Solid Modeling Project

Mitsubishi SpaceJet M90 Wooden Mahogany Model

 

ME 371: Computer-Aided Design

Professor Benenson

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OVERVIEW

In this project, I will be reverse engineering an object by taking measurements of the object and using SolidWorks to create a model of the object according to the measurements I obtained.

I chose to model a wooden mahogany model of the Mitsubishi SpaceJet M90. I received this airplane model as an internship completion gift and felt that using it as a model for this project would be a good way of developing my skills in SolidWorks and use it as a further learning opportunity. With its relatively straight body and simplified structure, I thought that this would be a challenging but completable project.

In this report, I will first discuss the names of different parts of the airplane which I will reference to throughout the rest of the report. Then, I will explain my process of taking measurements of the airplane and creating the model. Finally, I will reflect on my experience working on this project.

By working on this project, I hope to develop my creativity in working around problems and learn SolidWorks tools that I have not used before.

Wooden Model

This is the object I will be reverse engineering in this report. This physical model will be referred to as the "airplane" hereon.

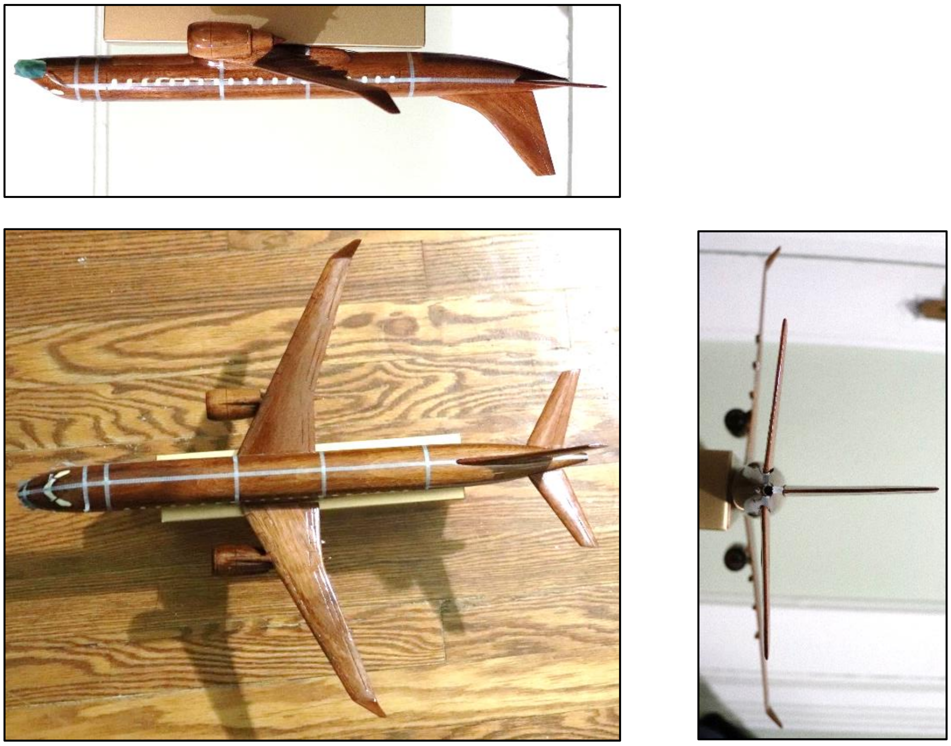


Figure 1. M90 wooden model

Freehand Sketch

These are sketches of the airplane with their parts labeled.

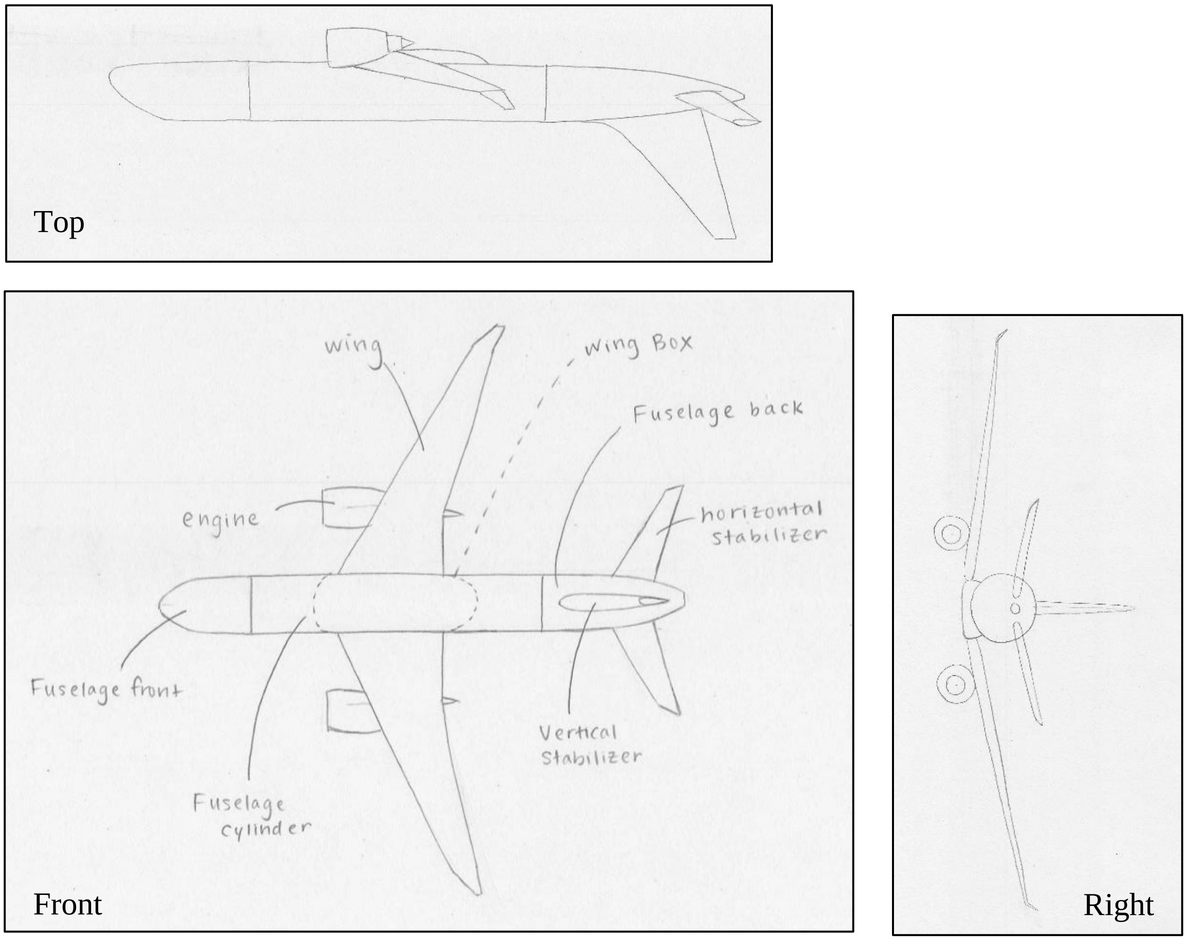


Figure 2. Freehand sketches

I chose this front view because it is the view that most clearly showcases all the features of the airplane, including the symmetry. Although it is difficult to see the vertical stabilizer and engine, I decided that it was more beneficial to see the wings and horizontal stabilizers and note the symmetry.

Parts of the Airplane

For this project, I broke down the airplane model into parts, defined as follows:

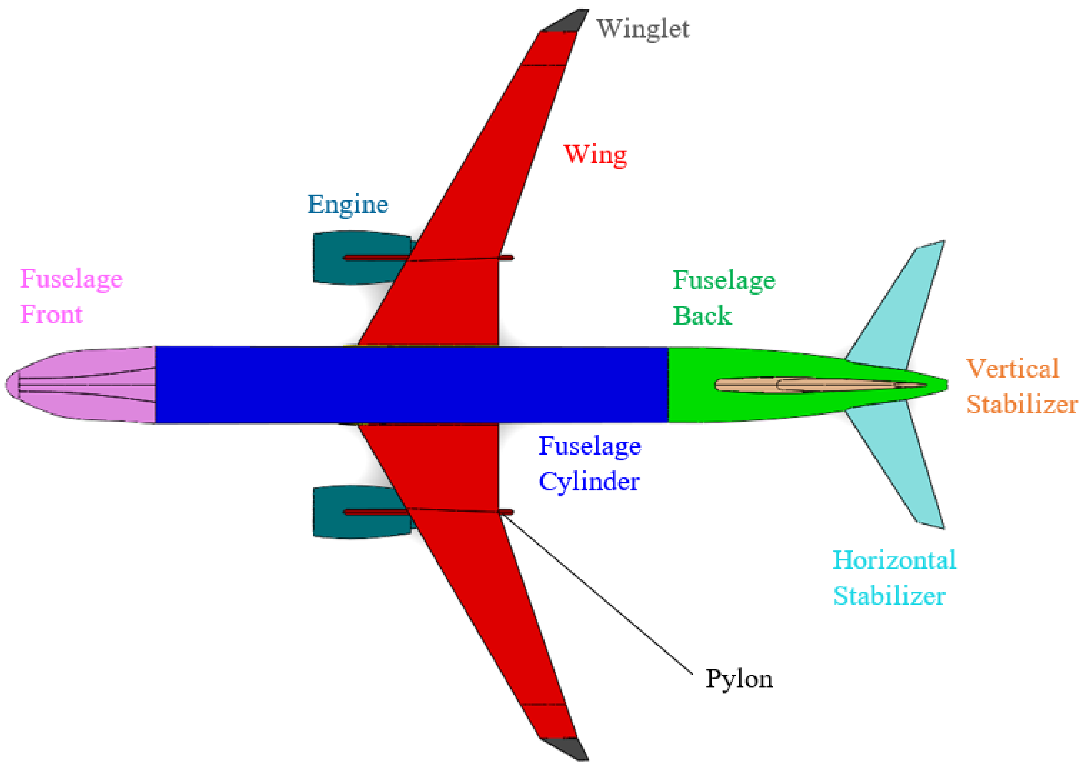


Figure 3. Parts of the airplane

Airfoil Terminology

Additionally, the airplane had many airfoils which will be described using the terminology below:

Figure 4. Airfoil Terminology

PROCEDURE – MEASUREMENT AND MODELING

Cylindrical Portion of Fuselage

The "front" will refer to the side of the cylinder close to the nose of the airplane, and the "back" will refer to the side of the cylinder close to the tail of the airplane.

In order to find the dimensions of the cylinder, I first had to mark the start and end of the cylinder on the physical airplane. After an initial observation, I decided that the approximate locations where the doors were carved would be a good location to start and end the cylinder.

I decided to use a thin grid washi tape to mark the references in order to reduce the errors in taking measurements to the thin width of the tape. Using washi tape allowed me to remove the tape off after this project was done, minimizing the amount of damage done on the airplane.

Circular Profiles

I wrapped grid tape around the circumference of the cylinder body, where the doors were located. It was difficult to wrap the tape around completely circumferentially, and I tried multiple techniques to align the tape. Eventually, I settled on wrapping a dollar bill around the circumference and lining the tape along the edge, as it was the most conveniently-sized straight edge I found around me. I carried this process out for both the front and back side.

Figure 5. Wrapping a dollar bill to tape along the circumference

During this process, I noticed that the doors on either side of the airplane were not aligned exactly on opposite sides. Therefore, I had to choose one point on one of the doors as a starting point but then follow the dollar bill to get the tape across the other side. This demonstrated that I could not use the etched features, such as the doors or the line on the vertical stabilizer, as reliable reference points.

I also realized that the cylinder was not a traditional cylinder with equal radii on the front and back side, and that it was likely closer to a tapered cylinder with the front side having a larger radius than the back side. This conclusion was verified when I used a caliper to measure the diameter of the two circular profiles I taped.

One problem the tape wrapping created was the added thickness of the tape to the overall profile diameter. However, because the thickness of the tape is very thin in comparison to the overall diameter of the model, I concluded that the effect of the tape thickness on the diameter is negligible.

Using the locations where I taped as guidelines, I measured the length of the fuselage cylinder using a caliper.

Figure 6. Length of the fuselage cylinder

I found the distance of the nose to the front side of the cylinder by aligning the airplane against datums and using a caliper. I then created a plane to represent the cylinder front and drew a circular profile.

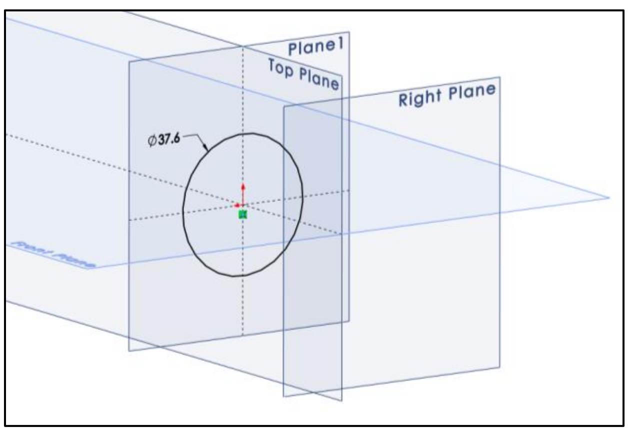


Figure 7. Front side of the cylinder, diameter dimensioned

Next, I found the length of the cylinder using a caliper and created another reference plane to draw the circular profile for the back side of the cylinder. Although I had the option of assuming the cylinder to have equal radii, I ultimately decided to create a tapered cylinder using loft since it was not a very difficult or time-consuming process and would allow the model to be more accurate.

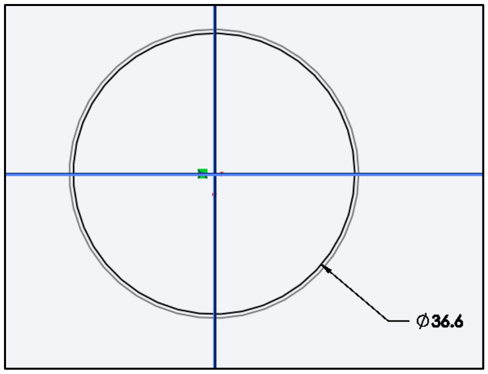


Figure 8. Front and back side of the cylinder, diameters dimensioned

Then, I drew a straight line connecting the two profiles to use as a guide curve and created a loft between the two circular profiles. Although I did not need the line since SolidWorks automatically assumed the sides to be straight, I used one to ensure that I had as much control over the loft as possible.

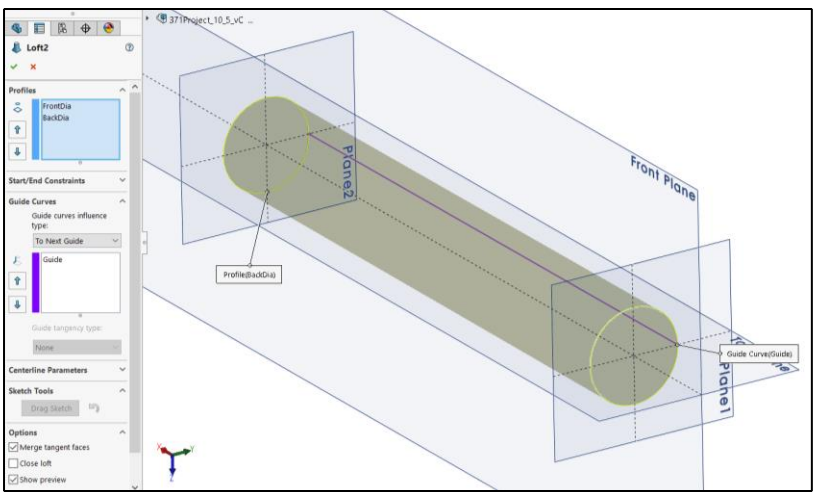


Figure 9. Fuselage cylinder loft

Fuselage Front

The front of the fuselage will be modeled using a loft with multiple profiles in order to represent the changing cross-sections.

Front Contour – First Attempt

In order to determine where I would take the profile contours, I looked at the model from the top view and guessed approximately where the curvature was changing. I then wrapped the tape around the circumference using the dollar bill.

This contour location was based on observation of where the top guide curve has the smallest radius of curvature

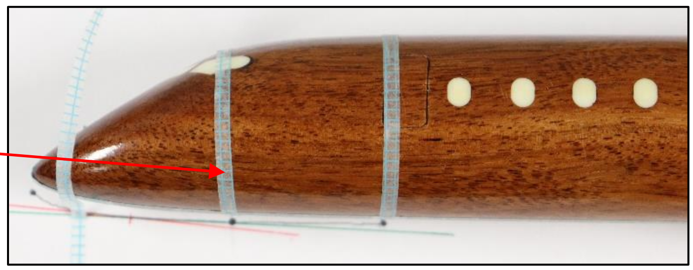


Figure 10. Taping contour profile locations

In order to take the profile contours, I initially set the airplane down on the bottom of its wing box. However, because the wing box did not have a flat bottom surface, the airplane kept wobbling when I attempted to take the contour. Therefore, I decided to lay the plane on its side to increase stability, take the contour of the side, and mark where the symmetry line of the plane was with respect to the contour to establish the correct orientation of the contour. (see Figure 17 in the next section)

Front Contour – Second Attempt

After taking this initial contour, I rethought the accuracy of the location of this profile since I made the decision solely by eye. To more systematically define the locations, I decided that the shape of the guide curve and the points required to create the shape of the guide curve could instead dictate where the profiles should be located.

Therefore, I decided to scrap the initial attempt of making the front contour.

Top Guide Curve

I used a contour gauge to take the shape of the guide curve and imported the contour into SolidWorks.

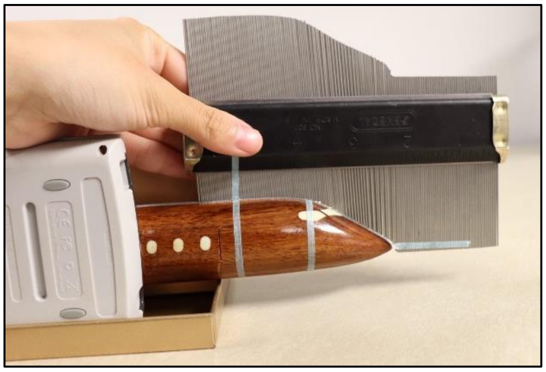


Figure 11. Using a contour gauge to obtain the fuselage front guide curve

I did not have access to a scanner readily available as I measured and modeled, so for every sketch picture import, I took a photograph using the setup below to keep my photographs level and as centered as possible.

Figure 12. Sketch picture import photographing setup

The following was the contour of the fuselage front, imported and scaled as a sketch picture in SolidWorks to ensure that the nose touched the front plane.

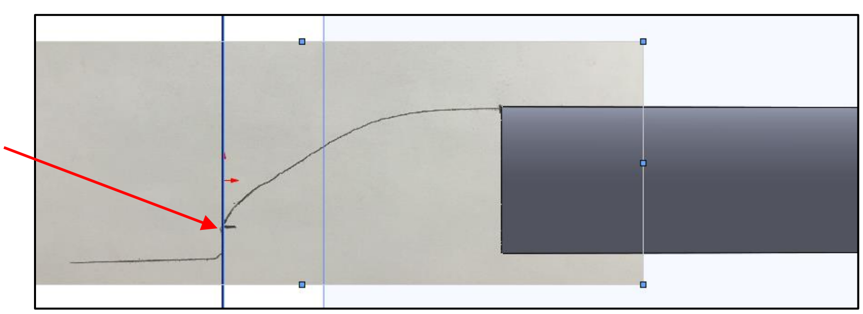


Figure 13. Sketch picture, guide curve of fuselage front

In order to figure out what types of lines or curves could be used to model this contour, I first created a rough sketch following the contour. I determined that a line, two different three-point arcs, and another line could be used to model the shape. I then found the dimensions of the line and arcs using geometric constructions.

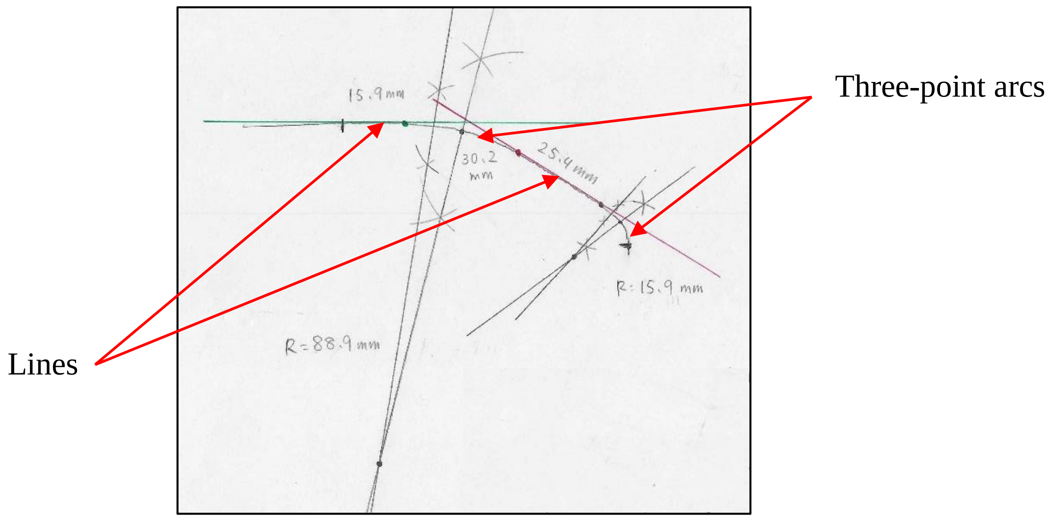


Figure 14. Geometric construction to find radii of the guide curve

These measurements were reflected in the sketch:

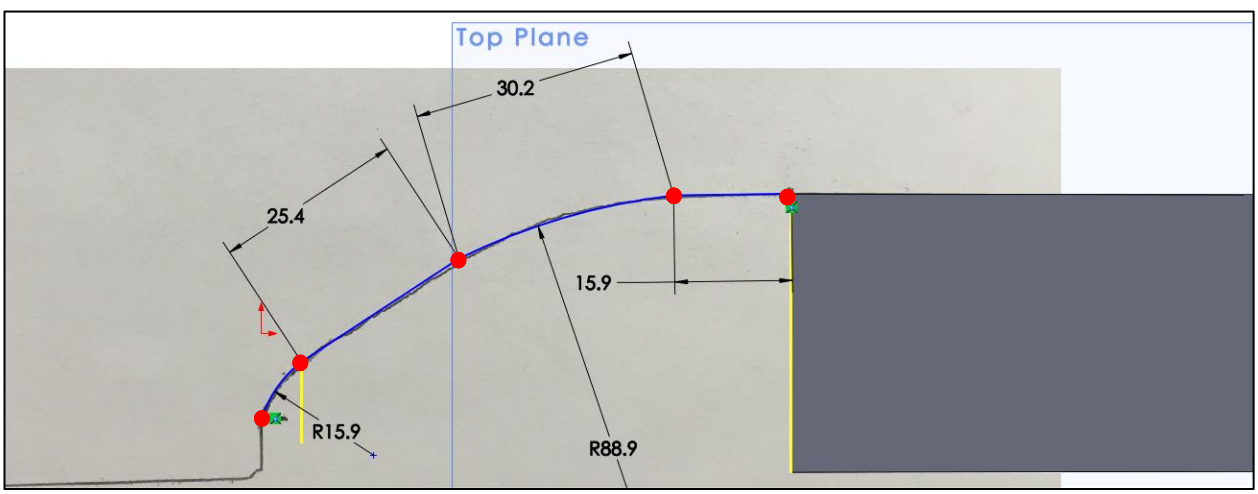


Figure 15. Guide curve of fuselage front, dimensioned.
Red points indicate location of endpoints of lines and curves.

Then, I determined the horizontal distances between each point (marked in red above) on the guide curve using Solidworks' horizontal dimensioning tool. These points will serve as the horizontal location for where my loft profiles will be.

Loft Profiles

To mark the profile locations on the airplane, I applied tape around the circumference of the fuselage front where each of the three inner points of the guide curve was located. Since the horizontal distances between the profiles had to be projected down onto the surface of the curved fuselage, it was very difficult to physically apply tape accurately.

Additionally, since the profiles were no longer circular, it was not possible to lay the tape flat around the entire circumference of the fuselage. Therefore, I simply marked the locations where the profile crossed the centerlines of the entire body.

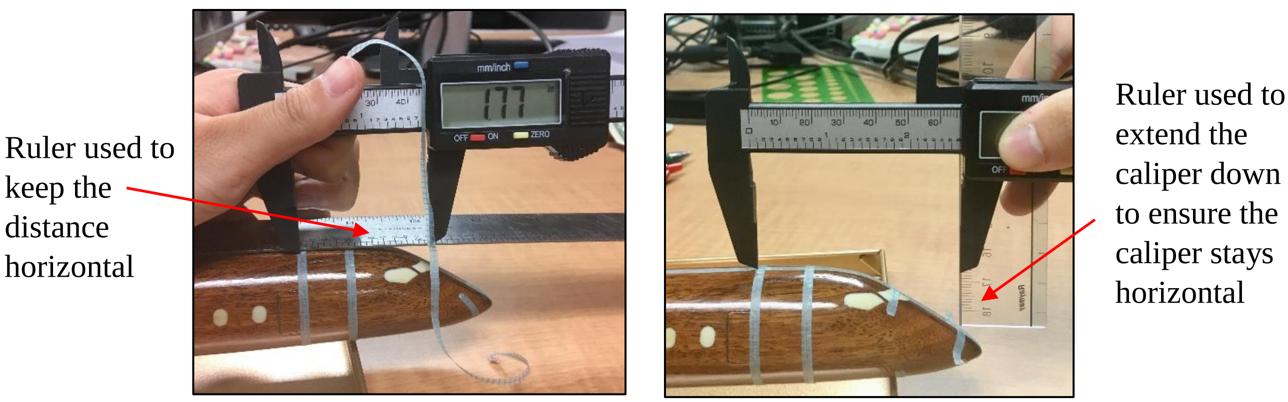


Figure 16. Using a caliper to measure out the profile distance and apply tape

Next, I used the contour gauge to find the shape of half of the profile, using tape to mark where the center was located. I then imported the contour into SolidWorks. Due to the curvature of the fuselage body, some pins slipped to the side of the body and had to be manually adjusted.

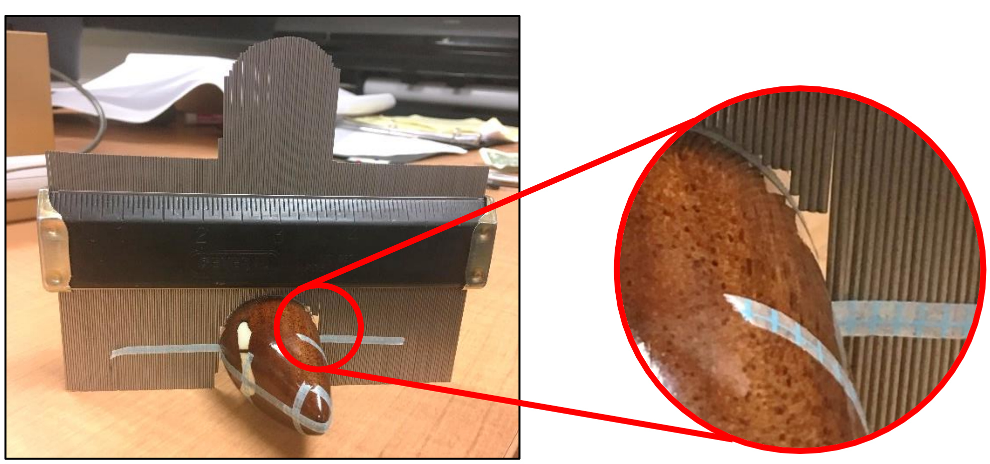


Figure 17. Using a contour gauge to find the profile shape. Some pins had to be adjusted.

I encountered a lot of problems when tracing over the contour and dimensioning it:

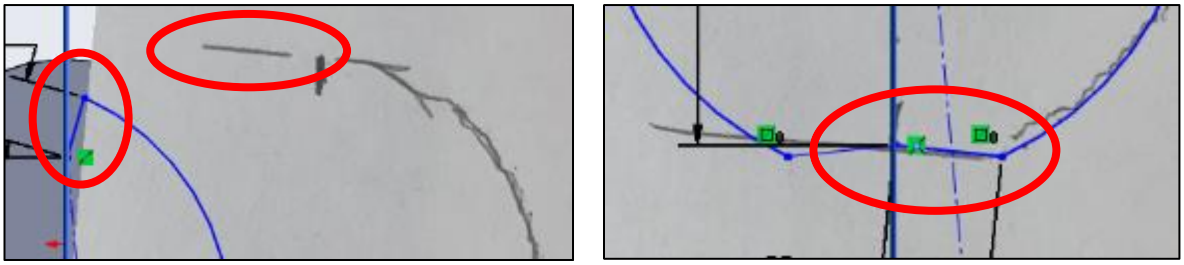


Figure 18. Some problems encountered with profile sketch
Left: Deformed sketch, circled sketch line supposed to be horizontal as shown in the photo.
Right: The bottom of the fuselage is supposed to be curved radially outwards.

Every time I took a contour, the shape looked slightly different. Ultimately, I chose the contour that looked the most accurate based on observation of the physical model. The difference in contours demonstrated that there were errors associated with taking the measurement.

After multiple attempts to sketch and dimension the contour and have it look similar to the airplane profile, I concluded that the most efficient way of sketching the profile was to create a centerline coincident with the top plane, dimension the centerline according to the profile height determined by a caliper, and then align and scale the sketch picture according to the centerline.

In order to rotate the sketch picture to match the orientation of the contour to the model, I drew two construction lines, one that was vertically straight with respect to the contour, and one that was vertically straight with respect to the coordinate system in SolidWorks. Then, I found the angle between the two lines within SolidWorks and used that angle to rotate the sketch picture.

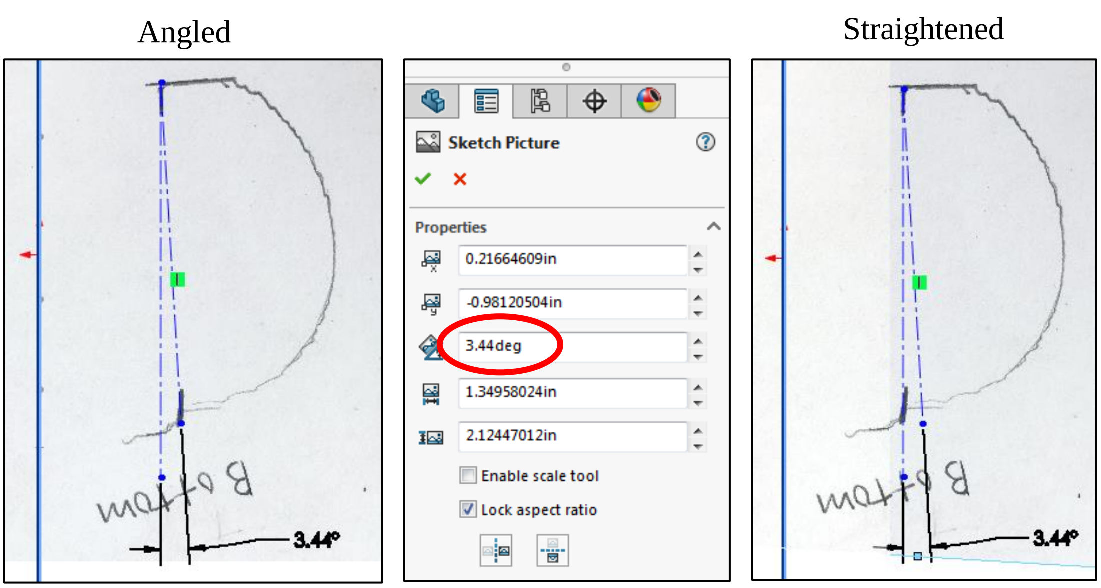


Figure 19. Rotating the sketch picture

I then aligned the contour so that the contour was coincident with the top of the guide curve.

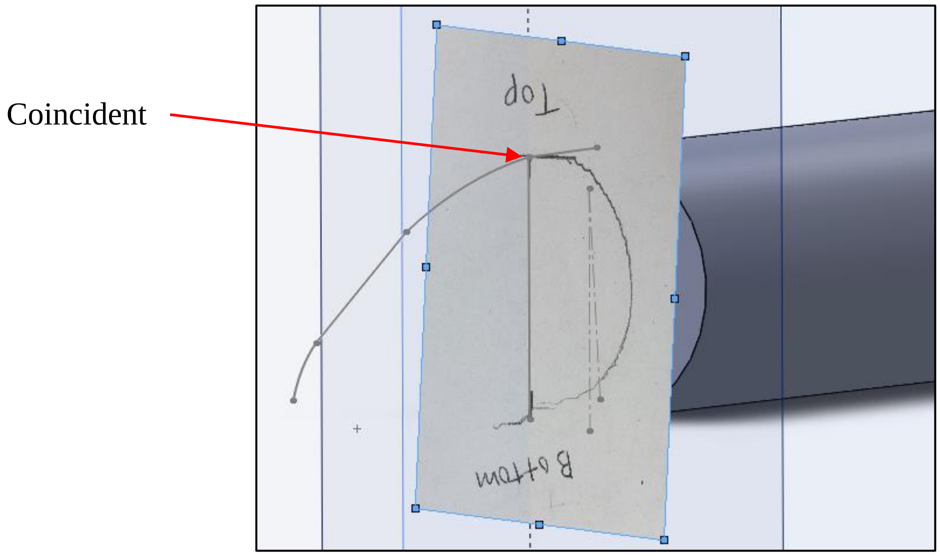


Figure 20. Sketch picture, aligned and scaled

I found the radius of the contour arc using a geometric construction:

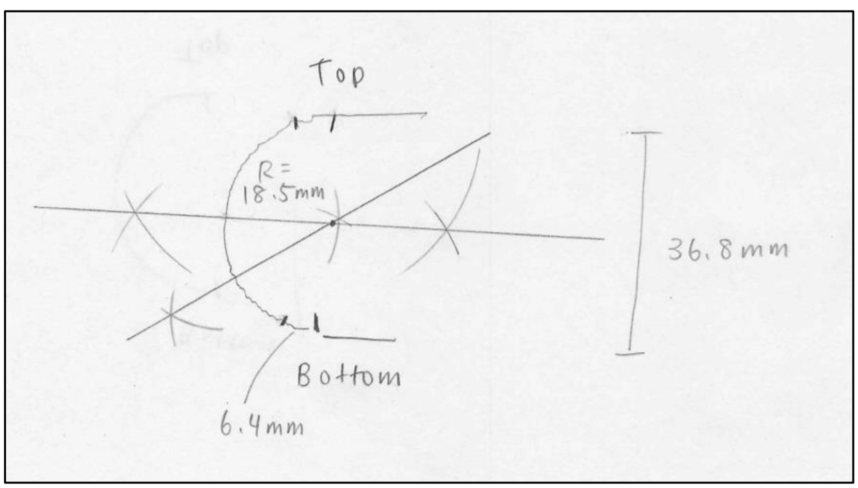


Figure 21. Geometric construction used to find radius of the first profile

I then sketched the contour, dimensioned it, and mirrored it.

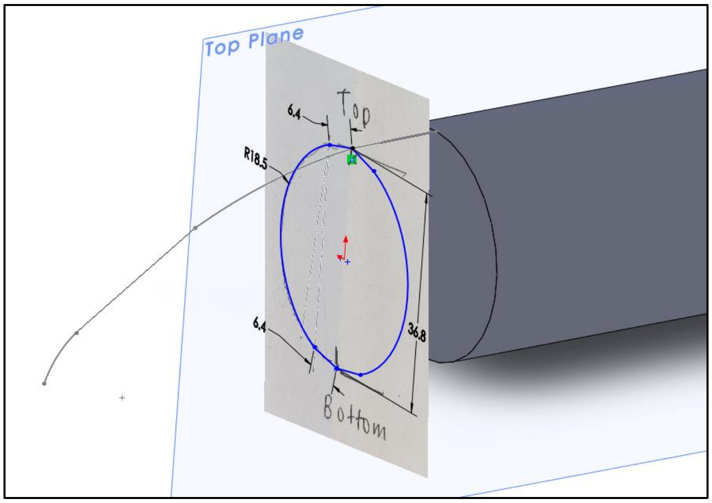


Figure 22. Contour sketched, dimensioned, mirrored

The top and bottom were sketched using straight lines; therefore, the contour was not very smooth. To smooth the profile out, I created a perimeter circle using the points of the straight lines on both the top and the bottom.

During this process, I encountered some errors:

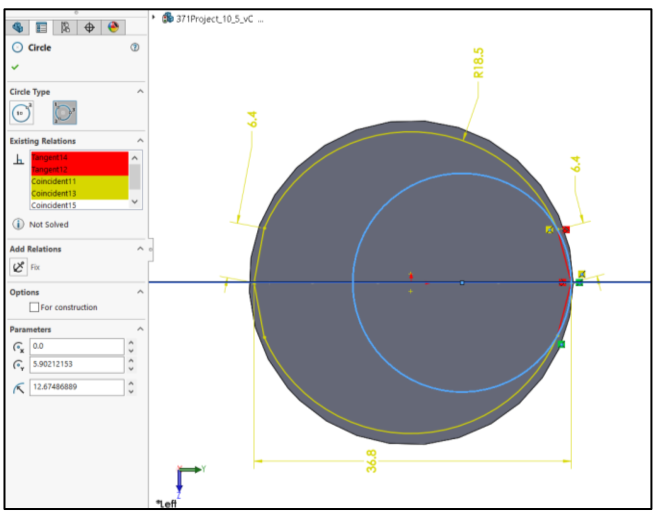


Figure 23. Error encountered during perimeter arc sketch

I realized that as I was choosing points for the perimeter circle, I was also creating additional relations that conflicted with other pre-existing relations. Therefore, I had to make sure that I was choosing perimeter points that only created a coincident relation with the rest of the sketch.

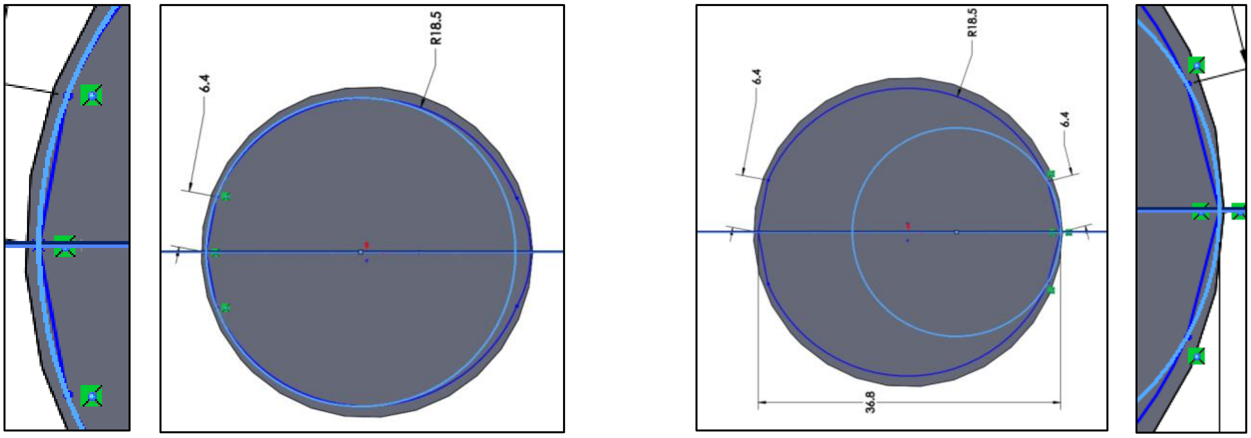


Figure 24. Perimeter circles were used to round out the profiles

I then trimmed the excess away to create the final profile.

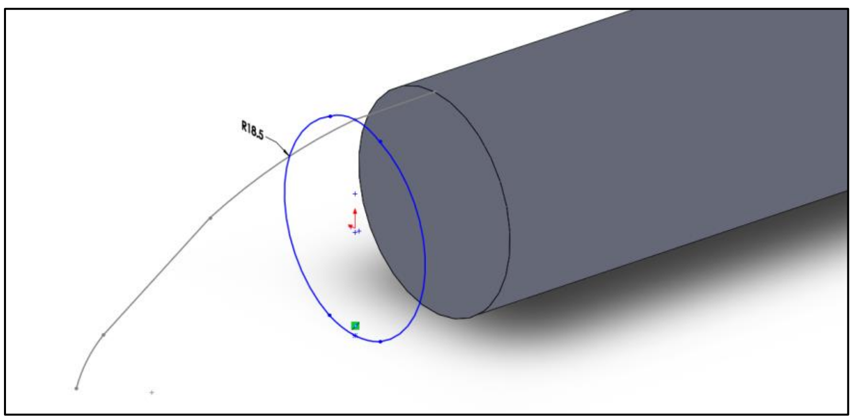


Figure 25. Final profile, smoother than previous profile

The perimeter circles were created to visually bring the model closer to the physical fuselage shape and is not a product of measurement; therefore, there will be some inconsistencies between the airplane measurements and sketch dimensions.

After finishing this profile, I realized that the bottom guide curve also had to intersect the profile in the same locations while maintaining the proper shape for the loft feature to work. Therefore, I took a contour of the bottom side of the fuselage and imported the contour into SolidWorks.

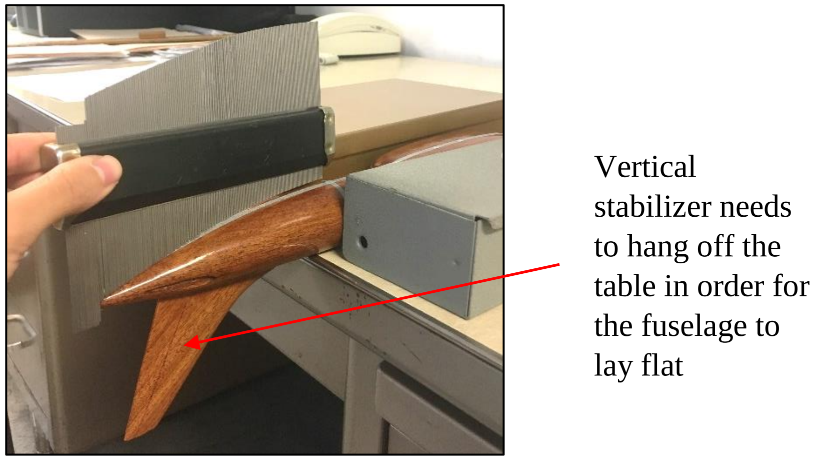


Figure 26. Using a contour gauge to take the contour of the bottom of the fuselage

I drew vertical construction lines from the top guide curve points in order to determine where the points of the sketch on the bottom guide curve will have to be located. Then, I outlined a rough sketch of the sketch picture using lines and arcs to ensure that it was possible to make the shape of the bottom guide curve using the same location of points as the top guide curve.

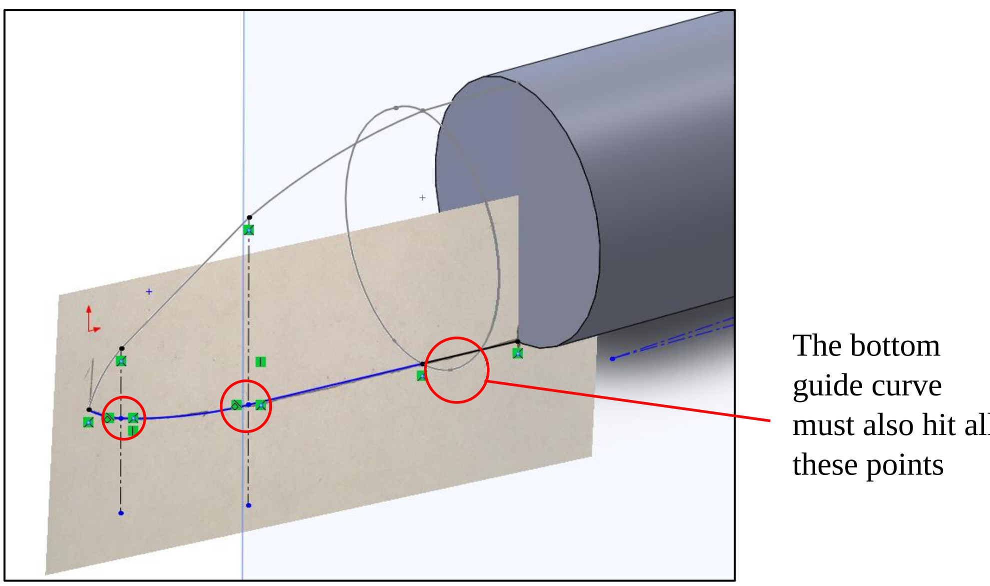


Figure 27. Rough sketch of bottom guide curve

Since this was only a verification that I could continue to use the locations of the profiles dictated by the top guide curve, no dimensions were imported yet and this sketch was deleted.

In order to do the next profile, I again created a new plane, aligned and scaled the sketch picture of the profile, and created a sketch with the dimensions obtained by geometric construction.

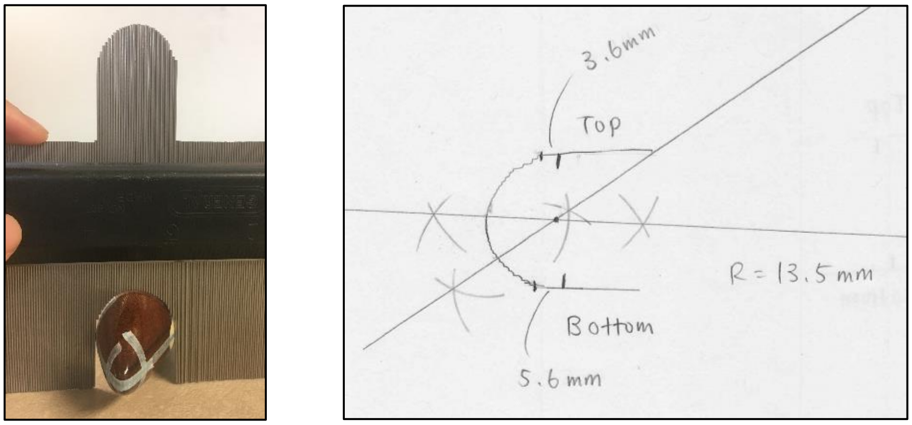


Figure 28. Getting the contour and using geometric construction to determine radius of second profile

The dimensions obtained from the figure above were used to dimension the sketch below:

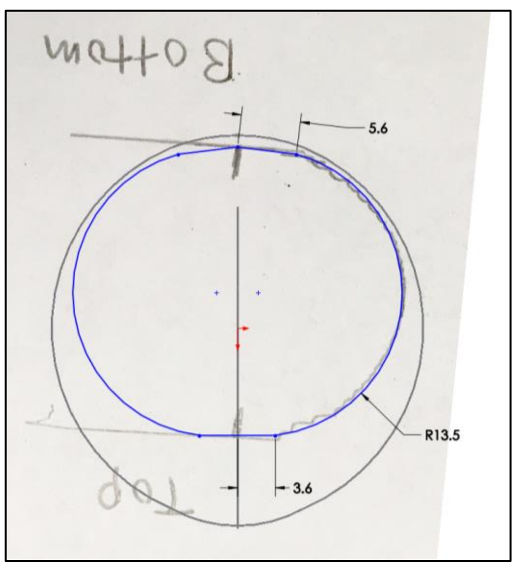


Figure 29. Second profile contour, sketched, dimensioned, mirrored

When looking at the airplane, the top portion seemed relatively flat along the circumference, so I decided to keep the top as sketched. However, the bottom still needed to be rounded and therefore, I chose to use a perimeter circle again.

This is how my second profile turned out:

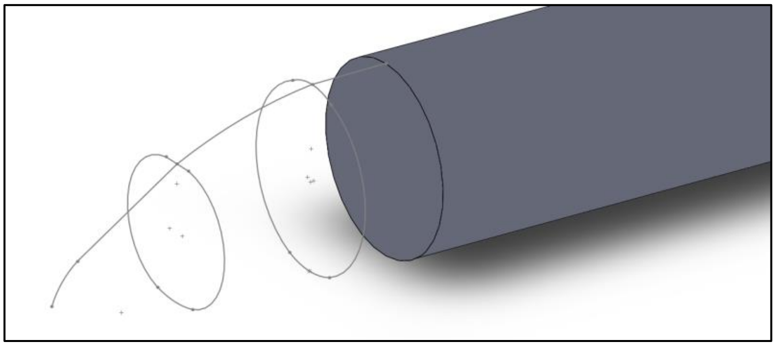


Figure 30. Loft profile progress

I repeated the steps for the final contour. The geometric construction is shown below:

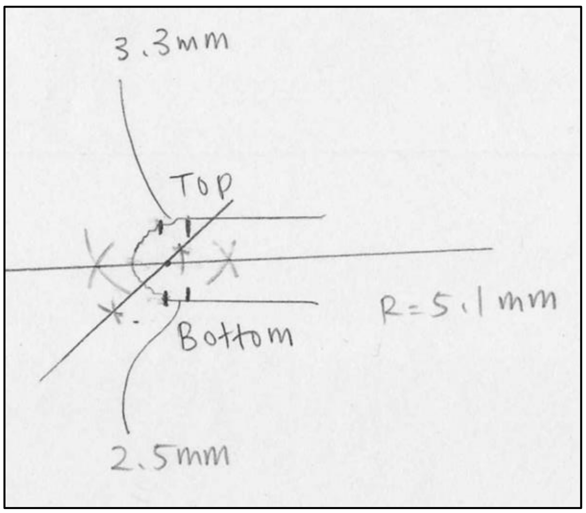


Figure 31. Geometric construction used to find radius of third profile

These dimensions were used in the sketch below.

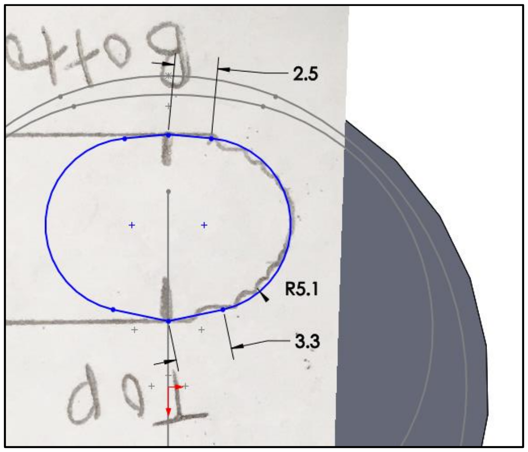


Figure 32. Third profile, sketched and dimensioned

When I created a perimeter arc for the top, it came out slightly bumpy:

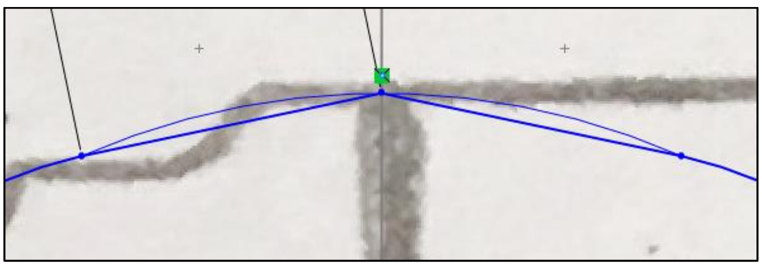
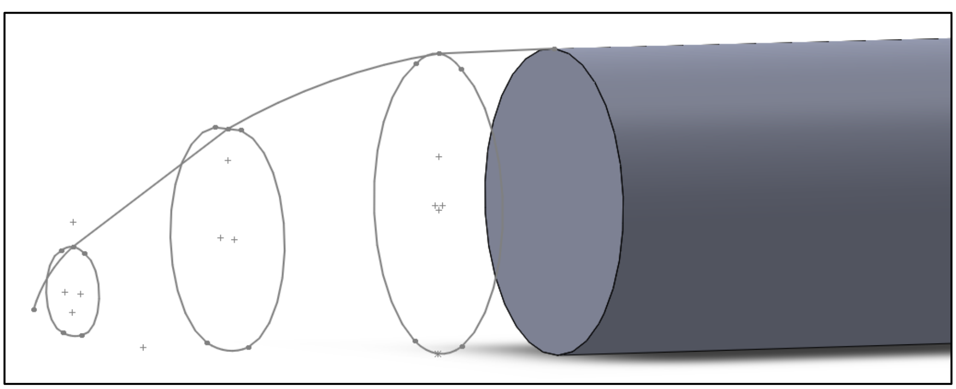


Figure 33. Bumpy profile top

However, it was not possible to mitigate this without changing my dimensions so I decided to leave it as is.

I finally had my three contours.



Third Second First profile

Figure 34. All three profiles

Bottom Guide Curve

Finally, I created the guide curve on the bottom using the points that lie on the profiles.

I approximated the guide curve connecting the front side of the cylinder to the first profile and the guide curve connecting the first profile to the second profile to be straight lines.

I decided to use tangent arcs for the guide curve connecting the second profile to the third profile and the curve connecting the third profile to the nose of the airplane. I decided to use tangent arcs because they looked smoother when connected. This was another decision made based on visual observation.

Since the distance between the profiles were already dimensioned and tangent arcs are limited by their tangent relation, I was not able to dimension the guide curve. However, the guide curve overall seemed to fit the sketch well.

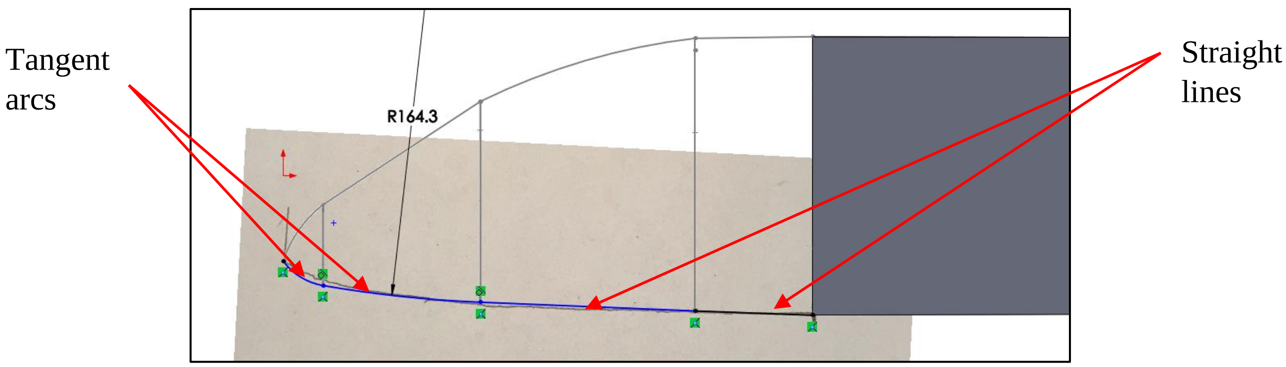


Figure 35. Bottom guide curve, dimensioned automatically by SolidWorks

The final loft profiles and guide curves are shown below:

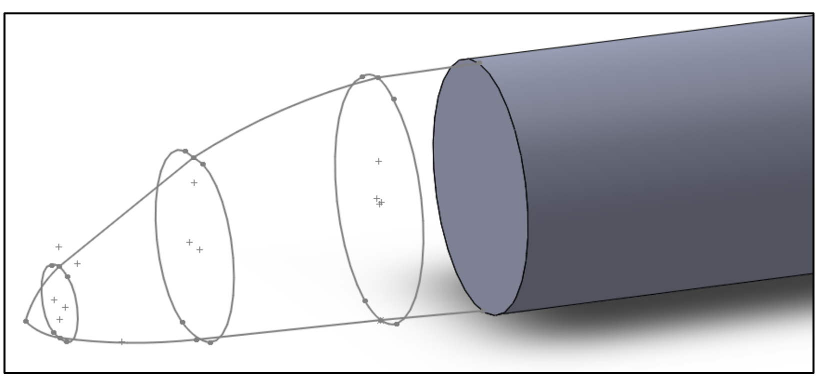


Figure 36. Loft profiles and guide curves

Loft

Next, I tried doing a loft with the profiles and guide curves. However, I learned that it was not possible to loft up to the point at the airplane nose.

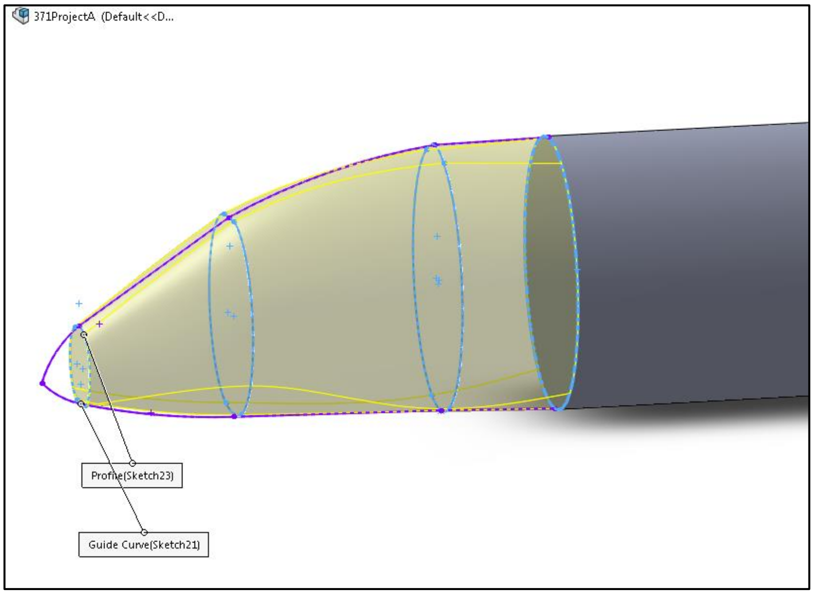


Figure 37. Problem completing loft to a point

I could not figure out how to complete this loft; therefore, I decided to stop the loft at the third profile and find a different way to complete it.

In order to round out the front and fill in the part that was not lofted, I tried a dome.

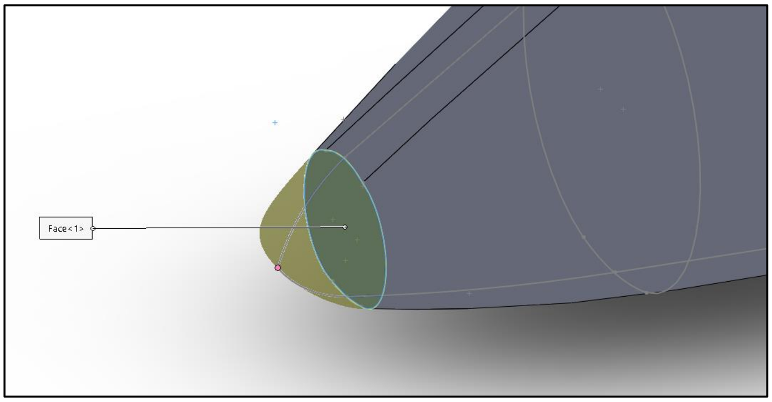


Figure 38. Doming the front

When I domed the nose, it looked very similar to the way the airplane nose looked, and therefore I decided to keep this dome.

The final fuselage front is shown below:

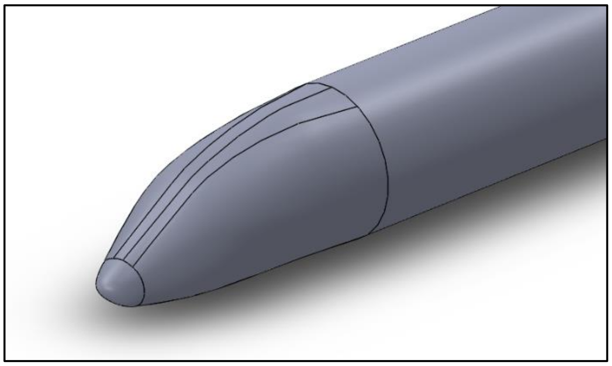


Figure 39. Completed fuselage front

Fuselage Back

Next, I worked on the back portion of the fuselage extending from the back of the cylinder.

First, I measured the distance between the back end of the cylinder and the very back of the airplane and used this distance to create a new plane for the very back of the fuselage.

Figure 40. Making datums out of boxes to find the distance using a caliper

Next, I found the diameter of the circular fuselage back end using a circle template and sketched it on the new plane. I measured and dimensioned the distance from the bottom of the fuselage cylinder to the center of this circular back end.

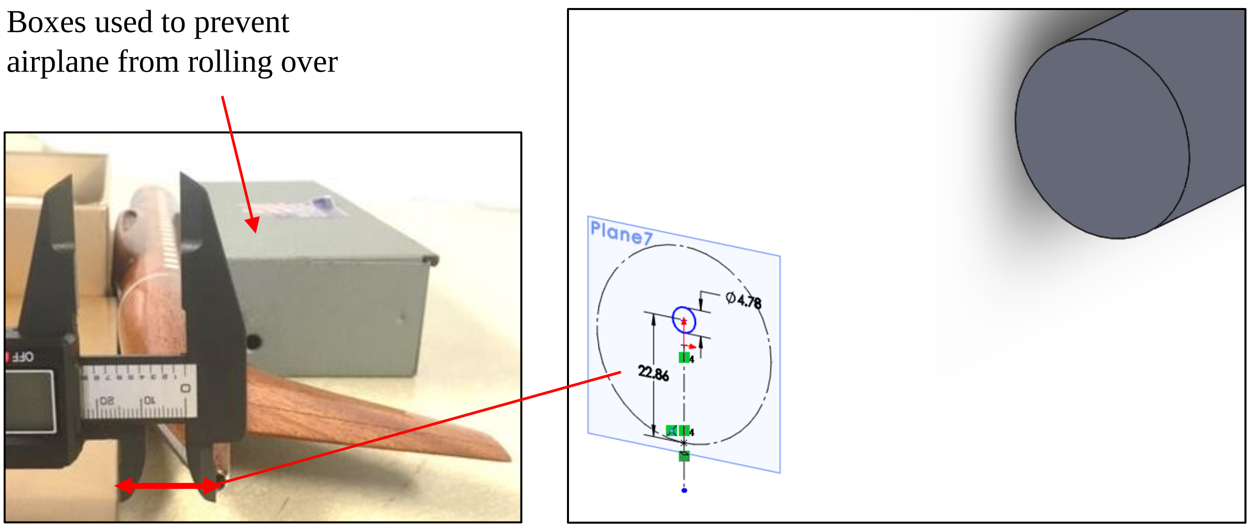


Figure 41. Measuring the distance between the bottom of the fuselage and the circular end of the fuselage

Bottom Guide Curve

I then used a contour gauge to get the loft guide curve for the bottom side, since it had a greater curvature than the top side and therefore seemed to be the better curve for choosing the loft profile locations.

This was difficult because the back portion of the fuselage was long and barely fit along my contour gauge. It was also difficult to keep the model grounded since I had the back portion hanging off the desk and was further placing weight on it to take the contour. (See Figure 26)

I then imported the contour into SolidWorks and tried tracing the contour as an arc and a spline:

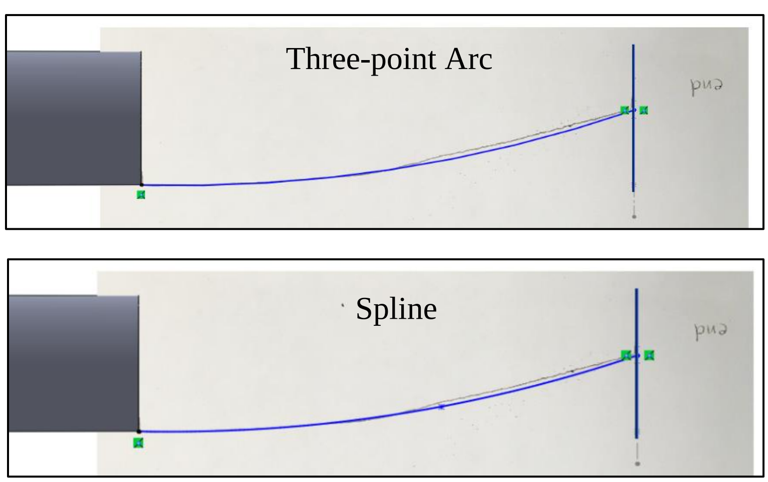


Figure 42.
Top: Three-Point Arc
Bottom: Spline

Both the three-point arc and spline seemed to fit the curve well, so I decided to model this curve as an arc since it is a measurable entity. However, due to the large size of the arc, I could not do a geometric construction to determine the radius. Therefore, I simply followed the three-point arc along the sketch picture, letting SolidWorks determine the radius based on what I traced along the picture.

Top Guide Curve

Next, I had to sketch the top guide curve. The guide curve contour was not possible to obtain using a contour gauge since the vertical stabilizer was in the way but could not be removed from the fuselage. Therefore, I decided to take a photograph of the top view and trace the contour using the photograph as a sketch picture.

It was very difficult to take the photograph in a way such that the camera was facing straight down and taking an accurate top view. Once I had the photograph as a sketch picture, I was able to trace over the top curvature using a three-point arc. Since this arc was not drawn on a sheet of paper, the radius of the arc was again determined by SolidWorks.

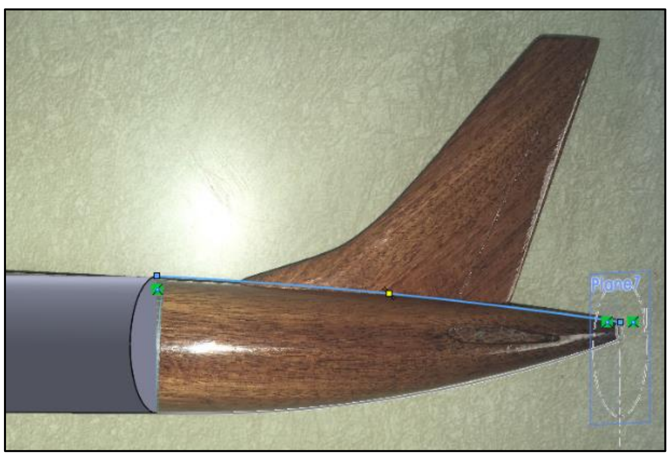


Figure 43. Outlining the guide curve of the back of the fuselage

The image above shows that the angle of the airplane model photograph relative to the SolidWorks model is slightly off. This could be attributed to errors such as measurement or photography errors.

Loft Attempt 1

After obtaining the two guide curves, I created a loft.

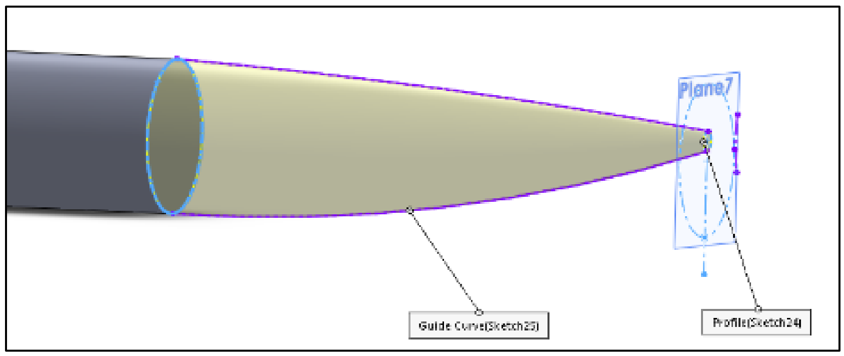


Figure 44. Fuselage back loft attempt 1

When looking at the loft from the front, however, the sides of the fuselage back were straight unlike in the actual model:

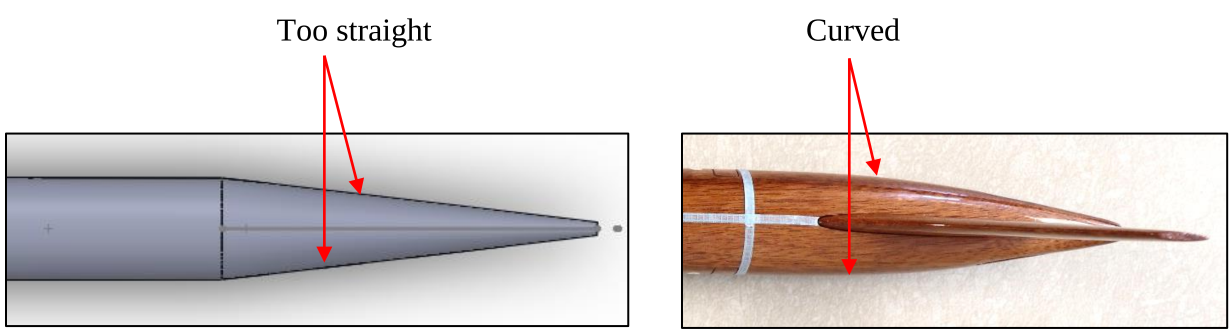


Figure 45. Solid model versus physical airplane

Therefore, I had to add guide curves to the sides as well.

Loft Attempt 2

In order to add guide curves, I had to determine where on the airplane I wanted the guide curves to be. Ultimately, I chose to have the guide curve lie along the length of the horizontal stabilizer airfoil to make it easier to reference and to tape the grid tape.

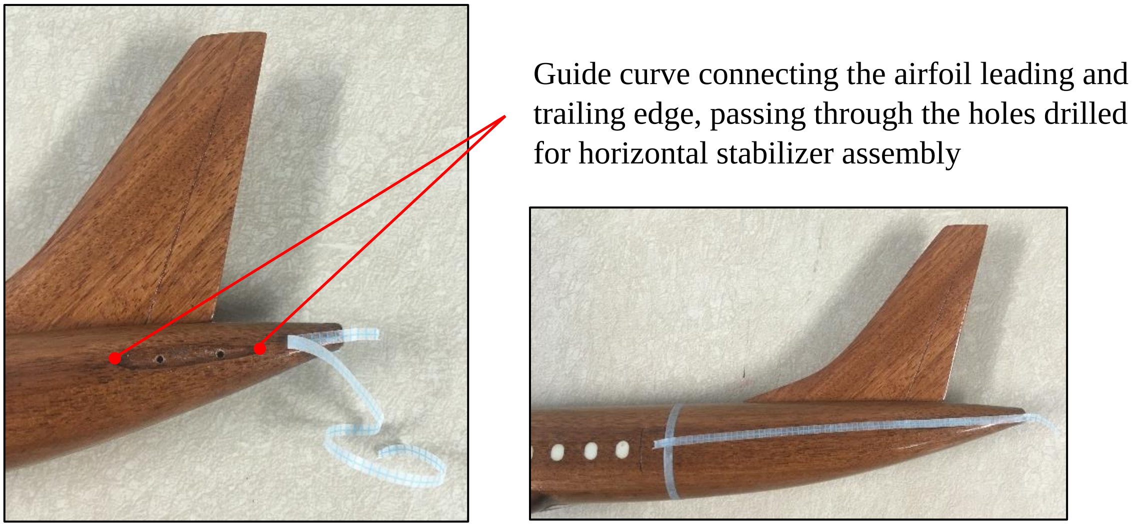


Figure 46. Taping the guide curve

I then used a contour gauge along the tape to obtain the guide curve shape.

Figure 47. Taking the contour of the side guide curves

The radius of curvature of the arc following the contour was too large to measure using geometric construction, so I used a three-point arc connecting the endpoints and had SolidWorks determine the radius. Then, I attempted to redo the loft, adding the two new guide curves.

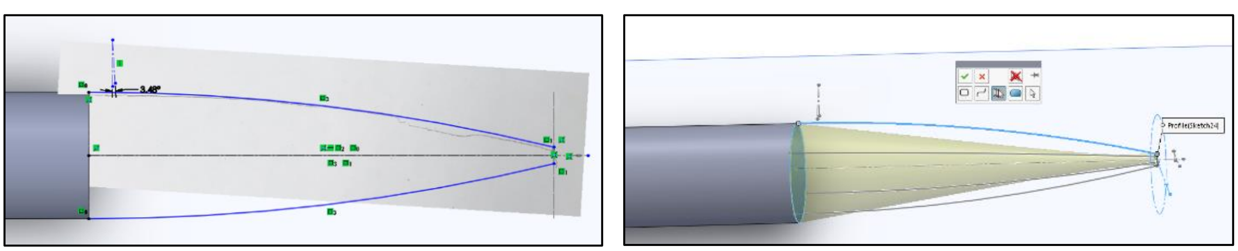


Figure 48. Loft attempt using side guide curves

However, I could not get this loft to work. I thought it might have been due to the guide curves not being on the profiles; therefore, I tried it again by using a pierce relation between the guide curve and the profiles.

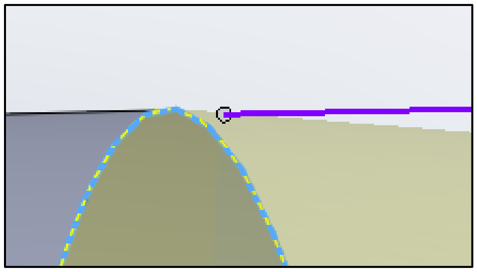


Figure 49. Guide curve not on profile

There was still a problem with the guide curve.

Ultimately, I ended up using the guide curves as open curves. I am not sure what it signifies, but the loft seemed to resemble the physical model well enough and therefore, I decided to keep it this way.

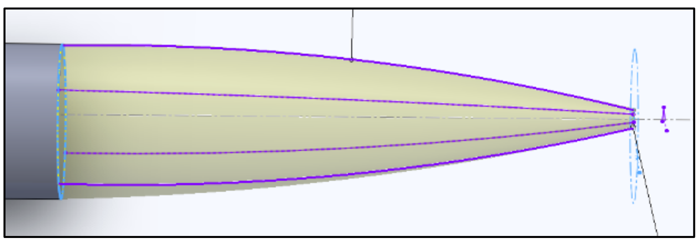


Figure 50. Fuselage back loft

Wing Box

The next part I modeled was the wing box. I separated the wing box into three sections – the front curved part, the middle relatively straight part, and the back curved part.

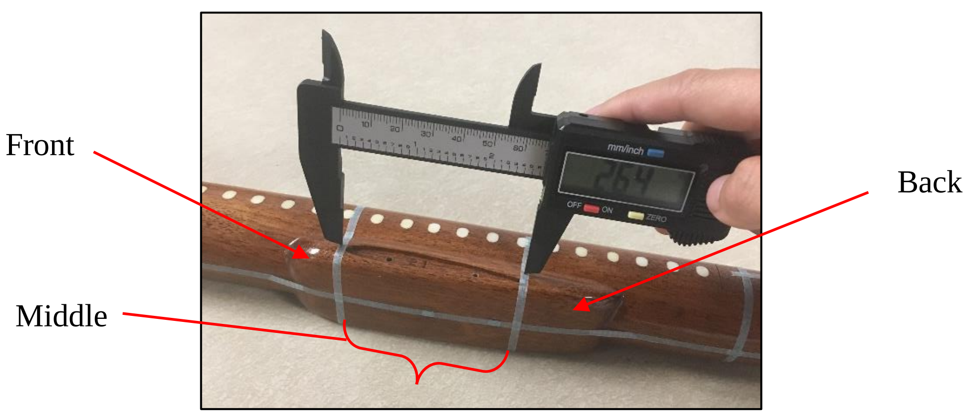


Figure 51. Separating the wing box into sections

I then started working on the middle portion. I decided to try doing a boundary surface, which required me to have a guide curve. Therefore, using a contour gauge, I found the shape of the bottom portion of the wing box to use as my first guide curve. I imported the contour into SolidWorks, and using dimensions I found using a caliper, adjusted and scaled the sketch picture.

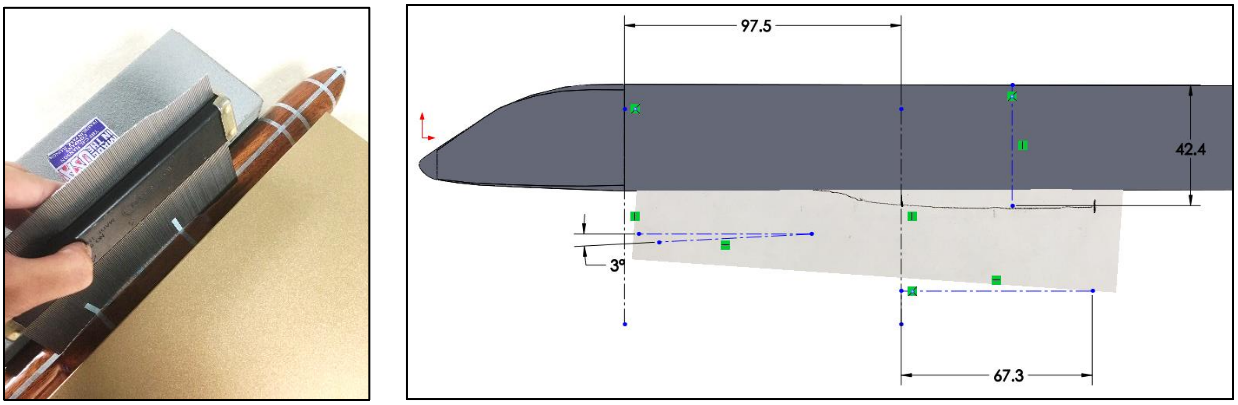


Figure 52. Taking a contour of the wing box bottom

I sketched the bottom of the wing box using a three-point arc. The radius of the arc was again, too large to determine using geometric constructions.

Next, I used a contour gauge to get the profiles of the front and back sides of the wing box.

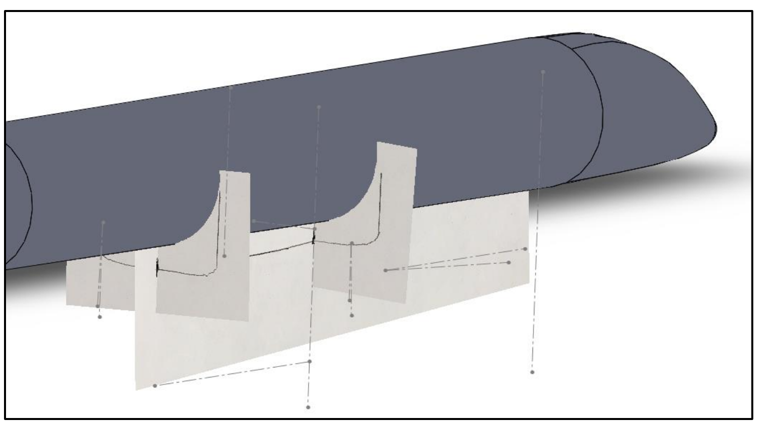


Figure 53. Sketch pictures of the wing box

I decided to use a straight line to model the bottom side and use geometric constructions to measure the radius of the arc curving up on the side.

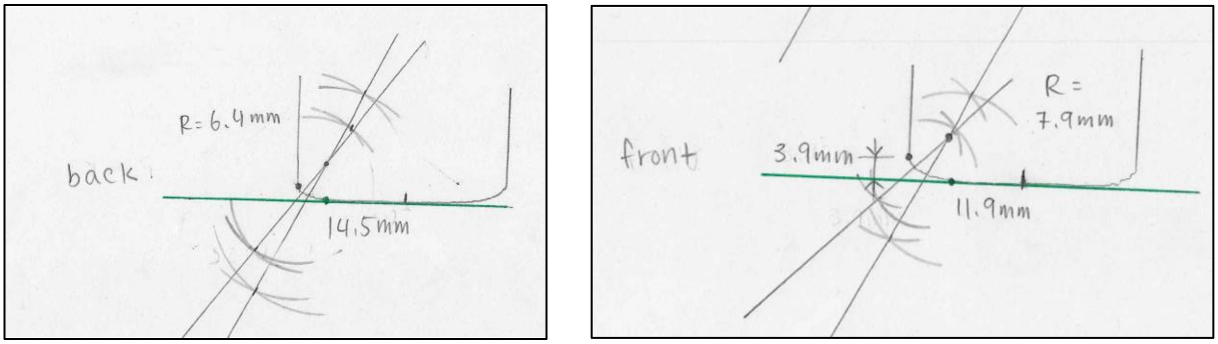


Figure 54. Geometric construction to find the radius of the arcs

I used these measurements to dimension the arcs in SolidWorks.

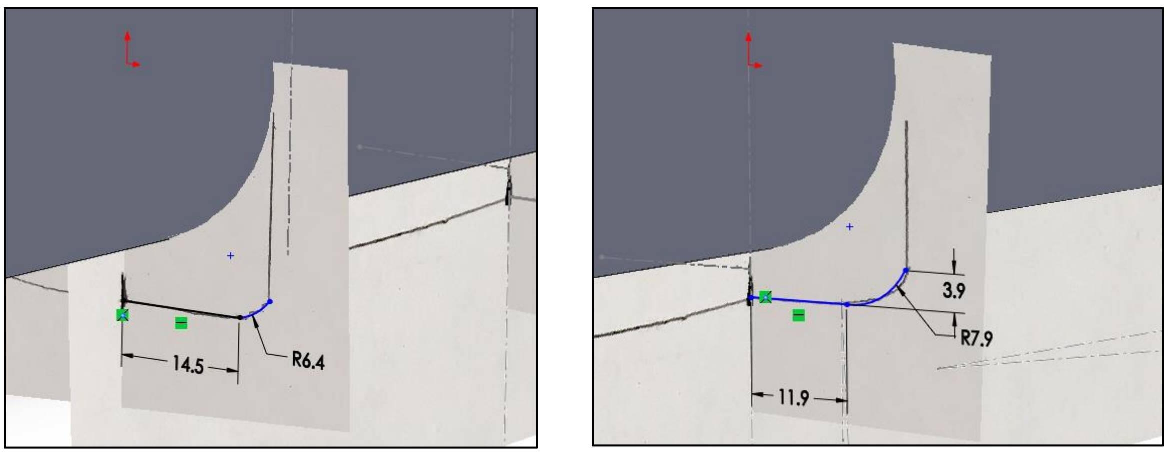


Figure 55. Back side profile (left) and front side profile (right)

At this point, I tried doing a boundary surface, which turned out well.

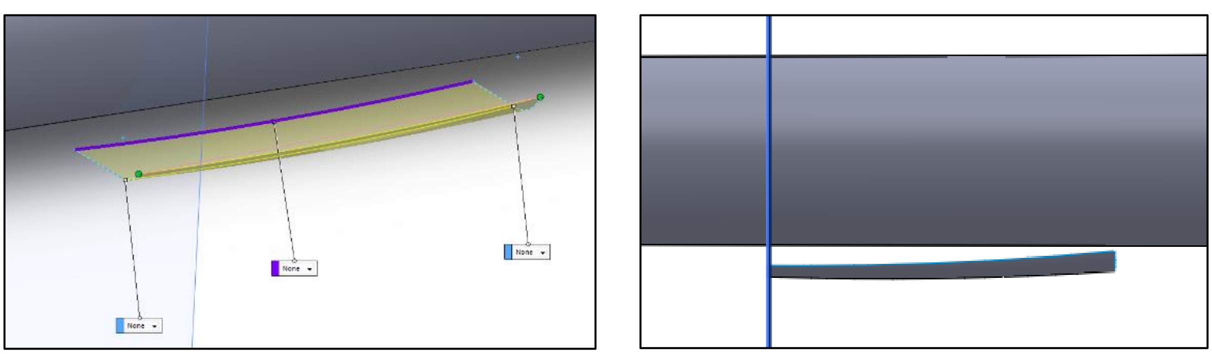


Figure 56. Initial boundary surface

Since the boundary had to extend upwards to reach the body of the fuselage, I undid the boundary surface and imported contours of the sides.

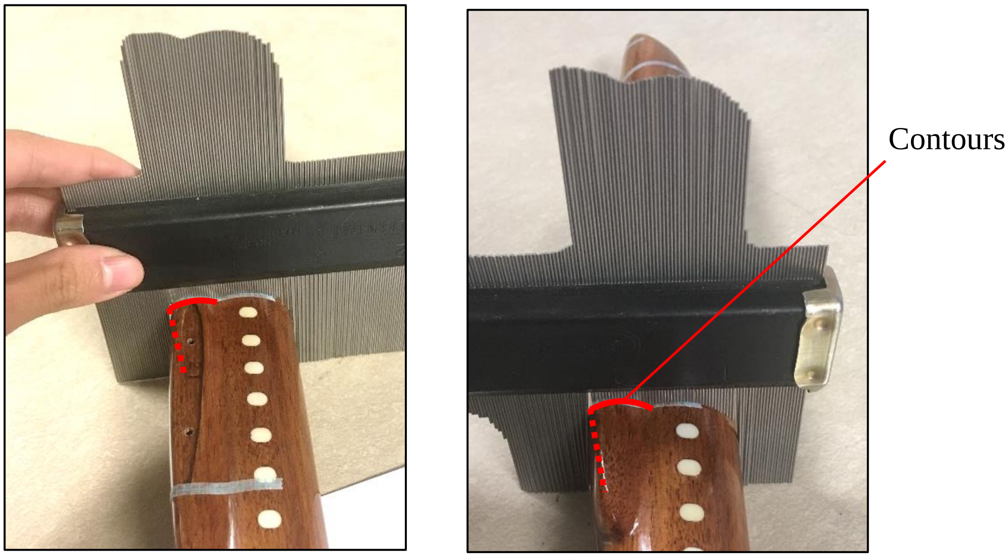


Figure 57. Contours of front and back wing box

I then took the contours and imported them into SolidWorks as sketch pictures, again adjusting and scaling the pictures to match the physical airplane.

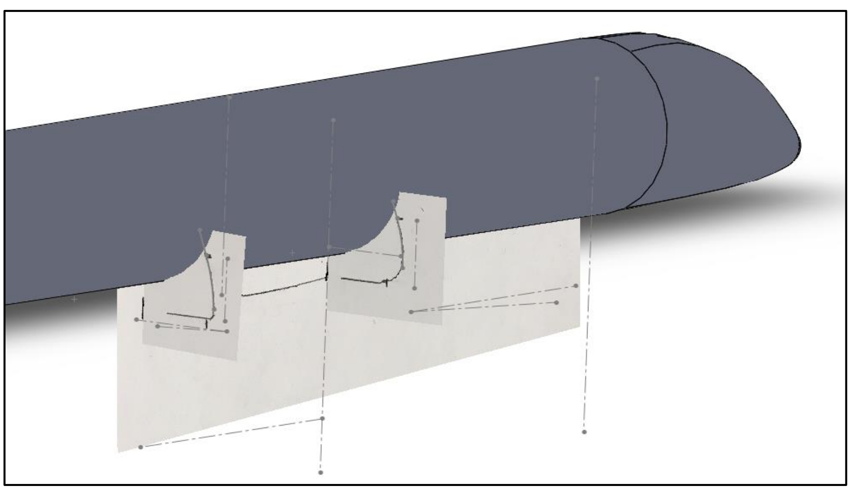


Figure 58. Contour sketch pictures imported

Then, I used geometric constructions on the contours to find the distances and radii of arcs and dimensioned the sketches accordingly.

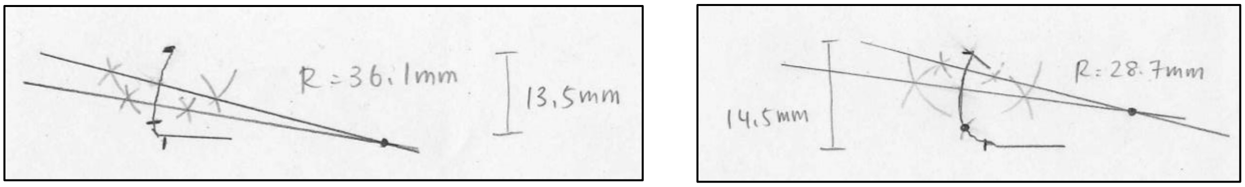


Figure 59. Geometric construction to find the radius of the arc

The dimensions were reflected in the SolidWorks model:

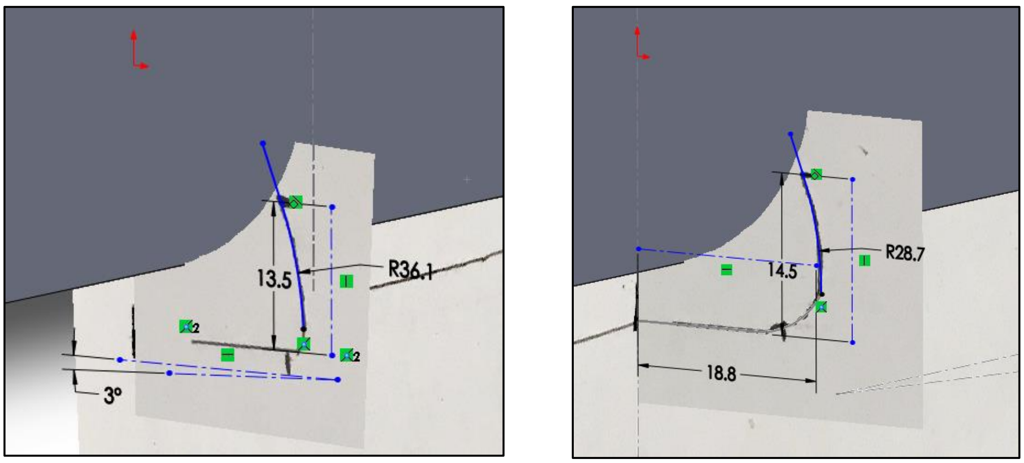


Figure 60. Contour of the back (left) and front (right) of the wing box

The profile below gave me the following boundary surface:

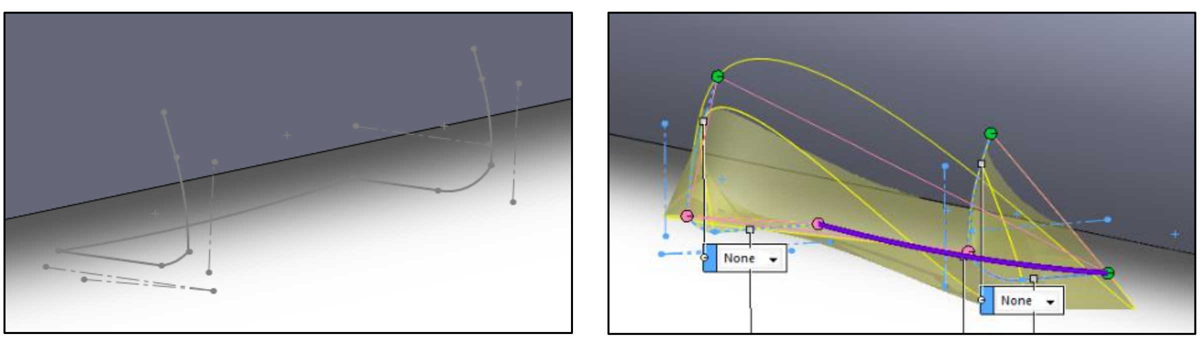


Figure 61. Boundary surface attempt

This did not look the way it was supposed to. It occurred to me that it may be because the profile curves were created in four total different sketches, for the bottom and the side. Therefore, I decided to redraw the profiles on two sketches, one for the front, and one for the back. The following was the boundary surface when I retried it with the combined sketches:

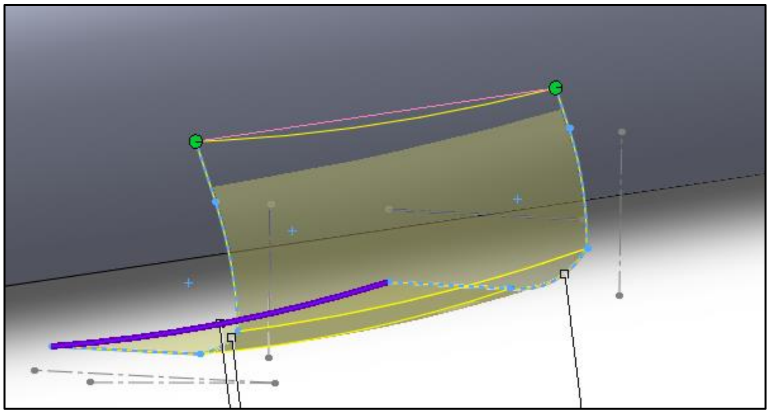


Figure 62. Boundary surface

This looked as expected.

Next, to close the surface, I attempted to make the profiles closed.

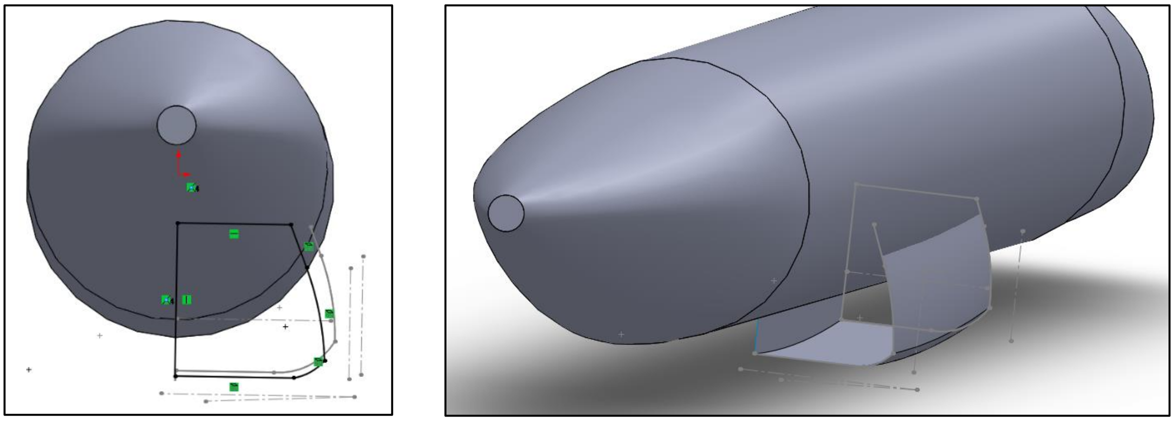


Figure 63. Attempting a closed boundary surface

Although the boundary was now closed, the boundary surface option to make the part solid did not appear.

Additionally, in looking at the boundary surface, I realized that I also needed to create a guide curve for the top part of the wing box, which I did so by taking a photograph of the wing box, importing it as a sketch picture, and tracing an arc over it:

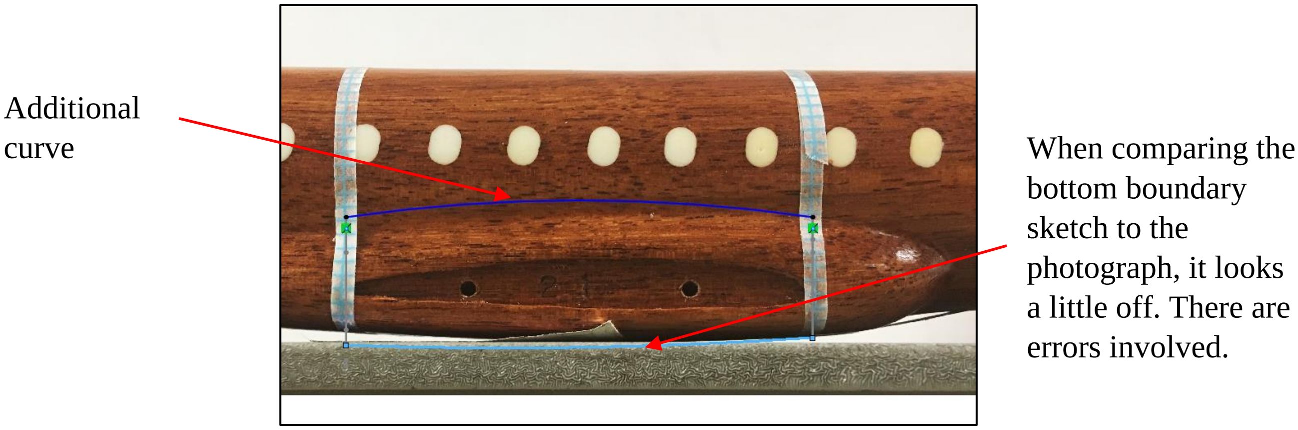


Figure 64. Sketching the top guide curve

I then used this sketched arc as another guide curve to get the following boundary surface.

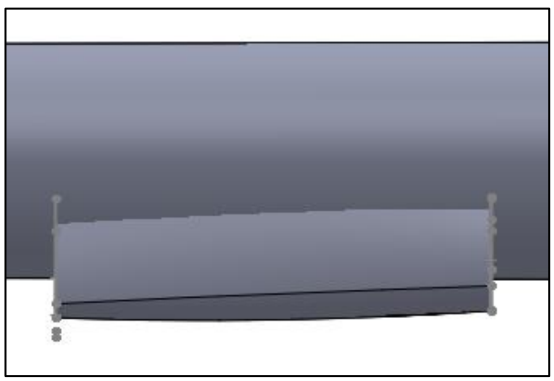


Figure 65. Boundary surface of the middle portion of the wing box

I then tried to use "thicken" to fill in the empty space, but it did not work out.

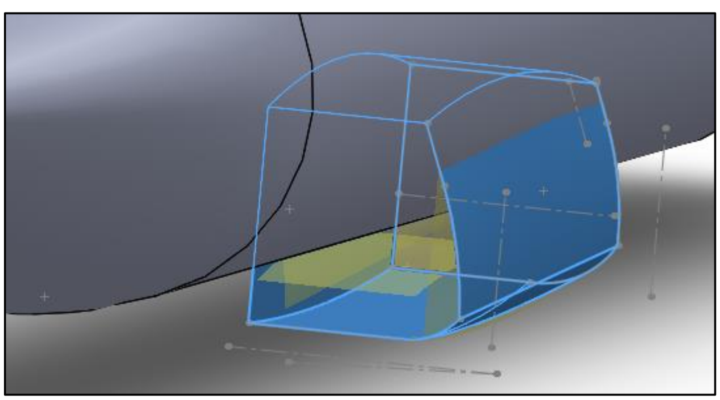


Figure 66. Thicken only worked up until a certain thickness, which did not fill up the entire empty area

At this point, I realized that for my structure of profiles and guide curves, a surface loft made more sense than a boundary surface. Therefore, although the results looked the same, I decided to remodel the wing box using a surface loft.

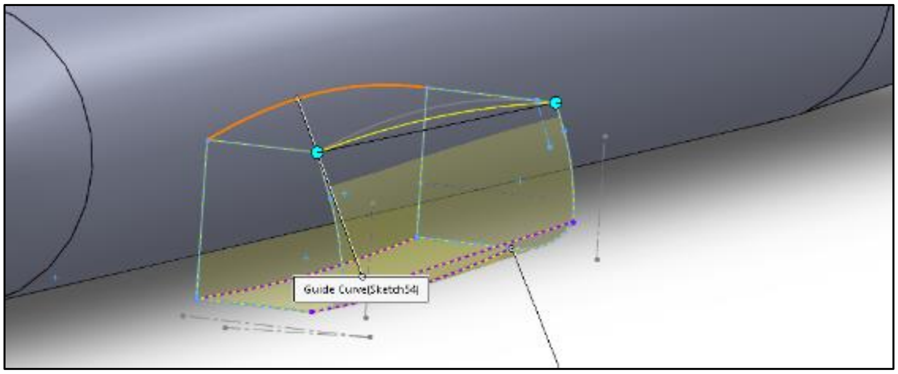


Figure 67. Surface loft of the middle portion of the wing box

Then, I decided to close the profile using a planar surface.

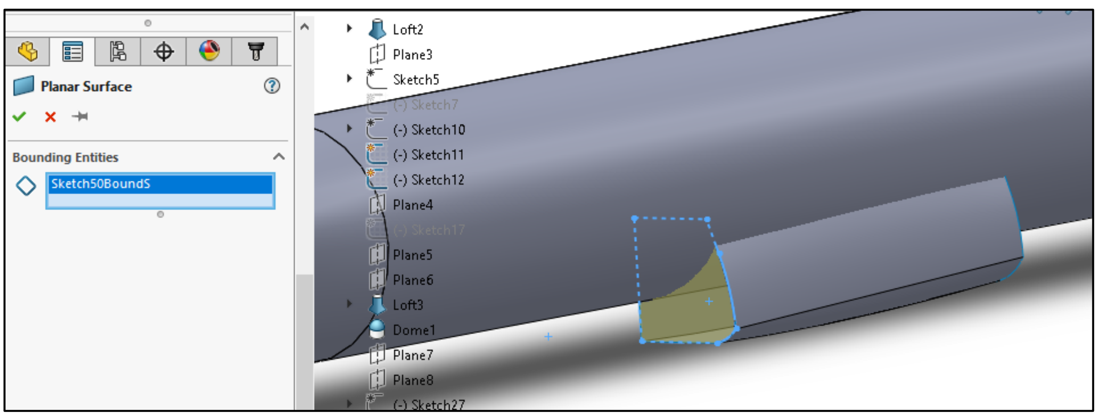


Figure 68. Closing the surface using a planar surface

Finally, to make the inside solid, I used the “knit” function. Below is the section view demonstrating the solid inside:

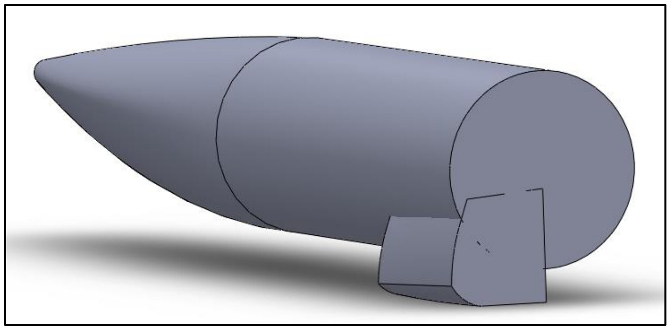


Figure 69. Solid wing box

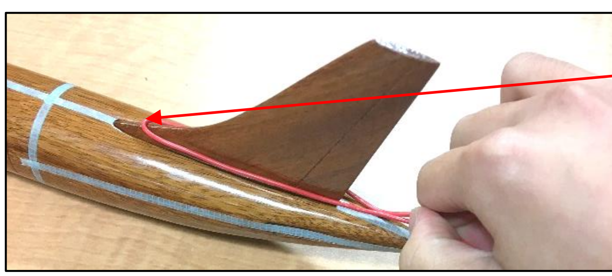
Since the curved portions of the wing box seemed harder to model, I decided to work on some other parts of the airplane before coming back to finish the wing box.

Vertical Stabilizer

The vertical stabilizer could not be detached from the fuselage. Therefore, it was difficult to take the associated measurements.

Large Airfoil

In order to get the shape of the larger airfoil, I had to find a way to trace out the shape of the area connected to the fuselage. I first tried using a piece of wire to shape the outline of the airfoil. However, the wire did not hold the shape of the airfoil well due to the very subtle curvature the airfoil had. Additionally, the wire kept slipping up the stabilizer and it was not possible to tighten the wire completely around the bottom airfoil to get a tight and accurate contour.



The wire is not aligned with base of the stabilizer

Figure 70. Wire slipped off the base of the stabilizer

Eventually, I decided to stick a piece of tape around the airfoil and use a box cutter to trace out the shape, since there was a gap between the stabilizer and the fuselage that could act as a guide for the box cutter while preventing the airplane from scratching.

I had to ensure that I stuck the tape along the centerline, which was difficult to do so due to the vertical stabilizer obstructing the center.

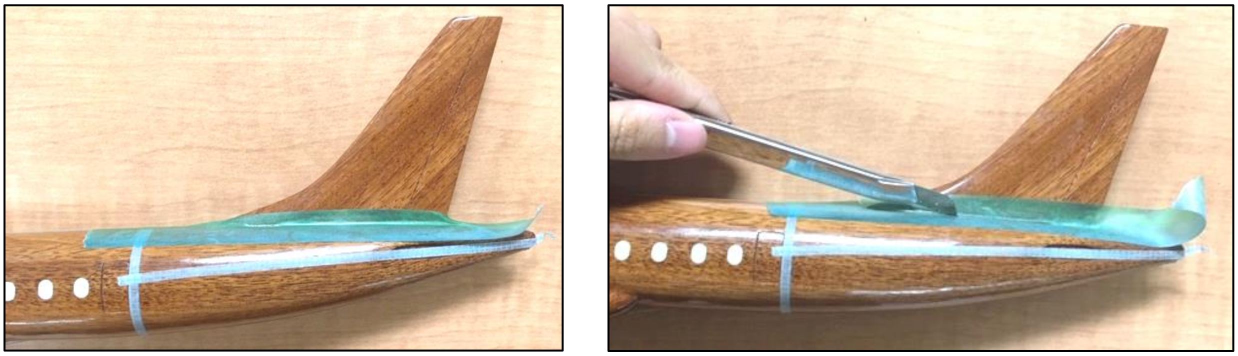


Figure 71. Finding the airfoil shape

I then stuck the tape on a sheet of paper, stretching the cut part of the tape slightly to make a gap with the shape of the airfoil. After coloring within the gap, I peeled the tape off to reveal the contour.

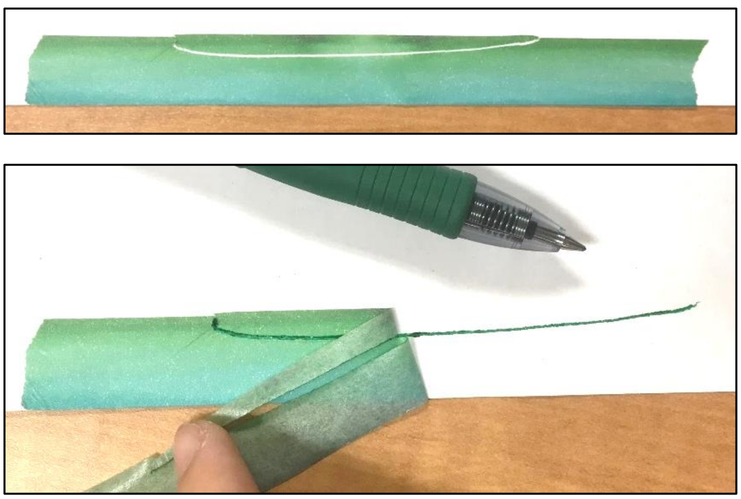


Figure 72. Finding the airfoil shape

I chose to sketch this airfoil on a flat plane because it was too difficult to trace the shape onto the curved surface of the fuselage back. However, in order to create the plane, I needed to create two initial planes to serve as guides for making the final sketch plane.

The first was a plane that represented the distance of the fuselage cylinder back to the airfoil leading edge. I took this distance using a caliper, since the fuselage was still approximately flat. I attempted to justify this assumption by placing a flashlight underneath the airplane body and seeing if any light leaked out in the transition between the fuselage cylinder and the location of the stabilizer airfoil leading edge.

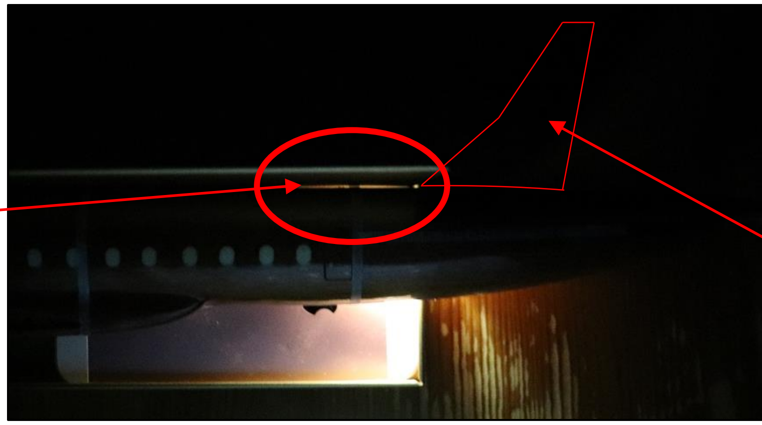


Figure 73. Determining the gap between the fuselage cylinder and vertical stabilizer leading edge

The second was a plane that intersected the fuselage back at the location where the stabilizer airfoil trailing edge is located. This distance was taken using a caliper but with a more elaborate datum setup.

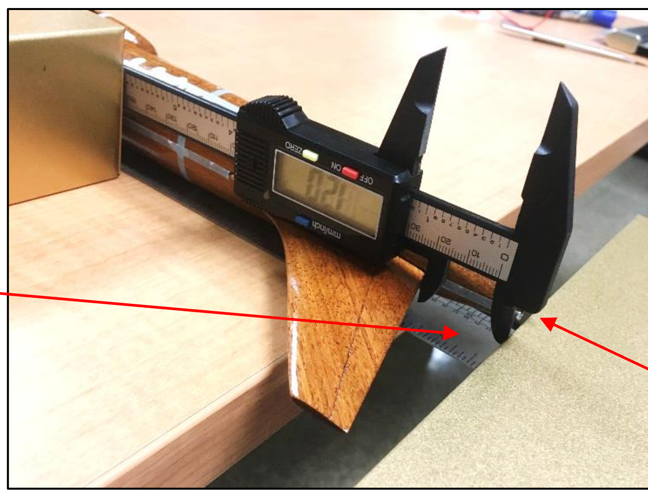


Figure 74. Measuring the distance between the stabilizer trailing edge and the back of the fuselage

On both planes, I sketched an intersection curve of the fuselage. Then, I created a plane that connected the top of the two profiles.

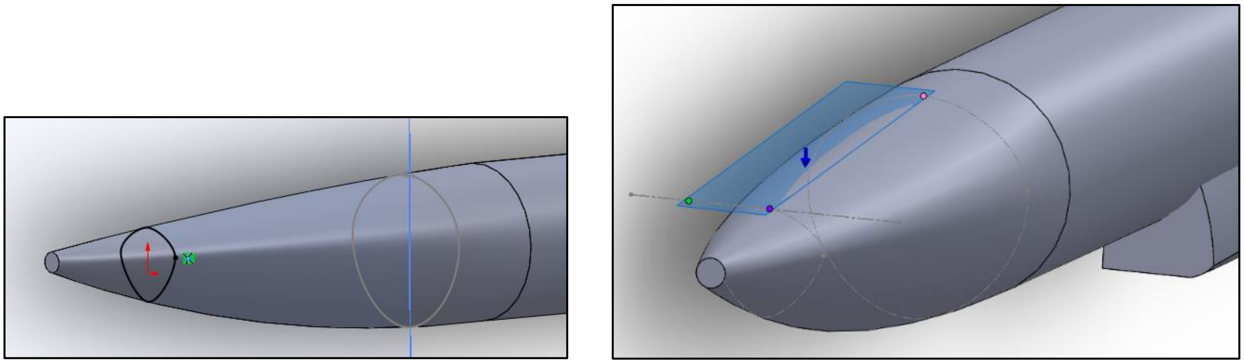


Figure 75. Creating a plane to sketch the vertical stabilizer airfoil

I then imported the shape of the airfoil as a sketch picture and traced it out using a short tangent arc and longer three-point arc. I decided that the radius of the three-point arc was going to be too large to find using a geometric construction, so I left the sketch as traced.

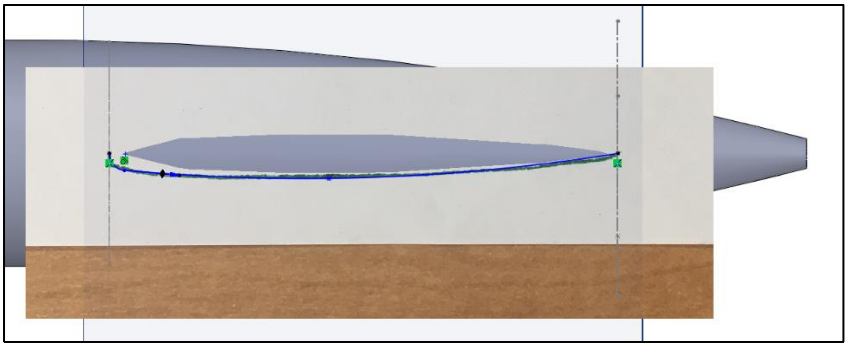


Figure 76. Tracing the vertical stabilizer airfoil

Since the vertical stabilizer lies on the line of symmetry of the entire airplane, I had to mirror the airfoil to ensure that both sides were equal.

Guide Curves

Next, I got the angle of the stabilizer by tracing the stabilizer trailing edge on paper and using a protractor to find the angle relative to the horizontal (edge of paper). I had to make sure that the body was completely horizontal as I lowered the stabilizer to trace the shape.

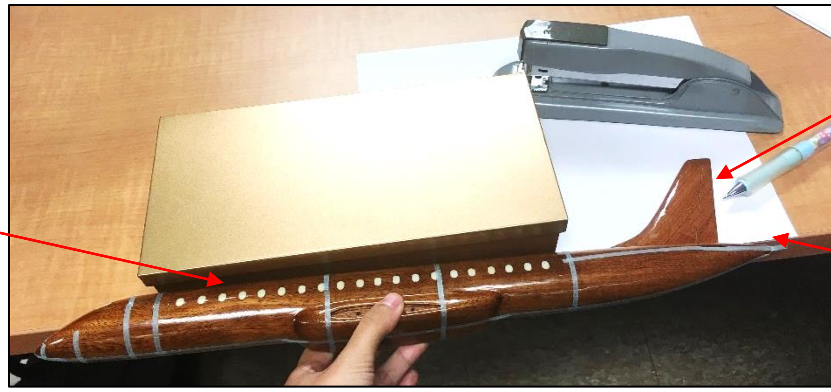


Figure 77. Setup to trace the vertical stabilizer trailing edge

I drew this line on the top plane with the found angle and the length of the trailing edge I measured using a caliper. Using the endpoint of this line, I then created a new plane parallel to the larger airfoil plane. This parallelism of the large and small airfoil was an observation-based assumption.

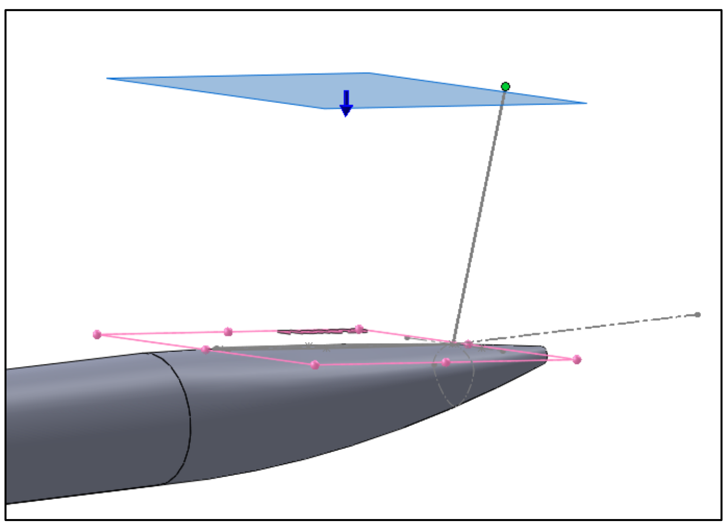


Figure 78. Trailing edge line and new plane for stabilizer tip

For the tip of the vertical stabilizer, I traced the shape out. This resulted in an airfoil shape that was slightly larger than the original, but I decided that if I obtained the length of the airfoil from the physical airplane, the scale of the sketch picture should bring the contour to its true size.

I used a geometric construction to find the radius of the airfoil arc:

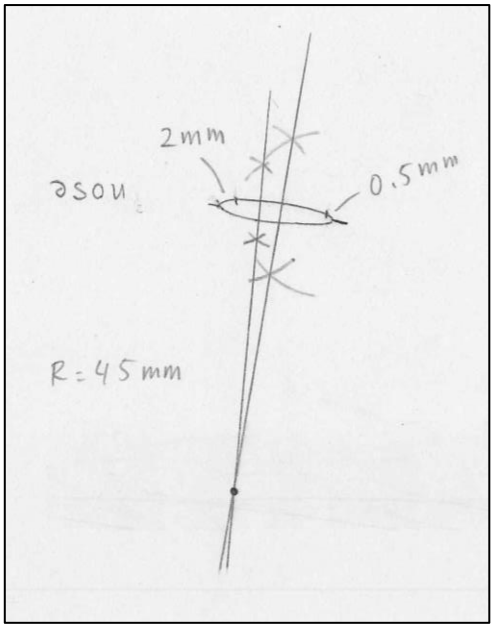


Figure 79. Geometric construction of smaller airfoil arc radius

Then, I used the radius and the rest of the distances I measured using a ruler to dimension my sketch.

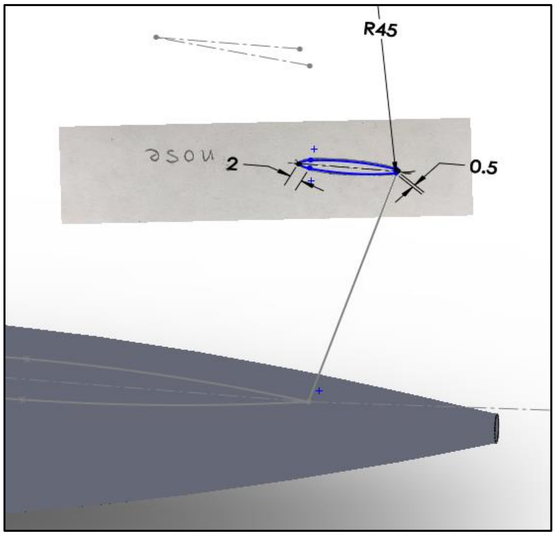


Figure 80. Dimensioning the smaller airfoil

Next, I had to figure out how to obtain the guide curve of the leading edge. Since the edge was very thin, it was not possible to use a contour gauge. The edge could not be laid flat on a sheet of paper in order to trace the shape either. Therefore, I decided to take a photograph of the top view of the stabilizer and import the photograph into SolidWorks.

In order to get as accurate of a top view as possible, I had to set the airplane up as shown below:

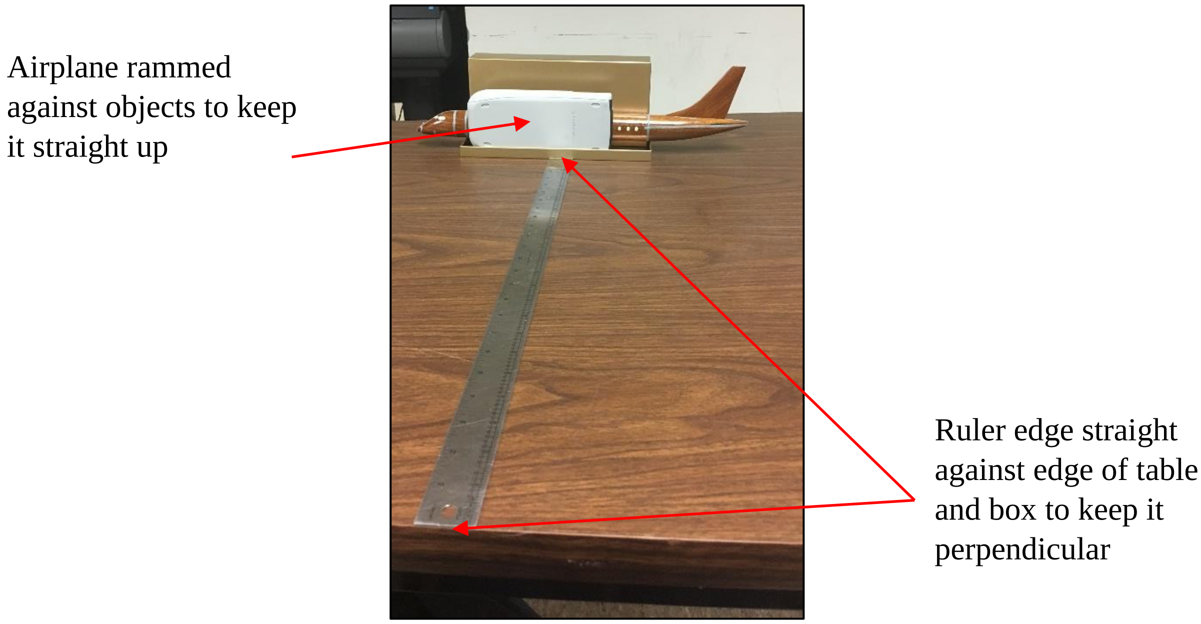


Figure 81. Top view photograph setup.
The phone used for taking the photograph was also set against the edge of the table.

I then imported the photo and aligned the photograph against the model.

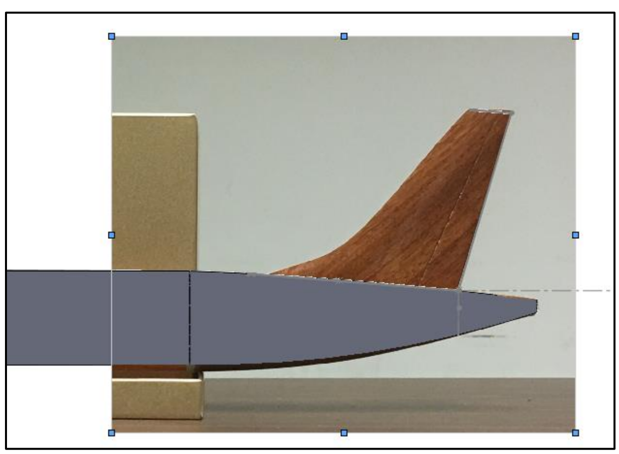


Figure 82. Sketch picture of the vertical stabilizer

As I sketched out the curve, however, I realized that the length of the larger airfoil on the bottom was slightly bigger in the model than in the photograph. This created a sketch that was slightly off the curve in the photograph.

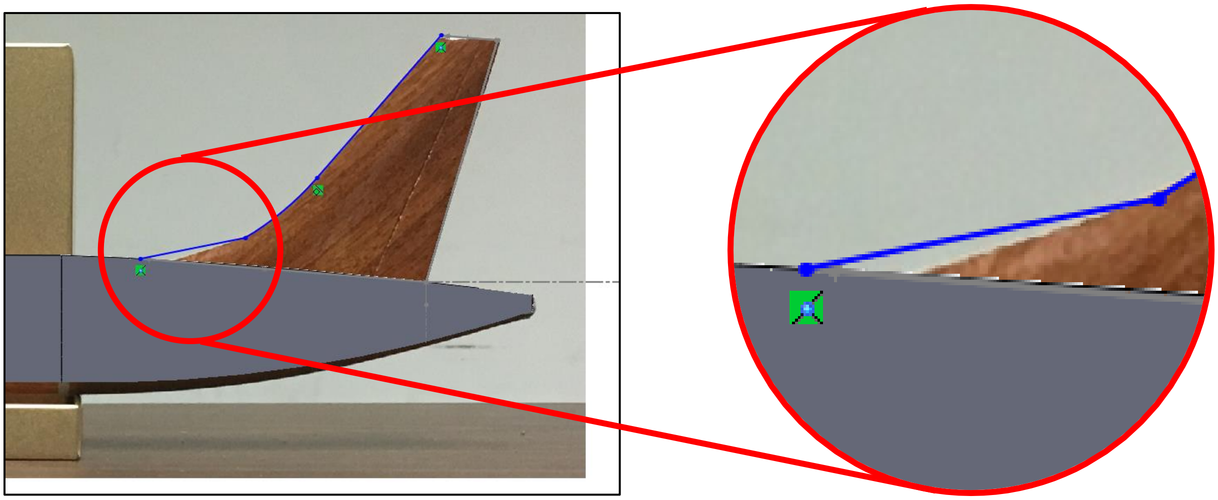


Figure 83. Vertical stabilizer sketch and photograph are slightly off

However, there was not much that could be done about this, so I kept this guide curve and moved on to the loft.

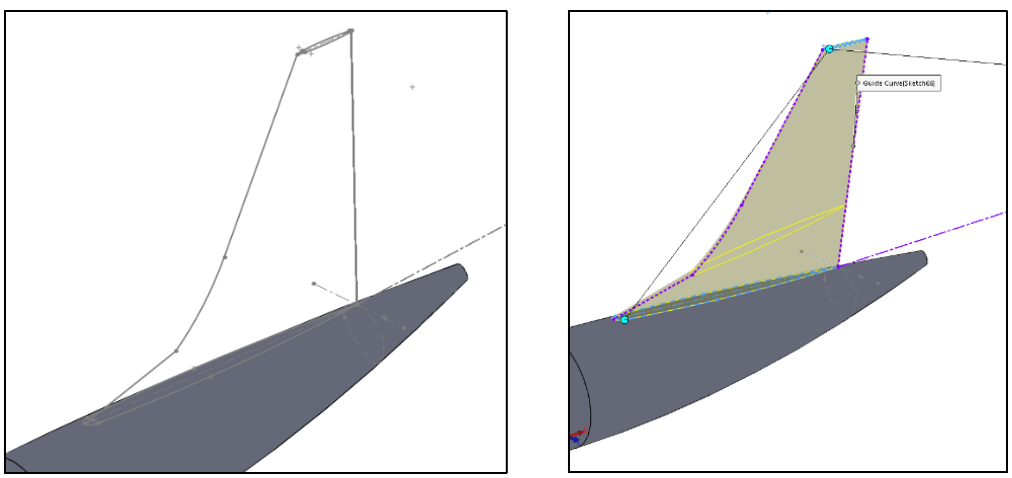


Figure 84. Vertical stabilizer loft

This was the completed vertical stabilizer:

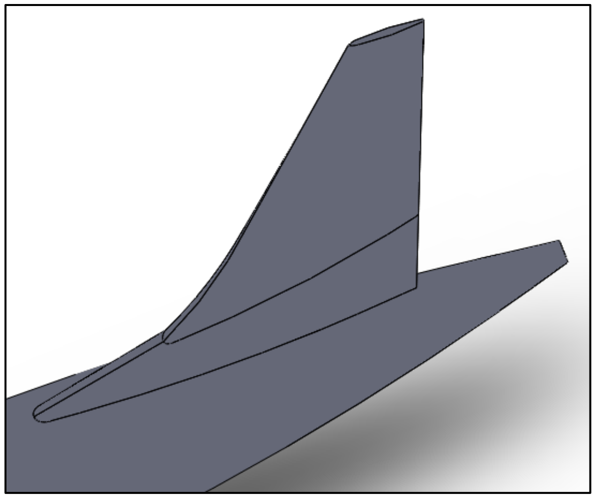


Figure 85. Completed vertical stabilizer

Wings

Next, I worked on the wings. I had initially thought of using clay to take the shape of the airfoil since the shape was carved out of the fuselage. However, I realized that it would be too time consuming to wait for the clay to air dry and was also damaging to the physical airplane since the clay tended to squeeze into the holes that were drilled to keep the wings in place.

After thinking of other ways to take the contour, I decided to stick a piece of tape on top of the contour and use a box cutter to cut along the edge of the airfoil, leaving the tape with an airfoil-shaped hole. I then stuck the tape onto a sheet of paper and traced the airfoil out, to import into SolidWorks as a sketch picture.

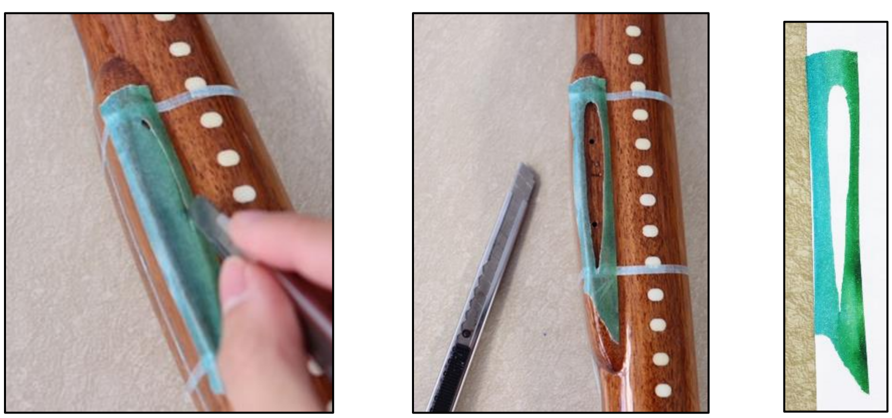


Figure 86. Taut tape method to obtain airfoil shape

I decided to sketch this airfoil on the top plane since it was not possible to sketch the airfoil shape onto the curved wing box body. I sketched an arc and a tangent arc to represent the airfoil.

The radius of the arc was too large to do geometric construction and measure, so I left the sketch as traced using the sketch picture.

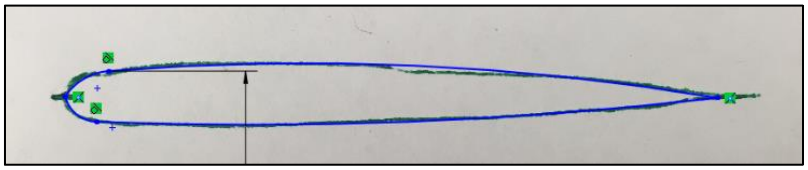


Figure 87. Sketch of wing airfoil

Then, I extruded the airfoil to the surface of the wing box in order to create a surface that the wing loft will accept as a profile. I could not extrude the airfoil to the surface, so I chose to extrude it to the highest point of the wing box to ensure that the entire airfoil was visible from the outside.

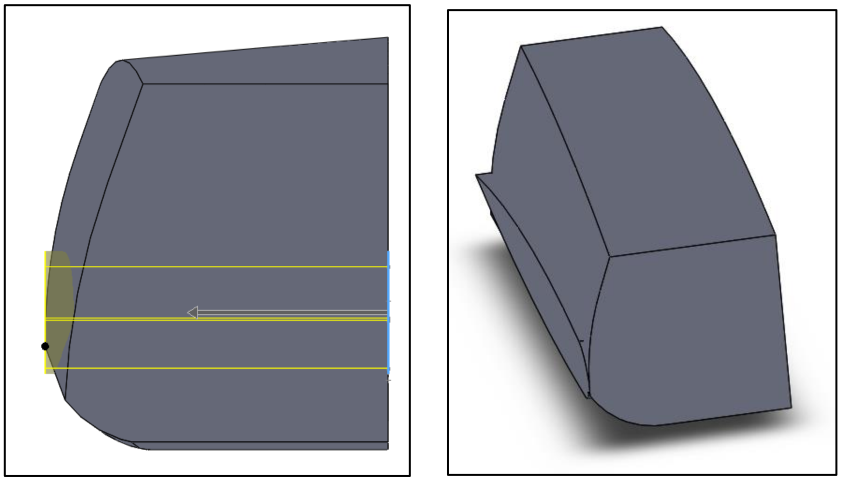


Figure 88. Airfoil extrusion and result

Due to the winglet being angled, it was difficult to obtain the contour of the airfoil at the end of the wing where it met the winglet. Although I could have used a contour gauge, due to the small size of the airfoil, I decided that the width of the pins in the contour gauge relative to the small airfoil would limit the accuracy of the profile, making it unreliable while adding extra measuring steps. Therefore, I decided to scale the larger airfoil shape down into the size, using a caliper to obtain the size to shrink it down to.

I calculated the scaling ratio by determining:

$$\frac{Small\ airfoil\ length}{Large\ airfoil\ length} = \frac{18.2\ mm}{68.2\ mm} = 0.267$$

This ratio was used as the parameter for scaling.

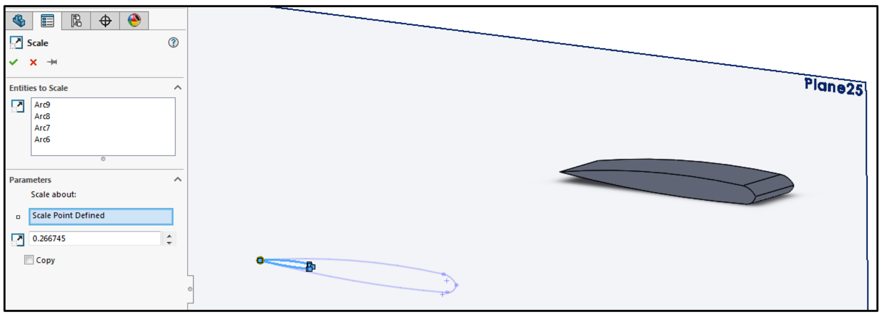


Figure 89. Scaling the smaller airfoil

I used a level between the location of the front plane of the airplane to the small airfoil and determined that the small airfoil was located approximately where the front plane was.

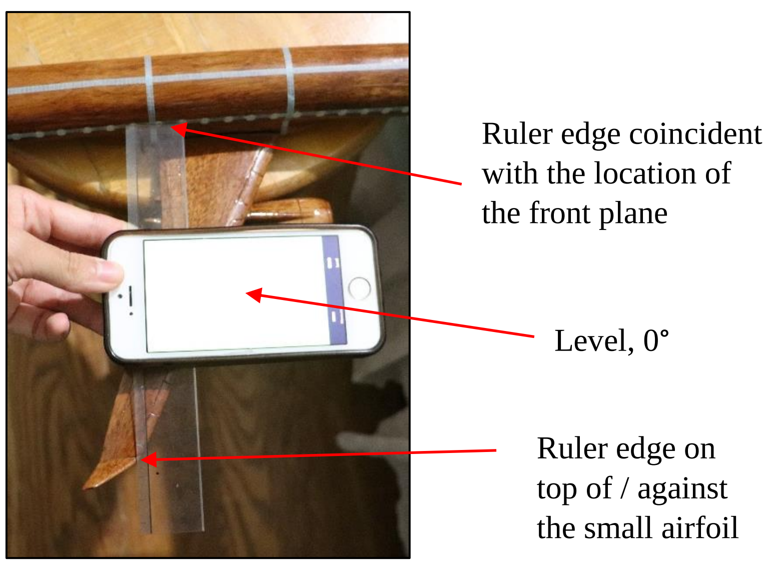


Figure 90. Small airfoil is level with the front plane

Therefore, I made the small airfoil chord line coincident to the front plane. Then, I used the large airfoil and small airfoil as references for a new plane to draw the leading and trailing edge lines.

I started sketching the edges, using a caliper to obtain the lengths and an angle finder to determine the angles.

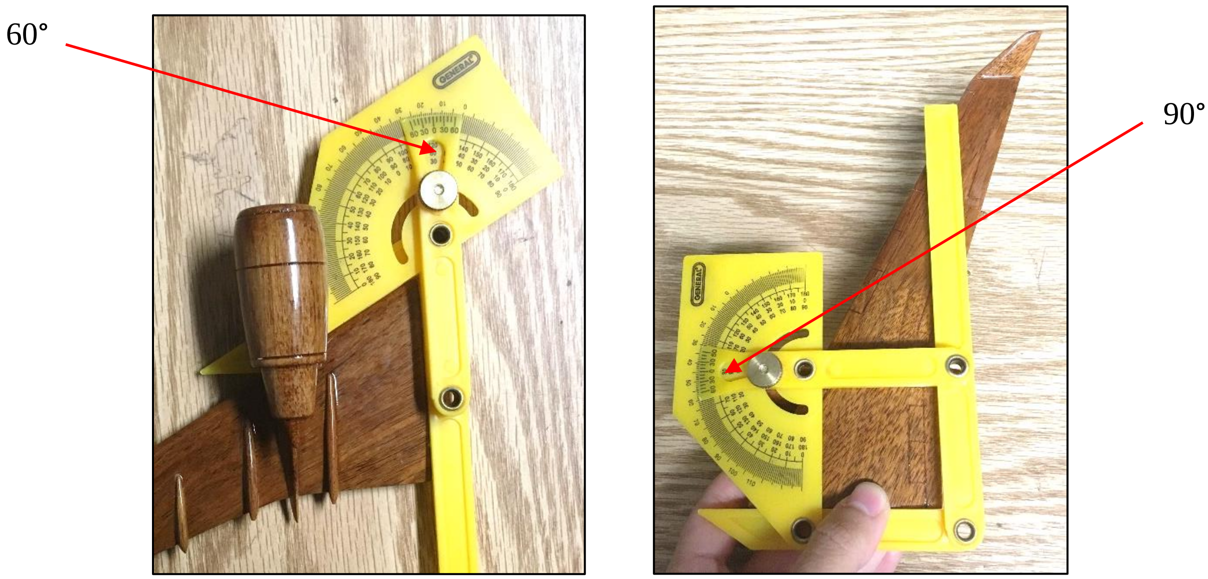


Figure 91. Using an angle finder to determine angles of the wing relative to the larger airfoil surface

When I tried to dimension the sketch according to my measurements, however, I encountered problems:

This airfoil was restricted and could not move according to the angle

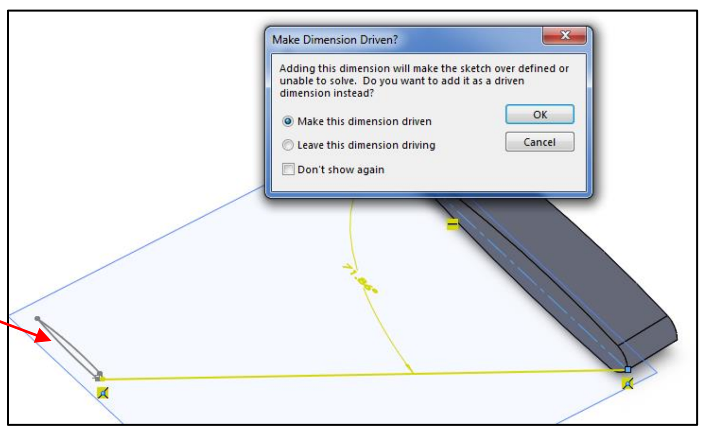


Figure 92. The angle was restricted

Therefore, I had to make the small airfoil a construction geometry, angle the leading-edge line, and then create a new small airfoil based on the location of the leading edge line.

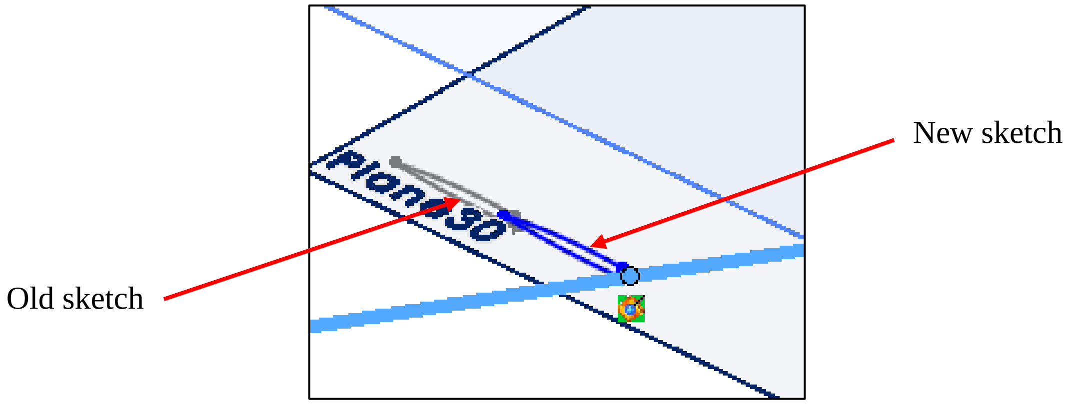


Figure 93. Creating a new scaled airfoil sketch

I then approximated the trailing edge guide curve to be made up of two straight lines. Although in the physical model, there was a slight curve in between the straight lines, I decided that it was too difficult to measure due to the pylon sticking out in the middle of the curve. I noted that the line closer to the fuselage body was approximately perpendicular to the fuselage, and therefore decided to use the perpendicularity and length of edge obtained using a caliper to sketch that line. The measurements of the other line were then dependent on the end point of the first line and the end point of the trailing edge of the small airfoil. Due to the inevitable errors associated with the smaller airfoil and the first line, this constrained line will likely not have the same dimensions as the measurements of the physical wing.

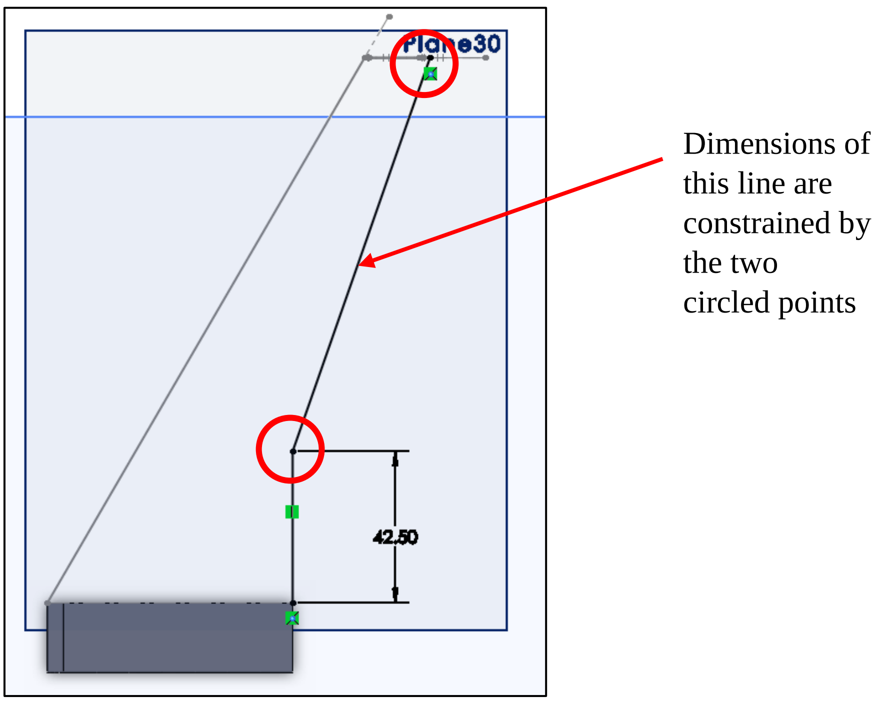


Figure 94. Wing guide curve sketch

Using the sketches, I lofted the wing:

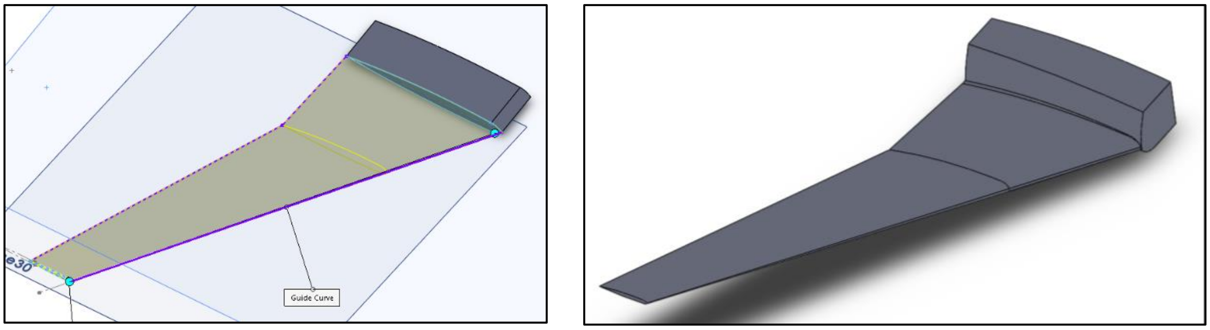


Figure 95. Wing loft and completed main wing body

Wing Box Curves

Since the wing box was still missing the curved feature on the sides, I decided to think about how to create the feature. Initially, I thought about doing another surface loft. However, it seemed difficult to take a contour of the curves and measure. Therefore, I looked for other options that could provide a similar effect with less complexity.

I decided to see if I could create a dome. I stuck a piece of tape horizontally along the body to find the point where I would measure between the already-modeled wing box and the endpoint of the full wing box on the physical airplane.

Using a caliper, I measured the distance, and used the dimension for the dome distance.

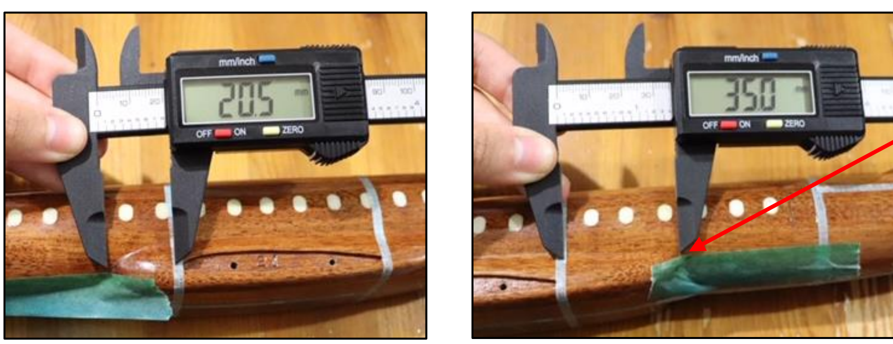


Figure 96. Measuring the dome height

The dome turned out as follows:

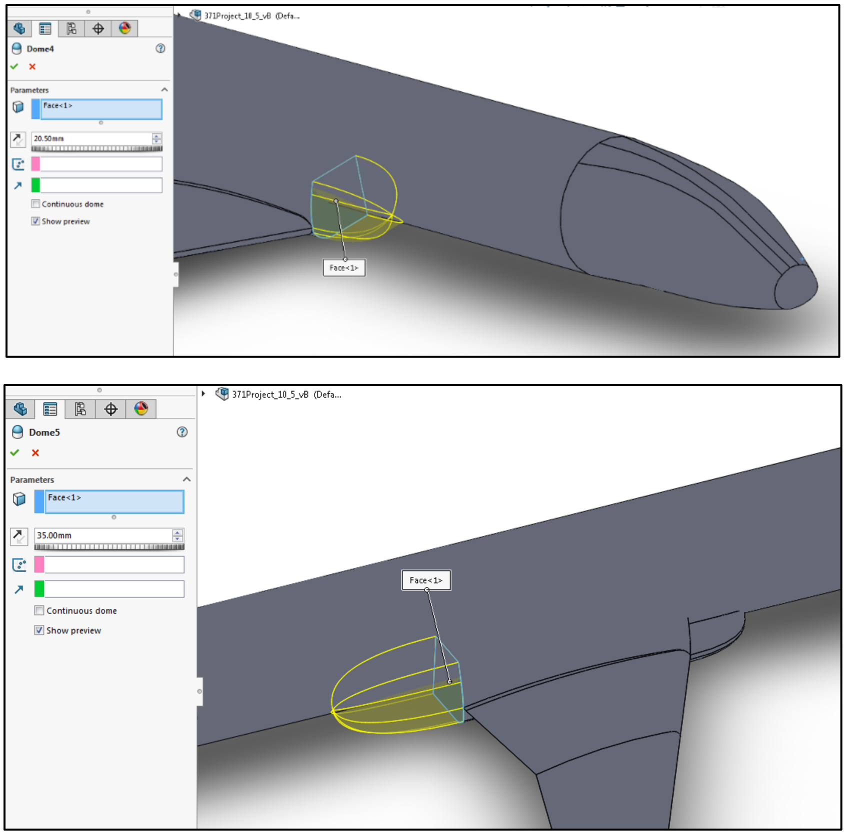


Figure 97. Doming the wing box

After doming, the wing box in the model looked like the wing box of the airplane. Therefore, I decided to keep this dome.

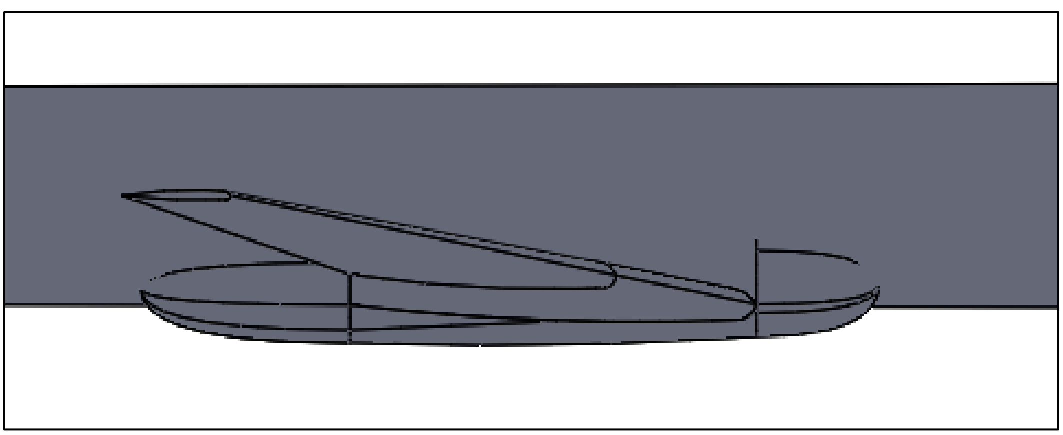


Figure 98. Competed dome

Engine

Next, I worked on the engine.

I took the distance between the airplane nose and engine inlet using the setup below:

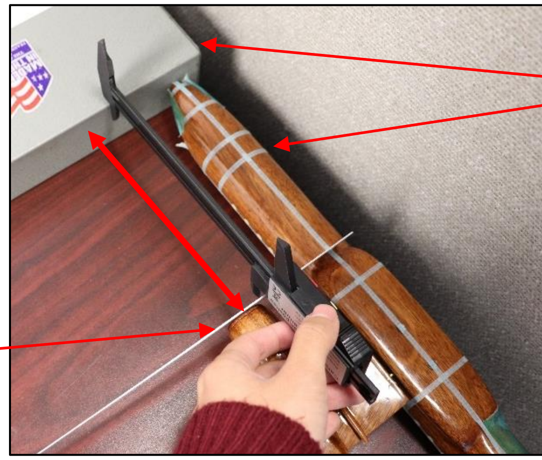


Figure 99. Measuring the distance between the airplane nose and engine inlet

Under this setup, I assumed that the engine inlet was flat and parallel with the right sketch plane. Then, I created a new plane using the obtained measurement.

In order to locate the engine inlet along the width of the aircraft, I assumed that the position of the center of the engine was aligned with the point where the trailing edge side of the airplane wing changed angles. Therefore, I created a vertical relation between the point and the center of the engine circle.

I used a circle template in order to get the diameter of the inlet. The circle template only provided inches, so the measurement was converted into millimeters automatically by SolidWorks.

I found out that the aircraft is roughly level when placed in an upright position with the winglet touching the table.

Figure 100. The airplane is level when placed on its wingtip

This was used in order to justify taking the measurement using a caliper from a level stack of boxes. I determined the center of the circle using the setup below:

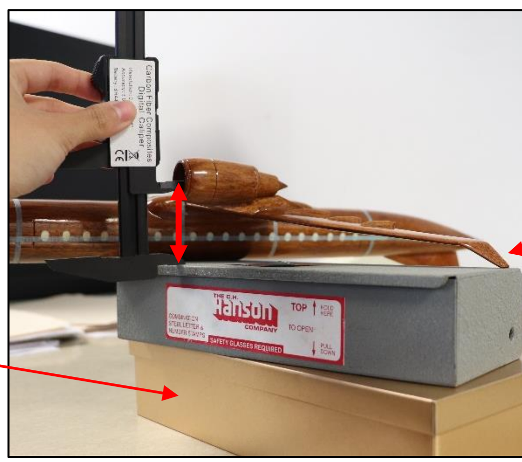


Figure 101. Finding the engine center location

The only sketch point I had to reference the center of the inlet against was the point located on the circular profile of the front side of the cylinder body. Although this was an awkward reference, it was the only viable option to use given my options for physically measuring the distance.

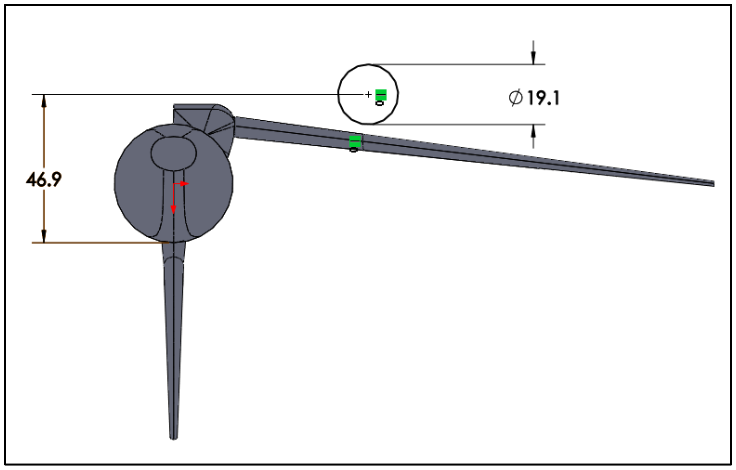


Figure 102. Dimensioning the engine inlet

I used a caliper to measure the remaining circular diameters of the engine to get the following contours, assuming that all profiles are concentric:

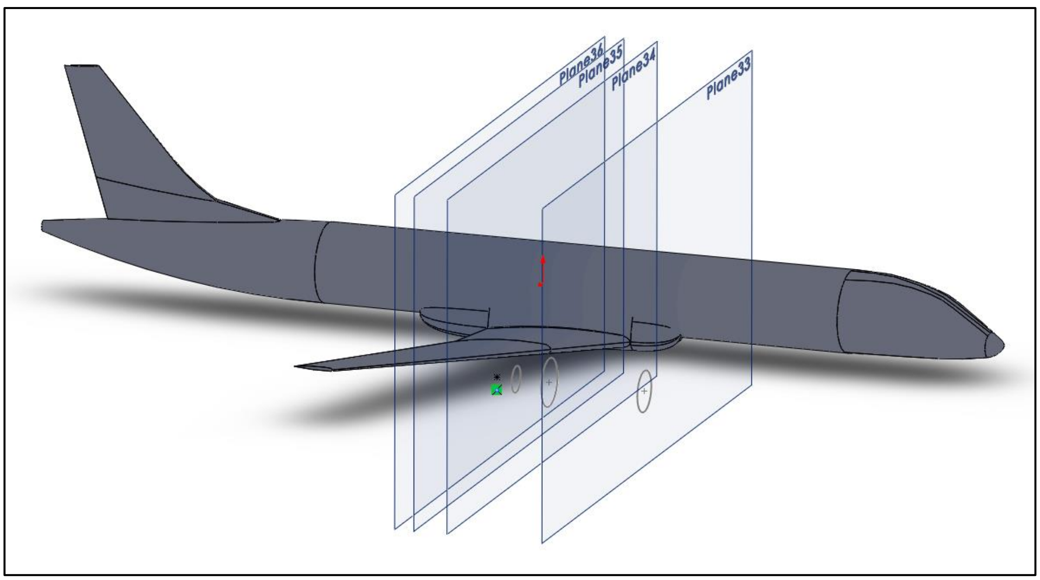


Figure 103. Profiles of the engine

In order to create a loft for the front portion of the engine, I realized I needed another contour representing the maximum diameter of the engine in order to create a guide curve. However, the pylon connecting the engine to the wing was in the way of figuring out where the true maximum diameter was; therefore, I decided to approximate the location to be where a circumferential etching was located. Although I had previously stated that the etchings were unreliable, it seemed to be appropriate to use for this circumstance.

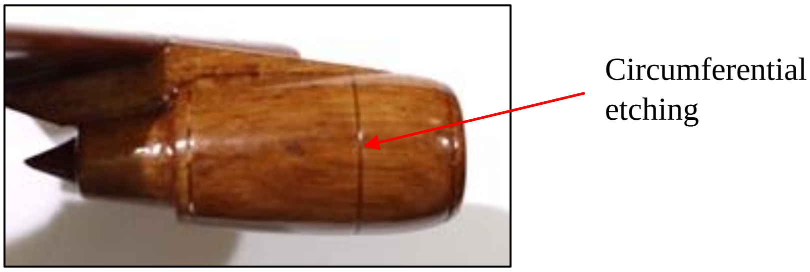


Figure 104. Etching used as maximum diameter profile location

In order to obtain the guide curve, I used a contour gauge along the engine and used a three-point curve for the front portion. I then connected the second and final profile using a tangent arc in order to ensure a smooth transition.

I found the radius of the three-point arc using the geometric construction below:

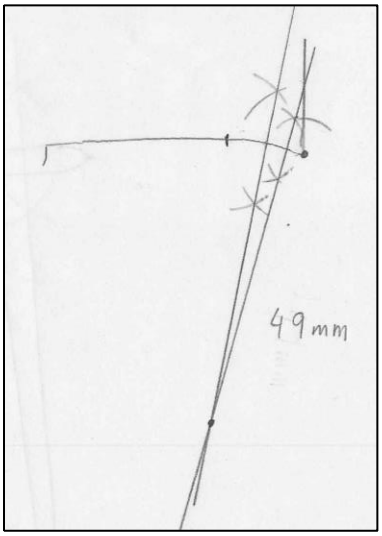


Figure 105. Geometric construction to find the radius of the engine guide curve arc

The result of the guide curve is shown below.

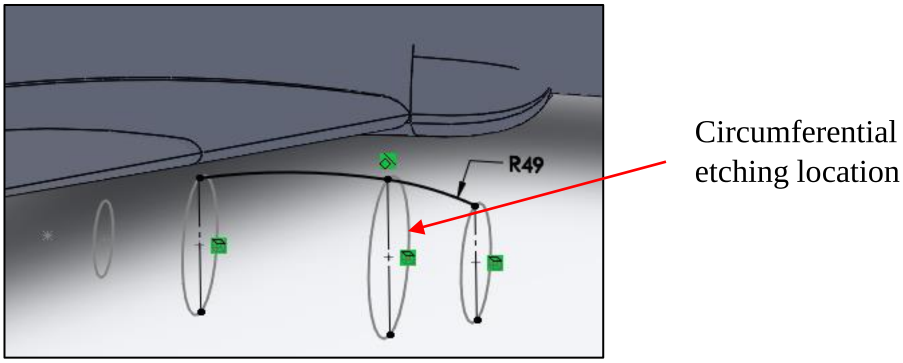


Figure 106. Guide curve of engine casing

When I lofted the part using just the single guide curve, however, it took the following shape:

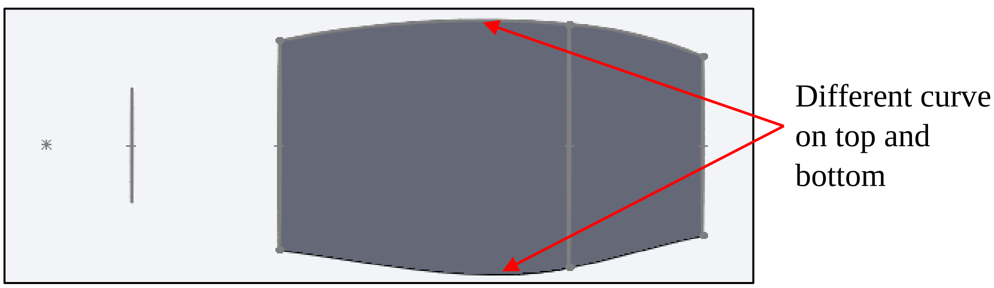


Figure 107. Uneven loft

The loft did not turn out axisymmetric; therefore, I decided to replicate the guide curve on the other side as well.

Additionally, looking at the profile, I noticed that the overall shape looked slightly different from the model. After thinking about the measurements I had taken, I realized that I used the circle template on the inside surface of the engine inlet to get the inlet contour, but used the caliper on the outside of the engine case to get the other two contours. Therefore, the diameter of the other two contours included the thickness of the engine case.

I fixed this problem by reducing the diameter of the other two contours by 4 mm, based on the engine case thickness of 2 mm obtained using a caliper. Although the thickness of the case did not seem uniform, I simplified it to be uniform since there was no easy way of measuring the changing thicknesses.

Then, I repeated the loft using the adjusted diameters with two guide curves.

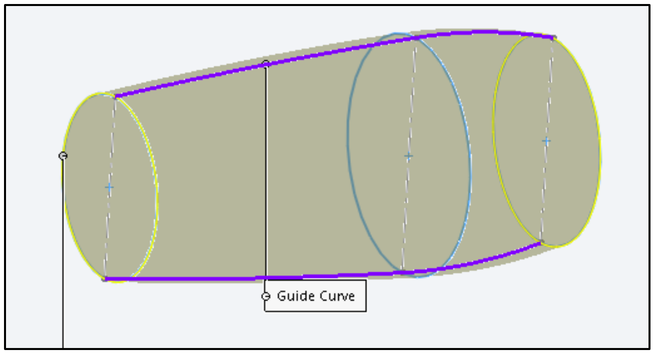


Figure 108. Engine loft with adjusted diameters and two guide curves

The following was the final loft:

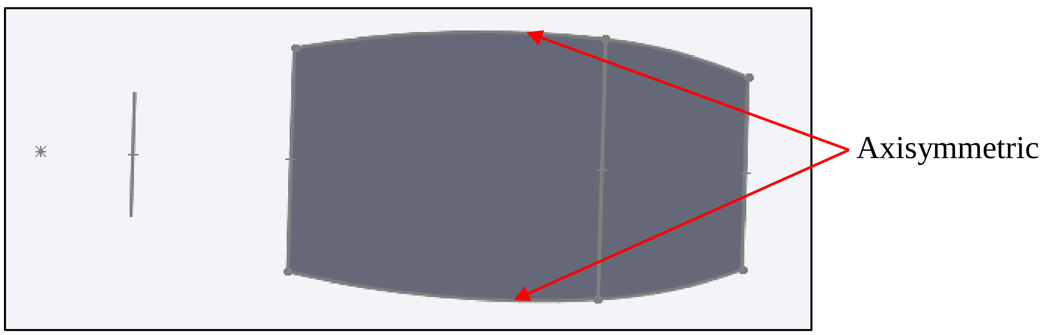


Figure 109. Loft with two guide curves

This shape was axisymmetric and looked closer to the shape of the model.

Next, I decided to add an outward shell in order to accommodate for the 2 mm engine case thickness I had removed earlier.

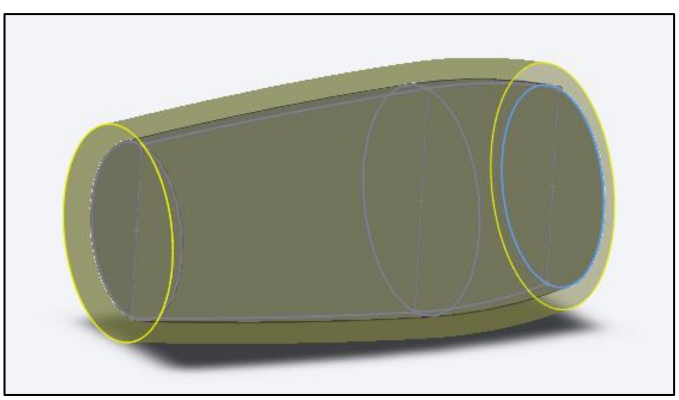


Figure 110. Shell 2 mm outwards

The next portion of the engine was a loft with straight guide curves. I used the inside diameter of the first portion of the engine as one profile, and the profile I had drawn for the next portion, in order to create the guide line and construct the loft.

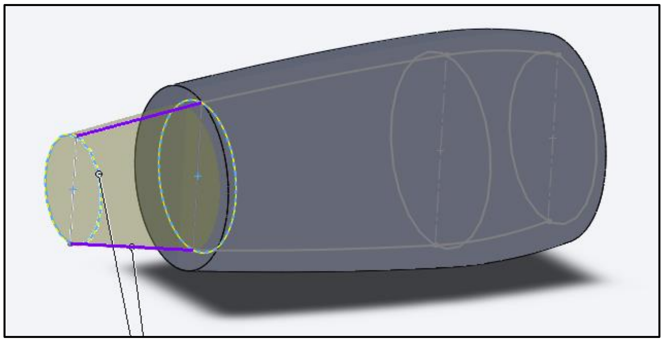


Figure 111. Lofting the second portion of the engine

For the final loft, I had to create another sketch on top of the profile for the previous loft for a smaller profile. Therefore, I created an offset entity of 2 mm on the surface of the previous loft and used it as the profile for this loft.

Although previously, a loft to a point did not work, I tried lofting to the last point. This time around, it created the cone shape I needed.

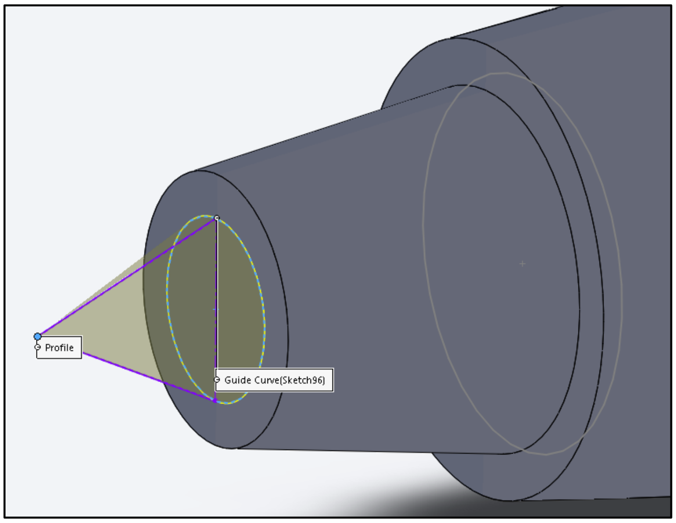


Figure 112. Lofting the last portion of the engine

This was the completed engine, alongside the physical engine:

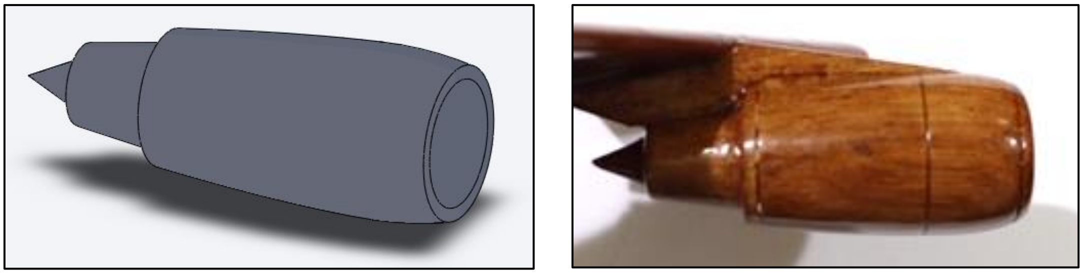


Figure 113. Engine, model versus actual

Next, I decided to create the pylon by approximating it to be a triangle. For my first sketch, I drew a triangle with vertices on the point where the wing trailing edge angles, the point above second contour where the engine diameter is maximum, and the point where the second portion of the engine ends. The locations of these points were chosen based on observation of the physical model to find the nearest convenient sketch point.

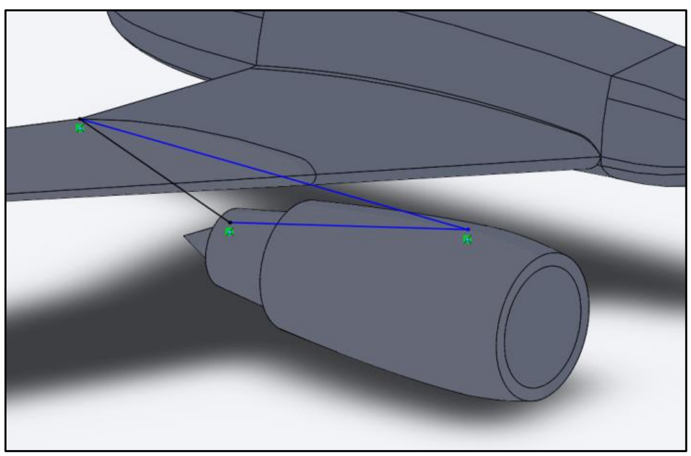


Figure 114. Pylon sketch

I then extruded the triangle using mid plane, with an approximated uniform total thickness of 5 mm obtained using a caliper.

However, a small portion of the extrusion stuck out on top of the wing as seen below.

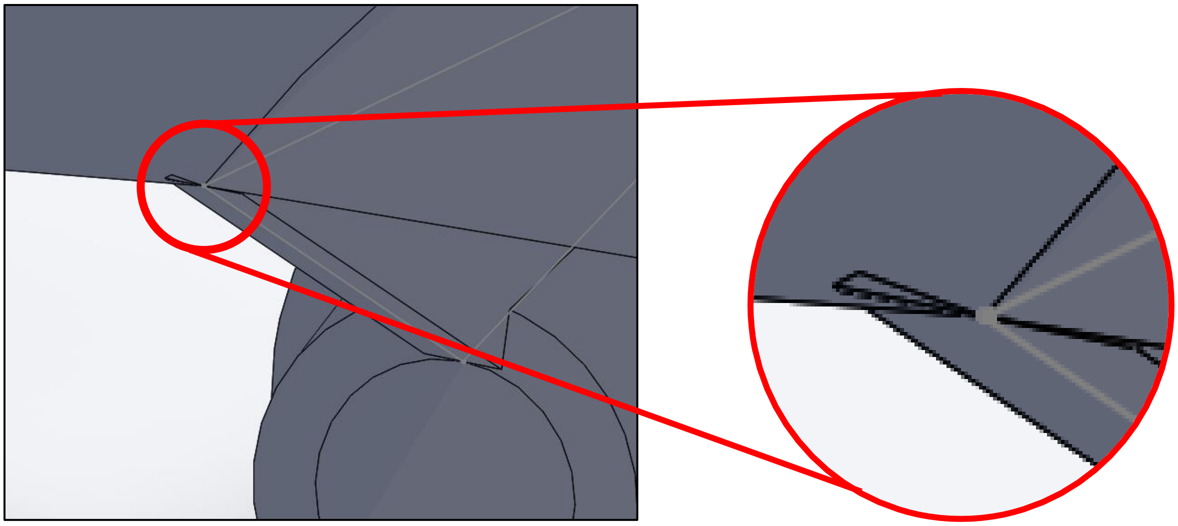


Figure 115. Pylon extrusion protruded above the wing

To mitigate this issue, I specified a draft angle. This was not measured; it was an additional feature added for aesthetic reasons.

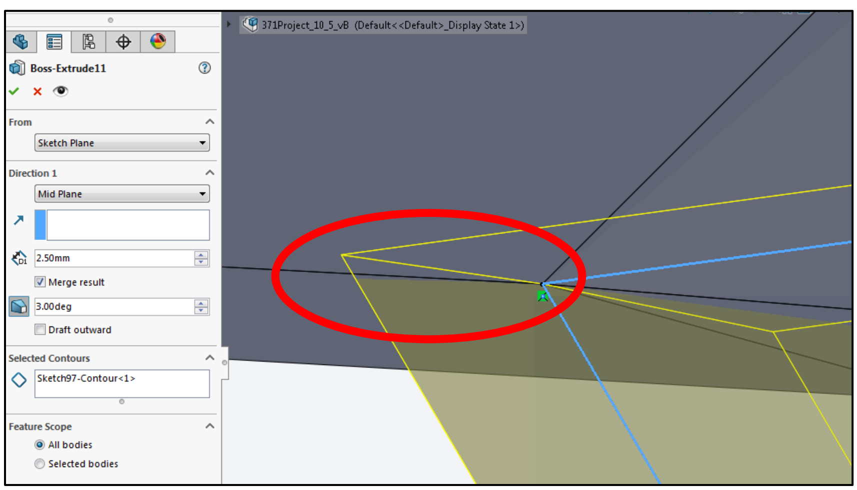


Figure 116. With a draft angle, the extrusion (shaded yellow) remains underneath the surface of the wing.

The result is shown below:

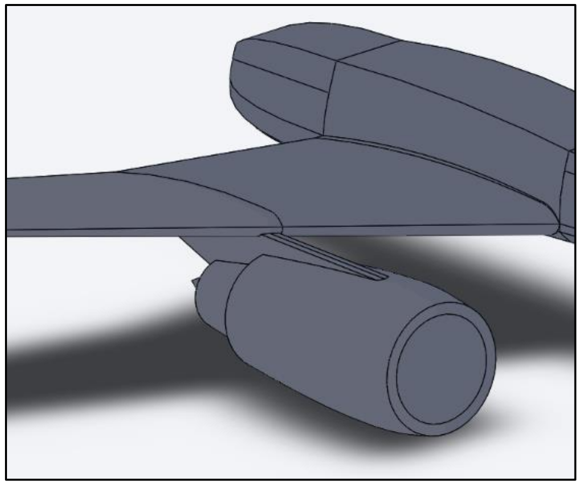


Figure 117. Engine with initial pylon

Although this looked good enough, I decided to extend the triangle to try and create the portion of the pylon sticking out under the wings. I used a caliper to measure the amount sticking out and dimensioned the triangle accordingly. Finally, I extruded it, adjusting the draft angle once again to ensure that no pylon material was sticking up on top of the wing.

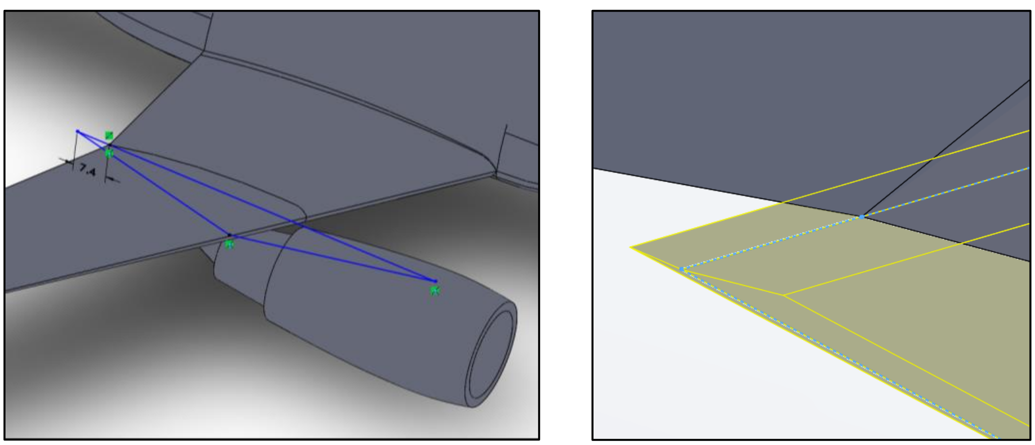


Figure 118. Pylon, adjusted dimensions

I noticed that in adding a draft angle, the pylon had a sharp point at the end which was like the sharp point at the end of the pylon in the original model. Although this was not my intention, it seemed to work out well.

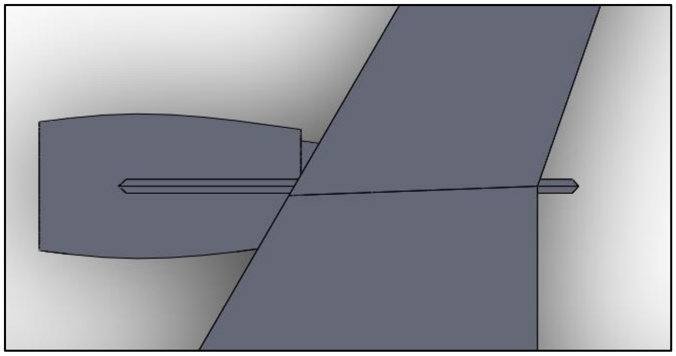


Figure 119. View of pylon

This airplane wing had other pylons, but I decided to work on them later as finishing touches if I have time since they were not used to connect any other part of the airplane to the wing.

Additionally, the physical model has fan blades on the inside of the engine, but I decided to leave it hollow in order to simplify my model.

Winglet

I still had the winglet on the wings to create, so I worked on it next.

Winglet Loft

I decided to see if I can continue working on the same plane I worked with for the wing, and then somehow bend the wing tip up.

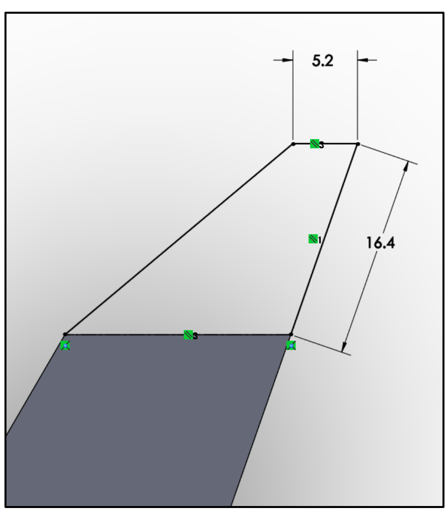


Figure 120. Winglet sketch and dimensions

Since the tip of the actual winglet was a straight line rather than an airfoil shape but loft does not allow a straight-line profile, I decided to convert entities on the larger airfoil on the fuselage and scale it down to the size of the line. I took the length of the larger airfoil and winglet tip and found the scaling ratio.

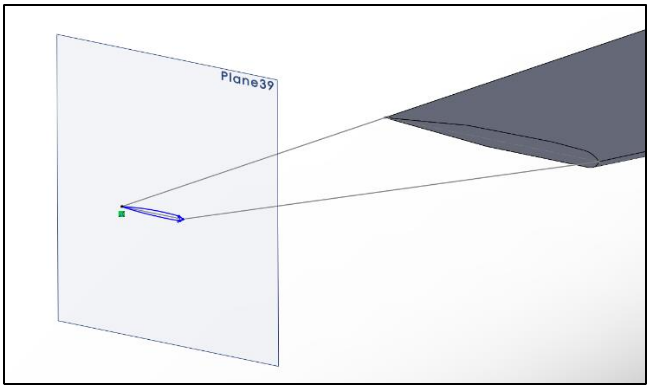


Figure 121. Winglet tip, scaled

Then, I lofted the winglet.

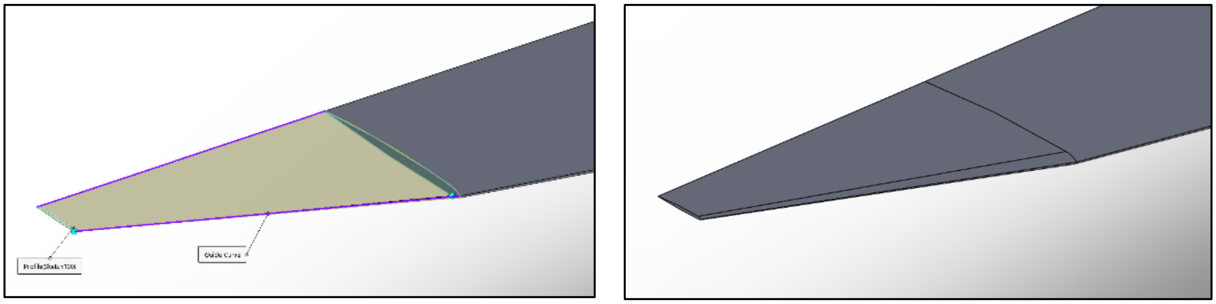


Figure 122. Winglet loft

Flex

Next, I tried to see if a flex could give me the desired result. I had difficulties figuring out what inputs flex needed in order to flex the right location.

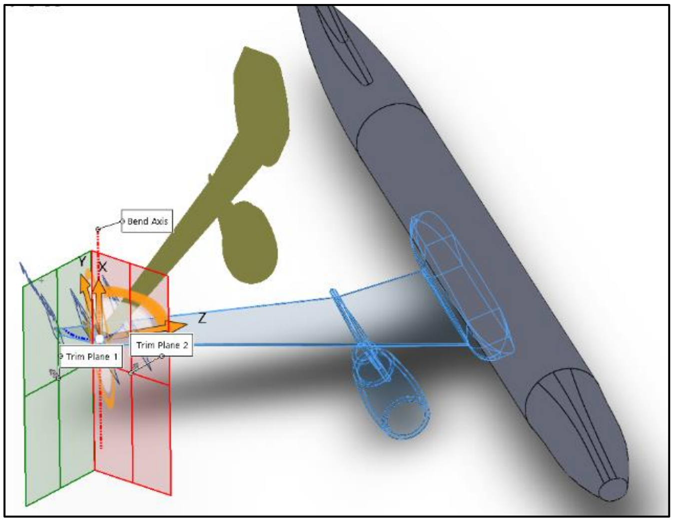


Figure 123. Difficulties figuring out flex

As seen in the screenshot above, when I initially attempted flex, I could not figure out how to locate and orient the planes or triad. I also did not know how to apply flex only to the tip of the wing and not the rest of the wing.

Therefore, I first started by splitting the wing into bodies so that only the end of the wing could be selected. The flex looked more manageable this time around.

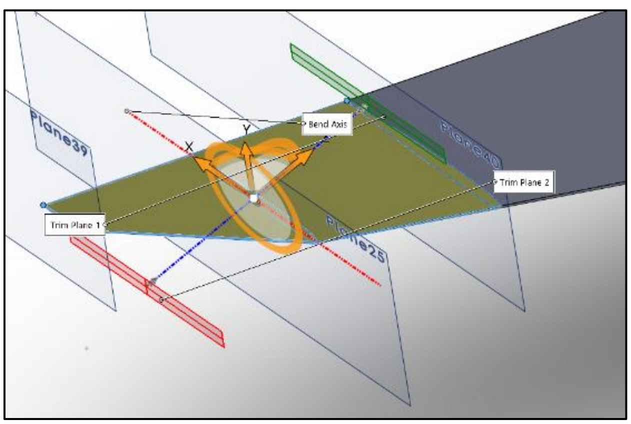


Figure 124. Figuring out flex

I found out that the triad had to be located on the plane that was to be kept stationary. After readjusting the options in flex to reflect what I had in mind, I got the flex to look as shown below:

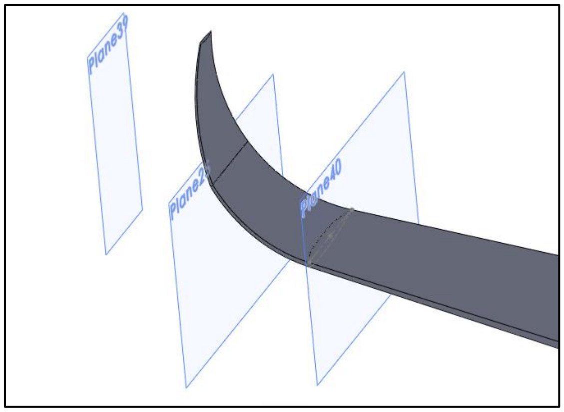


Figure 125. Flex

Although it did work somewhat according to what I had in mind, I realized that flex was much more suitable for a bend with a large radius of curvature. Since the winglet is sharply bent, flex was not the suitable option. However, it was interesting to learn how flex works.

Move/Copy Body

Next, I tried to see if I could rotate the entire winglet body. It took me some time to set up the body to rotate about the right axis in the right direction. I found the angle of rotation by using the level on my phone to find the horizontal, and then the angle of the winglet with respect to the horizontal.

Figure 126.
Leftmost: Level wing surface
Right: Winglet angle

I then tilted the winglet -40 degrees.

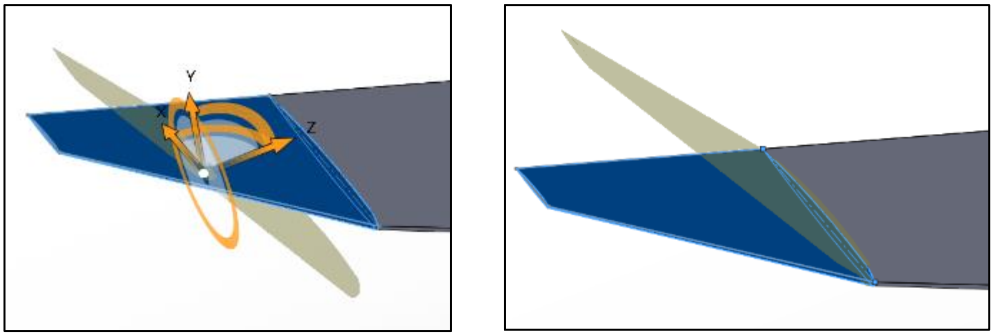


Figure 127. Finding the right line of rotation and rotating the winglet body

This worked out well. However, due to the rotation, there was now a gap between the wing and the winglet:

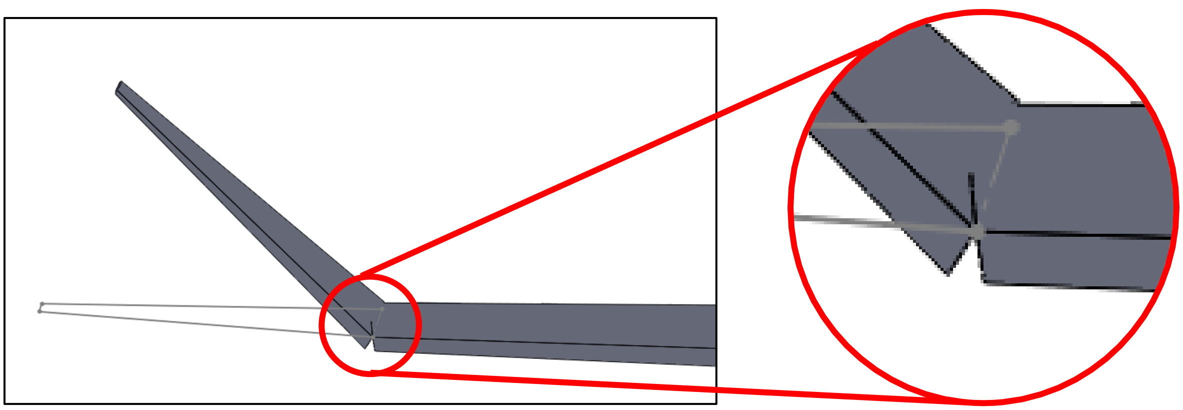


Figure 128. Winglet-wing gap

I decided to see if I can move the entire winglet, although this would cause some distance measurements to be altered.

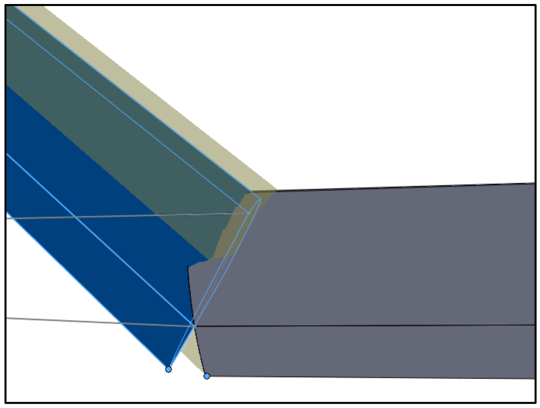


Figure 129. Moving the entire winglet

However, this caused one side of the winglet to overlap with the wing:

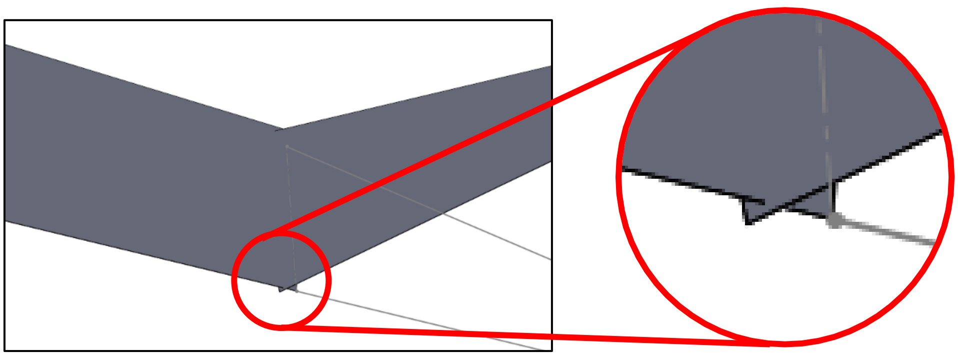


Figure 130. Winglet overlaps with wing

Therefore, I tried to see if I can loft in between the gap instead. For the loft to work, I had to uncheck “merge tangent faces” and “merge result.”

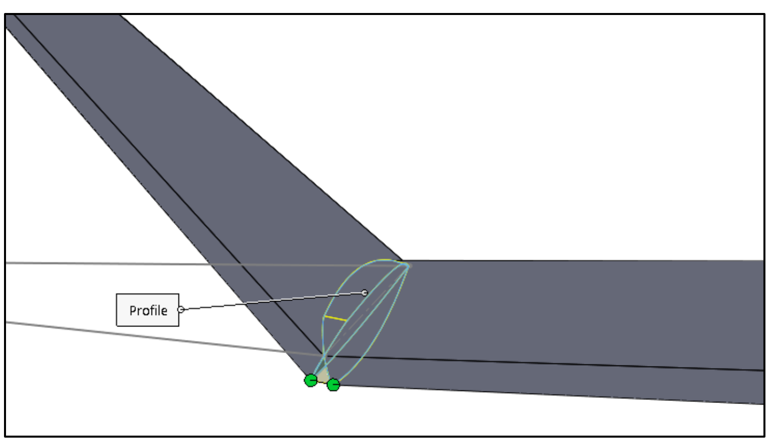


Figure 131. Lofting the gap between the winglet and wing

This was the result:

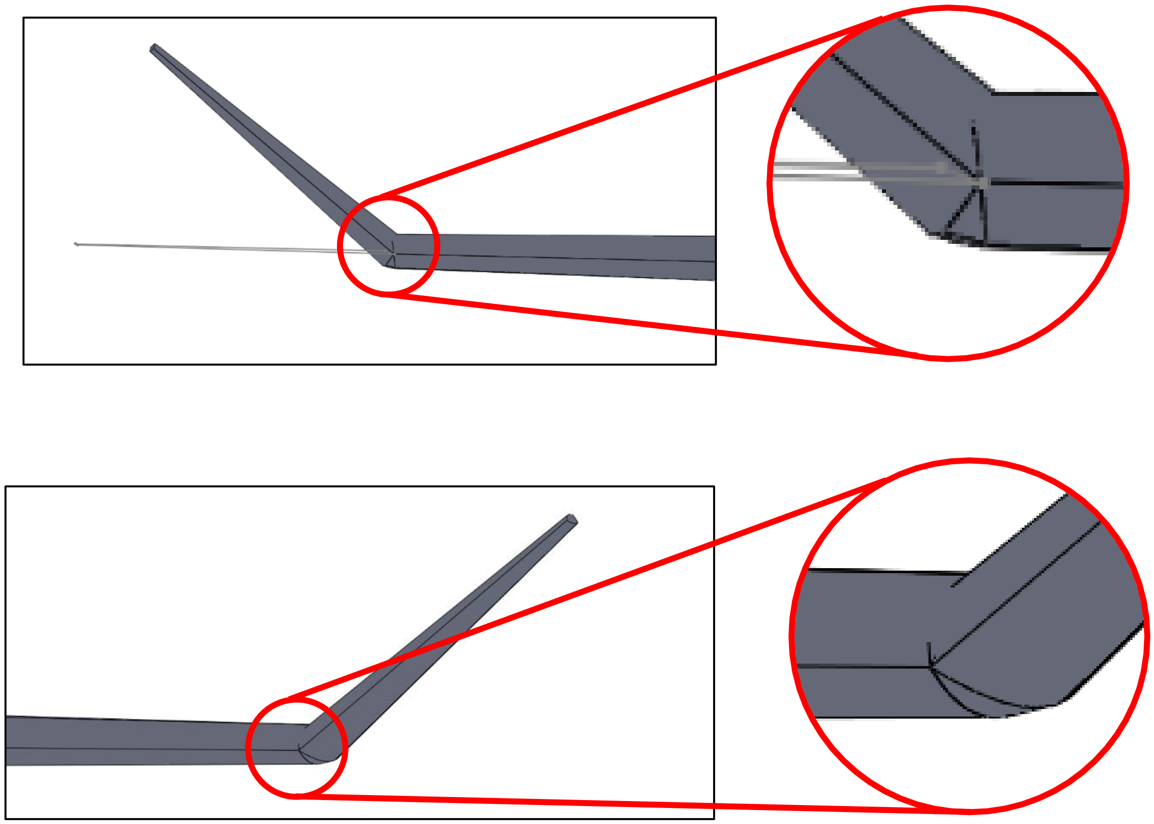


Figure 132. Loft results

This looked correct and therefore, I decided to keep these results.

Horizontal Stabilizer

Next, I worked on the horizontal stabilizer.

In order to get the contour of the larger airfoil, I used the taut tape and cutter method (see Figure 86) and used a geometric construction to measure the radius of the arc that comprised the shape.

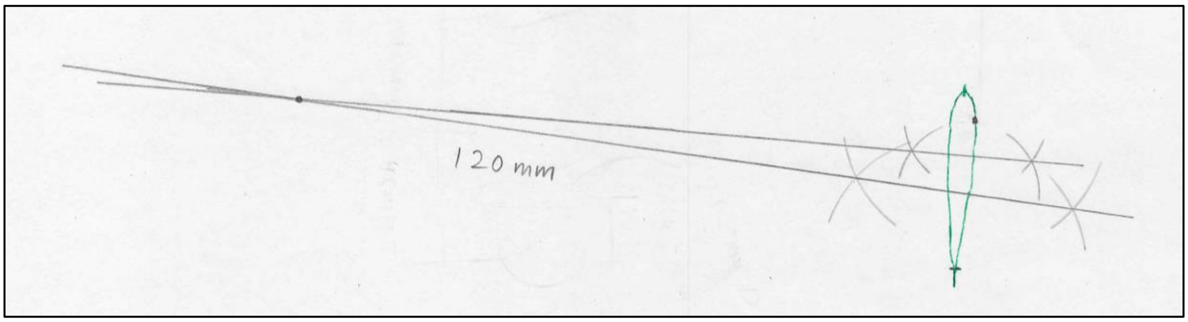


Figure 133. Geometric construction to find the radius of the larger airfoil three-point arc

Next, I used the guide lines from the fuselage back loft as a reference since those guide lines were originally based off the location of the horizontal stabilizer airfoil. (See Figure 46)

I scaled the sketch picture using the measurements I took, and made a three-point arc and tangent arc to trace the outline of the airfoil:

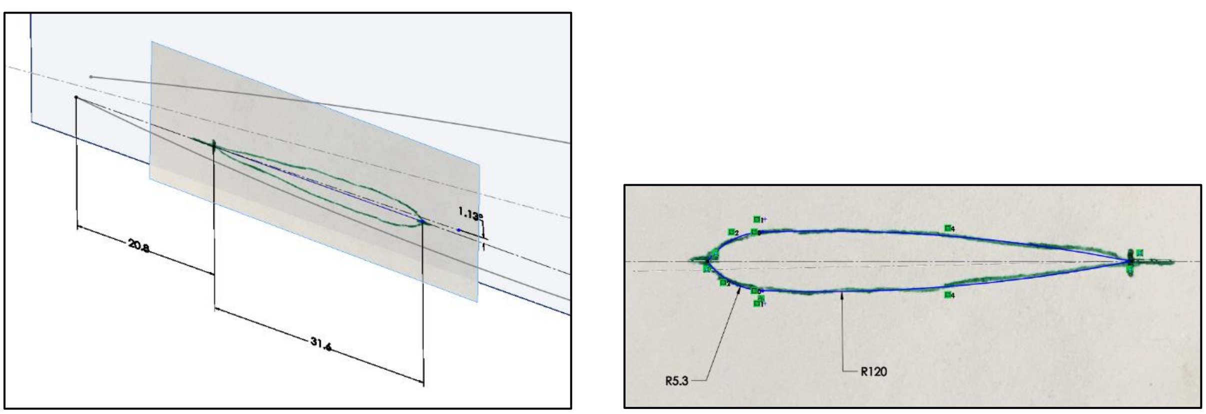


Figure 134. Horizontal stabilizer airfoil

I then extruded the airfoil to the surface of the fuselage.

Next, I needed to create an angled plane to create the guide curves, which will then determine the location of my smaller airfoil.

In order to get the angle of the horizontal stabilizer, I placed the airplane model on its wingtip, and ensuring that the model was level using my phone, then aligned my phone with the stabilizer to read the angle relative to the horizontal.

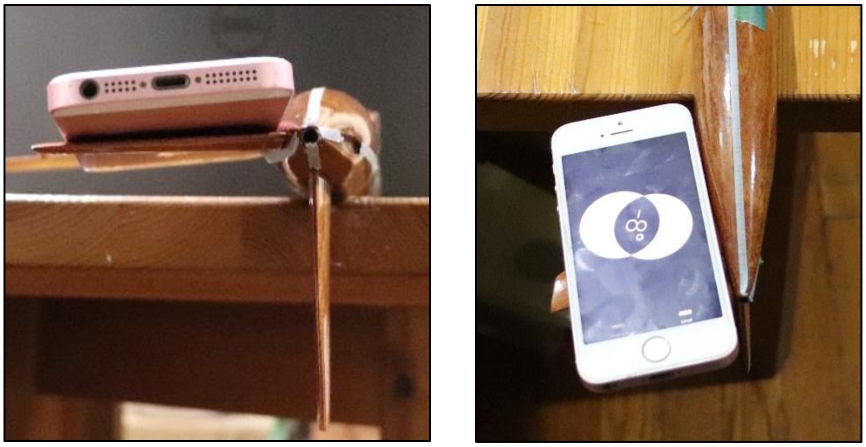
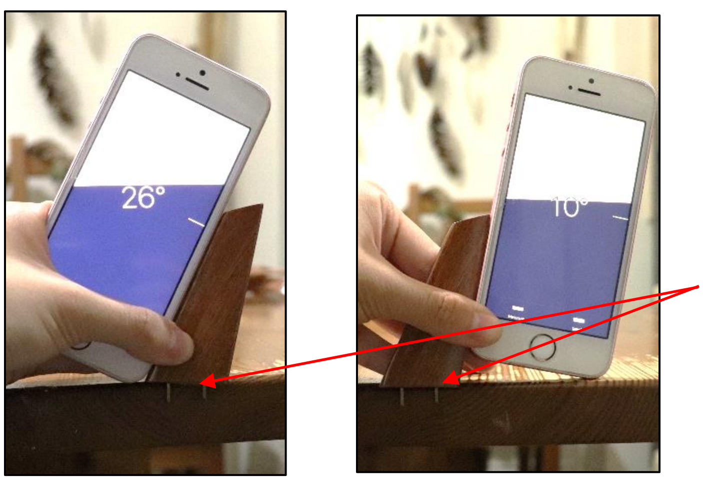


Figure 135. Finding the horizontal stabilizer angle

I created an angled plane, found the measurements of the edges of the stabilizer using a caliper, and then dimensioned a sketch accordingly. In order to find the angles of the edges of the stabilizer, I used my phone level.



Bottom of the stabilizer is rested on top of the level table

Figure 136.
Left: 26 degrees from perpendicular equals 64 degrees
Right: 10 degrees from perpendicular equals 80 degrees

I then used the caliper and level measurements to dimension the stabilizer sketch.

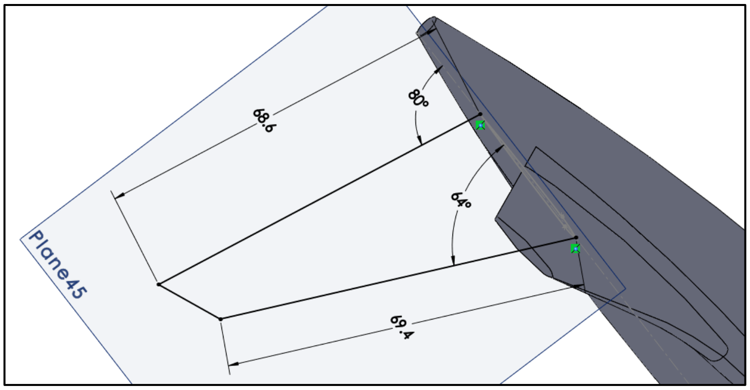


Figure 137. Horizontal stabilizer guide curves

Since the stabilizer is partially embedded in the fuselage on the actual model, I neglected the distance between the sketch of the large airfoil and the surface of the fuselage by assuming that the distance approximately represented the amount embedded.

For the smaller airfoil at the tip, I traced the shape out and again, used geometric constructions to find the radii.

When I tried sketching and dimensioning the top arcs and mirroring it on the bottom side, the sketch did not follow the curve of the bottom side well. Therefore, I decided to find the radius of the three-point arc on the bottom side as well. Although the second attempt was not a complete match, it looked better than the mirrored attempt.

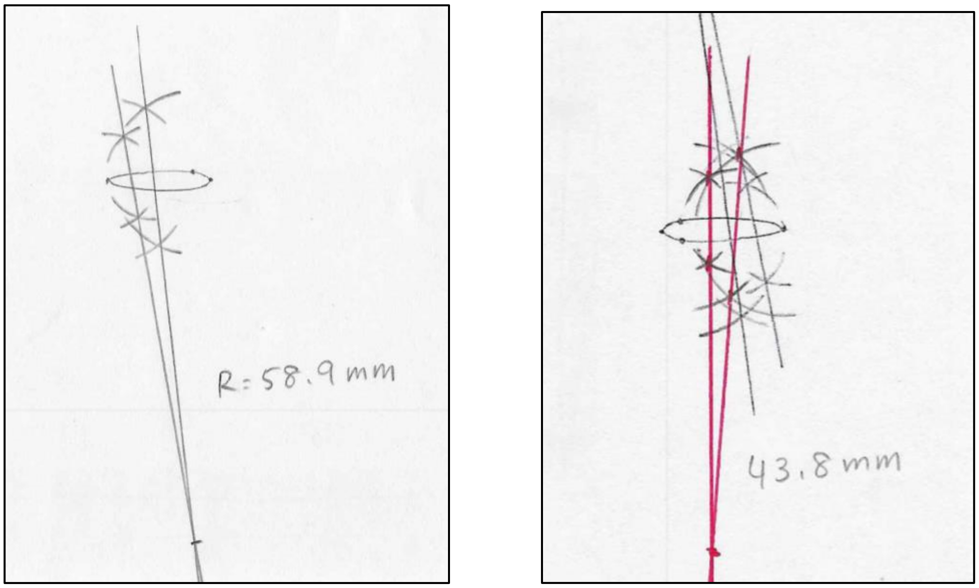


Figure 138. Geometric constructions to find the radii of the arcs in the small airfoil

Below is the initial airfoil I sketched by mirroring the airfoil arc on one half, and the adjusted airfoil I sketched by using two different dimensions for the two different radii.

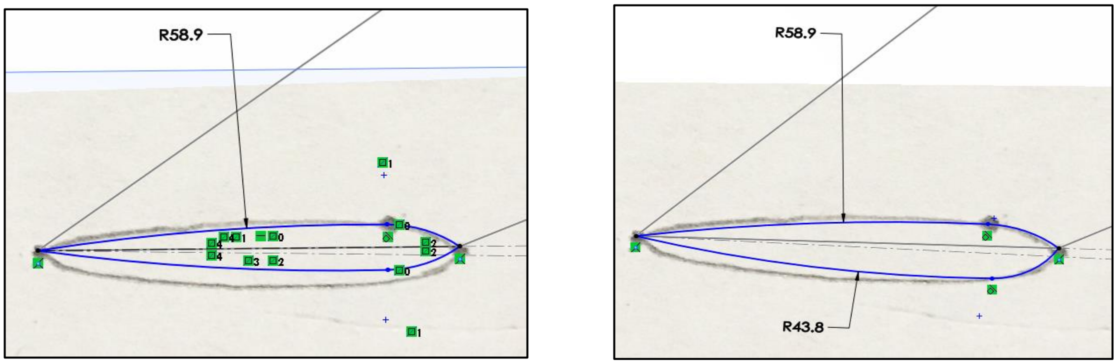


Figure 139.
Airfoil mirrored (left) versus individually defined arcs (right)

Since the airfoil with the different arc radii fit the sketch picture contour better, I decided to use that airfoil.

Finally, I lofted the horizontal stabilizer.

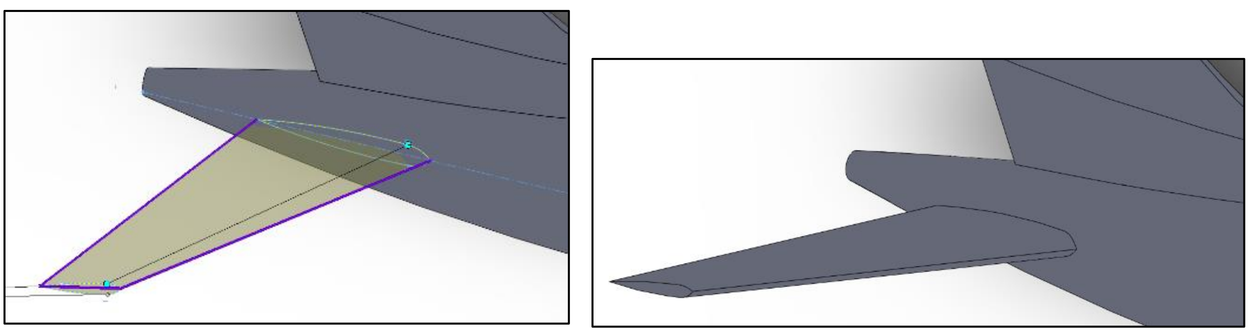


Figure 140. Horizontal stabilizer lofted

This completed my solid modeling process.

RESULTS

Solid Model

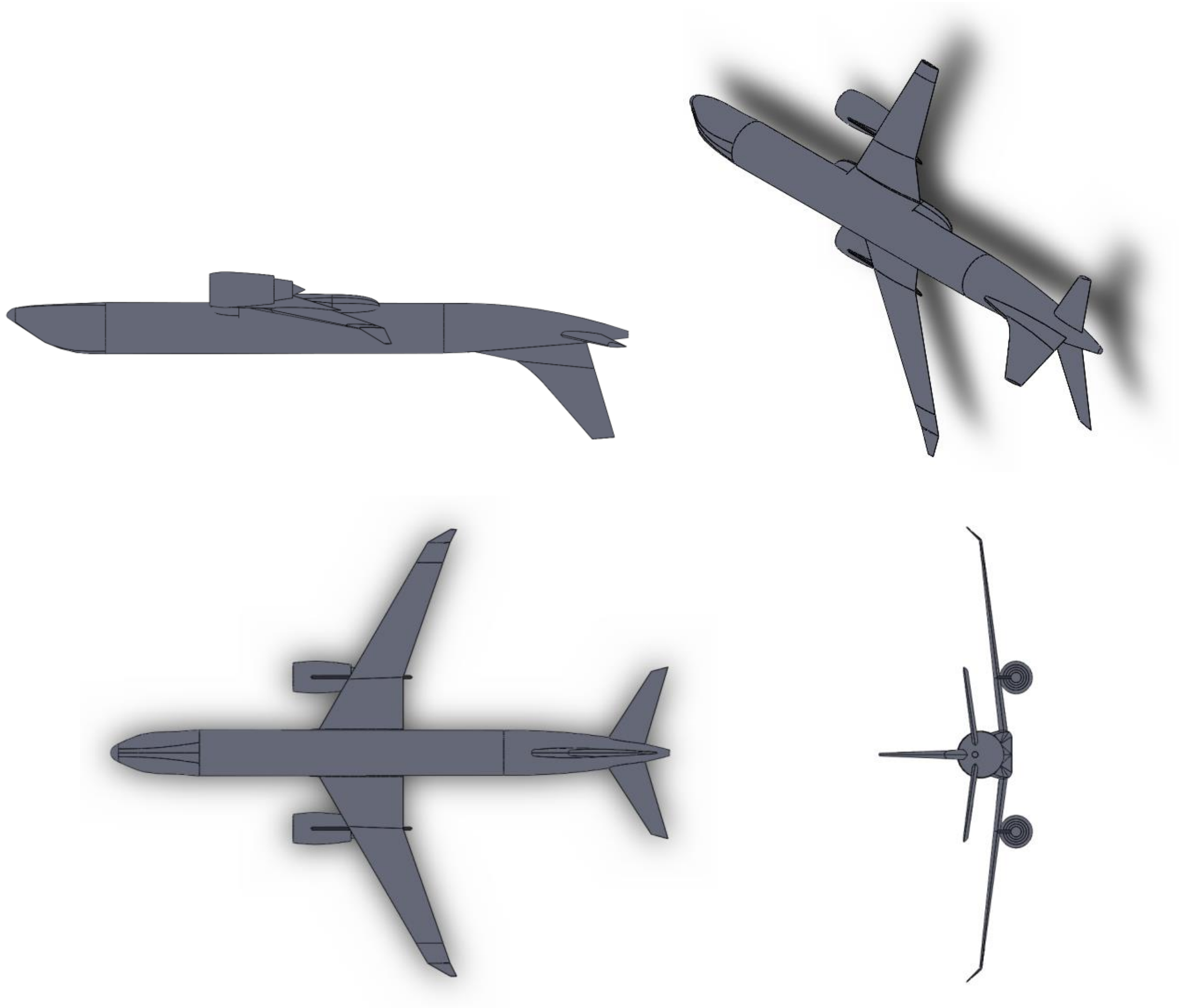


Figure 141. Completed model

Drawing

As I was trying to dimension the entire length of the model, I realized that in creating the dome, the point the dome referenced did not locate the very tip of the dome. Therefore, in order to dimension the full length, I needed to create a point on the drawing approximating where the tip of the airplane nose is, and dimension that point against the back of the airplane. I realized that in the front view, the centerline crosses the dome at the highest point and therefore, if I create a point on the intersection of the centerline and the dome and dimension it against the tail, I can figure out what the maximum length is and then find a point on the top view that gives the same measurement.

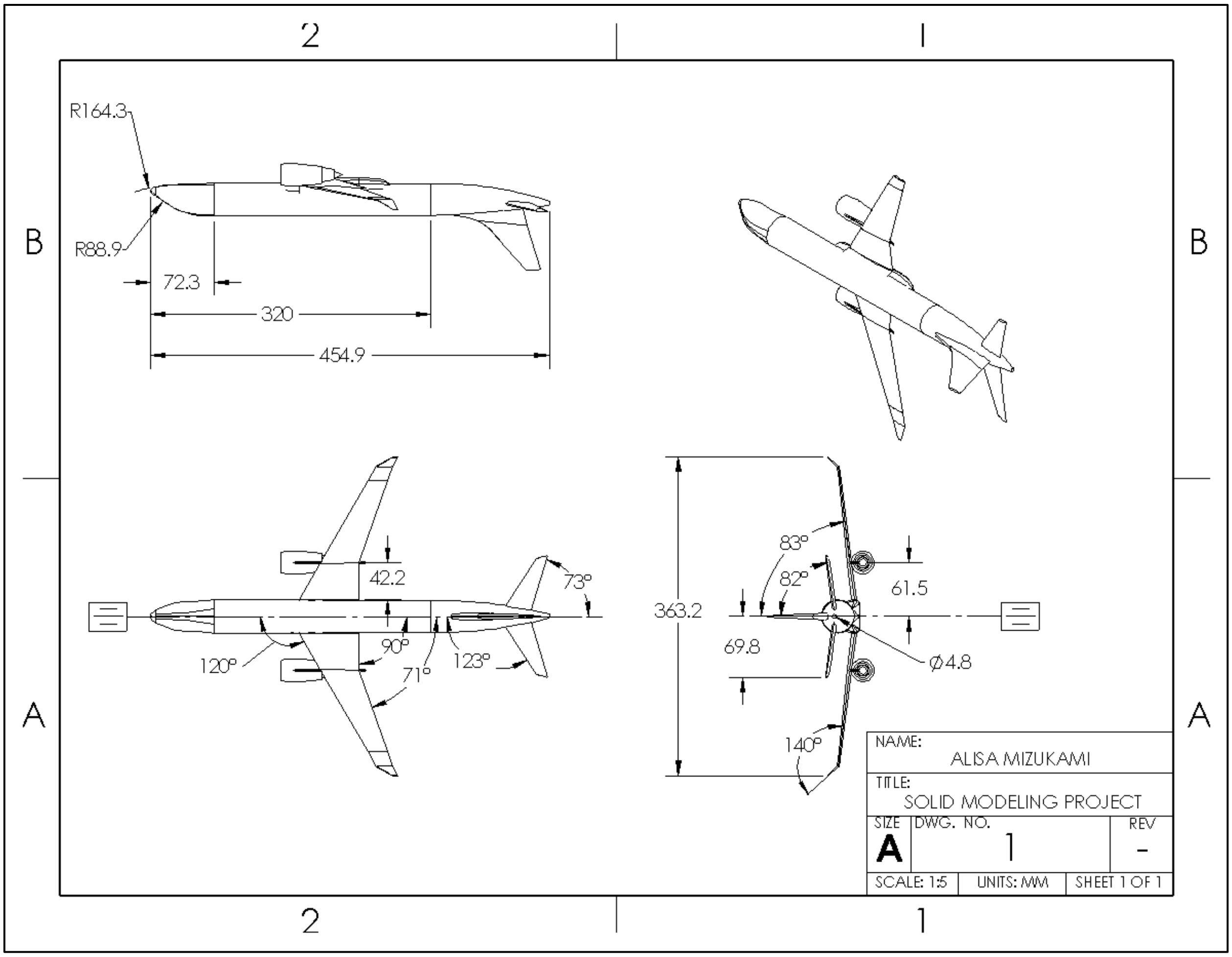


Figure 142. Engineering drawing with major dimensions

The curves where I used splines could not be dimensioned.

DISCUSSION

I learned about the complexity of taking measurements and reverse engineering an object through this project.

Measurement Inaccuracies

Many inaccuracies in measurements presented themselves in my model, causing certain measurements and relations to conflict with one another.

One cause of measurement inaccuracy may be that I did not have a scanner readily available while I was measuring and using SolidWorks; therefore, any sketch pictures I imported into SolidWorks was a photograph. Although I tried to keep my photographs as level as possible, I could not tell for sure whether the photos were angled or not. This may have caused some discrepancies between the measurements I found using geometric constructions on paper and the sketch I made in SolidWorks following the sketch picture. Therefore, if I were to do this project again, I will use a scanner to scan my contours and see if the sketch I create with my measurements line up better against the sketch picture.

I also learned about the importance of dimensioning and tolerancing in reducing error stack-up. Since I took measurements by referencing various locations of the model instead of using only a few datums, as I continued to add dimensions to my model, the overall error for parts continued to stack up. When I did attempt to set up the airplane for measurement using datums, I also relied on the assumption that all my datums were flat and level. Since the objects I used as datums were household objects not meant for use as engineering datums, they were not as reliable to use.

In addition to datums, all of the tools I used to take measurements had assumptions associated with them. For example, a caliper relied on the fact that I had the object straight inside the jaws in order to take accurate measurements. However, with many parts that were round, the jaws of the caliper slipped often, causing the part to be slightly angled within the caliper.

The contour gauge was also difficult to use with round parts because the pins often slipped to the side instead of pressing down onto the surface. This caused some contours to have a straight flat drop where the curve was supposed to continue along the length of the contour gauge, creating an inaccurate profile.

Object Improvement Suggestions

Some modifications to the physical airplane I would suggest would be to make the vertical stabilizer detachable. Due to the small thickness of the vertical stabilizer as well as its location at the center of the fuselage causing only the end of the stabilizer to be able to touch the ground when the fuselage is laid on its side, the stabilizer seems prone to breaking. This will be a problem in transporting the airplane because additional padding will need to be placed underneath the vertical stabilizer to fill the gap when the fuselage is laid on its side to be stored in its box.

Another fragile part of the airplane are the engines on the wings. When I was taking the wings on and off the fuselage, the engines were in the way of me getting a good grip on the wing to pull it out. I was also told when receiving this model that the engines are the most fragile part of the model and to take extra care when handling the wing. Therefore, the engine might be less prone to breaking if the wings have a slot for the engine to slide into, while keeping the engine detachable.

SolidWorks Experience

Features I learned

Through this project, I learned about how to use loft properly, including what parameters it takes, the types of guide curves it accepts, and how the profiles need to interact with the guide curves. I also learned about surface lofting and how it works both similarly and differently to solid lofting.

Another interesting tool I learned was doming. I used it as a simplification for complex features that I could not easily measure on my model, and although some of the accuracies may have been compromised, it reflected the complex curvature on my model well visually. I was very surprised to be able to use dome to approximate the end curvature of the wing box, making the modeling process a lot simpler and faster than I had expected.

Although I did not end up using this feature in my final model, I also had the opportunity to experiment with flex. It took me a lot of time to figure out what the planes and triad signified, but it was interesting to see the effect it could have on a part.

In this project, I tested many different features I had never used in order to see what could suit my model. I did not do much background research on each feature and therefore, I spent a lot of time trying to figure out the features on my own and making it work with my part. While this gave me an opportunity to learn a lot about the feature by finding out firsthand what works and does not work, it also took up a lot of time only to often end up not using the feature. Therefore, in a future project, I may want to do more extensive research on features before attempting to work with them to cut down on the amount of time I spend modeling.

Improvements on the Software

The user interface for SolidWorks, although in my opinion more user-friendly and intuitive than other computer-aided modeling software such as NX or Creo, still had its flaws, making certain features difficult to find and access. I had to constantly remind myself that the tools related to features were located under the “Insert” tab, while the tools related to sketches were located under the “Tools” tab.

Since there was also no tab such as “Features” and “Sketch” dedicated to surfaces, I did not know about surfaces until the topic was brought up in class. I believe that surfaces are very useful and should be more prominently displayed.

I also had a lot of difficulty dimensioning the drawing. In order to get the radii of arcs, I had to import dimensions, which caused many other unnecessary dimensions to come up as well, making it difficult to deal with.

Final Thoughts

Through this project, I learned about the difficulties of measuring parts and accounting for the assumptions that had to be made in order to keep the measuring process simple. As a student working on this project under a short time frame, I had to sacrifice a lot of accuracy in getting the measurements in exchange for being able to take measurements cheaply and quickly. For a multi-million company requiring very tight tolerances in their products, their method in taking measurements will likely be very different and much more advanced in order to minimize the amount of assumptions and simplifications that must be made.