Evaluation of a Hybrid Hydraulic Launch Assist System for use in Small Road Vehicles

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Introduction

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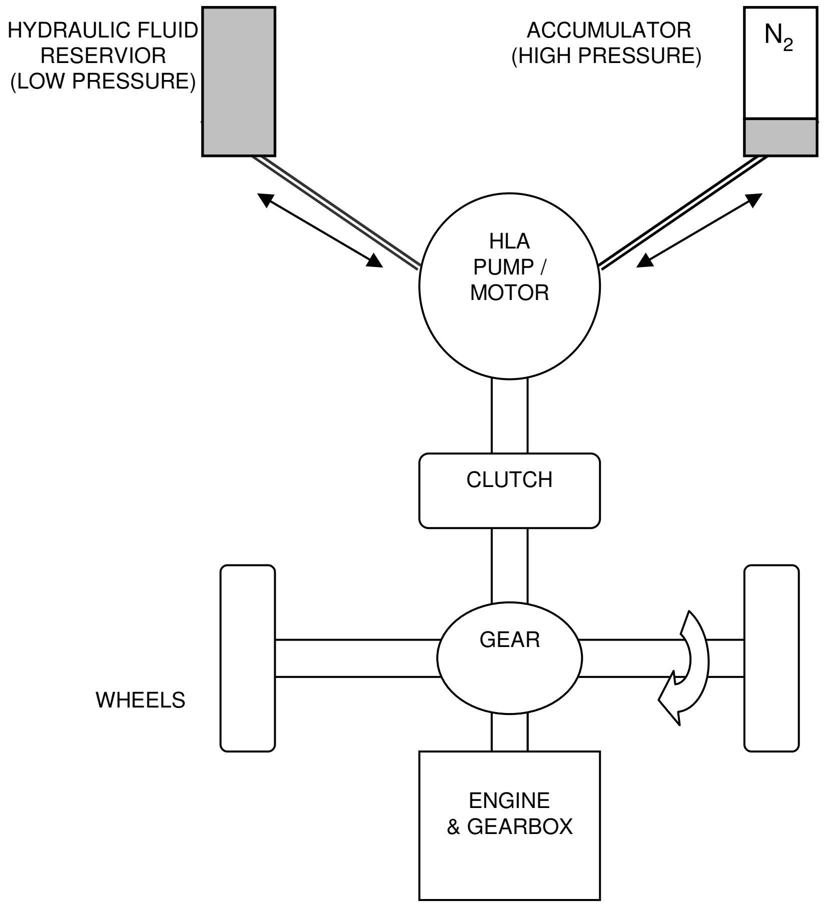
1. Hydraulic Launch Assist (HLA) vehicles



System Components:

Standard driveline

- Engine & gearbox
- Final drive
- Wheels

HLA system

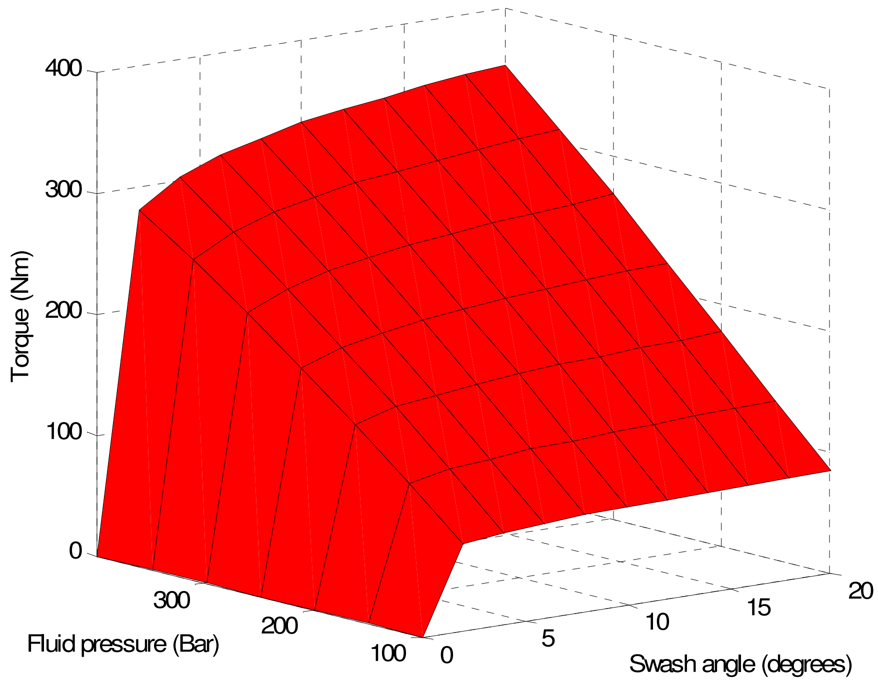
- Hydraulic accumulator
- Low pressure reservoir
- Pump / motor
- Clutch
- Final drive

Potential fuel savings of 30-70% [1], [2]

2. Hydraulic System Modeling

Axial piston pump modelling

- Based on Frazer et al.'s design [3]



Accumulator modeling

- 3.6kg of nitrogen stored in an 18 litre chamber at initial pressure of 172 bar
- Overall compression ratio is 2:1
- Compression is isothermal
- Energy stored calculated by

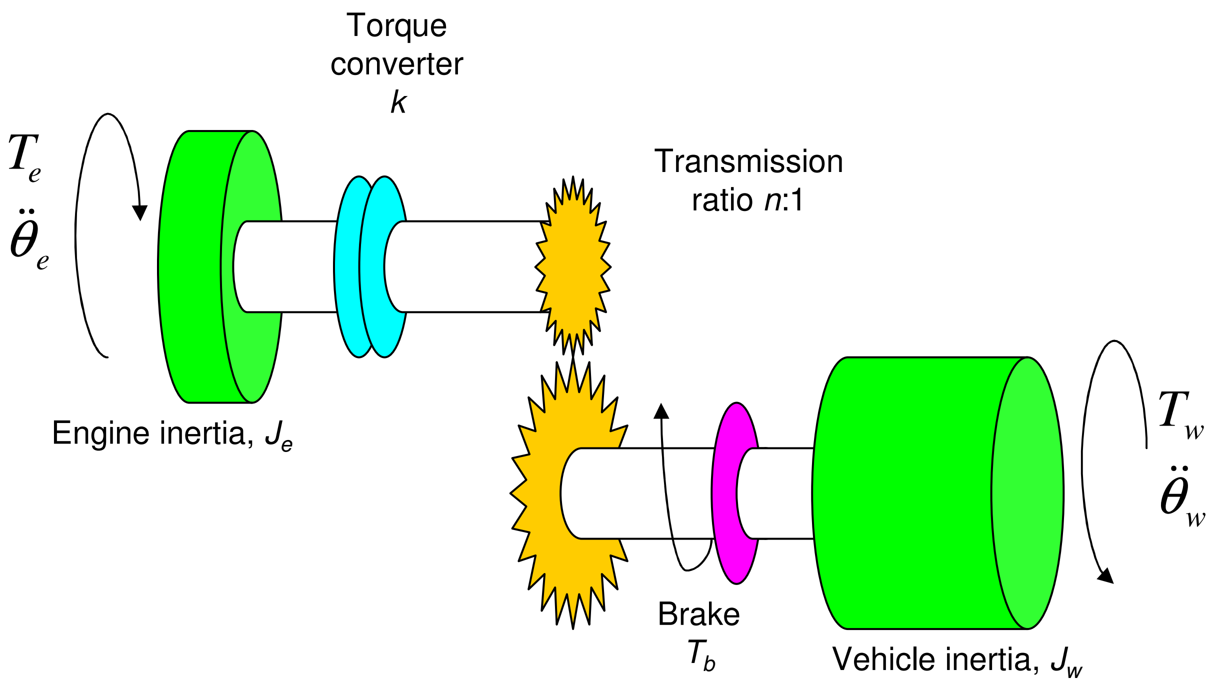
$$W = \int_1^2 PdV = P_1 V_1 \ln \frac{P_1}{P_2}$$

- Total storage capacity = 215kJ

2. Hydraulic System Modeling

- Accumulator design parameters
  - Based on kinetic energy available for a vehicle travelling at 64kph
- Final drive gear
  - Pump operating speed (maximum speed is 4800rpm)
  - Vehicle final drive (3.9 : 1)
  - HLA gear (2.1 :1)
  - (approximate) maximum 300Nm of HLA torque is geared up to approximately 2500Nm of available wheel torque
- Mechanical clutch
  - Disengage HLA system

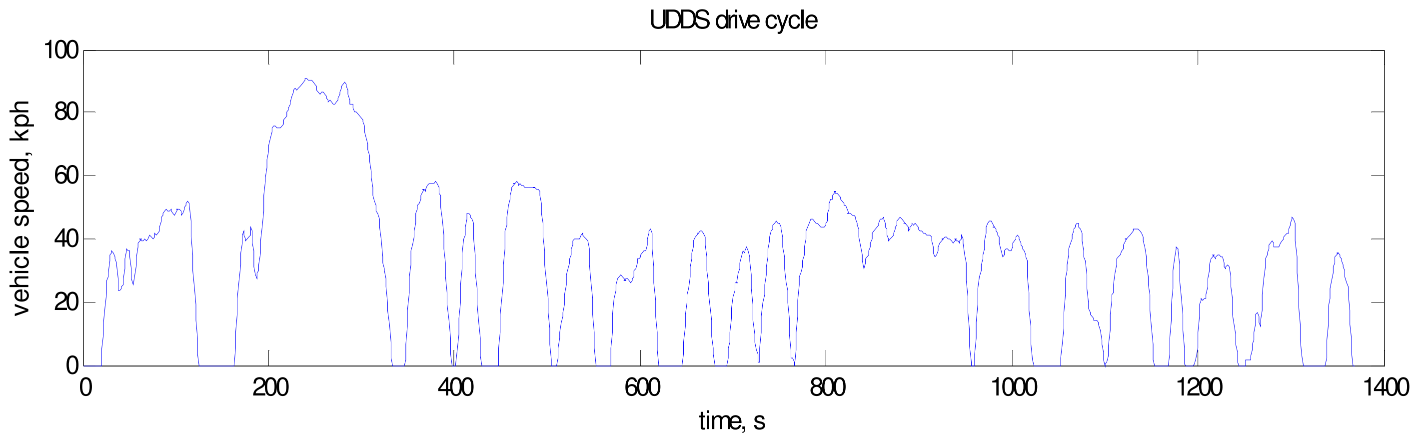
3. Vehicle Modeling

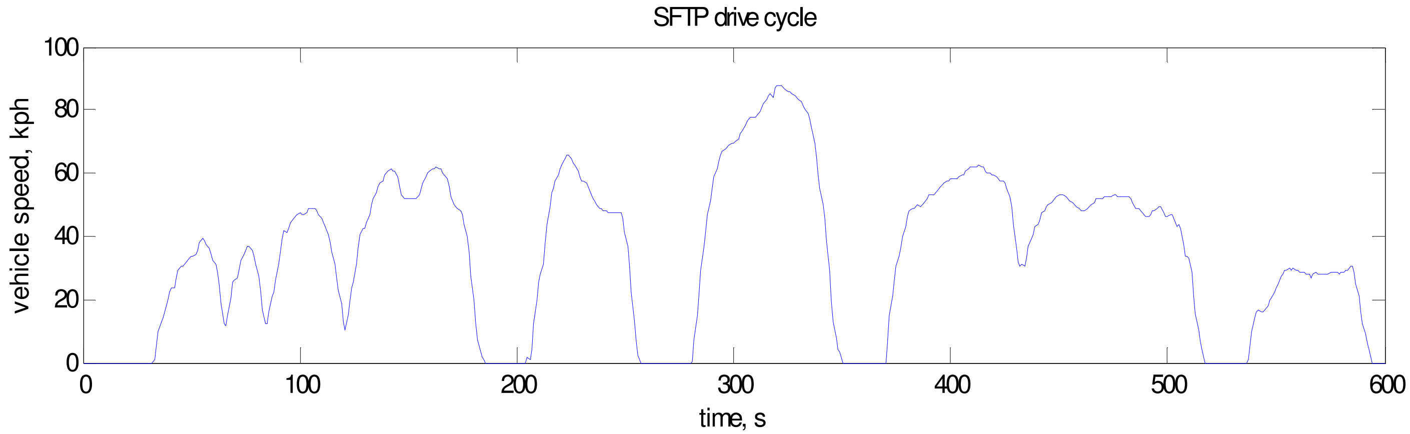


- The vehicle engine model used is based on the model described by Crossley and Cook [4].
- Environmental forces (drag, road friction, gravity)

4. Driver and Drive-Cycle Model

In particular the Urban Dynamometer Driving Schedule (UDDS) and the Supplemental Federal Test Procedure (SFTP) have been used for analysis [5]





5. Hybrid System Control

The hybrid system controller (HSC) looks at the driver demand – in terms of a desired speed setpoint – and converts this into various torque demands on the vehicle

- Engine
- Brakes
- HLA

For example, during an acceleration from standstill:

1. The HSC should first request torque from the HLA system.
2. If more torque is required (to accelerate faster) then additional torque should be requested from the ICE
3. As the HLA system uses up its stored energy, the amount of torque request of the engine should be gradually increased.

The HSC must estimate the torque available in the HLA system

- Not possible to measure torque stored in the HLA
- Only possible to measure pressure, volume and temperature

5. Hybrid System Control

HLA system engage / disengage

- At speeds above the maximum hydraulic pump/motor rpm, the HCS must reduce all HLA torque requests to zero, and physically disengage the HLA from the vehicle driveline.

Swash plate control

- The swash plate can only move from the closed position to the open position in a finite time. Therefore predictions must be made for choosing the correct time to process activation and deactivation.

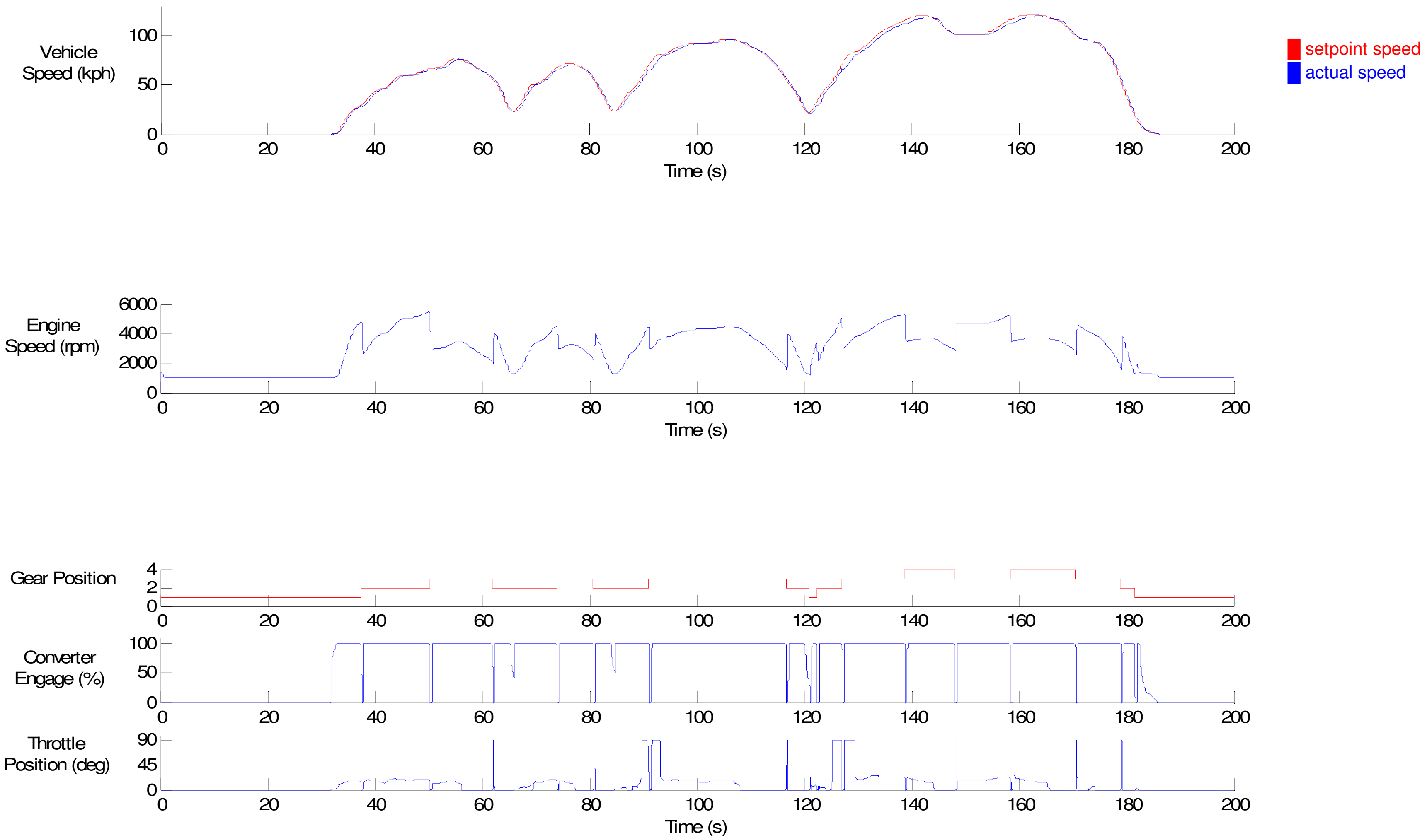
Valve port switching

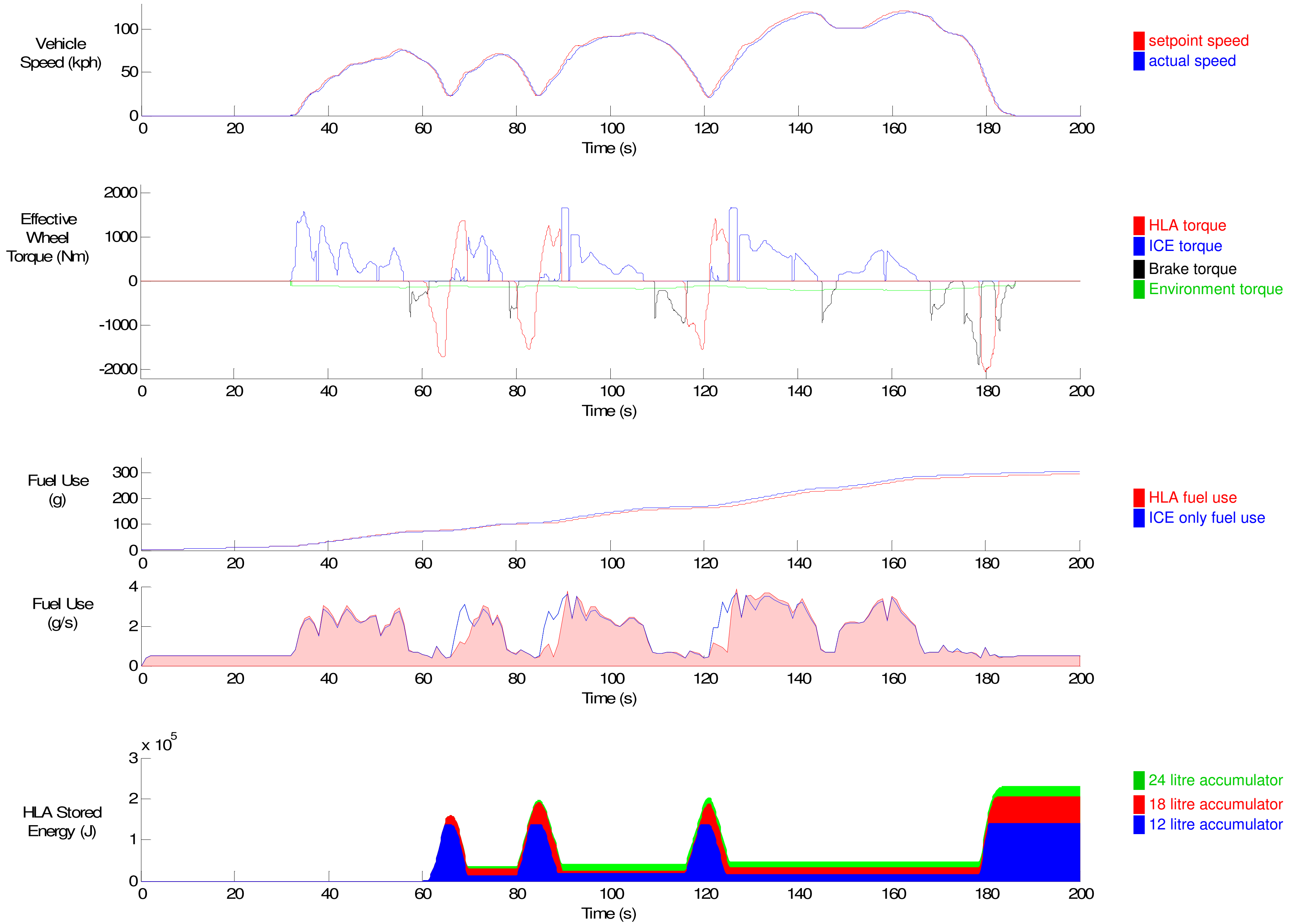
- Switching hydraulic valves from one position to another with hydraulic fluid at 300bar requires advanced closed loop control.

Safety control

- Control strategies need to be implemented in order to deduce what action to take in events such as a vehicle crash or system failure.

6. Simulation results




Vehicle Speed (kph)
100
50
0
0 20 40 60 80 100 120 140 160 180 200
Time (s)
setpoint speed
actual speed
Effective Wheel Torque (Nm)
2000
1000
0
-1000
-2000
0 20 40 60 80 100 120 140 160 180 200
Time (s)
HLA torque
ICE torque
Brake torque
Environment torque
Fuel Use (g)
300
200
100
0
0 20 40 60 80 100 120 140 160 180 200
HLA fuel use
ICE only fuel use
Fuel Use (g/s)
4
2
0
0 20 40 60 80 100 120 140 160 180 200
Time (s)
HLA Stored Energy (J)
x 10^5
3
2
1
0
0 20 40 60 80 100 120 140 160 180 200
Time (s)
24 litre accumulator
18 litre accumulator
12 litre accumulator

6. Simulation results

	UDDS Fuel Use (g)	Fuel Saving	SFTP Fuel Use (g)	Fuel Saving
Standard Vehicle	1291.5	9.80 %	807.2	7.45 %
HLA Vehicle	1165.0		747.1	

7. Conclusions

- The theoretical fuel savings of 30-70% are very difficult to achieve in reality. This simulation shows only a 7-10% improvement in fuel efficiency on urban drive cycles

- The added weight of the HLA system will actually cause a fuel use increase during some driving scenarios

- This research has highlighted a number of methods for performance enhancement:
  - Integration with an engine shut-off strategy system
  - Advanced predictive algorithms
  - Geared hybrid system

- Hybrid vehicle control strategies can considerably improve exhaust cleanliness over and above the actual fuel use savings

7. Conclusions

- System design parameters need optimising to achieve the best possible performance:
  - There will be an optimal accumulator size for a particular vehicle and drive cycle
  - Enhancements to HLA system packaging and weight reduction
  - Choice of operating pressures and compression ratios

- One key hurdle, however, is the safety implications of such a hybrid system
  - System shut down?
  - Vehicle crash?
  - Explosive failure?

- Overall conclusion:

It appears that the HLA system is a viable option for small road vehicles, though current knowledge and research is a long way off providing a complete solution. With the advancement of physical design, control strategy development and safety systems development the HLA system should have a valuable role to play in the future of hybrid vehicles.

8. References

[1] S. R. Anderson, T. J. Blohm, D. M. Lamberson and W. Turner “Hybrid route vehicle fuel economy”, In: Advanced Hybrid Vehicle Powertrains 2005, SAE International, pp. 169 - 180, April 2005.

[2] R. P. Kepner, “Hydraulic power assist - a demonstration of hydraulic hybrid vehicle regenerative braking in a road vehicle application”, International Truck & Bus Meeting & Exhibition, November 2002, Detroit, USA, pp. 1-8, November 2002.

[3] H. I. Frazer, E. W. Raymond and M. P. Russell, “Hydraulic energy storage systems”, Patent No. ES2266300T, January 2007.

[4] P. R. Crossley and J. A. Cook, “A nonlinear engine model for drivetrain system development”, IEE International Conference ‘Control 91’, Conference Publication 332, vol. 2, pp. 921-925, 25-28 March, 1991, Edinburgh, U.K.

[5] “Emission test cycles”, www.dieselnet.com/standards/cycles/index.ht ml, accessed November 2007.