02-18-2019

CI 103

4-Stroke IDI Turbocharged Diesel Snowmobile Design Clean Snowmobile Challenge 2019

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École de technologie supérieure (ETS)

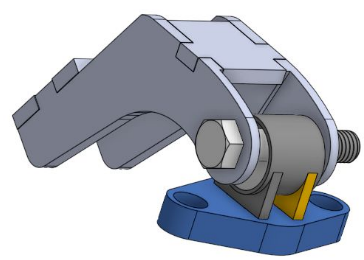
Introduction

Team QUIETS is proud to present our 2019 Clean Snowmobile Challenge submission for the DUC. This year, we took on the challenge of designing and building a second snowmobile. Seeing the growing interest for diesel powered UTVs, it seems inevitable that diesel utility snowmobiles will also appear on the market in the near future. With this in mind, we were set on showing the world our team's view of what a diesel snowmobile should be like. We believe that this new platform will open up a plethora of possibilities for future modifications and improvements. Many of the advantages of the diesel engine make it a great powertrain for a utility snowmobile - namely, the high torque output as well as low noise and great fuel economy. We also believe that this year's project is considerably more economically viable than its predecessors, as it relies more on readily available components and high-value modifications. We have accomplished a lot in a relatively short time, and we look forward to show our improvement at the CSC 2019.

Innovations

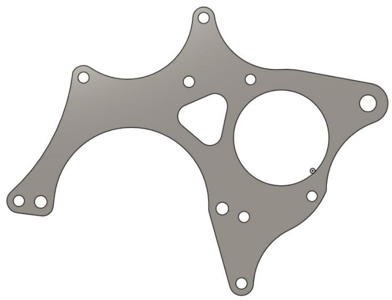
Flexible Engine Mounts

In response to the vibration issues we had using the second-generation mounts we designed last year, we have decided to severely re-design the engine mounts to include rubber bushings. We chose cylindrical shape dampener closely inspired from the automotive industry. This type of engine mount and material helped the team reduce vibration and movement caused by the running engine. To determine the maximum deformation and stress applied to the mounts, a finite element analysis was made. To make this analysis, the worst case scenario was used where 100% of the weight of the engine is on only one mount. The diesel engine weighs 80 kg (784.8 N), which is the force used to conduct the analysis. Below is a table with the FEA data. The results are very positive since geometrically, the engine mounts shapes provides better structural capabilities besides last generation.



Redesigned starter plate

With the new engine mounts design, the starter plate had to be optimized to give extra room to the new mounts. To achieve our goal, the starter has been relocated closer to the engine in order to fit the engine assembly as low as possible for upper clearance. New rear left engine mounts were designed to be fastened on the starter plate.



Exhaust System

We had issues with PM emissions last year due to the fact that we couldn't get our partial DPF hot enough to ensure proper passive regeneration. one of the main reasons is the excessive pipe length and diameter difference between the engine and the exhaust gas treatment system. The previous year configuration handled engine vibration very poorly. So we came up with a fully rigid manifold that also acts as the turbo mount. With this new configuration, we've addressed our exhaust leak problem from last year. We've moved the DOC as close as possible to the turbocharger and the DPF as close as possible to the DOC. The piping length has also been optimized to a minimum length without compromising flow. Exhaust insulation wrap is also used to minimize the heat within the exhaust system. These modifications should allow the DOC to reach its regeneration temperature of 300ºC and function properly throughout the competition.

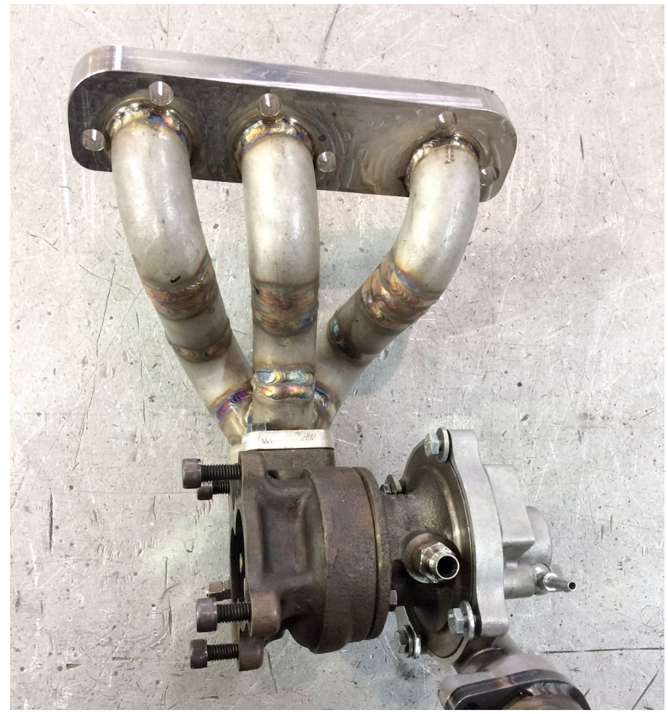


Figure 2. New Exhaust System

Air Intake Design

In an effort to reduce induction noise, we've decided to mimic what we've done successfully on our gasoline snowmobile for the past 2 years. We've designed an intake muffler that will help reduce the induction noise made by the turbo. The design is very similar to the one used on our IC snowmobile, which is a round canister in which a 1'' layer of sound insulation foam is glued to the walls. This very basic muffler has helped quiet down our gasoline engine significantly and we hope to achieve the same results on our diesel engine.

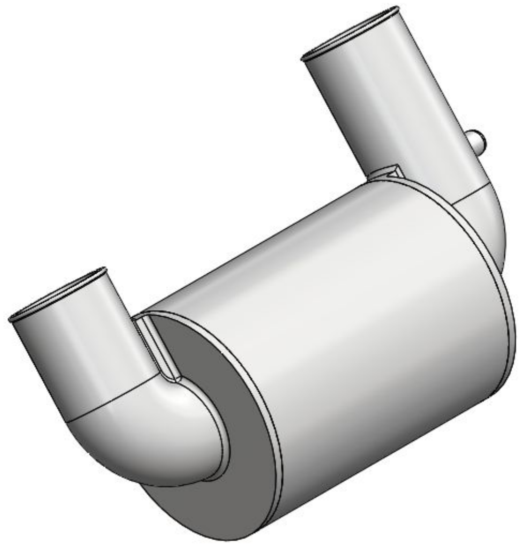


Figure 3. Intake Muffler Model

Exhaust After-Treatment

Even though our engine is EPA Tier IV compliant, it is not clean enough to score over 175 E-Score at the emissions event lab . This is mostly due to the fact that it does not come with any emission reduction equipment from the factory. As part of our emissions reduction strategy, we decided to fit two exhaust after-treatment solutions to our engine that work in conjunction with one another. The first one is a diesel oxidation catalyst that effectively converts up to 95% of carbon monoxide (CO) and hydrocarbons (HC) emissions when operated under lean conditions. Since a diesel engine operates lean by definition, this is a very potent emissions reduction device. An additional bonus of running a DOC is the oxidation of several other non-regulated pollutants such as aldehydes and PAHs. A DOC also contributes to reducing the typical diesel odor smell, making our snowmobile a more attractive choice for sensitive consumers.

A significant side effect of the DOC is that the oxidation reaction results in a high production of NO2, which is counted in the infamous NOx. Luckily, there is another after-treatment solution that uses this pollutant to oxidize particulate matter present in the exhaust. The partial flow diesel particulate filter is arranged in a way that diverts part of the exhaust flow into multiple metal fleece layers that store the particles. These particles are continuously oxidized when the exhaust gas temperature is above 300ºC, meaning that this system doesn't require active regeneration. This also means that the risk of clogging the filter is greatly reduced, making this a safer choice for the competition. The end result is a filtration efficiency that can reach 70% and a reduction of the harmful nanoparticles by almost 90%. Since part of the NO2 found in the exhaust is used for the regeneration of the filter, a noticeable reduction in total NOx is also typical.

Figure 4. DPF and DOC Used with our Kohler Engine

Another great advantage of this DPF is its versatility. Because it uses passive regeneration to eliminate particulate matter, it can be retrofitted to almost any application as long as a DOC is fitted upstream. Since the exhaust is only partially routed through the metal fleece layers, the increase in backpressure is minimal compared to a typical wall flow DPF. This results in a minimal efficiency and performance loss compared to an engine running without after-treatment, allowing us to make the most out of our engine.

Continuously Variable Transmission (CVT)

Since diesel engines have a lower maximum RPM than gasoline engines, we had to find a way to make the clutches work properly. We figured that working with a specialized company in this field would be easier for us instead of modifying the clutches by ourselves. This is why we've decided to work with CVtech-IBC, which is a well known company in the CVT industry and is based in Quebec.

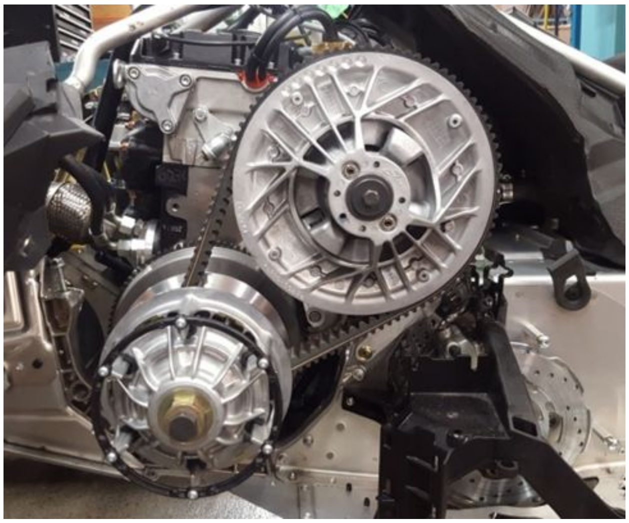


Figure 5. CVtech-IBC CVT

Prior to our arrangement, they had already developed a drive clutch specifically for the Kohler KDW1003. This meant that the clutch would work perfectly with the RPM range of our engine, which represents around 900 RPM at idle and 3600 RPM at rated power. We only had to adjust it to match the proper engine RPM at trail speed. Our goal was to maintain 35 mph around 2400 RPM, which is where the engine has the lowest BSFC. At this point, the engine develops most of its torque on its own. With the addition of the turbocharger, this operating condition should shift slightly lower and be close to ideal for trail riding. This will help us to maintain the required trail speed at a lower RPM.

For the driven clutch and the belt, we've decided to complete the package with standard component from CVtech because they have been designed to work together. This meant that we had to position the engine in the chassis to match the correct belt length and to have the proper clutch offset.

Team Organization and Time Management

Throughout the season, 1h progress meetings were held every other week to keep track of objectives as well as to discuss issues and project ideas. An initial timeline was planned, and a Gantt chart was made to help visualize time constraints. The Gantt chart is presented in appendix A. Table 1 shows team structure.

Table 2. Team Structure

Member	Role
Edouard Levesque	Team Captain
Jean-Daniel Meyer	Interim Captain
Mathieu Bisson	DUC everyday operations oversight
Jean-Daniel Meyer	IC everyday operations oversight

Snowmobile Description

Chassis

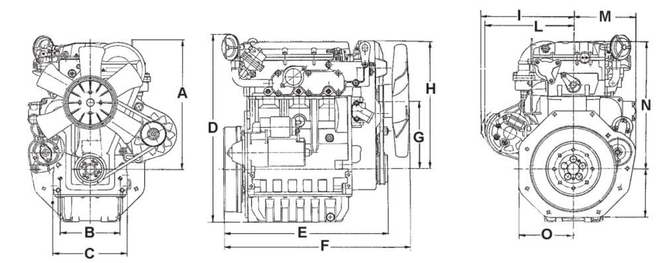
BRP Ski-Doo Tundra Sport 2017

Engine

Table 3. Engine Specifications

Manufacturer	Kohler
Model	KDW 1003
Fuel	Diesel
Type	4 stroke
Displacement	1028 cc
Peak Horsepower	40hp (estimated)
Induction	Turbocharged

We've decided to choose a proven platform with tremendous potential: the Kohler KDW1003 IDI 3 cylinders 1000cc mechanically injected engine. This is the same engine available in the diesel UTV made by Polaris as well as in many light duty applications. It sports unit injectors for precise fuel control and ease of adjustment, a cast iron block, an aluminum cylinder head and glow plugs that allow the engine to start and operate at temperatures as low as -30ºC. It is also capable of operating on Biodiesel up to B20 without any modifications — an important consideration for us. As seen below, the KDW1003 is only slightly larger than the BRP 1200 4-Tec engine which is widely used in this platform. This meant that this engine would require minimal frame modifications to fit.



COPPA OLIO STANDARD IN LAMIERA - CARTER D'HUILE EN TÔLE STANDARD - SHEET METAL STANDARD OIL SUMP - STANDARD BLECHÖLWANNE - CÁRTER DE ACEITE STANDARD EN PLANCHA - CÁRTER DE ÓLEO STANDARD EM CHAPA

DIMENSIONS mm (in.) - DIMENSIONI mm - MESURES mm - EINBAUMAßE mm - DIMENSIONE mm - DIMENÇÕES mm													
A	359 (14.13)	C	204 (8.03)	E	450 (17.72)	G	186 (7.32)	I	269.2 (10.6)	M	169.5 (6.67)	O	150 (5.90)
B	165 (6.5)	D	515.5 (20.3)	F	510 (20.08)	H	351.5 (13.84)	L	242.5 (9.54)	N	484.5 (19.07)		

Figure 6. Diesel Engine Dimensions

The graph below shows the power (NA), torque output (MA) and brake specific fuel consumption (C) of the engine in its stock configuration.

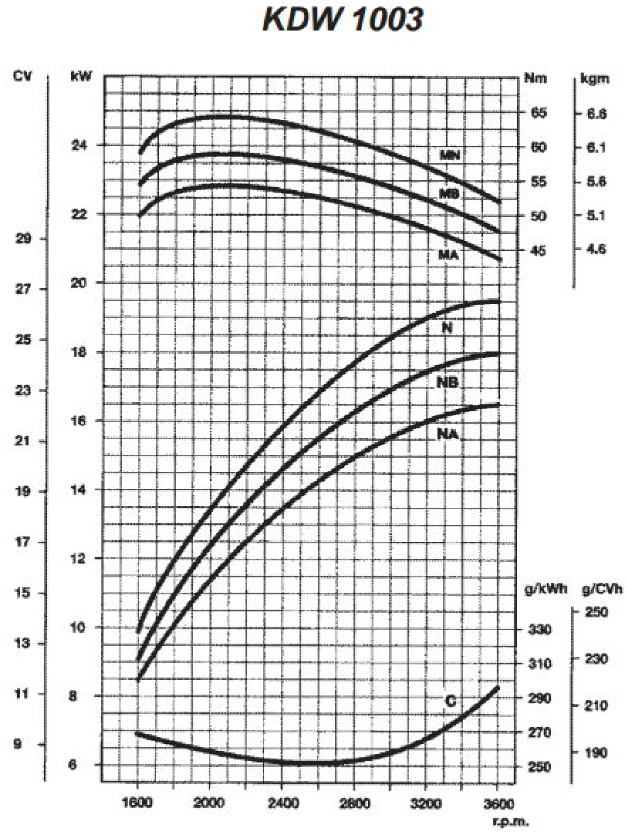


Figure 7. Power, Torque and BSFC of the Kohler KDW1003

As seen on the graph above, the best BSFC in the stock configuration is 250 g/kW-hr, an impressive figure for a mechanically injected engine. We hope that by adding a turbocharger, we can achieve even better fuel economy.

Track

Camso Ice Ripper XT 137 in

Muffler

OEM 900 ACE

Catalytic Converter

Emitec DOC, 400 cpsi, 4” dia. x 6” long

Diesel Particulate Filter

4.5” dia x 4.13” long

Skis

BRP Pilot DS2

Suspension

The LTS front suspension is the typical front suspension offered by BRP for their utility snowmobiles. They are easy to adjust and work with compared to conventional trail suspension because the only thing you can adjust is the preload of the springs. This reduces the versatility of the suspension but the dampening is usually acceptable for a utility snowmobile. We've decided to change the springs for stiffer ones because of the extra weight of the diesel engine, turbo and other modifications in the front part of the snowmobile. The compression rate of the new springs is 90lbs/in which is almost 30% stiffer than the stock ones. We also added a *Stability and Turning Enhancement Kit* offered by Qualipieces as shown on *Figure 8.*

Figure 8, Stability and Turning Enhancement Kit

This system increases the ski stance by 4" and moves them forward by ¾" to improve the stability of the snowmobile in trail. It should also help at the handling event of the competition. It raises the front of the snowmobile 3" compared to the stock setup. This allow us to have a better weight transfer to the track to have more traction and less resistance from the skis on the snow for a better fuel consumption.

S-Module Re-Design

Because of its additional height and depth, we had to modify the frame to suit the new engine. The two OEM alloys tubes forming the S-Module are 1.00 inch OD with 0.065 inch wall. These would interfere with the engine so they had to be re-designed. FEA (finite element analysis) was done on Ansys with a force of 3400 N. This force was found by calculating the breaking force of the OEM parts and considering a safety factor of about 2. Results show a safety factor of 2.23 and 112 MPa of stress as shown in figures 9 and 10.

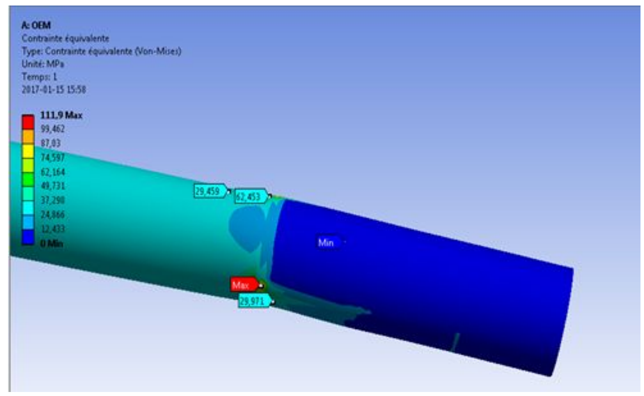


Figure 9. Maximum Stress of the OEM Part

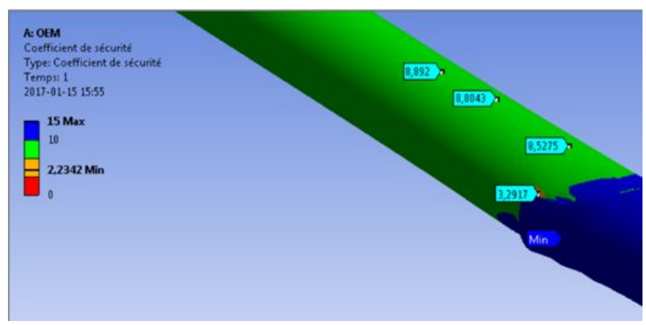


Figure 10. Safety Factor of the OEM Part

We used a special design to keep the air box fixed to the frame without changing any parts. The team also aimed for a stronger design because of the additional weight from the diesel engine. After many FEA tests, a 1.00 inch od with 0.250 inch wall gave interesting result as shown in figures 11 and 12. The new tubes have a security factor of 3.34, an increase of 150 % from the OEM part. The stress in the tubes decreased to 75 MPa. The new design is now stronger, more resistant and most importantly, it allows the engine to fit in the chassis.

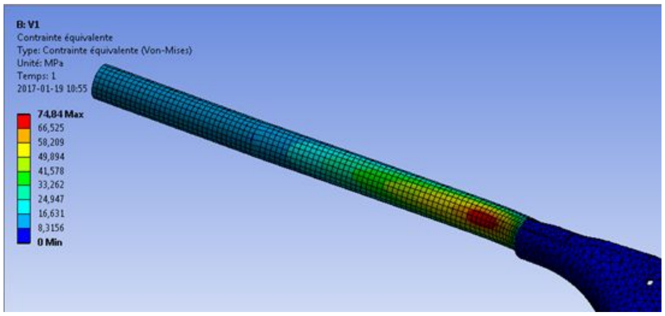


Figure 11. Maximum Stress of the New Part

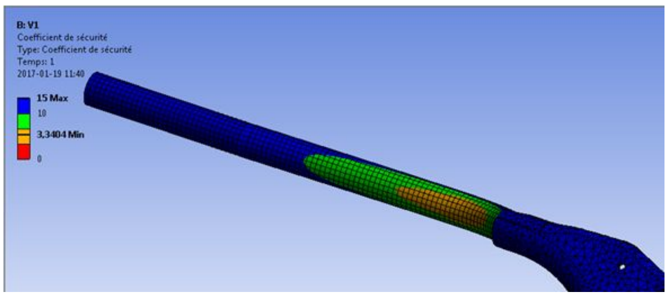


Figure 12. Safety Factor of the New Part

We had the parts professionally welded to ensure maximum strength and durability. The result fits the frame perfectly and allows our engine to sit comfortably in place with plenty of room to work around it. It also integrates seamlessly because the body panels fit without modifications.

Figure 13. New vs OEM S-Module

Steering Stem Re-Design

We had to modify the shape of the steering stem to avoid interference with the valve cover of the diesel engine. The new power plant is bigger and larger than the original, so the original shape of the steering stem was hitting the valve cover as soon as we were turning the bars. We had to move the radius earlier and make it bigger to retain as much steering angle as possible.

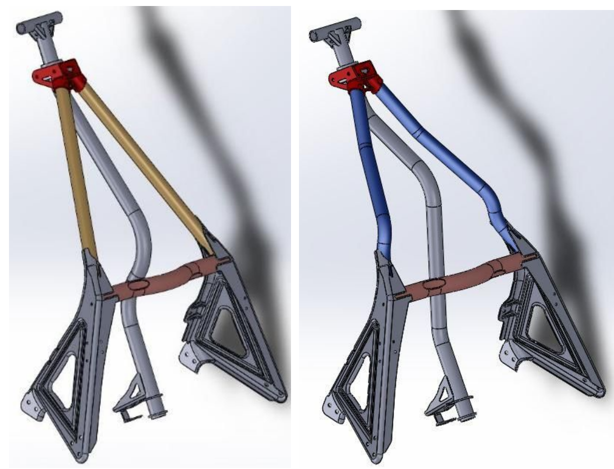


Figure 14. OEM Steering Shaft and S-Module vs New Parts

Originally, the Tundra bars could turn to 48 degrees at maximum. With the diesel engine, the modification of the frame and the new steering stem shape, we were able to achieve 45 degrees of turning angle.

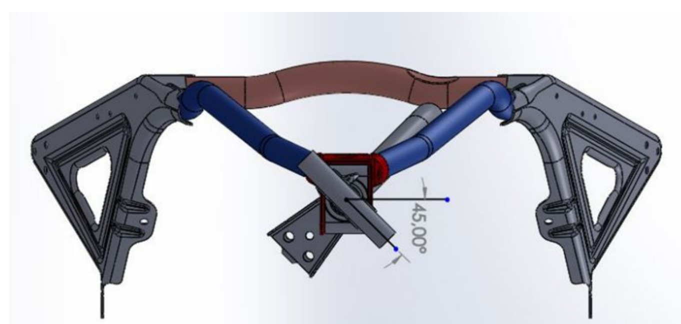


Figure 15. Steering Angle of the Re-Designed Steering Stem

We took the original ends of the steering stem and we welded them to the new steering stem with some inserts that we added inside. Below is a picture to compare both of the steering stem shapes. In black is the original one and in silver the new one.

Figure 16. OEM vs New Steering Tube

Summary/Conclusions

Our new endeavor, the diesel-powered Tundra is a great project that's aimed at proving the need for DUC snowmobiles in today's market. By offering great low-end torque, low fuel consumption and good work characteristics, a snowmobile of this kind makes for a great replacement to a UTV for winter outdoor work. Our team's vehicle is quiet, efficient and reliable, which makes it a robust alternative. The perfect transmission match and upgraded suspension makes it a great trail sled as well, showing the multiple capabilities of this vehicle. We look forward to hearing feedback from the judges and riders this first year, as we strive to improve the upcoming prototypes.

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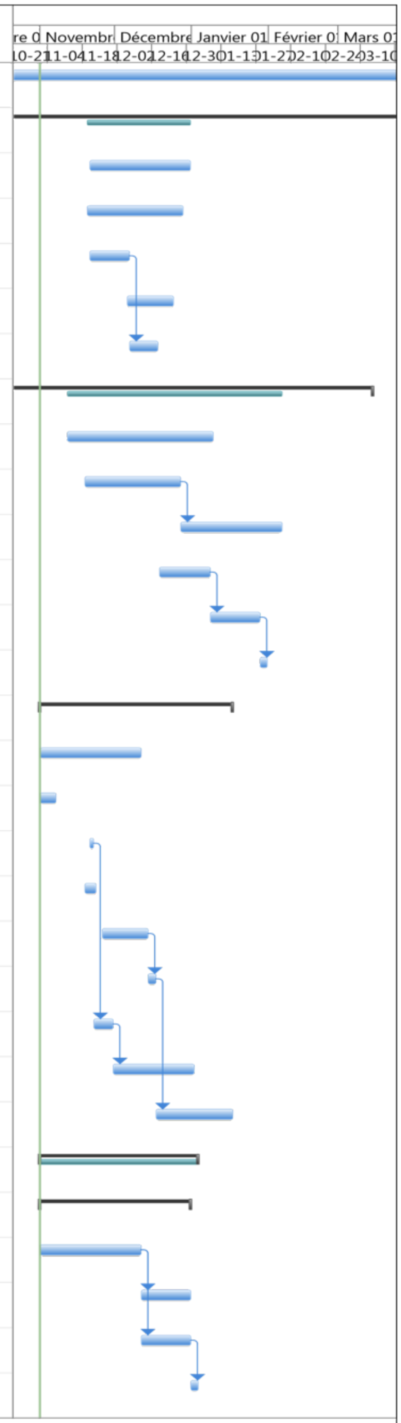
Definitions/Abbreviations

CO	Carbon monoxide
HC	Hydrocarbon
NOx	Nitrogen oxides
DPF	Diesel Particulate Filter
DOC	Diesel Oxidation Catalyst
PM	Particulate matter
OEM	Original Equipment Manufacturer

Appendix A

Gantt Chart

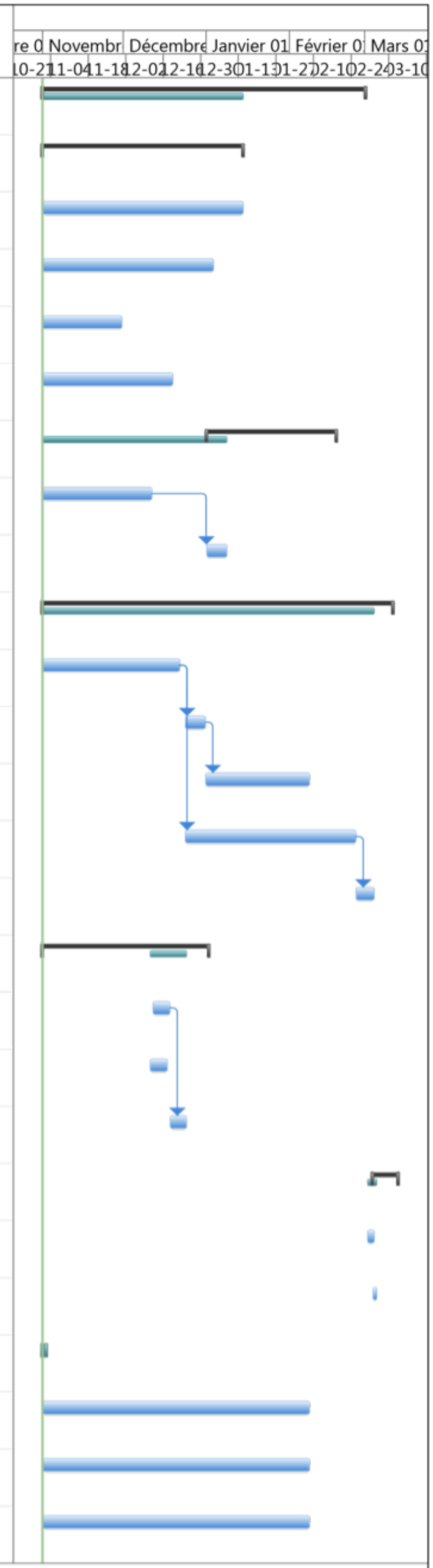
N°		Mode Tâche	Nom de la tâche	Durée	Début
1			Début session H-18	128,1 jours	Mar 18-09-04
2			**Moteur HPDI**	**221,6 jours**	**Mar 18-09-04**
3			Fabrication support pompe V2	1 mois	Mer 18-11-21
4			Fabrication tête V3 (commandite)	1 mois	Mar 18-11-20
5			Achat pièces backup	8,4 jours	Mer 18-11-21
6			Fabrication Cam V2	9 jours	Jeu 18-12-06
7			Remonter Base 600ACE	5 jours	Ven 18-12-07
8			**Moteur diesel**	**98,7 jours**	**Sam 18-09-01**
9			Commande turbo 2019	30 jours	Lun 18-11-12
10			Layout couette motec m400	20 jours	Lun 18-11-19
11			Fabrication couette motec	20 jours	Jeu 18-12-27
12			Dessin support moteur V3	10 jours	Mer 18-12-19
13			Découpe support moteur V3	10 jours	Mar 19-01-08
14			Test support moteur dans XU	2 jours	Lun 19-01-28
15			**Dyno 2.0**	**38,9 jours?**	**Jeu 18-11-01**
16			Assemblage panneau 2.0	20 jours	Jeu 18-11-01
17			Installation moteur 600 stock	3 jours	Jeu 18-11-01
18			Départ dyno 600 ace stock	1 jour?	Mer 18-11-21
19			Dyno 600 ACE stock	3 jours	Lun 18-11-19
20			Montage moteur diesel sur dyno	10 jours	Lun 18-11-26
21			Début du dyno diesel	1 jour?	Ven 18-12-14
22			Montage 600 HPDI sur dyno	4 jours	Jeu 18-11-22
23			Dyno 600 HPDI	16 jours	Ven 18-11-30
24			Dyno diesel	16 jours	Lun 18-12-17
25			**Suspension arrière**	**32 jours**	**Jeu 18-11-01**
26			**Anti stab variable**	**30 jours**	**Jeu 18-11-01**
27			Fin de conception	20 jours	Jeu 18-11-01
28			Envoi à la découpe des pièces	10 jours	Mar 18-12-11
29			Tournage des pièces	10 jours	Mar 18-12-11
30			Instalation sur banc de test	2 jours	Lun 18-12-31



Page 1

Gantt Chart (continued)

N°		Mode Tâche	Nom de la tâche	Durée	Début
31			**Électronique**	**60,5 jours**	**Jeu 18-11-01**
32			**Nouveau cadran de bord HPDI**	**37 jours**	**Jeu 18-11-01**
33			debug écran E-Controls	37 jours	Jeu 18-11-01
34			Modification interface	32 jours	Jeu 18-11-01
35			Lecture du signal CAN du Motec	15 jours	Jeu 18-11-01
36			Connection GPS	24 jours	Jeu 18-11-01
37			**Kit graphique**	**24 jours**	**Mar 19-01-01**
38			Achat nouveaux plastiques	20 jours	Jeu 18-11-01
39			Kit graphique	4 jours	Mar 19-01-01
40			**Embrayage EVT**	**65,6 jours?**	**Jeu 18-11-01**
41			Révision conception Mécanique	25,9 jours?	Jeu 18-11-01
42			Achat des composants standards	4 jours	Lun 18-12-24
43			Fabrication des pièces sur mesure	20 jours	Lun 18-12-31
44			Programmation	32 jours	Lun 18-12-24
45			Essai sur banc de test acoustique	4 jours	Lun 19-02-25
46			**Assemblage prototype**	**30,8 jours**	**Jeu 18-11-01**
47			Diesel	3 jours	Mer 18-12-12
48			Essence	3 jours	Mar 18-12-11
49			essai sur neige	3 jours	Mar 18-12-18
50			**Compétition**	**5,2 jours?**	**Lun 19-03-04**
51			Départ	1 jour?	Sam 19-03-02
52			Retour	1 jour?	Lun 19-03-04
53			**Nouveau prototype (pour comp. 2020)**	1 jour?	Jeu 18-11-01
54			Choix du moteur 2020	50 jours	Jeu 18-11-01
55			Choix du ECU 2020	50 jours	Jeu 18-11-01
56			Choix de la plateforme 2020 (Essence)	50 jours	Jeu 18-11-01



Appendix B

Turbo Match Data (Compressor Map)