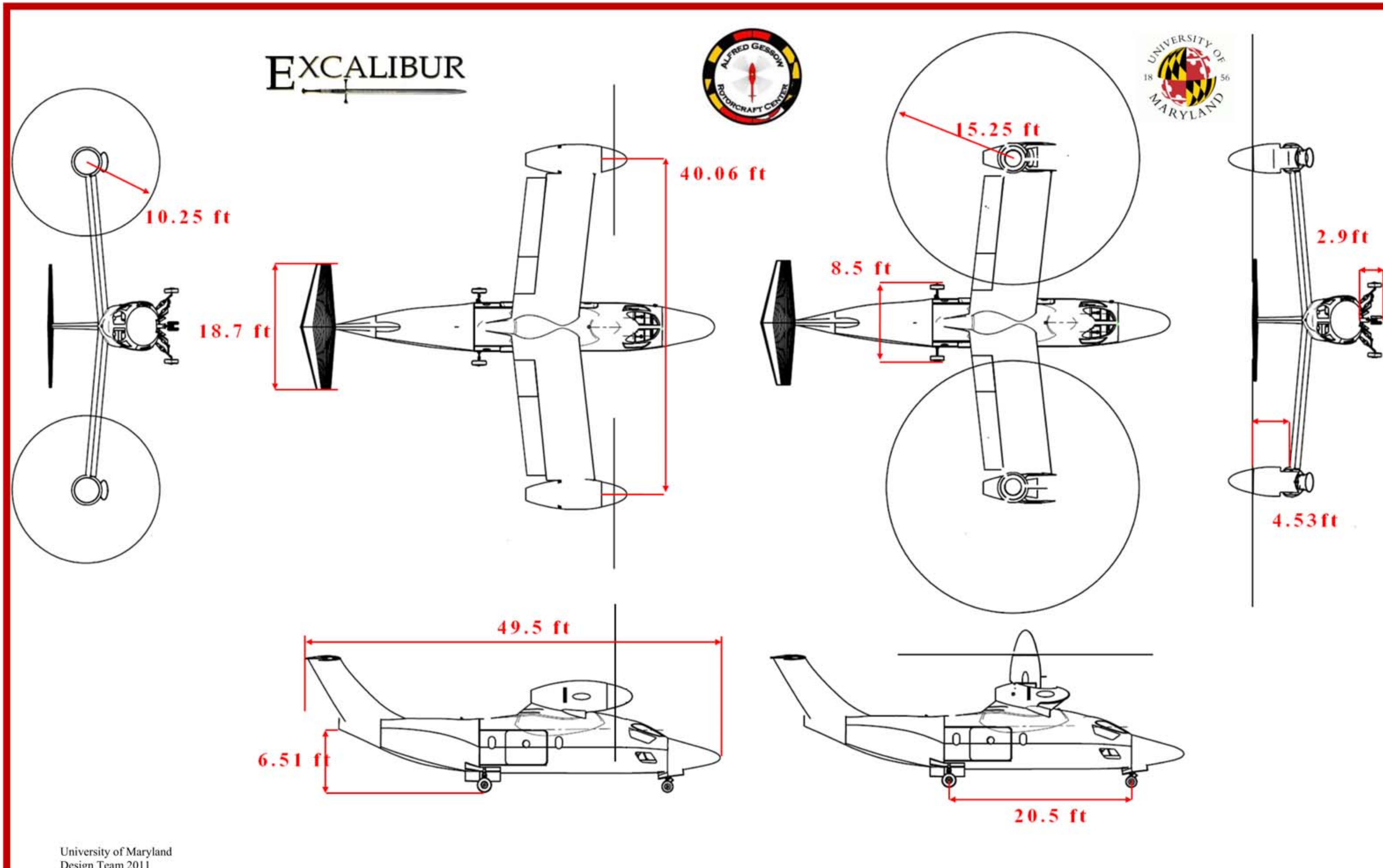

EXCALIBUR
10.25 ft
18.7 ft
40.06 ft
15.25 ft
8.5 ft
2.9ft
4.53ft
49.5 ft
6.51 ft
20.5 ft
University of Maryland
Design Team 2011

Proposal Summary

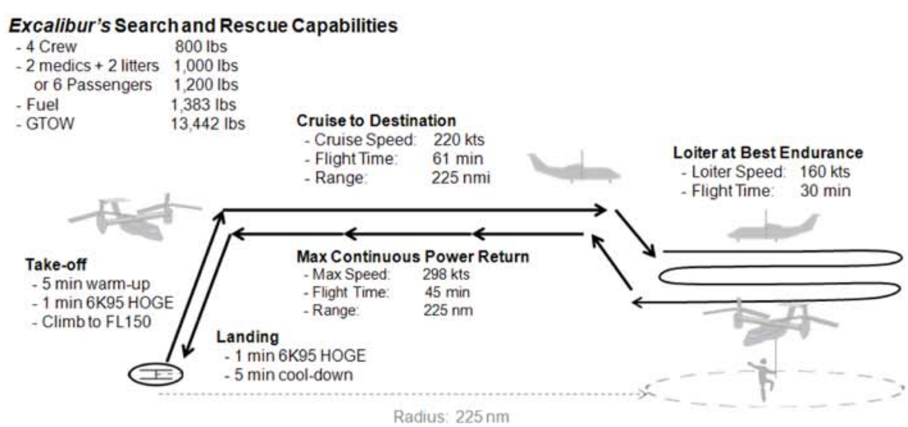
Concept Design

In response to the 2011 AHS Student Design Competition Request for Proposal (RFP) for a multi-mission aircraft, co-sponsored by Bell Helicopter Textron, the University of Maryland graduate student team presents *Excalibur*, a multi-role tiltrotor. The graduate team was assembled to take on this challenge of designing a new multi-mission, VTOL aircraft. The team consisted of five students with specialties in aeromechanics, computational fluid dynamics, simulation, and one of the students is also a certificated pilot. *Excalibur* was designed as a variable diameter tiltrotor to meet the requirements of the RFP by providing excellent hover and forward flight performance. All sizing and rotor optimization codes were developed and extensively validated in-house and were applied within the project timeframe. Custom software developed at UMD was utilized to provide all aerodynamic, acoustic, and performance analysis. Computer aided design, component design, and solid modeling conceptual images were developed using a variety of solid design tools including CATIA, SolidWorks, and the Modo 501 Design Tool.

The Request for Proposals

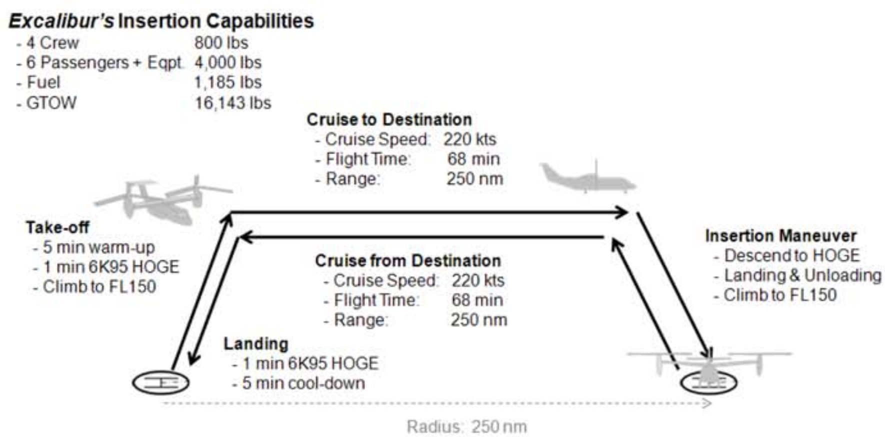
The RFP specifies the need for a new vertical lift aircraft with increased versatility that is capable of multiple missions. Having one rotorcraft that can be widely deployed and used for many different missions reduces inventory and maintenance costs by increased commonality of parts. The goal of the multi-mission design is to optimally blend the competing requirements of three very different missions, which are motivated by the needs of current events. To satisfy these requirements the team proposes the design of a tiltrotor. A description of these three missions along with the proposed capabilities of the design include:

Mission 1: Search and Rescue



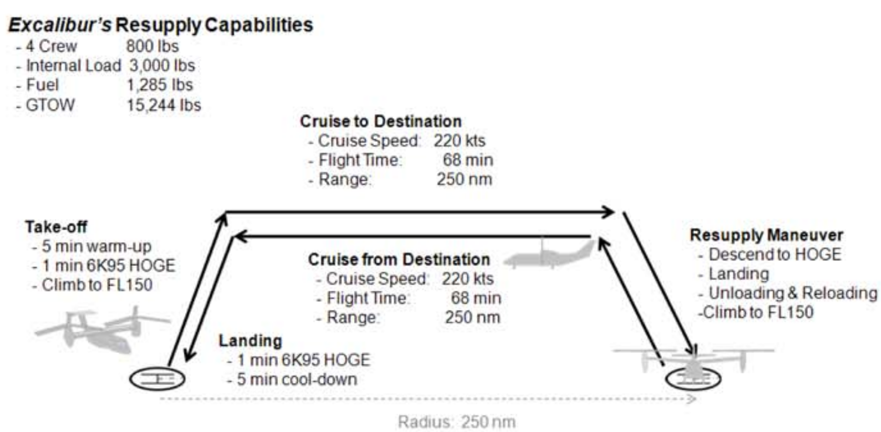
ion requires the aircraft to carry a crew of four on the outbound leg, effect a rescue, and return home carrying two litters and two medical personnel or an additional six passengers. Critically injured passengers are best served if they reach the medical facility in the "golden hour," a window which is defined in the RFP as 50 to 70 minutes on the return flight. This mission, therefore, requires the vehicle to be capable of flying between 190 kts and 270 kts to satisfy the "golden hour" requirement. *Excalibur* is capable of a 220 kts cruise speed, a 298 kts maximum speed, and a 330 kts dash speed ensuring that rescued persons are returned within this critical timeframe.

Mission 2: Insertion



This mission requires the aircraft to carry a crew of four and six additional persons plus equipment, totaling a minimum payload of 4,000 lbs internal for a minimum distance of 250 nm.

Mission 3: Resupply



This mission requires the aircraft to carry a crew of four and a payload of at least 3,000 lbs internal for a minimum distance of 250 nm, and then return to the starting point with an alternate payload of 3,000 lbs internal. Common to all missions is the need for hover out-of-ground-effect

(HOGE) at 6000 ft and 95ºF (6K95). This is equivalent to a density altitude of near 9,800 ft.

The *Excalibur* tiltrotor was developed to meet, and in many cases exceed, the requirements of the multi-mission focused RFP emphasizing the requirements of medium lift, long range, and high speed. This design, is capable of being reconfigured quickly for any mission, and is designed to effectively carry out search and rescue (SAR), military insertion, or re-supply missions.

Multi-Mission Design

These three missions, based on the needs of current events, have diverse performance requirements, necessitating the use of both proven and cutting edge technologies to simultaneously achieve the objectives that have traditionally been believed as conflicting ones. Each of these missions has its own impact on sizing the aircraft. The common requirement for HOGE at 6K95 at maximum gross takeoff weight (MGTOW) demands a proprotor with a large diameter to give high efficiency and low power requirements. Mission 1 requires that the aircraft be able to carry out a search and rescue mission with a mission radius of 225 nm and return the rescued persons within the "golden hour." This mission demands high speed capability of the order of 200 kts. A smaller diameter proprotor with a lower tip speed is required to maintain low helical tip Mach numbers and high propulsive efficiencies during high-speed cruise. The aircraft must also be capable of carrying internal payloads upwards of 4,800 lbs over a range of 250 nm, and then return without the need to refuel. The insertion mission determines the sizing for the aircraft, through the demands imposed on performance for payload and range.

Motivated by the needs of current events, an accelerated development timeline of 8–9 years is important for this rotorcraft. The team decided that this requires the use of viable, proven technologies. An analytical hierarchy process (AHP) was used to evaluate different helicopter configurations. This AHP is mathematically-based multi-criteria evaluation scheme ranks the relative importance of various design criteria against each other based upon the voice of the customer, leading to the determination of different feasible configurations that are capable of meeting the RFP requirements. The different configurations examined included the conventional single main rotor, compound, tandem, and tiltrotor. Conventional helicopters cannot reach the minimum speed requirements set in the SAR mission. However, they offer a high reliability and excellent hover capability. Compound configurations have the potential to meet the speed requirements set by the RFP but the issue of empty weight fraction and fuel burn are considerations. The tandem rotor design was also considered, but was once again limited in its capabilities by the inability to meet the speed requirements. A tiltrotor was, therefore, decided to be the best way to simultaneously satisfy the requirements for payload, range, and speed because it has the capability to hover and then transition to high speed forward flight, while still being able to meet the payload and range requirements.

A tiltrotor configuration presents its own set of challenges. Influenced by the need to hover at 6K95, to have a low downwash that will not hamper rescue, and have low susceptibility to brownout, it was decided that a disk loading of around 10 lbs/ft^2 was required. This decision led to a large diameter rotor that proved inefficient in airplane mode. Conflicting forward flight requirements are what makes designing a tiltrotor so challenging. Thus, the team decided upon a variable diameter tiltrotor (VDTR) concept that has a larger diameter in hover and a lower diameter in propeller mode. Variable diameter rotors have been studied, and in many cases considered for other tiltrotor designs because the concept provides the necessary performance in hover without compromising forward flight efficiency. The VDTR has also been successfully wind tunnel tested, demonstrating its feasibility for use on an aircraft within the project development timeline.

Sizing the tiltrotor was performed using a modified Tischenko methodology, where helicopter parameters and weights associated with the tail rotor were removed and wing related terms were added. The modified sizing code uses statistical data to estimate the various component weights. Certain component weights were estimated by using the NASA Design and Analysis of Rotorcraft (NDARC) code. To ensure the confidence in the prediction of the team's sizing code, it was validated using the NDARC. Using the same initial values, the UMD and NDARC codes converged within 6% in their empty weight calculation

The resulting tiltrotor is shown in Foldout 1 where the overall vehicle dimensions are illustrated.

Variable Diameter Rotor Design

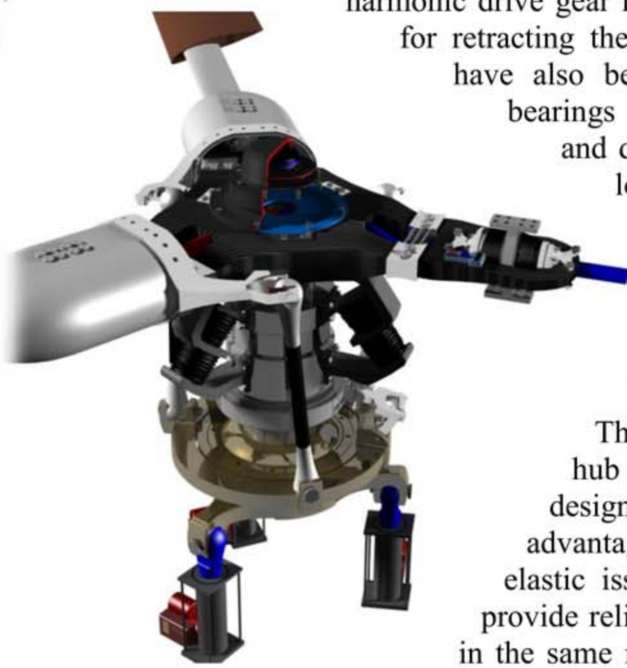
Excalibur is different from traditional tiltrotors because it is has been developed from the beginning with emphasis on the variable diameter concept. This makes the aircraft not just a tiltrotor but a true convertible rotor aircraft. Such an innovative rotor system offers numerous advantages.

Hover efficiency is greatly improved, with a power loading of 7.5 lb/hp and a disk loading of only 11 lb/ft^2, comparable to conventional helicopters. In forward flight, decreasing the proprotor diameter resulted in a significant increase in propulsive efficiency.

An added advantage of the VDTR concept is the ability to take off and land on runways like fixed-wing aircraft when the rotor is fully retracted. This feature significantly increases the payload capacity, compared to a tiltrotor without retracting rotor blades, allowing the vehicle to take off with 50% more payload compared to helicopter mode. Not only does this increase operational capability, but also increases survivability as the aircraft can now safely land as an airplane in the event of engine failure in forward flight or in the event that the nacelle tilting mechanism fails.

Innovative Rotor and Hub Design

Excalibur's innovative hub design contains a spooling motor, coupled with a harmonic drive gear reduction to reel in the tension strap for retracting the rotor blades. Elastomeric bearings have also been used in place of conventional bearings as they provide vibration damping and do not require lubrication, leading to lower maintenance. The design allows the tension strap to pass through to the center of the hub to minimize strap redirection and reduce complexity of the blade retraction system.



The use of a homo-kinetic gimbaled hub was also incorporated into the design. Gimbaled hubs have distinct advantages that alleviate structural and aero-elastic issues. The gimbaled hub is used to provide relief for the 1/rev blade flapping loads in the same manner as for a teetering rotor. The ability of the entire hub to rotate, therefore, virtually eliminates the Coriolis forces that are induced by blade flapping, and thus reduces in-plane bending moments and lead-lag forces.

Rotor Tilting Mechanism

Another key feature of the *Excalibur* is its stationary engine rotor tilting mechanism, where the engine always remains horizontal, and only the rotor system and secondary transmission are tilted. This design offers a significant advantage as it is both simpler and safer. Accessories attached to the engine, including fuel, electric, and hydraulic lines, no longer need to be designed to rotate at the nacelle, resulting in a more elegant design. From a safety standpoint, this system also ensures that hot engine exhaust gasses are continuously directed rearward and, therefore, do not burn to takeoff surfaces or injure persons that might be under the vehicle while in hover.

Exceptional Performance

Excalibur offers many significant performance advantages over other vertical lift aircraft. In particular, its high speed cruise capability. The *Excalibur* provides strategic advantages when it comes to performing missions in a timely manner, with greater range and endurance while requiring less fuel. This leads to a more economical aircraft. Key features of the aircraft include:

Increased Speed: The RFP requirement is for a max continuous speed of 190–270 kts. The ability to cruise at 225 kts over distances of 500 nm, with a dash speed of 330 kts, ensures that the mission is completed quickly and efficiently.

Longer Range: *Excalibur* satisfies the RFP requirement of 500nm. Because of its higher cruise efficiency, it has a combat radius 52% further than the UH-60A Black Hawk, a helicopter with a similar empty weight.

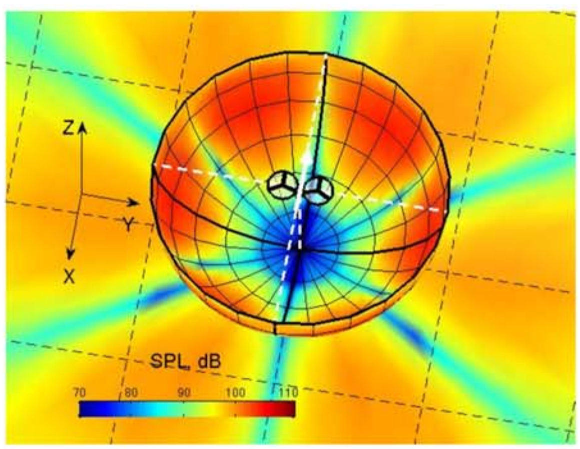
Fuel Efficient: With its ability to fly further and faster, *Excalibur* offers a great increase in its fuel efficiency over all previous helicopter or tiltrotors

Optimized Rotor Design: The ability to change rotor diameter results in a propulsive efficiency of 85% while maintaining a hover power loading of only 7.4 lb/hp, greater than many utility helicopters.

Survivability: Low rotor disk loading, high tip speeds, and high rotor inertia provides good autorotational capability. Also, the reduced diameter rotors in forward flight make conventional airplane landings possible without compromising operational safety.

HOGE Capability: HOGE at MGTOW is ensured at the RFP-required 6K95 with a good thrust/operating margin for maneuvers. This capability is currently unmatched by today's current tiltrotor aircraft.

Quieter: The low disk loading and high aspect ratio blades means *Excalibur* is much quieter than current tiltrotors and meets ICAO Level 4 noise requirements.



Acoustic Signature of *Excalibur* in Hover

Engine and Transmission

Excalibur utilizes an innovative engine and transmission configuration unlike other tiltrotor aircraft, which have full tilting engine/transmission assemblies. These designs present significant technical challenges, because lubrication systems, generators, cooling systems, and hydraulics must operate over a wide range of nacelle angles. *Excalibur* has engines that remain horizontal in all flight modes and only the rotor hub and second stage transmission need to be tilted. The engines also operate at a lower SFC than many other engines with similar power ratings, enabling rotor speed to be decreased by up to 10% through engine speed variations.

Mechanically simple design eliminates the redesign of generators, cooling systems, and other engine mounted accessories

Rearward directed exhaust gasses eliminate danger to personnel during search and rescue.

Avionics

The *Excalibur* utilizes the state-of-the art flight controls and avionics. The system is capable of displaying any and all necessary information to the pilot while minimizing his/her workload. *Excalibur* employs an all Rockwell Collins avionics system that is triply redundant through the use of an air data altitude and heading reference system as well as traditional analog instruments as emergency backups. The all-glass cockpit has five flight displays that can be used interchangeably and provide state-of-the-art features such as traffic collision avoidance system, terrain awareness warning system, and NEXRAD weather radar overlay for all terrain and navigation maps.

The advanced automatic flight control system also ensures that operational limitations are not exceeded by preventing the pilots from performing maneuvers that could cause structural, transmission, or engine damage. The pilot/co-pilot controls also make use of force feedback from the control surfaces to enable precision control.

Mission Capable

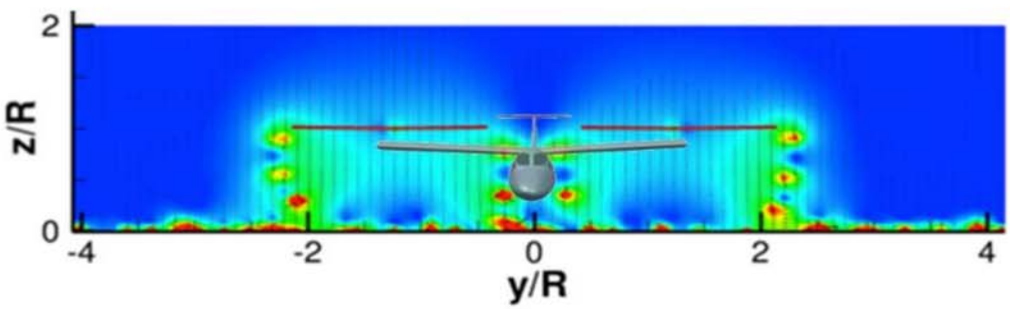
The features of *Excalibur* are driven to ensure true multi-mission capability. State-of-the-art tiltrotor design, including variable diameter rotors, stationary engine rotor tilting, bend-twist coupled composite wing structure, and enlarged load volume, ensure that *Excalibur* can complete all missions more effectively than any other VTOL aircraft.

High cruise speed and high maximum level flight speed make the *Excalibur* ideally suited to search and rescue missions.

Large cabin interior provides room for two stretchers while comfortably accommodating two medical personnel and medical equipment.

The easily reconfigurable design seats 6 fully-equipped troops with equipment, and the large door and low floor level allow unhindered ingress and egress.

Benign Brownout Signature compared to contemporary tiltrotors from the low disk loading and low downwash velocities.



Low noise levels from the retracted rotor blades in forward flight ensure a quieter ride and lower noise signature.

Ability to take off and land in airplane mode means that even larger payloads can be carried than taking off in helicopter mode.

Conclusion

Excalibur's design is optimized to ensure the greatest multi-mission flexibility making it the ideal vehicle for completing search and rescue, insertion, and resupply missions. The *Excalibur* VDTR expands upon a new direction in VTOL development. Design parameters are custom tailored to ensure that RFP requirements are not only met, but well exceeded. *Excalibur* offers cutting-edge performance and safety, while exceeding the RFP requirements for payload, range, and speed. *Excalibur* heralds a new generation of multirole fast-response/SAR/medium-lift rotorcraft.

Excalibur – The cutting edge of tiltrotor technology, flying further, higher, and faster.