Heavy Goods Vehicle Simulation Tool

Model definition, build and validation

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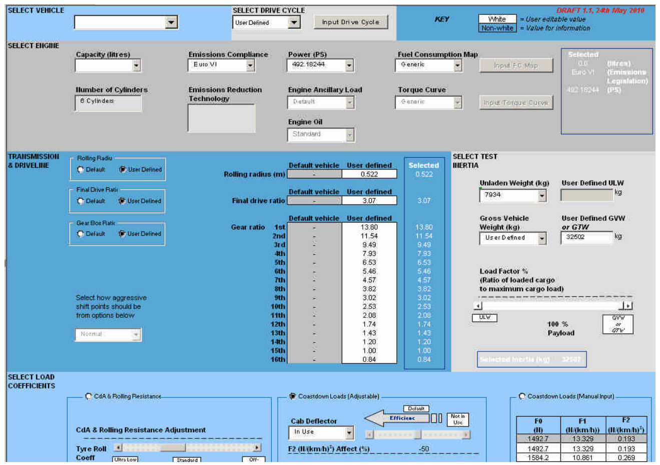

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Report by	**Ali Raja & James Baxter**
Approved	
	Pascal Revereault

Contents

Introduction

- Ricardo was contracted by the Department for Transport to investigate and demonstrate the role of vehicle computer modelling as a cost effective supporting tool for the accreditation of low carbon HGVs
  - This study is the fifth of a group of five projects to be undertaken by the DfT in partnership with the Low Carbon Vehicle Partnership (LowCVP).
- The work entailed the definition and build of a vehicle simulation tool, followed by its testing and suitability review through comparison with vehicle data measured during the course of the Technology Testing Project, lead by Millbrook Proving Ground.
- This document provides a technical description of the tool, including its operation and limitations, together with a comparison of the tool predicted results with measured data

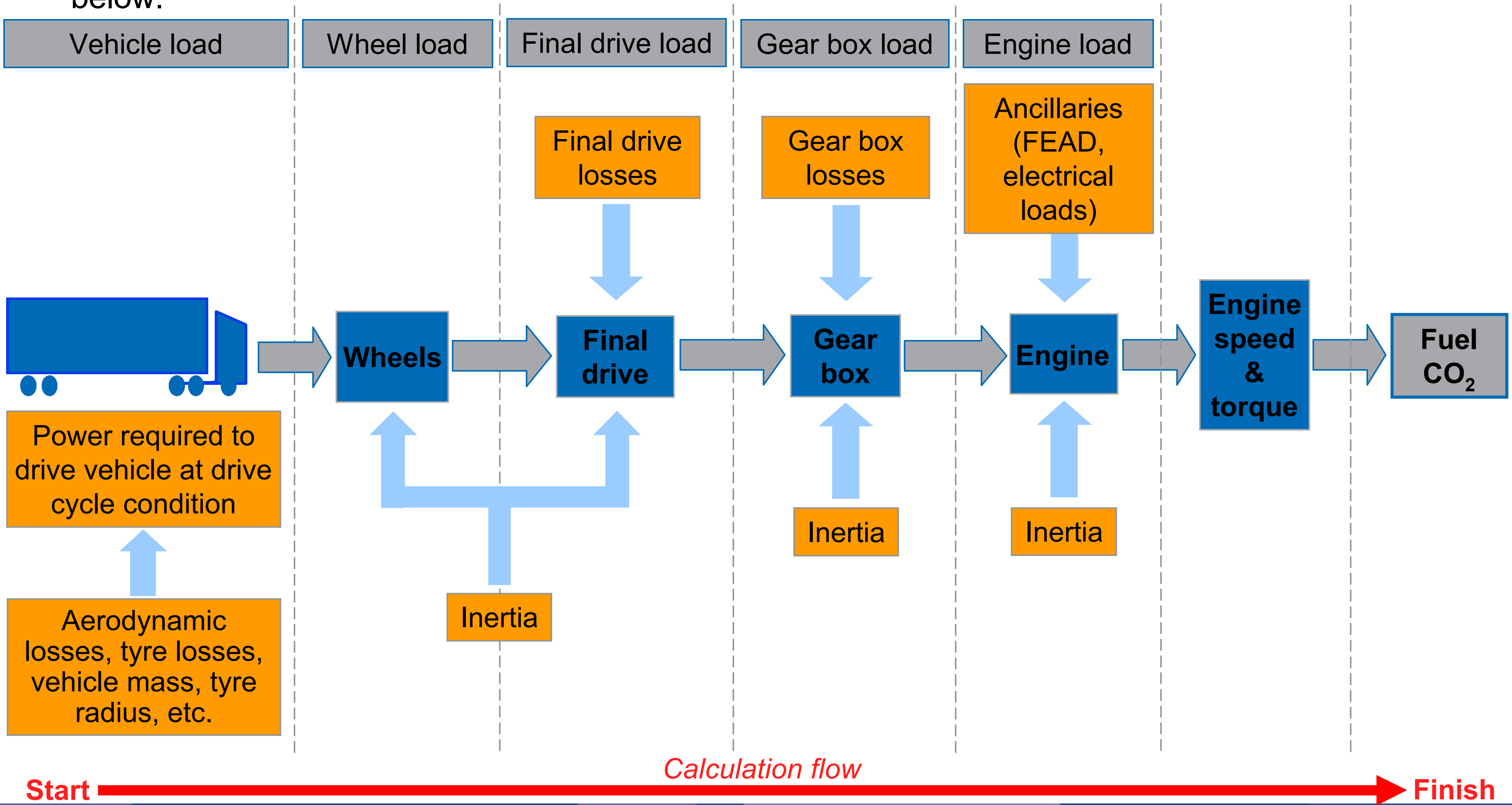
Contents

Model methodology (1)

- This section presents the methodology adopted in the definition and build of the vehicle simulation tool
- Microsoft Excel was chosen as the platform for the simulation tool for the following reasons:
  - Ease of use for non simulation experts
  - Ease of dissemination within DfT
  - No licensing issues

Model methodology (2)

- The fundamental principles used in the definition of the vehicle model are depicted on the diagram below.



Model methodology (3)

- The model is a backward facing calculation tool (no driver control model). It performs the following actions:
  - Calculates wheel speed and torque conditions based on drive cycle definition and vehicle characteristics
  - Propagates torque and speed information back towards the engine, accounting for system ratios, losses and power consumption
  - Required engine torque might be greater than the engine can provide
    - In this case, the actual speed achieved from the limited torque is not calculated. This would require the addition of a second forward facing model
- The model layout in Excel, shown below, follows the same principle as the diagram on the previous page

Cycle Definition				Speed, Accel, Dist.				Vehicle Load (N.B. use either CdA or a,b,c coefficients)						
Time s	Vehicle Speed km/h	Mid-step Veh Speed km/h	Gear number -	Vehicle Speed m/s	Mid-step Veh Speed m/s	Vehicle Accel m/s^2	Distance m	Vehicle Mass Accel Force N	Surface Gradient (deg)	Vehicle Gradient Force N	a (Aerodynamic Drag) N	b (Viscous Friction) N	c (Rolling Resistance) N	...
0	0.000	0.000	0	0.0	0.0	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
1	0.267	0.133	1	0.1	0.0	0.074	0.04	1923.48	0.00	0.00	0.02	0.48	1255.42	
2	0.400	0.333	1	0.1	0.1	0.037	0.13	961.74	0.00	0.00	0.04	0.73	1255.42	

	Engine & Auxiliaries									
...	Idle Speed rev/min	Idle Flag -	Engine Speed rev/min	Engine Speed rad/s	Engine Inertia Torque Nm	Engine min torque Nm	Engine max torque Nm	Engine Torque Nm	Engine Power kW	Hot Fuel Consumption g/s
	730	TRUE	730	76	0.00	-154.556	1616.84	103.49	7.911563	0.7440
	729	TRUE	729	76	-0.01	-154.5306	1616.84	145.36	11.09265	0.9660
	727	TRUE	727	76	-0.01	-154.5052	1616.84	132.65	10.1047	0.8967

Model methodology (4)

- The following two slides provide the data parameter inputs used by the tool

Engine	
Swept volume	l
Number of cylinders	*Indicator*
Torque curve (mapped against engine speed)	-
Fuel consumption map (mapped against engine speed and load)	-
Engine emissions standard compliance	(Euro III, IV, V or VI)
Selective catalyst reduction (SCR) in use	*Indicator*
Diesel particulate filter (DPF) in use	*Indicator*
Exhaust gas recirculation (EGR) in use	*Indicator*

Note: *indicator* represents an output that is associated to a previously selected input (e.g. EGR indicator flagged when Euro V engine selected)

CO2 Reduction Technology	
Cab deflector in use	Yes/No
Trailer type (e.g. standard, double-deck, tear-drop, etc.)	-
Trailer side skirts	Yes/No

Gearbox	
Gear ratios	-
Final drive ratio	-

Model methodology (5)

Vehicle Data	
Vehicle mass (i.e. unladen mass + cargo mass)	kg
Vehicle frontal area	m^2
Cd	-
Tyre friction factor	-
Tyre radius	m
Road load terms F0, F1, F2	-, N/(m/s), $[N/(m/s)]^2$

Drive Cycle	
User defined (vehicle demand speed, gradient vs time; auxiliary load)	-
FIGE (ETC)	-
Other to be confirmed	-

Possible Inputs (for Future Model)	
Electrical ancillary load	kW
Engine oil type	(Low Viscosity/High Viscosity)
Shift maps	(Economy, Normal, Aggressive)

Model methodology (6)
Transmission

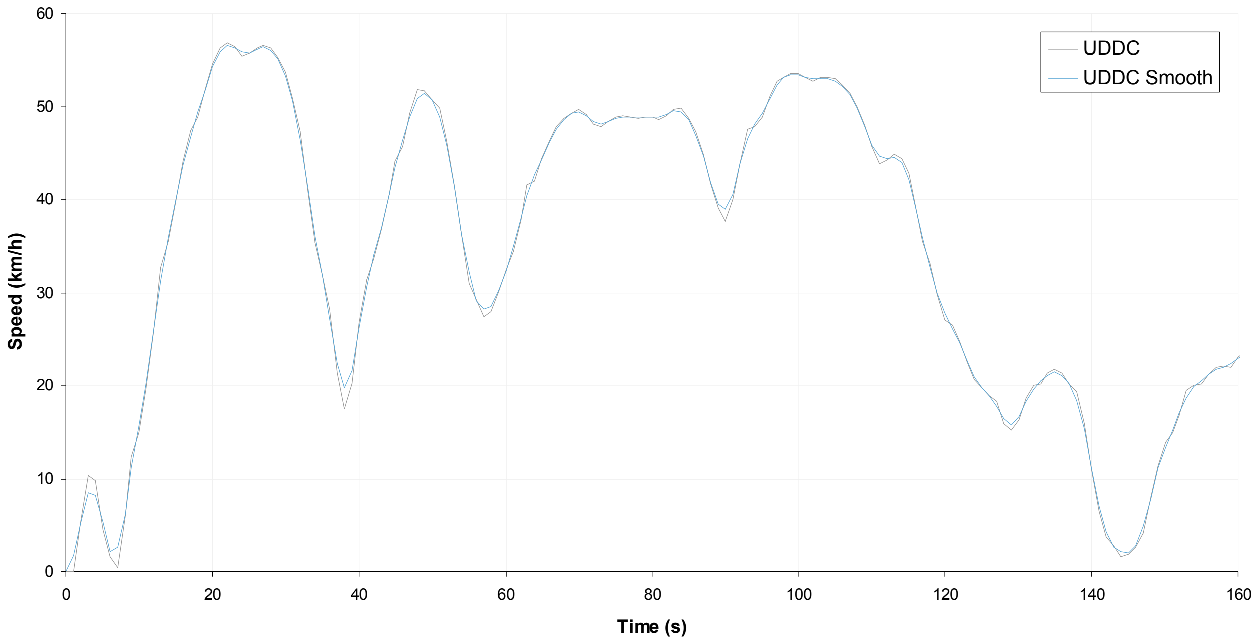
- As all cycles of considerations in this study do not provide a prescribed gear number schedule, a shift map has been designed
  - To allow the same map to be used with various gear ratios, they are stored based on engine speed
  - For use in the model, the engine speeds are then translated to vehicle speeds based on the vehicle characteristics
- Transmission losses are also stored within the model file
  - The losses are separate for each gear
  - The losses vary with input torque
- Final drive loss is stored as an efficiency value

Model methodology (7)
Engine Maps

- The engine maps for fuelling and torque are generic maps, created by analysing a number of real vehicle maps
- Fuelling map
  - The stored maps are based on BMEP (Brake Mean Effective Pressure) and engine speed inputs
  - The relevant map is selected according to vehicle type and engine calibration, and then scaled according to engine capacity
  - For use in the model, the BMEP input is then translated into torque
- Torque map
  - The torque map is interpolated between min and max torque curves
  - The stored minimum and maximum curves are expressed as BMEP, to make them independent of capacity
  - The maximum BMEP curve is scaled based on the engine specific output, the minimum BMEP curve is the same for all engines
  - Both curves are then converted from BMEP to torque for use in the model torque map
- Engine ancillary loads are applied as a constant mechanical power drain to represent alternator and pump loads

Model methodology (8)
Drive Cycles

- Drive cycle definition data is specified at 1 Hz, and consist of vehicle speed vs. time
  - The cycles considered in this work are highly transient cycles (see Model Validation section), and contain regions of rapidly changing speed demands. When vehicles are tested over these cycles, the driver and vehicle response, in terms of actual vehicle speed, is typically a speed profile with 'smoothed' features
    - In order to capture these effects in the model, the model pre-defined drive cycles have been smoothed to ensure good model engine torque response
    - Opposite is an example of the effect of cycle smoothing on the UDDC cycle



Model methodology (9)
Model scope limitations

- The model is a backward facing model. Subsequently, for high load vehicle conditions that exceed the engine torque or power limits, the model will be able to flag the torque or power shortfall, but will not allow to quantify the resulting difference between actual vehicle speed and demanded speed (from the drive cycle)
  - However this does not impact the validation process as it makes use of measured vehicle data, hence for conditions that were indeed achievable on the vehicles
- The model does not account for cold start effects on fuel consumption
  - This has little impact for Heavy Duty Vehicles, for which cold start effects have an insignificant influence on the vehicle life fuel consumption
- The model is a quasi steady state model, in that engine fuel consumption is calculated using a fuel map which is a collection of steady state fuel consumption points, measured at various engine speed and load conditions (however please note that the vehicle dynamics model is indeed fully transient)
  - This has a relatively low impact on fuel consumption for modern engines, thanks to improvement in air handling and fuel injection systems, providing better intake air management and AFR control

Model methodology (10)
Inherent simulation limitations

- The model methodology is well proven and is expected to yield acceptable levels of accuracy (within 5% of measured data)
  - This is highly dependant on data being available to fully characterise each of all the vehicle systems (e.g. engine mapping, transmission efficiency, vehicle aerodynamic properties etc.)
  - As such results generated with the tool should be qualified in terms of the quality of the input data used to generate the results. This applies to:
    - Vehicle input data: parameter swings should be performed to quantify the global impact of a parameter for which data has been assumed with a relatively low level of confidence. This will allow the definition of a vehicle fuel consumption value together with its associated error band
    - Vehicle duty cycle profile: this includes vehicle speed demand, gradient (or height) information, road surface and wind conditions. Lack of or poor data on either of these cycle definition attributes will greatly affect the apparent accuracy of the model

Contents

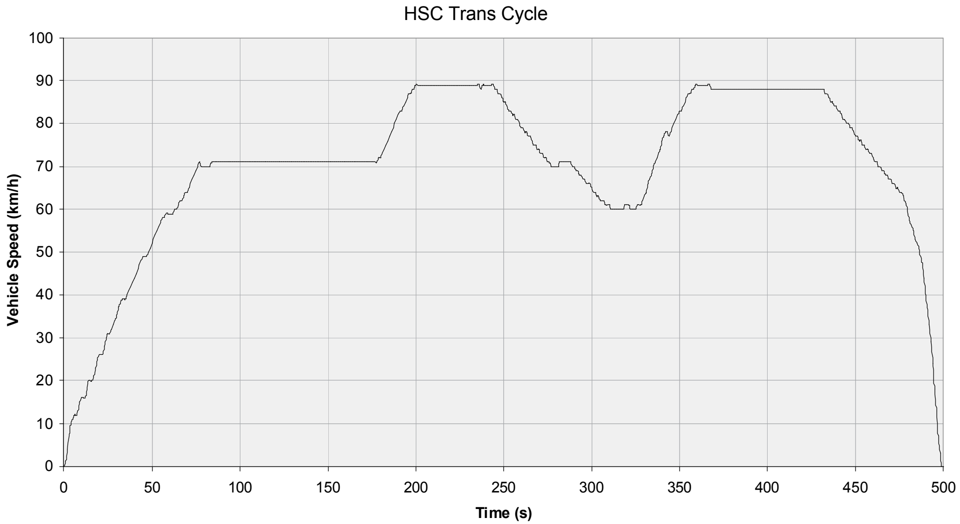
Measured vehicle test data was provided by Millbrook for 4 different vehicles

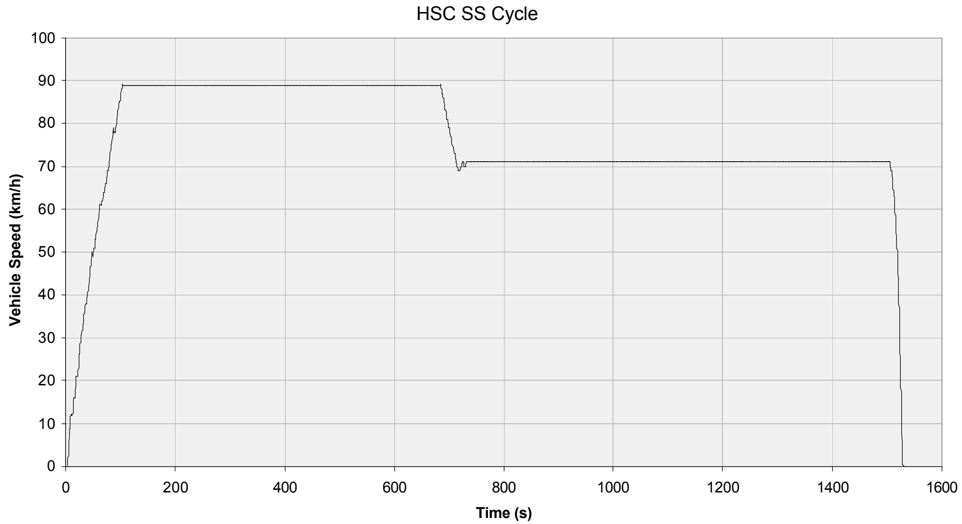
- This section summarises the work conducted to validate the Excel based vehicle simulation model, using testdata provided by Millbrook
- The work has entailed reviewing data that was recorded by Millbrook on four different trucks, with various vehicle technology set-ups, as described in the table below:

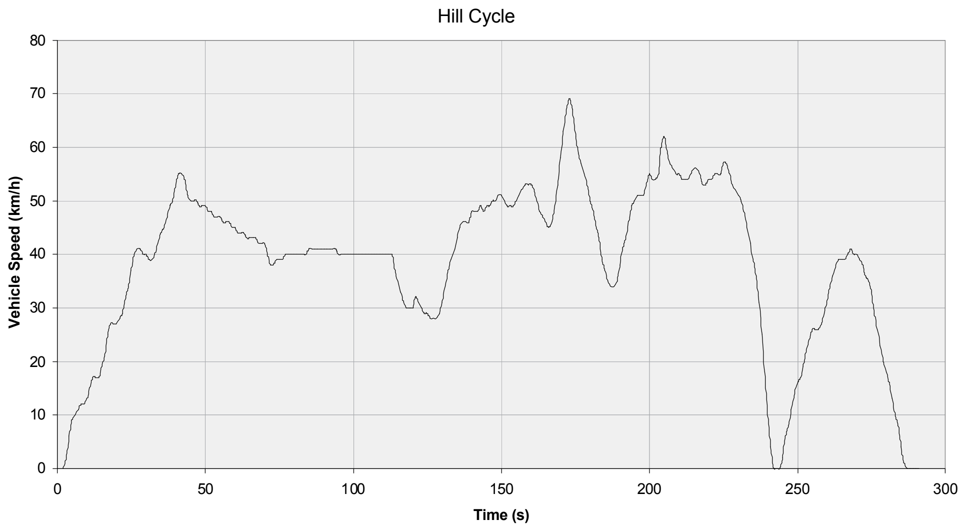
	Scania P230 18t Rigid	Scania R420 44t Artic.	DAF CF85 44t Artic.	Mercedes Benz Actros 2544 44t Artic.
Standard build	✓	✓	✓	✓
Low rolling resistance tyre		✓		
Roof cab deflector			✓	
Teardrop trailer				✓
Teardrop trailer & side skirts				✓
Double deck				✓
Low tyre pressure				✓

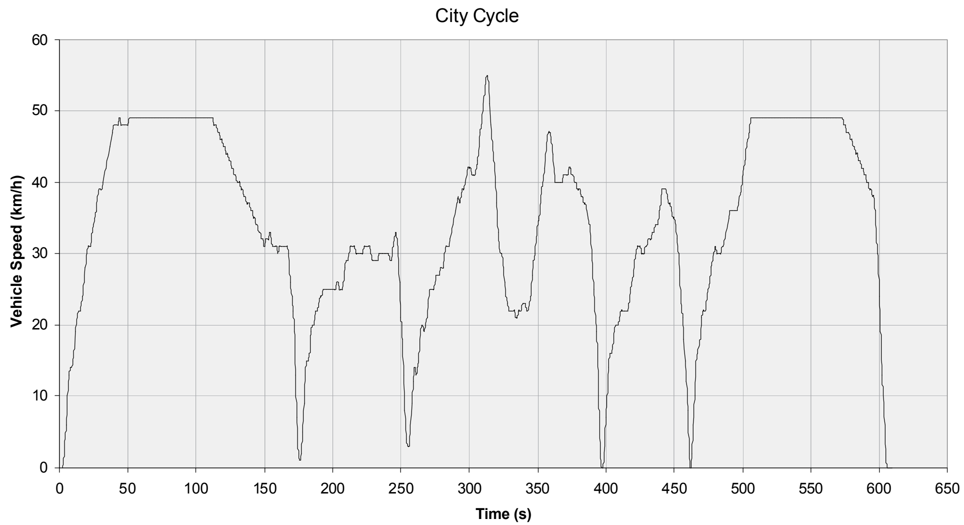
All the vehicles and configurations were tested on the Millbrook outdoor tracks and circuits, over the same four cycles

Drive cycles









Validation Process Overview

Model was validated against Millbrook test data using this process flow

Review Millbrook data

- Check that the values provided are within the expected range
- Compare data from similar tests to ensure there are no obvious discrepancies

Post-process the Millbrook data for use in the model

- Derive gear numbers by comparing vehicle speed to engine speed
- Convert CO2 signals to fuelling
- Smooth the vehicle speed trace
- Filter the height channel in order to remove noise/ high frequencies from the signal
- Process the coastdown times in order to derive the necessary coefficiencts (F2, F1, F0)

Tune model to match measured fuel consumptions

- Populate model with data for relevant vehicle
  - Coastdown terms
  - Gear ratios (incl final drive)
  - Tyre radius
- Generic fuel maps and torque curves were used – these are engine capacity and technology specific
- Ancillary loading was assumed to be a constant power, and the value remained unchanged for each specific vehicle

Post processing Millbrook's data

The second by second data channels were processed to derive further information

Gear Ratios / Gear number

- For each time step, the current engine speed was divided by the current vehicle speed,
  - The tyre radius and final drive ratios are constant, and so any differences between successive values represents a gear change
- By completing this process for all time steps, an approximation of the gear number used by the driver can be obtained, along with the gear ratio (this can then be checked against publically sourced data)
- This gear number versus time trace is then used as an input to the model for the purposes of validation

CO_2 → fuelling

- The second-by-second data provided by Millbrook included a CO_2 channel
  - Assuming all fuel is fully burnt, this CO_2 can be converted to instantaneous fuelling

Smooth the vehicle speed

- There were instances where the vehicle speed trace oscillated between two values during steady cruises
  - At such times, the value was set to a constant in order to avoid large oscillations in the engine's output torque

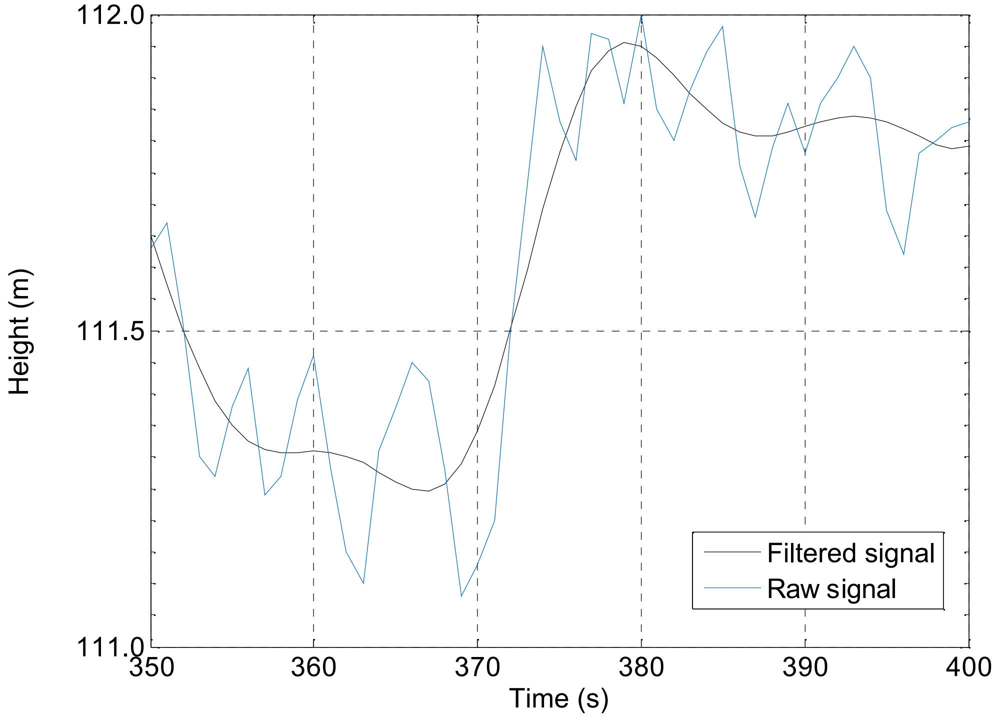
Post processing Millbrook's data

All the data was checked and some data filtered in order to derive usable traces

Filter the height data

- There was significant noise / uncertainty in the height data, leading to the model calculating large swings in torque between time steps due to it 'seeing' large gradient changes
  - Therefore, a low-pass butterworth filter was used to smooth this height signal
- The order of the filter, and cut off frequency, were varied on a case by case basis until a reasonable trace was obtained

- This filtering improved the results, **however a degree of uncertainty remains** which impacts upon the accuracy of validation



Post processing Millbrook's data – Good coastdown factors fit to coastdown data

Coastdown coefficients (F2, F1 and F0) were derived from the coastdown times

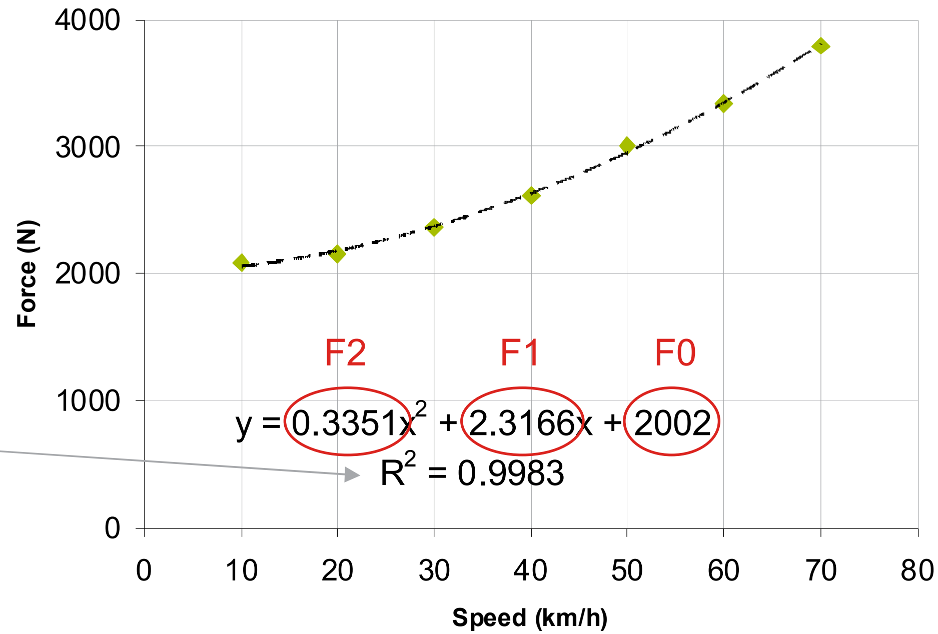
Coastdown terms

- Data recorded by Millbrook was in the form of time taken for vehicle speed to reduce in 10km/h intervals

Speed (km/h)		OVERALL
High	Low	AVERAGE
95	85	
85	75	
75	65	24.69
65	55	28.02
55	45	31.16
45	35	35.86
35	25	39.64
25	15	43.40
15	5	45.03

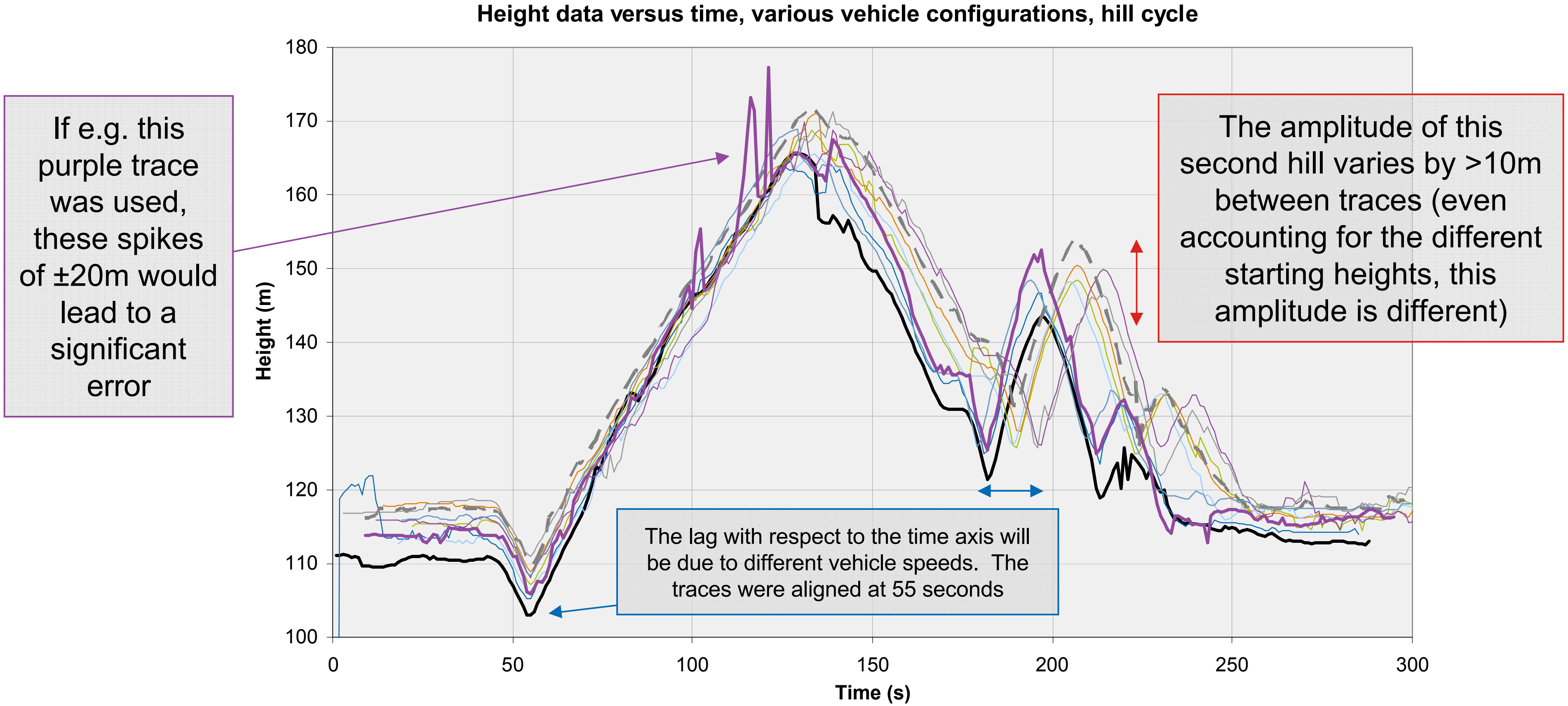
Time in seconds

- This was then converted to average acceleration (and hence force) acting upon the vehicle over that time period
- A quadratic trendline fitted through all the data points in order to obtain the values of F0, F1 and F2
  - These values then used as an input to the model for validation purposes
- In all cases, the trendline had a **very good fit coefficient** (denoted R^2)



Despite filtering, uncertainty remains with the height data – this impacts greatly upon the validation accuracy

- This plot shows the height data received for the hill cycle for a selection of the vehicles/ configurations
- It can be seen, that despite all these tests being conducted over the same route, there are significant differences in the logged traces
  - The same issues are observed across all drive cycles



Rigid heavy duty truck recorded results: the spread of measured data was acceptable

Scania P230 Rigid Body – GVM 18t

- 8 speed manual transmission
- No cab deflector or side skirts in use
- Two test weights used – 17,662kg & 16,482
- Extensive test data available (from approximately 10 different days) over four drive cycles for the 17,662kg truck
  - Only two data sets for the lighter mass were obtained, so this data was not used
- The measured cumulative fuel consumptions for the 17,662kg truck are summarised thus:

Coastdown term	Units	17,662kg	16,482kg (not used)
F2	$N/(km/h)^2$	0.095	0.112
F1	N/(km/h)	17.81	15.71
F0	N	776	701

Cycle	Max FC from all the tests	Min FC from all the tests	Percentage spread	Average FC (Validation target)
	l/100km	l/100km	%	l/100km
HSC Trans	28.72	27.42	5	28.08
HSC SS	28.39	27.63	3	28.04
Hill	52.23	51.37	2	51.75
City	36.09	35.08	3	35.74

Model validation; over track data, model under-predicts FC by 13-19%

Scania P230 Rigid Body – GVM 18t

- The cycle definition was input to the model using the measured traces. The model was also provided with gear numbers and height data derived from the test data as described previously
- The **model is consistently under-predicting** the fuel consumption by a large margin (between 13 and 19 percent)

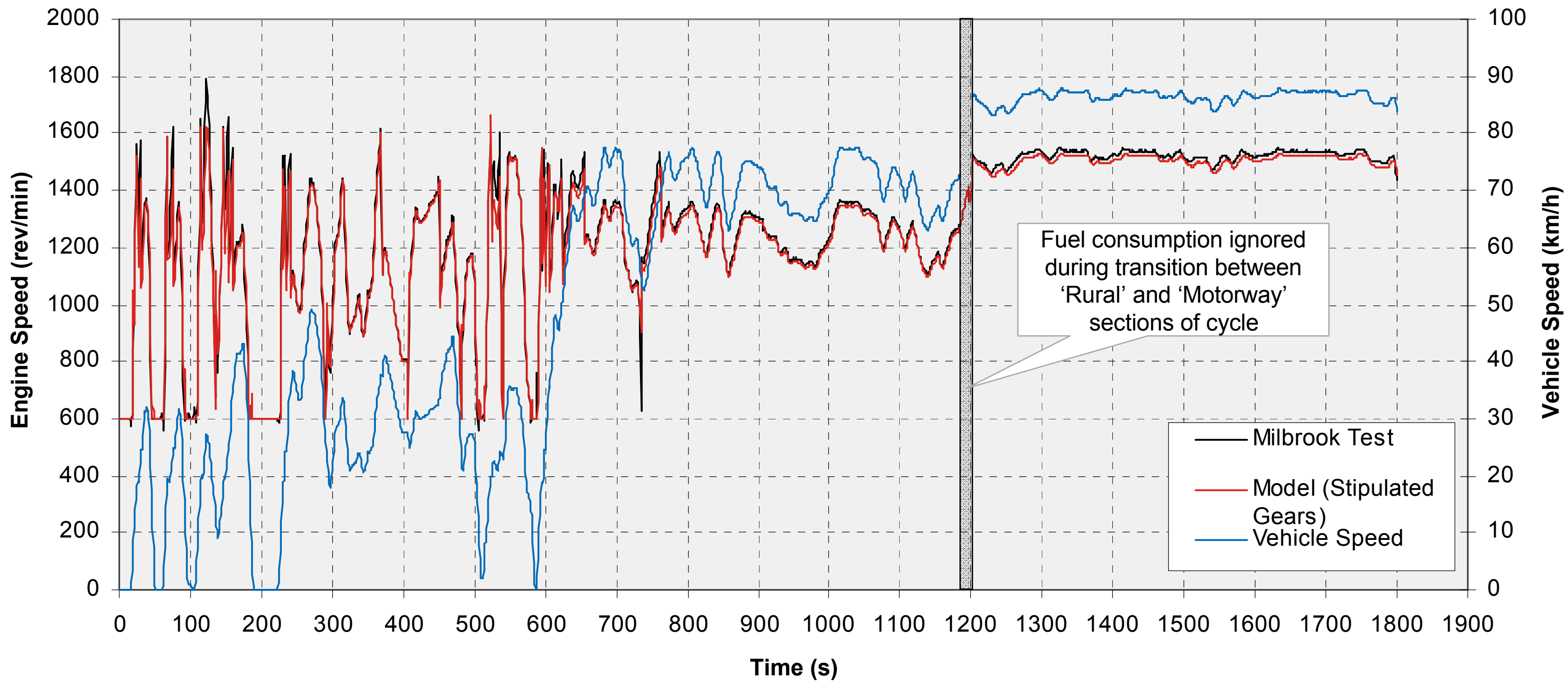
Cycle	Average measured FC (Validation target)	Model results	Percentage difference
	l/100km	l/100km	%
HSC Trans	28.08	24.50	**-12.8**
HSC SS	28.04	23.93	**-14.7**
Hill	51.75	42.18	**-18.5**
City	35.74	31.01	**-13.2**

- As seen on the previous slide, the scatter in the measured data is a maximum of 5%
- The generic fuel maps used will differ from the actual vehicle, but again this variation is expected to be only a few percents
- The accuracy of the Ecolog fuel consumption measurement device, used for these tests, is being questioned
- **However, Millbrook have also provided further measured data, from the more controlled conditions of a chassis dynamometer (VTEC)**
  - **This additional data has been used to validate the model and to mitigate the differences seen in the track data**
  - **The validation is presented over the next few slides**

Model validation; validation performed using 17,662kg FIGE chassis dynamometer data

Scania P230 Rigid Body – GVM 18t

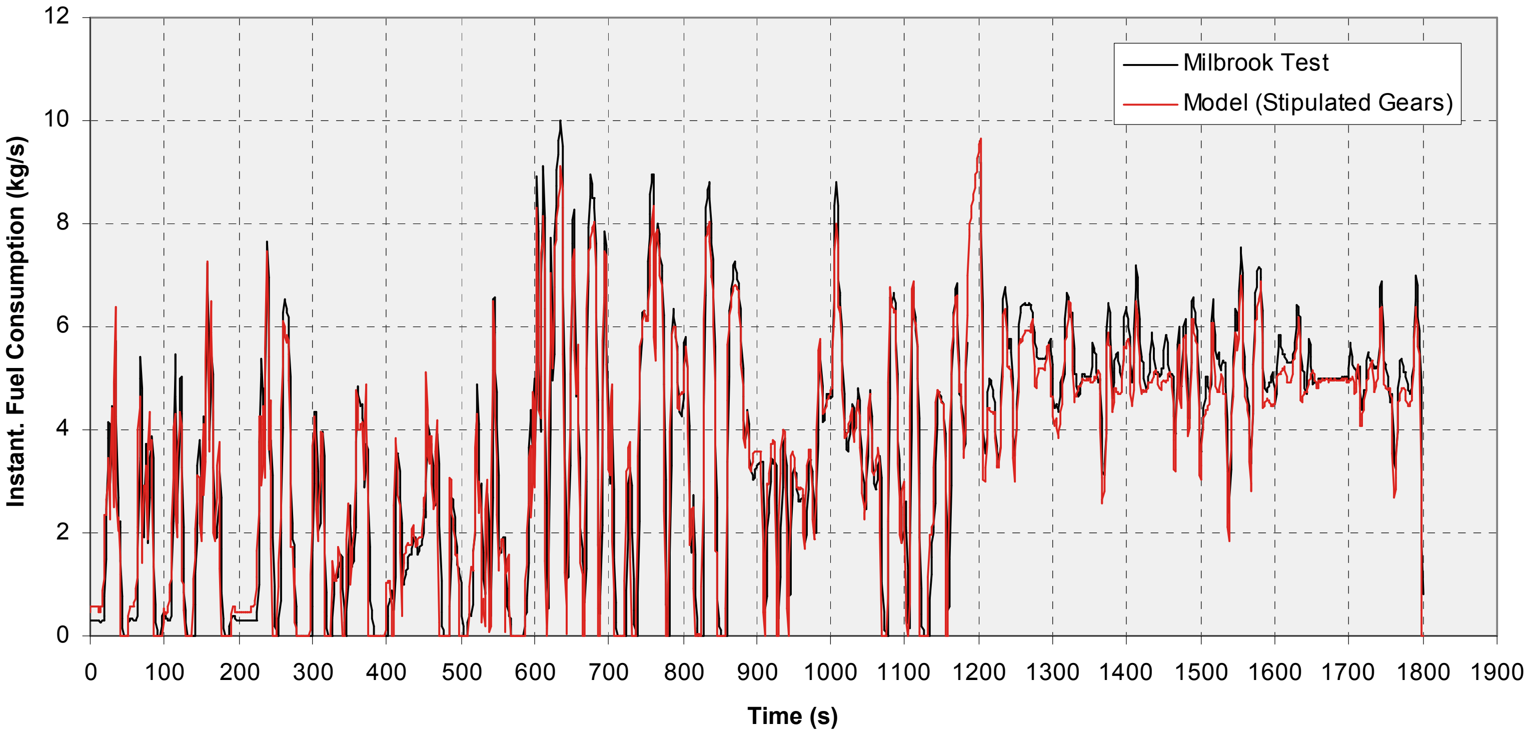
- Three sets of test data for the 17,662kg vehicle were provided, with a **scatter of 2.5%**
  - Validation was performed against that 17,662kg vehicle



- The above plot shows a very good correlation between measured and modelled engine speeds

Model validation; model predicted fuel consumption within 5% of measured chassis dynamometer data on the FIGE cycle

Scania P230 Rigid Body – GVM 18t

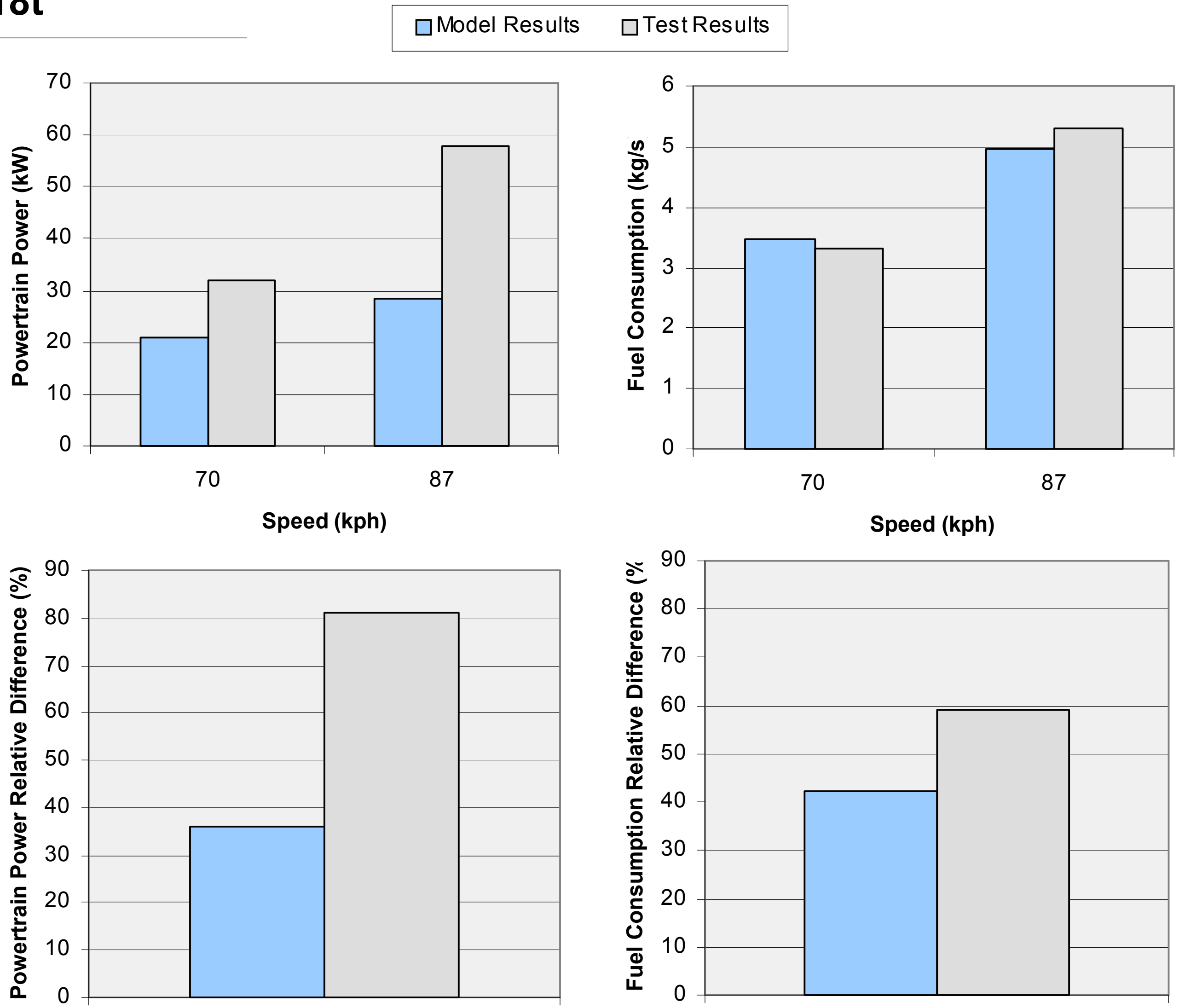


- The **relative fuel consumption between model and test data is -4.5%**
  - This lays within the **5% margin**
  - There is a relatively good correlation between instantaneous fuel consumptions

Model validation; further chassis dynamometer data, measured over constant vehicle speeds, bring a poorer match from the model. However measured data quality is being questioned and under investigation

Scania P230 Rigid Body – GVM 18t

- The test data indicates that by **increasing speed from 70 to 87 kph**, an 80% power increase is required
  - This is deemed too high
  - In contrast, calculating directly from the coastdown data, this speed increase should require a 36% relative power increase
- Similarly, the test data indicates a relative difference of 59% in instantaneous FC between these two speeds, compared to 42% from the model results
- The **model's 42% FC increase vs. 36% power increase** is more realistic compared to the **test data's 59% FC increase vs. 80% power increase**
  - Milbrook are currently looking into this matter but due to time constraints, no conclusion can be drawn at this stage



Model validation, HD artic. vehicle (Scania) , GVM 44 tonnes
Data for standard and low resistance tyres

Scania R420 Articulated – GVM 44t

- 14 speed manual transmission
- For both vehicles: cab deflector fitted, no side skirts
- Both vehicles weighed ~ 33,700kg
- As expected, fitting low rolling resistance (low RR) tyres yielded lower fuel consumption

Coastdown term	Units	Value for standard tyres	Value for low RR tryes
F2	$N/(km/h)^2$	0.335	0.299
F1	N/(km/h)	2.32	2.48
F0	N	2002	1660

Cycle	Measured FC, standard	Measured FC, low RR tyres	Percentage difference
	l/100km	l/100km	%
HSC Trans	36.46	33.12	-9.2
HSC SS	33.55	29.78	-11.2
Hill	78.35	77.74	-0.8
City	46.83	45.05	-3.8

The difference in FC for the hill cycle is far smaller.

The FC will be dominated by the effects of gradients and accelerating the vehicle's inertia, and so one would expect tyres to be less important

Modelled fuel consumptions are closer than those predicted for the rigid vehicle over the same test conditions

Scania R420 Articulated – GVM 44t

- Acceptable test to model correlation was achieved, albeit with height data filtering strategies varying from test to test. These are:

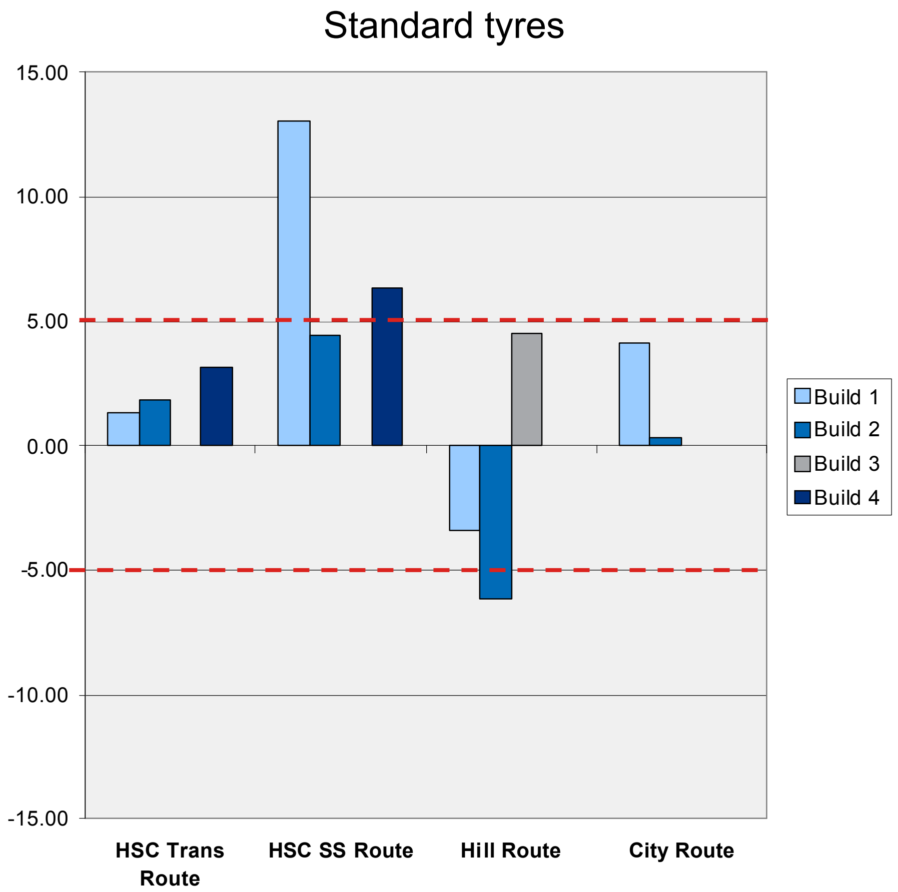
1. Using the filtered height profile from the data supplied with the Scania R420 fuel consumption data
2. As filter 1, but the height data used was the same as for the Scania P230 modelling
3. Applied to hill cycle only, using the height data from the Scania R420 dataset, but without applying any filtering
4. The height data was set to constant – the HSC Trans and SS cycles were conducted at Millbrook within the circular test track

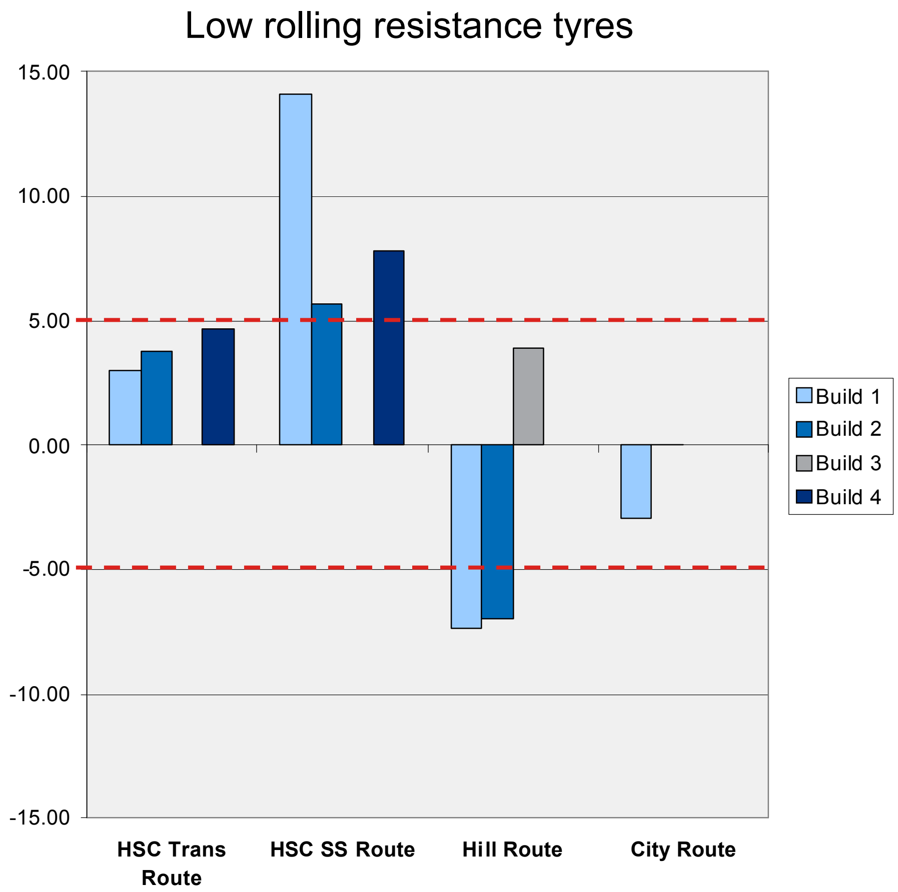
Cycle		Validation target	Filter 1, % difference	Filter 2, % difference	Filter 3, % difference	Filter 4, % difference
		l/100km	%	%	%	%
HSC Trans	Standard	**36.46**	**1.3**	1.8		3.1
	Low RR	**33.12**	**3.0**	3.8		4.7
HSC SS	Standard	**33.55**	13.1	**4.4**		6.3
	Low RR	**29.78**	14.1	5.7		7.8
Hill	Standard	**78.35**	**-3.4**	-6.1	4.5	
	Low RR	**77.74**	-7.3	-7.0	4.0	
City	Standard	**46.83**	4.1	**0.3**		
	Low RR	**45.05**	-3.0	**0.0**		

Summary of validation results

Scania R420 Articulated – GVM 44t

± 5% is felt to be an acceptable range given the assumptions made in the model's input data





It is possible to obtain a good match on measured fuel consumption, but different input datasets used for each cycle

Scania R420 Articulated – GVM 44t

- It was seen on the previous slide just **how sensitive the model is** to the input data, especially the **height data**. Unfortunately, the **height data obtained from Millbrook is subject to some large variations** (as shown on slides 21 & 23)
  - For instance, the HSC SS cycle FC was **~ 13% too high with one set** of (filtered) height data, **~ 5% too high with another set** and ~ 6-8% too high if assumed flat
  - This makes it difficult to progress the validation further, as the model is more sensitive to input data fluctuations and filtering techniques (pre processing) as it is to e.g. tuning the engine ancillaries and driveline losses
  - This large sensitivity also serves to mask any underlying trends / errors in the rest of the model input data

- It has been shown that by varying which set of height data is used, and even by changing the filtering, that a good validation will be possible
  - Although this is not a robust solution as different techniques have to be used cycle to cycle for the present validation exercise, this does not affect the model ability to assess various technology solutions, providing that model input data are kept constant (e.g. height) between consecutive Case A vs Case B type simulations

Model validation, HD artic vehicle (DAF), GVM = 44 tonnes Data with / without cab deflectors

DAF CF85 Articulated – GVM 44t

- 14 speed manual transmission
- For both configurations: no side skirts
- Both vehicles weighed ~ 33,700kg
- Tests conducted with and without cab roof deflectors

Coastdown term	Units	Value WITH deflector	Value WITHOUT deflector
F2	$N/(km/h)^2$	0.193	0.269
F1	N/(km/h)	13.33	10.86
F0	N	1493	1584

Cycle	Measured FC, WITH cab deflector	Measured FC, WITHOUT cab deflector	Percentage difference
	l/100km	l/100km	%
HSC Trans	36.24	38.64	+6.6
HSC SS	33.17	35.84	+8.0
Hill	79.56	81.77	+2.8
City	43.83	45.34	+3.5

These figures follow expected trends. The cab deflector is a purely aerodynamic device, so one would expect the majority of benefits to be seen on higher speed cycles (which Trans and SS are)

Again good model correlation to test data is obtained with appropriate selection of gradient profile data

DAF CF85 Articulated – GVM 44t

- Acceptable test to model correlation was achieved, albeit with height data filtering strategies varying from test to test. These are:

1. Using the filtered height profile from the data supplied with the DAF CF85 fuel consumption data
2. As filter 1, but the height data used was the same as for the Scania P230 modelling
3. Applied to hill cycle only, using the height data from the DAF CF85 dataset, but without applying any filtering
4. The height data was set to constant – the HSC Trans and SS cycles were conducted at Millbrook within the circular test track

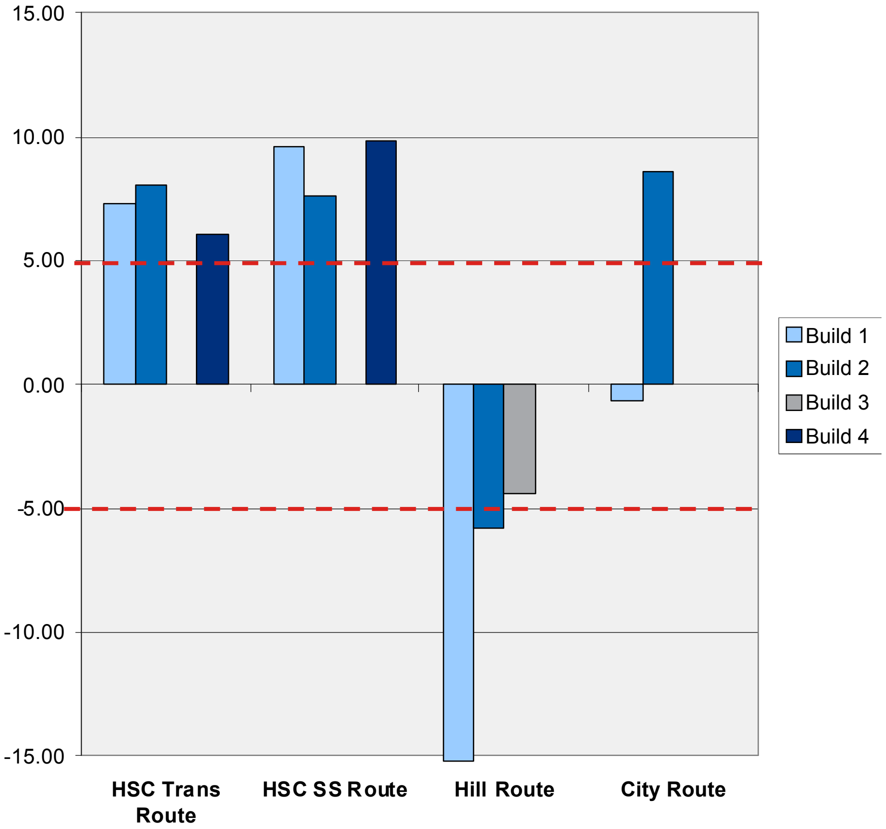
Cycle		Validation target	Filter 1, % difference	Filter 2, % difference	Filter 3, % difference	Filter 4, % difference
		l/100km	%	%	%	%
HSC Trans	Deflector	**36.24**	7.3	8.0		6.1
	No deflector	**38.64**	3.4	6.2		5.2
HSC SS	Deflector	**33.17**	9.6	7.6		9.8
	No deflector	**35.84**	9.7	6.6		8.8
Hill	Deflector	**79.56**	-15.2	-5.8	-4.4	
	No deflector	**81.77**	3.8	-7.8	16.1	
City	Deflector	**43.83**	-0.6	8.6		
	No deflector	**45.34**	12.0	6.3		

Summary of validation results

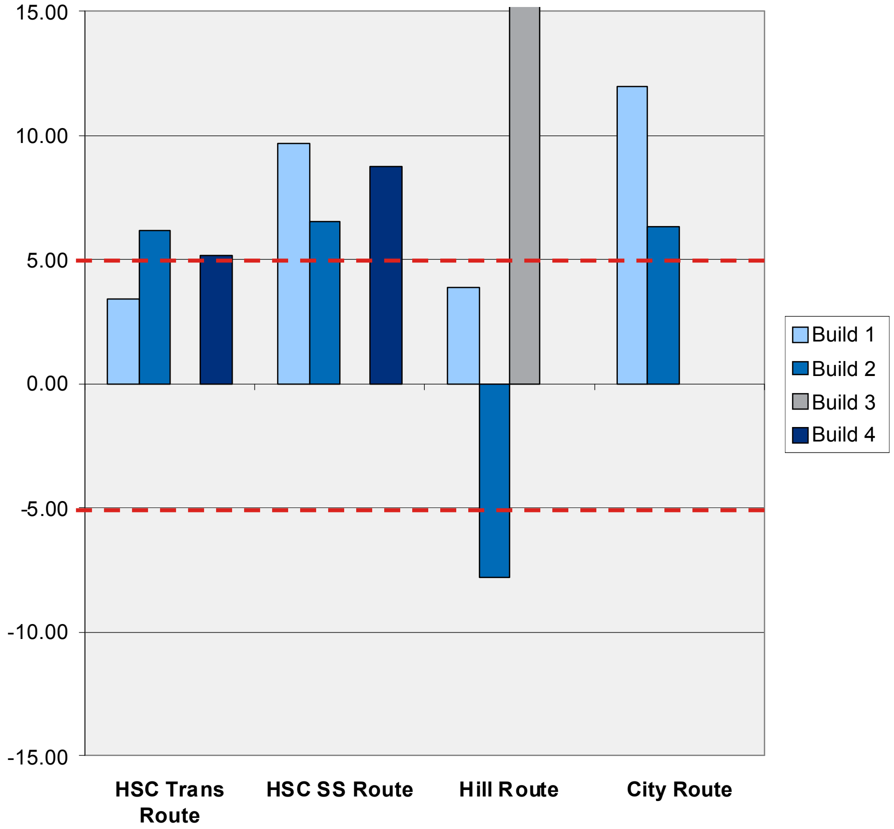
DAF CF85 Articulated – GVM 44t

± 5% is felt to be an acceptable range given the assumptions made in the model's input data

With deflector



WithOUT deflector



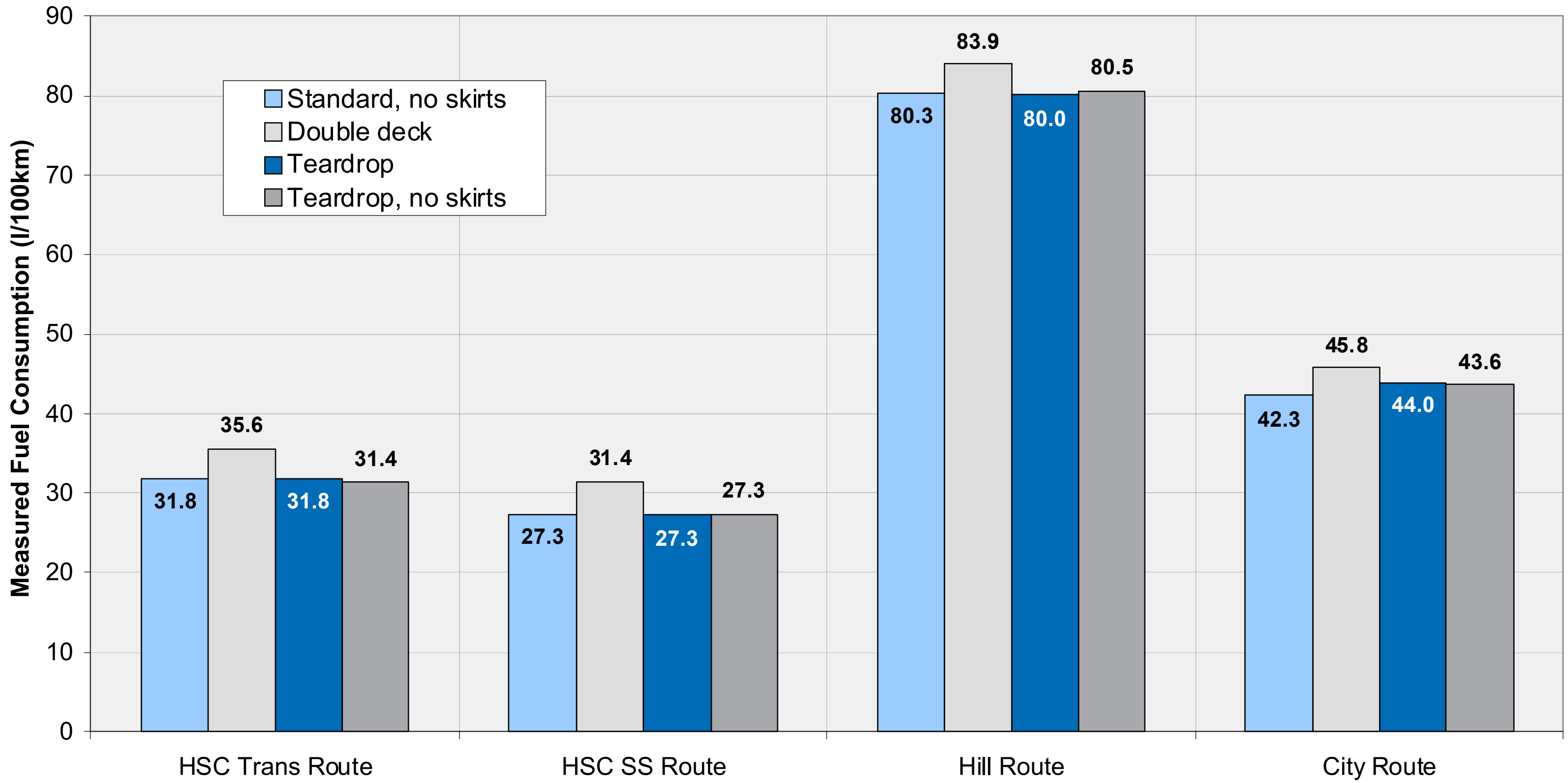
Conclusions are identical to those shown on slide 32 for the Scania R420 Truck: it is possible to obtain an acceptable match on measured fuel consumption, providing different input datasets are used for each cycle

The fuel consumption data for the Mercedes-Benz truck is difficult to interpret. In particular benefit of teardrop/ skirts is impossible to derive

Mercedes Benz Actros 2544 Articulated – GVM 44t

- 12speed manual transmission
- Test with variety of trailer configurations, standard, double deck, teardop (with and without side skirts)
- Test vehicle masses ranged 34,500 – 38,300kg

Summary of Mercedes Benz Actros Fuel Consumptions

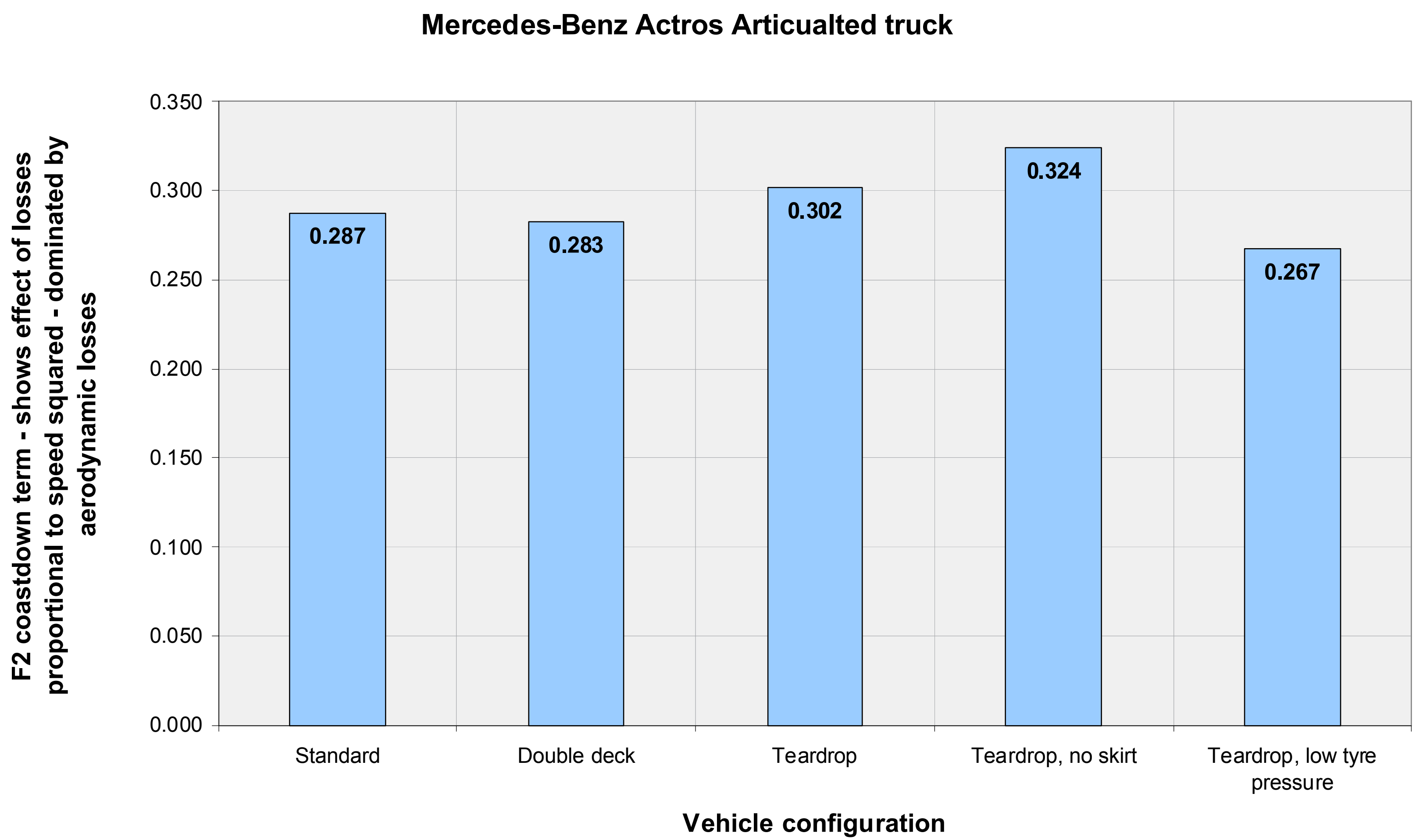


Teardrop and standard trailers show very similar FC across all cycles.

Effect of removing side skirts is also impossible to quantify

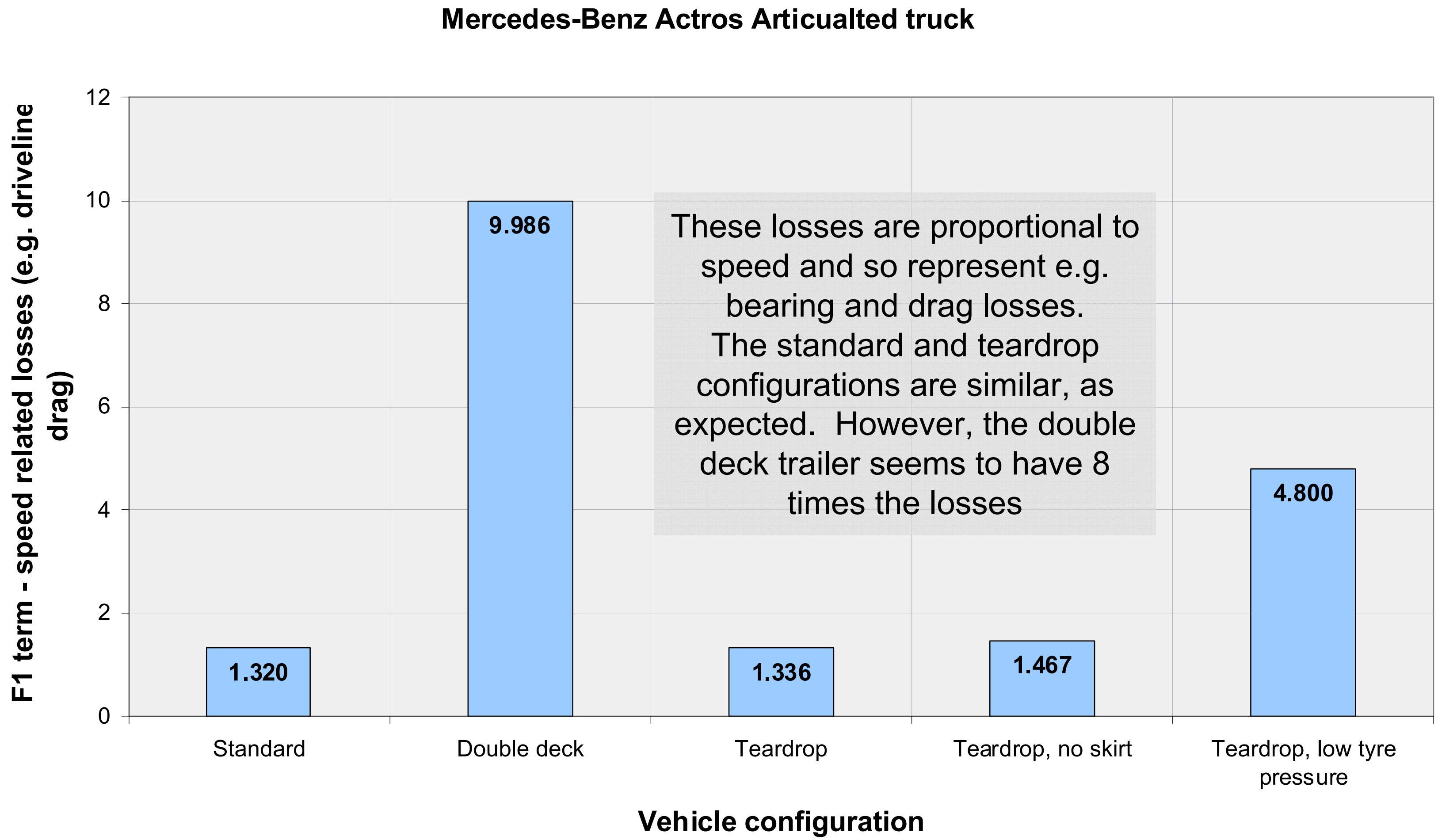
The coastdown terms for the M.B. truck, between the different vehicle configurations did not follow the expected pattern, but were consistent with the fuel consumption data

The double deck trailer's aerodynamic losses are smaller than the standard, whilst the teardrop's is greater



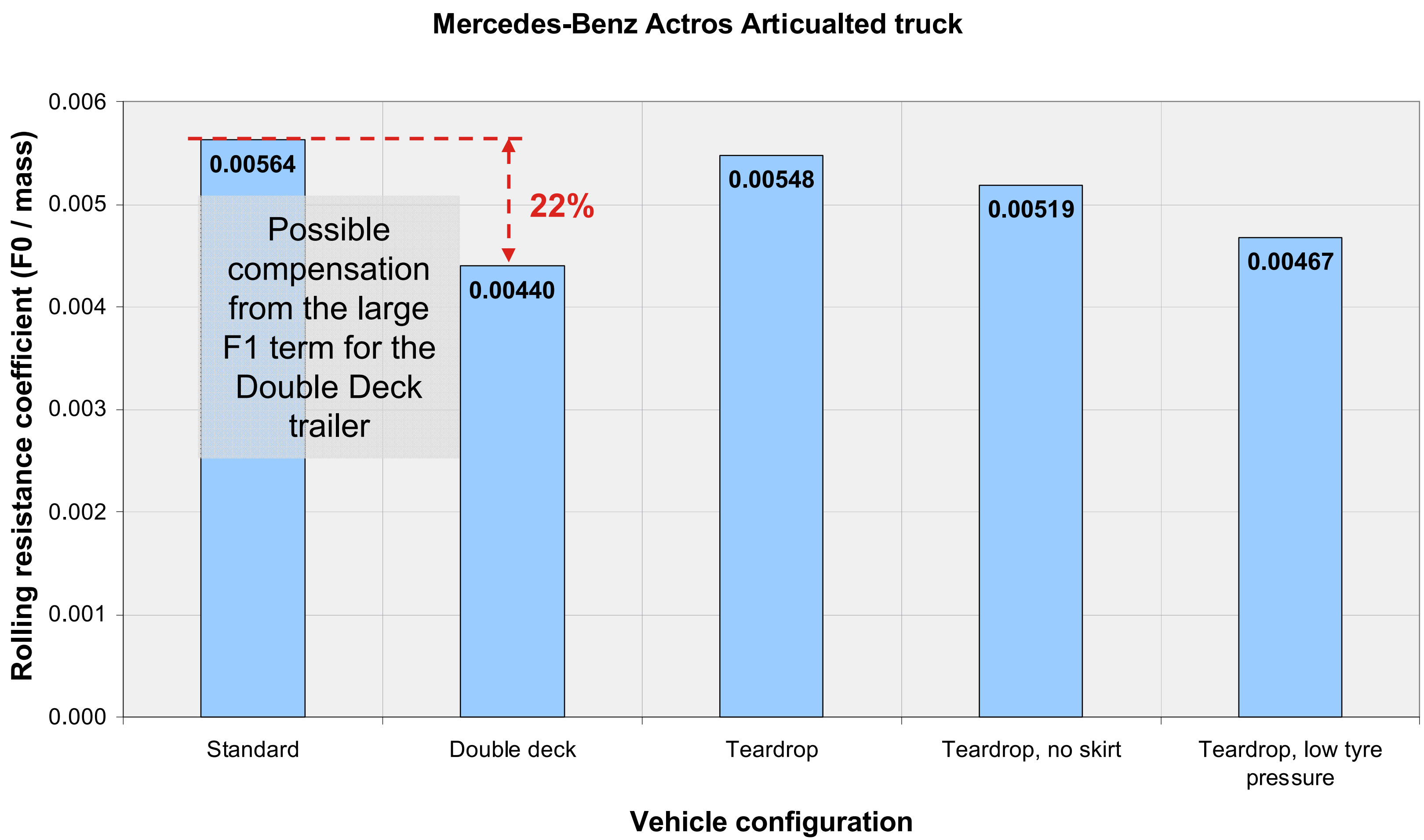
The coastdown terms for the M.B. truck, between the different vehicle configurations did not follow the expected pattern, but were consistent with the fuel consumption data

The F1 term was expected to be much the same across the configurations as the same tractor unit was used



The coastdown terms for the M.B. truck, between the different vehicle configurations did not follow the expected pattern, but were consistent with the fuel consumption data

When comparing the F0 coastdown terms between configurations, it was difficult to extract any visible patterns



Model validation was not attempted due to data concerns from both Ricardo and Millbrook

Mercedes Benz Actros 2544 Articulated – GVM 44t

- **Model validation was not attempted** on this vehicle because concerns were raised on the measured fuel consumption data
  - However analysis of the individual vehicle coastdown characteristics was carried out and showed that these were consistent with the (counter-intuitive) fuel consumption measurements
- Still, these concerns lead to abandon the calibration of the the model GUI slider bars, whose initial purpose is to predict the effect of trailer type and side skirts (see Model technical operation section) on vehicle coastdown characteristics
  - A larger data set will be required to enable calibration of these model features

Model validation summary

- The validation process has shown that quality input data, both in terms of vehicle input parameters and drive cycle definition, is a key requirement to achieving acceptable model correlation
  - The model validation for the heavy duty rigid truck against data measured on the track and outdoor circuits has shown that the model is under predicting by 13-19%, whereas model validation for the same truck against data recorded in the more controlled environment of the chassis dynamometer (VTEC) proved more fruitful, with predictions contained within a 5% band of measured data
  - Validation work on two articulated vehicles, a Scania and a DAF, had mixed success, with some configurations showing a very good match on some drive cycles
    - Again it was shown how sensitive the model is to the input data (drive cycle speed and especially height data)

- The data for the Mercedes Benz truck was not consistent with the expected patterns, both in terms of coastdown data or indeed the raw fuel consumption figures. Due to these concerns, no model validation activities was conducted on these data

Contents

Discussion

- The model methodology has been used and validated extensively in the past (including for LGV's in a version previously released to the DfT) therefore confidence can be placed in the methodology employed
  - In particular it is a powerful tool to assess various technology solutions, providing that model input data are kept constant (e.g. height) between consecutive Case A vs Case B type simulations
- The use of simulation tools can provide huge support and greatly reduce costs in the global HGV CO_2 certification process
  - The challenge resides in defining the process to quantify the effects of a given technology on vehicle coastdwon parameters, which are essential sets of input data for the CO_2 prediction model
- Different levels of model complexity may be considered to support the HGV certification process. The model produced during this work is relatively detailed, however this should not preclude the use of simpler analytical approaches
  - These will still provide a significant benefit in the global accreditation process
  - An example is that used by the Japanese Government Top Runner scheme, to quantify and certify Heavy Duty Trucks CO_2 at vehicle level. The process hinges on the characterisation of the vehicle tractive force requirements through simulation, followed by CO_2 testing on engine testbed

Source: 'Final report by Heavy vehicle fuel efficiency standard evaluation group, heavy vehicle standard evaluation subcommitte, energy efficiency standards subcommittee of the advisory committee for natural resources and energy

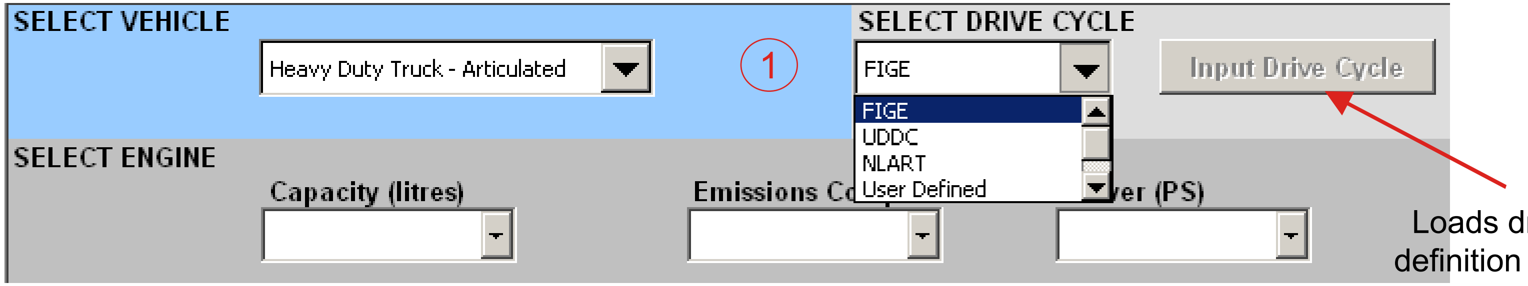
Conclusions

- The validation process has shown that quality input data, both in terms of vehicle input parameters and drive cycle definition, is a key requirement to achieving acceptable model correlation
- With appropriate datasets, good model correlation can be obtained against measured vehicle data
- The use of simulation tools can therefore provide huge support and greatly reduce costs in the global HGV CO_2 certification process

Contents

Setting up the Model (1)

- First, select the vehicle and drive cycle you want to simulate from the two drop-down menus

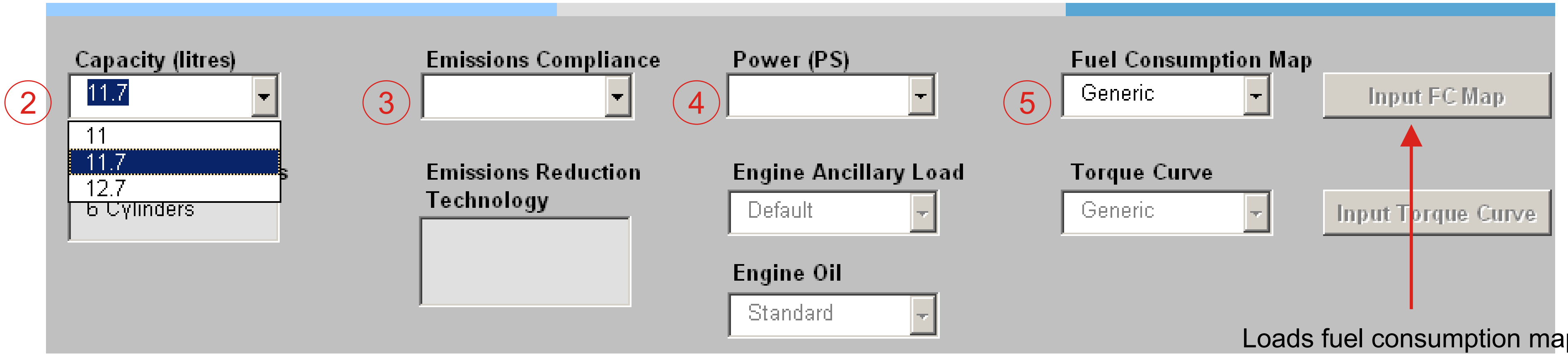


Loads drive cycle definition worksheet

- By selecting “User Defined”, the user has the option to click the “Input Drive Cycle” button
  - This directs the user to a separate worksheet where the following parameters of a drive cycle can be defined
    - Vehicle speed vs time
    - Surface gradient vs time
    - Gear number vs time (optional)
    - Auxiliary power (optional)

Setting up the Model (2)

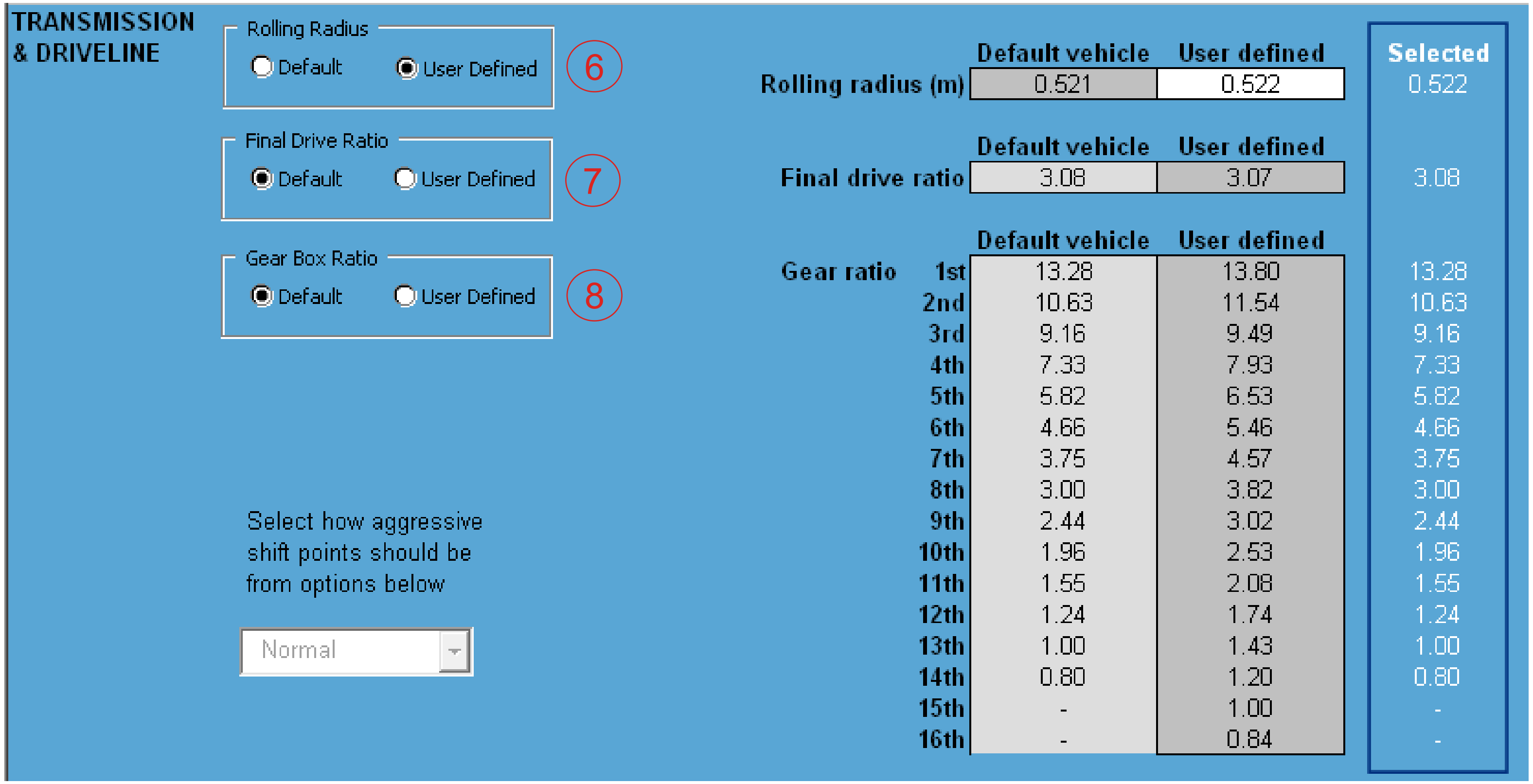
- Second, select the required engine capacity
  - This will update the number of cylinders indicator
- Third, select the applicable engine emissions standard
  - This will update the emissions reduction technology indicator
- Fourth, select the corresponding engine power rating
- Fifth, choose whether a generic or user-defined fuel consumption map is to be used
  - By selecting “User Defined”, the user has the option to click the “Input FC Map” button
  - Again, this loads a separate worksheet where the fuel consumption map can be defined



Loads fuel consumption map definition worksheet

Setting up the Model (3)

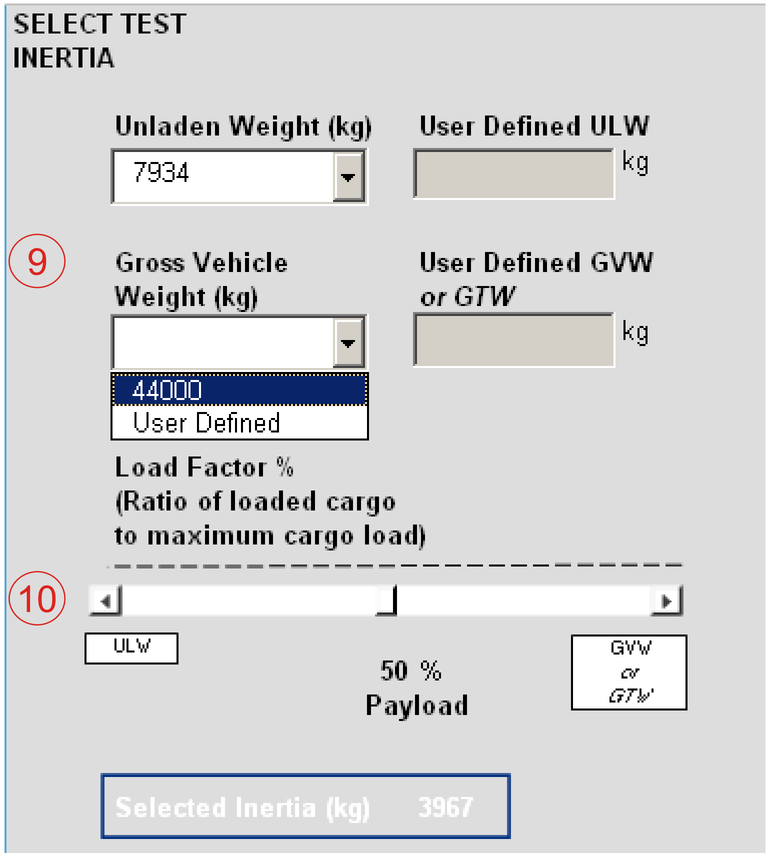
- Sixth, choose whether a generic or user-defined tyre rolling radius is to be used
  - By clicking “User Defined” the corresponding cell will turn white, ready for data entry (as illustrated)
- Seventh, as above select either a default or user defined final drive ratio
- Eighth, as above select either the default gear ratios or manually define them



		Default vehicle	User defined	Selected
Rolling radius (m)		0.521	0.522	0.522
Final drive ratio		3.08	3.07	3.08
Gear ratio	1st	13.28	13.80	13.28
	2nd	10.63	11.54	10.63
	3rd	9.16	9.49	9.16
	4th	7.33	7.93	7.33
	5th	5.82	6.53	5.82
	6th	4.66	5.46	4.66
	7th	3.75	4.57	3.75
	8th	3.00	3.82	3.00
	9th	2.44	3.02	2.44
	10th	1.96	2.53	1.96
	11th	1.55	2.08	1.55
	12th	1.24	1.74	1.24
	13th	1.00	1.43	1.00
	14th	0.80	1.20	0.80
	15th	-	1.00	-
	16th	-	0.84	-

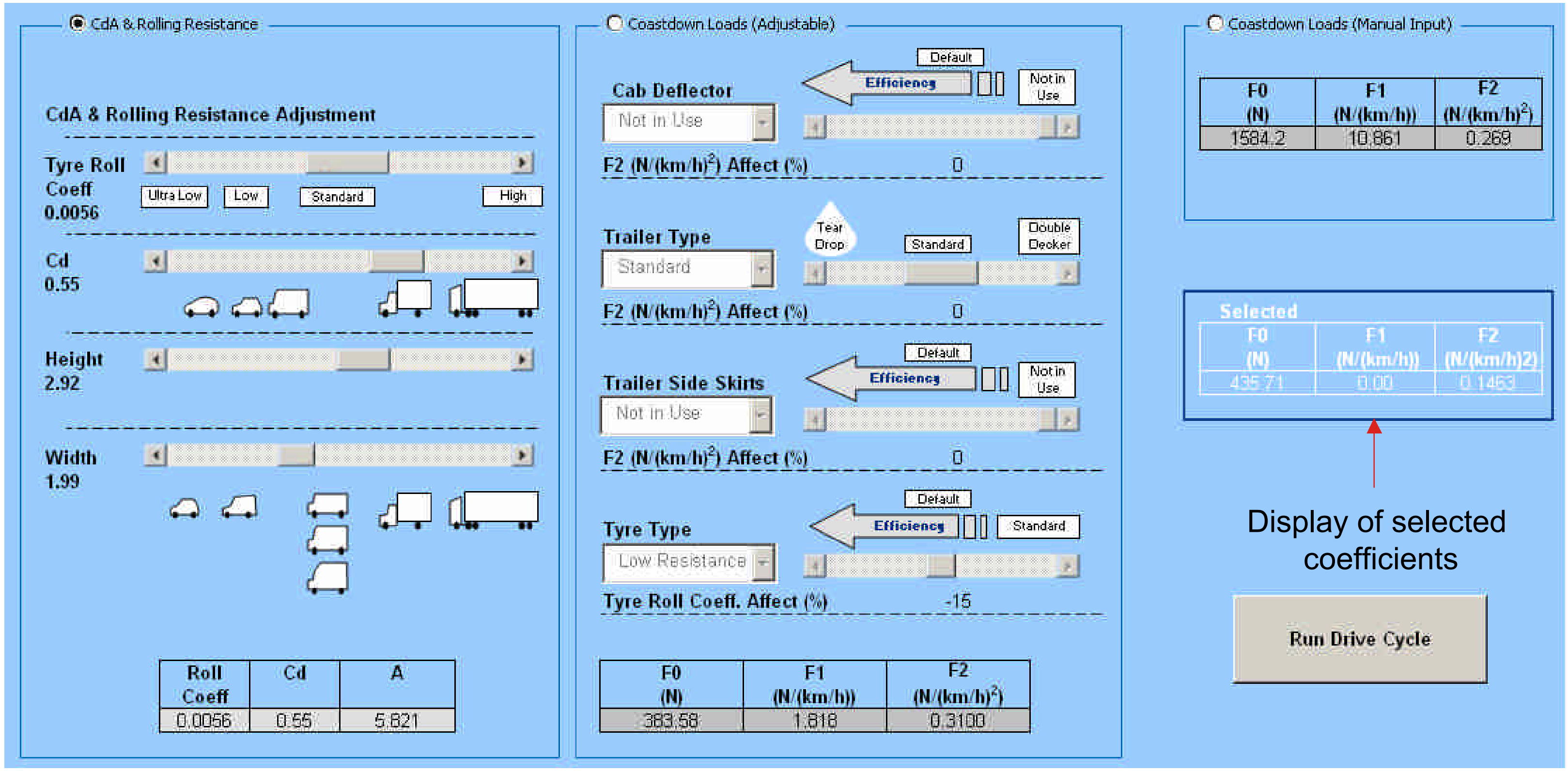
Setting up the Model (4)

- Ninth, select either the default weight values for both ULW and GVW values, or manually define them
- Tenth, define the vehicle payload by altering the position of the scroll bar
  - The far right position represents maximum payload
  - The far left position represents no payload



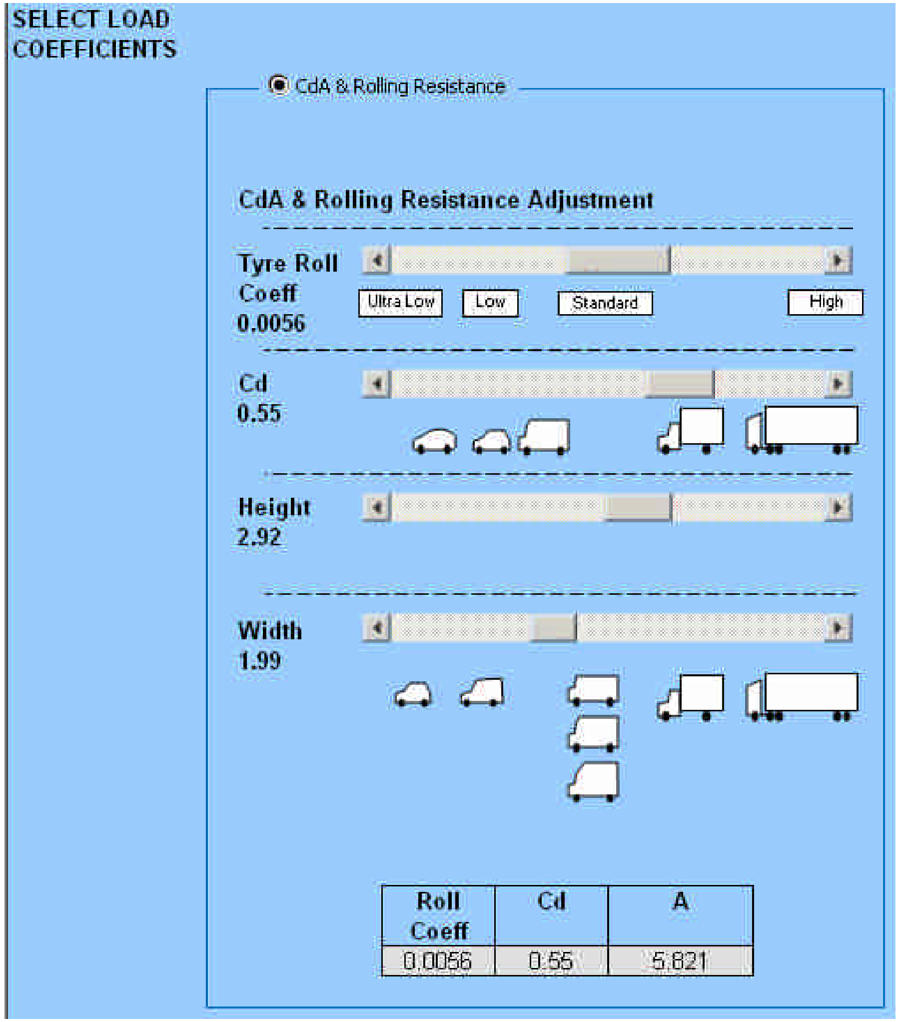
Setting up the Model (5)

- Finally, select the load coefficients
  - These define the characteristic of the vehicle resistance to motion, such as aerodynamic resistance (F2), driveline frictional losses (F1, often set to zero) and tyre rolling resistance (F0)
  - Within the model there are three options for defining the load coefficients (explained subsequently)
  - Details of the calculations can be found in the “Model methodology” section of this user guide



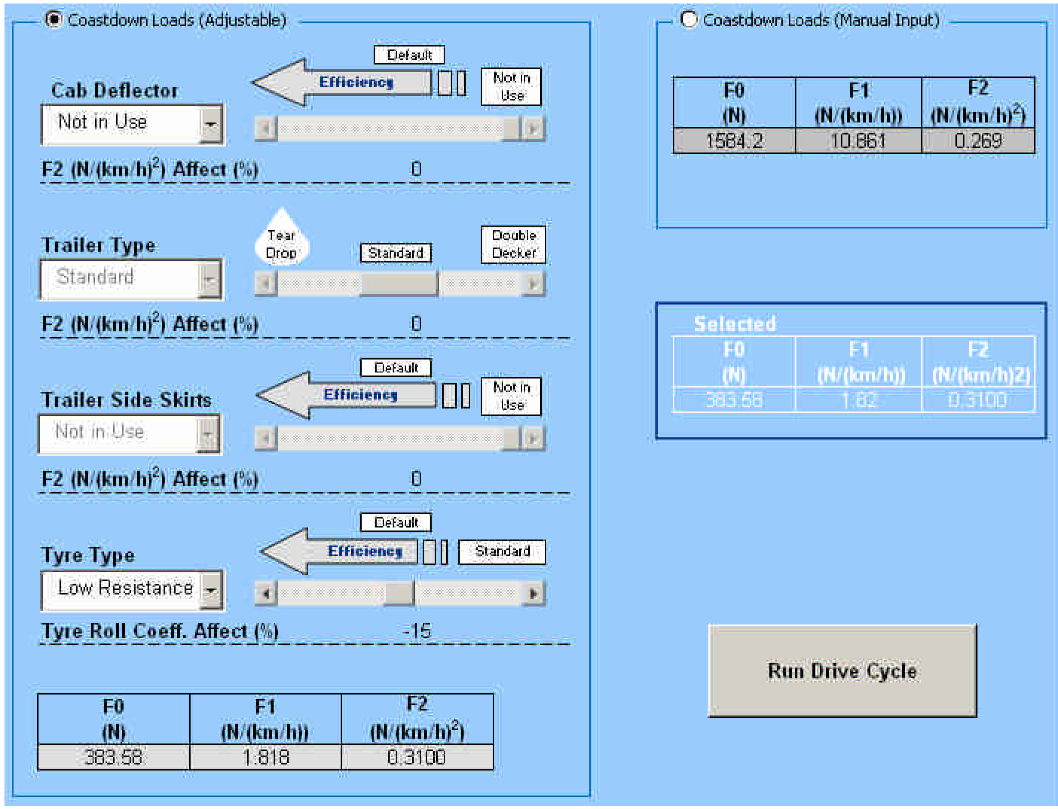
Setting up the Model (6)

- CdA & Rolling Resistance
  - This calculates the load coefficients from the selections made using the corresponding slider bars



Setting up the Model (7)

- Coastdown Loads (Adjustable)
  - Vehicle coastdown data (provided by Milbrook) have been used to derive the standard F0, F1 and F2 terms
  - By default (i.e. no CO2 reduction technology selected), these standard values are used
  - When a CO2 reduction technology is selected (i.e. low resistance tyres) the reduction in the corresponding load term is set to a value derived from test data
  - However, this reduction value can be altered as the user pleases by altering the scroll bar
    - The far left position represents maximum reduction in load term value
  - Due to lack of confidence in test data, the “Trailer Type” and “Trailer Side Skirts” options have been disabled
- Coastdown Loads (Manual Input)
  - Alternatively, the user can directly define the F0, F1 and F2 coastdown load terms by selecting this option

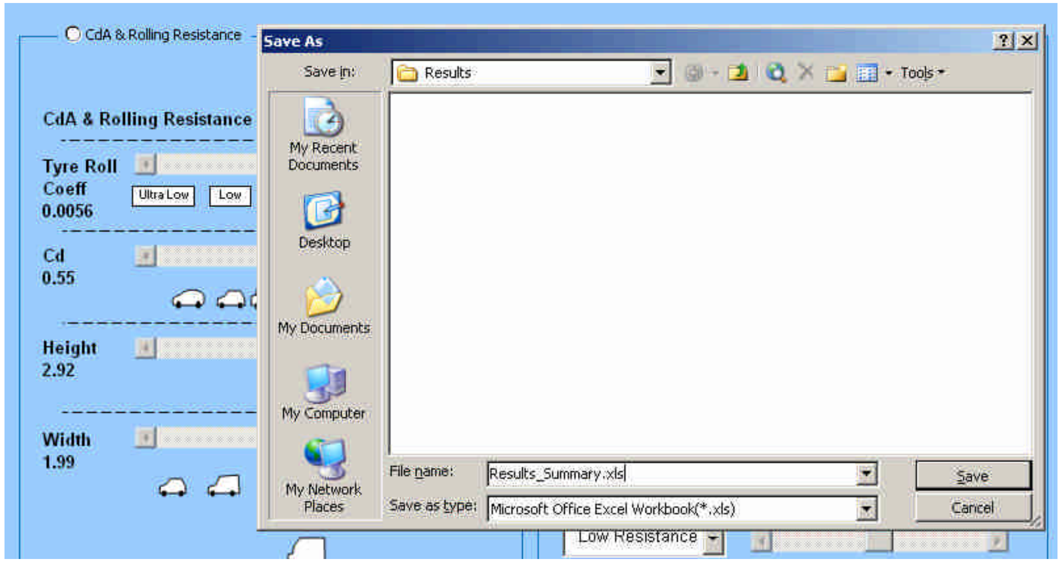


Contents

Running the model (1)

- Once the desired settings for the simulation have been made, simply click the “Run Drive Cycle” button in the bottom right corner of the GUI

- New Excel windows will appear in the task bar as the model file is updated, a results file created and the results summary is pasted into the results comparison sheet
- The user does not need to do anything until a “Save As” dialog appears
  - This requires the user to provide a filename under which the results for the simulation run will be saved (an initial name of “Results_Summary” is suggested)
  - The results workbook is saved in a new folder called “Results” within the same directory that the model files are stored



- Shortly afterwards you will see the Results Comparison sheet and at this point the run has finished

Running the model (2)

- The results comparison sheet
  - The results summary for the latest run is added to the top row of the sheet
  - If the cycle has distinct sub-sections (e.g. urban, extra-urban) then the sub-section results are displayed in the rows below

	A	B	C	D	E	F	G	H	I	
1	RESULTS COMPARISON		*Further vehicle details in column K onwards, result notes in column AC*							
2										
3	Date	Cycle	Vehicle	Fuel Consumption		CO2 Emissions		Engine out BSFC		Results Filename
4				Cold	Hot	Cold	Hot	Cold	Hot	
5				l/100km	l/100km	g/km	g/km	g/kWh	g/kWh	
6										
7	02/07/10	FIGE	Heavy Duty Truck - Rigid	-	*18.53*	-	*491.2*	-	*201*	***********.xls
8		Part 1 (Urban)		-	18.72	-	496.3	-	247	
9		Part 2 (Extra-Urban)		-	*17.78*	-	*471.3*	-	*198*	
10		Part 3 (Motorway)		-	19.10	-	506.2	-	193	
11	02/07/10	FIGE	Heavy Duty Truck - Articulated	-	25.98	-	688.8	-	244	***********.xls
12		Part 1 (Urban)		-	22.01	-	583.3	-	309	
13		Part 2 (Extra-Urban)		-	23.31	-	617.9	-	235	
14		Part 3 (Motorway)		-	29.27	-	775.9	-	239	

  - Where figures are shown in red italics, this denotes that in that cycle (or sub-cycle) the engine could not meet the full torque requirement to stay on the cycle speed trace
    - In this situation the "Notes" column (AC) contains suggestions on the use of these results
    - It is advisable to explore results more fully in the results workbook (see next section)
  - All settings for the simulation run are stored here for reference, together with the results workbook filename and path
- The third Excel window now open, is the results workbook for the simulation run
  - Further details of what is in this workbook are described in the next section

Contents

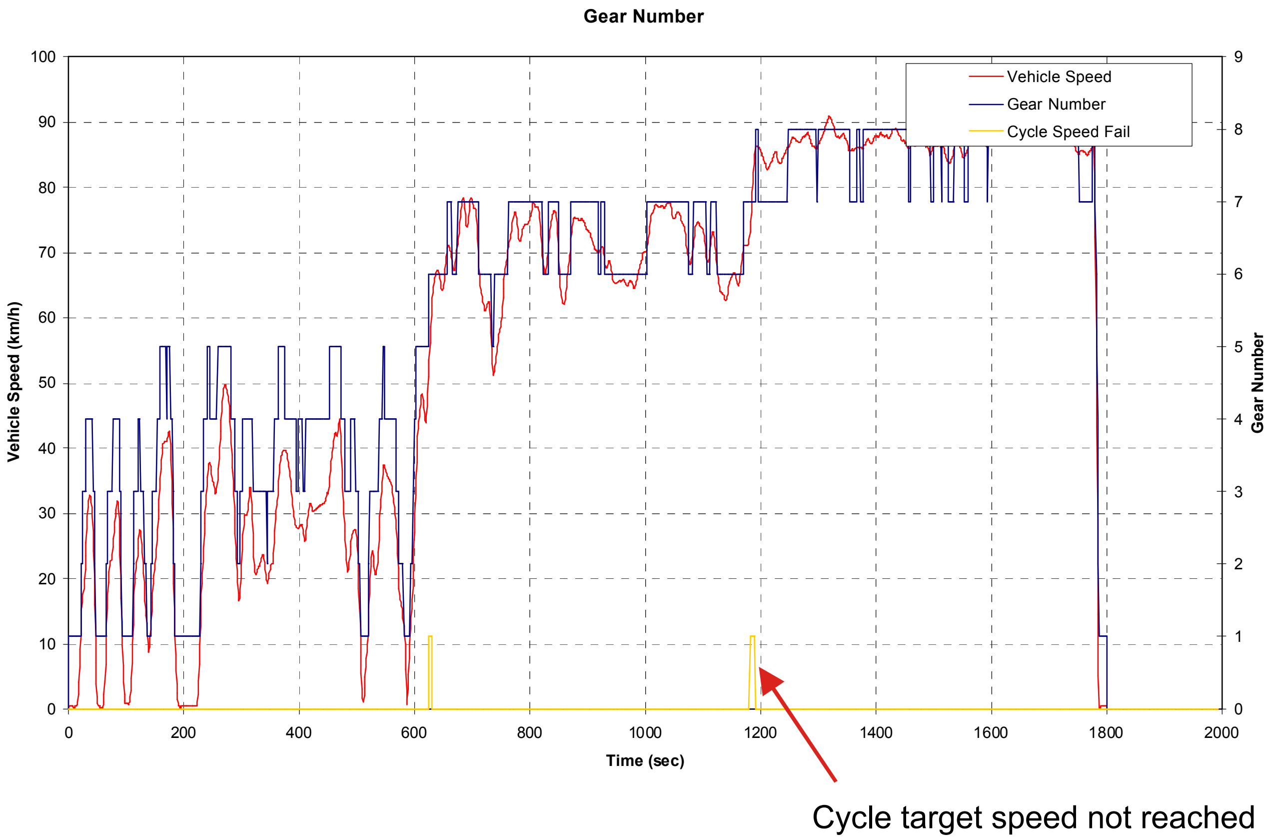
Model results (1)

- When the user clicks to view the open results workbook for the simulation that has just finished, the “Results Summary” tab will be visible
  - This contains the same information that was copied into the results comparison sheet

	A	B	C	D	E	F	G
1	RESULTS SUMMARY						
2	02/07/10						
3			Unit				
4	Cycle		-	FIGE	Part 1 (Urban)	Part 2 (Extra-Urban)	Part 3 (Motorway)
5	Vehicle		-	Heavy Duty Truck - Rigid			
6							
7	Fuel Consumption	Cold	l/100km	-	-	-	-
8		Hot	l/100km	*18.53*	18.72	*17.78*	19.10
9	CO2 Emissions	Cold	g/km	-	-	-	-
10		Hot	g/km	*491.2*	496.3	*471.3*	506.2
11	Engine out BSFC	Cold	g/kWh	-	-	-	-
12		Hot	g/kWh	*201*	247	*198*	193
13	Urea Consumption	Euro IV onwards	g	159			
14	Mass		kg	9366			
15	F0		N	343.52			
16	F1		N/(km/h)	16.76			
17	F2		N/(km/h)^2	0.1040			
18	Tyre Roll Resistance Coeff		-	-			
19	Drag Coefficient (Cd)		-	-			
20	Frontal Area (A)		m^2	-			
21							
22	Engine	Capacity	litres	7.2			
23		Power	PS	240			
24	Final Drive Ratio		-	3.42			
25	Gear Ratios	1st	-	7.01			
26		2nd	-	4.94			
27		3rd	-	3.48			
28		4th	-	2.46			
29		5th	-	1.67			
30		6th	-	1.22			
31	Rolling Radius		m	0.52			
32	Shift Point Aggressiveness		-	Normal			
33							
34				FAILED TO MEET REQUIRED SPEED TRACE, USE RESULTS WITH CAUTION		FAILED TO MEET REQUIRED SPEED TRACE, USE RESULTS WITH CAUTION	

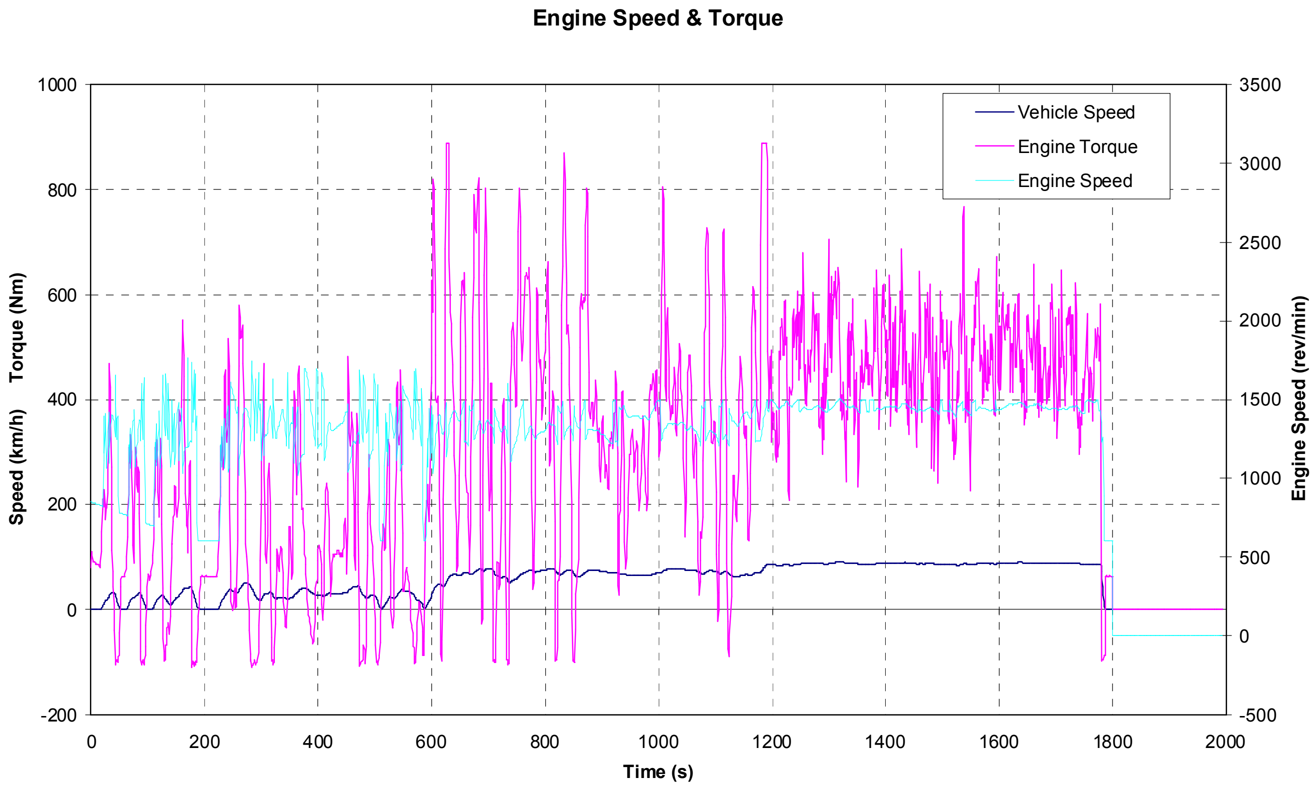
Model results (2)

- The second tab shows a plot of drive cycle speed and gear number against time
  - It should be noted that this is target cycle speed and not necessarily achieved cycle speed
- However, it does display in yellow, any periods where the engine torque was not high enough to meet the cycle speed trace
  - This allows the user to assess the validity of the results by looking at the frequency and duration of these periods



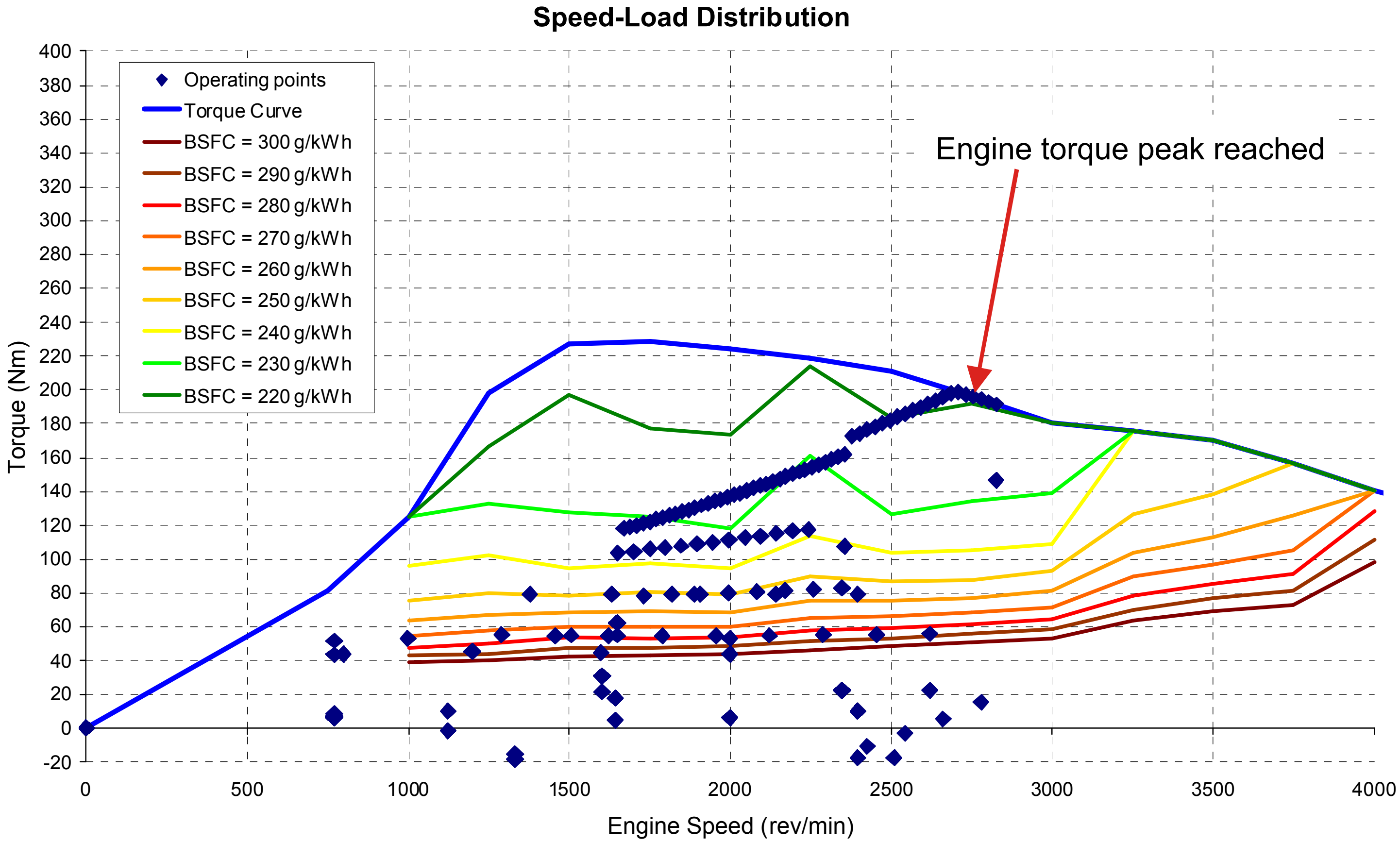
Model results (3)

- The third tab shows a graph of engine speed and torque with the cycle speed trace displayed for reference
- The fourth tab shows engine temperature and the associated fuelling correction factor
  - As all vehicles are tested in hot condition, the temperature is set to a constant value and the fuelling correction factor is set to 0
- The fifth tab shows both instantaneous fuel consumption (second-by-second) and cumulative fuel consumption



Model results (4)

- The final plot in the results file shows the engine speed/load distribution overlaid on the BSFC (brake specific fuel consumption) map of the engine
  - Each marker on the plot represents 1 second of engine operation in the cycle
  - Lower BSFC represents more efficient engine operation
- The maximum torque curve of the engine is also displayed
  - Where the markers sit on the maximum torque curve indicates that the cycle torque requirement might have been greater than the engine could produce



Model results (5)

- The final tab contains all of the data used in the plots
  - This data is not linked to the original model in any way and will not update for future runs
  - Each results workbook is specific to the simulation setup displayed in the Results Summary sheet