The Blue Ninja Turtles Team *presents*

Aerial Screw VTOL Rotorcraft

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PROJECT OVERVIEW

Background: In honor of the historic engineer and inventor Leonardo DaVinci, the Vertical Flight Society (VFS) has designed the 37th Annual Student Design Competition around his aerial screw concept, the first known concept of a vertical take-off and landing aircraft. Since its origin, limited research has been conducted on the implementation of an aerial screw style rotor in a production flight system. This provides a unique opportunity for students to research and ultimately gain a better understanding of what an aerial screw rotor system has to offer in the field of vertical flight[1].

Requirements: Per VFS's competition guidelines, the aircraft must rely on lift from at least one aerial screw, be able to carry a single passenger weighing at least 60kg, accomplish vertical takeoff, maintain hover for a minimum of five seconds, sustain forward flight for one minute, covering a distance of at least 20 meters at an altitude of one meter, and land vertically within a 10 meter radius of the project landing location (See Figure 2).

Approach: The team utilized an iterative approach throughout the design process. Estimations were made, calculations were completed, and simulations were run. Once result from said calculations and simulations had been gathered, adjustments were made to optimize the system. This process was repeated until adequate results were obtained, leading to the final design illustrated here.

ANALYSES

Calculations: Many different methods of analysis were used throughout the process. However, hand calculations served as the foundational step throughout the design process. From the initial sizing and weight, to the rotorcraft's performance in hover and forward flight conditions, the variables were optimized through iterative calculations, and tested using computational analysis methods. The hand calculations provided a basis for which simulation data could be verified, while the simulation data in turn gave depth to the calculations.

Further analyses were done for specific selections, such as performance and propulsion calculations for the selected NACA 0006 airfoil and KDE Direct motors. A few of the most important sizing, weight, and performance variables, along with their equations and results can be seen in Figure 4 to the right.

Simulations/modeling: Upon each iterative refinement of the sizing calculations, solid models were generated for both the rotor assembly and the overall design. A wide range of airfoil characteristics were studied, including thickness, camber, and angle of attack.

Each successive rotor was subjected to both aerodynamic and internal stress simulations, as shown in Figures 3 and 6. The subsequent results were used to validate hand calculations.

Decision Analysis: TOPSIS Methodology was used in order to support the team's decision of using the four electric motors for the design. Values input into the data matrix included the power to weight ratio, weight, cost, and angular velocities for each of the power supply options. After adjusting the Prioritization Matrix to suit this particular design, the TOPSIS Final Ranking resulted in an "Closeness to Ideal" value of .715 for the KDE Direct motors compared to the value .475 for the Compact Radial Engine.

Selections: In order to complete the design, component selection was required. The final design was a quadcopter style aircraft with four aerial screw rotors, each powered by a KDE8218XF-120 motor. The rotors were modeled with a NACA 0006 airfoil wrapped around a shaft in a helical structure in order to create an aerial screw. Each rotor blade has a kevlar skin with 7075-T6 aluminum ribs and spars.

The quadcopter supports a single passenger located at the center of the aircraft, where the control systems, batteries, and other miscellaneous components are housed. The frame structure is also made of the same aluminum. The final model of this design can be seen in Figure 1 to the right.

Figure 1: Final Quadcopter Design

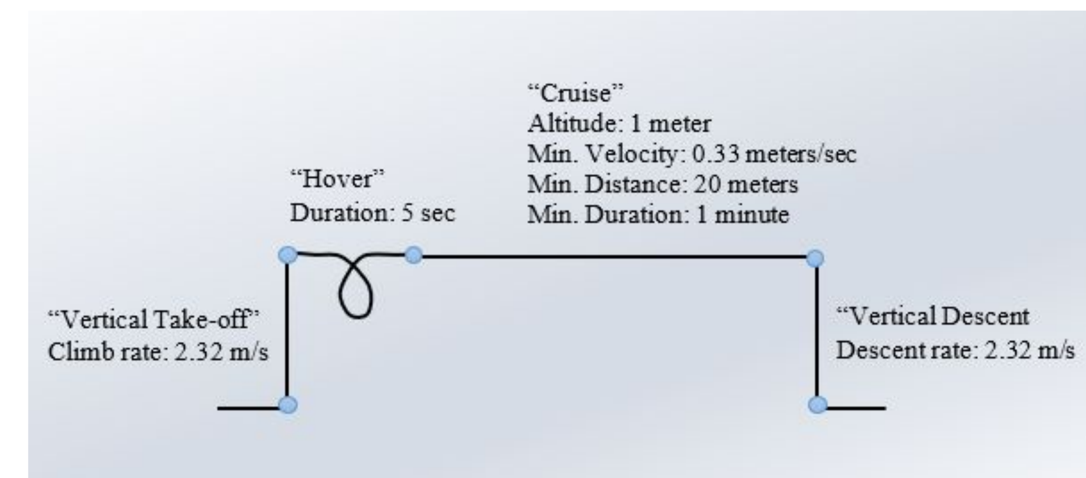

Figure 2: Mission Profile

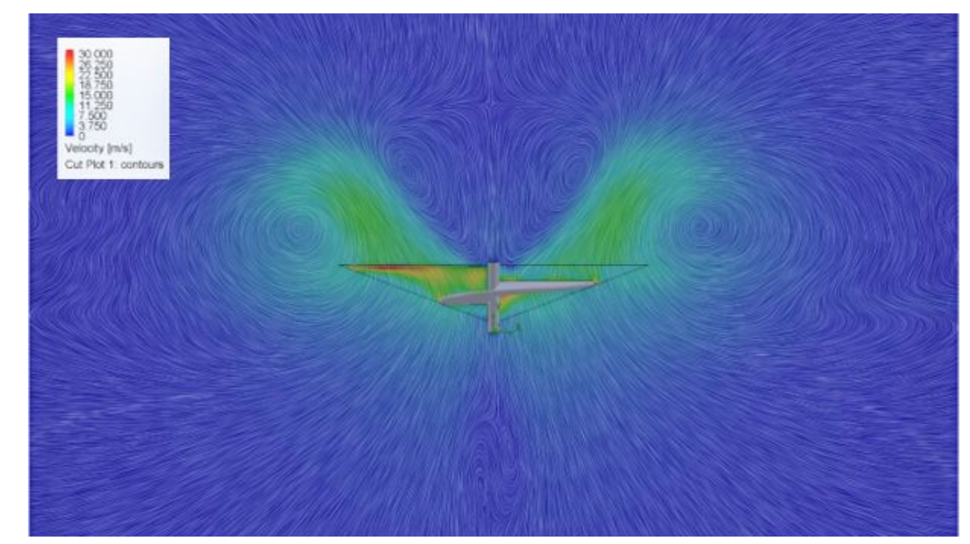

Figure 3: Aerodynamic Analysis

Major Final Results			
Variable	**Equation**	**Metric**	
Rotor Radius	*selected*	0.305	m
Solidity	*σ=A_blade/A_disk*	1.500	
Angle of Attack	*selected*	4.600	deg
Gross Weight	*Wgross=Σ(component weights)*	311.078	kg
Total Lift	*Ltot=TL(power)(no.Rot.)*	8962.230	N
Maximum Thrust	*Tmax=115.62*no.Rot*	462.480	N
Thrust for Forward Flight	*Equation is too long*	311.570	N
Thrust/Weight Ratio	*T/W=T_max/W_gross*	1.487	
Power Available	*Pavail=Σ(power each motor)*	6531.200	W
Power Req. Hover	*Pideal=T*√(T/2ρA)*	935.292	W
Power Req. for Forward Flight	*Pff=TV_∞*sin(α)+T*vi*	504.761	W
Lift/Drag Ratio	*from drag polar*	21.200	
Figrue of Mertit	*Pideal/Pactual*	14.300	%

Figure 4: Final Results

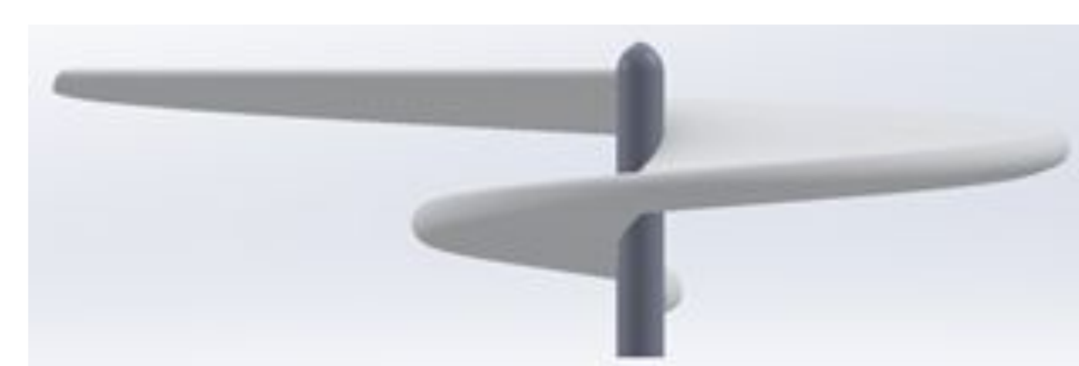

Figure 5: Final Rotor Design

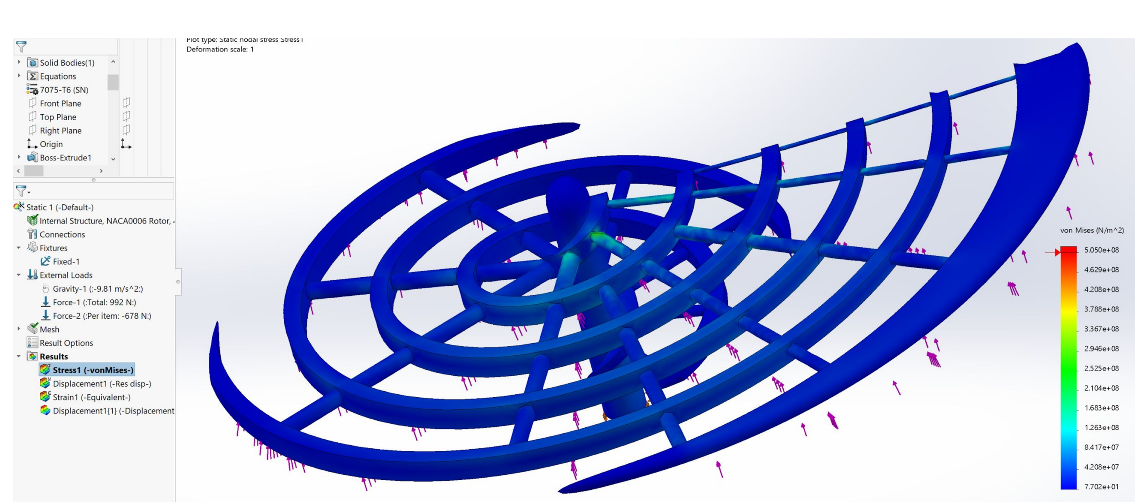

Figure 6: Rotor Frame Stress Analysis

Parts & Materials		Description	Cost ($/Unit)	Quantity	Total Cost
Power Supply					
	Electric Motors (Brushless)	KDE Direct KDE8218XF-120	$596.95	4	$2,387.80
	Motor Controller	350W Brushless, DC Motor Driver Board	$35.75	1	$35.75
	Battery	LiPo 3250 12S 44.4v Battery Pack	$269.99	4	$1,079.96
	Misc Components	Wiring, switches, etc.	$200.00		$200.00
Rotors					
	Exterior Skin	Kevlar	$69.34	4	$277.36
	Support (Ribs & Struts)	Aluminum 7075-T6; -T651			
Fuselage					
	Main Body Structure	Aluminum	$5.33/kg	200 kg	$1,066.63
Miscellaneous					
	Pilot Seating & Harness	Braum® BRH-BKS5 5-Point Harness Set	$169.99	1	$169.99
	Controls	Cyclic & Collective Pitch	$1,500.00	1	$1,500.00
	Personal Protection Equipment	Helmet, Eye Protection, gloves, etc.	$200.00	1	$200.00
Total Investment					**$6,917.49**

Figure 7: Parts & Materials Budget

FINDINGS

Major Calculation Results: As shown in Figure 5, the design features four rotors, each with a radii of 0.305 meters and a solidity of 1.5. The rotors have an effective angle of attack of 4.6 degrees. The system has a gross weight of 311.078 kg.

This design has an available power of 6.531 kW. This greatly exceeds the power required for hover, which was found to be 0.935 kW. The power available yielded a total lift value of 8.962 kN.

The maximum thrust produced by this design is 462.48 N, giving the rotorcraft a thrust to weight ratio of 1.487. This indicates its ability to hover.

For forward flight, the power and thrust required were determined to be 0.503 W and 311.078 N, respectively. These both are within the limitations of the design's performance. Other resultant data can be seen in the referenced figure.

Simulation results: Aerodynamic analysis, depicted in Figure 3, demonstrated consistent symmetry in terms of flow trajectory and vortices across the rotor's main axis. Additionally, the high velocity zone indicated in red shows that lift was generated evenly near the leading edge, and that the resulting downwash interacted minimally with the lower blade faces.

Coinciding with this study was a lift analysis, which calculated lift forces as high as 6 kN, and as low as 0.3 kN. This range is consistent with the 2.24 kN of maximum lift found in hand calculations.

Stress analysis of the rotor frame, shown in Figure 6, validated that 7075-T6 aluminum was capable of handling the loading required to execute the mission profile. Repeated testing showed that the frame failed at approximately 1.489 kN. With that, a factor of safety was implemented so that the rotor was specified for a maximum lift load of 1.25 kN. Given that the overall takeoff weight was calculated at 3.052 kN, it can be stated that the combined rotors are capable of safely producing 1.948 kN excess lift.

CONCLUSION

Final Recommendations and Future Work: Through various methods of analysis, it was determined that this design would be able to perform the actions specified by its mission profile. While this was the primary purpose of the project, further optimizations could be made to create a more efficient version of this rotorcraft. The next stage in the design process would be to build a testable model to gather physical test data.

A future goal for this product would be to prepare the design to be marketable as a kit helicopter. Doing so would require further market research, a more extensive component selection process in terms of flight controls and electrical components, physical testing of structures, and obtaining an airworthiness certification.

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