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8 Engine and Transmission Concepts

During the engine selection process, aspects of the ULSAB-AVC concepts, such as package space, crashworthiness targets mass avd vehicle dynamic performances, were considered.

8.1 BACKGROUND

One of the program targets for ULSAB-AVC was CO_2 emissions (< 140 g/km), therefore; the selection of the powertrain (engine and transmission) was one of the most important tasks. In order to fulfill program requirements, another important task was to include options for both diesel and gasoline engines.

During this engine selection process, all aspects of the ULSAB-AVC vehicle concept, such as package space, crashworthiness targets, mass and vehicle dynamic performances were considered. Additionally, the program goal of affordability ruled out alternative hybrid powertrains (internal combustion engine or fuel cell plus electric motor). It was assumed that by 2004, the utilization of these technologies would not allow the ULSAB-AVC vehicles to be manufactured at an affordable cost. The detailed study of a range of alternative engines (configuration, displacement and number of cylinders) did not comply with the program targets. This variation would have led to an increase in total vehicle mass and an increase in CO_2 emissions.

8.2 Engine Concepts Selection Criteria

During the selection process, various criteria (see Figure 8.2-1) were established to guide the selection of basic engine concepts.

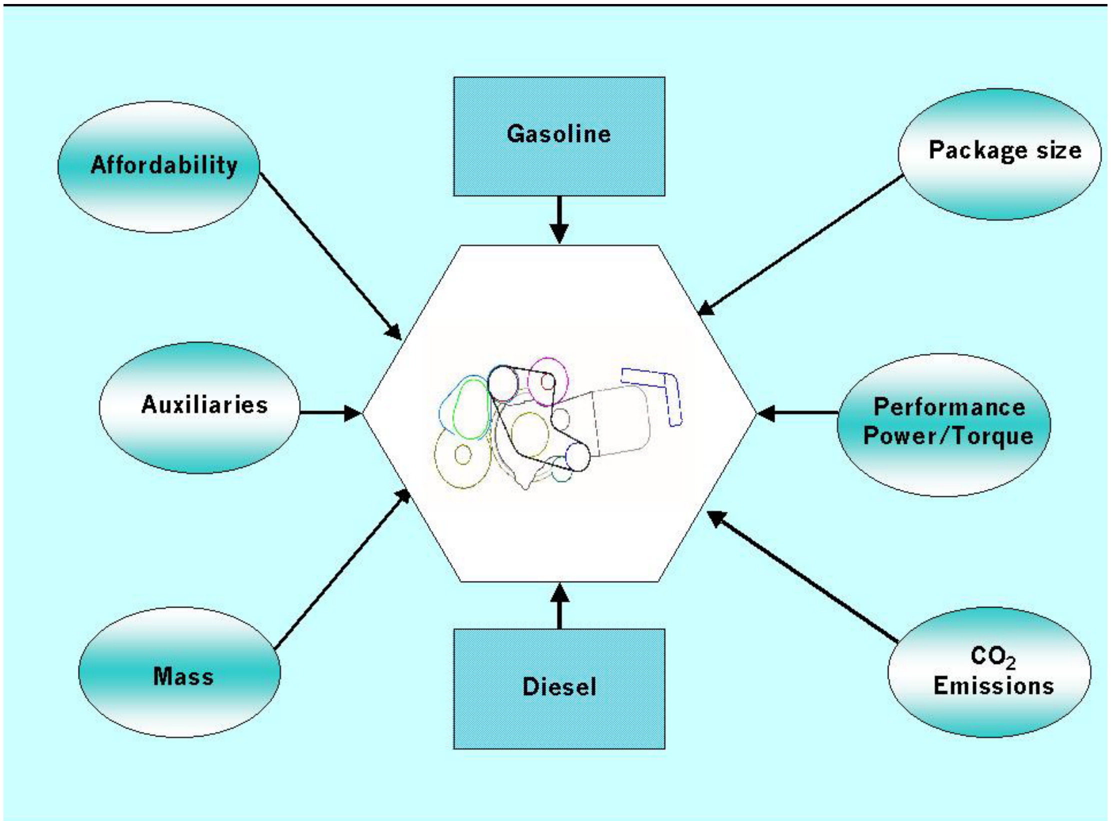

Figure 8.2-1 Engine concept selection criteria

The concepts had to be suitable for the development of both a diesel and gasoline engine. The powertrain sizes, including auxiliaries, had to be developed in a tight envelope in order to stay in the space provided by the package concept of body structure and suspension. The powertrain concept had to provide the potential to achieve low mass. It was necessary that both engine concepts show potential to meet the CO_2 emission targets. To achieve the total vehicle performance of acceleration and cruising speed, both concepts needed to provide sufficient power and torque. As already mentioned, both concepts had also to be affordable.

8.3. Calculation of Engine Displacements

To determine the engine displacements, which ultimately would influence the engine size, type, number of cylinders, vehicle mass, CO_2 emissions, as well as vehicle acceleration (0-100 km/h in < 14 sec.), transmission gear ratios had to be considered in the calculation.

8.3.1. CO_2 Emissions Calculation Parameters

8.3.1.1. Driving Cycle

CO_2 emissions for various engine displacements were calculated based upon the program targets. This first calculation was done in the summer of 1999 and was done in accordance with the NEDC (New European Drive Cycle) 2000 requirements, which currently (summer 2001) is required for new vehicle models produced after January 1, 2000. The NEDC 2000 requires the CO_2 emissions to be measured immediately without a 40-second delay (start-up phase) as it was specified in the MVEG* driving cycle, which was the legal requirement at this stage of the program (summer 1999). It was anticipated that by achieving the target of < 140 g/km CO_2 under the NEDC 2000 conditions, the CO_2 emissions target using the US Combined Driving Cycle (FTP 75, Highway) would also be achieved. (*Motor Vehicle Emission Group)

The applied test driving cycle is made of two parts as shown in Figure 8.3.1.1-1 (see next page).

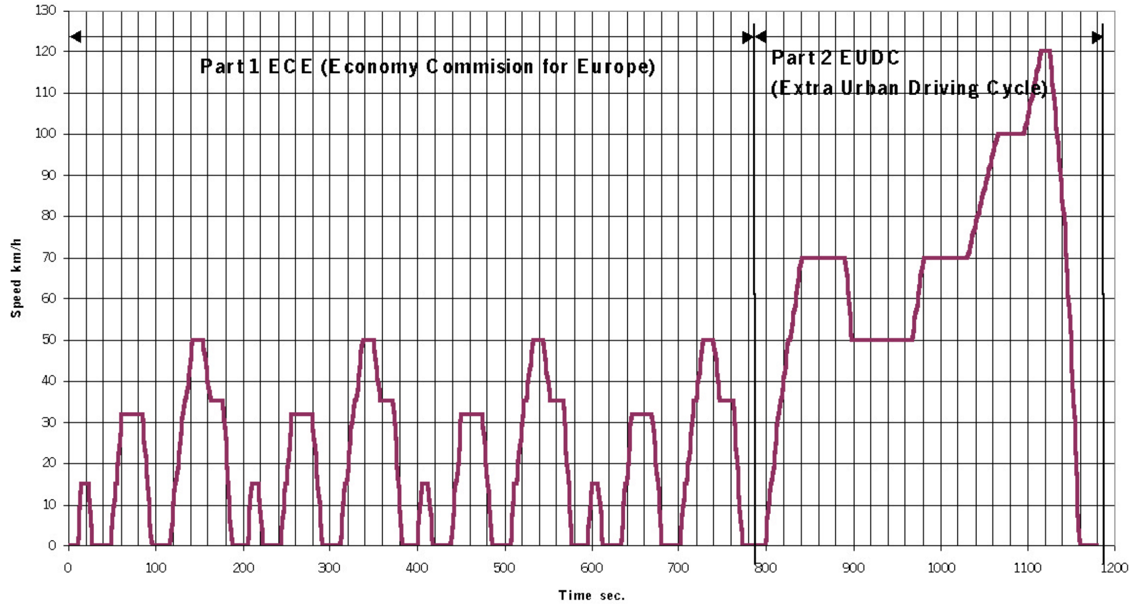

Figure 8.3.1.1-1 NEDC 2000 driving cycle

- Part one is prescribed by the Economy Commission for Europe (ECE) and describes a city driving cycle, which considers variation of speed in km/h over time, including stopping intervals.
- Part two is the Extra Urban Driving Cycle (EUDC) describing a cycle with variation of speed in km/h over a given time period without stopping intervals.

8.3.1.2. Transmission

For vehicles with manual shift transmission, the shifting points have to be set in accordance with NEDC requirements. For vehicles with automatic transmission, the specific internal shifting program is used in the calculation.

For the ULSAB-AVC Program, both manual and automatic shifting have been considered in the calculation.

8.3.1.3. Vehicle Mass

The requirements for the fuel consumption calculation describe the vehicle mass to be used as the curb mass with an additional 100 kg. Curb mass is defined as the mass of the vehicle equipped for normal driving conditions including fluids such as coolant, lubricants and fuel tank filled to a minimum of 90%.

For the calculation of CO_2 emissions, the target mass of the PNGV-Class vehicles in diesel and gasoline engine configurations was used in the heaviest configuration (see Table 8.3.1.3-1).

Table 8.3.1.3-1 Total vehicle mass for CO_2 emissions calculation

Vehicle Variant	Diesel (kg)	Gasoline (kg)
PNGV-Class vehicle curb weight target	1102	1059
Additional Mass	100	100
Total Vehicle Mass	1202	1159

8.3.1.4. Specific Power / Torque Characteristics

For the calculation of CO_2 emissions and vehicle acceleration, specific power/torque characteristics (specific torque characteristic = 1.0 L engine displacement) for both diesel and gasoline engine were calculated from state of the art power/torque characteristics of existing engine technology.

For the diesel engine, the specific power/torque characteristic curve (see Figure 8.3.1.4-1) was calculated using the power/torque characteristic of an existing turbocharged diesel engine.

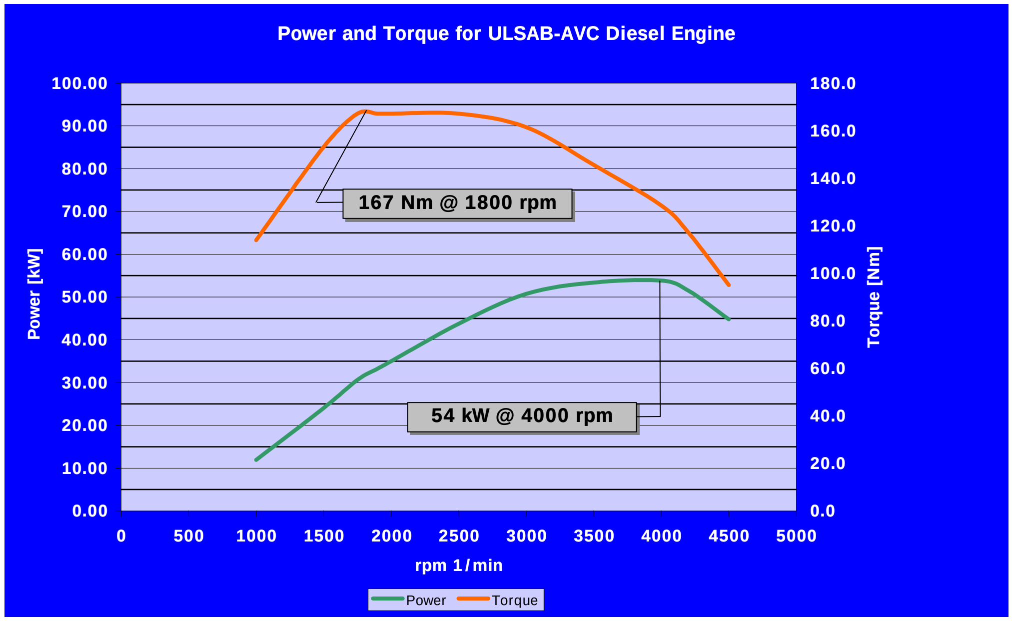

Figure 8.3.1.4-1 Power and torque for ULSAB-AVC diesel engine

For the gasoline engine, the specific power/torque characteristic curve (see Figure 8.3.1.4-2) was calculated using a characteristic of a normally aspirated gasoline engine.

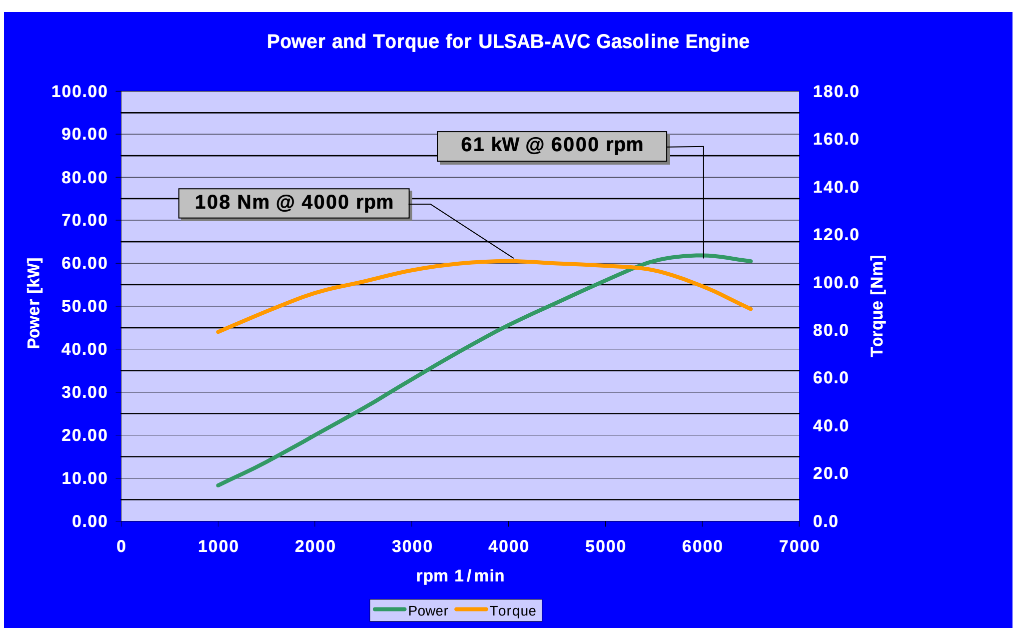

Figure 8.3.1.4-2 Power and torque for ULSAB-AVC gasoline engine

8.3.2. CO_2 Emissions Calculation

The next step was the calculation of vehicle acceleration time with a pre-selected transmission in manual and automatic shift mode using the specific torque characteristics for various engine displacements (0.8 L - 1.4 L)

Under these boundary conditions, the CO_2 emissions/fuel consumption for these engine displacements was calculated using the MVEG driving cycle requirements.

8.3.2.1. Engine Displacement Determination

The calculation results for diesel engine (see Figure 8.3.2.1-1) and the gasoline engine (see Figure 8.3.2.1-2) both show that for an engine displacement of 1.2 L in combination with a 5-speed transmission under manual shift conditions, the target for CO_2 emissions can be met.

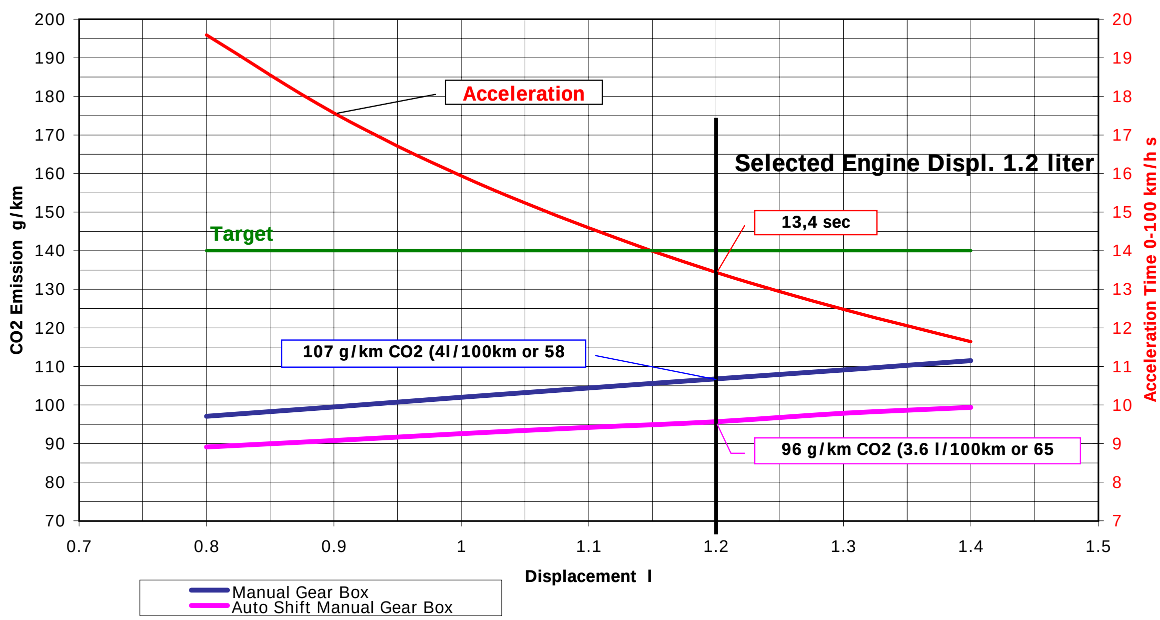

Figure 8.3.2.1-1 Definition of diesel engine displacement in correlation with CO_2 emission and acceleration time with selected transmission

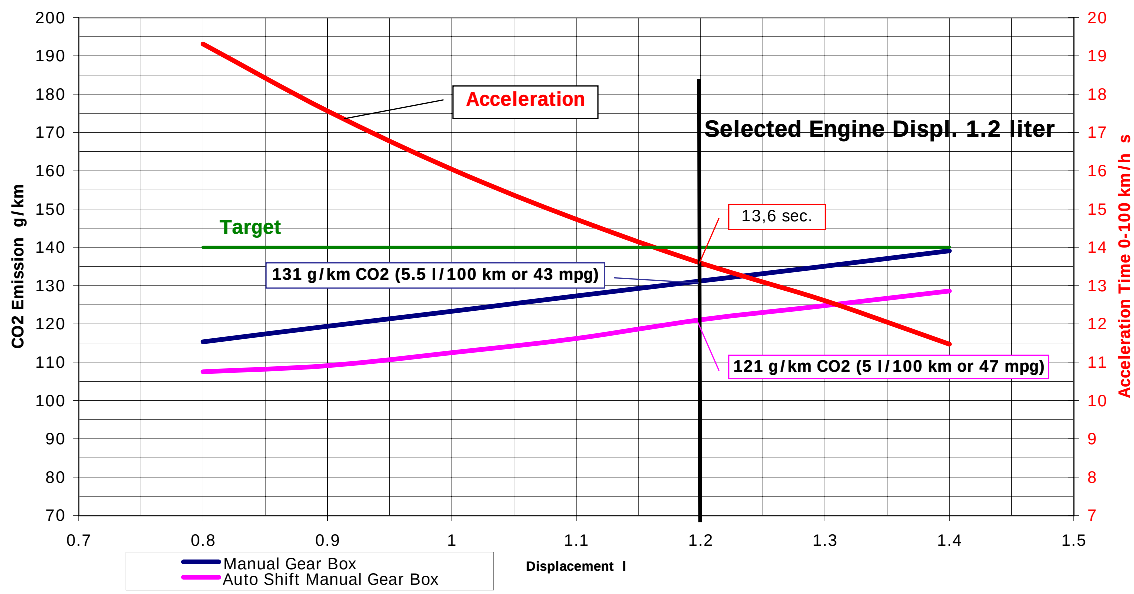

Figure 8.3.2.1-2 Definition of gasoline engine displacement in correlation with CO_2 emission and acceleration time with selected transmission

The calculations also show that with an engine displacement of 1.2 L and a 5-speed transmission equipped with an automatic gearshift actuator activated by an electronic shift program, it is feasible to further reduce the CO_2 emissions. This can be achieved while still meeting the targets for vehicle acceleration for both PNGV-Class vehicles (heaviest variant) equipped with diesel or gasoline engine.

The summary (see Figure 8.3.2.1-3) shows the calculations indicate results which meet program targets with the assumed vehicle target mass.

Table 8.3.2.1-3 Calculation summary

	Diesel 1.2L manual shift mode	Diesel 1.2 L automatic shift	Gasoline 1.2 L manual shift mode	Gasoline 1.2 L automatic shift mode	Target
CO_2 (g/km)	107	96	131	121	< 140
Fuel consumption (L/100km)	4.0	3.6	5.5	5.0	--
Fuel consumption (mpg)*	58	65	43	47	--
Acceleration 0-100 (sec)	13.4	13.4	13.6	13.6	14

* mpg are calculated from L/100 km values, they do not represent the fuel consumption according to the US combined driving cycle

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The assessment of CO_2 emissions would be lower for the C-Class vehicles, as a consequence of lower total vehicle mass. The final calculation of CO_2 emissions was done after final development of both vehicle concepts with the calculation using the final total vehicle mass and is described in Chapter 15 – Calculation of Vehicle Emissions.

8.4. Engine Type Selection

The engine type was determined based on the calculated engine displacement and the engine bay concept considerations. The vehicle package considerations required the engine to be located horizontally behind the transmission rearward of the front axle inside the tunnel of the body structure.

This requirement led to a preliminary decision to select a three (3)-cylinder inline engine which enabled an engine with reduced width, compared to a four (4)-cylinder inline engine. First investigations showed that such a conventional engine could cause interference with the tunnel of the body structure.

To further reduce the engine width and optimize available package space, the VR principle for locating the cylinders in a 15° angle with one common cylinder head was investigated and finally chosen for the vehicle concept development. Figure 8.4-1 shows comparison of the engine width of a three (3)-cylinder inline engine to a three (3)-cylinder VR engine type.

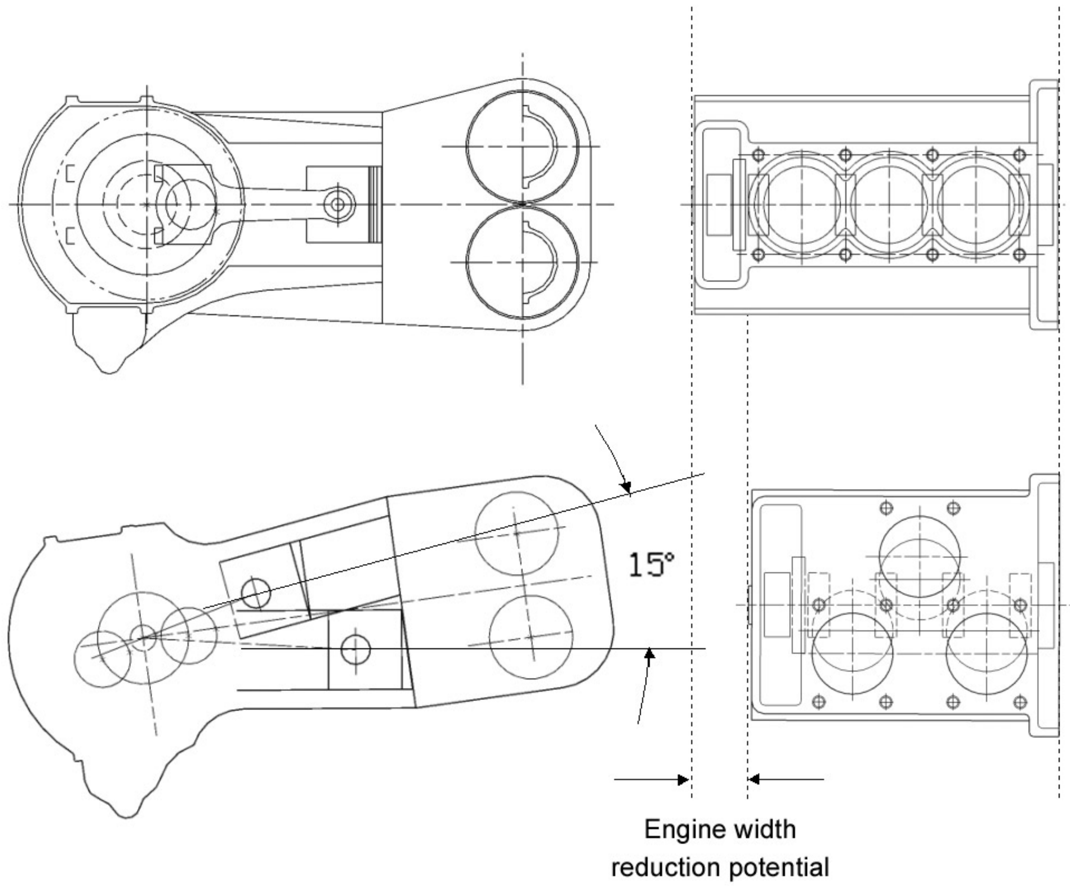

Figure 8.4-1 Inline engine layout compared to VR principle layout

The VR principle of locating the cylinders reduces the width of the cylinder head by approximately 60 mm compared to a three (3)-cylinder inline engine with the same displacement of 1.2 L.

8.5. Engine Concept Design Layout

8.5.1. Engine Specifications

Based on the calculated displacement and the chosen VR principle, the engine specifications were determined. The engine specifications for both the diesel and gasoline engine are shown in Table 8.5.1-1

Table 8.5.1-1 ULSAB-AVC engines' specifications

Specification	Diesel	Gasoline
Concept Type	VR-3	VR-3
No. of Valves	2	4
No. of Camshafts	2	2
Displacement [ccm]	1200	1200
Stroke [mm]	82.6	81.6
Bore [mm]	78.5	79
Cylinder distance [mm]	134	134
Connector Rod Length [mm]	160	148
Compressio Ratio	19:01	11:01
Power [kW] [1/min]	54/4000	61/6000
Torque [Nm] [1/min]	167/1800	108/4000
Idle Speed [1/min]	600	700
Lubrication System	Dry sump	Dry sump

8.5.2 Engine Description

The main engine components for ULSAB-AVC diesel and gasoline engines are described below.

Crankcase – housing in die cast aluminum with 3 cast-iron cylinder liners, closed deck design, bedplate in aluminum pressure casting with cast-in iron inserts

Crankshaft – forged steel

Flywheel – dual mass design with chain gear drive to gearbox

Alternator & AC Compressor Drive – single belt (poly-V / K6) with belt tensioner and vibration damper

Piston – Gasoline engine:- forged aluminum, crown height 32mm. diesel engine:- cast aluminum with integrated cooling channel and machined piston top, crown height 44mm

Connecting rod – forged steel rod, cracked, L=148mm (gasoline engine), L=162.5mm (diesel engine) small end sputter-bearing

Cylinder head – die cast aluminum (steel die), two-piece design of cylinder-head and camshaft housing, 10 cylinder head bolts. Gasoline engine:- roof shaped combustion chamber, 4 valves, valve angle approx. 42 degrees diesel engine:- flat combustion chamber (“Heron” design), 2 valves in line, valve angle 0 degrees

Cylinder head gasket – steel, 3-layer.

Valve adjustment – conical, single valve spring, (gasoline engine), 12 hydraulic valve clearance compensation elements (HVCCE), (diesel) 6 hydraulic valve clearance compensating elements integrated in bucket-lifters

Camshaft drive – two stage, double chain drive via intermediate shaft sprocket, duplex-chain with 9.525 pitch, plastic tensioning- and guiding rails, 2 hydraulic chain tensioners, 2 camshaft sprockets with central locking, (gasoline engine has axial camshaft actuator)

Valve drive – Gasoline engine:- camshaft housing with provision for HVCCE, intake camshaft with 4 bearings and cylinder head oil-scavenge pump power take-off, exhaust camshaft with 4 bearings, valve activation by roll- finger followers. Diesel engine:- camshaft housing with provision for bucket-style lifters, upper camshaft with 3 bearings and power take-off for high pressure pump, cylinder head- and turbo charger scavenge pumps, lower camshaft with 4 bearings

Cylinder head cover – pressure die cast aluminum, provisions for Hall sensor, high-pressure pump and return lines

Cooling system – demand optimized cooling system with electric coolant pump and coolant thermostat

Dry sump lubrication – pressure and scavenge pump in oil sump, separate scavenge pumps for the cylinder head and the turbo charger. Auxiliary shaft is actuated via oil pump, return lines to the oil tank, oil-water heat exchanger, piston jet nozzles (diesel only), oil pan cover, oil pump driven by simplex chain with chain tensioner.

Intake system – die cast aluminum, metal flaring seal to cylinder head

Fuel system – Gasoline engine:- electronic indirect fuel injection, 3 electric injector valves, returnless pressure control, fuel tank ventilation. Diesel engine:- common rail injection system, gear prime-pump, high pressure radial piston pump, rail with pressure sensor and regulator, 3 high pressure injectors, cold start device

Exhaust system – Gasoline engine:- air-gap insulated sheet metal manifold, metal flaring seal to cylinder head, start catalyst converter directly downstream exhaust manifold, main catalyst converter, muffler with end pipe, exhaust gas re-circulation. Diesel engine:- air gap insulated manifold, metal flaring seal to cylinder head and turbo charger, oxidation catalyst converter directly downstream turbine, muffler with end pipe, exhaust gas re-circulation

Engine mounts – 3-point-mounting system with engine mount brackets made with steel. (see Chapter 7 - Chassis and Suspension Concepts)

Boosting – Diesel engine:-, exhaust turbocharger with adjustable turbine geometry (VTG) and boost-pressure control, actuation via electric motor, water-cooled housing

Ancillary components – AC-compressor mounted directly to the engine, alternator mounted to the transmission housing via console

Engine management – electronic for gasoline and diesel engine

8.5.2.1. Diesel Engine Concept Design Layout

Figure 8.5.2.1-1 shows the diesel engine with the configuration of the main engine auxiliary parts. In Figure 8.5.2.1-2 the concept layout of the camshaft control is shown.

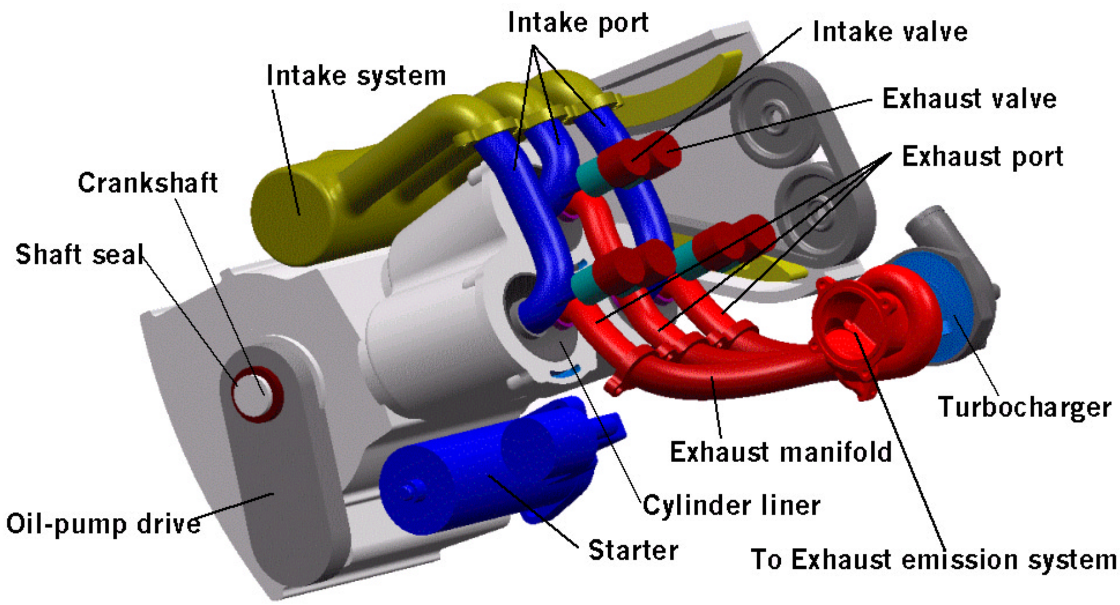

Figure 8.5.2.1-1 Diesel engine description

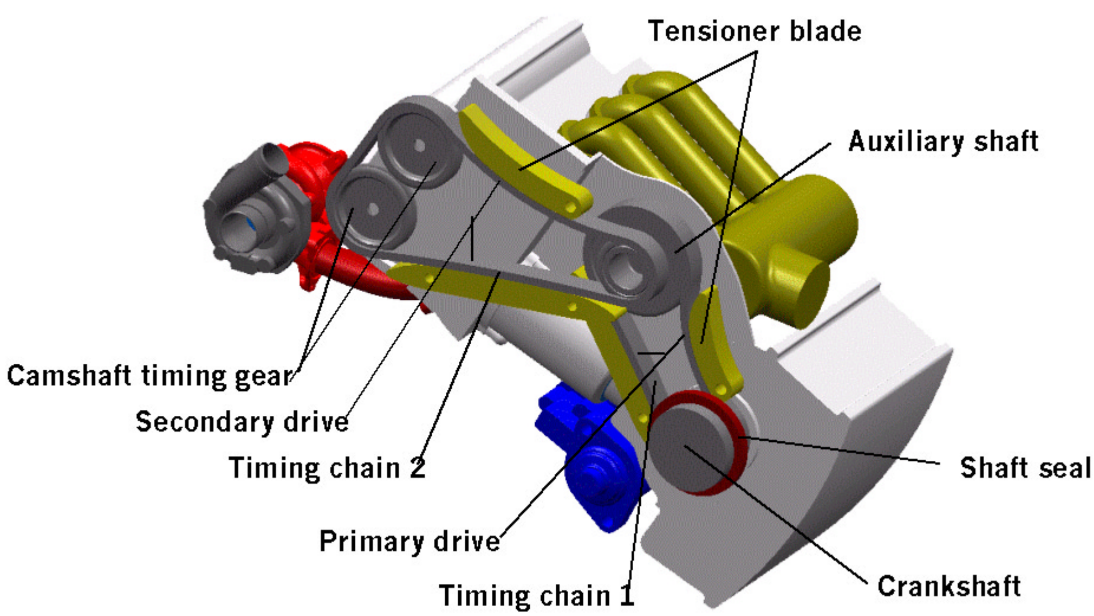

Figure 8.5.2.1-2 Diesel engine camshaft control

8.5.2.2. Gasoline Engine Concept Design Layout

Figure 8.5.2.2-1 shows the gasoline engine with the configuration of the main engine auxiliary parts. In Figure 8.5.2.2-2 the concept layout for the gasoline engine camshaft control is shown.

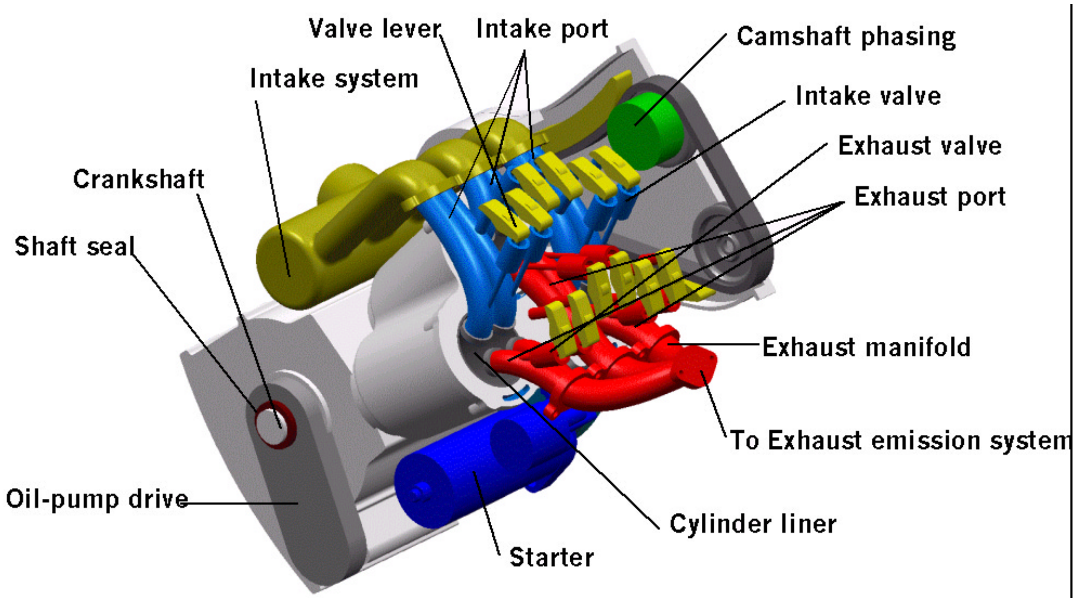

Figure 8.5.2.2-1 Gasoline engine description

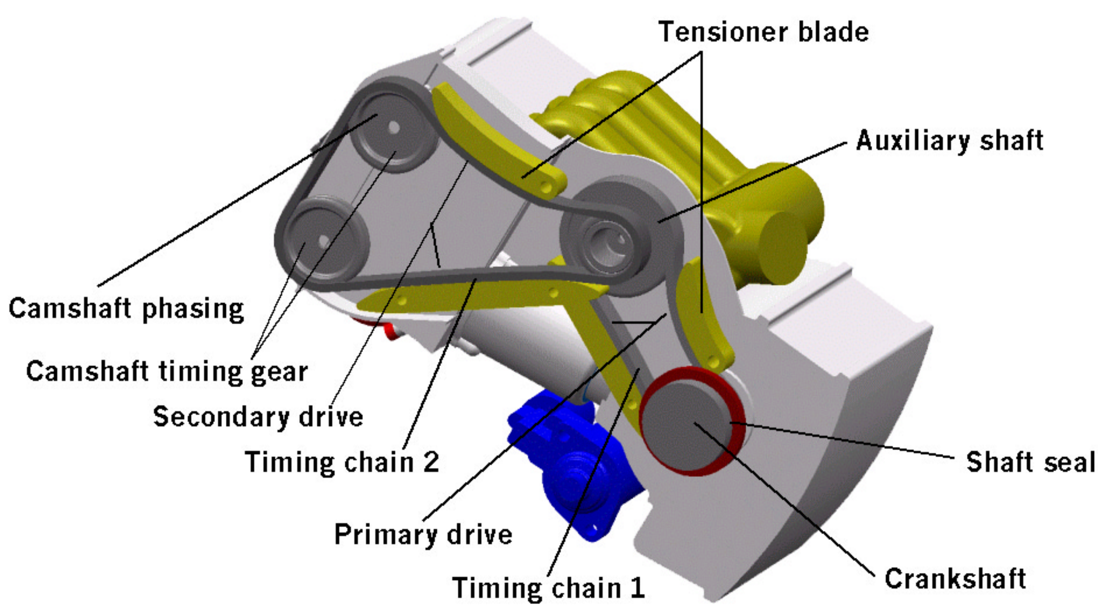

Figure 8.5.2.2-2 Gasoline engine camshaft control

8.5.3. Engine Mass

8.5.3.1. Engine Mass Specification

For the estimation of the engine mass, it is important to specify what is included within this mass. ULSAB-AVC's engine mass is specified according to DIN 70020-A. The engine mass includes all auxiliaries and brackets directly mounted to the engine. Add-on parts are defined as:

- Engine Electrics
- Starter
- Generator - 120 A
- A/C Compressor (with clutch) - 40 W
- Intake Manifold
- Single Spark Ignition Coil (gasoline engine)
- Glow Plugs/Spark Plugs
- Fly-wheel
- Fly-wheel Housing
- Turbocharger
- Mounted Fuel Lines
- Electrical Water Pump (7500 L/h diesel) (4800 L/h gasoline)
- Injection System
- Oil Tank with Hoses
- Oil Pressure Sensor
- Exhaust Manifold
- Air Temperature Sensor
- Electrical Coolant Temperature Sensor
- Lambda Oxygen Sensor (catalytic converter)
- Electrical Fuel Pump (integrated in fuel tank)
- Electrical Control Unit (ECU) including Boost control (diesel)
- Engine Wiring Harness

Air filter, lubricants and engine mounting brackets are not included.

8.5.3.2. Engine Mass Assessment

Table 8.5.3.2-1 shows the engine mass assessment for both diesel and gasoline engines.

Table 8.5.3.2-1 Engine mass

Description	C-Class (kg)	PNGV-Class (kg)
Diesel Engine	113.00	113.00
Gasoline Engine	8[illegible]00	85.00

8.6. Transmission Concept Selection Criteria

For the development of the transmission, the first step was to select the criteria, which had to be taken into account as shown in Figure 8.6-1.

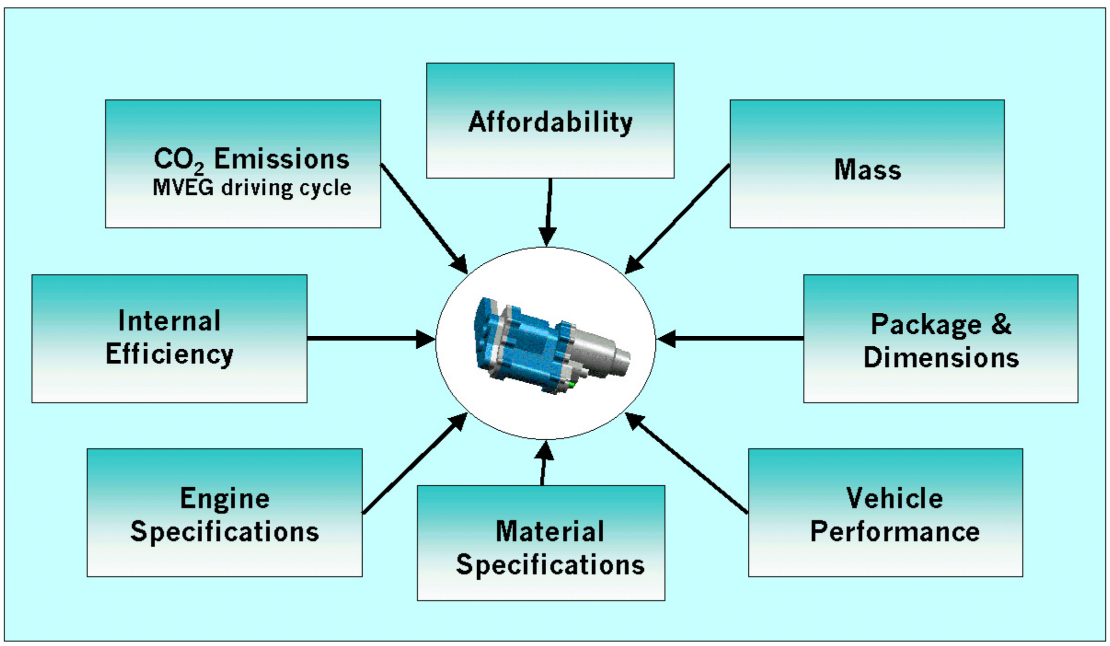

Figure 8.6-1 Engine transmission selection criteria

The transmission had to fit into a tight space as defined in the engine bay package studies, therefore it was designed in a way that it would provide the possibility for a primary drive chain connection with the engine. A similar system is already in use by other OEMs (e.g. SAAB).

The internal transmission layout for the size and number of gears had to be based on the calculation of CO_2 emissions (driving cycle) and the desired vehicle performances. Other considerations were to reduce the vehicle components, in this case, the elimination of a gear lever including the necessary connecting parts to the gearbox to achieve advantages for vehicle assembly, package and mass reduction. The transmission housing had to be suitable to fit both diesel and gasoline engine with the different power and torque characteristics.

8.6.1. Transmission Concept Layout

The transmission in its final layout is shown in Figure 8.6.1-1 and includes the primary drive chain housing.

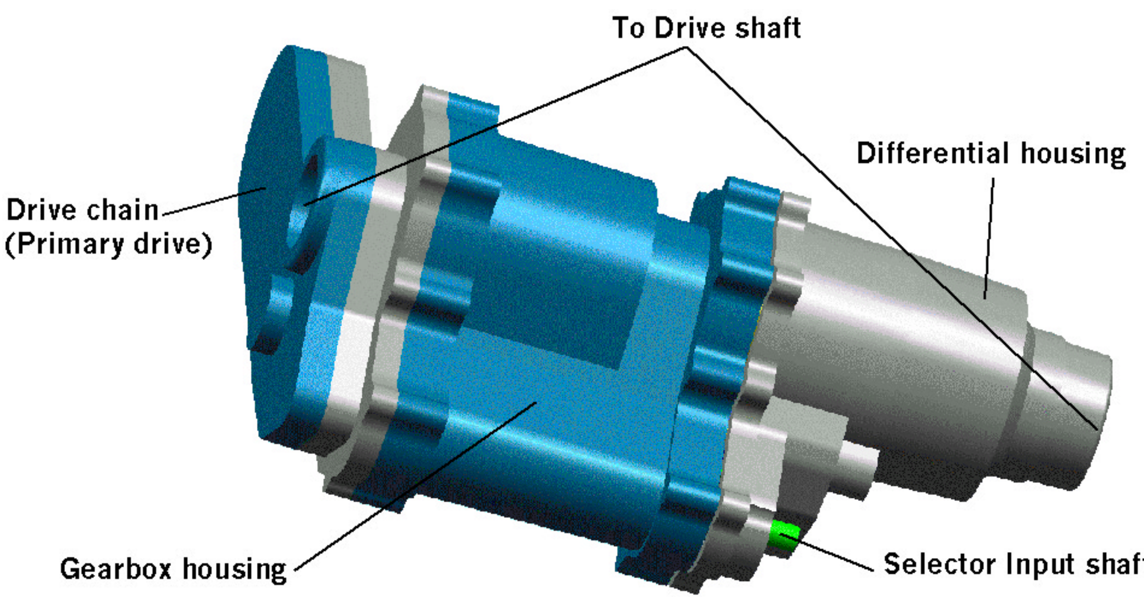

Figure 8.6.1-1 Transmission isometric view

Figure 8.6.1-2 shows a principle section cut through the transmission. The transmission features five (5) forward and one reverse gear.

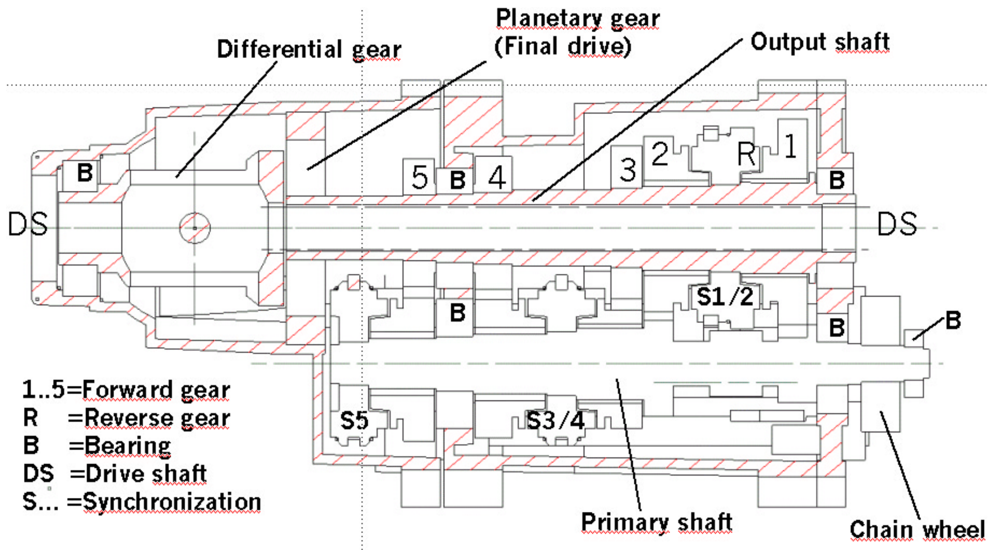

Figure 8.6.1-2 Section cut of transmission

The transmission ratios are specifically selected for the d iesel and gasoline engines to suit their different power and torque characteristics and are shown in Table 8.6.1-1 and 8.6.1-2.

Table 8.6.1-1 Diesel engine transmission ratios

Diesel Engine Transmission	Total Ratio	Single Ratio
Gear 1	13.296	3.324
Gear 2	5.596	1.399
Gear 3	3.544	0.886
Gear 4	2.592	0.648
Gear 5	2.044	0.511
Primary Transmission	1:4	
Final Drive	1:1	

Table 8.6.1-2 Gasoline engine transmission ratios

Gasoline Engine Transmission	Total Ratio	Single Ratio
Gear 1	12.744	3.186
Gear 2	7.024	1.756
Gear 3	4.848	1.212
Gear 4	3.7	0.925
Gear 5	2.992	0.748
Primary Transmission	1:4	
Final Drive	1:1	

As shown in Figures 8.3.2.1-1 and 8.3.2.1-2, it is possible to reduce the fuel consumption with the utilization of an automatic transmission according to the NEDC 2000 requirements. For ULSAB-AVC, it was decided to use a manual transmission with an automatic gearshift actuator to achieve lower CO_2 emissions and additionally, to reduce the number of parts with the elimination of a gear shifter and clutch pedal.

An automatic gearshift gives the driver the ability to drive like he would with an automatic transmission without increasing fuel consumption. An electric activator handles the work of engaging and disengaging the clutch. The driver changes gears by simply pressing a button on the steering wheel as shown on the ULSAB-AVC steering wheel sketch (see Section 5, Figure 5.5-3). Another option for the driver is the use of a comfortable automatic mode. In automatic mode, the electronics automatically select the right gear for the current driving situation and can jump over several gears at once. The clutch and the shifting are actuated with small electric motors.

Automatic gearshifts, or similar systems are already adopted by OEMs.

8.6.2. Transmission Mass

The estimated mass of the diesel and gasoline transmission for both C-Class and PNGV-Class vehicle variations amounts to 36.90 kg as shown in Table 8.6.2-1. The added mass for the electrical gear shifter actuator is estimated at 5.00 kg.

Table 8.6.2-1 Calculated transmission Mass

	C-Class		PNGV-Class	
Description	Diesel (kg)	Gasoline (kg)	Diesel (kg)	Gasoline (kg)
Transmission Total	31.00	31.00	31.00	31.00
Electrical Gear Shifter	5.00	5.00	5.00	5.00
Transmission Oil	0.90	0.90	0.90	0.90
Total Transmission Mass	36.90	36.90	36.90	36.90

8.7. Powertrain Layout

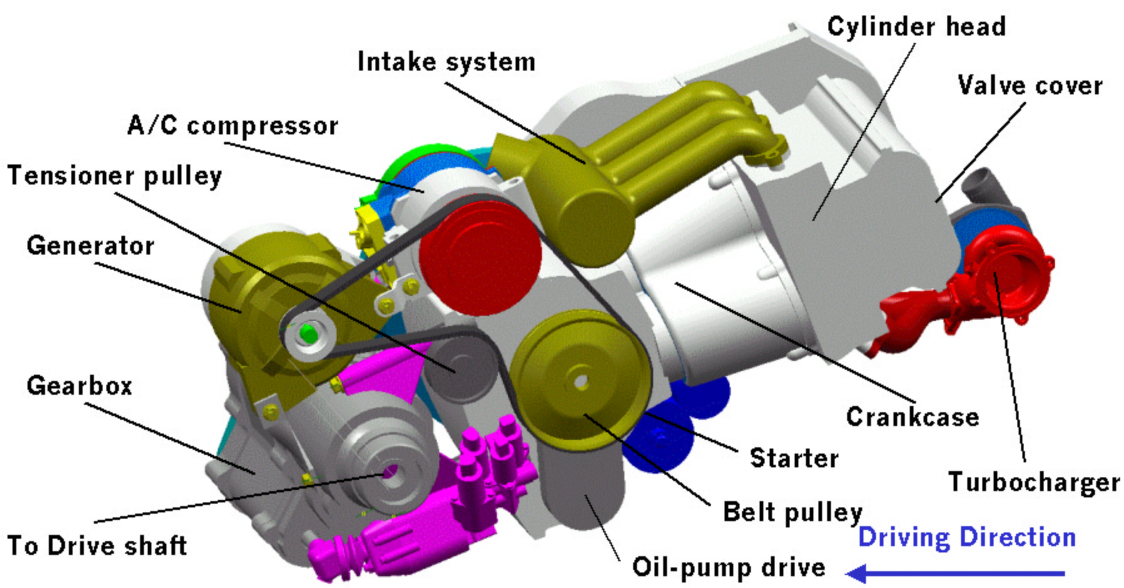

Figure 8.7-1 Powertrain diesel with auxiliaries

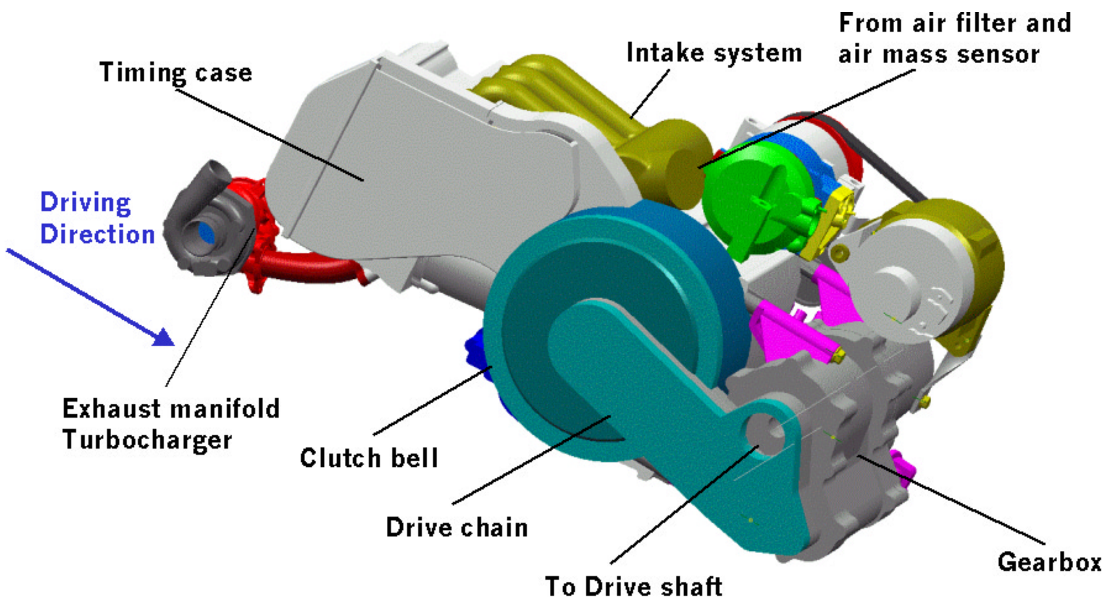

Figure 8.7-2 Powertrain diesel with auxiliaries

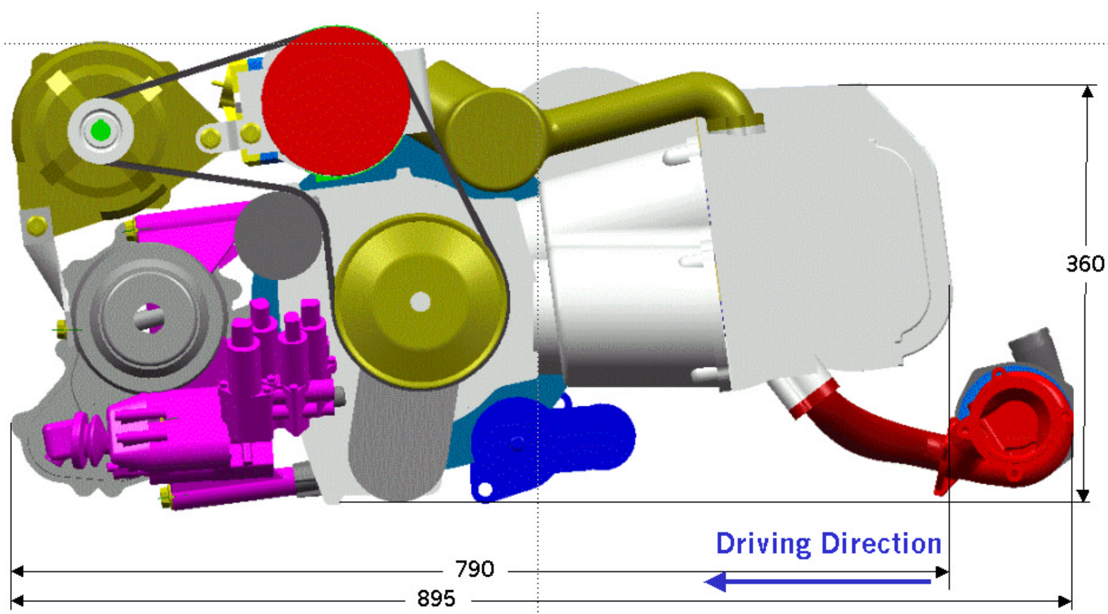

Figure 8.7-3 Powertrain diesel dimensions side view

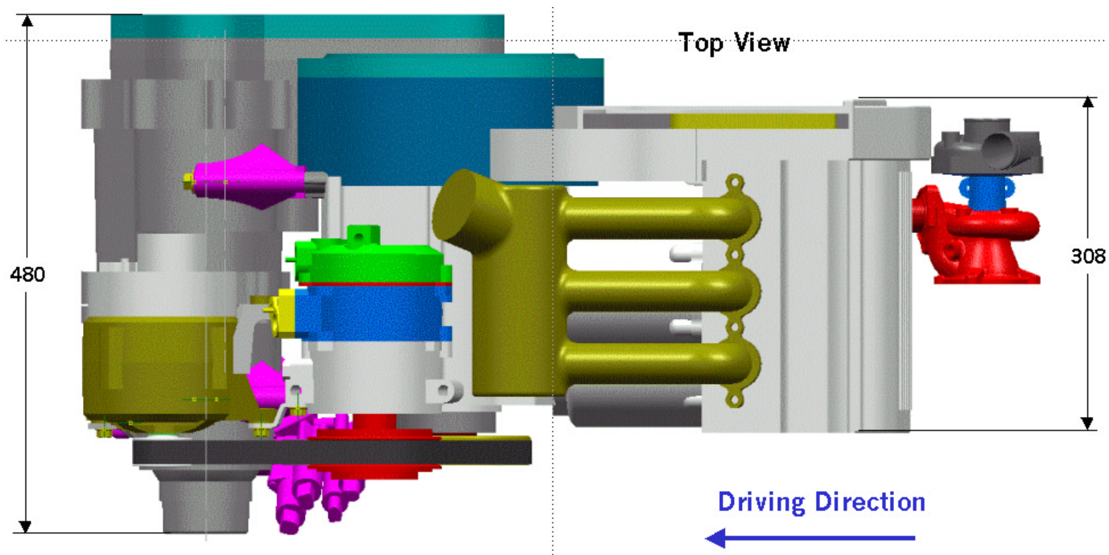

Figure 8.7-4 Powertrain diesel dimension top view

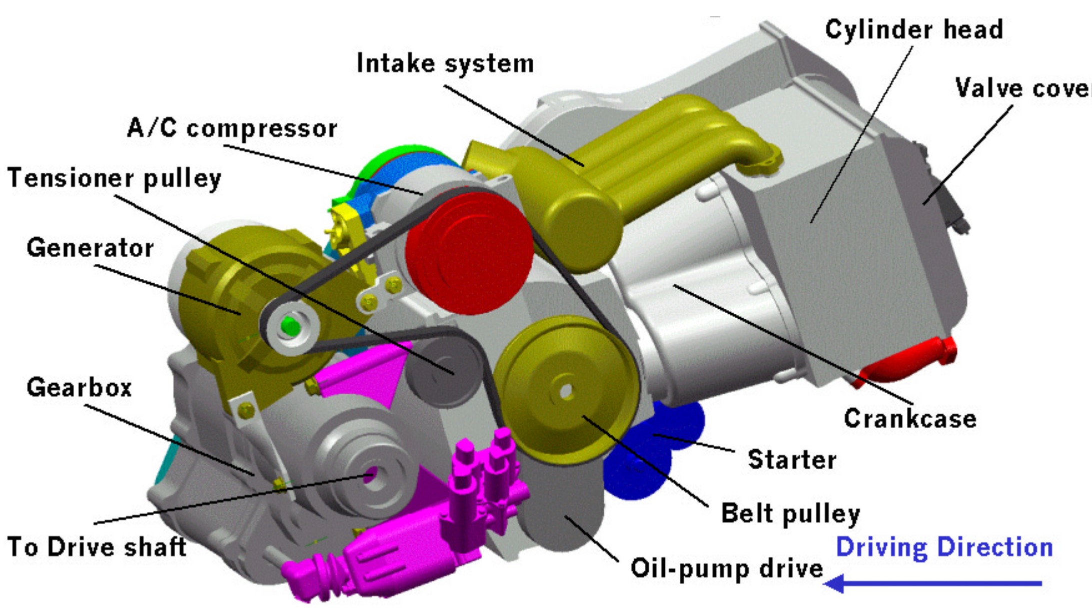

Figure 8.7-5 Powertrain Gasoline with auxiliaries

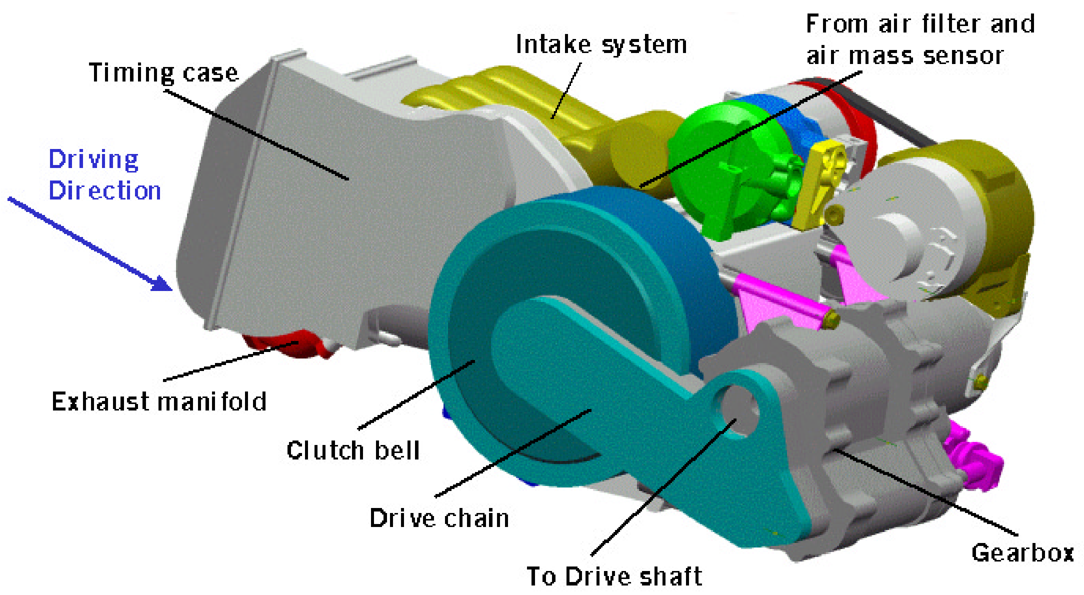

Figure 8.7-6 Powertrain Gasoline with auxiliaries

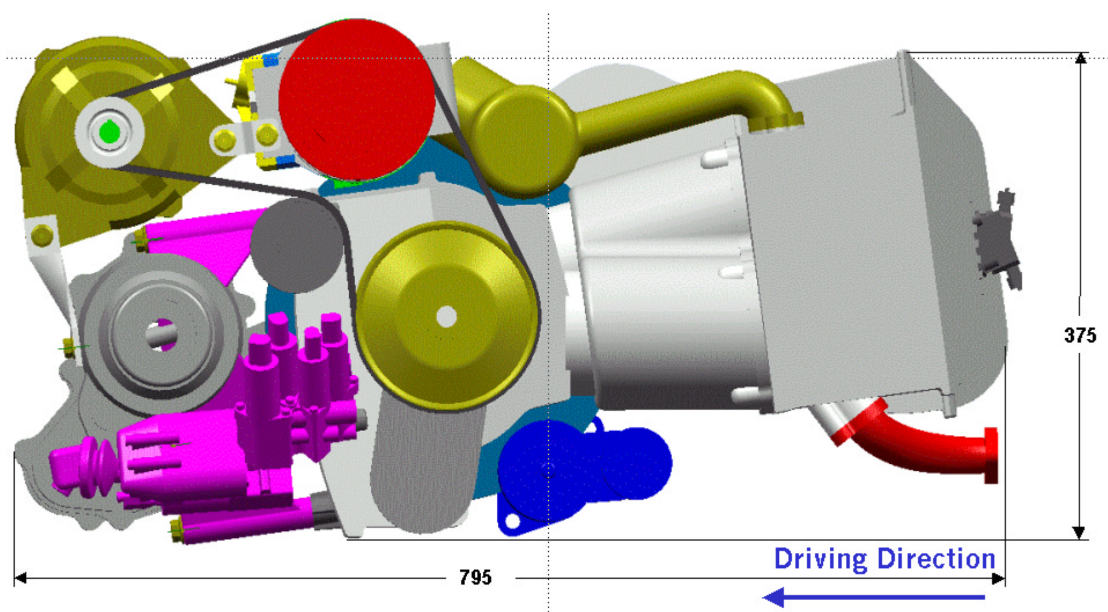

Figure 8.7-7 Powertrain Gasoline dimensions side view

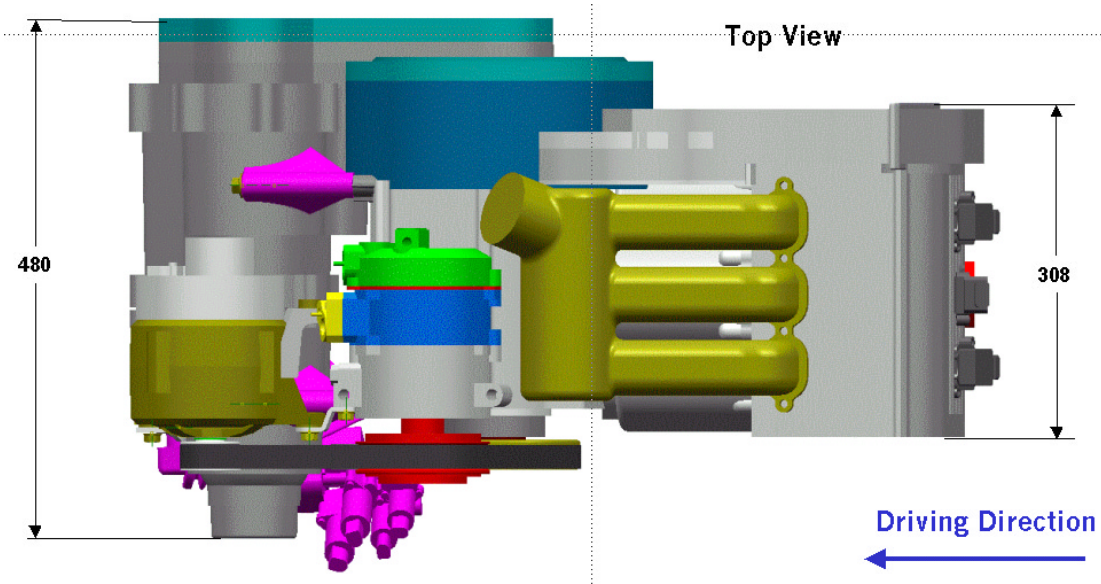

Figure 8.7-8 Powertrain Gasoline dimensions top view