Using the Boeing Aircraft Planning Documentation to configure an aircraft using VORLAX.

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Step 1: Retrieve the Necessary Planning Manual

To begin with a model of a known aircraft, we will need line art or a specification sheet that gives the dimensions of the aircraft. While this data is generally kept vague and difficult to obtain, aircraft manufacturers provide “Airport Planning Documents”, which include general dimensions necessary to determine gate configurations, taxi paths, and size clearances for a given aircraft. Because VORLAX exists primarily as a “90% design tool”, the tolerances on the available dimensions work perfectly in our case.

https://www.boeing.com/commercial/airports/plan_manuals.page

https://www.airbus.com/aircraft/support-services/airport-operations-and-technical-data/aircraft-characteristics.html

https://www.flyembraer.com/irj/portal/anonymous#

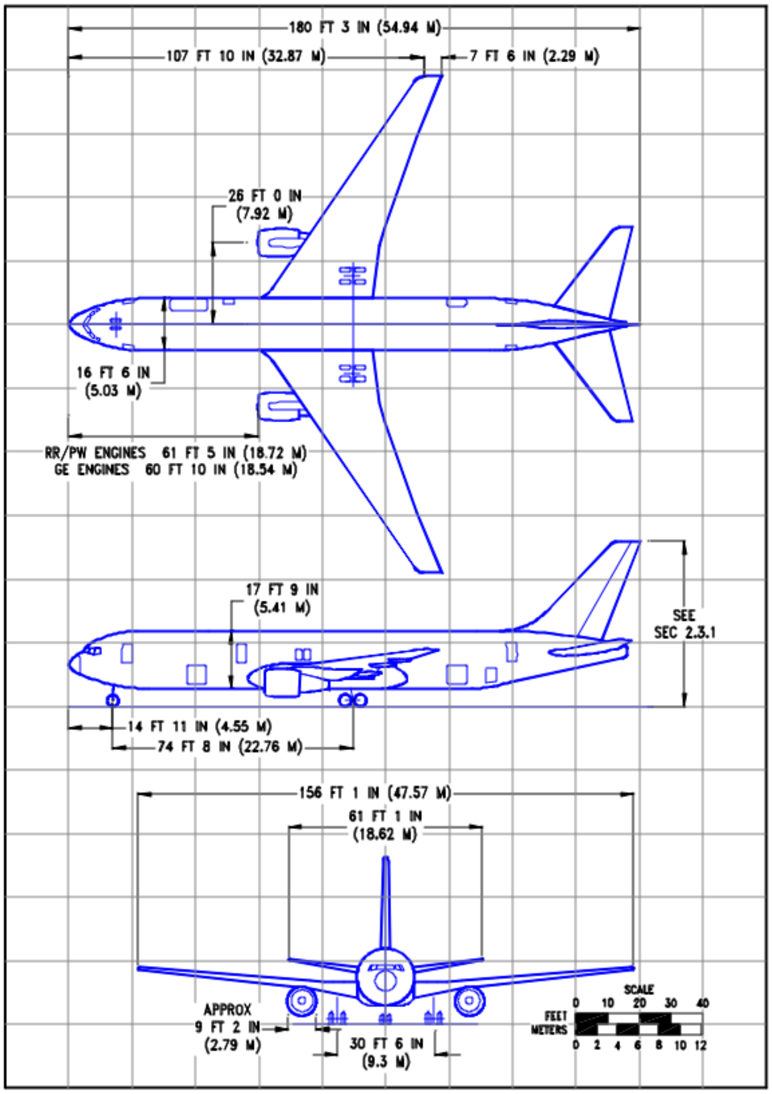
Above are the three main commercial airline manufacturers. Some other aircraft have planning manuals, though you are better served using Google to find the model you are interested in. For example, the CRJ aircraft manuals are available if you search for them, but Bombardier offers no hub that is easily linked.

Alternatively, go to Wikipedia and look at the sources for the aircraft specification tables. Oftentimes, they cite the European aircraft certification body, EASA. They will have the type certifications available, which should include the data necessary to determine the dimensions of your aircraft.

Step 2-a: Find the dimensions of the model of interest

In this tutorial, we will be using the Boeing 767-300ER as the example to model in VORLAX. To begin, you would go to the Boeing link given above and locate the 767-300ER in the available files. To save the trouble, I have included the wireframe drawings already.

Many times the airlines will put all of their aircraft models in one single document for the family, with the exception of aircraft showing large changes. For example, Airbus puts all of the Airbus A320 type aircraft in a single document, and you might need to navigate through the document in search of the specific model of interest.



Step 2-b: Initialize a VORLAX Input File

Before we get to measuring anything, we will want to have an input file for the information. To assist, I have provided a template input file specifically for this example.

Download the file named "767_Template.inp" from Canvas – we will use these settings for this tutorial. The header will ask for many dimensions – this information is mostly available via the lecture slides. The NMACH, MACH, NALFA, ALPHA parameters do not matter for this example, so leave them as-is. Starting off, we will have a single panel (NPAN=1), but this number will increase as we make the model more complex.

How do we get the information for the other input file settings? We will need to look at Wikipedia (or somewhere else reputable) to get a basic idea of the dimensions. Below is a screenshot from the page about the Boeing 767.

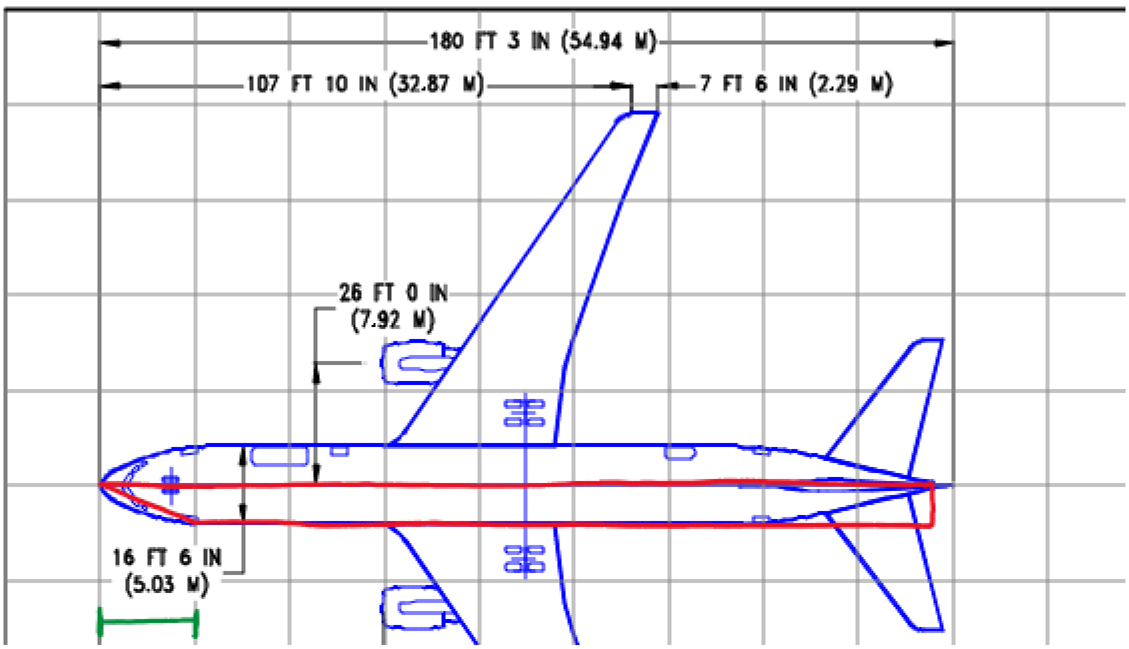
Wingspan[217]	156 ft 1 in / 47.57 m
Wing	3,050 ft² / 283.3 m², 31.5° sweepback[127]

We know the value for SREF=3050, WSPAN=156.08. We also know the mean chord, CBAR = SREF / WSPAN, therefore CBAR = 19.54. For the stability derivatives, we need to define the CG location. Generally, speaking this is around 45% of the total length of the aircraft, but it is not a set parameter. In my case, I specified XBAR = 80ft.

Step 3: Fuselage

We need to determine the X, Y, Z, and C values for the horizontal portion of the fuselage section. If you are unsure what this means, refer to the VORLAX guide slides from your lecture. Essentially, these are the measurements that define the geometry from the leading edge of a panel. As previously stated, VORLAX is meant for preliminary design performance analysis. Thus, we do not need to capture the intricate curves and shapes of the aircraft, but we must describe the general shape of the aircraft. So, as this guide proceeds, you will notice many cases where the match is "good enough". Obviously, the more care taken, the better; but this depends on the task at hand.

The nose of the fuselage is collocated with the origin of our coordinate system, thus X1=Y1=Z1=0. The wireframe art defines the overall length of the aircraft, telling us the axial length of the horizontal fuselage, which measures to 180.25ft, thus giving the value of C1. In terms of capturing the precise nosecone geometry, we will not do that. Rather, we shall approximate it via a single angle. Looking at the given scales, we see that the fuselage reaches full width approximately 20ft aft of the nose, thus X2=20. The document gives the width of the external fuselage, and so we know that the total width is 16.5ft. However, VORLAX mirrors the panels, and we are drawing only one half of the horizontal fuselage. Thus, the appropriate value for Y2=16.5/2=8.25. There is no variation in the vertical displacement, so Z2=0. Finally, C2 is whatever it needs to be to ensure the panel properly aligns at the end of the aircraft, in this case: C2=C1-X2=160.25.



For bookkeeping purposes, we will start an Excel sheet with these dimensions, which I have provided on Canvas for you to fill out. In the shared cells, a green cell represents an independent variable, while a grey cell represents a dependent variable calculated via dependencies on other dimensions.

1 - Fuselage Horizontal Component			
X1 =	0	X2 =	20
Y1 =	0	Y2 =	8.25
Z1 =	0	Z2 =	0
C1 =	180.25	C2 =	160.25

We will use these coordinates to draw our first panel of this aircraft.

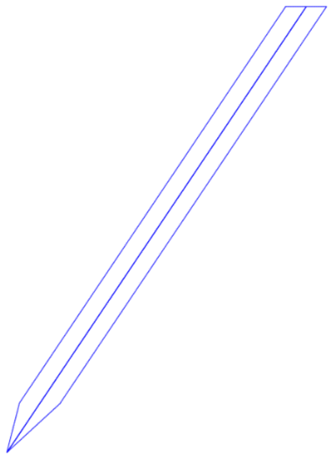
It is time to input our first panel – we will do so using the coordinates calculated earlier. In old FORTRAN syntax, spacing within the document matters. You will see at the top a series of repeating numbers, these represent the “columns” that the code reads from, and you need to make sure that whatever you type in stays within a single column.

For this panel, we have a very long section “chordwise” because VORLAX reads the entire length as its chord. Similarly, we have a narrow span, relatively speaking. For now, we set NVOR = 8 and RNCV = 50. The other parameters will equal zero, since there is no twist, the panel is double-impermeable, the panel is symmetric about the x-z plane, and we are not defining any camber points. SPC is the parameter which represents the leading-edge suction effect on the wing. For a panel that directly faces the oncoming wind, SPC will equal 1.0. If the panel lies behind something else, such as in the case of a trailing-edge flap which does not face the wind directly, SPC will equal 0.0.

```
* HORIZONTAL BODY
* PANEL
*X1       Y1       Z1       CORD1     Comment:
0.0       0.0      0.0      180.25
20.0      8.25     0.0      160.25
*NVOR     RNCV     SPC      PDL
8.0       50.0     1.0      0.0
*AINC1    ANINC2   ITS      NAP      IQUANT   ISYNT    NPP
0.0       0.0      0.0      0.0      0.0      0.0      0.0
*
```

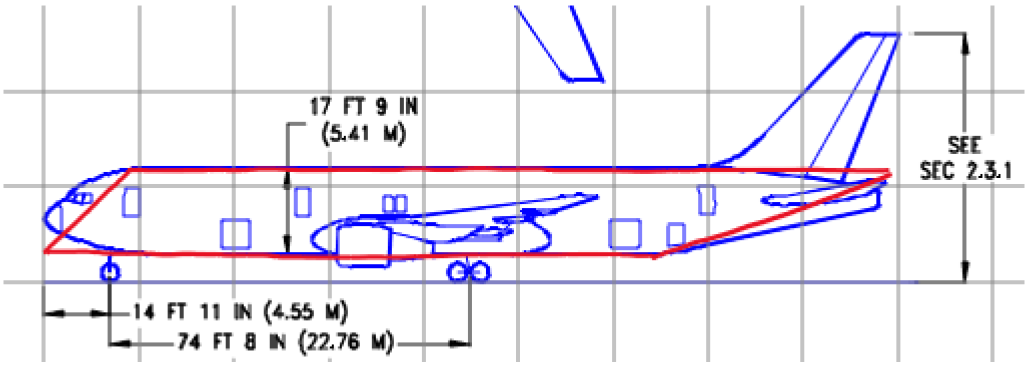
Above is the input section for the horizontal fuselage, use this to compare your work. If you save the input file in its current state and download the VOLRAX-model-visualizer that Dr. Takahashi has written (available on Canvas), you will see that our current geometry looks like a wooden stake. This is a great start, because this will be the foundation for the rest of the aircraft. Let us now have a look at the vertical component of the fuselage.

The vertical fuselage portion is very similar to that of the horizontal fuselage. This time, we will want to capture the vertical taper towards the rear of the aircraft, because one of the primary reasons for modeling the vertical fuselage is to determine the lateral stability of the aircraft. Again, we shall turn to the Boeing line art to determine what the dimensions need to be.



For starters, we know that this panel will also start at (0,0,0) for the nose, but now we do not know how large C1 needs to be. For this, we can look at the line art and its accompanying scale. We can see that the rear begins to taper about 130ft aft of the nose, and so we will set C1=130.

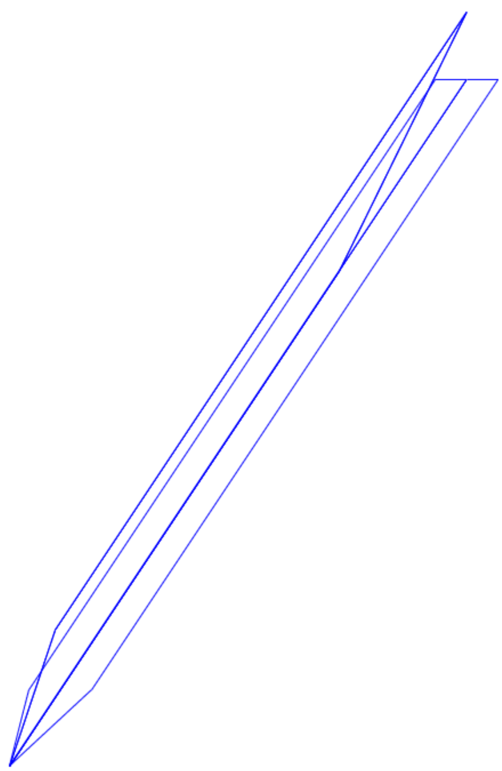
Continuing to look at the line art, we see that the height of the fuselage is 17.75ft, so Z2=17.75. The point at which the panel reaches the full height is at X2=18ft (give or take), going off the scaling in the image. Because this panel is vertical, Y1=Y2=0. Finally, we know that the upper fuselage point needs to run the entire length of the plane, so we can calculate it by subtracting X2 from the overall length of 180.25ft.



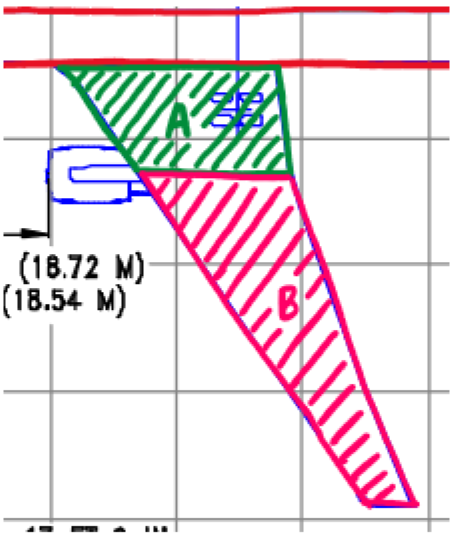
2 - Fuselage Vertical Component			
X1 =	0	X2 =	18
Y1 =	0	Y2 =	0
Z1 =	0	Z2 =	17.75
C1 =	130	C2 =	162.25

```
* VERTICAL BODY
* PANEL
*X1         Y1          Z1          CORD1       Comment:
0.0         0.0         0.0         130.00
18.0        0.0         17.75       162.25
*NVOR       RNCV        SPC         PDL
8.0         50.0        1.0         0.0
*AINC1      ANINC2      ITS         NAP         IQUANT      ISYNT       NPP
0.0         0.0         0.0         0.0         1.0         0.0         0.0
```

To update the input file for VORLAX, we will now need to set NPAN = 2 because we now have two panels. We also need to copy and paste the HORIZONTAL BODY section to use as a template where we can simply change the values. After updating the numbers, you can leave the parameters the same, except for IQUANT. Because this panel is vertical, you do not want to mirror it about the centerline. Thus, we shall set IQUANT = 1, to represent this asymmetry. For a brief explanation, because the panels are infinitely-thin, trying to mirror a panel that lies on the X-Z plane about the X-Z plane does not work, as the geometry lies on that plane. Attempting to do so will cause problems.



If you save the input file and reload the model visualizer, it should now have a sharp vertical fuselage panel perpendicular to your existing horizontal fuselage.



The final portion to this training will be the main wing. The method to resolve the dimensions of the main wing will follow that of the previous sections. First, we will utilize the dimensions defined directly in the artwork, then we will resort to geometric relations and approximations to draw the remainder of the wing.

Step 4: Main Wing

For this case, we will model the main wing as two panels with basic sweep and a Yehudi. Many of you will find yourselves needing many control points for the wing, which I assure you is not difficult to implement once you understand the basic principles of drawing the panels.

To best understand the coordinates of this wing, we will need to devise a numbering scheme that is clear for the two panels. To maintain the (1) and (2) numbering convention understood by VORLAX, I will refer to the inboard panel as Panel (A) and the outboard panel as Panel (B). When referring to the coordinates for these panels, I will write A-X1, A-X2, B-Y1, etc. Regarding this pair of panels, we must note that they share an edge. Thus, A-X2, A-Y2, A-Z2, and A-C2 must equal B-X1, B-Y1, B-Z1, and B-C1, respectively. This seems inconvenient, but it is opposite. Having this condition will provide a geometric "frame" of sorts which allows for easier Excel relations and calculations.

To draw the main wing, we need to determine where it begins. We are doing an aerodynamic analysis, and as such we only care about what the wind "sees". This means that the root chord, while a useful measurement for structures and geometric relations, is unnecessary in this case where we are copying an image. Thus, the starting Y-value (A-Y1) is at the side of the fuselage, which is a distance we already know from the fuselage portion. We may use our Excel sheet to establish that relation.

Another shortcut comes from the fact that we know the wingspan and tip chord, both of which the Boeing artists chose to detail. We may input the wingtip chord value for B-C2, and we know that the panel must terminate at the half-span, giving us the value of B-Y2. Finally, from the drawings we see the distance of the wingtip leading edge aft from the nose – this will serve as an anchor point from which we can determine the location of the rest of the wing. In this case, B-X2 = 107.83.

Now, we want to find the x-coordinate where the wing intercepts the side of the body. We know that the leading-edge sweep of the main wing is 31.5deg because of the Wikipedia dimensions.

Using this in conjunction with the given position of the wingtip, we can work backwards to determine where the wing intercepts the fuselage by using simple trigonometry. Using our defined parameters, we may relate the two via:

$$[B - X2] = [A - X1] + ([B - Y2] - [A - Y1]) \cdot tan(LESWEEP)$$

Quickly rearranging, we find that A-X1=65.06.

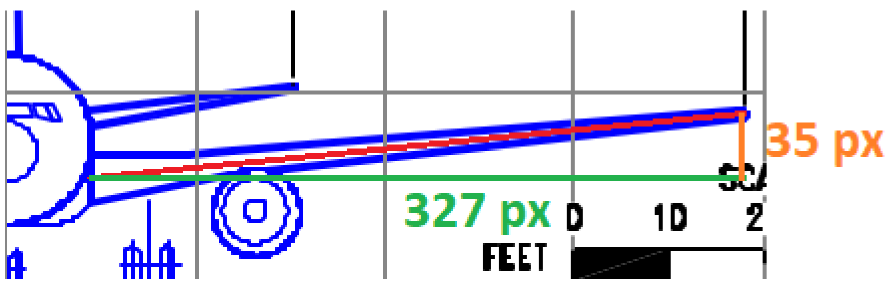
We will also need to determine the X-location for the junction between the inboard panel and the outboard panel. Recall, the two panels share a line, so we are only finding one set of coordinates that the two will share. They must share this line perfectly, or else VORLAX will run into problems determining the pressure distribution.

We may determine the X-value for A-X2 by using the same formula that we used for the side of body junction. We can see that the value of A-Y2 aligns with the centerline of the engine, as given by the drawing, hence A-Y2=26. Thus, to determine this junction X-value, we calculate via:

$$[B - X2] = [A - X2] + ([B - Y2] - [A - Y2]) \cdot tan(LESWEEP)$$

Note that the only difference with this equation is that we are interested in A-X2 instead of A-X1. As such, we change that parameter along with the associated Y dimension, changing from A-Y1 to A-Y2. This is nice because it forces the dimensions to remain consistent. There are cases where even if equations agree mathematically, they will lead to slight differences due to rounding, and you must be wary of this when determining panel locations.

The Boeing 767-300ER, like most aircraft, does not have a “flat” wing, it has dihedral. To determine the dihedral without any official published documentation, we will again turn to the wireframe drawing. In this case, a simple option is to count pixels. If you use Microsoft Paint, you can draw lines and the bottom bar shows you the length.



With simple trigonometry, we can calculate the dihedral angle: $\theta \approx tan^{-1}(35/327)$. This works out to $\theta = 6.1°$. To determine the Z-value at any point on the wing, assuming that Z=0 at the side of body (to avoid any gaps), we can use the simple equation: $Z = (Y - [A - Y1]) \cdot tan(\theta)$

Finally, we need to determine the chord lengths. In the portion with the Yehudi, we will assume that the panel maintains the same trailing edge X-coordinate throughout, i.e.

3 - Inboard Main Wing			
X1 =	65.06	X2 =	75.94
Y1 =	8.25	Y2 =	26
Z1 =	0	Z2 =	1.899
C1 =	35	C2 =	24.12
4 - Outboard Main Wing			
X1 =	75.94	X2 =	107.83
Y1 =	26	Y2 =	78.04
Z1 =	1.899	Z2 =	7.468
C1 =	24.12	C2 =	7.5

$$[A - C2] = [A - X1] + [A - C1] - [A - X2]$$

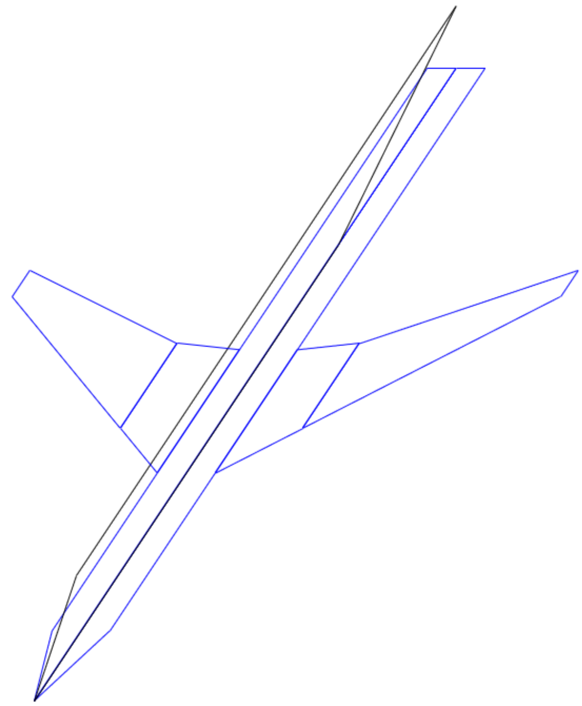
After computing the chord, we should have all the coordinates necessary to completely define the shape of the wing via infinitesimally thin panels. In the case of the 767, the Yehudi does not have the same trailing X-coordinate, but it is angled slightly aft. There is an easy correction to this – simply add a couple of feet to the value of A-C2 until the dimensions match close enough to the image.

When plotting the coordinates in Excel, I recommend having cells set equal to one another at the panel junctions, as it prevents you from over defining a panel. As you can see, I have the values of the B1 points set equal to the A2 points, forcing them to be the same. This simplifies things by tidying the locations of the calculations and can be easily expanded for as many panels as you choose. I do warn, there comes a point where a large number of panels is asinine because of the approximate nature of VORLAX. While you may carefully craft a pseudo-continuous wing based on 100 unique panel shapes, it is impossible to work with nicely. To define a wing, a series of 5 spanwise control points should be more than sufficient to accurately represent the behavior. With the final wing dimensions calculated, we may finally input the main wing into the VORLAX input file. Before doing so, remember to change NPAN=4, since we are adding two more panels to the aircraft. All said and done, the new entries should look like this:

```
* INBOARD MAIN WING
* PANEL
*X1       Y1       Z1       CORD1      Comment:
65.06     8.25     0.0      35
75.94     26       1.899    24.12
*NVOR     RNCV     SPC      PDL
25.0      8.0      1.0      0.0
*AINC1    ANINC2   ITS      NAP      IQUANT   ISYNT    NPP
0.0       0.0      0.0      0.0      0.0      0.0      0.0
*
*-----------------------------------------------------------------------------
* OUTBOARD MAIN WING
* PANEL
*X1       Y1       Z1       CORD1      Comment:
75.94     26       1.899    24.12
107.83    78.04    7.468    7.5
*NVOR     RNCV     SPC      PDL
25.0      8.0      1.0      0.0
*AINC1    ANINC2   ITS      NAP      IQUANT   ISYNT    NPP
0.0       0.0      0.0      0.0      0.0      0.0      0.0
*
```

The values for NVOR and RNCV have changed because the wing is not comprised of long and skinny panels, but instead short and wide panels. RNCV equal to 8 gives good performance, and we generally like to set NVOR so that the number of grid points tip-to-tip is about 100. In this case, we have 25 points for each panel and 8 for the horizontal fuselage. When we double that (because the configuration is mirrored), we arrive at 116 total spanwise points, which is close enough.

Run the visualizer one more time, and you will see the aircraft likes like the following:

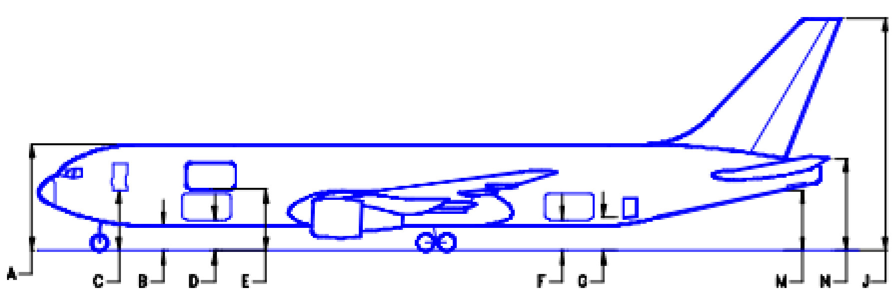


Step 5: Tail Surfaces

The tail surfaces are critical for obtaining any kind of accurate, useful data for stability and control purposes. While this guide will not cover the entirety of the SNC mini projects, we can cover how to model a tail. Generally speaking, it is done in a manner mimicking that of the main wing and the vertical fuselage. We shall begin with the vertical tail.

Much like the vertical fuselage, this panel cannot be mirrored across the X-Z axis. We will need to get the dimensions for the tail, which will be done with the wire diagram. The easy dimensions are Y1 and Y2, as they both equal zero. Next simplest are Z1 and Z2. Because we know that the tail needs to meet the fuselage, we know that Z1 will be equal to the Z2 value of the vertical fuselage.

We can look at the drawing to see that the vertical tail height is given by Section 2.3.1. When you navigate to this section, you see the following drawing:



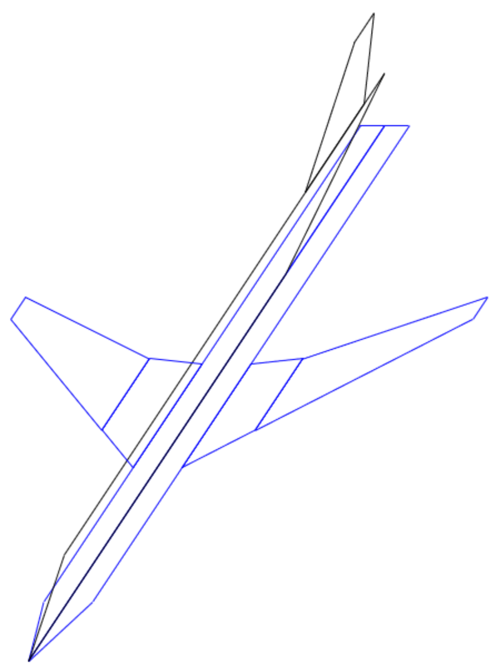
Obviously, this is not perfect, as the measurements are all relative to the ground. Easy enough, because the document tells us that Distance F = 7.42ft and Distance J = 50.75ft. With simple subtraction, we can find that the vertical tail goes up to 27.25ft above the bottom of the fuselage, thus giving us our Z2 value.

Finally, we need to determine the X- and C-values. If we look at the drawings, the vertical tail begins about 140ft aft of the nose, thus giving X1=140. At the fuselage junction, we see that the chord length is about 30ft, giving C1=30. At the tip of the tail, we see that the value of X2=165, with a chord length of about 10ft. While these values may not be perfect, they represent the size of the tail with enough accuracy to give ballpark performance figures.

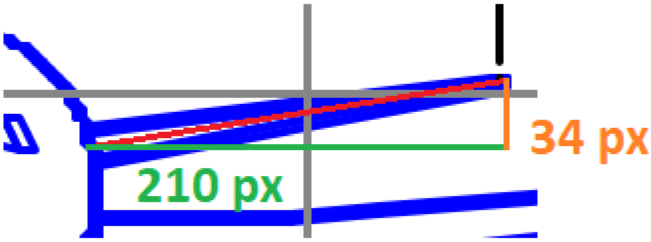
5 - Vertical Tail			
X1 =	140	X2 =	165
Y1 =	0	Y2 =	0
Z1 =	17.75	Z2 =	43.33
C1 =	30	C2 =	10

Now to add the tail, we will do the same as before. Again, because this panel is vertical, IQUANT = 1. For the dimensions of this panel, we want NVOR = 20 and RNCV = 8, which is enough to get a reasonable pressure distribution. When we update NPAN = 5 and insert the panel representing the vertical tail, we get the following:

```
* VERTICAL TAIL
* PANEL
*X1       Y1       Z1       CORD1      Comment:
140.0     0.0      17.75    30.00
165.0     0.0      43.33    10.00
*NVOR     RNCV     SPC      PDL
20.0      8.0      1.0      0.0
*AINC1    ANINC2   ITS      NAP      IQUANT   ISYNT    NPP
0.0       0.0      0.0      0.0      1.0      0.0      0.0
```



Once we have the vertical panel complete, we will model the horizontal tail. This process, as one may expect, mimics that of the main wing quite closely. First, we can determine the Y-values. We know that the horizontal tail must meet the horizontal fuselage, and thus we know the Y1 value. We also know that the span of the tail is 61.08ft overall, meaning that Y2=30.54, due to the mirroring of the panel.



The tail also has dihedral, much like with the main wing, and we will determine the angle so that we can calculate the Z-values. Again, counting pixels gives the dimensions to calculate the angle. In this case, we find that $\theta = tan^{-1}(34/210) = 9.2°$. Knowing that the tail meets the horizontal body at Z1 = 0, we find that Z2 = $(Y2 - Y1) \cdot tan(9.2°) = 3.61$.

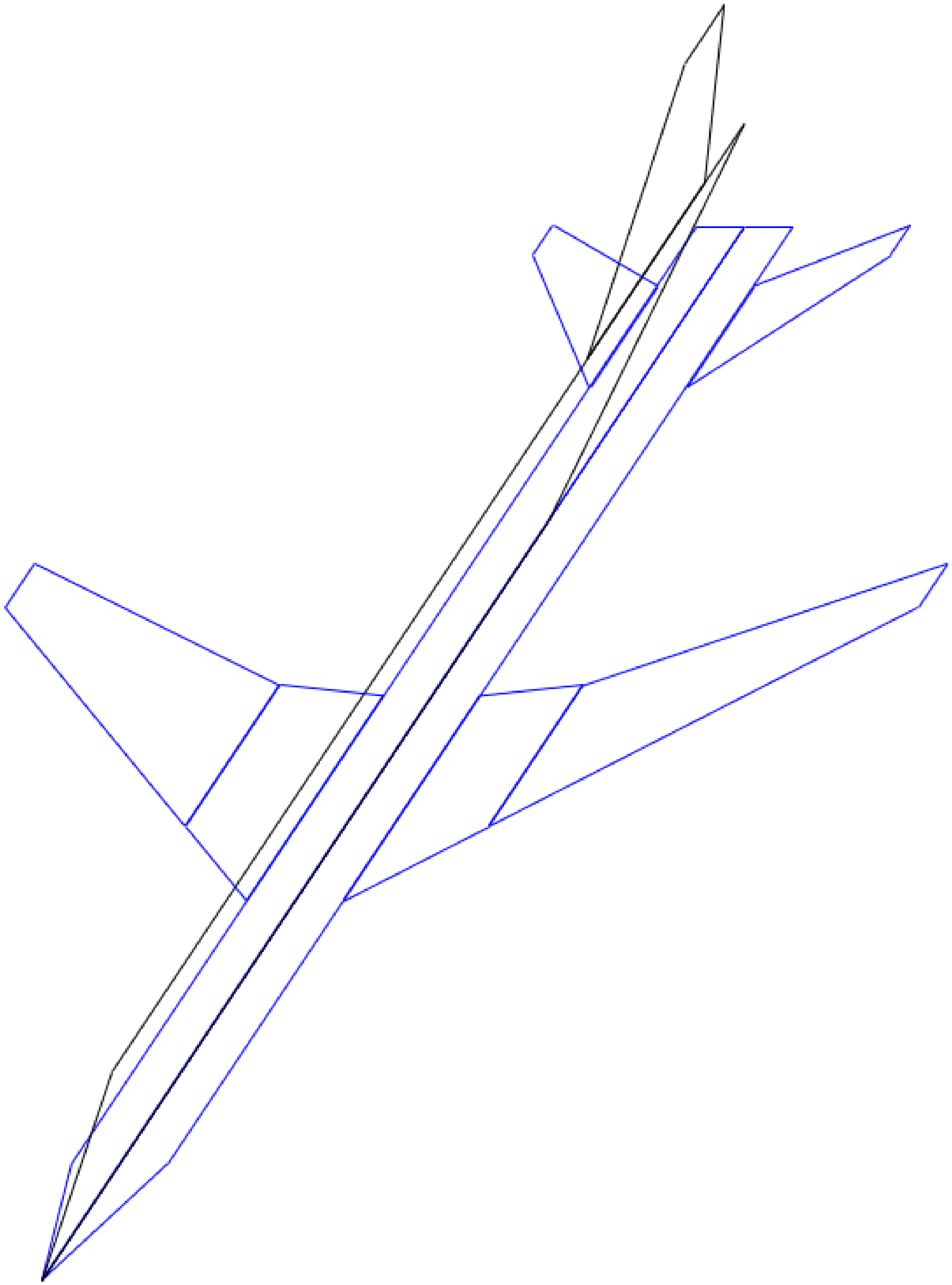
Finally, we need to establish the X- and C-values. From the drawing, we see that X1=153ft (or so), which goes back until about 10ft before the overall length of the train. Thus, we can determine C1 = 180.25ft - 10 - X1, giving C1 = 17.25. The tip of the tail appears to begin around X2 = 172ft, so we will use that value. This comes with a chord length of about 5ft, based on the drawing scale.

6 - Horizontal Tail			
X1 =	153	X2 =	172
Y1 =	8.25	Y2 =	30.54
Z1 =	0	Z2 =	3.61
C1 =	17.25	C2 =	5

We may plug this into the input file, updating NPAN = 6. For this panel, we want about 50 grid points tip-to-tip, and so we will use NVOR = 25 and RNCV = 8. This yields the following for the input:

```
* HORIZONTAL TAIL
* PANEL
*X1        Y1        Z1        CORD1      Comment:
153.0      8.25      0.0       17.25
172.0      30.54     3.61      5.00
*NVOR      RNCV      SPC       PDL
25.0       8.0       1.0       0.0
*AINC1     ANINC2    ITS       NAP       IQUANT    ISYNT     NPP
0.0        0.0       0.0       0.0       0.0       0.0       0.0
```

Finally, with everything combined, we can see the final version of the panel plane. While not the most complex variant of a VORLAX model, it provides meaningful insight to the performance of the aircraft. This is a baseline variant, and through your studies, you will discover your own ways to improve it.



Step 6: Run VORLAX

Once you have a suitable input file (I have provided a correct file to which you can compare), you need to run VORLAX to determine anything about it. To begin, open a command window on your PC by going to the start menu and searching “cmd”. After doing so, you will need to navigate to the folder where you have the input file and VORLAX saved. This is done using the “cd” command. For example, I type the following into the command window:

```
Microsoft Windows [Version 10.0.18363.1016]
(c) 2019 Microsoft Corporation. All rights reserved.

C:\Users\tsouders>cd C:\Users\tsouders\OneDrive - Arizona Stat
e University\School\Fall 2020\MAE 564\VORLAX GUIDE 767
```

Type the command using your desired folder and then press enter. From here, we will need to run VORLAX. This is relatively simple, and you may do so by typing:

VORLAX2020.EXE < INPUTFILENAME > OUTPUTFILENAME

We know the input file name, it is 767_Template.inp, and the output file name is whatever you want it to be. For example, I called it “Example_Output.out”. Make sure you specify some kind of file extension, or else your computer may not know how to open the file. To call VORLAX, your command window should look like below:

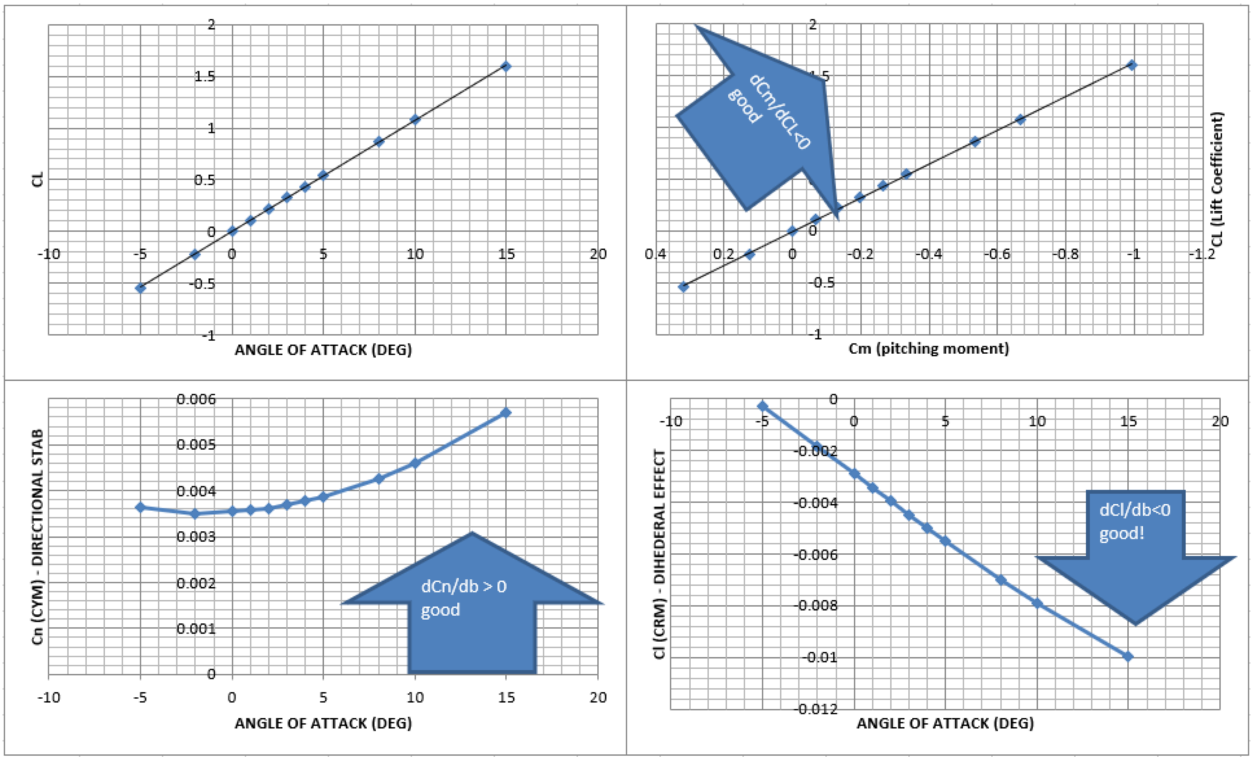
```
C:\Users\tsouders\OneDrive - Arizona State University\School\F
all 2020\MAE 564\VORLAX GUIDE 767>VORLAX2020.EXE < 767_Templat
e.inp > Example_Output.out
```

Hit “Enter” to run VORLAX. After running, there are two files you will need to pay attention to: VORLAX.LOG and the output file, which in my example is “Example_Output.out”. We will address the simpler file – the .out file. The .LOG file is much more involved in terms of parsing, and will be addressed later in MAE 564 and AEE 468, as necessary.

The simple output file comes in a standard CSV file format. Dr. Takahashi has provided a simple VORLAX data processor in Excel to demonstrate some basic analysis of the VORLAX output data. Simply copy the output data (excluding the headers) and paste it into cell A3. Excel should automatically detect that it is the same format as the existing data and enter the numbers into their appropriate places. If it does not, you will need to use the text import wizard, which you may do, selecting “Delimited” for the data type and having only “comma” selected for the delimiter. Anything else will lead to improper spacing in the columns.

We can see the lift-slope and the correlation between pitching moment and lift coefficient. We can also determine the necessary lift coefficient for a given indicated airspeed at an analysis weight of the aircraft. Note that in order to determine all of these stability derivatives (particularly those related to directional stability), we must have the aircraft positioned at a sideslip angle, in this case PSI = -1. We also want to have a realistic range of pitching angles, and so we have NALFA = 11, with angles ranging from -5 to 15 degrees. With this complete, we obtain the following figures.

These results are good, considering we are modelling a plane that is currently certified and flying. While the specific numbers are up to debate, there is no doubt that the general behavior of this configuration is stable in flight. Thus, this proves VORLAX as a viable tool for 90% analysis of a proposed airframe shape.



While this test case did not demonstrate everything, it is a good primer to the capabilities of VORLAX. We see here how it can determine the lift generated by the entire aircraft, not only that limited to the main wing. VORLAX allows you to add tail fixtures, fusiform body types, camber, and thickness. You can accurately model ailerons, rudders, and elevators, as well. As you progress through your respective clubs and projects, you will see the true value in VORLAX as an attainable CFD design tool.