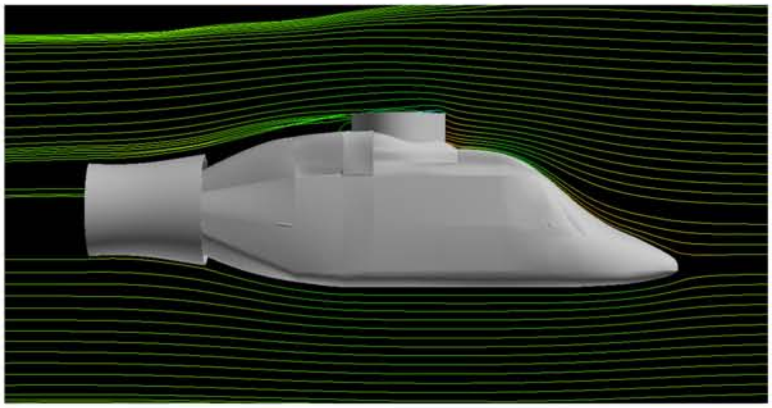
Apply the same principle investigated for axis-symetric bodies to fuselage ramp

Lynx Mk 7		
Component	f (ft^2)	%
Fuselage	6.31	30
Main Rotor Hub	7.36	35
Landing Gear (Skids)	2.10	10
Interference	1.47	7
Tail Rotor Hub	0.84	4
Empennage	0.42	2
Misc. Components	2.52	12
TOTAL	21.03 ft^2	100

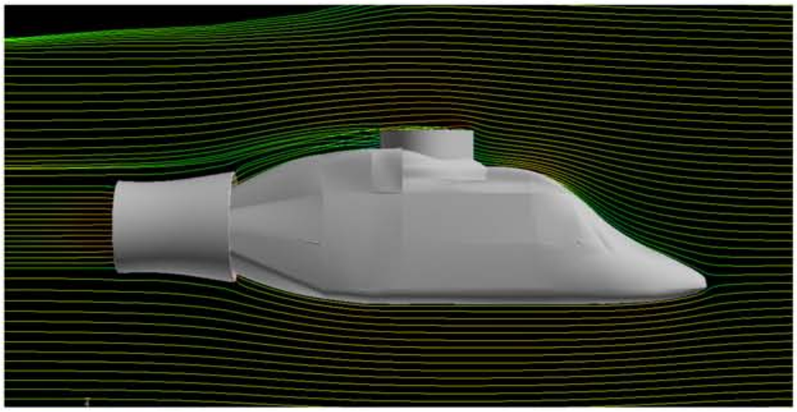
	f	C_D
No Prop	11.36 ft^2	0.064
Max Thrust	9.89 ft^2	0.059
Δf	1.47 ft^2	
% Reduction	12.9%	

Peregrine	fan off	fan engaged
Component	f (ft^2)	f (ft^2)
Airframe		
Fuselage	10.36	9.23
Fan Duct	1.00	0.66
Exhaust		
Pylon		
Sponsons		
Landing Gear		
Wheels	0.72	0.72
Struts	0.39	0.39
Hub	2.70	2.70
Hub Installation Drag	0.79	0.79
TOTAL	15.96 ft^2	14.49 ft^2

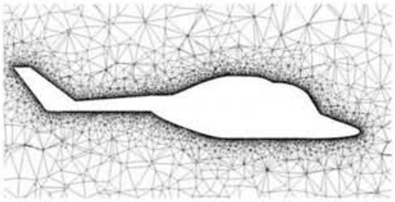
V = 100m/s, without propeller engaged



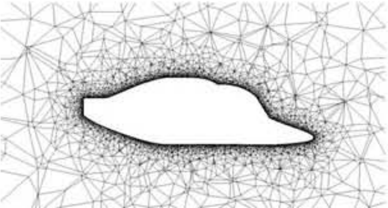
V = 100m/s, with propeller engaged



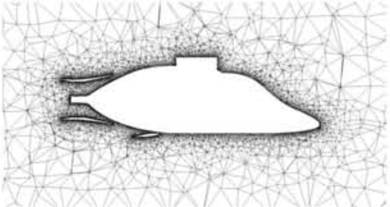
Baseline Design



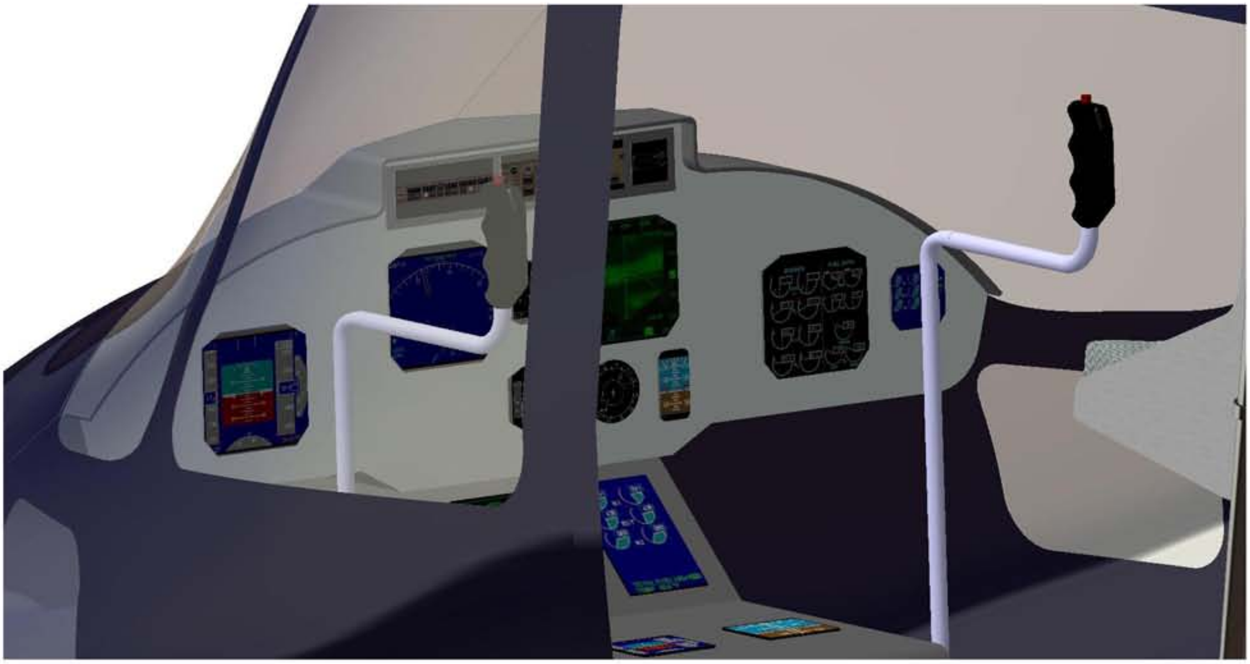
Initial Design



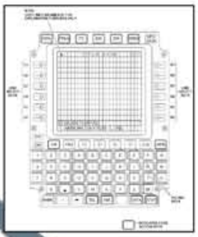
Final Design



Cockpit and Avionics



Four Multi-Function Displays (MFD):
- Management by Exception of Aircraft Systems
- Situational Awareness
- Flight Director



Two Control Display Units:
- Map control and accessible flight plans
- Data Input (Comms, Flight Path)
- Searchable airport database
- Data Link Capability
- USB data port

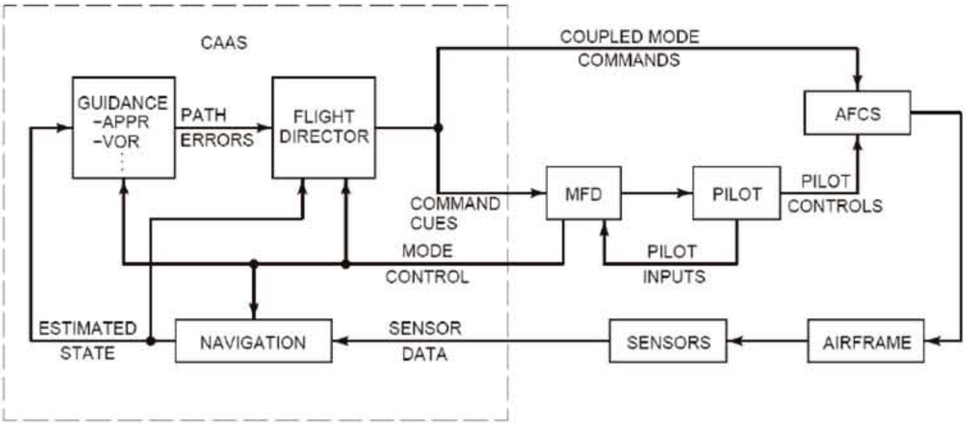
AFCS and Flight Control Architecture

Automatic Flight Control System (AFCS)

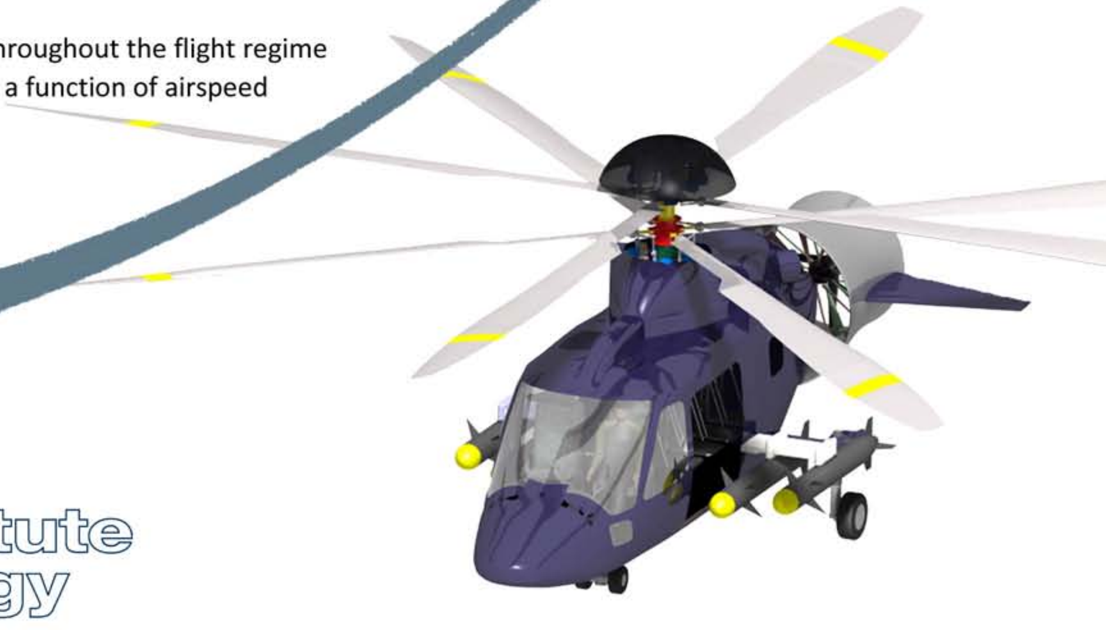
Sideslip stability
Bank angle hold
Turn coordination
Short term rate damping in pitch, roll, yaw
Pitch and roll attitude hold, and heading hold
Control response enhancement in all axis
Flight Director coupling to Cockpit Avionics

Flight Control Architecture

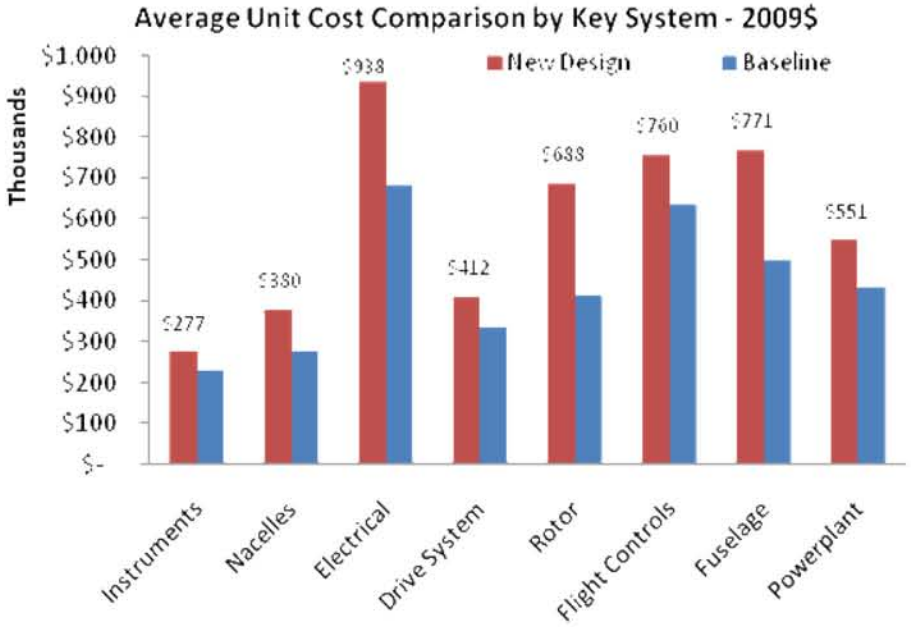
- Standard Mechanical Controls with springs and viscous dampeners for pilot inputs to LVDTs
- Fly-by-wire system to Roll Ring Transfer assembly
- Electrical inputs from Roll Ring to EHA
- Individual blade control allows some control of higher frequencies for vibrations control



Positive longitudinal stick gradient throughout the flight regime
Automatic longitudinal cyclic trim as a function of airspeed



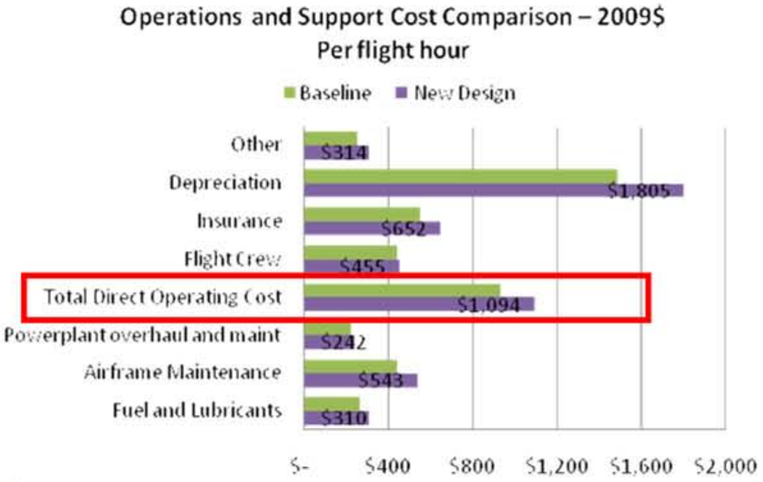
Cost Analysis

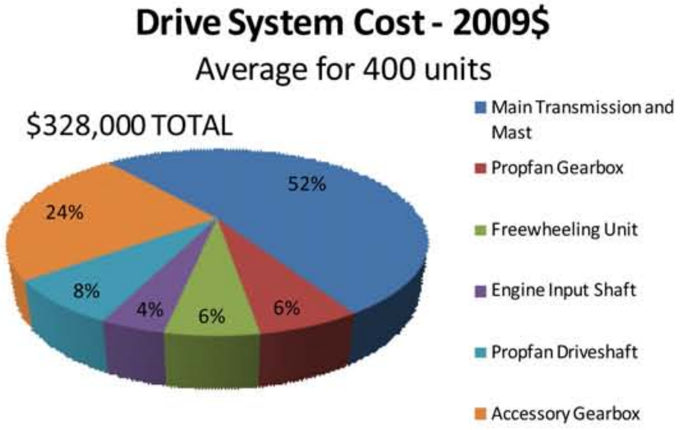


Recurring Cost: **$6.16 Million w/o profit (2009$)**
Bell PC Cost Model for aircraft; with amortized non-recurring cost and profit: $8.06 Million (2009$)

Direct Operating Cost: **$1,094 / FH (2009$)**
Bell Operating and Support Cost Model; 17% increase over baseline vehicle

Drive System Cost: **$328,000 (2009$)**
Bell PC Cost and Price H Relationships; 1,048 lb system total
Estimated average of production for 400 units; 2,920 Man hours for production and assembly





Customer Benefits

The Peregrine is an alternative drive system based on the Agusta Westland Super Lynx 300 that can achieve high speed flight while increasing payload, range, endurance and noise signature. To make these improvements, the aircraft uses:

- Alternative drive variable speed transmission
- Nonconventional ducted pusher propeller fan
- Alternative coaxial rotor hub design with individual blade control for vibration control and noise reduction
- Elliptical blade planform design

These alternatives to conventional systems make a superior aircraft capable of increased performance, safety and maintenance reliability.