NACA Submerged Duct Construction

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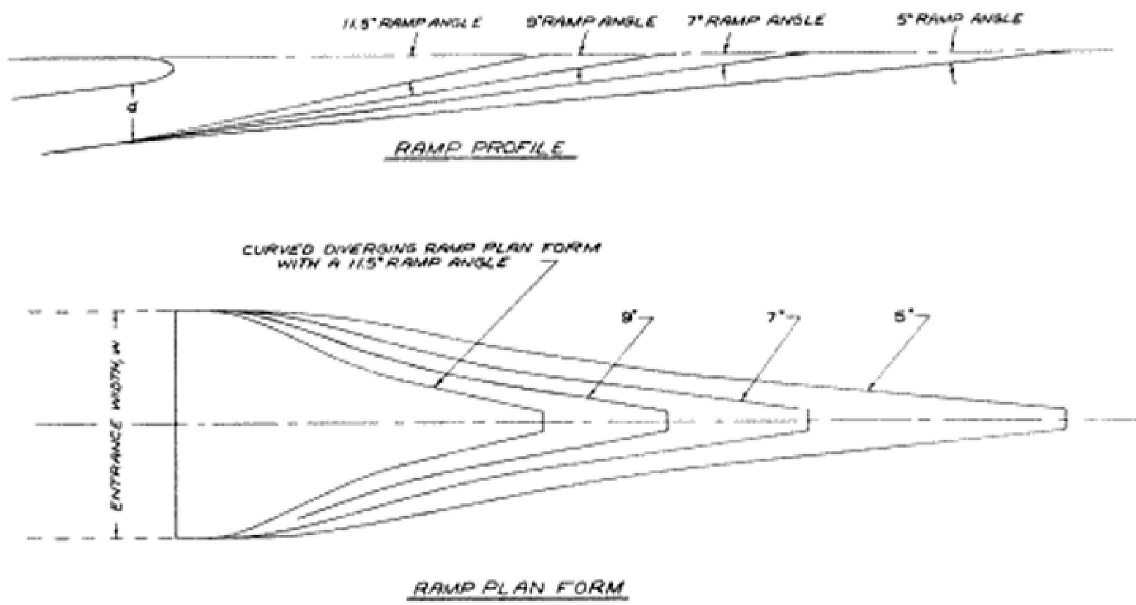
We have all seen the submerged ramp V shaped air ducts on our airplanes. Almost any hole of that general shape is referred to as a NACA Duct. The good news about this design is that it still works even when the similarity to an optimum NACA Submerged Duct is a stretch. However, if you are going to use this duct for your engine induction inlet and or other more critical purposes you might want the duct to be a little more efficient and effective. Therefore you may want to stick more closely to the actual NACA design. So what are the critical parameters for an NCAC duct?

I have searched for general design information on the Web before and found it hard to come by. There are three NACA reports in the NASA Digital Library from 1945, 1948 and 1951 that are experimental wind tunnel investigations on submerged ducts and have a lot of detailed measurements but they are not do-it- yourself documents. The web addresses are located in the references at the end of this article. Don't be surprised to find the pdf file sizes are 12 and 17 meg. There were a few other articles, sketchy descriptions and a mention of an article in the 1991 Sport Aviation on the Web. I have gathered some of this information and written a description of how to make an NACA submerged duct of any size. This article does not tell you the performance obtained in either air volume or pressure developed. It's still up to you to determine the size of duct you'll need. It should be of benefit even if you are constructing the duct from a purchased kit as the much of the effectiveness is in the details

The general attributes of an NACA submerged air duct is that it develops a source of pressurized air from the surface boundary layer with out generating highly significant turbulence and the associated drag. Reports indicate that icing is not a serious problem, as the heaver ice particles tend not to make the bend into the duct and thus continue on by the opening. Placement of the duct is best on the forward surface of the body where the air is being pushed aside by the expanding width of the body and the boundary layer is thin, compressed and attached to the surface. These ducts are less effective if the boundary layer is thicken by locating down stream from wings, control surfaces and drag producing protrusions. The layouts generally assume the area is generally flat in the vicinity of the duct location however.

Figure-1 on the next page shows a general cutaway profile and surface cutout or plan view of several different size NACA Submerged Ducts. The rear edge of the cutout is formed into an airfoil shape and is an important design element. The cutout ramps down from the surface to the bottom of the air inlet and are shown for angles between 5 and 11.5 degrees. The ramps are shown with a flat bottom at the described angle. A properly curved ramp bottom is reported to improve performance by approximately 2%. The examples are made with straight bottoms for ease of construction as the penalty paid is small. A chart in Figure 7 describes the shape of a curved bottom if it is desired. The shape of the curved sidewalls is another important parameter. The shape is optimized for the best pressure recovery. The shape is laid out in a table of dimensions provided in Figure –2 allowing scaling to any size duct. The upper edges of the

Figure-1



sidewalls should intersect with the surface in what was described as “crisply” manner. Meaning they remain sharp with the minimum edge smoothing and not be rounded.

The important elements of an NACA Duct are:

1) The shape of the airfoil at the rear of the cutout.
2) It is important to know that the duct entrance height is measured from the bottom of the airfoil at station 0.75 down to the floor of the extended ramp. This point on the airfoil is known as the Point of Rotation. The lower side of the airfoil may depart from the airfoil shape behind this point. You may continue the airfoil shape and level off or you may roll the lower edge back toward the inside of the surface to help in accommodating other demands for the shape of the interior of the air box. See Figure 2. Recommend continuing the airfoil shape until the thickness is ½ the airfoil length then go straight back.
3) The ratio of the width to the height of the entrance is another important element. The ratio works well in the range of 3 to 5. A ratio of 4 provides best pressure recovery.
4) The slope of the duct floor is a major parameter for optimizing performance. Ramp angles of 5 to 7 degrees are good 5 provides optimized performance as steeper angles work but increasing steeper ramps will degrade performance. The example duct using a 1 inch entrance height, a 4 inch width with a 7 deg ramp will need a length of 12.06 inches from the Rotation Point to the tip or 11.312 inches from the leading edge of the airfoil to the forward tip of the duct. Usually

the trade off in the ramp angle is the length of space available. You may choose the length and find the ramp angle and see if the angle is acceptable.

With these parameters selected the complete duct configuration is determined and the detail configuration can be developed.

The following steps will help you configure a complete NACA Submerged Duct .

Our example will have :

1) A 1-inch entrance height.
2) A 4-inch entrance width.
3) The ramp angle will be 7 degrees.

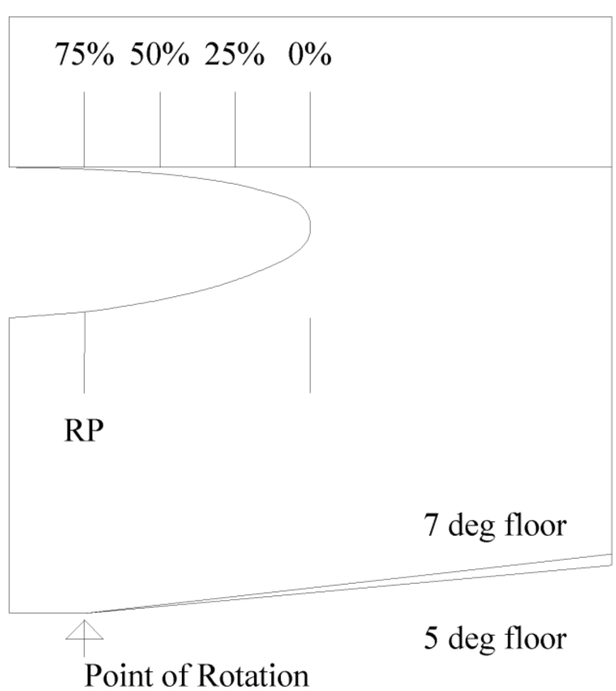
Step 1: Multiply the ordinates in Table-1 of Figure-2 by the entrance height.

In our example the entrance height is 1 inch so the table contains our measurements in inches and the airfoil becomes 1 inch long. If the entrance height is any other value you must multiply all the values in the table including the 0.094 leading edge radius by the entrance height. Use these values to draw the shape of the airfoil.

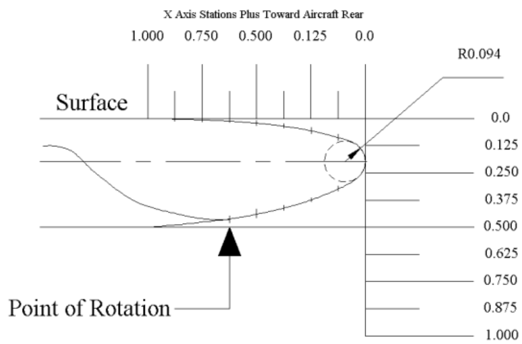
A CAD version is available of Figure 3 a template of the proper airfoil shape. The CAD drawing is full scale to the 1-inch entrance height. The drawing can be scaled by the ratio of a 1-inch height to your entrance height for a full-scale airfoil shape in one scaling step. Carefully cutting this template out of wood or aluminum will help in shaping your airfoil.

Figure not to scale in this document.

Template for Airfoil for Example Fig 3



LIP Airfoil Surface Plot
Figure 2



Station X axis	Upper Surface Y axis	Lower Surface Y axis
0.000	0.197	0.197
0.125	0.087	0.325
0.250	0.056	0.375
0.375	0.036	0.412
0.500	0.021	0.440
0.625	0.012	0.462
0.750	0.006	0.481
0.875	0.002	N/A
1.000	0.000	N/A

Leading edge of airfoil is a 0.94 inch radus.

A bezier curve is run through points and

Step 2: Using a Ramp angle of 7 Degrees to determine the length of the Duct cutout. First find the depth below the body surface of the lower surface of the airfoil at station 0.75. In Figure 2 the lower surface of the airfoil at station 0.750 is called the Rotation Point and is 0.481 in our example or 0.481 times the entrance height for any other entrance height value. The entrance height is the distance from this point to the bottom of the air box.

Second add the entrance height (1 inch in the example) to the depth of the rotation point 1.000 + 0.481=1.481. This is the depth below the surface at the bottom of the entrance.

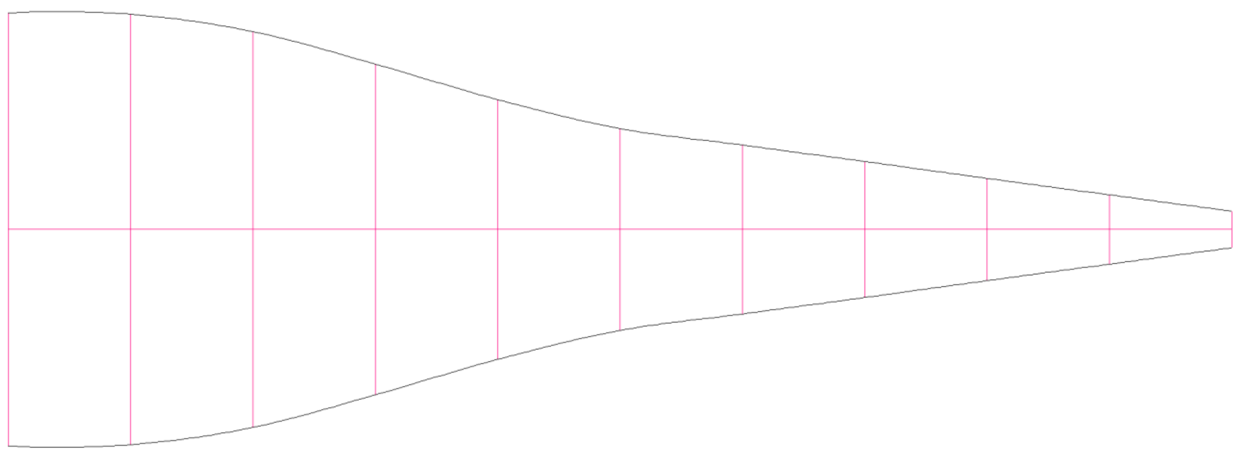
Third: find the tangent of 7 degrees. Tan 7=0.1228.

Fourth: Divide 1.481 by 0.1228 =12.062. This is the total length from the Rotation Point to forward tip of duct.

Fifth: Subtract the length of the airfoil from leading edge to the 0.750 station, from the total length of 12.062. Or 12.06 - 0.750 = 11.312 inches in the example. This is the length of the cutout from the leading edge of the airfoil to the tip of the cutout.
Step 3: Determine the shape of the cutout using the cutout length of 11.312 inches.

Note: The drawing in this document has been shrunk to fit and is not to scale.
A CAD drawing that may be scaled to any length is available.

Example NACA Cutout for a 4" by 11.32" Duct
Figure - 4



Measurements for Example Above

Length Unit Measure	Width Unit Measure from ctr.
0.0	0.500
0.1	0.497
0.2	0.457
0.3	0.382
0.4	0.300
0.5	0.233
0.6	0.195
0.7	0.157
0.8	0.118
0.9	0.080
1.0	0.042

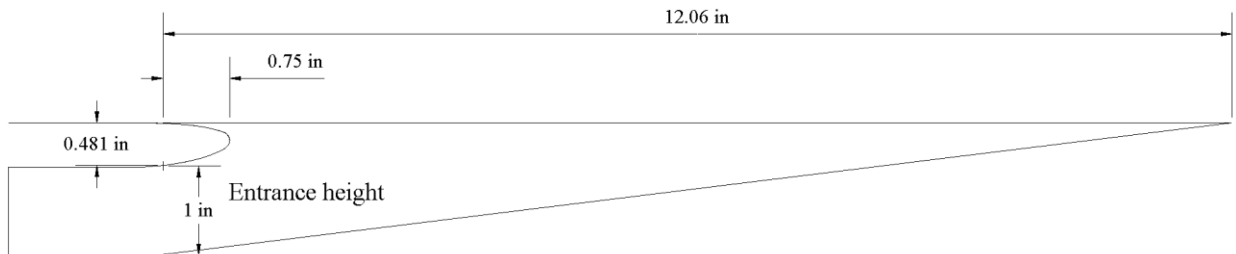
Length 11.321" times Unit table	Width 4" times unit table from ctr.
0.0	2.000
1.1312	1.988
2.2624	1.828
3.3936	1.528
4.5248	1.200
5.656	0.932
6.7872	0.780
7.9184	0.628
9.0496	0.472
10.1808	0.320
11.312	0.168

First: Multiply the Length Column of the Unit Value Ordinates in Table-2 by your length or 11.312 inches in our example and the Width Column by your duct width or 4 inches in our example.
Second: Draw the cutout shape using the new table developed.
The easiest way to do this is to use a CAD drawing program. Layout the grid with a 0.11312-inch spacing with every tenth grid line highlighted. Draw a centerline 100 grids

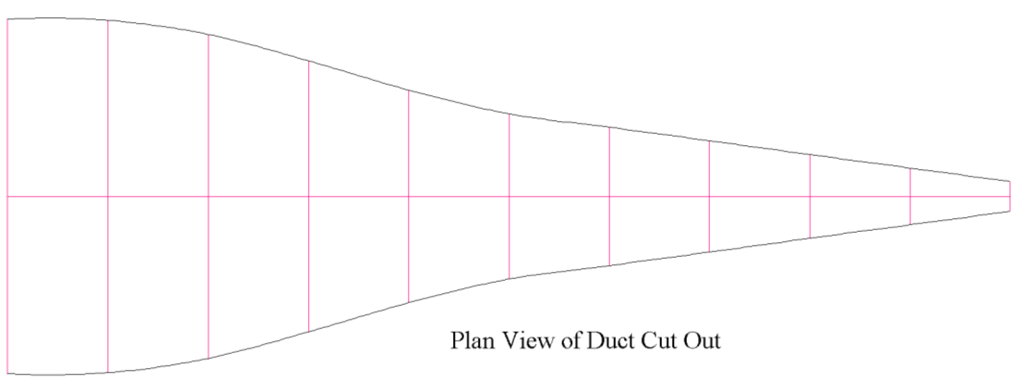
long. This will be 11.312 inches long. On each highlighted grid line draw a line up and down from the centerline in accordance with the Width Column values. Use a bezier curve to draw the smooth curve through the vertex of the lines. Do not use spline curve tools. The bezier tool is forced to go through each node point but spline curves use best-fit curves that are not forced through each node point. The CAD version for this cutout is available and can be rescaled for any length or width.

Figure 5 is a side view and a plan view drawing of the NACA Submerged Duct Example.

NACA Submerged Duct
Two View Figure 5



Cutaway Side View

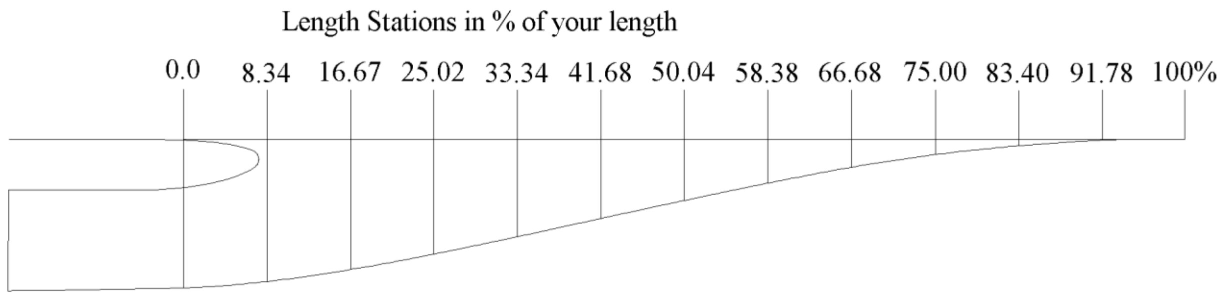


Plan View of Duct Cut Out

This Figure has been shrunk and is not to scale.

Figure 5 is a two view drawing of the example duct. The top Cutaway View as you would see if you sawed the completed duct in two down the middle. The surface of your body is the straight line at the top. Of course thickness of you body walls have not been taken into account. If you are going to make a fiberglass duct shape to place on the inside you will have to subtract the haul thickness. You must shape the airfoil and the final end of the ramp into the thickness of your haul.

NACA Submerged Duct Curved Bottom
Cut Away Figure 6



Example of Curved Bottom Ramp
Entrance Height is 1inch. Depth at entrance is 1.481 inches
Length from Station 0 to tip of Cutout is 10.00 inches
Ramp angle approx. 8.5 deg.

To plot any bottom from Station 0 to Tip Multiply Length into Station Column of Table for measurement along lengtl

Multiply Entrance Height times Depth Column in table for depth from surface at each station.

Table of Bottom Ordinates	
Station	Depth in %
100.00	0.00
91.78	0.40
83.40	4.05
75.00	10.15
66.68	18.70
58.38	29.35
50.04	41.09
41.68	53.20
33.34	65.48
25.02	77.20
16.67	87.62
8.34	95.70
0.00	100.00

Figure 6 is a cutaway with a curved bottom shape. You design the duct the same using a straight ramp. After you know the length of your cutout and the total length from the Rollover Point to the tip of the cutout you can use the table in Figure 6 to develop a curved bottom. A CAD drawing that can be scaled is available.

In conclusion an NACA Submerged Duct of the proper design ratios will prove effective for airflow inlets. Placement of the duct is as important as the design. You do not want the duct in a turbulent flow area or even down stream of anything that's a protuberant to the boundary layer.

As well the design trade offs can be chosen wisely. The lowest ramp angle you can use the better. Also remember that the deeper the entrance the longer the 5 deg ramp will be. It is probably better to use a higher width to depth ratio that can provide the same inlet area with less depth and stay with the lower ramp angle than sticking with a more optimum ratio of 4. If a ratio of 4.5 widens the inlet makes it less deep and shortens the 5-degree ramp length enough to fit the space available, a better compromise has been made than making the angle of the ramp greater.

References:

Three of the original NACA reports of interest have been put on the NACA report server.

Charles W. Frick, Wallace F. Davis, Lauros M. Randall and Emmet A. Mossman, **An Experimental Investigation of NACA Submerged-Duct Entrances,** NACA ACR-5I20, November, 1945, (12 MB).

Emmet A. Mossman and Lauros M. Randall, **An experimental investigation of the design variables for NACA submerged duct entrances,** NACA RM-A7I30, January, 1948, (17 MB).

Alvin H. Sacks and John R. Spreiter, **Theoretical investigation of submerged inlets at low speeds,** NACA TN-2323, August, 1951, pp. 49, (7 MB; pp. 38,40,42 are unnumbered and blank in the original report).