Introduction *The Era of Green*

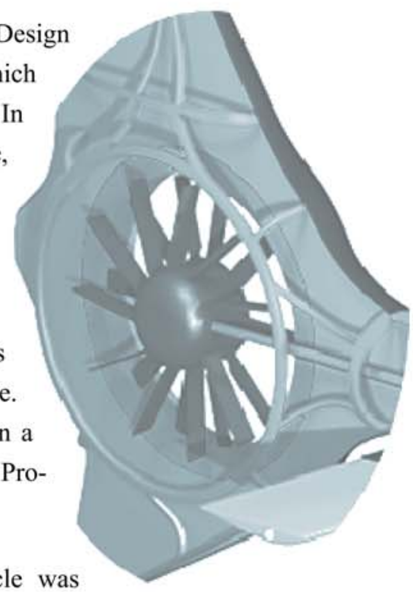
The aerospace vision has expanded far beyond that of individual pioneers striving to break technical performance barriers. Air travel has moved beyond being thought of as a luxury, reserved for the wealthy and the elite. We are fortunate enough to live in a time where the aerospace industry is now intricately woven into the fabric of our everyday global society. The *new* demand is for convenience, safety, reliability, simplicity of design, and above all else, a product with as little harmful impact on the environment and society as possible. This is the *Era of Green*, where aviation continues to expand its role as an international social and economic uniting force, while making monumental strides towards reducing the pollution, noise and wasteful energy consumption that it has unfortunately become associated with in the eyes of the general population.

VOLTERRA: VOL -French for *flight* | TERRA -Latin for *earth*

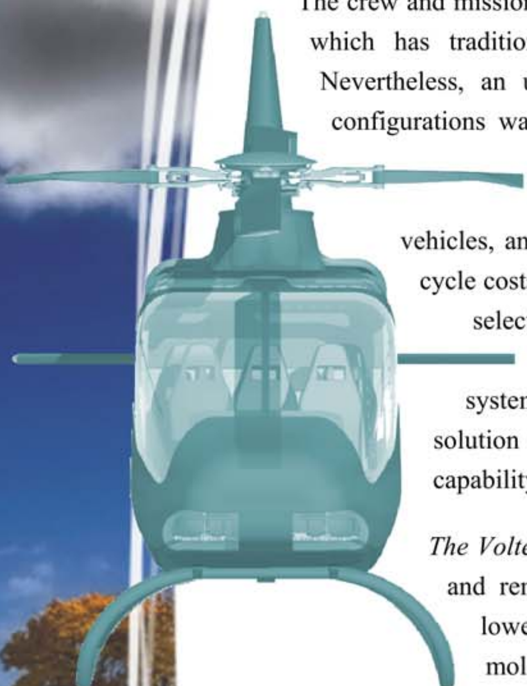
The *Volterra* epitomizes this new design philosophy as a multi-role helicopter capable of meeting the light transport or utility needs of nearly any civil, military or paramilitary operation, all while setting a new standard for environmental friendliness and fuel economy. Operators of the *Volterra* will be stewards of their environment without having to sacrifice performance, incur large acquisition costs, or worry about the end-of-life impact of their vehicle.

Concept Design

The *Volterra* was designed in response to the 2008 AHS Student Design Competition request for proposals for an advanced VTOL concept which minimized energy consumption throughout its entire life cycle. In conjunction with the one-semester ENAE 634 Helicopter Design course, a graduate student team consisting of 8 researchers specializing in a variety of areas such as aeroacoustics, computational fluid dynamics, and helicopter crash safety, was assembled to learn and apply the skills required for the comprehensive design of a VTOL vehicle. All design codes were developed in-house with a number of analysis codes being written, validated and applied within the design timeframe. Computer-aided design and conceptual visualization was performed in a highly synergistic framework involving extensive use of CATIA, Pro-Engineer, and Solid Works.



In addition to minimized energy consumption, the proposed vehicle was required to provide short-range, medium-speed, multi-role transport capabilities to civil, military and paramilitary operators. Utilized in devastated areas, the vehicle had to require little maintenance, be operable from unprepared areas and be capable of take-off within 10 minutes of positioning. Also, because of its expected use in congested or urban areas, the vehicle would require a high level of technology aimed specifically at enhanced safety, reduced noise, and minimal emissions. The payload requirements were one pilot plus either four passengers with luggage or 500 kg of freight. Mission capability included a range of 300 nm, a minimum cruise speed of 100 kts, hover capability out of ground effect at maximum take-off weight, 1500 m altitude and ISA +20^{o}C conditions, and minimal fuel consumption for a one-hour flight at 120 kts target flight speed.



The crew and mission capability requirements placed the vehicle in the light utility category, a role which has traditionally been filled by helicopters of the single-main-rotor configuration. Nevertheless, an unbiased survey of the capabilities of seven broad categories of VTOL configurations was conducted to narrow the design space for detailed evaluation. Evaluated concepts were single-main-rotor helicopters, compound helicopters, coaxial helicopters, canard rotor/wing aircraft, tandem rotors, tilt-rotor/wing/fan vehicles, and pure vectored-thrust aircraft. The complexity, weight, and consequent life-cycle costs of the tandem, tilting and rotor/wing configurations eliminated them from the selection pool. The coaxial configuration, while feasible, was also eliminated due to high hub drag and higher maintenance due to the complex dual-main-rotor system. With only the single-main-rotor choice remaining, the fan-in-fin, anti-torque solution stood above the rest because of its low noise, safety in operation, and proven capability.

The Volterra is designed to be a lightweight, low disk loading, extremely fuel efficient and remarkably quiet helicopter with significantly lower power requirements and lower cost than other helicopters in its class. The preliminary design code used to mold what would become the *Volterra* was developed based on Tishchenko's design methodology. Using this code, an extensive physics-based optimization was performed to select the number of blades, solidity, main rotor tip speed, blade loading and type of engine for the *Volterra*. The final design converged on a four-bladed, low tip-speed main rotor, optimized for weight efficiency and low acoustic signature.

Core Features

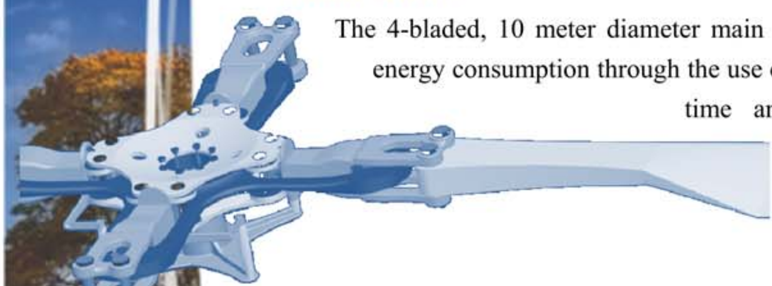
Performance

The *Volterra* is designed to offer superior performance improvements over all other helicopters in its class through greater endurance and range capabilities and simultaneously lower fuel requirements. A more economical aircraft is designed which increases payload capacity and internal volume.

- ✓ **Low-drag configuration** – A biologically-inspired fuselage, optimized pylon and hub geometries, and generous filleting lead to a configuration that has 10% lower drag than contemporary helicopters.

- ✓ **Energy efficient** – Based on the Tishchenko Energy Efficiency Index, the *Volterra* is more than twice (107%) as efficient as the Eurocopter EC-120B and 80% more efficient than the Robinson R44.
- ✓ **Higher payload capability** – The *Volterra* provides 100 kg more payload capacity than either the EC-120B or Bell 206.
- ✓ **Same range for half the fuel** – The revolutionary piston engine, low drag configuration, and efficient rotor offer identical range capabilities as the EC-120B and Bell 206 for half the fuel.
- ✓ **All electric controls** – A swashplateless main rotor control leads to elimination of heavy and maintenance intensive swashplate and hydraulic pumps and actuators.
- ✓ **Large cabin/cargo volume** – The streamlined cabin design offers a low-profile, modular arrangement with a 26% greater cabin volume and a 70% greater cargo volume than the closest competitor in its class (EC-120B) for enhanced multi-role support.
- ✓ **Increased HOGE ceiling** – The *Volterra's* superior HOGE ceiling of more than 2,900 meters offers versatile mission capability for higher altitude operation.
- ✓ **More affordable** – The direct operating costs ($104/flight hour) of the *Volterra* are significantly lower (by 45%) than those of EC-120B helicopter. The indirect operating costs ($228,000/year) are 5% lower than those of the EC-120B helicopter, making the *Volterra* a much more financially viable aircraft.

Main Rotor



The 4-bladed, 10 meter diameter main rotor of the *Volterra* is designed to minimize life-cycle energy consumption through the use of low maintenance components, the adoption of reduced-time and cost blade fabrication processes, the choice of environmentally friendly recyclable materials, and integration of low-risk technologies, all while providing superior performance, in both hover and cruise flight, over current helicopters in its class.

- ✓ **Rotor blade structure** emphasizes simple, low-cost fabrication and the use of recyclable thermoplastic composites.
- ✓ **Enhanced leading edge blade protection** against sand, water, and ice particles is achieved through novel, polyurethane nano-composite erosion tape as well as non-thermal-based de-icing technology, providing low rotor maintenance and power consumption.
- ✓ **Integrated trailing edge flaps** are used for primary control and active vibration/noise reduction, eliminating the need for a heavy, maintenance-intensive swashplate.
- ✓ **Semi-articulated hub** provides responsive handling qualities in high population density areas and uses established elastomeric bearings designed for a lifetime of 5,000 hours with minimal maintenance. The low parts count and use of proven elastomeric bearings lead to higher reliability and low maintenance costs.

Engine and Transmission

The *Volterra* features an innovative engine and transmission system that emphasizes longevity, low maintenance, and ultra-low fuel consumption. The power plant of the *Volterra* is the opposed piston opposed cylinder (OPOC) diesel engine developed by FEV Engine Technology through the Defense Advanced Research Projects Agency (DARPA).

- ✓ 450 hp OPOC engine has a specific fuel consumption of 0.339 lb/shp/hr and consumes **30% less fuel** than currently developed piston and turbine engines.
- ✓ OPOC features modular operation, effectively making the *Volterra* a **multi-engine helicopter**. One module can be deactivated during forward flight when power requirements are low.
- ✓ Capable of burning a **wide variety of fuels** including diesel, gasoline, bio-fuels, JP8, natural gas, and hydrogen.
- ✓ Since the engine system operates at a **lower RPM** than turbine engines, the transmission, featuring spiral bevel gears and a single planetary drive is very compact.
- ✓ Supported with an **integrated Health and Usage Monitoring System (HUMS)**, the transmission system has been designed for a **lifetime of 10,000 hours**.

Comfort Features

- ✓ **Internal Noise** – Cabin noise is minimized by placement of the engine and transmission aft of the main cabin. The engine design itself, with its low-RPM opposed-piston opposed-cylinder configuration, is relatively quiet when compared with current piston engines. Finally, the standard inclusion of noise-reduction headphones provides individual active noise cancellation, and clear inter-cabin communications.
- ✓ **Sun Protection** – Nanolayer-film-coated transparencies provide selective spectrum absorption of the sun's harmful UV rays and reduced solar heat gain. Because the visible light spectrum is not affected as in simple tinting, the transparencies remain clear, the pilots do not lose visibility and the passengers retain an unobstructed exterior view during the flight. This all translates into less wear on interior components and greater overall comfort for occupants.
- ✓ **Magnetorheological Seat Vibration Dampers** – Each crew and passenger seat is fitted with an innovative, lightweight, 2.3 kg vibration isolation damper capable of attenuating up to 90% of the dominant 4/rev vibrations, increasing comfort and pilot situational awareness.

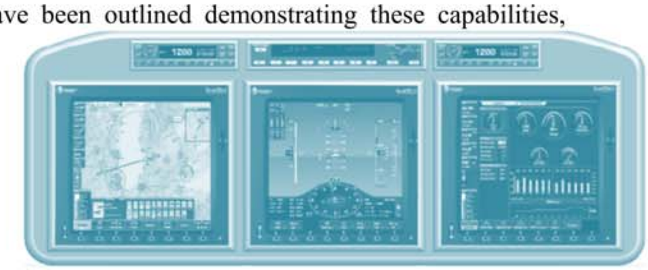
Avionics

- ✓ **MEMS Flight Certified Sensors** – The *Volterra* makes use of the first-ever flight-certified microelectromechanical-based (MEMS) attitude, heading and reference system. This system is as capable as traditional sensor packages at 30% less weight with a similar reduction in power consumption.

- ✓ **Autonomous Flight Control** – The advanced automatic flight control system, combined with optic-flow obstacle avoidance and triply redundant sensors for the stability augmentation system, allows fully autonomous staged take-off, cruise, and landing of the *Volterra*. While a pilot does remain in the control loop (but not necessarily in the vehicle), this capability in a civilian light utility helicopter is unique.
- ✓ **Force-Feel Trim** – The *Volterra's* cyclic, collective and yaw-pedal controls feature servo-actuated force feedback to give pilots the added benefit of tactile situational awareness. The *Volterra's* servo design minimizes the weight penalty allowing this traditionally larger-scale helicopter technology to become cost effective for the light utility helicopter.

Mission Capability

Because of its powerful state-of-the-art engine and avionics, the *Volterra's* mission capability list is virtually limitless. Potential mission scenarios have been outlined demonstrating these capabilities, including civilian transport, search and rescue, emergency medical service transport, cargo transport, law enforcement, and long endurance autonomous missions.



Safety

Safety is a high priority for the *Volterra* since its missions involve operations in congested areas and areas where ground access for other emergency equipment is not possible.

- ✓ **Crashworthiness** – Independent VLEA seats for all passengers and crew reduce g-loading to 12 g's for a broad spectrum of occupant weights.
- ✓ **Multi-engine design** – The modular OPOC engine provides up to 325 hp from a single module or 425 hp from both modules, which gives the added safety of a multi-engine configuration without associated weight and size penalties. This is essential for operation in congested areas and operations over water.
- ✓ **Active Obstacle Avoidance** – Biologically inspired optic-flow measurements from eight microelectromechanical cameras provide high frequency control input to the automatic flight control system, giving the *Volterra* the capability to detect and avoid oncoming obstacles.
- ✓ **Dual Integrated Trailing-Edge Flaps** – Two integrated trailing-edge primary control flaps provide controllability in the event of a single integrated flap failure.

Environmental Impact

Efficient Manufacture, Efficient Operation, *Leave only footprints*

The *Volterra* design focuses on energy efficiency of the *entire* vehicle system, from the production of raw materials, to the energy required to manufacture the components, to the recycling and reuse of those materials and components in the most energy efficient ways possible. The *Volterra* design demonstrates it is possible to use current technology to design a greener helicopter with low development risk.

- ✓ **Production** – The choice of raw materials used in the *Volterra* is based in large part on minimizing energy expenditure and harmful emissions. To accomplish this, detailed energy intensity, emissions, and recyclability surveys were conducted for a variety of traditional and non-traditional aerospace construction materials.
- ✓ **Extensive use of Thermoplastic Composites** – By weight, the structural components of the *Volterra* are 65% reinforced thermoplastic composites. While the initial *production* of the specific thermoplastic resin in use, PEEK, is slightly more energy intensive than a traditional epoxy resin, nearly 40 times less energy is required to *manufacture* PEEK composite *Volterra* components than the equivalent epoxy composite parts.
- ✓ The *Volterra* **minimizes the use of titanium alloys** which result in more than three times the CO_2 emissions per kilogram than aluminum, and require substantially more energy to machine.

The 30% reduction in SFC achieved by the *Volterra* significantly reduces its environmental impact by reducing life-cycle unburned hydrocarbons, CO_2, NO_x, SO_x, carcinogens, and a variety of other greenhouse gases

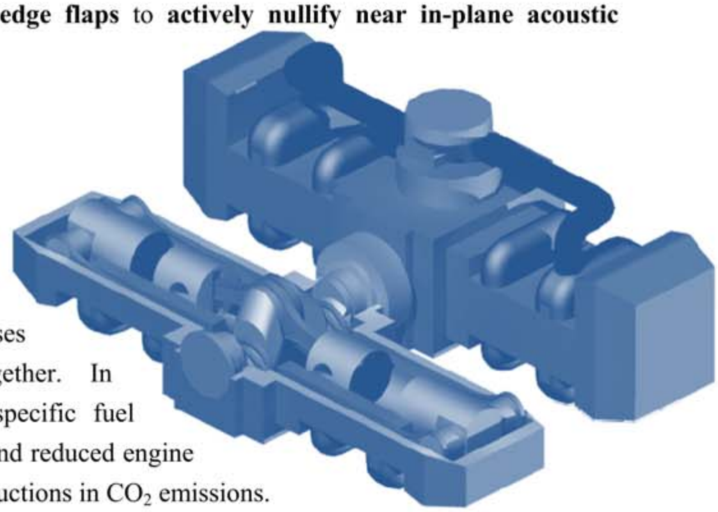
- ✓ PEEK based composites can be more easily formed into **large components**, since a correspondingly large autoclave is not required. This reduces the parts count of the *Volterra* which in-turn makes **assembly**, **maintenance**, and **disassembly** much **less energy intensive.**
- ✓ The *Volterra* is an **all-electric helicopter** using no environmentally unfriendly hydraulic actuators.
- ✓ Because PEEK-based composites can be **remolded** or chopped into **short-fiber components**, the service life of these materials used by the *Volterra* can be much greater than the vehicle itself.
- ✓ The *Volterra* uses **environmentally friendly bio-polymers** for the seat cushions, **compatible aluminum alloys** that can be recycled collectively for reduced energy consumption and higher material recovery at the recycling stage, **hexavalent-chromium-free** paints and electronics,

and high energy density lithium-polymer auxiliary batteries to **minimize the mass of hazardous chemicals** on board.

Acoustics

This effort is addressed at three levels: aeroacoustic blade design, flight path management, and active noise reduction.

- ✓ Based on the Ffwocs-Williams and Hawkings equations, the blade design is optimized to minimize the intensity of thickness noise, loading noise, and blade vortex interaction noise. Main rotor noise has additionally been reduced by selecting a **low tip speed**, **blades of a high aspect ratio**, and a **four-bladed rotor**.
- ✓ **Tail rotor noise has been reduced** by installing a fenestron with uneven blade spacing and duct shielding.
- ✓ **Blade vortex interaction is reduced** by using an innovative optics-based tip-path-plane tracking system that directs a flight path management system to give **visual cues** to pilots which helps them to maintain quiet flight trajectories.
- ✓ Lower frequency noise that is important for detection is also reduced at distinct observer positions using the **blade trailing edge flaps** to **actively nullify near in-plane acoustic waves.**



Emissions

- ✓ **CO_2** – From manufacturing to recycling, CO_2 emissions are minimized by choosing highly recyclable materials, in some cases closing the carbon cycle altogether. In operation, the 30% reduction in specific fuel consumption, reduced-drag design, and reduced engine idle time contribute to significant reductions in CO_2 emissions.
- ✓ **NO_x** – In addition to the approximately 30% reduction below current piston or turbine designs, the OPOC achieves further reductions in NO_x emissions by using a turbocharger to burn a leaner fuel mixture.
- ✓ **External Noise** – By appropriately sizing the *Volterra* and optimizing the blade design to minimize the intensity of thickness noise, loading noise, and blade vortex interaction noise, a perceived reduction of approximately 6dB has been achieved over the already remarkably quiet EC-120. Further reductions in noise are achieved by the active noise suppression functionality of the integrated flap system which reduces perceive noise by 4dB, a quiet piston engine, a fan-in-fin design with unequally spaced blades for frequency spectrum spreading, and a flight-tested, tip-path plane tracking method which provides a visual aid to the pilot for avoiding blade-vortex interactions.

Performance Comparison

	Unit	Volterra	EC-120B	Bell-206B3	RFP Requirements
Standard Accommodation		1 + 4	2+3		1+4
Design Gross Weight	kg (lb)	1750 (3858)	1715 (3780)	1451 (3198)	
Payload (Fuel excluded)	kg (lb)	500 (1102)	404 (891)	393 (866)	500 kg
Fuel Capacity	kg (lb) (gallon)	150 (331) (43.5)	321 (707) (107)	281 (619) (91)	Reduced fuel consumption
Speed for Best Range	km/hr (knots)	198 (107)	204 (110)	213 (115)	Recommended cruise speed over 100knots
Speed for Best Endurance	km/hr (knots)	124 (67)	120 (65)	96 (52)	
Fast Cruise Speed	km/hr (knots)	222 (120)	222 (120)		
Rate of Climb	m/s (ft/min)	10.63 (2091)	5.84 (1150)	6.9 (1358)	
HOGE Ceiling					
ISA	m (ft)	2931 (9614)	2316 7600	1615 (5298)	HOGE at 1500m ISA+20
ISA +20	m (ft)	2238 (7343)	518 1700	914 (2998)	
Maximum Range	km (n.m)	708 (382)	710 (383)	693 (374)	300 n.m
Maximum Endurance		3 hr 34min	4 hr 19min	4 hr 30min	
Endurance with useful load converted to fuel[1]		21 hour	9hr 39min	10hr 48min	
Main dimensions					
Length, (Rotor Turning)	m (ft)	11.67 (38.29)	11.52 (37.79)	11.96 (39.2)	
High	m (ft)	3.71 (12.17)	3.40 (11.15)	2.52 (8.3)	
Width	m (ft)	2.74 (8.99)	2.60 (8.53)	1.96 (6.4)	
Cabin volume	m^3 (ft^3)	2.70 (95.35)	2.14 (75.57)	1.12 (40)	
Cargo volume	m^3 (ft^3)	1.38 (48.73)	0.80 (28.25)	0.45 (16)	
Main rotor					
Diameter	m (ft)	9.74 (31.95)	10 (32.81)	10.16 (33.4)	
Chord	m (ft)	0.262 (0.86)	0.26 (0.85)	0.33 (1.1)	
Number of blade		4	3	2	
Tip speed	m/s (ft/s)	197 (645)	210 (689)	209 (687)	
Engine Data					
Specific Power	kw/kg	1.96	2.8	2.5	
SFC	kg/kw/hr	0.206	0.312	0.36	
Purchase Price	$ Million	0.9	1.45	1.3	
Life Cycle Energy Consumption		20.2 TJ			
Life Cycle Costs					
Direct Operation Cost[2]	$/FH	104	231	235	
Indirect Operation Cost[3]	$/Year	228,000	239,000	236,000	

* Note

1 : For EC-120 and Bell 206, endurance is calculated with the entire payload being the fuel.

2 : DOC is given for the first operational year (400 flight hour/year) of a new helicopter. Effect of inflation (2.75%/year) and helicopter aging is neglected for the first operation year.

3 : IOC is given for the average over 20 years (400 flight hour/year). This takes into account of yearly inflation of 2.75%

VOLTERRA

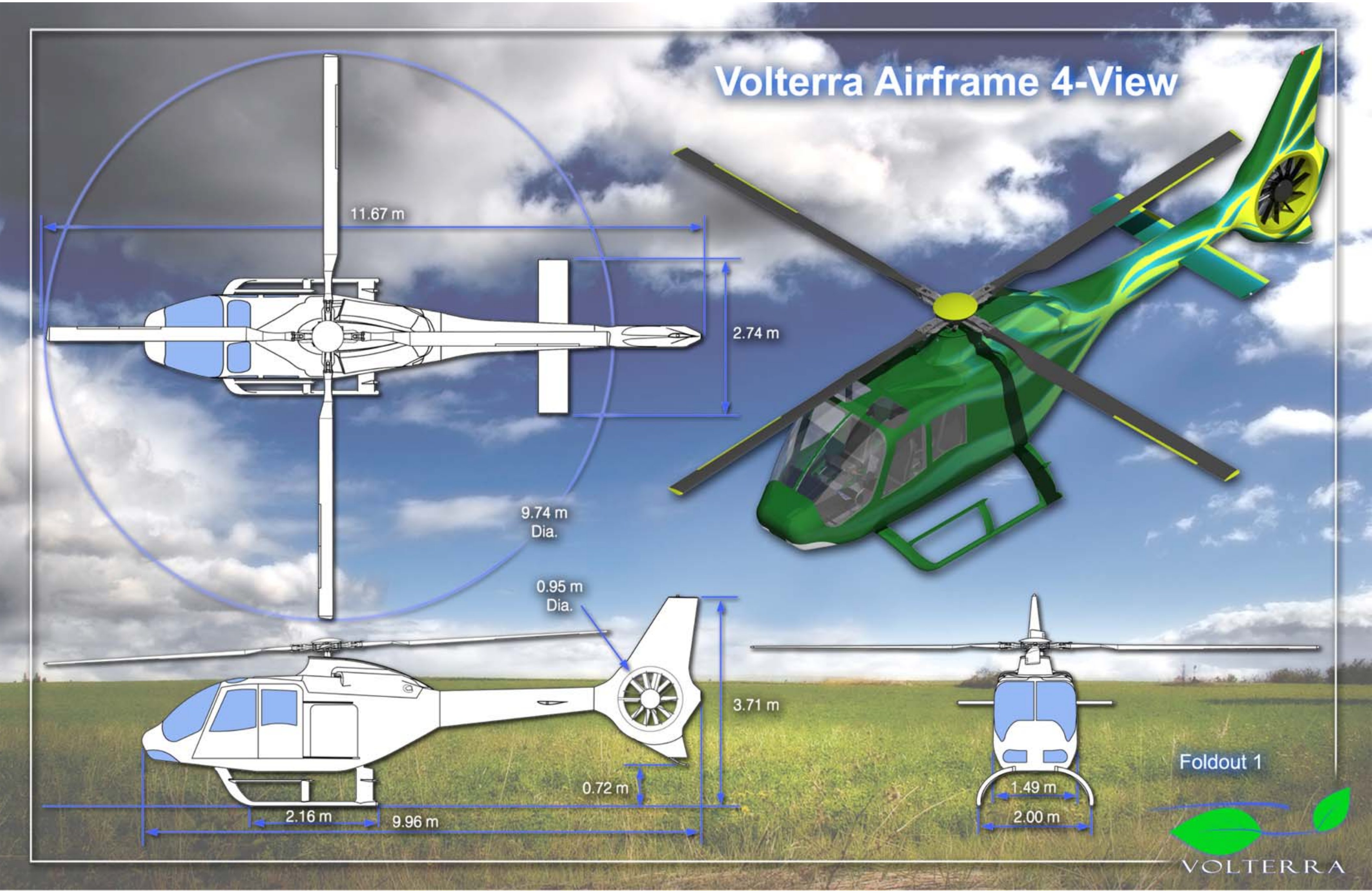
Conclusions

The *Volterra* represents a paradigm shift in helicopter design. Energy efficiency in all aspects of the helicopter's life cycle have been considered and minimized at the design stage, where these considerations can have the greatest impact on the final production vehicle. Most importantly, this all-embracing style of design does not sacrifice performance or capability. If the bottom line for the customer is environmental friendliness, the *Volterra's* specific fuel consumption, reduced emissions and low noise are unmatched by any production helicopter. For customers looking for the ultimate performance in a light utility helicopter, the dual module capability of the *Volterra's* OPOC engine gives multi-engine safety and performance at a lower weight and cost than was previously possible. If the customer demands the lowest cost for these features, then even with its autonomous flight capabilities, advanced composite structural components, and powerful engine, the operational and acquisition cost savings introduced by the OPOC engine make the *Volterra* the obvious choice for any operator looking to purchase a light transport helicopter in the 2020+ time-frame.

We as a design team are proud to introduce the rotorcraft community to the *Volterra*.

Welcome to the Era of Green. Welcome to the Era of the *Volterra.*

VOLTERRA



Volterra Airframe 4-View
11.67 m
2.74 m
9.74 m Dia.
0.95 m Dia.
3.71 m
0.72 m
2.16 m
9.96 m
1.49 m
2.00 m
Foldout 1
VOLTERRA

The Volterra's Exterior Layout