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TITLE:

A SIMPLIFIED MODEL FOR HEAVY VEHICLE PERFORMANCE AND FUEL CONSUMPTION SIMULATION

ABSTRACT

A heavy vehicle performance computer simulation model offering ease and low cost operation, and requiring only simple input to provide detailed output was developed at the University of Melbourne. This model uses readily available information for its runs and provides detailed information on vehicle velocity, distance driven, engine speed and power demand, gear shifts, fuel consumption and many other vehicle performance variables for every second duration of any driving cycle.

The model was written for heavy truck operation, although buses as well as light and medium weight vehicles of any category may be substituted. Fuel economy and performance calculations, yielded by the model agree well both with available measurements on urban and highway vehicle operation and with results obtained from the U.S. Department of Transport simulation program (HEVSIM).

This paper includes general descriptions of the simulation program and of the type of input data required together with a listing of results obtained by simulating a typical heavy vehicle.

INTRODUCTION

The SAE-A study of truck fuel consumption measurement methods and computer evaluation has a number of objectives. These include the development and verification of computer models which take in test data available to predict truck performance and fuel consumption, the demonstration of an expanded range of truck and bus fuel consumption test procedures and the presentation of the results directly into the point-of-sale decision-making arena (truck sales room) via computer modelling techniques [Close(1984)].

There are a number of models already in existence. These models span the range from highly complex main-frame, time-distance driven simulation down to vest pocket calculator programs for steady-speed fuel consumption. As these models are of a proprietary nature and are not available in the public domain, there is a need for the development of models which will be available to the SAE-A committee and to the public.

While the proposed models are aimed at predicting truck performance and fuel consumption for the evaluation both of duty cycles and of possible components to be selected for purchase, the models will be developed and documented so that they will be useful to and, or usable by traffic engineers, urban planners and, by virtue of adding straight forward cost of ownership subroutines, to owner drivers.

The first of these models, TABESAM (Truck and Bus Energy Simulation algorithm mission), was developed by the authors and is available in two forms: a simplified and brief form written and installed in a Hewlett Packard hand-held programmable calculator (HP 41cv) with extended memory, and a more sophisticated form, written in Fortran 77 and installed in the university of Melbourne VAX/VMS system.

In this paper, the development of TABESAM is traced and detailed descriptions of the program itself and of its requisite input data and output results are provided.

DESCRIPTION OF THE COMPUTER MODEL

Introduction

TABESAM is designed to assess the performance and fuel consumption of heavy vehicles under various operating conditions and with various power trains. The program will give the statistics of fuel consumption, power demand, driving cycle, gear shifts and transmission of any synthesised vehicle design over any driving pattern.

IABESAM

Simulation programs can be placed into two broad categories: first, those of the complex vehicle simulation category which suffer from:
- The necessity for large quantities of detailed input data and the need for this to be fed in a precisely formatted manner;
- high running cost and lengthy period of simulation exercise;
- the requirement for a highly skilled operator;
- the inability to simulate driving cycles in a velocity/time trace for every second duration;
- the requirement for large storage capacity and being machine dependent;

(b) second, those of simple vehicle steady state operation simulation models which have the following inadequacies:
- the inability to simulate dynamic operation of a vehicle;
- results are only approximate;
- the requirement for interactive operation and the provision of very limited output;
- the ability to calculate conditions of a vehicle for only one speed point rather than for micro trips;
- strict limitations of application and the ability to run on only one machine type [Khatib(1985)].

IABESAM is a combination of the positive factors of the two categories, hence the inadequacies are reduced and the advanteges are maximised in its design and features. It is rugged and compact model capable of simulating diverse operating conditions and behaviour, yet it requires minimal operating skill and general input data. This model's input requirement is readily available and many alternative input data files could be created in a very short period. Its output is more detailed than HEVSIM, see Khatib(1984), which is considered to reside at the pinnacle of the simulation model hierarchy. More detailed description of TABESAM may be found in Khatib(1986).

Model objectives

The objectives underlying development of such a model at the University of Melbourne were:
- To meet the demand for a fast and economical method to compute vehicle performance and fuel economy for any synthesised vehicle.
- To meet the need for a heavy vehicle simulation model which requires only simple input, which easy and cheap to operate, which gave the desired output and which could be made readily available in the public domain and to interested groups.
- To supply a model capable of simulating real driving cycles, such as a rigid truck driving cycle or urban and highway articulated vehicle driving cycles, with velocity time trace for every second duration; and so to correct the inadequacy of most existing models which are limited to segments of driving cycles simulation such as constant acceleration or constant throttle setting.
- To show that a simple input simulation model which uses hand held calculator, and simple routines describing the power equations is capable of producing results which compares quite favourably with those of such sophisticated models as HEVSIM.
- To meet the need for a simulation model which may be run on micro computers in addition to simplified hand held calculator routines.

Simulation requirements

Io successfully simulate the operation of a heavy vehicle over a specified driving cycle for fuel consumption and performance evaluation, the model is required to perform the following steps:
- determine the sequence of engine operating conditions for each second during the drive cycle;
- determine the vehicle wheel speed, corresponding engine speed and power demand for each second over the driving cycle;
- determine the instantaneous rate of fuel flow from an engine map for each second;
- integrate the instantaneous fuel flow and vehicle velocity versus time to obtain the total fuel consumed and total distance travelled and calculate other performance variables;
- obtain fuel economy by dividing the total fuel consumed by the total distance travelled (1/100km).
- obtain a summary of calculations of all other performance variables.

Development restrictions

The development of IABESAM was governed by the following considerations:
- the source program had to be short and it had to have very small storage requirements, especially in array declaration, to facilitate its installation in micro computers especially of IBM compatability;
- the input data had to be brief and consist of (data) that is readily available in technical specifications or handbook manuals;
- it had to use only short CPU time and provide options of either full simulation description or only a brief summary report;
- it had to be able to be operated by any technical personnel including those with very limited computer experience;
- it had to be possible to install a simplified version of the model in a hand held programmable calculator for field work where computers are not available;
- it had to have a satisfactory gear shift logic, enabling all types of transmission and driver behaviour to be modelled.

Program assumptions

(a) Steady-state engine tests can be used to predict their dynamic operation; that is during transients the engine behaves as though it was under steady conditions with respect to fuel rate at representative torque and speed.
(b) Simplified shift models can be used to simulate transmission shifts and the duration of gear shifting is one second.
(c) Drive train efficiency is assumed constant over the whole driving cycle irrespective of gears selection and propeller shaft speed.
(d) Engine motoring torque may be ignored.
(e) Idle and closed throttle deceleration fuel consumptions approximate to a constant value.
(f) Rotating inertia of all components may be ignored.
(g) Crosswinds are assumed to exert a known effect on drag cosfficient.
(h) Environmental conditions and variations are of no importance.

Program inputs

The simulation program requires specific information to successfully model the actual vehicle performance. The input data are fed interactively to a file called TKDES.DAT and are arranged in one value per line. The data point is followed by a brief description of the part for explanation purposes only, with this not imperative for program operation.

There are three data files which are read at the beginning of each simulation run: TKDES.DAT, FMAP.DAT and the driving cycle file, e.g. HIGHWY.DAT. The following are specific comments concerning the data structure:

(a) TKDES.DAT

This file consists of 31 lines of which 4 lines are comments and 27 lines specify data description. 2 lines are entered in a character (text) form and 25 lines are entered in decimal form.

1st line comments;
2nd line comments;
3rd line vehicle make or type, 25 character maximum length;
4th line engine make or model, 25 character maximum length;
5th line power to mass ratio, power in kW and mass in tonnes (f8.3)*;
6th line vehicle mass in tonnes (f8.3);
7th line vehicle height in metres (f8.3);
8th line vehicle width in metres (f8.3);
9th line aerodynamic drag coefficients (f8.3);
10th line rolling resistance coefficients (f8.3);
11th line engine accessory load coefficient (f8.3);
12th line engine cooling fan load coefficient (f8.3);
13th line driveline efficiency (f8.3);
14th line rear axle ratio (f8.3);
15th line tyre diameter in metres (f8.3);
16th line engine idling speed in rpm (f8.3);
17th line engine maximum speed in rpm (f8.3);
18th line wind speed in km/h, positive for head wind, (f8.3);
19th line road gradient as a percentage, 10 m in 1 km, (f8.3);
20th line total number of gears in a transmission (i8);
21st line comments
22nd line comments
23rd line transmission ratio of 1st gear (f6.3)
24th line transmission ratio of 2nd gear (f6.3)
25th line transmission ratio of 3rd gear (f6.3)
26th line transmission ratio of 4th gear (f6.3)
27th line transmission ratio of 5th gear (f6.3)
28th line transmission ratio of 6th gear (f6.3)
29th line transmission ratio of 7th gear (f6.3)
30th line transmission ratio of 8th gear (f6.3)
31st line transmission ratio of 9th gear (f6.3)
* denotes format specification

(b) Driving Cycle File

This file contains driving cycle data, with a velocity data point (km/h) at every 1 second interval. Data are entered in decimal form (1x,f6.2) with one data point per line. The length of the cycle is not specified and could range from as little as a small microtrip to several thousand seconds. Any data file written in this format could be read and the name of the cycle is given interactively to the model when the user is prompted for the name. The advantage of this structrue is it's ability to simulate vehicles over many driving cycles in one simulation session.

(c) Fuel Map File

The fuel map data file for Cummins 350 diesel engine was used and can be found later in this paper . The engine power axis has been rewritten in terms of kilowatt units and a grid drawn over the map; hence discrete specific fuel consumption values are represented at intervals of 20 kW and 100 rpm. The first line lists engine power which has 14 values ranging from zero kW to 265 kW and entered in the format (5x,14f5.0). The second to the fifteenth line show the engine speed and the specific fuel consumption both of which are entered in the form (1x,f5.0,14f5.2). The units of specific fuel consumption can be entered in lb/h or in kg/h and in this example the later was used. A more detailed grid is possible and may be achieved by reducing the interval spacing if more accurate interpolation is desired. Many engine fuel maps could be prepared in this form and fed into the model during simulation of different engines.

<u>Program output</u>

TABESAM is a performance simulation model capable of generating two types of outputs: a detailed simulation output, providing a full description of 16 vehicle performance variables for every second of the driving cycles together with a simulation summary report, or a simulation summary report alone at the conclusion of the simulation.

The program prompts the user to choose between the option of a detailed report or a summary report (answer 'f' or 's') . The program also asks the user to supply the name of the output file - this is convenient where a number of simulation runs are performed in one simulation session as these runs are able to be stored under different file names.

In general the output can be divided into the 3 following sections:

(a) reproduction of vehicle description input data together with vehicle make and model, engine make and model simulation title and date and time of simulation.

(b) sixteen vehicle variables that form a detailed output for every second of driving cycle. This output consists of the following:

secn	time in seconds, progressive cycle time;
gear	number of gear engaged;
sped	actual velocity attained by vehicle (km/h)
des.s	desired vehicle speed, from driving cycle data file (km/h)
erpm	engine speed during one second (r/min);
ptot	power delivered by the engine during one second (kW)
apwr	power available at current engine speed (kW);
ardp	aerodynamic power demand during one second (kW);
rolp	rolling resistance power demand during one second (kW);
acsp	accessories power demand during one second (kW);
losp	total power losses (ardp+rolp+acsp) during one second (kW)
accp	inertial acceleration power demand during one second (kW);
brake	brake power consumption during one second (kW);
cumdst	cumulative distance driven (progressive, km)
cumfc	cumulative fuel consumption (progressive, litre)
grad	vehicle gradibility (%)

These data can be plotted as well as printed, permitting quick cross comparisons among variables and as a function of time.

(c) Vehicle Performance Summary Report

This report contains 6 statistical summary segments for vehicle operation over a specified driving cycle. Specific comments concerning this section are as follows:

(1) Cycle Modes statistics;
- cumulative driving time (s)
  - the percentage of time spent in idle mode
  - the percentage of time spent in acceleration mode
  - the percentage of time spent in cruising mode
  - the percentage of time spent in decelerating mode
- cumulative distance driven over driving cycle (km)
  - the percentage of distance driven in idle mode
  - the percentage of distance driven in acceleration mode
  - the percentage of distance driven in deceleration mode
  - the percentage of distance driven in cruise mode
- cumulative power demand (kW)
  - the percentage of power demand during idle mode
  - the percentage of power demand during acceleration mode
  - the percentage of power demand during deceleration mode
  - the percentage of power demand during cruise mode
- cumulative fuel consumption over the simulation run (litre)
  - the percentage of fuel consumed during idle mode
  - the percentage of fuel consumed during acceleration mode
  - the percentage of fuel consumed during deceleration mode
  - the percentage of fuel consumed during cruise mode

(2) Fuel Consumption Statistics;
  - fuel economy in litres per 100 km
  - fuel economy in miles per gallon
  - the percentage of fuel consumption by engine friction
  - the percentage of fuel consumption by power train losses

- the percentage of fuel consumption by accessories
- the percentage of fuel consumption by aerodynamic drag
- the percentage of fuel consumption by rolling resistance
- the percentage of fuel consumption by inertial force

(3) Driving Cycle Statistics;
- average actual vehicle driving velocities (km/h)
- average actual vehicle driving velocities (mi/h)
- average driving cycle velocities (km/h)
- the percentage of actual to target average velocities

(4) Power Demand Statistics;
- the average power consumption over the driving cycle (kW)
- total vehicle energy consumption (kW-h)
- the average engine power supply over the driving cycle (kW)
- total engine energy supply (kW-h)
- vehicle kinetic power supply (kW)
- vehicle kinetic energy supply (kW-h)
- the average surplus power over the driving cycle (kW)
- the average power consumption by brakes (kW)
- percentage of power consumed due to power train losses
- percentage of power consumed due to air resistance
- percentage of power consumed due to rolling resistance
- percentage of power consumed due to engine accessories
- percentage of power consumed due to inertial accelerations

(5) Gear Shift Statistics;
- total number of gear shifts in either direction
- total number of up shifts for all gears
- total number of down shifts for all gears

(6) Iransmission Statistics;
- average engine speed over the driving cycle length (r/min).

For each gear (n) the following are calculated:
- average engine speed during the engagement in n gear(r/min)
- the percentage of time spent in n gear
- number of upshifts to n gear
- number of downshifts for n gear
- average vehicle speed while vehicle in n gear
- average engine power demand while vehicle in n gear

<u>Computing requirements</u>

Ihe model is written in Fortran 77 and is currently operating on a number of machines including DEC VAX/VMS system, and it is adaptable to any machine compatible to IBM. Calcomp plotter and associated software provide the graphic output. Since the model can print or plot the accumulated data, storage requirements are a function of the driving cycle length rather than of the number of simulation runs. Output data files can be deleted after each simulation run. The simplified version of IABESAM installed on HP41cv can simulate microtrips up to 200 seconds and the VAX/VMS version can perform simulation over many hours of driving cycles such as those involved in interstate trips.

Program subroutines

The model contains the main program and four subroutines: FMAP and PWRMAX which are necessary to any simulation run, and CYCPLT and FRQPLT which give graphical representation of results. Where memory space is critical, CYCPLT and FRQPLT could be detached from the program.

(a) FMAP performs a two way linear interpolation between four adjacent points in the engine map, for any given engine speed and power demand.

(b) PWRMAX performs a two way linear interpolation between two adjacent points to derive maximum power available for a particular engine speed.

(c,d) CYCPLT and FRQPLT perform a graphical function of results for quick scanning and comparison of results accumulation. They are used only where memory permits.

DRIVING CYCLE AND ROUTE

The basic operation of the model is to translate the demand of the driving cycle into an engine speed/power versus time trajectory. The driving cycle data are able to be fed in in any form, typically the speed at every second of the cycle's duration. It is not confined to segment division as is the case in other existing models, i.e., constant acceleration, constant speed, etc.

In the course of following a driving cycle, five modes were found to be pertinent to performance and fuel consumption. They are: initial motion, acceleration, crusing, deceleration and braking.

(a) Initial motion

The initial motion of a vehicle is the transition period between engine idle and power transmission to the ground. The slip time of a friction clutch is normally less than 1 second, and although this portion is of little importance to fuel consumption over the whole cycle, it does affect the driveline and the gradeability. The maximum torque imposed on the driveline is the capacity of the clutch and not the engine because accelerating during a clutch start is not dictated by the engine torque, but by the clutch torque. Starting gradeability is limited by engine torque because clutch torque exists for only a short period, and is affected by engine stall or lugging. During the engagement, engine speed decreases until clutch lockup so that the minimum engine speed should be high enough to prevent engine stall or lugging.

MAC has the ability to accept any initial conditions. It may be zero velocity (starting form rest) or a higher velocity (starting form cruise condition) or any other speed range. When the initial condition is zero km/h, MAC accepts clutch slippage until the engine speed is at idle rate or higher. When the vehicle velocity is too low and the corresponding engine speed for 1st gear is below idle rpm, the engine speed is set to idle. When the vehicle is initiated at other than 1st gear, the engine speed is calculated for the corresponding road speed and if the engine speed is below idle, it is not corrected and displayed to show slippage.

(b) Acceleration

The acceleration rate of a vehicle on a level road normally diminishes with increasing speed due to the increasing drag forces from air and rolling resistance. At lower speeds, rolling resistance is predominant, and at high speeds air resistance is approximately equal in magnitude.

The power to weight ratio for heavy vehicles is normally lower than that for a passenger car and therefore a full throttle acceleration is more common. Heavy trucks tend to be accelerated at full throttle throughout the gears and, as a result, fuel is consumed at a maximum rate.

Full throttle acceleration is responsible for the majority of fuel consumption, particularly for a stop-and-go duty cycle. Suffice it to say that grades, curves, passing manoeuvers and speed limit changes can cause extra fuel consumption particularly if they are negotiated at full throttle. Although the acceleration demand itself causes high fuel consumption, variations in engine efficiency substantially increase fuel consumption and loss of energy.

In following a driving cycle which requires full throttle operation, the operator may choose between economy driving and governed driving. In economy driving, the engine speed is kept as low as possible and an upshift is performed as soon as it is practical to do so. In governed driving, the routine will operate the engine up to the governor speed before shifting takes place.

Driving cycles are followed to the best possible level of accuracy. Deviation from the driving cycle is the last resort of the automatic driver which, when it senses deviation corrects it by increasing engine rpm and the power the engine is able to produce. If this fails, then it resorts to a reduction of the projected speed of the vehicle. It is possible for a number of successive cycle velocities to be unattainable. In this situation the automatic driver will 'chase' subsequent cycle velocities with its lower actual velocity until such time as the velocities match. In general, MAC can, with high accuracy, model the peaks and valleys of sequential driving microtrips in a driving cycle with minimal smoothing.

(c) Cruising

The definition of cruising (constant speed) operation differs between various literature sources. TABESAM considers a speed variation of 0.2 km/h to be a cruise mode, or constant speed and this may occur as a result of a driver choice (e.g., road speed restriction), engine horsepower speed limitation, engine governor setup or road speed governor limitation. As TABESAM attempts to model the velocity time trace of driving cycles to a very close approximation, it does not recognise the original cause of the cruising conditions.

The driver chooses constant speed by guiding the throttle position to the desired cruising speed. On level road the vehicle speed then rises asymtopically to cruise speed and power, unless the engine is controlled by a speed governor. Although this might not be considered to be cruising by some authors, (e.g. Smith(1970)), IABESAM takes the simple approach that where a speed of within 0.2 km/h has been reached, cruising speed logic takes control of that time step.

When the velocity of the vehicle is governor controlled, the engine power is rapidly reduced until the vehicle cannot go any faster. This type of operation is similar to the horsepower limited operation except that stabilisation speed is approached more rapidly. TABESAM attempts an upshift when engine governed speed is approached. However, in practice, and especially in rolling terrain, a gear shift either up or down is avoided as the driver is able to see ahead.

Cruising is usually undertaken in part throttle operation. IABESAM calculates the forces imposed on the vehicle, calculates the engine speed and power demand and looks up the fuel map for fuel consumption.

(d) Deceleration

The deceleration rate of a vehicle is typically between 1 and 2.2 m/s^2. This rate is some times exceeded, especially in urban operation, and the rate depends heavily on whether the deceleration is power deceleration (i.e. with a small amount of throttle open), zero throttle deceleration or braking.

If power decelaration, the power demand by the accessories, rolling resistance and aerodynamic drag resistance are added to form what is termed power losses. The vehicle's kinetic energy is subtracted from the losses because it acts as a positive power and the engine is required to make up the difference. If closed throttle deceleration, i.e., the vehicle is allowed to coast down, and as "motoring" data are difficult to obtain, this operation is grossly simplified compared to what actually occurs in real conditions and the fuel consumption is assumed constant during costdown. Should "motoring" data become available in the future, minor alterations will be needed to allow for power absorption by the engine and for increased fuel consumption.

If the decreasing rate desired is greater than the vehicle coastdown speed, brakes may be applied and an appreciable amount of energy is dissipated. This energy cannot be reused during acceleration up to speed (future vehicle design may permit the recovery of part or the whole of this energy).

e) Braking

Fuel consumption during braking is minor although it is ifficult to ascertain. Some engine governors have a fuel cut off for otoring, and this could reduce the fuel consumption during braking to lmost zero, especially when the clutch is engaged. If the clutch is isengaged, fuel is consumed at the idle rate. In some trucks, a small mount of fuel is allowed to flow during motoring for injectors

Route descriptipn

Routes are not required to be entered separately as driving cycles data contain all necessary information, including the length of a particular route. Grades and wind conditions are entered with the vehicle description data as constants throughout the trip. With minor adjustment the model can have a maximum flexibility by allowing these conditions to be changed along with vehicle speed or distance.

Realistic values of grade or wind speed are modelled. The wind speed is in km/h and could be a head wind, in which case it will have a positive value, or a tail wind, where the value will be negative. Cross-winds may also be considered, but are not simulated due to difficulties of considerable and uncertain change in aerodynamic drag with yaw angels.

IRANSMISSION SHIFI CONIROL

It is common for heavy vehicles with manual transmissions to have 9 or more possible gear ratios and they may not all be used by the driver. A representative model should be able to cater for all possible gear shifts.

The duration of a shift action can vary between vehicles and on average, a manual transmission requires 1-2 seconds during which the vehicle looses speed due to drag force. With some preselector transmissions, a shift can take place under full engine power and therefore requires a very short time. For a nonsynchronised transmission, the shift duration depends on the rate at which the engine slows down during double de-clutching and may require up to 2 seconds. Double de-clutching may also be used with synchronmesh transmission to extend their life but it is not a common practice. Gear shift time with synchromesh transmission are faster and the cluth absorbs the load and speed mismatches.

Io perform shift modelling, existing programs require shift logic input data which is usually cumbersome to prepare and limited in application. TABESAM differs in that no shift logic data or commands are needed. An automatic driver (MAC) is built into the program which gives the model extra simplicity, diversity and reduction in input data requirements. It also enables the model to perform any desired shift with minimal user interference.

MAC is able to model any vehicle performance and any driver's behaviour, including fuel efficient and governed driving conditions. It can also perform gear jumping and, because it can start the vehicle in any gear, there is no confinment to starting the vehicle in only first gear, i.e., some driving techniques for unladen conditions which involve starting in 3rd gear and shifting to the 6th, 7th gear, etc. can be modelled successfully. In down shift any gear selection is possible, including from the top gear staight to neutral or to first for sudden stops. The engine speed range for any gear is preset by the user and short circuiting any gear is possible, i.e. in a nine gear transmission, the selection of 1st, 3rd, 5th 7th, and 9th gears in a driving segment or over a prescribed route is possible. Analogously, it is possible to use only even gear numbers to drive over a given driving cycle. This, together with other possible techniques involved in driving heavy vehicles, can be modelled.

When a shift takes place, MAC allows one second for motoring and the vehicle speed during this period is a function of the vehicle losses and the vehicle inertia: half a second is allowed to simulate slipping of clutch and the other half for engagement in the new gear but no power is transmitted. MAC determines which suitable gear is to be engaged and looks up the appropriate gear ratio. Gear suitability is determined by the state of the engine and shift points. Shift point (rpm range) for each gear is preset by varying the UPREV and DNREV array in the data initialisation state. The allowable engine rpm for each gear can vary from the idle rpm to the governor rpm. When a particular gear needs to be skipped over, the UPREV(gear) is set to 800 rpm so that the automatic driver will sense this restriction and go to the following gear. The opposite operation is performed to gears in a downward direction: if a driver shifts gears from, for example, the 9th gear staight to the 5th, DNREV(8), DNREV(7) and DNREV(6) are set to the governor rpm, i.e. to 1900 rpm.

IABESAM is built to simulate vehicles with manual transmission, although with minor extention it can simulate automatic transmission as well. The program can manage transmissions of up to 20 gears, but as the experimental vehicles have a transmission of 9, this program is set to handle a 9 gears transmission without any modification.

To prevent "stutter," i.e., swithching back and forth from one gear to another, IABESAM prevents a shift from occuring if the projected speed following an upshift is below the downshift speed for the new gear, or if the projected speed following a downshift exceeds the upshift speed for the new gear. Should this condition occur, the routine assumes that a shift at that point would not be advisable, and would set the vehicle speed, and therefore the engine, speed to a value that would simply maintain the engine at the shift speed. This would continue for at least 3 seconds or until another new condition is requested.

The program output provides shift frequency statistics which may be used as an aid to determining the validity of the shift points. The user should check the number of shifts being performed and modify the shift points decleration. However it is unlikely for a "stutter" to occur as the routine (MAC) is built in a very rugged manner.

COMPUIAIIONAL PROCEDURES

Since TABESAM uses the continuous incremental approach, all caculations of power demand are performed for every time-step, which in this model is 1 second. Therefore, the power losses are computed at the end of every second in the driving cycle.

In vehicle performance computation, the primary considerations are the vehicle speed at the start of a time-step and acceleration of the overall vehicle. TABESAM uses standard Newtonian mechanics to compute gross vehicle motion. Therefore, the power demand on the engine is due to the force acting on the vehicle at any given second and is equal to the D'Alembert (inertial) force plus the sum of all the external forces. These external forces are aerodynamic drag, rolling resistance and gravity (grade) where applicable. Power losses due to engine accessories are also included.

The equations used to compute aerodynamic drag, rolling resistance and engine accessories are derived from algorithms supplied by Mr Harry Close (INI model), see in Khatib and Watson (1986).

INIERACIIVE SIMULAIION

A description of IABESAM execution through interactive operational modes is provided in this section. This mode permits the user to choose the type of output, to both specify the name of the driving cycle input and the name of the output file and to select any starting gear.

Although the truck description data are prewritten in IKDES.DAI. with minor modifications, the program can prompt the user for vehicle description data one item at a time until all data are loaded interactively. An example of interactive operation where gears 3, 5, 7 and 9 were used by unladen vehicle is shown below in Figure 1 and examples of tkdes.dat, which was descriped in details under program inputs and contains the vehicle description, and Cummins fuel map are shown in Figures 2, and 3 respectively. An example of the results of the simulation are tabulated in Figure 4. Figure 5 shows the speed-time profile for a microtrip extracted from a driving cycle of unladen vehicle. Figures 5b to f demonstrate how energy is dissipated in the various losses in the engine-vehicle system. Figure 6a to 6d shows the corresponding fuel proprtion attributed to each of the losses in figure 5. The total fuel usage rate is shown in figure 6e.

Figure 7 demonstrates the application of the program to sensitivity analysis of various vehicle design or operation parametres.

Fig. 1 An example of interactive operation.

Do you want a full listing or a summary answer F or S and return ....F
Ǝnter name of driving cycle ... ACDI.DAT
Ǝnter name of desired output file .... ACDI.OUT
Ǝnter gear you wish to start at 3

SIMULS - ONE ... UNIVERSITY OF MELBOURNE..... Mechanical Engineering Department
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16-FEB-86 16:04 Vehicle Performance Simulation Report page 1

Vehicle: International Harvester Engine: Cummins NTC 350

Input Driving Cycle: acdi.cyc Output Data File: acdi.out

ur to mass ratio = 18 500	total vehicle mass tonne =	14 000
ehicle height metre = 4 300	vehicle width metre =	2 500
rag coefficient = 0 700	rolling coef. =	0 900
ngine aces coef = 8 000	engine fan coef =	0 002
rive train eff = 0 860	rear axle ratio =	2 720
ng idle speed rpm = 800 000	max eng speed rpm =	1900.000
ind speed km/h = 0 000	road gradient % =	0 000
umber of gears = (9)		

Transmission Data (9) gears

ratio of gear no. 1 =	12 650
ratio of gear no 2 =	8 380
ratio of gear no 3 =	6 220
ratio of gear no 4 =	4 570
ratio of gear no 5 =	3 400
ratio of gear no 6 =	2 460
ratio of gear no 7 =	1.830
ratio of gear no 8 =	1.340
ratio of gear no. 9 =	1.000

2

gear	sped	des.s	erpm	ptot	apwr	ardp	rolp	acsp	losp	accp	brake	cumdst	cumfc	grad
3	2.7	2.7	800 0	2.9	40.0	0.0	0.3	2.6	2.9	0.0	0.0	0 0004	0 0015	15 00
3	6.1	6.1	800.0	14.9	60.0	0.0	0.9	2.6	3.5	11.4	0.0	0 0016	0 0030	12 52
3	9.7	9.7	855.8	31.9	75.6	0.1	1.7	2.8	4.5	27.4	0.0	0 0038	0 0055	7 62
3	14.9	14.9	1324.4	71.6	148.3	0.2	2.8	4.4	7.4	64.2	0 0	0 0072	0 0108	8 64
3	20.3	20.3	1794.0	110.4	204.0	0.6	4.2	6.1	10.8	99.5	0 0	0.0121	0 0191	7 77
3	19.7	19.7	1742.6	0.0	230.9	0.0	0.0	0.0	0.0	0 0	1 3	0.0176	0 0229	0 00
5	19.7	27.2	952.5	0.0	174.1	0.0	0.0	0.0	0.0	0 0	0.0	0 0231	0 0247	14 91
5	27.4	33.0	1441.6	200.0	205.0	1.1	3.9	4.8	9.8	190.2	0 0	0.0296	0 0326	0 31
5	33.5	36.4	1750.5	227.8	231.5	2.6	6.9	5.9	15.4	212.4	0 0	0.0381	0 0542	0 19
5	35.9	35.9	1736.6	115.9	244.5	3.8	8.7	5.9	18.4	97.5	0 0	0 0477	0 0629	6 04
7	35.3	39.8	920.3	0.0	175.6	0.0	0.0	0.0	0.0	0.0	0 0	0 0576	0 0645	8 29
7	39.4	43.8	1287.8	195.3	195.6	3.3	5.9	4.2	13.5	181.8	0.0	0.0660	0 0784	0 01
7	43.3	45.0	1556.0	213.4	220.9	6.0	9.6	5.2	20.9	192.5	0.0	0.0775	0 0930	0 29
7	47.2	46.7	1751.7	239.4	239.5	8.7	12.2	5.9	26.8	212.5	0.0	0.0920	0 1094	0 00
7	49.0	49.0	1277.7	136.4	226.5	10.7	13.8	4.2	28.8	107.7	0 0	0 1054	0 1189	3 10
7	51.2	51.2	1334.8	167.0	224.3	12.6	15.1	4.4	32.1	134.8	0 0	0 1193	0 1306	1 89
7	53.3	53.3	1388.5	167.7	226.5	14.5	16.1	4.6	35.2	132.5	0 0	0 1338	0 1423	1 66
7	55.2	55.2	1438.5	166.6	230.9	16.3	17.0	4.8	38.1	128.5	0 0	0 1489	0 1539	1 96
7	57.0	57.0	1486.7	169.3	236.5	18.2	17.9	5.0	41.0	128.2	0 0	0.1645	0 1657	1 97
7	58.9	58.9	1535.0	176.5	241.0	20.1	18.7	5.1	43.9	132.5	0 0	0 1806	0 1779	1 95
7	60.0	60.0	1565.2	132.1	243.8	21.8	19.3	5.2	46.3	85.8	0 0	0 1971	0 1872	3 13
7	61.4	61.4	1600.4	150.5	245.9	23.4	19.9	5.4	48.7	101.8	0.0	0 2140	0 1977	2 62
7	62.7	62.7	1634.5	152.0	248.3	25.0	20.5	5.5	51.0	101.0	0.0	0 2312	0 2083	2 57
7	63.9	63.9	1666.6	150.2	250.8	26.6	21.1	5 6	53.3	96 9	0 0	0 2498	0 2168	2.65
7	65.2	65.2	1698.6	154.4	253.4	28.3	21.6	5.7	55.6	98 8	0 0	0 2667	0 2296	2 55
7	66.4	66.4	1730.2	157.0	255.3	29.9	22.1	5.8	57.9	99 1	0 0	0 2850	0 2406	2 50
7	67.6	67.6	1761.5	160.3	256.9	31.6	22.7	6 0	60 3	100 1	0 0	0 3036	0 2519	2.41
7	68.8	68.8	1792.2	162.8	258.3	33.4	23.2	6.1	62.7	100.2	0 0	0 3225	0 2633	2 34
7	69.9	69.9	1822.4	165.3	259.1	35.2	23.7	6.2	65.1	100.2	0 0	0 3418	0 2749	2.26
7	71.1	71.1	1852.2	167.7	259.6	37.0	24.3	6.3	67.5	100.1	0.0	0 3614	0 2868	2 13
7	72.2	72.2	1881.9	171.8	259.8	38.8	24.8	6.4	70.0	101.8	0 0	0 3813	0 2990	2 05
9	71.2	72.9	1013.5	0.0	198.9	0.0	0.0	0.0	0.0	0.0	0 0	0.4012	0 3007	4 71
9	72.9	74.6	1266.5	195.9	205.1	21.0	12.8	4.2	37.9	157.9	0.0	0.4212	0 3149	0 21
9	74.5	76.3	1469.0	205.5	222.4	32.9	19.6	4.9	57.3	148.1	0 0	0.4417	0 3291	0 39
9	76.3	77.7	1631.1	235.7	236.4	40.4	23.4	5.5	69.3	166.3	0 0	0.4626	0 3452	0 02
9	78.0	78.7	1760.7	240.8	247.4	45.9	25.7	6.0	77.5	163.3	0 0	0 4841	0 3617	0 14
9	79.7	79.8	1864.5	249.0	253.7	50.3	27.3	6.4	83.9	165.1	0 0	0 5060	0 3788	0 10
9	80.8	80.8	1150.1	190.3	218.9	53.6	28.3	3.8	85.6	104.6	0.0	0.5283	0 3890	0 60
9	81.8	81.8	1164.4	190.6	203.4	56.3	29.0	3.8	89.2	101.4	0.0	0.5508	0 4002	0 26
9	82.8	82.8	1387 3	200.9	216.0	58.8	29.7	4.6	93.1	107.8	0 0	0.5737	0 4143	0 31
9	83.7	83.7	1192.1	188.8	205.9	61.1	30.2	3.9	95.2	93.6	0 0	0.5968	0 4275	0 34
9	84.7	84.7	1205.7	197.9	202.5	63.3	30.7	4.0	98.0	99 9	0 0	0 6202	0 4419	0 09
9	85.6	85.6	1218.9	199.6	202.1	65.5	31.2	4.0	100.7	98.9	0.0	0.6438	0 4563	0 05
9	86.5	86.5	1231.7	200.2	203.2	67.7	31.7	4.0	103.4	96.7	0.0	0 6677	0 4707	0 06
9	87.4	87.4	1244.4	202.8	205.1	69.9	32.1	4.1	106.1	96 7	0 0	0.6919	0 4541	0 04
9	88.2	88.2	1256.5	202.0	207.2	72.0	32.6	4.1	108.7	93.3	0 0	0 7163	0 4980	0 10
9	89.0	89.0	1268.2	202.2	209.4	74.2	33.0	4.2	111.3	90.9	0.0	0 7409	0 5119	0 14
9	89.8	89.8	1279.5	202.2	211.7	76.2	33.4	4.2	113.9	88.4	0.0	0.7657	0 5261	0.18
9	90.6	90.6	1290.6	204.4	213.9	78.3	33.8	4.3	116.4	86.0	0.0	0.7908	0 5403	0 18
9	91.4	91 4	1301.2	204.2	216.0	80.4	34.2	4 3	118.9	85.4	0.0	0.8161	0 5549	0 22

Fig. 2. Truck description data file (tkdes.dat)

```
Engine input data TNT model.
-------------------------------
International Harvester
Cummins     NTC 350                  vehicle
18.500                               engine
14 000                  power to mass ratio
04.300                  vehicle mass (tonne)
02 500                  vehicle height (m)
00 700                  vehicle width  (m)
00 900                  drag coefficient
08.000                  rolling coefficient
00 002                  engine accessory load constant
00 860                  engine cooling fan load constant
02 720                  driveline efficiency
01.013                  rear axle ratio
800.0                   tire diametre (m)
1900.0                  engine idle rpm
00 00                   engine full load governed rpm
00 00                   wind velocity km/h
9                       road gradient
gear ratio              number of gears
-------
12.65
 8 38
 6 22
 4 57
 3 40
 2 46
 1 83
 1 34
 1 00
```

Fig. 3. Cummins engine fuel map.

	0.	20.	40.	60.	80.	100.	120	140	160	180	200	220	240	260
800	4 3	4 9	9 1	13 3	17 5	21 7								
900	4 9	5.6	9 3	13 9	18 5	21 8								
1000	5 5	6 1	9 5	13.2	17 4	21.9	27 0	31 3						
1100.	6 1	6 7	9 7	13 3	17 3	21 5	26 0	30 6	36 0	41 0				
1200	6.8	7 3	9 9	13 4	17 4	21 2	25 5	29 8	34 6	39 4	44 0			
1300	7 5	7 7	10 2	13.5	17 5	21 2	25 4	29 5	33.9	38 3	43 2	47 5		
1400	8 3	8 0	10 5	13 7	17 6	21 4	25 4	29 5	33.7	38 0	42 2	46 3	50 5	
1500.	9 2	8 3	10 9	14.2	17 9	21 6	25 5	29 5	33.6	37 8	41 7	45 7	49 6	53 7
1600	10 1	8 5	11 4	14 4	18 2	21 9	26 3	29 5	33 7	37 8	41 3	45 5	49 6	53 7
1700	11.1	8 9	11 9	14 9	18 7	22 4	26 8	29 7	33 8	37 8	41 5	45 5	49 6	53 7
1800	12 1	9 2	13 4	15 7	19 5	22.9	27 5	30 4	34.0	38 1	42 0	45 9	49 6	53 7
1900	13.2	9 6	14 1	16 2	20 2	23 4	28 2	31 1	34 7	38 7	42 6	46.5	49 9	54 5
2000	14 5	10 0	14 8	16 8	20 9	24 3	29.2	31 8	35 5	39 4	43 2	47 4	50 3	
2100	15 7	10 3	15 8	17 7	21 6	25 2	30 3	32 3	36 0	39 4	43.5	47 5		

Fig. 4

Vehicle Performance Summary Report page 7

cycle modes Statistics :

variable	(units)	total	accel	cruise	decel	idle
time	s	212.00	29.72 %	33.02 %	13.68 %	23.58 %
dist	km	3.51	33.73 %	55.42 %	10.84 %	0.00 %
power	kW	101.60	49.84 %	49.55 %	0.01 %	0.60 %
fuel	litre	1.65	45.78 %	45.11 %	4.71 %	4.39 %

Fuel Consumption Statistics :

fuel consumption l/100km =	46.97	fuel economy (mi/gl) =	6.01
fuel cons : engine fric % =	7.98	p"train loss % =	12.30
accessories % =	4.13	rolling res % =	15.17
.... aerodynamic % =	37.78	.... inertial(acc) % =	22.64

Driving Cycle Statistics

average velocity km/h =	59.56	average velocity mi/h =	37.02
average cycle vel km/h =	59.72	vehicle to cycle vel % =	99.73

Power/energy Statistics :

avge pwr consumption kW =	105.34	total energy supply kW-h =	6.20
engn power supply kW =	101.60	engn energy supply kW-h =	5.98
kinetic power kW =	3.74	kinetic energy kW-h =	0.22
avge surplus pwr kW =	85.17	avg brake cons kW =	22.80

energy consumption breakdown :

powertrain losses % =	13.51		
engine accessories % =	3.47	rolling resistance % =	16.66
inertial(acc) % =	24.85	aero dynamic drag % =	41.51

Gear Shift Statistics

total gear shifts =	6.00		
total gear upshifts =	3.00	total gear dnshifts =	3.00

Transmission Statistics :

average trip engine RPM = 1259.055

gear	avg rpm	time in %	upshift	dnshift	avg velc	avg pwr
1	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00
3	853.90	29.72	0.00	1.00	1.91	5.74
4	0.00	0.00	0.00	0.00	0.00	0.00
5	1369.37	4.25	1.00	1.00	27.72	60.40
6	0.00	0.00	0.00	0.00	0.00	0.00
7	1570.50	15.09	1.00	1.00	58.80	104.86
8	0.00	0.00	0.00	0.00	0.00	0.00
9	1393.93	50.94	1.00	0.00	96.07	159.98

Fig 5. Power Consumption Statistics

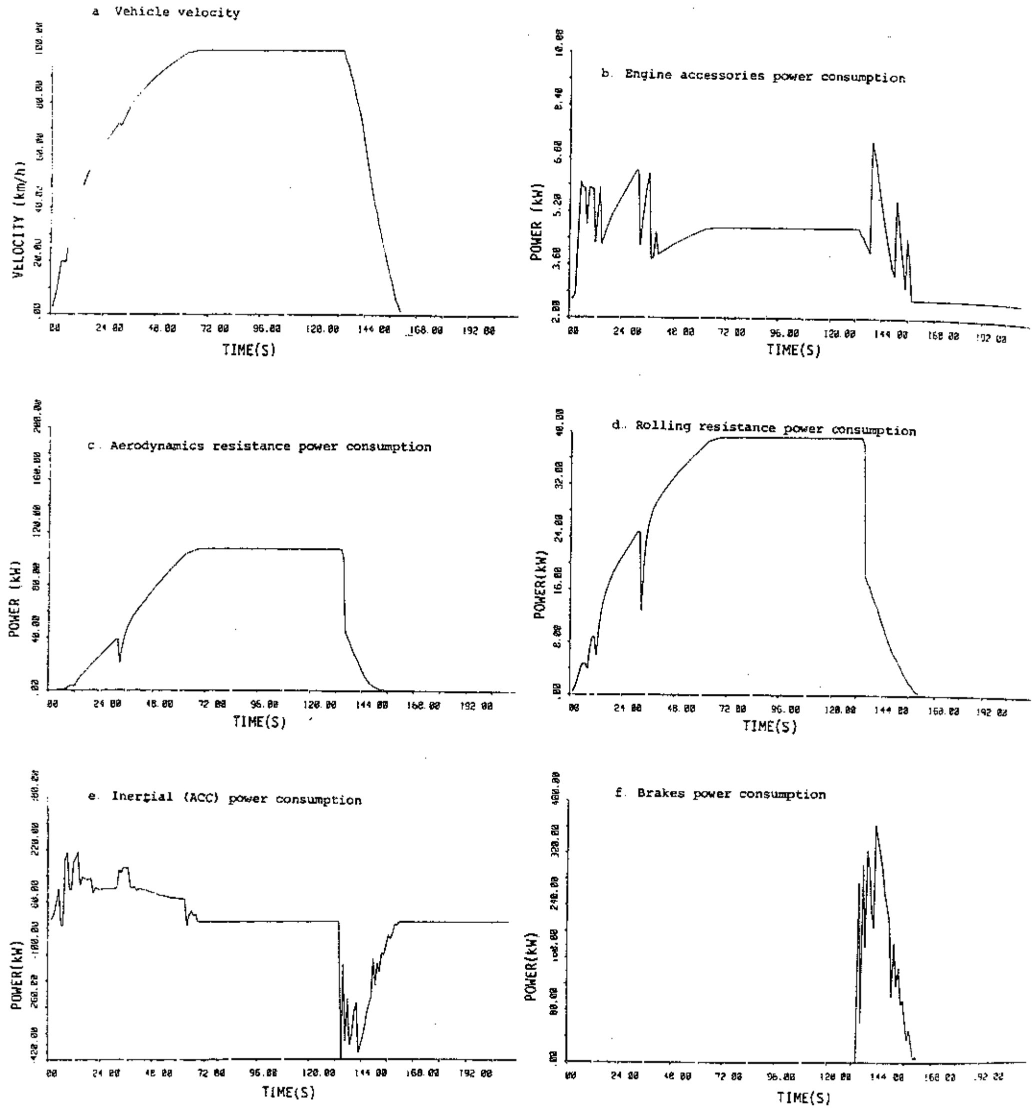


Fig 6. Fuel Consumption Statistics

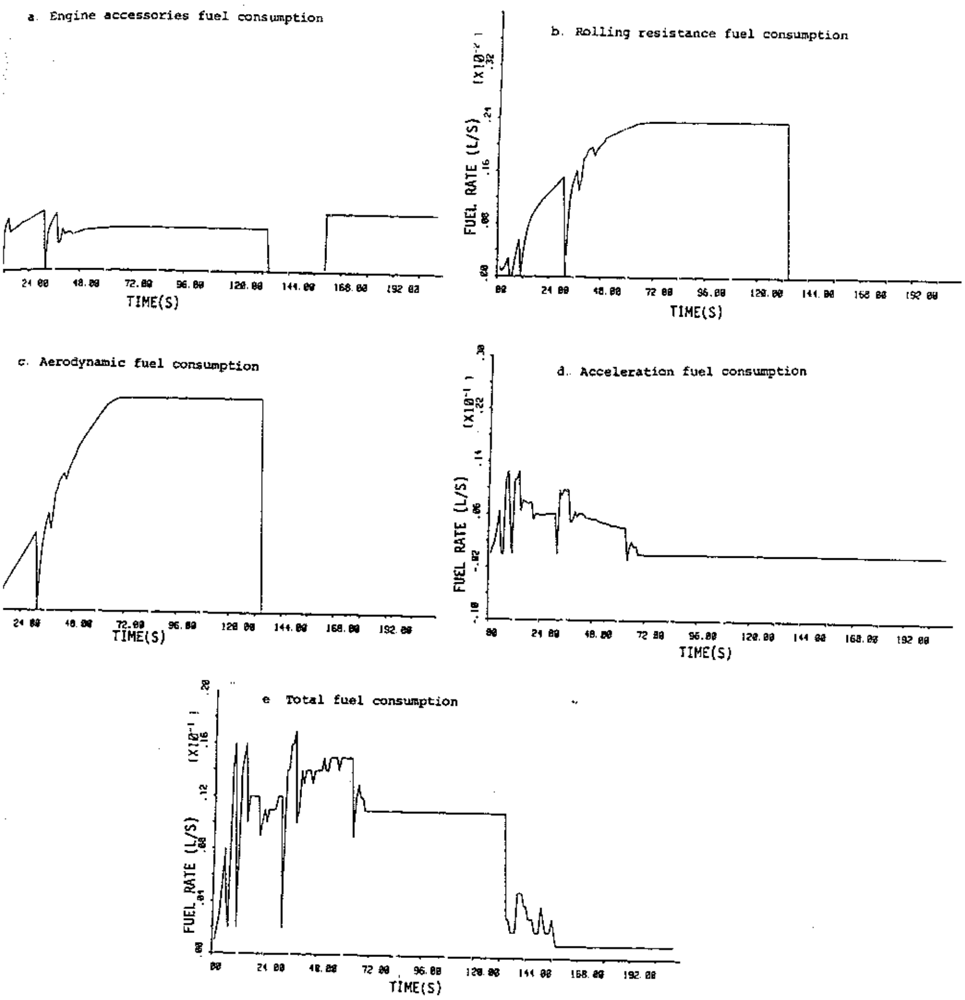
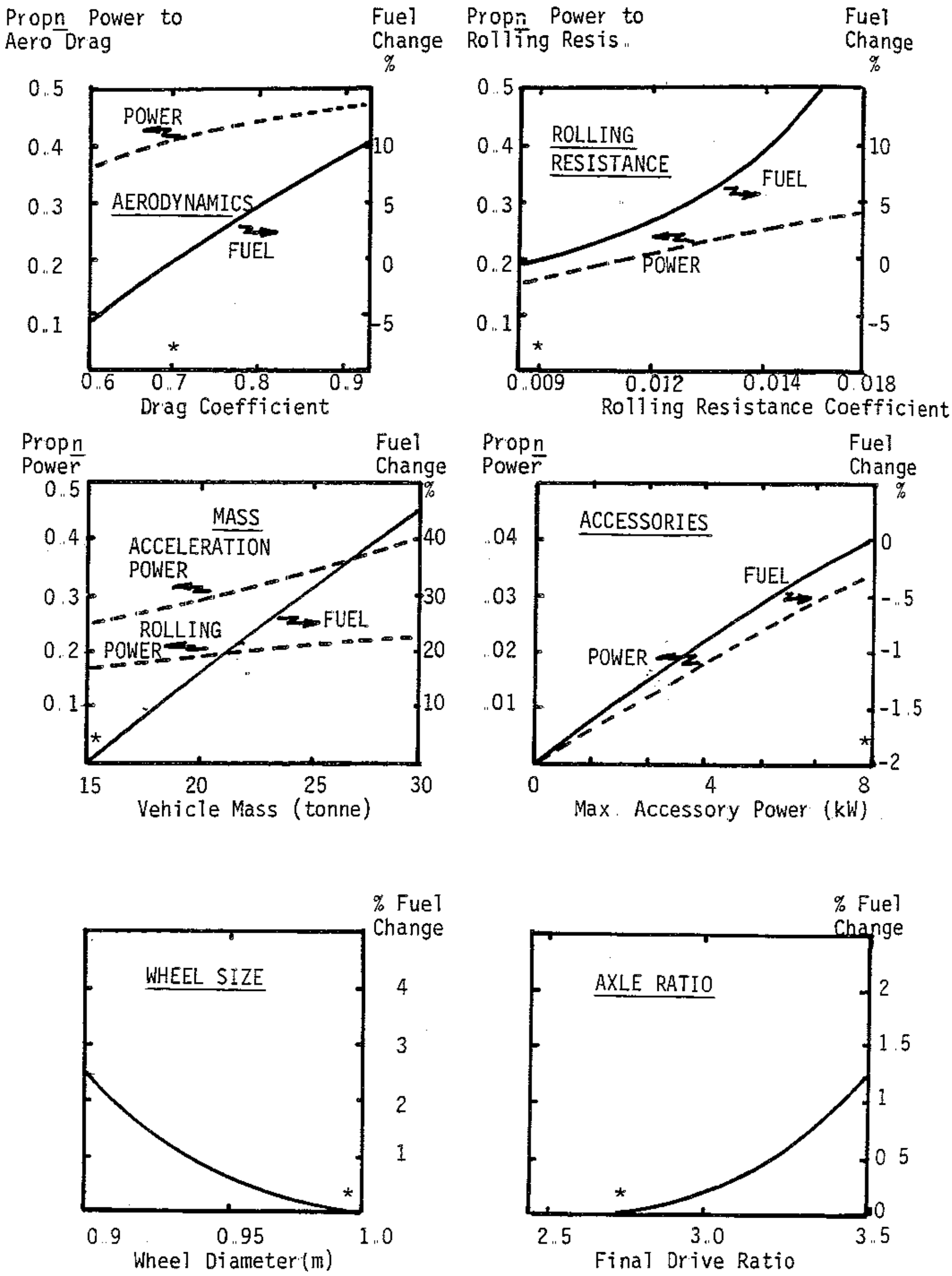


Fig 7. Sensitivity of truck fuel consumption and energy dissipation to changing vehicle design parameters. Base truck identified with *, i.e. Engine as in fig 2, body drag coefficient of 0.8, tyre rolling resistance coefficient of 0.012, gross vehicle mass (unladen) 15 tonnes, wheel diameter 1 m, final drive(axle) ratio 2.7 and maximum accessories' loss 8 kW.



CONCLUSIONS

The first of a number of simulation models (TABESAM) was developed at the Mechanical Engineering Department of the University of Melbourne with the support of NERDDC. The computer program simulates the performance and predicts the fuel consumption of diesel-powered heavy trucks for any desired driving cycle. The program meets the needs of a model with brief and simple input and small storage space; which is easy and cheap to run; which has a bulit-in automatic driver; which produces a detailed or simple output and which is free from proprietary constraints.

The simulation program was developed to study the effect of various operating conditions and vehicle design. The model's simulation output compares favourably with outputs provided by the HEVSIM simulation program. The project field work, which is expected to be concluded by April 1986, should offer excellent calibration for the model. To date, the results clearly show that the simulation model is very realistic and useful.

The program is adaptable to many micro computers and has been simplified to run on a hand-held programmable calculators.

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