4-Stroke IDI Turbocharged Diesel Snowmobile Design Clean Snowmobile Challenge 2018

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Introduction

Team QUIETS is proud to present our 2018 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 2018.

Innovations

Drive By Wire

One of the major aspects of last year's prototype that needed attention is the accelerator control. Due to a lack of time, we had to resort to using a cable driven throttle lever. Because the engine we are using is mostly found in stationary applications, the amount of force required to actuate the injection system is not well suited to a thumb-actuated lever. The amount of force required to maintain a steady speed is ridiculously high, causing arm pain after only a few minutes of driving. Therefore, we have decided to solve this problem by converting the acceleration input system to a drive by wire or electronic throttle control system. We have done so by using a high torque servo motor placed directly on the governor's lever using cnc machined parts that we've designed and welded together. The cable throttle lever has been replaced with an electronic lever as found on newer BRP Ski-Doo snowmobiles. Control is done using an Arduino microcontroller and the software was designed in house. The result is a smoother clutch engagement and less arm fatigue. Figure 1 shows the servo motor assembly as installed on the vehicle.

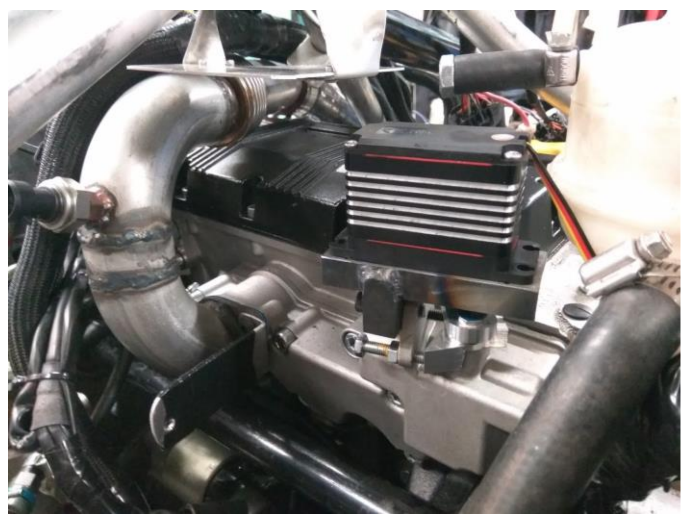


Figure 1. Drive By Wire Servo Motor Assembly

Turbocharger Improvement

In response to the poor turbo match we had last year, we've decided to team up with Borg-Warner to find the optimal compromise between spool time, low end torque and drivability, as we consider these the most important criteria for a diesel utility snowmobile. We have chosen an oil cooled KP35 turbocharger. The result is a better performing engine that makes more power throughout its entire operation range. Appendix B shows the turbo match data.

Flexible Engine Mounts

In response to the vibration issues we had using the solid mounts we designed last year, we have decided to re-design the engine mounts to include rubber bushings. We chose 0.250” A36 water cut steel welded in a box shape to optimize its strength and minimize its deformation under stress. 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 make the analysis. Below is a table with the FEA data. The results are very promising as the engine vibrations are barely noticeable compared to the solid mounts we had last year.

Table 1. Maximum Stress, Deformation and Safety Factor of the Four Engine Mounts

	Front left	Front right	Rear left	Rear right
Maximum Deformation (mm)	0.167	0.045	0.0113	0.0025
Maximum Stress (MPa)	131.77	64.5	33.76	18.561
Safety Factor	1.9	3.87	7.4	13.47

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. This was in part due to the excessive diameter of the exhaust tube, the distance between the DOC and the DPF as well as the improper turbo selection. We’ve addressed all of these issues by replacing the turbo and redesigning the exhaust system. 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 reduced to a minimum. Exhaust insulation wrap will also be used to contain the heat within the exhaust system. These modifications should allow the DOC to reach its regeneration temperature of 300^{o}C 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 layer of 1” 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.

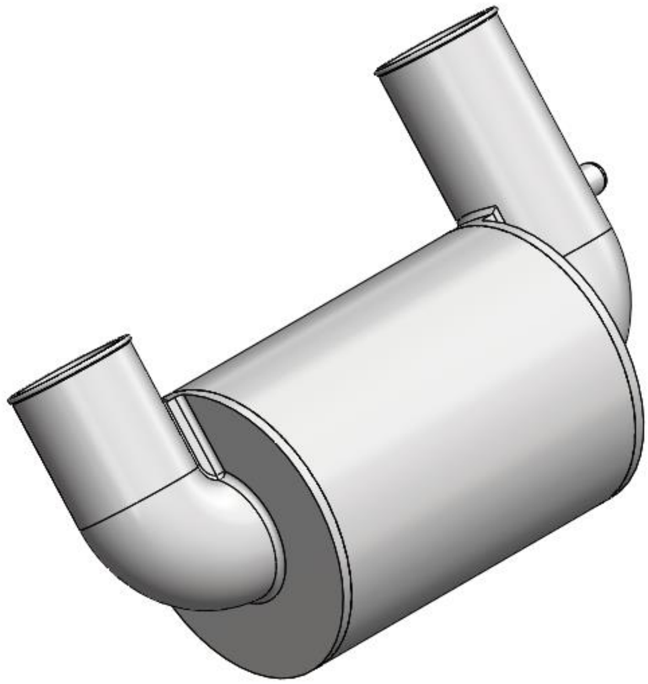


Figure 3. Intake Muffler Model

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 lab emissions event. 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 that is based in Quebec.

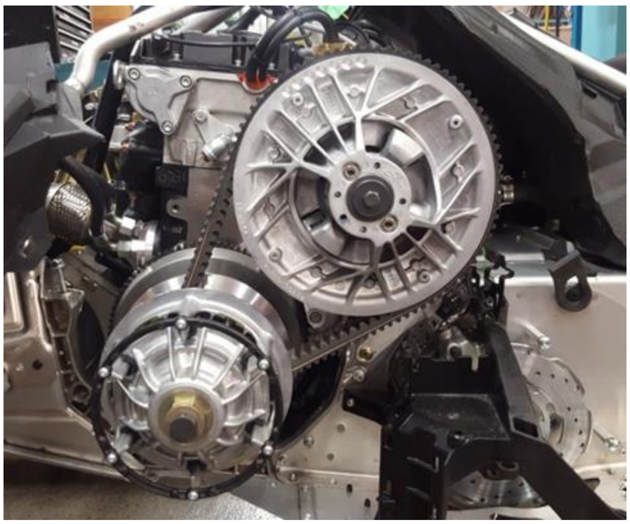


Figure 5. CVtech-IBC CVT

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**
Guillaume Verner	Team Captain
Edouard Levesque	Interim Captain
Dominic Mathieu	DUC everyday operations oversight
Pierre-Olivier Langlois	IC everyday operations oversight

Snowmobile Description

Chassis

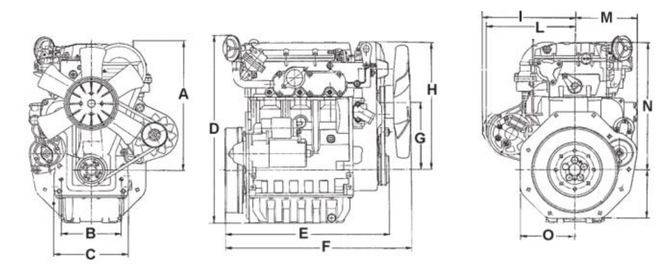
BRP Ski-Doo Tundra Sport 2017

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.

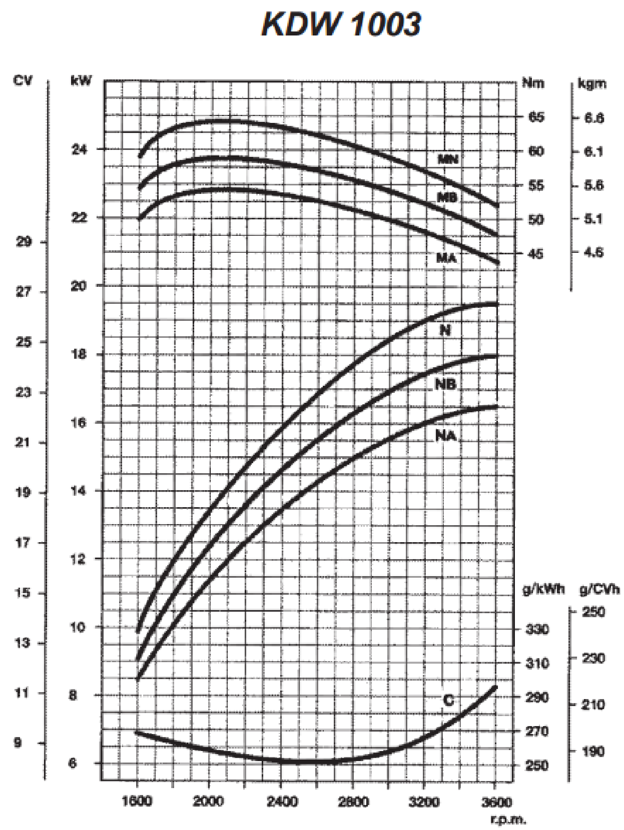


Figure 7. Power, Torque and BSFC of the Kohler KDW1003

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.

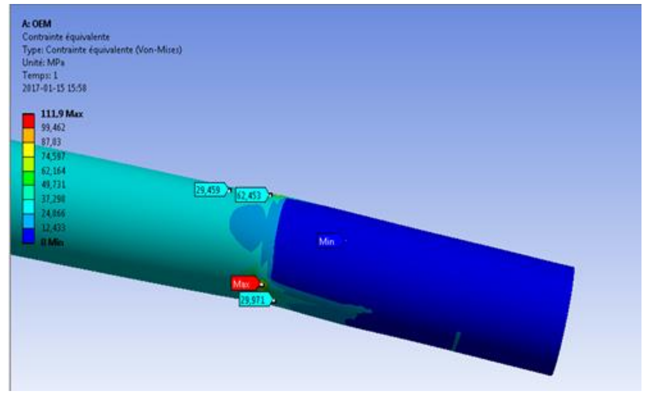


Figure 9. Maximum Stress of the OEM Part

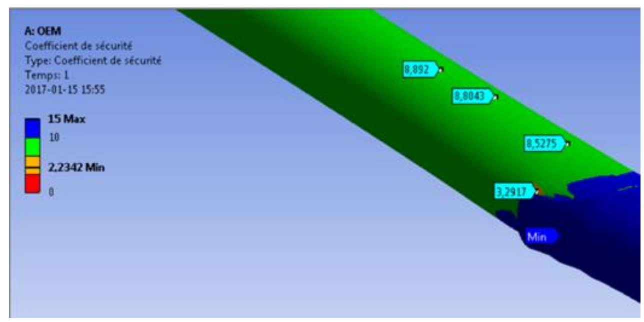


Figure 10. Safety Factor of the OEM Part

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.

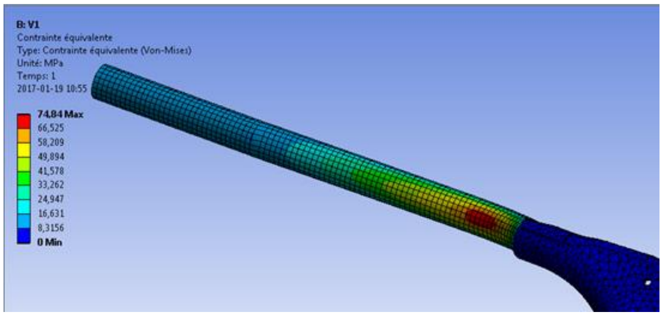


Figure 11. Maximum Stress of the New Part

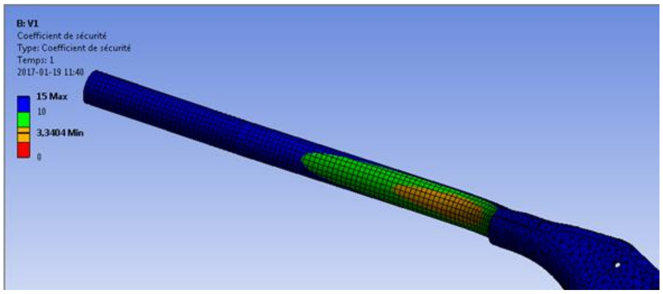


Figure 12. Safety Factor of the New Part

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.

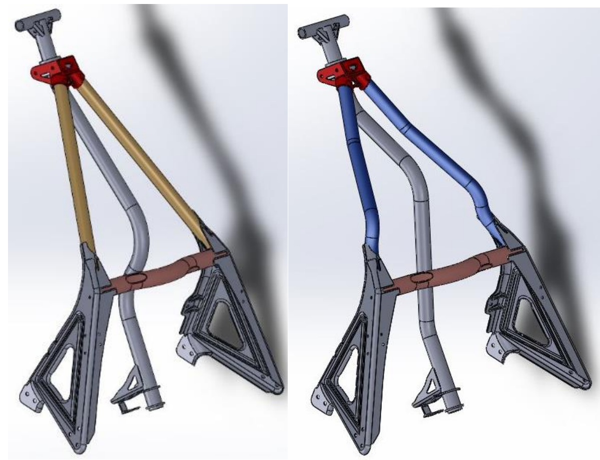


Figure 14. OEM Steering Shaft and S-Module vs New Parts

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.

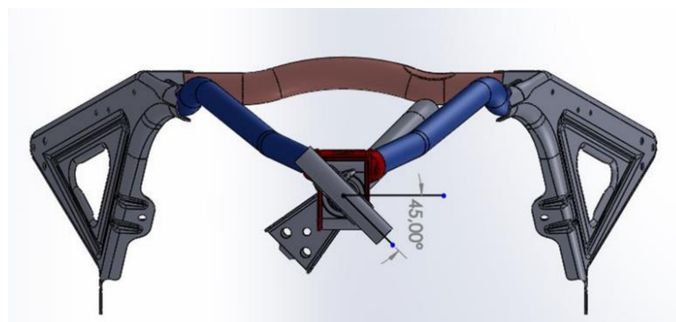


Figure 15. Steering Angle of the Re-Designed Steering Stem

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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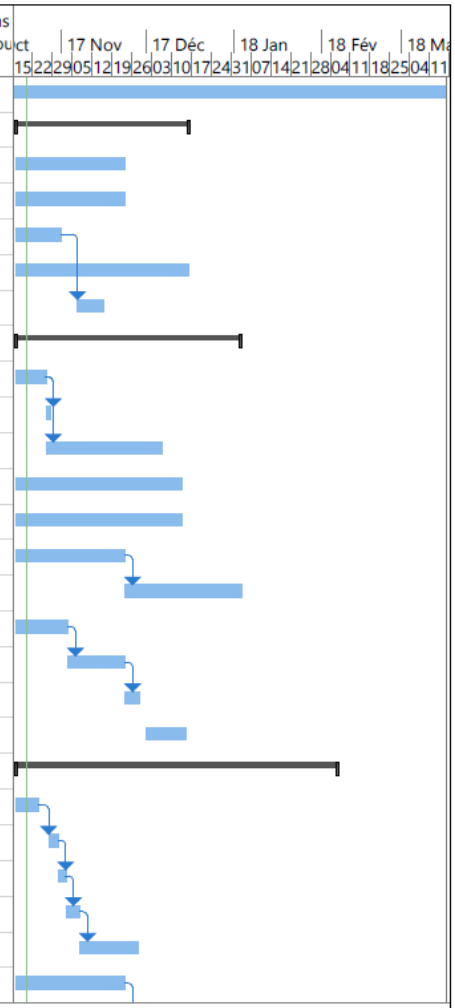
Definitions/Abbreviations

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

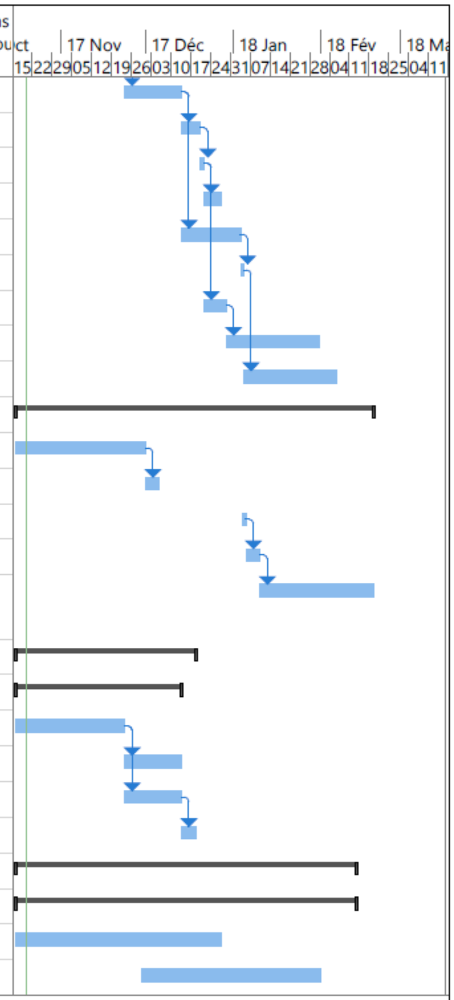
N°		Mod Tâch	Nom de la tâche	Durée	Début	Fin	Préd	Noms ressou
1			Début session H-17	98,7 jours	Ven 17-09-01	Ven 18-03-16		
2			**Moteur HPDI**	**31,5 jours**	**Lun 17-10-16**	**Ven 17-12-15**		
3			Fabrication support pompe V2	1 mois	Lun 17-10-16	Jeu 17-11-23		
4			Fabrication tête V2 (commandite)	1 mois	Lun 17-10-16	Jeu 17-11-23		
5			Achat pièces backup	8,4 jours	Lun 17-10-16	Mar 17-10-31		
6			Fabrication Cam V2	31,5 jours	Lun 17-10-16	Ven 17-12-15		
7			Remonter Base 600ACE	5 jours	Lun 17-11-06	Mer 17-11-15	5	
8			**Moteur diesel**	**40 jours?**	**Lun 17-10-16**	**Mer 18-01-03**		
9			Démonter injecteur	6 jours	Lun 17-10-16	Jeu 17-10-26		
10			Contacter fournisseur	1 jour?	Jeu 17-10-26	Ven 17-10-27	9	
11			Trouver solution injecteur	20 jours	Jeu 17-10-26	Mer 17-12-06	9	
12			Commander servomoteur	30 jours	Lun 17-10-16	Mer 17-12-13		
13			Commande turbo	30 jours	Lun 17-10-16	Mer 17-12-13		
14			Layout couette motec m400	20 jours	Lun 17-10-16	Jeu 17-11-23		
15			Fabrication couette motec	20 jours	Jeu 17-11-23	Mer 18-01-03	14	
16			Dessin support moteur V2	10 jours	Lun 17-10-16	Ven 17-11-03		
17			Découpe support moteur V2	10 jours	Ven 17-11-03	Jeu 17-11-23	16	
18			Test support moteur dans XU	2 jours	Jeu 17-11-23	Mar 17-11-28	17	
19			Remontage moteur diesel	7 jours	Ven 17-12-01	Jeu 17-12-14		
20			**Dyno 2.0**	**57 jours?**	**Lun 17-10-16**	**Mar 18-02-06**		
21			Découpe plaque support moteur	4,2 jours	Lun 17-10-16	Lun 17-10-23		
22			Soudage des supports	1 jour	Ven 17-10-27	Lun 17-10-30	21	
23			Montage sur banc de test	2 jours	Mar 17-10-31	Jeu 17-11-02	22	
24			Montage réservoir d'essence/fuel	2 jours	Jeu 17-11-02	Mar 17-11-07	23	
25			Fabrication ligne à essence	10 jours	Mar 17-11-07	Lun 17-11-27	24	
26			Assemblage panneau 2.0	20 jours	Lun 17-10-16	Jeu 17-11-23		



Page 1

Gantt Chart (continued)

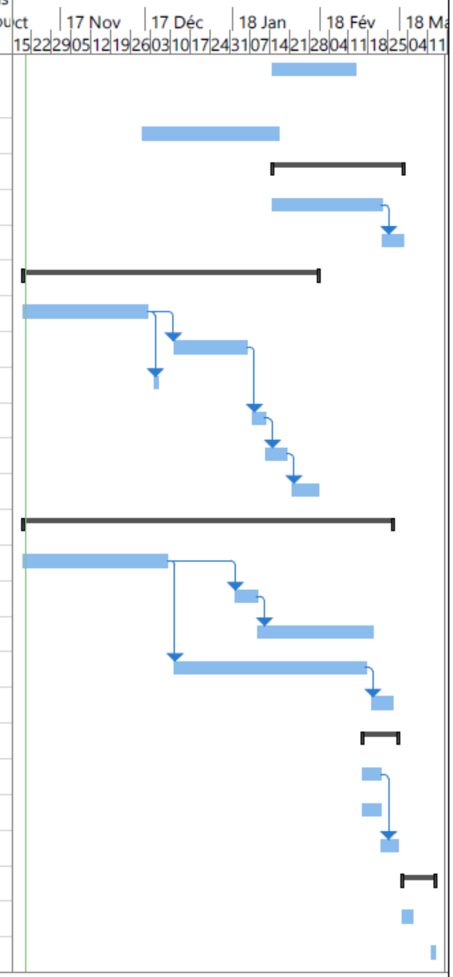
N°		Mod Tâch	Nom de la tâche	Durée	Début	Fin	Préd	Noms ressou
27			Pose du panneau sur banc de test	10 jours	Jeu 17-11-23	Mer 17-12-13	26	
28			Installation moteur 600 stock	3 jours	Mer 17-12-13	Mer 17-12-20	27	
29			Départ dyno 600 ace stock	1 jour?	Mer 17-12-20	Jeu 17-12-21	28	
30			Dyno 600 ACE stock	3 jours	Jeu 17-12-21	Mer 17-12-27	29	
31			Montage moteur diesel sur dyno	10 jours	Mer 17-12-13	Mer 18-01-03	27	
32			Début du dyno diesel	1 jour?	Mer 18-01-03	Jeu 18-01-04	31	
33			Montage 600 HPDI sur dyno	4 jours	Jeu 17-12-21	Ven 17-12-29	29	
34			Dyno 600 HPDI	16 jours	Ven 17-12-29	Mer 18-01-31	33	
35			Dyno diesel	16 jours	Jeu 18-01-04	Mar 18-02-06	32	
36			**Remontage banc de test acoustique**	**63,6 jours**	**Lun 17-10-16**	**Lun 18-02-19**		
37			Fabrication nouveau garde poulie	23,8 jours	Lun 17-10-16	Jeu 17-11-30		
38			Instalation garde poulie	2 jours	Ven 17-12-01	Mar 17-12-05	37	
39			Mise en marche banc de test	1 jour	Jeu 18-01-04	Ven 18-01-05		
40			Test de son Barbottin/Chaincase	2 jours	Ven 18-01-05	Mer 18-01-10	39	
41			Test son des nouvelles composantes	1 mois	Mer 18-01-10	Lun 18-02-19	40	
42			**Suspension arrière**	**32 jours**	**Lun 17-10-16**	**Lun 17-12-18**		
43			**Anti stab variable**	**30 jours**	**Lun 17-10-16**	**Mer 17-12-13**		
44			Fin de conception	20 jours	Lun 17-10-16	Jeu 17-11-23		
45			Envoi à la découpe des pièces	10 jours	Jeu 17-11-23	Mer 17-12-13	44	
46			Tournage des pièces	10 jours	Jeu 17-11-23	Mer 17-12-13	44	
47			Instalation sur banc de test	2 jours	Mer 17-12-13	Lun 17-12-18	46	
48			**Électronique**	**60,5 jours**	**Lun 17-10-16**	**Mar 18-02-13**		
49			**Nouveau cadran de bord HPDI**	**60,5 jours**	**Lun 17-10-16**	**Mar 18-02-13**		
50			Création interface motoneige	37 jours	Lun 17-10-16	Mer 17-12-27		
51			Modification interface	32 jours	Mer 17-11-29	Mer 18-01-31		



Page 2

Gantt Chart (continued)

N°		Mode Tâche	Nom de la tâche	Durée	Début	Fin	Préd	Noms ressources
52			Connection avec couette file HPDI	15 jours	Lun 18-01-15	Mar 18-02-13		
53			Connection GPS	24 jours	Jeu 17-11-30	Mer 18-01-17		
54			**Kit graphique**	**24 jours**	**Lun 18-01-15**	**Ven 18-03-02**		
55			Achat nouveaux plastiques	20 jours	Lun 18-01-15	Jeu 18-02-22		
56			Kit graphique	4 jours	Jeu 18-02-22	Ven 18-03-02	55	
57			**Banc d'essai injecteur**	**51,9 jours**	**Jeu 17-10-19**	**Mer 18-01-31**		
58			Conception Mécanique	22,4 jours	Jeu 17-10-19	Ven 17-12-01		
59			Fabrication mécanique	14 jours?	Lun 17-12-11	Ven 18-01-05	58	
60			Achat des composants standards	1 jour?	Lun 17-12-04	Mar 17-12-05	58	
61			Assemblage banc de test	3 jours	Lun 18-01-08	Ven 18-01-12	59	
62			Mise en marche banc de test	4 jours	Ven 18-01-12	Ven 18-01-19	61	
63			Aquisition de données	5 jours	Lun 18-01-22	Mer 18-01-31	62	
64			**Embrayage EVT**	**64,9 jours**	**Jeu 17-10-19**	**Lun 18-02-26**		
65			Conception Mécanique	25,9 jours	Jeu 17-10-19	Ven 17-12-08		
66			Achat des composants standards	4 jours	Mar 18-01-02	Mar 18-01-09	65	
67			Fabrication des pièces sur mesure	20 jours	Mar 18-01-09	Lun 18-02-19	66	
68			Programmation	35 jours	Lun 17-12-11	Ven 18-02-16	65	
69			Essai sur banc de test acoustique	4 jours	Lun 18-02-19	Lun 18-02-26	68	
70			**Assemblage prototype**	**6 jours**	**Ven 18-02-16**	**Mer 18-02-28**		
71			Diesel	3 jours	Ven 18-02-16	Jeu 18-02-22		
72			Essence	3 jours	Ven 18-02-16	Jeu 18-02-22		
73			essai sur neige	3 jours	Jeu 18-02-22	Mer 18-02-28	71	
74			**Compétition**	**5,2 jours?**	**Ven 18-03-02**	**Mar 18-03-13**		
75			Départ	1 jour?	Ven 18-03-02	Lun 18-03-05		
76			Retour	1 jour?	Lun 18-03-12	Mar 18-03-13		



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Appendix B

Turbo Match Data (Compressor Map)