

Definition of Gearshift Pattern: Innovative Optimization Procedures Using System Simulation

2011-01-0395

Published
04/12/2011

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doi:10.4271/2011-01-0395

ABSTRACT

Today's power trains are becoming more and more complex due to the increasing number of gear box types requiring gearshift patterns like conventional (equipped with GSI) and automatic-manual transmissions (AT, AMT), double clutch and continuous variable transmissions (DCT, CVT). This increasing variety of gear boxes requires a higher effort for the overall optimization of the powertrain. At the same time, it is necessary to assess the impact of different power trains and control strategies on CO₂ emissions very early in the development process. The optimization of Gear Shift Patterns (G.S.P.) has to fulfill multiple constraints in terms of objective customers' requirements, like drivability, NVH, performance, emissions and fuel consumption.

For these reasons, RENAULT and AVL entered an engineering collaboration in order to develop a dedicated simulation tool: CRUISE GSP. One of the major tasks of CRUISE GSP is to provide representative gearshift patterns for all available gearboxes on the market (including manual transmissions for GSI applications) at the very early stage of the powertrain development permitting to discriminate technical solutions.

Once a prototype exists, CRUISE GSP helps to refine and optimize the gearshift patterns for immediate usage during gear box tuning in the vehicle.

Being entirely integrated into AVL CRUISE™ (AVL's simulation tool for vehicle system simulation and driveline analysis), CRUISE GSP allows the efficient optimization of the gearbox shift patterns for different driving styles and thus the reduction of transmission calibration effort in the development process. By combining AVL CRUISE™ and CRUISE GSP with the engine tuning optimization tool AVL CAMEO™ a global Powertrain optimization (i.e. including both engine maps and gearshift patterns) can now be considered as a future perspective.

AVL powertrain engineering has been using CRUISE GSP on various calibration projects. For their specific needs AVL have implemented additional functionality to CRUISE GSP. The GSP WIZARD is a result of this development. The specific focus of AVL powertrain engineering is to have a continuous process from simulation to in-vehicle calibration. In the process the calibration tool is used by the calibration engineer to speed up the in-vehicle development and plausibility check results quickly. This helps to avoid a negative impact on fuel economy and performance while working on drivability.

Key words

Gearshift pattern, Simulation, Automated Transmissions, Global Powertrain Optimization, Transmission Management, Gear Shifting Program, Transmission Control Unit, Drivability, Fuel Economy, Performance, Variant Application

INTRODUCTION

Over the last ten years, the manual transmission market has shrunk and this trend seems to continue. Automated transmissions are democratizing progressively. Innovative technologies like DCT are gradually taking the upper hand on aging technology like AT, even if those are still being optimized (Torque converter with early lock-up capabilities, torque converter replacement by wet start clutch, frictions improvements, ...) or CVT (that have yet to concretely demonstrate all their efficiency improvement potential, and level of acceptance on European market).

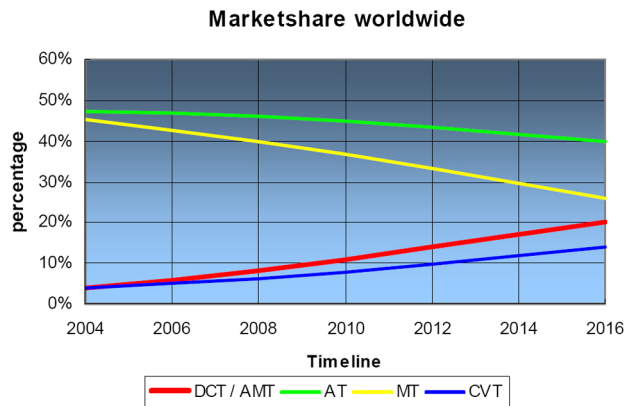


Figure 001. Transmissions Market Share Worldwide /
Source: Global Insight

Automated transmissions are already very complex systems, subject to many constraints, increasingly severe:

- CO₂, global and local requirements & Real Driving Fuel Economy
- Emissions constraints (Euro 6, Euro 7, ...),
- Level of market acceptance for each AT technology,
- Drivability and performance of the transmission
- Increasing complexity of new transmissions' technology

All those constraints associated to the high number of degrees of freedom for tuning makes AT transmissions like a big node of trade off. If we also consider that time to market must be drastically reduced and customer requests are becoming more precise, engineering teams have to face two challenges:

1. Be able to choose the right object at the right time from the very early and preliminary phases of projects
2. Reduce duration of shift pattern application process, by being able to focus on fine tuning activities instead of losing too much time on basic and repetitive parts of the process

The answer to these two requests lies in Numerical Tools and their associated process to manage the various stakeholders and skills and data flow. Being able to generate a gearshift pattern, by calculation only, requires first that:

- Vehicle physics and interactions with powertrain is well understood and mastered
- Subjective criteria (like for instance reserve of power or acceleration feeling) are well described as to be able to translate them into very objective criteria through mathematical algorithms.
- Interactions between the different customers requirements : drivability, CO₂, Real Driving FE, NVH, performance, and their mathematical transcription (if possible)

This is the result of all those reflections that will be presented to you in this paper: CRUISE GSP, a tool for gear shift pattern generation and optimization, which can be used for both upstream studies on very advanced powertrains as first GSP application process on real vehicles. Main objective is to ensure perfect consistency between those two kinds of activities.

THE GENESIS OF CRUISE GSP

This GSP calculation tool is a world premiere in the field of vehicle & powertrains calculation tools.

A SMALL HISTORY OF GSP

Renault has gained experience in the calculation of GSP for the past ten years. The effort to make these GSP more and more representative of a real tuning on vehicle forced Renault engineers to finely analyze engine and transmission interactions within a vehicle, and to be able to objectify most influent NVH / Emissions / CO₂ / Drivability / Performance / Reliability requirements.

At the beginning, GSP were so simple that they were only representative and usable to calculate CO₂ on NEDC cycle. As the relationship to the engine load was not taken into account, they were simple and quick to implement. Only 3 parameters were needed to generate such GSP:

1. Gear box ratio
2. Minimum engine speed requested for downshifting
3. Up / Down shifting hysteresis

CO₂ performance was over-estimated with this kind of GSP.

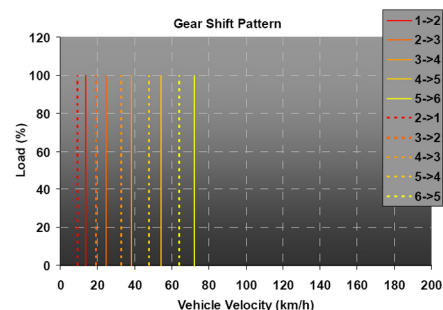


Figure 002. 1st gen. of calc. GSP : Straight line GSP

In order to be able to evaluate vehicle performance and be more representative for gear-shifting during accelerations on consumption cycles, previous GSP have evolved to:

- Take into account kick mode (based on a preliminary static acceleration's hooks calculation)
- Take into account some load dependency for intermediate acceleration pedal position, by drawing a straight line between kick points and the higher point of lower area of GSP

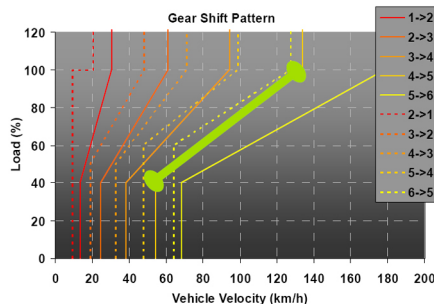


Figure 003. 2nd gen. of calc. GSP : Kick & Load dependency

Finally, establishment of objective criteria have helped to make the middle parts of GSP much more realistic and coherent with real AT tunings. So much so these GSP are directly usable on a vehicle.

On this basis, new criteria can be very easily implemented. For instance, a new criteria based on reserve power allows to define lower area of GSP with respect to drivability requirements (This was not always the case with “Minimum Engine Speed” methodology)

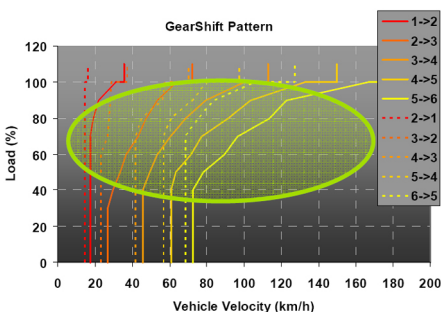


Figure 004. 3rd gen. of calc. GSP : Real life GSP

In the past [10], Renault engineering CO₂ & Emissions Teams have developed an optimization methodology to help defining the best gear ratio sequence on to minimize CO₂ in compliance with Emissions standards. This methodology allows to judge more accurately and more fairly the different powertrain technologies, especially those with diesel engines. This is also very useful to help optimize Real Driving Fuel Economy.

This methodology has been fully implemented in CRUISE GSP and offers now powerful graphical tools to help engineers to optimize their GSP.

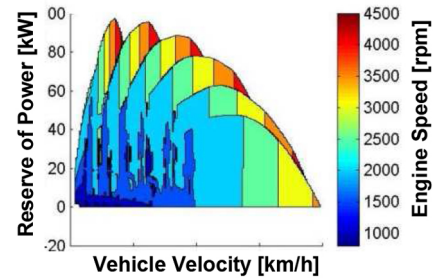


Figure 005. Optimal Eng. Speed function of Eng. Load & Velocity

CRUISE GSP is the result of a very close collaboration between Renault and AVL AST (Advanced Simulation Technologies). Renault has provided its know-how in terms of GSP calculation, and AVL has provided its know-how in terms of numerical tools for vehicle system simulation and driveline analysis (AVL CRUISE™).

This has resulted in a fully integrated and efficient tool, that allows to perform very detailed studies in a very flexible way. Prospects for improvement of this tool are still very important.

ONE TOOL - FOUR MODULES: QUICK DESCRIPTION OF THE TOOL AND ITS FUNCTIONALITIES

CRUISE GSP “Generation” as its name indicates allows generating fully exploitable GSP for calculations but also for testing/tuning on real vehicle. By generating gear shifting programs, lock up clutch programs drivability ranges as well as variograms for CVT models, CRUISE GSP Generation is usable with all kinds of transmissions (MT with Gear Shift Indicator [G.S.I.], conventional AT with torque converter, AT with wet start clutch, RMT, DCT, CVT). Using a set of advanced algorithm essentially based on drivability considerations, it helps you generate a fully adapted GSP to the vehicle and powertrain type you are studying.

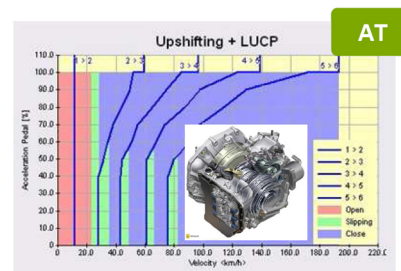


Figure 006. Example of Cruise GSP Generation outputs for AT



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And “How can do the more can do the less”, this methodology can be also applied on gasoline powertrains to get optimal setting for CO₂

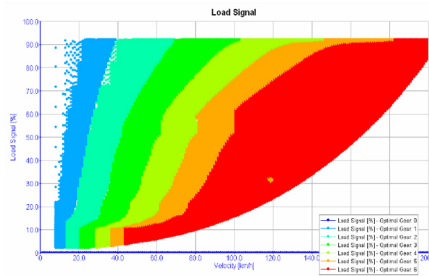


Figure 007. Example of Cruise GSP Optimization outputs

On the one hand the gear shift is carried out in the upper area of acceleration pedal (respectively load signal) if the driving performance in current gear is also available in the next gear (or the maximum engine speed is achieved).

On the other hand the fuel economy is considered in the lower areas of acceleration pedal and gear shift is carried out by using best points of BSFC map. That means Up-/downshift points are fixed along the optimum region.

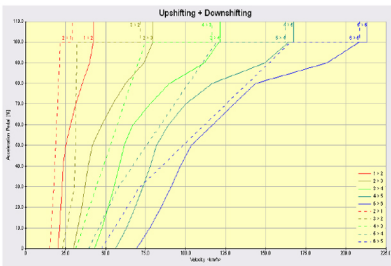


Figure 008. Example of Cruise GSP Wizard outputs

CRUISE GSP “Export to TCU” The aim is to convert/export generated Gear Shifting Programs into a format usable by the Transmission Control Units (TCU). Before exporting those into hardware intermediate setting processes should be at first specified with aim of fitting them to the formats used by respective TCU's.

In this context, the number of pedal sampling points can easily redefine/reduce in accordance with the type of hardware and the shifting points can thus be correlatively tuned.

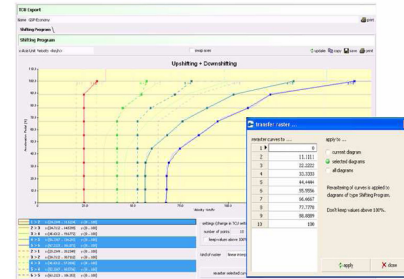


Figure 009. Export Tool: From Cruise to TCU

BASIC DESCRIPTION OF GEAR SHIFT PATTERN

Shift pattern basically represents the vehicle speed at which each shift (upshift or downshift) shall occur. Several shift patterns can coexist in a transmission control; each is adapted to a specific driving condition (city, sport, fuel economy, uphill, downhill, etc...); Shift pattern are traditionally represented as shift vehicle speed function of acceleration pedal position for a given gear ratio change (for instance: 2-3 shift, 3-2 shift...).

The following graph represents one part of a shift pattern for up and downshift. It represents the shift speed between two gear ratios. Dashed line represent a downshift speed form gear N to gear N-1, continuous line represent an up shift speed from gear N-1 to gear N A complete shift pattern is the addition of that graph for all the transmission gear ratio.

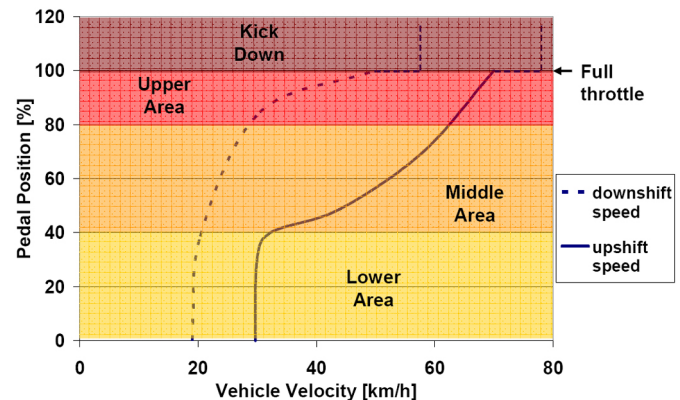


Figure 010. Up and Down Shift patterns around gear n

A shift pattern can be splitted into three parts: lower area, middle area, and upper area. In addition, two specific positions can be mentioned: full throttle (100% pedal position) and kick down points.

The lower area, which is the lower vertical part of the shift line (up shift or down shift), represents the intention to have shift speed independent of vehicle speed. It represents situations where the driver has a cool driving style, mainly requesting to maintain his vehicle speed or to follow the main traffic stream. The upper area represents situations where the driver request almost all engine power he needs for his driving style. If objective maximum power is not required, the driver's perception or feeling of full power is. Depending on manufacturer style, subjective perception of maximum power can be defined either by shifting at full engine speed, at full engine torque or a compromise to minimize the torque decrease feeling. It can also depend on the considered shift pattern (city, eco, sport, etc...)

The middle area is linking lower and upper area. It shall make a trade off between acceleration want, capabilities and optimal noise/consumption/emission.

Finally, like cruise-control system, automatic transmissions use a specific pedal position called Kick down. It is an extra travel over the 100% pedal position, transition between 100% pedal and Kick down is materialized by a hard point in the pedal travel. When a sufficient stress is applied to the accelerator pedal once at 100%, this extra travel becomes accessible. It materialize a need for a specific vehicle behavior, this specific behavior can change depending on the manufacturer policies.

Sensitivity to vehicle speed variation:

It can be noticed that a hysteresis is usually respected between up-shifts and respective downshifts in order to ensure a minimum robustness of the gear change decision. This hysteresis is especially important for transmissions with torque interruption (or for gear shift indicator on manual transmissions), as a speed loss occurs during the shift which could move the operating point back to the "before shift" situation initiating a up and down shift uninterrupted sequence.

Sensitivity to pedal position change:

The more vertical is a shift curve, the less sensible to pedal position variation it is. Shift points are then more robust. In the opposite side, if the shift curve is too vertical, the shift points engine speed dependency will be smaller inducing less available power variation with accelerator pedal position change. A trade off is to be made between power accessibility and shift speed robustness.

Evaluation criteria leading to shift pattern tuning are based on drivability performance, emissions, consumption and noise. While emissions and consumption are evaluated purely in objective terms, drivability is traditionally based on subjective appreciation, often related to acceleration feeling in relation to engine/car body noise and vibrations. This leads to numerous trial test and quotation in various driving style and geographic conditions.

From a performance and drivability point of view, an interesting data to use is the vehicle acceleration hook, which is illustrated for 1st and 2nd gear ratios at full throttle on the next graph:

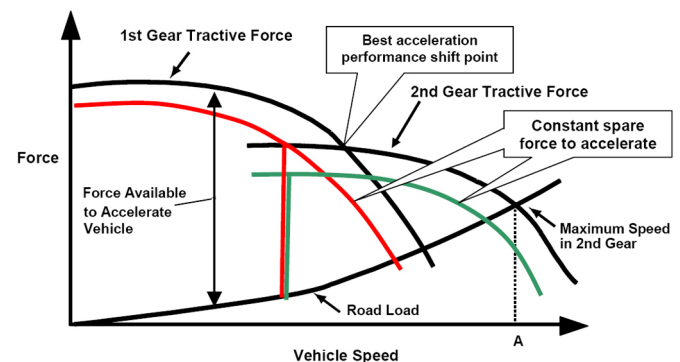


Figure 011. Objective criteria on acceleration's hooks

The best car performance is obtained when a shift occur at the intersection of the two curve. In addition, if the road load is subtracted to the full load force, the result illustrates the ability of a vehicle to reaccelerate in part throttle operation. In some vehicle speed area, two or more gear ratios can be selected. It is then possible to set for a given pedal position how much acceleration shall be available on a given gear for a given road load (e.g. for a given slope, vehicle weight etc...), by setting shifts at that limit points.

VIRTUAL SHIFT PATTERN GENERATION / OPTIMIZATION

Automotive environment becomes increasingly competitive. This pressure forces the engineering to optimize their efficiency along the development of new projects. This is especially true at very early stage of projects, when no technical definition is clearly available and several Powertrain definitions are in competition. This requires agility and responsiveness from engineering teams to be able to offer to customers the right product at the right time. In this context, powerful numerical tools have to be developed to assist:

- Establishment of product plan planning
- Management of CO₂ and Real Driving FE of innovative projects
- Establishment of Technical Policy
- Establishment of technical definition of new powertrains
- Fair comparison of different kinds of Powertrain
- Quick sensitivity studies

Before the availability of such tools for generating virtual GSP, the engineers should redouble their ingenuity to determine a GSP almost adapted to the given Powertrain + Vehicle configurations they were studying:

- Basic GSP (Straight lines with dependence to engine load)
- GSP derived from another GSP (for a vehicle with similar Powertrain)

Risks and limitations linked to this methodology were:

- Use of a GSP not really adapted to the studied powertrain and vehicle
- Use of a GSP that do not fairly take into account all customer requirements (CO₂/Emissions/Drivability/NVH)

For all those conditions, it had become urgent to find a solution to get out off this risky, non-effective and costly situation. This is one of the two major reasons we have launched the CRUISE GSP project. This tool has been developed following one fundamental rule: find the right compromise between modeling complexity and calculation time. This ratio dimensions the efficiency & usability of a tool in real projects life.

CRUISE GSP EASILY FITS INTO SIMULATION TOOLS WORKFLOW

Being directly available into AVL CRUISE™, CRUISE GSP is fully integrated in Renault CO₂ calculation tools workflow:

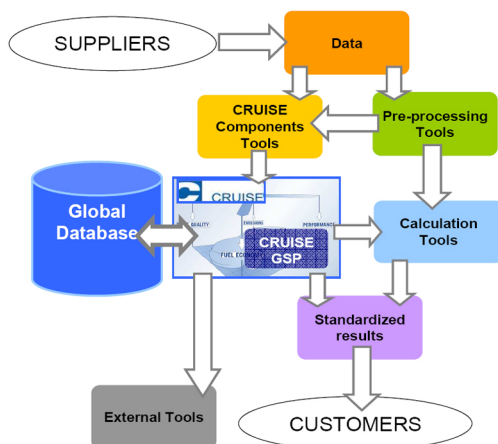


Figure 012. Renault CO₂ Tool Workflow

Suppliers (Internal or external tests & measurements results) provide to CO₂ calculation Team all the data required to establish a AVL CRUISE™ project (vehicle and powertrain data). All those data are compiled into AVL CRUISE™ components thanks to dedicated tools that allow to:

- Pre-format and verify data (to avoid dummy points)
- Automatically calculate missing parameters
- Automatically full-fill description fields and naming rules

Every input fields of a AVL CRUISE™ component is accompanied by a notice describing the filling method (philosophy, methodology, default values, etc ...). This ensures that anyone who tries to generate a AVL CRUISE™ component (engine, gearbox, vehicle, etc....) will always do it within the same way. This improves quality and traceability of data and participates to the deep synchronization and consistency between the needed data for the CO₂ calculation and the modeling of vehicle (level of details, simulated phenomenon, etc...).

All the generated components are stored into a central database, accessible from all Renault technical centers in the world.

Detailed steps of vehicle modeling will not be described in this paper. But, one must keep in mind that the more realistic the model is (amount of physical phenomenon taken into account), the more workable the resulting GSP will be, when using it in a CO₂ calculation or testing it on real vehicle. We will focus now on typical uses of the tool, and illustrate them by concrete studies' outputs.

VARIATION ON POWERTRAIN AND VEHICLE TECHNICAL DEFINITION

First way of using CRUISE GSP is to be able to establish huge variations on powertrain and vehicle parameters. This approach is particularly interesting when powertrains (technical definitions, settings) are not clearly defined, at very early stage of a project. Typical workflow can be:

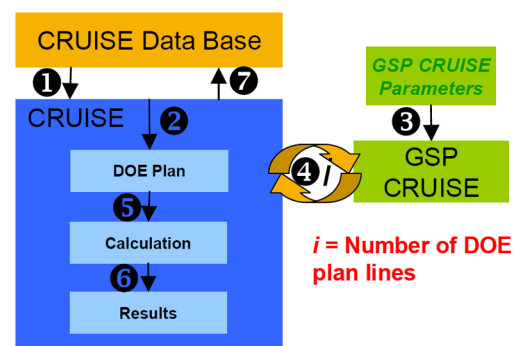


Figure 013. Powertrain variations workflow