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Executive Summary

For the past 4 months Team RentDR has been studying cooling ducts for Dodge Racing trying to find ways to increase the mass flow. We were working on NACA (National Advisory Committee for Aeronautics) ducts that are used in NASCAR to help cool the inside of the racecars. As this is a continuation of previous work our goal was to expand on what had been already done. After we studied what had been done we decided on what we thought would be best to proceed forward with. Since the previous work only tested a NACA duct with clay modification and vortex generators we decided our primary goal would be to see which had a more significant effect on the increase of mass flow. We used the University of Michigan’s 5 ft x 7 ft wind tunnel to best simulate actual racing conditions. We were able to vary the speed from 20 miles per hour (mph) all the way to 160 mph. While NASCAR racecars can reach speeds averaging 180 mph on the superspeedways we felt that 160 mph would be significant since most of the racetracks that NASCAR uses do not reach such high speeds.

Using a testing apparatus that was constructed previously, we were able to connect multiple static and total pressure ports to a manometer bank and tested three different variations that had been made to the ducts. After analyzing our data we found that only clay modifications gave an improvement of 37.3% increased mass air flow at 130 mph into the ducts. Based on this and due to the fact that we found that the vortex generators we were using hindered the flow, we recommend that Dodge Racing manufacture and implement these new duct designs into their racecars. We feel that this modification would be a very cheap and simple solution to implement.

1. Introduction

In the world of NASCAR every advantage a team can get over another team is very important. Many teams resort to cheating to get that advantage. This can be seen every year when there is a story in the news about how a team was caught for cheating. There is even a motto used in NASCAR that states “If you ain’t cheatin’ you ain’t tryin’!”. This shows how much teams are trying to get ahead of everyone else to improve their racecars. Dodge Racing is going about improving their cars the legal way by tasking us, Team RentDR in finding a way to improve the mass flow into the cooling ducts that are placed on the sides of the racecar.
Our work was a continuation of previous work done by the AERO 405 group working on this problem last semester. The main thing we were able to achieve was the ability to test the ducts in the 5 ft x 7 ft wind tunnel. Previously the ducts were only tested in the 2 ft x 2 ft wind tunnel and the boundary layers were studied. In studying the boundary layer, the previous group thought of adding vortex generators to help keep the flow attached. In addition, they added clay to try and smooth the flow into the duct. The way the ducts are currently designed is there are deep side pockets on either side of where the flow enters the circular tube of the duct, as is shown below in Figure 2. The previous team thought by eliminating these pockets that the flow would not need to be turned and would go directly into the tubing.
Since we were trying to improve mass flow we wanted to test how the clay and vortex generators affected the mass flow separately since this was not done before. Another scenario that we wanted to investigate was the yaw angle of the duct since this also was not tested previously. The ultimate purpose of the duct is to cool, so the more air entering the ducts the more effective the cooling will be. By investigating the design of the duct and how it is aligned with the flow we hope to present an improved model that can be used in the future.

2. NACA Duct History

The NACA Submerged Inlet, or NACA duct, was developed for use on air inlets for aircraft engines. The submerged inlet was advantageous because it allowed the air inlet to have virtually no exposed frontal area, which reduces the drag produced. In order to better understand the effects of submerged inlets, the National Advisory Committee for Aeronautics (NACA) performed an investigation on the effects of various parameters on the performance of these inlets. They published their results in 1948 in a research memorandum titled “An Experimental Investigation of the Design Variables for NACA Submerged Inlets.” The findings of this report related some suggested geometric parameters for optimal duct performance, such as ramp angles of 5° to 7° and width to depth ratios of 3 to 5. Figure 3 is a schematic showing these angles and ratios.

![Figure 3: Original Geometries of NACA Inlets](image)

Inlets with these geometries have since migrated from the aircraft industry to others, more specifically the motor sports industry. Motor sports team goals usually align very closely to the goals of aircraft design, namely producing lightweight, high performance machines. As racecar speeds increase, aerodynamics plays a larger and larger role in vehicle dynamics; thus, the submerged inlet has allowed race teams to effectively route air throughout the vehicle. However, as the majority of NACA duct development pertains to aircraft, the duct could possibly be improved to better perform under race conditions.
3. Criteria

The main focus for this examination was increasing the mass flow through the specified 3-inch inlet hose. As this inlet size is standard for this application, different duct geometries are the most effective way of changing the airflow through the duct. Therefore, this study concentrates almost entirely on measuring the mass flow through the duct. The four ducts tested were evaluated solely on the mass airflow through the hose. While the drag produced by the different ducts is very important, our test apparatus was not sufficient to ensure accurate data. The drag produced by the ducts can be studied at a later date at a facility with a larger wind tunnel to allow full scale testing of the entire racecar.

4. Bernoulli’s equation

The governing equation that was used to determine velocity through the outlet of the duct was Bernoulli’s equation defined as:

\[ p_s + \frac{1}{2} \rho v^2 = p_T \]  \hspace{1cm} (1)

Where \( p_s \) is the static pressure, \( \rho \) is the density of air, \( v \) is velocity in meter per seconds (m/s) and \( p_T \) is the total pressure.

After the air velocity is found using Equation 1, the mass flow rate can be calculated. Mass flow rate of air is determined by:

\[ \dot{m} = \rho A v \]  \hspace{1cm} (2)

Where \( A \) is the area of the outlet of the duct, \( v \) is the velocity of air through the outlet of the duct and \( \rho \) is the air density, assume incompressible flow through the duct.

5. Duct Modifications

Four ducts were tested for this study. A standard, unmodified NACA duct was tested to use as a baseline for all subsequent tests. This duct was then modified to promote better airflow into the inlet tube. The standard duct has large depressions near the tube that can be seen back in Figure 2.

These depressions were filled in with clay to smooth out the surface to allow the flow to go directly into the tube. These modifications can be seen in Figure 4.
Also, both the standard duct and the modified duct were tested with vortex generators near the inlet of the duct. Previous testing of these ducts suggested that the vortex generators would increase the mass flow by keeping the boundary layer attached, so we wanted to explore the generators effects on the flow.

6. Testing

All testing was done in the 5ft x 7ft wind tunnel in the Engineering Programs Building on the University of Michigan North Campus. The test rig was secured in the wind tunnel on a ground plane. The pressure ports on the duct were connected to the large manometer bank in the wind tunnel room. At every test point we took a picture of the manometer bank so that we could analyze the data later. A sample of the manometer pictures can be seen in Figure 5 on the following page.
This setup allowed us to perform all of the tests necessary to make a recommendation on our duct modifications.

The test apparatus constructed to house the duct was made of a section of a drum with a flat top. A rounded piece of foam was placed in front of the housing unit to encourage laminar flow entering the duct. This foam, ultimately, did not completely eliminate the turbulence created by the test rig. Figure 6 illustrates the test setup that was used in the 5’x7’ wind tunnel.
The duct was placed flush with the top of the drum, parallel to the flow stream. Smooth, flat tape was used to secure the duct to the top of the apparatus. Pressure ports were placed along the inside of the duct to measure the static pressure of the flow. A flexible tube was secured to the outlet of the duct inside of the apparatus and passed through the opening in the back of the apparatus as shown in Figure 7.
Figure 8 below shows the arrangement of the pressure ports along the side of the duct.

![Figure 8: Pressure ports along the side of NACA duct](image)

The radial pitot rake was placed inside of this flexible pipe, about six inches downstream of the outlet of the duct. The pitot rake was used to measure total pressure. These pressure measurements were then used to determine the mass flow rate through the duct. This pitot rake can be seen in Figure 9 below. Two static ports we also incorporated into the duct and we located at ports 11 and 12. A detailed schematic can be seen in Appendix C.

![Figure 9: Radial pitot rake at the outlet of NACA duct](image)

The entire apparatus was secured to the ground plane inside of the wind tunnel with bolts during testing. The ground plane was paramount in the testing of the performance of the NACA ducts during the yaw test due to its ability to be rotated to a predetermined angle.

**7. Results**

Using the previously described test set-up in section 6.1 our team tested two ducts with two different configurations. Figures 10-12 display the volumetric flow (V) versus the speed of the air (s) given in standard cubic feet per minute (scfm) versus miles per hour (mph). Using the program in Appendix A, we were able to calculate various characteristics of the flow. Not all of these characteristics are included because they were
not the primary focus of our study. The results of our first two tests, the baseline configuration and baseline with vortex generators at 0° yaw are shown in Figure 10.

![Figure 10: Standard Volumetric Flow Vs. Windtunnel For Baseline and Baseline with Vortex Generators at 0° Yaw](image)

As can be seen from Figure 10 the baseline duct has a much higher volumetric flow that the baseline with the added vortex generators. It should also be called out that the baseline is consistently better in the region of twenty to 160 miles per hour.

Figure 11 shows the resulting volumetric flow rate of our second set of tests using a clay modified duct and adding vortex generators. On the following page Table 1 displays the lines of best fit and the squared correlation coefficient.
Again in this test we found that vortex generators hinder the amount of flow passing through the ducts. However, compared to the baseline duct we see a substantial increase in mass flow for the clay modified duct, on the order of 37.3% at approximately 142 miles per hour. This is better visualized using Figure 12 on the next page, a plot of the baseline and clay modified ducts.

One major feature of the results is the linearity in the region of twenty to 160 miles per hour. As can be seen visually, and mathematically though the correlation coefficient close to 1, a linear fit is outstanding for this region. There are obvious non-linear effects as the velocity goes to zero because at zero, there can be no flow through the duct.

\[
\begin{align*}
\text{Test} & \quad \text{Line of Best Fit} & \quad R^2 \\
\text{Baseline} & \quad V = 1.2936s + 23.7699 & \quad 0.992 \\
\text{Baseline & V.G.} & \quad V = 1.2241s + 16.6705 & \quad 0.996 \\
\text{Clay Modification} & \quad V = 2.0178s + 11.1658 & \quad 0.983 \\
\text{Clay Modification & V.G.} & \quad V = 1.879s - 2.1669 & \quad 0.999
\end{align*}
\]

\textbf{Table 5: Line of Best Fit for Individual Tests}
Figure 12: Standard Volumetric Flow Vs. Windtunnel For Baseline and Clay Modified at 0° Yaw

Table 2 below shows the velocity and volumetric flow for the baseline and clay modified ducts.

<table>
<thead>
<tr>
<th>Baseline Velocity (mph)</th>
<th>Baseline Volumetric Flow (SCFM)</th>
<th>Clay Modified Velocity (mph)</th>
<th>Clay Modified Volumetric Flow (SCFM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.181</td>
<td>43.964</td>
<td>17.973</td>
<td>26.928</td>
</tr>
<tr>
<td>24.051</td>
<td>59.192</td>
<td>38.127</td>
<td>109.84</td>
</tr>
<tr>
<td>39.624</td>
<td>69.985</td>
<td>59.61</td>
<td>136.12</td>
</tr>
<tr>
<td>51.423</td>
<td>92.173</td>
<td>80.378</td>
<td>172.51</td>
</tr>
<tr>
<td>59.61</td>
<td>107.76</td>
<td>101.27</td>
<td>215.44</td>
</tr>
<tr>
<td>70.415</td>
<td>116.33</td>
<td>111.88</td>
<td>235.33</td>
</tr>
<tr>
<td>79.769</td>
<td>128.05</td>
<td>122.56</td>
<td>258.57</td>
</tr>
<tr>
<td>91.358</td>
<td>137.36</td>
<td>132.69</td>
<td>278.62</td>
</tr>
<tr>
<td>101.23</td>
<td>146.14</td>
<td>142.94</td>
<td>296.34</td>
</tr>
<tr>
<td>111.34</td>
<td>170.77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>122.64</td>
<td>181.61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>132.98</td>
<td>192.14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>143.45</td>
<td>215.69</td>
<td></td>
<td></td>
</tr>
<tr>
<td>154.27</td>
<td>231.34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>164.13</td>
<td>229.07</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6: Volumetric Flow versus Velocity for Baseline and Clay Modified Ducts
As mentioned before the clay modified ducts appear to be far better due to the rounding of the back corners and narrowing of the inlet aperture. Following the baseline tests for our ducts, we then changed the yaw angle of our test apparatus to determine the effect on volumetric flow. The results are surprising to say the least. As the yaw angle is increased, the more mass flow the driver receives. This can be seen in Figure 13.

![Figure 13: Volumetric Flow of Baseline and Clay Modified Ducts at 50 and 130 mph at varying Yaw Angles](image)

Table 3 gives the volumetric mass flow in and the percent change caused by the yaw angle. Base indicates baseline and clay indicates clay modified ducts. The key feature is to notice that there is a 44.29% increase in the clay modified duct at 30° yaw angle.

<table>
<thead>
<tr>
<th>Duct</th>
<th>Angle(°)</th>
<th>Velocity (mph)</th>
<th>Mass Flow (scfm)</th>
<th>Percent Increase From 0°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>0</td>
<td>50</td>
<td>107.4</td>
<td>0.00</td>
</tr>
<tr>
<td>Base</td>
<td>15</td>
<td>50</td>
<td>117.38</td>
<td>9.29</td>
</tr>
<tr>
<td>Base</td>
<td>30</td>
<td>50</td>
<td>136.87</td>
<td>16.60</td>
</tr>
<tr>
<td>Base</td>
<td>0</td>
<td>130</td>
<td>271.64</td>
<td>0.00</td>
</tr>
<tr>
<td>Base</td>
<td>15</td>
<td>130</td>
<td>339.03</td>
<td>24.81</td>
</tr>
<tr>
<td>Base</td>
<td>30</td>
<td>130</td>
<td>366.85</td>
<td>35.05</td>
</tr>
<tr>
<td>Clay</td>
<td>0</td>
<td>50</td>
<td>113.27</td>
<td>0.00</td>
</tr>
<tr>
<td>Clay</td>
<td>15</td>
<td>50</td>
<td>153.96</td>
<td>35.92</td>
</tr>
<tr>
<td>Clay</td>
<td>30</td>
<td>50</td>
<td>177.25</td>
<td>56.48</td>
</tr>
<tr>
<td>Clay</td>
<td>0</td>
<td>130</td>
<td>327.26</td>
<td>0.00</td>
</tr>
<tr>
<td>Clay</td>
<td>15</td>
<td>130</td>
<td>423.26</td>
<td>29.33</td>
</tr>
<tr>
<td>Clay</td>
<td>30</td>
<td>130</td>
<td>472.19</td>
<td>44.29</td>
</tr>
</tbody>
</table>

Table 7: Volumetric Flow of Baseline and Clay Modified Ducts at 50 and 130 mph at varying Yaw Angles
8. Conclusions and Recommendations

Overall we were very pleased with the results we obtained from testing. Our data had good linear trends so this makes it easy to make any predictions for higher speeds if needed in the future. We saw vast improvement in mass flow with the modifications that were tested. Our results show that there is a 145.8% increase in volumetric flow with the clay modifications over the standard NACA duct we used as our baseline.

Based on these results it is our recommendation to use the duct with clay modifications and angle the duct at 30 degrees on the side of the car. If further work is to be done, we recommend dimpling the ramp to create vortex generators without obstructing the flow. Last year’s group did find that vortex generator did help keep the flow attached and lowered the boundary layer though we found that the vortex generators they were using hindered the flow. Also more testing regarding the yaw angle would be advisable since we had such large incremental gaps in our testing angles.

9. Omissions

One thing we wanted to do but were unable due to software and time constraints was to make a Computer Aided Design (CAD) model import it into Computational Fluid Dynamic (CFD) software. We wanted to do this to look at theoretical data and to see how our close our test results came to theoretical numbers. Since the geometry of the ducts is very complex it was difficult to make an accurate model. We did try a laser scan to create a file that could be used as a CAD model to import into CFD software. The software did not like our model and did not create a good mesh in order to do any simulations. If future work is done, CFD analysis should be done but work on these need to be started earlier in order to compensate all the unforeseen problems with the software.
10. Costs

<table>
<thead>
<tr>
<th>Labor</th>
<th>Unit</th>
<th>Cost Per Unit</th>
<th>No. of Units</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineer</td>
<td>$30.00/hr</td>
<td>400</td>
<td>$12,000.00</td>
<td></td>
</tr>
<tr>
<td>Technician</td>
<td>$35.00/hr</td>
<td>20</td>
<td>$700.00</td>
<td></td>
</tr>
<tr>
<td>Machinist</td>
<td>$35.00/hr</td>
<td>8</td>
<td>$280.00</td>
<td></td>
</tr>
<tr>
<td>Faculty Consulting</td>
<td>$150.00/hr</td>
<td>4</td>
<td>$600.00</td>
<td></td>
</tr>
<tr>
<td><strong>Subtotal:</strong></td>
<td></td>
<td></td>
<td><strong>$13,580.00</strong></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Facilities</th>
<th>Unit</th>
<th>Cost Per Unit</th>
<th>No. of Units</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>5'x7' Wind Tunnel</td>
<td>$800.00/dy</td>
<td>2</td>
<td>$1,600.00</td>
<td></td>
</tr>
<tr>
<td>Student Shoppe</td>
<td>$35.00/hr</td>
<td>16</td>
<td>$560.00</td>
<td></td>
</tr>
<tr>
<td><strong>Subtotal:</strong></td>
<td></td>
<td></td>
<td><strong>$2,160.00</strong></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Materials</th>
<th>Unit</th>
<th>Cost Per Unit</th>
<th>No. of Units</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Inlets</td>
<td>$25.00/inlet</td>
<td>3</td>
<td>$75.00</td>
<td></td>
</tr>
<tr>
<td>Poster</td>
<td>$60.00/Poster</td>
<td>1</td>
<td>$60.00</td>
<td></td>
</tr>
<tr>
<td>Flow Meter</td>
<td>$500.00/unit</td>
<td>1</td>
<td>$500.00</td>
<td></td>
</tr>
<tr>
<td><strong>Subtotal:</strong></td>
<td></td>
<td></td>
<td><strong>$635.00</strong></td>
<td></td>
</tr>
</tbody>
</table>

Subtotal: **$16,375.00**

Overhead: 55% x Subtotal: $9,007.00

**Total**: $25,382.00
Figure 1414: Gantt Chart
12. Bibliography


Appendix A: Program

function pressuredata()
%{
port2man=xlsread('Port to Manometer.xls','A2:B20');
f=dir(fullfile('Picture Data','*.xls'));%Reads all the Microsoft Excel...
%file names in directory
s3=size(f);

for n=1:s3(1)
    [d1]=xlsread(f(n).name,'Test Info','B1:B5');
data(n).con=d1(1);
data(n).P=d1(4);
data(n).T=d1(5)+459.67;
[num txt raw]=xlsread(f(n).name,'Data');
data(n).run=num(:,1);
data(n).Pic=num(:,23);
data(n).ang=num(:,24);
data(n).D=[num(:,2) num(:,3) num(:,port2man(:,2)'+1)];
data(n).vtun=.3048*14.439*sqrt((data(n).D(:,1)-data(n).D(:,2))*...
data(n).T/data(n).P);
data(n).P=d1(4)*3386;
data(n).T=(d1(5)+459.67)/1.8;
data(n).rho=data(n).P/(286.9*data(n).T);
clear('num','d1','txt','raw')
end

load('WTdata.mat')

}
psp=[2 3 4 5 6 7 8 11 12]+1;%Static Pressure Ports
pspb=[11]+1;%Static Pressure Port Bottom
ptpb=[13 14 15 16 20]+1;%Bottom Total Pressure Ports
pspt=[12]+1;%Top Static Port
ptpt=[17 17 17]+1;%Top Total Pressure Ports
pt=[13:20]+1;%Total Pressure Ports
value=struct('pspvel',{},'psp',{},'ptpvel',{},'ptp',{},'pres',{},...
    'vel',{},'mfr',{},'scfm',{});

%{
*.pspvel=Static Pressure Port Velocity
*.psp=Manometer Difference Static Pressure Port
*.ptpvel=Total Pressure Ports Velocity
*.ptp=Manometer Difference Total Pressure Port
*.pres=Pressure At Port
*.vel=Velocity At Port
*.mfr=Mass Flow Rate
*.scfm=Standard Cubic Feet Per Minute (SI STP)
%
}
for a=1:6
    value(a).pspvel=
    s1=size(data(a).D(:,ptpb));
    for b=1:s1(2)
        value(a).ptpvel(:,b)=
        3048*14.439*sqrt((data(a).D(:,ptpb(b))-data(a).D(:,pspb))*1.8*data(a).T/(data(a).P/3384));
        value(a).ptp(:,b)=data(a).D(:,ptpb(b))-data(a).D(:,pspb);
    end
    s2=size(ptpt);
    for c=1:s2(2)
        value(a).ptpvel(:,c+5)=
        3048*14.439*sqrt((data(a).D(:,ptpt(c))-data(a).D(:,pspb))*1.8*data(a).T/(data(a).P/3384));
        value(a).ptp(:,c+5)=data(a).D(:,ptpt(c))-data(a).D(:,pspb);
    end
    value(a).ptpvel=value(a).ptpvel(:,[1:4] [6:8] 5);
    value(a).ptp=value(a).ptp(:,[1:4] [6:8] 5);
    value(a).vel=[value(a).pspvel value(a).ptpvel];
    value(a).mfr=sum(value(a).ptpvel*3.683^2*pi/8*data(a).rho,2);
    value(a).psp=data(a).P-data(a).D(:,psp);
%{
figure(a)
plot(data(a).vtun,value(a).mfr,'k+');
xlabel('Velocity (m/s)')
ylabel('Volumetric Flow (cc/s)')
%
end
%
figure(1)
plot(data(1).vtun,value(1).mfr,'k+-',data(2).vtun,value(2).mfr,'ko--')
xlabel('Velocity (m/s)')
ylabel('Volumetric Flow (cc/s)')
title('Baseline Duct Volumetric Flow vs. Tunnel Velocity')
legend('Baseline','Baseline+V. Gen','Location','SE')

figure(2)
plot(data(3).vtun,value(3).mfr,'k+-',data(4).vtun,value(4).mfr,'ko--')
xlabel('Velocity (m/s)')
ylabel('Volumetric Flow (cc/s)')
title('Modified Duct Volumetric Flow vs. Tunnel Velocity')
legend('Modified','Modified+V. Gen','Location','SE')

figure(3)
xlabel('Angle (circ)')
ylabel('Volumetric Flow (cc/s)')
title('Volumetric Flow for Baseline and Modified Ducts')
legend('Modified 50 mph','Modified 130 mph','Baseline 50 mph','Baseline 130 mph','Location','E')
%
%%
figure(4)
[coef r1]=fit(2.2369*data(1).vtun,value(1).scfm,'poly1');
c1=[coef.p1 coef.p2]
r1
[coef r2]=fit(2.2369*data(2).vtun,value(2).scfm,'poly1');
c2=[coef.p1 coef.p2]
r2
hold on
plot(2.2369*data(1).vtun,value(1).scfm,'k+-',2.2369*data(2).vtun,... value(2).scfm,'ko--')
plot(2.2369*data(1).vtun.polyval(c1,2.2369*data(1).vtun),'k',... 2.2369*data(2).vtun.polyval(c2,2.2369*data(2).vtun),'k')
xlabel('Velocity (mph)')
ylabel('Volumetric Flow (scfm)')
%title('Baseline Duct Volumetric Flow vs. Tunnel Velocity')
legend('Baseline','Baseline+V. Gen',['Base: ' num2str(c1(1)) ...
figure(5)
    [coef r3]=fit(2.2369*data(3).vtun,value(3).scfm,'poly1');
    c3=[coef.p1 coef.p2]
    r3
    [coef r4]=fit(2.2369*data(4).vtun,value(4).scfm,'poly1');
    c4=[coef.p1 coef.p2]
    r4
    hold on
    plot(2.2369*data(3).vtun,value(3).scfm,'k+-',2.2369*data(4).vtun,...
        value(4).scfm,'ko--')
    plot(2.2369*data(3).vtun,polyval(c3,2.2369*data(3).vtun),'k',...
        2.2369*data(4).vtun,polyval(c4,2.2369*data(4).vtun),'k')
    xlabel('Velocity (mph)')
    ylabel('Volumetric Flow (scfm)')
%title('Clay Modified Reduced Inlet: Volumetric Flow vs. Tunnel Velocity')
    legend('Modified','Modified+V. Gen',['Mod: ' num2str(c3(1)) 'x+' ...
        num2str(c3(2))],['Mod&V.G.: ' num2str(c4(1)) 'x+'...
        num2str(c4(2))],'Location','SE')
    saveas(gcf,'modified','tif')

figure(6)
    plot(data(5).ang(1:3),value(5).scfm(1:3),'k+-',data(5).ang(4:6),...
        value(6).scfm(4:6),'ko--',data(6).ang(1:3),value(6).scfm(1:3),...
    xlabel('Angle (circ)')
    ylabel('Volumetric Flow (scfm)')
%title('Yaw Tests For Volumetric Flow for Baseline and Modified Ducts')
    legend('Modified 50 mph','Modified 130 mph','Baseline 50 mph',...
        'Baseline 130 mph','Location','E')
    saveas(gcf,'yaw','tif')

figure(7)
    plot(2.2369*data(1).vtun,value(1).scfm,'k+-',2.2369*data(3).vtun,...
        value(3).scfm,'ko--')
    xlabel('Velocity (mph)')
    ylabel('Volumetric Flow (scfm)')
%title('Baseline vs. Clay Modified Reduced Inlet: Volumetric Flow...'
%vs. Tunnel Velocity')
    legend('Baseline','Modified','Location','SE')
    saveas(gcf,'basevsmod','tif')
%
save('testdat.mat','value')
Appendix B: Data

Test Information:

Test 1
Duct Baseline
Date 10-Mar-08
Pressure 29.459 inHg
Tunnel Temperature 42.7 F

Test 2
Duct Baseline + Vortex Generators
Date 10-Mar-08
Pressure 29.459 inHg
Tunnel Temperature 56.5 F

Test 3
Duct Modified
Date 11-Mar-08
Pressure 29.142 inHg
Tunnel Temperature 26 F

Test 4
Duct Modified + Vortex Generators
Date 11-Mar-08
Pressure 29.142 inHg
Tunnel Temperature 26 F

Test 5
Duct Modified Angular
Date 11-Mar-08
Pressure 29.142 inHg
Tunnel Temperature 26 F

Test 6
Duct Baseline Angular
Date 11-Mar-08
Pressure 29.142 inHg
Tunnel Temperature 26 F
### Test 1: Data - Baseline

<table>
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<th>Test 2: Data – Baseline and Vortex Generators</th>
<th>Test 3: Data – Clay Modified</th>
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Test 4: Data – Clay Modified and Vortex Generators

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Test 5: Data – Clay Modified Yaw Tests

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Test 6: Data – Baseline Yaw Tests

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Appendix C: Final Pitot Configuration

Figure 15: Pitot Static Ports Numbering Scheme

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Table 8: Pitot Tube to Manometer Port
Figure 16: Pitot Total Pressure Ports Numbering Scheme