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

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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)

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

Empty Weight 7572 (3435 kg)
Max GW 14700 lbs (8165 kg)
GTOW 12360 lbs (5606 kg)
Payload 4500 lbs (2041 kg)
Fuel 2272 (1031 kg)
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)
Max Endurance
2.53 hours
IRP 3100 shp
MCP 2880 shp

Rotor Radius
21 ft (6.4 m)
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)
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 enhanced 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.
Key Features

- Coaxial rotor for reduced retreating blade stall
- Elliptical blades reduce noise signature and enhance high speed performance
- Electro-hydraulic actuators for Individual Blade Control with Higher Harmonic Control
- Aerodynamically enhanced fuselage
- Variable Speed Transmission
- LHTEC CTS 800-5N Engines
- Glass cockpit integrated with Flight Control system and Flight Director
- Crashworthy Composite Subfloor
- Two-stage counter rotating ducted pusher propeller fan
Design of Conceptual Model

Baseline Modeling

1. GTDPD: Georgia Tech Preliminary Design Program
2. RDFD: Requirements-Driven Fuselage Design Program

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

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)

Mission Profile:
- Flight (VBR) 252 NM at 2000 ft
- Take Off 2 min.
- Climb 4 min.
- Descent 4 min.
- Landing 2 min.
- Fuel reserve 20 min.

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

Bevel gear differential to ensure each rotor operates at the 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

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

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

Ring Gear Speed Control
- Provides rotor speed control

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 x 34 possible combinations
Increased probability of finding global optimum in presence of many local optimaums

<table>
<thead>
<tr>
<th>Mode</th>
<th>Tip Speed (ft/s)</th>
<th>Input</th>
<th>Output</th>
<th>Ring Gear Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Speed</td>
<td>650</td>
<td>Sun Gear</td>
<td>Planet Carrier</td>
<td>0 – Locked</td>
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<tr>
<td>Low Speed</td>
<td>400</td>
<td>Sun Gear</td>
<td>Planet Carrier</td>
<td>391 RPM</td>
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</table>

<table>
<thead>
<tr>
<th>System</th>
<th>A - Mixing Spur Gears</th>
<th>B - Planetary Reduction Stage</th>
<th>C - Rotor Drive Bevel System</th>
<th>D - Pusher Prop Intermediate</th>
<th>E - Pusher Prop gear box</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>Gear 1</td>
<td>Gear 2</td>
<td>Sun</td>
<td>Planets</td>
<td>Ring</td>
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<tr>
<td>Diameter (in)</td>
<td>2.625</td>
<td>10.25</td>
<td>4.75</td>
<td>5.00</td>
<td>14.75</td>
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<tr>
<td>Teeth</td>
<td>21</td>
<td>82</td>
<td>38</td>
<td>40</td>
<td>118</td>
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<tr>
<td>Material</td>
<td>Pyrowear 53</td>
<td>Pyrowear 53</td>
<td>Vasco X2M</td>
<td>Aisi 9310</td>
<td>Vasco X2M</td>
</tr>
<tr>
<td>Face Width (in)</td>
<td>6.8</td>
<td>2.8</td>
<td>3.9</td>
<td>2.7</td>
<td>3.1</td>
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<tr>
<td>Diametral Pitch (1/in)</td>
<td>8</td>
<td>8</td>
<td>3</td>
<td>10</td>
<td>10</td>
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<tr>
<td>Helical Angle (deg)</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Gear Ratio</td>
<td>3.9048 : 1</td>
<td>4.1053 : 1</td>
<td>3.00 : 1</td>
<td>1.0968 : 1</td>
<td>1.3222 : 1</td>
</tr>
</tbody>
</table>
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

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 m² stabilizer, inverted NACA 2410
- Vertical: 0.27 m² 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: 1.2 m = 3’ 11.25”
- Hub Diameter: 0.24 m = 9.45”
- Max chord (at tip): 0.17 m = 6.69”
- Min chord (at root): 0.065 m = 2.56”
- Twist: linear 35° from root to tip
- Leading-edge sweep angle: +3.13°
- Solidity: 0.519
- Inter-prop spacing: 0.13 m = 5.12”

**DUCT ATTRIBUTES**
- Outer Diameter: 1.4 m = 4’ 7.12”
- Inner Diameter (min): 1.22 m = 4.0’
- Length: 0.95 m = 3’ 1.4”
- Aft portion serves as diffuser (10 degree half-angle)
- Blade tip clearance = 0.01 m; 0.8% of inner duct diameter
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
LHTEC CTS 800-5N Engines

Efficient, reliable engine was determined 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

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**Power Curves**

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**Performance**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Minimum thermodynamic shaft horsepower</th>
<th>Sfc (lb/shp-hr) (max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contingency</td>
<td>1721</td>
<td>0.469</td>
</tr>
<tr>
<td>Maximum</td>
<td>1681</td>
<td>0.470</td>
</tr>
<tr>
<td>Intermediate</td>
<td>1550</td>
<td>0.473</td>
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<tr>
<td>Max. continuous</td>
<td>1276</td>
<td>0.490</td>
</tr>
<tr>
<td>4000 feet, 95°F, static</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contingency</td>
<td>1269</td>
<td>0.488</td>
</tr>
<tr>
<td>Maximum</td>
<td>1232</td>
<td>0.491</td>
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<tr>
<td>Intermediate</td>
<td>1110</td>
<td>0.502</td>
</tr>
<tr>
<td>Max. continuous</td>
<td>905</td>
<td>0.523</td>
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</table>
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.
Crashworthy Airframe

- Engine Mounts
- Primary Bulkheads
- Fixed Landing Gear
- Type III Tires (15,000 lbs max)

- Carbon Fiber frames
- Carbon Nomex skin and floor
- Foam Subfloor
- Crashworthy Full Composite Subfloor
- BAE Systems crashworthy seats
- S3000 crashworthy utility seats
- S7000 energy-absorbing crew seat
- Accommodate 5th-percentile female to 95th-percentile male

Georgia Institute of Technology

AgustaWestland
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 control without PC links

<table>
<thead>
<tr>
<th></th>
<th>$f$ (ft$^2$)</th>
<th>$C_D$</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Prop</td>
<td>11.36</td>
<td>0.064</td>
</tr>
<tr>
<td>Max Thrust</td>
<td>9.89</td>
<td>0.059</td>
</tr>
<tr>
<td>$\Delta f$</td>
<td>1.47</td>
<td></td>
</tr>
<tr>
<td>% Reduction</td>
<td>12.9%</td>
<td></td>
</tr>
</tbody>
</table>

Aerodynamic Static Pressure Thrust Concept (Goldschmied, 1987)

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

<table>
<thead>
<tr>
<th>Lynx Mk 7</th>
<th>$f$ (ft$^2$)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuselage</td>
<td>6.31</td>
<td>30</td>
</tr>
<tr>
<td>Main Rotor Hub</td>
<td>7.36</td>
<td>35</td>
</tr>
<tr>
<td>Landing Gear (Skids)</td>
<td>2.10</td>
<td>10</td>
</tr>
<tr>
<td>Interference</td>
<td>1.47</td>
<td>7</td>
</tr>
<tr>
<td>Tail Rotor Hub</td>
<td>0.84</td>
<td>4</td>
</tr>
<tr>
<td>Empennage</td>
<td>0.42</td>
<td>2</td>
</tr>
<tr>
<td>Misc. Components</td>
<td>2.52</td>
<td>12</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>21.03 ft$^2$</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

V = 100m/s, without propeller engaged

<table>
<thead>
<tr>
<th>Peregrine</th>
<th>fan off</th>
<th>fan engaged</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component</td>
<td>$f$ (ft$^2$)</td>
<td>$f$ (ft$^2$)</td>
</tr>
<tr>
<td>Airframe</td>
<td>15.96</td>
<td>14.49</td>
</tr>
<tr>
<td>Fuselage</td>
<td>10.36</td>
<td>9.23</td>
</tr>
<tr>
<td>Fan Duct</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exhaust</td>
<td>1.00</td>
<td>0.66</td>
</tr>
<tr>
<td>Pylon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sponsons</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landing Gear</td>
<td>0.72</td>
<td>0.72</td>
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<tr>
<td>Struts</td>
<td>0.39</td>
<td>0.39</td>
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<tr>
<td>Hub</td>
<td>2.70</td>
<td>2.70</td>
</tr>
<tr>
<td>Hub Installation Drag</td>
<td>0.79</td>
<td>0.79</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>15.96 ft$^2$</strong></td>
<td><strong>14.49 ft$^2$</strong></td>
</tr>
</tbody>
</table>

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

Average Unit Cost Comparison by Key System - 2009$

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

Drive System Cost - 2009$
Average for 400 units

$328,000 TOTAL
24%
8%
4%
6%
6%
52%
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.