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The potential for simulation of driveability of CVT vehicles

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ABSTRACT

This paper introduces the work ongoing at the University of Bath in a series of projects aimed at characterising the driveability of CVT equipped vehicles and using the findings to help develop a strategy for a prototype powertrain controller during transient driving situations. Results of the driveability investigation of a first project in this series have already been published [1], where the driveability of three CVT vehicles was appraised. A follow-up project extends this work appraising more CVT vehicles and also comparing driveability aspects of CVT transmissions to conventional AT. The paper relates the common experimental part of the two projects showing linked results and describing how a simulation program can be used to predict and improve the driveability of the powertrain controller.

INTRODUCTION

Simulation tools offer great potential for prediction of the fuel consumption, performance and emissions produced by passenger vehicles. This allows a large part of the powertrain control strategy to be designed in simulation. If this process is to be truly effective, it is also necessary to estimate subjective driveability at the simulation stage. This allows controllers to be designed, which properly consider fuel consumption, emissions *and* driveability, allowing the inherent compromises to be studied in detail. Much work is published in this area for conventional AT [2,3,4 and 5]. Relatively little has been published aimed at the particular characteristics of CVT powertrains.

The first part of the paper introduces the experimental driveability investigations, including the methodology and a description of the work program. The results of the driveability investigations, which demonstrate some of the characteristics describing CVT powertrain driveability are then presented. From these data some requirements for a simulation program for the prediction of driveability aspects are defined. Finally, such a simulation program is presented together with simulation data predicting aspects of vehicle driveability obtained using the prototype powertrain controller.

METHODOLOGY

Table 1 compares the vehicles used for the driveability work. They are referred to as car A to F and this naming convention reflects the order in which the cars were tested with cars A to C being inherited from the first project and cars D to F being part of the current project. Each vehicle was driven and appraised by 12 test drivers.

Table 1: Test Vehicles

	Car A	**Car B**	**Car C**	**Car D**	**Car E**	**Car F**
Fuel	Gasoline	Gasoline	Diesel	Gasoline	Gasoline	Gasoline
Engine Size/L	1.3	1.6	1.8	1.6	2.0	2.0
Mass / kg	850	1100	1100	1025	1328	1430
PWR/ (W/kg)	70.6 (100 %)	60 (86 %)	45.5 (71 %)	80 (113 %)	72.3 (102 %)	69.9 (99 %)
Transmission	CVT	CVT	CVT	CVT	CVT	4AT
Control	Electronic	Hydraulic	Hydraulic	Hydraulic	Electronic	Electronic

[1] Marie Curie Research Fellow (TMR Program of the European Commission)

Description of the Driveability Work

The driver's perception of driveability is a complex process and depends, amongst others things, on the driver's expectation of the vehicle and the particular driving situation. It is possible that two tests with fundamentally the same set of objective data can lead to completely contrary driveability perception in different driving situations. Therefore a number of driveability categories were defined which relate to real and distinctive driving situations, presented are here only results out of the following two categories.

Launch Feel: The tests in this category involved starting from rest with mainly large pedal movements.

Overall Performance Feel: In this category, the drivers expected the cars to provide maximum performance quickly, e.g. when joining a motorway or overtaking another vehicle. The pedal position is always depressed to its maximum position. The test presented out of this category had a starting velocity of around 12 kph.

The test drivers had to perform a number of tests in each category with different predefined pedal position inputs. All tests had in common that the drivers were requested to change the pedal position quickly to the new position and then keep it constant for a couple of seconds thus representing a step input.

Driveability Assessment Approach

The approach to the driveability investigations was to acquire objective data during the test-drives and to compare the results with subjective data, thus establishing which characteristics were liked by the drivers. The objective data were acquired during test drives using data acquisition equipment and the subjective data were gained by having the test drivers fill in questionnaires about their perception of the car.

Objective Data: The main variables acquired were: *engine and vehicle speed*, *vehicle acceleration* and *pedal position*. This allowed comparison between different characteristics in both qualitative and quantitative terms.

Subjective Data: The questionnaires included questions about driveability and performance attributes assessing a total of 14 different aspects. A rating was assigned in the range from 1 and 10, with the latter being the best possible assessment. The questions were chosen, so that they could be related to the driveability categories.

It is important to note that for each maneuver assessed by a test driver the subjective data were recorded for later analysis. This procedure generates large quantities of data but is important to allow the reasons for a particular assessment to be determined. If a driver returns an unusually low appraisal figure this may be explained by a slow application of the accelerator pedal or a final position which is too low. Alternatively it may be due to the normal differences of opinion between test drivers. The objective data allow these effects to be investigated.

QUANTIFICATION OF THE SUBJECTIVE RESULTS

Figure 1 shows different acceleration traces that are felt by the drivers during a test when starting from rest. The three traces share a similar basic shape. The acceleration is zero at the start of the test and rises rapidly to a peak value following a large step in pedal demand. There is then a period of relatively constant acceleration but with some fluctuations as the powertrain controller seeks to deliver demanded power by scheduling transmission ratio appropriately. Subsequently acceleration decays as the power required to maintain a given rate of acceleration rises with vehicle speed. There are clearly differences between these traces and the subjective scoring of the tests would be expected to reflect this. To be able to describe objectively the differences between the vehicles a means to characterize the time traces is necessary. For this, the following definitions for the characteristic values were adopted and are shown in Figure 2:

Delay time: The delay time is defined as the time between a first change in pedal position and the first change in the acceleration trace.

Acceleration Value: This is the peak value of the initial acceleration phase.

Jerk Value: The jerk value is defined as the value of the initial acceleration divided by the duration of the initial acceleration to give the rate of change of acceleration during the initial phase of the test.

It can be observed that our proposed characteristics concentrate very much on the first two or three seconds following the driver's demand. Other tests can be developed to analyze subsequent phases of the acceleration. These are not described here.

EXPERIMENTAL RESULTS

These characteristic values were used in the following to compare the achieved subjective and objective results in the two aforementioned driveability categories.

Launch Feel

Figure 3 shows the influence of the delay time on launch feel assessment. In all cases the data displayed represent the mean of both the subjective and objective data from all the test drivers. A clear correlation may be observed giving a useful design tool for the assessment of delay time in simulation. Interestingly the AT equipped vehicle excelled in this test. None of the CVT vehicles were equipped with torque converters. More recently CVTs have started to appear with torque converters.

Figure 4 shows a clear correlation between initial acceleration and subjective assessment of launch feel. Again the AT equipped vehicle outperforms the CVT vehicles. This is probably due to largely to its torque converter characteristics. Interestingly, car E received a worse subjective appraisal than seems warranted by its initial acceleration figure. This is due to its poor delay time, shown in Figure 3. There is clearly a degree of coupling between delay and initial acceleration when assessing launch feel. This has led to a revision of the subjective appraisal questionnaire to include separate assessments of delay and initial acceleration for each maneuver. Figure 5 shows no clear correlation between jerk and launch feel assessment. Jerk is therefore regarded as not being important for this driveability category. Delay time and initial acceleration value are the dominant features in the subjective assessment of launch feel.

Performance Feel

As described above, these tests were performed from a variety of initial velocities and are characterized by a rapid and large pedal step. The results presented are all recorded with a vehicle starting velocity of 12 kph. Figure 6 shows a good correlation between delay and subjective assessment of performance feel. Here car A, which was a CVT vehicle with electronic transmission control showed the best performance.

Figure 7 shows the correlation between initial acceleration and performance feel. Here also a very strong relationship is observed. Looking at Figures 6 and 7 together it seems that as above there is a degree of coupling between delay and initial acceleration in the subjective assessment of launch feel. Car C seemed to be assessed a little harshly in Figure 6, this is due to its poor initial acceleration, shown in Figure 7. Similarly, car B has an unduly favorable rating in Figure 7 which is due to its small delay time in Figure 6. Later tests with separate appraisals of delay and initial acceleration feel help to clarify this effect.

Figure 8 shows a good correlation in this case between jerk and subjective assessment of performance feel. One exception is car D. Its highly impressive jerk figure should earn it an exceptional rating but in practice its unexceptional delay and initial acceleration values drag the assessment down.

REQUIREMENTS FOR THE SIMULATION PROGRAM

The above analysis yields some clear requirements for a simulation program designed to predict subjective driveability. The simulation must be able to predict acceleration and jerk values as well as delay times with some accuracy. This has some implications for the level of dynamics captured by the simulation. For most purposes fuel consumption and emissions can be adequately represented by a very low order model. Even an instantaneous simulation with no states [6] can suffice. Where delays, acceleration and jerk are required to be accurately predicted a much higher level of dynamics must be represented. The dynamics of the system are principally determined by the engine and powertrain inertias, vehicle inertia, inlet manifold dynamics and controller behavior.

THE SIMULATION PROGRAM

In the course of a project to investigate the controller of an IVT powertrain a simulation program was developed in the simulation environment of Matlab/Simulink, which emulates the longitudinal movement of a vehicle. The structure of the simulation program is shown in Figure 9 and Figure 10 compares a simulated acceleration trace with an experimental acceleration trace for the same test. In the following the most important parts of the simulation program are introduced.

Engine Model: The engine model is based on a series of steady state engine maps and is realized by means of 2d look-up tables. The inlet manifold pressure is treated as a state.

Transmission Model: This model is based on equations governing the torque produced by the transmission in response to hydraulic control force applied. The dynamics of the transmission are sufficiently fast to avoid the necessity to model the hydraulic control mechanism in great detail. Inertias of the major components are included.

Controller Model: The Controller was supplied by the manufacturer of the transmission, also in the Matlab/Simulink environment which facilitated its incorporation into the simulation program, thus enabling the development of the further control code within the simulation environment.

Vehicle Model: The vehicle is modeled as a simple lumped inertia with a drag characteristic taken from experimental data.

Driver Model: The driver follows the vehicle speed demand with a feed forward and PID controller.

PREDICTION OF THE DRIVEABILITY BY MEANS OF THE SIMULATION PROGRAM

The simulation program was used to simulate the two maneuvers the test drivers had to perform using the prototype control algorithm. Comparing these results to the experimental results allows the prediction of the driveability the powertrain controller would achieve when used in a test car. Using the characteristic values, the performance achieved in the tests by our virtual car can be described as follows:

Launch Feel:	Delay Time: 0.42 / s Acceleration Value: 0.29 / g Jerk Value: 0.2 /(g*s)
Performance Feel:	Delay Time: 0.43 / s Acceleration Value: 0.27 / g Jerk Value: 0.18 /(g*s)

The predicted driveability values are obtained by putting linear fits through the experimental data points and finding the subjective assessment corresponding to the objective characteristics. According to the delay time and the acceleration value in Figure 11, the subjective assessment achieved for launch feel ranges between 7 and 7.6. The predicted subjective assessment for Performance Feel ranges between 6.3 and 7.3 as illustrated in Figure 12. It can be seen that the latter rating is confined by the low jerk values and a first approach to improve the driveability of the powertrain controller should be to increase the jerk values.

FURTHER WORK

Further work includes an extension of the comparison between CVTs and conventional automatic transmissions and further validation of the vehicle simulation. It is hoped that controllers designed in simulation will deliver the required subjective driveability with little requirement for major calibration changes on the test track. Thus the intended compromise between driveability, fuel consumption and emissions will be preserved.

CONCLUSION

It has been shown that CVT vehicle driveability can be characterised in a manner suitable for inclusion in a simulation aimed at control strategy development. This allows considerable advantages when compared with the iterative approach to calibration often adopted. Typically a calibration for emissions and fuel consumption can be developed in simulation but later tuning for driveability often results in degradation of performance over type approval tests. This approach allows calibration for driveability to be considered fully at the simulation stage and allows great flexibility in the design of control strategies.

CONTACT

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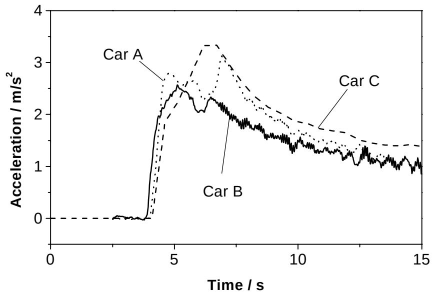


Figure 1: Acceleration from rest for the three vehicles

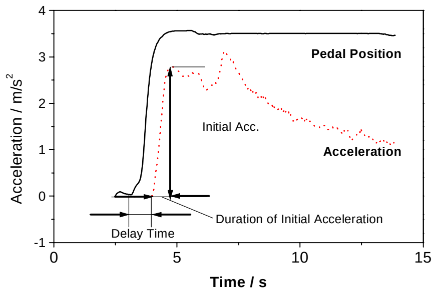
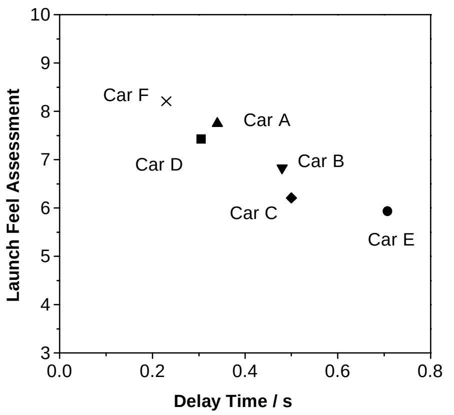


Figure 2: Illustration of the Characteristic Values



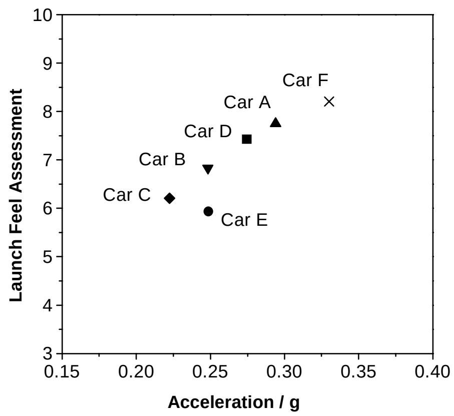
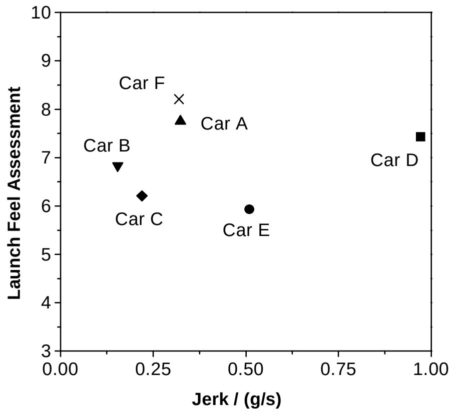


Figure 3: Influence of the Delay Times on the subjective Launch Feel Assessment

Figure 4: Influence of the Acceleration Values on the subjective Launch Feel Assessment



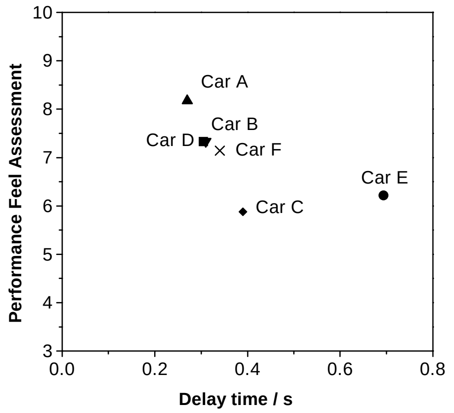
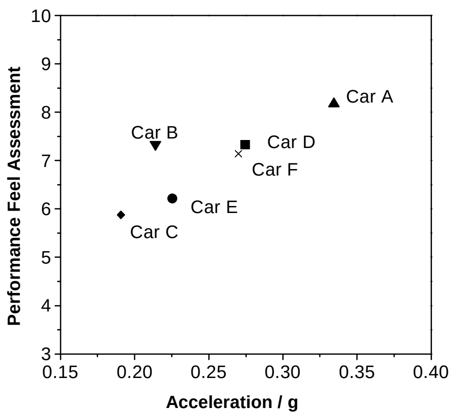


Figure 5: Influence of the Jerk Values on the subjective Launch Feel Assessment

Figure 6: Influence of the Delay Times on the subjective Performance Feel Assessment



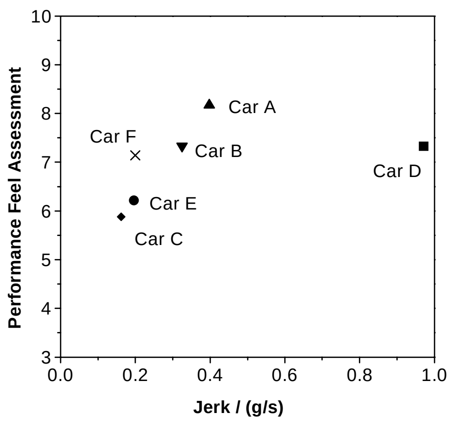


Figure 7: Influence of the Acceleration Values on the subjective Performance Feel Assessment

Figure 8: Influence of the Jerk Values on the subjective Performance Feel Assessment

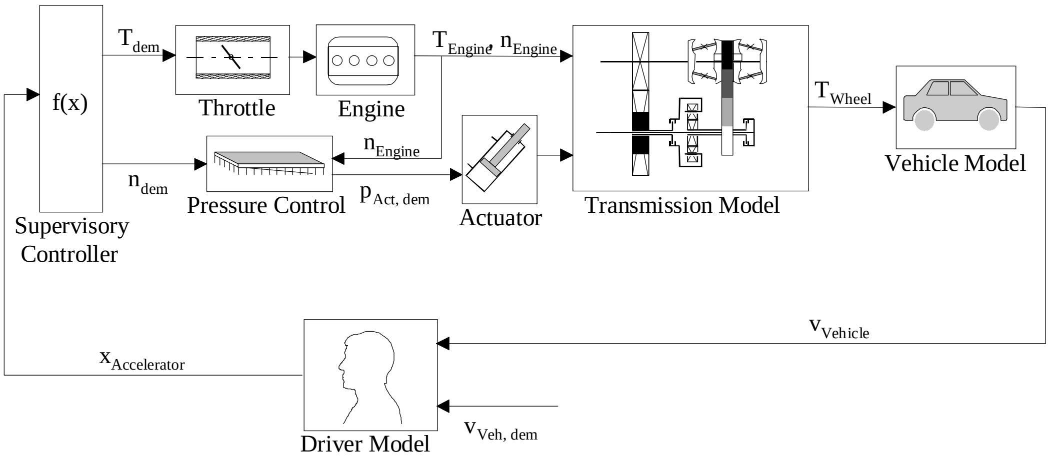


Figure 9: Structure of the Vehicle Simulation Program

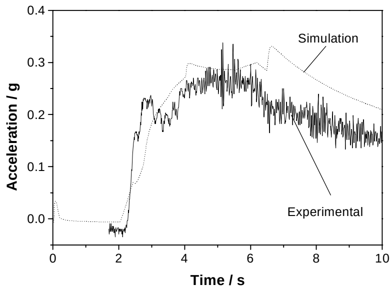


Figure 10: Comparison between an Experimental Acceleration Trace and Simulation Results

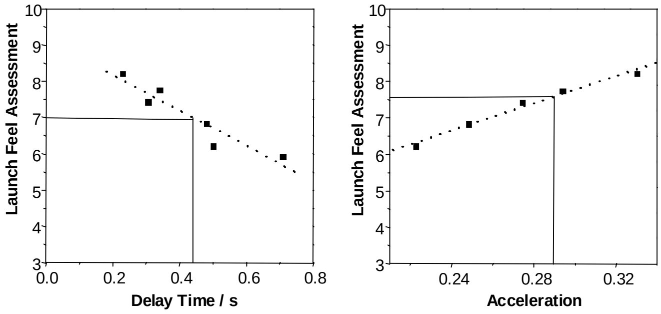


Figure 11: Prediction of the Driveability for the Powertrain Controller for Launch Feel by means of Linear Fits

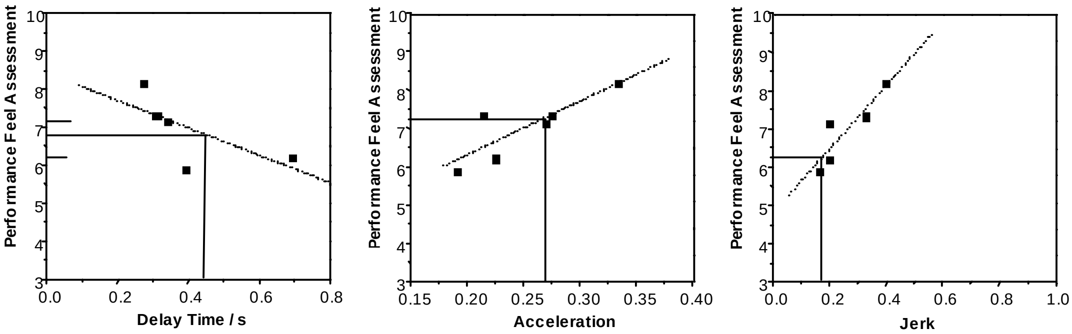


Figure 12: Prediction of the Driveability for the Powertrain Controller for Performance Feel by means of Linear Fits