Executive Summary

In LAB 03 (Concept Screening and Scoring), the team created a table containing success criteria for the AEV to be evaluated on based on the design of the vehicle. One of these criteria was power efficiency. In order to learn how to account for this factor in the design of the AEV, this lab had students use a wind tunnel and propellers in order to determine the optimal level of power output (measured as the thrust created by the propeller) to power input (measured by the given voltage and current of the wind tunnel). This calculation provided the propulsion efficiency value, which was then utilized by the team in choosing the most efficient propeller geometry and orientation for the completion of the AEV’s mission. The motivation behind performing this lab was to give students experience in the “experimental research” phase of the design process. The procedure allowed the group to obtain concrete, quantitative data that could be used to alter the design of their AEV, an opportunity that was not afforded prior to this. In the engineering field, efficiency is of the utmost importance in regards to both cost and performance. As a result, practical testing is a critical step in the real world manufacturing process and this lab prepares students well.

The group’s wind tunnel testing of the 3020 blade in the puller configuration produced some strange anomalies that will be discussed below, therefore the sample data provided by the instructor was used instead to evaluate the propeller configurations. As the blade was exposed to a variety of Arduino percentage power values, the raw data collected by the system was recorded at every 5% following the initial 10% recording (Table 1). The voltage of the system stayed constant throughout, however the electric current, thrust, and revolutions per minute of the propeller (RPM) increased steadily as the power rose. Following the collection of this raw data, the group then calculated six categories of values to aid in the efficiency analysis: calibrated thrust (g), power input (W), power output (HP), power output (W), propulsion efficiency (%), and advance ratio (unitless) (Table 2). Calibrated thrust is the true thrust value of the propeller- a counterweight and a moment arm were used in this experiment so the reading must be adjusted to accurately reflect the actual thrust. Input power was calculated using the voltage and current and is the amount of power given by the motor while output power is the amount available for use by the vehicle. The efficiency of the motor was determined by dividing the output power by the input power and is a measure of how well the vehicle uses the power available to it. Finally, this value was converted into a propeller advance ratio in order to make the efficiency results clearer to the group.

Figure 1 below depicts a plot of the thrust (g) against the Arduino power (%) for the 3020 blade the group tested in the pull configuration. As anticipated, the increase in power level of the system directly correlated to an increase in thrust for all values along the graph. An exponential regression curve seems to be a good fit for the data set, for at first the thrust increases by only a small amount...
but as the power rises the increase is greater. The one abnormality with the figure is that the thrust at “0%” is not zero, which may be due to human error or perhaps because recordings were first taken at 5% instead of 0%. Figure 2 depicts the propeller efficiency as a function of the advance ratio in order to give the team a clear picture of the most efficient power percentage. The plot was created so that the furthest right point was 0% power (or 5% as discussed above) and the furthest left point represented 60% power. Judging by the graph, the greatest efficiency occurs at the furthest right point and steadily declines from there. Although one value on the left-hand side is quite high, it is hypothesized that the spike in the graph is due to an outlier, as discussed in the error section below. This plot leads the team to conclude that the lowest possible power setting that still allows the AEV to move and complete its mission is the most efficient setting in the case of the 3020 pull propeller. As a result, when the team is writing their program, the motorSpeed() function should contain the lowest possible value that the AEV still runs inside the parentheses.

After comparing propeller configuration data gathered by the class, propeller type Pusher 3030 resulted in the highest thrust along with a low current requirement—therefore its advance ratio and propulsion efficiency were the best of all candidates. Pusher 3030 is a two bladed propeller with a diameter of 3 inches and a pitch angle of 30 degrees making this motor configuration highly efficient. The propeller tested by the group, Propeller Type Puller 3020, was a two bladed propeller with a diameter of 3 inches and a pitch angle of 20 degrees. Figure 2 represents the efficiency of motor configuration Puller 3020 and shows that the configuration was substantially less efficient than the Pusher 3030. This motor configuration had the lowest thrust of all the configurations per increment and had the second highest RPM of all the configuration, a sign of wasted power. The other two propeller configurations, Puller 3030 and Pusher 3020, were both mediocre in comparison to the Pusher 3030 and had efficiencies that fell between it and the propeller tested by the team. As a result, these configurations were both disregarded. The information gained from this data collection and analysis will aid the team in choosing the preferred propeller configuration for their AEV, most likely the Pusher 3030 setup based on the results.

Given the number of different measurements taken in this lab, the likelihood of error was high. After recording the raw data during lab and performing an analysis, the group realized that their efficiency values did not seem feasible. One of the propulsion efficiency numbers was at 80% (virtually impossible in this case) and therefore the team decided to use the provided sample data for this summary instead. The error may have been due to an error in the creation of an Excel formula, or perhaps a value was misrecorded during the initial collection. Another error in the lab can be seen in Table 2 where the power input for the wind tunnel was 3.441 watts (50% power). The propulsion efficiency at this reading proved to be an outlier compared with the rest of data. This error could have occurred as the result of human error, perhaps due to a mistake in the power input setup or due to measuring the thrust too soon between power levels. This could have also resulted from machine error within the wind tunnel where a discrepancy could exist between stated and actual power input.

Taking each different propeller configuration into account, it was recommended that the team proceed using the Pusher 3030 configuration. The advance ratio and propulsion efficiency of this set-up were the greatest of all the options and therefore it is recommended that the team changes
from the Puller 3030 configuration they are currently using to to the Pusher 3030. Judging from Figure 2, the most efficient power level at which the AEV can operate is the lowest setting (that still allows the AEV to complete its mission). Therefore, it is recommended that the team uses motorSpeed4,*lowest possible value*) when constructing their code. All in all, this lab succeeded in giving the students valuable design analysis experience and quantitative evidence to help them find the most efficient configuration.
Appendix A

Table 1: Raw Wind Tunnel Testing Data-Puller 3020, 2.8 m/s Wind

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Current</th>
<th>Thrust Scale Reading</th>
<th>Arduino Power Setting</th>
<th>RPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>volts</td>
<td>amps</td>
<td>grams</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>7.4</td>
<td>0.17</td>
<td>128</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7.4</td>
<td>0.28</td>
<td>130.3</td>
<td>10</td>
<td>2035</td>
</tr>
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<td>0.37</td>
<td>131.9</td>
<td>15</td>
<td>3173</td>
</tr>
<tr>
<td>7.4</td>
<td>0.47</td>
<td>133.9</td>
<td>20</td>
<td>4251</td>
</tr>
<tr>
<td>7.4</td>
<td>0.56</td>
<td>136.2</td>
<td>25</td>
<td>5209</td>
</tr>
<tr>
<td>7.4</td>
<td>0.66</td>
<td>139.8</td>
<td>30</td>
<td>6167</td>
</tr>
<tr>
<td>7.4</td>
<td>0.75</td>
<td>144.2</td>
<td>35</td>
<td>7005</td>
</tr>
<tr>
<td>7.4</td>
<td>0.84</td>
<td>149.3</td>
<td>40</td>
<td>7964</td>
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<tr>
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<td>0.93</td>
<td>154</td>
<td>45</td>
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</tr>
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<td>0.93</td>
<td>162.2</td>
<td>50</td>
<td>9760</td>
</tr>
<tr>
<td>7.4</td>
<td>1.08</td>
<td>164</td>
<td>55</td>
<td>10219</td>
</tr>
<tr>
<td>7.4</td>
<td>1.17</td>
<td>169.6</td>
<td>60</td>
<td>11077</td>
</tr>
</tbody>
</table>

Table 2: Wind Tunnel Data Analysis-Puller 3020, 2.8m/s Wind

<table>
<thead>
<tr>
<th>Thrust Calibration</th>
<th>RPM</th>
<th>Power Input</th>
<th>Power Output</th>
<th>Propulsion Efficiency</th>
<th>Advance Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>grams</td>
<td>RPM</td>
<td>Watts</td>
<td>Horsepower</td>
<td>Watts</td>
<td>%</td>
</tr>
<tr>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>0.945</td>
<td>2035.000</td>
<td>0.207</td>
<td>0.000</td>
<td>0.026</td>
<td>12.519</td>
</tr>
<tr>
<td>1.603</td>
<td>3173.000</td>
<td>0.411</td>
<td>0.000</td>
<td>0.044</td>
<td>10.709</td>
</tr>
<tr>
<td>2.425</td>
<td>4251.000</td>
<td>0.696</td>
<td>0.000</td>
<td>0.067</td>
<td>9.566</td>
</tr>
<tr>
<td>3.370</td>
<td>5209.000</td>
<td>1.036</td>
<td>0.000</td>
<td>0.092</td>
<td>8.926</td>
</tr>
<tr>
<td>4.850</td>
<td>6167.000</td>
<td>1.465</td>
<td>0.000</td>
<td>0.133</td>
<td>9.083</td>
</tr>
<tr>
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<td>0.000</td>
<td>0.183</td>
<td>9.405</td>
</tr>
<tr>
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<td>7964.000</td>
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<td>0.000</td>
<td>0.240</td>
<td>9.661</td>
</tr>
<tr>
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<td>3.097</td>
<td>0.000</td>
<td>0.293</td>
<td>9.468</td>
</tr>
<tr>
<td>14.056</td>
<td>9760.000</td>
<td>3.441</td>
<td>0.001</td>
<td>0.386</td>
<td>11.209</td>
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<tr>
<td>14.796</td>
<td>10219.000</td>
<td>4.396</td>
<td>0.001</td>
<td>0.406</td>
<td>9.237</td>
</tr>
<tr>
<td>17.098</td>
<td>11077.000</td>
<td>5.195</td>
<td>0.001</td>
<td>0.469</td>
<td>9.031</td>
</tr>
</tbody>
</table>
Figure 1: Thrust vs. Power (3020 Puller)

Figure 2: Advanced Ratio vs Propulsion Efficiency (3020 Puller)
Sample Calculations- Bryan Check

Wind Speed: 2.8 m/s, 128 g=T_o

\[
\begin{array}{|c|c|c|c|c|}
\hline
\text{Voltage} & \text{Current} & \text{Thrust Scale} & \text{Arduino} & \text{RPM} \\
\text{volts} & \text{amps} & \text{Reading} & \text{Power Setting} & \\
\hline
7.4 & 0.47 & 133.9 & 20 & 4251 \\
\hline
\end{array}
\]

<table>
<thead>
<tr>
<th>Thrust Calibration</th>
<th>RPM</th>
<th>Power Input</th>
<th>Power Output</th>
<th>Propulsion Efficiency</th>
<th>Advance Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>grams</td>
<td>RPM</td>
<td>Watts</td>
<td>Horsepower</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>2.425</td>
<td>4251</td>
<td>0.696</td>
<td>0.000</td>
<td>0.067</td>
<td>9.566</td>
</tr>
</tbody>
</table>

\[
P_{in} = V \times I \times (P_{x}/100)
\]

*Power Input*

\[
P_{in} = 7.4 V \times .47A \times (20\%/100)
\]

\[
P_{in} = .696 \text{ W}
\]

\[
P_{out} = T_{c} \times v
\]

*Power Output*

\[
P_{out} = 2.425 \text{ g} \times .0098 \text{ N} \times 2.8 \text{ m/s}
\]

\[
P_{out} = .067 \text{ W}
\]

\[
T_{c} = .411 \times (T - T_{o})
\]

*Calibrated Thrust*

\[
T_{c} = .411 \times (133.9 \text{ g} - 128 \text{ g})
\]

\[
T_{c} = 2.425 \text{ g}
\]

\[
J = v / ((\text{RPM} / 60) \times D)
\]

*Advance Ratio*

\[
J = 2.8 \text{ m/s} / ((4251 \text{ RPM} / 60) \times .03 \text{ m})
\]

\[
J = .519
\]

\[
N_{sys} = (P_{out} / P_{in}) \times 100
\]

*Propulsion Efficiency*

\[
N_{sys} = (.067 \text{ W} / .696 \text{ W}) \times 100
\]

\[
N_{sys} = 9.566 \%
\]

*The data gained using these equations will be used in the section of the code where the motorSpeed() function is used to determine the optimal Arduino power efficiency for the Advance Energy Vehicle*
Sample Calculations- Tyler Sargent

@ 10% Arduino Power:

\[ P_{in} = V \times I \times \left( \frac{P_{\%}}{100} \right) \]

\[ P_{in} = 7.4 \text{ V} \times .28 \text{ A} \times \left( \frac{10}{100} \right) = .2072 \text{ Watts} \]

\[ T_{c} = .411 \times (T - T_{o}) \]

\[ T_{c} = .411 \times (130.3 \text{ g} - 128 \text{ g}) = .9453 \text{ grams} \]

\[ P_{out} = T_{c} \times v \]

\[ P_{out} = .9453 \text{ g} \times 2.8 \text{ m/s} = 2.6468 \text{ Watts} \]

\[ N_{sys} = \left( \frac{P_{out}}{P_{in}} \right) \times 100 \]

\[ N_{sys} = \left( \frac{.26468 \text{ W}}{.2072 \text{ W}} \right) \times 100 = 12.786 \% \]

\[ J = \frac{v}{(\text{RPM} / 60)} \times D \]

\[ J = \frac{(2.8 \text{ m/s})}{((2035 \text{ RPM} / 60) \times .0762 \text{m})} = 1.0834 \]
Sample Calculations- Jordan Scully

At 33% Arduino Power

**Power input:**
Pin VI*(P%/100)
7.4V*.66A*(30/100) = 1.465 Watts

**Calibrated Thrust:**
\[ T_c = 0.411 \times (T - T_o) \]
\[ 0.411 \times (139.8g - 128g) = 4.849 \text{ grams} \]

**Power available:**
\[ P_{\text{out}} = T_c \times v \]
\[ 4.849g \times 2.8m/s = 13.577 \text{ Watts} \]

**Propulsion Efficiency:**
\[ N_{\text{sys}} = \left( \frac{P_{\text{out}}}{P_{\text{in}}} \right) \times 100 \]
\[ (1.3577W/ 1.465W)\times100 = 92.66\% \]

**Propeller Advance Ratio:**
\[ J = \frac{v}{(\text{RPM} / 60) \times D} \]
\[ (2.8 \text{ m/s})/((6167 \text{ rpm}/60)*0.0762m) = 0.36J \]
Sample Calculations - Nick Bova

@ 25 % Arduino Power:

\[
\text{Pin} = V \times I \times (P\% / 100) \\
\text{Pin} = 7.4 \, V \times 0.56 \, A \times (25 \div 100) = 1.036 \, \text{Watts} \\
\text{Tc} = 0.411 \times (T - T_0) \\
\text{Tc} = 0.411 \times (136.2 \, g - 128 \, g) = 3.3702 \, \text{grams} \\
\text{Pout} = \text{Tc} \times \text{v} \\
\text{Pout} = 3.702 \, g \times 2.8 \, \text{m/s} = 10.3656 \, \text{Watts} \\
\text{Nsyst} = (\text{Pout} \div \text{Pin}) \times 100 \\
\text{Nsyst} = (0.103656 \, \text{W} \div 1.036 \, \text{W}) \times 100 = 10.0054 \% \\
\text{J} = \text{v} \div ((\text{RPM} \div 60) \times \text{D}) \\
\text{J} = (2.8 \, \text{m/s}) \div ((5209 \, \text{RPM} \div 60) \times 0.0762 \, \text{m}) = 0.4233 \, \text{J}
\]
References
