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# Cryogenic Engine Treatment

## With Study of Proprietary Oil Additive

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## Abstract:

This project investigates the utilization of cryogenic treatment for engine components to study the effects related to heat transfer and horsepower. Additionally, a proprietary compound is being tested to study the effects of proposed increased horsepower. This project is intended to help Peter Paulin, President of 300 Below Inc., to validate his cryogenic treatment process, and to help him test the efficacy of an engine oil additive for commercial sale.

## Procedure:

The testing procedure itself is laid out in the Appendix A. Please read for more information.

To start, the Dynamometer from the 2016 senior design project was modified to operate as a direct drive rather than a CVT tuning dyno. This was done to gather data on horsepower by directly measuring the engine's torque output. By running a test at the advice of Kelly Van Dunn from Exmark, the engine was started and braking force was applied by the dyno gradually until the engine came to a stop and data points on both force and RPM were recorded every 50 milliseconds. This data points measuring RPM and force at the end of a lever arm were then converted to torque and horsepower output.

Data was obtained at increasing throttle positions using this technique. Starting at approximately 1600 RPM, the idle speed as dictated by the Baja SAE rules, and increasing 300-400 RPM for each test, seven sets of data points were collected at each phase of testing, for engine speeds up to 3800 RPM, the maximum allowed speed by Baja SAE. Once these data points were collected, analysis of the data reduced this raw data to a single usable number for horsepower. This analysis is summarized in Appendix B.

The next phase consisted of treatment of the engine cryogenically. This process requires cooling the disassembled engine components to -300 Fahrenheit and tempering the materials up to room temperature. In steel, this process reduces the amount of retained austenite within the martensite structure, making the steel stronger and more wear resistant, as well as increasing the heat transfer coefficient of the material. In aluminum, as the engine block is made, the effects are not as well studied. The theory of this phase is that heat transfer will increase dramatically in the engine block, leading to hotter temperature readings during engine running. This temperature decrease increases the efficiency of the engine per the Briggs user manual by 1% for every 10 degrees temperature decrease.

For both the Original and Cryo stages, temperature was recorded using a FLIR AC series thermal imaging camera. This process is summarized in Appendix A, and the analysis of images in Appendix B.

Using this testing and analysis procedure, data was collected for phases of study dubbed “Original”, “Cryo”, and “Additive”. The testing highlighted in this report is for the Briggs and Stratton Model 19 engine used by the Baja SAE teams. Additionally, data was taken from the new Model 20 engine, but due to insufficient data collection on the original test, it was deemed impossible to compare any increase in horsepower due to the additive to the original engine condition. The final engine curve is shown for reference.

## Results

*Results described in this section refer to the Model 19 engine tests

### Process Validation

Below in Figure 1 is the generally accepted horsepower curve, as created by the Baja SAE community. Figure 2 shows the plotted data from the original engine test compared to the generally accepted curve. The resulting curve matches generally well with the accepted horsepower curve, not accounting for ambient conditions, as the ambient conditions are not know for the test completed by the community.

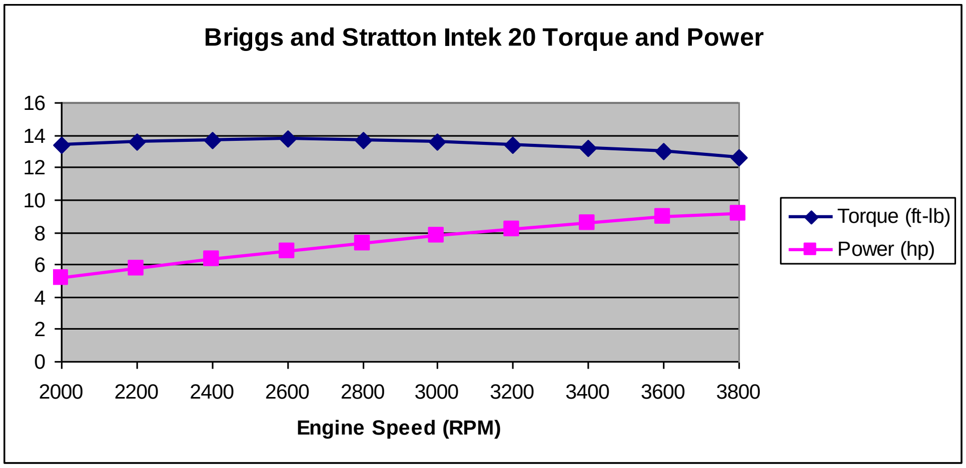


Figure 1: Generally Accepted Horsepower Curve

| Husker Racing | |
|---|---|
| RPM Set | HP |
| 1600 | 4.833149 |
| 2150 | 5.643804 |
| 2400 | 7.088554 |
| 2700 | 7.583023 |
| 3000 | 7.629948 |
| 3500 | 8.404426 |
| 3800 | 9.192756 |

| Baja Forums | |
|---|---|
| RPM Set | HP |
| 2000 | 5.2 |
| 2200 | 5.8 |
| 2400 | 6.3 |
| 2600 | 6.7 |
| 2800 | 7.5 |
| 3000 | 7.9 |
| 3200 | 8.2 |
| 3400 | 8.6 |
| 3600 | 9 |
| 3800 | 9.3 |

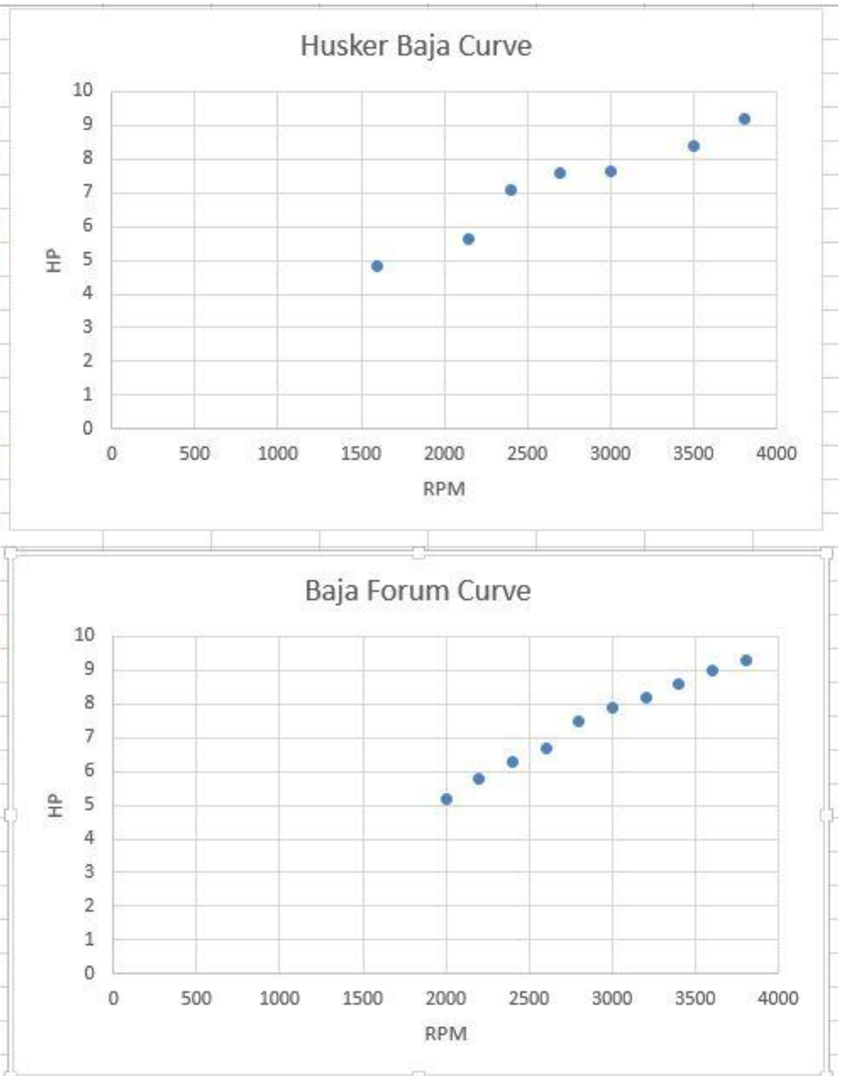


Figure 2: Side by Side Comparison of test data and accepted curve

This successful test shows that the testing procedure can produce reasonably accurate results, and that the proposed theory of testing and data analysis is sound.

## Horsepower Analysis

Using this testing and analysis procedure, the results from the Original, Cryo, and Additive phases are summarized below in Table 2, with graphical representation in Figure 3. The results of this study found a slight increase in horsepower from the Original phase to the Cryo phase, and a much more defined increase in horsepower from the Cryo phase to the Additive phase.

Interestingly, when charted, all 4 measured trend lines from the Model 19 engine, including the Baja community test that does not contain any power correction, intersect at the same point. This point is at approximately 3300 RPM and 8.1 Horsepower. What causes this intersection at this point is unknown but it could be related to the increase in horsepower having a non-linear effect, where this figure plots linear trends. More study is necessary.

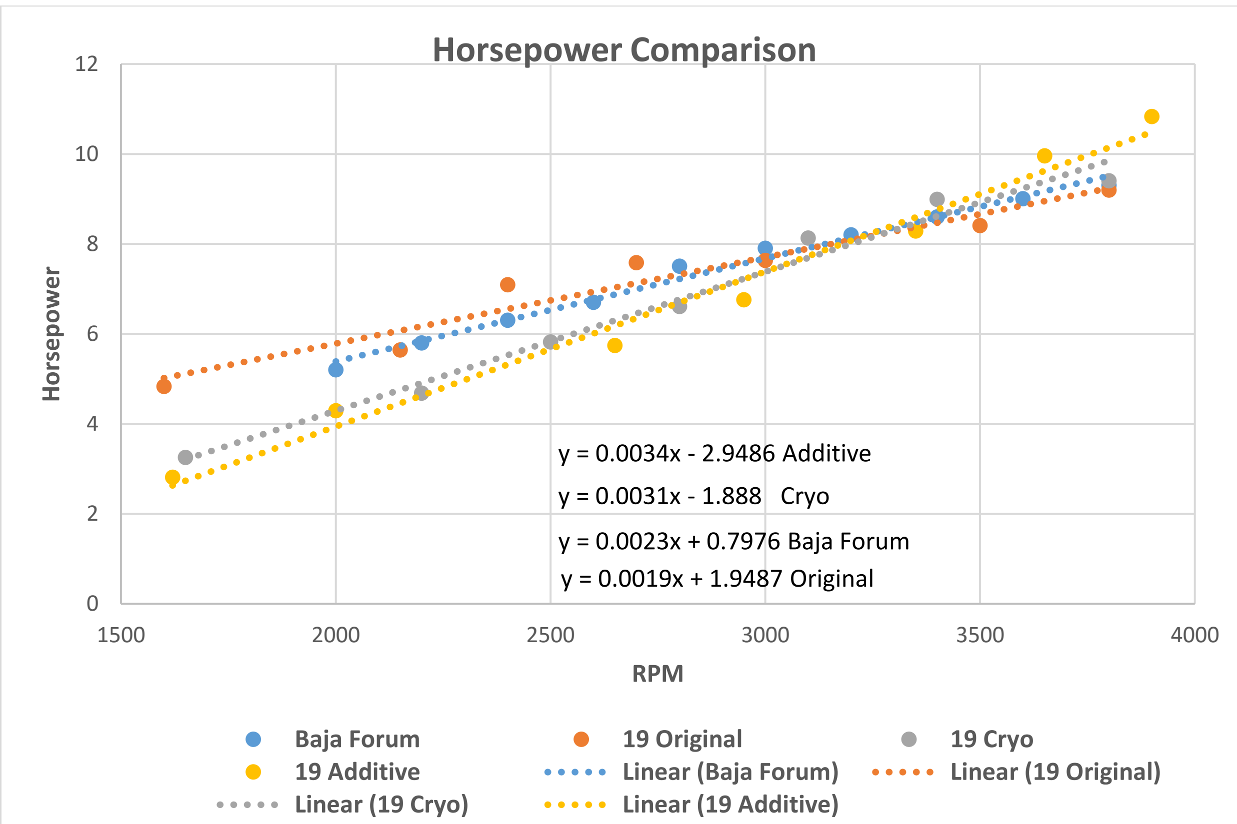


Figure 3: Model 19 Horsepower Comparison

| 19 Original | | 19 Cryo | CF | 1.011864034 | 19 Additive | CF | 0.99539 |
|---|---|---|---|---|---|---|---|
| RPM | HP | RPM | HP | Hp Corrected | RPM | HP | HP Corrected |
| 1600 | 4.833149488 | 1650 | 3.25 | 3.288558109 | 1620 | 2.81 | 2.7970459 |
| 2150 | 5.643804096 | 2200 | 4.68 | 4.735523677 | 2000 | 4.29 | 4.2702231 |
| 2400 | 7.088554183 | 2500 | 5.82 | 5.889048676 | 2650 | 5.741 | 5.71453399 |
| 2700 | 7.583022604 | 2800 | 6.605 | 6.683361942 | 2950 | 6.754 | 6.72286406 |
| 3000 | 7.629947942 | 3100 | 8.13 | 8.226454593 | 3350 | 8.282 | 8.24381998 |
| 3500 | 8.404426278 | 3400 | 8.99 | 9.096657662 | 3650 | 9.958 | 9.91209362 |
| 3800 | 9.192756439 | 3800 | 9.4 | 9.511521916 | 3900 | 10.83 | 10.7800737 |
| | | | | | | | |
| % difference | 100.00% | | Original | 103.47% | | Original | 117.27% |
| | | | | | | Cryo | 113.34% |

Table 1: Model 19 Horsepower Data

## Cryogenic Treatment Analysis

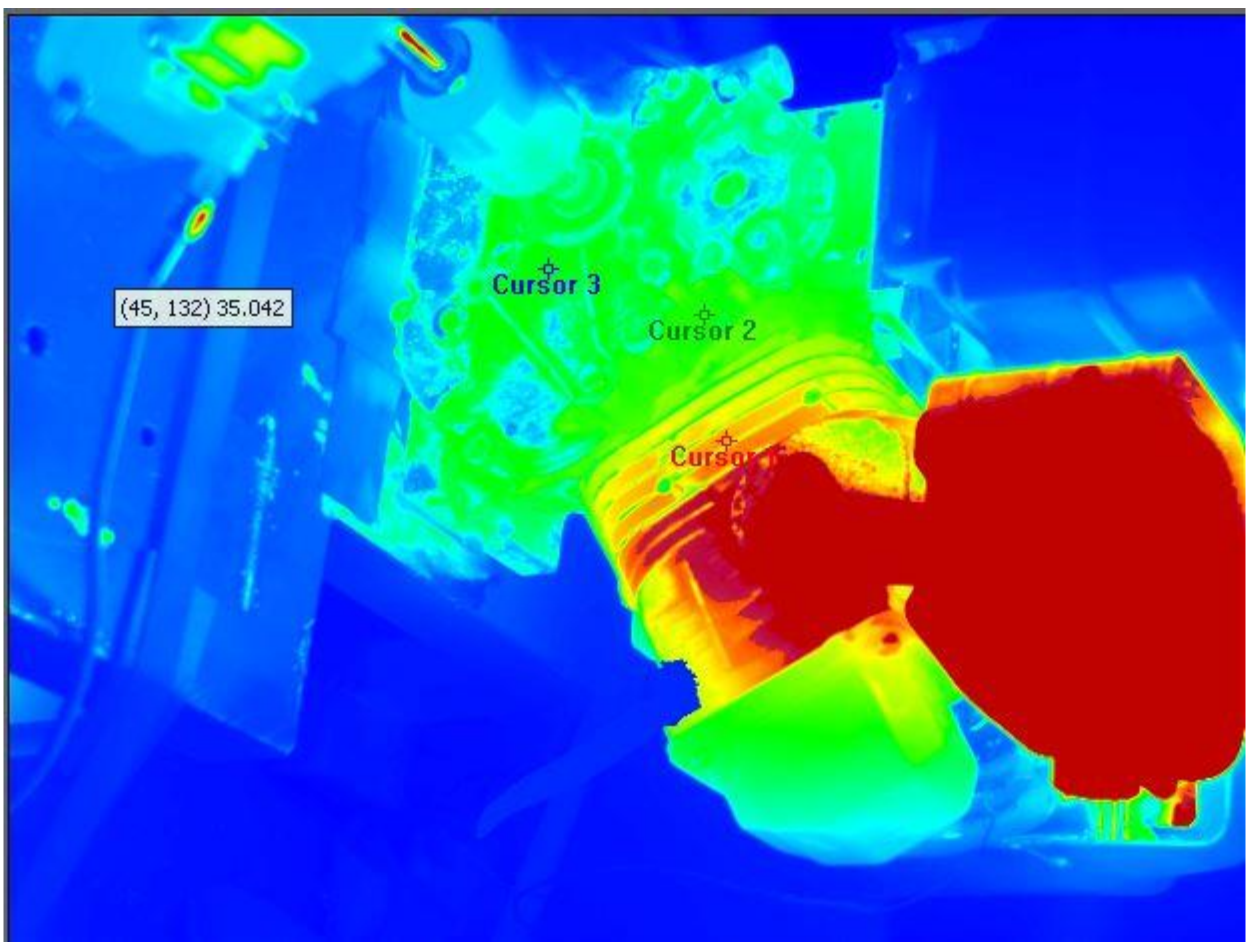

Figure 4: Original Thermal Scan

Figure 4 displays the Original scan captured during the peak of the 3800 RPM data collection test. This test was chosen to display as the engine had been running the longest and most consistently at this point for both the Original and Cryo phases. Having the most run time at this final stage, with the most horsepower being generated, it is assumed that the engine is operating at steady state during these tests.

Figure 5 displays the Cryo thermal scan captured during the peak of the 3800 RPM data collection test. This test was chosen for the same reason as Figure 4 during the Original, to simulate the steady state operation of the engine at maximum power generation, and to most accurately compare the two sets of temperatures.

Cursor point locations were determined for the following reasons. Cursor 1 was chosen as the hottest point on the engine block, the location of the exhaust valve ports. Cursor 2 was chosen as a decent interpretation of the “average” temperature of the entire engine block. Cursor 3 was chosen as an indication of oil temperature, as this location is low enough on the block for the pool of engine oil to act as a heat sink until steady state is reached, thereby indicating the temperature of the oil itself.

Each location that was cryogenically treated experienced noticeable drops in operating temperature at the measured conditions. For this experiment at Cursor 2, a drop of almost 19 °C was realized, a decline greater than 25%. Based on the Briggs and Stratton Owner’s Manual, this decline corresponds to an overall operation efficiency increase of 2%. The temperature comparisons for Cursors 1, 2, and 3 are displayed in Table 2.

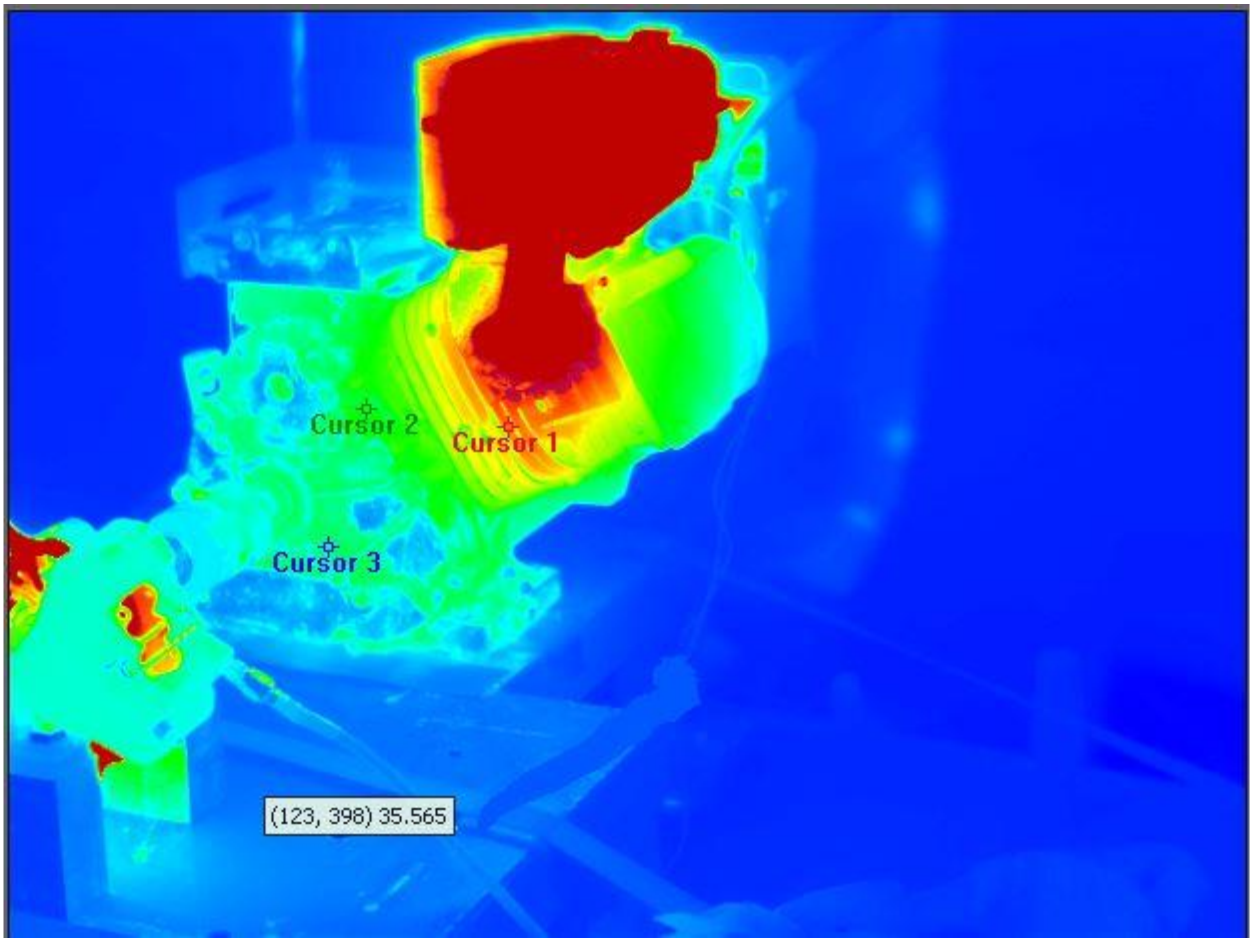


*Figure 5: Cryo Thermal Scan

| Thermal Comparison (°C) | | | |
|---|---|---|---|
| | Cursor 1 | Cursor 2 | Cursor 3 |
| Original | 137 | 93.7 | 88.5 |
| Cryo | 133.5 | 74.57 | 65.31 |
| % Difference | 2.6% | 25.7% | 35.5% |

Table 2: Thermal Comparison

*Due to camera alignment during testing, image is flipped 180°. Thermal measurement is not affected

## Conclusions

**Cryogenic Treatment:**

From the difference in data sets between the Original and Cryo phases, it can be seen that a modest, 3.47 % increase from 9.19 HP to 9.51 HP was observed. This increase can be attributed to minor, uncontrollable differences in engine assembly as the engine was tore down to process cryogenically. From a thermal analysis standpoint, it was found that the engine ran significantly cooler under similar testing conditions, with engine block temperature measuring approximately 19 °C cooler after treatment. If an increased heat transfer coefficient is assumed, then the same volume airflow over the engine block is removing more heat from the system at steady state run. The prediction of increased surface temperatures were not realized and the difference in ambient temperature, 74.57 °C Original to 93.7 °C Cryo, likely played some role in this. This temperature difference was taken at Cursor 2, which indicates the most average data point counting the entire engine block.

**Oil Additive Treatment:**

From the difference in data sets from the Original, Cryo, and Additive stages, it can be seen that modest increases in horsepower were realized from both treatments. An increase at the maximum 3800 RPM of 10.78 HP, 13.34 % increase, was identified between the Cryo and Additive phases. While two different phase comparisons can be made, the difference between the Cryo and Additive phase is the most accurate to highlight as the least variables were changed between these two phases, only the additive was introduced. This being said, the oil additive appears to have had a positive effect on the performance of the engine.

While it is difficult to determine exactly what mechanism drives the measured increase in horsepower resulting from the oil additive, due to its proprietary nature only speculation can be given in this report. From the limited knowledge of the additive itself, it is possible that the additive contains an agent that burnishes the internal surfaces of the crankcase, thereby eliminating some sources of internal friction. This would allow for the engine to become more efficiently transfer its generated mechanical energy, yielding more observed horsepower. This effect is compounded by the decreased operating temperature from the cryogenic treatment, thereby increasing the efficiency of power generation as well.

## Further Study

Working with this modified clutch tuning dynamometer, the most significant area for exploration is the construction of a new, Linux controlled dynamometer with servo variable control. This will ensure more consistent data collection and allow for a wider array of testing conditions and variable control. From what we have seen, cryogenic engine treatment is worth the investment for the small, aluminum block, single cylinder engine that is utilized by our teams.

**Disclaimer:**

This report is not linked to any research group or department at the University of Nebraska-Lincoln. This project was completed by the UNL Baja SAE team utilizing the equipment available to students of the University.

# Appendix A:

## Testing Procedure:

Experiment Design: Baja Engine Testing – Heat profile and Dynamometer changes from cryogenic treatment and oil additive treatment

Goals:

1) Track change in horsepower from treatment
2) Track heat transfer change from treatment
3) Quantify change in horsepower from oil additive

Process:

1) Deep cryogenic treatment of metal components in Briggs and Stratton Intek 305cc – Model 19 engine
2) Nanoparticle engine additive (experimental) to engine after cryogenic treatment test run

Equipment:

1) Flir Ac655sc thermal imaging camera (on loan from Dr. Zhulke's Lab)
2) Senior project clutch-tuning Dynamometer (modified with direct drive to measure Engine torque rather than clutch speeds)

Testing Procedure (to be run before/after cryo treatment, and after additive treatment):

1) Set up engine in dyno with direct drive
2) Arrange thermal camera at +45 degree upwards diagonal from parallel with crankshaft (this angle is to get maximum view of fins and crankcase to measure increases in temperature)
3) Initiate Arduino DAQ system and Flir Imaging software
4) Start motor (full choke)
5) Run motor at constant throttle position (no choke), set to desired rpm under no load
6) Once running at steady state, increase brake pressure on dyno slowly until motor stalls and stops running
7) Kill motor safety switch
8) Stop collecting data

Additive procedure:

1) Add oil additive to engine
2) Run at rpms ranging from idle to full throttle for 8 hours for additive to take effect

Predictions:

1) Engine should run significantly hotter (+10-15 degrees C) after treatment
2) No noticeable change in  HP after cryo treatment
3) Increase in horsepower after oil additive treatment

# Appendix B:

## Data Analysis Procedure:

Goals:

1. Reduce raw data gathered from Testing Procedure to useable information
2. Convert time, RPM, and force to Horsepower
3. Compare measured Horsepower to other tests using SAE J1349 Power Factor Conversion

Procedure

1. Receive data in Excel format from testing procedure. Raw information of time (ms), RPM, and force measured at a lever arm (lbs)
2. Data filtered for obviously false readings. (I.e. a RPM reading of 75,000,000 which occasionally occurred due to a coding error). These data points were discarded
3. Force data were converted to torque (inch pounds) using the following equation to account for the 6.7 inch lever arm:
   a. $Torque = Force * \frac{6.7}{12}$
4. RPM and Torque were used to calculate Horsepower using the following equation
   a. $Horsepower = \frac{RPM*Torque}{5252}$
5. Horsepower was then given a power correction factor using the SAE J1349 formula below. This was done to account for the varying ambient conditions of each test to ensure that data could be compared across tests. Where P is power, p is pressure, $p_v$ is partial pressure due to humidity, and T is temperature in Kelvin. Subscript "O" is to define the base test completed under "original conditions"
   a. $Correction\ Factor = \frac{P}{P_O} = \frac{(\mathrm{p-pv})}{(\mathrm{pO-pvO})} * (\frac{T_O}{T})^{0.5}$
6. Images collected from the FLIR camera are shown in this report of the tests conducted at the 3800 RPM stage for both the original and cryo phases. Data points were laid using the FLIR software and three points were analyzed for temperature at this maximum running condition.

# Appendix C

## Testing Condition Data

| Original | | | Cryo | | | Additive | | |
|---|---|---|---|---|---|---|---|---|
| | | | 1.0119 | Correction Factor | | 0.9954 | Correction Factor | |
| 295.1 | Temp | Kelvin | 293.3 | Temp | Kelvin | 302.2 | Temp | Kelvin |
| 0.96579 | Pressure | bar | 0.97678 | Pressure | bar | 0.97385 | Pressure | Bar |
| 25 | Humidity | % | 39 | Humidity | % | 58 | Humidity | % |
| 0.00666 | Partial pressure | bar | 0.00928 | Partial pressure | bar | 0.00777 | Partial pressure | bar |

Table 1: Ambient Atmosphere Conditions

| | |
|---|---|
| Oil | 27 oz. |
| | 10w-30 Quaker State |
| | |
| Gas | 91 octane |
| | ethanol free Shell |

Table 2: Fuel and Lubrication Information