GRIFFIN

Introduction

Tragedy has struck islands in the South Pacific. A tsunami of epic proportions has left thousands without basic necessities and challenges their very survival. Maritime vessels from allied nations immediately deploy, but only those with embarked aviation assets possess the capability of rendering effective humanitarian assistance to the survivors. Luckily, *Griffin* is onboard a number of the first responders' ships. The range and high speed of this advanced rotorcraft permit it to launch and arrive on scene before any other vertical takeoff platforms. Its extended endurance enable it to remain on station longer than all other search and rescue helicopters, and its expansive payload capability increases the effective reach of the responders. The *Griffin*'s reduced noise signature minimizes the obtrusiveness of 24-hour recovery efforts. While such a catastrophe is not without precedent, the capability of those assets relying on the *Griffin* most certainly is. This quantum leap in rotorcraft performance is powered by the innovative rotor system and drivetrain at the heart of the *Griffin*.

The Griffin: Part Lion, Part Eagle, All Performance

The griffin is the legendary creature traditionally portrayed as a fantastic hybrid of a lion and an eagle. In heraldry, griffins symbolize strength and courage. Though their portrayal in literature is diverse, griffins are most often depicted as guardians of treasure. The *Griffin* is thus aptly named, as it too is a hybrid of seemingly disparate entities working to power the whole system. *Griffin*'s innovative rotor system and variable energy drivetrain combine to propel it to unparalled performance. The *Griffin* exemplifies innovative engineering just as the mythological creature embraces its unique, non-conventional nature. Moreover, the *Griffin* serves as a true guardian by rendering priceless rotorcraft assistance to those in need during their darkest hour.

Concept Design

In response to the 2009 AHS Student Design Competition Request for Proposal (RFP) for a non-conventional rotor/drive system, a team from the University of Maryland consisting of seven graduate students — one of whom is a military rotary-wing aviator — was assembled to develop the skills required for successful helicopter design. Their individual specialties included aerodynamics, aeromechanics, acoustics, crash safety, and flight test. To most effectively design a helicopter, these graduate students enrolled in a one-semester Helicopter Design course, ENAE 634. This formal education, coupled with the students' technical specializations and the pilot's extensive operational experience accrued from over 1000 flight hours, culminated in the *Griffin* and its VERITAS: Variable Energy Rotor and Innovative Transmission ArchitectureS. All claims are substantiated by in-house design analyses which were extensively tested and verified with existing data wherever possible to ensure realistic analysis and, ultimately, physical meaning. The primary design method is a comprehensive coupled computer code that incorporates Tishchenko sizing and blade element performance predictions. The illustrations of the *Griffin* and its components were generated from a variety of computer-aided design applications including CATIA, Pro/ENGINEER, and SolidWorks.

The critical technical parameters of improved speed, range, endurance, payload, and noise signature detailed in the RFP drove selection of the *Griffin*'s primary mission. Humanitarian assistance missions typically require helicopters to launch from air-capable ships, transit expeditiously to an assigned location, deliver or retrieve a payload, and rapidly recover for subsequent tasking. The advanced performance required by the RFP — and the need for the proposed vehicle to retain the hallmark capabilities of a helicopter — are those same improvements needed to increase the ability of rotorcraft to render effective humanitarian assistance. The *Griffin* carries a greater payload over longer distances in shorter time than comparable light utility rotorcraft, and offers extended flight endurance with a minimal noise signature.

The VERITAS of *Griffin* emerged from careful analysis of numerous potential vehicle architectures in light of the following five criteria derived from either the RFP or the AHS Response to RFP Questions:

- ✓ Any potential architecture must empower the aircraft to better achieve the representative mission of humanitarian aid delivery. For the *Griffin*, these critical performance areas are its payload, speed, range, and endurance.
- ✓ Performance increases should not only be limited to those critical areas necessary for the helicopter's primary mission. Any potential architecture must endow *Griffin* with increased speed, range, payload, endurance, and noise signature to improve its overall utility.
- ✓ The proposed rotorcraft must be a derivative of an existing in-service helicopter. To maintain its derivative nature, structural modifications should be limited to those required to support integration of the advanced rotor/drive system.
- ✓ Feasibility, producibility, and maintainability must be key discriminators when examining potential architectures from an engineering perspective. These design drivers arose from the need to meet the required Initial Operational Capability of 2015.
- ✓ Though innovation must be considered at every design level of a potential architecture, increased performance — particularly as a payload delivery vehicle — must outweigh non-conventional solutions. That is, innovation must improve the capability of the derivative rotorcraft and should not be implemented simply for the sake of innovation.

The selection of an in-service helicopter and its existing architecture, from which a derivative rotorcraft and its non-conventional rotor system and drivetrain are designed, is not trivial. Indeed, the baseline aircraft bounds the possible missions of its derivatives and has traditionally dictated the rotor/drive system enabling mission completion. Among helicopters within the 3- to 5-ton weight class, the Eurocopter EC145 was selected as the baseline rotorcraft. It is a leader among light twin-engine utility helicopters and currently employed in a wide variety of roles, including search and rescue, civil transport, and para-military operations. The primary mission of the EC145 ultimately remains, however, payload delivery. Its commercial success lies in its class-leading productivity and impressive payload delivery efficiency. Nevertheless, the physical limitations that restrict the performance of all conventional helicopters affect the EC145. These phenomena ultimately prevent it from reaching across the capability gap between rotary- and fixed-wing aircraft to offer truly remarkable performance. The *Griffin*, however, not only improves upon the most capable rotorcraft in this weight class, but its innovative rotor system and drivetrain empowers the advanced rotorcraft to bridge the performance divide previously thought too expansive. Moreover, it retains the hallmark performance of rotorcraft: vertical takeoff and landing, omni-directional flight, and autorotational capability for safety.

Considering the application of the RFP requirements and derived criteria to the chosen baseline aircraft within its primary role, the VERITAS of *Griffin* emerged as the non-conventional rotor system and drivetrain best suited to enhancing payload delivery capability. From a technical viewpoint, VERITAS is an optimally-reduced rotational speed, thrust compounding rotor and drive system. The rotor system incorporates advanced rotor blades with Thinned Anhedral Lift-Optimized Notched (TALON) blade tips and trailing edge flaps for vibration suppression. The thrust-compounding tail prop swivels to provide anti-torque in low-speed flight regimes. Through automated engine modulation and transmission gear reduction, VERITAS lowers the main rotor speed in a manner that optimizes the associated power reduction while maintaining safe rotor stall margin. The thrust compounding tail prop amplifies this effect at higher forward flight speeds with an automatic swiveling schedule that enables the main rotor to operate at progressively lower thrust levels. This simultaneously decreases *Griffin*'s acoustic signature and the main rotor's profile power. As such, the *Griffin* operates at its optimal capability throughout the flight envelope and enables a quantum leap in performance over all helicopters in the weight class. *Griffin* is the multi-mission rotary wing platform of the future — capable of carrying a greater payload over longer distances in shorter time than traditional light helicopters — while offering extended flight endurance and minimal external noise.

Performance

VERITAS is designed to maximize the *Griffin*'s payload delivery capability. The complimentary benefits offered by rotor speed reduction and thrust compounding optimize the energy use of the *Griffin* in all flight regimes without sacrificing any capability inherent in the EC145. In fact, the VERITAS of *Griffin* maximizes the range and endurance of the advanced rotorcraft, while significantly improving its speed and payload, and minimizing its acoustic signature.

- ✓ **Faster**: With a maximum speed of 176 knots, *Griffin* sprints 26 knots faster than the baseline aircraft, permitting greater payload delivery in less time than the EC145.
- ✓ **Stronger**: Superior strength-to-weight material advancements endow *Griffin* with a 90 lbs improvement in payload capability over the EC145.

- ✓ **Farther**: *Griffin*'s maximum range is 64% greater than the EC145, allowing the helicopter to impact previously inaccessible regions.
- ✓ **Longer**: With a maximum endurance of 7 hours and 24 minutes, the *Griffin* soars 76% longer than the EC145.
- ✓ **Quieter:** Lower main rotor blade tip speeds reduce the size of *Griffin*'s noise footprint by up to 85%, significantly reducing its environmental impact.
- ✓ **Safer**: *Griffin*'s advanced rotor system retains nearly an identical autorotational index as the baseline EC145, maintaining its industry-leading safety rating.
- ✓ **Greener**: *Griffin* consumes 50% less power and 17% less fuel per flight hour than the EC145, vaulting it to the top of an increasingly energy-sensitive marketplace.

Core Features

The *Griffin* implements an extensive array of innovative technologies designed to optimize its capability. The technical, developmental, and flight safety risks associated with adoption of advanced technology has been minimized through careful system selection and design. Rather than employ technologies that have yet to fully mature, *Griffin*'s system architectures have been adapted from those commercially available, or currently employed on advanced technology demonstrators or rotorcraft in developmental test. In addition, commercial off-the-shelf (COTS) components are utilized where feasible within these advanced subsystem architectures. The performance calculations include a measure of engineering conservatism. As such, even greater performance may be realized by a production *Griffin*.

VERITAS — Main Rotor

The *Griffin*'s innovative 4-bladed main rotor is a primary contributor to its enhanced performance. It is an aerodynamically synthesized system that promotes performance at reduced rotor speeds. The *Griffin*'s rotor hub is designed to enhance effective payload delivery and permit stowage aboard air-capable ships.

- ✓ **Innovative TALON blade tip** avoids drag divergence penalties and increases the rotor figure of merit by incorporating elements of sweep, taper, and anhedral. It also features a notch that delays retreating blade stall, further improving rotor performance by addressing performance limits on either lateral side of the main rotor disk.
- ✓ **Integrated trailing edge flaps** are capable of extensive vibration suppression, eliminating the need for costly and weighty stationary frame vibration reduction systems. Driven by lightweight electric direct current motors rather than expensive smart actuators, the flaps are an innovative yet fiscally responsible solution.
- ✓ **Semi-articulated hub with small hinge offset** featuring established elastomeric bearings capable of a lifetime of 5,000 hours with minimal maintenance, provides lower vibration levels and eliminates the strong control cross couplings inherent in the EC145.

✓ **Blade folding capability** shrinks the footprint of the rotorcraft, a critical consideration for shipboard operations where storage space is at a premium.

VERITAS — Engine and Drivetrain

VERITAS is the heart of the *Griffin*, providing the capability for continuous variation in main rotor speed. The *Griffin* consumes 50% less power than the EC145 in forward flight, permitting replacement of the baseline Turbomeca Arriel 1E2 engines with more efficient Rolls Royce 250-C30 engines. This COTS engine is lighter than the baseline, contributing to the improved performance of *Griffin*. Moreover, it operates with a lower specific fuel consumption (SFC), permitting a nearly 5% savings in life-cycle cost through decreased energy consumption. Not only then does *Griffin* outperform the EC145, it is significantly "greener" than the baseline.

✓ **Low-maintenance drivetrain** designed for 5,000 hour overhaul intervals and usage of universal MIL-L-23699 oil. VERITAS features easy component access and relies on an extensive Health and Usage Monitoring System (HUMS) to enable Condition Based Maintenance.

✓ **Multi-speed main rotor gearbox** provides continuous and efficient rotor speed modulation over a 20% range of rotational speed.

✓ **Innovative dual-clutch mechanism** permits smooth and uninterrupted power delivery at all flight and rotor speeds.

✓ **Superior corrosion resistance and significant weight reduction** realized through the use of controlled solidification investment cast aluminum gearbox housings.

✓ Advanced electronics automate rotor drivetrain control and offer **"hands-off" rotor speed scheduling** based on flight condition with a manual override capability.

✓ Modular drivetrain controls allow for **more convenient and safer operation** with automatic start-up, engine relight, and surge detection and recovery features.

✓ Drive system architecture requires **no significant changes to the existing EC145 airframe**.

VERITAS — Tail Propeller

The dual-functional tail prop provides anti-torque in hover and propulsion in forward flight. Conversion from anti-torque to thrust compounding mode is performed automatically. The vertical stabilizers, which are mounted at an angle, begin to generate lift as forward airspeed increases, eventually providing sufficient anti-torque to permit the tail prop to swivel aft. Rudders on the vertical stabilizers trim the helicopter in forward flight. *Griffin*'s flight control laws accommodate control switching from the tail prop to the rudders, permitting a single cockpit controller for yaw authority. The tail prop provides ample yaw authority throughout its operational envelope. This increased anti-torque capability dramatically improves upon EC145's widely criticized loss of tail rotor effectiveness during high density altitude operations.

VERITAS — Avionics and Flight Controls

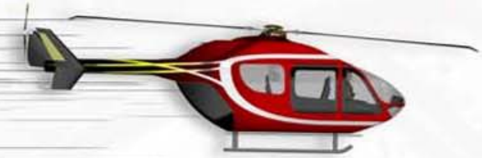
The avionics and flight control systems employed on *Griffin* were specifically designed to decrease the overall aircraft weight while increasing the capability of a fully equipped EC145. Reducing *Griffin*'s weight permits the reallocation of critical vehicle mass in support of the RFP's performance goals. To enable this weight redistribution and optimize *Griffin*'s safety, capability and life cycle costs, the avionics suite and flight controls feature:

- ✓ Aviation-certified and flight-proven **MEMS-based sensors** that improve system reliability and reduce component weight by 64% over comparable equipment in the EC145.
- ✓ Advanced **Health and Usage Monitoring System** that permits reduction of installed component redundancy and contributes to a 4.5% decrease in life cycle costs from the EC145's while improving operator safety.
- ✓ Exclusive **Obstacle Proximity Awareness System** that leverages recent advances in infrared energy sensing technology to offer the operator a 360° representation of objects in the vicinity of the aircraft at low altitude.
- ✓ **Lithium-Polymer batteries** that provide 20 minutes of generator-out power for all installed electrical components at *one-third* the weight of the EC145's battery.
- ✓ FAR Part 29-certified **Automatic Flight Control System** that provides true 'hands-off' capability with force-feel trim and embedded provisions for attitude, altitude, and airspeed hold as well as GPS way-point and glide slope tracking capability at 20% the weight of the baseline system.
- ✓ Innovative, commercially available electrohydrostatic actuators for primary flight control that **virtually eliminate environmentally hazardous hydraulic fluid**.
- ✓ 'Dual-triple' redundant **Fly-By-Wire** architecture that permits rapid incorporation of mission-specific flight control laws and reduces system weight by nearly 40% from EC145's traditional flight control system.
- ✓ Unique **3-axis side-stick flight controller** that increases the safety of ground personnel in close proximity to the rotor system while providing satisfactory handling qualities.

VERITAS — Safety

While historical pioneering helicopter architectures have not always included safety as a critical design driver, VERITAS employs a plethora of fail-safe features to ensure that *Griffin* guards its treasured payload.

- ✓ Twin Rolls Royce 25-C30 engines provide **OEI capability required for FAR Part 29 Category A certification** in the unlikely event of an engine failure.
- ✓ Variable Load Energy Absorbing (VLEA) seats provide *Griffin*'s passengers and crew **crashworthy protection from vertical loads** by limiting occupant lumbar loads to safe levels during decelerations of up to 12 g's.



- ✓ **Innovative "dual-triple" flight control processor approach** achieves the failure coverage of a quadruple cross-channel monitored system without the danger of cross-channel failure propagation or the complexity of a quad voter.
- ✓ **Rotor speed manual override capability** accelerates the main rotor to its maximum operating speed in only seconds to enhance pilot emergency response.
- ✓ **Light-weight swiveling tail prop gearbox** features a fail-safe recall function that returns the tail prop to its traditional antitorque configuration in the unlikely event of an actuation failure.

Comparison Metrics

Multiple metrics are utilized to quantify and compare the exceptional performance of the *Griffin* with other rotorcraft in the weight class. Two measures that are widely accepted in the helicopter industry are used to assess the design: Payload Delivery Efficiency and Productivity.

$$\textit{Payload Delivery Efficiency} = \frac{\textit{Payload} \times \textit{Range}}{\textit{Fuel Weight}}$$

$$\textit{Productivity} = \frac{\textit{Payload} \times \textit{Cruise Velocity}}{\textit{Empty Weight} + \textit{Fuel Weight}}$$

The first is the best metric to compare payload transportation helicopters such as the *Griffin*. It details the effective range per unit of energy consumed as a measure of efficiency in terms of cost. The second is a widely-used metric to assess the overall capability of helicopters across weight classes. It is best viewed as a measure of utility. These two metrics were computed for the *Griffin*, the baseline EC145, and representative light utility helicopters from the other primary manufacturers. As such, calculations for Agusta Westland's AW109E, Bell Helicopter's 430, and the Sikorsky S-76C++ are also included below.

Helicopter		*Griffin*	**Eurocopter EC145** (baseline)	**Bell 430**	**Agusta Westland AW109E**	**Sikorsky S-76C++**
PDE	*nm*	901	529	486	569	647
	Griffin Improvement	—	**70%**	85%	58%	39%
Productivity	*kts*	62.9	51.6	46.0	59.8	43.1
	Griffin Improvement	—	**22%**	37%	5%	46%

Additionally, *Griffin*'s gains in the targeted performance capabilities of speed, range, payload, endurance, and noise signature are compared to the baseline EC145 through a Composite Utility Index. This is a simple index derived to specifically address the performance parameters in the RFP, that weights each capability equally in the following manner:

Composite Utility Index =

$$\left(\frac{Cruise\ Velocity_{Griffin}}{Cruise\ Velocity_{EC145}}\right)\left(\frac{Payload_{Griffin}}{Payload_{EC145}}\right)\left(\frac{Range_{Griffin}}{Range_{EC145}}\right)\left(\frac{Endurance_{Griffin}}{Endurance_{EC145}}\right)$$

Griffin's performance improvements are decomposed into the components of the comparative index and detailed below

Helicopter		***Griffin***	**Eurocopter EC145** (baseline)
Cruise Velocity	*kts (km/h)*	150 (278)	131 (243)
	Griffin Improvement	—	**15%**
Payload	*lb (kg)*	2332 (1060)	2242 (1019)
	Griffin Improvement	—	**4%**
Maximum Range	*nm (km)*	590 (1093)	360 (666)
	Griffin Improvement	—	**64%**
Maximum Endurance	*h:min*	7:24	4:12
	Griffin Improvement	—	**76%**
		CUI = 3.45	

Regardless of the comparison method, *Griffin* truly offers a quantum leap in rotorcraft performance. It offers a 77% increase in payload delivery efficiency, a 22% increase in productivity, and an astounding 245% increase in composite utility index over the baseline EC145. Although not within the target weight class, *Griffin*'s performance is so exceptional that it already meets, and in some cases exceeds, the requirements of the DARPA Mission Adaptive Rotor (MAR) Program.

Desired MAR Attributes	**Fulfilled**	***Griffin* Feature**
40% increase in specific range (range/fuel)	✓	64% increase
50% reduction in acoustic detection range	✓	50% reduction
90% reduction in vibration	✓	100% reduction capabile
Morphing rotor system	✓	RPM variability, Integrated trailing edge flaps
Availability	✓	Minimum significant fuselage changes, COTS equipment
Marinization	✓	Blade and empennage folding, Drivetrain corrosion resistance

Griffin's amazing capability enhancements are also cost-effective. The mere eight percent increase in acquisition cost from the equipped price of an EC145 is fully justified by the performance gains realizable immediately upon fielding *Griffin*. Regardless of this slightly increased initial investment, the total cost of ownership over an assumed 20 year service life with a 400 annual flight hour usage rate is calculated to be \$18.6 million for *Griffin* — nearly a 5% savings over the life cycle costs of the EC145. Despite the additional complexity accompanying VERITAS fabrication, operating costs are optimized by relying on an extensive HUMS. This robust COTS system improves safety and thus lowers insurance rates. In addition, the HUMS permits implementation of Condition Based Maintenance. This approach significantly decreases maintenance costs and improves operational availability, further reducing direct-operating costs. Ultimately, the *Griffin* is practical to own and operate — a true testament to its balance between innovation and feasibility. Careful materials selection, system design, fabrication techniques, and implementation of advanced yet reliable COTS components provides *Griffin* a quantum leap in helicopter capability at a lower cost to own and operate than all other helicopters in the weight class.

Conclusion

Since the earliest hoppers and hoverers, scientists, engineers, and inventors have endeavored to improve the capabilities of the helicopter. Although blessed with a relatively efficient hovering ability for its weight and good low speed maneuverability, the maximum speed — and therefore range — of the conventional helicopter is constrained by a variety of aerodynamic phenomena. Combined with a relatively harsh vibratory environment — one that can impose drastic dynamic component life limits and decrease operator comfort — these drawbacks have prompted the introduction of a plethora of vertical lift concepts seeking to mitigate the helicopter's most undesirable attributes. Few concepts, however, have gained widespread acceptance and this inhospitable environment has served to quash innovation in the rotorcraft marketplace. As a consequence, the notable advances — quantum leaps — in performance accompanying such innovation have been largely missing from the recent history of helicopter development. Indeed, despite decades of continued advances in power generation, rotor design, and materials technology, no recent quantum leap has been achieved. Innovation has been largely curtailed by the perception of excessive risk. Reliable and staid thinking has replaced confident advances in helicopter capability. *Enter the Griffin.*

The *Griffin* fills the capability gap that exists between traditional helicopters and fixed wing platforms while retaining the hallmark performance of rotorcraft: vertical takeoff and landing, omnidirectional flight, and autorotational capability. Indeed, *Griffin* is the multi-mission rotary wing platform of the future — capable of carrying a greater payload over longer distances in shorter time than traditional light utility helicopters — while offering extended flight endurance with minimal noise signature.

Ultimately, the *Griffin* represents more than a vastly improved EC145 derivative. It represents a true paradigm shift in helicopter design, one that trades cautious re-packaged designs for an innovative systemic perspective encompassing all flight regimes, aerodynamic phenomena, and physical configurations. *Griffin* represents an engineering marvel that strikes the ideal balance between creativity and practicality, innovation and feasibility, and embodies imagination tempered with producibility.

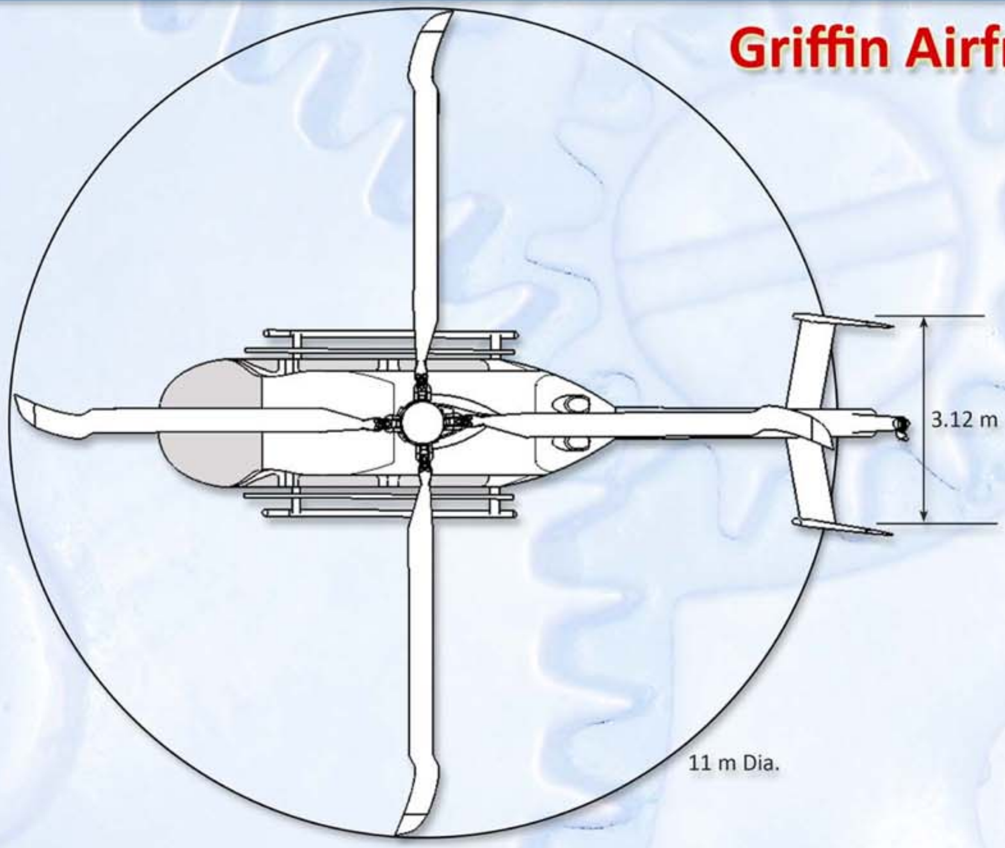
Welcome to the next quantum leap.

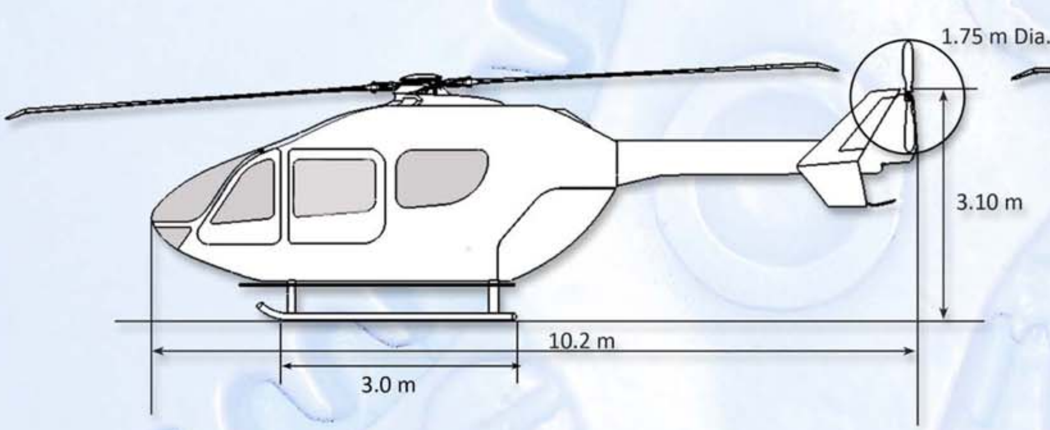
The VERITAS of Griffin:
Truly Innovative Engineering for Exceptional Performance

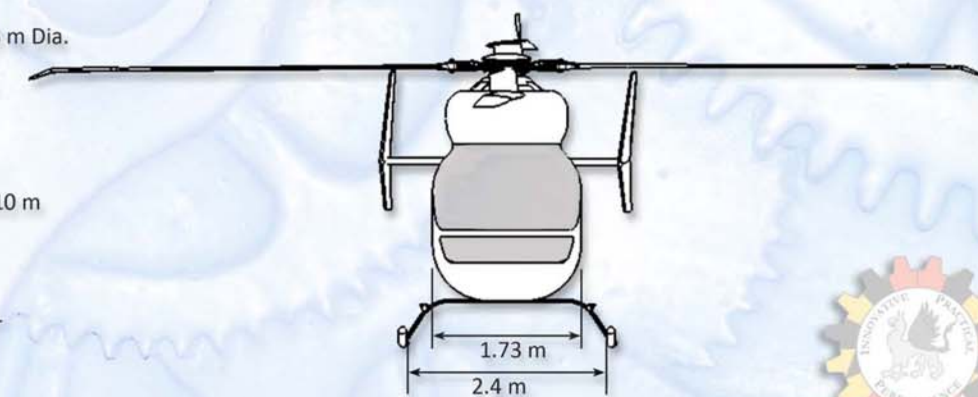
GRIFFIN

		Griffin	EC145
Standard Accommodation		1 + 9	
WEIGHTS			
Design Gross Weight	lb (kg)	7891 (3587)	7887 (3585)
Empty Weight		3858 (1753)	3951 (1792)
Payload (no fuel)		2332 (1060)	2242 (1019)
Fuel		1527 (694)	
SPEEDS			
Speed for Best Endurance	kts (kmph)	65 (120)	
Speed for Best Range		100 (185)	110 (204)
Recommended Cruise Speed		150 (278)	131 (243)
Never Exceed Speed		176 (326)	150 (279)
PERFORMANCE			
Maximum Range	nm (km)	590 (1093)	360 (666)
Maximum Endurance	h:min	07:24	04:12
HOGE Ceiling	ft (m)	7400 (2256)	9200 (2800)
Rate of Climb @ VBE	ft/min (m/min)	2600 (793)	1800 (549)
MAIN ROTOR			
Diameter	ft (m)	36.08 (11)	
Chord		1.05 (0.32)	
Number of Blades	–	4	
Tip Speed (hover)	ft/s (m/s)	723.5 (220.6)	
TAIL PROP/ROTOR			
Diameter	ft (m)	5.74 (1.75)	6.43 (1.96)
Chord		0.43 (0.13)	0.66 (0.20)
Number of Blades	–	2	
Tip Speed	ft/s (m/s)	751.4 (229.1)	730.1 (222.6)
POWERPLANT (x 2)			
Model	–	RR 250-C30	TM Arriel 1E2
Weight	lb (kg)	253 (115)	276 (125.5)
Takeoff Power	hp (kW)	650 (485)	748 (550)
Max. Continuous Power		557 (416)	701 (516)
SFC @ TOP	lb/hp/hr (kg/kw/hr)	0.592 (0.361)	0.573 (0.349)
LIFE CYCLE COSTS			
Acquisition Cost (base)	2009 USD	5.07M	4.24M
Direct Operating Cost / FH		1065	1166
Indirect Operating Cost /Year		0.36M	0.36M

Griffin Airframe View







Griffin's Exterior Layout