

Ground and Air Assistance Vehicle

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Introduction

The product that we have designed is an Unmanned Air and Ground Vehicle (UAGV) intended to deliver a payload while also being able to perform surveillance activities. The vehicle is a multifunction system, with the ability to deliver cargo for different clients as well as providing aerial and ground scouting and reconnaissance. This machine has a vertical take-off and landing (VTOL) system, along with ground functionality.

By combining ground and air capabilities, we are broadening the reach of unmanned vehicles. Many vehicles today are constrained to a certain medium; ground vehicles can only function on the ground, and aerial vehicles only function in the sky. This vehicle offers access to terrain that is difficult to reach safely by humans, which is often the case in disaster situations. The transportation system allows it to overcome obstacles. By accessing these various environments, vital services can easily be fulfilled that would otherwise be difficult or impossible to achieve, such as delivering aid to those in need and surveying in extreme climates, geography and urban environments. This product is aimed primarily to disaster relief agencies, the military, and surveyors.

Objectives

The major objectives in this project were to design an aerial vehicle, ground vehicle, and crane all in one package. This required six major assemblies: two intermeshing rotors (for heavy lifting), a tank tread system (for off-road capabilities), a heavy-lifting crane (for delivering and receiving cargo), the powertrain (to provide power and functionality), surveillance equipment, and a body to put all these parts into.

Geometric Modeling

Rotor Assembly

The rotor assembly consisted of many parts, intended to make it realistic and maintain the functionality of actual helicopter rotors, while performing the tasks that we desired. Because this assembly consisted of many parts, including bolts, nuts, and pins, only the integral components will be discussed. Figure 1 shows the overall assembly with labels for future reference.

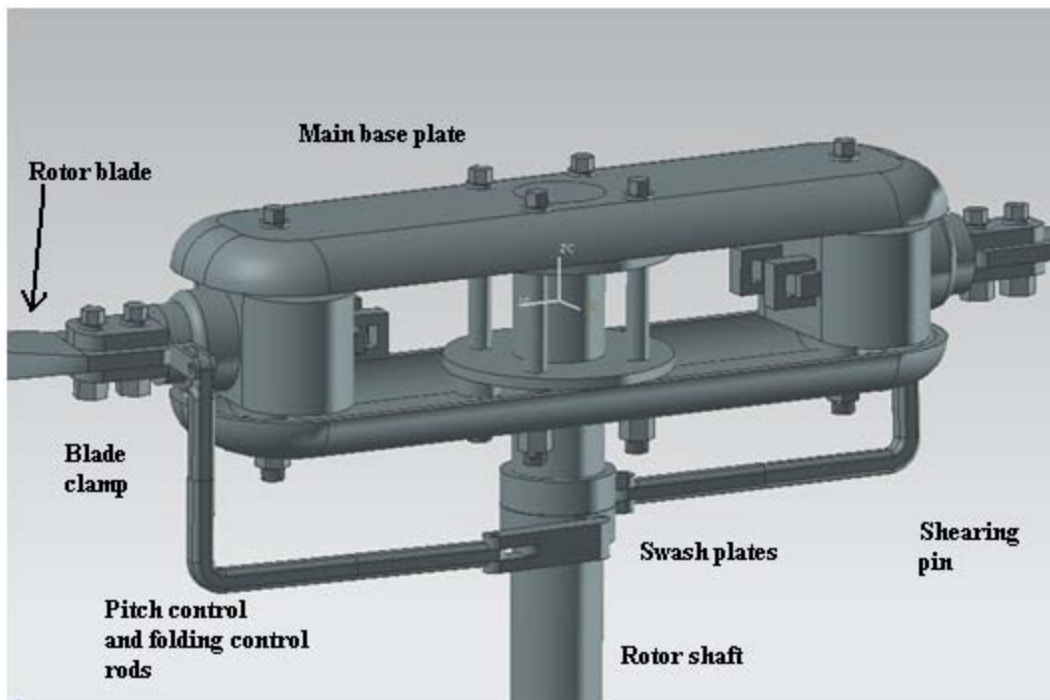


Figure 1. Rotor assembly

Rotor Shaft

The first major component was the rotor shaft. The rotor shaft connected many major mechanisms and was the object that was transmitted the rotational motion. This part was started by simply creating a 2.3 inch long, 2 inch diameter extrusion, seen in Figure 2a. Then a .25 inch thick, 5 inch diameter extrusion was placed on both sides of the previous protrusion (Figure 2b).

Holes were then created (circular array) around the radial axis for large bolts to go through (Figure 2c). Finally, the shaft was extended 3 feet downwards and 1 inch upwards, hollowed out, and a hole was placed at the bottom to later attach a universal joint coupling (Figure 2d), to make the final product seen in Figure 2e.

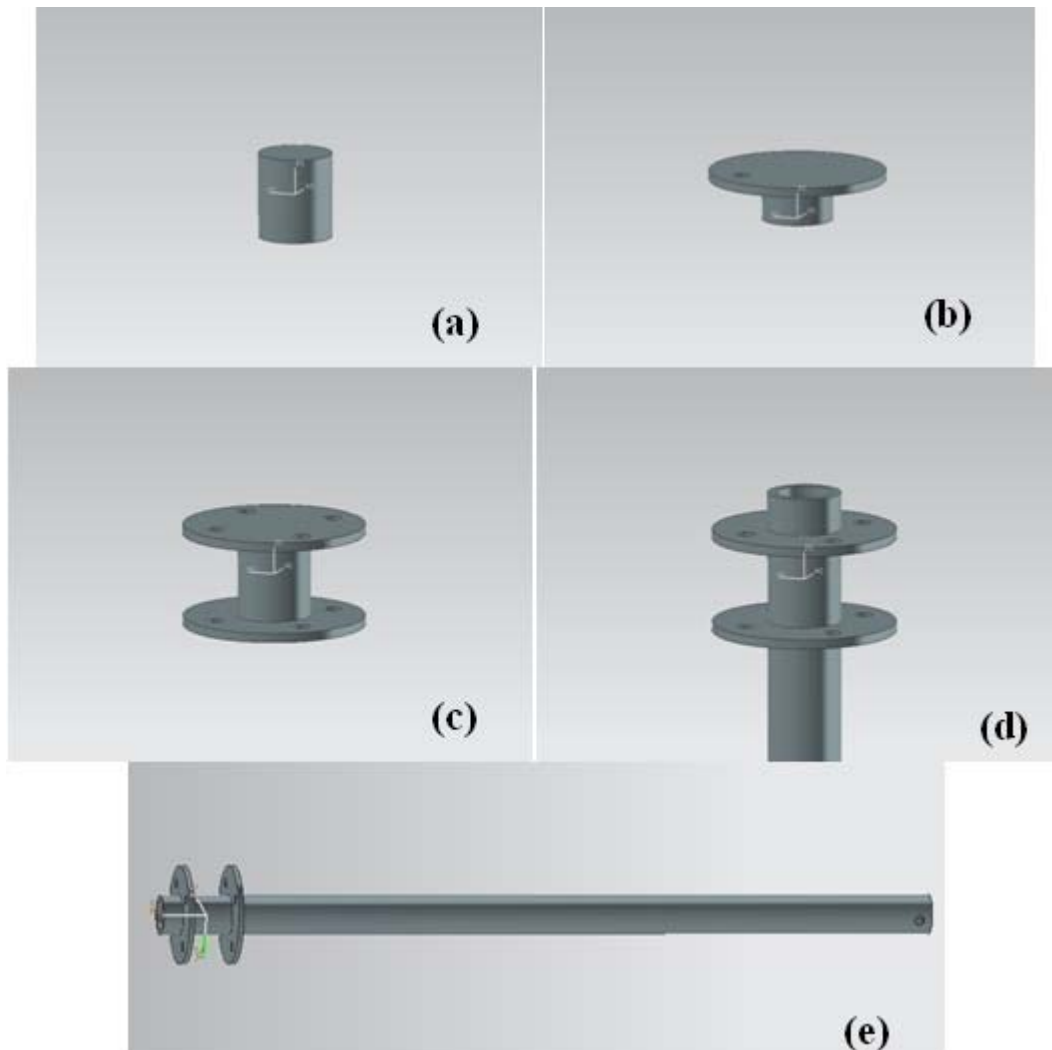


Figure 2. Creation of rotor shaft

Main Base Plate

The main base plate was connected to the rotor shaft and served as a clamp that held the rotor blade connectors in place. This began as a 5 in. x 18 in. rectangular protrusion with rounded

edges (Figure 3a), and the upper lip was then rounded to be more aerodynamic (Figure 3b). Three holes were then created and are shown in Figure 3c; one for the rotor shaft, and 2 for rods that acted as pivot points for the folding rotor blades. Holes were then patterned around the rotor shaft hole for bolts, and the inside surface was shelled to make the part lighter (Figure 3d).

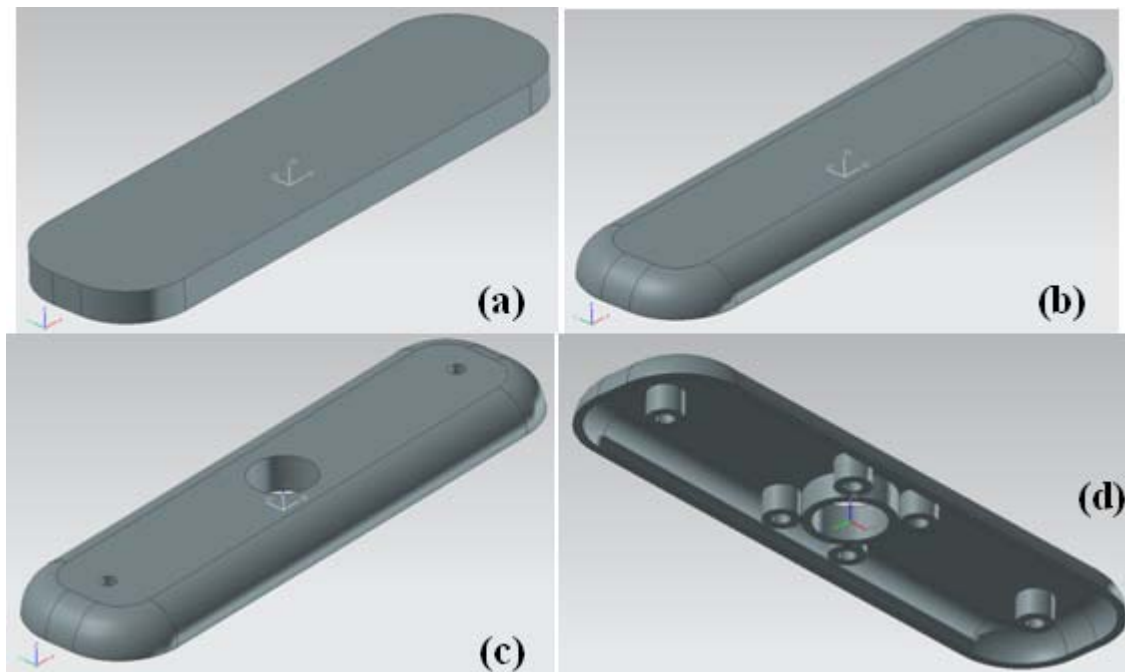


Figure 3. Creation of main base plate

Blade Clamp

The blade clamp specifically locked the blades in place with a couple of bolts, and was able to be rotated by connecting rods to control the blade pitch. This part began as a .5 inch thick, 1.75 inch diameter protrusion (Figure 4a). From this, two rectangular protrusions were created that were 2 inches long and .35 inches apart (Figure 4b). Holes were created for bolts, and a protrusion was created in the back to serve as a pivot point, allowing for a pitch mechanism (Figure 4c). A protrusion was then created to act as the moving arm whereby a connecting rod could control the rotation of this part.

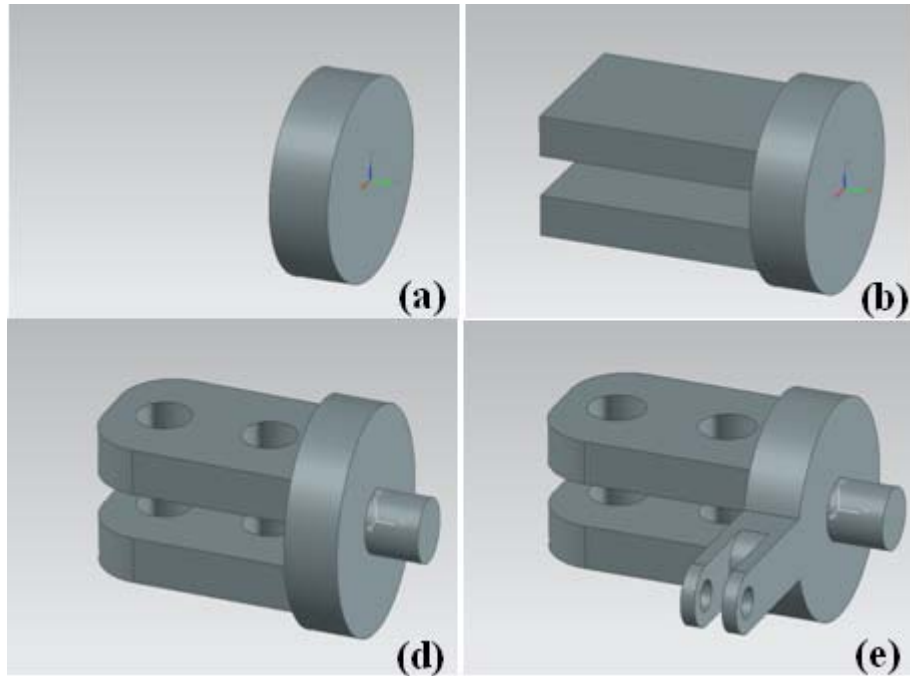


Figure 4. Creation of blade clamp

Blade Clamp Pivot

The blade clamp pivot acted as the base for the blade clamp. With this part, the blade clamp was able to rotate about its radial axis to provide pitch control for the aircraft. Creation of this part began with two rectangular, parallel protrusions. A circular protrusion was then created (Figure 5a) with a hole large enough to mesh with the circular protrusion on the end of the blade clamp. Holes were then created on the ends of the rectangular protrusions where a shearing and locking pin would be inserted to constrain the clamps (Figure 5b).

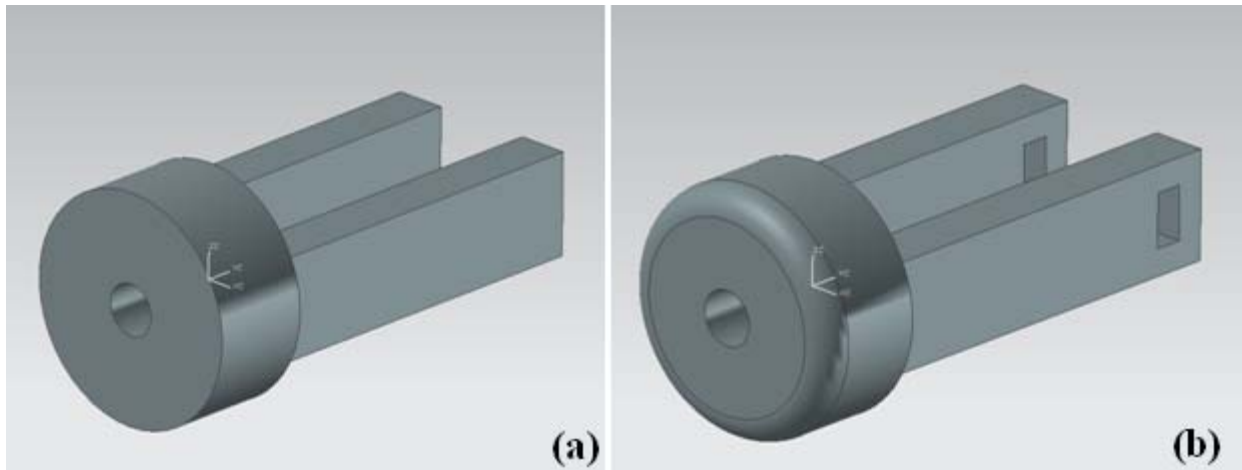


Figure 5. Creation of blade clamp pivot

Clamp constrainer/Blade rotator

Because of centripetal forces, it was necessary to have the blade clamps constrained and locked in place. This was accomplished by the part shown in Figure 6. Additionally, since it was desired to have folding rotor blades, this part could also pivot about its axis. Thus, this functionality was designed into this piece by creating a pivot point. The clamp constrainer began as a fairly elliptical extrusion with a circular hole placed from top to bottom (Figure 6a). This is where a bolt would be placed to allow for motion about that axis. Additionally, two rectangular cut-outs were made through the component, which is where the rectangular protrusions from the blade clamp pivot would be inserted. Finally, a circular protrusion was created for ball bearings to sit (Figure 6b).

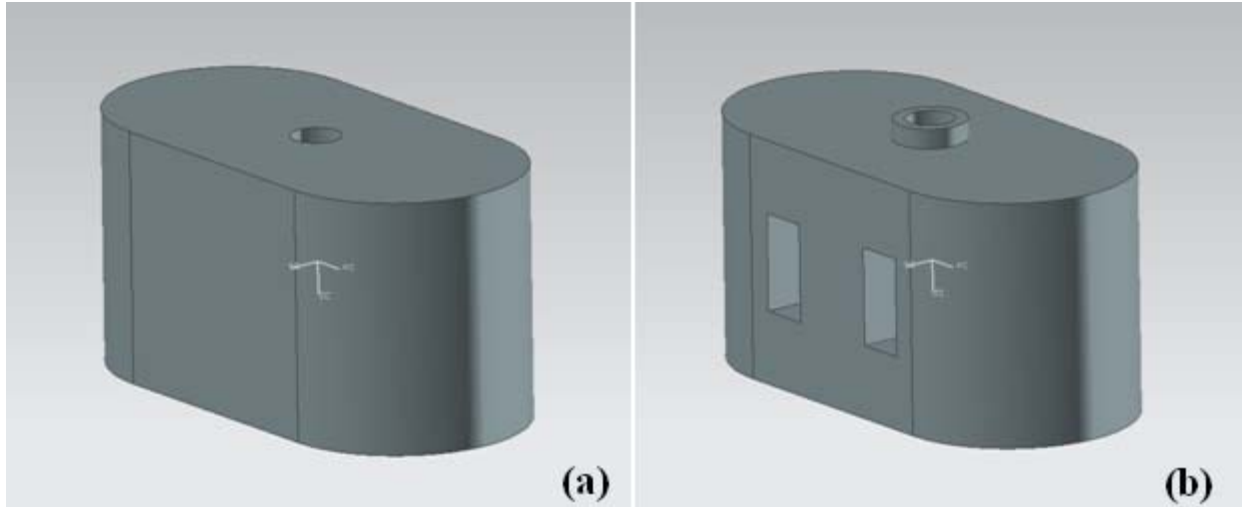


Figure 6. Creation of clamp constrainer/blade rotator

Shearing Pin

The shearing pin was simply an insert meant to lock the blade clamps in place, and intended to make the blades easily removable for repair while also being secure. The pin was simply an “L” shaped protrusion with a triangular pushbutton slider on the end (Figures 7a and 7b).

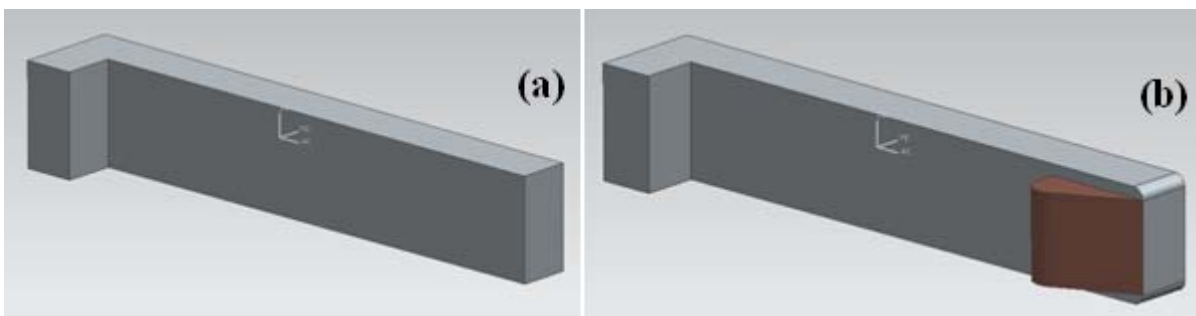


Figure 7. Creation of shearing pin

Standard Bolt

Bolts were needed in a variety of places. Although the lengths varied, they were all created in the same manner. A bolt began with a simple circular extrusion of varied length, but usually half inch in diameter (Figure 8a). A hexagonal sketch was then created and projected

onto a plane at the top of the bolt. This hexagon was then extruded to create the bolt's head (Figure 8b). A helix was then created at the base of the bolt. Once created, a circle was drawn in a sketch at the general location where the thread would begin. A swept protrusion was then created, with the circle as the element to be swept, and the helix as the guide curve (Figure 8c). When this swept body was created, it was subtracted from the main bolt to give the appearance of thread (Figure 8d).

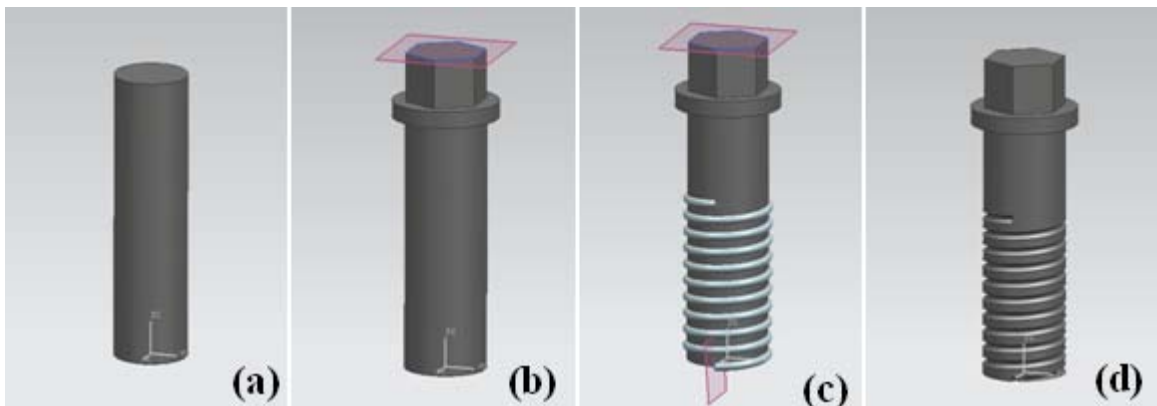


Figure 8. Creation of general bolt

Standard nut

Nuts and bolts were used extensively throughout this project. The nut was created by making a circular sketch of the same diameter as the bolt diameter. A hexagonal sketch was then created outside of the circle. This was then extruded to create the exterior of the nut (Figures 9a and 9b). A helical sketch was then drawn, and a circle was placed at the base of the nut in the same fashion as the process used when creating the bolt. A swept protrusion was then created to make the thread on the inside of the nut (Figure 9c).

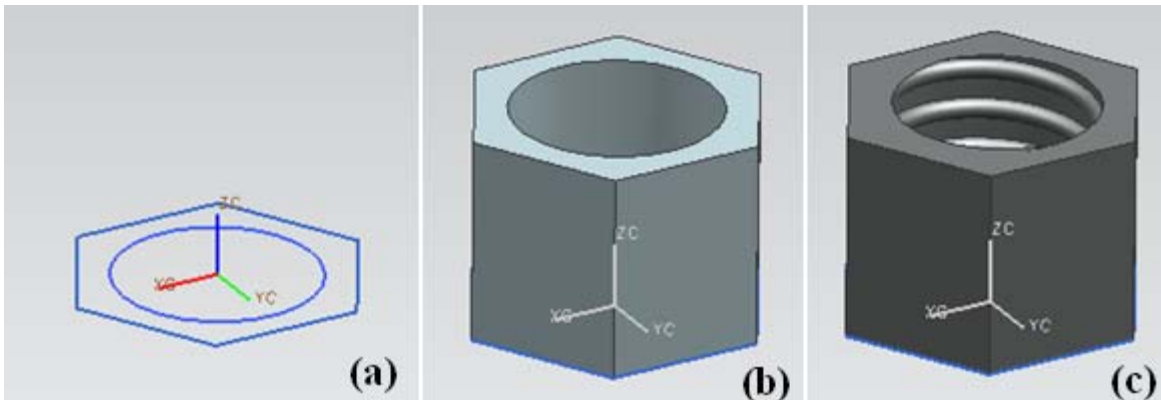


Figure 9. Creation of standard nut

Ball bearings

Because of the many rotating components, it was necessary to create ball bearings for a more realistic design. The most common ball bearing design used in this project consisted of a simple bearing case that fitted 8 steel balls. The cage was simply an extruded ring with holes punched out to accommodate the bearings (Figures 10a and 10b). The bearings were simply spheres and placed within the holes in the bearing cage (Figures 10c and 10d).

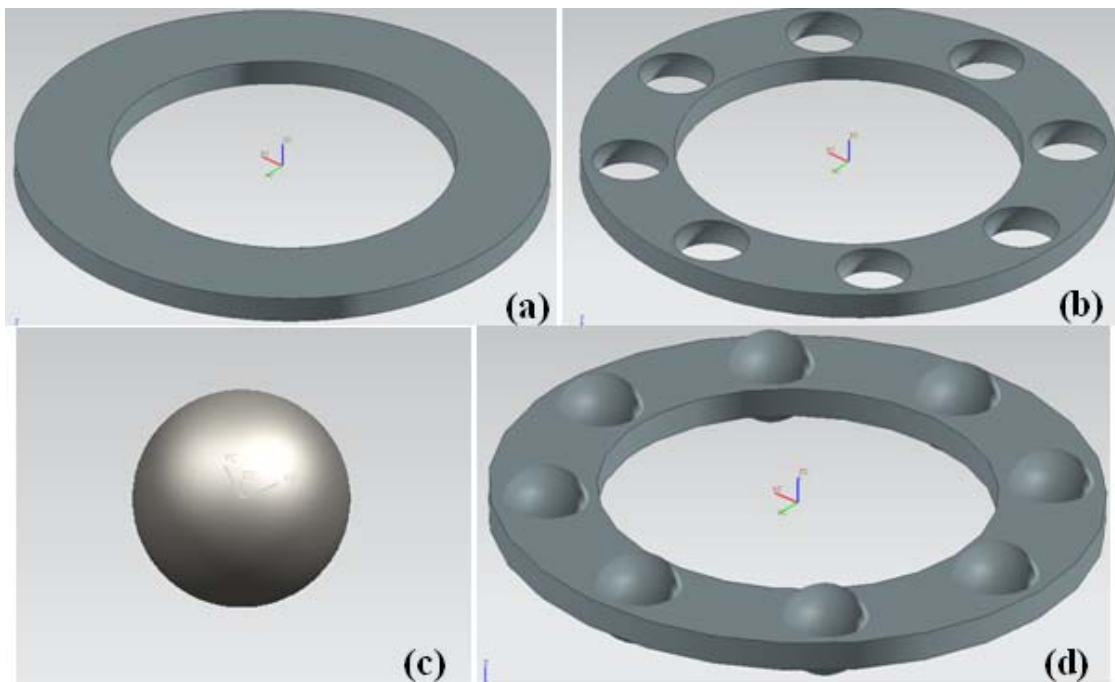


Figure 10. Creation of ball bearing assembly

Rotor blade

The rotor blade utilized an airfoil cross-section that was swept from the root to the tip of the blade. Part of the rotor was constrained between the blade clamps; this portion of the part was simply a rectangular protrusion with two hole cut-outs, seen in Figure 11a. An airfoil sketch was created on a distant plane, and this was swept over a curved line towards the clamped region (Figure 11b). The tip of the blade was then swept further back along a separate sketch (Figure 11c). The main portion of the blade was then connected to the clamped region by using the “Through Curves” option and creating surfaces to build a body in the open region, finalizing the blade (Figure 11d).

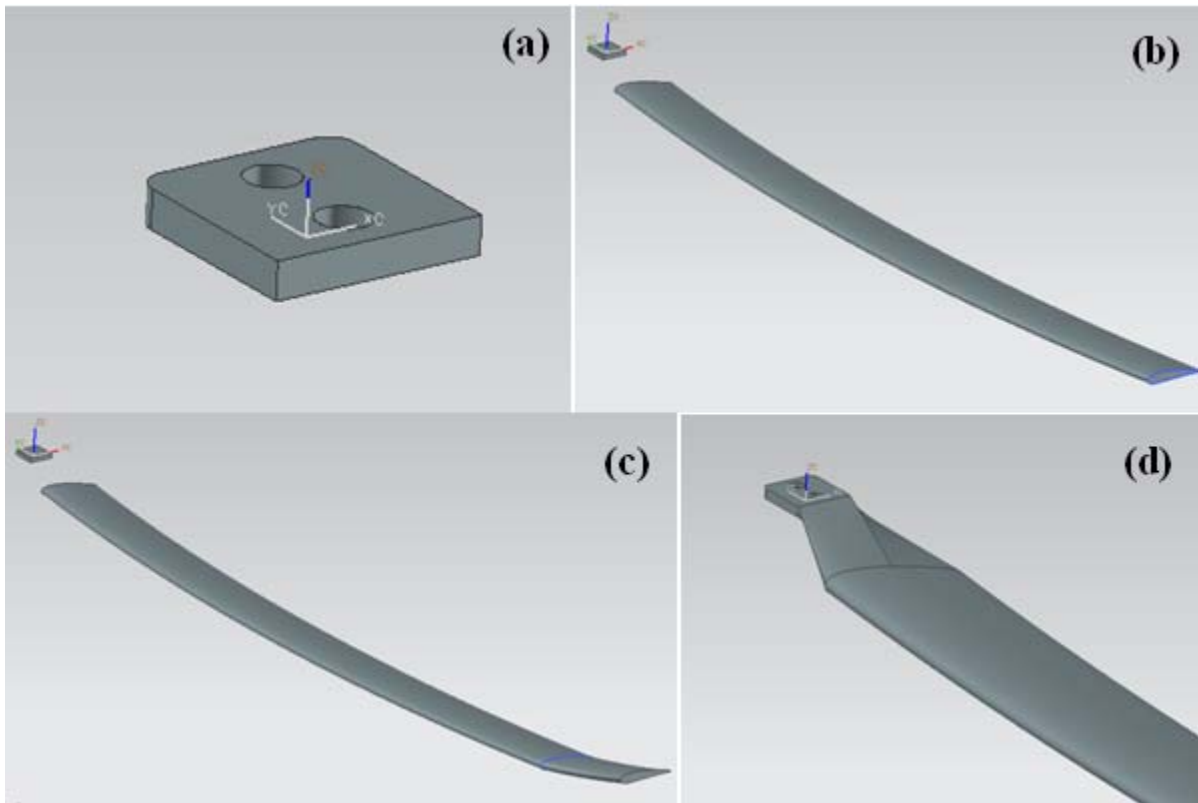


Figure 11. Creation of rotor blades

Swash plates

The swash plates were used to control the pitch of the blades. On normal helicopters, this is just one piece. However since this required an unconventional design to fold the rotor blades, two separate and slightly different swash plates were used. The following will give details on only one of the plates. In essence, this part needed to fit around the main rotor shaft and required an arm branching from it to be able to fold the rotors. The creation of this part started with an extruded circular ring with a protrusion from one side (Figure 12a). A rod branched from this protrusion is where a connecting rod would later be attached to provide pitch and folding abilities. Cut-outs were made where necessary to appropriate fit another rod.

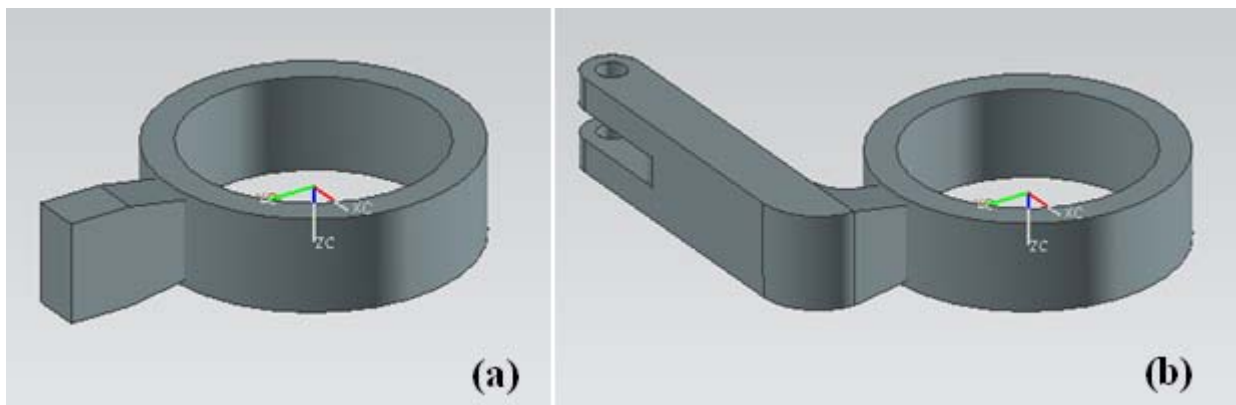


Figure 12. Creation of swash plate

Pitch Control Rods

The pitch control rods were used to adjust the angle of attack of the blades, making proper flight feasible. They also provided the ability to fold the rotors due to their simple, yet unique, design. Figure 13 shows the three rods in the actual design.

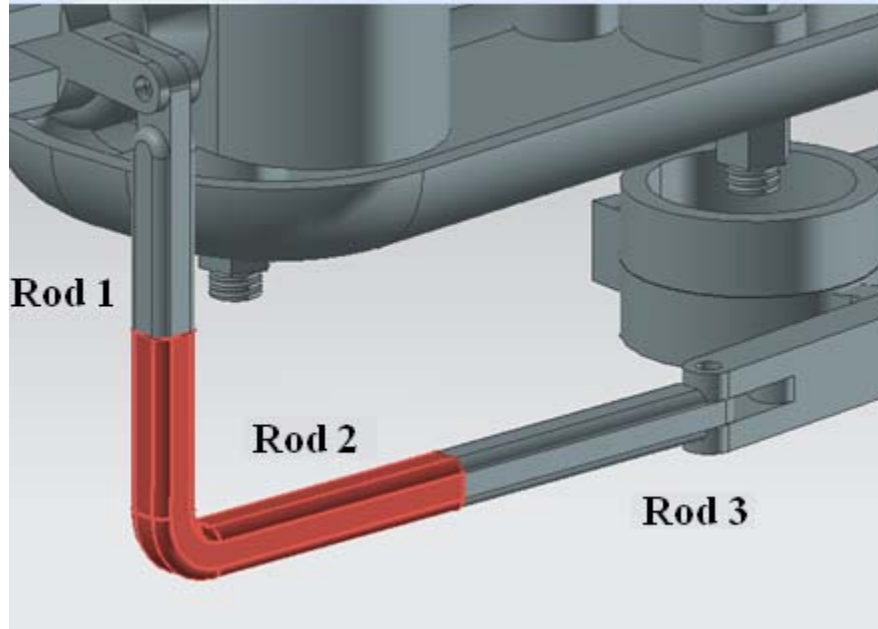


Figure 13. The three rods that functioned to control pitch and blade folding

To design these three rods, they were first designed as one solid component, taking the general shape of the desired rods (Figure 14a). The “L” shaped rectangle had the edges blended to be more aesthetically pleasing, and also had the ends cut out to make the joints (Figures 14b and 14c). Once completed, the rods were individually cut out from the overall part, creating Rod 1, Rod 2, and Rod 3 seen in Figure 13. These individual components either had holes placed on the ends or cylindrical protrusions meant to mesh with the holes (Figures 14d, 14e, and 14f)

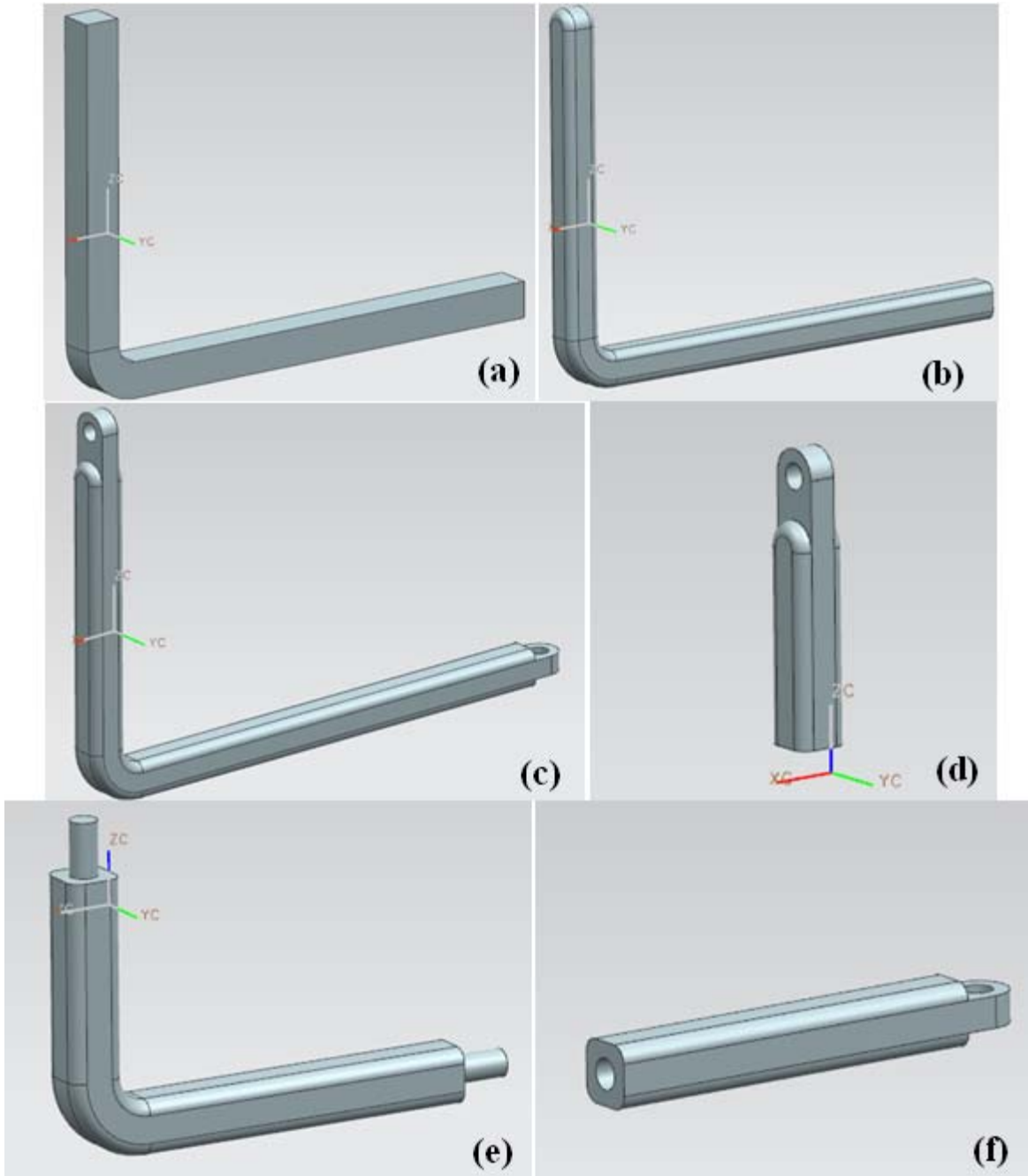


Figure 14. Creation of control rods

Drivetrain Assembly

To make the unmanned vehicle realistic, various components of the drivetrain were modeled. This included universal joints, a motor, crankshaft, and axles to the rear portion of the treads. This assembly is seen in Figure 15.

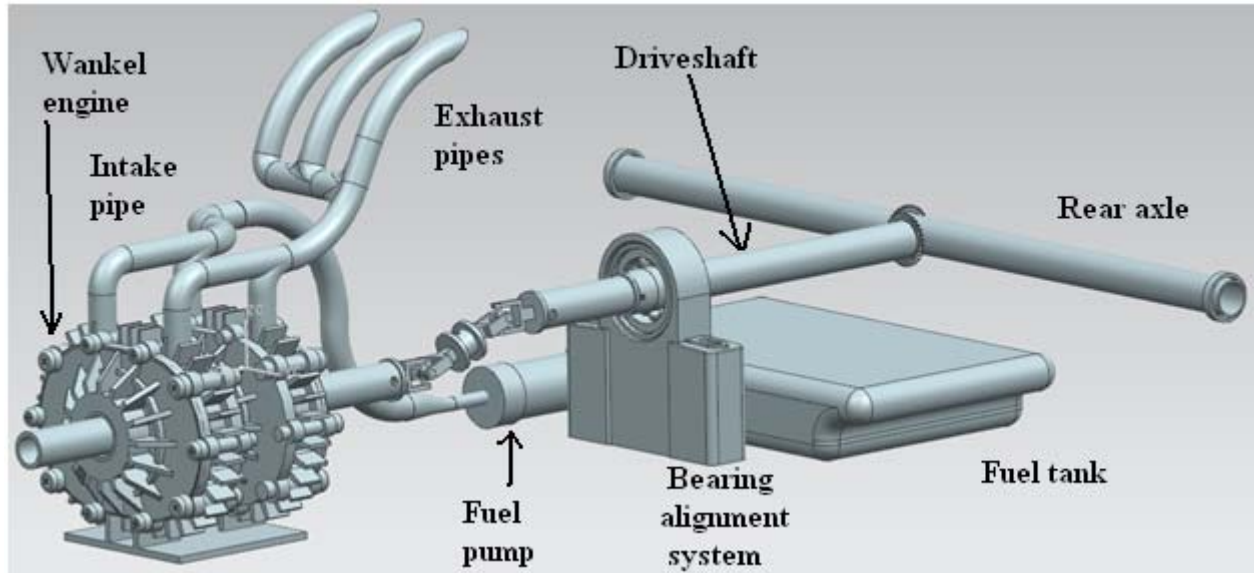


Figure 15. Drivetrain components

Because of the complexity of some components, many steps will be excluded and the overall manner in which the part was made will be details.

Dual Wankel Engine

The dual wankel engine was the powerplant for the UAGV. The creation of the Wankel engine began by performing an elliptical protrusion with cutouts for bolts, seen in Figure 16a. Next, a fin was created for structural integrity, and then was patterned in a circle around the centerpoint of the first plate (Figure 16b). Next, another fin was created on the backside of the main plate, and patterned in both circular and rectangular arrays, and mirrored, to create fins all around the perimeter of the part (Figure 16c). This was then mirrored create one Wankel engine, which was then mirrored entirely to create the dual Wankel engine seen in Figure 16d.

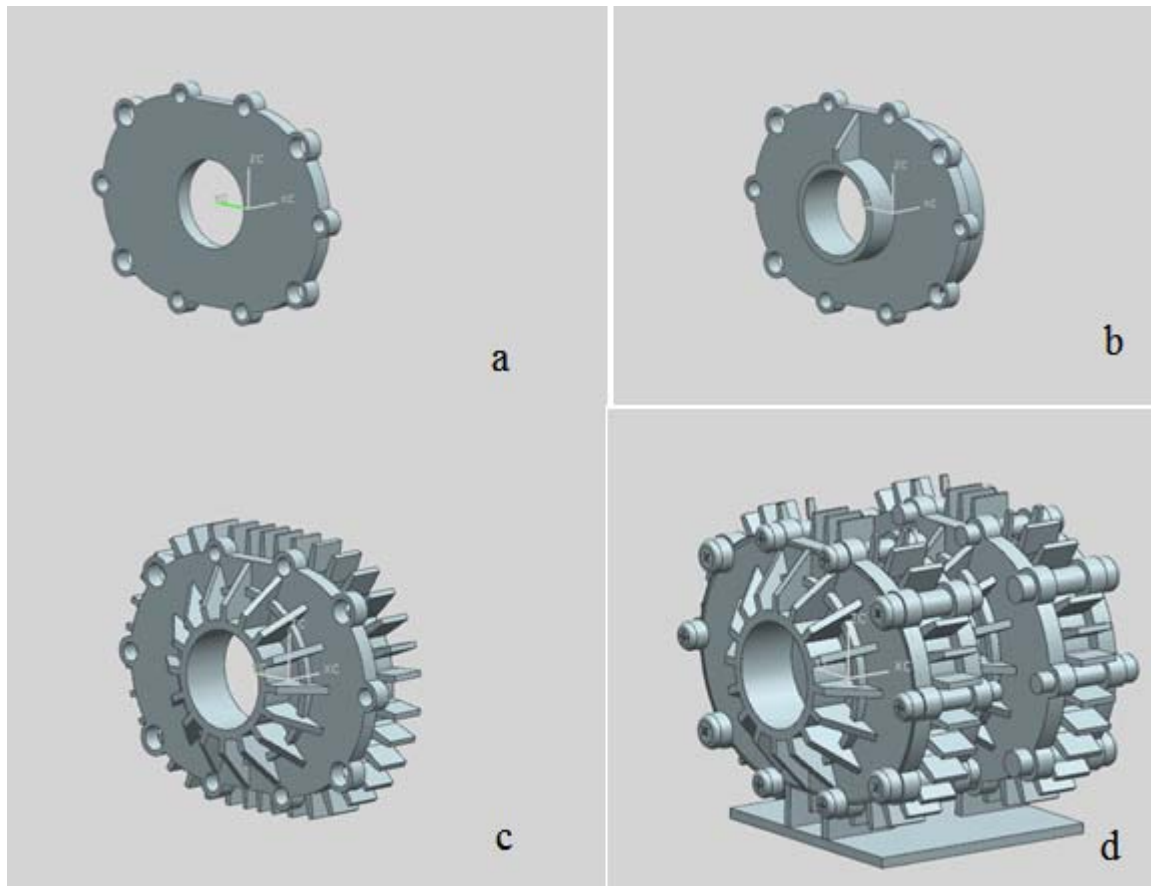


Figure 16. Creation of Wankel engine

Intake/Exhaust System, Fuel Pump, Fuel Tank

To make the vehicle more realistic and to take note of the limited amount of internal space it would have, the intake pipes, exhaust pipes, fuel pump and fuel tank were roughly modeled. When the Wankel engine was created, cutouts were left for the pipes to enter and exit the combustion chamber. The pipes were largely swept circles that followed linear and curved patterns (Figures 17a-d).

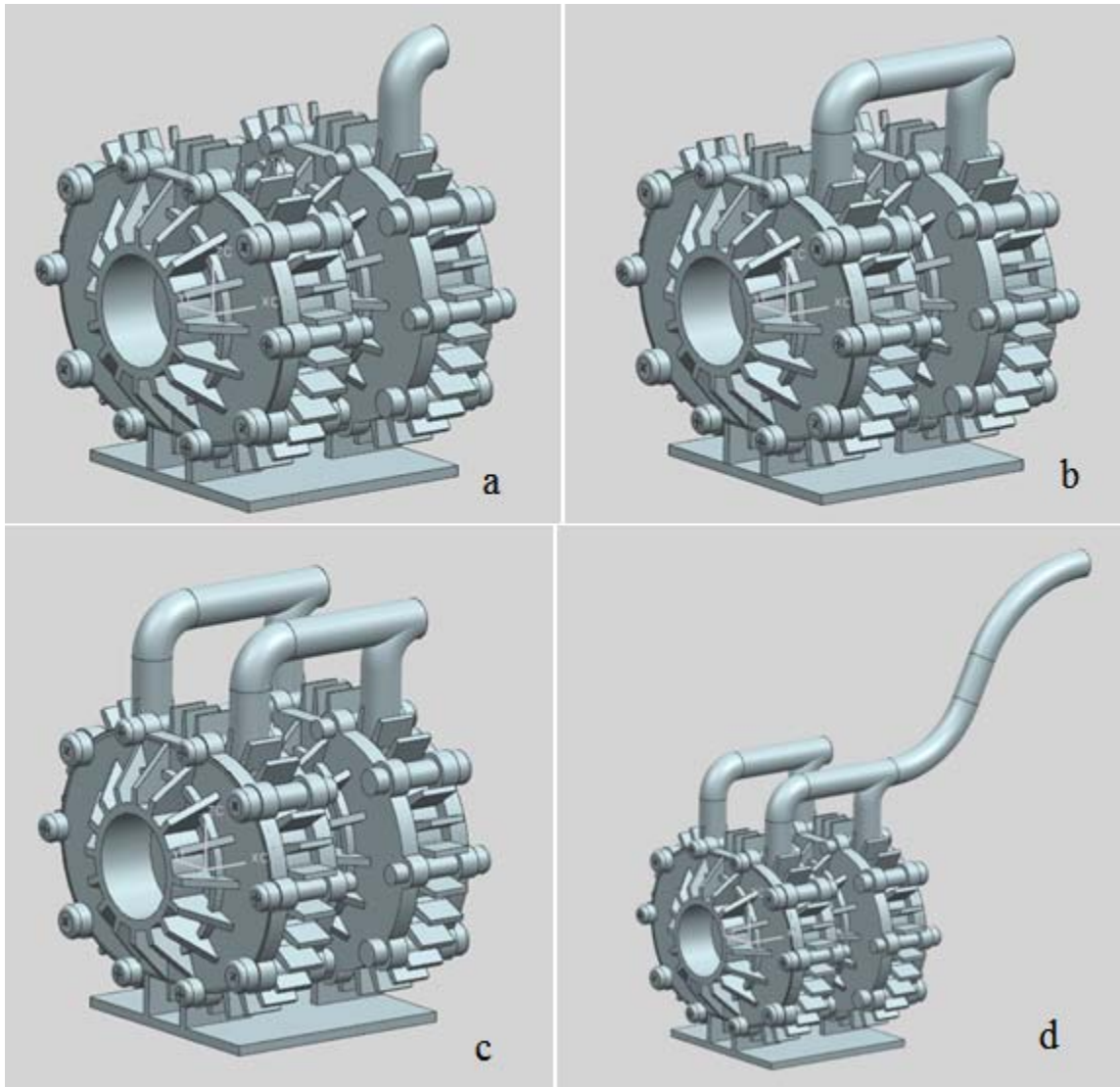


Figure 17. Creation of the intake and exhaust pipes

These pipes were linked and directed to the desired areas; the intake pipes went from a fuel pump and fuel tank, and the exhaust pipes extended upwards to exhaust to open air. The fuel pump was simple a series of circular protrusions, and the fuel tank was an extruded rectangle with cutouts, edge blends, and a hollowed inside (Figures 18a-d).

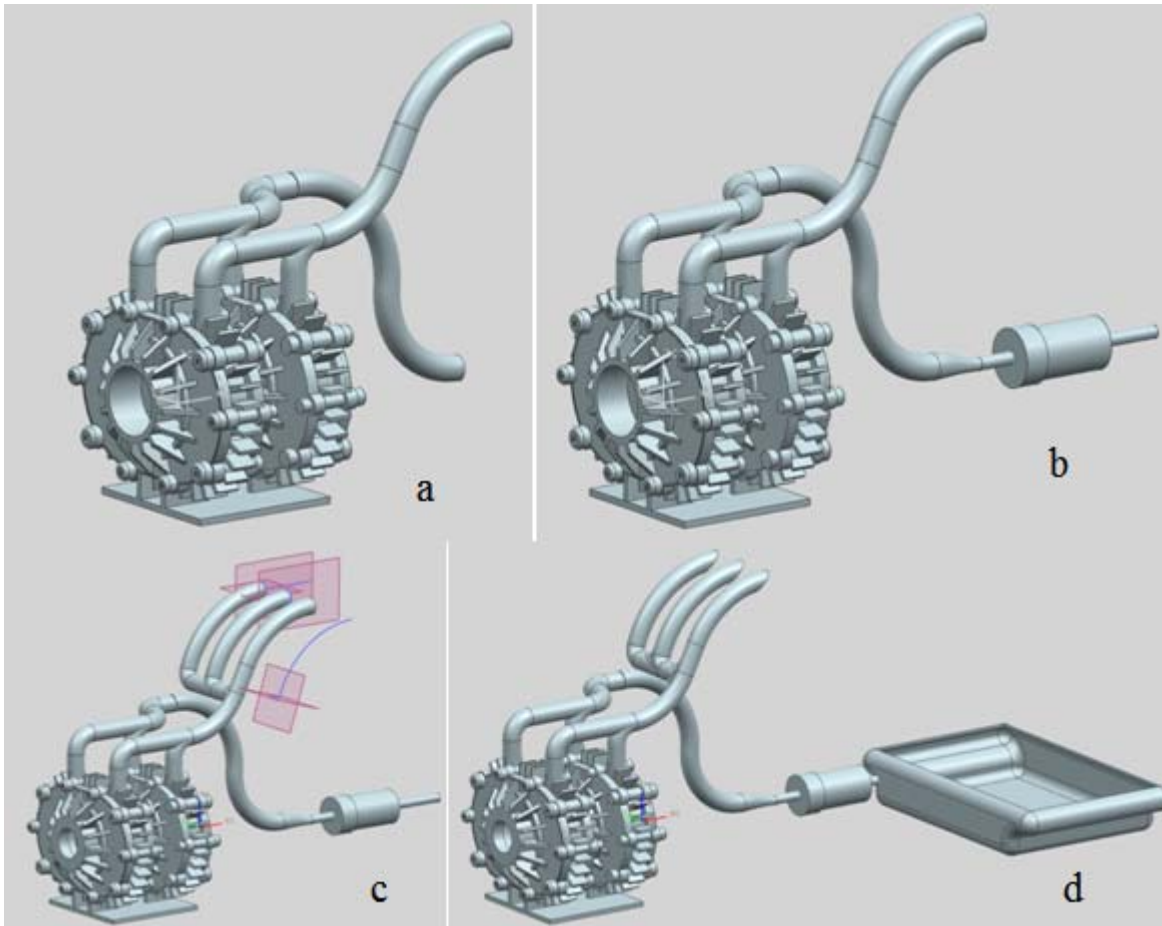


Figure 18. Creation of pipes, fuel pump and fuel tank

Driveshaft and Universal Joints and Connectors

The drive shaft was simply a hollow tube with holes at the end to attach a universal joint connector (Figure 19).

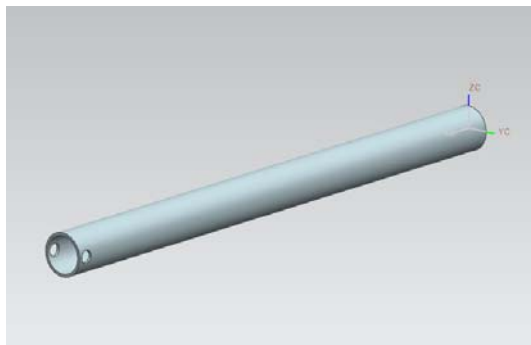


Figure 19. Main driveshaft

Connected to the driveshaft was a universal joint connector, intended to transmit power in a different direction than radial direction of the motor. To make a universal joint connector, simple circular and rectangular protrusions were performed (Figures 20a-d). The universal joint was a circular protrusion patterned in a circle, with the inner corners having edge blends (Figures 20e-g).

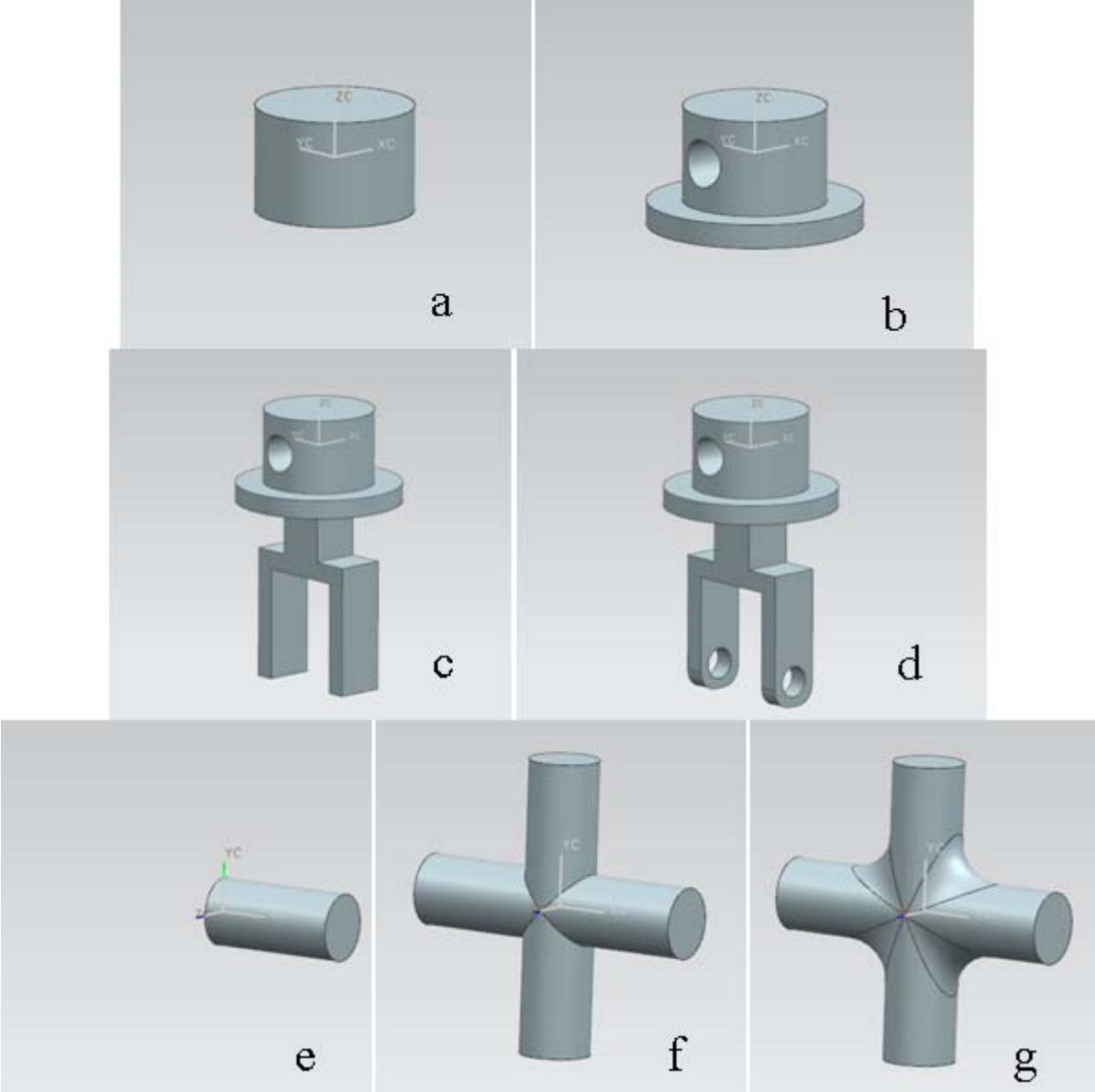
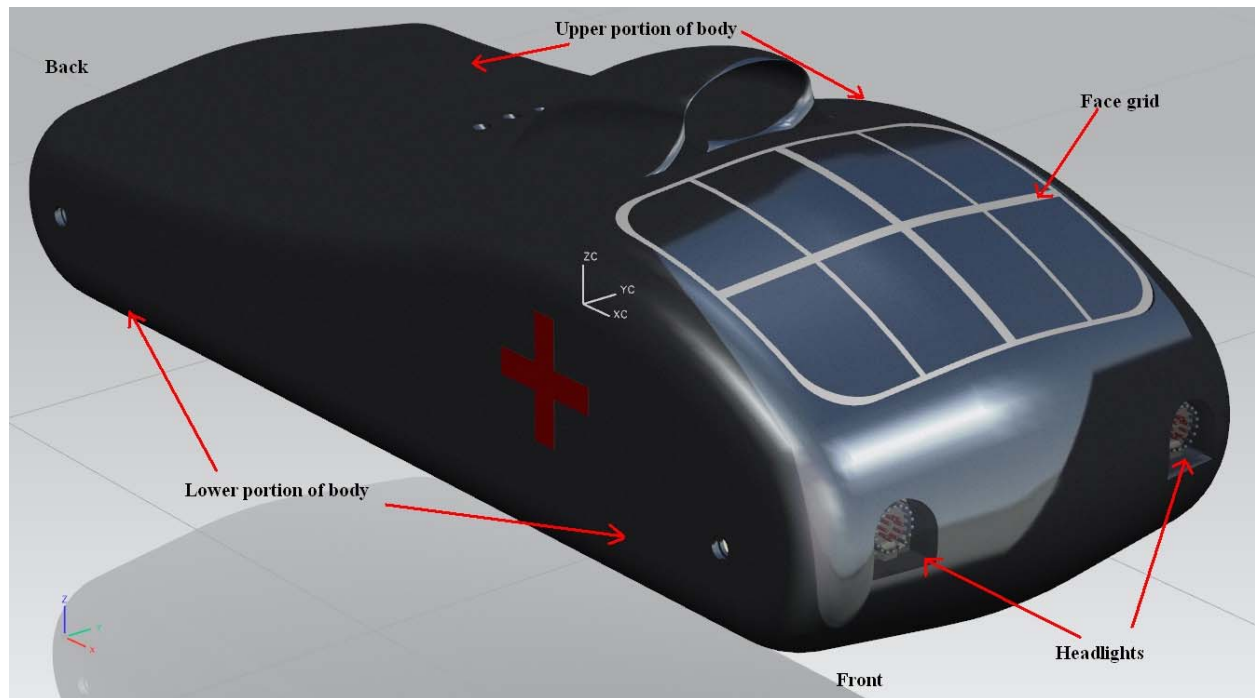


Figure 20. Creation of universal joint parts

Vehicle body assembly

The body of the vehicle consisted of four main parts: the upper half, the lower half, the headlights and the face grid. These four items are labeled in Figure 21, and their creation will be explained in detail in the following sections.



Upper and lower halves of body

The body of the vehicle was constructed as one solid piece at first, seen in Figures 21a and 21b. This was later hollowed out and cut into two large pieces; the top and the bottom, so that two manufacturable portions were made (Figures 21c-e). The upper half of the body was also divided into three separate components: the main portion of the upper body, the headlights, and the face grid. The face grid was simply for aesthetics. To create this part, a grid-looking sketch was created below the body. This was then extruded through, and then the grid was subtracted from the main body (Figure 21f – h). To create the face grid as a separate component,

the intersection of the two bodies seen in Figure 21g was found, and this was set to be a separate component, seen in Figure 21i.

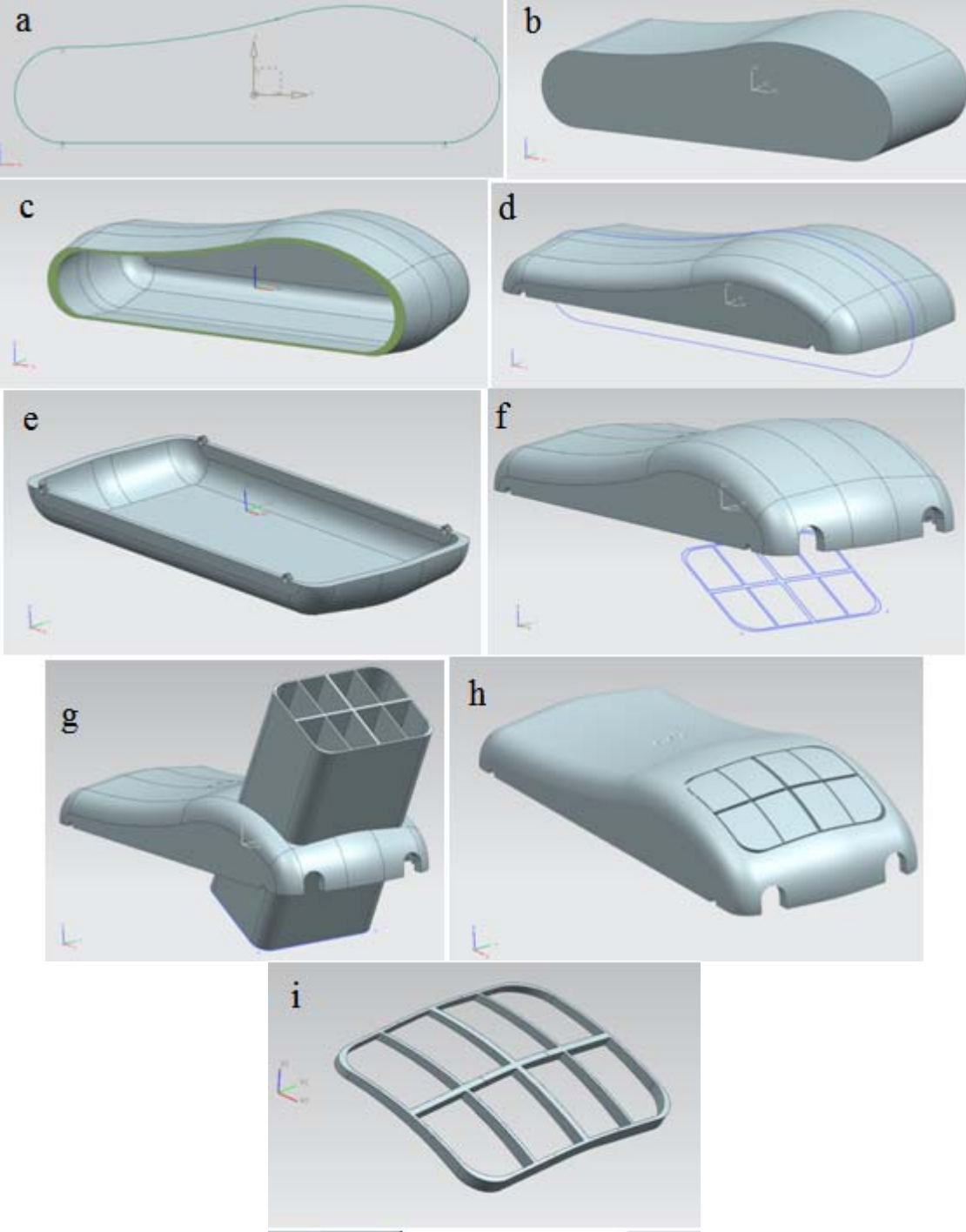


Figure 21. Creation of body components

An air intake on the roof was created to give better performance and aesthetics for a UAV. The intake began as a series of ellipses that were offset from each other, seen in Figure 22a. The “Through Mesh” command was used to join these curves to make a solid body, which was then shelled and had edge blends for better aerodynamics (Figure 22b and c). Additionally, a Red Cross symbol (the cross) was added to the side to cater this product towards disaster relief efforts (Figure 22d).

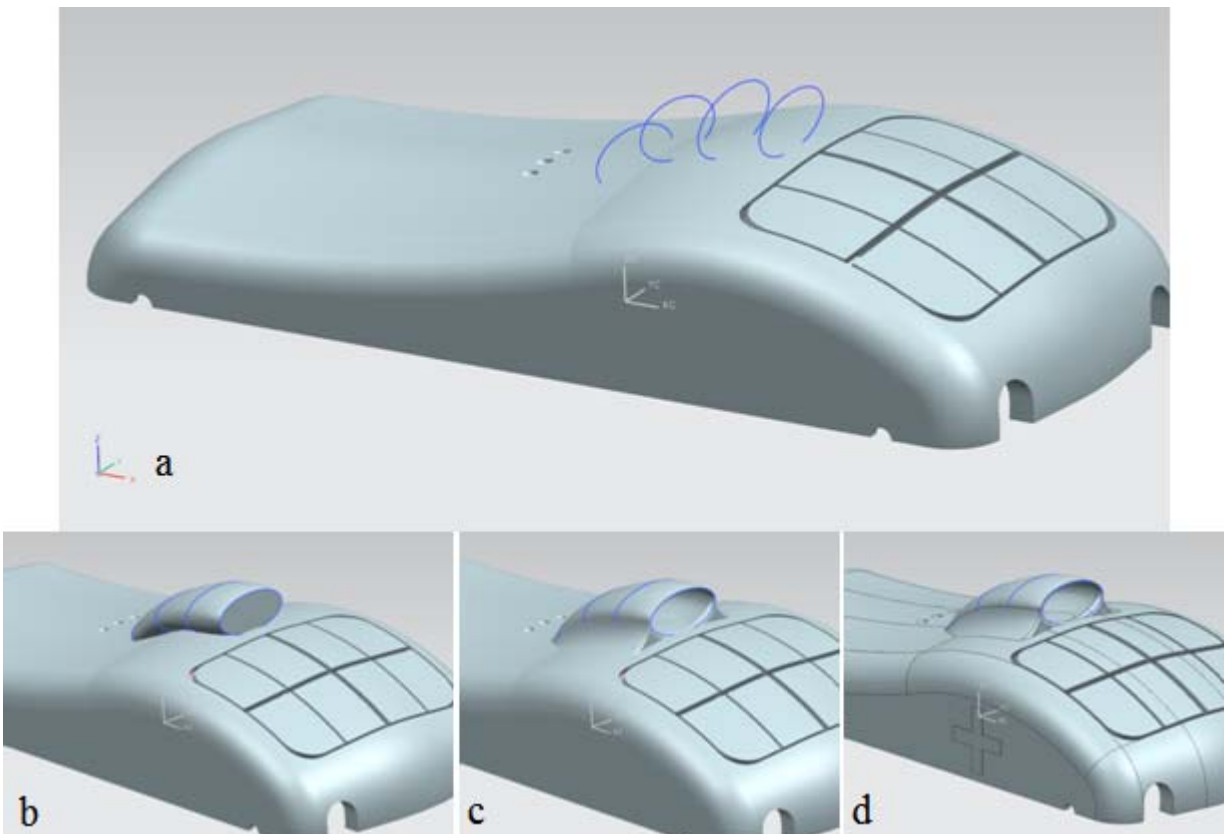


Figure 22. Creation of air intake

Headlights

The headlights were started by reusing the cutouts from the upper half of the body (Figure 23a). This was then hollowed, and protrusions to place the actual LED lights were created (Figure 23b). Finally, the lights were made by creating simple patterns (Figure 23c).

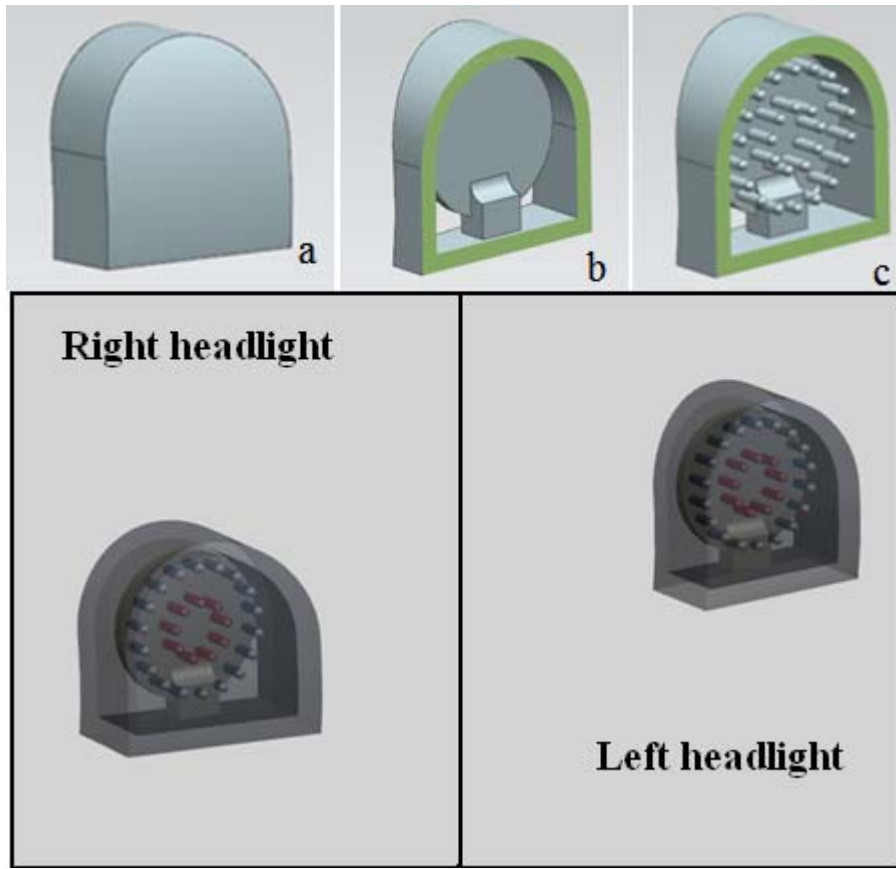


Figure 23. Creation of headlights

With all these components created, the overall assembly for the body, helicopter rotors, and drivetrain were completed. These can be seen in their rendered forms in Figure 24.

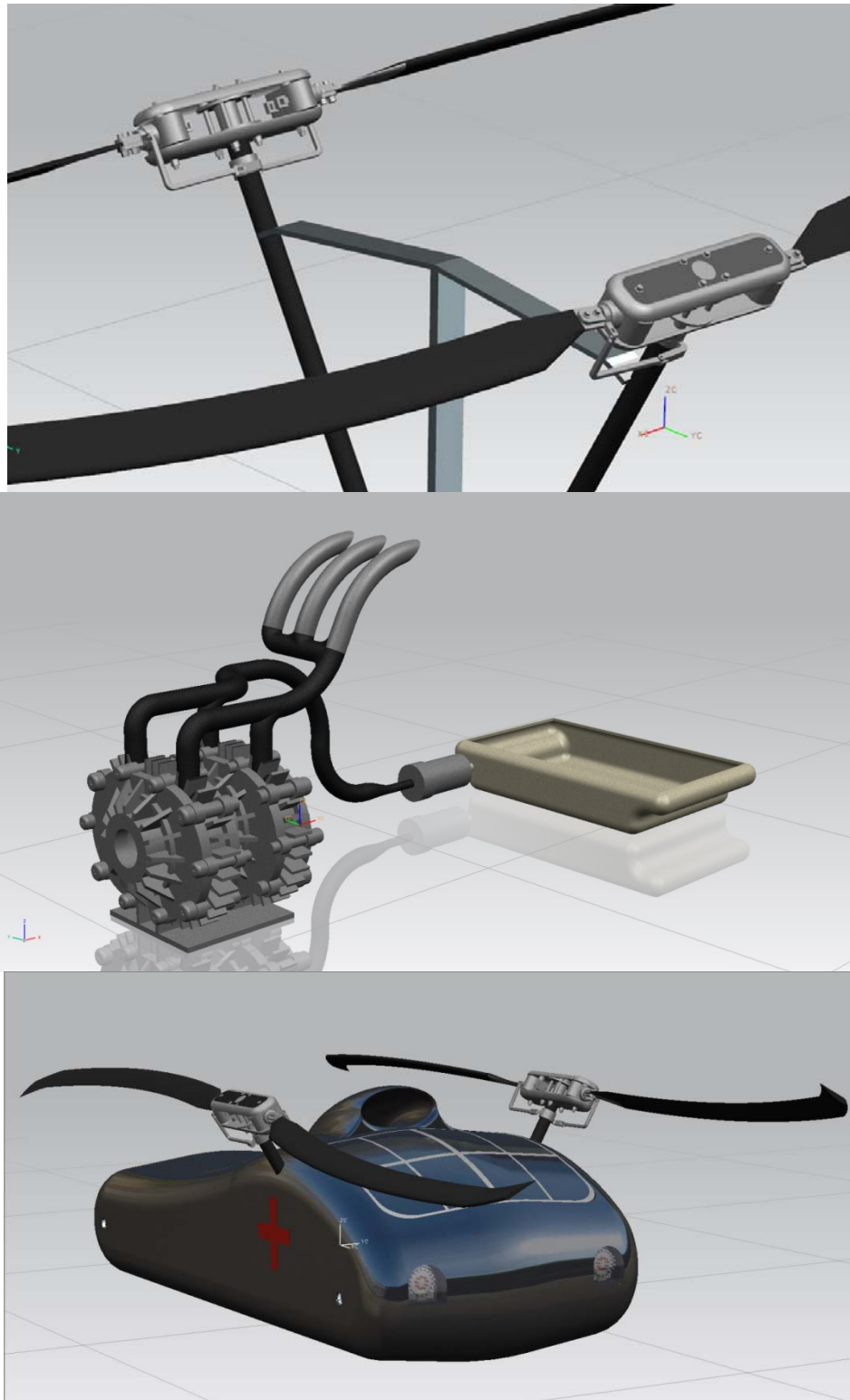


Figure 24. Renderings of three major assemblies

Crane Assembly

The boom crane used in the UAV concept has several parts including three arms that extend out from an extension arm, a pivoting base arm, several pneumatic cylinders, a gear, pinion, and electric motor. The crane was designed to fold into a 7 inch high space while maintaining a reach of several feet. A design was chosen in which the extension arm lays flat parallel to the base arm and both arms move up and down by way of pneumatics. To explore the CAD modeling process of the boom crane, several key features were chosen to review for either their importance or their complexity.

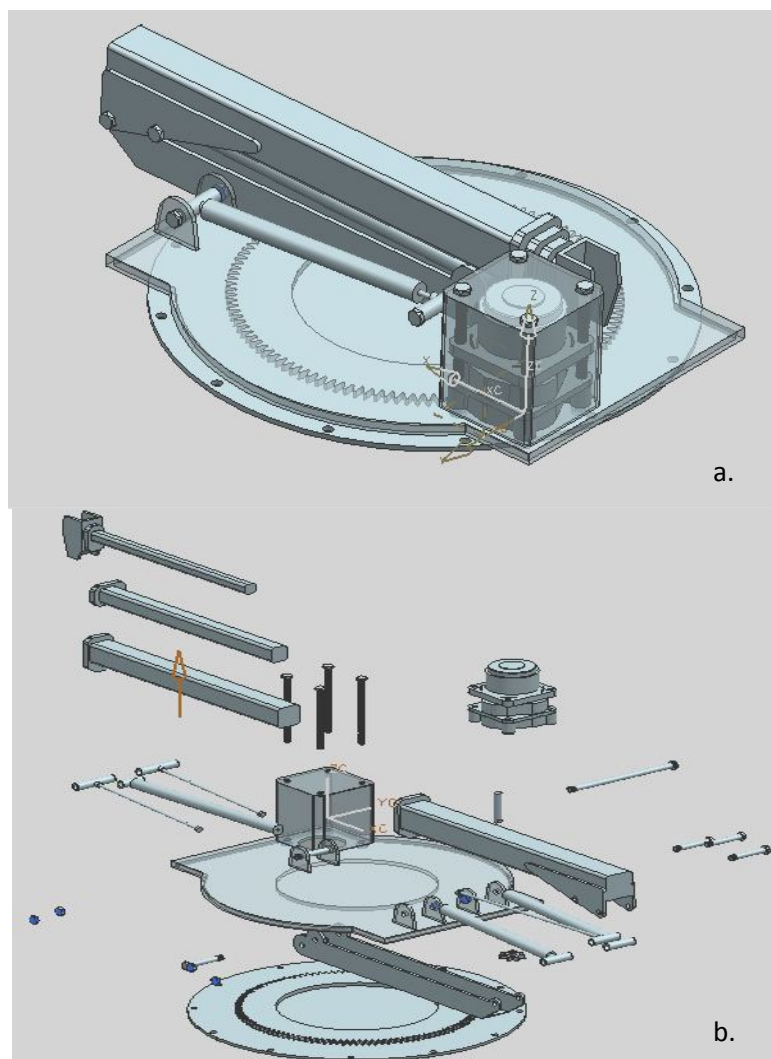


Figure 25. Crane Assembly

Piston

The piston is a pneumatic cylinder that provides the crane motion by applying force at different points of the arm to move each arm in different positions. It is composed of two parts, the plunger and the piston case.

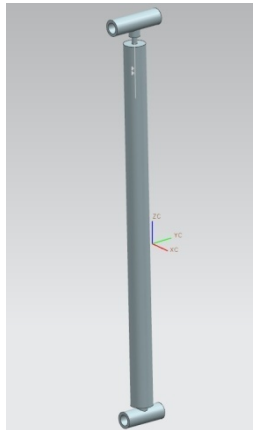


Figure 26. Pneumatic Cylinder

Plunger

The plunger is modeled by sketching two concentric circles on the XZ plane and extruding the sketch 3.5 in. Then two datum planes are created, one parallel to the XZ plane at the middle of the new cylinder and the other tangent to the inner circle and parallel to XY plane. On the plane parallel to the XY plane at the intersection between the two planes a 0.5 in diameter circle is extruded 0.375 in using the Boolean operation unite to unite it to the first cylinder created. Then a 0.25 diameter circle is sketched on the top of this new cylinder and extruded 11.5 in. Finally a 0.5 in diameter circle is extruded 0.25 in atop of the 11.5 in cylinder.

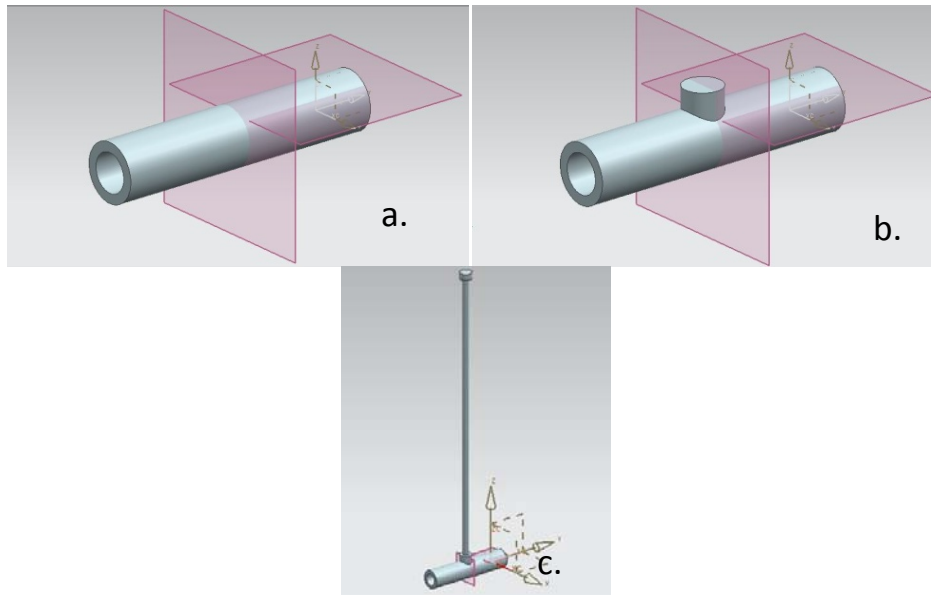


Figure 27. Plunger Creation Process

Piston Case

The piston case began by sketching two concentric circles and extruding the sketch 2.50 in. Then datum plane was placed tangent to the center circle at its top. A 0.5 inch circle was drawn on that plane at the center of the extruded cylinder. This new circle was then extruded 0.375 in and unite Boolean operation was used in the extrude dialog box. A 1 inch circle is sketched on top of the new cylinder and this new circle is extruded 12.5 in. This extrusion is then shelled with a thickness of 0.25 in. choosing the “Shell All Faces” type in the shell dialog box. A 0.25 in diameter is drawn on top of the cylinder and extruded using subtraction 0.25 in.

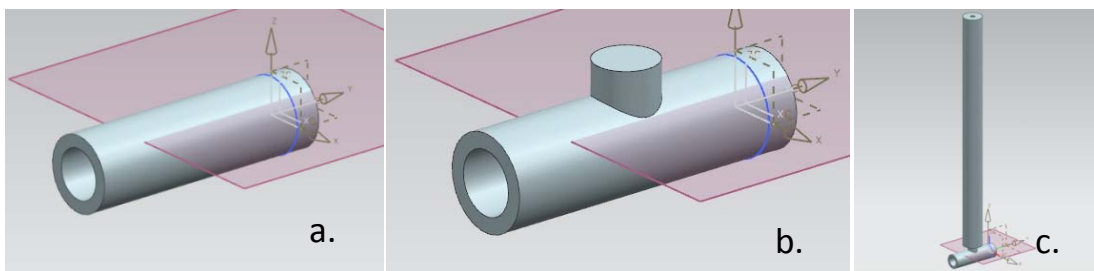


Figure 28. Piston Case Creation Process

Extension Arm

The first step is to sketch a triangular shape with rounded edges to act as a holder for the arm. The sketch is then extruded 0.25 in and then a 24 in by 2.5 in rectangle is sketched on the face of the new shape 1.7 inches from the bottom. Then the sketch is extruded 2.5 inches. A plane is then created 1.5 inches parallel to the XZ axis. The mirror body function is used to mirror the first body created as a holder. The rectangular extrusion is then shelled using the “Remove Faces, Then Shell” type with a .25 in thickness at the 2.5 x 2.5 face. The three bodies are then united using the unite command. Two simple wholes were created at the center of the two circular parts of the bottom triangular. Edge blends are used on the rectangular portion with a radius of 0.25 in. A 4 in by 3 in octagon is created on the surface of the 2.5 in by 2.5 in rectangular face and extruded 0.5 in. The edges of this extrusion are then edge blended with a 0.25 in radius.

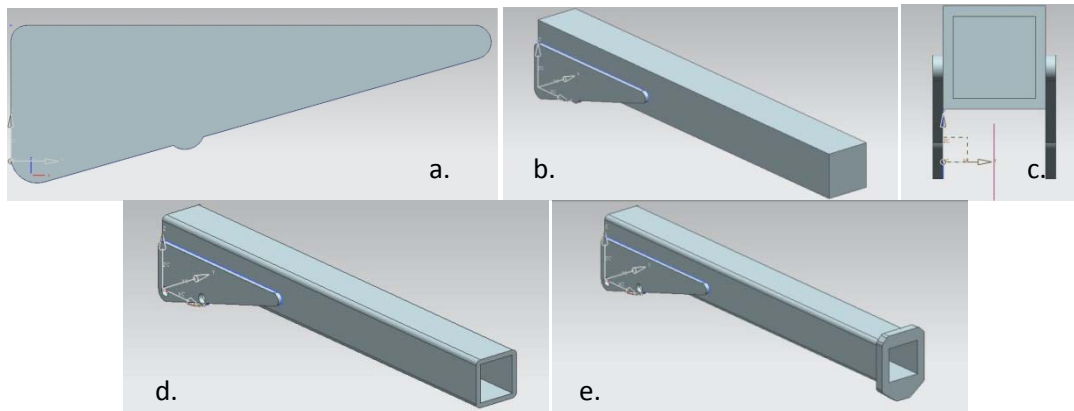


Figure 30. Extension Arm Creation Process

Base Arm

A 20 in long trapezoid is sketched with a 0.5 radius half circle at the end of the base. This is then extruded 2.5 in. Then a 2.00 by 3 inch sketch is made on the XZ plane at the flat end of the trapezoid with a top and end half circle of a 2 in diameter. The sketch is the extruded 2.5 in and united to the previous body. The new body is then shelled using the “Remove Faces, Then Shell” type and thickness of 0.25 in. At the center of each circle a 0.5 in diameter simple hole is made. Along the YZ plane a

sketch is made along the bottom of the new body between the two shelled faces 1.75 in by 2 in. Then it is extruded using the Boolean command subtract through all. This is done to remove a circular face without removing all faces with the shell.

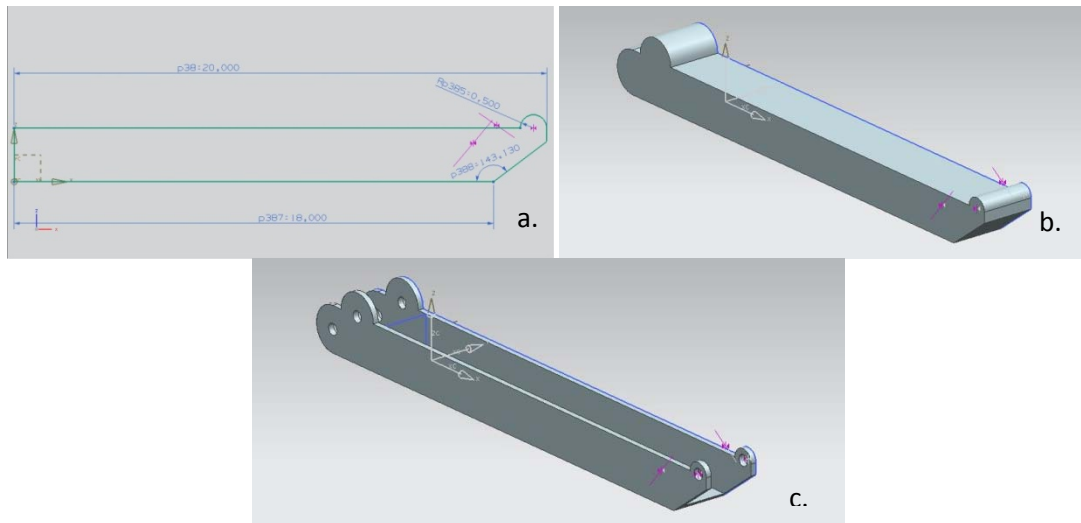


Figure 31. Base Arm Creation Process

Motor

A 4.918 in square is sketched along the XY plane and it is extruded 0.5438 in creating the first body. On the top face of this body sketch a circle diameter 2.118 in and extrude 0.18 in creating a new body. A 3.996 in diameter cylinder is extruded 1.65663 in on top of the new body. Then a 3.59 in diameter cylinder is extruded 0.455 in on top of the previous cylinder. An edge blend with a radius of 0.0625 in is used on this cylinder. Then a 1.891 in diameter cylinder is extruded 0.09 in creating a new body. Edge blends of 0.5 in are used on the square body. A 0.5 in diameter circle is created at the center point of the left edge and two circular arcs are created below that with a 0.1 in offset. The arcs are connected by circular arcs. Then the circle and the arcs are mirrored about center lines drawn on the X and Y axis. Then the sketch is extruded through all using the Boolean subtract operation. On the bottom of the rectangular body a 3.641 in diameter cylinder is extruded 0.32 in to creating a new body. A new shape is sketched using four circles connected using tangent lines and the quick trim sketch. Two circles

have a radius of 3.016 in, one circle has a radius of 3.04 in, and one circle has a radius 0.429 in. The new shape is extruded 1.07531 in and an identical square is extruded 0.32 in with the same edge blends and holes. The same shape using four circles is sketched on the bottom of the square extrusion and 1 in radius circles are created at the center of each edge with circles with 0.5 in diameter circles. These circles are then connected using quick trim and lines to the main shape creating one shape. This new shape is extruded 0.9929 in using the Boolean operation unite. A 1.310 in diameter circle and a 0.552 in concentric circle are sketched on the new face and extruded 0.2907 in. Finally a 0.552 in hole is sketched on the new face and extruded 2.388 in using the Boolean operation subtract.

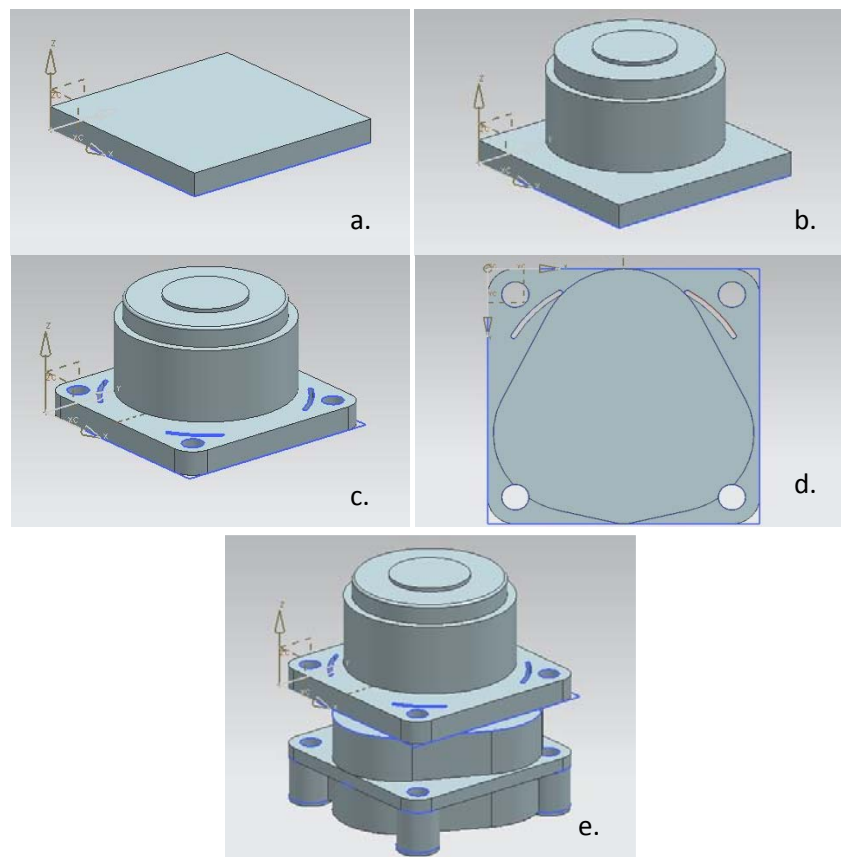


Figure 32. Motor Creation Process

Bolt

Nuts and bolts are used as fasteners for the crane. There are three sizes of bolts used in this model and the 6 in bolt's modeling process is explored. First the polygon tool is used to create a hexagon on the XY plane at the origin with a circumscribed radius of 0.375 in and then it was extruded. A sphere of diameter of 0.875 in was created at the origin using Boolean operation intersect. A sketch of 0.5 diameter circle is created at the bottom face of the new body. Then it is extruded 6 in and a thread is applied to the cylinder.

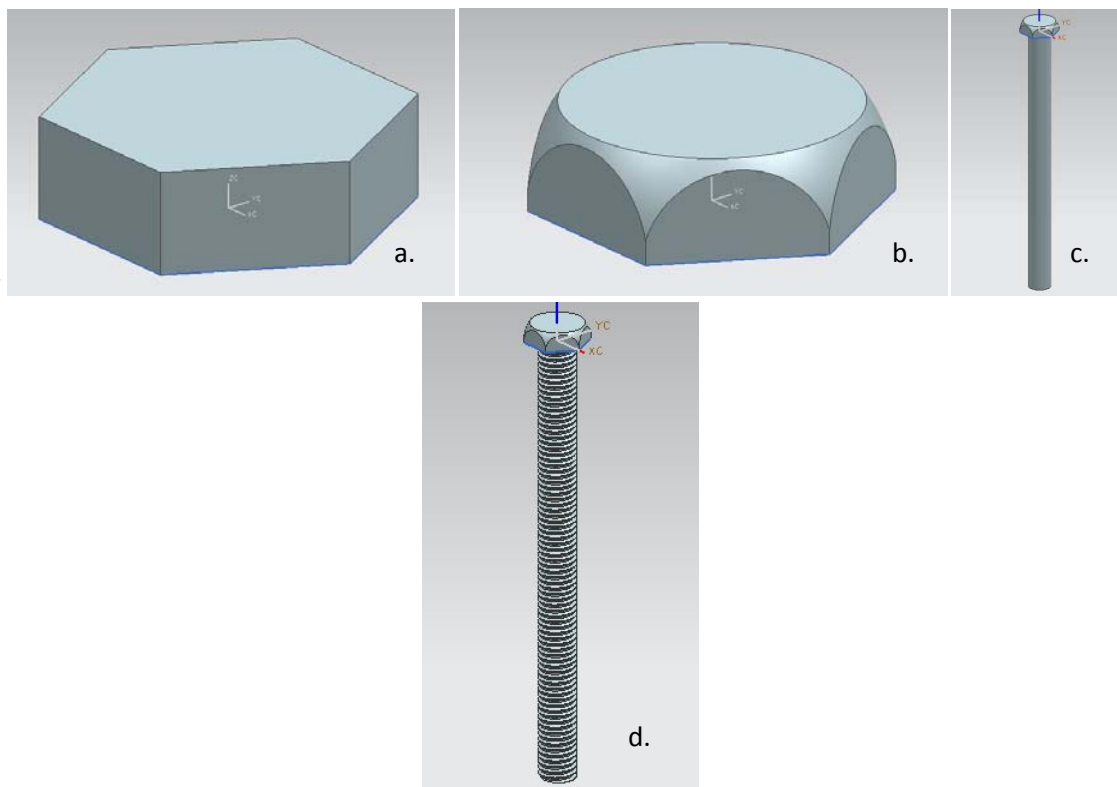


Figure 33. Bolt Creation Process

Ring Gear

To model the ring gear the two sketches are created of an 18.00 in and 17.00 in diameter circle and the profile of a tooth is then sketched. The profile is copied around the 17.00 in diameter circle using Instant Geometry and the type "Along Path" creating 115 copies and then the use a line to connect the original profile to a copy and Instant Geometry creating 115 copies. Extrude the gear shape to 0.35 in and

on the face of the gear sketch a 25 in diameter circle and extrude 0.25 in with the unite Boolean operation. Then on the face of the new part a 0.5 in diameter circle with its center 0.5 in from the perimeter of the circle. Instant geometry is used with the 25 in circle as the path and the circles are extruded using the Boolean operation subtract.

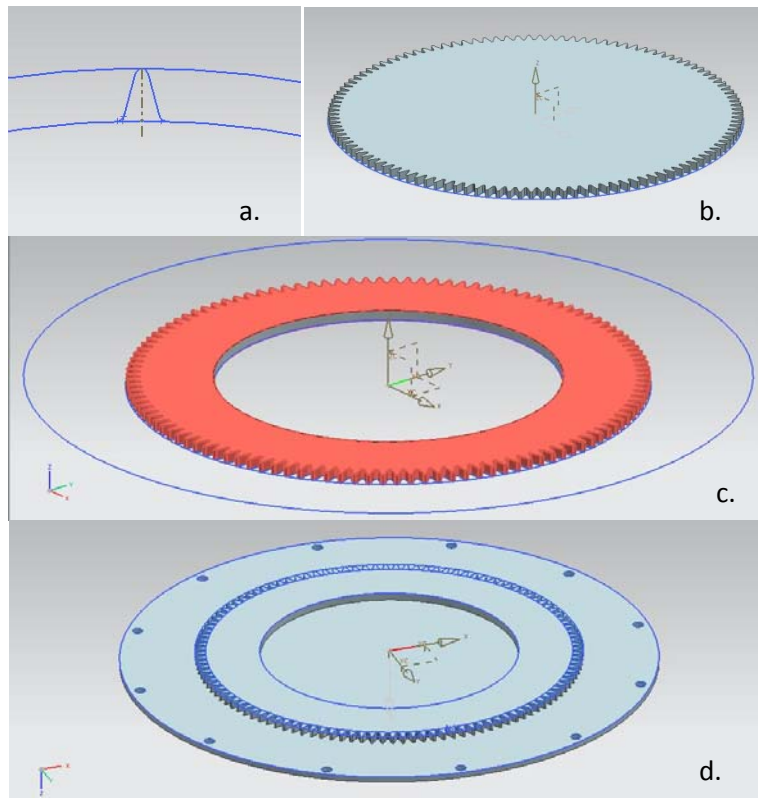


Figure 34. Ring Gear Creation Process

Tank Assembly

The tank used in the UAV concept has several parts including washers, idler gears, shafts, tank treads, and driver gears. The tank is designed to provide motion on the ground to the UAV. To explore the CAD modeling process of the tank the following key features were chosen to review; the drive gear and the tank treads.

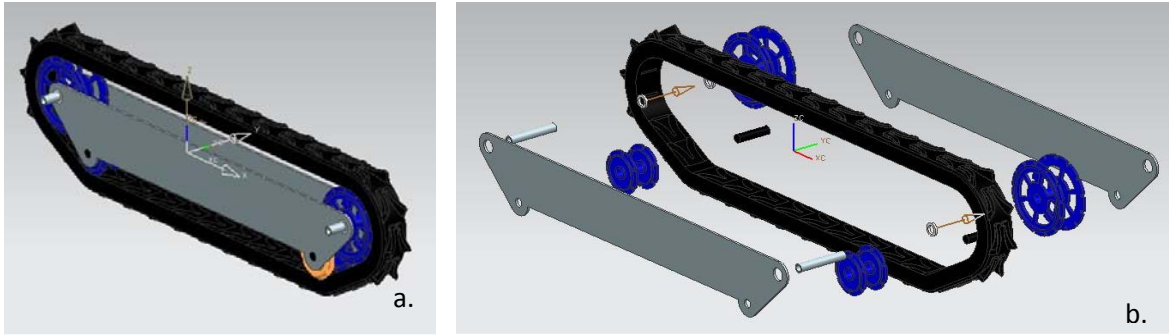


Figure 35. Tank Assembly

Drive Gear

First create a sketch on the XZ plane of 22.833 degree arc of an 8.5 in radius with two 0.5 in lines directed toward the center of the circle. Then create a 7.5 in radius circle and an Instant Geometry along the circular path is used to create 12 copies. A sketch is used to create a connection between the copy and the original profile. The copy is then copied 12 times using the 7.5 in diameter circle and the Instant Geometry feature. The copies and the profile are Extruded 0.5 in. A sketch is created on the face of the gear using a 2 in diameter circle in the center. Then a 7 in and a 12 in diameter of a circle are created. Two lines 48 degrees apart are created and bisect both circles. The quick trim tool is used to create a 48 degree section 3.5 in from the center of the gear face. Instant geometry is used to create 5 copies of the section around the 2 in circle. The sketch is then extruded using the Boolean operation subtract. Then a 7 in radius circle is created on the XZ plane and the 7.5 in and 7 in radius circles are extruded 0.5 in using the Boolean operation unite. A datum plane is created parallel to the XZ plane 3 in away and the new gear is mirrored about the new plane. A 2 in and 3 in diameter circles are created at the center of the gear and extruded 5 in using the Boolean operation unite.

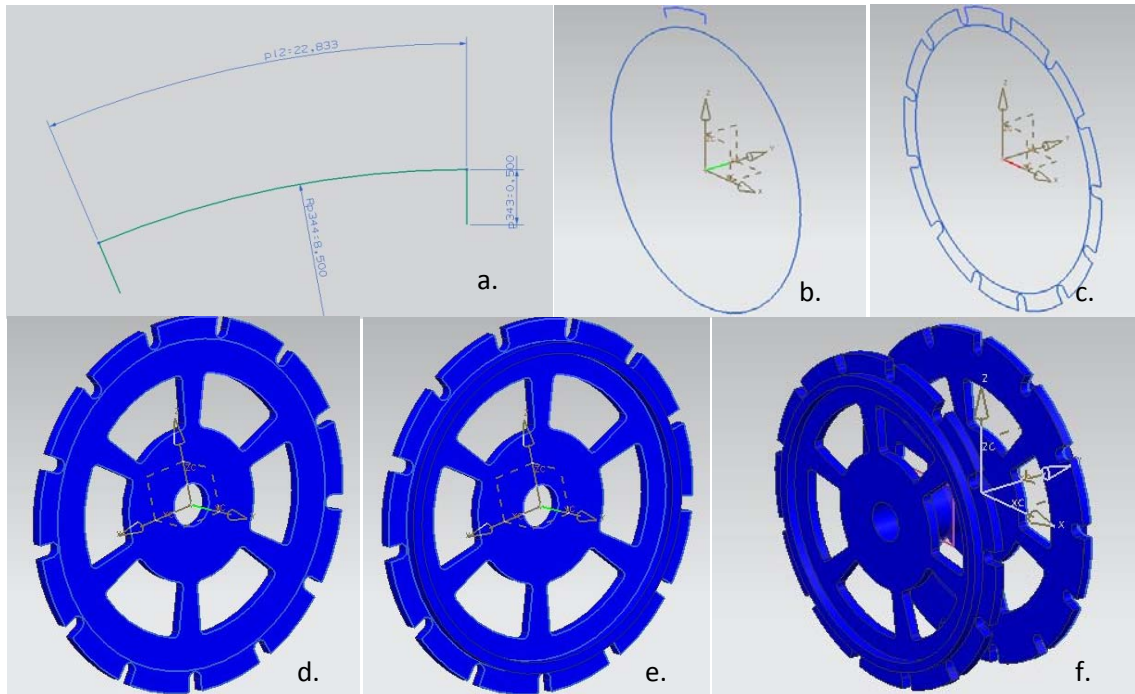


Figure 36. Drive Gear Creation Process

Tank Tread

A profile of the tank is sketched using two 17 in. diameter circles and two 10 in. diameter circles lines and the quick trim tool. Using an offset of 4 in an offset is created. The sketch is then extruded 6.5 in. to create a new body. The profile of a tread is sketched on the XY axis that is 2.5 in by 6.5 in and includes a 7 in and a 6.238 in radius arcs. Using the extrude command we start extrusion of the tread profile at the inside surface of the tank profile and end it at the outside surface. Use the offset face command to offset the tread profile by 0.5 in and create a datum plane on the outside surface of the tank profile. Draft the faces of the profile by 5 degrees using the draft command. Sketch a line along the top straight edge of the tank profile. Then use Instant Geometry to create copies along the straight edge of the profile. Then create an arc along the round edge of the tank profile and use Instant Geometry to create copies along that edge. This process is repeated until copies of the tread are created along the entire profile of the tread. A datum plane is created 3.25 in from the XZ plane and the tread copies are mirrored

about the new plane. Unite the treads to the tank profile using the unite command and using the edge blend command create 0.25 in radius and 0.0625 radius edges on each tread.

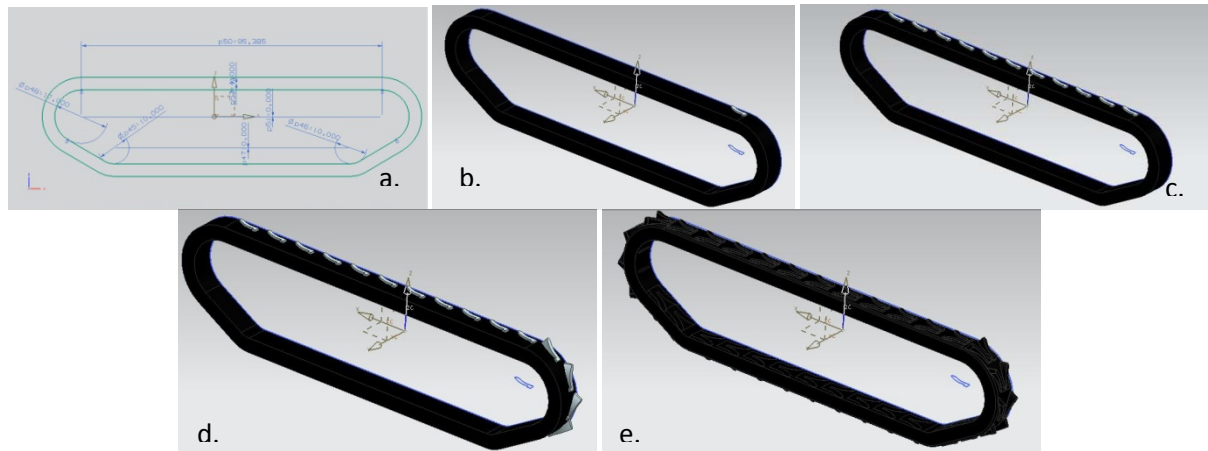


Figure 37. Tank Tread Creation Process

FEA Analysis

Problem 1: Bolt for helicopter blade

The design that our group chose involved helicopter components under high stress due to centripetal forces. Of particular concern were the helicopter rotor blades and how they were held in place. In our design, two ½ inch steel bolts ($E = 30 \times 10^6$ psi) are used to pin each blade and hold it in position. Due to complexities involving analysis on two bolts at the same time, one bolt was observed and the inertial forces were used to analyze the displacement. The inertial forces were calculated to be approximately 5000 lbf (2.5 tons) at the point where the blade is held in place, i.e. the bolt. Only .35 inches of the bolt, directly in the center, is touching the rotor blade; the remaining length of the bolt goes through a plate clamp and is thus constrained in all directions. The problem can therefore be viewed as a circular beam that is fixed on both sides, but subjected to a load in the middle, causing a shearing effect.

Hand Calculations

Figure 38 shows the basic setup of the bolt.

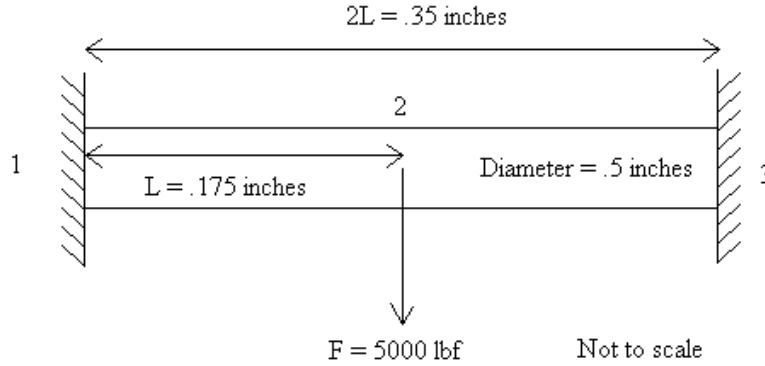


Figure 38. Schematic of the bolt

With this setup, the bolt has 3 nodes: 1 on each end (nodes 1 and 3), and one in the middle (node 2). Node 2 is the only node with an external, which is 5000 lbf, while nodes 1 and 3 are constrained to have no displacement. Equation 1 shows the matrix that set up to model this scenario.

$$\begin{bmatrix} f_{1y} \\ M_1 \\ f_{2y} \\ M_2 \\ f_{3y} \\ M_3 \end{bmatrix} = \frac{EI}{L^3} \cdot \begin{bmatrix} 12 & 6L & -12 & 6L & 0 & 0 \\ 6L & 4L^2 & -6L & 2L^2 & 0 & 0 \\ -12 & -6L & 12 + 12 & -6L + 6L & -12 & 6L \\ 6L & 2L^2 & -6L + 6L & 4L^2 & -6L & 2L^2 \\ 0 & 0 & -12 & -6L & 12 & -6L \\ 0 & 0 & 6L & 2L^2 & -6L & 4L^2 \end{bmatrix} \cdot \begin{bmatrix} d_{1y} \\ \varphi_1 \\ d_{2y} \\ \varphi_2 \\ d_{3y} \\ \varphi_3 \end{bmatrix} \quad (\text{Eq. 1})$$

By applying boundary conditions (nodes 1 and 3 having no displacement or angular change, since they're fixed), a much more simplified solution is found, seen in Equation 2.

$$\begin{bmatrix} f_{2y} \\ M_2 \end{bmatrix} = \begin{bmatrix} 12 + 12 & -6L + 6L \\ -6L + 6L & 4L^2 + 4L^2 \end{bmatrix} \cdot \begin{bmatrix} d_{2y} \\ \varphi_2 \end{bmatrix} = \begin{bmatrix} 24 & 0 \\ 0 & 8L^2 \end{bmatrix} \cdot \begin{bmatrix} d_{2y} \\ \varphi_2 \end{bmatrix} \quad (\text{Eq. 2})$$

By plugging in $L = .175$ inches, $E = 30 \times 10^6$ psi, $I = \frac{\pi \cdot R^4}{4} = 0.003068$ in⁴, and solving for the

displacement matrix, the displacements were found to be $\begin{bmatrix} d_{2y} \\ \varphi_2 \end{bmatrix} = \begin{bmatrix} 0.1213 \\ 0 \end{bmatrix} \cdot 10^{-4}$ inches.

Computer FEA with NX NASTRAN

To perform the FEA calculations with a computer, NX NASTRAN's buckling was used. The bolt was simplified to a simple cylinder made out of steel, with $E = 30 \times 10^6$ psi, and completely constrained except for a .35 inch section directly in the middle. At this section, a load of 5000 lbf was applied over half the circumference of the bolt. A mesh size of 0.05 was used. Once the analysis was ran and solved, a maximum displacement of 2.010×10^{-4} inches in the direction of the load was found and located directly at the midpoint of the bolt. These results are shown in Figure 39.

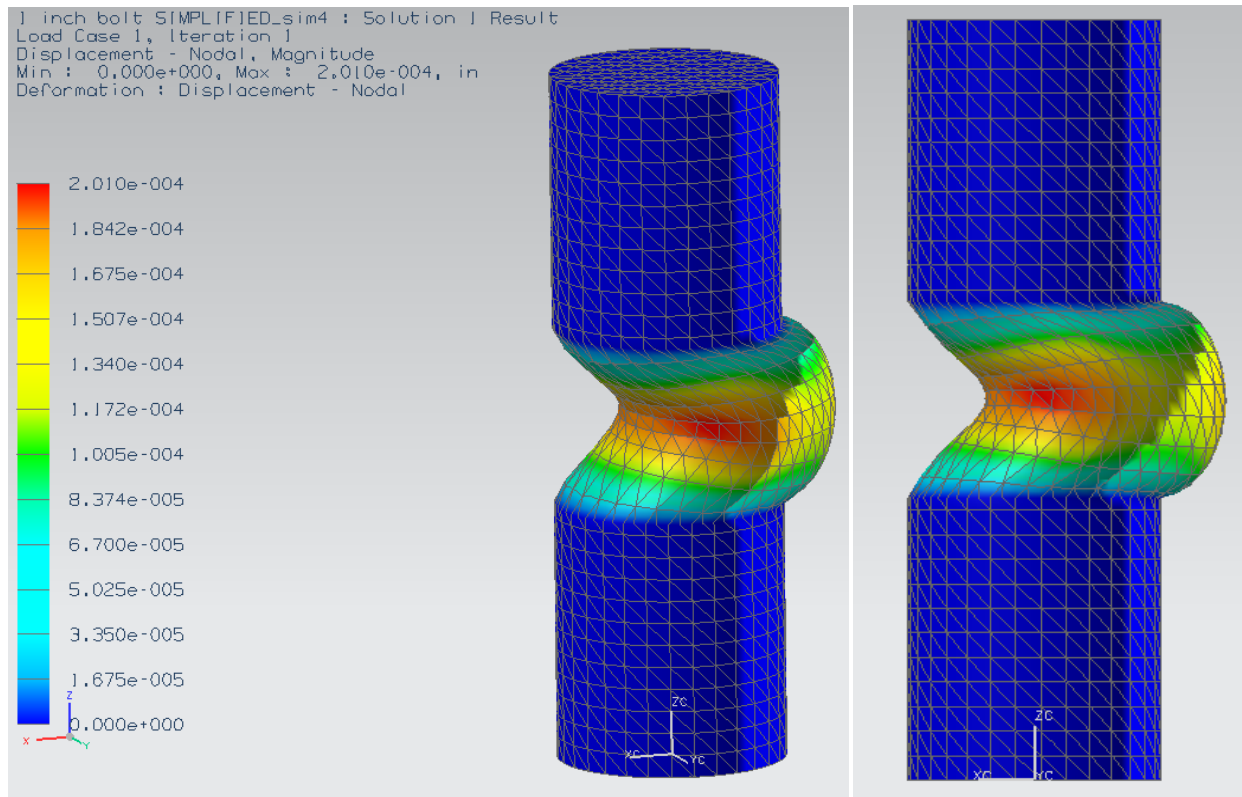


Figure 39. Angled view and side view of NX NASTRAN buckling load displacement

The computer calculation of 2.010×10^{-4} inches is about 16 times greater than the hand-calculated displacement of $.1213 \times 10^{-4}$ in. This is a big difference, and is likely the result of NX6 computing the 5000 lbf at each individual nodal point, which is a more realistic result. The hand calculation

was a simplification of an already-simplified scenario, and used a point load of 5000 lbf instead of a distributed load across the contact zone like the software did. In the least, the displacement pattern is sensible; no displacement occurs at the edges where the bolt is clamped and constrained, and the middle region (which is free) experiences the highest displacement.

Problem 2a. Helicopter blade deflection due to gravity

The helicopter was intended to have ground functionality, which requires landing and folding the rotors. Because the titanium-alloyed rotor blades are so long (78 inches) and thin, somewhat significant bending is expected to result from gravity alone. This is to be calculated such that this displacement is known and nothing on the robot interferes with the bent blades. In reality, the blades are curved inwards and also have an airfoil profile. However, for simplification, the blades are reduced to straight beams with a narrow, elliptical cross-section, with a major radius of 2.4 inches and a minor radius of .425 inches. In reality, the blades taper down significantly to a clamp point; this is ignored, however.

Hand Calculations

Figure 40 shows a sketch of the simplified blade system.

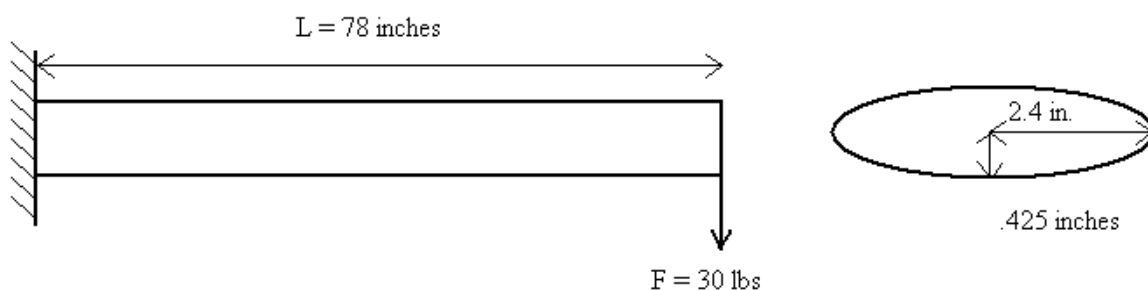


Figure 40. Simplified blade with loading

As can be seen in Figure 40, a load of 30 lb. is placed at the end of the beam. This concentrated load is simply the weight of the blade, and is the result of linearly increasing loads because of

gravity's effect on the beam's mass. Thus, the load is because of gravity. A beam in bending is represented by Equation 3.

$$\begin{bmatrix} f_{1y} \\ M_1 \\ f_{2y} \\ M_2 \end{bmatrix} = \frac{EI}{L^3} \cdot \begin{bmatrix} 12 & 6L & -12 & 6L \\ 6L & 4L^2 & -6L & 2L^2 \\ -12 & -6L & 12 & -6L \\ 6L & 2L^2 & -6L & 4L^2 \end{bmatrix} \begin{bmatrix} d_{1y} \\ \varphi_1 \\ d_{2y} \\ \varphi_2 \end{bmatrix} \quad (\text{Eq. 3})$$

By applying boundary conditions for this scenario (there is no displacement at the wall or angle change), a more simplified equation can be obtained in the form of Equation 4.

$$\begin{bmatrix} f_{2y} \\ M_2 \end{bmatrix} = \frac{EI}{L^3} \cdot \begin{bmatrix} 12 & -6L \\ -6L & 4L^2 \end{bmatrix} \begin{bmatrix} d_{2y} \\ \varphi_2 \end{bmatrix} \quad (\text{Eq. 4})$$

For this scenario, $L = 78$ inches, $I = \frac{\pi ab^3}{4} = .1447 \text{ in}^4$, and $E = 16,000,000$ psi for titanium.

With these values, the displacement matrix was solved for, yielding $\begin{bmatrix} d_{2y} \\ \varphi_2 \end{bmatrix} = \begin{bmatrix} 2.04973 \\ 0.03942 \end{bmatrix}$ inches.

Thus, from the hand calculations, a displacement at the blade-tip of 2.05 inches was found.

Computer FEA with NX NASTRAN

For the computer FEA computation, NX NASTRAN was again used. In this case, structural analysis of the rotor was performed with no actual external loading; the only loading present in the analysis was due to the mass of the blade and gravity's pull, making the analysis very realistic. The blade was completely constrained at the clamping region, as it actually would be. A mesh of 1 inch was applied across the blade, except for near the clamping region where most stress would occur. At the point where the blade tapers to the clamped zone, a mesh of 0.25 inches was applied. Once this was solved for, the Figure 41 was obtained.

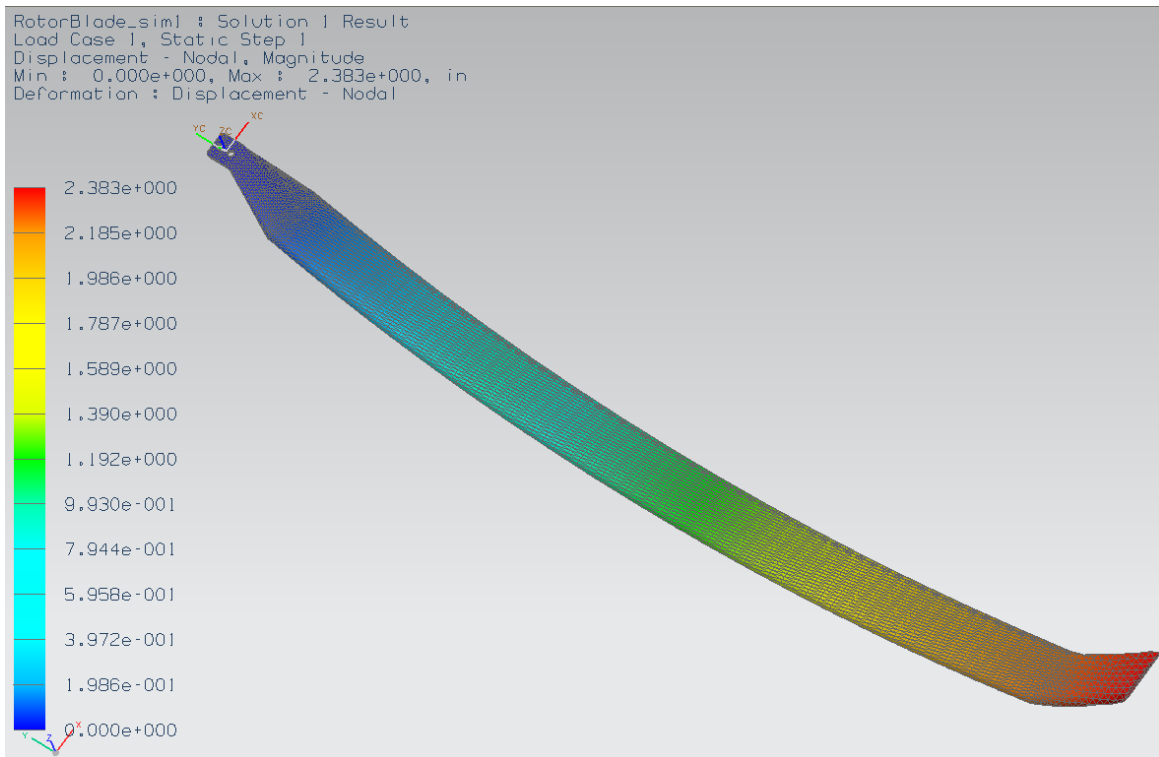


Figure 41. Displacement of rotor blade

A maximum displacement of 2.383 inches was found with the computer calculation. This compares very well to the hand calculation, which yielded 2.05 inches. Reasons for differences could be due to the curvature of the rotor and also the airfoil profile (approximated by hand as an ellipse). The single, biggest contributor to error is due to the tapered region near the clamp, seen in the upper left corner of the part in Figure 41. Because this region reduces in cross-section as it nears the clamped zone, the second moment of area decreases as well. This, in effect, makes the zone weaker and more prone to deflection from a load. This “tapering” was not accounted for in the hand calculation. Additionally, this displacement pattern makes sense. At the clamp, no displacement occurs (seen in blue), while the colors gradually change at the rotor length increases, ultimately reaching a red color, signifying high displacement at the tip.

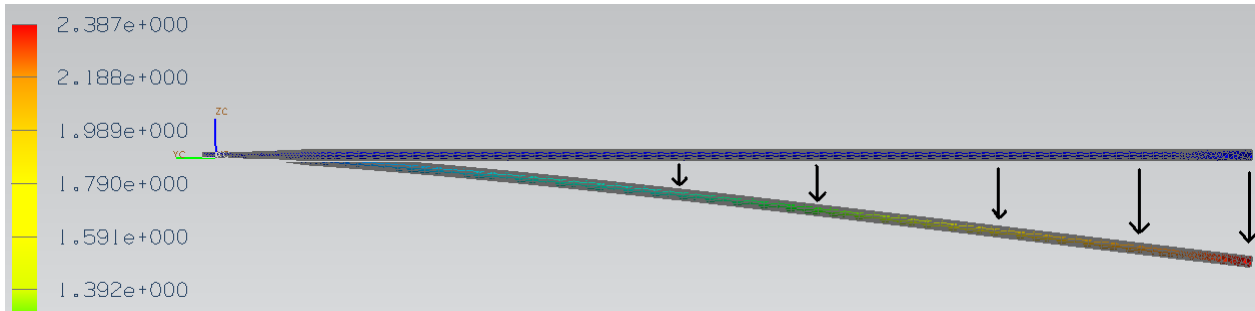


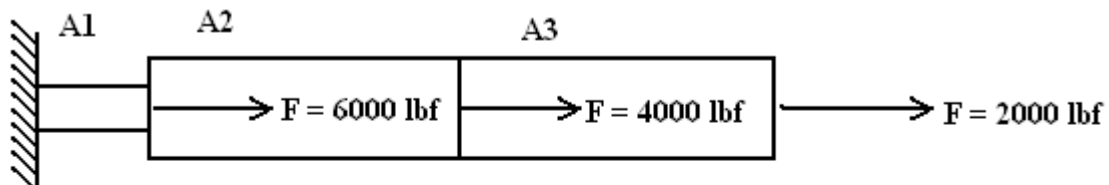
Figure 42. Displacement of rotor blade in the Z-direction (perpendicular to blade)

Problem 2b. Rotor blade elongation due to inertial forces while spinning

Spinning components, like the rotor blades on our helicopter section, will want to elongate due to centripetal forces. It is not uncommon there to be 5 to 10 tons or more of force on the blades (at the root) during flight. In our desired design, we have a 78 inch long rotor blade with an airfoil profile undergoing elongation from the centripetal force. The blade root tapers down into a small portion with a small cross-sectional area; this is a region of high concern, as it could potentially elongate too much or experience awkward loading and fail.

Hand Calculations

This problem at hand was simplified to the drawing shown in Figure 43.



$$A1 = .75 \text{ sq. in}$$

$$A2 = 3.20442 \text{ sq. in}$$

$$A3 = A2 = 3.20442 \text{ sq. in}$$

$$E = 17,000,000 \text{ psi}$$

Figure 43. Simplification in centripetal forces acting on spinning rotor blade

Because of the complexities involved with solving a distributed load (which would accurately represent centripetal force), the distributed load was simplified to three separate large loads; one at the beginning, middle and end of the blades, in higher to lower order. With this setup, the matrix in Equation 5 was created to represent this system.

$$\begin{bmatrix} f_{1y} \\ f_{2y} \\ f_{3y} \\ f_{4y} \end{bmatrix} = \begin{bmatrix} k_1 & -k_1 & 0 & 0 \\ -k_1 & k_1 + k_2 & -k_2 & 0 \\ 0 & -k_2 & k_2 + k_3 & -k_3 \\ 0 & 0 & -k_3 & k_3 \end{bmatrix} \begin{bmatrix} d_{1y} \\ d_{2y} \\ d_{3y} \\ d_{4y} \end{bmatrix} \quad (\text{Eq. 5})$$

In Equation 5, $k_1 = \frac{E_1 A_1}{L_1} = 6 \times 10^6 \frac{\text{lb}}{\text{in}}$, $k_2 = \frac{E_2 A_2}{L_2} = 1.31463 \times 10^6 \frac{\text{lb}}{\text{in}}$, and $k_3 = k_2 = 1.31463 \times 10^6 \frac{\text{lb}}{\text{in}}$. In this scenario, the only boundary condition is that $d_{1y} = 0$, or that the root of the blade does not move (it is fixed and connected to something). With this condition, Equation 6 is obtained.

$$\begin{bmatrix} f_{2y} \\ f_{3y} \\ f_{4y} \end{bmatrix} = \begin{bmatrix} k_1 + k_2 & -k_2 & 0 \\ -k_2 & k_2 + k_3 & -k_3 \\ 0 & -k_3 & k_3 \end{bmatrix} \begin{bmatrix} d_{2y} \\ d_{3y} \\ d_{4y} \end{bmatrix}, \quad \text{or}$$

$$\begin{bmatrix} 6000 \text{ lbf} \\ 4000 \text{ lbf} \\ 2000 \text{ lbf} \end{bmatrix} = \begin{bmatrix} 7.315 & -1.315 & 0 \\ -1.315 & 2.630 & -1.315 \\ 0 & -1.315 & 1.315 \end{bmatrix} \cdot 10^6 \begin{bmatrix} d_{2y} \\ d_{3y} \\ d_{4y} \end{bmatrix} \quad (\text{Eq. 6})$$

Solving for the displacements yields $\begin{bmatrix} d_{2y} \\ d_{3y} \\ d_{4y} \end{bmatrix} = \begin{bmatrix} 0.002 \\ 0.006563 \\ 0.008084 \end{bmatrix}$ inches. The displacement of d_{2y} was

particularly significant because this 0.002 inches of elongation occurred in only a 3 inch long piece. Nearly equivalent displacements occurred at the other two nodes (.004563 inches and .001521 inches). However those nodes covered lengths 13 times as long. This is a rough estimation of a realistic scenario at best.

Computer FEA with NX NASTRAN

The rotor blade that was created had elements that were not easily simplified by hand. These elements were maintained in NX to perform the FEA. Figure 43 shows the part in being analyzed.

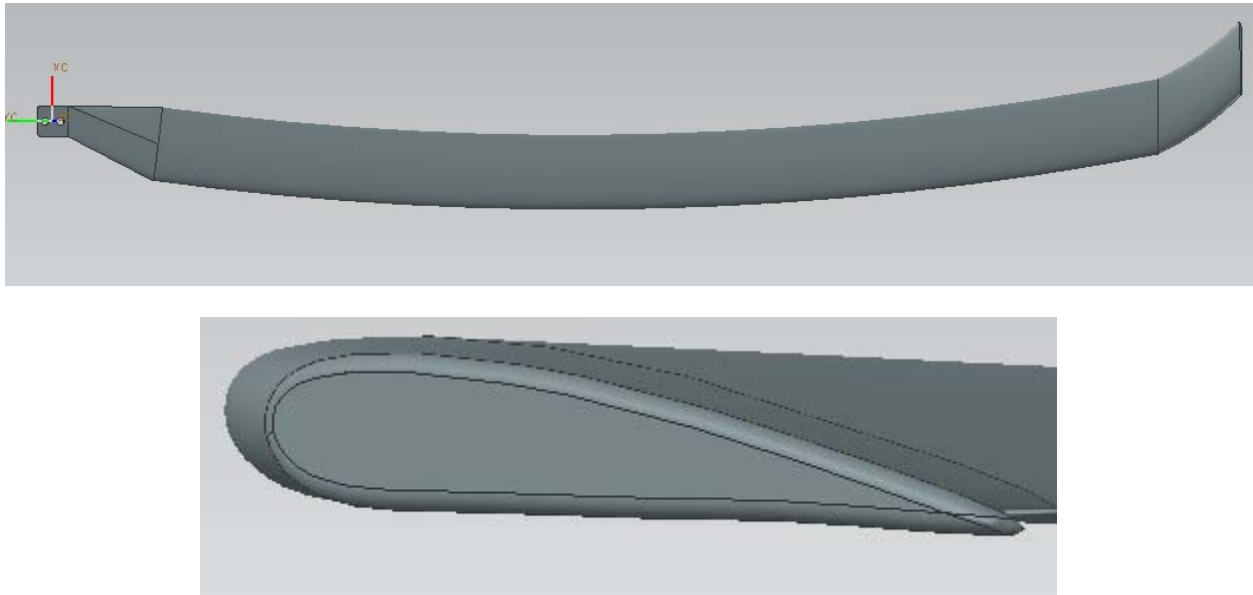


Figure 43. Helicopter rotor blade: Top view (top), Cross-sectional profile (bottom)

This scenario was constrained at the leftmost point since that is the general region that the blade would be pinned. Since the centrifugal loading was being problematic, the same three large loads were applied to the similar regions, representing forces due to the blade's mass. When the FEA was performed, a maximum displacement of .007618 inches was found. This compares very well to the maximum displacement .008084 inches, found with the hand calculations. Figure 44 shows the FEA results, highlighting the ever-increasing displacement in the Y-direction along the blade's length. Because the scale from negative displacement values to a value of 0, maximum displacement is blue in this case, which is why the blade-tip is blue.

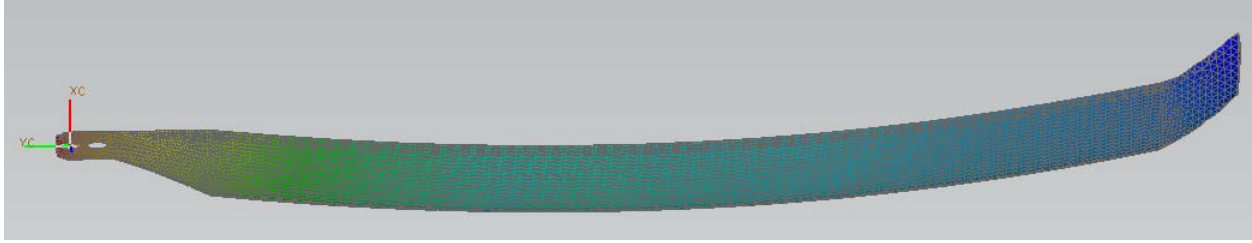


Figure 44. Displacement along Y-direction in rotor blade

Because the tapered and clamped zone was the thinnest, this was the region of concern. Figure 45 shows the fixed edge (at the left) and the entire clamp zone's elongation.

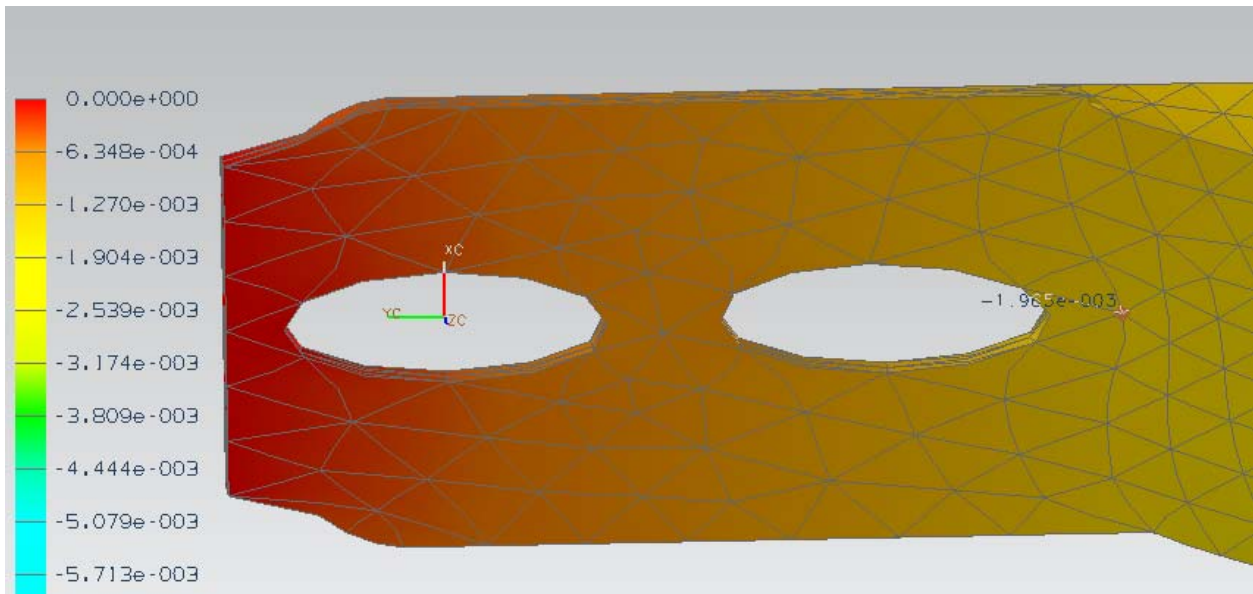


Figure 45. Clamped region elongation in Y-direction

The point in the figure (to the right of the second hole) is the same point as Node 2 in the hand calculations. In the hand calculations, this region suffered a .002 inch displacement. According to the computer FEA on the realistic part, this region undergoes a .001983 inch displacement. The hand calculations were very good predictors in this instance. Even though the true part had different features, including a different cross-section, holes, curvature, and rounded edges, the approximations were very similar. In reality, a rotor blade would not be under this much stress.

There would, however, be a lifting force due to the airfoil shape, which would make this not only a beam in tension, but a beam in bending.

Problem 3: Displacement of Boom Arm

The main purpose of the crane is to hold maximum of 100 lb load during ground operations of the UAV. To test this goal the finite element analysis functions of NX 6 is used to model the deformation of the crane with a 100 lbs load at its end. To test this in NX 6 an assembly was created of the fully extended boom. The material of the each arm was Aluminum 6061 which is a material commonly used in bicycles. The length of the fully extended boom is 6.7 ft and an element size of .25 in was used in the 3D tetrahedral mesh. Each beam element was connected together using mesh mating conditions. Pin constraints were applied where pins would normally be applied on the extension arm and a 100 lbf load was applied at the end to simulate the 100 lb maximum load the crane could carry. From Figure 46 it can be seen that the simulation found the maximum deflection of the boom was 1.75 in at the end where the load was applied. From Figure 47 it can be seen that most of the stress occurred at the top section of the beam where the beam was extending from the hollow beam it fits within and a maximum stress of 12.6 kpsi was found for the simulation.

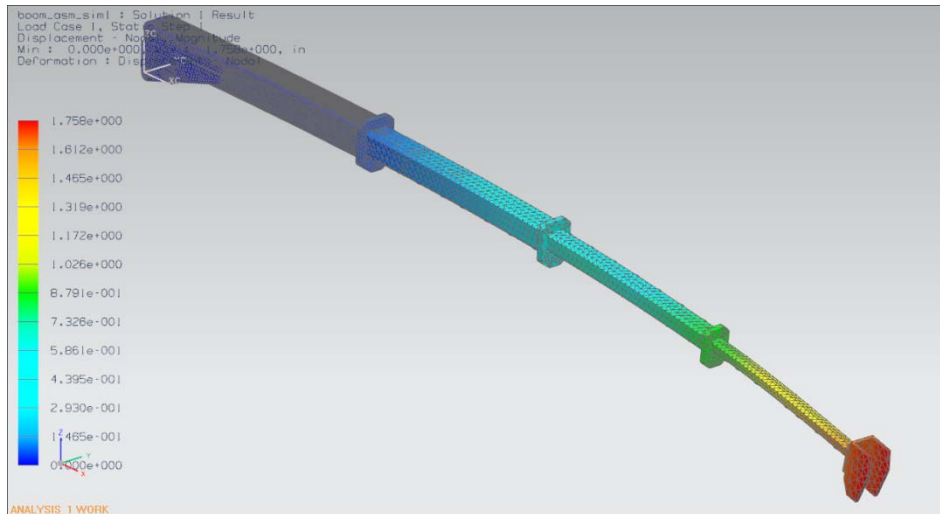


Figure 46. Displacement of Boom Arm

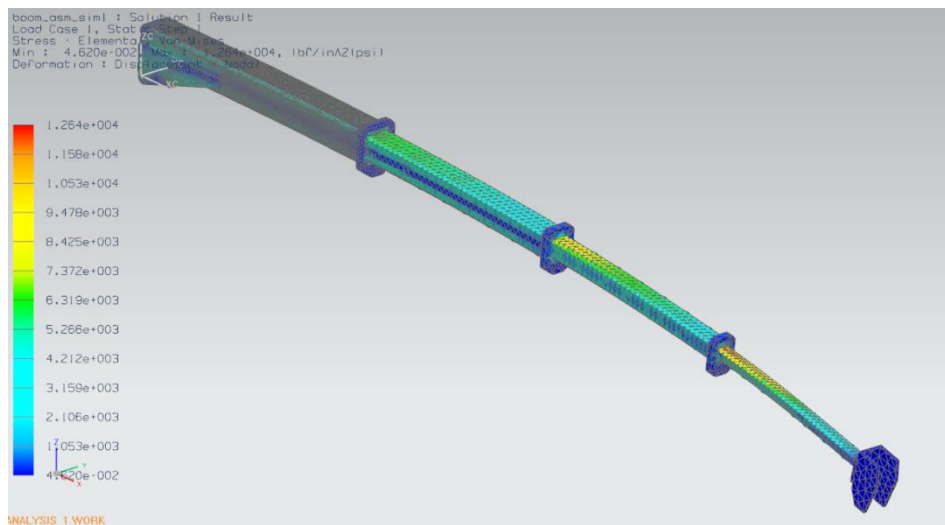


Figure 47. Stress of Boom Arm

Hand Calculations

The goal of the expandable boom is to hold 100 lbs. In performing hand calculations to support the finite element analysis of the boom, the geometry is simplified into four hollow beams. An external force is applied to the end node is 100 lbf. Figure 48 below shows a simplified version of the expandable boom.

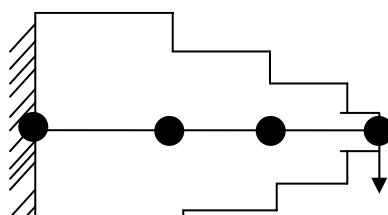


Figure 48. Simplified

Each beam segment is made from Aluminum and so the Young's modulus, E, used in our calculations is 1×10^4 Ksi. The length of each segment is not uniform where $L_1 = 24$ in, $L_2 = 20$ in, $L_3 = 18$ in, $L_4 = 16$ in. The moment of inertia for the cross section is found using the equation 7

$$I = \frac{(b_o - b_i)^3 (h_o - h_i)}{12} \quad (\text{Eq. 7})$$

where b_o is the outside base of the cross section and b_i is the inside base of the cross section. h_o is the outside height of the cross section and h_i . $I = 2.354 \times 10^{-7} ft - lb s^2$ for all cross sections because the thickness. The displacement can be found using the direct stiffness method with the Equations 8 and 9.

$$K^{(1)} = EI \begin{bmatrix} \frac{12}{L^3} & \frac{6}{L^2} & \frac{-12}{L^3} & \frac{6}{L^2} \\ \frac{6}{L^2} & \frac{4}{L} & \frac{-6}{L^2} & \frac{2}{L} \\ \frac{-12}{L^3} & \frac{-6}{L^2} & \frac{12}{L^3} & \frac{-6}{L^2} \\ \frac{6}{L^2} & \frac{2}{L} & \frac{-6}{L^2} & \frac{4}{L} \end{bmatrix} \quad (\text{Eq. 8})$$

$$\begin{Bmatrix} F_{1y} \\ M_1 \\ F_{2y} \\ M_2 \\ F_{3y} \\ M_3 \\ F_{4y} \\ M_4 \\ F_{5y} \\ M_5 \end{Bmatrix} = EI \begin{bmatrix} \frac{12}{L_1^3} & \frac{6}{L_1^2} & \frac{-12}{L_2^3} & \frac{6}{L_2^2} & 0 & 0 & 0 & 0 & 0 & 0 \\ \frac{6}{L_1^2} & \frac{4}{L_1} & \frac{-6}{L_2^2} & \frac{2}{L_2} & 0 & 0 & 0 & 0 & 0 & 0 \\ \frac{-12}{L_1^3} & \frac{-6}{L_1^2} & \frac{24}{L_2^3} & 0 & \frac{-12}{L_3^3} & \frac{6}{L_3^2} & 0 & 0 & 0 & 0 \\ \frac{6}{L_1^2} & \frac{2}{L_1} & 0 & \frac{8}{L_2} & \frac{-6}{L_3^2} & \frac{2}{L_3} & 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{-12}{L_2^3} & \frac{-6}{L_2^2} & \frac{24}{L_3^3} & 0 & \frac{-12}{L_4^3} & \frac{6}{L_4^2} & 0 & 0 \\ 0 & 0 & \frac{6}{L_2^2} & \frac{2}{L_2} & 0 & \frac{8}{L_3} & \frac{-6}{L_4^2} & \frac{2}{L_4} & 0 & 0 \\ & & & & & & \frac{24}{L_4^3} & 0 & \frac{-12}{L_5^3} & \frac{6}{L_5^2} \\ 0 & 0 & 0 & 0 & \frac{-12}{L_3^3} & \frac{-6}{L_3^2} & 0 & \frac{8}{L_4} & \frac{-6}{L_5^2} & \frac{2}{L_5} \\ 0 & 0 & 0 & 0 & \frac{6}{L_3^2} & \frac{2}{L_3} & 0 & \frac{L_4}{L_4} & \frac{-6}{L_5^2} & \frac{L_5}{L_5} \\ 0 & 0 & 0 & 0 & \frac{L_3^2}{L_3^2} & \frac{L_3}{L_3} & \frac{-12}{L_4^3} & \frac{-6}{L_4^2} & \frac{12}{L_5^3} & \frac{-6}{L_5^2} \\ 0 & 0 & 0 & 0 & 0 & 0 & \frac{6}{L_4^2} & \frac{2}{L_4} & \frac{-6}{L_5^2} & \frac{4}{L_5} \end{bmatrix} \begin{Bmatrix} d_{1y} \\ \phi_1 \\ d_{2y} \\ \phi_2 \\ d_{3y} \\ \phi_3 \\ d_{4y} \\ \phi_4 \\ d_{5y} \\ \phi_5 \end{Bmatrix} \quad (\text{Eq. 9})$$

With the boundary conditions of $d_{1y} = 0$ and $\phi_1 = 0$ and $F_{5y} = 100 \text{ lbf}$. The displacements of the boom under the load are calculated to be $d_{2y} = 0.5015 \text{ in}$, $d_{3y} = 1.0501 \text{ in}$, $d_{4y} = 1.4354 \text{ in}$, $d_{5y} = 2.4998 \text{ in}$. The deformation found using NX 6 was 1.75 in. showing a 42.85% error between the hand calculations and the value found from FEA.

Summary and Future Work

The objectives of this project were to design an aerial vehicle, ground vehicle, and crane all in one package. The purpose of this concept vehicle was to deliver cargo for different clients, such as the military, as well as providing aerial and ground scouting along with reconnaissance. In designing this vehicle the following systems were modeled using UGS NX 6: two intermeshing rotors, a heavy-lifting crane, the power train, and a tank tread system. After modeling the system key components of the system were analyzed using NX6's simulation functions. The bolt for helicopter blade was analyzed for displacement due to the inertial forces, the rotor blade due to inertial forces, the helicopter blade due to gravity, and the displacement of

the crane due to carrying a 100 lb load. Using NX 6, this potential UAGV was able to be modeled and go through a small series of preliminary testing.

This concept UAGV is not at the stage where it is ready to go through production yet. Future goals for the project include design a transmission for the tank tread system, explore more compact tread designs, test the aerodynamic effects for different types of bodies, and to analyze stress on the internal gears the crane use to turn. A transmission is important for this system because tanks use their transmissions to steer. We hope to decrease the weight of the vehicle along with the making the vehicle more aesthetically pleasing, while maintaining the functionality provided by the current design. By testing the aerodynamic affects on the current body, its design may be optimized for better performance. The goal of testing the internal gears on the crane is to ensure they do not fail over the lifetime of the vehicle. After using NX 6 or another virtual prototyping environment to improve the design of the vehicle, the next future goal is to build and test an actual prototype.