

The Fuel Efficiency Improvement through a Six Speed Manual Transmission Application in Passengers Vehicles with Low Displacement Engines

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ABSTRACT

The objective of this paper is to share the benefits regarding a study of fuel economy improvements involving Powertrain technologies. In this case our research was concentrated in vehicles transmissions initiatives like a Six Speed Manual Transmission application in Passengers Vehicles with low displacement engines.

During the last 10 years the fuel economy challenges has presented a significant growth mainly due to two simple factors. First of all the fuel price which is the main driver to keep this technological continuous improvement. This fact has a direct influence in customers satisfaction, so all car makers concentrate huge efforts to provide intelligent solutions in order to increase competitiveness, as for example, the flex fuel engines (Figure 1). In parallel, the “green” appeal raises everyday stronger. Therefore the air pollution caused by vehicles gas emissions reinforces this commitment.

So low displacement engines are the key to achieve these targets however it brings many limitations like short transmission ratios as consequence of low torque capacity.

Base on such assumptions, it's fundamental to maximize the torque usage provided by the engine which is managed through a mechanical transmission. So the gears ratios selection is an important technique to explore alternatives to get the best torque usage for a defined engine torque curve.

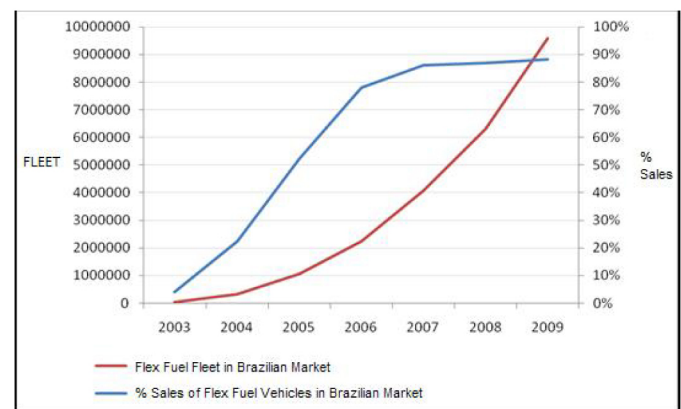


Figure 1. Flex Fuel Engines Volumes

INTRODUCTION

Today there are many methods capable to calculate gear sets based on vehicle and engine data.

Using this tool, it's possible to identify spread ratio constraints, once the final drive should be very short to attend vehicle startability and gradeability requirements. So an additional overdrive gear comes mandatory to explore engine torque over 4.000 rpm. Furthermore, when getting enough torque in low rpm ranges, less mass fuel is necessary to maintain vehicle speed. As consequence fuel economy gains around 5% in steady state and highway conditions can easily be reached with a sixth gear overdrive.

After this conclusion, my research also explores minimum technical changes to provide low cost solutions attending packaging requirements as well.

VEHICLE INPUT DATA

Basically the following information is necessary prior to start gear set calculation:

- Engine Power and Torque Curves
- Vehicle Curb Mass and Payload
- Aerodynamic coefficient (Cx)
- Dynamic wheel radius
- Frontal area

TECHNICAL REQUIREMENTS

In general, some requirements are mandatory to guarantee a perfect product usage and application in specific markets.

The first requirement regards startability, what means the capacity of vehicle to start in critical grades in GVW (Gross Vehicle Weight) conditions ([Figure 2](#)).



Figure 2. Typical Brazilian Road

In order to cover all global applications, these targets are distributed in 03 categories (Baseline, Intermediate and Severe) considering different altitude conditions during forward and reverse directions ([Figure 3](#)).

Requirement	Grade	Altitude	Load Condition	Direction	Ambient Temp.	AC On/Off
BASILINE	22%	1000 m	GVW	forward	30°C	On
BASILINE	22%	1000 m	GVW	reverse	30°C	On
BASILINE	12%	1000 m	GCVW	forward	20°C	On
INTERMEDIATE	30%	670 m	GVW	forward	30°C	On
INTERMEDIATE	25%	670 m	GVW	reverse	30°C	On
INTERMEDIATE	12%	1000 m	GCVW	forward	20°C	On
SEVERE	25%	2800 m	GVW	forward	30°C	On
SEVERE	25%	2800 m	GVW	reverse	30°C	On
SEVERE	8%	2800 m	GCVW	forward	30°C	On

	Baseline - all programs must meet
	Intermediate - Additional requirements for specified areas.
	Severe - Additional requirements for specified areas.

Figure 3. Startability Targets

The test procedure is composed by the following steps:

- 5 launches
- Vehicle with/without trailer
- Forward/reverse drive
- 5 minutes total time frame
- 1 second in handbrake before each launch
- 670/1000/2800m altitude
- 20/30°C ambient temperature
- Air conditioner on

Further another important requirement is named gradeability, which represents the capacity of vehicle keep minimum acceleration in top gears and different grades ([Figure 4](#)).

Vehicle Type	1 st Gear 10 km/h (m/s ²) / %	2 nd Gear 20 km/h (m/s ²) / %	Top Gear - 2 90 km/h (m/s ²) / %	Top Gear - 1 105 km/h (m/s ²) / %	Top Gear 90 km/h (m/s ²) / %	Top Gear 105 km/h (m/s ²) / %	Top Gear 120 km/h (m/s ²) / %
Sport, Minimum	4.50 / 45.9	3.00 / 30.6	NA	1.14 / 11.6	0.91 / 9.3	0.88 / 9.0	0.78 / 8.0
Base, Minimum	2.95 / 30.1	2.03 / 20.7	NA	0.82 / 8.4	0.67 / 6.8	0.65 / 6.6	0.58 / 5.9
'ECO' Label, Minimum	2.40 / 24.5	1.50 / 15.3	0.93 / 9.5	0.66 / 6.7	0.52 / 5.3	0.50 / 5.1	0.45 / 4.6
Mini & Small Segment, Minimum	2.40 / 24.5	1.50 / 15.3	NA	0.58 / 5.9	0.45 / 4.6	0.44 / 4.5	0.39 / 4.0

Figure 4. Gradeability Targets

GEAR SET CALCULATION

To calculate startability and gradeability values it's common to use the following methods (Figure 5):

$$X: F_{\text{drag}} - W \sin \alpha - F_{\text{aero}} + F_{\text{DragF}} - F_{\text{RF}} - F_{\text{RR}} = m \cdot a$$

$$Z: F_{\text{lift}} + R_R + R_F = 0$$

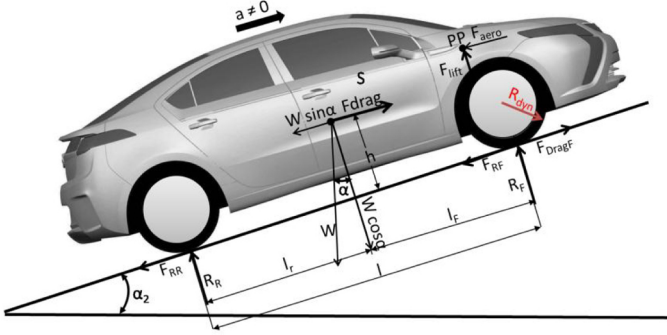


Figure 5. Loading Distribution

Legend:

F_{aero} = Aerodynamic force

F_{lift} = Lift Force

F_{drag} = Drag Force

W = Vehicle Weight

F_{DragF} = Drag Force for the Front Axle

F_{RF} = Rolling Resistance for the Front Axle

F_{RR} = Rolling Resistance for the Rear Axle

R_F = Normal Road Reaction for the Front Axle

R_R = Normal Road Reaction for the Rear Axle

Here the forces can be further explained as follows:

- In general the driving force will be:

$$F_{\text{drag}} = \sum_{j=1}^n \frac{T_{R,j}}{R_{\text{stat},j}} \quad (1)$$

- If equation (1) is reduced for the front axle then:

$$F_{\text{drag}} = \frac{T_R}{R_{\text{dyn}}} \quad (2)$$

- Here the lost torque can be written as:

$$T_R = (T_{\text{engine}} - T_{\text{losses}}) \cdot i_{\text{GB}} \cdot i_{\text{FD}} \quad (3)$$

- Combining relations (2), (3), (4) we can write:

$$T_{\text{losses}} = T_{\text{engineP}_0} \cdot (1 - \eta_{\text{DT}}) \quad (4)$$

$$F_{\text{drag}} = \frac{[T_{\text{engine}} - T_{\text{engineP}_0} \cdot (1 - \eta_{\text{DT}})] \cdot i_{\text{GB}} \cdot i_{\text{FD}}}{R_{\text{dyn}}} \quad (5)$$

Legend:

F_{drag} = driving force

T_R = resistant torque

R_{stat} = static rolling radius

R_{dyn} = dynamic rolling radius

T_{engine} = engine torque

T_{losses} = constant loss torque reduced at the drive train

T_{engineP_0} = nominal engine torque

η_{DT} = efficiency of the drive train

i_{GB} = gear box transmission ratio

i_{FD} = final drive transmission ratio

- The aerodynamic force will be:

$$F_{\text{aero}} = c_w \cdot \frac{\rho}{2} \cdot v_{\text{rel}}^2 \cdot A \quad (6)$$