FanFlyer Air-frame: Design, Structural Modeling and FEA

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Abstract

The NAU FanFlyer team has been given the opportunity to assist NovaKinetics AeroSystems with their design to compete in the Boeing sponsored, GoFly competition. Jim Corning, CEO of NovaKinetics, has tasked the team with designing and analyzing an interior frame for a prototype manned air vehicle. The frame is required to support loads at 900 lbs. while also supporting all interior systems. Finite Element Analysis (FEA), utilizing the computational program ANSYS, was employed for stress and deformation analysis to locate any at-risk-members. Closed-form hand calculations, and various mesh sizes were utilized in verifying the ANSYS simulations. This poster showcases the selected frame design that will serve as the foundational design for NovaKinetics, supported by both ANSYS simulations and hand calculations. In addition to the structural analysis of the frame, a secondary sub-analysis regarding material selection was performed. This analysis revealed a possible alternative substitution, Aluminum 7075-T6, to the client's default material 4130 steel.

Materials

Table 1: Materials Properties to Determine Price Per Weight [2] [3] [4] [5]

	OD	ID	Area (in^2)	Area (m^2)	Length	Volume (m^3)
	1	0.875	0.184	0.000	3.000	0.000
	1.5	1.375	0.282	0.000	3.000	0.001
	2	1.875	0.380	0.000	3.000	0.001
				Weight of test beam which is Area x Length		
	E(Gpa)	$/Kg	Density (Mg/m^3)	Weight-A1 (kg)	Weight-A2 (kg)	Weight-A3 (Kg)
4130 Steel	200.0	1.0	7.85	2.795	4.285	5.776
Medium Carbon	200.0	1.0	7.85	2.795	4.285	5.776
2024-T4 Aluminum	73.1	3.5	2.80	0.997	1.528	2.060
6061-T6 Aluminum	68.9	3.5	2.80	0.997	1.528	2.060
7075-T6 Aluminum	71.7	3.5	2.80	0.997	1.528	2.060
IMI 125 Titanium	120.0	50.0	4.51	1.606	2.462	3.318
IMI 318 Titanium	120.0	50.0	4.42	1.574	2.413	3.252
"S" Glass Epoxy	90.0	44.0	2.63	0.936	1.436	1.935
HT Graphite Epoxy	221.0	N/A	1.75	0.623	0.955	1.288
Boron-Epoxy	250.0	N/A	1.90	0.676	1.037	1.398
Boron-Aluminum	165.0	N/A	2.40	0.854	1.310	1.766
Kevlar-490-Resin	75.0	360.0	1.45	0.516	0.792	1.067
Glass Nylon	2.3	250.0	1.18	0.420	0.644	0.868

Table 2: Materials stress and deformation [1] [6] [7] [8]

		Force (N)	Area (in^2)	Area (m^2)	Area (m^2)			
		2500	0.000184	0.000182	0.000245			
	E(Gpa)	Yield Stress (Mpa)	Stress 1 (MPa)	Stress 2 (MPa)	Stress 3 (MPa)	Deformation 1 (m)	Deformation 2 (m)	Deformation 3 (m)
4130 Steel	200.0	460	136	137	102	0.007	0.007	0.005
2024-T4 Aluminum	73.1	435	136	137	102	0.019	0.019	0.014
6061-T6 Aluminum	68.9	276	136	137	102	0.020	0.020	0.015
7075-T6 Aluminum	71.7	505	136	137	102	0.019	0.019	0.014

- Materials were tested under specific load and moment forces.
- Materials were chosen based off typical bike frame materials as a suitable study point.
- The variables tested were price per weight, load stress, and deformation.
- Based on the analysis, Aluminum 7075-T6 is a good alternative to the client suggested 4130 steel.
- 7075-T6 Aluminum outperforms 4130 steel in weight and yield stress.
- 7075 Aluminum gives a 67% cut in weight at a 350% increase in cost.

Methods

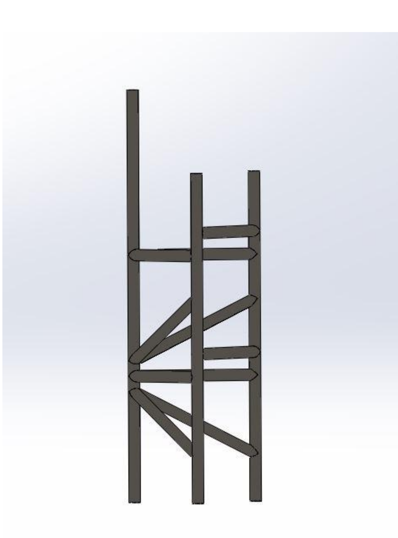

Figure 1: First Client Frame Design

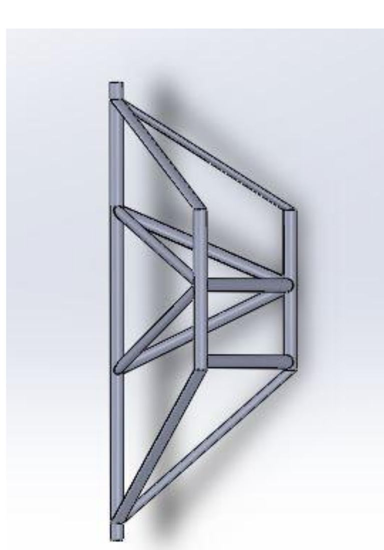

Figure 2: Mid-Term Frame Design

Figure 3: Final Frame Base

Designing the frame began by learning how to utilize the FEA program ANSYS. This allowed for the given loads and boundary conditions from the FanFlyer aircraft to be visualized and analyzed. Various Solidworks and hand-drawn concept sketches were generated for both the client and ANSYS simulations. The ANSYS simulations were based on expected flight forces and proposed frame geometries. Four final frames were presented to the client, and what follows below is the frame that performed optimally. Extensive research was also put into testing different materials for the frame to replace the client suggested 4130 Steel material. The suitable material, 7075-T6 Aluminum, surfaced as a potential replacement.

Results

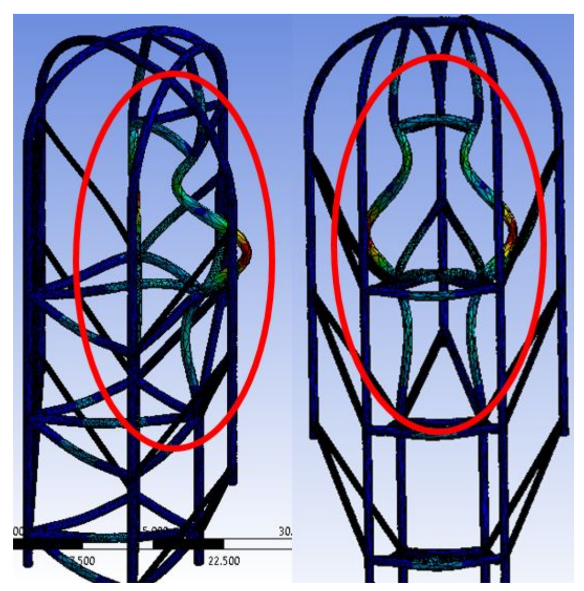

Figure 4: Final concept failure

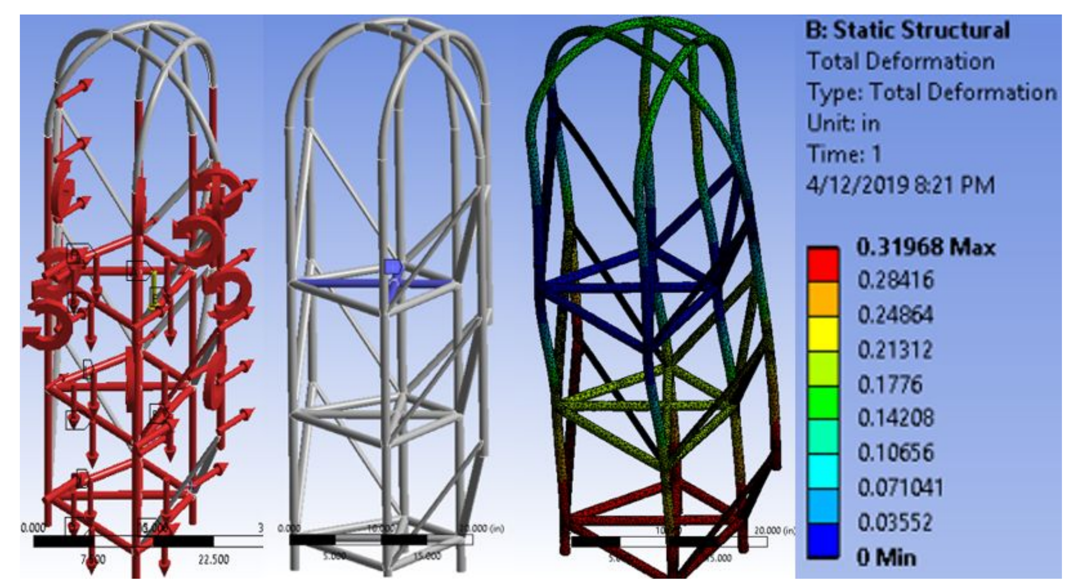

Figure 5: Improved Final Concept Deformation

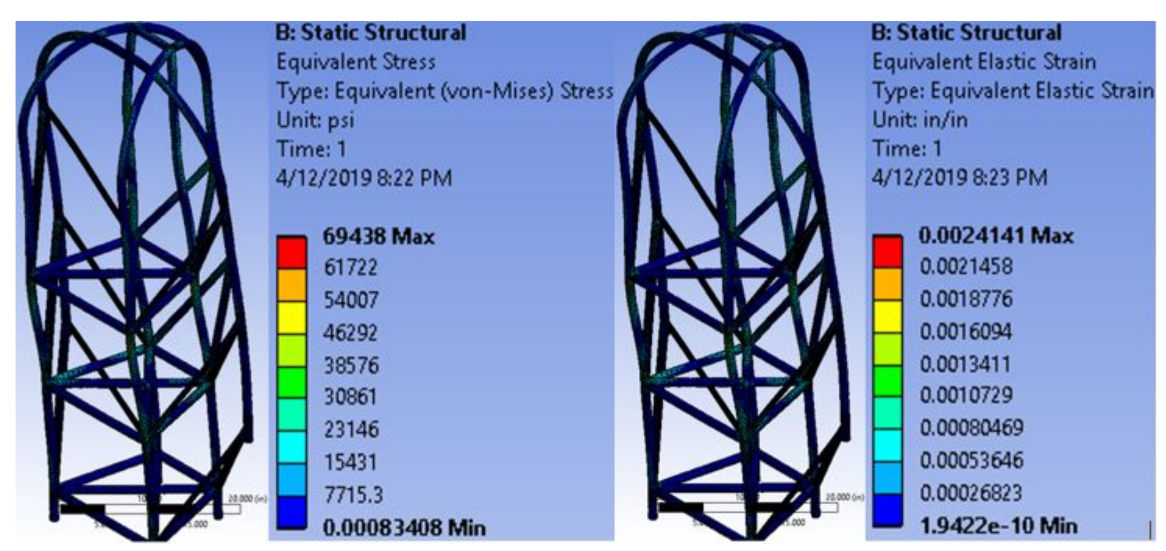

Figure 6: Improved Final Concept Stress & Strain

- An at-risk-member of the final frame was located via ANSYS in Figure 4.
- The ANSYS fixed point about the center of mass is highlighted in blue of Figure 5.
- Figure 5 shows the deformation given moment forces from the rotors, and linear forces due to gravity.
- Stress and Strain can be seen in Figure 6.

Conclusion

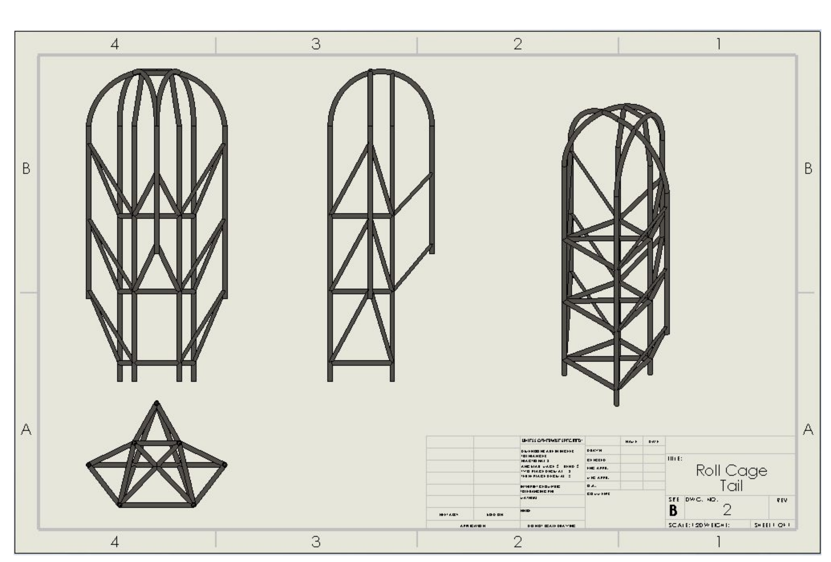

Figure 7: Final Concept

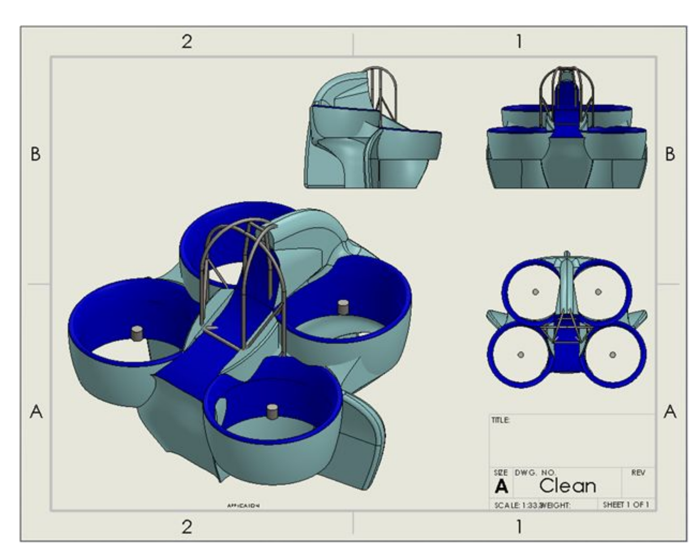

Figure 8: Frame inside FanFlyer

- The team's proposed frame fits within the client specifications, via the client CAD information.
- The frame fits within the client's geometrically designed Solidwork Shell of the FanFlyer.
- The frame was analyzed via ANSYS for an overall structure analysis with an emphasis on stress, strain and deformation.
- The given CAD Package proves the weight is within the client specified restrictions.
- The frame satisfies the conditions given under a 1.67 factor of safety, which meets the guideline of the FAA FAR Part 23.2265[9].

Validation

Statistics		Statistics		Statistics		Statistics	
Nodes	403016	Nodes	423547	Nodes	553217	Nodes	637792
Elements	204397	Elements	214642	Elements	284214	Elements	331977

Figure 9: ANSYS Validation: Statistics for Simulations 1 to 4 respectively

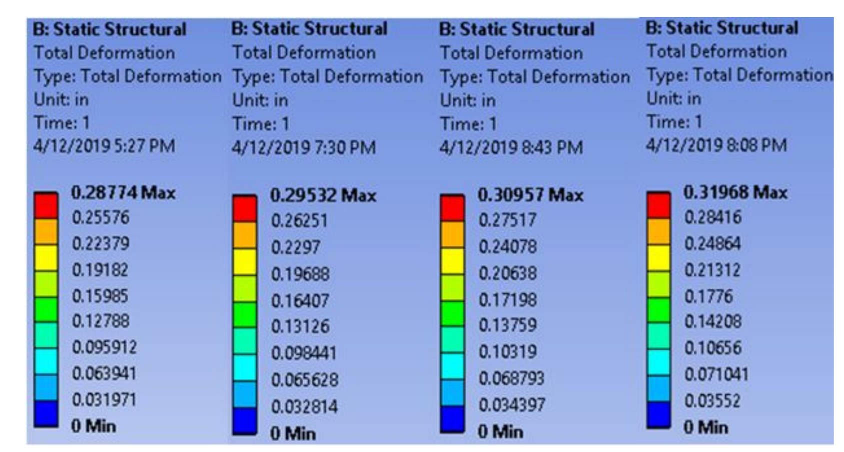

Figure 10: ANSYS Deformation Calculations for simulations 1 to 4 respectively

Simulation 1 - Default resolution setting with default geometry. The ANSYS program with no alterations to the default element geometry, resolution ('relevance' in older versions of ANSYS), node count, element count, and element size. This simulation resulted in a maximum experienced deflection of 0.287 inches as seen in Figure 10.

Simulation 2 - Resolution 2 (Low), Tetrahedral geometry. Altering the element geometry to a Tetrahedral increased the node and element count, Figure 9, while increasing the maximum experienced deflection to 0.295 inches, Figure 10. Specifying a certain type of geometry slightly refines the simulation thereby giving a more refined reading of the experienced deflection.

Simulation 3 - Resolution 5 (medium), Tetrahedral geometry. The resolution increased to a finer setting resulting in a finer mesh. This also increased the node and element count, Figure 9, indicating a smaller element size. This refined geometry increased the maximum deflection to 0.309 inches, Figure 9.

Simulation 4 - Resolution 7 (high), Tetrahedral geometry. This is finest mesh resolution available to ANSYS AIM 19.1. Utilizing this in relation to a defined geometry harnessing Tetrahedrons again increased the node and element count, Figure 9, implying and even small element geometry to allow for a much greater analysis. This resulted in an increase in the maximum experienced deformation to 0.319 inches, Figure 10.

For the side by side comparison of the maximum experienced deformations for simulations 1 to 4. It can be seen that as the mesh characteristics become more refined the data reasonably converges to a slightly larger value at a reasonable rate of 0.01 inches for each simulation. Changing from the default resolution of 2, to 5, to 7, then to 7-Tetra implies that initial simulations, based on simulation 1, can be reasonably trusted.

The even convergence of the max deformation to 0.319 inches from refined mesh characteristic indicate the initial analysis and all preceding analysis can be trusted because the data doesn't alter drastically, nor does it change without a predictable pattern.

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Acknowledgements

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