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CATALOG OF SELECTED HEAVY DUTY TRANSPORT ENERGY MANAGEMENT MODELS

Ralph G. Colello
Ashok B. Boghani
Nancy C. Gardella
Philip G. Gott
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Arthur D. Little, Inc.

November 1983

(NASA-CR-168299) CATALOG OF SELECTED HEAVY   N84-14991
DUTY TRANSPORT ENERGY MANAGEMENT MODELS
Contractor Report, Dec. 1982 - Nov. 1983
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TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 Program Objectives

Sponsor

This document presents a catalog of energy management models for heavy duty transport systems powered by diesel engines. The catalog was prepared under contract with NASA-Lewis Research Center (LeRC) as part of a program to survey, catalog and assess the major models currently used in the transportation industry.

Objective

The overall program objective was to aid NASA-LeRC in determining the most suitable models available for NASA to acquire, adapt and utilize for their specific analytical needs.

Scope

The scope of the energy management models included in this effort include:

- Heavy Duty Transport Systems
    - Highway Transport (vehicle simulation)
    - Marine Transport (ship simulation)
    - Rail Transport (locomotive simulation)
    - Pipeline Transport (pumping station simulation)

- Heavy Duty Diesel Engines
    - Models that Match the Intake/Exhaust System to the Engine
    - Fuel Efficiency
    - Emissions
    - Combustion Chamber Shape
    - Fuel Injection System
    - Heat Transfer
    - Intake/Exhaust System
    - Operating Performance
    - Waste Heat Utilization Devices
        - turbocharger
        - bottoming cycle

Time Frame

This catalog is a result of work performed in the time period from December 1982 to September 1983.

1.2 Description of Catalog Contents

Major Purpose

The main purpose of this catalog is to present detailed, comparable and structured information on major computer models used in the heavy-duty transport area related to diesel engines.

Contents of
Each Chapter

Chapter 1.0 of this volume contains the background information on this project and the description of how the catalog is organized. Chapter 2.0 contains summary tables to be used as guides to rapidly access the models of interest. Chapter 3.0 contains the detailed individual model descriptions in common formats organized by category and access number. Chapter 4.0 is an index by model category and by organization that sponsored the model development.

1.3 Completeness and Future Updating

Researching the
World Models

Although this program involved a comprehensive search of data bases, libraries, personal industry government and university contacts, it is possible that some references and models may remain undiscovered or uncataloged. Some of the model descriptions may be incomplete or contain inaccuracies due to unavailability of up-to-date documentation or original model authors/users.

Updating

With the possibility of continually updating and expanding our computer files containing the catalog model descriptions and references, any references regarding new or overlooked models or information would be welcomed by the authors.

1.4 Catalog Format and Definitions

The final set of information entries that were researched for each major model description are listed below. These entries are grouped so that entry descriptions of similar or related types of information would be easily referenced. The definition of the intended information for each entry follows:

Title	The model name refers to the commonly recognized name of the model if it has one. Otherwise, the name of the report in which the model is presented or the organization that developed the model
Date	When was the model completed and when did updates occur (if any)?
Authors	Who are the primary individuals that developed the model?
Organization	What organization or group developed the model?
Sponsor	What organization or groups provided funding for the development?
Transportation Mode	Highway, Rail, Marine or Pipeline.
Application	Military or civilian.
Objective	The objective of the model is the purpose for which the model was developed. This often includes the parameters which are analyzed in the model.
References	Papers, articles, manuals or other documents which describe the model or results of analysis on the model.
Relationship to Other Models	Is there any relationship between this model and other models? For example, is this a submodel or part of a family of models?
History of Model	What is the history of this model? For example, is this a second generation model based on an earlier, less sophisticated version?
Operational Capabilities	What is the model's range of capabilities for - primary output calculations, - steady-state, quasi-steady-state, or transient operation - ability to vary design factors of interest.
Assumptions	What are the major assumptions that the model is founded upon?
Limitations	What are the limitations or shortcomings of the current model and the comparison with other similar models?

Data Input Requirements	What data or parameters are required as givens or input to the model? For example, are engine maps required or the data from operating an actual engine.
Advantages	What advantages does this model have compared to other models with similar objectives and output?
Validation	What is the validation status of this model?
Computing Requirements	What is the computer hardware systems that have been or are presently used for processing this model? What language is the model code written in?
Cost of Operation	What is the average cost per run of operating this model on the current hardware referred to in previous entry?
Future Potential	What future modifications or changes are planned for this model?
Availability	What is the availability of this model for NASA-Lewis Research Center use or purchase?

2.0 SUMMARY GUIDE TO THE CATALOG

Type of Summary Tables.

As stated previously, this document presents a catalog of energy management models for heavy duty transport systems powered by diesel engines. The chapter that follows summarizes key features of these models in order to assist the reader in ascertaining those models of primary interest. First, the models are summarized according to application and transportation mode as follows:

- Table 2.1 – Applications of Heavy Duty Diesel Engine Models.
- Table 2.2 – Models by Transportation Mode

From these two tables the reader can select the category of interest. Models are summarized in more detail within categories in the following tables:

2.3.1 <u>Heavy Duty Transport Systems</u>

2.3.1.1 Highway Vehicle Models
2.3.1.2 Marine Models
2.3.1.3 Rail Models

2.3.2 <u>Heavy Duty Diesel Engine Models</u>

2.3.2.1 Models that Match the Intake/Exhaust System to the Engine
2.3.2.2 Fuel Efficiency Models
2.3.2.3 Emission Models
2.3.2.4 Combustion Chamber Shape Models
2.3.2.5 Fuel Injection System Models
2.3.2.6 Heat Transfer Models
2.3.2.7 Intake/Exhaust System Models
2.3.2.8 Operating Performance Models
2.3.2.9 Bottoming Cycle Models
2.3.2.10 Turbocharging Models

Description of Tables.

If one is interested in knowing which engine models have been developed for a particular functional application, Table 2.1 is a summary of the heavy duty diesel engine models by type of application. For each application, the scope is defined and the model title, organization and location in Chapter 3 is cited. For those interested in quickly ascertaining which models apply to a particular mode(s) of transportation, or those modes that are applicable to all models, Table 2.2 summarizes the models including title, organization and location in Chapter 3. Using either of these tables provides a group of two or more potentially interesting models. In order to select the appropriate model(s) for one's needs, the user can either read each of the model descriptions in detail in Chapter 3 or utilize the categorical summaries provided in Tables 2.3. Used as described below, these tables should enable the user to quickly ascertain the model(s) most likely to meet the particular needs and constraints of a given situation.

Selection of Model(s) from the Tables.

Model selection is highly dependent upon user constraints, such as: knowledge of computer programs, individual requirements (i.e., level of complexity), and facilities available for work. A potential user should ask the following questions in order to choose the appropriate program from Tables 2.3.

1. What issue am I interested in?
2. Does the program application meet my needs?
3. Is the annotated computer hardware system comparable to my own?
4. Can I operate the model within my budgetary constraints?
5. Has the model been sufficiently validated and documented? If not, will I be able to obtain assistance from the author(s)?

Hardware compatibility.

The third question is particularly important for determining the ease of using or adapting a program. For example, each program has been run on a particular type of computer system. Although software can be run on any system, some changes might be required in order to achieve operational performance on an alternative system. In addition, the cost of operation is frequently a concern among potential users. Therefore, the hardware has been described and cost estimates provided wherever possible.

The remaining details in the tables are provided for user convenience in model selection.

The access and page numbers are provided in the first column of the tables to assist the user in locating the more detailed information on the selected model(s) elsewhere in this document. The author and associated organization are also identified. The author(s) can be contacted in order to ascertain additional details with respect to recent updates, availability or the type and status of its validation, if any. The term "validation" as used in the following tables, is meant to imply that the model results have been favorably compared to experimental data. More complete details on the validation techniques are discussed in the individual summaries.

Concluding Remarks.

Finally, the reader should note that these tables serve merely as a summary guide to the catalog that follows; they are a tool for quickly assessing those models of primary interest. Detailed model descriptions can be found in Chapter 3, beginning on the page cited in the tables.

TABLE 2.1: APPLICATIONS OF HEAVY DUTY DIESEL ENGINE MODELS

APPLICATION	SCOPE	MODELS	ACCESS NO./ PAGE NO.
Matching Intake/Exhaust System to the Engine	● Simplified cycle thermodynamics yielding exhaust temperature and pressure	● Hitachi Model: HITACHI SHIPBUILDING, LTD	E-0034-72 pp. 3-83
		● University of Manchester: UMIST	E-0036-81 pp. 3-87
Efficiency or Fuel Consumption	● Heat release aattern ● Accurate gas properties ● Heat transfer ● Wall temperature	● Computer Simulation of a Diesel Engine: I.I.T., DELHI	E-0063-76 pp. 3-109
		● The Problem of Predicting Rate of Heat Release in Diesel Engines C.A.V. LTD.	E-0005-70 pp. 3-97
		● Wisconsin Diesel Spray Combustion Model: University of Wisconsin	E-0032-69 pp. 3-101
		● M.A.N.: MAN Augsburg	E-0070-74 pp. 3-115
		● Manchester (white house) UMIST	E-0004-77 pp. 3-91
		● Imperial College (Watson) Imperial College, M.E. DEPT.	E-0044-80 pp. 3-105

TABLE 2.1 (Continued)

APPLICATION	SCOPE	MODELS	ACCESS NO./ PAGE NO.
Emissions	● Detailed ignition and burning mechanisms of the spray	● Divided Chamber Diesel Engine Model: MIT	E-0001-81 pp. 3-119
	● Chamber temperature variations	● Cummins: CUMMINS ENGINE CO.	E-0003-78 pp. 3-131
	● Mixture composition variations; exchange between zones	● Ultrasystems Diesel Emissions Model: ULTRASYSTEMS, INC.	E-0006-74 pp. 3-135
		● Hiroshima: UNIVERSITY OF HIROSHIMA	E-0007-76 pp. 3-139
		● NREC Diesel Emissions Model: NREC	E-0008-71 pp. 3-143
		● C.A.V. Diesel Emissions Model: C.A.V. LTD	E-0026-73 pp. 3-147
		● Komatsu "DSA/DEC" KOMATSU/MIT	E-0002-78 pp. 3-125
		● Cranfield Model CRANFIELD INSTITUTE OF TECHNOLOGY	E-0071-75 pp. 3-151
Development of Combustion Chamber Shape	● Spatial resolution in 2-D or 3-D of the spray formation & combustion process	● Livermore Fuel Spray Model LAWRENCE LIVERMORE LAB	E-0009-78 pp. 3-155
		● Imperial College Diesel Spray Model IMPERIAL COLLEGE	E-0029-FI-80 pp. 3-165

TABLE 2.1 (Continued)

APPLICATION	SCOPE	MODELS	ACCESS NO./ PAGE NO.
		⊕ Los Alamos Direct Injection Engine Model LOS ALAMOS/GENERAL MOTORS RESEARCH LAB	E-0072-78 pp. 3-171
		⊕ Princeton Internal Combustion Engine Model PRINCETON UNIVERSITY	E-0010-73 pp. 3-159
Fuel Injection System	⊕ Examine the response of injector to control inputs	⊕ Hybrid (Analog) Computer Simulation of the Sampled-Data Model for Compression Ignition Engines: UNIVERSITY OF SUSSEX	E-0021-FI-70 pp. 3-177
		⊕ Diesel Fuel Injection System Simulation and Experimental Correlation: UNIVERSITY OF MICHIGAN	E-0039-FI-73 pp. 3-179
		⊕ Simulation of Processes of Fuel Injection (INJEC): KYOTO UNIVERSITY	F-0048-FI-71 pp. 3-185
		⊕ Computer Model of the Electronics Control System (ECS) for Diesel Fuel Injection Timing: UNIVERSITY OF MINN.	F-0069-FI-82 pp. 3-189
		⊕ Characterization and Simulation of a Unit Injector: WAYNE STATE UNIVERSITY	E-0049-FI-75 pp. 3-187

TABLE 2.1 (Continued)

APPLICATION	SCOPE	MODELS	ACCESS NO./PAGE NO.
Heat Transfer	• Through a series of assumptions, a classified heat transfer analysis is performed to study the affect on engine performance	• PROCES: NORWEGIAN INSTITUTE OF TECHNOLOGY	E-0023-HT-75 pp. 3-193
		• Computer Programs to Determine the Relationship Between Pressure Flow, Heat Release, and Thermal Load in Diesel Engines: M.A.N.	E-0067-HT-64 pp. 3-195
		• Mirrlees Heat Transfer Program DIESHT: MIRRLEES BLACKSTONE, LTD.	E-0073-HT-83 pp. 3-197
Intake & Exhaust System	• Optimize the design of the manifold system • Models based on steady compressible flow; unsteady compressible flow; pressure wave "organ pipe" theory	• Prediction of the Exchange Processes in a Single Cylinder Internal Combustion Engine: VARIOUS UNIVERSITIES	E-0014-IE-78 pp. 3-201
		• Computer Aided Design of the Exhaust of a Turbocharged Diesel Engine: UNIVERSITY OF MANCHESTER	E-0015-IE-74 pp. 3-205

TABLE 2.1 (Continued)

APPLICATION	SCOPE	MODELS	ACCESS NO./PAGE NO.
Intake and Exhaust System		● Computer Aided Design Package for Engine Manifold System UMIST	E-0022-IE-80 pp. 3-209
		● A Generalized Computer Aided Design Package for I.C. Engine Manifold System: UMIST	E-0043-IE-80 pp. 3-213
		● Computer Program to Predict the Gas Exchange Process of a Diesel Engine: RUSTON PAXMAN DIESFL STD.	E-0055-IE-74 pp. 3-219
		● Breathing Cycle of the Four- Stroke Automotive Engine: USDOT/NHTSA	E-0056-IE-79 pp. 3-225
		● Characteristics of Exhaust Gas Pulsation of Constant Pressure Turbocharged Diesel Engines: KAWASAKI HEAVY IND.	E-0053-IE-79 pp. 3-217

TABLE 2.1 (Continued)

APPLICATION	SCOPE	MODELS	ACCESS NO./PAGE NO.
Operating Performance	● Optimize the engine's performance for a given duty cycle ● Transient response based on steady state maps	● Application Engineering Techniques Related to High Performance, Medium Speed Diesel Engines: MIRRLEES BLACKSTONE, LTD.	E-0059-OP-75 pp. 3-239
		● Development of a Real-Time Digital Computer Simulation of a Turbocharged Diesel Engine: PAKISTAN STATE OIL CO., LTD.	E-0013-OP-79 pp. 3-229
		● A Combustion Correlation for Diesel Engine Simulation: IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY	E-0044-OP-79 pp. 3-233
		● Development of P.C. Engine Simulation Program: NIPPON KOKAN	E-0061-OP-74 pp. 3-243
		● Wholly Dynamic Model of a Turbocharged Diesel Engine for Transfer Function Evaluation UMIST	E-0062-OP-76 pp. 3-245
		● Title Unknown: NREC	E-0045-OP-69 pp. 3-235

TABLE 2.1 (Continued)

APPLICATION	SCOPE	MODELS	ACCESS NO./PAGE NO.
Operating Performance		● Simulation of a Turbocharged Diesel Engine to Predict the Transient Response: JOHN DEERE	E-0068-OP-77 pp. 3-249
Bottoming Cycle	● Analysis of waste heat utilization systems	● Boiler Analysis Program: FOSTER MILLER	F-0002-70 pp. 3-251
		● Rankine Cycle, Waste Heat Recovery Engine Performance Model: THERMO ELECTRON CORP.	W-0003-74 pp. 3-255
		● DRC Modeling (Rankine Bottoming Cycle Engines): MECHANICAL TECHNOLOGIES, INC.	W-0004-70 pp. 3-259
		● Brayton Bottoming Systems Evaluation: HSD & UTRC	W-0005-70 pp. 3-261
		● Rankine Bottoming Cycle Performance Code: ARGONNE NATIONAL LAB	W-0006-70 pp. 3-263

TABLE 2.1 (Continued)

APPLICATION	SCOPE	MODELS	ACCESS NO./ PAGE NO.
Turbocharging	⊕ Model turbocharges either alone or as part of an engine system ⊕ Simplified nozzle/orifice representation of turbine and compressor ⊕ Simplified nozzle/orifice losses included	⊕ Turbocharged Diesel Engine Simulation to Predict Steady State and Transient Performance CUMMINS ENGINE CO.	E-0018-TC-77 pp. 3-267
		⊕ Prediction and Measurement of Two-Stroke Cycle Diesel Engine Performance and Smoke at Altitude DETROIT DIESEL ALLISON	E-0019-TC-77 pp. 3-271
		⊕ A Real Time Analogue Computer Simulation of a Turbocharged Diesel Engine UNIVERSITY OF MANCHESTER	E-0035-TC-75 pp. 3-275
		⊕ A Dynamic Simulation of a Two-Stroke Turbocharged Diesel Engine: DETROIT DIESEL ALLISON	E-0036-TC-81 pp. 3-279
		⊕ A Non-Linear Digital Simulation of Turbocharged Diesel Engine Under Transient Conditions: IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY	E-0051-TC-76 pp. 3-283

TABLE 2.2: MODEL CROSSREFERENCE BY TRANSPORTATION MODE

HIGHWAY	RAIL	MARINE	PIPELINE
● Computer Simulation of a Diesel Engine: I.I.T. DELHI. pp. 3-109	● Computer Programs to Determine the Relationship Between Pressure Flow, Heat Release, and Thermal Load in Diesel Engines: M.A.N. pp. 3-195	● Development of P.C. Engine Simulation Program: NIPPON KOKAN pp. 3-243	
● Simulation of a Turbocharged Diesel Engine to Predict The Transient Response: JOHN DEERE pp. 3-249			
● Divided-Chamber Diesel Engine Model: MIT pp. 3-119			
● Cummins CUMMINS ENGINE CO. pp. 3-131			

TABLE 2.2 (Continued)

HIGHWAY	RAIL	MARINE	PIPELINE
⊕ Ultrasystems Diesel Emissions Model: ULTRASYSTEMS, INC. pp. 3-135			
⊕ Hiroshima: UNIVERSITY OF HIROSHIMA pp. 3-139			
⊕ NREC Diesel Emissions Model: NREC pp. 3-143			
⊕ Prediction of the Exchange Processes in a Single Cylinder Internal Combustion Engine: VARIOUS UNIVERSITIES pp. 3-201			
⊕ Computer Aided Design of the Exhaust of a Turbocharged Diesel Engine: UNIVERSITY OF MANCHESTER pp. 3-209			

TABLE 2.2 (Continued)

HIGHWAY	RAIL	MARINE	PIPELINE
● Turbocharged Diesel Engine Simulation to Predict Steady-State and Transient Performance: CUMMINS ENGINE CO. pp. 3-267		● PROCES: NORWEGIAN INSTITUTE OF TECHNOLOGY pp. 3-193	
● Prediction and Measurement of Two-Stroke Cycle Diesel Engine Performance and Smoke at Altitude: DETROIT DIESEL ALLISON pp. 3-271		● Application Engineering Techniques Related to High Performance, Medium Speed Diesel Engines: MIRRLEES, BLACKSTONE, LTD. pp. 3-239	
● Hybrid (Analog) Computer Simulation of the Sampled-Data Model for Compression Ignition Engines: UNIVERSITY OF SUSSEX pp. 3-177			
● Computer Aided Design Package for Engine Manifold Systems: UMIST pp. 3-209			

TABLE 2.2 (Continued)

HIGHWAY	RAIL	MARINE	PIPELINE
● C.A.V. Diesel Emissions Model: C.A.V. LTD. PP. 3-147			
● Imperial College Diesel Spray Model IMPERIAL COLLEGE PP. 3-165			
● Wisconsin Diesel Spray Combination Model: UNIVERSITY OF WISCONSIN PP. 3-101			
● Hitachi Model: HITACHI SHIPBUILDING, LTD. PP. 3-83			
● A Real Time Analogue Computer Simulation of a Turbocharged Diesel Engine: UNIVERSITY OF MANCHESTER PP. 3-275		● A Real Time Analogue Computer Simulation of a Turbocharged Diesel Engine: UNIVERSITY OF MANCHESTER PP. 3-275	

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TABLE 2.2 (Continued)

HIGHWAY	RAIL	MARINE	PIPELINE
• University of Manchester UMIST pp. 3-87			
• A Dynamic Simulation of a Two-Stroke Turbocharged Diesel Engine: UMIST pp. 3-279		• Computer Program to Predict the Gas Exchange Process of a Diesel Engine: RUSTON PAXMAN DIESEL STD. pp. 3-219	
• Diesel Fuel Injection System Simulation and Experimental Correlation: UNIVERSITY OF MICHIGAN pp. 3-179		• Characteristics of Exhaust Gas Pulsation of Constant Pressure Turbocharged Diesel Engines: KAWASAKI HEAVY IND. pp. 3-217	• Title unknown: NATIONAL RESEARCH COUNCIL OF CANADA pp. 3-235
• Komatsu "DSA/DEC" KOMATSU/MIT pp. 3-125			
• Manchester (Whitehouse) UMIST pp. 3-91			

TABLE 2.2 (Continued)

HIGHWAY	RAIL	MARINE	PIPELINE
⊕ A Combustion Correlation for Diesel Engine Simulation: IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY pp. 3-233		⊕ USCG Icebreaker Propulsion System Simulation, Prog. No. ENE-11: USCG HEADQUARTERS pp. 3-41	
⊕ A Generalized Computer Aided Design Package for I.C. Engine Manifold Systems: UMIST pp. 2-213			
⊕ Simulation of Processes of Fuel Injection (INJEC): KYOTO UNIVERSITY pp. 3-185			
⊕ Characterization and Simulation of a Unit Injector: WAYNE STATE UNIVERSITY pp. 3-187	⊕ Train Performance Calculator: AIRESEARCH MNFG.CO. pp. 3-81	⊕ Characterization and Simulation of a Unit Injector: WAYNE STATE UNIVERSITY pp. 3-187	

TABLE 2.2 (Continued)

HIGHWAY	RAIL	MARINE	PIPELINE
⊛ A Non-Linear Digital Simulation of Turbocharged Diesel Engines Under Transit Conditions: IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY PP. 3-283	←		
⊛ Breathing Cycle of the Four-Stroke Automotive Engine: USDOT/TSC PP. 3-225	←		
⊛ Wholly Dynamic Model of a Turbocharged Diesel Engine for Transfer Function Evaluation: UMIST PP. 3-245	←		
⊛ M.A.N. MAN AUGSBURG PP. 3-115	←		

TABLE 2.2 (Continued)

HIGHWAY	RAIL	MARINE	PIPELINE
● HEVSIM: USDOT PP. 3-5	● TPS: USDOT/TSC PP. 3-55	● A Method of Predicting the Speed Reduction of Turbocharged Marine Diesel Engines: UNIVERSITY OF HANNOVER PP. 3-43	
● TCAPE: INTERNATIONAL HARVESTERS PP. 3-17	● FUEL: EMERSON CONSULTANTS PP. 3-61	● Analysis of Shipboard Energy Systems: PFR ENGINEERING SYSTEMS PP. 3-47	
● A Simplified Program for Evaluating Diesel Truck Performance: UNITED TECHNOLOGIES RESEARCH CENTER PP. 3-31	● Freight Train Fuel Consumption Program: MITRE PP. 3-63	● Systematic Design of Marine Propulsion Systems: UNIVERSITY OF NEWCASTLE PP. 3-49	
● Imperial College (WATSON): IMPERIAL COLLEGE PP. 3-105			
● Cranfield Model: CRANFIELD INSTITUTE OF TECHNOLOGY PP. 3-151			

TABLE 2.2 (Continued)

HIGHWAY	RAIL	MARINE	PIPELINE
⊚ TRUKSIM: INTERNATIONAL HARVESTERS PP. 3-35	⊚ The Transportation Energy Model: CARNEGIE-MELLON PP. 3-67	⊚ Selection and Simulation of Marine Propulsion Control Systems: LIPS, NV, DRUNEN, HOLLAND PP. 3-51	
⊚ BAP: FOSTER-MILLER PP. 3-251	⊚ TPC: EE/CS DEPARTMENT OF UNION COLLEGE PP. 3-71	⊚ Computer Aided Marine Power Plant Selection: MIT PP. 3-53	
⊚ Rankine Cycle Waste Heat Recovery Engine Performance Model: THERMO ELECTRON CORP. PP. 3-255	⊚ TOS: SOUTHERN PACIFIC TRANS.CO. PP. 3-75		
	⊚ Train Performance Calculator: PP. 3-79		
⊚ A Computer Model of the Electronic Control System (ECS) for Diesel Fuel Injection Timing: UNIVERSITY OF MINN. PP. 3-189			

TABLE 2.2 (Continued)

HIGHWAY	RAIL	MARINE	PIPELINE
● The Problem of Predicting Rate of Heat Release in Diesel Engines LTD. pp. 3-97	→————————————————————————————————————→
● Los Alamos Direct-Injection Engine Model: LOS ALAMOS/GM RESEARCH LAB pp. 3-171	→————————————————————————————————————→
● Princeton Internal Combustion Engine Model: PRINCETON UNIVERSITY pp. 3-159	→————————————————————————————————————→
● Mirrlees Heat Transfer Program, DIESHT: MIRRLEES BLACKSTONE LTD. pp. 3-197	→————————————————————————————————————→
● Livermore Fuel Spray Model: LAWRENCE LIVERMORE LAB. pp. 3-155	→————————————————————————————————————→

TABLE 2.2 (Continued)

HIGHWAY	RAIL	MARINE	PIPELINE
● GPSIM: GENERAL MOTORS PP. 3-1		● Applied Computer Simulation in Marine Engineering-Clutch Maneuvering Assessment: Y-ARD LTD. PP. 3-45	
● Dynamic Model: FORD MOTOR CO. PP. 3-9			
● TOFEP: FORD MOTOR CO. PP. 3-11			
● ASIM: USDOT/TSC PP. 3-13		● DRC Modeling (Rankine Bottoming Cycle Engines): MECHANICAL TECHNOLOGIES, INC. PP. 3-259	
● VMS: CUMMINS ENGINE CO. PP. 3-15			
● TSO: GENERAL MOTORS RESEARCH LAB PP. 3-25			
● HEAVY: BOEING COMPUTER PP. 3-21			

TABLE 2.2 (Continued)

HIGHWAY	RAIL	MARINE	PIPELINE
⊛ Diesel Urban Bus Simulation Program: USDOT/TSC PP. 3-27			
⊛ DSLSIM: MIT PP. 3-29			
⊛ Brayton Bottoming System Evaluation: UTRC & HSD PP. 3-261	→————————————————————————→		
⊛ Development of a Real-Time Digital Computer Simulation of a Turbocharged Diesel Engine: PAKISTAN STATEOIL CO. PP. 3-229	→————————————————————————→		

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TABLE 2.3.1.1: HIGHWAY VEHICLE MODELS

ACCESS NO.	MODEL NAME	ORGANIZATION	AUTHOR(S)	APPLICATION
H-0002-77 pp. 3-5	Heavy Vehicle Simulation (HEVSIM)	U.S. Department of Transportation	E. Withjack S. Moffat A. Malliaris	o Civilian o Simulation of fuel economy over a given driving schedule
H-0010-78 pp. 3-17	Truck Computer Analysis of Performance and Economy (TCAPE)	International Harvester Group (IH)	Many	o Military and civilian o Sales promotion of IH trucks
H-0024-80 pp. 3-31	A Simplified Program for Evaluating Diesel Truck Performance	United Technologies Research Center	L.E. Greenwald	o Civilian, but applicable to military o To aid in the processes of driveline selection, engine sizing and parametric evaluation of driving cycle economy
H-0025-81 pp. 3-35	TRUKSIM	International Harvester Group (IH)	P. L. , et al.	o Military and civilian o Internal engineering analysis and development

ADVANTAGES	AVAILABILITY	HARDWARE	COST OF OPERATION	VALIDATION	DOCUMENTATION
o Flexibility in I/O parameters	Yes – no charge	DEC 10, DEC 20, IBM	$25	Not stated	Extensive
o Easy to use as a sales promotion tool	o Not available outside IH o Customer access is available at no charge	DEC	Proprietary	Yes	Yes
o Easy to use o Simple input o Rapid turnaround o Graphical output	Yes; cost is user application dependent	Univac 1100/81A	3 sec/run	Currently underway	None
o Extremely flexible	o Proprietary	IBM or DEC	Proprietary	Yes	Proprietary

ACCESS NO.	MODEL NAME	ORGANIZATION	AUTHOR(S)	APPLICATION
H-0001-72 pp. 3-1	General Purpose Automobile Vehicle Performance and Economy Simulator (GPSIM)	General Motors Corporation	William C. Waters	o Civilian o Computes operating conditions of the engine, transmission and vehicle performance and economy
H-0003-81 pp. 3-9	Dynamic Model	Ford Company	Delosh; Brewer; Bush; Ferguson; Tobler	o Civilian o Simulates the dynamic behavior of the total vehicle system
H-0004-81 pp. 3-11	Testing Operations Fuel Economy Program (TOPEP)	Ford Motor Co.	Not stated	o Civilian o Evaluation of fuel and performance effects of power train changes
H-0005-78 pp. 3-13	Automotive Simulator (ASIM)	USDOT/TSC	E. M. Withjack	o Civilian o A tool for automotive fuel economy evaluation
H-0012-81 pp. 3-21	Hybrid & Electric Advanced Vehicle Systems (HEAVY) Simulation	Boeing Computer Services Co.	Hammond; McGehee	o Civilian o Evaluates electric and hybrid vehicle propulsion systems

ADVANTAGES	AVAILABILITY	HARDWARE	COST OF OPERATION	VALIDATION	DOCUMENTATION
o Can simulate a large variety of vehicles	Proprietary	IBM 360/65	Depends on type and degree of simulation	Limited	Yes
o Useful for design and analysis of electronic engine control systems	Proprietary, but possibly available	DEC 2050	9 sec of computer time for 1 second of vehicle system operation	Yes	Extensive
o Useful in all phases of power-train optimization	Proprietary	Honeywell or DEC	Less than 1 minute cpu	Some	Some
o Rapid execution o Easy operation	Yes	Not stated	Not stated	Not stated	Some
o Simple to use o Built in system components, description and operational descriptions	Yes	CDC Cybder	Minimal (Approximately $1 per run)	Some	Extensive

ACCESS NO.	MODEL NAME	ORGANIZATION	AUTHOR(S)	APPLICATION
H-0009-76 pp. 3-15	Vehicle Mission Simulation (VMS)	Cummins Engine Co.	D.A. Klokkenga	o Civilian o Provides truck performance information
H-0013-78 pp. 3-25	Transient System Optimization (TSO)	General Motors Research Laboratory	Alan Dohner	o Civilian o Optimization of fuel economy by accounting for various phenomena
H-0018-79 pp. 3-27	Diesel Urban Bus Simulation Program	USDOT/TSC	G. Larson; H. Zuckerberg	o Civilian o Assesses the performance and fuel consumption of buses under various operating conditions
H-0023- pp. 3-29	DSLSIM (Diesel Engine Control Systems Computer Simulation Model)	Massachusetts Institute of Technology; Department of Mechanical Engineering	D. Wormley; J. Nye; J. Rife	o Civilian o Defines control system configurations o Identifies performance characteristics

ADVANTAGES	AVAILABILITY	HARDWARE	COST OF OPERATION	VALIDATION	DOCUMENTATION
o Can be used by truck operators to choose options for particular routes	Proprietary	Honeywell DPS/8 CP/6	Less than 10 minutes cpu time needed/run	Yes	Yes
o Considers transient system operation o Can utilize test data	Proprietary	Not stated	Not stated	Some	Some
o Straightforward	Yes	Graphic output available Model 663 Calcony Plotter	Not stated	Good	Some
o Output available in different representations	Proprietary	VAX	Not stated	Some	None

TABLE 2.3.1.2: MARINE MODELS

ACCESS NO.	MODEL NAME	ORGANIZATION	AUTHOR(S)	APPLICATION	ADVANTAGES
M-0001-68 pp. 3-41	USCG Icebreaker Propulsion System Simulation, Program No. ENE-11	U.S. Coast Guard Headquarters, Office of Engineering, Icebreaker Design Branch	Lt. J. W. Lewis, LCDR Lecourt P. W. Scoville	o Military and Civilian o Icebreakers o Ice-Strengthened Cargo and Service Ships	o A wide variety of diesel-electric systems can be simulated
M-0002 pp. 3-43	A Method of Predicting the Speed Reduction of Turbocharged Marine Diesel Engines	University of Hannover	M. Grohn, Prof. Dr. Groth	o Military and Civilian o Medium Speed, 4-Cycle, marine diesels loaded by a fixed propeller	o As a design tool
M-0004-81 pp. 3-45	Applied Computer Simulation in Marine Engineering Clutch Manoeuvering Assessment	Y-ARD Ltd., Glasgow	K. W. McTavish	o Military and Civilian o Design evaluation for a CODOG Ship with controllable pitch propellers	o Different component characteristics can be inverted
M-0006-78 pp. 3-47	Analysis of Shipboard Energy Systems	PFR Engineering Systems	J. Puke; T. Rozenman; J. Pundyk	o Military and Civilian o Fuel consumption rate comparisons	o Permits substitution of reporting arrangements and profiles

AVAILABILITY	HARDWARE	COST OF OPERATION	VALIDATION	DOCUMENTATION
o Yes	IBM 1130	Proportional to length of maneuver and time steps used	Yes	Yes
o Yes	Not stated	Not stated	Yes	Yes
o Proprietary	Not given	Not stated	Some	Some
o Yes	Not given	Not given	Some	Some

TABLE 2.3.1.2: MARINE MODELS

ACCESS NO.	MODEL NAME	ORGANIZATION	AUTHOR(S)	APPLICATION	ADVANTAGES
M-0007 pp. 3-49	Systematic Design of Marine Population System	University of Newcastle	R. V. Thompson	o Military and Civilian o Comparison of alternative arrangements for a specialized mine sweeping with distinct operating modes	o A wide variety of systems can be simulated
M-0008-70 pp. 3-51	Selection and Simulation of Marine Propulsion Control Systems	Lips, N. V., Drunen, Holland	C. Pronk	o Military and Civilian o Diesel engines driving marine controllable pitch propellers	o Provides performance predictions during the design phase of main propulsion systems
M-0009-73 pp. 3-53	Computer Aided Marine Power Plant Selection	MIT	R. I. Newton	o Military and Civilian o Merchant Type Ships	o Simplicity o Approach is with ship as a whole

AVAILABILITY	HARDWARE	COST OF OPERATION	VALIDATION	DOCUMENTATION
o Proprietary	Not given	Not given	Some	Some
o Proprietary	IBM 1130	Not given	No	Yes
o Proprietary	IBM 370/165	Not given	Yes	Yes

TABLE 2.3.1.3: RAIL MODELS

ACCESS NO.	MODEL NAME	ORGANIZATION	AUTHOR(S)	APPLICATION	ADVANTAGES
L-0002-78 pp. 3-55	The US DOT/TSC Train Performance Simulator (TPS)	DOT/TSC	M.E. Hazel	o Civilian o Simulation of train over a railroad route	o Useful for planning train operations over a particular route o Simple to use o Modifications easy
L-0005-81 pp. 3-63	Freight train Fuel Consumption Program	MITRE	J. D. Muhlenberg	o Civilian o Calculation of fuel consumption of a freight train	o Incorporates information on most commonly used railcars and locos o Easy to use and modify
L-0009-77 pp. 3-67	The Transportation Energy Model, Carnegie-Mellon	Carnegie-Mellon University	S.N. Talukdar and R.A. Uher	o Civilian o Prediction of energy consumption for diesel and electric powered trains	o Detailed modeling capabilities o Flexibility in modifying parts of program

AVAILABILITY	HARDWARE	COST OF OPERATION	VALIDATION	DOCUMENTATION
Yes (\$150 fee)	DEC 10 & IBM	Typical, \$20	Extensive	Yes
Yes (cost of production)	IBM 370	100 cpu for a 100 gallon simulation	Yes	Extensive
Yes (\$625 fee)	DEC 20, VAX	15 cpu sec for 50 mile run	Yes	Extensive

ACCESS NO.	MODEL NAME	ORGANIZATIONS	AUTHOR(S)	APPLICATION	ADVANTAGES
L-0010-78 pp. 3-71	A Multi-Purpose Train Performance Calculator (TPC)	EE/CS Dept. Union College	R. Mittal and A. Rose	o Civilian o Simulation of passenger train operation	o Written specifically to simulate a limited case of passenger train operation
L-0011-83 pp. 3-75	Train Operations Simulator (TOS)	Southern Pacific Transportation Co.	N. W. Lutterlle	o Civilian o Performance simulation of diesel-electric loco and conventional freight car	o Simulates various methods of train handling and its effects on fuel consumption
L-0012-65 pp. 3-79	Train Performance Calculator -AAR	Association of American Railroads (AAR)	Operated by Stuart and McEwan	o Civilian o Prediction of energy usage	o Performs operations quickly
L-0013-79 pp. 3-81	Train Performance Calculator	AiResearch and Manufacturing Co. of California	J.J. Lawson & L. M. Cook	o Civilian o Performs train performance calculations	o Provides very detailed analysis o Can simulate diesel, electric or mixed-mode operations

AVAILABILITY	HARDWARE	COST OF OPERATION	VALIDATION	DOCUMENTATION
Yes ($150 fee)	Burroughs B-6700 DEC 10		Train scheduling-- Yes Fuel Use - No	Yes
Yes ($50 fee)	IBM, DEC-20, Prime, Burr	12 cpu sec per 1 mile of calc.	Fuel calculations hand checked	Extensive
Yes (cost of production)	CDC 3500, IBM 370, DEC-20	1 cpu minute per 10 miles	No information available	Yes
Proprietary	Univac 1108		Yes	Some

ACCESS NO.	MODEL NAME	ORGANIZATION	AUTHOR(S)	APPLICATION	ADVANTAGES
L-0004-75 pp. 3-61	Fuel Utilized Effective Locomotives (FUEL)	Emerson Consultants, Inc.	J. N. Cetinich	o Civilian o Investigation of the effect of train operating strategies	Provides overview of effects of train operating strategies on a territory

AVAILABILITY	HARDWARE	COST OF OPERATION	VALIDATION	DOCUMENTATION
Note stated	Not stated	Not stated	Yes	Some

TABLE 2.3.2.1: MODELS THAT MATCH THE INTAKE/EXHAUST SYSTEM TO THE ENGINE

ACCESS NO.	MODEL NAME	ORGANIZATION	AUTHOR(S)	APPLICATION	ADVANTAGES
E-0034-72 pp. 3-83	Hitachi Model	Hitachi Shipbuilding, Ltd., Osaka	K. Mizushima, M. Nagai, T. Asada	o Civilian and government o Matching intake/ exhaust system to the engine	o Covers entire cycle o Predicts cylinder pressure accurately
E-0036-81 pp. 3-87	University of Manchester (UMIST)	University of Manchester	Winterbone, Loo, Benson, Wellstead, Thiruarooran	o Civilian and government o Matching intake/ exhaust system to the engine	o Particularly useful for detailed design of turbochargers

AVAILABILITY	HARDWARE	COST OF OPERATION	VALIDATION	DOCUMENTATION
Probably Proprietary	Not stated	$120-$200/run (estimate)	Yes	Yes
From UMIST, at cost	Not stated	$240-$400/run (estimated)	Some	Yes

TABLE 2.3.2.2: FUEL EFFICIENCY MODELS

ACCESS NO.	MODEL NAME	ORGANIZATION	AUTHOR(S)	APPLICATION	ADVANTAGES
E-0070-74 pp. 3-115	M.A.N.	M.A.N. Augsburg and Institut fur Kolbenmaschinen Technical University	G. Woschni F. Anisits	o Civilian and government o Efficiency or fuel consumption	o Simple to use
E-0004-77 pp. 3-91	Manchester (Whitehouse)	UMIST	Whitehouse, Way, Sareen, Clough, Abughres, Baluswamy	o Civilian or military o Efficiency or fuel consumption	o Simple o Inexpensive
E-0044-80 pp. 3-105	Imperial College (Watson)	Imperial College	N. Watson M. Marzouk	o Civilian and military o Efficiency or fuel consumption	o Inexpensive to run o Useful for extending known engine performance

AVAILABILITY	HARDWARE	COST OF OPERATION	VALIDATION	DOCUMENTATION
Yes	Not stated	$12-$20 run (estimate)	Yes	Yes
Unknown	Not specified	$60-$100/run	Some	Extensive
Unknown	Not specified	$30-$50/run	Yes	Yes

TABLE 2.3.2.2 (Continued)

ACCESS NO.	MODEL NAME	ORGANIZATION	AUTHOR(S)	APPLICATION	ADVANTAGES
E-0005-70 pp. 3-97	The Problem of Predicting Rate of Heat Release in Diesel Engines	C.A.V. Ltd. -England	H.C. Grigg & M.H. Syed	o Civilian o Fuel consumption	
E-0032-69 pp. 3-101	Wisconsin Diesel Spray Combustion Model	University of Wisconsin	Shipinski, Myers, and Uyehara	o Civilian and military o Fuel consumption	o Covers, the effect of fuel injection o Emphasizes physical mechanisms
E-0063-76 pp. 3-109	Computer Simulation of a Diesel Engine: I.I.T., DELHI	I.I.T., DELHI	R. D. Garg K.K. Agarwal R. Desikachari	o Military or civilian o Fuel consumption	o Simple to use o Inexpensive

AVAILABILITY	HARDWARE	COST OF OPERATION	VALIDATION	DOCUMENTATION
Not stated	Not stated	Not stated	Not stated	Some
Yes	Not stated	$30-50/run	Fair	Yes
Yes	Not stated	$60-$100/run	Fair	Yes

TABLE 2.3.2.3: EMISSION MODELS

ACCESS NO.	MODEL NAME	ORGANIZATION	AUTHOR(S)	APPLICATION	ADVANTAGES
E-0001-81 pp. 3-119	Divided Chamber Diesel Engine Model	Massachusetts Institute of Technology	S.H. Mansouri; J. B. Heywood; K. Radhakrishnan	o Civilian o Emissions	o Requires little computer time to run, therefore engine maps can be easily developed
E-0003-78 pp. 3-131	Cummins	Cummins Engine Company	S. M. Shahed, P. F. Flynn, W. T. Lyn, and W. S. Chin	o Military or Civilian o Emissions	o Allows for temperature gradient
E-0007-76 pp. 3-139	Hiroshima	University of Hiroshima	H. Horowasu and T. Kadota	o Military and civilian o Emissions	o Cost effective o Predicts effects to changes in fuel injector

AVAILABILITY	HARDWARE	COST OF OPERATION	VALIDATION	DOCUMENTATION
Proprietary	IBM370	$20 per run	Yes	Some
Unknown	Xerox Sigma 9	$60-$100/run	Some -- needs further work	Yes
Not stated	Not stated	Not stated	Some	Yes

TABLE 2.3.2.3 (Continued)

ACCESS NO.	MODEL NAME	ORGANIZATION	AUTHOR(S)	APPLICATION	ADVANTAGES
E-0008-71 pp. 3-143	NREC Diesel Emissions Model	Northern Research and Engineering Corporation	Bastress, Chng, and Dix	o Military and civilian o Emissions	o Simplicity
E-0071-75 pp. 3-151	Cranfield Model	Cranfield Institute of Technology	P. Hodgetts, H. D. Shroff, I. R. Isaac	o Civilian and Military o Emissions	o Treats fuel-air ratio and temperature gradients
E-0026-73 pp. 3-147	C.A.V. Diesel Emissions Model	C.A.V. Ltd., Acton, London	Khan, Greeves, Probert, Grigg, and Syed	o Civilian and military o Emissions	o Handles soot formation, fuel injection parameters and air swirl level

AVAILABILITY	HARDWARE	COST OF OPERATION	VALIDATION	DOCUMENTATION
From NREC (Cost in 1974 was $100)	CDC; IBM	$10-$20/run	Some	Some
Through inter-national technology exchange	Not specified	$30-$50/run	Yes	Extensive
Probably	Not stated	$60-$100/run	Adequate for design	Extensive

TABLE 2.3.2.3 (Continued)

ACCESS NO.	MODEL NAME	ORGANIZATION	AUTHOR(S)	APPLICATION	ADVANTAGES
E-0002-78 pp. 3-125	Komatsu "DSA/DCE"	Komatsu/ MIT	H. Hiraki, J. M. Rife	o Civilian, Military o Emissions	o Models cylinder heat transfer to coolant o Turbocharged calculation is included o Effect of fuel spray design parameters included
E-0006-64 pp. 3-135	Ultrasystems Diesel Emissions Model	Ultrasystems, Inc.	C. J. Kau, R. P. Wilson, L. J. Muzio, C. H. Waldman, M. P. Heap, T. J. Tyson	o Military or civilian o Emissions	o Can model fuel injection pressure orifice size, and air swirl

AVAILABILITY	HARDWARE	COST OF OPERATION	VALIDATION	DOCUMENTATION
Unknown	Not specified	$120-$200/run (estimated)	Yes	Extensive
Yes	CDC 6600	$180-$300/run	Yes	Extensive

TABLE 2.3.2.4: COMBUSTION CHAMBER SHAPE MODELS

ACCESS NO.	MODEL NAME	ORGANIZATION	AUTHOR(S)	APPLICATION	ADVANTAGES
E-0072-78 pp. 3-171	Los Alamos Direct-Injection Engine Model	Los Alamos/ General Motors Research Laboratory	T. D. Butler, L. D. Cloutman, R. B. Krieger, et. al.	o Civilian and military o Development of combustion chamber shape	o Can predict flow field, spatial flame propagation, spatial temperature profiles and locations of peak NO_x formation
E-0010-77 pp. 3-159	Princeton Internal Combustion Engine Model	Princeton University	F. V. Bracco, H. C. Gupta, P. J. O'Rourke	o Civilian and military o Development of combustion chamber shape	o Detailed description of spray crag and evaporation
E-0029-80 pp. 3-165	Imperial College, Diesel Spray Model	Imperial College	Gosman and Johns	o Civilian and military o Combustion chamber shape	o Describes the spatial distribution of the diesel spray
E-0009-78 pp. 3-155	Livermore Fuel Spray Model	Lawrence Livermore Lab	L. C. Haselman C. w. Westbrook	o Civilian or military o Combustion chamber shape	o Treats chamber shape effects o Models unsteady, effects of spray penetration

AVAILABILITY	HARDWARE	COST OF OPERATION	VALIDATION	DOCUMENTATION
Yes	Not stated	$600-$6000/run (estimated)	Yes	Extensive
Yes	IBM 360/91	Without spray: $120-180/run with spray: up to $5000/run	No	Extensive
On a contract basis	Not stated	$600-$1000/run	Some	Yes
Yes	CDC7600	$5,000-$6,000/run	Some	Extensive

TABLE 2.3.2.5: FUEL INJECTION SYSTEM MODELS

ACCESS NO.	MODEL NAME	ORGANIZATION	AUTHOR(S)	APPLICATION	ADVANTAGES
E-0039-FI-73 pp. 3-179	Diesel Fuel Injection System Simulation and Experimental Correlation	University of Michigan	Bolt, El-Erian, Wylie	o Military and civilian o Fuel injection	o Good accuracy and economy
E-0048-FI pp. 3-185	Simulation of Processes of Fuel Injection (INJEC)	Kyoto University	M. Ikegami H. Horike F. Nagao	o Military and civilian o Fuel injection	o Reduced computing time
E-0049-FI-75 pp. 3-187	Characterization and Simulation of a Unit Injector	Wayne State University	N.A. Henein T. Singh J. Rozanski	o Military and civilian o Simulation of fuel pressure histories	o Simple
E-0069-FI-82 pp. 3-189	Computer Model of the Electronic Control System (ECS) for Diesel Fuel Injection Timing	University of Minnesota	M. J. Pipho D. B. Kittelson	o Military and civilian o Performance simulation	o Provides complete engine response to an optimization control system
E-0021-FI-70 pp. 3-177	Hybrid (Analog) Computer Simulation of the Sampled-Data Model for Compression Ignition Engines	University of Sussex	C. R. Burrows, P.W. VanEctrelt, G. P. Windett	o Military or civilian o Fuel injection	Simple of use

AVAILABILITY	HARDWARE	COST OF OPERATION	VALIDATION	DOCUMENTATION
From the EPA	Not stated	Not stated	Yes	Yes
From Kyoto University	FACOM 230-60	12 seconds/ iteration (5 iterations/ run)	Some	Some
Yes	Not stated	Low	Some	Some
No	Not stated	Not st. d	Some	Yes
Yes	Not stated	Not stated	Poor to fair	Some

TABLE 2.3.2.6: HEAT TRANSFER MODELS

ACCESS NO.	MODEL NAME	ORGANIZATION	AUTHOR(S)	APPLICATION
E-0023-HT-75 pp. 3-193	PROCES	Norweigian Institute of Technology	H. Valland	o Military and civilian o Heat transfer
E-0067-HT-64 pp. 3-195	Computer Programs to Determine the Relationship Between Pressure Flow, Heat Release and Thermal Load in Diesel Engines	MAN	Gerhard Woschini	o Military and civilian o To determine the relationships between pressure flow, heat release and thermal load
E-0073-HT-83 pp. 3-197	Mirrlees Heat Transfer Program DIESHT	Mirrlees Blackstone Ltd.	R. T. Green K. Jambunathan, S. D. Probert	o Civilian and military o Heat transfer

ADVANTAGES	AVAILABILITY	HARDWARE	COST OF OPERATION	VALIDATION	DOCUMENTATION
o Seemingly simple to use	Yes	Not stated	Not stated	Not stated	Little
o Heat transfer through each of the major components is done separately	Yes - Refer to SAE paper	IBM 1060	8 Minutes of machine time/run	No	Some
o Easily used by designers	Yes, with permission of Mirrlees Blackstone	Not stated	$5-$20/run	Yes	Extensive

TABLE 2.3.2.7: INTAKE/EXHAUST SYSTFM MODELS

ACCESS NO.	MODEL NAME	ORGANIZATION	AUTHOR(S)	APPLICATION
E-0015-IE-74 pp. 3-205	Computer Aided Design of the Exhaust of Turbocharged Diesel Engine	University of Manchester	J. D. Ledger	o Military or civilian o Intake and exhaust system
E-022-IE-80 pp. 3-209	Computer Aided Design Package for Engine Manifold System	University of Manchester, Institute of Science and Technology	S. C. Low, R. S. Benson, D. E. Winterbone	o Civilian o Intake and exhaust systems
E-0014-IE-78 pp. 3-201	Prediction of the Exchange Processes in a Single Cylinder Internal Combustion Engine	Various universities	P.A. Lakshmi- narayanan P.A. Jr.akiraman M.K. Gajendra Sabu B.S. Murthy	o Military and civilian o To model gas flow
F-0043-IE-80 pp. 3-213	A Generalized Computer Aided Design Package for I.C. Engine Manifold System	University of Manchester Institute of Science & Technology (UMIST)	S.C. Low P.C. Baruah	o Military and civilian o Performance prediction of manifolding systems

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ADVANTAGES	AVAILABILITY	HARDWARE	COST OF OPERATION	VALIDATION	DOCUMENTATION
o Rapid turnaround o Graphical display	Yes	DEC-PDP10	Not stated	None reported	Yes

o Rapid data changes
  possible
o Relatively simple
  to use
	Probably	CDC Cyber 72;
		DEC;
		Tectronics 4010
			Not stated	Yes	Some

o Accuracy	Not stated	Not stated	Not stated	Some	Some

o Minimal input
  data needed
o Interactive
o Throttled and
  unthrottled
	From UMIST	Not stated	Not stated	No	Some

ACCESS NO.	MODEL NAME	ORGANIZATION	AUTHOR(S)	APPLICATION	ADVANTAGES
E-0053-IE-79 pp. 3-217	Characteristics of Exhaust Gas Pulsation of Constant Pressure Turbocharged Diesel Engines	Kawasaki Heavy Industries	T. Azuma Y. Tokunaga T. Yura	o Military and civilian o Clarify characteristics of exhaust and gas pulsations	o Unique (first to model exhaust pulsations and gas flow interactions)
E-0055-IE-74 pp. 3-219	Computer Program to Predict the Gas Exchange Process of a Diesel Engine	Ruxton Paxman Diesel Standard	A. J. Hallam S. Cottam	o Military and civilian o Intake and exhaust	o Flexible and user friendly
E-0056-IE-79 pp. 3-225	Breathing Cycle of the Four-Stroke Automotive Engine	U.S. Department of Transportation/ Transportation Systems Center	T. J. Trella	o Military and civilian o Model the intake system of a four-stroke open chamber engine	o Novel approach to gas flow calculations

AVAILABILITY	HARDWARE	COST OF OPERATION	VALIDATION	DOCUMENTATION
No	Not av.	Not stated	Yes	Some
Proprietary	Not stated	Not stated	Yes	Some
US DOT/TSC	DEC 10	Not stated	Yes	Some

TABLF 2.3.2.8:   OPERATING PERFORMANCE MODELS

ACCESS NO.	MODEL NAME	ORGANIZATION	AUTHOR(S)	APPLICATION
E-0013-OP-79 pp. 3-229	Development of a Real-Time Digital Computer Simulation of a Turbocharged Diesel Engine	Pakistan State Oil Company Ltd.	S. S. Shamsi	o Military and Civilian o Model response of a turbocharged diesel engine
F-0044-OP-79 pp. 3-233	A Combustion Correlation for Diesel Engine Simulation	Imperial College of Science and Technology	N. Watson A. D. Pilley M. Marzouk	o Military and civilian o To provide a means of increasing accuracy of engine models which do not incorporate combustion models
E-0061-OP-74 pp. 3-243	Development of P.C. Engine Simulation Program	Nippon Kokan	K. Shiraishi, K. Murakami; M. Mizushima T. Nakayama	o Military and civilian o To model a test engine to make performance predictions

ADVANTAGES	AVAILABILITY	HARDWARE	COST OF OPERATION	VALIDATION	DOCUMENTATION
o It is the only digital engine response model available	Unknown	PDP10	o Considered "economical"	Some	Some
o Can be used to expand the accuracy of other models	Yes	Not stated	Not Stated	Some	Some
~	Unlikely	Not stated	Not stated	Yes	Some

ACCESS NO.	MODEL NAME	ORGANIZATION	AUTHOR(S)	APPLICATION
E-0062-OP-76 pp. 3-245	Wholly Dynamic Model of a Turbocharged Diesel Engine for Transfer Function Evaluation	University of Manchester, Institute of Science and Technology (UMIST)	Winterbone, Thiruarooran Wellstead	o Military and civilian o To describe engine response
E-0068-OP-77 pp. 3-249	Simulation of a Turbocharged Diesel Engine to Predict the Transfer Response	John Deere	M. R. Goyal	o Military and civilian o To predict engine performance
E-0059-OP-75 pp. pp.239	Application Engineering Techniques Related to High Performance, Medium Speed Diesel Engines	Mirrlees Blackstone, Ltd.	R. Greenhalgh P. Tooth I.I. Bickley	o Military and civilian o Engine response to load, pressure and temperature
E-0045-C pp. 3-235	Not stated	National Research Council of Canada	F. Rueter A. Swiderski	o Civilian o Performance prediction of a turbocharged 2-cycle free piston diesel engine

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ADVANTAGES	AVAILABILITY	HARDWARE	COST OF OPERATION	VALIDATION	DOCUMENTATION
o Requires less empirical data than other models	From UMIST	PDP-10 CDC-7600	600 CPU/Engine ppm on a PDP10 20 CPU/Engine rpm for a CDC-7600	No	Some
-	Unlikely	Not stated	Not stated	Some	Some
o Accurate predictions of engine performance under new conditions	Unlikely	Not stated	Not stated	None	Some
o A free piston model	From NRC	Electronic Associates Model 690 Hybrid Computer	Not stated	None	Yes

TABLE 2.3.2.9: BOTTOMING CYCLE MODELS

ACCESS NO.	MODEL NAME	ORGANIZATION	AUTHOR(S)	APPLICATION
W-0002-70 pp. 3-251	Boiler Analysis Program (BAP)	Foster-Miller	J. Gerstman (recently modified by I.P. Krepchin)	o Military and civilian o Design and analysis of fired and waste heat boilers
W-0003-74 pp. 3-255	Rankine Cycle, Waste Heat Recovery Engine Performance Model	Thermo-Electron Corporation	F.A. DiBella, C. Wang	o Military and civilian o To determine the full and part load performance of a Rankine cycle system
W-0004-70 pp. 3-259	DRC Modeling (Rankine Bottoming Cycle Engines)	Mechanical Technologies, Inc.	Various	o Civilian o Performance and cost tradeoffs
W-0005-70 pp. 3-261	Brayton Bottoming System (BBS) Evaluation	United Technologies Corporation	Gene Wilmot, et al.	o Civilian o Design and performance calculations of Brayton cycle waste heat recovery systems
W-0006-81 pp. 3-263	Rankine Bottoming Cycle Performance Code	Argonne National Laboratory	Koruzinski; Ash	o Civilian and military o Estimates organized Rankine engine performance

ADVANTAGES	AVAILABILITY	HARDWARE	COST OF OPERATION	VALIDATION	DOCUMENTATION
–	Fee for use	CYBER 170 VAX 11/780	$.20/run	Yes	Yes
o Versatile with various energy recovery scenarios	Unavailable--must be contracted from Thermo-Electron	Xerox	Not stated	Yes	Maintained by Thermo Electron
Analyses and cost data verified by tests and fabrication	Yes	IBM	Not Stated	Yes	Of results only
o Rapid execution of complex systems	o Proprietary o Indirectly available through contract	IBM 3380	$1/run	Yes	Proprietary manuals
o Useful for general scoping studies	o Needs more documentation prior to release	IBM 3033	$1.50-$2.50 (30-70 cases)	Some	Yes

TABLE 2.3.2.10: TURBOCHARGING MODELS

ACCESS NO.	MODEL NAME	ORGANIZATION	AUTHOR(S)	APPLICATION	ADVANTAGES
E-0018-TC-77 pp. 3-267	Turbocharged Diesel Engine Simulation to Predict Steady State and Transient Performance	Cummins Engine Co.	A.S. Ghuman, M.A. Iwamuro, and H.C. Weber	o Military and civilian o Turbocharging	o Rapid assessment of parameteric changes
E-0019-TC-77 pp. 3-271	Prediction and Measurement of Two Stroke Cycle Diesel Engine Performance and Smoke at Altitude	Detroit Diesel Allison	Schmidt, Venhuis, and Hinkle	o Military and civilian o Turbocharging	o Rapid calculations
E-0051-TC-76 pp. 3-283	A Non-Linear Digital Simulation of Turbocharged Diesel Engine Under Transient Conditions	Imperial College of Science and Technology	Neil Watson Maged Marzouk	o Military and civilian o Turbocharging	o Appears to be a very powerful model
E-0036-TC-81 pp. 3-279	University of Manchester (UMIST)	University of Manchester	Winterbone, Loo	o Civilian and government o Turbocharging	o Applicable over a wide range of engines and speeds
E-0035-TC-75 pp. 3-275	A Real Time Analogue Computer Simulation of a Turbocharged Diesel Engine	University of Manchester	Benson, Winterbone, Shamsi, Closs, Mortimer, Keynon	o Military and civilian o Turbocharging	

AVAILABILITY	HARDWARE	COST OF OPERATION	VALIDATION	DOCUMENTATION
Not available	Not stated	1 cpu minute	Some	Some
Refer to source document	o Hand calculator	Negligible	Some	Some
Unknown	Not stated	Not stated	Yes-- "Excellent" agreement	Some
Unknown; possibly IMIST	Not stated	Not stated	Some	Some
Not stated	DEC PDP 15	Not stated	Some	Yes

3.0 MODEL CATALOG

TITLE   General Purpose Automotive Vehicle Performance
                                 and Economy Simulator (GPSIM)

DATE   Initially 1972 with successive revisions

AUTHORS   William C. Waters

ORGANIZATION   General Motors Corporation

SPONSOR   General Motors Corporation

TRANSPORTATION MODE   Highway

APPLICATION   Civilian

OBJECTIVE   GPSIM is an automotive vehicle simulator designed
                                 to compute the operating conditions of the engine
                                 and transmission and the performance and economy of
                                 the vehicle as the vehicle is operated in a
                                 prescribed manner.

REFERENCES   W.C. Waters, "General Purpose Automotive Vehicle
                                 Performance and Economy Simulator," SAE Automotive
                                 Engineering Congress, Detroit, MI, January 10-14,
                                 1972, SAE Paper # 720043.

RELATIONSHIP TO OTHER   Vehicle simulation models have been developed and
MODELS/HISTORY OF MODEL   used at GM since 1960. The simulation/modeling
                                 program has been under development since then, and
                                 has led to GPSIM.

OPERATIONAL CAPABILITIES   GPSIM is used to estimate performance of a vehicle
                                 (e.g. acceleration, passing ability), fuel economy
                                 over specified driving schedules, and, to a more
                                 limited extent, exhaust emissions. GPSIM utilizes
                                 a combination of the stabilized vehicle concept and
                                 the integration method. In the first case, vehicle
                                 performance is calculated as a succession of
                                 distinct vehicle performance combinations, and is
                                 used to minimize computer time and provide quite
                                 acceptable accuracy. In the second case, the
                                 vehicle is defined by a set of differential equa-
                                 tions driven by various functions. The equations
                                 are numerically integrated over time. The integra-
                                 tion method is used during rapid vehicle tran-
                                 sients. The basic assumptions behind GPSIM are:

- Look-up tables mapping out the various
  performance regimes can be used instead of a
  comprehensive set of equations to describe
  vehicle and component performance and
  characteristics;

- Steady-state tests can be used to predict
  dynamic operation because, unless explicitly
  accounted for, transient conditions are assumed
  to be short enough to be ignored;

- Hydrodynamic similarity laws apply to the torque
  converter.

- Simplified shift models can be used to simulate
  transmission shifts, wherein the amount of
  energy transferred during the shift is
  important, but how it is transferred is
  unimportant; and,

- The steady-state operation of the vehicle is
  defined by a set of tables that is used to
  generate more dense intermediate tables for
  reference during simulation.

Transient conditions modelled are shifts, engine
lag due to hydraulic effects in the transmission,
and certain gas turbine characteristics. Shifts
can be either torque shifts such as from synchro
mesh transmissions, or power shifts from automatic
transmissions.

GPSIM has two operating modes: COMPUTE or SIMULATE.
In the COMPUTE mode, the total or a well-defined
subset of the vehicle's performance range and
capabilities is characterized, enabling various
vehicles to be compared in many respects. The
SIMULATE mode generates the operating conditions
for the vehicle, engine, and transmission vs. time
and distance as the vehicle follows the specified
schedule.

DATA INPUT REQUIREMENTS

Typical GPSIM data requirements are:

Engine: torque, fuel rate, throttle, etc.

Transmission: converters and/or clutch, Gear
Ratios, Gear Efficiencies, Spin Losses, Inertias,
Shift Pattern.

Vehicle: Weight, Frontal Area, Rolling Resistance
Coefficients, CG, Location, other Rotational
Losses, Driver half inertia.

Axle: Ratio, Efficiency, Additional Rotational
Losses.

Tires: Rolling Radius, Contact Efficiency, Wheel
Inertia.

Accessories: Alternator, Air Conditioner, etc.

GPSIM has built in data files for many vehicle
components and characteristics. The program can be
run with a minimum of input data descriptions but
can accept more complete data if required.

Data handling features are designed to:

- Reduce input volume required to accomplish a
  given test;

- Allow user to structure input sequence to fit
  the problem;

- Simplify data submission rules.

There are various arrangements of data blocks that
describe a part of the vehicle, a route, a sche-
dule, or other simulation requirements. Specifi-
cations are statements that cause GPSIM to operate
on the data in a particular fashion that is some-
what different from the normal methods. Commands
can be given to cause particular actions within the
program.

ADVANTAGES

The program can simulate a large variety of vehicles, using a set of limited data for proposed vehicle combinations. It can also use component tests from production vehicles to make more accurate computations. Program structure enables many types of simulations or performance calcula- tions using built-in functions or commands. Model is quite comprehensive in its abilities to simulate in detail many aspects of vehicle performance.

FUTURE POTENTIAL

VALIDATION

Because of the expense involved in running a suffi- cient number of tests to demonstrate the simula- tions ability to represent reality, the model has not been validated in this fashion. Limited attempts have been made, and the results of the simulation were within the range of the tests.

COMPUTING REQUIREMENTS

Program is written in PL/1 and is operating on an IBM 360/65. Program has 500 kbytes (8-bit) of machine instructions overlayed in 180 kbytes. Two to nine external online files of 10-300 kbytes are required.

Example computation times are 30 sec for computa- tion of intermediate tables, 30 sec to simulate four miles of urban driving and 3 sec to simulate 10 sec of wide-open throttle acceleration.

COST OF OPERATION

Depends on type and degree of simulation.

AVAILABILITY AND COST
OF DATA BASE

Program has built-in data for specific components and user can add data for other components.

AVAILABILITY

Proprietary.

TITLE   Heavy Vehicle Simulation (HEVSIM)

DATE   1977, derived from VEHSIM

AUTHORS   Original VEHSIM authors - Withjack, E., Moffat, S.,
                                   Malliaris, A.

ORGANIZATION   U.S. Department of Transportation

SPONSORS   UMTA, National Highway Traffic Safety
                                   Administration (NHTSA), and Society of Automotive
                                   Engineers (SAE)

TRANSPORTATION MODE   Highway

APPLICATION   Civilian

OBJECTIVE   The primary objective of this model is to simulate
                                   the fuel economy and performance of specified tasks
                                   and buses over a given driving schedule.

REFERENCES   SAE 760045; SAE 800215; R.E. Buck, A Computer
                                   Program (HEVSIM) for Heavy Duty Vehicle Fuel
                                   Economy and Performance Simulation, Volumes 1, 2
                                   and 3.

RELATIONSHIP TO OTHER   HEVSIM is derived from VEHSIM which was developed
MODELS/HISTORY OF MODEL   at the U.S. Department of Transportation primarily
                                   for simulating the fuel economy and performance of
                                   specified automobiles.

OPERATIONAL CAPABILITIES   The model is capable of simulating performance and
                                   fuel economy of a given truck of bus over any drive
                                   schedule. HEVSIM utilizes the method of continuous
                                   incremental time step simulation to model the
                                   vehicles performance. HEVSIM has three primary
                                   modes of operation during a driving cycle; constant
                                   acceleration, constant velocity or constant
                                   throttle setting.

Output: The major output parameters resulting from
the simulation are:
- Fuel economy
- Engine work/mile
- Average brake specific fuel economy
- Average speed
- Emissions (if simulated)
- Energy breakdown
- Work breakdown by various losses

DATA INPUT REQUIREMENTS   Input data are required for the following areas:

Specified Truck or Bus:
- Vehicle
- Engine
- Transmission
- Rear axle
- Tires
- Converter
- Gears
- Accessories

Driving Cycle:
- Driving schedule
- Route
- Shift logic

Input Data Accuracy: The accuracy of the input
data reflects the requirements of the SAE
specifications as described in the 1983 SAE
handbook.

ADVANTAGES   This model has a large degree of flexibility in
specifying the input and output parameters.

VALIDATION   This simulation process is currently being
evaluated for validation. Battelle is performing
sensitivity tests on bus components at TRC in Ohio.
Results are expected in September 1983.

COMPUTING REQUIREMENTS	The model lode is Fortran 10 and the system used is the DEC 10. To date the program has been converted to use on DEC 20 and IBM systems with some difficulty.
COST OF OPERATION	The computer time cost is approximately $25, depending on the specification of the particular case to be run.
FUTURE POTENTIAL	No modifications are planned at this time.
AVAILABILITY	All bus data used is proprietary to the manufacturer but has been available to DOT with that constraint. This program is available free of charge.

TITLE	Ford Motor Company <u>Dynamic Model</u>
DATE	1981
AUTHORS	R.G. Delosh, K.J. Brewer, L.H. Buch, T.F.W. Ferguson, W.E. Tobler
ORGANIZATION	Ford Motor Company
SPONSOR	Ford Motor Company
TRANSPORTATION MODE	Highway
APPLICATION	Civilian
OBJECTIVE	The computer dynamic simulation is capable of modelling the engine, control system, and drivetrain. It simulates the dynamic behavior of the total vehicle system for warm engine emissions and fuel consumption for the Federal Test Procedure and other driving cycles, and vehicle driveability and performance. Output permits detailed analysis of various factors influencing system performance. Generally is used to analyze vehicles on board computer system and vehicle performance due to changes in control features (engine, transmission, etc.).
REFERENCES	R.G. Delosh, et. al., "Dynamic Computer Simulation of a Vehicle with Electronic Engine Control," SAE Paper 810447; L.T. Wong, and W.J. Clemens, "Powertrain Matching for Better Fuel Economy, "SAE Paper 790045; P.N. Blumberg, "Powertrain Simulation: A Tool for the Design and Evaluation of Engine Control Strategies in Vehicles," SAE Paper 760158; D.N. Hwang, "Fundamental Parameters of Vehicle Fuel Economy and Acceleration," SAE Paper 690541.
RELATIONSHIP TO OTHER MODELS/HISTORY OF MODEL	Model has been progressively developed as detailed in the References given above.
OPERATIONAL CAPABILITIES	The model consists of more than sixty linked subroutines to simulate various components, control strategies, and other operational activities. The model is a mixture of physical and regression based submodels. In physical models, phenomena are described by physical process and properties. In regression models, complex phenomena are described

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by equations derived from regression data. The model is capable of analyzing engine operation, including power, torque, fuel flow, temperatures, emissions, drivetrain, including transmission, tires, axle and driveshaft, and gear shifting, and engine controls, including electronic systems.

DATA INPUT REQUIREMENTS

The model can be used by a non-expert with minimal computer experience. The program asks the user a series of questions to determine the test description, system and component specifications, control strategy requirements, and engine calibration. This procedure also determines output type. Each component requires rather extensive input data to describe its operation.

ADVANTAGES

The models appear to have particular relevance to design and analysis of electronic engine control systems. Dynamic programming techniques are used to optimize system performance.

FUTURE POTENTIAL

Model has been continuously upgraded to meet changing requirements.

VALIDATION

Extensive model verification has been done at four levels:

- Bench testing of individual components;

- Engine dynamometer testing of components and subsystems;

- Vehicle testing of subsystems over the FTP cycle; and

- Overall vehicle system function testing.

Agreement is quite good.

COMPUTING REQUIREMENTS

Model is implemented on DEC-System 2050. Written in structured Fortran.

COST OF OPERATION

Model uses about 9-10 sec up to 30 sec of computer time to simulate one second of vehicle system operation. Total drive cycle could be fairly expensive to run.

AVAILABILITY

Proprietary but could be accessible by outside users.

TITLE	Testing Operations Fuel Economy Program (TOFEP)
DATE	1981
AUTHORS	Contacts: Dave Wernette, John Manning, Joe Greenbaum
ORGANIZATION	Ford Motor Company
SPONSOR	Ford Motor Company
TRANSPORTATION MODE	Highway
APPLICATION	Civilian
OBJECTIVE	Primary purpose of TOFEP is the evaluation of fuel and performance effects of powertrain changes. A secondary purpose is the prediction of absolute fuel economy and performance.
REFERENCES	D.J. Bickerstaff, "Light Truck Fuel Economy by Design Efficiency," SAE, 1978.
HISTORY OF MODEL	Based on continuing program development.
OPERATIONAL CAPABILITIES	A vehicle is modelled and the model is put through a series of fuel economy cycles and performance tests. The model is used primarily to evaluate alternatives in vehicle performance rather than to determine absolute vehicle characteristics. Model does a second-by-second simulation of vehicle performance based on a specified driving cycle and component and system performance specifications. Emissions modelling is being developed.

Basic types of use for the model are:

- Comparison of multiple vehicle alternatives sharing a common engine;

- Comparison of different powertrains having different engines; and,

- Projection of fuel economy and performance.

DATA INPUT REQUIREMENTS

Model requires large quantity of input data, essentially a fairly complete description of a vehicle, i.e.:

- Vehicle physical description

- Engine information

- Transmission information

- Other drivetrain information.

ADVANTAGES/DISADVANTAGES

Program can be used in all phases of powertrain optimization. Model exhibits some inaccuracies in representing transient conditions, particularly at low speeds (0-10 mph).

FUTURE POTENTIAL

Emissions modeling is being developed. A new comprehensive model called CVSP is being developed by Dick Radtke and Phil Tuchynski.

VALIDATION

Not directly used for economy predictions because test results were not particularly good; performance results fairly good.

COMPUTING REQUIREMENTS

Fortran 77 program runs on Honeywell/DEC machines.

COST OF OPERATION

Depends on number of iterations. Less than minute CPU time.

AVAILABILITY AND COST OF DATA BASE

Engine maps must be developed based on bench tests. Other components must be specified based on tests at various operating conditions.

AVAILABILITY

Corporate proprietary.

TITLE   Automotive Simulator (ASIM)

DATE   August 1978

AUTHORS   E.M. Withjack

ORGANIZATION   U.S. Department of Transportation
                                   Transportation Systems Center
                                   Cambridge, Massachusetts

SPONSOR   U.S. Department of Transportation

TRANSPORTATION MODE   Highway – Automobile

APPLICATION   Civilian

OBJECTIVE   ASIM is an engineering tool for evaluation of
                                   automotive fuel economy and performance.

REFERENCES   E.M. Withjack, "A Description and User's Guide to
                                   the Automotive Simulator ASIM," Project Memorandum
                                   No. DOT-TSC-HS827-PM-78, U.S. Department of
                                   Transportation, Transportation Systems Center,
                                   Cambridge, MA, August 15, 1978.

HISTORY OF MODEL   ASIM is a more versatile version of an original
                                   program by K. Hegenrother and A.C. Malliaris.

OPERATIONAL CAPABILITIES   ASIM   utilizes a continuous simulation
                                   approach in which initial vehicle conditions are
                                   set up, and at time intervals new vehicle
                                   conditions are computed using appropriate driving
                                   schedule data. Output is basically a summary of
                                   fuel economy. Performance values related to
                                   segments of the driving cycle, and other factors
                                   concerning engine performance, drivetrain effi-
                                   ciency, and fuel flow.

DATA INPUT REQUIREMENTS   Input data required is not particularly sophisti-
                                   cated, but each particular part must be described.
                                   The simulation parts requiring descriptions are:

                                   – Automobile;
                                   – The drive cycle;
                                   – Transmission
                                   – Shift logic.

ADVANTAGES   This program executes rapidly and is easy to
                                operate. Data input requirements are not extensive
                                or difficult. Primary use is for an evaluative
                                engineering tool.

VALIDATION   The program was validated against DOT's VEHSIM
                                (vehicle simulator) model, and was also validated
                                against EPA certification test data. Validation is
                                reported in SAE 760157.

FUTURE POTENTIAL   The model is currently out of use by DOT or any
                                other organization.

COMPUTING REQUIREMENTS   Program is in FORTRAN and is not excessively large.
                                Can be run on interactive system.

COST OF OPERATION   The program is relatively inexpensive to run.

AVAILABILITY   Program listing is available.

TITLE	Vehicle Mission Simulation (VMS)
DATE	1976
AUTHORS	D.A. Klokkenga
ORGANIZATION	Cummins Engine Company, Inc. Columbia, IN
SPONSOR	Cummins Engine Company, Inc.
TRANSPORTATION MODE	Highway Trucks
APPLICATION	Civilian
OBJECTIVE	The model is intended to provide sufficient truck performance information so that a user can make choices among alternative configurations.
REFERENCES	D.A. Klokkenga, "Selecting Powertrain Components for Heavy Duty Trucks" SAE 760830; P.W. Schutz, D.A. Klokkenga, and D.B. Stattenfield, "Vehicle Mission Simulation," SAE Paper 700567.
HISTORY OF MODEL	Originally built in late 60's.
OPERATIONAL CAPABILITIES	The program uses a specified route and its characteristics (grades, distances, speeds, etc.) to drive the vehicle simulation (gear changes, throttle required, fuel flow, engine load, etc.). At the end of the finite-time-step simulation, incremental performance characteristics are added to generate the summary of performance. Primary output data are driving time, average speed, fuel used, fuel mileage, percent of time at full throttle, engine load factor, and number of gear shifts. This can be done for different trucks to facilitate performance comparisons.
DATA INPUT REQUIREMENTS	The vehicle must be specified by weight, aerodynamic characteristics, and rolling resistance. The engine is described by a torque-throttle fuel flow map. The transmission gear, torque, and shift characteristics are given. Other drivetrain brake data are also needed. The driving route is specified in detail, with distances, grades, speeds, and starts/stops given. Wind is an input to use in aerodynamic calculations.

ADVANTAGES

The model is oriented particularly to truck performance over generalized driving routes. It is useful in helping truck operators choose among options for equipment on their particular routes. The model has a variable time increment to increase for computational efficiency. Model includes database for 140,000 miles of highway driving routes.

FUTURE POTENTIAL

Work progresses on expanding capabilities, in particular automatic transmissions, lighter vehicles, and urban congestion.

VALIDATION

Fairly well validated by actual road tests.

COMPUTING REQUIREMENTS

Uses Honeywell DPS/8 CP/6 op system 2 megabytes storage.

COST OF OPERATION

In proportion to length and complexity of route (less than 10 min CPU will almost all cases).

AVAILITY AND COST

Can be sold as service in certain circumstances.

AVAILABILITY

Code is proprietary.

TITLE   Truck Computer Analysis of Performance
                               and Economy (TCAPE)

DATE   Announced in 1978.

AUTHORS   Many contributors.

ORGANIZATION   International Harvester Truck Group

SPONSOR   International Harvester Corporation

TRANSPORTATION MODE   Highway and off-highway.

APPLICATION   All applications of large and small trucks and
                               similar vehicles.

OBJECTIVE   The primary use of this model is for sales promo-
                               tion of IH trucks. Optimization of specifications
                               for IH trucks prior to purchase by users through
                               dealers with or without direct user input is a part
                               of this promotion.

                               Output: The major output parameters resulting from
                               the simulation are:

                               ⊛ An echo of the input data on the same page as
                                  output.

                               ⊛ A table of miles per gallon, average mph, and
                                  mission minutes for three selected routes, city,
                                  suburban, and highway.

                                  – City: 9.42 miles, 20 to 45 mph speed
                                     limit, 12 stops

                                  – Suburban: 34.5 miles, 25 to 55 mph speed
                                     limit, 7 stops

                                  – Highway: 157.76 miles, 35 5o 68 mph speed
                                     limit, 2 stops

                               ⊛ A table of vehicle speed (mph), engine speed
                                  (rpm) wheel power (HP) and gradeability for each
                                  gear at each of four different engine speeds:
                                  clutching rpm, peak torque rpm, rpm from which
                                  engine will be at governed rpm in the next lower
                                  gear and governed rpm (or maximum recommended

rpm if the engine does not use a governor).
This table can be in graphical form if the user
has access to a suitable terminal with a cathode
ray tube (CRT terminal).

- An in-process table to help the user select the
  proper axle ratio. It shows geared speed (mph),
  engine power available, road load power required
  and reserve power available (all at the wheels
  in top gear) for each axle ratio available for
  the selected axle code. It also shows maximum
  low gear gradeability for the selected codes
  (axle and transmission) for each available axle
  ratio.

REFERENCES	IH Truck Group Product Bulletins, most recent CT-623Y, dated March 1983, includes descriptions of TCAPE and use manual.
RELATIONSHIP TO OTHER MODELS	Although it uses an entirely separate program, TCAPE shares some component library files with TRUKSIM and is based on the same background of simulation expertise.
HISTORY OF MODEL	TCAPE was announced in 1978 as a new program designed specifically for sales promotion. Changes since 1978 have been made only at specific intervals. It was preceded by some simple performance simulations.
OPERATIONAL CAPABILITIES	TCAPE is arbitrarily limited to three routes, two types of tires (or a mixture of these two), fixed ambient air conditions, and one driver pattern, but has an extremely wide variety of component variations. The purpose of the simulation is primarily to show the effects of changes in components.
ASSUMPTIONS	The major assumptions in the model are that transient events are simulated by steady-state minor increments in one mph steps. TRUKSIM allows the user to specify smaller steps and has demonstrated that one mph gives good results for TCAPE.

LIMITATIONS

DATA INPUT REQUIREMENTS

ADVANTAGES

VALIDATION

Described under Operational Capabilities.

As inputs, the interactive program asks the user a
minimum of 23 questions with up to 32 questions
depending on the responses given. As of March 23,
1983, there were 313 engine libraries, 214 main
transmission libraries, 32 auxiliary transmission
or transfer case libraries and 100 driving axle
libraries in the component files. Any number of
the 32 input variables can be changed for subse-
quent cases.

Accuracy: TCAPE is intended to show the effect of
changes in specifications prior to purchase of
vehicles and is not intended to reflect differences
in ambient air conditions, driver patterns, nor
specific route differences. To show these effects,
refer to TRUKSIM (H-0025-81).

Input Data Accuracy: The accuracy of the input
data requirements reflect:

- Improved availability of data from component
  suppliers determined using the new SAE test
  procedures:
    - Engines: J1312 (also J1349 and J816b)
    - Tires: J1379 (also J1380)
    - Aero: J1252
    - Driveline: J643b, J651c, J1266 and another
      for manual transmissions
    - Fans and Accessories: J56, J1339, J1340,
      J1341, J1342, and J1343

- Onboard recording, in sequence, of driver choice
  patterns for a variety of drivers on a variety
  of routes with a variety of vehicles.

It is specifically designed for easy usage as a
sales promotion tool. It is easily accessible by
any interested customer or user through the IH
truck dealer network.

Results have been "verified by thousands of miles
of actual truck usage" in user's normal operations.
Twenty comparisons compiled for the original 1978
announcement shows absolute values 6 percent low to
5 percent high averaging a conservative 1.5 percent
low. Relative results are even closer.

COMPUTING REQUIREMENTS

The program is written in Fortran on a Digital Equipment computer. Output is in tabular form unless a CRT terminal is available to the user.

COST OF OPERATION

Cost information is proprietary. User access (customer access) is available through the IH truck dealer network at no charge.

FUTURE POTENTIAL

Modifications will be made as needed, but only at well advertised intervals. Component library files are added or deleted at any time.

AVAILABILITY

Cost information on the data base and the component data files are proprietary. TCAPE can be accessed through IH Truck Group and IH truck dealers, but has not been made available outside IH. Negotiations for sale of the program might be possible.

TITLE	Hybrid and Electric Advanced Vehicle Systems (HEAVY) Simulation
DATE	November 1981
AUTHORS	Ronald A. Hammond Richard K. McGehee
ORGANIZATION	Boeing Computer Services Company Energy Technology Applications Division 565 Andover Park, West Tukwila, WA 98188
SPONSOR	U.S. Department of Energy Conservation and Renewable Energy Office of Vehicle Engine R&D Energy and Aero Branch Energy Section NASA Lewis Research Center (Mr. Raymond Beach, P.O.)
TRANSPORTATION MODE	Highway
APPLICATION	Civilian
OBJECTIVE	HEAVY is used to evaluate electric and hybrid vehicle propulsion systems by predicting the performance of a proposed drive train using a library of predefined component models.
REFERENCES	Final Report – Hybrid and Electric Advanced Vehicle Systems (HEAVY) Simulation, R.A. Hammond and R.K McGehee, U.S. Department of Energy, Washington, D.C., November 1981, NASA CR-165536, DOE/NASA/0151-1, BCS 40357 Hammond, R.A. and R.K. McGehee, "User's Guide to the Hybrid and Electric Advanced Vehicle Systems (HEAVY) Simulation," NASA Contract DEN 3-151, September 1981.
HISTORY OF MODEL	This model is a modification of the SIMWEST computer program.

OPERATIONAL CAPABILITIES

This model is intended for use early in the design process to:

- Evaluate concepts

- Compare alternatives

- Do preliminary designs

- Develop strategies for control and management

- Size components

- Do sensitivity studies

The model has component library that contains data for typical components in a vehicle drive train. The user can select drive system components and the model will formulate the complete vehicle and drive train. A simulation of vehicle performance is done based on specification of trip duration, driving cycle, and output data required. The model is general enough so that it can be effectively used by analysts and designers with little programming or simulation experience. Furthermore, a set of predefined, typical baseline vehicles contained within the program enables the user to make simple changes to a known data set in order to create a desired vehicle.

DATA INPUT REQUIREMENTS

The model contains descriptions of system components and simulation conditions. The user selects the desired components and organizes them into the vehicle system. Default values for many of the system components or operational parameters enable the user to bypass specific data inputs; however, if desired, the user may modify or specify values. Required values are prompted by the system and the user makes the choice whether to use or change default values.

ADVANTAGES

The advantages of this system are:

- Simple to use since it requires the analyst to make few data specifications;

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- Built in system components, description, and operational descriptions;

- Model structure and language that is user oriented

- User specifies required output

- Multiple simulations in one computer run

FUTURE POTENTIAL

Activity has been limited since the 1981 report, but there ir presently interest in modifying the model to .un on desktop computers. A parameter optimization capability is also of interest.

VALIDATION

Model was compared to an ETV-1 drivetrain on the Cleveland road load simulator.

COMPUTING REQUIREMENTS

Code is available through COSMIC (Computer Program Library) for application on CDC CYBER computers. Code is in Fortran 66, and is 12000 lines long. Requires a minimum of 70k Octal storage. Also available through Boeing Computer Service timesharing system.

COST OF OPERATION

Cost is minimal--on the order of a dollar for individual cases.

AVAILABILITY AND COST
OF DATA BASE

Data is contained within program or user can specify other values.

AVAILABILITY

(See Computer requirements above).

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TITLE	Transient System Optimization (TSO)
DATE	1978
AUTHOR	Alan R. Dohner
ORGANIZATION	General Motors Research Laboratory
SPONSOR	General Motors Corporation
TRANSPORTATION MODE	Highway
APPLICATION	Civilian
OBJECTIVE	To optimize fuel economy subject to emissions constraints by accounting for transient system interactions, cold start/warm up, exhaust after treatment, driveability, and other phenomena.
REFERENCES	Transient System Optimization of an Experimental Engine Control System Over the Federal Emissions Driving Schedule, Alan R. Dohner, SAE Technical Paper 780286, February/March 1979.
RELATIONSHIP TO OTHER MODELS/HISTORY OF MODEL	Several theoretical treatments of the problem consider the steady-state vehicle operation during the Federal Test Procedure (FTP). This procedure extends to the transient behavior of the vehicle.
OPERATIONAL CAPABILITIES	The model procedure applies control/optimization in theory to an engine-controller-vehicle-catalytic converter system and methodically improves the feedback control functions with respect to fuel economy, emissions, and drive-ability constraints. This is an iteration model that uses actual test data rather than mathematical data to formulate improved feedback control functions. By applying the method to successive tests and by adjusting control variables, optimization is achieved. The experimental basis is used because realistic mathematical models do not exist (1978) to analyze transient performance. Parameter values acquired during a test are subjected to gradient optimization methods and increasingly better control is achieved. The end result is optimal control over the given cycle (FTP) to maximize fuel economy while controlling emissions.

DATA INPUT REQUIREMENTS

From a test cell set-up consisting of an engine, transmission, catalytic converter, dynomometer (vehicle simulator), engine control computer, and automatic driver, a data acquisition records fuel flow, emissions, airflow, spark advance, speed, EGR, temperatures, and other engine/accessory parameters.

ADVANTAGES

The primary advantages of this model are that it considers transient system operation and that it can utilize actual test data rather than relying on as-yet (1978) undeveloped mathematical models of transient system operation.

FUTURE POTENTIAL

Extensions of the model to include control of EGR.

VALIDATION

System is applied to actual tests and results are immediately evident under actual operating conditions

COMPUTING REQUIREMENTS

COST OF OPERATION

AVAILABILITY AND COST
OF DATA BASE

Data comes from actual tests.

AVAILABILITY

Proprietary.

TITLE   Diesel Urban Bus Simulation Program

DATE   April 1979

AUTHORS   G. Larson, H. Zuckerberg

ORGANIZATION   U.S. Department of Transportation, Research and
                                  Special Programs Administration, Transportation
                                  Systems Center, Cambridge, MA 02142

SPONSOR   U.S. Department of Transportation Urban Mass
                                  Transportation Administration Office of Technology
                                  Development and Deployment Washington, D.C. 20590

TRANSPORTATION MODE   Highway

APPLICATION   Civilian

OBJECTIVE   The Diesel Urban Bus Simulation Program is designed
                                  to assess the performance and fuel consumption of
                                  buses under various operating conditions and with
                                  various power drives.

REFERENCES   Diesel Bus Performance Simulation Program, Final
                                  Report, G. Larson and H. Zuckerberg, U.S. Depart-
                                  ment of Transportation Systems Center, Cambridge,
                                  MA, April, 1979, Report No. UMTA-MA-06-0044-79-1.
                                  NTIS PB-295-524.

RELATIONSHIP TO OTHER   Modeling technique similar to that described by
MODELS/HISTORY OF MODEL   Beachley, N.H. and Frank, A.A., "Digital Automo-
                                  tive Propulsion Simulator Programs and description,
                                  "Vol. II, Department of Electrical and Computer
                                  Engineering, University of Wisconsin-Madison,
                                  Contract No. DOT-OS-30112, December, 1974.

OPERATIONAL CAPABILITIES   The program was developed to simulate all elements
                                  of the power drive subsystem for transit bus opera-
                                  tion over a given drive cycle. This is done by:

                                  - Determining sequence of engine operating
                                     conditions for each moment during the drive
                                     cycle;

                                  - Determining the instantaneous fuel flow;

- Integrating fuel flow and velocity vs. time to obtain total fuel consumed and total distance travelled;

- Estimating fuel economy and emissions.

Power levels are computed using drive cycle data, vehicle friction, aerodynamic drag, inertial acceleration, rotational inertias, rotational speeds and torques, and component performance characteristics. The driving cycle segments are specified - length, grade, dwell time or idling time; and desired vehicle cruise speed. Output includes torque and horsepower, velocity and acceleration, engine speed, fuel consumption and emissions.

DATA INPUT REQUIREMENTS

Input specifies the vehicle, driving cycle configuration, route terrain profile. Inputs are vehicle data, engine performance data, power drive characteristics, acceleration, cruising speed, deceleration, vehicle idle time at stops, number of stops per mile, grade profile along route, head or tail winds, and adhesion characteristics between tires and road.

ADVANTAGES

The model is straightforward in achieving its intended purpose and has no apparent advantages.

FUTURE POTENTIAL

VALIDATION

Model results have been compared to fuel economy test results for actual buses following prescribed driving cycles. Agreement is quite good.

COMPUTING REQUIREMENTS

Model written in Fortran IV. A Model 663 Calcomp Plotter and associated software provide graphic output. Storage requirements depend on number of drive cycle segments used in each run.

COST OF OPERATION

AVAILABILITY AND COST
OF DATA BASE

Data is contained within program or user can specify other values.

AVAILABILITY

Available in reference.

3-28

TITLE   DSLSIM (Diesel Engine Control Systems
                                  Computer Simulation Model)

DATE   1980

AUTHORS   D. Wormley, J. Nye, J. Rife

ORGANIZATION   Department of Mechanical Engineering, Massachusetts
                                  Institute of Technology, Cambridge, MA

SPONSOR   Hamilton Standard Division of United Technologies
                                  Corporation

TRANSPORTATION MODE   Highway

APPLICATIONS   Civilian

OBJECTIVE   ● Identification of control and performance
                                    characteristics for light and heavy duty diesel
                                    engines to meet 1980-1985 requirements of fuel
                                    economy, emissions, driveability

                                  ● Define control system performance.

                                  ● Develop basic control system configurations.

REFERENCES

RELATIONSHIP TO OTHER
MODELS/HISTORY OF MODEL

OPERATIONAL CAPABILITIES   Models primary purpose is for investigating control
                                  strategies for engine operations, fuel economy,
                                  performance, and emissions. The model can analyze
                                  turbocharged or normally aspirated ergines. Stan-
                                  dard, automatic, or continuous gearing transmis-
                                  sions can be handled. Various velocity profiles,
                                  including EPA FTP, Fuel Economy test, or other user
                                  specified velocity profiles can be modelled. Output
                                  includes up to 27 engine and vehicle parameters as
                                  well initial conditions and final cumulative fuel
                                  economy and emissions. Data can be stored in a
                                  file. Plots of any of the variables can be made.

DATA INPUT REQUIREMENTS

The engine is represented by a quasi-static engine map (power, speed, torque, emissions, fuel flow, etc.). The transmission is represented by masses, friction, mechanical efficiencies, and shift points. Driving cycles initiate the calculation procedure by specifying vehicle velocity as a function of time.

ADVANTAGES

Model can provide output in many different representations and can accommodate a range of engine and transmission options.

VALIDATION

Simulation results have been compared to actual test results for EPA driving cycles. Areas for improvement are noticeable; however, some parameters agree fairly well.

COMPUTING REQUIREMENTS

VAX computer.

COST OF OPERATION

FUTURE POTENTIAL

No follow-up work has been done.

AVAILABILITY

Proprietary.

TITLE   A Simplified Program for Evaluating Diesel
                               Truck Performance

DATE   Basic program dates back to December 1980. Latest
                               modification in March 1983.

AUTHOR   Greenwald, L.E.

ORGANIZATION   United Technologies Research Center

SPONSOR   Corporate

TRANSPORTATION MODE   Highway

APPLICATION   Primarily civilian but could be applied to
                               military.

OBJECTIVE   The primary objective of this model is to aid in
                               the processes of driveline selection, engine
                               sizing, and parametric evaluation of driving cycle
                               economy for large diesel trucks.

                               Output: The major output parameters resulting from
                               the simulation are:

                               - Vehicle performance (grade capability, engine
                                  speed, available and required power).

                               - Fuel economy.

                               - Average speed and total cycle distance.

                               - Emissions (requires additional input).

REFERENCES   No formal documentation available.

HISTORY OF MODEL   The model is one of a number of powertrain
                               simulation programs developed by the United
                               Technologies Research Center for the purposes of
                               evaluating automotive engine and drivetrain
                               concepts at the systems level.

OPERATIONAL CAPABILITIES

The basic dynamical equations are Newton's Laws which are common to all drivetrain simulations. It is the specific application as well as specialized graphics and output routines which make the model unique.

The model's capabilities are:

⊛ Applicability to all vehicles with manual transmissions, including gasoline powered.

⊛ Quasi steady-stated dynamics.

⊛ All vehicle, chassis, and engine map parameters can be varied.

⊛ Hard copy computer graphics output of vehicle performance.

⊛ Versatility in synthesizing arbitrary driving cycles.

ASSUMPTIONS

The major assumptions are:

⊛ Quasi steady-state dynamics.

⊛ Simple gear shifting laws.

LIMITATIONS

The transient operation is ignored; this introduces error if a significant portion of the driving cycle cannot be approximated by steady-state operation.

DATA INPUT REQUIREMENTS

The data required as input to the model are:

⊛ Vehicle and chassis data (weight, rolling distance, drag coefficient, wheel radius, etc.).

⊛ Engine data (maximum torque curve and fuel flow map).

⊛ Driving cycle specification.

Accuracy: No changes needed or anticipated.

Input Data Accuracy: The accuracy of the input
data must be with ±5 percent.

ADVANTAGES

The advantages of this model are:

● Very rapid execution time (3 sec) making it
   desirable for systems level or parametric design
   and evaluation studies.

● Ease of operation (interactive or batch mode).

● Simple input (amount and format).

● Graphical output of vehicle performance, engine
   maps, and other data.

VALIDATION

The model is currently being validated.   Some
portions of model have been substantiated at this
time.

COMPUTING REQUIREMENTS

The model code is written in Fortran 77 and
currently run on a Univac 1100/81A.

COST OF OPERATION

The model requires approximately 3 sec per case on
the Univac.

Costs would be user and application dependent.
Truck chassis data is inexpensive and easy to
obtain or approximate.   The cost of engine maps
depends on whether they can be approximated from
the literature, must be obtained from test cells,
etc.   Engine map library for present use is
proprietary, but any engine can be used as input to
program.

FUTURE POTENTIAL

The model is continuously tailored for specific
studies as the need arises.

AVAILABILITY

This model is proprietary to United Technologies.
It is available for use in funded and internal
studies.   It is being used on current NASA/DOE
program.

TITLE	TRUKSIM
DATE	Predecessor program ENG 008 in 1961-1962. Name changed, graphics added and made interactive in 1981.
AUTHORS	Bracht, P.L., with many contributors.
ORGANIZATION	International Harvester Truck Group (IH).
SPONSOR	International Harvester.
TRANSPORTATION MODE	Highway and off-highway.
APPLICATION	All applications of large and small trucks and similar vehicles.
OBJECTIVE	The primary use of this model is for internal engineering analysis and development; in addition special user applications are also performed. It is capable of simulation of day-to-day vehicle tests.

Output:
- The primary output from a route simulation is a summary page, usually a hard copy from a CRT terminal. There are also six optional tabulations and five optional graphical outputs currently available. Included in the output is:

Tabular Output:
- Summary page with line-by-line major increments.
- Engine fuel map.
- Numbers of upshifts and downshifts to each gear at various torque levels.
- Time and number of cycles in each gear at various torque levels.
- Matrix of time and percent of time in rpm bands for each gear.
- Energy audit - HP-hours energy to each end dissipation location.

Graphical Output:
- Gradeability - Wheel HP available and required for each gear and a series of grades vs. mph.
- Acceleration Performance - MPH and distance versus time on a specified grade.
- Steady-State Fuel Economy - MPH vs. vehicle mph, all gears, clutching rpm to governor run-out rpm.
- Gear Selection Chart - Engine rpm vs. mph for all gears.
- Engine fuel map.

REFERENCES

None published outside IH.

RELATIONSHIP TO
OTHER MODELS

TRUKSIM was derived directly from ENG 008 and shares some component library files with TCAPE. Due to the large number of variables which can be modified for both hardware and driver or route variations, it is equivalent to a whole series of more rigid simulation programs.

HISTORY OF MODEL

The original program developed in 1961-62 was titled ENG 008 and used machine language in batch mode only with tabular output. It has been continuously upgraded and improved. In 1981, a major change was made to an interactive mode and cathode tube graphic output and it became known as TRUKSIM.

OPERATIONAL CAPABILITIES

The model has capabilities for both steady-state and transient operation.

Routes are divided into major increments of constant grade (+, - or 0) with assigned distance, initial speed limit and final speed limit for each of these major increments. Steady-state periods are combined with transient accelerations and decelerations, each calculated as a series of minor increments of one mph change. Smaller mph increments are optional to the user.

ASSUMPTIONS

It is assumed that transient operations can be accurately simulated by a series of steady-state minor increments which have a small mph change from one minor increment to the next. The magnitude of the mph change can be selected by the user.

LIMITATIONS

A limitation of the current model is that certain drivers' vehicle operation at times cannot be exactly simulated with the existing simulation options. More exact optional simulation of these would produce minor changes in the performance and economy calculated.

DATA INPUT REQUIREMENTS

The user must furnish answers to a minimum of 57 questions up to 133 questions depending on the responses given for the various optional choices.

Inputs include:
- Engine type and related data
- Transmissions
- Rear axle
- Body and trailer specifications
- Tire size
- Weights
- Shifting data
- Climate conditions (temperature, humidity, and wind)
- Accessories installed
- Driving cycle

Data Input Accuracy: The accuracy of the input data requirements reflect:

⊛ Improved availability of data from component suppliers determined using the new SAE test procedures.

- Engines: J1312 (also J1349 and J816b)
- Tires: J1379 (also J1380)
- Aero: J1252
- Driveline: J643b, J651c, J1266 and another for manual transmissions.
- Fans and Accessories: J56, J1339, J1340, J1341, J1342 and J1343.

● Onboard recording, in seq ence, of driver choice
patterns for a variety of drivers on a variety
of routes with a variety of vehicles.

Accuracy: The long term development of the model
has resulted in flexibility in input data, route
data and optional driver variations such that final
accuracy now depends very little on the model.
Absolute accuracy depends on knowledge of all of
the 57 to 133 input variables. Relative accuracy
depends on knowledge of only those variables
directly involved in a specific vehicle change.
The input variables can be classified:

Descriptive of Exact Mathematically – 22 to 66
items (such as gear and axle ratios).

Reasonably Accurate Input Available – 6 to 26 items
(such as gross weight and frontal area).

Driver Choices – 9 to 15 items (such as "Does the
driver observe the speed limits?").

Difficult to Obtain Accurate Data – 7 to 13 items.

The vehicle related items that are most critical to
absolute accuracy (difficult to obtain and with a
large effect) are tire rolling resistance and drag
coefficients in the presence of wind at some yaw
angle. On some routes with lower road speeds
differences in driver extremes can double the fuel
consumption.

ADVANTAGES

An advantage to this model is the extreme
flexibility with optional procedures, assumptions,
and a large library. New routes and/or components
can be readily added once data is available.
Changes in the program, the assumptions or the
output can be made by IH whenever needed without
accountability outside IH.

VALIDATION

Virtually all highway fuel economy tests run on controlled route profiles by IH Truck Group Engineering have been simulated as well as many fleet average results furnished by IH customers. When the critical input parameters and driver habits can be based on measured rather than on estimated input values, agreement close to two percent or better is expected. More typically, some of the parameters must be estimated. Even then, the effect of a change in a single component can be predicted with excellent accuracy if the parameters for the particular component (original and alternate) are well known.

COMPUTING REQUIREMENTS

The simulation program written in Fortran has been adapted to several different computer hardware systems, usually Digital Equipment or IBM.

COST OF OPERATION

Computers which can handle the program at all can complete the simulation calculations in a few seconds even on a complicated route. The interactive input/output time depends on the skill of the user, but is usually several minutes. Many manhours may be required to accumulate the input information. Exact cost information is proprietary.

FUTURE POTENTIAL

Continued enhancement whenever needed.

AVAILABILITY

This model is used by Truck Group Engineering. The program and the library files are competitive proprietary tools and to date have not been offered for use outside IH. Negotiations for sale of the program might be possible.

TITLE	USCG Icebreaker Propulsion System Simulation, Program No. ENE-11
DATE	Completed August 1968
AUTHORS	Lt. J.W. Lewis, USCG; LCDR E.J. Lecourt, USCG; F.W. Scoville, CONSULTEC
ORGANIZATION	U.S. Coast Guard Headquarters, Office of Engineering, Icebreaker Design Branch
SPONSOR	U.S. Coast Guard
TRANSPORTATION MODE	Marine

APPLICATION

* Icebreakers; Ice-strengthened cargo and service ships.

* civilian and military.

OBJECTIVE

Powertrain design analysis and evaluation of alternatives.

REFERENCES

* Lewis, J.W., Lecourt, E.J., United States Coast Guard Icebreaker Propulsion System Simulation, United States Coast Guard, Office of Engineering, Phase I, II, III, IV, 1967-69.

* Major, R.A., Kotras, T.V., Lawrence, R.G.A., Digital Simulation of a Diesel AC-DC Icebreaker Propulsion Systems

RELATIONSHIP TO OTHER MODELS

The model is an assemblage of accepted relationships between ship motion, shaft and propeller motion, motor controller, generator and motor armature currents, generator field, diesel engine with governor, and bridge controller.

HISTORY OF MODEL

A design project of a 12,000 ton 20,000 SHP icebreaker (M-13) generated the need for this simulation.

OPERATIONAL CAPABILITIES

The model can be adapted for diesel-electric propulsion of any ship. The modular form permits changes in components and loading.

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ASSUMPTIONS
Various simplifying assumptions are implicit in the relationships used in the model. Others can be introduced via the Initial Conditions. Assumptions concerning component characteristics can be introduced via the Input Data.

LIMITATIONS
No direct fuel efficiency output is provided, nor is there a built-in optimization procedure. Integration of the diesel power over time would provide a measure of fuel consumption for a given maneuver under specified conditions. Optimization must be done by comparison of the results of individual runs.

DATA INPUT REQUIREMENTS
104 data cards (up to 7 values on each) are required to describe all system components, plus definition of Initial Conditions. The fifth section of the report gives instructions for each of the 104 data cards.

ADVANTAGES
The model describes relationships in sufficient detail that a wide variety of diesel-electric systems may be simulated.

VALIDATION
The icebreaker model has been compared to and calibrated by USCGC GLACIER performance data with good results. Extrapolation into other ship types would require similar procedure.

COMPUTING REQUIREMENTS
Developed for use on an IBM 1130, with disk in Fortran IV.

COST OF OPERATION
Proportional to length of maneuver and the time steps used (.08 sec to .20 sec). About 7 minutes of computer time for 15 seconds of ship time, i.e., about 28 sec computer time per 1 second real time.

FUTURE POTENTIAL
A library of subroutines and input data for different types of components can be assembled to make the program flexible and useful for a wide range of diesel-electric ships.

AVAILABILITY
Unclassified and in the public domain available from Defense Technical Information Center, Defense Logistics Agency. A full program listing is given in the report (Phases I to IV plus a volume entitled Ship Design and Maintenance Computer Program).

TITLE

A Method of Predicting the Speed Reduction of
Turbocharged Marine Diesel Engines (in German)

DATE

Published 1978 (Motortechnische Zeitschrift)

AUTHORS

Michael Grohn, Prof. Dr. Ing., Klaus Groth

ORGANIZATION

University of Hannover

SPONSOR

Research funding from the government of Lower
Saxony

TRANSPORTATION MODE

Marine

APPLICATION

- Medium speed, 4 cycle, marine diesels loaded by
  a fixed propeller.

- Civilian and military.

OBJECTIVE

Design and sizing of turbochargers for engines with
marine propeller loading.

REFERENCES

Grohn, Michael, Ein Verfahren Zur Ermittlung der
Drehzahlaruckung aufgeladner Hochlerstungs-
Schiffsdieselmotoren, Motortechnsiche
Zeitschrift 39 (1978) 9.

RELATIONSHIP TO
OTHER MODELS

Five thermodynamic systems are included: power
cylinder; exhaust manifold; air receiver;
compressor; exhaust turbine. The simulation
basically is on an energy and mass exchange
formulation.

HISTORY OF MODEL

Apparently extension of previous investigations at
various places.

OPERATIONAL CAPABILITIES

Steady state performance to investigate stability
of the turbocharger installation, and SFC
variation.

ASSUMPTIONS

Ideal gas; homogenous cylinder charge; no leakage;
stochiometric combustion; pressure and temperature
uniform in space; structural component temperature
uniform in space with no cyclical variation; no
heat transfer to cool side; no variation in RPM of
the combustion air system.

LIMITATIONS

Specific type of marine power plant.

DATA INPUT REQUIREMENTS   Description of the five thermodynamic systems and
                                        their interfaces.

ADVANTAGES   Valuable design tool.

VALIDATION   The model was validated by measurements taken by
                                        the firm of MAN on an MAN Model V6V 52/55 engine.

COMPUTING REQUIREMENTS   Unknown. However, since this is a steady state
                                        model, the requirements are not expected to be
                                        prohibitive.

COST OF OPERATION   Unknown.

FUTURE POTENTIAL   Further refinement and adaptation expected to be
                                        feasible.

AVAILABILITY   Via Government-to-government channels or via
                                        academic avenues.

TITLE

Applied Computer Simulation in Marine Engineering-Clutch Maneuvering Assessment

DATE

Published January/February 1981 (Shipbuilding & Marine Engineering International).

AUTHOR

K.W. McTavish

ORGANIZATION

Y-ARD Ltd., Glasgow

SPONSOR

Royal Navy

TRANSPORTATION MODE

Marine, naval

APPLICATION

● Design evaluation of transient loads, energy losses and control schemes for components of a twin screw CODOG ship with controllable pitch propellers during maneuvering.

● Civilian and military.

OBJECTIVE

Assess the duty of a friction clutch in the diesel engine drive train.

REFERENCES

McTavish, K.W., "Applied Computer Simulation in Marine Engineering - Clutch Maneuvering Assessment," Shipbuilding and Marine Engineering International, Feb. 1981.

RELATIONSHIP TO OTHER MODELS

Based on Y-ARD experience in simulation. The governing general equations are given.

HISTORY OF MODEL

Not given

ASSUMPTIONS

Not given except as implicit in the general relationships provided.

LIMITATIONS

Assembled from accepted component modules for a specific type of propulsion plant.

DATA INPUT REQUIREMENTS

Individual ship (hull) characteristics and machinery component characteristics. The ship data requires preliminary tank testing of a model.

ADVANTAGES

Different component characteristics can be inserted. The model can be exercised for transient conditions.

VALIDATION	By practical trial results of a full scale ship.
COMPUTING REQUIREMENTS	Not given
COST OF OPERATION	Not given
FUTURE POTENTIAL	Expansion, adaptation and refinement feasible.
AVAILABILITY	Proprietary

TITLE	Analysis of Shipboard Energy Systems
DATE	Published 1978, Society of Automotive Engineers, Inc.
AUTHORS	J. Fake, T. Rozenman, J. Pundyk
ORGANIZATION	PFR Engineering Systems, Marina Del Rey, California
SPONSOR	U.S. Navy, David Taylor Naval Ship Research and Development Center, Carderock, Maryland.
TRANSPORTATION MODE	Marine, naval.
APPLICATION	⊚ Fuel consumption rate comparisons for a marine power plant. The original simulation was for a DD 963 plant of two gas turbines with a diesel generator.
	⊚ Civilian and military.
OBJECTIVE	Compare total fuel consumption for alternative arrangements under a given operation profile.
REFERENCES	Fake, J., Rozenman, T., Pundyk, J., "Analysis of Shipboard Energy Systems," SAE/P-78/75.
RELATIONSHIP TO OTHER MODELS	Each component is modelled according to some simplifying assumptions.
HISTORY OF MODEL	Contract development.
OPERATIONAL CAPABILITIES	Annual total fuel consumption and fuel rates at different speeds can be determined.
ASSUMPTIONS	A speed-power curve was stipulated, gas turbine performance was portrayed by a generalized map, diesel engine fuel curve was assumed and generator efficiency was assumed versus output, 3000 hours per year operation was assumed with no time at anchor.
LIMITATIONS	This is a steady state model. More detailed component characteristics may be required for finer results.

DATA INPUT REQUIREMENTS

Component characteristics in the form of arrays or functions and ship resistance data to give a speed-power curve.

ADVANTAGES

A reasonably accurate design tool which permits substitution of operating arrangements and profiles.

VALIDATION

From shop trial data.

COMPUTING REQUIREMENTS

Not given. Would appear to be reasonable.

COST OF OPERATION

Not given.

FUTURE POTENTIAL

Can be adapted to new types of prime movers and energy systems by modular substitution. The schematic diagram of the system permits adaptation by change of individual components and interface relationships.

AVAILABILITY

Unclassified, government property. Some of the original data may be classified.

TITLE   Systematic Design of Marine Propulsion Systems

DATE   Not shown. (Published in proceedings of
                                International Symposium on Advances in Marine
                                Technology.)

AUTHORS   Prof. R.V. Thompson

ORGANIZATION   University of Newcastle upon Tyne, England

SPONSOR   Vosper Thornycroft (UK) Ltd.; Royal Navy

TRANSPORTATION MODE   Marine

APPLICATIONS   ⊚ Comparison of alternative arrangements for a
                                   specialized minesweeping vessel.

                                ⊚ Civilian and military.

OBJECTIVE   Evaluation overall dynamic performance capabilities
                                of a minesweeper with distinct operating modes.

REFERENCES   Thompson, R.V., Systematic Design of Marine
                                Propulsion Systems, International Symposium on
                                Advances in Marine Technology.

RELATIONSHIP TO   Based on experimental relationships or previously
OTHER MODELS   accepted formulations, but a new ship and propeller
                                model was devised for the slow speed drive mode.

HISTORY OF MODEL   A result of the long term program of mathematical
                                analysis and simulation for design evaluation and
                                for specification of components. In this case, the
                                design of a shore test facility also was required
                                and considered.

OPERATIONAL CAPABILITIES   Identify dynamic loads during maneuvering and
                                various modes of plant operation.

ASSUMPTIONS   Linearized relationships applied where feasible.
                                Generalized relationships and block diagram shown.

LIMITATIONS   This particular model is described to indicate the
                                complex propulsion systems that can be simulated.
                                Limitations become a matter of simulation economics
                                rather than technical bounds.

DATA INPUT REQUIREMENTS   Individual component characteristics must be
                                 defined. Ship and propeller characteristics are
                                 derived from preliminary model test.

ADVANTAGES   Substitution of component modules is feasible and a
                                 wide variety of systems can be simulated under
                                 transient or dynamic conditions.

VALIDATION   Shore test facility results how good agreement.
                                 Full scale ship trial results for the plant
                                 described were not yet available at time of writing
                                 of the paper.

COMPUTING REQUIREMENTS   Not given.

COST OF OPERATION   Not given.

FUTURE POTENTIAL   The model can be expanded and adapted as necessary
                                 to suit specific power plant installations.

AVAILABILITY   Proprietary

TITLE	Selection and Simulation of Marine Propulsion Control Systems
DATE	Post- 1970
AUTHORS	C. Pronk
ORGANIZATION	Lips, N.V., Drunen, Holland
SPONSOR	Lips, N.V.
TRANSPORTATION MODE	Marine
APPLICATION	● Diesel engines driving marine controllable pitch propellers. (Lips produces marine propellers.) ● Civilian and military.
OBJECTIVE	The selection of control parameters for the installation and behavior of the entire system while maneuvering can be examined.
REFERENCES	Pronk, C., "Selection and Simulation of Marine Propulsion Control Systems."
RELATIONSHIP TO OTHER MODELS	Not given. Some of the relationships used are shown.
HISTORY OF MODEL	Commercial project.
OPERATIONAL CAPABILITIES	Steady state performance and dynamic conditions.
ASSUMPTIONS	Ship motions other than ship translation and shaft rotation are considered as time dependent disturbances. Waves are considered as sine functions with a probability distribution of amplitude. Other assumptions are implicit in the equations shown.
LIMITATIONS	The simulation is designed for diesel or gas turbine drive of a single propeller.
DATA INPUT REQUIREMENTS	The system and the environment must be fully characterized, including the hull.
ADVANTAGES	Performance predictions, including fuel rates, and control requirements during the design phase of a particular type of marine propulsion system.

VALIDATION	Requires full scale ship trial data.
COMPUTING REQUIREMENTS	Coded for an IBM 1130 with 5.5K core storage. Uses approximately 9 minutes for a 25 second real time maneuver (67 time steps).
COST OF OPERATION	Not given.
FUTURE POTENTIAL	Can be modified for other types of prime mover.
AVAILABILITY	Proprietary

TITLE	Computer Aided Marine Power Plant Selection
DATE	1973
AUTHOR	R.I. Newton
ORGANIZATION	Massachusetts Institute of Technology
SPONSOR	U.S. Navy
TRANSPORTATION MODE	Marine
APPLICATION	● Merchant-type ships, 10,000 to 50,000 SHP range.
	● Civilian and military.
OBJECTIVE	Assist in power plant selection at the preliminary design stage, considering the ship as a whole including economic factors.
REFERENCES	Newton, Roy Irwin, Computer Aided Marine Power Plant Selection, Bachelor's Thesis, MIT, June 1973.
RELATIONSHIP TO OTHER MODELS	Derived from many other models.
HISTORY OF MODEL	Developed as Thesis in the Department of Ocean Engineering for the degree of Ocean Engineer.
OPERATIONAL CAPABILITIES	Gives comparable economic indices for 6 types of plant (steam turbine, non-reheat and reheat; medium speed diesel; direct-connected diesel; A/C derivative gas turbine; 2nd generation GT) for a given set of hull, speed, utilization conditions and cost functions.
ASSUMPTIONS	Steady operating profile at design speed and power. No alteration to hull structure costs due to varying plant + fuel weight or volume.
LIMITATIONS	Speed and power ranges; technical data inputs; inflexibility since some data is implicit in the program statements.
DATA INPUT REQUIREMENTS	21 Variables (3 data cards). All other data, relationships and cost factors are within the program and difficult to vary or update.

ADVANTAGES   Simplicity and ship-as-a-whole approach.

VALIDATION   Has been compared to similar type manual design
                                    estimates with good results.

COMPUTING REQUIREMENTS   Programmed for IBM 370/165 computer in Fortran IV,
                                    Level G-1. Listing (464 cards) is given.

COST OF OPERATION   Not given

FUTURE POTENTIAL   Modification and modularization feasible to provide
                                    greater flexibility as a preliminary design tool.

AVAILABILITY   Proprietary to M.I.T.

TITLE   The U.S. DOT/TSC Train Performance Simulator (TPS)

DATE   Completed 1978

AUTHOR   M.E. Hazel

ORGANIZATION   U.S. Department of Transportation
                                   Transportation Systems Center
                                   Kendall Square
                                   Cambridge, MA 02142

SPONSOR   U.S. Department of Transportation
                                   Federal Railroad Administration
                                   Office of Research and Development
                                   Washington, D.C. 20590

TRANSPORTATION MODE   Railway

APPLICATION   Civilian

OBJECTIVE   The objective of this model is to simulate the
                                   operation of a train over a railway route. It can
                                   be used for a variety of applications, e.g., for
                                   determining the effects of operational strategy or
                                   equipment change on energy consumption and
                                   schedule.

REFERENCES   1. Hazel, M.E., "The U.S. DOT/TSC Train Perform-
                                      ance Simulator," Report No. FRA/ORD-77/48, U.S.
                                      Department of Transportation, Federal Railroad
                                      Administration, Washington, D.C., September
                                      1978.

                                   2. Hopkins, J.B., Hazel, M.E., and McGrath, T.,
                                      "Railroads and the Environment, Estimation of
                                      Fuel Consumption in Rail Transportation, Volume
                                      III - Comparison of Computer Simulations with
                                      Field Measurements." Report No. FRA-OR&D-75-74.
                                      III, U.S. Department of Transportation, Federal
                                      Railroad Administration, Washington, D.C.,
                                      September 1978.

3. Hitz, J.S., "Amtrak Fuel Consumption Study,"
   Report No.FRA/ORD-81/42, U.S. Department of
   Transportation, Federal Railroad Administra-
   tion, Washington, D.C., February 1981.

RELATIONSHIP TO
OTHER MODELS

This model was originally developed by the Missouri
Pacific Railroad. It has been adapted to the TSC
DEC system-10 computer and has been modified to
further expand its capabilities. Currently, it is
available in two versions — one for DEC-10 and the
other as an ANSI-compatible FORTRAN Source code.

OPERATIONAL CAPABILITIES

Results of Simulation: Calculates gallons of fuel
used over a particular train route. In addition,
it generates a listing which provides speed,
coupler force, acceleration, throttle notch
settings, brake application and release as well as,
optionally, incremental energy used at every time
or distance interval.

Structure: U.S. DOT/TSC TPS is a very flexible
program. It has built-in (default) values for
almost every parameter, including the complete
specification of a train.

The program calculates fuel consumption from
estimates of tractive effort and velocity at any
instant. The acceleration and deceleration values
are calculated based on balance between locomotive
tractive effort and train resistance. Significant
flexibility is built in for selecting the ideal
train resistance equation for a particular
application. Optional features allow for coasting
overspeed and complete specification of the
tractive effort curve.

ASSUMPTIONS

The fuel consumption is calculated based on
horsepower being generated at any instant and
running energy rate in gallons per horsepower-hour.
This assumes a constant transmission efficiency and
a running energy rate for the locomotive. These
can, however, be curve fit with an accompanying
data file.

LIMITATIONS

1. Velocity initialization is not permitted, i.e., the speed profile begins and ends at zero mph.

2. If wind effects are to be incorporated in calculating the train resistance, the velocity and direction of wind have to be constant for the entire run.

3. There are no provisions for simultaneous application of power and brakes as done in real life to keep the train stretched.

4. The train resistance models are not accurate above 80 mph.

5. The tractive effort is assumed to be in a continuous curve, not quantized by notch settings as is the case in a real locomotive.

DATA INPUT REQUIREMENTS

Locomotive Data:
- Wt. in tons
- Length in feet
- Rated HP
- Number of axles
- Running energy rate in gallons/HP-hour
- Idling energy rate in gallons/minute, and
- Transmission efficiency

Train Data:
- Number of loaded and empty cars
- Weights of loaded and empty cars, and
- If desired, all parameters for each car

Route Data:
- Lengths
- Stops
- Curvatures
- Elevations, and
- Speed limits for the route segments

Obtaining and inputing these data are very labor intensive tasks.

Train Resistance Model — Option of one of the
following six models (see Ref. 1)
- Modified Davis
- Canadian National
- Canadian National-Erie Lackawanna
  for TOFC/COFC
- Totten-Streamlined passenger
- Totten-nonstreamlined passenger, and
- Custom coefficients

ADVANTAGES

This program is written primarily to assist a
railroad in planning its train operation over a
particular route. It can be, and perhaps has been,
used to estimate the effects of various options on
fuel consumption and schedule. Some of the options
that can be considered are:

● Effects of adding or dropping a locomotive unit
  to or from the train,

● Effects of adding or dropping tonnage to or from
  the train,

● Effects of track relocation or reconstruction,
  etc.

The program is simple to use and changes can be
made with relative ease.

VALIDATION

The program has been extensively validated (see
Refs. 2 and 3). It has been used to simulate the
operation of several different freight trains over
different terrains. The overall agreement is shown
to be within 2%; however, some specific runs have
shown variations as large as 10% to 15% from test
results.

COMPUTING REQUIREMENTS

The program runs on DEC-10, although an IBM version
is also available. Both DEC and ANSI versions are
available. A typical Northeast corridor run (New
York to Boston) costs about $20 to run. However,
the cost is strongly dependent on how many speed
changes and how many track segments are included in
the simulation.

AVAILABILITY   The program is available to any user for $150 from
                                      TSC. A 9-track tape (1600 bpi), control no. FR028,
                                      is provided. This tape includes the source code as
                                      well as user documentation.

TITLE	Fuel Utilized Effective – Locomotives (FUEL)
DATE	December 1975
AUTHOR	J.N. Cetinich
ORGANIZATION	Emerson Consultants, Inc. 30 Rockefeller Plaza New York, New York 10020
SPONSOR	Union Pacific Company
TRANSPORTATION MODE	Railway
APPLICATION	Civilian
OBJECTIVE	The model is used to investigate the effect of train operating strategies upon consequent changes in fuel consumption, horsepower required and minimum train running time over a territory.
REFERENCE	Cetinich, J.N., "Fuel Efficiency Improvement in Rail Freight Transportation," Report NO. FRA-OR&D-76-136, PB 250 673, Dept. of Transportation, Federal Railroad Administration, Washington, D.C., December 1975.
RELATIONSHIP TO OTHER MODELS	This model needs as an input the output of a Train Performance Calculator computer model.
OPERATIONAL CAPABILITIES	Results of Simulation: The model determines fuel consumption, horsepower required and minimum train running time for given maximum speeds allowed and horsepower per trailing ton limits between all power change points (i.e., locations where train consist may change, either the locomotive set or trailing cars, or both).
ASSUMPTIONS	The Modified Davis Formula in a Train Performance calculator is used to calculate train resistance for use in the model.

LIMITATIONS

1. The energy calculation assumes the train to be one mass, which would make the prediction for long train traversing an undulated terrain inaccurate.

DATA INPUT REQUIREMENTS

The following data are required:
- Dispatcher's record of movement of trains
- Listing of premium and regular trains (they have different speed limits)
- Locomotive horsepower list
- Manifest train schedules.
- Locomotive tonnage rating tables
- Terrain profile
- Train information, such as horsepower used and total trailing ton for each train
- Output from a Train Performance Calculation Computer Model

ADVANTAGES

The model provides a global overview of effects of train operating strategies on a particular territory.

VALIDATION

The output from the Train Performance Calculator (TPC) was validated as were other elements of the FUEL Program and the overall output of the program. The TPC validation included dynamometer car runs, as well as locomotive speed tapes. The TPC program was found to underestimate fuel consumption by 8%. From the extensive validation, it was concluded that the program can accurately provide differences in fuel consumed, horsepower required, and minimum running time for changes in operating strategies.

TITLE   Freight Train Fuel Consumption Program

DATE   February 1981

AUTHOR   John D. Muhlenberg

ORGANIZATION   The MITRE Corporation
                               1820 Dolly Madison Boulevard
                               McLean, Virginia 22102

SPONSOR   U.S. Department of Transportation
                               Federal Railroad Administration
                               Washington, D.C. 20590

TRANSPORTATION MODE   Freight Train

APPLICATION   Civilian

REFERENCES   1. Muhlenberg, J.D., "Resistance of a Freight
                                  Train to Forward Motion – Volume IV, User's
                                  Manual for Freight Train Fuel Consumption
                                  Program", Report NO. FRA/ORD-78/0.4 IV, U.S.
                                  Dept. of Transportation, Federal Railroad
                                  Administration, Washington, D.C. 20590.

                               2. Computer program magnetic tape available as
                                  FRA/ORD/MT-78/C.4 IV.

RELATIONSHIP TO   Unlike most train operation simulator programs,
OTHER MODELS   this program was specifically written to calculate
                               fuel consumption of a freight train. Although it
                               provides values of other parameters needed to
                               calculate fuel consumption, the program does not
                               purport to be a train operation simulator.

OPERATIONAL CAPABILITIES   Structure: The program consists of a main program
                               and two subroutines, one deals with the track
                               characteristics and the other incorporates the
                               tractive effort characteristics of various
                               locomotives.

The program calculates energy usage (and conse-
quently fuel consumption) by multiplying tractic
effort by distance travelled at that effort. When
the net tractive effort is zero, the engines are
assumed to be idling and the fuel consumption
reflects this idle rate.

Results of Simulation: The output of the program
includes time, distance, fuel consumpcion, cumu-
lative fuel consumption, velocity, acceleration,
train resistance, throttle position or braking
effort, and rate of fuel consumption.

ASSUMPTIONS

The fuel consumption at each iteration step is
calculated based on multiplying train tractic
effort by distance travelled in that iteration
step. The transmission efficiency is assumed to be
constant in doing so. Also, the track corres-
ponding to each vehicle in the train is assumed to
be described by the same track record. Thus,
variations in track characteristics along a long
train cannot be accommodated. Also, since the
program is not intended to be a train performance
simulator, some details of operating the braking
system or throttle which could possibly affect fuel
consumption are omitted.

LIMITATIONS

1. The program cannot handle the commonly used
   practice of train stretching (by applying power
   and brakes simultaneously).

2. The effects of cross wind are neglected.

3. The equation used to calculate acceleration of
   the train treats the whole train as a lumped
   mass. This will be inaccurate while simulating
   a long freight train over an undulating profile.

4. Locomotives can be located only in front of the
   train.

DATA INPUT REQUIREMENTS

The program already contains two general data files, one containing the characteristics (such as areas of cross-section, weight, aerodynamic parameters, etc.) of 21 types of rolling stock including three types of locomotives, the second containing additional information on locomotives (such as initial tractive effort, fuel consumption rates in idle and while dynamic braking, etc.)

The operator needs to prepare three other stored data files. The first among these is the train file which provides car type (referred to the above data file) and net weight of vehicle load in tons for each car. The second file contains order in which the cars are placed in the train. The third file includes track information, i.e., distance, grade, grade equivalent of curvature, and speed limit.

Finally, as it is set up, the operator is supposed to provide the following additional data on an interactive basis:

- No. of locomotives,
- No. of vehicles in train,
- No. of track record,
- Start print,
- Operational speed limit (max. speed limited for the simulated trip),
- Estimated headwind, and
- Data print option.

ADVANTAGES

Since this program already incorporates information on most commonly used railcars and locomotives, it is relatively easy to use. Also, it is easy to modify since it is extensively documented.

VALIDATION

The program is claimed to have been validated with comparative success and is expected to predict actual fuel consumption within +0% and -10%.

COMPUTING REQUIREMENTS   The program is written in FORTRAN IV for an IBM 370
                                          system. A typical case which simulates consump-
                                          tion, 100 gallons of fuel, uses approximately 100
                                          cpu secs.

AVAILABILITY   The program is available to any user. The
                                          reference cited earlier contains a listing of the
                                          program. Alternatively, MITRE will provide a card
                                          deck for the cost of producing it. Finally, NTIS
                                          can provide a magnetic tape of the program.

TITLE	The Transportation Energy Model, Carnegie-Mellon
DATE	July 1977
AUTHORS	S.N. Talukdar and R.A. Uher
ORGANIZATION	Carnegie-Mellon University Pittsburgh, Pennsylvania
SPONSORS	Department of Transportation AAR
TRANSPORTATION MODE	Electric and Diesel Powered Trains
APPLICATION	Civilian
OBJECTIVE	The model was originally developed to provide a realistic, computer-based tool to predict energy consumption and cost associated with an electric-powered transportation system. Later it was modified to incorporate diesel-powered trains as well.
REFERENCES	1. Talukdar, S.N., and Uher, R.A., "Energy Management for Electric Powered Transportation Systems," prepared by Carnegie-Mellon University for the Dept. of Transportation, July 1977.
	2. Conversation with Dr. R.A. Uher, (412) 578-2961 (since no documentation exists for the modification incorporating diesel-powered trains).
RELATIONSHIP TO OTHER MODELS	The model contains two principal components which are linked together to simulate the actual operation of a transportation system. The components are:

1. The Train Performance Simulator

2. The Electric Network Simulator

For the diesel-powered trains, the second component is not needed.

HISTORY OF MODEL

The model was originally developed to simulate only an electric-powered transportation system. Later it was modified to include capabilities to simulate a diesel-powered train. The research team at Carnegie-Mellon is now in the process of creating data files to simplify data input for standard vehicles and tracks.

OPERATIONAL CAPABILITIES

This model is one of the most detailed models available. Examples of its versatile capabilities are:

● Given a schedule, it can compute an optimum operational strategy which will minimize fuel usage.

● The train is split in cells to allow accurate simulation of a long train traversing a profile with many short length grades and curves.

● A complete graphic package is provided.

● It has the ability to predict the affect of track class on train resistance and, hence, on fuel usage.

Results of Simulation: Primary variables describing energy consumption, power demand, speed vs. position, time vs. position and cost of energy for a given schedule.

Structure: The program contains two components: The Train Performance Simulator and The Electric Network Simulator. An optional Energy Cost Simulator can be added if desired. For an application dealing with diesel-powered trains, the second component is unnecessary. Each component incorporates a large number of modules, which are easy to change. Also, the Train Performance Simulator has been designed to interact with the automated control and Optimization Program so that optimum speed profiles, etc. can be determined and tested.

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ASSUMPTIONS

There are no major assumptions made in the program.

LIMITATIONS

The developers of the program are in the process of constructing libraries for track, freight car and locomotive data. Until these libraries are made available, the data input will take some effort.

DATA INPUT REQUIREMENTS

The following input parameters are required:

1. The physical characteristics of the train, e.g., weight, length, cross-sectional areas, etc.

2. The Performance Characteristics of the propulsion system, e.g. gallons/minute as a function of notch position, speed and tractive effort (if not available, gallons/minute as function of horsepower).

3. Vehicle braking system characteristics.

4. Transportation system layout, e.g., track, terminal, station location.

5. Track profile, e.g., speed limits, grade, curvature, etc. Also, PSD of track geometry variations, if available; otherwise, track class (1-6).

6. Train time table.

7. Control philosophy, e.g., acceleration-braking rates.

ADVANTAGES

This model is one of the most detailed models available. Also, it is structured in such a way that one can simulate as simple a case or as complicated a case as one wants to. The structure allows significant flexibility in changing and modifying parts of the program.

VALIDATION

The following validation tests have been performed:

● The Washington Metro Blue and Red Lines test in which the energy consumption was predicted within ±3%.

● The Metroliner test in which the energy consumption was predicted within ±5%.

● The Amtrak tests on 5 passenger train routes in which the energy consumption was found to be within ±5% of predicted values.

COMPUTING REQUIREMENTS

The program is written in FORTRAN to run on DEC-20 and VAX computers. A typical 50 mile run will use 15 seconds of CPU. It uses 60k Byte of space.

AVAILABILITY

The program is available to any user, in any format desired. For $625, the university will provide the tape, guideline books, and test cases.

TITLE	A Multi-Purpose Train Performance Calculator (TPC)
DATE	December 1978
AUTHORS	R. Mittal and A. Rose
ORGANIZATION	EE/CS Department Union College Schenectady, New York 12308
SPONSORS	U.S. Department of Transportation Federal Railroad Administration Washington, D.C. 20590
TRANSPORTATION MODE	Passenger Train
APPLICATION	Civilian
OBJECTIVE	The program simulates the operation of a passenger train over a rail route and predicts route schedule and fuel use.
REFERENCE	Heilman, H., Kahrs, C., and Williams, G., "A Multi-Purpose Train Performance Calculator, Volumes 1 and 2", prepared by Union College, Schenectady, prepared for the U.S. Dept. of Transportation, Federal Railroad Administration, Washington, D.C. 20590.
RELATIONSHIP TO OTHER MODELS	Although this program is similar to other train performance calculator programs, it seems to have been developed entirely at Union College.
OPERATIONAL CAPABILITIES	Results of Simulation: The TPC output is in the form of tables showing speed, time, fuel used, and energy consumption to reach each station along the route. In addition, plots of speed, time and fuel versus distance travelled are generated. Structure: TPC is designed to run in a batch-processing environment in which its input comes from data cards or from on-line disk files containing locomotive data, car data and track data.

The program is modular in structure with fifteen subroutines supporting the main program.

The train is treated as a point mass which is acted on by accelerating and retarding forces. The resulting acceleration (or retardation), speed, location and energy used are then calculated at each time interval. Two guidelines are followed in simulating the operating cycle:

- accelerate to the speed limit, using maximum effective motive power, and

- brake at the maximum rate permitted to maintain passenger comfort.

ASSUMPTIONS

The program assumes that the train can be modelled as one lumped mass. This is probably adequate to describe a relatively short passenger train (i.e., it would not be so for long freight trains).

The fuel consumption in gallons/hour is assumed to depend only on percent of available tractive effort being used at any instant. Also, the transmission efficiency is assumed to depend only on the speed of the train.

LIMITATIONS

1. The program uses the Davis' equation for calculating train resistance, which is accurate only up to speed of 50 mph. A more accurate equation (such as that developed by Tuthill) can be incorporated only by a program change.

2. Like in most programs of this type, the fuel consumption characteristic of the locomotive is not calculated explicitly from the design parameters, but has to be provided as a function of percentage tractive effort.

DATA INPUT REQUIREMENTS

Locomotive Data: The data for the most popular locomotives are already provided. For a locomotive not in the list, the following data are required:

- Weight in tons,
- Length in feet,
- Frontal area in square feet,
- Auxiliary power in kilowatts,
- Maximum traction horsepower,
- Fuel consumption in gallons/hour of auxiliary generators
- Tractive effort and transmission efficiency for each mph value from 0 to 120 mph, and
- Fuel consumption in gallons/per hour corresponding to each percent of its available tractive force.

Car Data: The data for the most popular rail cars are already provided. For a coach not in the list, the following parameters are required:

- Values of coefficients for the Davis'equation
- Car weight in tons,
- Car length in feet,
- Passenger capacity, and
- Frontal area in square feet.

Track Data: The following data are required for each track segment:

- Length,
- Grade,
- Curvature, superelevation,
- Speed limit for passenger train,
- Mile post,
- Station name, and
- Compensated grade (for a section with both grade and curve).

ADVANTAGES

This program is written specifically to simulate a limited case of passenger train operation. The advantages of making it so specific are:

- The data for most commonly used locomotives and coaches are already provided.

- The requirements which are specific to a
  passenger train operation, such as auxiliary
  power usage, are included in the program.
  This makes the fuel use prediction more
  accurate than if a freight train program were
  used for this application.

VALIDATION   The program has been used to study the energy
                              intensity of AMTRAK trains in the New York to
                              Buffalo corridor. Although the program is claimed
                              to predict the schedule quite accurately, no
                              information is available on the accuracy of its
                              fuel use predictions for those runs.

                              The program has been validated against TSC's Train
                              Performance Simulator.

COMPUTING REQUIREMENTS   The program is writen in FORTRAN and is designed
                              for execution in a medium-sized machine. The model
                              has been implemented on a Burroughs B-6700 at Union
                              College and on DEC-10 at the Transportation Systems
                              Center (TSC), U.S. DOT, Cambridge, Massachusetts.

AVAILABILITY   The program is available to any user. It is
                              available from TSC on the same tape as TSC's Train
                              Performance Simulator for a total price of $150.

TITLE	Train Operations Simulator (TOS)
DATE	1983 (Latest update)
AUTHOR	N.W. Luttrell
ORGANIZATION	The Southern Pacific Transportation Company
SPONSOR	The Track-Track Dynamics Program AAR
TRANSPORTATION MODE	Railway
APPLICATION	Civilian
OBJECTIVE	To simulate the performance of a diesel-electric locomotive and conventional freight car running over a specified territory. The user has the option of having the program calculate the in-train forces developed during the run or calculate the amount of fuel consumed.
REFERENCE	Luttrell, N.W., et al, "Train Operations Simulator, User's Manual, Track-Train Dynamics," Release 4.20, the Association of American Railroads (AAR) Technical Center, Chicago, IL, 1983.
RELATIONSHIP TO OTHER MODELS	Independently developed as a part of Track-Train Dynamics Research Program.
HISTORY OF MODEL	The TOS is one of the most widely used models in the industry. Initially developed to study train make-up and train handling, it is now capable of providing estimates of fuel consumption of a train over a given track.
OPERATIONAL CAPABILITIES	The program is exceptionally detailed in modeling the behavior of air brakes and dynamic braking. Also, the train handling instructions can be provided explicitly in terms of throttle and brake settings and specifications. An automatic train operation option is also provided, which attempts to operate the train over the specified track in the minimum running time. Finally, a relatively sophisticated method is used to estimate wheel/rail adhesion.

The program can be run either to calculate in-train forces or the amount of fuel consumed.

Results of Simulation:

When the program is used to calculate fuel consumption, the output includes:

- time,
- mile post,
- distance,
- speed limit,
- throttle position,
- actual speed,
- status of the air brake system,
- accumulated fuel consumption, and
- load factor (which indicates how "hard" the locomotives are working)

ASSUMPTIONS

- Tracks are considered to be perfect

- An arbitrary division between vehicle and load weight is made

- Locomotive tractive effort and dynamic braking data are approximated by linear, quadratic, and hyperbolic curve segments.

LIMITATIONS

1. Due to the detail and flexibility inherent in TOS, its execution time is higher than most other fuel consumption models.

2. TOS assumes perfect track. Thus, the effects of track irregularities on fuel consumption cannot be simulated.

3. There are still some bugs in the program which are being fixed.

4. The plotting routines require an inordinate amount of computer time.

5. Under the automatic operation command, the throttle position may advance unrealistically fast.

DATA INPUT REQUIREMENTS

The following input parameters are needed:

1. Title Information

2. Track Data
   - Direction
   - Speed limits and station names
   - Curvature data
   - Elevation data

3. Vehicle data
   The vehicle consist can be specified by either utilizing standard vehicle library or by entering relatively detailed vehicle characteristics. Data required in the latter case includes weight, lengths and specifications of coupler and brake systems, Davis equation coefficients, etc.

   For locomotives, additional data are required including tractive and dynamic braking data.

ADVANTAGES

One advantage of TOS is its ability to simulate various methods of train handling and its effects on fuel consumption. Most other programs do not have this option; they simulate automatic operation in which the train's running time is minimized within the constraints of the speed limits. The program, on the other hand, may be more expensive to run than the other programs.

VALIDATION

Many railroads are using the TOS program including Burlington-Northern, Chicago & North Western, CONRAIL, CSX, Illinois Central Gulf, Norfolk Southern, and Western Pacific. The fuel calculations have been hand checked.

COMPUTING REQUIREMENTS

Various versions of the program are available to run on IBM, DEC-20, PRIME and Burroughs computers. It needs 12 cpu sec. to produce fuel consumption estimates for one mile of track.

AVAILABILITY

The program is available to any user for $50, AAR
will provide a tape and the following four
documents.

⊚ User's manual (to run the program).

⊚ Technical manual (to understand the model).

⊚ Programming manual (to make changes).

⊚ Validation report (TOS against a Southern
   Pacific test train).

TITLE   Train Performance Calculator - AAR

DATE   Mid 1960s

AUTHOR   Operated by Stuart McEwan at AAR.

ORGANIZATION   Association of American Railroads (AAR)

TRANSPORTATION MODE   Freight and Passenger Trains

APPLICATION   Civilian

OBJECTIVE   To predict energy usage of a train with a
                               diesel-electric, an electric or a steam propulsion
                               system.

REFERENCES   Anon., "User's Manual for NRPC Train Performance
                               Calculator," AAR. Available from Stuart McEwan
                               (312-567-3593).

RELATIONSHIP TO   This model is a FORTRAN rewrite of Canadian
OTHER MODELS   National Railway's TPC.

OPERATIONAL CAPABILITIES   This model uses the original Davis formula for
                               obtaining resistance of diesel-electric locomotives
                               and passenger cars. The power being used at any
                               instant is compared with the maximum power
                               available at that velocity. The resulting load
                               factor provides fuel consumption. Just one
                               tractive effort curve is provided.

ASSUMPTIONS   1. The original Davis formula is used for
                                  calculating train resistance. This is accurate
                                  only at low speeds.

                               2. Only one tractive effort curve is used.

LIMITATIONS   No provision for throttle position changes.

DATA INPUT REQUIREMENTS   Locomotive, car, and track data are input from
                             cards, with one card for each type of car and
                             locomotive and separate track cards for speed,
                             temporary orders, curvature and elevation.

ADVANTAGES   ● Available in the public domain.

                             ● A relatively fast program.

VALIDATION   The program has been used by several railroads, but
                             no information on validation is available.

COMPUTING REQUIREMENTS   The program is available in CDC 3500, IBM-370, and
                             DEC-20 versions. One minute of CPU time is used
                             for every 10 miles of track.

AVAILABILITY   The program is available to any user for the cost
                             of writing the program on a user supplied tape and
                             the cost of mailing the tape.

TITLE	Train Performance Calculator – AiResearch
DATE	February 1979
AUTHORS	J. J. Lawson and L. M. Cook
ORGANIZATION	AiResearch Manufacturing Company of California
SPONSORS	Initially, Department of Transportation Federal Railroad Administration. Subsequently, internally funded.
TRANSPORTATION MODE	Passenger and Freight Trains
APPLICATION	Civilian
OBJECTIVE	This model was developed to provide train performance calculations required by the FRA-sponsored wayside energy storage study. It was then extensively modified to simulate dual mode locomotive.
REFERENCES	Lawson, J.J., and Cook, L.M., "Wayside Energy Storage Study, Volume II -- Detailed Description of Analysis", Final Report, Report No. FRA/ORD-78/78, II, Department of Transportation, Federal Railroad Administration, Washington, D.C., February 1979.
RELATIONSHIP TO OTHER MODELS	None
OPERATIONAL CAPABILITIES	The TPC was designed to perform analysis of long-haul freight service, with an emphasis on energy and power demand requirements of multi-train operations. It can also be used to analyze intercity rail passenger service. The program simulates a diesel, electric, electric with regeneration or mixed mode operation.
ASSUMPTIONS	The train is modeled as a single point mass. The train resistance equation is the Modified Davis Formula.
LIMITATIONS	It is a proprietary model.

DATA INPUT REQUIREMENTS

Characteristics of the locomotives and rolling stock are internal program parameters. Route and Schedule data are input from a card reader or from disk or tape file in card-image form.

ADVANTAGES

This model is quite detailed. For example, drag calculations are performed for each car. Also, it can simulate diesel, electric or mixed mode operations.

VALIDATION

Calculations of energy usage were found to be within 6% of actual measured usage.

COMPUTING REQUIREMENTS

The program is written for a Univac-1108 computer in ANSI Fortran. A 1500 mile run takes 3-4 minutes on the Univac computer. The company is willing to provide a tape to run on any machine.

AVAILABILITY

The original program written for the U.S. DOT was significantly modified. This modified program and its documentation are considered proprietary by AiResearch. The company will, however, be willing to negotiate if a user is interested in acquiring the program.

TITLE	Hitachi Model
DATE	1972
AUTHORS	Mizushima, K., Nagai, M., and Asada, T.
ORGANIZATION	Hitachi Shipbuilding, Ltd., Osaka
SPONSOR	Same as above
TRANSPORTATION MODE	All modes
APPLICATION	Civilian or Government
OBJECTIVE	To predict thermodynamic performance of 2-stroke and 4-stroke diesel engines, including scavenging, exhaust, and turbocharger phenomena.

REFERENCES

Mizushima, K., Nagai, M., and Asada, T., "Some Analyses of Diesel Engine Performance by Means of Computer Simulation," J. MESJ, Vol. 1, No. 5, p. 35 (1972).

See also J. MESJ, Vol. 6, No. 9, p.49 (1971) and Nagui, Mizushima, and Asada, J. MESJ, Vol. 5, No. 1, p. 41 (1970).

RELATIONSHIP TO
OTHER MODELS

The authors paid close attention to the 1960-1961 work of Austen and Lyn.

HISTORY OF MODEL

Developed specifically for medium and large bore marine diesels (turbocharged); this early model is a rare combination covering.

- Intake and exhaust flows; and
- Detailed combustion rates.

OPERATIONAL CAPABILITIES

Results of Simulation:
- Direct Injected Engines
- Calculates Intake and Exhaust Flows
- Calculates Thermal Efficiency and Fuel Consumption (isfc)
- Calculates Heat Transfer to Walls

Structure: List of Submodels or processes
included.
- Intake, exhaust
- Blower, turbocharger
- Ignition delay
- Combustion rate
- Gas properties
- Heat transfer
- Scavenging

ASSUMPTIONS

Intake, exhaust: Flow coefficients

Supercharger: specified blower characteristics

Ignition delay: Arrhenins Law, pressure
coefficient minus .624.

Combustion rate/mixing of air-fuel: Two-stage
combustion, semi-empirical, Weibe function.

Fuel-air ratio of burned gas: Not treated.

Gas properties: Polynominal functions.

Heat transfer: Separate wall temperatures for
various components, depend on load. Pflamm
(1961) expression.

NO_x Model: Not included.

Soot Model: Not included.

Burned gas mixing: Not included until scavenging
process.

LIMITATIONS

(1) Inadequate treatment of fuel-air mixing and
gas temperature non-uniformities: Fuel spray
not modelled; burning rates must be specified
empirically.

(2) Inadequate treatment of heat transfer:
- Heat transfer coefficient is different for
each load
- No radiation, no boundary layer; and
- No gas temperature gradient.

(3)   Inadequate treatment of burned gas mixing.

(4)   Soot, NO_x not modelled.

(5)   "Combustion efficiency" of about 92% to 97% had to be assumed, depending on load.

DATA INPUT REQUIREMENTS

Geometrical and Design Parameters:
- Bore
- Stroke
- Conn. rod length
- Chamber volume
- Valve areas vs. time

Coefficients:
- Flow coefficients and turbine efficiency
- Scavenging coefficient
- Heat transfer coefficient
- Combustion duration and rate

Operating Parameters:
- Load
- Speed
- Injection timing
- Intake manifold temperature
- Intake manifold pressure
- Injection rate
- Cylinder wall temperatures for each area

ADVANTAGES

◉ Covers entire cycle including intake and exhaust

◉ Has realistic heat release patterns and, therefore, predicts cylinder pressure accurately.

VALIDATION

Engine description:

(1)   2-stroke
(2)   4-stroke

Variables tested; model agreement: Predictions of cylinder pressure, gas flow rate, and exhaust temperature as function of crank angle agree well with data.

Assessment of accuracy: Sufficient degree of accuracy for the intended purpose of the model.

COMPUTING REQUIREMENTS   Unknown

COST OF OPERATION   2 minutes of CPU time at $60 to $100/min (estimated)

FUTURE POTENTIAL   - Pulsations in exhaust
                                - Emissions
                                - Improved heat transfer model

AVAILABILITY   Presumably this model is unavailable to the public since Hitachi is a competitive shipbuilder.

TITLE   University of Manchester, Institute of Science and
                              Technology (UMIST)

DATE   1976, 1981

AUTHORS   Winterbone, Loo, Benson, Wellstead, Thiruarooran

ORGANIZATION   University of Manchester

SPONSOR   Unknown

TRANSPORTATION MODE   All modes

APPLICATION   Civilian or Government

OBJECTIVE   To describe the transient response of diesel
                              engines, including turbocharger speed, to load
                              application.

REFERENCES   (1) Winterborne, D.E., Wellstead, P.E., and
                                   Thiruarooran, C., "A Wholly Dynamic Model of
                                   a Turbocharged Diesel Engine for Transfer
                                   Function Evaluation," SAE Paper 770123
                                   (1977).

                              (2) Winterbone, D.E., and Loo, W.Y., "A Dynamic
                                   Simulation of a Two-Stroke Turbocharged
                                   Diesel Engine," SAE Paper 810337 (1981).

                              (3) Benson, R.S., "A Comprehensive Digital
                                   Computer Program to Simulate a Compression
                                   Ignition Engine, Including Intake and Exhaust
                                   Systems, SAE Paper 710173 (1971).

RELATIONSHIP TO   The University of Manchester, starting with
OTHER MODELS/HISTORY   Benson's steady-state model in 1971, has concen-
OF MODEL   trated on diesel models which treat the transient
                              turbocharger matching problem. The three papers
                              summarized here cover digital computer models; see
                              also the analogue simulations covered in Benson,
                              Winterbone and Shamsi (1976), and Winterbone,
                              Benson, Closs, and Mortimer (1976).

OPERATIONAL CAPABILITIES

Results of Simulation:
- Direct Injected Engines
- Calculates Transient Intake and Exhaust Flows
- Calculates Compressor Outlet Pressure and Temperature
- Turbine Inlet Pressure and Temperature
- Turbocharger speed and air flow rate
- Calculates turbocharger performance

Structure: List of Submodels or processes included.
- Air receiver (intake manifold)
- Exhaust manifold with wave action
- Turbocharger compressor
- Turbine
- Scavenge blower (roots)
- Intercooler
- Engine system (combustion rate, gas properties, heat transfer)

ASSUMPTIONS

- Compressor: Specified characteristics.
- Roots blower: Orifice plus positive displacement.
- Scavenging: Perfect mixing.
- Intake exhaust: Orifice equations, quasi-steady
- Intercooler: Pressure drop and cooling
- Turbine: Specified efficiency and flow rate as function of pressure ratio.
- Ignition delay: Prescribed.
- Fuel spray evaporation: Not treated.
- Combustion rate/mixing of air-fuel: Simplified prescribed model based on Whitehouse and Way (1969).
- Fuel-air ratio of burned gas: 2-zone system.
- Gas properties: Moles change is accounted for; polynominal functions. Perfect ideal gas during intake and exhaust.
- Heat transfer: Annand expression.
- No_x Model: Not treated.
- Soot Model: Not treated.
- Burned gas mixing: Not treated.

LIMITATIONS

(1) Not intended to cover engine combustion variables.

    (a) Inadequate treatment of fuel-air mixing and gas temperature non-uniformities

    (b) Inadequate treatment of heat transfer

    (c) Inadequate treatment of burned gas mixing

    (d) Soot, No_x not covered.

(2) Underestimates scavenging.

(3) Speed effect of turbine not modelled well.

DATA INPUT REQUIREMENTS

Geometrical and Design Parameters:
- Bore
- Stroke
- Conn. rod length
- Chamber volume
- Valve areas vs. time
- Manifold geometry
- Compressor and turbine characteristics
- Intercooler performance

Operating Parameters:
- Load
- Speed
- Injection timing
- Intake manifold temperature
- Intake manifold pressure
- EGR or residual fraction

ADVANTAGES

Primary advantage is for detailed design and development of turbochargers and intake/exhaust systems.

VALIDATION

(1) Engine description: GM, 6-cylinder, 2-stroke turbocharged engine, Model 6V-TAE.

(2) <u>Variables tested; model agreement</u>: In steady state, predicted power to 1.4%, compressor outlet pressure to 4.9%, turbine inlet pressure to 10%, turbocharger speed to 5%, and air flow to 7%.

(3) <u>Assessment of accuracy</u>: Model not tested in transient mode. Therefore, accuracy is unknown.

COMPUTING REQUIREMENTS   Fortran IV. Fourth-order Runge-Kutta solution.

COST OF OPERATION   4 minutes of CPU time at $60 to $100/min (estimated)

FUTURE POTENTIAL   (1) Model needs to be validated against transient engine data.

                                          (2) Would be advisable to add a transient smoke model to predict "puffs."

AVAILABILITY   Presumably available at cost. University of Manchester has a robust consulting activity with UK industry.

TITLE   Manchester (Whitehouse)

DATE   1971 - 1977

AUTHORS   Whitehouse, N.D., Way, R.J.B., Sareen, B.K.,
                                Clough, E., Abughres, S.M., and Baluswamy, N.

ORGANIZATION   University of Manchester, Inst. of Science and
                                Technology (UMIST)

SPONSOR   Science Research Council, UK

TRANSPORTATION MODE   All modes

APPLICATION   Civilian or Government

OBJECTIVE   To predict performance and NO_x emissions of a
                                direct injection diesel engine based on a simpli-
                                fied fuel spray model.

REFERENCES   (1) Whitehoue, N.D. and Way, R.J.B., "Rate of
                                    Heat Release in Diesel Engines and its
                                    Correlation with Fuel Injection Data,"
                                    Symposium on Diesel Engine Combustion, IME,
                                    April 1970. Covers essentially the same
                                    material as SAE Paper 710134,1971.

                                (2) Whitehouse, N.D., and Sareen, B.K.,
                                    "Prediction of Heat Release in a Quiescent
                                    Chamber Diesel Engine Allowing for Fuel/Air
                                    Mixing," SAE Paper 740084, 1974.

                                (3) Whitehouse, N.D., Clough, E., "The Effect of
                                    Changes in Design and Operating Conditions on
                                    Heat Release in Direct-Injection Diesel
                                    Engines," SAE 740085, 1974.

                                (4) Whitehouse, N.D. and Abughres, S.M.,
                                    "Calculation of Fuel-Air Mixing in a Diesel
                                    Engine with Swirl for the Purpose of Heat
                                    Release Prediction," IME Publication C97/75,
                                    1975.

                                (5) Whitehouse, N.D. and Baluswamy, N.,
                                    "Calculation of Gaseous Products of Combustion
                                    in a Diesel Engine Using a Four-Zone Model,"
                                    SAE Paper 770410, 1977.

RELATIONSHIP TO
OTHER MODELS/HISTORY
OF MODEL

In 1970, Whitehouse (NDW, hereafter) published an empirical burning rate model with all the gas in a single zone.

In 1974, NDW and Sareen extended this to a two-zone model which gives more realistic hot-zone temperature.

In 1975, Abughres and NDW extended the two-zone model to account for swirl effects.

In 1977, Baluswamy and NDW extended the two-zone model to four zones, in order to achieve enough temperature resolution to attempt NO_x emission predictions.

OPERATIONAL CAPABILITIES

Output of Simulation:
- Direct injected engines
- Calculates thermal efficiency or fuel consumption (isfc)
- Calculates heat transfer to walls
- Calculates emissions (NO_x only)
- Calculates fuel jet mixing with air

Structure: (List of submodels or processes included):
- Intake, exhaust
- Fuel injection (specified)
- Fuel-air mixing
- Ignition delay
- Combustion rate
- Gas properties
- NO_x model
- Heat transfer

ASSUMPTIONS

Intake, exhaust:
Incompressible flow through valves, taken from Baruch (1973).

Fuel spray evaporation:
Instantaneous evaporation assumed. No droplet atomization included.

Ignition delay:
Specified delay period.

Mixing of air-fuel:
Conical gaseous fuel jet entrains air (specified
coefficient) according to Sareen and NDW (1974)
model. Wall impingement effects included.

Combustion rate:
Taken from Whitehouse and Way (1970), the com-
bustion rate expression is semi-empirical and
requires five coefficients (K_1, ℓ, m, K_2, and
"act").

Fuel-air ratio of burned gas divided into two
zones:
(1) Stoichiometric burning zone and (2) products/
air zone which is lean.

Gas properties:
Taken from Baruch (1973) and Vickland (1962)

Heat transfer:
Annand (1963) type of correlation for convective
heat transfer, plus radiation proportional to the
amount of carbon present in each zone.

NO_x model:
Extended Zeldovich Kinetics.

Burned gas mixing:
Arbitrary mixing coefficient.

LIMITATIONS

(1) Treatment of fuel-air mixing and gas tempera-
    ture non-uniformities is quite simple: all
    burned gas is at only two temperatures. This
    limits the NO_x predictive capability.

(2) Treatment of heat transfer has over-
    simplified radiation and no boundary layer
    effects are included.

(3) Treatment of burned gas mixing is arbitrary
    in that the user specifies mixing coefficients
    for exchange of gas between zones.

(4) Soot production is not modeled.

(5) Burning rate expression has an Arrhenius term, which is not consistent with diffusion-controlled combustion.

(6) Excessive number of specified coefficients.

DATA INPUT REQUIREMENTS

Geometrical and Design Parameters:
- Bore
- Stroke
- Connecting rod length
- Chamber volume
- Valve areas vs. time

Model Coefficients:
- Jet entrainment coefficients (2)
- Burning rate coefficients (5)
- Burned gas entrainment rate (1)

Operating Parameters:
- Load
- Speed
- Injection timing
- Intake manifold temperature
- Intake manifold pressure
- EGR or residual fraction
- Injection rate
- Swirl level

ADVANTAGES

(1) Relatively simple and inexpensive

(2) Attempts to include the temperature differences in the combustion space in a very simple manner.

VALIDATION

Engine description:
130 psi bmep, 500 RPM

Variables tested; model agreement:
Timing, speed, number of injector holes

Assessment of accuracy:
Only tested at part load; agreement was fair.
Needs further development and testing.

COMPUTING REQUIREMENTS   Not specified

COST OF OPERATION   1 minute of CPU time at $60 - 100/min
                                      (Estimated)

FUTURE POTENTIAL   More than four zones are needed in the
                                      model. Future potential is limited.

AVAILABILITY   Unknown

TITLE   The Problem of Predicting Rate of Heat Release in
                               Diesel Engines

DATE   1970

AUTHORS   H.C. Grigg and M.H. Syed

ORGANIZATION   C.A.V. Ltd., Acton, England

SPONSOR   C.A.V. Limited

TRANSPORTATION MODE   Engine model applicable to all modes.

APPLICATION   Civilian

OBJECTIVE   This relatively simple model was developed to
                               predict rate of heat release diagrams based upon
                               approximations of the physical factors involved.
                               The model is based on the process of air entrain-
                               ment into fuel sprays, turbulent mixing in fuel
                               sprays, and chemical kinetics. Constants were
                               chosen such that the predicted rate of heat release
                               fit experimental data. The experimental data used
                               were diesel engine rate of heat release diagrams
                               calculated from cylinder pressure records furnished
                               from tests on a turbo-charged Dorman 6LBT engine.

REFERENCES   Grigg, H.C. and M.H. Syed, "The Problem of
                               Predicting Rate of Heat Release in Diesel Engines,"
                               Symposium on Diesel Engine Combustion, London,
                               April 7-9, 1970, Institution of Mechanical
                               Engineers.

OPERATIONAL CAPABILITIES   Model Description:

                               The following factors are the basis of this rate of
                               heat release model:

                               1. Ignition delay (experimentally determined)

                               2. Engine dimensions including nozzle hole diameter
                                  and number of holes

                               3. Period of injection (experimentally determined)

4. Rate of entrainment of air into sprays. The rate of entrainment is calculated by use of the Schweitzer formula for which it is assumed that the entrained air has the same velocity as the fuel droplets. Modifications are made to allow for air density changes arising from the piston motion during the development of the fuel spray by assuming that the fuel spray expands radially about its axis to maintain the equal pressure inside and outside the spray.

The fuel spray was considered in two different forms: a set of conical plumes, issuing from the nozzle holes (the Schweitzer configuration) and an expanding doughnut of spray fed from a central nozzle. In the conical plume model the spray develops unimpeded as in an infinite atmosphere in a conical form. This is justified by recognizing that the air motions in an engine cylinder turn the spray so that it maintains a conical form with a bent axis. The cone angle of the plumes is a function of air density.

In the doughnut model it is assumed that the doughnut cross-sectional area and circulating velocity relative to the surrounding air vary to conserve momentum. The rate of entrainment of air is the same as for a fuel spray of similar cross-sectional area and velocity relative to the surrounding air. The doughnut cross-sectional area is zero at the beginning of injection and increases as it is fed fuel and momentum from the central nozzle. At the end of injection no further momentum is added, but the cross-sectional continues to expand by entraining air.

5. Rate of turbulent mixing of fuel and air. It is assumed that the regions of weak mixture consist solely of air, and the regions of rich mixture consist solely of fuel vapor. The concentrations of fuel or air, or mixed fuel and air, are calculated by dividing the total mass of the component in the spray by the total instantaneous volume of the spray.

The turbulent mixing of fuel vapor and air within the body of the fuel spray is represented by a diffusion process. To simplify the treatment, the mean rate of diffusion per unit volume of the spray is equated to the concentration of the component (air or fuel vapor) which is diffusing, multiplied by a diffusivity coefficient.

6. Rate of burning of fuel based on chemical rate of fuel is calculated by an Arrhenius type formula in which the specific rate of burning is proportional to the product of mean concentrations of turbulently mixed fuel and air, and is a function of temperature. The temperature is calculated from the pressure and cylinder volume.

The use of mean concentration of mixed fuel and air implies that the jet is geometrically similar from time to time.

Results of Simulation - Calculates rate of heat release. Calculates rate of air entrainment into the spray for the conical plume model.

ASSUMPTIONS

Swirl has no effect on the mixing rate, apart from turning the spray to prevent it hitting the wall of the combustion chamber.

LIMITATIONS

Droplet evaporation is not evaluated separately.

DATA INPUT REQUIREMENTS

Geometrical and Design Parameters:

1. Bore
2. Stroke
3. Nozzle hole size
4. Number of nozzles

Operating Parameters:

1. Speed
2. Instantaneous compression ratio
3. Inlet manifold air conditions
4. Volumetric efficiency
5. Mean fuel injection pressure
6. Period of injection

TITLE	Wisconsin Diesel Spray Combustion Model
DATE	1969
AUTHORS	Shipinski, Myers, and Uyehara
ORGANIZATION	University of Wisconsin
SPONSOR	Unknown
TRANSPORTATION MODE	All modes
APPLICATION	Civilian or Government
OBJECTIVE	To predict the burning rate of a diesel spray as a function of fuel injection parameters.

REFERENCES

(1) Shipinski, J., Myers, P.S., and Uyehara,, O.A., "A Spray-Droplet Model for Diesel Combustion," Proc. IME, Vol. 184, Part 3J, p. 28, 1969.

(2) Shipinski, J.H., "Relationships Between Rates-of-Injection and Rates-of-Heat Release in Diesel Engines," Ph.D. Thesis, University of Wisconsin, 1967.

RELATIONSHIP TO OTHER MODELS/HISTORY OF MODEL

Shipinski's model was the forerunner of the current diesel models which attempt to describe the spray combustion in detail (Ultrasystems, Cummins, Hiroshima). He attempted to extend the work of Lyn (1961) on diesel burning rates, by using the gas turbine spray results of Probert (1946) and Tanasawa (1953).

OPERATIONAL CAPABILITIES

Results of Simulation:
- For direct injected engines
- Calculates fuel spray evaporation and mixing with air
- Calculates thermal efficiency or fuel consumption (isfc)
- Calculates heat transfer to walls

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Structure: List of submodels or processes
included.
- Fuel injection and atomization
- Fuel evaporation
- Ignition delay
- Combustion rate
- Gas properties

ASSUMPTIONS

Intake, exhaust: Not included

Fuel spray evaporation: Tanasawa (1953) dropsize
distribution and vaporization coefficient C_b.

Ignition delay: Correlation of Wolfer (1939)

Combustion rate/mixing of air-fuel:

(a) Premixed combustion stage occurs at specified
rate.

(b) Vaporization – limited combustion occurs
according to a single droplet law with a
specified burning coefficient C_E which
depends on A/F, P, rpm, and temperature.

Fuel-air ratio of burned gas: 2-zone model

Gas properties: Standard tables

Heat transfer: Treated implicitly

No_x Model: Not included

Soot Model: Not included

Burned gas mixing: Not included – all burned gas
in single zone.

LIMITATIONS

(1) No attempt to cover the air entrainment or
variations in A/F ratio of burned gas and
resulting gas temperature non-uniformities.

(2) Treatment of heat transfer is not clear from the paper; however, it can be surmized that the heat transfer model is not based on radiation or boundary layer details.

(3) Emissions (soot, NO_x) are not covered.

(4) Closed cycle only; intake and exhaust processes not included.

DATA INPUT REQUIREMENTS

Geometrical and Design Parameters:
- Bore
- Stroke
- Conn. rod length
- Chamber volume

Model Coefficients:
- Vaporization coefficient C_b
- Burning coefficient C_F

Operating Parameters:
- Load
- Speed
- Injection timing
- Intake manifold temperature
- Intake manifold pressure
- Residual fraction
- Injection rate
- Fuel orifice size and number
- Fuel injection pressure

ADVANTAGES

(1) Covers the effect of fuel injection variables such as hole size and injection pressure on the combustion rates.

(2) Emphasizes physical mechanisms of spray combustion rather than empiricism.

VALIDATION

Engine description: 2,000 rpm, 175 imep, automotive diesel (4.5 in bore, 4.5 in stroke)

Variables tested; model agreement: Predicted cylinder pressure vs. crank angle showed good agreement with data.

Assessment of accuracy: Fair accuracy and more flexibility than empirical models such as Woschni.

COMPUTING REQUIREMENTS   Not specified.

COST OF OPERATION   0.5 minutes of CPU time at $60 to $100/min (estimated)

FUTURE POTENTIAL   This early work provided a foundation for many of the state-of-the-art diesel models.

AVAILABILITY   Presumably could be obtained from Prof. Borman at Wisconsin, or from Shipinski, who is at John Deere, Waterloo, Iowa.

TITLE   Imperial College (Watson)

DATE   1977-1980

AUTHORS   Watson, N., and Marzouk, M.

ORGANIZATION   Imperial College, Dept. of M.E., London

SPONSOR   Unknown

TRANSPORTATION MODE   All modes

APPLICATION   Civilian or Government

OBJECTIVE   To correlate diesel performance with operating
                                parameters.

REFERENCES   (1) Marzouk, M. "Transient Response of Turbo-
                                    charged Diesel Engines," Ph.D. Thesis,
                                    University of London, 1976.

                                (2) Watson, N., and Marzouk, M., "A Non-Linear
                                    Digital Simulation of Turbocharged Diesel
                                    Engine Simulation," SAE Paper 770123, 1977.

                                (3) Watson, N., Pilley, A.D., and Marzouk, M.,
                                    "A Combustion Correlation for Diesel Engine
                                    Simulation," SAE Paper 800029, 1980.

RELATIONSHIP TO OTHER   Similar to the approaches of Shipinski et al
MODELS/HISTORY OF MODEL   (1968) and Woschni and Anisits (1974), this
                                simulation does not describe the fuel-air mixing
                                and combustion processes. Instead, the shape of
                                the burning rate curve is postulated. The
                                coefficients are then related to speed, load,
                                timing, air temperature, etc.

OPERATIONAL CAPABILITIES   Output of Simulation:
                                - For direct injected engines, calculates rate of
                                   pressure rise, maximum pressure
                                - Calculates intake and exhaust flows
                                - Calculates thermal efficiency or fuel
                                   consumption (isfc)

Structure: List of submodels or processes included
- Ignition delay
- Combustion rate; fuel-air mixing
- Gas properties

ASSUMPTIONS

(1) Intake, exhaust: Incompressible flow

(2) Ignition delay: Correlation based on Wolfer
($E = 4200$ cal/mole)

(3) Combustion rate/Mixing of air-fuel: Wiebe
function for diffusion-controlled burning.

(4) Gas properties: Standard tables

(5) Heat transfer: Indirectly incorporated in
choice of Wiebe function coefficients.

LIMITATIONS

(1) Does not predict temperature profiles within
the combustion space.

(2) Does not predict soot or NO_x emissions

(3) Cannot be used to predict the effect of
chamber shape, fuel injection parameters,
air swirl, etc.

(4) Requires experimental data such as cylinder
pressure trace for each specific engine to
be simulated.

DATA INPUT REQUIREMENTS

Geometrical and Design Parameters:
- Bore
- Stroke
- Connecting rod length
- Chamber volume
- Valve areas vs. time

Combustion Rate Coefficients:
- Δ (combustion duration)
- β (premixed proportion)
- Cd_1 (rate of diffusion burning)
- Cd_2 (shape parameter)

Operating Parameters:
- Load
- Speed
- Injection timing
- Intake manifold temperature
- Intake manifold pressure
- EGR or residual fraction

ADVANTAGES

(1) Relatively inexpensive

(2) Useful for extending known engine performance to changing altitude, air temperature, boost, etc.

VALIDATION

Engine descriptions:
- Engine 2 - V8, turbocharged 2600 RPM, 10.7 bar bmcp
- Engine 1 - turbocharged truck engine, 6 cyl., deep bowl, 2500 RPM

Variables correlated:
- Peak pressure
- Apparent ignition delay

Assessment of accuracy:
- 5-10 percent error in predicting the effects of pressure, turbocharger speed, air-fuel ratio.

COMPUTING REQUIREMENTS

Not specified.

COST OF OPERATION

0.5 minutes of CPU time at $60 - 100/min (Estimated)

FUTURE POTENTIAL

Model is of limited use for detailed model predictions. Not intended to be readily modified for emissions or performance design studies.

AVAILABILITY

Unknown

TITLE   Computer Simulation of a Diesel Engine:
                             I.I.T., Delhi

DATE   1974-1976

AUTHORS   Garg, R.D., Agarwal, K.K., and Desikachari, R.

ORGANIZATION   I.I.T., Delhi

SPONSOR   Indian Institute of Technology
                             (Industry-Supported)

TRANSPORTATION MODE   All modes

APPLICATION   Civilian or military

OBJECTIVE   To evaluate the accuracy of various diesel heat
                             transfer models. To predict basic thermodynamic
                             performance characteristics (imep, P_{max}, $P(\phi)$,
                             exhaust temperature, heat loss, and efficiency)
                             subject to variations in (a) timing, (b) rate of
                             heat release, (c) overall A/F, (d) engine speed,
                             (e) compression ratio, (f) air pressure and
                             temperature.

REFERENCES   (1) Garg, R.D., Agarwal, K.K., and Desikachari,
                                  R., "Computer Simulation of a Diesel Engine,"
                                  IE (India) Journal ME, Vol. 55, p. 67,
                                  November 1974.

                             (2) Garg, R.D., Gaur, R.R., and Jagota, H.,
                                  "Parametric Studies of a Four-Stroke Diesel
                                  Engine on Digital Computer," IE (India)
                                  Journal ME, Vol. 57, p. 112, September 1976.

RELATIONSHIP TO   This model, which appears to be based on the
OTHER MODELS/HISTORY   dissertation of Agarwal and Desikachari, draws
OF MODEL   from the early work of Whitehouse, et al (1962),
                             Austen and Lyn (1962), and Woschni (1967).

OPERATIONAL CAPABILITIES

Results of Simulation:
- Direct or Indirect Injected Engines
- Calculates Intake and Exhaust Flows
- Calculates Thermal Efficiency or
  Fuel Consumption (isfc)
- Calculates Heat Transfer to Walls

Structure: List of Submodels or processes
included.

Included	Not Included
Intake, exhaust	Fuel injection
Combustion rate	Fuel evaporation
Gas properties	Ignition delay
Heat transfer	Fuel-air mixing
	NO_x Model
	Soot Model
	Mixing of burned gas

ASSUMPTIONS

Intake, exhaust: The 1976 paper treats the manifold and valve phenomena as 1-D compressible, quasi-steady flow; with specified volumetric efficiency and residual fraction. Flow may be either subsonic or sonic.

Fuel spray evaporation: Not treated.

Ignition delay: Specified. Ignores effect of variables such as engine speed on the delay period.

Combustion rate: Based on Lyn (1960) and Woschni (1962). Specified triangular rate law; 40 degrees duration.

Fuel-air ratio of burned gas: Not treated. Each successive burned gas element has an individual temperature, however.

Gas properties: From Keenan and Kaye.

Heat transfer: Wall temperature assumed. Four
models examined:

- Nusselt
- Eichelberg (appeared best)
- Annand
- Woschni

NO_x Model: Not treated.

Soot Model: Not treated.

Burned gas mixing: Not treated.

LIMITATIONS

(1) Not intended to treat fuel-air mixing and
     gas temperature non-uniformities: variations
     in F/A of burned gas not treated.

(2) Inadequate treatment of heat transfer:
     Boundary layer near wall not treated. Also
     heat transfer by radiation not treated (and
     effect of soot).

(3) Does not calculate emissions (soot, No_x, HC.
     CO)

(4) Cannot predict effects of air swirl, fuel
     orifice changes, or piston shape.

(5) Arbitrarily assumes combustion efficiency is
     92% to 96%, depending on CR.

DATA INPUT REQUIREMENTS

Geometrical and Design Parameters:
- Bore
- Stroke
- Conn. rod length
- Chamber volume
- Valve areas vs. time

Model Coefficients:
- Ignition delay
- Combustion duration
- Heat transfer coefficient

Operating Parameters:
- Load
- Speed
- Injection timing
- Intake manifold temperature
- Intake manifold pressure
- Residual fraction and volumetric efficiency
- Injection rate and duration
- Cylinder wall temperature

ADVANTAGES

- Does treat the complete cycle of a four-stroke engine, including intake and exhaust processes.

- Relatively simple and inexpensive.

- Could be used to estimate effect of engine parameters on imep, efficiency.

- Interesting framework for comparing heat transfer models.

VALIDATION

Engine description:

(1) 6-cylinder, precombustion chamber, 4.58 liter, 100 HP @ 3,000 RPM, CR = 19.5

(2) 6-cycle, direct injection, 11.1 liter, 147 HP @ 2,000 RPM, CR = 15.8

Variables tested; model agreement
- Speed
- Fuel timing and duration
- Air temperature
- Stroke/bore ratio

Model agreement is fair.

Assessment of accuracy: Stated in the reference, cylinder pressure phase error of about 5 degrees is disturbing. Model only checked against power output (20% lower than measured).

3-112

COMPUTING REQUIREMENTS   Program called "ENGINE"; Fortran IV

COST OF OPERATION   Approximately 1 minute of CPU time at $60 to
                                $100/min (estimated)

FUTURE POTENTIAL   Not superior to other models of this type such as:

                                ● Manchester (Whitehouse)
                                ● Cummins (Austen & Lyn)
                                ● Wisconsin (Myers, et al)

AVAILABILITY   Presumably could be made available.

TITLE	M.A.N.
DATE	1974
AUTHORS	Woschni, G., and Anisits, F.
ORGANIZATION	M.A.N. Augsburg and Institut fur Kolbenmaschinen Technical University
SPONSOR	M.A.N.
TRANSPORTATION MODE	All modes
APPLICATION	Civilian or Government
OBJECTIVE	To predict the effect of altered operating conditions (i.e., fuel-air ratio, air temperature, engine speed, and timing) on heat release rate in a diesel engine. From heat release rate, then, one can determine thermal performance parameters such as maximum pressure, isfc, etc.
REFERENCES	Woschni, G., and Anisits, F., "Experimental Investigation and Mathematical Presentation of Rate of Heat Release in Diesel Engines Dependent Upon Engine Operating Conditions," SAE Paper 740086, 1974.
RELATIONSHIP TO OTHER MODELS/HISTORY OF MODEL	The present work developed from Woschni's earlier research into heat transfer (SAE Paper 670931, 1967), and on the computation of thermal loads on diesel engine components (MTZ Vol. 31, No. 12, p. 491, 1970). Woschni's approach relies on empirical determination of a four-parameter expression for heat release and deliberately avoids any attempt to model the fuel spray combustion mechanism.
OPERATIONAL CAPABILITIES	Results of Simulation: - Direct injected engines - Calculates cylinder pressure vs. crank angle, including pressure rise rate and maximum pressure - Calculates thermal efficiency or fuel consumption (isfc) - Calculates heat transfer to walls

Structure: List of submodels or processes
included.
- Computation starts after valves close
- Ignition delay
- Combustion rate

ASSUMPTIONS

⊚ Intake, exhaust: Not included

⊚ Fuel spray evaporation: Not included

⊚ Ignition delay: Arrhenius expression,
following Wolfer (1938).

⊚ Combustion rate/mixing of air-fuel: Weibe
function with empirical coefficients.

⊚ Fuel-air ratio of burned gas: Not included

⊚ Gas properties: Presumably standard
thermodynamic tables.

⊚ Heat transfer: Not explicitly modelled; the
Weibe function accounts for both burning rate
and heat loss rate.

⊚ No_x Model: Not included

⊚ Soot Model: Not included

⊚ Burned gas mixing: Not included

LIMITATIONS

(1) Limited treatment of heat transfer, which
is "folded" into the Weibe function, which
essentially gives the net heat release over
and above the heat lost to the walls.

(2) Does not attempt to treat fuel-air mixing or
gas temperature non-uniformities.

(3) No attempt to model emissions (soot, NO_x).

(4) Experiments required to fix coefficients for
each engine to be modelled (this is true for
most models).

Application is limited (this is true for most models).

DATE INPUT REQUIREMENTS

Geometrical and Design Parameters:
- Bore
- Stroke
- Conn. rod length
- Chamber volume
- Valve areas vs. time

Coefficients (empirical):
- Ignition delay coefficients (a,b,c)
- Effective air-fuel equivalence ratio
- Duration of combustion
- Weibe function parameter, m

Operating Parameters:
- Load
- Speed
- Injection timing
- Intake manifold temperature
- Intake manifold pressure
- EGR or residual fraction
- Cylinder wall temperature

ADVANTAGES

⊚ Very simple to use, once coefficients are determined semi-empirically.

⊚ Weibe function simulates the physical mechanisms of diesel combustion and heat transfer moderately well, even though it was developed by Weibe for spark ignition engines.

VALIDATION

Engine description:

(1) Low speed, 2-stroke engine of 39.4 in. bore.
(2) Medium speed, 4-stroke engine of 15.7 in. bore.

Variables tested; model agreement: Predicted power and peak pressure (not fuel consumption, on exhaust temperature) for variations in air temperature, air pressure, and timing.

Assessment of accuracy: ±2% on heat release, but only after experimentation to establish coefficients for each engine.

COMPUTING REQUIREMENTS

Unknown

COST OF OPERATION

0.2 minutes of CPU time at $60 to $100/min (estimated)

FUTURE POTENTIAL

Woschni is of the opinion that diesel simulations will continue to rely on empirical data. He considers the modelling of details such as atomization, fuel jet spreading, wall impingement, and local gradients of temperature/concentration to be nearly impossible (and potentially expensive, if possible).

AVAILABILITY

This simple code could be written again by any user at low cost.

TITLE   Divided-Chamber Diesel Engine Model, MIT

DATE   Completed 1981

AUTHORS   S. Hossein Mansouri; John B. Heywood, and
                             K. Radhakrishnan

ORGANIZATION   Massachusetts Institute of Technology

SPONSOR   General Motors Corporation

TRANSPORTATION MODE   Highway

APPLICATION   Civilian

OBJECTIVE   The model was developed for a divided-chamber
                             automotive diesel engine which describes the
                             intake, compression, combustion and expansion, and
                             exhaust processes in sufficient detail to permit
                             calculations of pressure, fuel-air ratio
                             distribution, heat release distribution, NO
                             formation, particulate mass loading, and
                             particulate oxidation processes. A feature of this
                             model is the use of a stochastic mixing approach
                             during the combustion and expansion processes to
                             describe the nonuniform fuel-air ratio distribution
                             within the engine. In this approach, the fuel-air
                             ratio distribution during the combustion and
                             emissions formation processes can be followed as it
                             evolves with time. Primary output variables of
                             interest are the fuel efficiency and the NO_x
                             emissions.

REFERENCES   1. Mansouri, S.H., Heywood, J.B., and
                                Radhakrishnan, K., "Divided Chamber Diesel
                                Engine, Part I: A Cycle Simulation Which
                                Predicts Performance and Emissions," SAE Paper
                                820273, 1982 SAE International Congress and
                                Exposition, Meeting February 22-26, 1982.

                             2. Kort, R.T., Mansouri, S.H., Heywood, J.B., and
                                Ekchian, A., "Divided Chamber Diesel Engine,
                                Part II: Experimental Validation of a
                                predictive Cycle Simulation, and Heat Release
                                Analysis," SAE Paper 820274, 1982 SAE
                                International Congress and Exposition, Meeting
                                February 22-26, 1982.

RELATIONSHIP
TO OTHER MODELS

This is an original model which after its completion has been modified into a Spark Ignited Model and a Wankel Configuration Engine Model. It is currently being modified into an Open Chamber Diesel Engine Model under the sponsorship of NASA LERC.

HISTORY OF MODEL

No prior history.

OPERATIONAL CAPABILITIES

Model Description:

The flow into the engine cylinder during the intake process is modeled using quasi-steady one-dimensional flow equations. Mass flows past valves and between the two chambers are modeled by the equations for isentropic adiabatic flow through a nozzle. Discharge coefficients are used to relate the effective areas for the particular constriction (intake valve, connecting passageway, or exhaust valve) to the ideal areas for the isentropic flow. Plenum assumptions are used for the intake and exhaust manifolds.

The cycle-simulation uses a stochastic mixing approach during the combustion and expansion processes to describe the nonuniform fuel-air ratio distribution within the engine, including the way in which this distribution evolves with time. The combustion chamber is divided into three zones: the pre-chamber, the connecting passageway, and the main-chamber. In each zone, equal mass elements of air, fuel, and fuel-air mixture are present in proportions which agree with the overall fuel-air ratio in that region. These elements mix and react according to rules derived from classical models for turbulent reacting flows and combustion fundamentals. In this way, the fuel-air ratio distribution during the mixing, combustion, and emissions formation processes can be followed as it evolves with time.

The cycle-simulation is used to examine the origin of NO_x and particulate emissions in a divided-chamber diesel engine. The NO_x formation model is based on the extended Zeldovich kinetics in the burned gases. The particulate oxidation kinetic model proposed by Nagle and Strickland-Constable is

coupled with the cycle-simulation. The particulate
mass loading and the initial particulate size are
regarded as inputs for particulate oxidation
calculations. The initial value of particulate
mass loading level, assigned to each element after
it burns, is assumed to be the amount of solid
carbon calculated from the chemical equilibrium
model.

Results of Simulation:
- Calculates Volumetric Efficiency
- Calculates Heat Transfer During 4 Cycles
- Calculates Thermal Efficiency
- Calculates NO_x in Chamber and Total NO_x
- Calculates Particulate Emission

Modular Structure - Separate modules allow easy
replacement or change:
- Intake
- Combustion
- Heat Transfer
- Property Routines, i.e., Gas Properties
- NO_x Model
- Particulate Formation Model

ASSUMPTIONS

This model is zero dimensional or quasi dimensional
model. The model is based on a stochastic mixing
model.

LIMITATIONS

A major limitation of this model is that it can't
calculate local heat transfer, bulk heat transfer
only. It does not have a detailed combustion model
as the kinetics are not really known. The
combustion model is a stochastic one based on
modelling of steady state gas burners. The other
limitation is the nondimensionality of the model
compared to others which are two or three
dimensional.

DATA INPUT REQUIREMENTS

The input data requirements are in addition to those addressed as givens:

Geometrical and Design Parameters:
1. Bore
2. Stroke
3. Connecting rod length
4. Prechamber volume
5. Main chamber volume
6. Passageway diameter
7. Intake valve diameter
8. Exhaust valve diameter
9. Intake valve opening time
10. Intake valve closing time
11. Exhaust valve opening time
12. Exhaust valve closing time

Data Base Requirements:
For this model, the pressure data required was generated from an experimental test of the 5.7L (350 cu. in.) diesel engine. The data from this engine which were compared to the model results for calibration are volumetric efficiency, pressure data for each chamber, thermal efficiency, and NO_x emission levels.

Operating Parameters:
1. Intake manifold pressure
2. Inlet mixture temperature
3. Exhaust system pressure
4. EGR rate in intake
5. Load: mass of fuel injected per cycle
6. Speed
7. Injection timing
8. Prechamber wall temperature
9. Main chamber wall temperature
10. Passageway wall temperature

ADVANTAGES

The main advantage to this model particularly as compared to the two or three dimensional models is that it requires a relatively small amount of computer time per run. Therefore, it is possible to run many cases at many different conditions to develop engine maps, to identify areas for engine

tests for comparison, and to take various
parameters or variables to their limits to
understand the boundaries of the potential for the
engine.

VALIDATION

Experimental data generated on a single-cylinder
divided-chamber diesel engine (1979 5.7L GM) were
used to verify the accuracy of the model
predictions. Agreement between experimental data
and predicted values of engine performance and NO_x
emissions levels was good. The validation data is
presented in the SAE paper referenced in this
catalog entry.

Accuracy:
This model results in good agreement between the
predicted values and experimental data for thermal
efficiency, indicated mean effective pressure, peak
pressure values, NO_x emission levels, and chemical
ignition delay time. This agreement is obtained
over the normal load, speed, and injection timing.
The accuracy of the model prediction of particulate
formulation is only fair.

Input Data Accuracy:
The actual values of the pressure data from an
actual engine which is used as input data can be
recorded to within $\pm 1\%$.

COMPUTING REQUIREMENTS

The program code is written in Fortran and is
currently used on an IBM 370. Therefore, any major
facility would likely have the capability to run
the code. It is relatively easy to run and should
take approximately one day to set up in another
computing facility.

COST OF OPERATION

As it is currently used, the model requires about
two minutes of CPU time. Each run costs
approximately $20.

FUTURE POTENTIAL

This model is currently being modified under
contract to NASA here to model an open chamber,
turbocharged, turbo compounded, and four cycle
diesel engine.

AVAILABILITY   The Divided-Chamber Diesel Engine model was
                                    developed with General Motors as a sponsor.
                                    Therefore, permission would need to be obtained
                                    from General Motors before the code could be made
                                    available to other users.

TITLE   Komatsu "DSA/DCE"

DATE   1978

AUTHORS   H. Hiraki
                               J. M. Rife

ORGANIZATION   Komatsu/Massachusetts Institute of Technology

SPONSORS   Komatsu Ltd., Kawasaki, JAPAN

TRANSPORTATION MODE   Diesel engines used in buses, trucks, locomotives,
                               marine

APPLICATION   Civilian and Government diesel engines

OBJECTIVE   To predict the performance and NO_x emissions of
                               a direct injection diesel engine, given

                               - Engine dimensions
                               - Valve timing
                               - Turbocharger characteristics
                               - Cooling conditions

REFERENCES   Hiraki, H. and Rife, J.M., "Performance and NO_x
                               Model of a Direct Injection Stratified Charge
                               Engine," SAE 800050 (1980).

                               Hiraki, H., "Performance and NO_x Model of a
                               Direct Injection Stratified Charge Engine,"
                               S.M. Thesis, MIT, April 1978.

                               Rife, J.M. and Heywood, J.B., "Photographic and
                               Performance Studies of Diesel Combustion with a
                               Rapid Compression Machine," SAE 740948, 1974.

                               Hiraki, H. and Rife, J.M., "Performance Model for
                               a Direct Injection Diesel Engine."

RELATIONSHIP TO   Texaco funded Hiraki and Rife at M.I.T. to develop
OTHER MODELS/HISTORY   a stratified-charge, spark-ignition engine model,
OF MODEL   which then served as the basis for a direct in-
                               jection diesel model developed for Komatsu.
                               (Hiraki now works for Komatsu.)

OPERATIONAL CAPABILITIES

Output of Simulation – Direct injected engines of four types:
- naturally aspirated
- turbocharged
- turbocharged – aftercooled
- turbocompound

Calculates intake and exhaust flows, including turbocharger performance matching.

Calculates thermal efficiency or fuel consumption (isfc).

Calculates wall temperatures and exhaust temperatures based on heat transfer to walls and coolant.

Calculates emissions (NO_x only).

Calculates fuel spray evaporation and mixing with air.

Structure: List of submodels or processes included
- Intake, exhaust, turbocharger
- Fuel injection and evaporation
- Mixing of fuel and air
- Ignition delay
- Combustion rate
- Gas properties
- NO_x model
- Heat transfer

ASSUMPTIONS

(1) Intake, exhaust:
    Incompressible flow equations; turbocharger matching is performed

(2) Fuel spray evaporation:
    Assumed instantaneous

(3) Mixing of fuel and air:
    Turbulent jet entrainment expressions of Hoult and Well (1972). Air squish and swirl effects are also included. Took $\alpha = .11$ for jet spreading angle.

(4) Ignition delay:
Derived from purely fluid mechanic description

(5) Combustion rate:
Each element is conical and starts burning at
the boundary; "flame" propagates inward at
at the turbulent flame speed ($u' = s$). Behind
the "flame", eddies are assumed to exist which
burn according to a turbulent entrainment law
(Blizzard and Keck, 1970).

(6) Fuel-air ratio of burned gas:
Mixture is divided into elements of individual
fuel-air ratio derived according to turbulent
jet mixing theory.

(7) Gas properties:
Standard property equations for hydrocarbon
air mixtures, developed by Heywood and Martin
(1977).

(8) Heat transfer:
Separate Woschni (1967)-type heat equations
for burned gas region and unburned region;
area assumed proportional to mass.

(9) NO_x model:
Zeldovich kinetics with equilibrium values of
H, O, O_2, and OH.

(10) Burned gas mixing: assumed to be negligible.

LIMITATIONS

(1) Does not treat the effect of fuel injector
design changes on evaporation rate or atom-
ization.

(2) Ignition delay treatment includes no chemical
reaction rate effects. Initial ignition
delay is user-specified.

(3) Inadequate treatment of heat transfer:
No boundary layer included.

(4) Inadequate treatment of burned gas mixing:
     Cells are not allowed to mix with one another.

(5) Soot not included.

DATA INPUT REQUIREMENTS

Geometrical and Design Parameters:
- Bore
- Stroke
- Connecting rod length
- Chamber volume
- Valve areas   time

Operating Parameters:
- Load (fueling rate)
- Speed
- Injection timing
- Intake manifold temperature
- Intake manifold pressure
- EGR or residual fraction
- Injection rate
- Cylinder wall thickness and thermal
  properties
- Piston bowl diameter
- Fuel orifice size and number
- Swirl level
- Turbocharger characteristics
- Coolant flow rate and temperature

ADVANTAGES

(1) Includes detailed model of cylinder heat
    transfer to the coolant.

(2) Includes turbocharger matching calculation.

(3) Can predict the effect of fuel spray design
    parameters (orifice size, piston bowl
    diameter).

VALIDATION

Engine description:

(1) Komatsu S6D155 (155mm bore, 170mm stroke,
    2000 RPM, CR - 14.5, 6 cyl, 380 hp)

(2) CAV engine (4 cyl, 1 liter, CR = 16)

C - 3

Variables tested; model agreement:

(1) Effect of load:
     Generally good agreement

(2) Effect of Timing:
     Trends correct, but absolute bsfc values
     underpredicted by 5 - 10% and absolute NO_x
     values in error by up to 40%.

(3) Effect of swirl level:
     Very good agreement for bsfc, $\pm20\%$ for NO_x

Assessment of accuracy:

⊛ Exhaust temperatures and wall temperatures
   incorrectly predicted because of oversimpli-
   fied heat transfer model.

⊛ Maximum pressure correctly predicted.

⊛ NO_x predictions are useful to reveal trends
   but not absolute values.

COMPUTING REQUIREMENTS	Not specified
COST OF OPERATION	2 minutes of CPU time at $60-100/min (estimated)
FUTURE POTENTIAL	(1) Excellent framework for an improved heat transfer model.
	(2) Includes turbocharger matching, which makes this model suitable for analyzing turbo-compound and adiabatic engines.
AVAILABILITY	Unknown; Current MIT model (by Mansouri et al) has taken a different direction.

TITLE   Cummins

DATE   1973 - 1978

AUTHORS   S.M. Shahed, P.F. Flynn, W.T. Lyn, W.S. Chiu

ORGANIZATION   Cummins Engine Co.

SPONSOR   Cooperative efforts with Mack Trucks, Inc.

TRANSPORTATION MODE   All diesel engines

APPLICATION   Civilian or Government

OBJECTIVE   Predictive capability for:
                               - BSFC, rate of heat release
                               - Emissions, (NO_x, soot, HC)
                               - Direct Injection Engines

REFERENCES   Engine Modeling Conference, 1979
                               Combustion Institute, 1978
                               SAE Paper No. 760128, 1976
                               IME, 1975
                               SAE 730083, 1973

RELATIONSHIP TO   1962   Lyn's paper was the first to take
OTHER MODELS/HISTORY   "scientific" approach to diesel combustion
OF MODEL   modeling. Now R&D director at Cummins.

                               1970   Adler and Lyn (IME 1970) spray-in-swirl
                                      study; this paved the way.

                               1971   Shahed advised on CRC/EPA diesel model
                                      project.

                               1972   Preliminary model published.

                               1975   Added "fuel spray" submodel based on experi-
                                      mental results.

OPERATIONAL CAPABILITIES   See list of data input requirements. Model can
                               predict the effect of these parameters on NO_x and
                               isfc, including pressure as a function of crank
                               angle.

ASSUMPTIONS

- User specified ignition delay

- (1973)--All burned gas packages are at stoichiometric fuel-air ratio (no spray formation, droplet evaporation, or fuel-air mixing).

- (1973)--Heat release rate taken from empirical expression of Lyn (1972).

- Droplets not treated.

- Spray model for fuel-air mixing (1975):

  (a) Hyperbolic distribution of F/A along spray axis
  (b) Distribution across the spray obeys:

  $$c/c_m = 1 - (y/b)^{1.5}$$

  (c) Spray growth equations for tip portion $(x \propto t^{0.6})$ and width $(b \propto x)$

- Flammable zones ignite and burning is controlled by the rate of entrainment of air.

- Flammability limits taken at $\phi = 0.5$ and $\phi = 3.0$.

- NO_x formation rate is single step Arrhenius expression with adjustable pre-exponential.

- Annand type heat transfer expression.

- Combustion does not affect mixing rates.

LIMITATIONS

- Only treats portion of cycle between ignition and valve opening.

- No droplet treatment.

- Direct injection only.

- 1973 version did not use authentic NO_x kinetic constants (fixed in 1975 version).

- 1973 version ignored details of spray combustion process. All burning gas is at single F/A ratio (fixed in 1975).

- No heat exchange between packages. (Some stay hot too long.)

- 1973 version used empirical heat release function (fixed in 1975).

- 1973 version could not predict smoke or CO, because no fuel rich zones (fixed in 1975).

- No spray impingement model.

- Instantaneous flame propagation after ignition.

- Radiation not treated well (not T^4).

DATA INPUT REQUIREMENTS

Operating Conditions	Engine Geometry
Injection timing	Bore
Injection duration	Stroke
Fuel orifice size and number	Conn. and length
Fuel injection pressure	Clearance volume
Swirl level	Angle of valve
Air temperature	closure
Air pressure	
Residual fraction	

ADVANTAGES

Does allow for temperature gradient (successive packages of burned gas have individual temperatures).

VALIDATION

1973 Version

(1) Validated against three engines.

(2) Agreement poor at light load naturally aspirated, high swirl, or high smoke conditions.

(3) Able to predict trends of NO_x vs. load, RPM, air temperature, timing, EGR.

1975 Version

(1) Validated against single cylinder engine

- speed   – injection pressure   – hole diameter
- load   – injection duration   – air pressure
- timing   – number of holes   – air temp.
- CR

(2) Only presented results for injector hole diameter and air swirl.

(3) No_x predicted within ± 30% or so (needs further work).

COMPUTING REQUIREMENTS   Xerox Sigma 9 Computer. Presumably Fortran.

COST OF OPERATION   This model requires 3-5 minutes of CPU time ($60-100 per run) since it is iterative for each package at each crank angle.

FUTURE POTENTIAL   No further development of the Cummins Model is planned in the near future. When 1975 Model was published, the following capabilities were being added:

- Soot
- Hydrocarbon
- Radiation
- Heat transfer between zones
- Wall effects

AVAILABILITY   Unknown

TITLE   Ultrasystems Diesel Emissions Model

DATE   1974

AUTHORS   Kau, C.J., Wilson, R.P., Muzio, L.J., Waldman,
                              C.H., Heap, M.P., and Tyson, T.J.

ORGANIZATION   Ultrasystems, Inc.

SPONSORS   EPA and Coordinating Research Council (CRC)

TRANSPORTATION MODE   Engine model applicable to all modes.

APPLICATION   Civilian or Government. Funded by Civilian
                              sector.

OBJECTIVE   To predict NO_x and soot emissions of
                              direct-injection engines based on detailed model
                              of spray atomization, air entrainment, and droplet
                              combustion.

REFERENCES   (1) Wilson, R.P., Waldman, C.H., and Muzio, L.J.,
                                   "Foundation for Modeling NO_x and Smoke
                                   Formation in Diesel Flames,"Final Report
                                   EPA-460/3-74-002a, January 1974.

                              (2) Wilson, R.P., and Waldman, C.H., "Assessment
                                   of Existing Models of Pollutant Formation in
                                   Diesel Combustion," Western States Section,
                                   Combustion Institute, Paper 74-1 (1974).

                              (3) Kau, C.J., Tyson, T.J., and Heap, M.P.,
                                   "Study on Oxides of Nitrogen and Carbon
                                   Formation in Diesel Engines," Final Report
                                   Phases II and III, EPA-460/3-76-008a (March
                                   1976)

                              (4) Kau, C.J., Heap, M.P., Tyson, T.J., and
                                   Wilson, R.P., "The Prediction of Nitric Oxide
                                   Formation in a Direct Injection Diesel
                                   Engine," Combustion Institute, 16th
                                   International Symposium, p. 337 (1976).

                              (5) Kau, C.J., and Tyson, T.J., "Computer Program
                                   Users Manual," March 1976,
                                   EPA-460/3-76-008-b.

RELATIONSHIP TO
OTHER MODELS/HISTORY
OF MODEL

Wilson, Waldman and Muzio (1974) surveyed previous diesel models and developed the framework for a new model which would include details such as fuel spray atomization, air entrainment, ignition, premixed and droplet combustion, and swirl effects. The model emphasis is on realistic temperature and fuel-air ratio variations within the chamber so as to accurately describe NO_x and soot formation. This model was put into a working computer code by Kau and Tyson (1976), who adjusted the model structure to agree with experimental data.

OPERATIONAL CAPABILITIES

Results of Simulation:
- Direct injected engines
- Calculates intake and exhaust flows
- Calculates thermal efficiency and fuel consumption (isfc)
- Calculates heat transfer to walls
- Calculates emissions (NO_x, soot)
- Calculates fuel spray evaporation and mixing with air

ASSUMPTIONS

Intake, exhaust: Compressible flow equations.

Fuel injection: Quasi-steady fuel jet with "Upper Limit" dropsize distribution.

Fuel evaporation: Godsave equation.

Air entrainment: turbulent jet with swirl, based on Adler and Lyn (1966).

Ignition delay: Based on Shipinski (1969) and Wolfer (1938).

Combustion rate:
(a) Premixed burning rate according to flame propagation.
(b) Mixing-limited burning rate according to both air entrainment and droplet combustion.

Gas properties: NASA equilibrium except carbon and NO_x.

NO$_x$ model: Extended Zeldovich kinetics; formation in the burned gas and around droplets.

Soot model: Formation and oxidation rates of the Arrhenius form.

Mixing of burned gas with air: Dilution rate proportional to size of package and available air.

Heat transfer: Radiation, convection, and boundary layer effects.

LIMITATIONS

(1) Model does not predict spatial position of various phenomena.

(2) Cannot predict effect of chamber shape.

(3) Coupling of turbulence and burning rate needs further work.

DATA INPUT REQUIREMENTS

Geometrical and Design Parameters:
- Bore
- Stroke
- Conn. rod length
- Chamber volume
- Valve areas vs. time

Model Coefficients:
- Mixing coefficient for burned gas/air
- Air entrainment coefficient
- Vitiation coefficient
- Heat transfer coefficient

Operating Parameters:
- Load
- Speed
- Injection timing
- Intake manifold temperature
- Intake manifold pressure
- EGR or residual fraction
- Injection rate
- Cylinder wall temperature
- Fuel orifice size and number
- Swirl level

ADVANTAGES

(1) Model can handle design details such as fuel injection pressure, orifice size, and air swirl.

(2) Model includes powerful heat transfer submodel, and includes a submodel for burned gas quenching (which most other models omit).

VALIDATION

Engine description: Single cylinder, 2.34 ℓ displacement, 1,500 RPM, CR = 17:1

Variables tested; model agreement:

- Predicted cylinder pressure gave excellent agreement with data

- Effects on NO_x of CR, turbocharging, timing, load, speed, swirl, and EGR all predicted to about 10-20%.

COMPUTING REQUIREMENTS

Fortran IV, CDC 6600

COST OF OPERATION

3 minutes of CPU time at $60 to $100/min

FUTURE POTENTIAL

Next plateau for this model is multi-dimensional coordinate system.

AVAILABILITY

Available through listing in reference (3) if not from Ultrasystems directly.

TITLE	Hiroshima
DATE	1974-1976
AUTHORS	Hiroyasu, H., Kadota, T.
ORGANIZATION	University of Hiroshima
SPONSOR	Japan Automobile Research Institute
TRANSPORTATION MODE	Applicable to all (highway, rail, marine or pipeline).
APPLICATION	Applicable to both military and civilian.
OBJECTIVE	To guide the design and development of direct injection diesel engines in order to achieve low emissions. Proposed low-emission designs are screened.
REFERENCES	SAE 760129 (Also see RELATIONSHIP TO OTHER MODELS).
RELATIONSHIP TO OTHER MODELS	Diesel counterpart to spark ignition engine model described in "Computer Simulation for Combustion and Exhaust Emissions in Spark Ignition Engine," 15th Symp. (Int'l) on Combustion, 1974, pp. 1213-1222, by same two authors.

This model contains several submodels published separately:

(1) Fuel Spray Model: Bulletin of the Faculty of Engineering, Hiroshima Univ. 23 #1 (1974), p. 55.

(2) Droplet Model: SAE Paper 740445, SAE National Power Plant Meeting, Milwaukee, 1974.

(3) Evaporation Model: JSME National Meeting, Paper 740-16, 1974.

(4) Ignition Model: Trans. JSME <u>41</u> #348 p. 2475 (1975).

(5) Fuel Injector Model: Trans. JSME <u>34</u> #260 p. 755 (1968).

ASSUMPTIONS

The major assumptions that the model is founded on are:

- Jet spreads at specified angle (no radial distribution) and entrains air.

- Same penetration for all packages.

- All droplets at same initial diameter; they evaporate without affecting each other.

- Vapor ignites after an ignition delay which is given by the expressions of Mullaney (1959), Hurn (1951).

- Diffusion flame exists around groups of droplets.

- Rate of burning controlled by fuel evaporation or air entrainment.

- All combustion at stochiometric.

- Heat transfer to walls by Woschni (1968) - no radiation.

- Each burnt gas package has its own temperature.

- Eleven species plus soot (all but NO_x and soot in equilibrium).

LIMITATIONS

⊛ Restricted to portion of cycle when valves are closed. (No intake, exhaust, or turbocharger.)

⊛ No rigorous treatment of wall impringement.

⊛ Radiation heat transfer not explicitly treated.

       ◉   No mixing between neighboring packages.

       ◉   No way to model chamber shape effects.

       ◉   Weak on air motion and turbulence.

ADVANTAGES

       ◉   Cost effective.

       ◉   Minimum of empiricism.

       ◉   Includes spray details and thus can predict the
             effects of changes to fuel injector.

VALIDATION

Validated against Mitsubishi DT-6 engine, as shown
in SAE Paper 760129 (1976).

Accuracy is sufficient to show emissions <u>trends</u> but
not absolute values.

Accuracy: Model could be improved in the areas
shown in LIMITATIONS. These improvements would
make model more versatile but not necessarily more
accurate.

Input Data Accuracy: Nothing special here: fuel
schedule to nearest degree CA.

FUTURE POTENTIAL

Hiroyasu's plans – unknown.

TITLE	NREC DIESEL EMISSIONS MODEL
DATE	1971
AUTHORS	Bastress, Chng, and Dix
ORGANIZATION	Northern Research and Engineering Corp.
SPONSOR	EPA
TRANSPORTATION MODE	Non-specific (all diesel engines)
APPLICATION	Originally inter_ed for civilian, but applicable to military engines as well.
OBJECTIVE	Emissions predictions for developing design criteria for fuel injection systems for two types of diesels:

OBJECTIVE (continued):

- Direct injection
- Indirect injection

Output:
- Emissions (NO_x)
- Performance (isfc)

Coefficients:
- Specified evap. duration of rate (C_1)
- Specified burn duration or burn rate (C_2)
- Average fuel/air ratio during burning (F1)
- Specified increment of fuel-air ratio (dispersion F)
- Specified mixing coefficient (C_3)
- Specified heat transfer coefficient (C_4)

REFERENCES	Bastress, E.K., Chng, I.M., and Dix, D.M., "Models of Combustion and Nitric Oxide. Formation in Direct and Indirect Injection Compression Ignition Engines." SAE Paper 7 9053, 1971.
RELATIONSHIP TO OTHER MODELS	This model was developed based on NREC's experience modeling gas turbine engines. Some of the same assumptions are used for diesel engine combustion as were used for gas turbines (e.g., distribution of fuel-air ratios).

HISTORY OF MODEL   Model was constructed under contract to EPA.

OPERATIONAL CAPABILITIES   Model has the capability to predict the effect of
                                    each of the input parameters on NO_x emissions and
                                    performance (isfc).

ASSUMPTIONS
- Evaporation rate specified as Gaussian shape (Lyn 1960).
- Ignition delay correlation of Tsao (1962).
- "Backlog" of fuel vapor burns over a range of F/A, "new" fuel vapor burns at average F/A (specified).
- Mixing rate proportional to available volume of each package.
- Specified burn rate equal to or exceeding the evaporation rate.
- Heat transfer: coefficient which is specified.

LIMITATIONS
- Only portion of cycle with valves closed is modeled.
- Mixing law is arbitrary not mechanistic (no jet theory).
- Evaporation law is arbitrary not mechanistic (no spray, no droplets).
- Six arbitrary coefficients must be specified (some rules of thumb given in the paper for how to do this).
- No soot prediction.
- Poor heat transfer capability (adiabatic engine not readily modeled).

DATA INPUT REQUIREMENTS   Engine geometry: bore, clearance volume, conn-rod
                                    length, stroke (crank diameter), valve closing.

                                    Operating conditions:
                                    - Fuel mass, injection rate and timing
                                    - Wall temperature
                                    - Air pressure, temperature
                                    - Residual fraction
                                    - RPM
                                    - Fuel schedule

Coefficients:
- Specified evaporation duration or rate (C_1)
- Specified burn duration or burn rate (C_2)
- Average fuel/air ratio during burning (F1)
- Specified increment of fuel-air ratio (dispersion F)
- Specified mixing coefficient (C_3)
- Specified heat transfer coefficient (C_4)

ADVANTAGES

- Simplicity
- Non-uniform temperature and fuel-air ratio is included.

VALIDATION

- Validated at single load and speed with 8-cylinder automotive engine (4 1/2" bore, 200 hp, 3200 RPM).

- Suspect that agreement would be relatively poor if the timing, speed, load, etc., of that engine had been varied.

- Attempts were made by Wilson and Kau in 1974 to use this model to fit some data from a 6"-bore Cummins diesel engine. Agreement was poor no matter what coefficients were picked.

Assessment of Accuracy

This model contains a number of mathematical (non-physical) expressions for evaporation, ignition, mixing, combustion. The coefficients must be changed for every engine the model is set up to simulate.

Substantial revisions would have to be made to improve this situation; it is doubtful if the effort would be worth it, compared to just using more physical models such as the Ultrasystems or Hiroyasu model.

COMPUTING REQUIREMENTS

Fortran; CDC, IBM machines. (Some code errors must be caught and fixed.)

COST OF OPERATION   Cost is relatively low, about $10-$20 per run.

FUTURE POTENTIAL   NREC is no longer active in this area.

AVAILABILITY   Public domain; was available from NREC for $100 in
                                     1974; probably currently available.

TITLE	C.A.V. Diesel Emissions Model
DATE	1970-1973
AUTHORS	Khan, Greeves, Probert, Grigg, and Syed
ORGANIZATION	C.A.V. Ltd., Acton, London
SPONSOR	C.A.V. Limited
TRANSPORTATION MODE	All modes
APPLICATION	Civilian or Government
OBJECTIVE	This model is designed to predict soot and NO_x formation in direct-injection engines, as well as rate of heat release, isfc, and related performance parameters.

REFERENCES

(1) Grigg, H.C., and Syed M.H., "the Problem of Predicting Rate of Heat Release in Diesel Engines," Paper 18, Symposium on Diesel Engine Combustion, Institution of Mechanical Engineers, 1970. Also SAE Paper 700503, 1970.

(2) Khan, I.M., Greeves, G., and Probert, D.M., "Prediction of Soot and Nitric Oxide Concentrations in Diesel Engine Exhaust," IME Publication C142, p. 205, 1971.

(3) Khan, I.M. and Greeves, G., "A Method of Calculating Emissions of Soot and Mitric Oxide from Diesel Engines," SAE Paper 730169, 1973.

RELATIONSHIP TO
OTHER MODELS/HISTORY
OF MODEL

Grigg and Syed (1970) developed the fuel-air jet mixing model as a basis for improved heat release predictions. Based on this model and emissions data of Khan and Wang (1971), an extended diesel emissions model was developed by Khan, Greeves, and Probert (1971). Then in 1973, an improved version was presented as SAE Paper 730169.

OPERATIONAL CAPABILITIES

Results of Simulation:
- Calculates fuel spray evaporation and mixing with air
- Direct injected engines
- Calculates rate of heat release
- Calculates thermal efficiency or fuel consumption (isfc)
- Calculates heat transfer to walls
- Calculates emissions (NO_x, soot, HC)

Structure: List of submodels or processes included:
- Fuel injection; fuel vapor jet
- Ignition delay
- Combustion rate (fuel-air macro-mixing and micro-mixing).
- NO_x Model
- Soot Model
- Heat transfer

ASSUMPTIONS

⊚ Intake, exhaust: Not included

⊚ Fuel spray evaporation: Instantaneous vaporization. Schweitzer formula for conical spray penetration and dispersion.

⊚ Ignition delay: Specified empirically.

⊚ Mixing of air-fuel: Air is entrained according to the fuel jet spreading expression. Entrainment and diffusion coefficients must be specified. Swirl effects on mixing rate are not treated.

⊚ Fuel-air ratio of burned gas: Three zones (fuel vapor, burned gas, and air).

⊚ Combustion rate: Proportional to air entrainment.

⊚ Heat transfer: Annand-type expression.

⊚ No_x Model: Zeldovich mechanism, but with adjusted coefficient.

    ◉ Soot Model: Arrhenius law for soot formation.
Oxidation model not included.

    ◉ Burned gas mixing: Not included.

LIMITATIONS

(1) Inadequate treatment of fuel-air mixing and
gas temperature non-uniformities. Predicted
temperatures are too low.

(2) Inadequate treatment of heat transfer:
single bulk gas temperature assumed rather
than local hot zones.

(3) Inadequate treatment of burned gas mixing:
some zones stay hot too long.

(4) Soot, NO_x: Neglects soot oxidation rate;
also modified the NO_x rate constant.

DATA INPUT REQUIREMENTS

Geometrical and Design Parameters:
- Bore
- Stroke
- Conn. rod length
- Chamber volume
- Valve closure time

Model Coefficients:
- Soot rate coefficient
- Ignition delay
- Diffusion coefficient
- Entrainment coefficient as function of RPM and
  swirl

Operating Parameters:
- Load
- Speed
- Injection timing
- Trapped gas temperature and pressure
- EGR or residual fraction
- Fuel injection pressure
- Injection rate
- Cylinder wall temperature
- Fuel orifice size and number
- Swirl level

ADVANTAGES

(1)   Takes into account fuel injection parameters and air swirl level in a simplified manner.

(2)   One of few models to include treatment of soot formation.

VALIDATION

Engine descriptions:

(1)   Turbocharged Dorman, 6LBT
(2)   0.97 ℓ engine
(3)   1.36 ℓ engine
(4)   1.89 ℓ engine

Variables tested; model agreement:

⊛ Cylinder pressure traces were matched by the model with suitable coefficients.

⊛ Soot predicted to ± 30% with variations in timing, rate of injection, load, swirl, and speed.

⊛ NO_x trends predicted fairly well but not absolute values.

Assessment of accuracy: Sufficient for design guidelines but not a <u>predictive</u> emissions model.

COMPUTING REQUIREMENTS

Not specified.

COST OF OPERATION

1 minutes of CPU time at $60 to $100/min (estimated)

FUTURE POTENTIAL

No further work on this model has been published in the last 10 years.

AVAILABILITY

Possibly available from C.A.V.

TITLE	Cranfield Model
DATE	1971-1975
AUTHORS	D. Hodgetts, H.D. Shroff, I.R. Isaac
ORGANIZATION	Cranfield Institute of Technology
SPONSORS	UK government and industry
TRANSPORTATION MODE	All modes
APPLICATION	Civilian or Government
OBJECTIVE	To predict nitric oxide emissions of a diesel engine, taking into account gradients of temperature and concentration

REFERENCES

(1) Shroff, H.D., "The Simulation and Optimization of the Thermodynamic Processes of a Diesel Engine," Ph.D. Thesis, Cranfield I.T., 1971.

(2) Shroff, H.D., "The Simulation and Optimization of the Thermodynamic Processes of a Diesel Engine," SAE paper 740194, 1974.

(3) Isaac, I.R., "A Study of the Formation of Nitric Oxide in a Diesel Engine," Thesis, Cranfield I.T., 1971

(4) Hodgetts, D. and Shroff, H.D., "More on the Formation of Nitric Oxide in a Diesel Engine," Combustion in Engines, page 129, IME, London, 1976.

RELATIONSHIP TO OTHER MODELS/HISTORY OF MODEL

This model extends the earlier published diesel spray work of Austen and Lyn with the thesis works of Isaac and Shroff into a two-dimensional multi-zone diesel model. The authors also rely on the simple semi-empirical expressions of Whitehouse (IME, 1970), for combustion rate.

OPERATIONAL CAPABILITIES

Output of Simulation:
- Direct Injected Engines
- Calculates fuel spray evaporation and mixing with air
- Calculates heat transfer to walls
- Calculates emissions (NO_x only)

Structure: List of submodels or processes included
- Fuel injection
- Fuel evaporation
- Ignition delay
- Fuel-air mixing
- Combustion rate
- Gas properties
- NO_x model
- Heat transfer

ASSUMPTIONS

(1) Fuel spray evaporation: Rate of evaporation proportional to amount of liquid fuel remaining in each zone (Whitehouse, 1970).

(2) Mixing of air-fuel:
- Macromixing by jet entrainment (cosine variation of radial velocity);
- Micromixing controlled by fuel evaporation

(3) Ignition delay: Wolfer type expression

(4) Combustion rate
- Proportional to fuel and/or air available
- Arrhenius with 11 kcal/mole activation energy (essentially instantaneous combustion)

(5) Fuel-air ratio of burned gas:
Varies according to jet entrainment of air.

(6) Gas properties:
From McBride et al (NASA SP 3001)

(7) Heat transfer:
Used Woschni (SAE 670931) as the source, modified by turbulence coefficient;

(8) NO_x model:
Extended Zeldovich equations with partial
equilibrium

LIMITATIONS

(1) Combustion rate expression is arbitrary and
not physically related to the local mixing
of fuel and air.

(2) Treatment of heat transfer does not include
boundary layer. Heat transfer rate is pro-
portional to volume of the zone instead of
surface area.

(3) Inadequate treatment of burned gas mixing.

(4) Soot, HC, CO emissions are not included in
the calculations.

(5) Fuel spray atomization and droplet surface
area are not modelled.

DATA INPUT REQUIREMENTS

Geometrical and Design Parameters:
- Bore
- Stroke
- Connecting rod length
- Chamber volume

Computational Parameters:
- Number of zones across the jet

Operating Parameters:
- Load
- Speed
- Injection timing
- Gas composition and density
  (Intake manifold temperature, pressure and
  EGR or residual fraction) at valve closure
- Fuel injection rate
- Cylinder wall temperature
- Piston bowl diameter and volume
- Fuel orifice size and number
- Swirl level
- Turbulence factor

ADVANTAGES

This model is one of few diesel combustion simulation which attempts to treat the actual fuel-air ratio and temperature gradients produced by the burning fuel jet.

VALIDATION

Engine description:
6-cylinder, direct injection, 98mm bore, 127mm stroke

Variables tested; model agreement:
- Cylinder pressure versus crank angle (agrees to ±10%)
- Rate of fuel injection (agrees)
- Below 70% load NO_x emission agrees to ±20% for variations in load and speed. Above 70% load, model seriously in error because fuel jet predicted to be too fuel rich.

Assessment of accuracy: Relatively poor accuracy due to limitations noted above. This model was a step in the right direction but (as the authors note) more work is needed in several areas.

COMPUTING REQUIREMENTS

Not specified

COST OF OPERATION

1 minute of CPU time at $60-100/min (Estimated)

FUTURE POTENTIAL

Model would need refinements in order to be useful:
- Add a fuel spray atomization model
- More work needed on wall impingement of fuel jet and associated air entrainment.
- More work needed on overspill of burning mixture from piston bowl into the quench area.
- More realistic combustion rate model.
- Improved model for mixing of burned gasses.

AVAILABILITY

Possibly available through international technology exchange programs; Cranfield is analogous to NASA Lewis for the UK.

TITLE   Livermore Fuel Spray Model

DATE   1978

AUTHORS   Haselman, L.C. and Westbrook, C.K.

ORGANIZATION   Lawrence Livermore Lab.,
                                   University of California,
                                   Livermore, CA.

SPONSOR   ERDA

TRANSPORTATION MODE   All modes

APPLICATION   Civilian or Government

OBJECTIVE   Two-dimensional model for fuel spray (applicable
                                   to either diesel or stratified charge).

REFERENCES   Westbrook, C.K., "Three-Dimensional Numerical
                                   Modeling of Liquid Fuel Sprays", 16th Symposium
                                   (Int'l) on Combustion, Cambridge, 1976.

                                   Westbrook, C.K., "Numerical Solution of the
                                   Spray Equation", UC. Lawrence Livermore Lab
                                   Report UCID-17361, 1977.

                                   Haselman, L.C., and Westbrook, C.K., "A
                                   Theoretical Model for Two-Phase Fuel Injection
                                   in Stratified Charge Engines", SAE 780318, 1978.

RELATIONSHIP TO OTHER   This Livermore computational effort on recipro-
MODELS/HISTORY OF MODEL   cating engines was part of the ERDA/DOE joint
                                   industry/gov't. effort to further basic research
                                   on engines. General Motors Research Laboratories
                                   worked with Westbrook on the model.

OPERATIONAL CAPABILITIES   Output of Simulation:
                                   - Direct or indirect injected diesel engines,
                                     stratified charge engines also.
                                   - Calculates fuel spray evaporation and mixing
                                     with air.

Structure: List of submodels or processes included
- Fuel injection
- Fuel evaporation
- Fuel-in mixing
- Gas properties

ASSUMPTIONS

(1) Fuel spray injection and evaporation:
Basic unsteady two-phase conservation equations
are solved in two dimensions, with a minimum of
simplifying assumptions. A droplet distribu-
tion function represents the location and size
of the droplets. The effect of the droplet
ensemble momentum on the air flow is included.
The effect of fuel vapor saturation in dense
sprays is also included. A source term for
momentum (S_v) is used to simulate the spray.

(2) Mixing of air and fuel: Turbulent diffusion
(coefficient specified) and spray evaporation
determines the amount of air and fuel vapor in
each call. Within each computational cell, the
fuel is considered instantaneously well mixed.

(3) Gas Properties: Constant specific heat, unity
Lewis Number, ratio of specific heats 1.4.

LIMITATIONS

(1) Covers fuel spray evaporation and mixing only,
not ignition, combustion, heat transfer or
emission formation.

(2) Relatively large computation time requirement.

DATA INPUT REQUIREMENTS

Geometrical and Design Parameters:
- Bore
- Stroke
- Connecting Rod Length
- Chamber volume
- Valve areas vs. time

Computational Parameters:
- α, turbulence coefficient
- grid spacing (typical 2 mm)

Operating Parameters:
- Load
- Speed
- Injection timing
- Intake manifold temperature
- Intake manifold pressure
- EGR or residual fraction
- Injection rate
- Cylinder wall temperature
- Piston or cylinder head shape
- Fuel orifice size and number
- Swirl level

ADVANTAGES

(1) Two-dimensional, can treat chamber shape effects.

(2) More realistic and accurate treatment of spray jet and air entrainment than most other models, except perhaps the GM or Princeton model.

(3) Includes unsteady effects of the spray penetration (most other diesel spray models are quasi-steady)

VALIDATION

Engine description: Model not tested against an actual engine. Instead, calculations were carried out for an ideal case of a flat circular disk chamber of 4 cm radius, 25 atm pressure, and 750°K temperature (similar to CR = 10/1 engine). Injector operates for 2 msec with fuel spray velocity 500 m/sec.

Assessment of accuracy: Cannot be gauged without measurements. However, model predictions appear qualitatively reasonable.

COMPUTING REQUIREMENTS

CDC 7600, Fortran IV

COST OF OPERATION

60-80 minutes of CPU time at $60-100/min for a 40x40 grid (droplet model). Approximately $5,000 - $6,000 per case.

FUTURE POTENTIAL

(1) Explore ways to shorten computer time
(2) Couple with combustion model
(3) Introduce ignition model
(4) Add heat transfer
(5) Add pollution formation

AVAILABILITY

Presumably available, since DOE
sponsored the work.

TITLE   Princeton Internal Combustion Engine Model

DATE   1973-1977

AUTHORS   F.V. Bracco, H.C. Gupta, P.J. O'Rourke

ORGANIZATION   Princeton University

SPONSORS   National Science Foundation, ERDA, Volkswagen
                               and Curtiss-Wright

TRANSPORTATION MODE   Diesel engines used in highway, rail, pipeline
                               and marine transportation.

APPLICATION   Civilian and Military Engines

OBJECTIVE   To develop a multi-dimensional, spatially
                               detailed model applicable to stratified change
                               and diesel engines.

REFERENCES   (1) Bracco, F.V., "Introducing a New Generation
                                    of More Detailed and Informative Combustion
                                    Models," S.A.E. Transactions, 1975, Vol. 84,
                                    Presented at the S.A.E. International
                                    Stratified Charge Engine Conference,
                                    30 October 1974.

                               (2) Bracco, F. V., "Theoretical Analysis of
                                    Stratified, Two-Phase Wankel Engine,"
                                    Combustion Science and Technology, Vol. 8,
                                    Nos. 1 and 2, October 1973, pp. 69-84.

                               (3) Gupta, H.C., Bracco, F.V., and Westbrook,
                                    C.K., "Mathematical Modeling of Two-Phase,
                                    Unsteady, Two-Dimensional Flows", Paper G5
                                    presented at the Fifth International Collo-
                                    quium on Gas-dynamics of Explosions and
                                    Reactive Systems, 8 Sept. 1975.

                               (4) Bracco, F.V., Gupta, H.C., Krishnamurthy, L.,
                                    Santavicca, D.A., Steinberger, R.L., and
                                    Warshaw, V., "Two-Phase, Two-Dimensional
                                    Unsteady Combustion in Internal Combustion
                                    Engines: Preliminary Theoretical-Experimental
                                    Results," Paper 760114 presented at the SAE
                                    Automotive Engineering Congress, 23rd
                                    Feb. 1976.

(5) Bracco, F.V., "Unsteady Combustion of a
     Confined Spray," American Institute of
     Chemical Engineers Symposium Series, Vol. 70,
     No. 138, 1974, pp. 48-56.

(6) Bracco, F.V., "Modelling of Two-Phase, Two-
     Dimensional Unsteady Combustion for Internal
     Combustion Engines," I. Mech. E. Paper
     C171-77, p. 167, 1977.

RELATIONSHIP TO OTHER
MODELS/HISTORY OF MODEL

Related to the Los Alamos model; in that both use
the "RICE" computer program for two-dimensional
unsteady combustion. P.J. O'Rourke worked at both
Los Alamos and Princeton on this model.

OPERATIONAL CAPABILITIES

Output of Simulation - For Direct and Indirect
Injection Engines:

- Calculates fuel spray evaporation and
  mixing with air

- Calculates rate of heat release by
  combustion

- Calculates heat transfer to walls

- Calculates thermal efficiency and
  fuel consumption (isfc)

- Calculates emissions (NO_x)

Structure; List of submodels or processes included:
- Fuel injection and evaporation
- Mixing of fuel and air
- Ignition delay
- Combustion rate
- Gas properties
- Mixing of burned gas
- NO_x model
- Heat transfer

ASSUMPTIONS

Chamber dimensions: Fixed; No piston motion. The model is directed at the 30 degrees crank angle after TDC during which piston motion is negligible.

Fuel spray evaporation: Ranz-Marshall vaporization rate, Stokes' drag equation, mono-disperse spray, specified spreading angle.

Mixing of fuel and air: Turbulent mixing of evaporated fuel and air according to simple diffusivity model (isotropic). Entrainment of spray not modeled.

Ignition delay: At specified time, ignition is accomplished numerically in a corner of the chamber.

Combustion rate: One step irreversible reaction rate. Fuel and air react in stoichiometric proportions.

Gas properties: Constant ratio of specific heats (over simplified - no dissociation). Constant and equal specific heats and molecular weights for all species.

Mixing of burned gases: Turbulent mixing of burned gas according to simple diffusivity model.

NO_x model: Extended Zeldovich with all species in equilibrium except NO.

Heat transfer: Fractional reduction of the heat of combustion (user designated) (McAdams-type correlation used to estimate the fraction).

LIMITATIONS

(1) No simulation of compression and its effect on gas motion.

(2) Excessive computer time, particularly for spray case.

(3) Does not include model for entrainment of air into fuel jet which controls combustion rate, emissions and bsfc. Emphasis placed on flame propagation through the gas mixture, which is not critical for the diesel engine.

(4) Inadequate boundary layer heat transfer and turbulence models.

DATA INPUT REQUIREMENTS

Geometrical and Design Parameters:
- Bore
- Chamber volume
- Chamber shape (piston and head)

Operating Parameters:
- Load (fueling rate)
- Speed
- Injection timing
- Intake manifold temperature
- Intake manifold pressure
- EGR or residual fraction
- Injection rate
- Fuel orifice size and number
- Swirl level

Computational Parameters:
- Chemical reaction rate parameters
- Ignition time and location
- Eddy diffusivity (500 cm^2/sec)
- Spatial resolution (0.5 cm)
- Wall temperature
- Initial spray dropsize coefficient

ADVANTAGES

(1) One of the first models to appear which was spatially detailed.

(2) Attempts a detailed description of spray drag and evaporation

VALIDATION

Not validated against real engine data. Predicted profiles appear qualitatively reasonable but accuracy is untested.

COMPUTING REQUIREMENTS   Run on IBM 360/91, Fortran.

COST OF OPERATION   Without spray (flame motion only):
                                      2 to 3 minutes computer time for each 1 msec
                                      (12°CA) engine process duration.

                                      With spray:
                                      Factor of 10 larger (20 to 30 minutes for each
                                      12°CA engine process duration; estimated $5000 to
                                      $10000 for complete (360°CA) revolution).

FUTURE POTENTIAL   (1) Better way of accounting for turbulent
                                           mixing than the "diffusivity" approach.

                                      (2) Inclusion of boundary layer concepts for
                                           wall heat transfer.

                                      (3) Better coupling of spray equations with
                                           gas-phrase equations (e.g., Los Alamos
                                           approach).

AVAILABILITY   Presumably available, since ERDA/NSF sponsored
                                      much of the work.

TITLE   Imperial College Diesel Spray Model

DATE   1978-1980

AUTHORS   Gosman, A.D., Johns, R.J.R., Watkins, A.P.,
                                and Melling, A.

ORGANIZATION   Imperial College

SPONSOR   Perkins Engine Company and UK Scientific
                                Research Council

TRANSPORTATION MODE   All modes

APPLICATION   Civilian or Government

OBJECTIVE   To predict the three-dimensional characteristics
                                of a diesel spray mixing with air, including
                                turbulence, droplet trajectory, droplet
                                evaporation, and impingement. (Heat release and
                                pressure rise are not predicted.)

REFERENCES   (1) Gosman, A.D., Melling, A., Whitelaw, J.H.
                                     and Watkins, A.P., "Axisymmetric Flow in a
                                     Motored Reciprocating Engine," Proc. I.
                                     Mech.E. 192, No. 11, p. 213, 1978.

                                (2) Gosman, A.D., and Johns, R.J.R., "Development
                                     of a Predictive Tool for In-Cylinder Gas
                                     Motion in Engines," SAE 780315, 1978.

                                (3) Gosman, A.D., Johns, R.J.R., Tipler, W., and
                                     Watkins, A.P., "Computer Simulation of
                                     In-Cylinder Flow, Heat Transfer and
                                     Combustion," 13th CIMAC Conference, 1979.

                                (4) Gosman, A.D., and Johns, R.J.R., "Computer
                                     Analysis of Fuel-Air Mixing in Direct
                                     Injection Engines," SAE Paper 800091, 1980.

                                (5) Gosman, A.D., Johns, R.J.R. and Watkins,
                                     A.P., "Development of Prediction Methods for
                                     In-Cylinder Processes in Reciprocating
                                     Engines," Combustion Modeling in
                                     Reciprocating Engines, p. 69, ed. by J.N.
                                     Mattavi and C.A. Amann, Plenum Press, 1980.

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RELATIONSHIP TO OTHER
MODELS/HISTORY OF MODEL

Gosman's group has pioneered the use of detailed multi-dimensional models for furnaces and gas turbines; these papers represent an attempt to apply these modeling techniques to diesel engines. The fuel spray model (SAE 800091) relies on the earlier work of Borman and Johnson (1962) on droplet evaporation and ballistics.

OPERATIONAL CAPABILITIES

Output of Simulation:
- Direct injected engines
- Calculates fuel spray evaporation and mixing with air in three dimensions, spatially resolved
- Calculates air motion and turbulence
- Does not calculate combustion rate or cylinder pressure

Structure; List of Submodels or processes included:
- Intake, exhaust
- Air motion
- Fuel injection and droplet trajectories
- Turbulence level
- Fuel evaporation
- Gas properties

ASSUMPTIONS

⊛ Three-dimensional, axisymetric.

⊛ Air motion: Conservation equations in moving, curvilinear orthogonal coordinates for axial, radial and circumferential velocity.

⊛ Intake, exhaust: Orifice flow

⊛ Turbulence: Two-equation model for turbulence energy and dissipation rate.

⊛ Fuel spray: Pintle nozzle creates "ring" of spray. Discrete droplet parcels issue from atomization zone and are followed in Lagrangian coordinates.

⊛ Dropsize distribution based on Hiroyasu (1978).

- Evaporation rate: Droplets evaporate by the d^2 Law.

- Assumes no effect of the spray on the turbulence.

- Wall impingement: droplets adhere to wall but continue to evaporate by the d^2 Law.

- Ignition delay: Not included

- Fuel-air ratio of burned gas: Not included

- Gas properties: Standard tables

- Combustion: Not included

- Heat transfer: Detailed gas temperature profile available, but boundary layer treatment not described (if any) and radiation not included.

- NO_x model: Not included
  Soot model: Not included

  Burned gas mixing: Not included, but easily added.

LIMITATIONS

(1) No ignition or combustion (fuel-air mixing only)

(2) Requires large amount of computer time.

(3) Inadequate treatment of heat transfer, which could be readily corrected to include boundary layer and radiation phenomena.

(4) Not capable of predicting emissions (soot, NO_x).

(5) Spatial resolution needed for the spray is much finer than that needed for the engine.

DATA INPUT REQUIREMENTS

Geometrical and Design Parameters:
- Bore
- Stroke
- Connecting rod length
- Chamber volume
- Valve area vs. crank angle

Model Coefficients:
- Turbulence energy coefficient
- Dissipation rate coefficient
- Mean droplet size
- Dropsize distribution coefficient
- Grid size
- Boundary conditions

Operating Parameters:
- Load
- Speed
- Injection timing
- Trapped gas pressure and temperature
- EGR or residual fraction
- Injection rate
- Cylinder wall temperature
- Piston or cylinder head shape
- Fuel orifice size and number
- Swirl level
- Spray angle

ADVANTAGES

This type of model is uniquely capable of describing the spatial distribution of the diesel spray, and the effect of chamber shape on air motion. Only the Los Alamos model is comparable in these ambitious features.

VALIDATION

Engine description: Open-chamber DI engine (9.14 cm bore, 12.7-cm stroke) with CR=21 at 1,400 RPM.

Variables tested; model agreement: Model not tested against experimental measurements. Computer plots appear plausible, however, and show that the spray creates its own turbulence.

Assessment of Accuracy: Agreement with motored engine velocity data was considered unacceptable by the authors.

COMPUTING REQUIREMENTS   IBM 360/195

COST OF OPERATION   40 minutes (about $3,000) for motored engine cycle (no fuel spray or combustion) with 30x30 grid. Presumably several hours ($10,000 or more) for a run with fuel spray, but still no combustion.

FUTURE POTENTIAL

(1)   Need improved sub-models to avoid grid resolution problems.

(2)   Need to add ignition and combustion including the coupling between turbulence and heat release.

(3)   Need improved atomization model.

AVAILABILITY   Available through Gosman's consulting firm.

TITLE   Los Alamos Direct-Injection Engine Model

DATE   1978

AUTHORS   Butler, T.D.   Dukowicz, J.K.
                                Cloutman, L.D.   Ramshaw, J.D.
                                Krieger, R.B.

ORGANIZATION   Los Alamos/General Motors Research Lab.

SPONSORS   DOE (Contract W-7405-ENG-36)

TRANSPORTATION MODE   Diesel engines used in highway, rail, pipeline
                                and marine transportation.

APPLICATION   Civilian or Military engines

OBJECTIVE   To compute the detailed (spatially-resolved) flow
                                and temperature profiles in a direct-injection
                                engine, and the resulting NO_x and power output
                                (isfc).

REFERENCES   (1) Butler, T.D.; Cloutman, L.D.; Dukowicz, J.K.;
                                    Ramshaw, J.D.; and Krieger, R.B., "Toward a
                                    Comprehensive Model for Combustion in a
                                    Direct-Injection Stratified-Charge Engine,"
                                    Combustion Modeling in Reciprocating Engines,
                                    p. 231, Ed. by J.N. Mattavi and C.A. Amann,
                                    Plenum Press, 1980.

                                (2) Hirt, C.W.; Amsden, A.A.; and Cook, J.D., "An
                                    Arbitrary Lagrangian-Eulerian Computing Method
                                    for All Flow Speeds," J. Comp. Phys. 14,
                                    p. 227, 1974.

                                (3) Dukowicz, J.K., "A Particle-Fluid Numerical
                                    Model for Liquid Sprays," J. Comp. Physics,
                                    1980.

RELATIONSHIP TO OTHER   This model has an unusual history in that, unlike
MODELS/HISTORY OF MODEL   most engine simulations, the original computer code
                                was developed by Los Alamos for nuclear fireball
                                calculations. The "YAQUI," "RICE," and "APACHE"
                                computer codes, developed from 1973 to 1979,

provided the basis for computing turbulent fluid
flow with chemical reactions. The idea of using a
computational mesh which moves with the flow (with
the piston) was an important break-through with
these codes. The spray model is also taken from
work on nuclear reactor two-phase flow.

OPERATIONAL CAPABILITIES

Output of Simulation - For Direct Injection Diesel
Engines and Stratified-Charge Engines:

- Calculates fuel spray evaporation and mixing
  with air

- Calculates rate of heat release by combustion

- Calculates heat transfer to walls

- Calculates thermal efficiency and fuel
  consumption (isfc)

- Calculates emissions (NO_x only)

Structure; List of submodels or processes included:
- Compression/Expansion
- Fuel injection, atomization and evaporation
- Mixing of fuel and air
- Ignition delay
- Combustion rate
- Gas properties
- Mixing of burned gas
- NO_x model
- Heat transfer

ASSUMPTIONS

Compression/Expansion: 2-D axisymetric turbulent
flow, with mesh moving with the piston. Turbulence
represented by eddy diffusivity.

Fuel spray, atomization and evaporation: Spray is
represented by a restricted number of discrete
particles rather than as a continuum; this saves
computer time. Each particle evaporates and
exchanges momentum and energy with the gas. Dropsize
distribution taken from Hiroyasu (SAE 740715)
experiments.

Mixing of fuel and air: Spray entrainment calculated from an assumed spray angle by a "Monte Carlo" method,based on ballistics of the spray particles.

Ignition delay: Specified delay (1.7 msec), mixture ignited by artificially raising one zone to 1600K.

Combustion rate: Finite chemical reaction rates are taken into account using a single step global first order reaction for octane. Flame propagation rate determined by turbulent transport equations.

Gas properties: Temperature dependent ratios of energy/temperature for each specie.

Mixing of burned gases: Described by complete turbulent diffusion equations.

NO_x model: Extended Zeldovich mechanism, but omitting the N+OH reaction in lean regions. The oxygen atom and OH,H concentrations are taken from a table of equilibrium values.

Heat transfer: No wall heat transfer included. Energy transport within the gas described by conservation equation.

LIMITATIONS

(1) Does not include intake, exhaust flow through valves or turbocharger operation; deals with closed cylinder processes only.

(2) Heat transfer to the walls is not included in a realistic manner.

(3) Turbulence model is overly simple for this powerful type of computer model.

(4) Chemical reaction rate for combustion is an unnecessary feature since combustion is thought to be mixing controlled.

(5) Large computer time required.

DATA INPUT REQUIREMENTS

Geometrical and Design Parameters:
- Bore
- Stroke
- Connecting rod length
- Chamber volume
- Valve areas vs. time
- Chamber shape (piston and head)

Operating Parameters:
- Load (fueling rate)
- Speed
- Injection timing
- Intake manifold temperature
- Intake manifold pressure
- EGR or residual fraction (scavenging efficiency)
- Injection rate
- Fuel orifice size and number
- Swirl level; Initial charge velocity distribution.
- Initial fuel spray dropsize and velocity distribution.

Computational Parameters:
- Grid size (25x25 is typical)
- Turbulent eddy diffusivity coefficient
- Reaction rate coefficient
- Ignition delay
- Average droplet size
- Spray angle

ADVANTAGES

⊚ Can predict development of flow field as affected by piston shape and compression.

⊚ Can predict spatial flame propagation along spray and transition from premixed to diffusion mode.

⊚ Can predict spatial temperature profiles which are quite important for heat transfer calculations.

⊚ Can predict locations of peak NO_x formation.

VALIDATION

Engine description (hypothetical engine):
    stratified charge
    98 mm bore, 95 mm stroke
    CR = 10
    cup in piston
    1600 rpm, low swirl
    n-octane fuel
    overall equivalence ratios
        ϕ = .95 and ϕ = .50

Variables tested; model agreement:
Model not validated against experiments because
flame traverses are not available for stratified
charge or diesel engines.

COMPUTING REQUIREMENTS

Not specified

COST OF OPERATION

Estimated to be 10-100 minutes ($600-6000) per
run on a large computer.

FUTURE POTENTIAL

(1) Need better turbulence model which includes
    both small scale diffusion and large scale
    "wrinkling" of the flame. Non-isotropic
    effects should be included.

(2) Important processes occur on a sub-grid scale
    and, therefore, new sub-grid models are needed.

(3) Need to add flame radiation and conductive heat
    flux to the wall, including boundary layer
    effects.

(4) May need to add local peak temperature to get
    accurate NO_x predictions.

(5) Need to add ignition delay model.

AVAILABILITY

Presumably available since DOE sponsored, unless
military classified.

TITLE	Hybrid (Analog) Computer Simulation of the Sampled-Data Model for Compression Ignition Engines
DATE	1970
AUTHORS	C.R. Burrows, P.W. VanEetvelt, G.P. Windett
ORGANIZATION	University of Sussex
SPONSOR	None stated
TRANSPORTATION MODE	All
APPLICATIONS	Military or civilian
OBJECTIVE	To study the effects of non-linearities in fuel injection components and engine load.

Output:
- Engine speed as a function of non-linear fuel rack motion.

REFERENCES	International Journal of Control, 1971, vol. 14, no. 4.
RELATIONSHIP TO OTHER MODELS	This investigation built upon the pioneering work of Welbourn (1959), Bowns (1971) and Hazell and Flower (1971).
HISTORY OF MODEL	Developed to prove the viability of sampled-data theory to model fuel injection on compression ignition engines. Prior to this investigation, linear continuous control theory had been applied.
OPERATIONAL CAPABILITIES	Examination of the influences of non-linear or repetitive changes in fuel rack position on engine speed under quasi-steady state conditions.
ASSUMPTIONS	Relationship between fuel rack position and engine speed is a constant function for any given load.

LIMITATIONS

- Program only considers the grossest of effects of fuel rack position on engine speed.

- Torque delay and other data must be empirically determined for each engine.

- Constant Load.

- Does not deal in <u>any</u> fundamental principals. Purely empirically based.

DATA INPUT REQUIREMENTS

- Number of cylinders.

- Phase relationship and angle between fuel pulse and engine torque pulse.

- Engine speed, at a constant load as a function of fuel rack position.

Accuracy – Authors will explore an alternate model (pulse-width simulation) in pursuit of improved accuracy.

Data Base – One for each engine at every load of interest.

ADVANTAGES   Simple

VALIDATION   Poor, but better than other, contemporary models.

COMPUTING REQUIREMENTS   Not stated; certainly antiquated.

COST OF OPERATION   Unknown.

FUTURE POTENTIAL   Superseded by newer models with better performance.

AVAILABILITY   Presumably available.

TITLE	Diesel Fuel Injection System Simulation and Experimental Correlation
DATE	1970-1973
AUTHORS	J.P. Bolt, M.F. El-Erian, E.F. Wylie
ORGANIZATION	University of Michigan, Ann Arbor
SPONSOR	U.S. Environmental Protection Agency
TRANSPORTATION MODE	Highway, predominantly
APPLICATION	Military and civilian

OBJECTIVE

To study the fuel flow and mechanical characteristics of jerk pump injection systems to understand and eliminate the cause of after-injection (needle bounce).

Output – As a function of pump cam angle:
- needle lift
- pumping chamber pressure
- delivery chamber pressure
- pipe end pressure
- upper nozzle pressure
- injection chamber pressure

REFERENCES

EPA Report EPA-460/3-74-001 (NTIS No. PB 237 208) (contains SAE Papers 710569, 730661, 730662).

RELATIONSHIP TO
OTHER MODELS

None stated.

HISTORY OF MODEL

One of the earliest significant contributions relative to fuel injection systems is due to Davis and Giffen. Their discussion includes mention of many of the significant variables involved in the system: fluid compressibility, elastic deformation, pressure wave propagation, fluid friction, and pump and nozzle characteristics, including secondary injection.

L. Juhasz used graphical water hammer concepts to provide an analysis of a linear model of typical simplified injection systems, including the elements of the pipeline, pump, nozzle, and a fluid volume.

Giffen and Row theoretically solve the equations
representing the injection system, taking into
account the effect of pressure waves in the delivery
pipe and the capacity effects of the volumes
concentrated in the pump and nozzle system. They
handled the differential equations by placing them
in finite difference form and finding an algebraic
expression for the solution. This method of
solution was limited to simple injection models
because of the time required for mathematical
solutions.

Knight introduced a model for viscous friction and
cavitation in the delivery pipe, and used the same
model for the pump and nozzle system described in
Giffen and Row. His calculations were performed on
a digital computer.

Becchi used a model which comprised a detailed
representation of the injector and the pump, but he
neglected friction in the delivery pipe and had no
provision for possible occurrence of vapor cavities.
He solved the system of differential equations by an
iterative method after writing them in finite
difference form.

Brown and McCallion combined Becchi's detailed
representation of the pump and injector with a model
that included viscous friction and possible
cavitation in the delivery pipe. They also
considered a detailed modeling of the delivery valve
as described by Stone, and solved the system of
equations by another iterative method.

The work of Walwijk, Van der Graaf, and Jansen is
also to be noted. Their experimental apparatus
enabled them actually to measure the motion of the
delivery valve and injector needle, as well as the
pressure in various locations in the system.
Particular attention was devoted to the motion of
the delivery valve in their simulation on a digital
computer. A good correlation was achieved between
experimental and computed results.

All of the investigators discuss some of the factors that are likely to affect the accuracy of the model. The value of the delivery pipeline base pressure is important for a meaningful comparison between the model and experimental results. A treatment of vapor pressure in the delivery pipeline is also needed for a complete model. Kreith and Eisentadt, and Lichtarowicz, Duggins and Markland presented experimental results of the variation of the coefficient of discharge over a wide range of Reynolds number and length-to-diameter ratio. Giffen and Row cautioned of the danger of using coefficients of discharge from the literature. They preferred to use experimentally determined values for the particular nozzle under consideration. The data of Gelalles in which he tested different nozzle configurations showed that the coefficient of discharge, besides depending on length-over-diameter ratio and Reynold's number, is also greatly dependent on the configuration of the reservoir leading to the nozzle holes.

Recent investigators also give considerable attention to the stability and convergence of their solutions. Henrici discusses three different methods of numerical solution of a system of differential equations; the iterative solution of simultaneous algebraic equations, the expansion methods (Taylor's method or Runge Kutta method), and the numerical integration methods. The third method includes the predictor-corrector method which offers the advantage of an adjustable time increment, dependent upon a given error bound. This particular advantage is of great value especially for reducing computation time. The first and second methods require the use of very small time steps and a prior knowledge of the size of the time step.

OPERATIONAL CAPABILITIES

Influence of geometric and mechanical design changes on jerk pump injection system performance can be ascertained.

ASSUMPTIONS

⊛ "Method of Characteristics," used

⊛ Fluid compressibility described by bulk modules of elasticity which in turn varies with pressure.

- Elastic deformation of solid (metallic) system components is ignored.

- Flow in fuel lines described by one dimensional model.

- Frictional effects during unsteady flow assumed equal to steady flow losses at same velocity and fluid property, and is a function of Reynolds number.

- Vapor cavities grow and collapse in accordance with the dynamic equations and a local mass continuity balance.

- Orifice discharge coefficients based upon steady state data.

- Gravitational effects ignored.

LIMITATIONS

Wave propagation through the fluid in the pipeline is treated as the main cause of after injection, with the pump and injector bounding either end of the pipeline.

DATA INPUT REQUIREMENTS

- Base pressure
- System geometry/characteristics
  - pipe length
  - pipe diameter
  - pump characteristics
  - discharge coefficients
  - pipe cross sectional area
  - volume of fluid chamber/pump and injector
  - friction coefficient at valve or needle
  - injector spring force/stiffness
  - mass of valve or injector needle
- Fluid properties
  - bulk modules of elasticity
  - specific weight

Input Data Accuracy: None stated, although great pains were taken to assure accuracy of experimental data used to validate model.

ADVANTAGES
A predictor-corrector type solution to the model equations is used instead of the more popular Runge-Kutta method. This allows variable time step increments to be studied in fluid characteristics, improving model accuracy and economy, as small increments are examined only when necessary.

VALIDATION
Comparisons against experimental data indicate that the model has very good overall correlation with dynamic phenomena.

COMPUTING REQUIREMENTS
None stated.

COST OF OPERATION
Not stated.

FUTURE POTENTIAL
None stated.

Potential Accuracy: Some fine tuning of flow coefficients and pressure data suggested. Quantifiable improvement potential not stated.

AVAILABILITY
From the EPA (Jose L. Boscunana, Project Officer in 1974).

TITLE	Simulation of Processes of Fuel Injection (INJEC)
DATE	1971
AUTHORS	M. Ikegami, H. Horike, F. Nagao
ORGANIZATION	Kyoto University
SPONSOR	None stated; may be Kawasaki Heavy Industries
TRANSPORTATION MODE	All
APPLICATIONS	Military and civilian
OBJECTIVE	To model the fuel flow and pressure within a diesel fuel injection system as a function of time.
	Output: Fuel pressure as a function of time.
REFERENCE	Bulletin of Japanese Society of Automotive Engineers, No. 5, 1973.
RELATIONSHIP TO OTHER MODELS	None
HISTORY OF MODEL	Original model

OPERATIONAL CAPABILITIES

- Presents graphical display of fuel system pressure and flow rate as function of time at a given engine speed and rack position.

- Can study different fuel system volumes, injector characteristics, pump characteristics.

- Steady state.

ASSUMPTIONS

- Fuel is incompressible.
- Speed of sound in fluid constant.
- No wave effects.
- Fuel system completely rigid.
- No voids form in fuel in system.

LIMITATIONS

⊛ Effect of cylinder pressure change during injection ignored.

⊛ Wave or resonance effects ignored.

⊛ Ignores injector needle bounce.

DATA INPUT REQUIREMENTS

⊛ Fuel system dimensions, volumes, orifice areas and flow coefficients

⊛ Delivery valve lifts and masses.

⊛ Cam (plunger drive) characteristics.

⊛ Delivery spring rates.

⊛ Injector nozzle needle lift, spring rate, mass and flow coefficients.

⊛ Cylinder pressure during injection.

ADVANTAGES

Authors report favorable trade-off of accuracy for reduced computing time.

VALIDATION

"Reasonable accuracy" reported for validation against one Bosch pump (PE1A60B100) and injector nozzle (DN4SI-pintle type).

Accuracy: Not stated.

COMPUTING REQUIREMENTS

FACOM 230-60 system.

COST OF OPERATION

12 seconds/iteration at best; 5 iterations per run.

FUTURE POTENTIAL

Not stated.

AVAILABILITY

Presumably from Kyoto University.

TITLE	Characterization and Simulation of a Unit Injector
DATE	1975
AUTHORS	N.A. Henein, T. Singh, J. Rozanski
ORGANIZATION	Wayne State University
SPONSOR	U.S. Army Automotive Tank Command
TRANSPORTATION MODE	Highway, marine
APPLICATION	Military or civilian
OBJECTIVE	To simulate the fuel pressure histories within a unit injector as a function of cam angle.

Output:
- Pressure vs. camangle
- Fuel flow vs. camangle

REFERENCE	SAE paper 750773.
RELATIONSHIP TO OTHER MODELS	None.
HISTORY OF MODEL	None mentioned.
OPERATIONAL CAPABILITIES	Steady fuel pressure and flow as a function of camshaft angle for a variety of speed and rack positions once the pressure history is known for at least one condition.

ASSUMPTIONS

- There are no wave effects or voids in the system due to short path lengths.

- Leakage, flow coefficients, and backpressure on needle assembly constant under all conditions.

LIMITATIONS

- Limited to unit injector.
- Empirically calibrated
- Applications to non DDA injectors questioned.

DATA INPUT REQUIREMENTS

- Injector system masses
- Spring constants
- Volume of injector chamber
- Fuel bulk modulus
- Discharge coefficients
- Flow areas
- Pressure and flow vs. camangle for one condition

Data Base: Fairly extensive instrumentation needed to get calibration data. However, program done for U.S. government. Data may be available from TACOM.

ADVANTAGES

Fairly simple model.

VALIDATION

"Fairly good," although pressure oscillations not predicted.

COMPUTING REQUIREMENTS

Not stated.

COST OF OPERATION

Low = small programs.

FUTURE POTENTIAL

Could perhaps be better "tuned."

Potential Accuracy: Needs to incorporate wave phenomena.

AVAILABILITY

Presumably available (U.S. government contract).

TITLE   Computer Model of the Electronic Control System
                                   (ECS) for Diesel Fuel Injection Timing

DATE   1982.

AUTHORS   M.J. Pipho, D.B. Kittelson.

ORGANIZATION   University of Minnesota.

SPONSOR   Optimizer Control Corporation.

TRANSPORTATION MODE   All

APPLICATION   Military and civilian.

OBJECTIVE   To simulate the performance of the ECS control and
                                   engine system and to determine the effects of ECS
                                   changes on system response and performance.

                                   Output: See list under Operational Capabilities.

REFERENCE   Closed Loop Digital Electronic Control of Diesel
                                   Engine Timing, SAE paper 830579.

RELATIONSHIP TO   None.
OTHER MODELS

HISTORY OF MODEL   None stated.

OPERATIONAL CAPABILITIES   Explore response with respect to time of injection
                                   timing and engine:

                                   - Speed
                                   - Emissions
                                   - BSFC
                                   - Smoke (Bosch)
                                   - Power

                                   as a result of changes in

                                   - ECS characteristics
                                   - Load
                                   - Engine speed

ASSUMPTIONS

          ⊛ Steady state engine maps valid for transient
            operation.

          ⊛ Engine can be modeled as a simple inertia
            system.

LIMITATIONS

          ⊛ Model focuses on ECS made by Optimizer Control
            Corp., probably not relevant to other control
            systems.

          ⊛ 2000 rpm maximum right now due to validation
            limitations (Model not limited, ECS is limited).

DATA INPUT REQUIREMENTS

Engine:
- Initial and off set point conditions
- Inertia
- Fuel maps
- Emission maps
- Smoke maps
- Speed/power/timing maps

ECS Characteristics:
- Signal pulses/revolution
- Phase delay
- Response time characteristics
- "Dither" amplitude
- "Dither" frequency
- Bias from MBT
- Correction amplitude
- Open loop yes or no
- Proportional yes or no
- Gain

Availavility of Data Base: Engine maps not
available from this source.

ADVANTAGES

Provides complete engine response to an
optimization control system.

VALIDATION

Good correlation observed at low engine speeds
range where ECS is functional and stable.

Accuracy: Not stated.

COMPUTING REQUIREMENTS   Not stated.

COST OF OPERATION   Not stated.

FUTURE POTENTIAL   ECS system being improved.

AVAILABILITY   Probably not, work done is relevant only to the ECS
                                which is a product of the sponsor.

TITLE	PROCES
DATE	1975
AUTHOR	H. Valland
ORGANIZATION	Norwegian Institute of Technology
SPONSOR	Unknown
TRANSPORTATION MODE	Marine and pipeline
APPLICATION	Military and civilian

OBJECTIVE   Computing the power output of a single cylinder, two or four cycle direct injected diesel.

Output:
- Combustion chamber wall temperatures
- Gas temperatures
- Mass flow
- BSFC
- Power
- Engine energy balance

REFERENCE   Model briefly described in: "A theoretical analysis of thermal barriers in diesel engine cylinders," by H. Valland in Norwegian Maritime Research, No. 2, 1982.

RELATIONSHIP TO   Unknown.
OTHER MODELS

HISTORY OF MODEL   Unknown.

OPERATIONAL CAPABILITIES
- Steady state
- Variable heat release patterns
- Variable heat transfer
- Altered engine geometry

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ASSUMPTIONS

- Homogeneous, stochiometric gas mixture
- Perfectly mixed charge
- Surface temperatures constant throughout cycle
- Coolant temperature is average of inlet and outlet temperatures
- Inlet port, combustion chamber, and exhaust port are three separate control volumes coupled by mass flow and heat

LIMITATIONS

- Steady state
- Single cylinder
- Direct injection
- No cycle analysis

DATA INPUT REQUIREMENTS

- Rate of heat release
- Speed
- Cylinder configuration and dimensions
- Intake and exhaust port configuration
- Fuel feed rate
- Mechanical efficiency
- Coolant temperature
- Cylinder wall thermal characteristics
- Ambient conditions

ADVANTAGES

- Probably a very simple, basic model which is fast and easy to use.

(Note: model not very well described in reference document. Users manual is reportedly in Norwegian.)

VALIDATION   Not stated.

COMPUTING REQUIREMENTS   Not stated.

COST OF OPERATION   Not stated.

FUTURE POTENTIAL   Most likely very limited.

AVAILABILITY   Presumably available.

TITLE	Computer Programs to Determine the Relationship Between Pressure Flow, Heat Release, and Thermal Load in Diesel Engines
DATE	1964
AUTHOR	Gerhard Woschini
ORGANIZATION	MAN
SPONSOR	MAN
TRANSPORTATION MODE	Pipeline, Marine, Rail
APPLICATION	Military and civilian
OBJECTIVES	1. Determine the rate of heat release from the pressure history diagram.
	2. Determine pressure and temperature flow from the heat release diagram.

Output:
- Peak pressure
- Peak temperature
- Indicated efficiency
- Exhaust temperature
- Parts of heat transfer to head, piston, cylinder walls.

REFERENCE	SAE Paper 65045C
RELATIONSHIP TO OTHER MODELS	Heat transfer is based upon the determination of the heat transfer coefficient using the method of Pflaum ("Der Warmeubergang bei Dieselmaschine mit und ohne Aufladang," 1960).
HISTORY OF MODEL	None given
OPERATIONAL CAPABILITIES	Method of determining rate of heat release has been superceded by GM method.

Heat transfer (thermal flow) is calculated independently for head, piston, and cylinder walls. Heat transfer is determined from a given heat release diagram.

ASSUMPTIONS
- Chamber wall temperature is constant
- No blow-by
- No heat transfer during scavenging

LIMITATIONS
- Can not determine influence of heat transfer on rate of pressure rise.

- Heat transfer coefficient calculation not accurate. Must be used with known pressure or heat release data: not extrapolatable

DATA INPUT REQUIREMENTS
- Pressure vs. crankangle
             or
- Heat release diagram
- Equivalence ratio
- Fuel composition
- Engine dimensions

ADVANTAGES
Heat transfer through each of the major components calculated separately.

VALIDATION
Not validated.

COMPUTING REQUIREMENTS
IBM 1060
Fortran II

COST OF OPERATION
Eight minutes of machine time per run.

FUTURE POTENTIAL
Efforts to improve the determination of heat transfer coefficient underway.

AVAILABILITY
Presented in the paper in sufficient detail to use.

TITLE

Mirrlees Heat Transfer Program, "DIESHT"

DATE

1983

AUTHORS

R.T. Green, K. Jambunathan, S.D. Probert

ORGANIZATION

Mirrlees Blackstone Ltd., with Trent Polytechnic and Cranfield Institute

SPONSORS

Science and Engineering Research Council

TRANSPORTATION MODE

Diesel engines used in highway, rail, pipeline and marine transportation.

APPLICATION

Civil and Government

OBJECTIVE

To provide an easy-to-use, CAD-compatible, specialized software package for predicting (for a medium-speed diesel engine):

(1)   the steady-state rate of heat transfer through the cylinder liner (or other axisymmetric components).

(2)   the surface temperature of the liner, which critically affects both lubricant breakdown and corrosion.

REFERENCES

C.F. Taylor and T.Y. Toong, "Heat Transfer in Internal Combustion Engines," ASME paper No.57-HT-17, 1957.

J.F. Alcock, "Evaporative Cooling for Internal Combustion Engines," Trans.I.Mar.I., 62(10) (1950) pp. 327-38.

J.R. Metz and A. Steiger, "Contribution to the Investigation of the Diesel Cycle with the Aid of Digital Computers," Proc. I. Mech.E., 182 (Pt.3C) (1967-68), pp. 79-90.

W.J. Seale and D.H.C. Taylor, "Spatial Variation of Heat Transfer to Pistons and Liners of Some Medium-Speed Diesel Engines," Proc. I. Mech. E., 182 (Pt.1) (1970-71), pp. 203-15.

RELATIONSHIP TO OTHER
MODELS/HISTORY OF MODEL

The model incorporates several "well tried and tested" empirical and semi-empirical relationships for gas-side heat transfer and a finite-element analysis to describe the rate of heat transfer through the cylinder liner. Emphasis is on developing a code that is compatible with a CAD system and easy to use interactively by engineers in the design phase.

OPERATIONAL CAPABILITIES

Output of Simulation – For Direct and Indirect Injection Engines:

- Heat transfer to cylinder liner
- Graphical temperature field in liner wall

Structure; List of submodels or processes included - Definitions of liner geometry and engine parameters:

- Calculation of gas properties
- Generation of mesh size
- Finite element analysis
- Graphical outputs

ASSUMPTIONS

Gas properties: Property tables are used to express viscosity, density, thermal conductivity and specific heat as polynomial functions of temperature.

Heat transfer:
(1) Hot gas side: treating convection only, this model uses a time-averaged correlation between the Nusselt and Reynolds number developed by Taylor and Toong (1957) and Annand (1963).

(2) Coolant side: uses a correlation for forced heat transfer to water in an annulus space developed by Alcock (1950), and by Seale and Taylor (1970-71).

(3) Through liner: finite element analysis of the steady-state heat conduction equation for an axisymmetric solid with gradients in the axial and radial directions.

LIMITATIONS

(1) Temperature of the hot gases must be input.

(2) Empirical relation for convective heat transfer from hot gases includes neither (a) gas motion effects nor (b) radiation effects and is not accurate at low engine speed (as recognized by authors)

(3) Temperature gradients in the gas, including boundary layer effects, are not modelled.

DATA INPUT REQUIREMENTS

Geometrical and Design Parameters:
- Cartesian coordinates describing the geometry of the cylinder liner (can be obtained from a CAD system)

- Material identifier; thermal conductivity of liner

Operating Parameters:
- Coolant velocity

- Charge air mass flow rate

- Temperatures of charge air, hot gases and coolant

Computational Parameters:
- Number of quadrilaterial regions describing the geometry

- Options for plotting temperature contours or temperature at each mesh

ADVANTAGES

Easy to use by design engineers without needing computer specialists. Can readily investigate the consequences of changing the liner wall thickness, coolant velocity, inner conductivity, etc.

VALIDATION

Engine description: 6-cylinder, 537 kW, 50 and 110% of design load, 750 RPM, 222 mm bore.

Variables tested; model agreement: At high load,
the predicted temperature profiles were within a
few percent of measurements, while at low load,
they differed by up to, roughly, 15%.

Assessment of accuracy: Model predictions depend
on the input value of the hot gas temperature and
its associated uncertainty; otherwise, computa-
tional accuracy is good to about a few percent
for fine mesh sizes (>100 elements).

COMPUTING REQUIREMENTS   FORTRAN

COST OF OPERATION   Unavailable, estimated at \$5-20 per run.

FUTURE POTENTIAL   (1) Refinement of the gas-side heat transfer
                                             correlation to account for radiation, gas
                                             motion, and boundary layer effects. (This
                                             need is recognized by the authors.)

                                        (2) Integration with other models that describe
                                             the combustion processes and thermal stress
                                             so that an interactive computerized tool can
                                             be made available to the designer.

AVAILABILITY   With the prior permission of Mirrlees Blackstone
                                        (Stamford) Ltd., copies of the computer program
                                        can be obtained from the authors.

TITLE	Prediction of the Exchange Processes in a Single Cylinder Internal Combustion Engine
DATE	1978
AUTHORS	P.A. Lakshminarayanan, P.A. Janakiraman, M.K. Gajendra Babu, B.S. Murthy
ORGANIZATION	Each author is a member of faculty of different universities; they are, respectively:

- University of Technology, Loughborough, England;
- Indian Institute of Technology, Madras, India;
- Indian Institute of Technology, Delhi, India;
- University of Santa Clara, Santa Clara, California.

SPONSORS	None stated
TRANSPORTATION MODE	All
APPLICATION	Military or civilian
OBJECTIVE	To model gas flow in the intake and exhaust systems of a single cylinder engine, including valve and end effects, in a simpler manner than other models.

Output:
- Manifold pressure
  - intake
  - exhaust
- Gas bulk velocity both as a function of crankangle, plus bulk mass flow rate.

REFERENCES	SAE paper 790359.
RELATIONSHIP TO OTHER MODELS	None.
HISTORY OF MODEL	None stated.
OPERATIONAL CAPABILITIES	Study the influence of manifold length and end conditions on gas pressure, velocity as a function of crankangle, as well as bulk mass flow rate.

ASSUMPTIONS

- Manifolds are divided into a number of cells, each containing uniform gas properties.
- Constant pipe friction.
- No pipe bend effects.

LIMITATIONS

- No pipe junction or cylinder-to-cylinder interference effects.
- No combustion or cycle analysis.
- Naturally aspirated engines only.

DATA INPUT REQUIREMENTS

- Piston movement
- Manifold length and diameter (intake and exhaust)
- End condition
  - nozzle type
  - area ratio
  - valve opening WRT piston positioning
- Cylinder pressure and temperature as a function of crankangle or piston position.
- Ambient gas conditions.
- Friction coefficient along manifold.
- Rate of heat transfer to or from manifold gas.
- Gas physical properties.

ADVANTAGES

- Accuracy above first order effects is claimed.
- Simpler (cheaper?) calculation procedure.

VALIDATION

Compared to "method of characteristics" techniques and also against single cylinder diesel tests. Model is claimed to be "accurate." Data displayed shows general trends can be predicted, but excursions from the general trend are missed under firing conditions. Motoring condition predictions appear to have good correlation with experiment.

Accuracy: Not stated.

Input Data Accuracy: Not stated.

COMPUTING REQUIREMENTS   Not stated.

COST OF OPERATION   Not stated, but allegedly less than other models.

FUTURE POTENTIAL   Not stated.

AVAILABILITY   Unknown.

TITLE

Computer Aided Design of the Exhaust of a
Turbocharged Diesel Engine

DATE

1968-1974

AUTHOR

J.D. Ledger

ORGANIZATION

University of Manchester, Institute of Science and
Technology

SPONSOR

None apparent

TRANSPORTATION MODE

All

APPLICATION

Military and civilian

OBJECTIVE

Interactive study of the compressible gas flows in
the exhaust pipe of a turbocharged (single cylinder
as model reported) diesel engine. Use as a CAD
tool to assess performance impact of different pipe
designs.

Output:
- Exhaust pipe
  - pressure (entry or exit)
  - gas velocity (entry or exit)
  - cylinder mass flow
  - cylinder pressure
  as a function of crank angle.

REFERENCE

"European Computing Conferences, Interactive
Systems," London, United Kingdom. ISBN 0903796066,
September 1975.

RELATIONSHIP TO
OTHER MODELS

Based somewhat on the work of Benson and his
"characteristics" methodology.

HISTORY OF MODEL

Development of model started in 1968 when only
hybrid-analog/digital computer systems were
available which would handle the
centered-difference method Ledger started out with.
Model was converted to all digital, interactive
with graphic displays as reported. Model is
reportedly being upgraded to employ Method of
Characteristics.

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OPERATIONAL CAPABILITIES

Exhaust manifold inlet and outlet (nozzle) characteristics such as

- exhaust valve timing,
- exhaust valve and port geometry
- turbocharger effective nozzle area

as well as manifold dimensions can be studied to determine their influences on cylinder blow-down under steady state operation.

Program is designed in a modular manner to facilitate easy alteration of design parameter and operating conditions.

ASSUMPTIONS

- One dimensional, unsteady isentropic flow of compressible gas
- No pipe bending effect (straight pipe)
- Cylinder expansion : pv 1.3 = constant

LIMITATIONS

- Simple cylinder
- No multi-pipe effects
- Single cylinder blowdown process
- No scanning effects
- Old model: superceded by newer ones which used this as a starting point.

DATA INPUT REQUIREMENTS

- Cylinder bore and stroke
- Connecting rod length
- Compression ratio (nominal)
- Exhaust pipe length and cross sectional area
- Exhaust and intake valve timing
- Valve opening and closing rates
- Supercharge (boost) pressure and temperature
- Exhaust nozzle open area ratio
- Engine speed
- Cylinder release pressure and temperature
- Estimates for exhaust pipe inlet pressure, temperature, and velocity
- Number of crank angles studied

ADVANTAGES

  • Fairly rapid
  • Graphical display
  • Modular configuration allows easy modification

VALIDATION

  None mentioned.

FUTURE POTENTIAL

  • Multi-pipe configuration under development
  • Method of characteristics to be further
   incorporated

COMPUTING REQUIREMENTS

  • DEC PDP10 with graphics terminals
  • Interactive in English

AVAILABILITY

  Presumably available.

TITLE   Computer Aided Design Package for
                               Engine Manifold System

DATE   1980

AUTHORS   S.C. Low, R.S. Benson, and
                               D.E. Winterbone

ORGANIZATION   University of Manchester, Institute of
                               Science and Technology

SPONSOR   Unknown

TRANSPORTATION MODE   All

APPLICATION   Civilian

OBJECTIVE   Interactive program for predicting the performance
                               of a total engine system capable of incorporating
                               manifold and valve design changes easily. This
                               allows basic design processes to be accelerated and
                               allows for a shorter data debugging time.

                               Output — Primary (graphical form):
                               — Pressure/crankangle diagrams for each end and
                                 middle of all manifold pipes.
                               — Pressure/crankangle diagrams for each cylinder,
                                 including pressure at manifold inlet/outlet.
                               — Mass flows and trapped mass for each cylinder.

                               Secondary:
                               — Pressure/crankangle diagrams for each cylinder,
                                 including peak pressure and rate of rise
                                 assessment.
                               — Cumulative work/crankangle:
                                 — IMEP
                                 — Power/cylinder
                                 — Trapped pressure and temperature
                               — Temperature/crankangle for each cylinder.
                               — Valve area/crankangle.
                               — Manufacturability of valve gear assessment.
                               — Adequacy of valve sizing/lift profile.

REFERENCE   Computer Aided Design Package for
                               Diesel Manifold System SAE 790277.

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RELATIONSHIP TO
OTHER MODELS

None, directly, although it is tied in philosophy to the University of Manchester MK 12 model.

HISTORY OF MODEL

One of the first programs based on the "method of characteristics." Probably the first program to combine the design and performance prediction processes.

OPERATIONAL CAPABILITIES

Engine treated as several modules under steady-state conditions.
- Power (in-cylinder calculations)
- Valve Gear (design only)
- Manifolds, including turbine nozzle.

Graphics - for plotting results only.

Power Module Model is based on simple heat release diagram which must be supplied, a polytropic compression and expansion, perfect gas laws, and first law of thermodynamics.

Manifold Module Model is a comprehensive wave model using non homentropic theory. Virtually any manifold design and its impact on engine performance can be assessed within program limitations. Cylinder to cylinder variations are determined.

ASSUMPTIONS

See description of power and manifold modules.

LIMITATIONS

Primarily a manifold and VALVE/VALVE GEAR assessment tool with a simple "power" or combustion model.

Limited for minimal computer space to:
- Four cylinders/manifold

- Five valve gear arrangements; three push rods and two overhead cams.

- Various rocker arm ratios

- Five cam definitions
  - three arc cam
  - constant acceleration cam
  - parabolic acceleration cam
  - sinusoidal acceleration cam
  - polynominal cam

- Orifice nozzle simulation of turbocharger turbine.

- Simple compressor model to assess turbocharger balance.

- Crude heat loss model.

- Simplified coefficients in internal energy.

DATA INPUT REQUIREMENTS

- Cylinder size
- Power
- Engine speed
- Fuel type
- Air fuel ratio
- Heat release diagram
- Combustion timing
- Firing order
- Manifold dimensions
- Inlet or cylinder exhaust conditions (calculated)
- Valves and valve gear geometry
- Camshaft profile

ADVANTAGES

- Program is interactive allowing for rapid incorporation of data changes. May be used by designers who need not understand the detailed workings of program.

- Assess design influences on engine performance.

- Predicts cylinder to cylinder variations due to manifold design.

- Provides manufacturability assessment of valve gear.

VALIDATION

Validation has been by comparison with the UMIST
Mk. 12 non-homentropic I.C. Engine formulation
program which has been extensively checked against
experimental data.

Pressure and mass parameters are in reasonable
agreement with UMIST Mk. 12 output. Acceptable
correlation between trends for all cylinders.
Temperatures vary up to 6 percent between programs
and there is poor correlation of values across
cylinders.

COMPUTING REQUIREMENTS

- ANSI Fortran IV
- Control Data Corporation CYBER 72
- Digital Computer; Tectronics 4010
- VDU's for graphics

COST OF OPERATION

Not stated.

FUTURE POTENTIAL

- May provide dynamic stress analysis of valve
  gear.

- Further reduction in data requirements by use of
  automatic mesh length generation.

- Extension of program to accept more cylinders
  and different configurations.

- Further refinement of the power module to
  increase accuracy without loss of speed.

AVAILABILITY

Probably available.

TITLE   A Generalized Computer Aided Design Package for
                                I.C. Engine Manifold System

DATE   1980

AUTHORS   S.C. Low, P.C. Baruah

ORGANIZATION   University of Manchester, Institute of Science and
                                Technology (UMIST)

SPONSOR   None apparent

TRANSPORTATION MODE   All

APPLICATION   Military and civilian

OBJECTIVE   To interactively predict the performance impact of
                                the manifolding systems design on a multi-cylinder
                                reciprocating engine.

                                Output - As a function of crankangle:
                                - cylinder pressure
                                - cylinder mass flow
                                - cylinder to cylinder variation in pressure and
                                  mass flow.
                                - IMEP

REFERENCE   SAE paper 810498.

RELATIONSHIP TO   Based upon "A Computer Aided Design Package for
OTHER MODELS   Diesel Engine Manifold Systems," SAE paper 790277
                                (E-0022-IE).

HISTORY OF MODEL   A "better" version of E-0022-IE which had a similar
                                objective.

OPERATIONAL CAPABILITIES   ⊛ Assess impact of different intake and exhaust
                                   manifold systems on cylinder pressures and mass
                                   flows as well as IMEP (estimated).

                                ⊛ Steady state.

                                ⊛ Study virtually any manifold configuration and
                                   dimensions.

ASSUMPTIONS

- Heat release unaffected by mainfolding.
- Polytropic compression and expansion.
- Perfect gas law.
- Gas is non-homentropic.

LIMITATIONS

- 10 cylinder
- No cycle analysis
- Steady speed

DATA INPUT REQUIREMENTS

- Power
- Number of cylinders
- Air-fuel ratio
- Bore and stroke
- Connecting rod length
- Ambient temperature and pressure
- Lower heating valve of fuel
- Cylinder heat loss (percent of total)
- Combustion timing
- Heat release curve
- Cam type and characteristics
- Valve lift (intake and exhaust)
- Valve diameter to cylinder bore ratio (intake and exhaust)
- Valve timing
- Compression ratio
- Engine speed
- Rocker arm ratio
- Exhaust back pressure
- Manifold dimensions (intake and exhaust) each pipe
- Manifold configuration (drawn on VDU)
- Outlet (exhaust) nozzle area to pipe area ratio
- Throttle setting

Input Data Accuracy: Manifold configuration need only be roughly sketched on VDU. Dimensions must be separately stated. No accuracy requirements stated.

ADVANTAGES

- Very rapid.
- Minimal input data needed.
- Interactive.
- Spark ignition (throttled) as well as diesel (unthrottled).

VALIDATION   With one engine in addition to E-0022-IE.
                                 Generally good agreement.

COMPUTING REQUIREMENTS   Not stated.

COST OF OPERATION   Not stated.

FUTURE POTENTIAL   Could incorporate cycle analysis to become powerful
                                 total engine model.

AVAILABILITY   Presumably available from UMIST.

TITLE   Characteristics of Exhaust Gas Pulsation of
                              Constant Pressure Turbo-Charged Diesel Engines

DATE   1979

AUTHORS   T. Azuma, Y. Tokunaga, T. Yura

ORGANIZATION   Kawasaki Heavy Industries

SPONSOR   Ship Building Research Association of Japan

TRANSPORTATION MODE   Marine

APPLICATION   Military or civilian

OBJECTIVE   Clarify the characteristics of exhaust gas
                              pulsations of constant pressure turbocharged diesel
                              engines.

                              Output: Pressure in various exhaust pipe ducts as
                              a function of crankangle.

REFERENCE   Journal of Engineering for Power, October 1980,
                              Vol. 102, Transactions of the ASME.

RELATIONSHIP TO   Uses the "method of characteristics."
OTHER MODELS

HISTORY OF MODEL   This model is claimed as a first (work such as
                              reported in E-0052 preceded it, however, even
                              though that was not a model).

OPERATIONAL CAPABILITIES   Can examine exhaust gas pulsations in turbocharged
                              diesels under steady state operating conditions.
                              Use as a design tool to optimize cylinder
                              interactions and exhaust gas energy delivery to
                              turbocharger turbine.

ASSUMPTIONS   ⊛ One dimensional flow.
                              ⊛ Perfect or ideal gas.
                              ⊛ No heat loss from exhaust system.
                              ⊛ Non-isentropic, adiabatic system.

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⊕ Any exhaust system can be modeled as a
combination of:
- flow in straight pipe
- branch flow
- nozzle flow
- flowless volume
- orifice flow (throttled)

LIMITATIONS

⊕ Turbocharged engine
⊕ Steady state
⊕ Exhaust gasses only, no engine performance
analysis

DATA INPUT REQUIREMENTS

⊕ Exhaust system characteristics.
⊕ Engine firing order.
⊕ Number of engine cycles (two or four).
⊕ Engine speed.
⊕ Scavenge air pressure and temperature.
⊕ Cylinder pressure and temperature at exhaust
valve opening.
⊕ Cylinder bore and stroke.
⊕ Number of cylinders.

ADVANTAGES

Fairly unique model in that this is perhaps the
first one to model exhaust pulsations and gas flow
interactions.

VALIDATION

Generally excellent agreement obtained when
compared to a physical air-only model of diesel
engines and a diesel exhaust system.

COMPUTING REQUIREMENTS

Not stated.

COST OF OPERATION

Not stated.

FUTURE POTENTIAL

Authors intent to "marry" this model with an engine
simulation model in order to use it to assess
performance effects of pulsations on turbochargers
and hence engines.

AVAILABILITY

Unlikely.

TITLE   Computer Program to Predict the Gas Exchange
                                Process of a Diesel Engine

DATE   1974

AUTHORS   A.J. Hallam, S. Cottam

ORGANIZATION   Ruston Paxman Diesel Std.

SPONSOR   Ruston Paxman Diesel Std.

TRANSPORTATION MODE   Marine (pipeline)

APPLICATION   Military or civilian.

OBJECTIVE   To predict the influence of design changes of a
                                diesel engine's working fluid handling systems on
                                engine performance. Specific components covered
                                include:
                                - Turbocharger
                                - Intake manifold
                                - Intake and exhaust valves
                                - Exhaust manifold

                                Output:
                                - Pressure versus crankangle for
                                     - manifold
                                     - cylinder
                                - Turbocharger performance map
                                     - pressure ratio vs air flow
                                - BSFC
                                - Boost pressure
                                - Air/fuel ratio
                                     - trapped
                                     - overall
                                - Exhaust gas temperature
                                - Heat input/cylinder
                                - Heat transferred to
                                     - piston
                                     - liner
                                     - cylinder
                                     - valves

REFERENCE   Computer Aided Design, Volume 7, Number 2, April
                                1975, pp. 83-88.

RELATIONSHIP TO
OTHER MODELS

None specifically. Uses "emptying and filling" concepts.

HISTORY OF MODEL

Developed as an easy to use model capable of handling virtually any configuration diesel engine. It was developed to replace a highly complex model with applications limited to existing engines.

OPERATIONAL CAPABILITIES

Examine impact of:
- Bore and stroke
- Manifold flow areas
- Nozzle or orifice characteristics
- Valve opening profiles
- Number of valves
- Manifold junctions
- Turbocharger performance

as well as ambient conditions on engine performance. Also provides gas side heat transfer coefficients and mean gas temperature in the locus of valves, pistons, cylinder liner, and cylinder head as well as the amount of heat transfer.

ASSUMPTIONS

⊕ Gases are treated as being thermodynamically perfect.

⊕ Atmospheric conditions remain constant, separate values are given at the inlet to and exit from the system.

⊕ A single value is used for gas constant R irrespective of gas composition and temperature.

⊕ At any instant the gas conditions are uniform within any one volume.

⊕ Gas entering the volume through the junctions mixes perfectly with the gas already present.

⊕ The cycle is taken as a series of finite intervals. The size of the interval remains constant. Energy and mass flow rate are constant throughout each interval as are the gas conditions 'n each volume.

● Fuel may be burned in any volume. Its mass is added at the same instant as the heat energy is released by combustion.

● To calculate heat transferred from the surface of a fixed volume a mean heat transfer coefficient is used throughout the cycle.

● To calculate heat transferred from the surface of a working volume, the surface is taken in sections, using a mean wall temperature for each one. The heat transfer coefficient is calculated for each step and can be varied for each section.

● Combustion characteristics are influenced only by fuel/air ratio, and presumably modeled only by P.V. characteristics.

LIMITATIONS

● Combustion process not modeled.

● A junction will be one of the following types:
   (a) fixed area orifice
   (b) variable area orifice
   (c) compressor
   (d) turbine
   (e) simplified compressor, having fixed air flow
   (f) simplified turbine, consisting of a
       swallowing capacity curve.

● A turbine junction has one exit volume and up to four entry volumes. All other junctions have one exit volume and one entry volume.

● There can be only one junction between a pair of volumes.

● The capacity of a working volume is controlled by a conventional piston motion. Alternatively, a capacity curve can be supplied. Both two-stroke and four-stroke cycles are permitted.

● There must be at least one working volume.

- Each working volume must be an entry volume to a variable area orifice junction and an exit volume from another variable area orifice junction.

- Any shaft delivering power out of the system must have a fixed speed.

- Any fixed-speed shaft that is not itself an output shaft must be connected to one that is.

- Variable-speed shafts cannot be linked to any other shaft.

- Each working volume is connected to a fixed-speed shaft and hence torque is output from the engine either directly or by transmission to another shaft.

- Each active junction (types (c)-(f)) is on a shaft.

DATA INPUT REQUIREMENTS

- Working fluid system
  - dimensions
  - flow coefficients
  - valve timing
  - valve lift profile
- Turbocharger characteristics
- Initial values of gas conditions
- Speed
- Load
- Heat release curve

ADVANTAGES

- Reportedly is very flexible and user friendly.

- Provides heat transfer information to cylinder components to assist in thermal design problems.

- Not limited to specific configurations of engines (within limits of combustion assumptions which are not stated).

VALIDATION   Very good agreement reported with both previous
                                validated engine models and measured performance on
                                a Ruston diesel.

COMPUTING REQUIREMENTS   Not stated.

COST OF OPERATION   Not stated.

FUTURE POTENTIAL   None stated. Could be combined with more rigorous
                                combustion model to become very powerful modeling
                                tool.

                                Potential Accuracy: "Errors" blamed on measurement
                                shortcomings as opposed to model deficiencies.

AVAILABILITY   Proprietary model.

TITLE   Breathing Cycle of the Four-Stroke Automotive
                               Engine

DATE   1979

AUTHOR   T.J. Trella

ORGANIZATION   U.S. Department of Transportation/Transportation
                               Systems Center

SPONSORS   U.S. Department of Transportation, National Highway
                               Traffic Safety Administration

TRANSPORTATION MODE   All

APPLICATION   Military and civilian.

OBJECTIVE   To model the intake system of a four-cycle open
                               chamber engine (DI diesel or spark ignited engine)
                               and determine the influence of design parameters on
                               engine performance.

                               Output:
                               — Volumetric efficiency
                               — Trapped residual fraction
                               — Air flow rate (Intake Manifold) all as a
                                  function of engine speed or intake manifold
                                  vacuum.

REFERENCES   Article of same title in unknown publication.

RELATIONSHIP TO   None.
OTHER MODELS

HISTORY OF MODEL   Much has been written about increased breathing and
                               torque output. Particular emphasis has been placed
                               on the design of the inlet manifold,
                               carburetor-inlet throttling, and exhaust system.
                               Recently, study reports have begun to appear on the
                               use of variable inlet/exhaust valve timing as a
                               means of reducing nitrous oxide and hydrocarbon
                               exhaust emissions in spark-ignition engines at wide
                               open and partial-throttle conditions. Such studies
                               show that valve overlap, when properly applied over
                               the load/speed range, has an appreciable effect on
                               reducing these emissions. In addition, engines

whose valves are timed for maximum power at high
speeds can be modified with variable valve timing
to exhibit increased torque at low speeds, thus
providing better overall vehicle performance.

The simulation model described in this paper was
designed to predict engine breathing performance.

The analytical methods used to perform the
simulations are based on extensions of a
nonconventional unsteady-fluid dynamic model which
makes use of a sequence of stationary but finite
fluid-control volumes to predict the dynamic
behavior of the gas in an inlet track. The gas
dynamics of the exhaust system are not simulated in
the present model.

OPERATIONAL CAPABILITIES

Engine performance (air consumption) and residual
trapped fraction are modeled as a function of inlet
track, camshaft, valve, part, and throttle design
dimensions as well as valve timing, lift and engine
speed.

The model is designed for steady speed engine
operation.

ASSUMPTIONS

- Working fluid is air only.
- Working fluid behaves as idled gas.
- Blumberg fuel burning rate assumed for SI,
  Triangular heat release rate assumed for CI.
- Gas properties uniformly distributed throughout
  combustion chamber.
- Quasi-steady state orifice theory is fundamental
  approach to gas flow calculations.

LIMITATIONS

- Does not calculate exhaust flow. Must be
  gathered empirically.

- Require empirical data obtained from specific
  engine under study.

DATA INPUT REQUIREMENTS

- Design data on:
  - Inlet track
  - Valve mechanism
  - Combustion chamber
  - Crank/read mechanism
- Engine valve lift speed.
- Engine control parameters.
- Manifold temperature and pressure.
- Valve part discharge coefficients.
- Combustion chamber and inlet manifold wall temperature.
- Empirical data on:
  - Exhaust back pressure
  - Inlet restrictions

Availability of Data Base:
None required, but input data publicly available from DOT/TSC.

ADVANTAGES

Uses novel approach to gas flow calculations, eliminating the time consuming "method of characteristics."

VALIDATION

Six engine study. "Reasonable" correlation achieved (up to 20 percent error in some reported comparisons).

COMPUTING REQUIREMENTS

Not stated

COST OF OPERATION

Not stated

FUTURE POTENTIAL

May include prechamber effects in future work.

AVAILABILITY

Available from U.S. DOT/TSC.

TITLE   Development of a Real-Time Digital Computer
                               Simulation of a Turbocharged Diesel Engine

DATE   1979

AUTHOR   S.S. Shamsi

ORGANIZATION   Pakistan State Oil Company Ltd.

SPONSOR   UMIST

TRANSPORTATION MODE   All

APPLICATION   Military and civilian.

OBJECTIVE   To model the response of a turbocharged diesel
                               engine to changes in shaft load.

                               Output:
                               - Engine speed as a function of time.
                               - Engine power
                               - Exhaust temperature
                               - Turbocharger speed
                               - Fuel rack position
                               - Manifold pressure
                               - Air flow
                               - Smoke

REFERENCE   SAE Paper 800521

RELATIONSHIP TO   None stated.
OTHER MODELS

HISTORY OF MODEL   None given.

OPERATING CAPABILITIES   Evaluate the influence of alternative governor/fuel
                               pump and/or turbocharger characteristics on a given
                               engine's transient response to changes in shaft
                               load.

ASSUMPTIONS   ● Transient response consists of a series of
                                 steady-state air flow conditions.

                               ● Mechanical accelerations governed by Newton's
                                 second law.

- Steady-state maps valid during transient operation.

- Scavenge mass flow = constant percentage of trapped mass flow rate.

- Compression efficiency is constant at 70 percent.

- During transients there is a 5 percent reduction in engine IMEP and turbine inlet temperature from steady-state values.

LIMITATIONS

- Depends on the existence of steady-state maps.

- Examines influence of turbocharger and governor/fuel pump characteristics only.

DATA INPUT REQUIREMENTS

Steady-state maps
- Engine performance
- Turbocharger characteristics
- Governor characteristics
- Engine friction

ADVANTAGES

- Only digital engine response model in existence (1980).

- Claimed to be very economical to run.

VALIDATION

"Good agreement" between test bed and model performance achieved except for short duration (1 second) spikes in test bed performance.

Validation only on one engine.

COMPUTING REQUIREMENTS

PDP-10 Digital machine.

COST OF OPERATION

Not stated except that it is "very economical."

DATA BASE   Not required.

FUTURE POTENTIAL   Incorporate study of means to improve turbocharger
                                    response.

AVAILABILITY   Unknown.

TITLE   A Combustion Correlation for Diesel Engine
Simulation

DATE   1979

AUTHORS   N. Watson, A.D. Pilley, M. Marzouk

ORGANIZATION   Imperial College of Science and Technology

SPONSOR   None apparent.

TRANSPORTATION MODE Highway, possibly others.

APPLICATION   Military and civilian.

OBJECTIVE   To provide a means for correlating the Apparent
Heat Rate Release (AHRR) with engine configuration
and operating conditions in order to improve the
accuracy of engine models which do not incorporate
combustion models.

            Output: Apparent heat release rate at engine
operating points not actually tested.

REFERENCE   SAE Paper 800029.

RELATIONSHIP TO   None, but could be incorporated into a number of
OTHER MODELS   models such as E-0051-OP or E-0055-IE.

HISTORY OF MODEL   Work by Shipinski as well as Woschini and Anisits
tried to obtain correlation between engine
configuration and operating parameters using a
Wiebe function. The subject method incorporates a
Wiebe function methodology but also considers
parameters influencing the fuel burning rate and
incorporates them into "shape factors" (Apparent
Fuel Burning Rate (AFBR) vs. crankangle). It also
considers premixing as well as the effects of
diffusion limited and combustion kinetic limited
burning.

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OPERATIONAL CAPABILITIES

Uses limited empirical data on effects of equivalence ratio, ignition timing, speed, load and cylinder pressure vs. crankangle to predict combustion AHRR over a very wide range of engine speeds and loads.

ASSUMPTIONS

Combustion always takes place in the same step-by-step manner regardless of engine speed and load.

LIMITATIONS

Based on empirical data measured for each engine of interest.

DATA INPUT REQUIREMENTS

- Cylinder pressure diagram (motoring and running)
- Injection timing and duration
- Needle lift diagrams
- Equivalence ratio as f. of crankangle
- Engine speed

Potential Accuracy: Very much a function of a number of initial data points.

Input Data Accuracy: Desired to be better than the accuracy claimed for cylinder pressure measurement, a key input.

ʌ VANTAGES

Expands the accuracy of other models which use a fixed rate of heat release for all engine conditions.

VALIDATION

Performed on three engines with varying degrees of success.

COMPUTING REQUIREMENTS

Not stated.

COST OF OPERATION

Not stated.

FUTURE POTENTIAL

None stated.

AVAILABILITY

Presumably.

TITLE	Model title unknown: explained in detail in: <u>Free Piston Gasifier Studies: Development of a</u> <u>Hybrid Simulation</u>, Rueter, F.; Swiderski, A.; NRC, DME Mechanical Engineering Report ME-230, National Research Council of Canada.
DATE	1968-1969
AUTHORS	F. Rueter, A. Swiderski
ORGANIZATION	National Research Council of Canada
SPONSORS	Unknown
TRANSPORTATION MODE	Pipeline
APPLICATION	Civilian
OBJECTIVE	.nvestigate the operation and performance of a turbocharged, two cycle free piston diesel engine and to develop the engine to an optimum configuration. Also to predict the effects of various design assumptions on engine performance and operation.

Output:
- Power
- Specific fuel consumption
- Piston frequency
- Diesel compression pressure
- Maximum diesel combustion temperature
- Maximum bounce pressure
- Hydraulic piston stroke
- Diesel piston stroke

REFERENCE	<u>Hybrid Computer Study of a Free Piston Engine with</u> <u>a Hydraulic Pump</u>; F. Rueter, A. Swiderski, and J. Samolewicz, National Research Council of Canada, Mechanical Engineering Report ME-236.
RELATIONSHIP TO OTHER MODELS	None.
HISTORY OF MODEL	Not given.

OPERATIONAL CAPABILITIES

Investigate the influence of various design parameters
- Bounce cylinder diameter
- Diesel exhaust port position
- Bounce cylinder effective clearance length
- Hydraulic cylinder diameter
- Mechanical spring rate
- Mechanical spring preload
- Bounce port position
- Component masses
- Boost pressure
- Cylinder bore (power and hydraulic)
- Engine friction
- Combustion efficiency
- Ambient conditions

All can be evaluated under steady state conditions, but include a start-up phase.

ASSUMPTIONS

- Mechanical and combustion efficiencies
- Combustion
  - Constant volume heat release up to 2500 psi
  - Constant pressure heat release over 2500 psi
  - Minimum A/F ratio = 18
  - Combustion efficiency = 98 percent
- Isentropic expansion/compression
- No leakage in diesel cylinder (i.e., No Blow By)
- Desired boost pressure always available

LIMITATIONS

- Free piston, 2 cycle turbocharged diesel
- Single combustion model
- Steady state
- Hydraulic power extraction
- Needs hybrid analog/digital computer

DATA INPUT REQUIREMENTS

- Engine dimensions and reciprocating component masses, spring rate
- Fuel injection system throttle setting
- Fuel properties
- Boost pressure
- Engine friction
- Combustion and thermal/mechanical efficiencies

ADVANTAGES   ● One of the few free piston models.
                                         ● Includes some cycle analysis.

VALIDATION   None done with this model, but approach is said to have been validated in other models.

COMPUTING REQUIREMENTS   Electronic Associates Model 690 hybrid computer (Model 680 analogue and 640 digital).

Fortran IV language for digital portion.

COST OF OPERATION   Not stated.

FUTURE POTENTIAL   None stated.

Potential Accuracy: Assumptions can be fine tuned to improve accuracy after an engine is built and run for comparison.

AVAILABILITY   Presumably available from NRC.

TITLE	Application Engineering Techniques Related to High Performance, Medium Speed Diesel Engines
DATE	Undated: probably mid 1970s.
AUTHORS	R. Greenhalgh, P. Tooth, I.I. Bickley.
ORGANIZATION	Mirrlees Blackstone, Limited
SPONSOR	Mirrlees Blackstone, Limited
TRANSPORTATION MODE	Marine, pipeline
APPLICATION	Military or civilian.
OBJECTIVE	To determine the response of an engine to changes in:

OBJECTIVE (continued):

- Load
- Ambient pressure and temperature

and evaluate alternative systems or installations to cope with these changes.

Output:
- Engine
- Speed
- Power
- Compressor Pressure Ratio
- Air Manifold Temperature
- Air Flow
- Exhaust Temperature

REFERENCES	Article of same title printed in unlabeled reference.
RELATIONSHIP TO OTHER MODELS	None mentioned.
HISTORY OF MODEL	Developed from hand calculation procedure used by Mirrlees Blackstone.

OPERATIONAL CAPABILITIES

Predict behavior of engine:

- Speed   )
- Turbocharger) - as a function of time
- Governor   )

in response to changes in load, which can be either
a step change or a ramp change.

Also, predict engine power and speed capabilities
at varying altitudes and ambient temperature.
Predict the influence of various accessories:

- Turbocharging (single or dual)
- Intercooling
- Aftercooling
- Alternate cooling systems

on engine performance under non-standard ambient
conditions.

DATA INPUT REQUIREMENTS

- Ambient Conditions
- Load
- Empirically derived performance data (or maps)
  for engine.
  - cylinders
  - boost devices
  - air cooling systems

- Potential Accuracy
  - Will improve and have expanded predictive
    range as the data base is expanded through
    experience.

- Input Data Accuracy
  - Highly influential to output accuracy.

ASSUMPTIONS

Not stated. However, this model is highly
empirical, based on the assumption that laboratory
experiments correlate with field performance.

LIMITATIONS

- Exclusively empirical.
- Requires performance "map" for each system
  component under study.

● Probably most applicable only to the Mirrlees Blackstone or similar large bore medium speed diesels.

ADVANTAGES

● Accurate, quick, predictions of engine performance under conditions not yet experienced (good application engineering tool).

● Model transient response of engine under actual operating conditions.

VALIDATION   Close agreement with in field measurements.

COMPUTING REQUIREMENTS   Computer type not mentioned: language is ICLJEAN.

COST OF OPERATION   Not stated.

FUTURE POTENTIAL   Continue to work, apparently on refining empirical data base, in order to improve range of conditions which can be modeled.

AVAILABILITY   Not stated, most likely not available.

TITLE   Development of P.C. Engine Simulation Program.

DATE   1971-1974

AUTHORS   K. Shiraishi, K. Murakami, M. Mizushima, and
                             T. Nakayama.

ORGANIZATION   Nippon Kokan (Japanese licensee for Pielstick-SEMT
                             Engines).

SPONSOR   Nippon Kokan

TRANSPORTATION MODE   Marine

APPLICATION   Military and civilian.

REFERENCE   Nippon Kokan Technical Report - Overseas July 1975.

OBJECTIVE   To model the NKK (Pielstick) 3PC2-5L test engine in
                             order to make performance predictions.

                             Output - As a function of horsepower:
                             - Fuel rate
                             - Speed (RAM)
                             - Air flow
                             - Turbocharger speed
                             - Supercharger speed
                             - Peak combustion pressure
                             - Manifold temperatures

RELATIONSHIP TO   Based on the 1971 modeling work of 130th Research
OTHER MODELS   Panel of Shipbuilding Association of Japan.

HISTORY OF MODEL   Not stated.

OPERATIONAL CAPABILITIES   Predicts the power output of the NKK-Pielstick
                             3PC2-5L engine over its entire operating range.

ASSUMPTIONS   ● Semi-perfect gas.
                             ● Combustion rate solely a function of crank
                               position.
                             ● Heat transfer rate governed by Eicherberg's
                               empirical formulae.

LIMITATIONS
- Steady-state performance only.
- Applicable only to subject engine.
- Empirical coefficients used to tune theoretical formulae.
- Even firing, single pipe exhaust systems.

DATA INPUT REQUIREMENTS
- Engine dimensional data.
- Supercharger/turbocharger characteristic curves.
- Gas temperature: pressure at various points in manifolds.
- Combustion start angle.
- Combustion duration.
- Heat release index.
- Various flow coefficients for the engine under study.

Availability of Data Base:
Required empirical correlations inherent in model.

VALIDATION
Validated against subject engine with agreement within 5 percent steady-state.

COMPUTING REQUIREMENTS
Not stated

COST OF OPERATION
Not stated

FUTURE POTENTIAL
- Will expand capabilities to uneven firing, multiple pipe exhaust manifolds.
- Improving turbine modeling system to get better correlation.

AVAILABILITY
Highly unlikely

TITLE	Wholly Dynamic Model of a Turbocharged Diesel Engine for Transfer Function Evaluation
DATE	1976
AUTHORS	Winterbone, Thiruarooran and Wellstead
ORGANIZATION	University of Manchester, Institute of Science and Technology (UMIST)
SPONSORS	Not stated.
TRANSPORTATION MODE	All
APPLICATION	Military and civilian.
OBJECTIVE	To describe the response of an engine to changes in shaft load with emphasis on an accurate description of the intake and exhaust systems coupled with a turbocharger.

OBJECTIVE (continued):

Output:
- Exhaust temperature
- Turbocharger speed
- Engine speed
- Fuel rack position

All as a function of time.

REFERENCE	SAE Paper 770124.
RELATIONSHIP TO OTHER MODELS	Not stated.
HISTORY OF MODEL	The model discussed in this paper attempts to overcome many of the shortcomings of the quasi-steady case by adopting a more fundamental approach. It is based on the 'filling-and- emptying' technique for evaluating turbocharged engine performance. Some empirical factors have been implied, these were assessed from steady-state results. It is felt that this model is the best compromise between the simple quasi-steady models and the complex wave-active based simulations. The program consists of two main sections, the gas flow section,

in which the filling of the cylinders is matched to
the turbine and compressor characteristics, and the
power section, in which the power output of the
engine is evaluated by a modified simple cycle
analysis. The final model consists of 30 simul-
taneous non-linear differential equations which are
integrated on a step by step basis.

OPERATIONAL CAPABILITIES

Determine the influence of turbocharger, intake,
and exhaust manifold on engine response to a change
in shaft load.

ASSUMPTIONS

● Turbine and compressor are adequately
represented by steady-state characteristics.

● Cycle-to-cycle variations neglected.

● Exhaust manifold heat losses are a constant
percentage of manifold input enthalpy.

LIMITATIONS

● Many of its fundamental equations are over-
simplified and model is hence "tuned" with
coefficients which may have to be empirically
determined from one engine to the next.

● Model not generally applicable from one engine
to the next without empirical "tuning" data.

● Actual determination of heat losses totally
ignored.

DATA INPUT REQUIREMENTS

● Turbocharger characteristics
● Governor characteristics
● Engine characteristics
  - Manifold systems details
  - Rotating component moment of inertia
    etc: (paper not legible).

ADVANTAGES   Claimed to be more fundamentally based than some
                              models, hence requiring less empirical data:
                              However, the "tuning" coefficients used are
                              empirically derived and may not be universally
                              applicable.

VALIDATION   Validated only to the extent that "tuning"
                              coefficients determined on one engine.

COMPUTING REQUIREMENTS   Fortran IV: uses CDC 7600 or PDP-10 computers.

COST OF OPERATION   CPU/Engine rpm = 600 for PDP-10
                              CPU/Engine rpm = 20 for CDC-7600

FUTURE POTENTIAL   Better validation work and more fine tuning is
                              underway.

                              Potential Accuracy: Improvements being sought.
                              Universally applicable accuracy improvement
                              doubtful.

AVAILABILITY   Presumably from UMIST.

TITLE   Simulation of a Turbocharged Diesel Engine to
                             Predict the Transient Response

DATE   1977

AUTHOR   M.R. Goyal

ORGANIZATION   John Deere

SPONSOR   John Deere

TRANSPORTATION MODE   Highway, perhaps others.

APPLICATION   Military and civilian.

OBJECTIVE   To predict engine performance (speed, A/F ratio,
                             pump rack position, turbocharger speed, intake
                             manifold pressure during speed and load transients.

                             Output:
                               As a function of time:
                               - Shaft speed
                               - Turbocharger speed
                               - Fuel rack position
                               - Intake manifold pressure
                               Fuel and AM flow
                               Power
                               Turbine inlet temp

REFERENCE   ASME paper 78-DGP-11

RELATIONSHIP   Based upon work of Borman and McAuley.
TO OTHER MODELS

HISTORY OF MODEL   None given.

OPERATIONAL CAPABILITIES   Uses quasi-steady state analysis to determine
                             engine response to changes in operator input
                             (throttle position) or shaft load. Effect of
                             changes in control, operations, and design can be
                             studied.

ASSUMPTIONS
- Engine and turbocharger pass through a series of quasi-steady states during transient.

- Heat transfer coefficients based on Annand's work.

- Each cylinder component has a constant, uniform surface temperature.

- Fuel mass heat release rate described by Wiebe's semi-empirical dimensionless equation.

- Burning schedule described by Benson.

- Engine friction estimated by method of Chen and Flynn.

LIMITATIONS
- Must be empirically tuned to engine under study.

- Simplified combustion model.

DATA INPUT REQUIREMENTS
- Steady-state Compressor Performance Charts
- Steady-state Turbine Performance Charts
- Mechanical Component Polar Moments of Inertia
- Engine Load Profile
- Governor and Pump descriptive equations
- Engine Dimensions

Data Base: Steady-state engine data needed on engine of interest.

VALIDATION
Good correlation achieved with turbocharged as well as turbocharged and intercooled engines (2 engines, 12 operating points total published).

COMPUTING REQUIREMENTS
Not stated.

COST OF OPERATION
Not stated.

FUTURE POTENTIAL
Not discussed.

AVAILABILITY
Unlikely.

TITLE	Boiler Analysis Program (BAP)
DATE	1970 (modification through 1982)
AUTHORS	J. Gerstman, with recent modifications by I.P. Krepchin.
ORGANIZATION	Foster-Miller
SPONSOR	Private
TRANSPORTATION MODE	Highway
APPLICATION	Both military and civilian.

OBJECTIVE

This model was developed for the design and analysis of once-through boilers, both fired and waste heat. The configuration assumed in the model is a patented conical helix.

Output – The major outputs of this model are:

- Steam flow for given gas conditions and desired steam temperature and pressure, or

- Gas flow for given water flow and desired steam temperature and pressure.

- Boiler efficiency.

- Steam and gas side pressure drops.

- Temperature distributions of the steam, wall and gas.

REFERENCES

Demler, R.L., "Design and Development of an Automotive Propulsion System Utilizing a Rankine Cycle Engine (Water Based Fluid)," for U.S. ERDA, EY-76-C-02-2701 A001, September 1977.

RELATIONSHIP TO
OTHER MODELS

The BAP model can be used in conjunction with steam expander model to simulate bottoming cycle systems.

HISTORY OF MODEL

Over the years since 1970, the model has been modified to accommodate: alternate fuels, split-fin tubing, interactive design use. The capability to model waste heat boilers and to converge faster are also recent additional capabilities.

OPERATIONAL CAPABILITIES

This model includes the following range of capabilities.

- Steady-state calculations, some information available for transient behavior.

- Complete parametric capabilities.

Limited to 10 water/steam passes - Any tube and fin sites and any coil diameter.

ASSUMPTIONS

The major assumptions are:
- Uniform gas flow distribution.
- Constant steam pressure.

LIMITATIONS

None identified.

DATA INPUT REQUIREMENTS

The data that are required as input to the model are:
- Boiler geometry.
- Water inlet and outlet temperature and pressure.
- Water flow or gas flow.
- Gas temperature or fuel and fuel-air ratio for fired boilers.

ADVANTAGES

None identified.

VALIDATION

This model has been validated by experiment and prototype performance. Validation described in Demler, R.L., "Demonstration of a Steam Powered Face Haulage Vehicle," FMA/DOE ET-75-C-01-0916, July 1979.

COMPUTING REQUIREMENTS   The model code written in Fortran and used on
                               CYBER 170 series and VAX 11/780.

COST OF OPERATION   The average cost per run of operating this model on
                               the current hardware described above is $.20/run.

FUTURE POTENTIAL   No current plans.

AVAILABILITY   This program is not for sale, however, it can be
                               used for a fee.

TITLE

Rankine Cycle, Waste Heat Recovery Engine
(part-load and full-load) Performance Model

DATE

1974

AUTHORS

DiBella, F.A., and Wang, C.

ORGANIZATION

Thermo Electron Corporation, Waltham, Massachusetts

SPONSOR

Thermo Electron Corporation (TECO)
Internal R&D funding

TRANSPORTATION MODE

All modes

APPLICATION

This model is applicable to military and civilian
use.

OBJECTIVE

This program is used to determine the full and
part-load performance of a Rankine Cycle system
using specified heat exchanger and turbine compon-
ents. It will calculate the performance of a
Rankine Cycle System with a minimum of input data;
and with either a water cooler or air cooled
condenser cooling system specified. An indirect
heating or cooling sub-system can also be accom-
modated for Solar Rankine Cycle System Analysis,
for example. Radiator fan cooling curves are also
available for accurate power consumption versus
cooling performance evaluations.

The model also permits the working fluid to be
changed in order to evaluate the Rankine Cycle
Performance for various working fluids.

Output: The major output parameters are the
Rankine Cycle System's net power output, component
(far, pump, etc.) parasitic losses as well as heat
exchanger and turbine operating efficiencies for
operating point at full or part-load conditions.

REFERENCES

Not identified. However, Thermo Electron maintains
all of the necessary program documentation and/or
manuals.

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RELATIONSHIP TO
OTHER MODELS

This computer model is the "Main" program for which
several sub-programs have been written in order to
separately evaluate any of the principle Rankine
Cycle Components. This main model does not require
the sub-programs to function however, the sub-
programs will only identify the performance that
can be expected of an individual component. By
observing each individual component's performance
taken separately; the engineer can identify and
make improvements to that component before it is
used in the main program.

In this sense, this computer program is the main
program of a family of shorter computer models.

HISTORY OF MODEL

This Rankine Cycle System performance model was
developed by Thermo Electron Corporation to support
its development work in the design, assembly and
testing of Organic Rankine Cycle Systems.

This model has been used to predict the full and
part-load performance characteristics of TECO's
systems ranging in size from 35 kW to 450 kW. It
can be used for systems with any power output
provided the necessary heat exchanger size and
turbine design point performance is known and input
into the computer program.

The model has been updated with regards to turbine
aerodynamics and/or heat exchanger heat transfer
coefficients as testing of the developed systems
have been performed and test results confirmed.

OPERATIONAL CAPABILITIES

The model is essentially a steady-state model of
the Rankine Cycle's full and part-load performance.
It can identify its operational characteristics
with only a minimum of essential inputs; for
example, heat energy temperature and flowrate and
ambient temperature. The sizes of any of the heat
exchangers or the pumping curve characteristics or
the turbine's aerodynamic design point charac:er-
istics can be readily changed; particularly if the
system is used with a computer that has a time
share capability.

ASSUMPTIONS

The computer model does not require any assumptions to be made concerning the Rankine Cycle System performance. Each component of the Rankine Cycle System model used either TECO tested results or manufacturers performance guarantees (i.e., pump and fan curves, heat exchanger performance data).

LIMITATIONS

The computer model may be limited in modeling a Rankine Cycle System below 30 percent of its Rated-Design Point power output.

DATA INPUT REQUIREMENTS

Input data for the Rankine Cycle System computer model includes heat energy inlet temperature and flowrate and the ambient or "Heat Sink" temperature. The system's component sizes and turbine size and Design Point operating characteristics are also required. However, these component descriptions are input only once, at the start of the program, and are used to determine the part-load performance of the Rankine Cycle System when part-load heat energy conditions are identified to the model.

Input Data Accuracy: The input data can be to only one decimal place.

Cost of Data Base: The cost for the data base varies with the type of heat source, the amount of part-load data, and the degree of fluctuation of this data. A specific cost for the data base is, therefore, not readily determined without a description of the size of the data to be run.

ADVANTAGES

It is thought that this Rankine Cycle System model is very versatile for use with various energy recovery scenarios. For example, the heat source can be a solar heated heat transfer fluid or a fuel oil or coal-fired heat exchange. The heat source may involve waste heat energy recovery from diesel or gas turbine engines. The "cold sink" may also involve a simple air-cooled or water-cooled condenser or involve the more complicated, indirect heat transfer cooling system. For example, a radiator and cooling fan assembly to reject heat from a water-cooled condenser.

VALIDATION

The computer model has been used to verify the performance of a 35 kW, 75 kW, 100 kW, and 450 kW Organic Rankine Cycle System with success. The operation of the 35 and 100 kW units are documented in several DOE and internal reports, respectively.

COMPUTING REQUIREMENTS

The computer model is currently used with a Xerox computer and is written in Fortran IV language.

COST OF OPERATION

TECO's cost to operate this program is not representative because of TECO's access to an inexpensive time share service. The actual running time for the program is typically measurable in seconds and not minutes.

FUTURE POTENTIAL

The computer model continues to be updated whenever methods are found to perform the system calculations quicker, with fewer iterations. Modifications of the turbine aerodynamic models are made to reflect current state-of-the-art.

Potential Accuracy: The performance accuracy is very much dependent upon manufacturers heat exchanger, pump and/or fan data as well as on the extent of the working fluid properties available for the program's computations. It is necessary to have friction as well as heat transfer versus flow-rate data for each heat exchanger in the system. The plumbing diameters and the number of 90° and 180° returns in the plumbing is also necessary for an accurate pressure drop calculation. The amount and location of insulation used with the components is also required.

AVAILABILITY

The model presently unavailable to external organizations. Rankine Cycle modeling can be contracted from the Thermo Electron Corporation or adapted for use by NASA/Lewis provided contractual arrangements are made.

TITLE	DRC Modelling (Rankine Bottoming Cycle Engines)
DATE	1980-1983
AUTHORS	Various
ORGANIZATION	Mechanical Technologies, Inc. (MTI)
SPONSORS	Various including DOE and MTI
TRANSPORTATION MODE	Has been applied to pipeline and marine applications.
APPLICATION	Civilian
OBJECTIVE	Optimum sizir performance and cost trade-offs including thermodynamic inputs as well as financial DCF analyses.
REFERENCES	Model results have been incorporated in numerous articles, papers and reports published by MTI. There is no formal documentation of the models themselves.
RELATIONSHIP TO OTHER MODELS	This model is a stand alone model. Models covering the use of steam Rankine bottoming and topping cycles draw upon the same economic subroutines.
HISTORY OF MODEL	The current model is the latest version of a series of models developed by MTI since 1975. These include inputs from studies funded by various governmental and commercial customers and MTI.
OPERATIONAL CAPABILITIES	It provides thermodynamic and mechanical design and performance, estimated costing and economic analyses. It is a steady state model. Transient operation in stationary applications is not relevant.
ASSUMPTIONS	Not identified.

LIMITATICNS

The model is for steady state operation and does not explicitly incorporate the performance characteristics of the diesel engine in order to obtain an engine system performance map. The characteristics of the diesel engine are accounted for by input as external data, the steady state temperatures, and flow rates of the diesel engine waste heat streams.

DATA INPUT
REQUIREMENTS

Heat flows and temperatures for input stream, cooling water temperatures, energy economic parameters.

OUTPUT PARAMETERS

Performance, design parameters, costs, and DCF.

ADVANTAGES

The analyses and cost data have been verified by actual tests and fabrications.

VALIDATION

The model has been validated. No publication has been prepared.

COMPUTING REQUIREMENTS

The model is written in a Fortran language which can be run on IBM compatible equipment. Input data needs include operating temperature levels, input heat flows, and energy economic parameters.

COST OF OPERATION

Not identified.

FUTURE POTENTIAL

The performance and cost data are updated periodically to incorporate the most recent data.

AVAILABILITY

The model can be applied by MTI for funded studies.

TITLE	Brayton Bottoming System (BBS) Evaluation
DATE	This model is an evolution of an existing model that has been developed and modified over the past five years.
AUTHORS	Gene Wilmot, et al., Hamilton Standard Division (HSD). Adapted to Diesel Engine Application by T.N. Obee, United Technologies Research Center (UTRC).
ORGANIZATION	HSD of United Technologies Corporation and United Technologies Research Center (UTRC).
SPONSOR	UTC
TRANSPORTATION MODE	Any diesel engine-powered mode.
APPLICATIONS	Mostly civilian.
OBJECTIVE	To perform design and performance calculations of Brayton-cycle waste heat recovery systems under both design and off-design conditions.
REFERENCES	Proprietary manuals.
RELATIONSHIP TO OTHER MODELS	This is a self-contained model that combines the design and performance characteristics of compact heat exchangers with those of turbomachines. The heat exchanger part of this model can be accessed separately for heat exchanger design and sizing purposes.
HISTORY OF MODEL	This model represents an adaptation to BBS of a sophisticated aircraft environmental control air-cycle system model which has been in use at HSD for many years.
OPERATIONAL CAPABILITIES	This model can be used both for design and heat exchanger sizing calculations and for off-design performance calculations of the entire system. Design factors of interest can be varied easily.
ASSUMPTIONS	Validity of compact heat exchanger maps such as those given in Kays & London, and validity of turbomachinery similarity and scaling laws.

LIMITATION

The model assumes that only air will flow through turbomachines. Also, only uniform fouling of heat exchanger surfaces can be accounted for.

DATA INPUT
REQUIREMENTS

Design Mode: Cold and hot side flow rates and inlet/outlet temperatures; pressure levels and allowable pressure drops; heat exchanger configuration and fin geometry (Stanton Number and friction factor maps are stored in computer library for a wide variety of finned surfaces).

Performance Mode: Characteristics of heat exchangers and turbomachines (e.g., performance maps or data) and external conditions such as diesel exhaust temperature, pressure and flow rate at a given speed, ambient conditions and heat exchanger fouling factors.

ADVANTAGES

Fast simulation of complex systems consisting of several heat exchangers and several turbomachines and connecting conduits, both for design and off-design calculations.

VALIDATION

The original version of the model has been successfully used for designing air-cycle aircraft cabin cooling systems, e.g., the HSD-designed and built system used on the F-16 Falcon.

COMPUTING
REQUIREMENTS

The model is written in Fortran and usually ran on an IBM 3380.

COST OF OPERATION

Less than $1 per run.

FUTURE POTENTIAL

Extending the simulations to fluids other than air, and an improved model for heat exchanger fouling.

AVAILABILITY

The model is proprietary to UTRC. Can be used only by UTC Divisions. Indirectly available to NASA through contracts to UTRC or HSD.

TITLE	Rankine Bottoming Cycle Performance Code
DATE	June 1981
AUTHORS	Korazinski, J.L. and Ash, J.E., were the people primarily involved inthe code development.
ORGANIZATION	Argonne National Laboratory
SPONSOR	Initially: DOE – Office of Industrial Programs; Currently: DOE – Office of Vehicle and Engine R&D.
TRANSPORTATION MODE	The initial application was for stationary systems in the size range of 600-2400 kW.
APPLICATIONS	Program can, however, estimate organic Rankine engine performance in quasi steady state applications associated marine or pipeline applications.
OBJECTIVE	To calculate the performance (efficiency, power output, etc.) and cost of Rankine bottoming cycle systems as a function of working fluid and operating parameters.
REFERENCES	1. Manciniak, T.J., et al, "Comparison of Rankine-Cycle Power Systems: Effects of SEven Working Fluids," Argonne National Laboratory Report ANL/CNSV-TM-87 (June 1981).
	2. Ash, J.E., "Analytical Expressions for Thermodynamic Properties of Rankine Bottoming Cycle Organic Working Fluids," (draft), (June 1982).
RELATIONSHIP TO OTHER MODELS	The current model is not a submodel or part of a family of models. The current model can be used as a separate entity. It could, however, be adopted for use as a subroutine to estimate the performance of combined diesel engine/RBC systems.
HISTORY OF MODEL	The current ANL model is based upon the model described in the report ANL/CNSV-TM-87. The major modifications involved the inclusion of equations into the code for the calculation of fluid properties.

OPERATIONAL
CAPABILITIES

- The performance calculations are independent of the size or type of the heat source. The cost data presently in the code applies to systems in the range of 600-2400 kW.
- Steady-state or quasi-steady-state.
- Gross factors (heat source flow rate and temperature, cooling water temperature, turbine efficiency, etc.) can be readily changed for parametric studies.

ASSUMPTIONS

The model inputs specific assumptions relative to heat transfer coefficients, working fluid properties, and component performance characteristics. As such, it is valid only under the specific design conditions where these design point conditions apply.

LIMITATION

The model was not set up to do a detailed design analysis of a specific bottoming cycle system. It is intended for scoping studies to assess the impact of the working fluid on the system performance and cost.

DATA INPUT
REQUIREMENTS

The input data required include a description of the heat source (temperature, flow rate), some basic properties of the working fluid (e.g., molecular weight, boiling point), and cost data for the sizes of components of the bottoming cycles being studied.

ADVANTAGES

The model is useful for quickly and cheaply performing scoping studies to determine the effect of working fluid selection and gross operating parameters (temperatures, capacity, etc.) on RBC performance and cost. It is intended to fully document the model and make the computer code readily available to potential users. The model is useful for quickly performing scoping studies to determine the effects of changes in fluid properties on system performance and cost.

VALIDATION

Some validation of the model was done for the Sundstrand 600 kW bottoming cycle system. This validation data has not been formally published.

COMPUTING
REQUIREMENTS

The code is written in Fortran. It has been run on an IBM 3033 computer.

COST OF OPERATION

The average run cost about $1.50-$2.50 depending on the number of cases run for a specific fluid, which may range from about 30 cases to about 70 cases. Each case corresponds to a different operating condition (different maximum temperature and pressure) for the fluid.

FUTURE POTENTIAL

Additional development work is planned on the fluid property subroutines. It is also intended to modify the component models and improve their flexibility. It is also planned to change the cost models to cover a size range more appropriate to bottoming cycles for heavy-duty transportation systems.

AVAILABILITY

Prior to its release, the model needs to be more thoroughly documented.

TITLE	Turbocharged Diesel Engine Simulation to Predict Steady-State and Transient Performance
DATE	1977
AUTHORS	A.S. Ghuman, M.A. Iwamuro, H.G. Weber
ORGANIZATION	Cummins Engine Company
SPONSOR	Cummins Engine Company
TRANSPORTATION MODE	Highway and other adaptations of highway engines (may be limited to direct injected engines).
APPLICATION	Military and civilian.

OBJECTIVE

⊚ Predict relative merits of various methods used to improve transient engine response.

⊚ Predict steady-state and transient performance of a particular engine system at some untested operating condition.

Output:
- Engine
    - IMEP
    - Engine friction
    - Pumping work
    - Volumetric efficiency
    - Exhaust manifold temperature

- Turbocharger
    - Speed
    - Pressure ratio
    - Efficiency
    - Mass flow

REFERENCES	ASME Paper 77 DGP5
RELATIONSHIP TO OTHER MODELS	None stated.

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OPERATIONAL CAPABILITIES

- The model uses limited experimental data to develop steady-state engine performance maps.

- Steady-state engine maps are used to develop engine transient response performance.

- Various engine parameter variables (see input data) or forcing functions (such as fuel rate variation with time, engine load variation, etc.) can be varied to assess the impact on steady-state and transient performance.

ASSUMPTIONS

- Steady-state performance maps for engine and turbocharger are valid during each instant of transient operation.

- In-cylinder heat transfer rate is constant.

- Steady-state engine performance can be adequately mapped by curve fitting between a few experimentally determined points.

- The exhaust manifold metal is assumed to be divided into two layers, the inner much thinner than the outer. This allows improved modeling of the thermal responsiveness of the wall during transients.

LIMITATIONS

- "Emptying and Filling" model

- The model demands inputs which are estimated or experimentally derived. Few fundamental engine parameters are considered. For example, the effect of an insulated manifold is predicted by estimating the change in manifold gas temperature.

- Ignores "cycle analysis" completely.

- No in-cylinder time delay for gas flow.

- Will not predict manifold resonances and hence cylinder to cylinder variations.

DATA INPUT REQUIREMENTS

- Steady-State
  - Engine speed
  - Fuel rate or air/fuel ratio
  - Compressor inlet temperature and pressure
  - Turbine exit temperature
  - Coolant temperature into aftercooler
  - Aftercooler effectiveness
  - Turbocharger bearing losses
  - Intake manifold pressure and temperature
  - Exhaust manifold pressure

- Transient
  - Steady-state performance maps
    - engine speed
    - fuel rate or air/fuel ratio
    - turbocharger speed
    - compressor inlet pressure and temperature
    - turbine exit pressure
    - intake manifold pressure and temperature
    - exhaust manifold pressure and temperature
    - exhaust manifold metal temperature
  - Coolant temperature into aftercooler
  - Aftercooler effectiveness
  - Engine system inertia
  - Turbocharger inertia
  - Load on the engine
  - Exhaust manifold lead transfer area
  - Exhaust manifold inside diameter
  - Volumes of intake and exhaust manifold ports
  - Thermal properties of exhaust manifold metal
  - Valve timing

Input Data Accuracy: No special requirements
listed. Obviously the more accurate and more
numerous, the better.

Accuracy:
- Steady-state - generally within 5 percent
  claimed.

- Transient - "generally good agreement."

ADVANTAGES

Very rapid assessment of the impact of parametric
changes on the performance of a four-stroke
turbocharged diesel engine.

VALIDATION   Model, as reported, has been validated for
                                transient conditions only under low load
                                acceleration, and apparently for only one engine.

                                Data published in source document.

COMPUTING REQUIREMENTS   None stated.

COST OF OPERATION   One minute of computer time.

FUTURE POTENTIAL   Authors hope to develop this into a model capable
                                of handling two stage turbocharging. Weber
                                indicates this model obsoleted at Cummins by one
                                written by Watson, Imperial College, London.

                                Potential Accuracy: No claims for future
                                improvements were made.

AVAILABILITY   Not available.

TITLE	Prediction and Measurement of Two-Stroke Cycle Diesel Engine Performance and Smoke at Altitude
DATE	1977
AUTHORS	W. Schmidt, D. Venhuis, S. Hinkle
ORGANIZATION	Detroit Diesel Allison
SPONSOR	Detroit Diesel Allison
TRANSPORTATION MODE	Highway
APPLICATION	Military and Civilian

OBJECTIVE

To predict changes in two-stroke, turbocharged and blown diesel engine power output and smoke with changes in altitude.

Output:
- BSFC
- BHP
- Bosch Smoke Number

REFERENCE   ASME 77 DGP-3

RELATIONSHIP TO OTHER MODELS   None mentioned.

HISTORY OF MODEL   None given.

OPERATIONAL CAPABILITIES

Steady state performance (power ISFC, and smoke) of a two-stroke, turbocharged and blown diesel as influenced by altitude is calculated from measured baseline performance using performance characteristics of:

- Turbocharger
- Blower
- Engine air trapping
- Fuel mass flow
- Air/fuel ratio

Design factors can be altered by changing the baseline coefficients describing a particular engine's performance.

ASSUMPTIONS

- Turbocharger output constantly proportional to inlet air density

- Altitude has no effect upon fuel supply system and cooling system.

- Indicated power and exhaust property characteristics of the cylinders are influenced by altitude only as they influence trapped air/fuel ratio.

LIMITATIONS

- The model is empirically based.

- Limited to the influence of ambient air density (altitude) on the air side systems. Calculates smoke, BHP and BSFC with changes in altitude only, taking into account only gross air density effects.

- Different manifold configurations cannot be modeled.

- Each engine under study must be tested to determine the performance coefficients. Considers only power, BSFC, smoke.

DATA INPUT REQUIREMENTS

- Air density
- Turbocharger effectiveness
- Air box density
- Rotary blower speed
- Rotary blower displacement
- Rotary blower efficiency
- Rotary blower pressure ratio
- Engine air mass flow rate engine trapping efficiency
- Fuel flow rate
- Engine smoke characteristics
- Engine speed
- Combustion chamber and cylinder volume

Various performance coefficients for each system:
- Turbocharger
- Blower
- Cylinder
- Smoke

must be empirically determined at baseline operating conditions.

ADVANTAGES

Rapid, single calculation of engine performance as a function of altitude.

VALIDATION

"Reasonably" good correlation with test data shown.

COMPUTING REQUIREMENTS

Suitable for hand calculator.

COST OF OPERATION

Almost none.

FUTURE POTENTIAL

Apparently none.

Potential Accuracy: Further refinement at this level of sophistication probably not warranted.

AVAILABILITY

Model fully described in source document.

TITLE	A Real-Time Analogue Computer Simulation of a Turbocharged Diesel Engine
DATE	1975
AUTHORS	R.S. Benson, D.E. Winterbone, S.S. Shamsi, G.D. Closs, A.G. Mortimer, P. Kenyon
ORGANIZATION	University of Manchester, Institute of Science and Technology
SPONSORS	None listed
TRANSPORTATION MODE	Highway, Marine
APPLICATION	Military and civilian
OBJECTIVE	To simulate for the purpose of analytically improving the transient response of a turbocharged diesel engine when subjected to a step change in load. Engine response is modeled as:

-   Engine speed
-   Turbocharger speed
-   Rack position
-   Compression boost
-   Air/fuel ratio

all as a function of time.

Output:
-   Engine speed
-   Turbocharger speed
-   Exhaust temperature
-   Rack position
-   Engine speed
-   Boost ratio
-   Engine air flow

as a function of a set speed and time from a step shaft load input.

REFERENCES	IME Proceeding 1976 SAE Paper 770122 ASME 76-WA/DGP1

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RELATIONSHIP TO
OTHER MODELS

Based on model developed by Ledger (see SAE Paper 710177 and 730666).

HISTORY OF MODEL

Previous work has been performed at UMIST on the modeling of a Ruston and Hornsby 6APC diesel engine. This had a 0.20 m (8 in.) bore, and produced a maximum output of 19 bar (270 $lb_f/in.^2$) bmep at 1000 rpm, with a boost pressure of 2.7 bar (80 ins mercury abs). The engine was fitted with a large valve overlap camshaft to enable it to achieve the maximum benefit from turbocharging. The computer models were based largely upon on-design steady state test results; the combustion equations were extended using off-design results obtained from a single-cylinder version of the same engine. The model predictions agreed reasonably well with empirical results, but deficiencies were noticeable in the prediction of turbocharger response, air mass flow and exhaust temperature. Furukawa extended a digital computer model of the engine to include air injection into the compressor of the turbocharger. The aim of this work was to show that assisted acceleration of the turbocharger would improve the system response when a sudden load is applied.

OPERATIONAL CAPABILITIES

● Take empirically measured steady and transient data and develop model for transient engine response.

● Turbocharger response characteristics can be altered.

ASSUMPTIONS

Many simplifying assumptions made to linearize or reduce the mathematical complexity of modeling the engine. These assumptions are inherent in the equation used and are too numerous to list here.

LIMITATIONS

● The model is based on a vast amount of empirical data for a specific engine. Hence it is not easily transferred from one engine to another.

● Air fuel ratio is deduced rather than directly
measured. The deduction is based on the
assumptions inherent in the methodology.

● Ignores cycle analysis completely.

DATA INPUT REQUIREMENTS

● Virtually all engine data required as output,
plus friction (Willan's line format).
● Manifold pressure and temperature
● Turbine inlet pressure and temperature
● Smoke
● BMEP
● Fuel flow and pressure
● Crankangle
● Cylinder pressure
● Needle lift
● Air mass flow
● Engine torque

ADVANTAGES

The model appears to be somewhat cumbersome to use
due to the need for both an analog and a digital
computer, while its accuracy is about the same as
less restrictive models (E-0018-TC).

VALIDATION

Engine performance is claimed to have been
predicted within about 5 percent.

COMPUTING REQUIREMENTS

Unknown analog computer used: Program apparently
not limited to this specific unit. But a digital
(DEC PDP15 with two disc drive) used to interface
between the engine and analog computer for data
acquisition purposes.

COST OF OPERATION

Not stated.

FUTURE POTENTIAL

None

Potential Accuracy: Probably can't be improved.

AVAILABILITY

Model described in ASME paper. However, much
empirical data needed as described in IME paper.

TITLE

A Dynamic Simulation of a Two-Stroke Turbocharged Diesel Engine

DATE

1981

AUTHORS

D.E. Winterbone, W.Y. Loo

ORGANIZATION

University of Manchester, Institute of Science and Technology (UMIST)

SPONSOR

Detroit Diesel Allison

TRANSPORTATION MODE

Highway

APPLICATION

Military or civilian

OBJECTIVE

To describe the transient (and steady-state) performance of a two-stroke turbocharged (and blown) diesel using control volume emptying and filling concepts.

Output:
- Load
- Fuel injected (percent of full)
- Compressor outlet pressure (percent of full)
- Compressor outlet temperature (percent of full)
- Blower outlet temperature (percent of full)
- Air box pressure (percent of full)
- Turbine inlet pressure (percent of full)
- Turbine inlet temperature (percent of full)
- Turbocharger speed
- Air mass flow rate (percent of full)

REFERENCE

SAE Paper 810337

RELATIONSHIP TO OTHER MODELS

● Based upon a four stroke model reported by Winterbone, Benson, and Furukawa in SAE 730665.

● Uses combustion model developed by Whitestone and May "Rate of Heat Release in Diesel Engines and its Correlation with Fuel Injection Data," IME Vol. 184, 1969-1970, a single zone rate of heat release model.

HISTORY OF MODEL

First reported in SAE 810337.

OPERATIONAL CAPABILITIES

- Evaluate steady-state performance over a broad range of load conditions (30-100% full load).

- Predict transient performance of an engine in
  - response to step changes in load
  - "typical" operation in a truck

Design factors may be varied by altering the parameters which define the state of the working fluid as well as fundamental engine or system parameters (inertia, speed, load, swept volume, etc.)

ASSUMPTIONS

- Gas flows can be modeled by first order non-linear differential equations.

- Turbine, compressor, and blower can be represented by their steady-state characteristics.

- Cycle to cycle variations are not important.

- Gas pressure and temperature driving compression stroke modeled assuming polytropic compression.

- Combustion process in two parts:
  (1) preparation limited combustion and air
  (2) reaction limited combustion rate

- Heat transfer calculated using ANNAND expression.

- Scavenging process based on assumption that the entering fresh charge is mixed completely and immediately with the cylinder contents.

- During scavenging:
  - gas mixture contains only CO_2, H_2O, O_2 and N_2
  - gas obeys perfect gas law ($p\bar{V} = \bar{m}RT$)
  - internal gas energy is a function solely of temperature and air/fuel ratio.

LIMITATIONS

@ Uses filling and emptying concepts

@ Two-stroke engine only

@ No emissions information

@ Turbocharger speed effects ignored.

@ Ignores manifold resonances which cause cylinder to cylinder variations.

DATA INPUT REQUIREMENTS

Mechanical characteristics of:
- turbocharger
- blower
- intercooler
- air receiver
- engine cylinder
- valving
- exhaust system

as they effect air flow and combustion. The model is based upon fundamental principles and hence very little empirical data is required.

ADVANTAGES

@ Can be easily applied to a range of engines because little if any empirical data required.

@ Applicable over a wide speed range.

@ Models each component within the engine air flow and combustion system separately based on fundamentals.

@ Includes simulation of engine in a truck.

VALIDATION

@ Shows good steady-state correlation with engine for which model initially developed (error within 5 percent).

@ Transient response appears "realistic" but not fully validated yet.

COMPUTING REQUIREMENTS   Uses ANSI Fortran IV

                                       – All equations are in paper: Runge Kutta
                                           technique (4th order) is used to solve in the
                                           computer.

COST OF OPERATION   Not specified.

FUTURE POTENTIAL   Look forward to incorporating a smoke model.

                                Potential Accuracy: Further work promises
                                sharpening up the model as some combustion
                                coefficients are fine-tuned.

AVAILABILITY   Unknown: may be recreated from reference.

TITLE	A Non-Linear Digital Simulation of Turbocharged Diesel Engines Under Transient Conditions
DATE	1976
AUTHORS	Neil Watson, Maged Marzouk
ORGANIZATION	Imperial College of Science and Technology
SPONSOR	Ministry of Defense (U.K.) Military Vehicle and Engineering Establishment
TRANSPORTATION MODE	All
APPLICATIONS	Military or civilian
OBJECTIVE	To study and analyze the transient response of a turbocharged diesel engine due to a change in load or power demand (throttle position). Output: Primary output is the engine speed and exhaust characteristics (pressure, temperature) in response to load change. However, program is designed to provide diagnostic data allowing analysis of phenomena listed under "Range of Capabilities." The only independent variable is crankangle.
REFERENCE	SAE paper 770123
RELATIONSHIP TO OTHER MODELS	⊛ Combustion: Kreiger, Borman, Fowell, and Marzouk ⊛ Heat transfer: Woschini ⊛ Engine power losses: Chen
HISTORY OF MODEL	There are many sources of non-linearity in diesel engines. However, linearized models (based on either continuous control or sampled-data concepts) have been used to investigate the stability of engine controllers. Sampled data models are closer to the discontinuous nature of a reciprocating engine, but a major handicap is imposed by the assumption of a constant sampling interval. Quasi-linear models, which employ steady-state characteristics of the engine, constitute a further step towards the dynamic simulation of turbocharged diesel engines. The most widely reported

simulation is that developed at UMIST, although Bowns has published a similar model. These models link steady-speed experimental data representing engine thermodynamics and gas flow with dynamic models of the mechanical components. The major disadvantage of quasi-linear models is their heavy reliance on empirically determined data; particularly at "off-design" conditions such as those which occur during transients. Furthermore, the representation of complex combustion and air flow phenomena tends to be oversimplified. By representing the air-flow characteristics of an engine as a steady-flow phenomenon, possible differences between inward and outward flow are not explicitly considered. Evidence suggests that reverse flow from cylinder to inlet manifold, significantly affects the response of highly rated engines.

The unsteady thermodynamic and gas flow processes occurring inside a turbocharged diesel engine are satisfactorily evaluated at constant engine speed by quasi-steady engine simulation programs. Since these programs calculate unsteady phenomena, regardless of engine running conditions, such techniques are potentially suitable for extension to transient operation. This forms the basis of this model. However, different formulation and solution procedure was essential, since the periodicity condition (constant engine speed) does not hold during transient operation.

OPERATIONAL CAPABILITIES

The model is rather thorough, so a number of effects can be explored including:

- Different loading rates
- Turbocharger match
- Turbocharger inertia
- Engine and load inertia
- Exhaust manifold design
- Inlet manifold design
- Valve timing
- Charge air cooling
- Variable geometry turbocharging
- Re-matching with an exhaust waste-gate valve

- Fuel-pump rack limiters
- Compression ratio
- Engine friction
- Thermal inertia of combustion chamber surfaces

All under transient _and_ steady-state conditions.

ASSUMPTIONS

- Thermodynamic equilibrium at all times
- Ideal-gas behavior at all times
- All control volumes contain homogeneous mixture of air and combustion products
- Ignore property gradients and phenomena
  - non-equilibrium compositions
  - fuel vaporization before and during combustion
  - spatial variations within manifolds
- Combustion products assumed from
  - Kreiger and Borman (lean)
  - Marzouk (rich)
- Cylinder heat transfer by Woschini
- Combustion process in 2 distinct phases:
  (1) ignition delay (duration of propagation of pressure wave along the fuel line)
  (2) heat generation
      - premixed portion of burning
      - diffusion portion of burning

LIMITATIONS

- Simple combustion model.

- Model appears sensitive to small errors in describing engine characteristics such as governor response to engine speed.

DATA INPUT REQUIREMENTS

- Heat transfer area and coefficients
  - manifolds
  - combustion chamber
- Engine friction torque
- Load
- Cylinder diameter
- Internal energy
- Fuel burning rates
  - premixed
  - diffusion
- Engines polar moment of inertia
- Load polar moment of inertia

- Turbocharger polar moment of inertia
- Initial and upsetting conditions
- Ambient conditions
- Mode of fuel burning proportionality factor
- Engine speed
- Efficiency
  - turbine
  - compressor
  - turbocharger
- Engine dimensions
- Fuel injection system characteristics

Input Data Accuracy: Reportedly transient response of some engine systems, particularly turbocharger and governor is hard to measure. Present techniques appear inadequate. Improvement needed in this area.

ADVANTAGES

- This appears to be a very powerful model.

- Takes the entire power producing system into account.

- Combustion model is better than that of other similar models studied, but is still rather simple.

- Uses a minimum of empirically determined coefficients.

VALIDATION

"Excellent" agreement. Only serious discrepancies appear to be prediction of maximum cylinder pressure (to be expected) and turbine inlet temperature (attributed to thermocouple lag rather than model deficiencies).

COMPUTING REQUIREMENTS

Not stated.

COST OF OPERATION

Not stated.

FUTURE POTENTIAL

Not stated.

Potential Accuracy: Not stated; very good already.

AVAILABILITY

Unknown.

4.0 INDEXES

All of the models are indexed in two separate ways:
(1) by model category, and (2) by organizational
author.

Model Category Index

The model category index is organized as follows:

⊚ Heavy Duty Transport System Models
   (1) Highway Transport
   (2) Marine Transport
   (3) Rail Transport

⊚ Heavy Duty Diesel Engine Models
   (4) Matching Intake/Exhaust Systems to the
       Engine
   (5) Fuel Efficiency
   (6) Emissions
   (7) Combustion Chamber Shape
   (8) Fuel Injection System
   (9) Heat Transfer
   (10) Intake/Exhaust System
   (11) Operating Performance
   (12) Bottoming Cycle
   (13) Turbocharger

Within each of the thirteen model categories, each
model is listed in numerical order according to its
access code (which merely signifies the
chronological order in which the model literature
was acquired by the project team).

Organizational Author Index

This index organizes all models alphabetically by
the organization that authored the model.

4.1 MODEL CATEGORY INDEX

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Highway Transport	H-0001-72	General Motors Corporation	3-1
Highway Transport	H-0002-77	U.S. Department of Transportation	3-5
Highway Transport	H-0003-81	Ford Motor Company	3-9
Highway Transport	H-0004-81	Ford Motor Company	3-11
Highway Transport	H-0005-78	U.S. Department of Transportation	3-13
Highway Transport	H-0009-76	Cummins Engine Company, Inc.	3-15
Highway Transport	H-0010-78	International Harvester Truck Group	3-17
Highway Transport	H-0012-81	Boeing Computer Services Company, Energy Technology Applications Div.	3-21
Highway Transport	H-0013-78	General Motors Research Lab	3-25
Highway Transport	H-0018-79	U.S. Department of Transportation, Research and Special Programs Administration, Transportation Systems Center	3-27
Highway Transport	H-C023-80	Massachusetts Institute of Technology, Department of Mechanical Engineering	3-29
Highway Transport	H-0024-83	United Technologies Research Center	3-31
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Marine Transport	M-0001-68	U.S. Coast Guard Headquarters, Office of Engineering, Icebreaker Design Branch	3-41
Marine Transport	M-0002-78	University of Hannover	3-43
Marine Transport	M-0004-81	Y-ARD Ltd., Glasgow	3-45
Marine Transport	M-0006-78	PFR Engineering Systems, Marina, Del Rey, California	3-47
Marine Transport	M-0007-83	University of Newcastle upon Tyne, England	3-49
Marine Transport	M-0008-70	Lips, N.V., Drunen, Holland	3-51
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Rail Transport	L-0010-78	EE/CS Department, Union College, Schenectady, New York	3-71
Rail Transport	L-0011-83	Southern Pacific Transportation Co.	3-75
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Rail Transport	L-0013-79	AiResearch Manufacturing Company of California	3-81
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Fuel Efficiency	E-0063-76	Indian Institute of Technology, Delhi	3-109
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Intake/Exhaust System	E-0014-IE-78	University of Technology, Loughborough, England; Indian Institute of Technology, Madras, India; Indian Institute of Technology, Delhi, India; University of Santa Clara, Santa Clara, California	3-201
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Intake/Exhaust System	E-0022-IE-80	University of Manchester	3-209
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