Design of Diesel Snowmobile with Pressure Wave Supercharger Phase 1

Indiana University Purdue University, Indianapolis (IUPUI) – Clean Snowmobile Challenge 2017

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(Jaguar Wave)

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Abstract

The IUPUI design team is confident that they have a snowmobile that will operate in the diesel utility class of the competition with success. Integration of a Kubota (D782-E D902-E) diesel engine into a 2015 Polaris 600 Pro-RMK 155 snowmobile was successful. Throughout this engine integration process, the team experienced many design challenges from space accessibility to pressure wave supercharger design to emission calculations to automated stress analyses. Throughout the workings of this project, noise and emissions reduction was on the forefront of the design process, but also competing at a high level at the competition was a large motivator as well.

Introduction

The SAE International Clean Snowmobile Challenge has prompted the innovative thinking of many young minds throughout the nation. The main objective of this competition is to reengineer a snowmobile with the two aspects in mind: emissions reduction and noise reduction. As many people use snowmobiles for recreation and labor, there is always a need for a more efficient engine.

Indiana University-Purdue University Indianapolis (IUPUI) chapter of the Society of Automotive engineers (SAE) are competing in the Clean Snowmobile Challenge (CSC) for the first time. The design team has chosen to enter the diesel utility class of the competition. The team members will collaborating on this project to reach the goals mentioned above. The purpose of the CSC is to design and develope a snowmobile that is better than it was before. The engine has largest impact on how well the vehicle powers through the terrain it is on. If a snowmobile can be run on an engine that is more efficient, then this would hold a niche in the snowmobile engine market. Diesel engines are said to be more efficient, last longer, and release less waste heat while in operation. This is why there is a diesel engine sector to the competition. If a design for a diesel engine snowmobile were to arise, then it will considerably change how people use and look at snowmobiles. The design group from IUPUI has designed a snowmobile that will interest snowmobilers alike.

As a team, this is the first year that IUPUI has entered into this category of competition. The identity of the team has not yet taken root considering there is uncertainty about what will be faced at the competition. Also, time has been a major constraint for this rookie team as there is no data or information to go off of from past years. There will be aspects about this design paper that refer to innovation that will not be seen at the 2017 competition, but that can be expected to be designed and added in future phases of the project. IUPUI is making a commitment to this project for the long haul. Apart from the major constraint of time, there have been other engineering, budget, and safety constraints as well, which will be mentioned in the following sections.

Engine Integration

Snowmobile

The snowmobile that the team designed is a 2015 Polaris 155 with a Liberty, 2-cylinder, liquid cooled engine in it. The following image is what the snowmobile looks like, acquired from the

Powersports Network Website:

Figure 1: 2015 Polaris 155

Engine

Once the snowmobile arrived at IUPUI's facilities, the 2-cylinder engine was removed, and measurements were taken upon the purchase of the desired diesel engine. The diesel engine that was purchased for integration within the Polaris is a Kubota diesel engine (D782-E D902-E). (Figure 2) The team wanted to choose an engine that enables the driver efficiency of performance and sufficient power, keeping in mind the low emissions requirement. This Kubota engine in particular was chosen because of its compactness, strength and cleanliness to the environment. A figure of this engine is seen below:

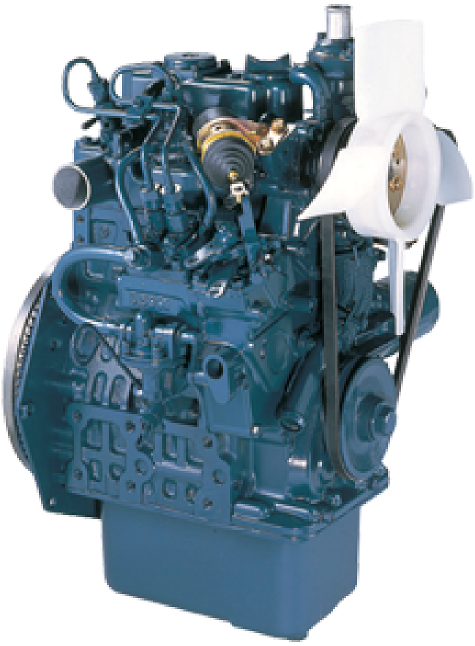
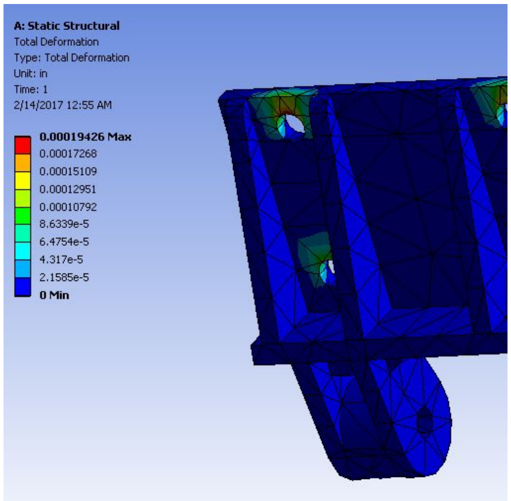


Figure 2: Kubota diesel engine (D782-E D902-E)

Engine Mounts/Frame Adjustments

Like all engineering tasks, mounting the engine into the frame had more difficulties than expected. The design team went to work on mounting a new engine into the vehicle. The conceptual birth of new engine mounts that would be compatible with the old frame and the new engine. Through a series of design iterations, CAD drawings was finalized and run through several stress analyses to confirm that the weight of the engine and other turbulent forces would not compromise the integrity of the engine mounts. In the Figure 3 below, is an FMEA of 10x the weight of the engine (1570 lbs/ 714 kg) on the mount.



A: Static Structural
Total Deformation
Type: Total Deformation
Unit: in
Time: 1
2/14/2017 12:55 AM

Figure 3: CAD FMEA of the engine mount

As one can see from this cropped image of the mount, there is no structural failure and the loads can bare far greater a load than that of the weight of the engine, its torque, or any natural force put on the engine. The mounts were manufactured out of pieces of quarter inch stainless steel that were welded together. The plates were then attached to the chassis, using the previous engine's motor mount bushings.

This was a difficult task because the dimensions of the original engine bay would not allow the diesel engine to sit in the bay without interference from small extrusions. For example, bolts that did not interfere with the 2-cylinder engine would not allow clearance of the diesel engine. In order to fix this dilemma, the alteration that was done was removing the bolts and taking out the bottom. This allowed clearance for the engine to fit into the bay so that it could be bolted in. Even after this modification to the bottom of the engine bay, the design team was led to make other corrections to make sure other components did not interfere with pieces crucial to running the engine. This time, the alternator was coming into contact with the engine cover, not allowing it to fully close. The belt of the alternator becomes taught when a bolt of the alternator is slid through a track made of ⅛ inch steel that came with the engine. It is able to slide because the alternator hinges on another bolt 3 inches below the track. The design team postulated that if the hinge bolt were to become the rotating bolt and the rotating bolt were to become the hinged bolt, then the belt would still be able to be adjusted, the alternator would still be fully functional, and the interference with the engine cover would be no more. After machining a piece that would serve as a track for the new bottom bolt to rotate through, the alternator was reapplied and worked with no stress. This reverse in rotation, freed up the space to secure the original top of the engine frame and ensured the functionality of the alternator. This was the only modification necessary in order secure the engine cover to the frame. Attaching the engine in place was promising as a design group because once the engine was mounted, other pressing matters of the integration could go into effect, such as, wiring the engine, creating an exhaust system, and designing a drive shaft taper.

The final part of integrating the engine to the sled required an adaptor shaft to be modeled and manufactured to have a locking shaft taper for the primary clutch. This tapered shaft had to able to withstand the torture test of having up to 50 lbs of force tangent to the plane and 45 ft-lbs of torque over the lifetime of the part. Figure 4 is a picture of one of the stress planes regarding the part. There is a full stress analysis workbook up available upon request.

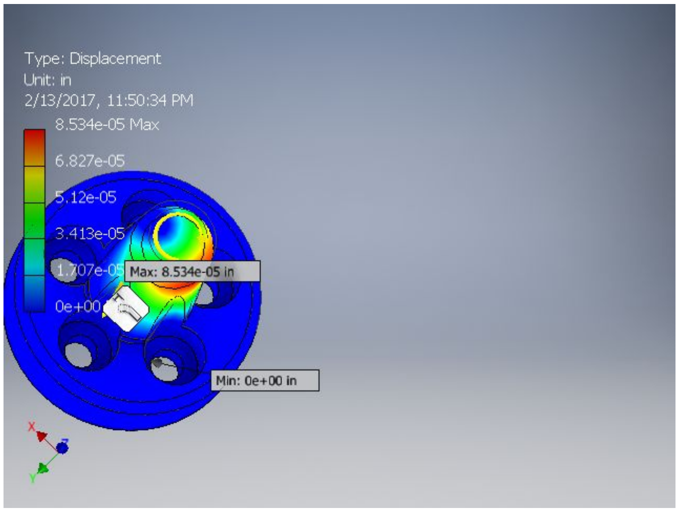


Figure 4: Taper Shaft

Design Specifications

Emissions

Rudimentary calculations were accomplished for the engine at maximum revolutions per minute and horsepower. It is postulated that the engine will be running near its peak horsepower limit during the course of the race as our sled is under powered without the pressure charger being implemented this year. When the accelerator is pressed, dynamic changes happen on the dual cycle that the kubota diesel is modeled to run, and with our compressed time table it became imperative to do the calculations with assumptions that will impact the comparison between calculation and real world numbers. The six assumptions that were made are listed below:

(1) The calculations are accomplished at 25 horsepower running 3850 revolutions per minute.
(2) Because it is adiabatic and isentropic, the ideal gas law can be employed.
(3) 98% combustion efficiency.
(4) Argon and other elements in air are negligible. Leaving just oxygen and nitrogen.
(5) The amount of residual gas after combustion is 4% of the overall intake.
(6) All the dissociation of nitrogen is oxidized in

an NO2 manner (see Appendix 1).

The solution of the amount of emissions of NOx starts with an ideal gas approximation of the engine, and to do this a dual cycle was selected as the operating characteristics of the engine. The selection of the Dual Cycle came from the information found in Appendix 2 which is a copy of the engine specifications. The defining specification being that the timing of the injector is 20 degrees before Top Dead Center. The diesel cycle works at 0 degrees; thus, it is imperative to use both the otto and diesel cycles as the injector is continuing to fuel the piston before and after top dead center. The equations for the 4 main processes in the cycle are derivatives of $PV = MRT$. The most interesting and important of these values is the temperature attained at process x-3 which is 3811.79 kelvin. This value and the pressure of 181.14 atm were used in conjunction with the formulas:

$$log_{10} K = Table\ Value(temp)$$

$$K = [(2x^2)/(1-x)]/[P_{atm}/(2x+(1-x))]^{2-1}$$

$$N_2 => \ 2\,xN + (1-x)N_2$$

(citation 10)

These formulas gave a simplified calculation of how much Nitrogen of the total nitrogen dissociates under the conditions within the kubota engine.

x= portion of Nitrogen dissociated

x*100 is percentage nitrogen dissociated

K is chemical equilibrium constant

P is absolute pressure in ATM

The formula is the dissociation reaction for nitrogen, which only occurs at temperatures greater than 2500 K. The final value attained gave an x value of 0.0004297% Nitrogen to dissociate during each cycle per cylinder. The engine is rated as a tier 4 off road vehicle, but Tier 4 rating is in g/bhp-hr not ppm. A conversion was done and the engine output of 0.00164922 g/bHp-hr was found. This is a relatively high number when comparing to an on road vehicle, but falls right into the range of the Tier 4 standards that Kubota specified the engine to be following. The challenge after determining the amount of NOx production now becomes specifying engineering solutions to fix the emissions issues associated with the NOx. The future use of the pressure charger should work brilliantly to reduce this, as the charger allows for much more recirculation of gases leaving the combustion chamber so that the NOx can be dissociated and returned to a sustainable diatomic nitrogen molecule. This year; however, it is imperative to place filters and catalyst between the external outlet and the exhaust manifold. The team chose to use a Jetta TDI diesel particulate filter, for the unburnt hydrocarbons associated with high concentrations of fuel and low concentrations of oxygen inherent in the dual and diesel cycle, and the use of a NOx catalyst. This should help reduce, but not alleviate the issue of emissions that the off road diesel will be producing. A photo of the entire exhaust system is in the following figure:

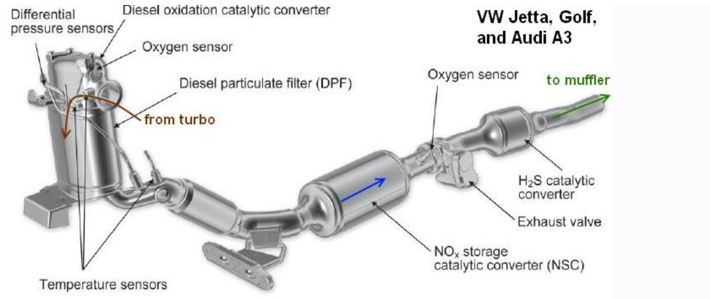


Figure 5: Exhaust System

Future study will take place in phase 2 to determine the amount of carbon monoxide the engine is producing, but the project time constraints do not allow for that study within phase 1. Under the assumption that high amounts of NOx means low carbon monoxide, and that diesels are lean running engines in spite of the indirect nature of the Kubota's injection system, it is imperative that a study be done on the carbon monoxide emissions of the engine. This is based on the nature of the burn within the combustion chamber. The diffusion flame has a byproduct of localized high concentrations of fuel with low concentrations of air at the same time as high concentrations of air with low to zero concentrations of fuel. This creates local zones of rich mixture allowing for the formulation of carbon monoxide.

Noise Reduction

A diesel engine is an internal combustion engine in which the heat produced by the compression of the air in the cylinder is used to ignite the fuel. Because, of this sudden mixing of the vaporized fuel with the air the ignition process is characterized by hard combustion which makes it very loud, rattling noise Diesel engines are loud and out of balance, which is why they are mainly implemented in larger vehicles, such as trucks and tractors.

In order to reduce and control noise, the modifications the design team made are the following: The motor mounts that the team designed consist of rubber bushings that will reduce the vibrations, resulting in noise control. If the motor mounts were simply metal-on-metal, the entire frame of the engine would shake and be very loud. The muffler that came with the engine itself will be implemented that will cancel out most of the engine's noise. The muffler itself is designed in a way to cancel the sound waves produced by the engine. The engine itself will be running on an exhaust manifold rather than a header. While exhaust manifolds and headers play the same role in engines, channeling the exhaust away from the main cylinder towards the exhaust pipe there are few differences. A visual of an exhaust header is in figure 6:

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Figure 6: Exhaust Header

Headers are upgraded manifolds that use an individual tube for each cylinder. All these individual steel pipes connect to a collector pipe. This makes sure that gasses from each cylinder get to the collector individually avoiding back pressure. The downside to a header comes from the sound reverberation that occurs along the pipes. On the other hand, the exhaust manifold in this engine will collect all the exhaust and quickly press the flows into a single flow. It is also compact which will come in handy when the catalytic converter is installed. We will also be adding a diesel particulate filter along with the catalytic converter to reduce the noise, and emissions.

Figure 7: Catalytic Converter

Innovation

One internal goal for IUPUI in regards to this project is to pave a way for the future charging system that will further decrease the overall emissions that the diesel is producing by forcing more air into the combustion chamber. The dynamic adjustment of the compression ratio via forced induction will allow for a more complete burn under the time constraints based on the revolutions of the engine.

Being a pressure charger, this type of supercharger allows for further reduction in emission by the definition of how the charger works. The pressure charger uses the hot expanding gasses flowing out of the exhaust to force air into the intake manifold. But in the process of forcing the air, some of the exhaust, including but not limited to soot, NOx, and CO, are recirculated into the combustion process. This recirculation allows for the unburnt fuel, NOx, and CO to have an opportunity to become more oxidized. In this manner, instead of sending all the carbon monoxide created inherently by the cold temperature of the IDI Kubota diesel to a catalyst, the gas is allowed to be reheated and thus oxidized further to carbon dioxide. The effect is to reduce the needs of the catalyst; however, there is no plan to remove the catalyst.

Figure 8: Supercharger

Figure 8 is an image of the outside of the charger. This image shows the air intake and outflow on one side of the charger and the exhaust intake and outflow on the other side of the charger. A former IUPUI senior project team, charged to design the above supercharger, ran a CFD explained via Figure 9.

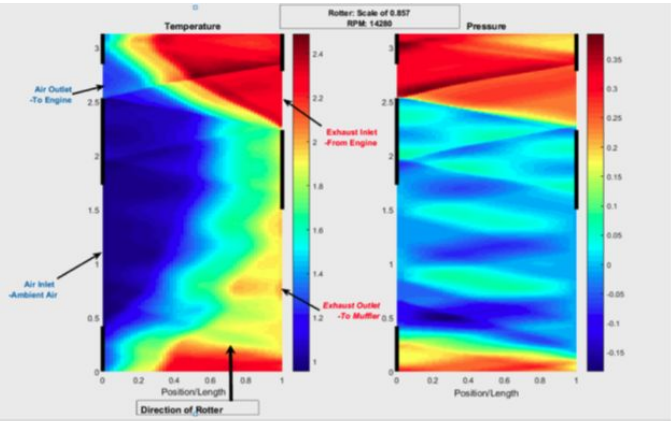

Figure 9: CFD of Supercharger

The CFD run for .857 scale was chosen by the team and accepted by the sponsors. This figure represents a single channel as it rotates around in the rotor. This figure also only displays half of the rotor itself as there are two of each port on the actual rotor. The process starts by opening of the exhaust port. This creates a pressure difference within the rotor resulting in a small pressure wave propagating through the channel. At the same time ambient air can start to accumulate into the rotor chamber. As the AI port closes, another pressure is created through the channel again. Next the opening of the EI at a much higher pressure, opens and creates a very strong pressure wave (PW) that compresses the air from the AI port. Much of the compression occurs within this portion of the process (Mataczynski, Polanka, Paxson, & Nees, 2015). This PW propagates all the way to the AO opening of the rotor just as it opens. This then forces the freshly compressed air out by the AO port and into the intake manifold of the engine. As the rotor rotates, the AO port closes right before the EI gasses get a chance to enter into the AO port. If this happens, exhaust gasses in the engine wouldn't be ideal. The process then starts again with the opening of the EO port to expel the gasses to the diesel particulate filter, the catalyst, muffler, and out of the engine.

The specific expectations for this project were to determine the correct size of a pressure wave supercharger to make the device compatible with the Kubota D902-E engine chosen by the sponsors. The design of the pressure wave supercharger was taken directly from the model made by Comprex, the new supercharger is a direct scaled down version. A pressure wave supercharger works by letting hot exhaust and ambient air interact in a spinning chamber which functions like a fan. The interaction between the hot air and cool air creates a pressure wave that propagates through the channel and eventually pushes condensed air back into the engine, thereby increases the engine's pressure ratio (swissauto.com). Modifying the engine cycle encompasses many design challenges. The objective for this project consisted of resizing the Comprex supercharger in order to match the airflow from the engine. The overall objective in supercharging a diesel engine is improving the engine's air pressure ratio while reducing emissions.

The main driving factor for the design of the product was scaling. The primary task was to scale the Pressure Wave Supercharger (PWS) down to a scale that performed well with a Kubota D902 engine. This supercharger was to work as well as it should on its normal scale. To start this process, the mass flow rate of the engine was calculated. The mass flow rates of both the intake to the cylinders and outports of the exhaust were calculated. This became the bottom line that would help achieve the redesign of the comprex. Since the PWS operates off of the exhaust gases of the engine, the mass flow rate was calculated at maximum torque. By using this calculated torque, the optimal range of how much air into the engine was found, along with exhaust gases out. The specifications of the engine used in these calculations included 18.5 KW at 3600 RPM along with 56 N*m at 2600 RPM.

The next step included gathering already existing information about the already manufactured Comprex. In this part, information of the 5th generation comprex used on a Mazda 626 Capella was used. The 2.0 L (1998 CC) RF-CX diesel engine was outfitted with the comprex. The engine specifications included 60 kW at 400 RPM, 181 N*m at 2000 RPM, 80.46 b.h.p, and 133.49 ft.*lb of torque at 2000 RPM. With these two mass flow rates in hand, a ratio was determined. Initially three different ratios were derived; a volume ratio, area ratio, and linear ratio. In our preliminary research, scaling the comprex just based on linear ratios wasn't the team's initial thought. With the different areas of openings and closings and volume of different flow rates, assumptions were made that led to the three different ratios. It wasn't until a conversation with the sponsor did the team arrive at the fact that a 1:1 ratio based on linear geometry was sufficient to the design. The concluded ratio and the one based on the team's design is a linear ratio of 0.857. This ratio helped in the design of the final comprex for the Kubota D902. In the process of finding the proper ratio for the rescaling of the comprex, a low baseline and high baseline were found. The high baseline was based on the Mazda Capella integration of the comprex. This comprex was significantly bigger and ran as expected. The low baseline was based on a scaled down comprex that was used on drones by the air force. The design for the comprex would sit in the middle of these two scales: no bigger than the Mazda case and bigger than that of the air force drone.

Performance

In hindsight to integrating the engine within the system of the snowmobile successfully, the competition's standards of performance are of importance as well. Not only is emission control and noise reduction important, adhering to the confines and events of the competition is also. The design team desires to excel all categories - range, drawbar pull, exhaust, cold start, acceleration, and objective handling. Like other schools have shown in the past, each design is slightly catered to certain events. Considering the IUPUI engine will not have a pressure wave supercharger this year, it will be difficult to best the other teams that do. As written in the opening statements of this design paper, the design team intends to run a snowmobile successfully, but future work is needed. Therefore, they will not be relevant until the 2018 competition. In the range category, the IUPUI sled will have advantages because of its lightweight sled featuring carbon fiber material. Given that the team is confident in the reliability of the engine's functionality, the team will do well in this category. The cold start will be a trouble like it is to every team each year, but IUPUI does not have a large disadvantage apart from lack of experience from past years. Because the average speed was brought from 45 mph to 35 mph, the IUPUI sled should do well even lacking a supercharger. The vehicle will be reliable and the Kubota engine will be functioning at its best.

Conclusion/Summary

As a design project, there were many hurdles that took place throughout the entirety of the design, implementation, and testing stages. The most rewarding part of any project is seeing the final product function successfully. Before functioning at the competition in early March, this section is a brief summary of the process the team took to run their snowmobile. The process encompasses purchasing a snowmobile and diesel engine for the first time. Next was designing a mounting system that would be compatible with the existing snowmobile frame, minimizing any serious modifications. There were a few hurdles to ensure spacing was correct and physical interference with engine components was eliminated. After the engine was in place, the team focused on reducing emissions and noise, which are staples in the Clean Snowmobile Challenge. Though the engine will not have the IUPUI-designed pressure wave supercharger installed into the system, there was much insight gained on the benefits of doing this in the future.

Considering the current IUPUI team members are paving a way for many future teams, there are a few things to reflect back on. The largest impediment that the design team faced was moreso logistically than actual design or implementation. For the future IUPUI projects, it is very important for everyone to be on the same page with an identical vision in mind. Communication, task distribution, and time management should be extremely emphasized. Also, using the data from this year's competition and making additions and modifications for the next will ensure the continual growth of IUPUI's presence in the competition.

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Weight Reduction Includes:

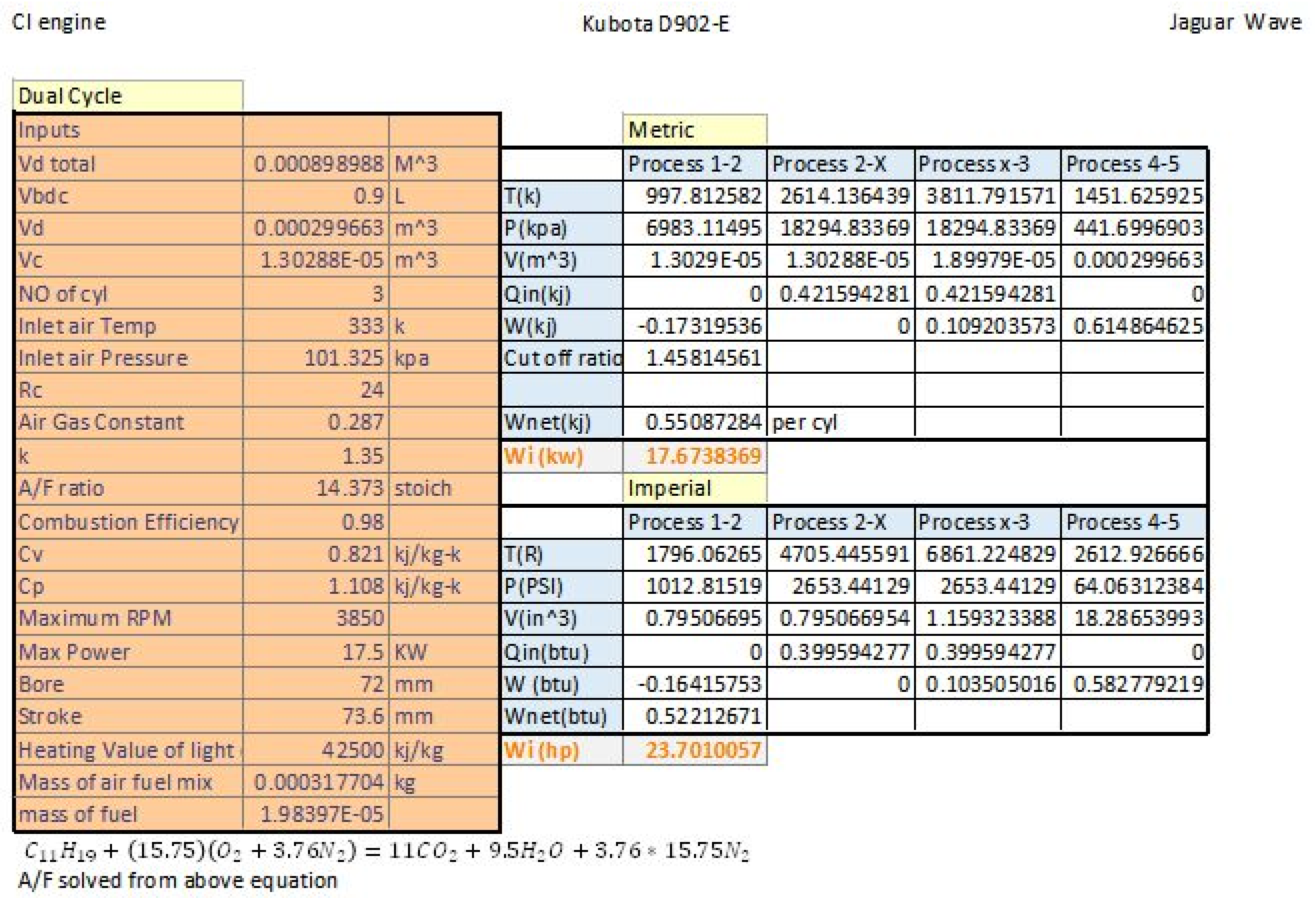
1. Carbon fiber frame rails
2. aluminum chassis
3. 155x15x2.4” series S.1 track
4. Reduced aluminum in engine bay

Handling Improvements:

Better Shock absorbers than adventure

Appendix

Appendix 1



CI engine | Kubota D902-E | Jaguar Wave

Dual Cycle		
Inputs		
Vd total	0.000898988	M^3
Vbdc	0.9	L
Vd	0.000299663	m^3
Vc	1.30288E-05	m^3
NO of cyl	3	
Inlet air Temp	333	k
Inlet air Pressure	101.325	kpa
Rc	24	
Air Gas Constant	0.287	
k	1.35	
A/F ratio	14.373	stoich
Combustion Efficiency	0.98	
Cv	0.821	kj/kg-k
Cp	1.108	kj/kg-k
Maximum RPM	3850	
Max Power	17.5	KW
Bore	72	mm
Stroke	73.6	mm
Heating Value of light	42500	kj/kg
Mass of air fuel mix	0.000317704	kg
mass of fuel	1.98397E-05	

Metric

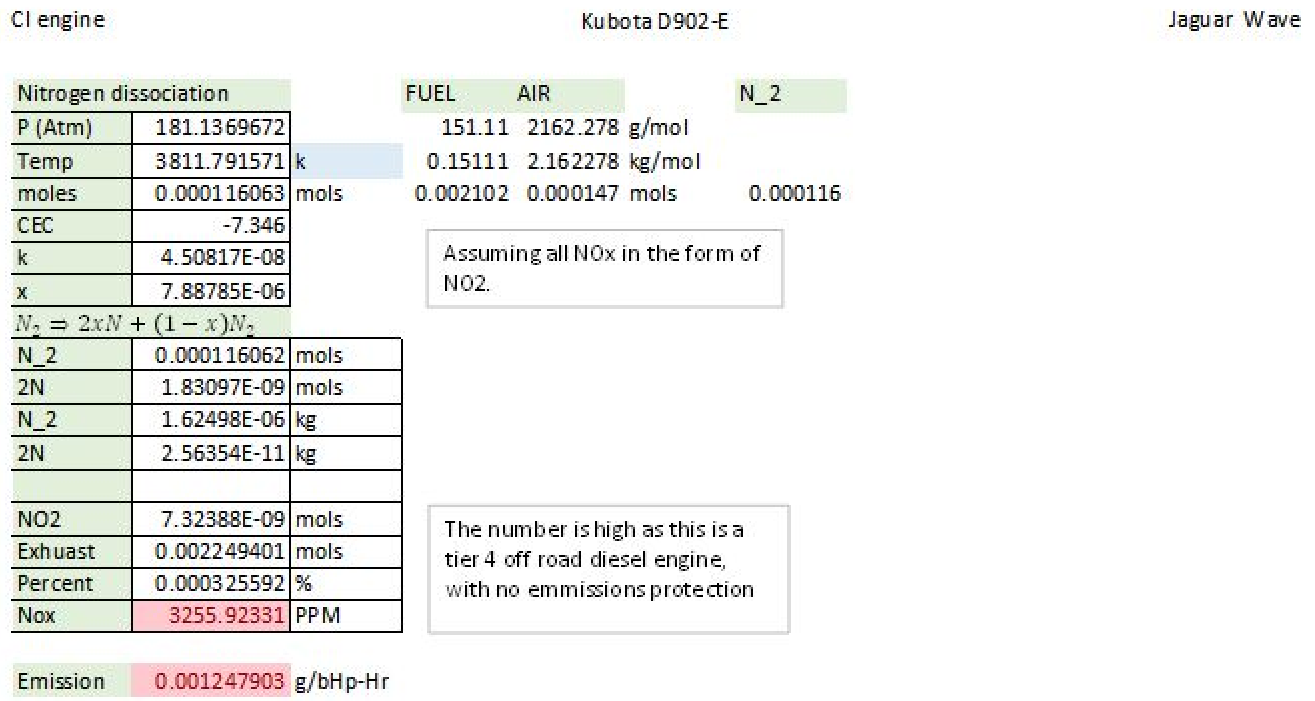
	Process 1-2	Process 2-X	Process x-3	Process 4-5
T(k)	997.812582	2614.136439	3811.791571	1451.625925
P(kpa)	6983.11495	18294.83369	18294.83369	441.6996903
V(m^3)	1.3029E-05	1.30288E-05	1.89979E-05	0.000299663
Qin(kj)	0	0.421594281	0.421594281	0
W(kj)	-0.17319536	0	0.109203573	0.614864625
Cut off ratio	1.45814561			
Wnet(kj)	0.55087284	per cyl		
Wi (kw)	17.6738369			

Imperial

	Process 1-2	Process 2-X	Process x-3	Process 4-5
T(R)	1796.06265	4705.445591	6861.224829	2612.926666
P(PSI)	1012.81519	2653.44129	2653.44129	64.06312384
V(in^3)	0.79506695	0.795066954	1.159323388	18.28653993
Qin(btu)	0	0.399594277	0.399594277	0
W (btu)	-0.16415753	0	0.103505016	0.582779219
Wnet(btu)	0.52212671			
Wi (hp)	23.7010057			

$C_{11}H_{19} + (15.75)(O_2 + 3.76N_2) = 11CO_2 + 9.5H_2O + 3.76 * 15.75N_2$

A/F solved from above equation



CI engine | Kubota D902-E | Jaguar Wave

Nitrogen dissociation		
P (Atm)	181.1369672	
Temp	3811.791571	k
moles	0.000116063	mols
CEC	-7.346	
k	4.50817E-08	
x	7.88785E-06	

$N_2 \Rightarrow 2xN + (1-x)N_2$

N_2	0.000116062	mols
2N	1.83097E-09	mols
N_2	1.62498E-06	kg
2N	2.56354E-11	kg
NO2	7.32388E-09	mols
Exhuast	0.002249401	mols
Percent	0.000325592	%
Nox	3255.92331	PPM

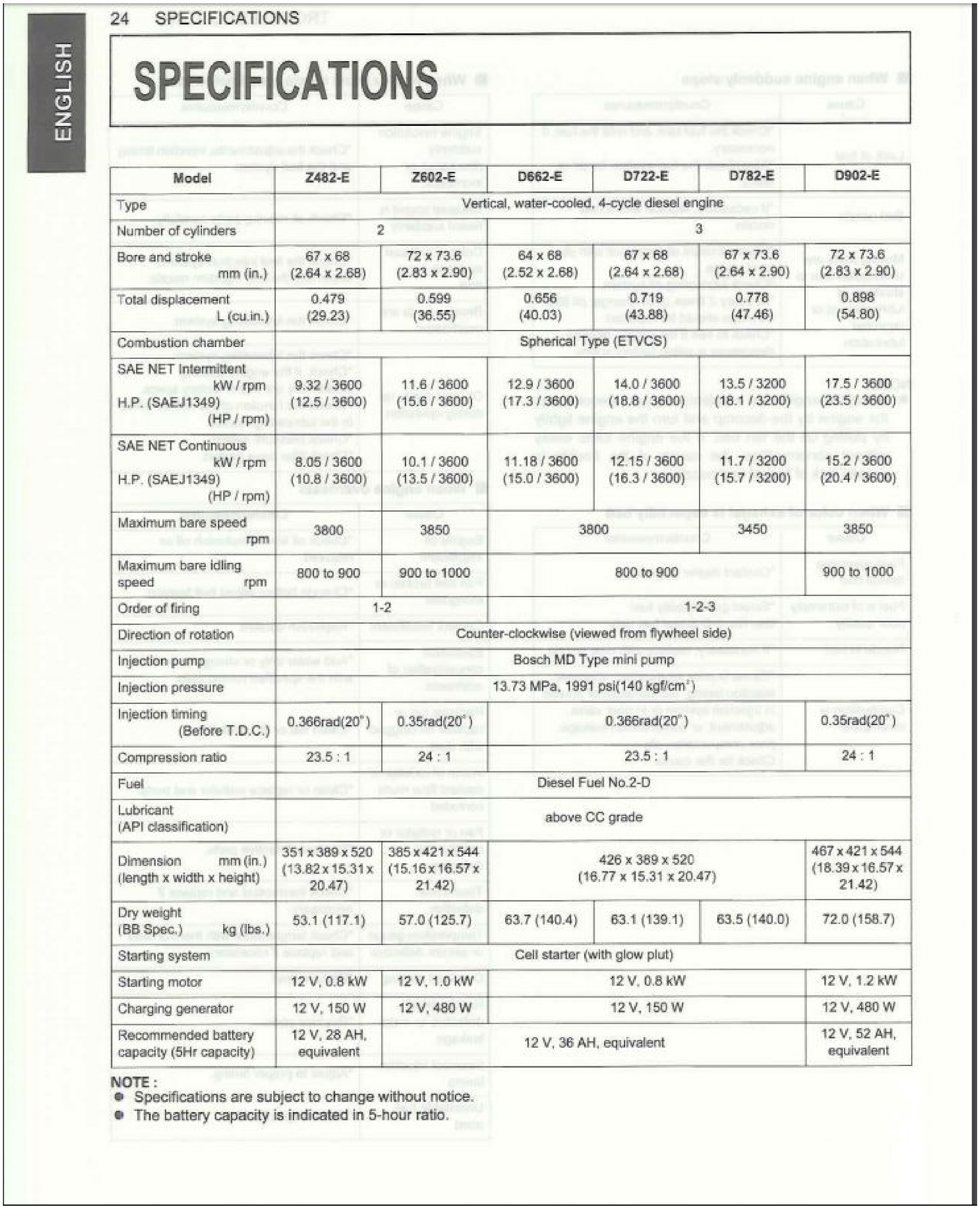
FUEL	AIR		N_2
151.11	2162.278	g/mol	
0.15111	2.162278	kg/mol	
0.002102	0.000147	mols	0.000116

Assuming all NOx in the form of NO2.

The number is high as this is a tier 4 off road diesel engine, with no emmissions protection

Emission 0.001247903 g/bHp-Hr

Appendix 2



SPECIFICATIONS

Model	Z482-E	Z602-E	D662-E	D722-E	D782-E	D902-E
Type	Vertical, water-cooled, 4-cycle diesel engine					
Number of cylinders	2		3			
Bore and stroke mm (in.)	67 x 68 (2.64 x 2.68)	72 x 73.6 (2.83 x 2.90)	64 x 68 (2.52 x 2.68)	67 x 68 (2.64 x 2.68)	67 x 73.6 (2.64 x 2.90)	72 x 73.6 (2.83 x 2.90)
Total displacement L (cu.in.)	0.479 (29.23)	0.599 (36.55)	0.656 (40.03)	0.719 (43.88)	0.778 (47.46)	0.898 (54.80)
Combustion chamber	Spherical Type (ETVCS)					
SAE NET Intermittent kW / rpm H.P. (SAEJ1349) (HP / rpm)	9.32 / 3600 (12.5 / 3600)	11.6 / 3600 (15.6 / 3600)	12.9 / 3600 (17.3 / 3600)	14.0 / 3600 (18.8 / 3600)	13.5 / 3200 (18.1 / 3200)	17.5 / 3600 (23.5 / 3600)
SAE NET Continuous kW / rpm H.P. (SAEJ1349) (HP / rpm)	8.05 / 3600 (10.8 / 3600)	10.1 / 3600 (13.5 / 3600)	11.18 / 3600 (15.0 / 3600)	12.15 / 3600 (16.3 / 3600)	11.7 / 3200 (15.7 / 3200)	15.2 / 3600 (20.4 / 3600)
Maximum bare speed rpm	3800	3850	3800		3450	3850
Maximum bare idling speed rpm	800 to 900	900 to 1000	800 to 900			900 to 1000
Order of firing	1-2		1-2-3			
Direction of rotation	Counter-clockwise (viewed from flywheel side)					
Injection pump	Bosch MD Type mini pump					
Injection pressure	13.73 MPa, 1991 psi(140 kgf/cm^2)					
Injection timing (Before T.D.C.)	0.366rad(20°)	0.35rad(20°)	0.366rad(20°)			0.35rad(20°)
Compression ratio	23.5 : 1	24 : 1	23.5 : 1			24 : 1
Fuel	Diesel Fuel No.2-D					
Lubricant (API classification)	above CC grade					
Dimension mm (in.) (length x width x height)	351 x 389 x 520 (13.82 x 15.31 x 20.47)	385 x 421 x 544 (15.16 x 16.57 x 21.42)	426 x 389 x 520 (16.77 x 15.31 x 20.47)			467 x 421 x 544 (18.39 x 16.57 x 21.42)
Dry weight (BB Spec.) kg (lbs.)	53.1 (117.1)	57.0 (125.7)	63.7 (140.4)	63.1 (139.1)	63.5 (140.0)	72.0 (158.7)
Starting system	Cell starter (with glow plut)					
Starting motor	12 V, 0.8 kW	12 V, 1.0 kW	12 V, 0.8 kW			12 V, 1.2 kW
Charging generator	12 V, 150 W	12 V, 480 W	12 V, 150 W			12 V, 480 W
Recommended battery capacity (5Hr capacity)	12 V, 28 AH, equivalent	12 V, 36 AH, equivalent				12 V, 52 AH, equivalent

NOTE :

- Specifications are subject to change without notice.
- The battery capacity is indicated in 5-hour ratio.