Universal Adjustable Antenna Mounting System

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Abstract

The Syracuse student team has been tasked by L3Harris with designing an adjustable antenna mount that can be temporarily installed onto a range of helicopters. These helicopters usually have no native communications systems and are required to be retrofitted for each application. The onus of the solutions has fallen on the customers of L3Harris, usually involving (1) strapping antennas to landing skids or external handles with zip-ties to (2) building custom mounting fixtures to accommodate the communications systems in the better but more costly cases. Sometimes, these solutions involved strapping a handheld radio to the helicopter; these radios would not perform well as they were not designed for air-to-ground communications.

However, the focus of the Syracuse student team is to develop a solution for the primary use case of product demonstrations involving temporary installation on helicopters. This means that the designed mounting system is not intended for extreme combat or environmental conditions. Rather, it is meant to be an early-stage product that addresses a myriad of concerns and use conditions (for example, being able to be used as a counterpoise for mono-pole antennas) but has the potential to be further developed into specialized and more robust products.

The Syracuse team focused on modularity of design, durability, and cost efficiency of materials. The assembly consists of a system of modular links, a low-profile lashing belt with a metal cinch, and a mounting plate that can attach all the provided antenna specifications.

1) The links can be assembled to fit the attachment point in the helicopter.
2) The lashing belt was chosen for its low profile as compared to a ratcheting mechanism but can be replaced with a different type of strap if desired.
3) The mounting plate can be easily redesigned for attaching other types of antennas.

Environmental and life-cycle concerns were continuously addressed throughout the design process to ensure a balance of sustainability (in materials and reusability), reliability, and ease of use.

Theoretical calculations and FEA simulations were conducted as the first step of analysis which determined the imposed drag force and stress distribution. Vibration and wind tunnel testing were conducted to qualitatively gauge the failure resistance of the design. Field testing was conducted with a small low-altitude unmanned aerial vehicle. Overall the tests verified the structural reliability of the design, so it was not necessary to alter the design.

Future work involves streamlining the manufacturing process, if desired by L3Harris, to mass-produce the design. Additionally, this design also has a lot of potential in L3Harris's other domains; further work can include tailoring the design for those applications.

Contents

1 Introduction

1.1 Problem Background

L3Harris has a Roll-On, Roll-Off (RORO) kit for temporary installation of tactical radios onto aircraft in a non-intrusive manner. This kit consists of a Transport Case containing a Falcon II airborne radio and end-user devices such as headsets. The use case of the RORO kit is typically a quick response mission providing air-to-ground communications or an airborne demonstration. *However, the user often needs to provide a temporary method of installing antennas without modifying the aircraft.* These methods range from (1) strapping antennas to landing skids or external handles with zip ties to (2) building custom mounting fixtures to accommodate the blade antennas. The latter situation requires a survey and detailed measurements of these physical mounting features. *Ultimately, while the RORO kit provides a rapid method of integrating radios onto an aircraft, there does not exist a similarly efficient and safe way to mount antennas.*

1.2 Problem Statement

The Syracuse student team has been tasked with designing an adjustable antenna mount that can be temporarily installed onto a range of helicopters. The design should feature a mounting surface that can accept a wide range of antennas. The mounting surface should also have enough space for a Logic Control Unit or Antenna Tunable Adapter to be installed in proximity to the antenna. Finally, there is a desire for the mount to contain enough metalwork to act as a counterpoise to a mono-pole antenna.

The mounting system is intended to be integrated into the RORO kit, to further streamline the complementary installation of radio systems and their corresponding antennas onto helicopters. Additionally, the design will increase the reliability, sustainability, and user-friendliness of temporary communications systems installation on helicopters.

1.3 Constraints on the Solution

Per the use case, L3Harris specified parameters for the design to be able to:

- Withstand up to 150 mph wind-speed
- Secure antennas up to 10 lbs.
- Be user-friendly for installation and removal
- Mount a variety of antennas
- Be attachable to 1–5-inch diameter surfaces on helicopters
- Function as counterpoise for mono-pole antennas
- Create no damage nor permanent modification to helicopters

There were several motivations for L3Harris's interest in moving away from their current solutions: zip-ties and hook-and-loop fasteners were not reliable even throughout a single-use period and were limited in the type of antennas they could be used to mount; and the custom mounting solutions that their customers built were costly, time-consuming, and could not be applied to other helicopter models nor antennas.

One of the initial design concepts was using suction cups to attach the antennas; L3Harris responded that they had tried similar approaches but that the CARC paint used for military helicopters was not conducive for suction cups. Other concepts included a modular link design, a ratchet strap, and magnets, which were later combined into the current design. The modular links provided the basis of the design, and the other concepts were integrated to address the weaknesses of the initial modular link concept. As seen in the Pugh matrix (Table 1), the team took the design with the highest score and made it the basis for the Universal Adjustable Antenna Mounting System (UAAMS). Other concepts with high scores were combined with the modular link idea to make the design stronger.

After careful and iterative considerations, the Syracuse University student team has developed a final working version of the UAAMS.

Specific deliverables that will be provided to L3Harris at the end of this project include a package of CAD files, step by step instructions for UAAMS installation, the full-scale working prototype, and any additional supporting documents. The CAD files will be provided in a Solidworks compatible format (.sldprt or .sldasm). These files will include each individual component of the UAAMS as well as the entire assembly.

2 Design Approach

2.1 Generation of Candidate Concepts

Table 1 depicts the reason L3Harris sought a new solution. The scoring system is as follows: 0 is not satisfactory, 1 is somewhat satisfactory and 2 is satisfactory. Using this key, the design concept with the highest score will be the solution that most adequately meets the clients needs. The student team decided to combine the two design concepts with the highest scores (modular links and ratchet strap) because although both had higher scores than any of the current solutions, neither solution had a perfect score.

Table 1: Pugh Matrix for Concept Selection

Selection Criteria	**Current Solutions**			**Design Concepts for New Solutions**		
	Zip-tie	**Velcro strap**	**Custom mount**	**Suction cup**	**Modular links**	**Ratchet strap**
Withstand up to 150 mph wind-speed	1	1	2	0	2	2
Secure antennas up to 10 lbs.	2	1	2	0	1	2
User friendly for installation and removal	2	2	0	2	0	1
Adaptable to various antennas	1	1	0	2	2	1
Adaptable to various helicopters	1	2	0	2	2	2
Secure counterpoise for monopole antennas	0	0	2	1	2	1
No damage nor permanent modification to helicopter or antenna	2	2	0	2	2	2
Sustainable	0	0	1	2	2	1
Limit parts that can become airborne projectiles	2	2	2	1	2	2
Reliable for use case period	1	1	2	0	1	1
No slippage between mounting system and helicopter	0	0	2	0	1	0
No loosening from vibrations nor wind shear	0	0	2	0	1	1
Economically efficient	2	2	0	2	1	2
Score for Design Selection	14	14	15	14	19	18

2.2 Identification of Components and Hardware

Table 2 outlines the parts necessary to make one full UAAMS. It is intended that the mounting plate and mounting links will come assembled using twelve $\frac{1}{2}$" screws. Additionally, each link will come fully assembled with the magnet, magnet cap, magnetic surface, and rubber link-surface interface installed. The client will be provided with a kit including components in *Table 2* assembled as described. The client will then be responsible for using six 1" long screws to attach the desired antenna to the mounting plate. They will also need to decide now many links will be needed for their desired mounting surface. Then, they will connect the links and feed a reinforcement strap through the links. They will also feed the safety wire through the links, to then secure to a safety wire attachment point on the helicopter.

Table 2: Parts List for Universal Adjustable Antenna Mounting System

Part	Description	Quantity
Magnet	15 lb_f neodymium magnets	16
Magnetic surface	1 mm ferrous steel sheet to provide a magnetic surface for the magnets	16
Magnet cap	ASA cap designed to press fit into the links to secure the magnet	16
Link-surface interface	EPDM criss-cross sheets cut to fit the inner surface of each link	16
Reinforcement strap	Lashing strap to be fed through each link	2
Safety wire	Safety wire to be fed through each component of the UAAMS	1 (roll)
Large link	Made of ASA filament	7
Small link	Made of ASA filament	7
Mounting link	Made of ASA filament to be attached to the mounting plate	2
Screws	Mil. Spec. Alloy Steel Socket Head Screw, 10-32 Thread Size, 1" Long	6
	Mil. Spec. Alloy Steel Socket Head Screw, 10-32 Thread Size, 1/2" Long	12
Mounting plate	Machined from 1/4" aluminum sheet (6" x 24")	1

2.3 Development of Preliminary Models

The initial focus of the design was the adjust-ability of the mounting method to fit a range of circular and elliptical attachment surfaces of 1" to 5" diameters. Hence, the design took inspiration from removable wristwatch links, which allow the user to adjust the watch to better fit their wrist. The link ring (*Figure 1*) mounts the antenna to the helicopter.

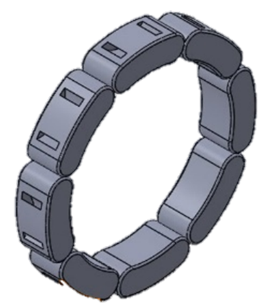


Figure 1: Initial concept based on wristwatch

A nylon strap is to feed through each link to provide the compressive force to hold the ring to the attachment surface. However, the strap is susceptible to fraying from left-right shifting, and the geometry of the links also allows for front-back sliding (under/over adjacent links). The design was then changed to include magnets to restrict movement freedom while retaining the modularity of the design. The magnetic force intends to assist the strap in stabilizing the link ring geometry, not to provide the primary force to hold the mounting system to the helicopter. The strap will continue to be the compressive force securing the system to the helicopter. Additionally, using magnets requires the links to have differentiated ends – a magnet and a magnetic surface.

In the second major iteration of the design, the symmetric links are altered to feature male and female ends. *Figure 2* shows how the male end (left, as pictured) is to fit directly into the right side of the link. Additionally, a hollow cylindrical magnet is to slide onto the pin (left end). However, such a magnet would have to be custom-made, significantly decreasing the ease of manufacturability and increasing cost. Ultimately, it was determined that adjusting the link design to accommodate a solid cylinder would provide the same function while increasing the overall structural integrity.

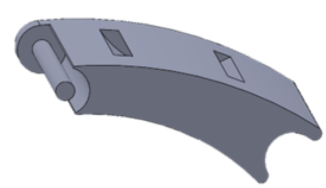


Figure 2: Differentiated ends limit rotational freedom and allow for magnetic connection

2.4 Selection of Design

The current link design (*Figure 3*) alters the original channel for the nylon strap (*Figures 1 and 2*) to an external boss with a cut-through to increase manufacturability and ease of assembly. A window further limits left-right shifting and facilitates positive contact for the magnetic surfaces. Through a dedicated side channel, this design also introduces a safety wire as a fail-safe.

3 Components and Hardware

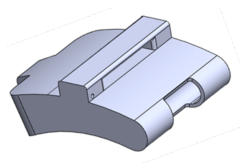


Figure 3: Final link design

A single run of 1.04 mm diameter safety wire feeds through every component in the assembly. The stainless-steel safety wire is corrosion-resistant and has a tensile strength of 325-355 kPsi [**1**]. The inclusion of the safety wire will prevent components from becoming airborne projectiles in the event the assembly falls apart.

The bottom curvature of the link is designed to fit the surface of a 5" diameter rod - the maximum specified diameter of the mounting surface. However, an elastic layer (rubber surface, *Figure 4*) will also be epoxied to the bottom surface of the links for added conform-ability to irregularly shaped surfaces and smaller diameters.

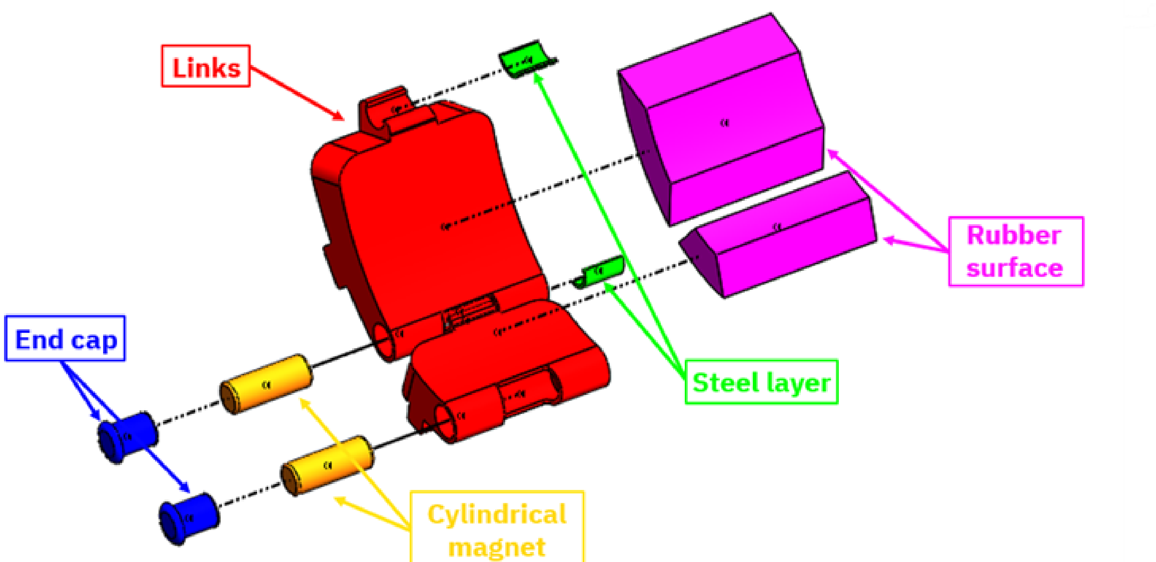


Figure 4: Exploded view of link assembly

EPDM crisscross rubber is used for the rubber surface for its weather and wear resistance; the crisscross texture provides friction between the links and mounting surface to limit sliding [**7**]. Additionally, the EPDM rubber damps the effect of vibration from the helicopter's fuselage on the mounting system.

The cylindrical neodymium magnets are 1" long with 3/8" diameters. The diametrically-oriented pull force is 30 lbs. [**9**] but when mated with a steel surface – as in the design – the force is halved to 15 lbs. This is strong enough to not lose connection unintentionally and weak enough to be pulled apart for quick assembly and removal. For context, fridge magnets have pull forces between 2-5 lbs.

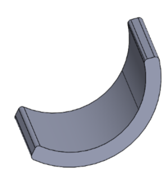


Figure 5: Steel shim

The magnets will be inserted into a channel bore partially through the links. An end cap press-fitted and epoxied into the end of the magnet channel secures the magnet in place. A window is cut out of the link (*Figure 3*) for direct contact between the magnetic surfaces so that the entire 15 lbs. of pull force is utilized.

The magnets will be attracted to adjacent links through a ferrous steel shim epoxied to the female end. The concept of these steel layers can be seen in *Figure 4*. *Figure 5* depicts the intended shape of the steel, which will be cut and bent from a 1 mm-thick 430 stainless steel sheet. Teeth (*Figure 6*) are implemented as an extra precaution to ensure the magnetic force will not detach the steel from the links.

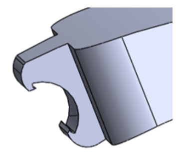
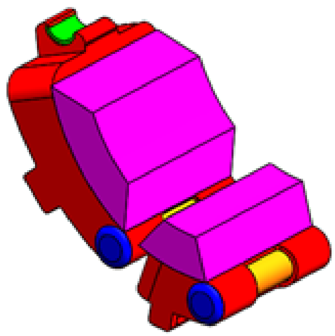
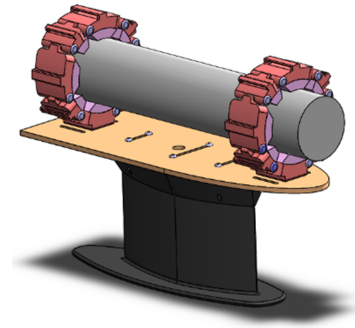


Figure 6: Female end

Figure 7a shows two links as they will be provided in the kit. *Figure 7b* shows the mounting system as it is intended to be used. The link rings surround the helicopter mounting surface. Two link rings attach to a $\frac{1}{4}$" aluminum mounting plate with six screws each. A nylon strap feeds through each link and the mounting plate to provide more stability to the entire system. The antenna mounts to the plate with six additional screws in the typical bolt pattern for blade antennas.



(a) Large and small links



(b) Mounting system

Figure 7: Assembled subsystem and system

4 Advanced Modeling and System Simulation

4.1 Development of Preliminary Analytical models

One of the important calculations for the UAAMS is determining the type of forces that will be enacted on it during its operation. Due to the high velocities of a rotary aircraft, drag force is a critical component that needs to be determined to analyze the applied stresses. In this case, drag force is a function of the air density, relative air velocity, drag coefficient, and wetted area. Air density can be assumed constant and wind assumed negligible, the relative air velocity can be represented as the aircraft's velocity. The drag coefficient is a function of an object's geometric properties, meaning it must be experimentally determined for any shape. Since the mounting plate and the antenna are the main drag-inducing components, they will determine the drag coefficient of the system. Assuming the mounting plate has zero holes and is perfectly rectangular, and the antenna is perfectly rectangular, a rectangular plate's drag coefficient is used for the calculation (*Appendix*).

The wetted area is the area normal to the relative air velocity which depends entirely on the angular tilt of the mounting plate. Using basic trigonometric properties, the wetted area can be determined as a function of the tilt angle. By plugging all these variables into the drag force equation, the drag on the system with changing angle of attack is determined. Using this equation, a plot of drag force versus tilt angle can be done in MATLAB to determine the maximum drag force at the critical angle.

ANSYS Mechanical was used to run finite element analysis on the mounting plate of the system. From preliminary analysis, the maximum drag force and critical angle from MATLAB computations were used as input boundary conditions for simulation. The other boundary condition implemented was gravitational force. For this, a maximum antenna weight of 6 lbs was assumed, which was then converted into Newtons. Before setting up the simulation, a force in the x- and y- directions needed to be calculated as input conditions based on the critical angle. This is because when the plate is at the critical angle, the drag force should be in a direct horizontal direction. In our case, this vector points in-between the x- and y- directions, thus the force in the x and y must create an absolute force magnitude equal to the max drag force. The next step was to apply the combination of x- and y- forces to the entire bottom surface of the mounting plate. The same process was used to get the force of gravity on the plate. Using the critical angle, a combination of forces in the x- and y- directions were calculated to equal the magnitude of the force pointing vertically down. This force was also then applied to the entire bottom surface of the mounting plate. The mesh used for simulation was roughly half the smallest dimension on the mounting plate to ensure accurate results. With the mesh and boundary conditions, the max strain and stress, as well as the minimum safety factor were calculated for the mounting plate.

The results of this simulation are shown in the *Appendix*. The stresses on the mounting plate associated with the above boundary conditions have a maximum value of 29.5 MPa. These stresses result in a maximum deformation of 0.11 mm which is well within a safe range and should not pose any problems to the structural integrity of the system.

5 Testing and Experimentation

5.1 Vibration Testing

Vibration testing will be conducted to evaluate critical frequencies and modes of vibration present in aerial vehicles that may cause structural failure in the mounting system. Testing will be based on MIL-STD-202 Vibration testing standards [1], which specify predominant frequency ranges and magnitudes encountered during field service. These effects include loosening of or relative motion between parts. This loosening can produce noise, wear, and unwanted physical deformations, which can lead to fatigue and failure of the mounting system. The data from this test will inform risk mitigation against effects of undue vibration.

According to MIL-STD-202 Vibration, observations should be taken during and after each vibration test. Results from testing will be presented by frequency (or timestamp to estimate frequency), orientation of vibration motion, and any breakage observed. If applicable, results will be further expanded to be more quantitative by categorizing by breakage size (diameter or deflection). It is anticipated that the critical frequencies will be like those from ANSYS modal analysis. If there is failure, it is likeliest that it will be between the link rings and the mounting plate. Then, the design will be re-evaluated by modifying the geometry or the material.

The goal is to test for failure at critical frequencies listed in MIL-STD-202 vibration tables for aerial vehicles with shaking induced, at minimum, along the z-axis.

Vibration table testing was completed at L3Harris's facility in Rochester, NY. The entire mounting system - excluding an antenna - was mounted into the tri-axial vibration table and attached to an accelerometer (*Figure 8*). The two experiments that were run included random vibrations with a set point of 5 g's and 7 g's. Each test was run for a duration of 5 minutes while the system was continually monitored.

The results of this test ended up being purely qualitative because the accelerometer malfunctioned and was unable to collect any data. Given more time, the vibration trials should be repeated using functioning equipment however, this was not possible during the time that the student team was visiting L3Harris.

Overall, no failure or undesired motion was detected during the testing. After the completion of the test, the UAAMS was further examined and it was determined that the design passed the test. Therefore, the Universal Adjustable Antenna Mounting System is able to withstand random vibrations associated with the motion of helicopter

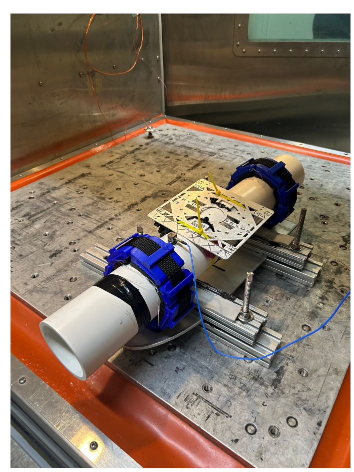


Figure 8: UAAMS mounted in vibration table

flight. In the future it is important that the UAAMS will be tested at vibration frequencies between 225 and 400 RPM because this is the typical range that military helicopters generate during flight [**3**].

5.2 Wind Tunnel Testing

The first goal of the wind tunnel test is to test the strength and durability of the straps in the mounting system. The straps themselves are what secure the links and mounting plate to the rotary aircraft. The second goal of this experiment is to determine if there is any movement between the links of the mounting system and the surface it is in contact with. The third and final goal of this experiment is to determine if the drag force will cause any bending within the screws of the mounting plate and mounting links.

The first anticipated result of this experiment is that the straps will incur zero abrasions and will remain at the same tightness before and after entering the wind tunnel. This will indicate that the straps are strong and durable enough to stay secure while being used in flight. The second anticipated result is that the links will not be displaced at all during the experiment. This will indicate that the EPDM rubber surface attached to the inside of the links will provide enough friction combined with the straps to allow for zero relative motion between the mounting system and the mounting surface while in flight. The third anticipated result is that the screws will experience zero bending during the experiment. This will indicate that the moment that each of the screws experience while in flight will not overcome the strength of each screw.

Due to confidentiality reasons, the student team was not able to utilize a real antenna for their testing procedures without the supervision of L3Harris. To further simulate the forces that will be applied to the UAAMS during a flight demonstration, the student team generated an antenna mass model. The 3D model was generated using CAD, the few dimensions L3Harris was able to provide regarding their antennas, and photos of the antennas. To ensure the UAAMS could support the full weight that an antenna might have, the 3-D printed model of the antenna was filled with a dough mixture that allowed the model to reach a weight of 3.5 lbs. Based on the antenna specifications that the student team was provided with, they believed that this weight was sufficient for validation testing as it was equal to the weight of one of the heavier antennas.

After approval and aid from Dr. Casey Laurent, the student team configured the UAAMS inside of the low speed, closed-circuit wind tunnel located in the sub-basement of Syracuse University's Link Hall. The UAAMS was mounted in the wind tunnel using ratchet straps similar to those used in the design of the UAAMS itself. *Figure 9* shows the experimental set up of the student's prototype inside of the wind tunnel. The green figure is the antenna mass-model.

To create a quantitative output, the mounting system was mounted to a 3/4" diameter PVC pipe with ticks marks placed 1 cm apart. The initial position of the links on the mounting surface was recorded and measured again at the end of each trial.

Based on the company's requests the students intended to test the prototype in wind speeds up to 150 miles per hour. The wind tunnel was first set to 30 Hz and held there for a duration of 30 seconds. Then the wind tunnel was shut off and the system was viewed for damage or failure. This procedure was repeated for 40, 50, and 60 Hz. There was no damage, wear, or relative motion between the mounting system and the mounting surface during any of the tests.

Based on Dr. Laurent's expertise, it was assumed that Hertz to meters/second have a 1:1 conversion. With the acceptance of this conversion, the wind speeds within the tunnel ranged from 67 to 134 miles per hour. Therefore, due to the capabilities of the on-campus wind tunnel, trials were not able to be conducted at the maximum wind speed that L3Harris requested. Nonetheless, due to the strength and integrity of the UAAMS seen at lower speeds, the student team is confident that their design will meet the company's requirements. In the future, before the design is implemented, more tests will need to occur including testing at higher wind speeds and for longer amounts of time.

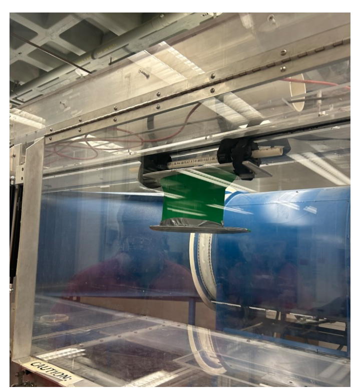


Figure 9: UAAMS mounted inside low speed, closed-circuit wind tunnel

5.3 Field Testing

Field testing is conducted to test the composite effects of vibration, wind, and environmental effects on the mounting system. Similar to the previous tests, a goal of this experiment is to determine if there is any movement between the links of the mounting system and the mounting surface. The second goal is to observe for any structural failure or from mechanical and/or environmental effects.

The anticipated result of this experiment is that the links will not be displaced at all during the experiment and that no failure from vibration, drag, and other mechanical and environmental effects will be observed. This would indicate that the EPDM rubber surface attached to the inside of the links will provide enough friction combined with the straps to allow for zero movement while in flight and that the straps provide enough compressive force to keep the system attached to the mounting surface.

During the same visit to L3Harris where the vibration testing took place, the student team, company sponsor Pete Burke, and a drone pilot took the prototype to Ellison Park in Rochester, NY to perform field testing. The UAAMS carrying a genuine L3Harris antenna was attached to the drone as seen in *Figure 10*.

Figure 10: UAAMS mounted to drone for field test

After a secure attachment of the UAAMS to the drone was ensured, the drone was deployed. The drone operator flew the drone up to 400 feet in the air, reaching speeds up to 35 miles per hour. The system made multiple 45 degree turns and was controlled to rock back and forth to simulate a rough flight. After ten minuets, the drone was brought back down to the ground. Upon inspection, it was determined that no relative motion between the mounting surface and the UAAMS occurred during flight. In conclusion, the UAAMS confidently passed all tests which verified the robustness of the student design. In the future, more quantitative experiments need to be conducted to further ensure the safety of the mounting system.

6 Production and Manufacturing

Production of the final UAAMS product will be very similar to the production of the prototype since the UAAMS is not to be mass-produced. It is intended that metal components of the system including the steel surface inside of the links and the aluminum mounting plate will be machined using a laser cutter. The initial production is projected to include 10 aluminum mounting plates and 160 steel surface components.

The associated 160 links for the initial production are to be extrusion-printed using ASA filament. It is understood that printing this volume of links may take a significant amount of time, especially with the desired resolution and infill. The team is open to the possibility of injection molding the links to decrease the manufacturing time, and the shape of the links is mostly compatible with injection molding but would require some adjustments. However, because there are three different link designs, the total number of each to be manufactured would decrease the value of injection molding. There are to be 20 mounting links, 70 large links, and 70 small links. These numbers would likely make the mold for each different link not worth the cost.

Due to the complex shape of the links and the small volume that will be produced, it is evident that some type of 3D printing will be best suited. Whether the most cost-effective method with the best results is SLA, SLS, or FDM, will require more analysis.

7 Design Assessment

7.1 Required Achievements

Referencing Introduction Part III: Constraints on the Solution, the design parameters to meet include:

- Withstand up to 150 mph wind speed
- Secure antennas up to 10 lbs.
- Be user-friendly for installation and removal
- Mount a variety of antennas
- Be attachable to 1"–5" diameter surfaces on helicopters
- Function as counterpoise for mono-pole antennas
- Create no damage nor permanent modification to helicopters

Additionally, for experimental and field testing, the mounting system must be able to withstand the vibration profiles of common military helicopters, withstand fight conditions, and survive impact forces. Currently, the design is user-friendly, reusable, can function as a counterpoise, mount a variety of antennas, is attachable to 1"-5" diameter surfaces, and creates no damage nor permanent modification to helicopters. Work in progress: experimental and field testing, secure up to 10lbs, and withstand up to 150mph.

7.2 Failure Analysis

One important aspect of the design is determining the drag forces the mounting plate will experience in flight. We applied the drag force formula, which consists of the drag coefficient, density of the fluid, wetted area, and velocity of the fluid flow relative to the object. For calculations, general assumptions include constant air density and constant flow velocity. The other assumptions were that there will be no holes in the mounting plate, negligible wind interference, and a simplified rectangular plate area. Drag coefficients are experimentally determined values, so published drag coefficients of a rectangular plate that were determined using the ratio of length to width of the surface were used. From here, linear interpolation was used to find the length to width ratio of the mounting plate. The wetted area was a key component in determining drag – the area essentially induced the drag. Ultimately the wetted area is a function of the tilt angle (as stated in the analytical model section). As seen in *Figure 11*, the drag force formula was utilized to calculate the maximum drag force (296.96 N) as a function of tilt angle.

To further verify the conclusions drawn from the students numeric calculations, FEA simulations were run on the mounting plate using Ansys Mechanical. Static structural simulations where the boundary conditions acting on the surface of the plate are the maximum conceivable forces applied during flight. *Figure 12* shows the result of this Ansys simulation and illustrates the deflection of the mounting plate. The output of the simulation stated that the maximum Von-Mises stress the plate will fell under these conditions is 29.5 MPa. There are stress concentrations located around the edges of the screw slots which can be expected. The maximum deformation is only 0.11 m occurring in the center of the plate which can be considered negligible for our purposes. It was determined that the minimum safety factor for this design is 9.5. This value is far greater than the desirable value which means that the design is very robust and it is very unlikely that damage to the plate due to stress will be a cause for concern. In the future, the design of the plate may be re-evaluated to potentially remove material to make the product lighter and cheaper.

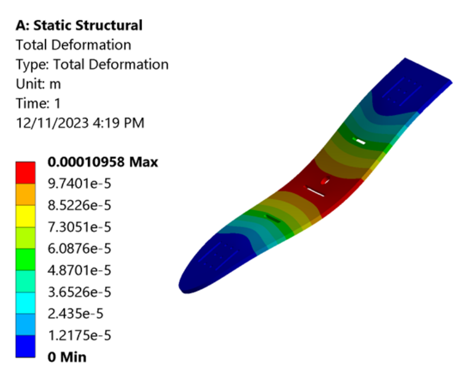


Figure 12: Ansys Simulation Depicting Deflection

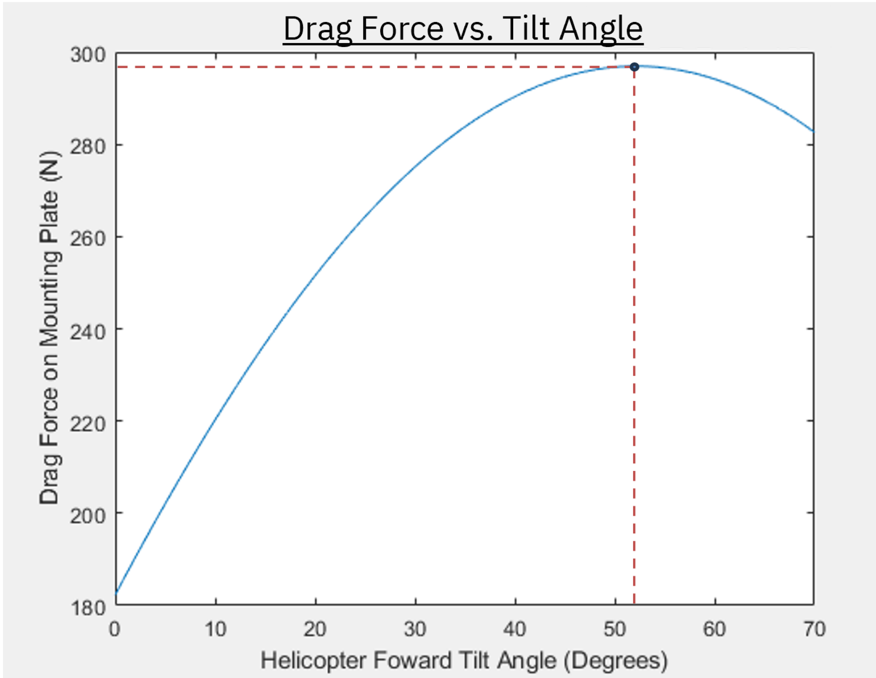


Figure 11: Drag force acting on mounting plate as a function of tilt angle

7.3 Applicable Standards

MIL-STD-810G is a set of standards from the United States Department of Defense to regulate environmental and laboratory testing for military equipment [8]. These standards emphasize tailoring tests to the specific battlefield conditions encountered by the device.

Applicable standards to the antenna mounting system design include Methods from Part 2 of MIL-STD-810G, when tailored to devices being deployed for use on aircraft. The equipment must endure laboratory testing conditions based on the intended use and environmental test conditions to determine the mounting system's reaction to high temperature, low temperature/freezing, rain, solar radiation, rain impingement, and sand/dust impingement. Methods applicable to the antenna mounting system include:

Part Two – Method 500.5 Low Pressure (Altitude)
Part Two – Method 505.5 Solar Radiation (Sunshine)
Part Two – Method 506.5 Rain
Part Two – Method 514.6 Vibration
Part Two – Method 520.3 Temperature, Humidity, Vibration, and Altitude
MIL-STD-810H: Method 516.8
MIL-STD-202 Vibration

The testing will not be tailored to withstand combat nor extreme weather conditions but to the primary use case of product demonstration. Additionally, experimental testing will focus on Method 514.6 (runway-induced vibration, random vibration, maneuver buffet vibration, etc.), and environmental testing will focus on Method 520.3 (compounded weather conditions).

7.4 Product Enhancements

Throughout the design process, the mounting system was most significantly enhanced with a focus on usability and durability against use and weather conditions. As mentioned in the Design Approach section, the differentiated ends allowing for magnetic connections greatly increased the ease of assembly. Materials and dimensions were revisited to ensure the robustness of the mounting system while balancing the cost of components.

In the future, the link design may be adjusted to further increase the ease of manufacturability.

With the current link design, one of the only options for manufacturing is some type of additive manufacturing. In the case where L3Harris decides to open the scope of the UAAMS to more applications than just antenna demonstrations utilizing rotary aircrafts, the links may need to be mass produced. If this was to happen, 3D printing each link will not be feasible and the design of the links shall be adjusted to be compatible with a faster method such as injection molding.

7.5 Life Cycle Analysis

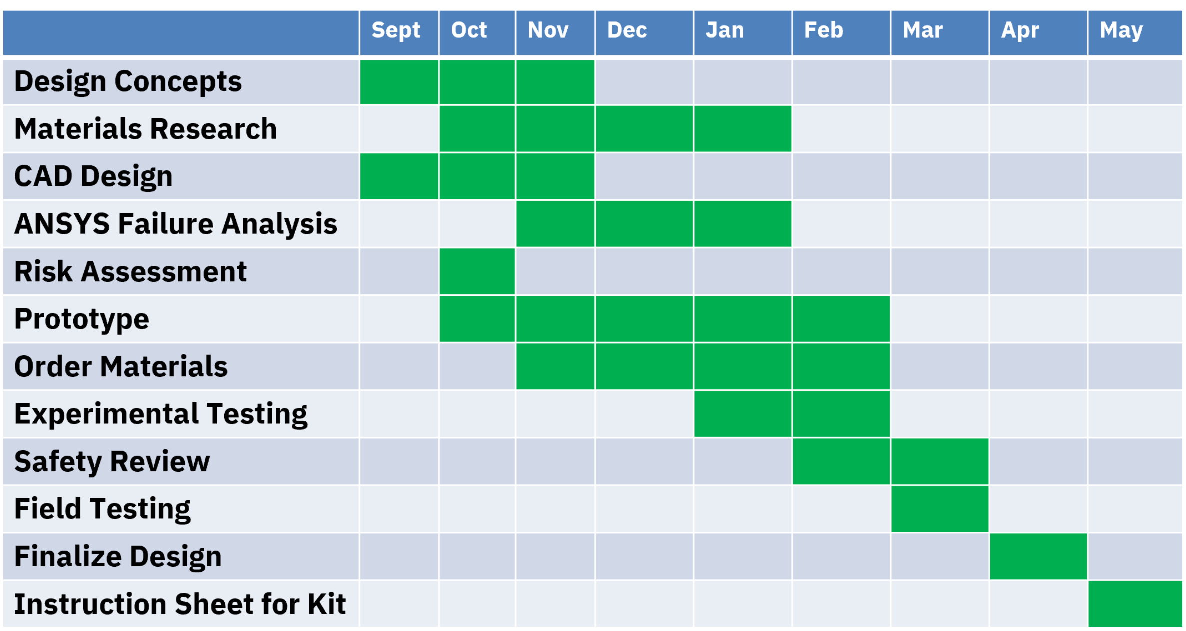
The UAAMS is designed to be highly sustainable from cradle to grave. The main aspect of the system that makes it environmentally favorable is that the UAAMS will greatly decrease the volume of single use plastic being used and discarded by L3Harris. By replacing disposable zip ties with the reusable antenna mount, the environmental impact of manufacturing the device will be outweighed.

When the UAAMS becomes worn and in need of replacement, each part has the potential to be replaced from the screws, the links, and the rubber sheets to the mounting plate. If a part does need to be replaced, every aspect of the design is recyclable given that one takes the time to properly dispose of it. Notably, the neodymium magnets are recyclable but, they must be specially taken care of in order to send it to the correct recycling facility. More research must be done to determine the steps needed to take to ethically dispose of the magnets.

8 Project Management Timeline

The student team completed this project as a part of the courses MEE 471 and MEE 472. The project was introduced in September 2023 and had to be complete before the students finished their undergraduate degree in May 0f 2024. *Table 3* depicts how the students used time management skills to ensure they provided a thorough and satisfactory project to the client.

Table 3: Project Time Line



9 Economic Analysis

9.1 Cost Consideration

The universal adjustable antenna mounting system (UAAMS) is estimated to cost L3Harris $12,012.80 from concept development to manufacturing and implementation. This product is unique as it will be provided to L3Harris not to be sold, but to be utilized in demonstrations which showcase their various product lines to potential clients. Currently, there is no intention of making the UAAMS a commercial product. However, both L3Harris and the student team are open to the possibility of selling this product in the future. Due to the nature of the products' use, it is estimated that there will only be 10 universal antenna mounting systems produced in the first year with additional units being manufactured as needed.

Because the product will be used for demonstration purposes, it is thought that the robust design will last for many years, and it is unlikely that the assembly will need to be replaced. The intention is that due to the level of safety factor incorporated into the design, the initial 10 products will last for years as a supplement to L3Harris' antenna demonstrations. Therefore, each of the following sections will outline the estimated cost of producing full units.

To participate in the capstone project, L3Harris had to provide a base of about $8000 to Syracuse University. Market research, design and concept development has been completed by the student team throughout the past five months. Additionally, the student team will produce a prototype and complete experimental testing to provide proof of concept. The team was provided $1000 of the $8000 for the project's duration to be allocated, however they see fit. The cost of the prototype including materials and manufacturing can be seen in *Table 4*. The total cost of the prototype is $382 which leaves $618 of the initial amount of capital provided.

Table 4: Cost Breakdown for Materials

Materials	Quantity per set	Number of sets	Material cost per piece	Labor cost per hour	Labor hours per piece	Total labor cost	Total cost
Magnets	16	10	$2.3 [**9**]	N/A	N/A	N/A	$392.00
Steel link surfaces	16	10	$1.70 [**11**]	$21.29	0.2	$681.28	$953.12
EPDM sheets	16	10	$1.72 [**7**]	$22.00 [**4**]	0.05	$176.00	$450.56
Lashing belt	2	10	$4.94	$0.00	0	$0.00	$98.80
ASA links - 3D printed	16	10	$0.50	$22.00 [**10**]	0.1	$352.00	$432.00
Mil. Spec. Alloy Steel Socket Head Screw, 10-32 Thread, 1"	10	10	$2.73	N/A	N/A	N/A	$273.00
Mil. Spec. Alloy Steel Socket Head Screw, 10-32 Thread, 1/2"	20	10	$2.63	N/A	N/A	N/A	$526.00
1/4" aluminum sheet (6 in x 24 in)	1	10	$21.09	$21.29	3	$638.70	$849.60
Loctite 243	N/A	10	$3.00 [**6**]	$0.00	0	$0.00	$30.00
Epoxy glue	N/A	10	$0.70	$0.00	0	$0.00	$7.00
Total First Year Cost	$4,012.08						

9.2 Sales and Profit Consideration

The UAAMS is intended to be used by L3Harris for demonstration purposes only. Therefore, the product will not be sold or distributed. It is assumed that there will be no associated distribution costs. Since the product's purpose is for the L3Harris team to promote their product line during field demonstrations, the UAAMS will not directly create any revenue for L3Harris. However, the UAAMS will allow clients to experience L3Harris' antennas without the distraction of struggling to mount the antennas to the aircraft for demonstrations. Hence, the product will indirectly increase the sales of our client's products through streamlining field demonstrations. The direct cash flow from the UAAMS will be zero; however, it will create indirect cash flow from sales of L3Harris's antennas after a seamless product demonstration process.

According to Amazon, it costs $3.75 for a pack of 100 heavy-duty zip ties [**2**]. If at least 5 zip ties are required to securely mount the antenna to a helicopter for flight - and zip ties must be cut off the helicopter when the demonstration is over – the pack of 100 zip ties will only last for 20 demonstrations. This estimate assumes that no zip ties are lost or wasted. The universal adjustable antenna mounting system will be able to be used for hundreds of demonstrations before any component needs to be replaced.

The UAAMS is designed to be extremely durable and reusable, making it more cost-effective and environmentally friendly than zip ties. Although the initial cost of the UAAMS is higher than that of the zip ties, over time the zip ties will be much less cost-effective as they are single-use consumables. But, each mounting system is a one-time purchase. Therefore, it is evident that the $401.21 per mounting system will be well worth the cost.

10 Environmental Impact Analysis

The main environmental impact of the UAAMS will be to reduce waste associated with L3Harris's antenna demonstrations. Currently, zip ties are used to mount the antennas for the demonstration, and they are cut off after the demonstration is over. These zip-ties are single-use plastics, which are leading contributors to pollution. The introduction of the UAAMS will decrease the generation of plastic waste per demonstration to zero. The robust design will allow the UAAMS to be used for many years, far outweighing the environmental cost of manufacturing through its re-usability.

11 Conclusions and Future Work

L3Harris indicated an interest in applying the link design across their other domains, for example, scaling the design for smaller or larger applications or configuring it for use on land or sea vehicles. With this possibility, manufacturing the links would move from 3D printing to a design change allowing for injection molding. 3D printing has many downsides when it comes to printing high volumes including high cost and time requirements. Injection molding would negate these negative effects. However, the current design is not compatible with injection molding because of the complexity of the features.

Additionally, the team was not able to collect any data on the performance of the UAAMS due to equipment availability and time constraints. The student team would encourage L3Harris to perform more testing in accordance with military standards to ensure the safety and robustness of the product.

Finally, the student team will be providing L3Harris with the previously specified deliverables. From this point on, L3Harris will have ownership of the intellectual property for them to implement or adjust based on their needs. The company has previously expressed their intention to pursue a patent for the UAAMS whereas the student team will be listed as inventors but, will not be entitled to any further benefit (as per the agreement between L3Harris, Syracuse University, and the student team at the onset of the project).

12 Project and Report Responsibilities

The student team consists of Nicholas Frank, Teagan Kilian, and Pei Ren. The responsibilities were delegated as follows: Nicholas conducted FEA failure analysis; Teagan oversaw drafting CAD models; and Pei was the materials researcher.

13 References

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14 Appendixes

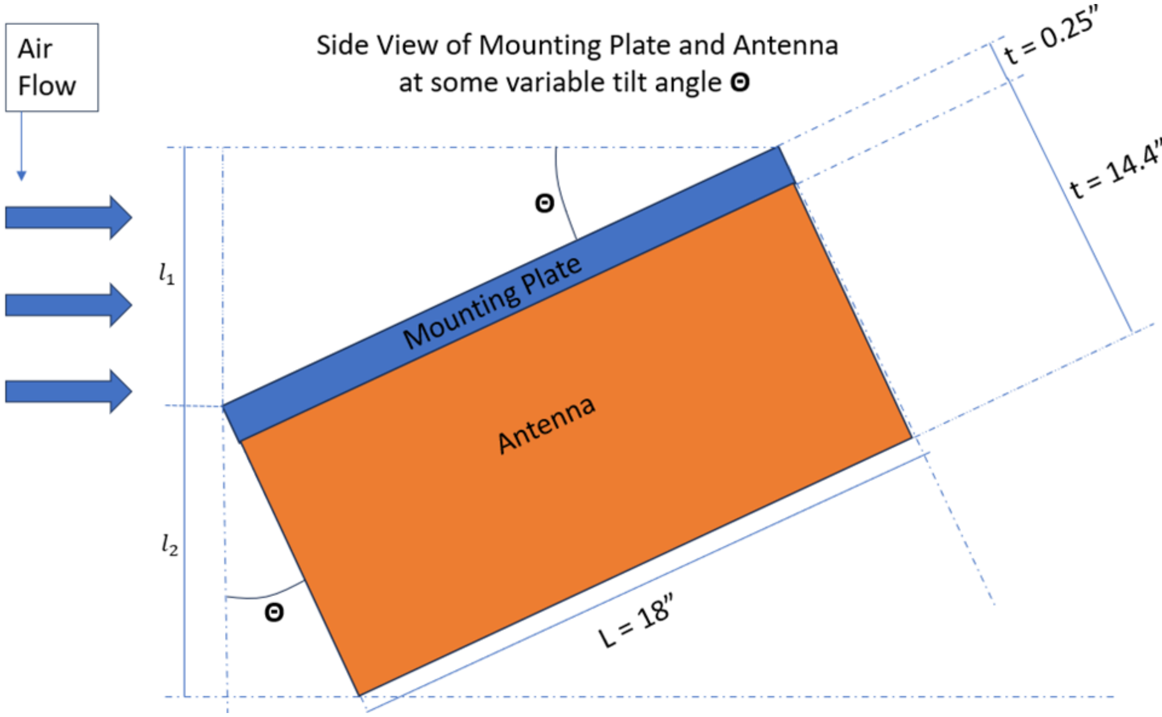

Figure 13: Side view of UAAMS calling out parameters used in drag force calculations

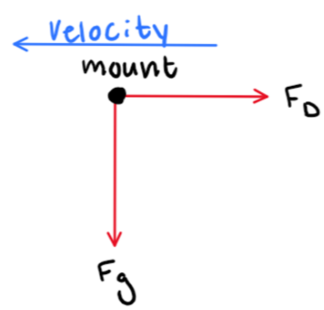

Figure 14: Free body diagram of forces acting on UAAMS during flight

Drag Force Derivations: Assume: velocity is at a constant 150 mph, air density is constant, wind is negligible, plate area is a full rectangle

Drag Coefficient:

$$\frac{L}{W} = 1 \rightarrow C_d = 1.16$$

$$\frac{L}{W} = 5 \rightarrow C_d = 1.20$$

Antenna Dimensions:

$$\text{Length(L)} = 18 \text{ in}$$
$$\text{Width(W)} = 5.88\text{in}$$
$$\text{Thickness(t)} = 0.25 + 14.4 = 14.65 \text{ in}$$

$$\frac{18in}{5.88in} = 3.06 \rightarrow C_d = 1.1806\text{(By linear interpolation)}$$

Wetted Area Derivation

$$l_1 = Lsin\theta$$
$$l_2 = tcos\theta$$
$$L' = l_1 + l_2$$
$$A_w = W * L'$$
$$A_w = 0.15(0.48sin\theta + 0.37cos\theta) = 0.072sin\theta + 0.0566cos\theta[m/s]$$

Unit Conversions:

$$1 \text{ in} = 0.0254 \text{ m}$$
$$1\text{mph} = 0.447 \text{ m/s}$$

Max Velocity:

$$V = 150 \text{ [mph]} = 67.1 \text{ [m/s]}$$

Desity of Air at STP [5]

$$\rho = 1.225[\tfrac{kg}{m^3}]$$

Drag Force Equation:

$$F_d = \tfrac{1}{2}C_d\rho A_w V^2$$
$$F_d = .5(1.1806)(1.225)(0.072sin\theta + 0.0566cos\theta)(67.1^2)$$

Drag Force as a Function of Theta:

$$F_d = 234.4sin\theta + 182.3cos\theta[N]$$

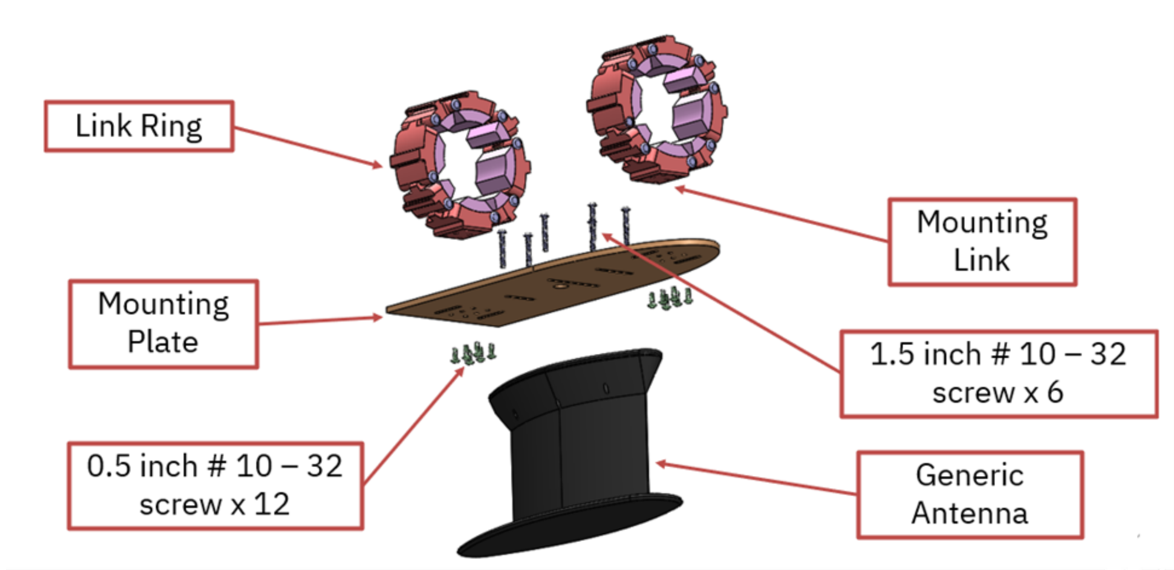

Figure 15: Exploded view of UAAMS and all its components

Table 5: Failure Modes

Failure Mode	Severity	Control Methods				RPN	Rank
		Prevention Control	Occurrence	Detection Control	Detection		
Instability due to vibration	9	**Multi-axial vibration testing**	9	Monitor the mounting system throughout the flight mission	4	324	1
Airborne projectiles	10	Designing with minimal parts that can be removed; Safety wire to catch parts; Simulation testing and experimental testing in **wind tunnel**	4	Field test with L3Harris; Appearance and torque check before takeoff	6	240	2
Lack of Adjustability to Various Mounting Surfaces	7	EPDM rubber allows links to conform to more shapes; Designing two sizes of links, limiting gap size in ring; **Testing prototype for rotational degree of freedom**	4	Before helicopter takes off, ensure the links are conforming tightly to the mounting surface	4	112	3
Mounting System Cannot Support its Own Weight	8	Specialized polymer with 3D printing to allow for complex, lighter, and stronger geometries	6	**Field test** with UAV	2	96	4
Composite Effects	6	**Field test** with UAV	10	Appearance check for fatigue failure effects before installation on helicopter	1	60	5

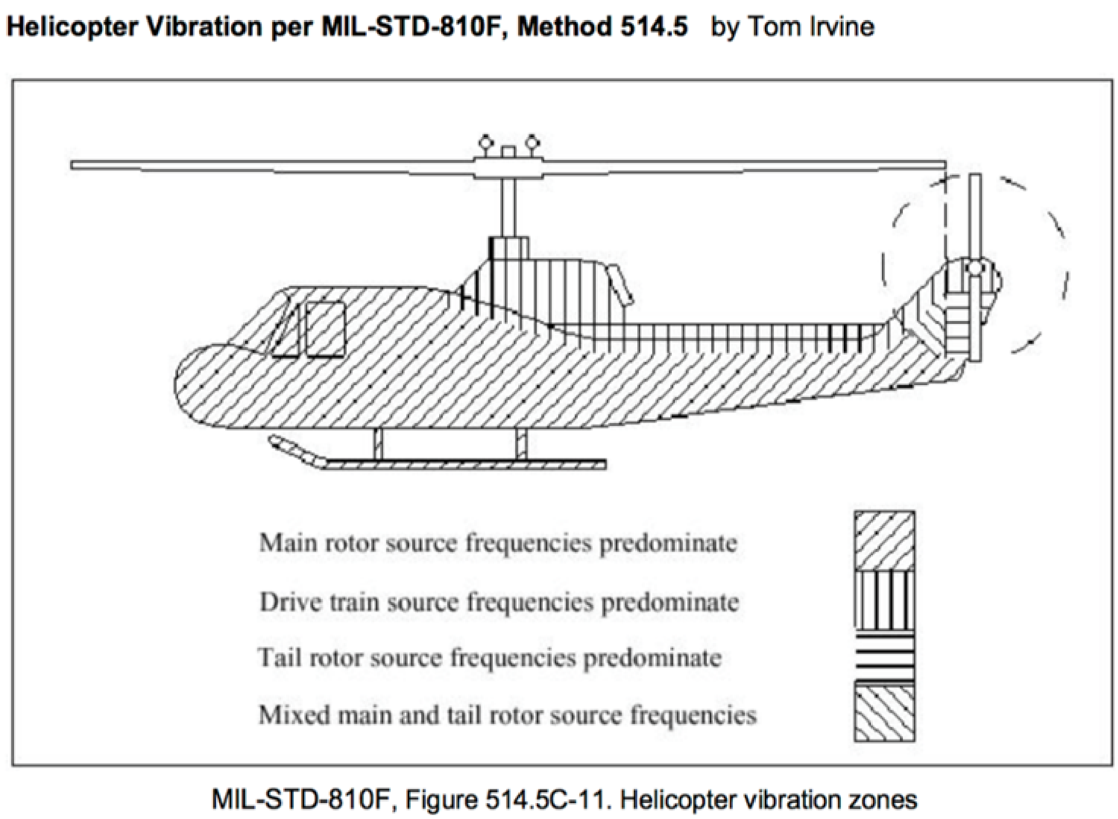

Figure 16: Frequency of vibration of various parts of a helicopter

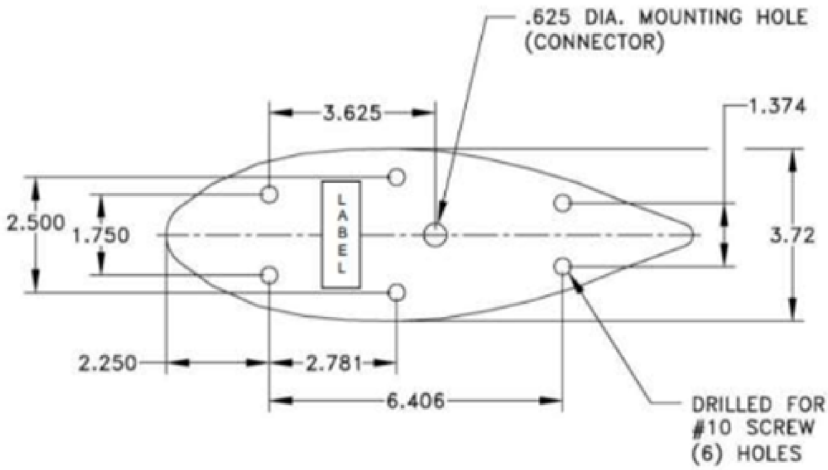

Figure 17: Typical mounting pattern of L3Harris antennas

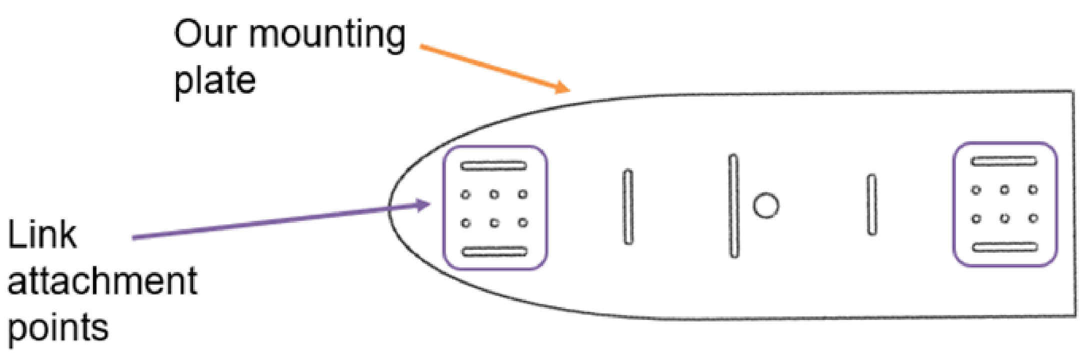

Figure 18: Mounting plate designed by student team with attachment points for mounting links and an antenna

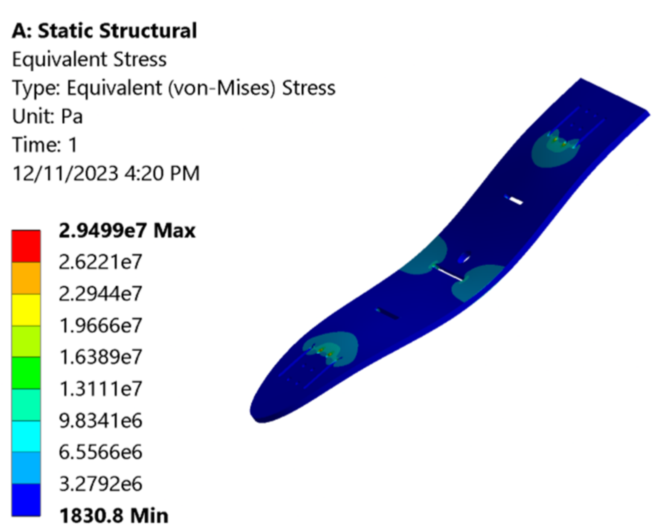

Figure 19: Ansys simulation outputting Von-Mises Stress acting on mounting plate

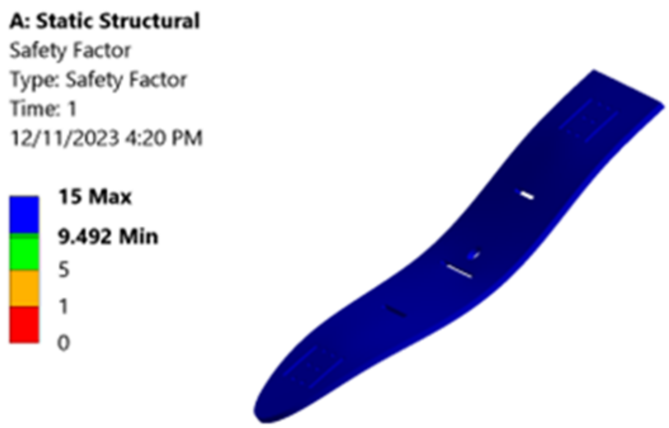

Figure 20: Ansys simulation outputting safety factor of the antenna mounting plate design

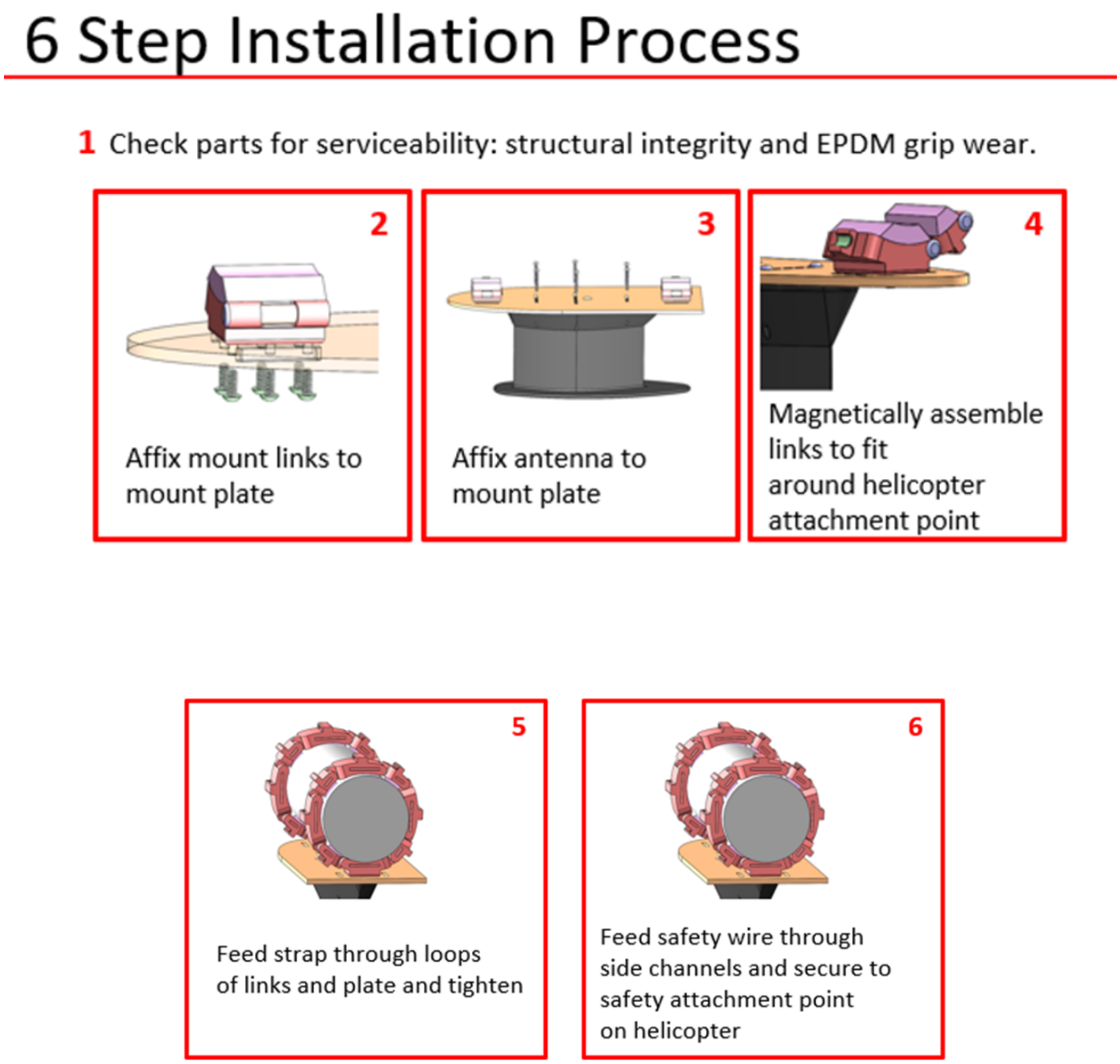

Figure 21: Process of installing the UAAMS onto a rotary flight vehicle