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A STUDY OF TECHNOLOGICAL IMPROVEMENTS IN AUTOMOBILE FUEL CONSUMPTION
Volume IIIB: Appendixes IV through VII

Donald A. Hurter et al

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FINAL REPORT

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16. Abstract

A study was conducted to determine potential improvements in automobile fuel consumption based on innovative design and components. Standard and compact-size reference vehicles were selected, and a study of how power is used was conducted. Obvious technological innovations (e.g., powerplants (such as spark-ignited, turbocharged, stratified charge, electronic fuel injected, and diesel), transmissions and drive train systems, tires, accessories and auxiliaries, aerodynamics, and weight) that would save on fuel consumption were identified and evaluated, and then screened against program constraints. Operation of reference vehicles equipped with innovative components or redesigned was computer-simulated to predict fuel usage and performance. Techniques to measure fuel economy performance were also developed, and a statistical evaluation of published driving modes was performed. Compliance of innovative components with constraints (such as emissions and safety) and user requirements was determined. Optimized synthesized standard and compact-size vehicles were simulated and total systems evaluation of each vehicle was performed on the basis of fuel usage, performance, technical compatibility, compliance with constraints, user acceptability, and manufacturer adaptability. Synthesized vehicles were ranked in accordance with study objectives, and conclusions and recommendations on designs were drawn. Program plans for synthesized vehicles were also selected.

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APPENDIX IV

VARIOUS FUEL ECONOMY TEST PROCEDURES

AND EXHAUST EMISSION TEST PROCEDURES AND STANDARDS

PURPOSE

The purpose of this procedure is to determine the fuel economy of a vehicle under simulated customer conditions.

DEFINITIONS

.1 CURB WEIGHT

The vehicle as built to production parts list including engine oil, engine fuel and coolant to capacity.

.2 OPTIONAL [illegible] WEIGHT

The combined weight (in excess of those standard items which may be replaced) of automatic transmission, power steering, power brakes, power windows, power seats, radio, heater and air conditioning to the extent that these items are available as factory equipment (whether installed or not).

.3 OCCUPANT WEIGHT

For vehicles with a seating capacity of two, occupant weight = 300 lbs (136 kg). Vehicles with a designated seating capacity of three or four, occupant weight = 450 lbs (204 kg). Vehicles with a seating capacity of five or greater, occupant weight = 600 lbs (272 kg).

~~.4 GROSS VEHICLE WEIGHT~~

EQUIPMENT

TEST FACILITY

.1 Fuel economy tests shall be conducted on a road surface and under ambient conditions with the following limitations.

.1.1 The road surface may have a maximum grade of 1 percent. ~~(?)~~

.1.2 The road surface must be dry.

.1.3 No restrictions are placed on temperature, solar load, barometric pressure and humidity; however, ambient conditions will be recorded on Data Sheets 3 and 4.

TEST EQUIPMENT AND INSTRUMENTATION

2.2.1 Fuel meter with provisions for measuring fuel consumed, elapsed time and temperature of the fuel at the fuel measuring element.

2.2 Fifth wheel and meter.

2.2.3 Accelerometer.

2.2.4 Stop watch (for timing idle intervals during economy schedules).

2.2.5 Tachometer.

~~2.2.6 Other instrumentation if requested to monitor operation of exhaust emission control system~~

~~2.2.61 Example: Manifold, distributor, and EGR vacuum gages.~~

~~2.2.6.2 Example: Temperature measuring equipment for snorkel and carburetor air temperatures.~~

~~NOTE: Calibrate instrumentation as required by Divisional practices; record instrument details and date calibrated on Form GMUTS 1 - Rev. 1-72.~~

2.3 TEST MATERIAL

2.3.1 Vehicle to be tested as described on Data Sheet 2.

3. PROCEDURE

3.1 VEHICLE PREPARATION

3.1.1 Engine break-in will be a minimum of 2,000 miles (3218 km). Other driveline componen should receive a minimum of 150 (241 km) break-in miles.

3.1.2 Tune and time engine, and make all other adjustments and functional checks in accordan with manufacturer's published procedures. Particular attention should be given to the adjustments and check items on Data Sheet 2.

3.1.3 Test weight will be the combination of curb weight + occupant weight + optional accesso weight ~~or ____ % GVW if requested.~~

3.2 GENERAL VEHICLE OPERATING INSTRUCTIONS

3.2.1 Bring the vehicle to normal operating temperature by driving a minimum of 10 miles (16 k between 60 (97) and 80 mph (129 kph) before performing the economy tests.

3.2.2 Vehicles equipped with automatic transmissions will be operated in "drive" and allowed shift normally when operating on the driving schedules. Idles will be made in "drive."

3 Vehicles equipped with manual transmissions will be shifted in the following manner when operating on the driving schedules. Idles will be made in gear, clutch disengaged. Decelerations will be made in gear, and the clutch will be disengaged at 15 mph on a stop. Downshifts will be permitted to obtain specified acceleration rate after a deceleration or to obtain smooth engine operation on a slow steady speed.

3.1 Vehicles with manual 3-speed transmissions will be shifted at (1-2) 20 mph and (2-3) 35 mph or when the specified speed is reached during normal part-throttle accelerations.

3.2 Vehicles with manual 4-speed transmissions except truck-type transmissions will be shifted at (1-2) 15 mph, (2-3) 25 mph and (3-4) 40 mph or when the specified speed is reached during normal part-throttle accelerations.

3.3 Vehicles with manual 4-speed truck-type transmissions will be treated as 3-speed transmissions, using the top three gears.

3.4 Shift points for accelerations specified as wide-open throttle (in Suburban and Highway schedules) will be at the manufacturer's rated engine rpm for peak net horsepower for both manual 3 and 4 - speed transmission-equipped vehicles.

4 Vehicles incapable of attaining acceleration rates specified by the driving schedules will be driven at wide-open throttle until the specified speed is reached.

5 Accessories absorbing relatively large amounts of power (such as the A/C system) will not normally be operated during economy testing.

6 Vehicle windows will normally be closed during testing. ~~provided this condition does not cause undue discomfort to the vehicle occupant(s)~~. If tests are run with windows partially open for occupant comfort, A-B comparison tests should be run with windows in similar positions.

3.3 SIMULATED BUSINESS DISTRICT FUEL ECONOMY

3.3.1 After proper warm-up, the Business District simulation is performed according to the following drive schedule.

3.3.2 BUSINESS DISTRICT FUEL ECONOMY DRIVING SCHEDULE

Average speed: 16 mph (26 kph)
Running time: 7.6 min/cycle

Distance, Miles (km)	Operation	Fuel Temp
0.0 (0.0)	Start fuel meter, idle 15 sec., accel to 15 mph (24.1) at 5 fps^2 (1.52)	
0.2 (0.32)	Stop at 6 fps^2 (1.83), accel. to 15 mph (24.1) at 5 fps^2 (1.52)	
0.3 (0.48)	Decel. to 5 mph (8.0) at 5 fps^2 (1.52), accel. to 15 mph (24.1) at 5 fps^2 (1.52)	
0.5 (0.80)	Stop at 6 fps^2 (1.83), idle 15 sec., accel. to 20 mph (32.2) at 8 fps^2 (2.44)	(1)
0.7 (1.13)	Stop at 6 fps^2 (1.83), accel. to 20 mph (32.2) at 8 fps^2 (2.44)	
0.8 (1.29)	Decel. to 10 mph (16.1) at 5 fps^2 (1.52), accel. to 20 mph (32.2) at 5 fps^2 (1.52)	
1.0 (1.61)	Stop at 6 fps^2 (1.83), idle 15 sec., accel. to 25 mph (40.2) at 8 fps^2 (2.44)	(2)
1.2 (1.93)	Stop at 6 fps^2 (1.83), accel. to 25 mph (40.2) at 8 fps^2 (2.44)	
1.3 (2.09)	Decel. to 15 mph (24.1) at 5 fps^2 (1.52), accel. to 25 mph (40.2) at 5 fps^2 (1.52)	
1.5 (2.41)	Stop at 6 fps^2 (1.83), idle 15 sec., accel. to 30 mph (48.3) at 8 fps^2 (2.44)	(3)
1.7 (2.74)	Stop at 6 fps^2 (1.83), accel. to 30 mph (48.3) at 8 fps^2 (2.44)	
1.8 (2.90)	Decel. to 20 mph (32.2) at 5 fps^2 (1.52), accel. to 30 mph (48.3) at 5 fps^2 (1.52)	
2.0 (3.22)	Stop at 6 fps^2 (1.83) and stop fuel meter, record fuel consumed, elapsed time and fuel temperature	(4)
0.0 (0.0)	Run recheck cycle	

3.3.3 The schedule will normally be run on a straightaway; running on a one-mile (1.6 kilometer) straightaway requires a break at the 1.0 mile (1.61 kilometer) distance.

~~The recheck cycle will be run in the opposite direction from the first cycle~~ to reduce ~~cancel~~ wind effects.

3.3.4 Acceleration rates are initial; hold initial throttle position until specified speed is reached.

3.3.5 Driving schedule maneuvers are initiated at the points indicated. For example, brake application for the first 6 fps^2 (1.83 mps^2) stop will begin at the 0.2 mile (.32 kilometer) distance.

3.3.6 Fuel temperatures will be recorded on Data Sheet 3 during the idles as indicated in the above schedule.

BUSINESS DISTRICT DRIVING SCHEDULE

Distance, km (miles)	Operation
0.0 (0.0)	Start fuel meter, idle 15 sec., accel. to 25 kph (15.5) at 1.6 mps^2 (5.2)
0.3 (0.19)	Stop at 1.8 mps^2 (5.9), accel. to 25 kph (15.5) at 1.6 mps^2 (5.2)
0.5 (0.31)	Decel. to 10 kph (6.2) at 1.6 mph^2 (5.2), accel. to 25 kph (15.5) at 1.6 mps^2 (5.2)
0.8 (0.50)	Stop at 1.8 mps^2 (5.9), idle 15 sec., accel. to 30 kph (18.6) at 2.4 mps^2 (7.9)
1.1 (0.68)	Stop at 1.8 mps^2 (5.9), accel. to 30 kph (18.6) at 2.4 mps^2 (7.9)
1.3 (0.81)	Decel. to 15 kph (9.3) at 1.6 mps^2 (5.2), accel. to 30 kph (18.6) at 1.6 mps^2 (5.2)
1.6 (0.99)	Stop at 1.8 mps^2 (5.9), idle 15 sec., accel. to 40 mph (24.9) at 2.4 mps^2 (7.9)
1.9 (1.18)	Stop at 1.8 mps^2 (5.9), accel. to 40 kph (24.9) at 2.4 mps^2 (7.9)
2.1 (1.31)	Decel. to 25 kph (15.5) at 1.6 mps^2 (5.2), accel. to 40 kph (24.9) at 1.6 mps^2 (5.2)
2.4 (1.49)	Stop at 1.8 mps^2 (5.9), idle 15 sec., accel. to 50 kph (31.1) at 2.4 mps^2 (7.9)
2.7 (1.68)	Stop at 1.8 mps^2 (5.9), accel. to 50 kph (31.1) at 2.4 mps^2 (7.9)
2.9 (1.80)	Decel. to 30 kph (18.6) at 1.6 mps^2 (5.2), accel. to 50 kph (31.1) at 1.6 mps^2 (5.2)
3.2 (1.99)	Stop at 1.8 mps^2 (5.9) and stop fuel meter, record fuel consumed, elapsed time and full temperature
0.0 (0.0)	Run recheck cycle

( ) = English system equivalent

km ⟶ Nearest tenth

kph ⟶ Nearest 5

mps^2 ⟶ Nearest <u>even</u> tenth

3.4 SIMULATED SUBURBAN FUEL ECONOMY

3.4.1 After proper warm-up, the Suburban simulation is performed according to the following schedule.

4.2 SUBURBAN FUEL ECONOMY DRIVING SCHEDULE

Average speed: 24 mph (39 kph)
Running time: 9.3 min/cycle

Distance, Miles (km)	Operation	Fuel Temp
0.0 (0.0)	Start fuel meter, accel. to 20 mph (32.2) at 6 fps^2 (1.83)	
0.1 (0.16)	Accel. to 25 mph (40.2) at 3 fps^2 (0.91)	
0.3 (0.48)	Stop at 6 fps^2 (1.83), accel. to 25 mph (40.2) at 6 fps^2 (1.83)	
0.5 (0.80)	Decel. to 10 mph (16.1) at 4 fps^2 (1.22), accel. to 30 mph (48.3) at 6 fps^2 (1.83)	
1.3 (2.09)	Stop at 6 fps^2 (1.83), idle 25 sec., accel. to 30 mph (48.3) at 6 fps^2 (1.83)	(1)
1.5 (2.41)	Decel. to 25 mph (40.2) at closed throttle, accel. to 35 mph (56.3) at 3 fps^2 (0.91)	
2.0 (3.22)	Stop at 6 fps^2 (1.83), accel. to 40 mph (64.4) at W.O.T.	
2.8 (4.51)	Stop at 6 fps^2 (1.83), idle 25 sec., accel. to 25 mph (40.2) at 6 fps^2 (1.83)	(2)
3.0 (4.83)	Decel. to 5 mph (8.0) at 4 fps^2 (1.22), accel. to 25 mph (40.2) at 6 fps^2 (1.83)	
3.2 (5.15)	Stop at 6 fps^2 (1.83), idle 25 sec., accel. to 35 mph (56.3) at 8 fps^2 (2.44)	(3)
3.4 (5.47)	Decel. to 25 mph (40.2) at closed throttle, accel. to 35 mph (56.3) at 3 fps^2 (0.91)	
3.7 (5.95)	Stop at 6 fps^2 and stop fuel meter, record fuel consumed, elapsed time and fuel temperature	(4)
0.0 (0.0)	Run recheck cycle	

3.4.3 The schedule will normally be run on an oval or circular track, or can be run on a two-mile (3.2 kilometer) straightaway with a break at the 2.0 mile (3.22 kilometer) distance.

3.4.4 Acceleration rates are initial; hold initial throttle position until specified speed is reached.

3.4.5 Driving schedule maneuvers are initiated at the points indicated. For example, brake application for the first 6 fps^2 (1.83 mps^2) stop will begin at the 0.3 mile (.48 kilometer) distance.

3.4.6 Fuel temperatures will be recorded on Data Sheet 3 during the idles as indicated in the above schedule.

SUBURBAN DRIVING SCHEDULE

Distance km (miles)	Operation
0.0 (0.0)	Start fuel meter, accel. to 30 kph (18.6) at 1.8 mps^2 (5.9)
0.2 (0.12)	Accel. to 40 kph (24.9) at 1.0 mps (3.3)
0.5 (0.31)	Stop at 1.8 mps^2 (5.9), accel. to 40 kph (24.9) at 1.8 mps^2 (5.9)
0.8 (0.50)	Decel. to 15 kph (9.3) at 1.2 mps^2 (3.9), accel. to 50 kph (31.1) at 1.8 mps^2 (5.9)
2.1 (1.31)	Stop at 1.8 mps^2 (5.9), idle 25 sec., accel. to 50 kph (31.1) at 1.8 mps^2 (5.9)
2.4 (1.49)	Decel. to 40 kph (24.9) at closed throttle, accel. to 55 kph (34.2) at 1.0 mps^2 (3.3)
3.2 (1.99)	Stop at 1.8 mps^2 (5.9), accel. to 65 kph (40.4) at W.O.T.
4.5 (2.80)	Stop at 1.8 mps^2 (5.9), idle 25 sec., accel. to 40 kph (24.9) at 1.8 mps^2 (5.9)
4.8 (2.98)	Decel. to 10 kph (6.2) at 1.2 mps^2 (3.9), accel. to 40 kph (24.9) at 1.8 mps^2 (5.9)
5.1 (3.17)	Stop at 1.8 mps^2 (5.9), idle 25 sec., accel. to 55 kph (34.2) at 2.4 mps^2 (7.9)
5.5 (3.42)	Decel. to 40 kph (24.9) at closed throttle, accel. to 55 kph (34.2) at 1.0 mps^2 (3.3)
6.0 (3.73)	Stop at 1.8 mps^2 (5.9) and stop fuel meter, record fuel consumed, elapsed time and fuel temperature
0.0 (0.0)	Run recheck cycle

( ) = English system equivalent

km ——▷ Nearest tenth
kph ——▷ Nearest 5
mps^2 ——▷ Nearest <u>even</u> tenth

3.5 SIMULATED HIGHWAY FUEL ECONOMY

3.5.1 After proper warm-up, the Highway simulation is performed according to the following driving schedule.

3.5.2 HIGHWAY FUEL ECONOMY DRIVING SCHEDULE

Average speed: 47 mph (76 kph)
Running time: 18.9 min/cycle

Distance, miles (km)	Operation	Fuel Temp
0.0 (0.0)	Start fuel meter, accel. to 15 mph (24.1) at 5 fps^2 (1.52), then to 50 mph (80.4) at 2 fps^2 (0.61)	
1.5 (2.41)	Decel. to 30 mph (48.3) at CT*	
2.0 (3.22)	Accel. to 50 mph (80.4) at 2 fps^2 (0.61)	
3.5 (5.63)	Decel. at CT	
3.7 (5.95)	Stop at 6 fps^2 (1.83), idle 10 sec., accel. to 15 mph (24.1) at 5 fps^2 (1.52), then to 55 mph (88.5) at 2 fps^2 (0.61)	(1)
5.3 (8.53)	Decel. to 30 mph (48.3) at CT	
5.8 (9.33)	Accel. to 55 mph (88.5) at 2 fps^2 (0.61)	
7.3 (11.75)	Decel. at CT	
7.5 (12.07)	Stop at 6 fps^2 (1.83), idle 10 sec., accel. to 15 mph (24.1) at 5 fps^2 (1.52), then to 60 mph (96.5) at 2 fps^2 (0.61)	(2)
9.0 (14.48)	Decel. to 30 mph (48.3) at CT	
9.5 (15.29)	Accel. to 60 mph (96.5) at 2 fps^2 (0.61)	
11.0(17.70)	Decel. at CT	
11.3(18.18)	Stop at 6 fps^2 (1.83), idle 10 sec., stop fuel meter and record fuel consumed, elapsed time and fuel temperature, start fuel meter and accel. to 15 mph (24.1) at 5 fps^2 (1.52), then to 70 mph (112.6) at 2 fps (0.61)	(3)
12.8(20.60)	Decel. to 45 mph (72.4) at 4 fps^2 (1.22), accel. to 70 mph (112.6) at W.O.T.	
14.8(23.81)	Stop at 6 fps^2 (1.83) and stop fuel meter, record fuel consumed, elapsed time and fuel temperature	(4)
11.3(18.18)	Run recheck lap	

* Closed Throttle

3.5.3 The schedule will normally be run on an oval or circular track.

3.5.4 Acceleration rates are held constant until specified speeds are reached.

3.5.5 Driving schedule maneuvers are initiated at the points indicated. For example, brake application for the first 6 fps^2 (1.83 mps^2) stop will begin at the 3.7 mile (5.95 kilometer) distance.

3.5.6 Fuel temperatures will be recorded on Data Sheet 3 during the idles as indicated in the above schedule.

HIGHWAY DRIVING SCHEDULE

Distance, km (miles)	Operation
0.0 (0.0)	Start fuel meter, accel. to 25 kph (15.5) at 1.6 mps^2 (5.2), then to 80 kph (49.7) at 0.6 mps^2 (2.0)
2.4 (1.49)	Decel. to 50 kph (31.1) at CT*
3.2 (1.99)	Accel. to 80 kph (49.7) at 0.6 mps^2 (2.0)
5.6 (3.48)	Decel. at CT
6.0 (3.73)	Stop at 1.8 mps^2 (5.9) , idle 10 sec., accel. to 25 kph (15.5) at 1.6 mps^2 (5.2), then to 90 kph (55.9) at 0.6 mps^2 (2.0)
8.5 (5.28)	Decel. to 50 kph (31.1) at CT
9.3 (5.78)	Accel. to 90 kph (55.9) at 0.6 mps^2 (2.0)
11.7(7.27)	Decel. at CT
12.1(7.52)	Stop at 1.8 mps^2 (5.9), idle 10 sec., accel. to 25 kph (15.5) at 1.6 mps^2 (5.2), then to 95 kph (59.0) at 0.6 mps^2 (2.0)
14.5(9.01)	Decel. to 50 kph (31.1) at CT
15.3(9.51)	Accel. to 95 kph (59.0) at 0.6 mps^2 (2.0)
17.7(11.00)	Decel. at CT
18.2(11.31)	Stop at 1.8 mps^2 (5.9), idle 10 sec., stop fuel meter and record fuel consumed, elapsed time and fuel temperature, start fuel meter and accel. to 25 kph (15.5) at 1.6 mps^2 (5.2), then to 115 kph (71.5) at 0.6 mps^2 (2.0)
20.6(12.80)	Decel. to 70 kph (43.5) at 1.2 mps^2 (3.9), accel. to 115 kph (71.5) at W.O.T.
23.8(14.79)	Stop at 1.8 mps^2 (5.9) and stop fuel meter, record fuel consumed, elapsed time and fuel temperature
11.3(18.18)	Run recheck lap

* Closed Throttle

( ) = English system equivalent

km ⟶ Nearest tenth
kph ⟶ Nearest 5
mps^2 ⟶ Nearest <u>even</u> tenth

3.6 SIMULATED INTERSTATE FUEL ECONOMY

3.6.1 After proper warm-up, the Interstate simulation is performed according to the following driving schedule.

3.6.2 INTERSTATE FUEL ECONOMY DRIVING SCHEDULE

Average speed: 70 mph (112.6 kph)
Running time: 12.8 min/cycle

Distance, miles (km)	Operation	Fuel Temp
0.0 (0.0)	Record fuel temperature, start fuel meter, accel. to 40 mph (64.4) at 6 fps^2 (1.83), then to 75 mph (120.7) at 3 fps^2 (.91)	(1)
2.0 (3.22)	Decel. to 70 mph (112.6) at CT*	
3.0 (4.83)	Accel. to 75 mph (120.7) at 2 fps^2 (.61)	
5.0 (8.04)	Decel. to 70 mph (112.6) at CT	(2)
6.0 (9.65)	Decel. to 60 mph (96.5) at CT	
6.5 (10.46)	Accel. to 75 mph (120.7) at 3 fps^2 (.91)	
9.0 (14.48)	Decel. to 70 mph (112.6) at CT	
10.0(16.09)	Accel. to 75 mph (120.7) at 2 fps^2 (.61)	(3)
12.0(19.31)	Decel. to 70 mph (112.6) at CT	
13.0(20.92)	Decel. to 60 mph (96.5) at CT	
13.5(21.72)	Accel. to 75 mph (120.7) at 3 fps^2 (.91)	
14.5(23.33)	Decel. at CT	
14.9(23.97)	Stop at 6 fps^2 (1.83), record fuel consumed, elapsed time and fuel temperature	(4)
0.0 (0.0)	Run recheck cycle	

* Closed Throttle

3.6.3 The schedule will normally be run on an oval or circular track.

3.6.4 Acceleration rates are held constant until specified speeds are reached.

3.6.5 Driving schedule maneuvers are initiated at the points indicated. For example, closing the throttle for the first deceleration to 70 mph (112.6 kph) will occur at the 2.0 mile (3.22 kilometer) distance.

3.6.6 Fuel temperatures will be recorded on Data Sheet 3 at the times indicated in the above schedule.

INTERSTATE DRIVING SCHEDULE

Distance, km (miles)	Operation
0.0 (0.0)	Record fuel temperature, start fuel meter, accel. to 65 kph (40.4) at 1.8 mps^2 (5.9), then to 120 kph (74.6) at 1.0 mps^2 (3.3)
3.2 (1.99)	Decel. to 110 kph (68.4) at CT*
4.8 (2.98)	Accel. to 120 kph (74.6) at 0.6 mps^2 (2.0)
8.0 (4.97)	Decel. to 110 kph (68.4) at CT
9.7 (6.03)	Decel. to 95 kph (59.0) at CT
10.5(6.53)	Accel. to 120 kph (74.6) at 1.0 mps^2 (3.3)
14.5(9.01)	Decel. to 110 kph (68.4) at CT
16.1(10.00)	Accel. to 120 kph (74.6) at 0.6 mps^2 (2.0)
19.3(12.00)	Decel. to 110 kph (68.4) at CT
20.9(12.99)	Decel. to 95 kph (59.0) at CT
21.7(13.49)	Accel. to 120 kph (74.6) at 1.0 mps^2 (3.3)
23.3(14.48)	Decel. at CT
23.9(14.85)	Stop at 1.8 mps^2 (5.9), record fuel consumed, elapsed time and fuel temperature
0.0 (0.0)	Run recheck cycle

* Closed Throttle

( ) = English system equivalent

km ——> Nearest tenth except 23.9 km distance; 24.0 would be closer to original 14.9 miles, ~~but would be inconvenient to start re-check cycle on DPG track~~

kph ——> Nearest 5 except 110 kph speeds; 115 would be closer to original 70 mph, but speed drop from 120 kph would only be 3.1 mph from 120 to 115 kph

mps^2 ——> Nearest <u>even</u> tenth

3.7 LEVEL ROAD LOAD FUEL ECONOMY - CONSTANT SPEED

3.7.1 After proper warm-up, level road economy tests are performed according to the following instructions.

7.2 Level road tests will normally be performed on a straightaway.

3.7.3 Level road test speeds will normally be 30, 50 and 70 mph (48.3, 80.4 and 112.6 kph). Additional speeds may be run if requested.

3.7.4 Enter straightaway at highest test speed and start fuel meter at selected beginning point. Stop fuel meter at selected end point and record fuel consumed, elapsed time and fuel temperature on Data Sheet 4. Proceed through turn-around loop, enter opposite straightaway at the test speed and repeat above.

3.7.5 Proceed with lower test speeds in similar manner.

3.8 OPTIONAL FUEL ECONOMY TESTS

3.8.1 IDEL FUEL ECONOMY

3.8.1.1 After proper warm-up, the idle economy test is performed according to the following instructions.

3.8.1.2 The idle test will be performed in any safe, convenient and level location.

.8.1.3 Vehicles equipped with automatic transmissions will be idled in "drive" and manual transmission-equipped vehicles will be idled in neutral.

3.8.1.4 Idle 10 seconds, start fuel meter and record fuel temperature. Idle 2 minutes, stop fuel meter and record fuel consumed, elapsed time and fuel temperature on Data Sheet 4.

3.8.2 ADDITIONAL LEVEL ROAD LOAD SPEEDS

3.8.2.1 Speeds in addition to the 30, 50 and 70 mph (48.3, 80.4 and 112.6 kph) level road speeds may be run as described in Item 3.7.

3.9 DATA REDUCTION

3.9.1 Observed fuel economy for any driving schedule or test speed is obtained by an appropriate calculation, taking into account the actual (not nominal) distance in the particular traffic lanes in which the schedule or test speed was run and the stopping distance at the end of the schedule.

3.9.2 Observed idle fuel economy is given by the following equation:

$$\text{Obs. Idle Economy, hr/gal} = \frac{\text{elapsed time, sec.}}{\text{fuel consumed, cc}} \times 1.05$$

$$\left(\text{Obs. Idle Economy, hr/l} = \frac{\text{elapsed time, sec.}}{\text{fuel consumed, cc}} \times .278\right)$$

3.9.3 Observed economies can be adjusted to conditions of 60°F (15.6°C) fuel and ambient air temperatures by the following equation:

$$\text{Adjusted Economy} = \text{Obs. Econ.} \times \frac{\text{Ambient Air Temp. Factor}}{\text{Fuel Temp. Factor}}$$

3.9.4 These factors are found in Tables 1 and 2 and correspond to the average fuel and ambient air temperatures observed during the particular schedule or level road speed.

For adjusting fuel economy to
60 deg. F. ambient air temperature

$mpg_{60} = mpg_{obs}$ X Factor for observed ambient air temperature

Obs.Amb.Air Temp. °F	Business District	Suburban & Hwy	INTST	IDLE	LEVEL ROAD	Obs.Amb.Air Temp. °F	Business District	Suburban & Hwy	INTST	IDLE	LEVEL ROAD
30	1.060	1.040	1.029	1.039	1.033	70	.982	.988	.991	.975	.98
31	1.058	1.039	1.028	1.085	1.032	71	.981	.987	.990	.972	.98
32	1.056	1.037	1.027	1.082	1.031	72	.979	.985	.989	.970	.98
33	1.053	1.036	1.026	1.079	1.030	73	.977	.984	.989	.967	.98
34	1.051	1.035	1.025	1.075	1.029	74	.975	.983	.988	.965	.98
35	1.049	1.033	1.024	1.072	1.028	75	.974	.981	.987	.963	.98
36	1.047	1.032	1.023	1.069	1.027	76	.972	.980	.986	.960	.98
37	1.045	1.031	1.022	1.066	1.025	77	.970	.979	.985	.958	.98
38	1.043	1.029	1.021	1.063	1.024	78	.969	.978	.984	.956	.98
39	1.041	1.028	1.020	1.060	1.023	79	.967	.977	.983	.953	.98
40	1.039	1.026	1.019	1.057	1.022	80	.965	.976	.983	.951	.97
41	1.037	1.025	1.018	1.054	1.021	81	.964	.975	.982	.949	.97
42	1.035	1.024	1.017	1.051	1.020	82	.962	.974	.981	.947	.97
43	1.033	1.022	1.016	1.048	1.019	83	.961	.972	.980	.944	.97
44	1.031	1.021	1.015	1.045	1.017	84	.959	.970	.979	.942	.97
45	1.029	1.019	1.014	1.042	1.016	85	.957	.970	.978	.940	.97
46	1.027	1.018	1.013	1.039	1.015	86	.956	.969	.978	.938	.97
47	1.025	1.017	1.012	1.036	1.014	87	.954	.968	.977	.935	.97
48	1.023	1.016	1.011	1.033	1.013	88	.953	.967	.976	.933	.97
49	1.021	1.014	1.010	1.030	1.012	89	.951	.965	.975	.931	.97
50	1.019	1.013	1.009	1.027	1.011	90	.949	.964	.974	.929	.96
51	1.017	1.012	1.008	1.024	1.010	91	.948	.963	.974	.927	.96
52	1.015	1.011	1.007	1.022	1.009	92	.946	.962	.973	.925	.96
53	1.013	1.009	1.006	1.019	1.008	93	.945	.961	.972	.923	.96
54	1.011	1.008	1.005	1.016	1.006	94	.943	.959	.971	.920	.96
55	1.009	1.007	1.005	1.013	1.005	95	.942	.958	.970	.918	.96
56	1.007	1.005	1.004	1.011	1.004	96	.940	.957	.970	.916	.96
57	1.006	1.004	1.003	1.008	1.003	97	.939	.956	.969	.914	.96
58	1.004	1.003	1.002	1.005	1.002	98	.937	.955	.968	.912	.96
59	1.002	1.001	1.001	1.003	1.001	99	.936	.954	.967	.910	.9
60	1.000	1.000	1.000	1.000	1.000	100	.934	.953	.966	.908	.9
61	.998	.999	.999	.997	.999	101	.933	.952	.966	.906	.9
62	.996	.998	.998	.995	.998	102	.931	.951	.965	.904	.9
63	.995	.996	.997	.992	.997	103	.930	.950	.964	.902	.9
64	.993	.995	.996	.990	.996	104	.928	.948	.963	.900	.9
65	.991	.994	.996	.987	.995	105	.927	.948	.962	.898	.9
66	.989	.992	.995	.985	.994	106	.926	.946	.962	.896	.9
67	.987	.991	.994	.982	.993	107	.924	.945	.961	.894	.9
68	.986	.991	.993	.980	.992	108	.923	.944	.960	.892	.9
69	.984	.988	.992	.977	.990	109	.921	.943	.959	.890	.9
70	.982	.988	.991	.975	.989	110	.920	.942	.959	.889	.9

Table 2

FUEL TEMPERATURE FACTORS

For adjusting fuel economy to
60° F fuel temperature

$$\text{mpg of Fuel at } 60°F = \frac{\text{mpg of Fuel at Observed Temperature}}{\text{Fuel Temperature Correction Factor}}$$

Obs. Temp. °F	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9
0	1.0361	1.0355	1.0349	1.0343	1.0337	1.0331	1.0325	1.0319	1.0313	1.0307
10	1.0301	1.0295	1.0289	1.0283	1.0277	1.0271	1.0265	1.0259	1.0253	1.0247
20	1.0241	1.0235	1.0229	1.0223	1.0217	1.0211	1.0205	1.0199	1.0193	1.0187
30	1.0181	1.0175	1.0169	1.0163	1.0157	1.0151	1.0145	1.0139	1.0133	1.0127
40	1.0121	1.0115	1.0109	1.0103	1.0097	1.0091	1.0085	1.0079	1.0072	1.0066
50	1.0060	1.0054	1.0048	1.0042	1.0036	1.0030	1.0024	1.0018	1.0012	1.0006
60	1.0000	.9994	.9988	.9982	.9976	.9970	.9964	.9957	.9951	.9945
70	.9939	.9933	.9927	.9921	.9915	.9909	.9903	.9897	.9891	.9885
80	.9879	.9873	.9867	.9860	.9854	.9848	.9842	.9836	.9830	.9824
90	.9818	.9812	.9806	.9800	.9794	.9788	.9782	.9776	.9769	.9763
100	.9757	.9751	.9745	.9738	.9732	.9726	.9720	.9714	.9708	.9702
110	.9696	.9690	.9684	.9678	.9672	.9666	.9660	.9654	.9647	.9641
120	.9635	.9629	.9623	.9617	.9611					

4. TEST CRITERIA

~~4.1 LEGAL REQUIREMENTS~~

~~4.1.1 None~~

~~4.2 CORPORATE FUEL ECONOMY OBJECTIVES~~

~~4.2.1 None – Division responsibility.~~

4.3 GUIDELINE INFORMATION

4.3.1 Data Variability

4.3.1.1 Because of the unpredictable effects of wind on vehicle fuel consumption, the following guideline is suggested as an acceptable variation in economy data.

a. Fuel consumption on driving schedule recheck cycles should not vary more than 2% from the consumption on the first cycle.

b. Fuel consumption on level road runs in the same direction should not vary more than 2% from each other.

c. The fuel consumption for level road runs in one direction should not vary more than 7% from the consumption of runs in the opposite direction.

4.3.2 AMBIENT CONDITIONS

4.3.2.1 Ambient weather conditions, temperature, barometric pressure and humidity will affect vehicle fuel economy. Therefore, engineering judgment must be used whenever A–B comparisons are to be made of data obtained under different ambient conditions. Normalizing data to 60° F (15.6°C) fuel and ambient air temperatures, as described in Item 3.8.4, can be a significant help in interpreting A–B comparison results.

4.3.3 OTHER TEST EQUIPMENT AND INSTRUMENTATION

4.3.3.1 For the purpose of evaluating the operation of various vehicle components during a fuel economy run, other test equipment and instrumentation may be installed in the vehicle provided the vehicle test weight conforms to Item 3.1.5 and their operation does not alter fuel economy. Optional instrumentation described in Items 2.2.6 falls in this category.

4.3.4 OTHER VEHICLE CONFIRGURATIONS

4.3.4.1 Evaluation of the effect on fuel economy of external vehicle configuration changes such as additions of car-top carriers or pickup camper bodies may be made. However, such tests will be treated as non-standard tests.

4.3.4.2 Evaluation of the effect on fuel economy of vehicle components such as fan clutches, air conditioning compressors, E.G.R. valves, etc., may be made. However, such tests will be treated as non-standard tests.

4.3.5 TEST WEIGHT

4.3.5.1 The test weight specified in this procedure is a moderate loading condition chosen to provide information that ~~best~~ represents the fuel economy that a customer would normally receive. However, other test weights on light trucks as indicated in Item 3.1.5 may be used.

INSTRUMENT CALIBRATION

(Include this record with designated test data sheets)

Instrument Description	Instrument Number	Date Calibrated
1. ______	______	______
2. ______	______	______
3. ______	______	______
4. ______	______	______
5. ______	______	______
6. ______	______	______
7. ______	______	______
8. ______	______	______
9. ______	______	______
10. ______	______	______
11. ______	______	______
12. ______	______	______
13. ______	______	______
14. ______	______	______
15. ______	______	______
16. ______	______	______
17. ______	______	______
18. ______	______	______
19. ______	______	______
20. ______	______	______

Recorded by: ______________________ **Date** ______________

Data Sheet 1 of 4

FUEL ECONOMY TEST PROCEDURE - AUTOMOBILES AND LIGHT TRUCKS
DATA SHEET

TEST VEHICLE SPECIFICATIONS AND PREPARATION

Car No. ____________________ Date ____________

Year and Make ______________________________

Model and Body ______________________________

Engine Type ______________ Disp. ____________

Net HP __________________ C.R. ____________

Engine No. ______________________________

Carb. type & No. ______________________________

Distributor No. ______________________________

Exhaust Sys. Type ______________________________

Transmission ______________________________

Rear axle type and ratio ______________________________

Brakes: F ________________ R ______________

Steering ______________________________

Tire Make ______________ Size ______________

Load Range ______________ Type ______________

Tire Pres: F ___________ R ______________

Test Wt. ______________________________

Fuel Used ______________________________

Idle RPM ______________________________

Spark Timing ______________________________

Ign. Point Dwell ______________________________

Check List

( ) Engine oil level

( ) Coolant level

( ) Transmission fluid level

( ) Belts and hoses tight

( ) EGR valve function

( ) W.O.T. capability

( ) Choke function

( ) Air cleaner element clean

( ) Thermac valve function

( ) Spark plug and coil wires tight

( ) Brake drag not excessive

( ) Trans, shift points in spec.

( ) Remove A/C compressor lead

( ) No fuel leaks

Comments: ______________________________

____

____

____

Car Checked by: ______________________________

Data Sheet 2 of 4

FUEL ECONOMY TEST PROCEDURE - AUTOMOBILES AND LIGHT TRUCKS

DRIVING SCHEDULE DATA SHEET

Car No.________________ Date________________ Start Odometer______________

Accessory Operation______________ Driver__________ Observer______________

Other Information____

SCHEDULE________________ Time: S______ F______ Wind: Dir._____ Speed____

Ambient dry bulb__________ Wet bulb__________ Bar. pressure____________

	Elapsed Time, Sec.	Fuel Consumed, cc	Fuel temperature °F 1	2	3	4
First Cycle						
Recheck Cycle						

SCHEDULE________________ Time: S______ F______ Wind: Dir._____ Speed____

Ambient dry bulb__________ Wet bulb__________ Bar. pressure____________

	Elapsed Time, Sec.	Fuel Consumed, cc	Fuel temperature °F 1	2	3	4
First Cycle						
Recheck Cycle						

FUEL ECONOMY TEST PROCEDURE - AUTOMOBILES AND LIGHT TRUCKS

LEVEL ROAD AND IDLE DATA SHEET

Car No. ________________ Date __________________ Start Odometer ______________________

Accessory Operation ________________ Driver ________________ Observer ________________

Other Information ____

LEVEL ROAD & IDLE   Time: S_____ F_____ Wind: Dir. ______ Speed ______

Ambient dry bulb _________ Wet bulb __________ Bar. Pressure __________

Direction	Speed mph	Miles Per run	Elapsed Time (Sec.) First Run	Elapsed Time (Sec.) Recheck	Fuel Consumed (cc) First Run	Fuel Consumed (cc) Recheck	Fuel Temperature °F First Run	Fuel Temperature °F Recheck
	30							
	50							
	70							

IDLE   Start ______ Finish ______

Data Sheet 4 of 4

SUMMARY SHEET

Car No. ____________

Mileage at Beginning of Tests: Engine ____________________ Chassis ____________________

Non-Standard Test Conditions ____

____

FUEL ECONOMY TEST RESULTS

	Observed MPG	Adjusted* MPG	Avg. Fuel Temp°F	Air Temp°F.	Baro. Pres. in. hg.	Spec. Hum., Gr. H_2O/#air	Wind Speed - Di
Business District							
Suburban							
Highway							
Interstate							
Level Roads:							
30 mph							
50 mph							
70 mph							
Idle, Hr/gal							

*Normalized to 60°F ambient air and fuel temperatures.

Does data meet data variability guide lines? Yes ________ No ________

Tests conducted at ____

Test Road Names ____ Grade, % ____________

Tested by: ____________________________ Date: ____________________

SIMULATED CITY-SUBURBAN FUEL ECONOMY TEST FOR PASSENGER CARS

1. INTRODUCTION. This procedure describes a method for obtaining fuel economy data on passenger cars under driving conditions typical of congested metropolitan areas and of relatively open suburban locations.

1.1 DESCRIPTION. There are 20 stops in the 3.60 mile city route and maximum speed is 30 mph. There are 2 stops in the 5.20 mile suburban route and maximum speed is 60 mph. Prescribed acceleration rates vary from 3 to 7 ft/sec/sec and transmissions are operated in the range or gears required to maintain these acceleration rates.

2. INSTRUMENTATION

(a) Fuel burette, Ford Design shown on Drawing No. VTL-FF-6-7, sheets 1 through 4; 1/2 gal. size for light vehicles; 1 gal. size for custom vehicles; accuracy ±1%.

(b) Fifth Wheel Assembly, WO 26650, Ford Designed, supplied by Performance Measurements Co., for speed and distance measurement.

(c) Six-inch U-tube, liquid Accelerometer, Ammco Tool Inc. or equivalent.

(d) Stop watch.

(e) Thermocouple and potentiometer for measuring top coolant temperature (locate in top hose or intake manifold at coolant exit).

(f) Tachometer for engine rpm. Sun Electric Model PTT 16-1 or Motorola Co., Model 8TC.

2.1 CALIBRATION. Instruments must be calibrated in accordance with the instrument Calibration Procedures Manual and have current calibration cards.

3. EQUIPMENT AND FACILITIES. The test is run on a hard surface road without significant gradient and where traffic will not interfere with the speed, accelerations or stops. The high-speed track and straightaway at all three U.S. proving grounds are satisfactory sites.

4. VEHICLE PREPARATION

4.1 Install instrumentation.

4.2 Check fuel, lubricants, and coolant levels; adjust if necessary.

4.3 Ballast vehicle according to performance weight as outlined in Procedure P6-1, Test Weight Standards, or as specified in the Test Order.

4.4 Check and regulate tire pressure in accordance with Procedure P6-2, Tire Pressure Standard.

4.5 Tune vehicle in accordance with Procedure P6-4, Vehicle Tune-Up Standards.

SIMULATED CITY-SUBURBAN FUEL ECONOMY
TEST FOR PASSENGER CARS

5. OPERATION

5.1 WEATHER DATA. Record the following data. Unless otherwise requested, perform test only if ambient temperature is above 25°F and wind velocity does not exceed 18 mph.

(a) Wet bulb temperature - °F
(b) Dry bulb temperature - °F
(c) Barometric pressure - in. Hg
(d) Wind velocity and direction

5.2 ACCELERATION - DECELERATION RATES.

5.2.1 Suburban Route

(a) Accelerations

. 0-15 mph @ 7 ft/sec/sec
. 15-25 mph @ 5 ft/sec/sec
. 25-40 mph @ 3 ft/sec/sec
. 40-60 mph @ 3 ft/sec/sec

(b) Decelerations

. 60-30 mph retard @ 5 ft/sec/sec
. 50-0 mph stop @ 10 ft/sec/sec

5.2.2 City Route

(a) Accelerations

. 0-15 mph @ 7 ft/sec/sec
. 15-30 mph @ 5 ft/sec/sec
. 15-25 mph @ 5 ft/sec/sec

(b) Decelerations

. All stops @ 7 ft/sec/sec

5.3 TRANSMISSION SHIFT PROCEDURE DETERMINATION. Prior to starting the test, determine the shift procedure to be used.

5.3.1 AUTOMATIC TRANSMISSION.

(a) Place transmission in the drive range which automatically incorporates the maximum number of forward gears. Accelerate at the rates prescribed in paragraphs 5.2, allowing the transmission to upshift automatically. If the vehicle maintains the acceleration rates without the transmission down-shifting, perform the tests in this drive range. If the transmission shift points are different than 1-2 at 15 mph and 2-3 at 25 mph record on the Drivers Data Sheet.

SIMULATED CITY-SUBURBAN FUEL ECONOMY
TEST FOR PASSENGER CARS

(b) If the transmission down-shifts automatically while attempting to maintain any of the prescribed rates, perform the acceleration during test with the transmission locked in the gear to which the transmission downshifted. Manually up-shift the transmission at the completion of that acceleration rate or at the full throttle shift point for that gear (even if operation is at part throttle), whichever occurs first.

5.3.2 MANUAL TRANSMISSION. Perform accelerations in the gear specified unless acceleration rates cannot be maintained, in which case the shift procedure and shift points must be determined.

(a) Three Speed Transmission

- 1st gear - all 7 ft/sec/sec accelerations.
- 2nd gear - all 5 ft/sec/sec accelerations.
- 3rd gear - all 3 ft/sec/sec accelerations and constant speed operation.
- If the vehicle cannot maintain the prescribed acceleration rates, shift according to paragraph 5.3.2 (e).

(b) Four Speed Transmission - Suburban Route

- 1st gear - all 7 ft/sec/sec accelerations.
- 2nd gear - all 5 ft/sec/sec accelerations.
- 3rd gear - all 3 ft/sec/sec accelerations when going through gears from stops, as in paragraph 5.4.1 (d) and (f).
- 4th gear - all 3 ft/sec/sec accelerations following retard or constant speed, as in paragraph 5.4.1 (b), (c) and (e), and all constant speed operations.
- If the vehicle cannot maintain the prescribed acceleration rates, shift according to paragraph 5.3.2 (e).

(c) Four Speed Transmission - City Route

- 1st gear - all 7 ft/sec/sec accelerations.
- 2nd gear - all 5 ft/sec/sec accelerations will be made only to 25 mph.
- 3rd gear - all 5 ft/sec/sec accelerations continued from 25 mph to 30 mph and all 25 mph constant speed operation.
- 4th gear - all 30 mph constant speed operation.
- If the vehicle cannot maintain the prescribed acceleration rates, shift according to paragraph 5.3.2 (e).

SIMULATED CITY-SUBURBAN FUEL ECONOMY
TEST FOR PASSENGER CARS

(d) Overdrive Transmission. Applies where control is separate from the main transmission control.

- Suburban Route - Drive with the overdrive in operation, up-shifting to overdrive at 40 mph. Where the 3 ft/sec/sec acceleration cannot be maintained in overdrive, make the complete acceleration in conventional gear and up-shift to overdrive upon reaching constant speed.

- City Route - Drive the complete route with the overdrive locked out.

(e) Special Shift Procedure. When the vehicle cannot maintain the prescribed rate of acceleration in any gear, determine the shift point for optimum acceleration when up-shifting to this gear and shift the transmission as follows:

- Where the highest gear will not maintain the 3 ft/sec/sec acceleration, down-shift at the beginning of the acceleration to the highest gear that will maintain the 3 ft/sec/sec acceleration. Up-shift at the optimum shift point and up-shift to the highest gear upon reaching constant speed.

5.4 ROUTE. Over-all elapsed time must be between 820 and 826 seconds on the city route and between 441 and 445 seconds on the suburban route. In addition, the resultant economies of the two accepted runs must agree within plus or minus 2 percent. If these time and economy requirements are not met on a particular run, repeat the test. If, after repeated attempts with a particular vehicle, it is obvious that the maximum time requirement cannot be met regardless of how the vehicle is operated, retain the data reflecting the best consistency with respect to fuel economy.

5.4.1 Suburban Economy Route

	MILES	
(a)		Warm up vehicle by operating a distance of approximately 10 miles at 60 mph; include 2 brake stops at 10 ft/sec/sec during the last 5 miles. Approach starting (first) marker at 40 mph.
(b)	.00	Start burette and stop watch when passing the starting marker. Accelerate from 40 to 60 mph at 3 ft/sec/sec.
(c)	.70	At second marker decelerate from 60 to 30 mph at 5 ft/sec/sec and then accelerate from 30 to 50 mph at 3 ft/sec/sec. Proceed to third marker at 50 mph.
(d)	2.00	Stop at 10 ft/sec/sec at third marker. Idle for 3 seconds. Accelerate from a standing start to 15 mph at 7 ft/sec/sec; continue accelerating at 5 ft/sec/sec from 15 to 25 mph, and at 3 ft/sec/sec from 25 to 40 mph.
(e)	2.60	At fourth marker accelerate from 40 to 50 mph at 3 ft/sec/sec. Proceed to next marker at 50 mph.

SIMULATED CITY-SUBURBAN FUEL ECONOMY
TEST FOR PASSENGER CARS

MILES

(f) 3.30 Stop at 10 ft/sec/sec at fifth marker. Idle for 3 seconds. Accelerate from a standing start to 15 mph at 7 ft/sec/sec; continue accelerating at 5 ft/sec/sec from 15 to 25 mph, and at 3 ft/sec/sec from 25 to 40 mph. Proceed to sixth marker at 40 mph.

(g) 5.20 Stop the burette and stop watch when passing the sixth marker. Stop and record fuel consumed, elapsed time, and operating temperature.

(h) Restabilize vehicle warm-up by operating a distance of approximately 5 miles at 60 mph; include 2 brake stops at 10 ft/sec/sec. Approach starting (first) marker at 40 mph.

(i) Repeat above steps (b) through (g).

5.4.2 City Economy Route

MILES

(a) Warm up vehicle by operating 1.80 miles in accordance with the route in steps (b) through (k). Do not use fuel burette during warm-up.

(b) .00 Start a U-turn from the first marker. Simultaneously start fuel burette and stop watch. Complete turn in 25 seconds.

(c) .05 Stop at second marker at 7 ft/sec/sec. Accelerate from 0 to 15 mph at 7 ft/sec/sec; continue accelerating to 30 mph at 5 ft/sec/sec. Proceed to third marker at 30 mph.

(d) .31 Stop at third marker at 7 ft/sec/sec. Idle engine for 25 seconds. Accelerate from 0 to 15 mph at 7 ft/sec/sec; continue accelerating to 30 mph at 5 ft/sec/sec. Proceed to fourth marker at 30 mph.

(e) .49 Stop at fourth marker at 7 ft/sec/sec. Accelerate from 0 to 15 mph at 7 ft/sec/sec; continue accelerating to 30 mph at 5 ft/sec/sec. Proceed to fifth marker at 30 mph.

(f) .68 Stop at fifth marker at 7 ft/sec/sec. Idle engine for 25 seconds. Accelerate from 0 to 15 mph at 7 ft/sec/sec; continue accelerating to 30 mph at 5 ft/sec/sec. Proceed to sixth marker at 30 mph.

(g) .90 Stop at sixth marker at 7 ft/sec/sec. Make a U-turn (opposite direction to first turn); elapsed time to turn, 25 seconds.

(h) .95 Stop at seventh marker at 7 ft/sec/sec. Accelerate from 0 to 15 mph at 7 ft/sec/sec; continue accelerating to 30 mph at 5 ft/sec/sec. Proceed to eighth marker at 30 mph.

SIMULATED CITY-SUBURBAN FUEL ECONOMY
TEST FOR PASSENGER CARS

MILES

(i) 1.17 Stop at eighth marker at 7 ft/sec/sec. Accelerate from 0 to 15 mph at 7 ft/sec/sec; continue accelerating to 30 mph at 5 ft/sec/sec. Proceed to ninth marker at 30 mph.

(j) 1.35 Stop at ninth marker at 7 ft/sec/sec. Idle for 25 seconds. Accelerate from 0 to 15 mph at 7 ft/sec/sec; continue accelerating to 30 mph at 5 ft/sec/sec. Proceed to tenth marker at 30 mph.

(k) 1.54 Stop at tenth marker at 7 ft/sec/sec. Accelerate from 0 to 15 mph at 7 ft/sec/sec; continue accelerating to 30 mph at 5 ft/sec/sec. Proceed to 11th marker at 30 mph.

(l) 1.80 Stop at 11th marker at 7 ft/sec/sec. Make a U-turn (same as first turn); elapsed time for turn, 25 seconds.

(m) 1.85 Stop at 12th marker at 7 ft/sec/sec. Accelerate from 0 to 15 mph at 7 ft/sec/sec; continue accelerating to 25 mph at 5 ft/sec/sec. Proceed to 13th marker at 25 mph.

(n) 2.11 Stop at 13th marker at 7 ft/sec/sec. Idle for 25 seconds. Accelerate from 0 to 15 mph at 7 ft/sec/sec; continue accelerating to 25 mph at 5 ft/sec/sec. Proceed to 14th marker.

(o) 2.29 Stop at 14th marker at 7 ft/sec/sec. Accelerate from 0 to 15 mph at 7 ft/sec/sec; continue accelerating to 25 mph at 5 ft/sec/sec.

(p) 2.48 Stop at 15th marker at 7 ft/sec/sec. Idle for 25 seconds. Accelerate from 0 to 15 mph at 7 ft/sec/sec; continue accelerating to 25 mph at 5 ft/sec/sec. Proceed to 16th marker at 25 mph.

(q) 2.70 Stop at 16th marker at 7 ft/sec/sec. Make a U-turn (opposite to first turn); elapsed time for turn, 25 seconds.

(r) 2.75 Stop at 17th marker at 7 ft/sec/sec. Accelerate from 0 to 15 mph at 7 ft/sec/sec; continue accelerating to 25 mph at 5 ft/sec/sec. Proceed to 18th marker at 25 mph.

(s) 2.97 Stop at 18th marker at 7 ft/sec/sec. Accelerate from 0 to 15 mph at 7 ft/sec/sec; continue accelerating to 25 mph at 5 ft/sec/sec. Proceed to 19th marker at 35 mph.

(t) 3.15 Stop at 19th marker at 7 ft/sec/sec. Idle engine for 25 seconds. Accelerate from 0 to 15 mph at 7 ft/sec/sec; continue accelerating to 25 mph at 5 ft/sec/sec. Proceed to 20th marker at 25 mph.

(u) 3.34 Stop at 20th marker at 7 ft/sec/sec. Accelerate from 0 to 15 mph at 7 ft/sec/sec; continue accelerating to 25 mph at 5 ft/sec/sec. Proceed to 21st marker at 25 mph.

SIMULATED CITY-SUBURBAN FUEL ECONOMY
TEST FOR PASSENGER CARS

MILES

(v) 3.60 Stop at 21st marker at 7 ft/sec/sec. Shut off fuel burette and stop watch, and record elapsed time, fuel consumed and operating temperature.

(w) Immediately repeat above steps from (b) through (v).

6. GENERAL.

6.1 Operate the test vehicle for 2 circuits of the City Route and 2 circuits of the Suburban Route.

6.2 Operate electrical accessories as follows:

(a) Headlamps are to remain on low beam throughout test.

(b) If it is necessary to use the heater, the blower motor must be used in the "low" position only.

(c) On vehicles with air conditioning disconnect the air conditioning compressor clutch wire before start of test. Reconnect compressor clutch wire on completion of test.

(d) Radio operation is optional.

(e) All other electrical accessories must be in the off position.

6.3 Record on the Drivers Sheet all occasions when the Special Shift Procedure, paragraph 5.3.2 (e), must be used to maintain accelerations.

6.4 Record on the Drivers Sheet all occasions where the Special Shift Procedure was used but the vehicle was still unable to maintain the acceleration rate.

7. PRESENTATION OF DATA

7.1 Compute the following:

(a) A single average speed and single fuel economy for each route, dividing total distance by total fuel, using the data from both runs.

(b) Unless otherwise specified, correct the above fuel economy data to a base line condition of $60^{\circ}F$ temperature and 27.8 in. Hg dry air pressure. This correction is to be accomplished by use of the tables contained in Appendix VIII, "Ambient Condition Correction Factor Tables for Passenger Car Fuel Economy", as published by the Fuel Economy and Performance Committee. Assure carburetor air temperature equal to 35° higher than ambient air temperature for use in Tables.

(c) In addition, correct the fuel economy data from the test weight at which the vehicle was run to a standard test weight condition of Actual Weight plus 300 lbs. in accordance with the method recommended by the Fuel Economy and Performance Committee.

SIMULATED CITY-SUBURBAN FUEL ECONOMY
TEST FOR PASSENGER CARS

(d) Compute an average City-Suburban fuel economy by adding the City and Suburban economies and dividing by 2.

7.2 Tabulate the following:

(a) Fuel economy and corresponding average speed and operating temperatures for each route.

(b) Weather data at the start and finish of the test.

(c) Vehicle speed at transmission up-shift and down-shift points.

7.3 Record on Data Sheet.

(a) All occasions when the special shift procedure must be used to maintain accelerations.

(b) All occasions when the special shift procedure was used but the vehicle was still unable to maintain the acceleration rate.

... REFERENCES

(a) Ambient Condition Correction Factor Tables for Passenger Car Fuel Economy, published by the Fuel Economy and Performance Committee.

(b) Procedure P6-1, Test Weight Standard

(c) Procedure P6-2, Tire Pressure Standard

(d) Procedure P6-4, Vehicle Tune-Up Standard

(e) Ford Drawing No. VTL-FF-6-7, sheets 1 through 4, Fuel Burette, from Product Development Office, Equipment and Facilities Planning Department.

FUEL ECONOMY TEST PROCEDURE

1. Object

To determine fuel economy of a vehicle under simulated city, suburban, and highway traffic conditions.

2. Instrumentation

a. Fuel flow measuring system
b. Accelerometer
c. Fifth wheel assembly for speed and distance
d. Tachometer
e. Stop watch
f. Thermocouple and potentiometer for measuring:
   1. Top coolant temperature - locate in top hose or intake manifold at coolant exit.
   2. Fuel temperature - locate upstream of fuel measuring system.
g. Flowed E.G.R. valve

2.1 Calibration

Instruments must be calibrated or have current calibration cards.

3. Test Road

The test is run on a hard surface road without significant gradient and where traffic will not interfere with speed, accelerations or stops. The high speed 2 mile oval at Michigan International Speedway is a suitable site.

4. Vehicle Preparation

A. Ride check

1. Ride check car for general tightness, performance and operation of components. Note transmission up shift speed, shift quality and overspeed. Note general carburetion performance leanness, sags, stumbles and pop-backs.

2. Have deficiencies corrected.

B. Inspection

Axle Ratio - Check and record axle ratio and type (suregrip or regular) either by tag or manual inspection.

Exhaust System - Check manifold heat control valve for freeness, wrap of coil and for movement when engine speed is increased. Correct if necessary. Record exhaust system dimensions, branch pipe O.D., main pipe O.D., muffler, catalytic converter (if any), resonator and tailpipe dimensions. Check and record all part numbers, lab numbers or other identification markings.

Brakes - Check service brake of all four wheels for freeness of rotation. Adjust if necessary.

Heated Air System - Check air cleaner heating valve assembly for proper operation.

Carburetor - Record carburetor make, model and lab number if any. Check the linkage to make sure that it does not bind, that throttle goes wide open and that the throttle returns to idle. Check to ensure proper operation of secondary and also idle solenoid on vehicles so equipped.

Choke - Check choke specifications and make sure choke mechanism is free and not binding.

Engine - Record engine number.

Compression Pressure - Check compression pressures and record results.

Spark Plug - Install new spark plugs if required. Set plugs to proper gap.

Distributor - Record distributor number and lab number if any. Distributor should be previously tested and calibrated.

Ignition Timing - Set timing to specified setting and record. To insure that distributor vacuum does not affect the setting, disconnect the vacuum line.

Idle - Set engine idle, speed and mixture according to manufacturer's specifications.

Stall Speed - With a warm engine measure the engine stall speed with a calibrated tachometer.

Air Cleaner - Replace air cleaner element.

Transmission - Record transmission and converter type. If tests include extended W.O.T. running, equip automatic transmission cars with a thermocouple in the transmission oil and restrict test to oil temperatures under 300°F.

Tires - Record make, size, type, number of plys, and DOT serial number. Note general tire condition (tread wear and wear pattern). If the wear pattern so indicates, have front end aligned. Install new tires if necessary. Set tire pressures (cold) to manufacturer's specifications.

5. Vehicle Weight

Adjust weight of loaded vehicle (driver, observer(s), and test equipment) to specified test weight. Check and record vehicle weight and equipment. Note: Fifth wheel should be in the "up" position when weighing.

6. Weather Data

Unless otherwise specified, perform test only if ambient temperature is above 15°F. and wind velocity does not exceed 15 mph. Record the following data:

a. Wet bulb temperature (°F)
b. Dry bulb temperature (°F)
c. Barometric pressure (in. Hg.)
d. Wind velocity and direction

7. Wet Pavement

A fuel economy test is terminated if the pavement becomes damp enough that the car leaves visible tracks.

8. Test Track Marker Arrangements

Test cycles will begin at the start-finish line on the oval. Markers are placed every 0.1 mile around the oval and are to be used as reference points only. Actual distance measurements are to be made from the fifth wheel distance readout.

9. Acceleration and Deceleration Rates

9.1 City route

a. Accelerations - 0-26 mph @ 3 ft/sec/sec
0-35 mph @ 3 ft/sec/sec

b. Decelerations - 26-0 mph stop @ 5 ft/sec/sec
35-0 mph stop @ 5 ft/sec/sec

9.2 Suburban route

a. Accelerations - 0-15 mph @ 7 ft/sec/sec
15-25 mph @ 5 ft/sec/sec
25-40 mph @ 3 ft/sec/sec
40-60 mph @ 3 ft/sec/sec

b. Decelerations - 60-30 mph retard @ 5 ft/sec/sec
50-0 mph stop @ 3 ft/sec/sec

DELETED from PROGRAM 8/2/73 Per L.J.D. & R.A.P.

9.3 Highway route

a. Accelerations -
0-15 mph @ 5 ft/sec/sec
15-50 mph @ 2 ft/sec/sec
30-50 mph @ 2 ft/sec/sec
15-55 mph @ 2 ft/sec/sec
30-55 mph @ 2 ft/sec/sec
15-60 mph @ 2 ft/sec/sec
30-60 mph @ 2 ft/sec/sec
45-70 mph @ W.O.T.

b. Decelerations -
70-45 mph @ 4 ft/sec/sec
50-30 mph retard @ closed throttle
55-30 mph retard @ closed throttle
60-30 mph retard @ closed throttle
All stops @ 6 ft/sec/sec

10. Vehicle Warm-up

Each vehicle shall undergo a warm-up prior to test cycle by operating at 60 mph for ten (10) laps of the oval or twenty (20) miles.

11. Transmissions

11.1 Automatic transmissions

a. Place transmission in the drive range which automatically incorporates the maximum number of forward gears. Accelerate at prescribed test rates allowing transmission to upshift automatically. If vehicle maintains the acceleration rates without the transmission down-shifting, perform tests in this range. If transmission shift points are different than 1-2 at 15 mph and 2-3 at 25 mph, record on driver's data sheet.

b. If transmission down-shifts automatically while trying to maintain any of the perscribed rates, perform the acceleration during test with transmission locked in the gear to which the transmission down-shifted. Manually upshift the transmission at the end of that acceleration rate or at the full throttle shift point for that gear, whichever comes first.

11.2 Manual transmissions

If vehicle cannot maintain acceleration rates in specified gears, procedure and test points must be determined.

A. <u>City route</u>

Aa. Three speed transmission

0-26 acceleration: 1-2 shift @ 15 mph
2-3 shift @ 26 mph

0-35 acceleration: 1-2 shift @ 15 mph
2-3 shift @ 35 mph

Ab. Four speed transmission

0-26 acceleration: 1-2 shift @ 15 mph
2-4 shift @ 26 mph

0-35 acceleration: 1-2 shift @ 15 mph
2-3 shift @ 26 mph
3-4 shift @ 35 mph

B. <u>Suburban route</u>

Ba. Three speed transmission

1st gear - all 7 ft/sec/sec accelerations
2nd gear - all 5 ft/sec/sec accelerations
3rd gear - all 3 ft/sec/sec accelerations
and constant speed operations

Bb. Four speed transmission

1st gear - all 7 ft/sec/sec accelerations
2nd gear - all 5 ft/sec/sec accelerations
3rd gear - all 3 ft/sec/sec accelerations
when going through gears from stops
4th gear - all 3 ft/sec/sec accelerations
following retards or constant speed

C. <u>Highway route</u> DELETED from PROGRAM 8/2/73

Ca. Three speed transmission

1st gear - all 5 ft/sec/sec accelerations
2nd gear - all 2 ft/sec/sec accelerations
3rd gear - all 2 ft/sec/sec accelerations
and constant speed operation

Cb. Four speed transmission

1st gear - all 5 ft/sec/sec accelerations
2nd gear - all 2 ft/sec/sec accelerations
3rd gear - all 2 ft/sec/sec accelerations
4th gear - all 2 ft/sec/sec accelerations
and constant speed operations

12. Test Procedure

12.1 City traffic route

a. Warm-up vehicle according to Section 10.

b. Record fuel consumed and elapsed time in running one complete test cycle as outlined in the following procedure. Repeat the test until two close checks (within .003 gallons) are obtained.

c. There will be a total of 24 stops per test, two (2) from 35 mph, all others from 26 mph.

d. Limit distance traveled from start of acceleration to stop to .17 miles (898 ft.) during 0-26 mph acceleration and .44 miles (2323 ft.) during 0-35 mph accelerations.

12.1.1 Detailed procedure: City traffic cycle

After proper vehicle warm-up (Section 10), the city traffic fuel economy test is performed according to the following schedule.

Distance Miles (ft.)	Operation
0.0 (00.0)	Start fuel meter and stop watch, accelerate to 26 mph at 3 fps^2.
.17 (898)	Stop at 5 fps^2, idle 7 seconds (in gear), then accelerate to 26 mph at 3 fps^2.
.34 (1795.2)	Stop at 5 fps^2, idle 7 seconds (in gear), then accelerate to 26 mph at 3 fps^2.
.51 (2692.8)	Stop at 5 fps^2, idle 7 seconds (in gear), then accelerate to 26 mph at 3 fps^2.
.68 (3590)	Stop at 5 fps^2, idle 7 seconds (in gear), then accelerate to 26 mph at 3 fps^2.
.85 (4488)	Stop at 5 fps^2, idle 7 seconds (in gear), then accelerate to 26 mph at 3 fps^2.
1.02 (5386)	Stop at 5 fps^2, idle 7 seconds (in gear), then accelerate to 26 mph at 3 fps^2.
1.19 (6283)	Stop at 5 fps^2, idle 7 seconds (in gear), then accelerate to 26 mph at 3 fps^2.

12.1.1 Detailed procedure: City traffic cycle

Distance Miles (ft.)	Operation
1.36 (7181)	Stop at 5 fps^2, idle 7 seconds (in gear), then accelerate to 26 mph at 3 fps^2.
1.53 (8078)	Stop at 5 fps^2, idle 7 seconds (in gear), then accelerate to 35 mph at 3 fps^2.
1.97 (10,402) (1 lap)	Stop at 5 fps^2, idle 7 seconds (in gear), then accelerate to 35 mph at 3 fps^2.
2.15 (11,326)	Stop at 5 fps^2, idle 7 seconds (in gear), then accelerate to 26 mph at 3 fps^2.
2.32 (12,250)	Stop at 5 fps^2, idle 7 seconds (in gear), then accelerate to 26 mph at 3 fps^2.
2.49 (13,147)	Stop at 5 fps^2, idle 7 seconds (in gear), then accelerate to 26 mph at 3 fps^2.
2.66 (14,045)	Stop at 5 fps^2, idle 7 seconds (in gear), then accelerate to 26 mph at 3 fps^2.
2.83 (14,942)	Stop at 5 fps^2, idle 7 seconds (in gear), then accelerate to 26 mph at 3 fps^2.
3.0 (15,840)	Stop at 5 fps^2, idle 7 seconds (in gear), then accelerate to 26 mph at 3 fps^2.
3.17 (16,738)	Stop at 5 fps^2, idle 7 seconds (in gear), then accelerate to 26 mph at 3 fps^2.
3.34 (17,635)	Stop at 5 fps^2, idle 7 seconds (in gear), then accelerate to 26 mph at 3 fps^2.
3.51 (18,533)	Stop at 5 fps^2, idle 7 seconds (in gear), then accelerate to 35 mph at 3 fps^2.
3.95 (20,856) (2 laps)	Stop at 5 fps^2, idle 7 seconds (in gear), then accelerate to 26 mph at 3 fps^2.

12.1.1 Detailed procedure: City traffic cycle

Distance Miles (ft.)	Operation
4.12 (21,754)	Stop at 5 fps^2, idle 7 seconds (in gear), then accelerate to 26 mph at 3 fps^2.
4.29 (22,651)	Stop at 5 fps^2, idle 7 seconds (in gear), then accelerate to 26 mph at 3 fps^2.
4.46 (23,549)	Stop at 5 fps^2, idle 7 seconds (in gear), then accelerate to 26 mph at 3 fps^2.
4.63 (24,446)	Stop at 5 fps^2, stop fuel meter, record fuel consumed and elapsed time.

12.2 Suburban traffic route

a. Warm-up vehicle according to Section 10.

b. Record fuel consumed and elapsed time in running one complete test cycle as outlined in the following procedure. Repeat the test until two close checks (within .003 gallons) are obtained.

c. There are two (2) stops per test cycle, one from 50 mph and one from 40 mph.

d. Driving schedule maneuvers are initiated at the points indicated. For example, brake application for the first 10 fps^2 stop will begin at the 2 mile (10,560 ft.) distance.

e. Approach starting point at 40 mph.

12.2.1 Test procedure: Suburban traffic driving schedule

Note: Approach starting point at 40 mph.

Distance Miles (ft.)	Operation
0.00 (00.0)	Start burette and stop watch when passing starting point. Accelerate from 40-60 mph at 3 fps^2.
.7 (3696)	Decelerate from 60 to 30 mph at 5 fps^2 then accelerate to 50 mph at 3 fps^2.
2.0 (10,560)	Stop at 10 fps^2, idle for 3 seconds, accelerate to 15 mph at 7 fps^2, then to 25 mph at 5 fps^2, then to 40 mph at 3 fps^2.
2.6 (13,728)	Accelerate to 50 mph at 3 fps^2.
3.3 (17,424)	Stop at 10 fps^2, idle 3 seconds, accelerate to 15 mph at 7 fps^2, then to 25 mph at 5 fps^2, then to 40 mph at 3 fps^2.
5.2 (27,456)	Stop at 10 fps^2, stop fuel meter, record fuel consumed and elapsed time.

TEST PROCEDURE

SUBJECT: Fuel Economy: Constant Speed, Road Load

OBJECT: Determination of the constant speed fuel economy of a vehicle under road load conditions.

INSTRUMENTS:
1 - Fifth wheel
2 - Fuel economy outfit with vacuum (oval outfit or free piston).
3 - Stop watch

TEST ROAD: Oval Test Track

GENERAL PROCEDURE: Fuel used for one lap of the oval test track is measured. Additionally, manifold and distributor vacuum readings are taken. NOTE: Do not run test below 15°F unless specifically instructed to do so.

DETAILED PROCEDURE:

1 - Preparation

A - Condition the vehicle according to Preparation Procedure No. 903-A-08.2.

B - Install test instruments.

2 - Stabilization

A - Drive approximately 10 miles at 60 mph and about 5 miles at 20 mph prior to the 20 mph test.

B - Calibrate fifth wheel meter during warm-up at 60 mph. The time should be within 59.9 to 60.1 seconds, inclusive for 1 mile.

3 - Test

A - Operate vehicle at constant speed.

B - Start at the lowest test speed and run the highest speed last.

C - Record fuel used in thousandths of a gallon and lap times for the warm-up lap and one additional lap at each test speed requested. Do not run a third lap unless the economy difference between the warm-up lap and the warmed-up lap exceeds .003 of a gallon. Run each speed in designated lane as follows:

MPH	20	30	40	50	60	70	80
Lane	1	1	2	3	4	4	5

D - Stabilize at the next speed for a minimum of 1/2 lap.

E - Observe and record the following items on Form No. 800-140 for 20, 30, 40, 50, 60, 70, and 80 mph speeds.

(1) Fuel economy
(2) Manifold vacuum in north and south straightaways.
(3) Distributor vacuum in north and south straightaways.
(4) Driveability
(5) Ambient air temperature
(6) Lap time

F - Observe and record air temperature, barometer, humidity (except below 20°F) and wind at the beginning and end of test.

Revised 1/19/73

TEST PROCEDURE

SUBJECT: Fuel Economy: Constant Speed, Part Throttle or Grade Simulation.

OBJECT: To determine the constant speed fuel economy of a vehicle under various grade conditions.

INSTRUMENTS:

1 - Fifth wheel and meter
2 - Fuel economy outfit with vacuum gagues (oval outfit or free piston meter).
3 - Towing and absorption car with load call and null indication meter.
4 - Tow cable (100 feet - downgrade) (20 feet - upgrade).

TEST ROAD: Oval Test Track

GENERAL PROCEDURE: Fuel used for one lap of the oval test track is measured. Readings of manifold and distributor vacuum and lap time are taken as well.

DETAILED PROCEDURE:

A - Preparation

1 - Condition the vehicle according to Preparation Procedure No. 903-A-08.2.

2 - Install test instruments.

B - Stabilization

1 - Drive approximately 10 miles (2 laps of the oval) at 60 mph before beginning to run or after any time period, stoppage, etc.

2 - Calibrate the fifth wheel meter at 60 mph. The time should be within 59.9 or 60.1 seconds inclusive for 1 mile.

C - Test

1 - As the full test will probably extend over several days, start each day by taking data on a standard road load run (2 laps) at 56 mph or any other speed requested. This will provide information on the effect of weather from day to day. Omit this on the day that road load running (zero grade) includes 56 mph or the speed requested above.

2 - After initial stabilization and the road load check, level off at the specified beginning condition and make one lap of the oval per condition. The test, unless otherwise specified, will begin at high speed and load (highest percent upgrade). See chart below.

3 - Attempt to hold drawbar pull constant for each specified grade. Drawbar pull will be specified for the test vehicle at each grade. Speeds will be specified only as guides. These speeds unless otherwise noted will be 32, 38, 44, 50, 56, and 62 mph. The grades used unless otherwise noted will be ±1%, ±3%, ±6%, ±8% and level grade. Lanes for each speed are designated below with lap times for each speed as guides.

MPH	32	38	44	50	56	62
Lane	1	2	2	3	3	4
Lap Time	8:43.1	7:21.5	6:21.3	5:36.3	5:00.3	4:31.9

4 - Seek to maintain a good average level of fill in the fuel tank. Refill to the same point at each opportunity.

5 - Keep the same crew throughout if possible. Weight variations are especially important when simulating grades and every attempt should be made to keep variations to a minimum.

6 - Record the following on modified Form No. 800-140 for each lap: drawbar pull, manifold and distributor vacuum, lap time, fuel used in thousandths, grade, nominal mph, lane and air temperature in °F. Record full weather (air temperature, barometer, humidity @ 20°F and above, and wind) at the beginning and end of each test period. Record any pertinent comments.

7 - Other data such as torque and slip may be requested.

Chart of Grades and Speeds

	% Upgrade								% Downgrade			
Grade %	-8		-6		-3		-1	Level	-1	-3	-6	-8
DBP	Gear		Gear		Gear							
MPH	III	II	III	II	III	II						
32	x	x	x	x	x	?	x	x	x	x	?	?
38	x	x	x	x	x	?	x	x	x	x	?	?
44	x	x	x	x	x	x	x	x	x	x	x	?
50	x	x	x	x	x	x	x	x	x	x	x	x
56	x	x	x	x	x	x	x	x	x	x	x	x
62	x	?	x	?	x	?	x	x	x	x	x	x

? Indicates point may not be feasible or possible. All grade work will be run in direct gear unless otherwise requested.

Revised 1/19/73

TEST PROCEDURE

SUBJECT: Fuel Economy: Simulated Interstate Operation

OBJECT: To determine the fuel economy level of a vehicle employing an abbreviated cycle developed to describe. Typical interstate operation.

INSTRUMENTATION:
1 - Accelerometer
2 - Free piston fuel meter outfit
3 - Stop watch

TEST TRACK: Oval Test Track

GENERAL PROCEDURE: Measure the fuel used in traveling one lap of the oval using the simulated interstate cycle.

DETAILED PROCEDURES:

I - Preparation

A - Condition the vehicle according to Preparation Procedure No. 903-A-8.2.
B - Install test instrumentation.

II - Vehicle Stabilization

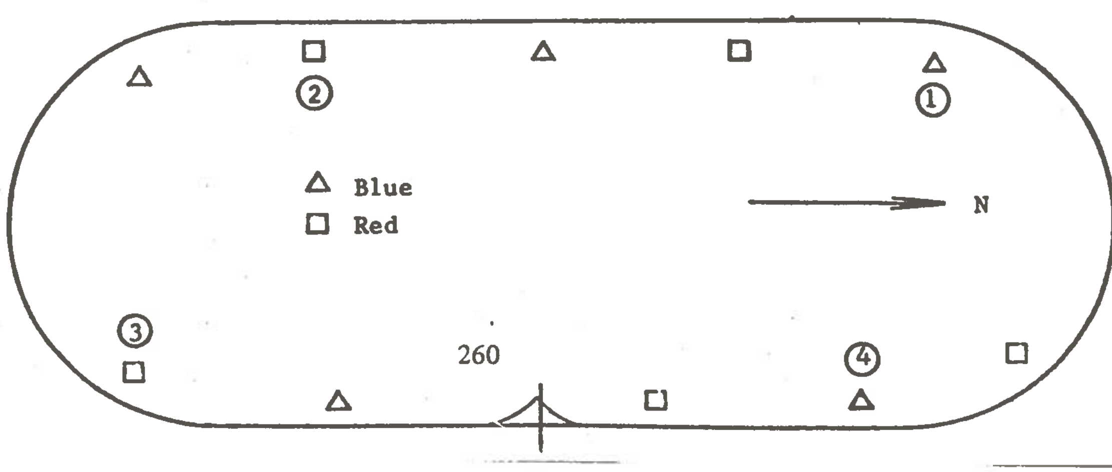
Drive 2 laps of the oval or approximately 10 miles at 60 mph prior to starting the test.

III - Test

A - Run 2 laps at each speed noting fuel counts and time per lap.

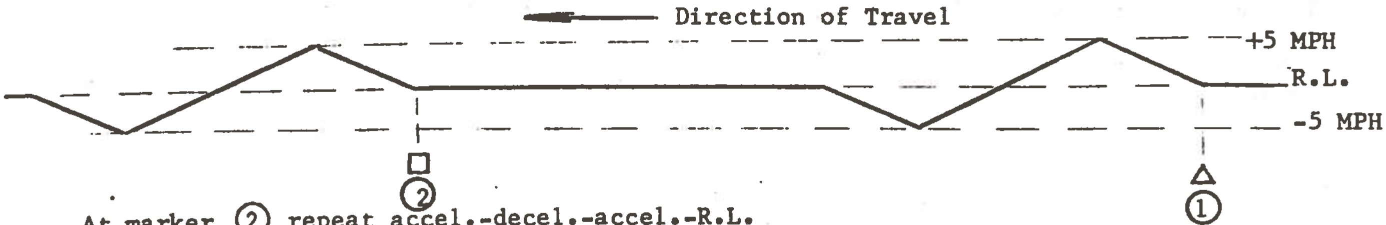
1 - 50 mph average speed (50-55-45-50) in Lane 3.
2 - 70 mph average speed (70-75-65-70) in Lane 4.

B - Run as follows, using the AMA cycle reflector marks on the oval (red or blue) as noted below.



C - The test is to be run as follows:

Road Load to marker 1
Start instrumentation
Accelerate at 1 ft/sec^2 to road load speed plus 5 MPH
Decelerate at 1 ft/sec^2 to road load speed minus 5 MPH
Accelerate at 1 ft/sec^2 to road load speed
Hold road load till marker 2



At marker 2 repeat accel.-decel.-accel.-R.L.
Repeat at markers 3 and 4
Shut off instrumentation at marker 1

D - When two or more test conditions are requested they should run back to back at the low speed before proceeding to the high speed portion of the test.

2-22-73

TEST PROCEDURE

SUBJECT: Fuel Economy: Urban Traffic Cycle, Cold and Warmed-Up

OBJECT: To determine city traffic fuel economy of a vehicle, employing an abbreviated cycle.

INSTRUMENTS:
1 - Accelerometer
2 - Free piston fuel meter
3 - Stop watch
4 - Fifth wheel

TEST ROAD: Oval Test Track

GENERAL PROCEDURE: Measure fuel consumed in traveling one lap of the oval test track, under a simulated city traffic procedure.

DETAILED PROCEDURE:

I - Preparation

A - Condition the vehicle according to Preparation Procedure No. 903-A-08.2

B - Install test instruments.

II - Test

A - Cold and Warm Urban Cycle

1 - Soak test vehicle on oval test pad for 16-24 hours prior to start of test.

2 - Run three laps in accordance with Part III (A or B, as appropriate), starting from a cold start with no warm-up laps. Note fuel counts used in starting the vehicle. These counts should include all fuel used prior to moving the vehicle.

3 - The second and third laps (warmed-up) should repeat within .003 gallons. Additional warmed-up laps should be run until the two close laps are within .003 gal.

B - Warm Urban Cycle Only

After running two warm-up laps of the oval at 60 mph, record fuel consumed in traveling one complete lap of the oval under the procedure in Part III, A or B. Repeat the test until two close checks (within .003 gallon) are obtained.

III - Procedure

A - Automatic Transmission

Record fuel consumed in traveling one complete lap of the oval under the following procedure.

1 - Accelerate at 3 $ft/sec^2/sec.$ to 26 mph.

2 - Upon attaining 26 mph, continue at road load (at that speed). Limit distance traveled (from start of acceleration to stop) to about 0.17 mile. Begin stopping at the paint stripe on track, and brake car at a deceleration rate of 5 ft/sec/sec.

3 - Idle engine normally for 7 seconds (in gear).

4 - Accelerate at 3 ft/sec/sec. to 35 mph.

5 - Upon attaining 35 mph, continue at road load (at that speed). Limit distance traveled (from start of acceleration to stop) to about 0.46 mile. Begin stopping at paint stripe on the track, and brake car at a deceleration rate of 5 ft/sec/sec.

6 - Idle engine normally for 7 seconds (in gear).

7 - Repeat steps 1-3 twenty-one more times limiting distance traveled (from start of acceleration to stop) to .17 mile.

8 - Complete one lap by repeating steps 4-6 limiting distance traveled (from start of acceleration to stop) to .42 miles. Laps should end at Pritchard Road. There will be a total of 24 stops per lap with the second and last ones being from 35 mph, and all others from 26 mph.

9 - Lap times should be noted and recorded.

B - Manual Transmission

Procedure is the same as outlined in "A" above for automatic transmissions, with manual transmission shifts made in accordance with the following schedule:

<u>0-26 Acceleration</u>

3 Speed Trans.:	1-2 shift at 15 mph
	2-3 shift at 26 mph
4 Speed Trans.:	1-2 shift at 15 mph
	2-4 shift at 26 mph

<u>0-35 Acceleration</u>

3 Speed Trans.:	1-2 shift at 15 mph
	2-3 shift at 35 mph
4 Speed Trans.:	1-2 shift at 15 mph
	2-3 shift at 26 mph
	3-4 shift at 35 mph

Deceleration

Declutch at approximately 15 mph.

TEST PROCEDURE

SUBJECT: Idle Fuel Consumption

OBJECT: To determine the idle fuel consumption of a vehicle.

INSTRUMENTS:

1 - Fuel burette
2 - Manifold and distributor vacuum gauges
3 - Stop watch
4 - Two thermometers
5 - Tachometer

TEST LOCATION: Inside garage or in parking area adjacent to garage.

GENERAL PROCEDURE: The vehicle is parked in the test area following a thorough warm-up. The time required to consume a fixed quantity of fuel is then determined for specified engine idle speeds.

DETAILED PROCEDURE:

1 - Preparation

a - Condition vehicle according to Preparation Procedure No. 903-A-08.2.

b - Install test instruments

2 - Stabilization

a - Drive vehicle approximately 10 miles at a speed of 60 mph then return to test area.

3 - Test

Test should be performed in area free from air currents with no rapid changes in ambient conditions. The hood should be open during tests and the radiator pressure cap installed.

a - Set engine idle to requested speed and readjust mixture if necessary.

b - Obtain fuel consumption in both neutral (not park) and drive conditions if car is equipped with an automatic transmission. Headlights and accessories should be off.

c - When using the dual bottle fuel burette (97.43 cc/ bottle) run five bottles for each test condition listed.

d - Clear the engine between each bottle by operating at 2000 rpm for 15 seconds.

e - Record the following information - for each bottle fuel used - on Form No. 800-140.

1 - Average engine speed and engine rpm variation.

2 - Manifold and distributor vacuum - inches of mercury.

3 - Fuel used - cc's.

4 - Elapsed time - minutes and seconds.

5 - Transmission setting - neutral (not park) or drive.

6 - Ambient air temperature.

7 - Inlet air temperature at the air cleaner inlet.

8 - Idle quality description - good, poor, rough, smooth, etc.

TEST PROCEDURE

SUBJECT: Car Conditioning: Car Break-In for Performance Tests

OBJECT: To insure that new cars used for performance evaluation are thoroughly broken in prior to testing.

TEST LOCATION: Oval Test Track

PROCEDURE: 1. - Preparation

a - Inspect car
b - Check torques of running gear parts
c - Install break-in oil
d - Ballast - none required
e - Use gasoline recommended for car

2 - Standard 500 Mile Break-In for all Cars

Miles	MPH
50	50
50	55
100	60
150	65
150	70

3 - Preparation for High Speed Break-In

a - Change oil to that currently being used by Proving Grounds endurance cars.
b - Install spark plugs recommended for WOT operation.
c - Set tire pressure to 40 psi cold on V8 engine-equipped cars for speeds above 90 MPH.

4 - High-Speed Break-In - 700 Miles

a - Six cylinder cars

Schedule A
("G" and "RG" engine cars)

Miles	MPH
200	70
250	75
250	80

b - Eight cylinder cars

Schedule B ("A" Engine Cars)	
Miles	MPH
100	75
200	80
200	90
200	95

Schedule C ("B" Engine Cars)	
Miles	MPH
100	75
150	80
150	90
100	95
100	100
100	105

5 - Cycle Break-In - Final 300 Miles

Using direct gear go to detent (without getting kickdown except part throttle) at 30 mph and accelerate to 100 mph (8 cyl.) or 80 mph (6 cyl.) and run 1 lap. Repeat for 300 miles.

NOTE: Cars with less than 1500 miles on the odometer should be started on the break-in schedule at the point that corresponds to the mileage. Cars with more than 1500 miles but less than 2500 miles should run only the last 300 miles of the break-in.

RECORDS: Failures and work done

Driver's comments

TEST PROCEDURE

SUBJECT: Car Conditioning: Vehicle Preparation for Performance Tests

OBJECT: To prepare a vehicle for performance tests and to eliminate as many variables as possible from the test results.

GENERAL PROCEDURE:

1 - Ride test vehicle

2 - Tune engine and inspect parts

3 - Install test equipment

DETAILED PROCEDURE:

I - Ride Check

A - Install seat cover

B - Ride car for general tightness, performance and operation of components. Note transmission upshift speed, shift quality and over speed. Note general carburetion performance leanness, sags, stumbles and pop-backs.

C - Have deficiencies corrected

D - Have car washed

II - Inspection

Use Form No. 800-296 for a check list and verify the parts and specifications listed on the back of the Test Request (Form No. 800-170 or P.G. 66).

Axle Ratio - Count and record axle ratio and type (sure-grip or regular).

Hotchkiss Drive - Regular: Turn one rear wheel 20 complete revolutions while holding the other rear wheel stationary. Count the resulting propeller shaft revolutions and divide by 10.

Hotchkiss Drive - Sure Grip: Turn one rear wheel 10 complete revolutions. Count the resulting propeller shaft revolutions and divide by 10.

Torque Tube Drive: Remove axle housing rear cover and count teeth of ring gear and pinion.

Exhaust System - Check manifold heat control valve for freeness, wrap of coil and for movement when engine speed is increased. Correct if necessary. Record exhaust system dimensions branch pipe o.d., main pipe o.d., muffler and resonator dimensions and tail pipe o.d. dimensions and tail pipe o.d. Check for and record all part numbers, lab. numbers or other visible signs of identification.

Brakes - Check service brake of all four wheels for freeness of rotation. Adjust if necessary to eliminate binding.

Heated Air System - The vacuum modulation of the pre-heat air valve should be checked. Checks should be performed to insure that the valve is modulated at the proper carburetor inlet air temperature. For acceleration and maximum speed tests the preheated valve will be made inoperative by removing and plugging the vacuum hose to the valve.

Carburetor - Record carburetor make, model and lab. number if any. Check the linkage to make sure that it does not bind, that throttle goes wide open and that the throttle returns to idle. Where applicable, ensure proper operation of secondary. On cars so equipped check that the idle solenoid is functioning.

Choke - Check choke specifications. Inspect to make sure choke mechanism is free and not binding (make choke inoperative for all but owner's cycle or other tests so specified by the engineer).

OSAC (Orifice Spark Advance Control) - In neutral, operate the engine at 2000 rpm or on step two of the fast idle cam. With a short piece of hose, tee a vacuum gage in the line between the distributor and OSAC unit. Also install a gage at the carburetor spark port and reconnect the line. There should be an immediate gradual rise of distributor vacuum which stabilizes to within 1" of Hg in approximately a minute. If no rise or a slower rise is noted, inspect for leaks. If none are found, replace the unit.

EGR (Exhaust Gas Recirculation) -

Floor Jets

Without removing the carburetor open the choke and throttle baldes. Visually inspect the orifice plugs in the manifold to insure that they are free of carbon deposits.

Ported & Venturi Signal-PEGR

With the vehicle in neutral, raise engine speed to approximately 2000 rpm. Movement of the recirculation valve should be observed. This indicates the valve is operating.

With the engine at idle apply 10 inches of mercury vacuum to the recirculation valve. A drop of 150 rpm or an engine stall should be noted. This indicates exhaust gas is flowing thru the valve. Replace faulty or inoperative valve.

TIC (Temperature Operated Vacuum By-Pass Valve) - Check hose routing. Install vacuum gages at the carburetor spark port and at the distributor vacuum advance unit. Any rise in vacuum between the carburetor and distributor indicates a faulty valve. Replace if necessary.

Cylinder Head - Record the cylinder head number on calibrated heads. Where applicable cylinder head description should be recorded.

Engine - Record engine number

Compression Pressure - Check compression pressures and record the results. Show those results to the engineer requesting the tests.

Spark Plug - Install new spark plugs if required. Set plugs to proper gap. For maximum speed runs, install dynamometer plugs with a rating of 300 IMEP or equivalent.

Distributor - Record distributor number and laboratory number if any. If the distributor has not previously been calibrated remove and check calibration including solenoid operation (where applicable). Correct if necessary.

Ignition Timing - Set timing to specified setting and record. To insure that distributor vacuum does not affect the setting disconnect the vacuum line.

Idle - Set engine idle, speed and mixture according to manufacturers specification. Record idle speed mixture and vacuum. (Briefly: run 2 laps on oval at 60 mph. Set idle with Horiba gas analyzer to the proper CO% at the specified idle speed).

Stall Speed - With a warm engine measure the engine stall speed with strobotac or calibrated tachometer. Record the stall speed. Stall speed is to be measured with the car on a hoist so that the wheels are off the ground.

Air Cleaner - Clean the air cleaner, replace if necessary. On oil bath units fill the indicated level with proper oil. Check the air cleaner part number.

Transmission - Record transmission and converter type (i.e. A727 transmission, A862 converter). If tests include extended WOT running, equip automatic transmission cars with a thermocouple in the transmission oil pan and restrict test to oil temperatures under 325°. Install "burp pipe" extension on filler pipe.

Heater & Air Conditioning - If heater is needed it should be operated on low blower speed only. On vehicles equipped with air conditioning the wire to the air conditioning compressor clutch should be disconnected unless test request specifies otherwise.

Tires - Record make, size, type, number of plys, and DOT serial number. Note general tire condition (tread wear and wear pattern). If the wear pattern so indicates have front end aligned. Install new tires if necessary.

Set tire pressures as follows:

A - If car has been parked outside, set tires (cold) to recommended pressures.

B - If car has been parked inside, increase recommended pressure according to approximate outside air temperature as per attached temperature compensation graph.

C - For high speed tests increase pressure per engineers direction.

Gasoline - Fill tank with specified gasoline. If grade of fuel in tank is questionable drain tank before refilling. A fixed low RVP fuel, e.g. indolene, will be used on all cars starting testing in the period of 1 May to 1 November. Normal RVP fuels will be used in cars being tested at other times, unless otherwise specified by the engineer.

III - Install necessary test equipment and instruments. Check for fuel and vacuum leaks.

IIII - A fire extinguisher is to be available in the car.

V - Check vehicle weight and record vehicle equipment per Engineering Road Weight Data Sheet (Form No. 800-95). Include vehicle identification number, engine number and tire serial number on this sheet.

VI - Adjust weight of loaded vehicle (driver, observer and test equipment) to specified test weight. Note: The fifth wheel should be in the "up" position when weighing. Record test on Log Sheet (Form P.G. 53) each time vehicle is weighed.

EXHAUST EMISSION TEST PROCEDURES

1968 Federal Test Procedure (FTP) - Fed. Reg. Vol. 33 No. 108 (6/1/68)

. Cold start followed by 137-second cycle repeated 7 times for a total of 6 miles
. Emission concentrations measured continuously and data from specific portions of the test weighted.
. Result expressed as concentrations.

1972 Mass Emissions Procedure (CVS-72) - Fed. Reg. Vol. 36 No. 55 (3/20/71)

. Cold start followed by 7.5 mile simulated urban trip.
. Proportional mass sample of exhaust collected in a bag throughout test and emission concentrations in bag measured after test.
. Result expressed as grams per mile.

1975 Mass Emissions Procedure (CVS-75) - Fed. Reg. Vol. 36 No. 128 (7/2/71)

. Cold start followed by 7.5 mile simulated urban trip, consisting of 3.6 mile warm up trip (Bag 2) and 3.9 mile hot trip (Bag B).
. Car stopped and allowed to stand for ten minutes.
. Car restarted and 3.6 mile warm-up trip repeated (Bag C).
. Proportional mass samples of exhaust collected in three bags and emission concentrations in bags measured after test.
. Weighted emissions = 43% Bag A + 100% Bag B + 57% Bag C.
. Result expressed as grams per mile.

ESTIMATED EXHAUST EMISSIONS PRIOR TO EMISSION STANDARDS

(EXPRESSED IN GRAMS PER MILE)

Exhaust Emission Test Procedure	Exhaust Emission HC	CO	NOx
FTP	(11.0)	(80.0)	(4-6)
CVS-72	(9.5)	(98.0)	(3.4)
CVS-75	(8.6)	(87.5)	(3.5)

EVAPORATIVE EMISSIONS STANDARDS

(Evaporative Emissions Expressed in Grams per Test)

YEAR	EVAPORATIVE HC EMISSION
Prior to 1971	No Standard
1971	6.0
1972 - 1977	2.0

AUTOMOBILE EXHAUST EMISSION STANDARDS (1966-1971)

(HC Concentrations Expressed in Parts per Million)
(CO Concentrations Expressed in Percent)
(NOx Standard Not Applicable)

	FEDERAL EXHAUST EMISSION STANDARD		CALIFORNIA EXHAUST EMISSION STANDARD		
YEAR(S)	HC (ppm)	CO (%)	HC (ppm)	CO (%)	CID
1966 - 1967	No Standard		410	2.3	50-100
1968 - 1969	275	1.5	350 275	2.0 1.5	101-140 Over 140
1970 - 1971	180	1.0	180	1.0	ALL

AUTOMOBILE EXHAUST EMISSION STANDARDS (1966 - 1977)
(EXPRESSED IN GRAMS PER MILE)

APPLICABLE YEAR(S)	EXHAUST EMISSION TEST PROCEDURE	FEDERAL EXHAUST EMISSION STANDARDS HC	CO	NOX	CALIFORNIA EXHAUST EMISSION STANDARDS HC	CO	NOX
1966 - 1967	FTP	*	*	*	(3.4)	(35.0)	*
1968 - 1969	FTP	(3.4)	(35.0)	*	(3.4)	(35.0)	*
1970	FTP	(2.2)	(23.0)	*	(2.2)	(23.0)	*
1971	FTP	(2.2)	(23.0)	*	(2.2)	(23.0)	(4.0)
1971	CVS - 72	(4.6)	(47.0)	*			
1972	CVS - 72	3.4	39.0	*	3.4	39.0	3.2
1973	CVS - 72	3.4	39.0	3.0	3.4	39.0	3.2
1974	CVS - 72	3.4	39.0	3.0	3.4	39.0	2.0
1975 Original	CVS - 75	0.41	3.4	3.0	1.0	24.0	1.5
1975 Interim	CVS - 75	1.5	15.0	3.1	0.9	9.0	2.0
1976 Original	CVS - 75	0.41	3.4	0.4	0.41	3.4	0.4
1976 Interim	CVS - 75	0.41	3.4	2.0			
1977	CVS - 75	0.41	3.4	0.4			

* No standard was applicable

( )Numbers in parentheses are not standards but are estimates of average emission levels, in gra per mile, had the indicated test procedure been used.

APPENDIX V

FINAL REPORT OF ARTHUR D. LITTLE, INC., SUBCONTRACTOR --

SCIENTIFIC ENERGY SYSTEMS CORP.

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1.0 PURPOSE OF WORK AND SCOPE

The objective of this study program was to identify and evaluate various technological improvements capable of reducing fuel consumption of automobiles and to identify various combinations of improvements which could reduce the average fuel consumption of individual vehicles by 30%. Vehicles of two different weight classes were investigated as follows:

Compact car - 3200 $\pm$ 200 LB
Standard car - 4500 $\pm$ 300 LB

A baseline of fuel economy behavior was established by selecting popular 1973 model year reference vehicles within these weight classes from all major U.S. manufacturers and determining the fuel economy characteristics of these reference vehicles. Then the various technological improvements selected for the study were evaluated in terms of the reduction in fuel consumption below these 1973 model year reference vehicles.

Several constraints were imposed on the study as follows:

1. Technology - technological improvements considered in the study were restricted to those already available or in an advanced state of development and capable of meeting constraint 2.
2. Time Frame - capable of being demonstrated in a few vehicles by 1976 and in mass production (10^6 vehicles/yr) by 1980.
3. Exhaust Emissions - must be capable of meeting US/EPA 1976 interim standards, e.g. 2.0 gm/mile NO_x, 3.4 gm/mile CO, 0.41 gm/mile HC.
4. Safety - must meet all US/DOT safety standards, current and projected.
5. Noise - must meet all US/EPA noise standards, current and projected.
6. Performance - all alternative vehicle designs must have acceleration performance and driveability substantially equal to that of the selected reference vehicles without the fuel conservative improvements.
7. Reliability - must be substantially equal to that of the selected reference vehicles.
8. Acceptability to User - technological improvements must not sacrifice user acceptability to gain fuel conservation.

The investigation of technological improvements encompassed the following broad technical areas:

1. Engine and auxiliaries
2. Transmission and drive train
3. Accessories
4. Vehicles aerodynamics
5. Vehicle Weight (not size)
6. Tires

Scientific Energy Systems (SES) was engaged as a subcontractor to Arthur D. Little (ADL) on this program principally to employ its computer simulation program for predicting automobile fuel consumption over the Federal driving cycle and at steady-speed, level-road cruise at various speeds. This method of analysis was applied first to four different reference vehicles for which extensive basic data were obtained (2 compacts and 2 standard cars) and then to evaluate several selected technological improvements which met the constraints above. A comparison of the results for the technological improvements against those of the reference vehicles provided an estimate of the probable reduction in fuel consumption.

The following specific technological changes were investigated both separately and in various combinations by means of computer simulation during this study.

Vehicle - Weight reduction
- Drag coefficient and frontal area reduction

Engine - Stratified charge engine
- High speed automotive diesel engine

Drive Train - 4 speed automatic transmission with torque converter lock-up
- continuously variable traction transmission
- axle ratio changes

Tires - Bias ply tires (standard equipment on 1973 reference vehicles) replaced with radial ply tires.

Accessories - constant speed accessory drive

Several other technical improvements were evaluated only by means of information and data made available by developers and industry sources due to lack of time and/or adequate basic component data available for computer simulation. Improvements in this latter category are

1) engines with catalytic converters and optimized spark timing (both fuel rich and stoichiometric)

2) engines operating with lean air/fuel ratios such as lean carburetors, electronic fuel injection etc.

3) smaller displacement engines with means for power boost such as turbocharging.

2.0 DESCRIPTION OF APPROACH TO EVALUATION OF TECHNOLOGICAL IMPROVEMENTS

The basic approach adapted for this study was to start by selecting and characterizing reference vehicles (both compact and standard sizes), identify various technological changes offering reduced fuel consumption and then make a quantitative evaluation of the fuel consumption benefit, to be considered along with the cost, availability, impact on manufacturing facilities, consumer acceptance and other factors to permit an overall evaluation of each technological improvement. Finally, it was desired to examine various combinations of technological improvements to determine those combinations which could yield a 30% reduction in fuel consumption using hardware which could be available in production by 1980. The choice of reference vehicles, identification of technological improvements, determination of availability for early production, and assessment of impact on natural resources, manufacturing facilities, and consumer acceptability are all treated in the Arthur D. Little portion of this report. This volume will focus on the problem of evaluating the various technological improvements for their quantitative impact on vehicle fuel consumption.

Three basic methods were employed to estimate the effect of various technological changes on vehicle fuel economy:

1. Obtaining information and data on various devices from studies reported in the technical literature.
2. Obtaining information and data from interviews with developers of various devices and from automotive industry representatives and consultants having independent experience in evaluating the various devices.
3. Computer simulation of automobile operation using detailed technical data on all system components which influence the overall vehicle fuel consumption and investigating the effect of various system and components changes.

The principal role played by Scientific Energy Systems (SES) was the evaluation of various devices by computer simulation of vehicle fuel economy. As a result most of this report is devoted to a description of that activity and presentation of the results obtained. In reporting the results of the computer simulation work, frequent reference is made to results from the technical literature to help corroborate the accuracy of the simulation method and the results obtained. The principal effort on idea evaluation via interviews and discussions with innovative device developers, industry representatives, and consultants was performed by Arthur D. Little and the results are contained in their final report on this program.

2.1 FIELD TRIP EFFORT TO GATHER TECHNICAL INFORMATION

A significant part of the computer simulation task involved the gathering of reliable performance data on vehicles and power train components. It was recognized early that the accuracy and reliability of results so obtained would be highly dependent on the use of up-to-date reliable component input data. Therefore field trips were made to visit various equipment manufacturers and innovative device developers in an effort to gather the needed reliable data. SES joined Arthur D. Little on some of these trips which related more closely to the simulation effort. Although much of the information gathered from these trips was used in the simulation work, some of the devices discussed were not able to be included in the simulation work for one or more of the following reasons:

1. Insufficient detailed performance data available for computer simulation.
2. Performance data available was not obtained on a comparable basis to that used for the reference vehicles against which it would be compared.
3. Fuel economy improvement appeared to be small and did not warrant the effort required for computer simulation.
4. Insufficient time and manpower available for computer simulation effort eliminated it from further study during this program.

Since it was desireable to present the findings from some of these field trip efforts not used in the simulation studies, this report also contains a brief account of that activity in Section 3.0.

The following tabulation lists the various companies visited by SES representatives during this study and indicates the principal subject discussed and whether or not data supplied by them was used in the computer simulation studies.

	Data Used In Computer ?
I. AUTO INDUSTRY REPRESENTATIVES	
All four major U.S. auto firms - Ref. vehicle data	yes
Ethyl Corp. - Lean reactor powerplant	no
Bendix Corp. - Electronic Fuel Injection System	no
Borg-Warner - Transmissions	yes

II. INNVOATIVE DEVICE DEVELOPERS (Non Auto Industry)	Data Used In Computer ?
Tracor Inc., Continuously variable traction transmission	yes
Dresser Industries - Lean burning engine via improved carburetion	no
Autotronic Controls - Lean burning engine via improved carburetion	no
McCulloch Corp. - Lightweight diesel	no
Ricardo Cons. Engrs. - Automotive diesel	yes
U.S. Army - TACOM - Stratified charge engine	no
Southwest Research Institute - Stratified charge engine	no

Further details regarding the information gathered and findings from these visits are presented in Section 3.0.

2.2 EVALUATION OF VEHICLE CHANGES AND INNOVATIVE DEVICES THROUGH COMPUTER SIMULATION

In this study the primary emphasis is placed on evaluating improvements in fuel mileage resulting from a wide variety of changes in the vehicle and power train design parameters. It is a relatively easy matter to calculate the fuel mileage (miles per gallon of fuel - MPG) obtained under steady-speed level-road driving conditions. However, this is not representative of most people's driving habits. The average driver spends a great deal of time under transient conditions; accelerating, decelerating, braking and idling, as well as steady speed cruising. In an attempt to simulate customer average driving conditions each of the major automobile manufacturers has established its own driving cycles to simulate city, suburban, country, and interstate highway type driving. All manufacturer's test cycles are a little different from the others, although they have certain features in common. At the present time there is no universal agreement on a driving cycle (or set of driving cycles) that represents customer average driving. However, a committee was recently formed by the Society of Automotive Engineers to consider the establishment of such a universally approved "fuel economy driving cycle."

In the absence of this approved driving cycle it was decided that the Federal Urban driving cycle (FDC) established by the EPA for use in automobile exhaust emissions testing would be used in this study to represent the urban driving situation. The fuel mileage over the FDC plus calculations of miles per gallon at steady speeds of 20, 30, 40, 50, 60 and 70 miles per hour on level roads were selected as the operating conditions to evaluate for use as building blocks to assess the overall average customer fuel useage.

Computer simulation provides a useful tool for determining vehicle fuel use over a wide variety of different operating conditions. The simulation program used for this study is described in the following section. It was originally created specifically to perform fuel economy and emission calculations* for vehicles operating over the FDC but it will accept any chosen driving cycle as input if expressed in the required format. The program also calculates steady speed fuel economy but is not capable of determining maximum vehicle acceleration performance.

* While the program was designed to include calculations of emissions for an automotive steam engine, it is much more difficult to construct good transient emissions models for the spark ignition gasoline engine. Therefore, no attempt was made to simulate exhaust emissions for this study.

2.2.1 DESCRIPTION OF COMPUTER SIMULATION PROGRAM

The objective of the computer program for vehicle simulation is to predict the fuel consumption characteristics of any synthesized vehicle design over various specified transient operating conditions and during steady speed level road driving. The steady state driving is, of course, a special case of transient operation (acceleration=0) so the following discussion will be directed toward a description of the transient case. It is desired to simulate vehicle operation over a specified driving pattern (driving cycle) which may consist of a combination of transient and steady state operating conditions, as required. Since it was desired to run the simulation program over the Federal Driving Cycle (FDC) employed by the EPA for exhaust emissions certification, the computer program was written to conveniently accommodate the FDC. This driving cycle is described in detail in the Federal Register (27) and is summarized in Appendix C of this report. The FDC is defined by a table of values for vehicle velocity versus time consisting of 1371 points (one for each second of the driving cycle). Salient characteristics of this cycle are

7 1/2 miles long
22.8 minutes
Average speed = 19.7 miles per hour
Maximum speed = 56.7 miles per hour
No. times at idle = 18
No. minutes at idle = 4.33

To simulate operation of an automobile over a specified driving cycle to determine fuel consumption, it is necessary to

1) determine the sequence of engine operating conditions necessary to make the vehicle follow the specified driving cycle,

2) determine from an engine map the instantaneous rate of fuel flow for each instant of time over the driving cycle.

3) integrate the instantaneous fuel flow versus time and vehicle velocity vs. time to obtain the total fuel consumed and total distance traveled.

4) obtain fuel economy by dividing the total miles traveled by the total number of gallons of fuel consumed.

In order to carry out step 1) above it is necessary to utilize reliable input data to describe the following vehicle, drive train, and powerplant characteristics:

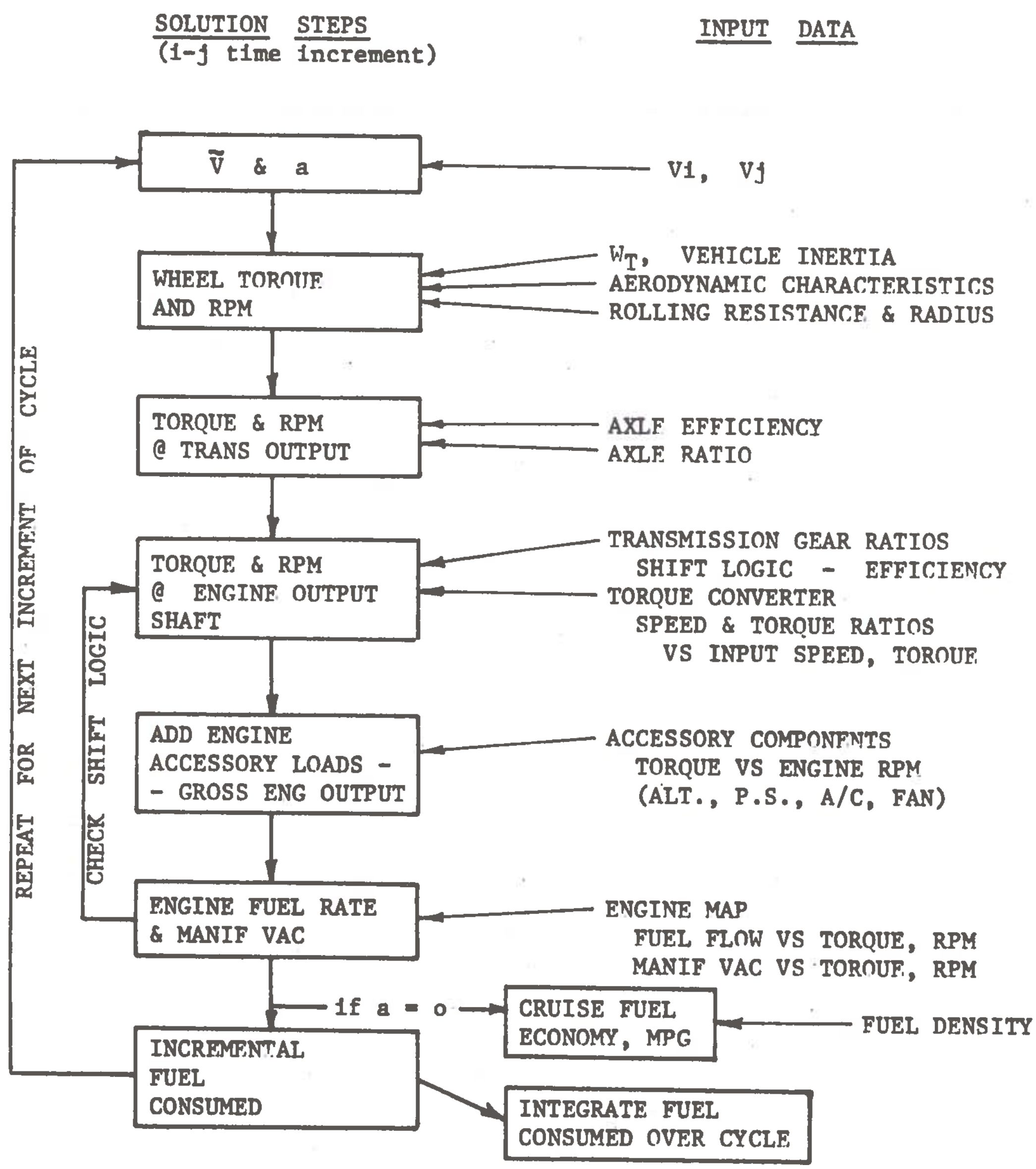
Input Data Required

1) Vehicle road load power requirements.
   a) aerodynamic drag characteristics
   b) rolling resistance characteristics
2) Drive Train Component Efficiencies
   a) Tire efficiency (if road load characteristics determined by towing test)
   b) Rear axle efficiency
   c) Transmission efficiency
      i) gear box bearing and gear losses for automatic transmissions
      ii) torque converter characteristics and losses
      iii) gear box spin losses
      iv) front pump losses
   d) Transmission shift logic
   e) Accessory power requirements
      i) radiator fan
      ii) alternator
      iii) power steering pump
      iv) air conditioner
      v) other
   f) Engine operating map
      i) Torque vs. speed and manifold vacuum
      ii) Fuel flow vs. torque and speed.

The computational sequence utilized in the simulation program is illustrated in the flow diagram of Figure 1. The various computational steps are illustrated by the blocks in the left hand column of the diagram whereas the input data utilized for each computational step is listed in the right hand column. The Federal driving cycle is broken down into 1371 separate time increments, one for each second of the cycle. During each of these time intervals the engine power and speed necessary to allow the vehicle to travel at the defined average velocity and acceleration is determined. From this information the fuel consumed

FIGURE 1

COMPUTER SIMULATION FLOW DIAGRAM



during each time interval is calculated and summed up to obtain fuel economy over the entire cycle.

Figure 1 illustrates the solution steps for a typical time interval during the cycle as follows:

1. First the average vehicle velocity and acceleration are computed from the initial and final velocities specified by the input drive cycle definition.

2. Wheel torque and RPM are determined from empirical equations expressing the steady state aerodynamic drag and rolling resistance characteristics of the vehicle and from vehicle inertia characteristics using selected numerical values for vehicle test weight, drag coefficient, and frontal area. Vehicle inertia consists of both vehicle weight and polar moment of inertia of all rotating parts of the drive train.

3. Torque and RPM at the transmission output shaft are then determined by applying axle ratio and axle efficiency parameters.

4. By consideration of transmission gear ratios, shifting logic, gear and spin losses the speed and torque at gear box input shaft is then determined. If the transmission includes a torque converter, its characteristics such as torque ratio, and speed ratio vs. K factor are used to obtain engine output shaft torque and speed required. The transmission front pump loss is also included if appropriate.

5. Next the engine accessory power consumption is determined for the required engine RPM. Accessory component torque loads are typically input as being solely a function of engine RPM. Adding this load to the engine output shaft power gives the gross engine output.

6. The instantaneous engine fuel rate is then determined from an engine map expressing fuel flow as a function of gross output torque and RPM.

7. If steady speed fuel economy is being calculated for zero acceleration, then the miles per gallon of fuel is calculated from the vehicle speed, fuel flow rate and the appropriate fuel density.

8. If a driving cycle calculation is being performed, the fuel consumed during the one second interval is computed and added to the previously accumulated fuel consumed whereupon the program indexes to the next one second interval of the driving cycle and repeats the above 8 calculation steps.

At certain points in the driving cycle, the vehicle is brought to a stop and the engine idles for a finite period of time before accelerating again. During this period the above calculation procedure is by-passed and an idle fuel flow value is used. Also during rapid decelerations where engine braking (which is incorporated in the engine map treatment) is insufficient, and the brakes must be applied, the idle fuel flow is assumed.

After indexing through the entire driving cycle and making the above calculation for each time increment the total distance traveled is divided by the total fuel consumed to obtain the miles per gallon fuel economy over the driving cycle.

A typical computer output summary sheet is shown in Table 2-1. Each separate computer run is identified by a "calculation number" hereinafter referred to as "run no", followed by the Vehicle Identification, Engine Identification, Accessory Loads, Torque Converter Identification, Transmission Identification, Tire Identification, Axle ratio, Road (curb) Weight, and Test Weight, and Transmission Gear Ratios. Three items of interest in the upper right corner are the vehicle frontal area (AREA-Ft^2), the drag coefficient (CD), and the engine displacement (DISP).

The output results for steady speed level "Road Load Performance" is given in a table listing the following parameters as a function of vehicle speed from 20 to 90MPH in increments of 5 MPH.

Engine RPM, Torque Converter Speed Ratio

Engine HP, BSFC, Fuel Flow

Tractive Force at Wheels, Fuel Economy-MPG

Finally, the fuel economy over the Federal Driving Cycle is printed at the bottom of the page and is labeled "EPA Cycle".

TABLE 2-1

..F.S. PROGRAM FOR FUEL ECONOMY OVER FEDERAL DRIVING CYCLE — DATE = 11/29/73

CALCULATION NUMBER	601	
VEHICLE IDENTIFICATION	COMPACT REFERENCE VEH - X CO	
ENGINE IDENTIFICATION	X COMPANY COMPACT	
ACCESSORY LOADS	X. COMP. COMPACT	
CONVERTER IDENTIFICATION	X COMP. 11.25 IN. TC	
TRANSMISSION IDENTIFICATION	X COMP. - 3 SPEED AUTOM.	
TIRE IDENTIFICATION	6.45 X 14 BIAIS PLY	
AXLE RATIO	2.7900	
ROAD WEIGHT = 2851.0000	TEST WEIGHT = 3351.0000	

TRANSMISSION RATIOS

GEAR	GEAR RATIOS
1	2.4600
2	1.4600
3	1.0000

PWR	.4600	CGW	
GRADE	0.0000	WIND	
AREA	21.4200	CD	
ECONID	.00017000		
		GNOXI	0
GCOI	0.00000000	GHCI	0
MU	0.0000	DISP	
START	20.0000	STOP	
KEYRR	1	EXP	0.
KEY	3	KEY3	
WMUPG	0.0000	TGAL3	
WMUPN	0.0000	TNOX3	
WMUPC	0.0000	TCO3	
WMUPH	0.0000	THC3	

ROAD LOAD PERFORMANCE

SPEED MPH	ENGINE RPM	CONVERTER SPEED RATIO	ENGINE HP	BSFC LBS/ BHP-HR	FUEL FLOW LBS/HR	FORCE REQUIRED LBS	FUEL ECONOMY MPG	NOX GR/MILE	CO GR/MILE	HC GR/M
20.00	949.73	.8437	6.003	.8500	5.1020	63.0467	24.9550			
25.00	1103.18	.9039	7.549	.7654	5.7774	68.7096	27.5468			
30.00	1288.06 45	.9251	9.539	.7172	6.8409	75.6310	27.9175			
35.00	1474.33	.9394	11.893	.6777	8.0598	83.8107	27.6446			
40.00	1663.17	.9486	14.682	.6411	9.4122	93.2489	27.0543			
45.00	1854.86	.9541	17.970	.6281	11.2877	103.9455	25.3790			
50.00	2046.73 71	.9584	21.792	.6139	13.3792	115.9006	23.7906			
55.00	2241.14	.9608	26.234	.6007	15.7600	12[illegible].1140	22.2163			
60.00	2437.84	.9620	31.358	.5872	18.4146	143.5859	20.7422			
65.00	2635.00	.9631	37.198	.5808	21.6035	159.3162	19.1538			
70.00	2832.90 86.5	.9640	43.817	.5719	25.0596	176.3050	17.7824			
75.00	3031.79	.9648	51.274	.5585	28.6385	194.5521	16.6716			
80.00	3231.92	.9656	59.630	.5665	33.7788	214.0577	15.0769			
85.00	3433.55	.9662	68.947	.6182	42.6202	234.8217	12.6961			
90.00	3636.92	.9669	79.286	.6683	52.9864	256.8442	10.8130			

THE SUBURBAN ROUTE (20,30,40 AVERAGE) ECONOMY, 26.6423

THE COUNTRY ROUTE (50,60,70 AVERAGE) ECONOMY, 20.7717

THE AVERAGE FUEL ECONOMY DURING THE EPA CYCLE = 17.48 MPG

2.2.2 CAPABILITY OF SIMULATION PROGRAM AND LIMITATIONS

The computer simulation system described above is basically capable of estimating the overall vehicle fuel economy (miles per gallon of fuel) for operations over any prescribed driving cycle consisting of accelerations steady speed cruise, decelerations and idle conditions interspersed in any prescribed manner. While the program is capable of accepting any driving cycle, within the performance capability of the input vehicle, the Federal Driving Cycle used by EPA for emissions certification is the only one used to date for calculations. The program also computes level road steady speed fuel economy over a range of vehicle speeds. It is not capable of computing wide-open-throttle (WOT) acceleration performance because that type problem requires a different set of computation logic and it was not incorporated into this program.

No provisions have been made in the simulation to account for excess fuel used during engine warm-up due to choking, higher engine friction, etc., or for excess fuel use by the carburetor accelerator pump which provides richer fuel-air mixtures during rapid acceleration transients. Moreover, the program does not account for extra energy dissipation in the transmission during shifting transients or for clutch slippage, wheel slippage, etc. However, in spite of these limitations, the simulation program has been found to provide reasonably good agreement with manufacturer's test data and is a useful tool for rapid, low cost examination of the effect of various system changes on vehicle fuel economy.

2.2.3 ACCURACY CHECK OF COMPUTER SIMULATION

The accuracy of the simulation program in predicting vehicle fuel use is basically dependent on the quality of the input data used to describe the performance of the various individual components of the vehicle. When realistic, accurate input data is employed good agreement is obtained between simulation results and test data.

Three methods were employed for checking the accuracy of the simulation

1) Check against manufacturer's test data for steady speed MPG on reference vehicles

2) Check against EPA certification data for average MPG over the Federal driving cycle.

3) Check of sensitivity coefficients for effect of single parameter changes in vehicle weight, axle ratio, and aerodynamic drag against values reported in the literature by various vehicle manufacturers.

Four reference vehicles were analyzed by computer simulation:*

		Computer
Company X	Compact -	run 601
	Standard-	runs - 701, 702
Company Y	Compact -	runs - 302, 306, 311
	Standard-	run - 401

* * * * * * * * * * *

These runs are described in more detail in Section 4.2; however, the results are summarized and compared with manufacturers test data for steady speed on the following page. Examination of these sheets will reveal that the simulation and test results always agree within about 10% and in most cases agree within 2-5%. This is considered to be excellent agreement considering the degree of sophistication of the analytical model.

Next the experimental data from EPA on Miles per gallon over the FDC obtained from certification tests on 1973 model cars (Ref. 15) was used to compare with computer simulation results as follows:

	Simulation Run No.	Simulation MPG over FDC	EPA Test Results MPG
Company X Compact	601	17.45	12.2-14
Company X Standard	701	11.6	8-10
Company Y Compact	302	13.77	12.5-13
Company Y Standard	401	10.4	9.9-12

*See Pages 255 to 272 for computer runs.

COMPARISON OF FUEL CONSUMPTION OF COMPUTER PREDICTION AND MANUFACTURER'S DATA

Description	Simulation Fuel Consumption in MPG	Manufacturer's Data in MPG
Company Y Compact (1973)	(3760 lb, run 302)*	(3765 lb)
30 MPH	22.4	22.4†††
40	21.2	NA
50	19.6	20.9
60	17.4	NA
70	14.0	15.9
Company Y Standard (1973)	(4856 lb, run 401)**	(4966 lb)
30	18.6	19
40	18.5	NA
50	17.3	18.4
60	15.4	NA
70	14.0	15.2
Company X Standard (1972)	(5008 lb, run 701)†	
30	19.0	18.9
40	19.8	19.5
50	18.6	18.3
60	16.5	16.9
70	14.6	14.9
Company X Compact (1972)	(3380 lb, run 601)††	
30	27.9	NA
40	27.1	NA
50	23.8	NA
60	20.7	NA
70	17.8	17.9

*See Page 258, Table 4-2
**See Page 259, Table 4-2
†See Page 256, Table 4-2
††See Page 255, Table 4-2
†††N.A. = Not Available

A range of values is listed for the EPA test results because the carbon balance method used to determine fuel useage from exhaust emissions data is not as accurate as direct fuel measurement and as a result the EPA test data on miles per gallon over the FDC exhibit substantial scatter among similar vehicles with the same engine, body and same vehicle weight. Several vehicles with the same engine and inertia weight class were examined to determine the range of MPG values listed above. It was concluded that, once again, good agreement is obtained between simulation and EPA tests over the FDC. The agreement is better for the Company Y vehicles than for the Company X vehicles. This is, no doubt, due largely to the fact that the Company X vehicle simulation was run with 1972 engine data which does not account for the additional fuel economy penalty caused by the 1973 NO_x controls. While certain isolated cases differ by as much as 20%, on the average the agreement is within 5-10% for the Co. Y cases. This is considered quite adequate for the model employed and the EPA test data accuracy.

Although it is of interest to know that the computer simulation results agree well with vehicle test data on an absolute basis, it is of even greater interest to determine whether the simulation can predict the correct relative effect of various vehicle changes on fuel economy. This type of check on simulator accuracy was performed by examining a number of single parameter changes in the reference vehicles (e.g. reduced weight, aerodynamic drag, axle ratio, and rolling resistance) and comparing the results with published results of a similar nature based on work reported by the various automobile manufacturers. This work is described in more detail in Section 4.2, and summarized in the table on the following page. The results of this exercise demonstrated that not only do the quantitative effects of single parameter changes in vehicle characteristics agree well from one reference vehicle to another but also these effects are in good quantitative agreement with results reported by the auto manufacturers. This favorable comparison greatly enhances the value of the computer simulation as a tool for examining the relative effect of system changes on vehicle fuel economy.

IMPROVEMENT RESULTS OBTAINED FOR COMPACT AND STANDARD CAR COMPUTER RUNS COMPARED TO OTHER EXPERIMENTAL DATA SOURCES

Data Source	Weight Reduced by 10%			Axle Ratio Reduced By 10%			Combined Weight & Axle Reduction By 10%			Aerodynamic Drag Reduced By 10%			Radial Tires		
	% Improvements			% Improvements			% Improvements			% Improvements			% Improvements		
	Federal Urban Driving Cycle	50 MPH Steady State	70 MPH Steady State	Federal Urban Driving Cycle	50 MPH Steady State	70 MPH Steady State	Federal Urban Driving Cycle	50 MPH Steady State	70 MPH Steady State	Federal Urban Driving Cycle	50 MPH Steady State	70 MPH Steady State	Federal Urban Driving Cycle	50 MPH Steady State	70 MPH Steady State
Compact Car Computer Run	4.0	2.5	2.5	1.0-1.5	3.0	3.5	5.8	3.2	6.0	1.0	3.5	7.5	2.7	3.5	4.0
Standard Car Computer Run	3.3	2.5	2.5	1.0-1.5	4.0-5.0	3.0-4.0	5.0	6.0	5.5	0.5	2.3	4.4	2.0	4.0	4.5
S.A.E. Paper, No. 730518 By Huebner	4.3	--	2.5	0.9	--	3.7	--	--	--	Negligible	--	4.4	1.8	--	2.5
S.A.E. Paper, No. By Lapointe	3.0	--	--	3.3	--	--	6.5	--	--	--	--	--	--	--	--
S.A.E. Paper, No. 730790 By Marks	4.1-4.6	--	--	2.5-3.0	--	--	--	--	--	--	--	--	--	--	--

3.0 RESULTS OF FIELD TRIP EFFORT

The principal objectives of the field trips for gathering data and expert opinions were (1) to obtain sufficient reliable data on reference vehicle and power train characteristics to permit accurate computer simulation of vehicle fuel economy, and (2) to discuss various potential technological improvements with the developers and with auto industry representatives to obtain data for computer simulation studies and/or to obtain data and judgments from developers and industry concerning the probable fuel economy impact of their devices. It is appropriate to first discuss the gathering of data for reference vehicle evaluation and then to discuss various engine and drive train improvements and the efforts to obtain technical information to evaluate them.

3.1 REFERENCE VEHICLE DATA

Reference vehicles conforming to the compact and standard size categories as defined in the contract work scope were chosen by ADL* for all four of the major American automobile manufacturers. From this selection a composite vehicle specification was created for each of the compact and standard vehicle categories. All four major U.S. automobile manufacturers were then visited and asked to supply technical data on two of their 1973 production automobiles, one each conforming to the composite vehicle specs for the compact and standard cars.

Data requested consisted of all items required to run the computer simulation of vehicle fuel economy as described in Section 2.2.

Some data were received from all four companies. However, complete data in the form required for computer simulation were obtained from only two. Therefore, computer simulation studies were conducted on reference vehicles from only these two sources. To preserve their anonymity they are referred to throughout this report as Company X and Company Y. During the course of the computer simulation work it was necessary to go back to these companies several times for resolution of questions and problems regarding the data supplied. The authors are indeed grateful to these anonymous representatives of Co X and Co Y for their help, without which the simulation study would have been much less reliable.

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*The reference vehicle selection process is discussed in the ADL report.

3.2 ENGINE AND TRANSMISSION CHANGES--GENERAL DISCUSSION OF POTENTIAL IMPROVEMENTS

Before discussing details of the field trip efforts to gather information on engine and transmission improvements it seems appropriate to discuss the salient characteristics of current automotive engines and delineate some of the possible technological improvements which need to be explored.

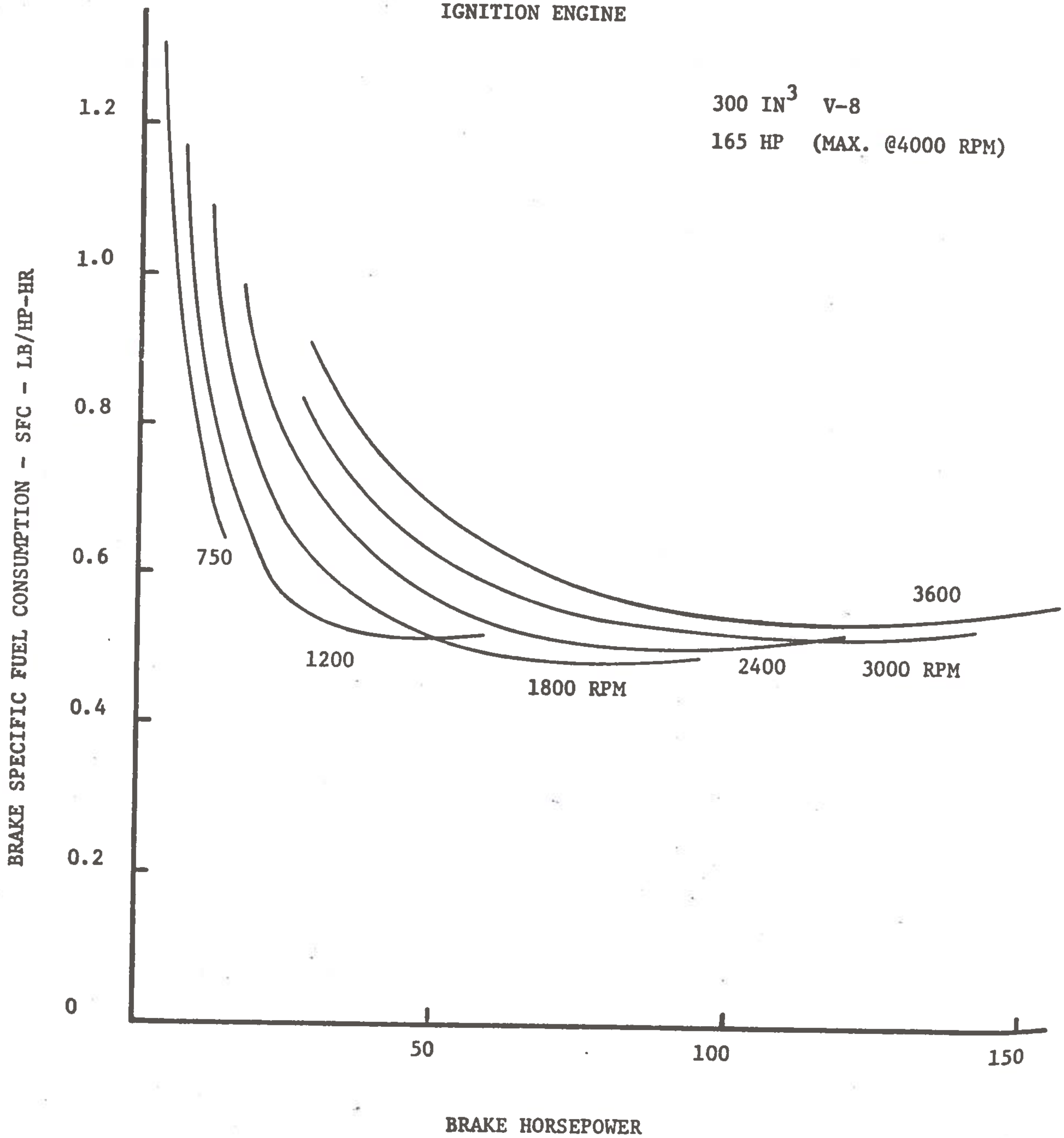
The current spark ignition engine employed in most automobiles is a highly developed machine which delivers rather good efficiency, particularly in the upper part of its load range. Over the past seventy years, this engine has enjoyed myriad evolutionary improvements which have brought it to its present advanced state of development. Perhaps it is the gradual increase in compression ratios, made possible by improved higher octane fuels, that is chiefly responsible for the improvements in specific fuel consumption. Today's engines can deliver a best brake specific fuel consumption (BSFC) equal to about 0.5 LB Fuel/BHP-HR. This best specific economy point occurs near wide open throttle (WOT) at about half of rated engine speed. It corresponds to a thermal efficiency for energy conversion of about 28%. By comparison the best stationary powerplants and large diesel engines yield thermal efficiencies of about 40% (or SFC = 0.33 to .35).

If the automotive gasoline engine could maintain its best SFC over a wide operating range it would indeed provide very attractive fuel economy. Unfortunately, this is not the case, due principally to the method of power control required in the automotive spark ignition engine. Due to the necessity for employing intake air throttling as a means for power modulation, the gasoline engine BSFC values rise sharply under light loads as shown by the curves in Figure 2 for a typical engine at various operating speeds.

The basic underlying reasons for this light load economy problem are the following. The combustible mixture ratio limits for ignition and flame front propagation in premixed gasoline-air mixtures are roughly from f/a = 0.05 to 0.10. Stoichiometric mixture ratio is 0.067. Since only a small degree of power modulation is possible by varying the fuel flow while maintaining constant airflow, it is conventional practice in gasoline engines to vary power output by means of inlet air throttling downstream of the carburetor venturi, thereby varying both air flow and fuel flow in a

FIGURE 2

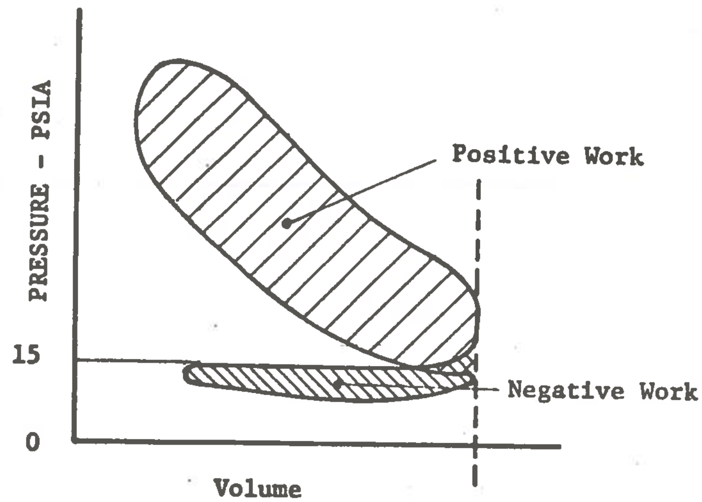
SFC VS POWER FOR TYPICAL GASOLINE SPARK IGNITION ENGINE



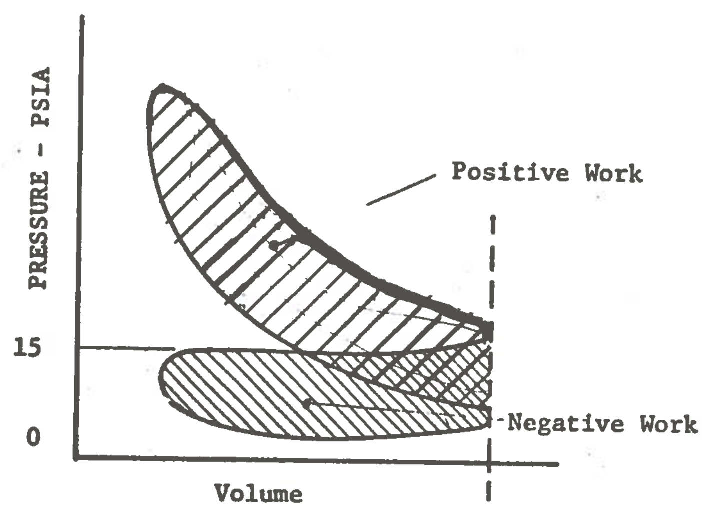
manner such that the fuel-air ratio remains essentially constant. Power modulation is thus achieved by varying the mass of fuel-air "charge" admitted to the cylinder per cycle. As a result of this inlet air throttling, a large "pumping loop" is obtained during the intake stroke (Figure 3-) wherein the piston must do extra work against the pressure of the atmosphere in the crankcase. At very light loads where the intake manifold pressure is 15-20 in Hg vacuum (or more) this pumping loop becomes large relative to the net output and thus substantially decreases the efficiency. Moreover, the high manifold vacuum at light load causes a significant increase in "residual charge dilution" which decreased flame speed, combustion temperatures and engine thermal efficiency. In contrast, the compression ignition or Diesel engine does not operate with a throttled air intake and hence does not suffer from this malady. It is capable of maintaining good light load BSFC.

Besides this light load economy problem, the gasoline engine likes to operate with fuel-rich-mixtures and this characteristic also adversely impacts its fuel economy over the entire operating range. As indicated above, the combustible limits of fuel-air mixtures range from slightly lean to over 50% rich mixtures. By selecting the design fuel-air ratio so that it lies in the mid-range of the combustible zone (10-20% rich) a greater margin is achieved to allow for error due to production tolerances, carburetor malfunction, improper fuel atomization and mixing, and many other factors which affect operating fuel-air ratios. Moreover, experience has shown that carburetors designed for rich mixtures provide smoother, more reliable engine operation with better drivability and fewer field service problems, hence the reason for the long established practice of rich carburetion with the attendant problems of large CO and unburned hydrocarbon emissions and fuel consumption greater than required according to the theoretical combustible mixture limits.

Schweitzer (32 and 33) discusses the correct mixtures for gasoline engines and shows that the best economy point occurs typically at a mixture ratio which is about 10% lean. This mixture ratio would be ideal from the viewpoint of maximizing fuel economy. However, to date the practical problems of accurate fuel-air metering and control, uniform fuel distribution among cylinders, proper atomization and mixing, etc.,



Case a) Low Intake Manifold Vacuum-High Efficiency



Case b) High Intake Manifold Vacuum-Low Efficiency

FIGURE 3 TYPICAL P-V DIAGRAMS FOR THROTTLED GASOLINE ENGINE ILLUSTRATING PUMPING LOOP.

have prevented the practical achievement of lean operation. Today, new technical advances promise to launch a new era of accurate gasoline engine fuel control. Since a 10-20% reduction in fuel consumption is at stake this is an important subject for inclusion in this study.

The foregoing paragraphs have outlined the two principal problems relating to the fuel economy of present day gasoline engines as applied to the passenger automobile. Several potential improvements relating to these problems were the subject of study and evaluation under this program as follows:

1. Optimum loading of engine for best BSFC under all operating conditions through improved transmission and power control system.
2. Operation with lean mixtures by means of lean carburetion or electronic fuel injection techniques.
3. The use of an unthrottled stratified charge engine which delivers good part-load fuel economy.
4. A lightweight, low-cost diesel engine capable of providing good part-load fuel economy.
5. Improved engine BSFC at light load by use of smaller engine with supercharging to achieve maximum power required for acceleration.

3.3 OPTIMUM ENGINE LOADING THROUGH IMPROVED ENGINE/TRANSMISSION MATCHING

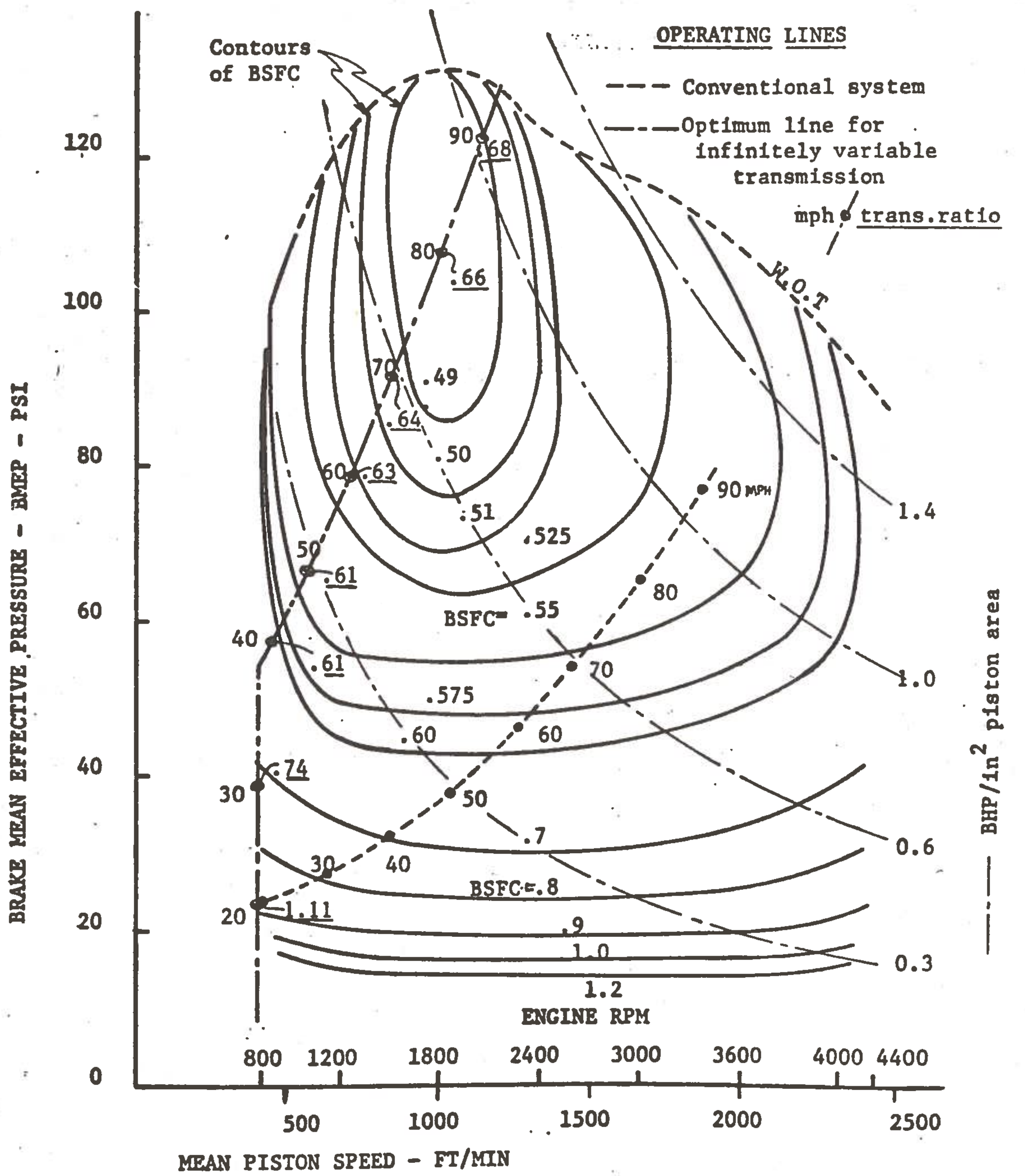
A substantial improvement in fuel economy could be achieved if a transmission were available which provided a better selection of engine operating point under all vehicle operating conditions. Figure 4 shows a typical engine performance map with BSFC contours. Note that the best BSFC values occur near full throttle at somewhat less than half rated engine speed. A typical operating line for vehicle steady-speed level road load conditions is shown. It does not pass through the region of maximum efficiency due to the requirement of a sufficient acceleration allowance by means of throttle opening alone (no transmission gear changes).

For best vehicle operating economy, it is clear that the operating line should pass through the region of lowest BSFC. Such an "optimum operating line" is illustrated in Figure 4. As output power is increased from idle, the engine speed remains constant at some minimum value while the air throttle opening is increased. When the power level reaches that corresponding to the minimum SFC contour, then engine speed is increased along with throttle opening in such a manner as to traverse the center of the minimum BSFC island as shown in Figure 4 until the full throttle condition is reached. Thereafter, the engine speed alone is increased to the maximum value thereby yielding maximum horsepower. In order to achieve this optimum operating line in practice it is necessary to have a continuously variable ratio transmission and suitable control system so that the most desirable engine speed can always be selected independent of the vehicle road speed. The speed ratios R (transmission input speed ÷ output speed) required to traverse this ideal operating line are designated at various points along the line. For the engine and vehicle system illustrated, the required speed ratios range from 0.61 to 1.11. If this ratio range is excessive for a practical transmission the operating line can be modified slightly to reduce the speed ratio but still pass through the most favorable BSFC region.

The two principal types of continuously variable transmissions are the traction type and hydraulic (hydrostatic or hydromechanical). This entire subject is discussed in greater detail in the ADL report. However, one development activity in traction type continuously variable transmissions was the subject of a field trip and resulted in the acquisition of performance

FIGURE 4

PERFORMANCE MAP - TYPICAL GASOLINE ENGINE - 300 IN^3 V-8



data that was used in the computer simulation studies. That development is discussed briefly below.

Tracor, Inc., Austin, Texas, is engaged in the development of a dual cavity toroidal type traction transmission which is suitable for automotive use. Their unit is described by J. Kraus (28) and C. Kraus (30), and in the field trip report on Tracor contained in Appendix E. The general findings are summarized below.

The Tracor traction transmission (CVT) is in an advanced state of development. Significant advances in durability, efficiency and response seem to have been made over the G.M. torroidal drive and other similar units. The Tracor double cavity unit is capable of operation over a ratio range of 9:1 with extremely fast ratio change response (full ratio range change in 8-10 revolutions). It is claimed to have a very good efficiency characteristic as shown in Figure 5 (exceeds 90% over most of the operating range). Tracor claims a size, weight, and cost equal to or less than conventional 3-speed automatics. Besides allowing engine operation at higher BSFC values, the CVT can provide improved vehicle acceleration performance by smoothly and rapidly increasing engine speed during acceleration manuevers. This permits using an engine of smaller displacement and realizing further benefits in fuel economy. Kraus (28) claims that this transmission provides 25-30% increase in MPG and about 30-50% better acceleration compared with the same car equipped with equal engine HP and a 4-speed manual transmission. When the traction transmission car is compared to a standard car with higher engine power to provide equal acceleration performance, the fuel economy of the traction transmission car is about 60% greater than the reference car (for both urban driving and 60 MPH highway driving).

Problem Areas

Opposing these substantial benefits are the following problem areas associated with the CVT.

1. Improvements in BSFC are obtained by operating the engine at higher load factor (greater BMEP) thereby increasing the durability requirements. The engine to be used with a CVT will therefore require a complete redesign and development with larger and heavier structure to provide the needed durability at the higher average BMEP values. Additional cost and weight could become prohibitive.

2. Good acceleration performance would be attained by allowing high engine speeds during WOT accelerations. This will result in a substantial increase in engine noise level during accelerations. There is some question whether the added noise level will be acceptable to the customer as the price for improved fuel economy.
3. The CVT transmission will be constantly changing ratio in response to changing driving conditions. Therefore, wear and durability of the transmission mechanism poses a potential problem whose solution has not yet been demonstrated.

Despite these problem areas, the large potential benefit in reduced fuel consumption makes it attractive to pursue the development and possible future introduction of this type transmission. The computer simulation work to investigate the benefits of the CVT is described in Section 4.4. To simplify the evaluation it was based on an assumed 90% transmission efficiency over the entire operating range based on the information from Figure 5. Computer simulation results agree reasonably well with those claimed by Kraus (28).

A four speed automatic transmission with torque converter lock-up was also the subject of study during this program. This type transmission has already been produced and marketed by Borg-Warner Corporation and was used by Studebaker during the 1950's. This type transmission is discussed further in Section 4.1.4 where the computer simulation work is described.

TRACOR TRACTION DRIVE PROPOSED HI-EFFICIENCY AUTO DRIVE COMPUTED EFFICIENCY DATA

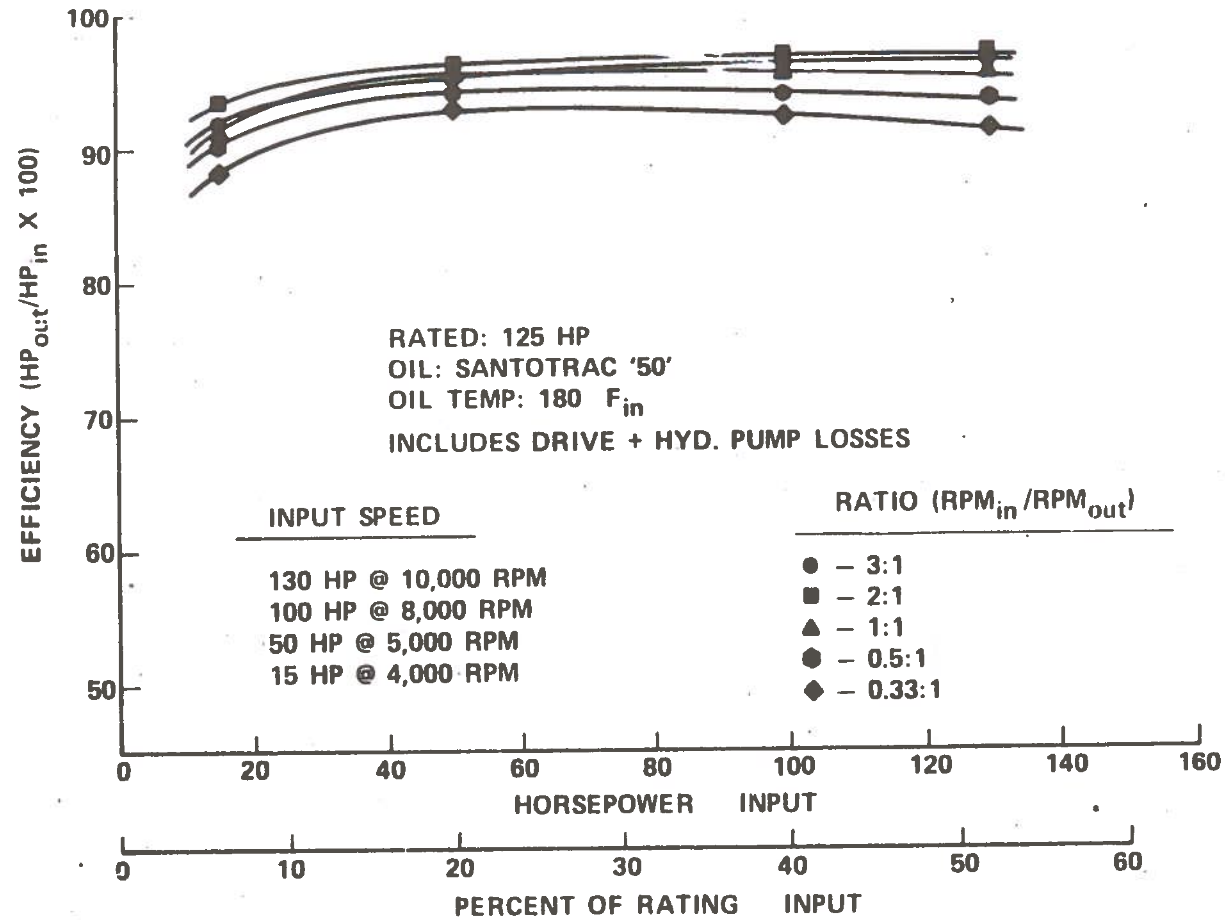


FIG. 5 TYPICAL EFFICIENCY CURVE

4.0 RESULTS OF COMPUTER SIMULATION WORK

During the course of this program a total of 195 computer simulation runs were made to study the effect of a variety of component changes, both singly and in combinations, on four different reference vehicles. These computer runs were made with an orderly set of changes in various input parameters in order to generate the computer data necessary to conduct the studies and reach the conclusions presented in the following paragraphs. A wealth of information is contained in the output data from all of these computer runs and the reader may wish to examine these results in detail and draw his own conclusions regarding the effects of certain design changes. To facilitate this sort of activity, all of the computer output summary sheets for the 195 runs are reproduced in Appendix B where they are arranged in numerical order. An index to these sheets is provided at the beginning of Appendix B. The index sheets are segregated according to reference vehicle as follows:

Index Sheet No.	Reference Vehicle	Simulation Run Nos.
1	Company Y-Compact	302 - 385
2	Company Y-Standard without A/C operating	401 - 535
3	Company Y-Standard with A/C operating	451 - 585
4	Company X-Compact	601 - 632
5	Company X-Standard without A/C operating	701 - 735
6	Company X-Standard with A/C operating	801 - 835

Each run is identified on the index sheet by listing the values of the principal input parameters such as test weight, frontal area, drag coefficient, tire rolling resistance coeffs, axle ratio, accessory load, engine description, transmission description and comments. Thus, by carefully examining these six index sheets the reader will quickly obtain the full scope of input parameter changes studied by computer simulation during the course of this project.

The orderly changes in input parameters were selected to permit an organized examination of the following factors to identify those changes which will lead to an improved vehicle having a 30% reduction in fuel consumption.

1. Reference Vehicles - must be characterized to provide a baseline to evaluate fuel economy improvements. (SS-1 to SS-4)*

2. Single Parameter Changes - in vehicle weight, aerodynamic drag, axle ratio, tire losses, and accessory loads to determine sensitivity of vehicle fuel economy to changes in each of these parameters individually. This study establishes the incentive for making each of these individual changes. (SS-5 thru SS-10)*.

3. Cumulative Changes in vehicle area, drag coefficient, weight, tire losses, axle ratio, and accessory power to determine the combined effect of changing several design parameters simultaneously since the cumulative effect is not necessarily equal to the sum of the individual single parameter effects (SS-11 thru SS-16)*.

4. Transmission Changes to examine the effect of transmission losses on vehicle fuel economy and determine the gains available by incorporating transmissions which a) allow the engine to operate in a more efficient region of the engine performance map and b) have lower transmission power losses (SS-17 thru SS-21).

5. Engine Changes to determine the possible economy improvements from innovations such as lean burning SI engine, reduced engine displacement with power boost, stratified charge engine, or from a diesel engine. (SS-22 thru SS-30).

The above topics are each treated fully under the corresponding headings below. In each case the component changes are first examined individually to access their effect on improving fuel economy of the reference vehicle and then they are examined in combination with the vehicle changes treated in the foregoing sections to obtain the combined effect of several component changes.

The highlights of the discussion in these sections are contained on summary sheets which identify the purpose of the simulation sequence, computer run numbers, input data, and provide a summary of results with pertinent comments and conclusions. A sample summary sheet is contained on the following page. The remainder of the summary sheets are contained in Appendix A. These sheets are identified by page numbers denoted SS-1 thru SS-30 and those pertaining to each of the above subjects regarding vehicle changes are denoted in parentheses at the end of the identifying description.

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* These numbers refer to the summary sheets SS-1, SS-2 etc. which summarize the computer simulation results for this subject. These sheets are found in Appendix A.

4.1 REFERENCE VEHICLES

Four reference vehicles were employed in the computer simulation study, a compact and standard size car from each of two U.S. manufacturers, designated Company X and Company Y. The salient features of these four reference vehicles are summarized below.

Vehicle Designation	Curb Weight-lb.	Engine	Transmission	Axle Ratio	Accessories
Co X Compact	2851	250 CID-6	3 Sp. Auto.	2.79	P.S.
Co X Standard	4508	400 CID-8	3 Sp. Auto	2.75	P.S.,A/C
Co Y Compact	3377	250 CID-6	2 Sp. Auto	3.08	P.S.
Co Y Standard	4356	350 CID-8	3 Sp. Auto	2.73	P.S., A/C

Input data was obtained from the vehicle manufacturers in sufficient detail to meet the requirements of the simulation program as described in Section 2.2. The manufacturers also supplied fuel economy test data for comparison to the computer simulation results.

Simulation runs were made on these vehicles using the manufacturer's vehicle and component input data. In the case of the standard size vehicles equipped with air conditioning, runs were made with and without the air conditioning equipment operating. Manufacturers' data applied only to the case where the A/C equipment was inoperative. These reference vehicle simulation runs are presented on summary sheets SS-1 thru SS-4 as follows:

Reference Vehicle	Summary Sheet	Simulation Run No(s)
Co X Compact	SS-1	601, 602 *
Co X Standard	SS-2	701, 702*, 801
Co Y Compact	SS-3	302, 306*, 311*
Co Y Standard	SS-4	401, 451

Throughout the computer simulation studies a 500 lb. vehicle payload was assumed i.e. the"test weight" used for the fuel economy calculations was taken as curb weight plus 500 lb. Reference vehicle runs were done on this basis. However,

* Runs made for comparison with manufacturers data at different test weight.

these runs could not always be compared directly with manufacturers data which frequently was based on a different test weight. Therefore, appropriate additional simulation runs were made as denoted by the asterisks in the above tabulation.

Fuel economy results are compared with the manufacturers' test data on the summary sheets with a table showing comparative values of MPG for steady speed driving at 20, 30, 40, 50, 60 and 70 MPH and over the federal driving cycle, and other city/suburban test cycles as available. Generally good agreement is obtained between simulation results and manufacturer data. The following observations and comments are applicable to this comparison:

1. Engine and accessory component data supplied by company X was for 1972 model year equipment so it is necessary to compare the simulation results to the 1972 vehicle test data. For the X Compact excellent agreement is obtained with the one test data point available at 70 MPH. However, 1973 test data, show a considerable discrepancy at lower vehicle speeds with the simulation predicting values too high. It is not known whether the detrimental effect of EGR on the 1973 engine can account for most of this discrepancy. Excellent agreement is obtained on the Co X standard. Here again, the 1973 vehicle has substantially lower MPG at low speeds.

2. Although the numerical values compare quite favorably, it is not proper to compare the FDC fuel economy figures with the manufacturer's data for his city-suburban cycle since the driving conditions are different from those of the FDC. However, the city/suburban cycle does represent another means of approximating urban type driving and the close agreement of results is nonetheless interesting.

3. The company Y Compact reference vehicle differs from the one for which manufacturers data was available in both weight and axle ratio. Therefore a special run (#311) was made to provide a case directly comparable to the vehicle test data. Comparing run 311 with mfgrs. data shows perfect agreement at 30 MPH but the simulation is 13% low at 70 MPH. The drag coefficient of 0.568 supplied by Co Y for this vehicle seemed unusually high since drag coeffs for all other reference vehicles were in the range of 0.47-0.50. As a matter of interest a case

was run (#306) with a drag coeff of 0.5 and the 2.73 axle to compare with manufacturer's test data. This comparison shows considerably better agreement, ranging from 1% high @ 30 MPH to 5% low at 70 MPH.

4. The Company Y standard vehicle comparison with test data shows results similar to those from the Y Compact ranging from 2% below test data @ 30 MPH to 8% below test data @ 70 MPH. No fuel economy figures were obtained from Company Y for the FDC or their city-suburban test cycle.

5. It is interesting to note that whereas the Company X vehicle test data was always below the values obtained by computer simulation the trend with Company Y vehicles was the opposite. This suggests that there is no obvious evidence that the computer model is consistently in error due to the oversight of some important element in the model.

4.2. SINGLE PARAMETER CHANGES IN WEIGHT, DRAG, ROLLING RESISTANCE AXLE RATIO AND ACCESSORY LOADS

Small fuel economy gains are readily available by means of improvements in vehicle design to reduce weight, aerodynamic drag, rolling resistance and accessory loads. If improvements of this type are made and the same engine is retained, the acceleration performance will be improved. Lowering the axle ratio is one means of bringing the acceleration performance back to the original level and realizing a further improvement in fuel economy. An alternate method of reducing performance back to the original level would be to reduce engine displacement. This possibility is treated in Section 4.5.

The effects on reference vehicle fuel economy of single parameter changes* in vehicle weight, frontal area, drag coefficient, tire rolling resistance, axle ratio, and reduced accessory power were investigated by computer simulation for all four reference vehicles. Detailed listing of the input parameter changes used for each run and summaries of results are contained in summary sheets SS-5 through SS-10 as follows:

VEHICLE	SUMMARY SHEET
Co X Compact	SS-5
Co X Standard - A/C not operating	SS-6
Co X Standard - A/C operating	SS-7
Co Y Compact	SS-8
Co Y Standard - A/C not operating	SS-9
Co Y Standard - A/C Operating	SS-10

The nominal changes in the various parameters studied in this sequence are:

Test Weight - 10% reduction from reference vehicle
Frontal Area - 10% reduction from ref. vehicle.
Drag Coeff - 10% red. from ref. veh. - combined with 10% area reduction
Radial Ply tires - approx. 15% reduction in rolling resistance
Axle Ratio - 9% reduction from ref. vehicle

Some early parametric studies on effect of changes in weight (runs 302, 303, 304, 451, 458, 479) and aerodynamic drag, (runs 302, 305, 319, 451, 452, 453) with the Co Y compact and standard cars revealed

* The term "single parameter changes" is used here to describe the procedure of changing only one parameter on the reference vehicle to observe the effect of that change in MPG.

that the sensitivity coefficients for these single parameter changes ($\Delta MPG/\Delta W_t$ or $\Delta MPG/\Delta DRAG$) are essentially independent of the magnitude of the change in weight or drag within the range of interest (5-20% changes). Simultaneously, studies conducted at Arthur D. Little indicated that it was reasonable to expect to achieve reductions in weight, frontal area and drag coefficient of approximately 10% from the 1973 reference cars. For these reasons a 10% reduction in those three parameters was used on all reference vehicles as a basis of examining the effect of weight, area and drag reductions. The 9% axle ratio reduction represents a commonly available step reduction within the available axle ratio options.

The results from these studies of single parameter changes are summarized in tables 4-1 through 4-6 which show fuel economy in MPG over the FDC and at steady speeds of 20, 30, 40, 50, 60, and 70 MPH. Also shown to the right side of each table are a matrix of numbers listing the percent increase in MPG over the reference vehicle case for the same vehicle operating conditions. The results for all reference vehicles are brought together and compared in Table 4-7 where they are also evaluated against the results of similar studies reported in the technical literature by the various automobile manufacturers (refs. 17, 18 & 26). Table 4-7 shows percent improvement in MPG over the reference vehicle for the FDC and at 50 MPH and 70 MPH steady speed for 1) 10% weight reduction, 2) 9% axle ratio reduction, 3) combined weight and axle reduction, 4) 10% aerodynamic drag reduction, 5) replacement of bias ply tires with radial ply tires. All six reference vehicles cases yield remarkably similar numerical results for the single parameter sensitivity coefficients expressed in terms of percent improvement in MPG for a 10% change in the given parameter.

Weight Reduction

A 10% weight reduction gives a 3 1/2-4% increase in MPG over the FDC but only 2-2 1/2% increase in MPG at 50 and 70 MPH. Simulation results agree well with the industry findings as reported by Huebner (26) Lapointe (17) and Marks (18). The effect of weight reduction is well established by industry experience and this excellent agreement of simulation results is cited as a good demonstration of the validity of the simulation for predicting the effect of changes in vehicle design variables.

Axle Ratio Reduction

Simulation results indicate that a 9% reduction in axle ratio gives a 1/2-1 1/2% improvement in MPG over the FDC, a 4-5% improvement at 50 MPH and a 3 1/2-4 1/2% improvement at 70 MPH. These results agree well with those of Huebner (26) but are somewhat less than those reported by LaPointe (17) and Marks (18) for the FDC (or more appropriately the Ford and GM urban driving cycles). The effect of axle ratio reduction is not constant but rather depends on the magnitude of axle ratio as shown by Marks (18). This may explain the somewhat wider scatter of results for effect of axle ratio on FDC mileage.

Combined Weight and Axle Ratio Reduction

A few simulation runs were performed on the Co Y cars to show the combined effects of a 10% weight reduction and 9% axle ratio reduction for comparison with similar figures from LaPointe (17) (simulation runs 302, 312, 453, 483). Examination of the results shown in Table 4-7 reveals that about 6% increase in MPG is obtained over the entire range of operating conditions (i.e. FDC, 50 MPH and 70 MPH) and good agreement is obtained with results from LaPointe (17).

Aerodynamic Drag

The reduction of aerodynamic drag through a combination of reducing vehicle frontal area and drag coefficient has very little effect on low speed mileage but can be quite important at interstate highway cruise speeds. Simulation results for all six reference vehicles cases are in good agreement and predict about 0.5-1.0% increase in MPG over the FDC for a 10% drag reduction whereas this increases to about 2.4% improvement at 50 MPH and about 4% at 70 MPH. Results presented by Huebner et al (26) are in close agreement with these simulation figures.

Radial Tires

Tire resistance is the major factor contributing to vehicle rolling resistance (force required to move vehicle in the absence of aerodynamic drag and vehicle inertia). The simulation model used a formula of the following form to describe the rolling resistance.

$$F_{RR} = C_1 W + C_2 W V$$

where F_{RR} = rolling resistance - lb.

W = vehicle weight - lb.

V = vehicle velocity - MPH

and C_1 and C_2 are coefficients selected to describe the behavior of the vehicle with a specific type and size tire. In addition to this rolling resistance formula (based on vehicle towing tests) a tire efficiency (η_T) was included as a multiplier of final drive train HP to account for additional tire deflection losses under a torque load.

The question of how to reduce tire losses was examined in detail during this study by Arthur D. Little, Inc. and they made recommendations for use in the computer simulation. The ADL studies indicated that radial ply tires can provide a lower rolling resistance than the bias ply tires used as standard equipment on all of the 1973 reference vehicles. The effect of radial tires was incorporated into the computer simulation runs by decreasing the above tire loss coefficients as follows:

Reference vehicle	Tire Loss coefficients (Radial Tires) C_1	C_2	$(1-\eta)$
Co X Compact	-13.3%	-16.6%	η_T = 100%
Co X Standard	-13.3%	-16.6%	"
Co Y Compact	-13.3%	-16.6%	-16.6%
Co Y Standard	-13.3%	-16.6%	-15 %

This model for radial tires provides about 15% reduction in rolling resistance under all driving conditions. Computer simulation runs (Table 4-7) show about 2% increase in MPG over the FDC and about 3-4% improvement at 50 and 70 MPH. These results compare well with figures reported by Huebner et al (26) for a 10% reduction in rolling resistance which is nearly equal to what they claim is the advantage of a steel belted radial tire over a bias-ply non-belted polyester cord tire. The ADL studies of radial tire improvements suggest that, while they provide a definite improvement in MPG at low vehicle speeds, no advantage is obtained over bias ply tires at very high speeds. Thus, the above model used for computer simulation may not be representative of radial tire performance at high speeds.

<u>Accessory Power Reduction</u>

Only limited computer simulation studies were conducted on the effect of reduced accessory power requirements. All reference vehicles (and/or synthesized vehicles) were run with a case where all accessories except the radiator (e.g. alternator power steering pump and air conditioning compressor) were operated at constant horsepower over the entire engine RPM range. This case simulates the effect of a constant speed accessory drive for these accessories. Although it would be possible to realize some further improvement from an alternate form of radiator fan drive such as a thermostatic viscous clutch, flex fan, electric clutch, etc., that case was not considered in the simulation. Results of the constant horsepower accessory load cases are summarized in Table 4-1 thru 4-6 for both single parameter changes and cumulative changes in several vehicle design parameters. Fair agreement is obtained among the six reference vehicle cases studied although it is not as good as obtained for the changes in the other design parameters discussed above. From a careful examination of these results the following conclusions may be drawn:

1. Only 1-2% improvement in MPG is obtained over the FDC and at low vehicle speeds (20-30 MPH).

2. Approximately 2-5% increase in MPG is obtained at the higher vehicle speeds (40-70 MPH).

3. A greater percentage improvement in MPG is obtained when the air conditioning is operating due to the significant waste of A/C compressor power at high engine speeds with the conventional drive scheme.

Although the conventional automotive accessory drive arrangement is extremely wasteful of power at high engine speeds, the relatively low engine speeds involved in urban driving and moderate speed highway cruise result in only a small improvement in vehicle fuel economy under normal use conditions. Nevertheless, this improvement may be worth seeking since it is comparable in magnitude with the effects of some of the other vehicle changes explored above.

4.3 CUMULATIVE CHANGES IN VEHICLE AREA, DRAG COEFF., WEIGHT, TIRE LOSSES, AXLE RATIO AND ACCESSORY POWER

In the previous section it was seen that individual changes in certain vehicle design parameters would each yield a small improvement in fuel economy. While none of these changes came close to producing the desired 30% reduction in fuel consumption, a combination of these vehicle changes would appear to produce a worthwhile improvement in economy. It was recognized that the individual effects of these design parameter changes could not necessarily be added to yield the total fuel economy improvement. Accordingly, computer simulation runs were made where these changes were incorporated, one at a time, in a cumulative fashion to develop the combined effect of all changes incorporated in the vehicle. The sequence followed in that study began with the reference vehicle and incorporated the following sequential changes: 1) 10% reduction in frontal area, 2) 10% reduction in drag coefficient, 3) 10% weight reduction, 4) radial ply tires, 5) 9% lower axle ratio and finally 6) constant HP accessory load. This sequence of changes was applied to all four reference vehicles. Details of run numbers, input data, summaries of results and conclusions are presented on the summary sheets in Appendix A as follows:

Summary Sheet	Summary Table	Reference Vehicle
SS-11	4-1	Co X Compact
SS-12	4-2	Co X Standard without A/C operating
SS-13	4-3	Co X Standard with A/C operating
SS-14	4-4	Co Y Compact
SS-15	4-5	Co Y Standard without A/C operating
SS-16	4-6	Co Y Standard with A/C operating

The results of these studies of cumulative vehicle changes are summarized on the lower portion of Tables 4-1 thru 4-6 (as indicated above) which show for each sequential change the fuel economy in MPG over the federal drive cycle and at steady speeds of 20, 30, 40, 50, 60 and 70 MPH. Also shown to the right side of each table are a matrix of numbers listing the percent increase in MPG over the reference vehicle case for the same vehicle operating conditions.

The sensitivity coefficients for single parameter changes reported in the previous section (Table 4-7) can also be obtained from this sequence of cumulative changes. The results are in very good agreement with those of Table 4-7. Although it was stated at the beginning of this section that the single parameter changes could not necessarily be added to determine the combined effect of making several changes simultaneously, in fact, these changes are approximately additive on a % MPG increase basis as can be seen from Table 4-1 thru 4-6. To facilitate a comparison of the results for all six reference vehicle cases Table 4-8 was constructed to show the percent MPG improvement figures side-by-side for each step in the cumulative sequence of vehicle changes. The following conclusions may be drawn from a careful examination of this table:

1) Results for all reference vehicles are in generally good agreement.

2) The total fuel economy improvement resulting from simultaneous changes in area, drag, weight, tires, and axle ratio averages about 8-9% over the FDC and about 12 to 18% for steady speed driving.

3) The total fuel economy improvement resulting from simultaneous application of the constant accessory HP plus changes in area, drag, weight, tires and axle ratio averages about 12% over the FDC and about 19 to 23% for steady speed driving.

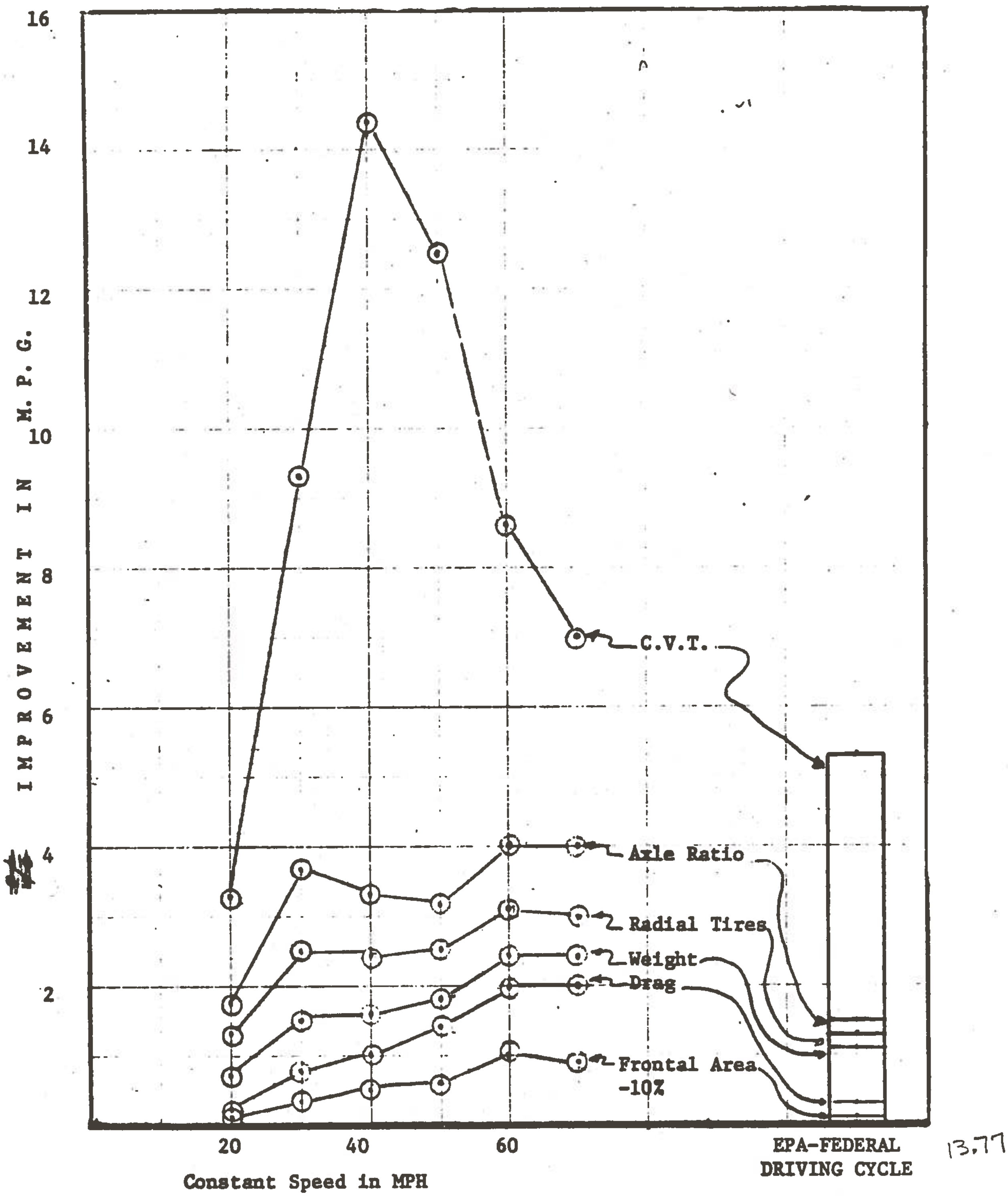
It is also interesting to display the results of this study graphically as improvement in miles per gallon versus vehicle speed in MPH and illustrate how each sequential vehicle change contributes to the total improvement in MPG at each speed. This treatment is shown for the Co Y Standard car in Figure 6. The figures for the FDC fuel economy are shown in bar chart form at the right_side of this graph. These results are typical of all reference vehicles. The following observations may be made from this display:

1. Decreases in frontal area and drag provide significant improvement at high speeds accounting for 1/2 of the total gain, but are not very significant over the FDC or at low speeds.

2. The effect of weight reduction is nearly constant over the entire speed range. It is the most significant factor contributing to improved economy over the FDC.

Figure 6

FUEL ECONOMY OF VEHICLE DESIGN #8--COMPANY "Y" STANDARD



Vehicle Acceleration Performance

One of the constraints of this study is that vehicle acceleration performance must not be sacrificed in order to achieve improved fuel economy. All of the above changes except axle reduction will improve vehicle acceleration while axle ratio reduction deteriorates acceleration performance. Therefore, it is of interest to examine the acceleration performance of the synthesized vehicle incorporating all of the changes relative to that of the reference vehicle. While the computer program is not capable of calculating vehicle acceleration performance, it does print out engine power output and RPM. This information, in combination with an engine map with a wide open throttle (WOT) power curve, can be used to determine the incremental power available for acceleration. The instantaneous acceleration at any given vehicle speed is approximately proportional to the engine power increment divided by vehicle weight as follows:

$$\text{vehicle acceleration} \propto \frac{\text{WOT HP} - \text{R.L. HP}}{\text{weight}}$$

Using this method for approximating vehicle acceleration the performance of the Co X Compact and standard vehicles were examined for several synthesized vehicle cases relative to the reference vehicle. The results of this exercise are summarized in Table 4-9 which lists the percent increase (or decrease) in WOT acceleration performance compared with the reference vehicles (simulation runs 601, 701) at steady speeds of 20, 30, 40, 50, 60 and 70 MPH. Cases are shown for axle ratio reduction only, and for synthesized vehicles with and without axle ratio reduction. A 9% axle ratio reduction causes a decrease in acceleration performance of about 9%. Reducing the vehicle weight, frontal area, drag coefficient, and switching to radial tires (cases 612 and 712) causes an increase in acceleration performance ranging from 10-20%. When axle ratio reduction is added to these changes (cases 613 and 713) the resultant net increase in acceleration performance over the reference vehicle is only about 5% at low speeds and increases to about 10% at higher speeds.

This net increases in performance should be counteracted with either a further reduction in axle ratio or a reduction in engine displacement. Suppose a further 9% reduction in axle ratio is selected. This would bring the net acceleration performance back to a value slightly poorer than the reference vehicle. According to Table 4-7 it would provide another 2-4% increase in fuel economy (MPG).

The cumulative effect of the vehicle changes treated here is not sufficient to achieve the program goal of 30% reduction in fuel consumption (requires 43% increase in MPG). Even if larger decreases in weight, drag and axle ratio were considered, it is still evident that the 30% goal cannot be met without resort to some other vehicle changes beyond those treated in this section. The transmission and engine will next be examined to see what kind of improvements in fuel mileage are available with changes to those components for incorporation into a synthesized vehicle which includes the changes discussed above.

4.4. TRANSMISSION CHANGES

A substantial improvement in fuel economy could be achieved if a transmission were available which provided a better selection of engine operating point under all vehicle operating conditions. Figure 4, as discussed, shows a typical engine performance map with BSFC contours. Note that the best BSFC values occur near full throttle at somewhat less than half rated engine speed. A typical operating line for vehicle steady-speed level road load conditions is shown. It does not pass through the region of maximum efficiency due to the requirement of a sufficient acceleration allowance by means of throttle opening alone (no transmission gear changes).

For best vehicle operating economy, it is clear that the operating line should pass through the region of lowest BSFC. Such an "optimum operating line" is illustrated in Figure 4 . As output power is increased from idle, the engine speed remains constant at some minimum value while the air throttle opening is increased. When the power level reaches that corresponding to the minimum SFC contour, then engine speed is increased along with throttle opening in such a manner as to traverse the center of the minimum BSFC island as shown in Figure 4 until the full throttle condition is reached. Thereafter, the engine speed alone is increased to the maximum value thereby yielding maximum horsepower. In order to achieve this optimum operating line in practice it is necessary to have a continuously variable ratio transmission and suitable control system so that the most desirable engine speed can always be selected independent of the vehicle road speed. The speed ratios R (transmission input speed ÷ output speed) required to traverse this ideal operating line are designated at various points along the line. For the engine and vehicle system illustrated, the required speed ratios range from 0.61 to 1.11. If this ratio range is excessive for a practical transmission the operating line can be modified slightly to reduce the speed ratio but still pass through the most favorable BSFC region.

4.4.1 CONTINUOUSLY VARIABLE TRANSMISSION

The continuously variable transmission (CVT) is one which offers any desired gear ratio between the upper and lower limits of its ratio range and is capable of changing ratio smoothly in a continuous sweep from one end of its ratio range to the other. The two principal types of continuously variable transmissions are the traction type and hydraulic (hydrostatic or hydromechanical).

An ideal transmission would provide continuously variable, drive ratios, have zero power transmission losses, and would be capable of changing ratios rapidly to provide good vehicle acceleration.

To obtain a measure of the fuel economy gains available from an efficient continuously variable transmission, computer simulation runs were made on all reference vehicles assuming a 90% efficient unit. This assumption was intended to approximate the claimed behavior of the Tracor Traction transmission discussed in Section 3.3 (refs. 28,30) whose transmission efficiency characteristic is shown in Figure 5, as discussed. In the simulation, the transmission ratios were selected to allow the engine to operate at all times at its most efficient point (lowest BSFC) for the instantaneous power level demanded. It was assumed that the transmission could change ratio instantaneously during transient vehicle operation and that its ratio range was infinite. (In actual practice the ratio range is restricted to about 9:1 which requires clutch slippage at very low vehicle speeds).

Results of the computer simulation runs on the CVT cases are summarized in Table 4-1 thru 4-6 and summary sheets SS-17 thru SS-20 as follows:

Vehicle	Table No.	Summary Sheet	Reference Vehicle run	Synthesized Vehicle Run
Co X Compact	4-1	SS-17	608	616, 617
Co X Std. A/C off	4-2	SS-18	708	715
Co X Std. A/C on	4-3	SS-18	808	815
Co Y Compact	4-4	SS-19	351, 352	353
Co Y Std. A/C off	4-5	SS-20	442	443, 444
Co Y Std. A/C on	4-6	SS-20	492	493, 494

These tables show the MPG and percent improvement in MPG over the reference vehicle for the FDC and steady speeds of 20, 30, 40, 50, 60, and 70 MPH. The first CVT run on each table shows the CVT as a single parameter change in the reference vehicle, whereas the CVT runs at the bottom of each table combine the CVT with the other vehicle changes in weight, area, drag, tires to provide a "so-called" synthesized vehicle. Pertinent comments and conclusions for each reference vehicle case are given on the summary sheets SS-17 thru SS-20 found in Appendix A.

In order to illustrate the effect of an "ideal" transmission Case No. 351 was run on the Co Y compact car using a 100% transmission efficiency. This case illustrated the "upper limit" to the fuel economy improvement which could be obtained if such an "ideal" transmission were available. The results (Table 4-4) show an increase of 33% in MPG over the FDC and from 25-50% increase in MPG at steady speeds. This improvement would be nearly sufficient to meet the program goal without any additional vehicle changes. However, when a realistic efficiency is employed, such as the 90% figure used in the computer simulations, substantially less fuel economy improvement is available, (typically 18% over FDC and 20-30% for steady speeds).

The results for all CVT cases on all four reference vehicles are brought together into a common summary in Table 4-10 which shows the percent increase in MPG due to the CVT alone. The left hand portion of the table shows the improvement in MPG for the CVT in the reference vehicles with no other vehicle changes. The right hand portion of the table shows the improvement in MPG due to the CVT when installed in the synthesized vehicle containing the reduced weight, area, drag, and radial tires. However, the percent MPG improvement shown is referenced to the synthesized vehicle with 3 speed automatic transmission so the effect shown is due solely to the addition of the CVT.

Good agreement is obtained between the reference vehicle and synthesized vehicle cases with the exception that the synthesized vehicles seem to benefit somewhat more from the CVT at 50 MPH. On the average the CVT provides about 18% increase in MPG over the FDC and 25-30% increase during steady speed driving. This is a very significant improvement and certainly warrants a closer examination of the problems involved in development of a practical, cost effective CVT system.

When the CVT is combined with the 10% reduction in weight, frontal area, drag, and radial tires the total percent increase in MPG over the reference vehicle is nearly 30% over the FDC and about 30% at 30 MPH, 55% at 50 MPH and 50% at 70 MPH. Therefore, it appears that this combination of CVT with other vehicle changes can meet the goal of 30% reduction in fuel consumption. (43% increase in average MPG). See Figure 6 discussed earlier.

It should be noted that with the CVT there is no benefit to be derived by a constant speed accessory drive since the CVT essentially provides the same function by allowing the engine to operate at nearly constant speed. Computer runs 444 and 494 on the Co Y standard vehicle prove this argument.

4.4.2 FOUR SPEED AUTOMATIC WITH LOCK-UP TORQUE CONVERTER

Although the continuously variable transmission looks very attractive from the viewpoint of potential fuel savings, it is not a full-developed, proven concept and will not be available for mass produced automobiles for several years. It is, therefore, necessary to seek an alternative means of improving the transmission/engine relationship. A four-speed manual transmission or a three-speed with overdrive can provide an improved overall system efficiency by allowing the engine to operate at lower speeds (larger throttle setting) during cruise conditions and provide adequate acceleration power by downshifting to a lower gear to increase engine speed. Because in recent years the automatic transmission has enjoyed overwhelming popularity on American made cars, it is believed that a return to manual transmissions would not prove acceptable to American car buyers. Therefore, a four-speed automatic transmission with lock-up torque converter was chosen as a viable alternative for an improved efficiency power train. This type transmission has already been supplied on production automobiles in the past by Borg-Warner and is known to be a practical alternative.

The choice of four speeds allows the use of a low final drive ratio to reduce engine speed (increase throttle opening) during cruise conditions while allowing a downshift into a 3rd gear ratio which can provide acceptable acceleration performance for passing, merging with freeway traffic, hill climbing, etc. In addition to providing the fourth speed ratio for boosting cruise fuel economy, the fuel consumption can be reduced under urban driving conditions by torque converter lock-up to eliminate the converter slip losses.

To evaluate the potential fuel economy improvement of the 4-speed automatic transmission with T.C. lock-up several computer simulation runs were made on the CoY compact and standard cars using a transmission having the following general characteristics as advised by the transmission study team at ADL.

Gear Ratios (both Compact and Standard)

1st Gear	2.0:1
2nd Gear	1.5:1
3rd Gear	1.0:1
4th Gear	0.8:1

Shift Pattern*	Compact	Standard
1st to 2nd gear	15 MPH	16 MPH
2nd to 3rd gear	22 MPH	24 MPH
3rd to 4th gear	27 MPH	30 MPH

* Shift speeds were assumed to be independent of vehicle acceleration (manifold vacuum) over the range of conditions encountered in the FDC.

The torque converter was assumed to be operative in 1st gear but fully locked-up in 2nd, 3rd and 4th gears. No attempt was made to simulate the operation of the torque converter during shifting followed by the subsequent lock-up. This is believed to have only a small detrimental effect on driving cycle economy. Gear box efficiency of 98% was assumed for 2nd, 3rd and 4th gears. In 1st gear the conventional CoY torque converter, and gearbox losses were used. Front pump and spin losses were retained throughout.

This transmission characteristic was applied to both the reference vehicle cases and the synthesized vehicle cases with about 10% reduction in weight, frontal area, drag coeff, rolling resistance and axle ratio. The CoY standard car was simulated for cases with air conditioning "on" and "off". The results of the computer simulation runs are summarized in Table 4-11 and on summary sheet SS-21 where run numbers and critical input data parameters are listed.

Table 4-11 shows for each simulation run the MPG and the percent improvement in MPG over the reference vehicle for the FDC and for steady speeds of 20, 30, 40, 50, 60 and 70 MPH. Percent improvement figures are listed to show the improvement due to the 4 speed lock-up transmission alone and in combination with the other changes in vehicle wt, drag, etc. comprising the "synthesized vehicle". Certain comments and conclusions regarding these runs are contained on the summary sheet SS-21.

Since one object of the four speed transmission is to improve fuel economy during cruise by lowering engine speed, and this action has a detrimental effect on vehicle acceleration, it is important to assess the effect on acceleration performance to evaluate the overall effect of the transmission change. The WOT acceleration performance was calculated for all cases by the method described in section 4.3* and was normalized with the corresponding acceleration values

* Numbers available from this calculation represent the instantaneous rate of acceleration at any given vehicle speed (level road) by suddenly opening the throttle wide (WOT) without changing engine speed.

of the reference vehicle to obtain a set of "relative acceleration" figures at vehicle speeds of 30, 50 and 70 MPH. These relative accelerations are tabulated at the extreme right hand side of Table 4-11 to provide a measure of the performance capability of each simulation case. To obtain acceptable WOT acceleration with the 4 speed transmission, it should be necessary to downshift into 3rd gear to increase engine speed and power. The numbers in parentheses in the acceleration columns of Table 4-11 denote the relative WOT acceleration results obtained in 3rd gear.

The simulation on the Company Y compact was performed for only a single value of axle ratio whereas several axle ratios were investigated with the CoY standard vehicle. The sequence of runs with varying axle ratio illustrate the trade-off between economy and acceleration performance. By careful examination of the results in Table 4-11 the following conclusions may be drawn:

CONCLUSIONS

1. The improvement due to the 4 speed lock-up transmission is greater for the compact car than for the standard car due mainly to the two speed transmission and high axle ratio employed in the compact reference vehicle.

2. With acceleration performance equal to the reference vehicle (after downshifting into 3rd gear) the 4 speed lock-up transmission alone offers about 8-10% increase in MPG over the FDC and about 10-15% increase in MPG at steady speeds.

3. Allowing the acceleration performance to deteriorate about 10% below the reference vehicle, the MPG improvement becomes 10-12% over the FDC and about 20% for steady speed. Approximately the same increment of improvement is available if the performance is allowed to decrease further to 20% below the reference vehicle.

4. Combining the 4 speed lock-up transmission with the synthesized vehicle, the total improvement in MPG over the reference vehicle becomes 22% over the FDC and 35-40% for steady speeds if acceleration performance is maintained equal to the reference vehicle. Allowing acceleration performance to deteriorate 10% below the reference vehicle the total MPG improvement becomes 28-30% over the FDC and 40-45% for steady driving.

5. It therefore appears that the target of 30% reduction in fuel consumption can just be met by the combination of synthesized vehicle, 4 speed lock-up transmission and axle ratio reduction to yield a 10-15% loss in acceleration performance after downshifting into 3rd gear.

Further studies to optimize the transmission ratios and shift logic might improve upon these results somewhat.

4.5 ENGINE CHANGES

The underlying principles and general qualitative aspects of various engine changes offering reduced fuel consumption are treated in Section 3.2. Five general categories of engine changes were identified as follows:

1. Catalytic muffler with optimized spark timing (both rich and stoichiometric versions)
2. Lean burning spark ignition engines with thermal reactor for emission control
3. Stratified charge spark ignition engine
4. Lightweight automotive diesel engine
5. Smaller conventional spark ignition engine with power boost for acceleration (e.g. by means of a turbocharger)

The literature survey and field trip effort attempted to assess the potential fuel consumption improvement for each of these schemes and to obtain the basic engine performance map data needed for computer simulation. However, engine performance data sufficiently accurate for computer simulation was obtained only for the stratified charge and diesel categories so they are the only ones treated in this section.

4.5.1 STRATIFIED CHARGE ENGINE

The only data obtained on stratified charge engine performance were engine maps for the Texaco L-141 engine developed for TACOM (49, 51) and the Ford 430 CID FCP engine reported by Bishop (53). Neither engine represents the latest developments in stratified charge technology aimed at achieving low exhaust emissions. However, to obtain an approximate assessment of the fuel economy benefit available with unthrottled stratified charge, the 430 CID Ford FCP engine map (53) was used for a simulation run in the Co Y standard reference car.

The performance map for the FCP engine (Figures 35 of ref. 53) shows a minimum BSFC value of 0.39 which is significantly lower than either the standard gasoline engine or the automotive diesel (Figures 7 and 8). This map apparently does not include the effect of a vehicle intake and exhaust system. An approximate correction was made to the FCP performance map based on data available from the Co X standard 400 CID engine for the effect of vehicle exhaust system on WOT performance. Negatative corrections were made to both torque and fuel flow at WOT as a function of speed. (BSFC increased due to these corrections,) For part load operation the corrections were scaled in proportion to fuel flow.

The single stratified charge simulation run (no. 501) on the Co Y reference vehicle is discussed on summary sheet SS-22 (Appendix A) where the results of the run are tabulated and compared with the reference vehicle. These results indicate that the stratified charge engine can offer improvement in vehicle MPG on the order of 20% for urban driving and about 10% for highway driving. At high road speeds or near full load, the stratified charge engine economy becomes equal to that of a conventional engine.

Ford vehicle test data for steady speed driving reported in ref (53) is shown on summary sheet SS-22 for comparison with the computer simulation results. The Ford data show about 30% increase in MPG at all speeds from 30-70 MPH. The larger economy improvement at higher speeds shown by the Ford data is undoubtedly due to the fact that their comparison was with a conventional engine of equal displacement whereas the FCP simulation run was compared with a 350 CID engine (a 23% decrease in displacement). It is believed that the actual economy gain available from an emission controlled stratified charge engine will be somewhere between the simulation results and the Ford test data, say about 25% for urban driving and 15-20% for highway cruise.

4.5.2 DIESEL ENGINE

The diesel engine offers excellent fuel economy as a result of its high compression ratio (17-22) and ability to burn lean fuel/air mixtures. Moreover, it operates with an unthrottled air supply, achieving part load operation by means of very lean air/fuel ratios thereby avoiding the severe losses caused by throttling in the gasoline engine. Most industrial diesel engines such as those used in trucks, tractors, earthmoving equipment, etc. are considerably larger and more costly than automotive gasoline engines but they are capable of delivering brake specific fuel consumption (BSFC) values of 0.35-0.4 lb fuel/BHP-HR compared with best BSFC=0.5 for the automotive gasoline engine.

A good portion of the increased size, weight and cost of U.S. truck diesel engines is a result of design for the higher load factor and greater durability required in truck service. The only automotive diesel engines in production today come from Europe and Japan where they have been in limited service for a number of years.

Ricardo Consulting Engineers, Ltd., Sussex, England, (combustion engine development engineers with extensive experience in automotive diesel engine development) were engaged to make an assessment of the prospects for diesel engines for American automobiles corresponding to the compact and standard vehicle sizes investigated herein. Their detailed findings are presented in the ADL report.

One specific task undertaken by Ricardo was to provide estimated diesel engine sizes and performance maps for the compact and standard size vehicles for use in the computer simulation of fuel economy behavior. It was desired to choose diesel engine sizes that would be capable of providing acceleration performance competitive with that of the reference vehicles. Recognizing that even the high speed automotive diesel engines are somewhat larger and heavier than an automotive gasoline engine of equal horsepower, and desiring to avoid selecting excessively large engines, the horsepower specifications were selected to be appropriate for the synthesized vehicles after a 10% reduction in vehicle weight, frontal area, drag, and rolling resistance. Accordingly, the following horsepower specs were selected:

Automotive Diesel Power Specs

Compact Car -	100 HP @ 3600 RPM	6 cyl
Standard Car -	150 HP @ 4000 RPM	V-8

Figures 7 and 8 illustrate the estimated fuel consumption maps supplied by Ricardo for 237 CID 6 cylinder and 326 CID V-8 diesels to meet these two respective specifications. Both engines are based on use of the Ricardo Comet Vb indirect injection combustion system which is used in most European automotive diesels. An 80 lb. weight increase is projected for each of those engines over their gasoline engine counterparts.

These engine maps were input into the computer simulation and used to predict fuel consumption characteristics of both company X and company Y compact and standard cars. Simulation runs were made using both the original reference vehicles and also the "synthesized vehicles" which incorporate approximately 10% reduction in vehicle weight, frontal area, drag coefficient, and rolling resistance (radial tires). Various transmissions and axle ratios were employed as described below. Details of simulation run numbers, input data, summaries of results, comments and conclusions are presented on the summary sheets in Appendix A as follows:

Reference Vehicle	Summary Sheet	Summary Table
CoX Compact	SS-23	4-12
CoX Standard-A/C off	SS-25	4-13
CoX Standard-A/C on	SS-25	4-14
CoY Compact	SS-27	4-15
CoY Standard-A/C off	SS-29	4-16
CoY Standard-A/C on	SS-29	4-17
Synthesized Vehicle		
CoX Compact	SS-24	4-12
CoX Standard-A/C off	SS-26	4-13
CoX Standard-A/C on	SS-26	4-14
CoY Compact	SS-28	4-15
CoY Standard-A/C off	SS-30	4-16
CoY Standard-A/C on	SS-30	4-17

First the simulations were run with the conventional reference vehicle transmission (2 or 3 speed automatic with torque converter). Then, to assess the effects of improved transmissions, the runs were repeated with a 4 speed automatic transmission with lock-up torque converter (assumed locked-up in 2nd, 3rd and 4th gears) and finally with a 90% efficient continuously variable transmission. Axle ratio was varied in two or three steps for each case in order to study its effect on fuel economy and vehicle acceleration. A more detailed

A STUDY OF TECHNOLOGICAL IMPROVEMENT IN AUTOMOTIVE FUEL ECONOMY

Dwg. No. D 24604

Date 7. 11. 73

-56- ESTIMATED PERFORMANCE OF 100 HP 6 CYL INLINE DIESEL ENGINE FOR COMPACT CAR - FUEL CONS MAP

BORE DIA 3.5 IN	RICARDO COMET V6 CHAMBER
STROKE 4.1 IN	COMP. RATIO 20.5:1
CID 237	RATED SPEED 3600 RPM.

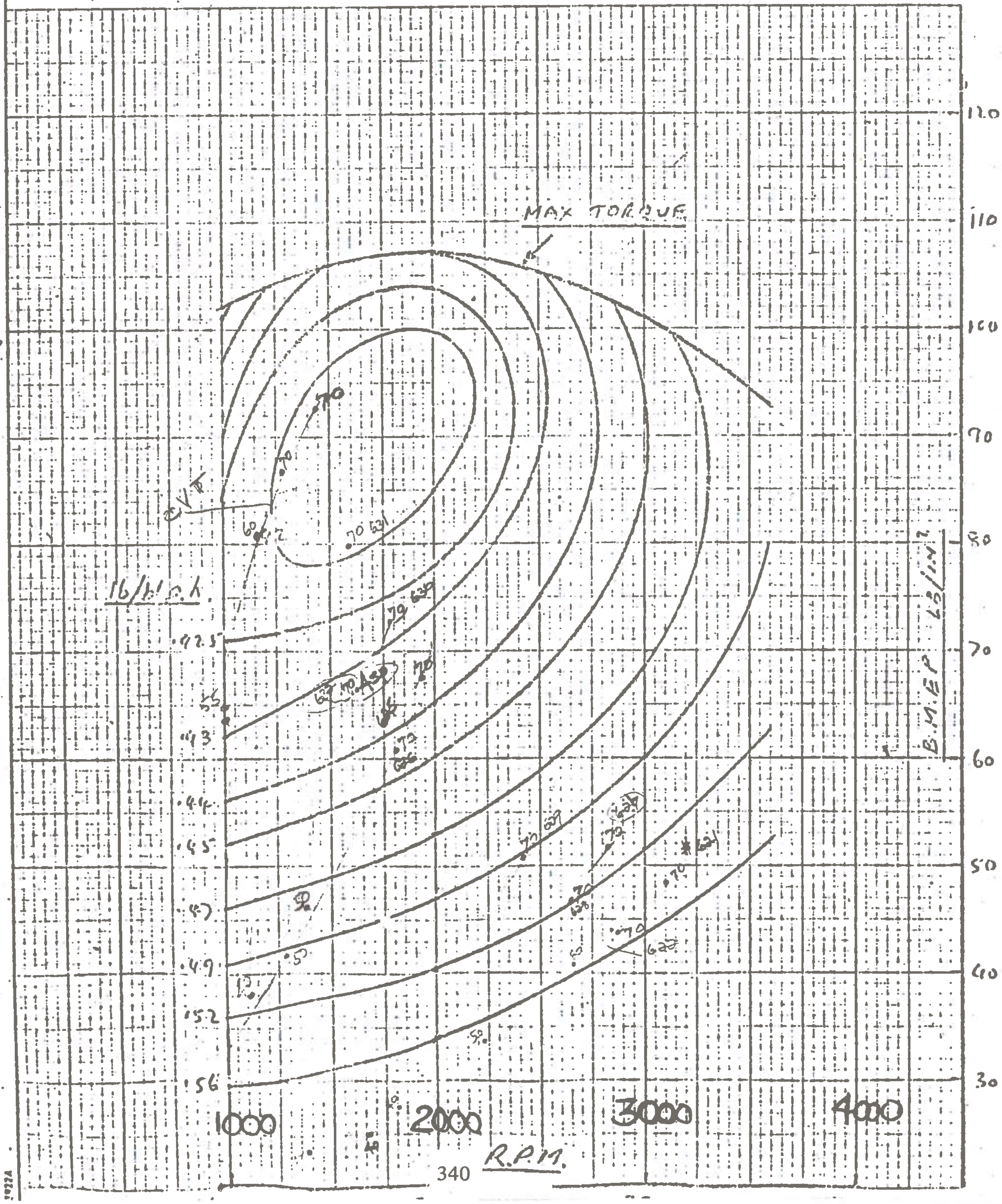


FIGURE 7

-57-

A STUDY OF TECHNOLOGICAL IMPROVEMENT IN AUTOMOTIVE FUEL ECONOMY

Date 7. 11. 73

ESTIMATED PERFORMANCE OF 150 HP V.8 DIESEL ENGINE FOR STANDARD CAR - FUEL CONS. MAP.

BORE DIA	3.8 IN	RICARDO COMET V6 CHAMBER	
STROKE	3.55 IN.	COMP RATIO	20.5 : 1
C.I.D.	326	RATED SPEED	4000 RPM

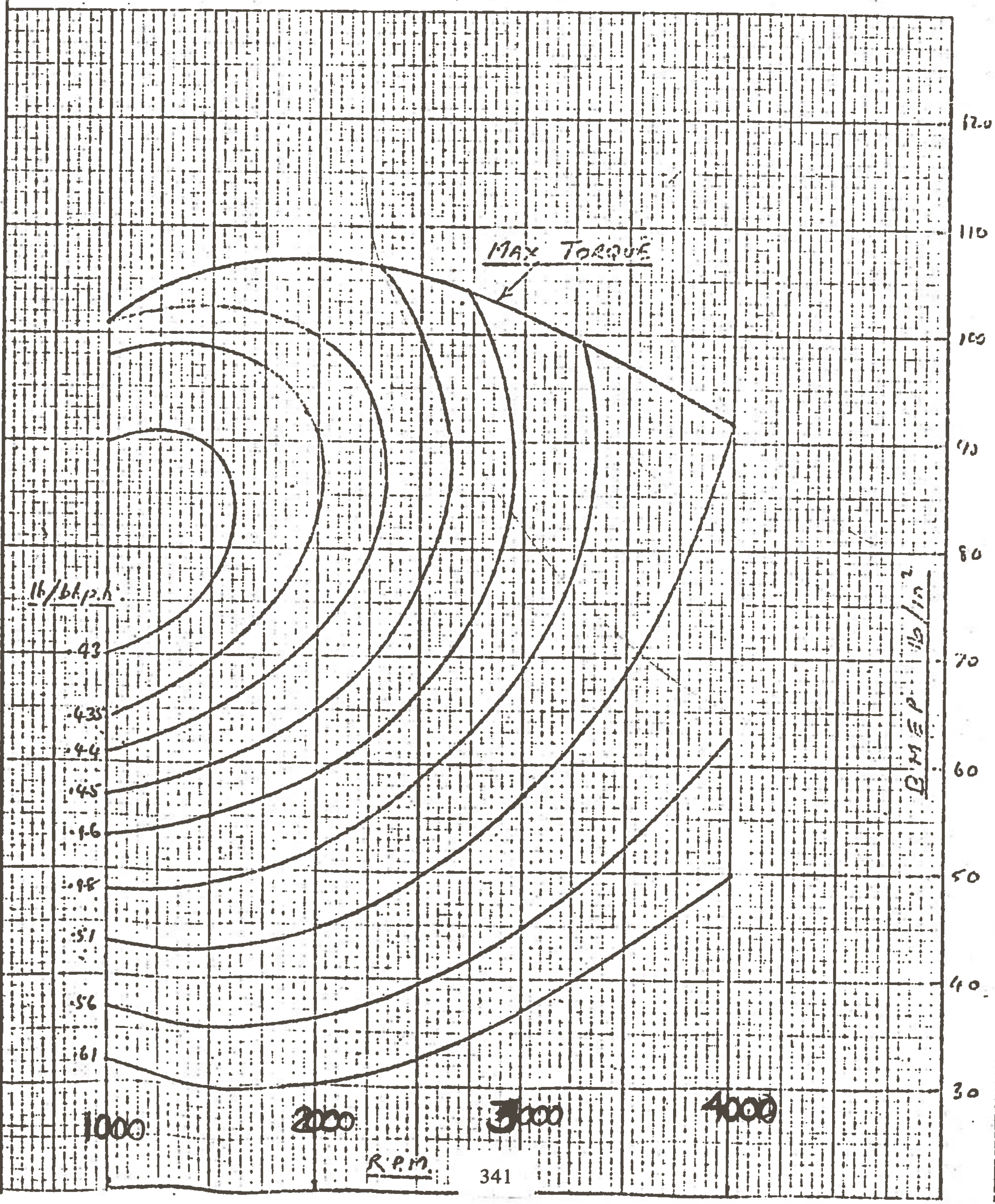


FIGURE 8

listing of input variables for these cases is found on the summary sheets referred to above (see Appendix A).

The results of these studies for diesel powered vehicles are summarized in Tables 4-12 through 4-17 in accordance with the above tabulation. Each table treats one reference vehicle case and summarizes results for both reference vehicle and synthesized vehicle cases with the various transmission and axle ratio options. These tables show for each case, the fuel economy in MPG for the Federal Drive Cycle and for steady speed level road driving at 20, 30, 40, 50, 60, and 70 MPH. On the right side of each table is shown a matrix of numbers listing the percent increase in MPG over the reference vehicle case for the same vehicle operating conditions.

Since the various transmission and axle ratio options increase fuel mileage at the expense of performance, the WOT acceleration performance was calculated for all cases (except those with air conditioning "on") by the method described in Section 4.3 and was normalized with the corresponding acceleration values of the reference vehicle to obtain a set of "relative acceleration" figures at vehicle speeds of 30, 50, and 70 miles per hour. These relative accelerations are tabulated at the extreme right hand side of Tables 4-12, 4-13, 4-15, and 4-16 to provide a measure of the performance capability of each simulation case. This performance information is essential to a proper interpretation of the fuel economy improvement results. Numbers available from this calculation represent the instantaneous rate of acceleration at any given vehicle speed (level road) by suddenly opening the throttle wide (WOT) without changing engine speed.

Both the four speed transmission with overdrive gear and the continuously variable transmission (CVT) increase fuel mileage during cruise by allowing the engine to run at a lower RPM (larger throttle opening) which severely degrades the "direct gear" acceleration performance as calculated by the above method. To obtain acceptable acceleration with the 4 speed and CVT it is necessary to downshift to a higher gear ratio (increases engine speed). The 4 speed lock-up transmission cases were allowed to downshift into 3rd gear to provide the acceleration performance shown by the numbers in parentheses in Tables 4-12 thru 4-16. Similar calculations for the CVT were not feasible due to the continuous ratio change available. However, by allowing the engine speed to rise to its maximum value during an acceleration, the CVT can provide better acceleration performance than any other transmission listed.

A great deal of information is contained in Tables 4-12 through 4-17 on the effect of diesel engines on automotive fuel economy. Several comments and conclusions derived from an analysis of this information are listed on the summary sheets SS-23 thru SS-30. Some of the principal comments follow:

COMMENTS REGARDING DIESEL SIMULATIONS

1. Two different four speed automatic transmissions with lock-up torque converters were studied; #1 having a first gear ratio of 2.5:1 and #2 having a first gear ratio of 3.2:1. The transmission #2 gave FDC fuel mileage results slightly lower than the reference vehicle transmission due principally to the higher average engine speeds caused by higher ratios in gears 1 and 2. Primary attention should be focused on the results from transmission #1. A different choice of shift logic also might improve these results somewhat.

2. Improvements in fuel economy due to the diesel engine are generally lower with the CoX compact car than with the other reference vehicles due principally to the relatively efficient gasoline engine installation of this reference vehicle. This can be seen by comparing the MPG figures with those of the other reference vehicles.

3. The CoX standard reference vehicle is equipped with a larger engine than the CoY standard and has a 14% higher power to weight ratio than any of the other reference vehicles. As a result its acceleration performance is about 15% above the other reference vehicles. This must be taken into account when examining the performance of the 326 CID diesel in this car by increasing the "relative acceleration" figures by about 15%.

4. The CoY compact car shows a generally greater improvement due to the diesel engine installation than for the other reference vehicles. This is due to the higher axle ratio employed in this reference vehicle to compensate for its low power to weight ratio. This inefficieint gasoline engine installation is illustrated by the low MPG figures in comparison with the other reference vehicles.

CONCLUSIONS

Conclusions regarding the results for each reference vehicle are listed on the summary sheets in Appendix A as outlined above. Relatively good agreement is obtained among the corresponding cases for the different reference vehicles after the effects listed in the above comments are taken into account. Therefore, from the composite results of all the diesel engine simulation runs, the following general conclusions may be drawn:

1. The diesel engine offers a substantial improvement in MPG under light load operating conditions. The improvement is much less at high vehicle speeds unless acceleration performance is sacrificed or a downshifting type transmission is employed.

2. At equal acceleration performance the diesel engine alone offers an average of 30% increase in MPG over the Federal Drive Cycle (FDC). For steady speed driving the improvement in MPG averages about 15-20% at 40 MPH and drops to 5-10% at 70 MPH.

3. By degrading acceleration performance about 10% below that of the reference vehicles the MPG increase due to the diesel becomes 33% over the FDC and goes from about 20% improvement at 40 MPH to about 15% improvement at 70 MPH.

4. Combining the diesel engine and a 4 speed automatic transmission with overdrive gear and lock-up torque converter, the MPG increase rises to about 35% over the FDC while the cruise MPG improves dramatically to 50% over the reference vehicle case. The gain in cruise efficiency results from the overdrive ratio which allows engine operation at low RPM except during WOT acceleration where the transmission downshifts to 3rd gear to provide acceleration capability about 15-20% below that of the reference vehicle.

5. Combining the diesel engine with the continuously variable transmission (CVT) boosts MPG improvement to about 50% for both FDC and steady speed driving. This combination makes a very efficient overall power train.

Still greater economy gains are available by combining the diesel engine with the synthesized vehicle consisting of the reference vehicle with approximately 10% reduction in weight, frontal area, drag, rolling resistance, and axle ratio.

6. With acceleration performance equal to the reference vehicle the diesel engine and synthesized vehicle increase MPG by about 45% over the FDC and 35-40% for steady speed driving.

7. By degrading acceleration performance of this combination by about 10-15% the mileage improvement becomes 48% over the FDC and 40-45% for steady speed.

8. Adding a 4 speed lock-up transmission in the synthesized vehicle boosts MPG increase to about 52% over the FDC and to approximately 80% for steady speed driving with about 15% degradation of performance below the reference vehicle.

9. The combination of diesel engine, synthesized vehicle and CVT provides a 60% increase in MPG over the FDC and 70-85% increase for steady speed driving.

These conclusions are brought together into a single summary chart for easy reference in Table 4-18.

TABLE 4-1 X COMPANY - COMPACT VEHICLE SUMMARY

CASE DESCRIPTION	COMP. RUN NO.	FUEL ECONOMY - MPG							% INCREASE IN MPG OVER REF. VEH. CASE 601						
		FED'L DR.CYC	STEADY SPEED - MPH						FED'L DR.CYC	STEADY SPEED - MPH					
			20	30	40	50	60	70		20	30	40	50	60	70
Reference vehicle	601	17.5	24.9	27.9	27.1	23.8	20.7	17.8	-	-	-	-	-	-	-
-320 lb. weight	602	18.2	25.2	28.8	27.6	24.3	21.1	18.1	4.01	1.0	3.2	1.8	2.1	1.9	1.7
-10% area	603	17.6	25.0	28.3	27.5	24.4	21.4	18.5	0.86	0.4	1.4	1.5	2.5	3.4	3.9
-20% aero drag	604	17.7	25.1	28.6	27.9	25.0	22.0	19.2	1.60	0.8	2.5	3.0	5.0	6.3	7.9
Radial tires only	605	17.8	25.4	29.1	27.5	24.2	20.9	17.9	1.83	2.0	4.3	1.5	1.7	1.0	0.6
Lower axle ratio only	606	17.6	25.7	28.6	28.5	25.0	22.0	18.9	0.68	3.2	2.5	5.2	5.0	6.3	6.2
Const. HP access. only	607	18.2	26.0	30.3	28.4	25.1	21.7	18.6	4.35	4.4	8.6	4.8	5.5	4.8	4.5
Ref. veh. w/90% eff. CVT	608	21.1	28.1	39.2	40.1	33.7	28.9	21.5	21.0	12.9	40.5	48.0	41.6	39.6	20.8
Area + drag reduction (1)	-	17.7	25.0	28.5	27.7	24.7	21.7	18.8	1.20	0.4	2.1	2.2	3.8	4.8	5.6
Wt., area, drag reduction (1)	611	18.4	25.3	29.3	28.2	25.1	22.0	19.1	5.21	1.6	5.0	4.0	5.5	6.3	7.3
Wt., area, drag, + radial tires (1)	612	18.7	26.1	30.5	28.6	25.4	22.2	19.2	6.99	4.8	9.3	5.5	6.7	7.2	7.9
Wt., area, drag, tires, + axle red. (1)	613	18.9	26.8	31.7	30.5	27.3	23.8	20.5	8.25	7.6	13.6	12.5	14.7	15.0	15.2
Wt., area, drag, tires, + axle red. (2)	614	19.0	26.8	32.0	30.7	27.7	24.3	21.1	8.71	7.6	14.7	13.3	16.4	17.4	18.5
Wt., area, drag, tires, axle, + const. HP access. (1)	615	19.7	27.3	34.5	32.4	28.7	25.2	21.6	12.7	9.6	23.7	19.6	20.6	21.7	21.3
CVT w/wt., area, drag + tires (1)	616	22.7	28.3	40.3	47.0	39.5	34.5	27.6	30.0	13.6	44.4	73.4	66.0	66.7	55.0
CVT w/wt., area, drag, + tires (2)	617	22.8	28.3	40.4	47.6	40.7	35.6	29.0	30.5	13.6	44.8	75.6	71.0	72.0	62.9

TABLE 4-2

X COMPANY - STANDARD VEHICLE SUMMARY - WITHOUT AIR CONDITIONING OPERATING

CASE DESCRIPTION	COMP RUN NO.	FUEL ECONOMY - MPG							% INCREASE IN MPG OVER REF. VEH. CASE 701						
		FED'L DR.CYC	STEADY SPEED - MPH						FED'L DR.CYC	STEADY SPEED - MPH					
			20	30	40	50	60	70		20	30	40	50	60	70
Reference vehicle	701	11.6	16.1	19.0	19.8	18.6	16.5	14.6	-	-	-	-	-	-	-
-500 lbs. weight only	702	12.0	16.2	19.3	20.1	19.0	16.9	14.8	3.70	0.0	1.6	1.5	2.2	2.4	1.4
-10% frontal area only	703	11.7	16.1	19.1	20.1	19.0	17.0	15.1	0.60	0.0	0.5	1.5	2.2	3.0	3.4
-20% aero drag only	704	11.7	16.1	19.2	20.3	19.4	17.5	15.6	1.12	0.0	1.1	2.5	4.3	6.1	6.8
Radial tires only	705	11.8	16.2	19.4	20.3	19.1	17.0	15.0	1.38	0.6	2.1	2.5	2.7	3.0	2.7
Lower axle ratio only	706	11.6	16.1	19.5	20.3	19.6	17.4	15.2	0.0	0.0	2.6	2.5	5.4	5.5	4.1
Const. HP access. only	707	11.6	15.9	19.0	19.9	18.8	16.8	14.8	0.34	-1.2	0.0	0.5	1.1	1.8	1.4
Ref. veh. w/90% eff. CVT	708	13.0	16.2	22.6	26.2	24.1	21.0	17.2	12.1	0.6	18.9	32.3	29.6	27.3	17.8
Area reduction	703	11.7	16.1	19.1	20.1	19.0	17.0	15.1	0.60	0.0	0.5	1.5	2.2	3.0	3.4
Area + drag coef. reduction	704	11.7	16.1	19.2	20.3	19.4	17.5	15.6	1.12	0.0	1.1	2.5	4.3	6.1	6.8
Weight, area + drag	711	12.2	16.2	19.5	20.6	19.8	17.9	15.9	4.91	0.6	2.6	4.0	6.5	8.5	8.9
Wt., area, drag, rad. tires	712	12.3	16.3	19.9	21.0	20.4	18.4	16.3	6.12	1.2	4.7	6.1	9.7	11.5	11.6
Wt., area, drag, tires, axle red.	713	12.4	-	20.6	22.0	21.6	19.6	17.3	6.55	-	8.4	11.1	16.1	18.8	18.5
Wt., area, drag, tires, axle, + const. HP access.	714	12.4	-	20.5	22.1	21.8	19.9	17.6	6.81	-	8.4	11.6	17.2	20.6	20.5
CVT w/wt., area, drag, tires	715	13.7	16.5	23.3	28.2	28.5	25.0	21.9	18.1	2.5	22.6	42.4	53.2	51.5	50.0

TABLE 4-3 X COMPANY - STANDARD VEHICLE SUMMARY - WITH AIR CONDITIONING

CASE DESCRIPTION	COMP RUN NO.	FUEL ECONOMY - MPG							% INCREASE IN MPG OVER REF. VEH. CASE 801						
		FED'L DR.CYC	STEADY SPEED - MPH						FED'L DR.CYC	STEADY SPEED - MPH					
			20	30	40	50	60	70		20	30	40	50	60	70
Reference vehicle	801	11.2	15.4	18.1	18.5	17.5	15.6	13.9	-	-	-	-	-	-	-
-500 lbs. weight only	802	11.6	15.5	18.4	18.8	17.9	15.9	14.2	3.58	0.6	1.6	1.6	2.3	1.9	2.2
-10% frontal area only	803	11.2	15.4	18.3	18.7	17.9	16.1	14.4	0.44	0.0	1.1	1.1	2.3	3.2	3.6
-20% aero drag only	804	11.3	15.4	18.4	19.0	18.3	16.5	14.8	0.89	0.0	1.6	2.7	4.6	5.8	6.5
Radial tires only	805	11.3	15.6	18.5	19.0	18.0	16.1	14.3	1.25	1.2	2.2	2.7	2.9	3.2	2.9
Lower axle ratio only	806	11.2	15.4	18.5	19.2	18.3	16.3	14.5	0.0	0.0	2.2	3.8	4.6	4.5	4.3
Const. HP access. only	807	11.3	15.2	18.2	18.9	18.1	16.3	14.4	0.80	-1.2	0.6	2.2	3.4	4.5	3.6
CVT (90%) only	808	12.6	15.6	21.7	24.7	22.7	20.0	16.6	12.6	1.2	19.9	33.5	29.7	28.2	19.4
Area reduction	803	11.2	15.4	18.3	18.7	17.9	16.1	14.4	0.44	0.0	1.1	1.1	2.3	3.2	3.6
Area + drag coef. reduction	804	11.3	15.4	18.4	19.0	18.3	16.5	14.8	0.89	0.0	1.6	2.7	4.6	5.8	6.5
Weight, area, drag	811	11.7	15.6	18.6	19.4	18.6	16.8	15.1	4.83	1.2	2.8	4.9	6.3	7.7	8.6
Wt., area, drag, tires	812	11.9	15.8	19.0	19.9	19.1	17.3	15.5	6.08	2.5	5.0	7.6	9.1	10.9	11.5
Wt, area, drag, tires, axle	813	11.9	-	19.7	20.7	20.3	18.4	16.4	6.62	-	8.8	11.9	16.0	17.9	18.0
Wt., area, drag, tires, axle, const. HP access.	814	12.0	-	19.7	21.1	20.8	19.1	17.1	7.33	-	8.8	14.0	18.8	22.4	23.0
CVT with wt., area, drag, tires	815	13.3	16.0	22.6	27.2	26.7	23.8	21.6	18.7	3.9	24.9	47.0	52.6	52.6	55.4

TABLE 4-4 Y COMPANY - COMPACT VEHICLE SUMMARY

CASE DESCRIPTION	COMP RUN NO.	FUEL ECONOMY - MPG FED'L DR.CYC	STEADY SPEED - MPH 20	30	40	50	60	70	% INCREASE OVER REF. VEH. CASE 302' FED'L DR.CYC	STEADY SPEED - MPH 20	30	40	50	60	70
Reference vehicle	302'	13.8	20.1	21.7	20.4	19.4	16.9	13.5	-	-	-	-	-	-	-
-400 lbs. wt. only	304'	14.4	20.6	22.5	21.0	19.9	17.5	13.8	4.6	2.38	3.60	2.84	2.48	3.13	2.38
-10% frontal area only	305'	13.9	20.2	22.1	20.9	20.0	17.9	14.4	0.95	.40	1.75	2.35	3.25	5.85	6.38
-22% aero drag only	319'	14.1	20.3	22.5	21.4	20.8	18.9	15.4	2.2	1.0	3.50	4.95	6.9	11.6	14.3
Radial tires only	321'	14.1	20.8	22.8	21.3	20.1	17.7	14.0	2.7	3.34	4.88	3.96	3.66	4.43	3.70
Lower axle ratio only	336	13.9	20.4	22.2	21.0	19.4	17.2	14.0	0.95	1.70	2.08	2.84	0	1.42	3.35
Constant HP access. only	310'	14.0	20.4	22.3	20.9	19.9	17.5	13.8	1.85	1.74	2.86	2.45	2.27	3.08	2.38
Ref. veh. w/100% eff. CVT	351	18.3	22.4	30.2	31.2	29.0	21.5	18.0	32.8	11.6	38.8	52.8	49.4	27.2	33.6
Ref. veh. w/90% eff. CVT	352	17.4	22.1	29.6	29.0	25.8	19.4	16.7	26.1	9.75	36.1	41.8	32.8	14.7	23.5
10% area reduction	305'	13.9	20.2	22.1	20.9	20.0	17.9	14.4	0.95	0.4	1.75	2.35	3.25	5.85	6.36
Area + drag coef. reduction	319'	14.1	20.3	22.5	21.4	20.8	18.9	15.4	2.2	1.0	3.50	4.95	6.9	11.6	14.3
Wt., area, + drag red.	320	14.9	20.8	23.2	22.0	21.2	19.4	15.8	8.2	3.44	6.95	7.83	9.3	14.3	17.1
Wt., area, drag red., radial tires	318'	15.1	21.4	24.3	22.9	21.9	20.1	16.4	9.6	6.36	11.9	12.0	12.8	18.7	21.9
Wt., area, drag, r. tires, + axle red.	309'	15.3	21.8	25.4	23.8	22.6	21.0	17.5	11.3	8.60	16.9	16.5	16.2	24.0	29.4
Wt., area, drag, r. tires, axle red., const. HP access.	316'	15.6	22.2	26.1	24.4	23.1	21.6	18.0	13.2	10.4	20.1	19.4	18.9	27.2	33.2
Synth. veh. w/90% eff. CVT	353	19.1	23.3	31.0	34.9	31.9	25.6	20.5	38.8	16.1	43.0	70.5	64.5	51.0	52.'

TABLE 4-5 Y COMPANY - STANDARD VEHICLE SUMMARY - WITHOUT AIR CONDITIONING OPERATING

CASE DESCRIPTION	COMP RUN NO.	FUEL ECONOMY - MPG FED'L DR.CYC	FUEL ECONOMY - MPG STEADY SPEED - MPH 20	30	40	50	60	70	% INCREASE IN MPG OVER REF. VEH. CASE 451 FED'L DR.CYC	% INCREASE STEADY SPEED - MPH 20	30	40	50	60	70
Reference vehicle	401	10.4	15.7	18.6	18.5	17.3	15.4	14.0	-	-	-	-	-	-	-
-500 lb. weight only	428	10.7	15.9	19.1	19.0	17.6	15.9	14.4	3.56	1.60	2.91	2.82	2.15	2.98	2.78
-10% frontal area only	402	10.4	15.7	18.8	18.8	17.5	16.0	14.5	0.63	0.25	1.08	1.57	1.57	3.37	3.78
-20% aero drag only	403	10.5	15.8	19.0	19.0	17.8	16.5	15.1	1.06	0.51	2.16	3.08	3.13	6.67	7.50
Radial tires only	413	10.6	16.0	19.2	19.3	17.8	16.2	14.6	2.12	2.30	3.40	4.38	2.96	4.86	4.28
9% lower axle ratio only	412	10.5	15.9	19.0	19.0	18.0	15.8	14.3	1.25	1.34	2.16	3.08	4.35	2.40	2.0[illegible]
Ref. veh. w/90% eff. CVT	442	12.5	16.5	22.3	24.8	22.4	19.6	15.7	20.6	4.97	19.8	34.2	29.6	26.9	11.9
10% area reduction	402	10.4	15.7	18.8	18.8	17.5	16.0	14.5	0.63	0.25	1.08	1.57	1.57	3.37	3.78
Area + drag coef. red.	403	10.5	15.8	19.0	19.0	17.8	16.5	15.1	1.06	0.51	2.16	3.08	3.13	6.67	7.50
Wt. + area + drag red.	429	10.8	16.0	19.3	19.6	18.2	17.0	15.5	4.63	2.10	3.71	6.33	5.68	10.0	10.6
Wt., area, drag red., rad. tires	430	11.0	16.3	19.6	20.5	19.2	17.6	16.1	5.89	3.95	5.21	10.9	11.6	13.9	14.7
Wt., area, drag, r. tires, axle red.	436	11.2	-	20.4	21.1	20.1	18.4	16.6	8.30	-	9.79	14.2	16.3	19.0	18.5
Wt., area, drag, r. tires, axle red., const. HP acces.	438	11.3	-	20.5	21.5	20.4	18.6	16.8	9.25	-	10.2	16.3	18.3	20.8	19.9
Case 430 w/90% eff. CVT	443	13.4	16.5	24.4	27.1	2[illegible].0	22.5	20.4	28.5	5.0	31.0	47.0	62	46	45
Case 430 w/90% eff. CVT + const. HP acces.	444	13.4	16.5	24.3	27.1	27.9	22.4	20.4	28.5	5.0	30.8	46.7	62	45.9	45.8

TABLE 4-6 Y COMPANY - STANDARD VEHICLE SUMMARY - WITH AIR CONDITIONING OPERATING

CASE DESCRIPTION	COMP RUN NO.	FUEL ECONOMY - MPG							% INCREASE IN MPG OVER REF. VEH. CASE 451						
		FED'L DR.CYC	STEADY SPEED - MPH						FED'L DR.CYC	STEADY SPEED - MPH					
			20	30	40	50	60	70		20	30	40	50	60	70
Reference vehicle	451	9.66	14.5	16.6	16.7	15.7	14.3	12.9	-	-	-	-	-	-	-
-500 lb. weight only	479, 481	10.0	14.9	17.0	17.1	16.2	14.6	13.2	3.42	2.82	2.35	2.22	2.80	2.32	2.48
-10% frontal area only	452	9.71	14.6	16.7	16.9	16.1	14.7	13.4	0.52	0.41	0.85	1.20	2.42	2.80	4.12
-20% aero drag only	453	9.76	14.7	16.9	17.1	16.5	15.0	14.0	1.04	0.82	1.75	2.58	4.70	5.46	8.55
Radial tires only	463	9.86	15.1	17.2	17.3	16.4	14.8	13.5	2.08	4.12	3.50	3.54	4.20	3.72	4.44
9% lower axle ratio only	462	9.78	14.7	16.9	17.2	16.5	14.6	13.3	1.25	1.03	2.05	3.18	4.50	2.66	3.50
Ref. veh. w/90% eff. CVT	492	11.5	15.5	20.2	22.4	19.2	16.8	13.8	19.0	6.45	21.6	33.8	22.2	17.6	7.14
10% area reduction	452	9.71	14.6	16.7	16.9	16.1	14.7	13.4	0.52	0.41	0.85	1.20	2.42	2.80	4.12
Area + drag coef. reduc.	453	9.76	14.7	16.9	17.1	16.5	15.0	14.0	1.04	0.82	1.75	2.58	4.70	5.46	8.55
Weight + area + drag red.	482	10.1	15.1	17.3	17.6	16.9	15.4	14.3	4.55	3.72	3.92	5.21	7.25	8.00	11.3
Wt., area, drag, rad. tires	486	10.3	15.7	17.8	18.2	17.4	16.0	14.8	6.53	7.90	7.00	8.91	10.7	12.3	15.0
Wt., area, drag, r. tires, + axle red.	487	10.5	-	18.3	18.9	18.4	16.5	15.4	8.50	-	10.4	13.1	17.0	16.0	19.3
Wt., area, drag, r. tires, axle red., const. HP acces.	489	11.3	-	20.5	21.4	20.4	18.6	16.8	17.0	-	23.3	28.2	29.4	30.6	30.4
Case 486 w/90% eff. CVT	493	12.4	16.3	21.2	24.9	24.6	20.0	17.4	28.5	11.9	27.9	48.8	56.5	40.5	35.4
Case 486 w/90% CVT + const. HP acc.	494	12.4	16.0	21.0	24.7	24.3	19.8	18.2	28.4	10.3	26.3	47.7	54.2	39.0	41.0

TABLE 4-7 SUMMARY - EFFECT ON FUEL ECONOMY OF SINGLE PARAMETER VEHICLE CHANGES FROM COMPUTER SIMULATION - COMPARISON WITH OTHER EXPERIMENTAL DATA SOURCES

Data Source	Weight Reduced by 10% % Improvements in MPG			Axle Ratio Reduced by 9% % Improvements in MPG			Combined Weight & Axle Reduction by 10% % Improvements in MPG			Aerodynamic Drag Reduced by 10% % Improvements in MPG			Radial Tires % Improvements in MPG		
	Federal Urban Driving Cycle	50 MPH Steady State	70 MPH Steady State	Federal Urban Driving Cycle	50 MPH Steady State	70 MPH Steady State	Federal Urban Driving Cycle	50 MPH Steady State	70 MPH Steady State	Federal Urban Driving Cycle	50 MPH Steady State	70 MPH Steady State	Rederal Urban Driving Cycle	50 MPH Steady State	70 MPH Steady State
Computer Runs:															
Co. X Compact	4.01	2.1	1.7	0.68	5.0	6.2				0.86	2.5	3.9	1.83	1.7	0.6
Co. X Std. A/C off	3.70	2.2	1.4	0.00	5.4	4.1				0.60	2.2	3.4	1.38	2.7	2.7
Co. X Std. A/C on	3.58	2.3	2.2	0.00	4.6	4.3				0.44	2.3	3.6	1.25	2.9	2.9
Co. Y Compact	4.6	2.42	2.45	0.95	1.0	4.08				0.95	3.20	6.40	2.7	3.7	3.94
Co. Y Std. A/C off	3.56	2.15	2.78	1.25	4.35	2.07				0.63	1.57	3.78	2.12	2.96	4.28
Co. Y Std. A/C on	3.42	2.80	2.48	1.25	4.50	3.50				0.52	2.42	4.12	2.08	4.20	4.44
Data from tech literature:															
Huebner (Ref.26)	4.3	-	2.5	1.7	-	3.7	-	-	-	Negli-gible	-	4.4	1.8	-	2.5
Lapointe (Ref. 17)	3.0	-	-	3.3	-	-	6.5	-	-	-	-	-	-	-	-
Marks (Ref. 18)	4.1-4.6	-	-	2.5-3.0	-	-	-	-	-	-	-	-	-	-	-

TABLE 4-8

SUMMARY OF CUMULATIVE CHANGES TO DEVELOP SYNTHESIZED VEHICLE

SEQ NO.	REF CAR CODE	FEDERAL DR. CYC	CUMULATIVE PERCENT INCREASE IN MPG OVER REF. VEH. STEADY SPEED - MPH 20	30	40	50	60	70
1 10% area red.	XC	≤0.86	≤0.4	≤1.4	≤1.5	≤2.5	≤3.4	≤3.9
" " "	XS	0.60	0.0	0.5	1.5	2.2	3.0	3.4
" " "	XS A/C	0.44	0.0	1.1	1.1	2.3	3.2	3.6
" ' "	YC	0.95	0.40	1.75	2.35	3.25	5.85	6.36
" " "	YS	0.63	0.25	1.08	1.57	1.57	3.37	3.78
" " "	YS A/C	0.52	0.41	0.85	1.20	2.42	2.80	4.12
2 Area + drag red.	XC	1.20	0.4	2.1	2.2*	3.8*	4.8*	5.6*
" " " "	XS	1.12	0.0	1.1	2.5	4.3	6.1	6.8
" " " "	XS A/C	0.89	0.0	1.6	2.7	4.6	5.8	6.5
" " " "	YC	2.2	1.0	3.5	4.95	6.9	11.6	14.3
" " " "	YS	1.06	0.51	2.16	3.08	3.13	6.67	7.5
" " " "	YS A/C	1.04	0.82	1.75	2.58	4.70	5.46	8.55
3 Wt., area, + drag red.	XC	5.21	1.6	5.0	4.0	5.5*	6.3*	7.3*
" " " " "	XS	4.91	0.6	2.6	4.0	6.5	8.5	8.9
" " " " "	XS A/C	4.83	1.2	2.8	4.9	6.3	7.7	8.6
" " " " "	YC	8.2	3.44	6.95	7.83	9.3	14.3	17.05
" " " " "	YS	4.63	2.10	3.71	6.33	5.68	10.0	10.6
" " " " "	YS A/C	4.55	3.72	3.92	5.21	7.25	8.0	11.3
4 Wt., area, drag red. + radial tires	XC	6.99	4.8	9.3	5.5	6.7*	7.2*	7.9*
" " " " " "	XS	6.12	1.2	4.7	6.1	9.7	11.5	11.6
" " " " " "	XS A/C	6.08	2.5	5.0	7.6	9.1	10.9	11.5
" " " " " "	YC	9.6	6.36	11.9	12.0	12.8	18.7	21.9
" " " " " "	YS	5.89	3.95	5.21	10.9	11.6	13.9	14.7
" " " " " "	YS A/C	6.53	7.90	7.0	8.91	10.72	12.3	15.0
5 Wt., area, drag, tires, axle ratio red	XC*	8.25	7.6	13.6	12.5	14.7	15.0	15.2
" " " " " " "	XS	6.55	-	8.4	11.1	16.1	18.8	18.5
" " " " " " "	XS A/C	6.62	-	8.8	11.9	16.0	17.9	18.0
" " " " " " "	YC	11.3	8.6	16.9	16.5	16.2	24.0	29.4
" " " " " " "	YS	8.30	-	9.79	14.2	16.3	19.0	18.5
" " " " " " "	YS A/C	8.5	-	10.4	13.05	17.0	16.0	19.3
6 Wt, area, drag, tires axle, const. HP acces., fan	XC	12.7	9.6	23.7	19.6	20.6	21.7	21.3
	XS	6.81	-	8.4	11.6	17.2	20.6	20.5
" " " " " " "	XS A/C	7.33	-	8.8	14.0	18.8	22.4	23.0
" " " " " " "	YC	13.2	10.4	20.1	19.4	19.0	27.2	33.2
" " " " " " "	YS	9.25	-	10.2	16.3	18.3	20.8	19.9
" " " " " " "	YS A/C	17.0	-	23.3	28.2	29.4	30.6	30.4

TABLE 4-9 RELATIVE ACCELERATION PERFORMANCE CO X COMPACT & STANDARD CARS

VEHICLE CHANGES	COMP. RUN NO	PERCENT INCREASE IN WOT ACCELERATION OVER REFERENCE VEHICLE					
		STEADY SPEED - MPH					
		20	30	40	50	60	70
Co X Compact							
9% Lower Axle Ratio Only	606	-9%	-6	-9	-9	-6	-1
Red. Wt, Drag Area, & Rad. Tires	612	+10	+15	+16	+18	+19	+27
Red. Wt, Drag, Area, Tires & Axle Ratio	613	0	+5	+5	+8	+14	+24
Co X Standard-no A/C							
9% Lower Axle Ratio only	706	-5.5	-9	-8	-10.5	-11	-11
Red. Wt, Drag Area, & Rad. Tires	712	+8	+11.5	+14	+15.5	+18	+22
Red Wt, Drag Area, Tires & Axle Ratio	713	+5	+2	+4	+4	+4.5	+10

% INCREASE IN MPG DUE TO CVT

CASE	REFERENCE VEHICLES WITH 90% EFFICIENT CVT						SYNTHESIZED VEHICLES WITH REDUCED WEIGHT, AREA, DRAG, AND RADIAL TIRES					
	CVT RUN NO.	BASE RUN NO.	FEDERAL DR. CYC	STEADY SPEED - MPH 30	50	70	CVT RUN NO.	BASE RUN NO.	FEDERAL DR. CYC	STEADY SPEED - MPH 30	50	70
Co X compact	608	601	21.0	40.5	41.6	20.8	617	614	20.0	26.0	47.0	37.2
Co X std. w/A/C	808	801	12.6	19.9	29.7	19.4	815	812	12.0	19.0	39.5	39.2
Co X std. w/o-A/C	708	701	12.1	18.9	29.6	17.8	715	712	11.2	17.0	39.6	34.2
Co Y compact	352	302	26.1	36.1	32.8	23.5	353	318	26.5	27.8	45.6	25.0
Co Y std. w/A/C	492	451	19.0	21.6	22.2	7.14	493	486	20.5	20	41.2	18
Co Y std. w/o-A/C	442	401	20.6	19.8	29.6	11.9	443	430	21.7	24.5	45.0	26.4
Average of results for all above cases			18.6	26.1	30.9	27.5			18.7	22.4	43.0	30.0

TABLE 4-10 CONTINUOUSLY VARIABLE TRANSMISSION - SUMMARY OF RESULTS PERCENT INCREASE IN MPG OVER BASELINE CASE WITH 3-SPEED AUTOMATIC TRANSMISSION

TABLE 4-11 4 SPEED AUTOMATIC TRANSMISSION WITH LOCK-UP TORQUE CONVERTER SUMMARY OF RESULTS

(see pages 326 – 335)

CASE DESCRIPTION	COMP RUN NO.	FUEL ECONOMY - MPG FED'L DR.CYC	STEADY SPEED - MPH 20	30	40	50	60	70	% INCREASE OVER REF. VEH. CASE FED'L DR.CYC	STEADY SPEED - MPH 20	30	40	50	60	70	RELATIVE WOT ACCELERATION CAPABILITY COMPARED WITH REFERENCE VEHICLE 30 MPH	50 MPH	70 MPH
I-CoY Compact - (Ref. Veh. Run 302)																		
Ref. Veh. w/4 Sp. 3.08 Axle	361	15.63	21.8	25.7	22.8	19.7	17.9	15.6	13.5	8.6	18.2	11.3	1.5	6.0	15.4	.64 (.92)*	.68 (.95)	.87 (1.03)
Synth. Veh. w/4 Sp.3.08 Axle	362	16.82	22.7	27.9	26.5	24.2	21.7	18.9	22.1	12.9	28.4	29.5	24.6	28.4	40.0	.75 (1.05)	.84 (1.13)	1.23 (1.40)
II-CoY Stand.A/COff(Ref. Veh Run 401)																		
Ref. Veh. w/ 4 Sp 3.08 Axle	511	11.08	-	21.1	20.9	19.6	17.2	15.2	6.95	-	13.4	13.0	13.3	11.7	8.6	.76 (1.04)	.78 (1.12)	.76 (1.15)
" 2.73 Axle	513	11.31	-	22.2	22.0	20.7	18.7	16.2	9.16	-	19.4	18.9	19.7	21.0	15.7	.65 (.88)	.63 (.93)	.58 (.94)
" 2.50 Axle	514	11.88	-	-	22.8	21.5	19.4	16.4	14.7	-	-	23.2	24.3	26.0	17.1	.58 (.80)	.54 (.82)	.47 (.80)
Synth Veh. w/4 Sp. 3.08 Axle	512	11.76	-	22.4	22.5	21.4	19.5	17.3	13.5	-	20.4	21.6	23.7	26.6	23.6	.92 (1.23)	.97 (1.35)	1.02 (1.44)
" 2.73 Axle	515	12.07	-	24.1	23.9	22.9	21.3	18.4	16.5	-	29.6	29.2	32.4	38.3	31.5	.79 (1.06)	.82 (1.14)	.83 (1.24)
" 2.50 Axle	516	12.64	-	-	25.0	23.9	22.1	19.5	22.0	-	-	35.1	38.2	43.5	39.5	.71 (.94)	.70 (1.0)	.71 (1.08)
" 2.30 Axle	517	13.23	-	-	25.8	24.7	22.9	20.5	27.7	-	-	39.5	42.8	48.6	46.5	.65 (.86)	.61 (.90)	.59 (.94)
III CoY Stand. A/C on (Ref. Veh. Run 451)																		
Ref. Veh. w/4 Sp. 3.08 Axle	561	10.23	-	18.7	18.7	17.9	16.9	14.2	5.9	-	12.6	12.0	14.0	18.2	10.1	.75 (1.06)	.77 (1.14)	.76 (1.20)
" 2.73 Axle	563	10.47	-	20.0	20.0	18.8	17.2	14.5	8.4	-	20.5	19.8	19.8	20.3	12.4	.63 (.90)	.62 (.95)	.57 (.97)
" 2.50 Axle	564	11.13			20.8	19.5	17.9	14.2	15.2	-		24.5	24.2	25.2	10.1	.56 (.80)	.52 (.82)	.45 (.82)
Synth. Veh. w/4 Sp.3.08 Axle	562	10.87	-	19.9	20.3	19.6	17.7	16.0	12.5	-	19.9	21.6	24.8	23.8	24.0	.91 (1.26)	.98 (1.39)	1.05 (1.52)
" 2.73 Axle	565	11.20	-	21.0	21.5	20.8	19.4	17.1	15.9	-	26.5	28.7	32.5	35.7	32.6	.78 (1.07)	.81 (1.17)	.84 (1.30)
" 2.50 Axle	566	11.85	-	-	22.4	21.8	20.2	18.1	22.7	-	-	34.1	38.9	41.3	40.3	.70 (.95)	.69 (1.02)	.70 (1.13
" 2.30 Axle	567	12.54	-	-	23.4	22.6	20.9	18.7	29.8	-	-	40.1	44.0	46.1	45.0	.63 (.87)	.59 (.91)	.57 (.97)

* Numbers in parentheses represent acceleration obtained with downshift into 3rd gear.

TABLE 4-12

DIESEL ENGINE SUMMARY   COMPANY X – COMPACT SIZE VEHICLE

(see pages 326 – 335)

CASE DESCRIPTION	COMP RUN NO.	FUEL ECONOMY - MPG FED'L DR.CYC	STEADY SPEED - MPH 20	30	40	50	60	70	% INCREASE IN MPG OVER REF. VEH. CASE 601 FED'L DR.CYC	STEADY SPEED - MPH 20	30	40	50	60	70	RELATIVE WOT ACCELERATION CAPABILITY COMPARED WITH REFERENCE VEHICLE 30 MPH	50 MPH	70 MPH
Original Ref. Vehicle	601	17.45	24.9	27.9	27.1	23.8	20.7	17.8								(NUMBERS IN PARENTHESES REPRESENT ACCELERATION OBTAINED WITH DOWNSHIFT TO 3RD GEAR)		
I Ref.Veh.w/237CID Diesel &																		
3 Sp.Auto Trans, 3.08 Axle*	621	21.41	30.9	30.5	27.8	24.6	21.3	18.4	22.7	24	9	3	3	3	4	0.92	1.01	1.12
" 2.79 Axle	627	21.87	31.6	32.1	29.8	26.6	23.2	20.0	25.3	27	15	10	12	12	13	0.83	0.88	1.06
4 Sp.Lock-Up Trans,2.79Axle*	625	18.98	-	44.1	39.2	35.2	30.6	26.2	8.8	-	58	45	48	47	47	.52 (.79)	.47 (.89)	.54 (1.1)
" 2.55Axle	630	20.17	-		41.4	37.0	31.9	27.2	15.6	-	-	53	56	54	53	.47 (.71)	.41 (.76)	.41 (.95)
" 2.30Axle	631	21.39	-	-	43.6	38.5	32.9	28.2	22.6	-	-	61	62	58	59	.43 (.64)	.33 (.64)	.28 (.80)
Continuously Variable Trans.	623	25.84	32.6	40.0	41.5	38.5	32.3	26.8	48.1	31	43	53	62	56	51	0.63**	0.23**	0.10**
II Synthesized veh. w/reduced wt, area, drag, & radial tires w/237 CID Diesel, and:																		
3 Sp.Auto Trans, 2.79 Axle	622	23.63	34.5	34.6	32.4	28.3	24.8	21.4	35.4	38	24	20	19	20	21	0.96	1.07	1.35
" 2.55 Axle	628	24.02	36.6	36.4	34.4	30.4	26.6	23.0	37.7	46	30	27	28	28	30	0.87	0.96	1.21
" 2.30 Axle	629	24.21	38.4	37.8	36.0	32.2	28.5	24.6	38.7	54	35	33	35	37	39	0.81	0.83	1.05
4 Sp.Lock-Up Trans,2.55Axle	626	21.33	-	-	45.5	40.3	35.4	30.3	22.2	-	-	68	69	70	70	.57 (.84)	.52 (.94)	.65 (1.24)
" 2.30Axle	632	22.73	-	-	48.0	43.1	37.2	31.9	30.3	-	-	77	81	79	79	.52 (.75)	.44 (.79)	.48 (1.08)
Continuously Variable Trans.	624	27.94	34.9	43.5	46.2	44.6	38.2	31.8	60.1	40	56	71	88	84	79	0.74**	0.33**	0.15**

*See pages 343 and 399

**These Accel. values are without the downshift which is essential to CVT application.

TABLE 4-13

DIESEL ENGINE SUMMARY COMPANY X-STANDARD SIZE VEHICLE, WITHOUT AIR CONDITIONING

(see pages 326 – 335)

CASE DESCRIPTION	COMP RUN NO.	FUEL ECONOMY - MPG FED'L DR.CYC	STEADY SPEED - MPH 20	30	40	50	60	70	% INCREASE OVER REF. VEH. CASE 701 FED'L DR.CYC	STEADY SPEED - MPH 20	30	40	50	60	70	RELATIVE WOT ACCELERATION CAPABILITY COMPARED WITH REFERENCE VEHICLE 30 MPH	50 MPH	70 MPH
Original Ref. Vehicle	701	11.60	16.1	19.0	19.8	18.6	16.5	14.6								(NUMBERS IN PARENTHESES REPRESENT ACCELERATION OBTAINED WITH DOWNSHIFT TO 3RD GEAR)		
I Ref. Veh. w/326 CID Diesel and:																		
3 SP. Auto Trans, 3.05 Axle	721	14.93	21.2	23.4	22.8	20.9	18.1	15.6	28.7	32.	23.	15.	12.	10.	7.	0.76	0.76	0.70
" 2.75 Axle	722	15.02	-	24.2	23.8	21.9	19.3	16.7	29.5		27.	20.	18.	17.	14.	0.68	0.67	0.60
" 2.50 Axle	723	14.98	-	24.8	24.6	22.7	20.2	17.5	29.1		31.	24.	22.	22.	20.	0.63	0.59	0.52
4 SP.Lockup Trans#1,2.75Axle	727	15.21	-	-	31.2	28.1	24.6	21.0	31.2			58.	51.	49.	44.	.35 (.64)	.33 (.66)	.14 (.62)
" 2.50Axle	728	15.59	-	-	33.0	29.5	25.7	21.4	34.3			67.	59.	56.	47.	.32 (.56)	.28 (.57)	.18 (.52)
4 SP.Lockup Trans#2,2.50Axle	731	14.70	-	-	33.0	29.5	25.7	21.4	26.8			67.	59.	56.	47.	.32 (.56)	.28 (.57)	.18 (.52)
Continuously Variable Transm	734	16.60	19.9	26.0	29.4	29.4	25.3	20.4	43.1	24.	37.	49.	58.	53.	40.	0.62	0.24	0.11
Synthesized vehicle w/reduced wght., area, drag, & radial tires w/326 CID Diesel, and:																		
3 SP.Auto Trans,2.75 Axle	724	16.15	-	26.2	26.1	24.4	21.9	19.0	38.3		38.	32.	31.	33.	30.	0.78	0.79	0.78
" 2.50 Axle	725	16.19	-	27.0	27.1	25.5	23.0	20.1	39.7		42.	37.	37.	39.	38.	0.70	0.70	0.68
" 2.30 Axle	726	16.17	-	27.5	27.9	26.2	23.7	21.0	39.5		45.	41.	41.	44.	44.	0.65	0.64	0.60
4 SP.Lockup Trans#1,2.50Axle	729	16.60	-	-	35.5	33.1	29.2	25.6	43.1			79.	78.	77.	75.	.36 (.66)	.36 (.70)	.30 (.69)
" 2.30Axle	730	16.97	-	-	-	34.6	30.5	26.4	46.4				86.	85.	81.	.33 (.58)	.31 (.61)	.25 (.60)
4 SP.Lockup Trans#2,2.50Axle	732	15.57	-	-	35.5	33.1	29.2	25.6	34.3			79.	78.	77.	75.	.36 (.66)	.36 (.70)	.30 (.69)
" 2.30Axle	733	16.04	-	-	-	34.6	30.5	26.4	38.4				86.	85.	81.	.33 (.58)	.31 (.61)	.25 (.60)
Continuously Variable Transm	735	17.64	20.6	27.7	31.7	33.1	31.0	25.7	52.2	28.	46.	60.	78.	88.	76.	0.72	0.33	0.10

TABLE 4-14

DIESEL ENGINE SUMMARY   COMPANY X-STANDARD SIZE VEHICLE, WITH AIR CONDITIONING

CASE DESCRIPTION	COMP RUN NO.	FUEL ECONOMY - MPG FED'L DR.CYC	STEADY SPEED - MPH 20	30	40	50	60	70	% INCREASE OVER REF. VEH. CASE 801 FED'L DR.CYC	STEADY SPEED - MPH 20	30	40	50	60	70
Original Ref. Vehicle	801	11.18	15.4	18.1	18.5	17.5	15.6	13.9							
I Ref.Veh.w/326CID Diesel and:															
3 SP.Auto Trans. 3.05 Axle	821	14.20	19.9	21.5	20.9	19.3	17.0	14.8	27.0	29.	19.	13.	10.	9.	6.
" 2.75 Axle	822	14.31	-	22.5	22.0	20.3	18.2	15.9	28.0		24.	19.	16.	16.1	14.
" 2.50 Axle	823	14.30	-	23.1	22.9	21.2	19.0	16.7	27.9		28.	24.	21.	21.4	20.
4 SP.Lockup Trans#1,2.75Axle	827	14.41	-	-	29.5	26.4	23.3	19.7	28.9			60.	51.	49.	42.
" 2.50Axle	828	14.80	-	-	31.3	27.9	24.3	20.3	32.4			70.	60.	55.5	46.
4 SP.Lockup Trans#2,2.50Axle	831	13.85	-	-	31.3	27.9	24.3	20.3	23.9			70.	60.	55.5	46.
Continuously Variable Trans.	834	15.69	18.4	24.3	27.7	27.7	23.7	19.1	40.3	20.	34.	50.	58.	52.	37.
II Synthesized Veh.w/reduced wt, area, drag, & radial tires w/326 CID Diesel, and:															
3 SP.Auto Trans.,2.75 Axle	824	15.40	-	24.1	24.0	22.5	20.3	17.9	37.7		33.	30.	29.	30.	29.
" 2.50 Axle	825	15.47	-	25.0	25.1	23.6	21.4	19.0	38.3		38.	36.	35.	37.	38.
" 2.30 Axle	826	15.48	-	25.7	25.9	24.5	22.3	19.7	38.7		42.	40.	40.	43.	42.
4 SP.Lockup Trans#1,2.50Axle	829	15.76	-	-	33.7	31.1	27.7	24.2	41.0			83.	78.	77.	74.
" 2.30Axle	830	16.15	-	-	-	32.7	28.9	25.0	44.4				87.	85.	80.
4 SP.Lockup Trans#2,2.50Axle	832	14.67	-	-	33.7	31.1	27.7	24.2	31.2			83.	78.	77.	74.
" 2.30Axle	833	15.15	-	-	-	32.7	28.9	25.0	35.5				87.	85.	80.
Continuously Variable Trans.	835	16.67	19.0	25.6	29.9	31.3	29.2	24.0	49.1	23.6	41.	62.	79.	87.	73.

TABLE 4-15

DIESEL ENGINE SUMMARY   COMPANY Y- COMPACT SIZE VEHICLE

CASE DESCRIPTION	COMP RUN NO.	FUEL ECONOMY - MPG FED'L DR.CYC	STEADY SPEED - MPH 20	30	40	50	60	70	% INCREASE IN MPG OVER REF. VEH. CASE 302 FED'L DR.CYC	STEADY SPEED - MPH 20	30	40	50	60	70	RELATIVE WOT ACCELERATION CAPABILITY COMPARED WITH REFERENCE VEHICLE (see pages 326 – 335) 30 MPH	50 MPH	70 MPH
Original Ref. Vehicle	302	13.77	20.1	21.7	20.5	19.4	16.9	13.5								(NUMBERS IN PARENTHESES REPRESENT ACCELERATION OBTAINED WITH DOWNSHIFT TO 3RD GEAR)		
I Ref.Veh. w/237CID Diesel &																		
2 SP.Auto Trans, 3.08 Axle	371	19.72	31.1	30.5	27.4	24.0	20.6	17.5	43.2	55	40	34	24	21	30	0.82	0.87	0.99
" 2.55 Axle	372	20.46	32.9	32.6	29.2	26.4	22.5	19.4	48.6	64	50	43	36	33	43	0.68	0.66	0.73
3 SP.Auto Trans., 3.08 Axle*	375	20.41	31.6	30.8	27.8	24.4	20.8	17.7	48.2	58	42	36	26	23	31	0.82	0.88	1.01
" 2.79 Axle	376	20.55	32.7	31.7	29.1	25.7	21.9	18.9	49.2	63	46	42	32	29	40	0.75	0.77	0.89
4 Sp.Lock-Up Trans.2.79 Axle*	381	18.56	-	-	37.8	32.5	27.3	22.7	34.8	-	-	85	67	61	68	.45 (.68)	.35 (.73)	.26 (.91)
" 2.55 Axle	382	19.51	-	-	39.0	33.4	27.9	22.9	41.7	-	-	91	72	64	70	.39 (.60)	.29 (.62)	.13 (.75)
" 2.30 Axle	383	20.47	-	-	40.2	33.7	28.1	22.9	48.7	-	-	97	74	66	70	.37 (.55)	.23 (.51)	0 (.56)
Continuously Variable Trans.	379	23.82	32.2	38.2	38.1	32.8	27.1	22.0	73.0	60	75	86	69	60	63	0.59**	0.20**	0.17**
II Synthesized veh. w/reduced wt, area, drag & radial tires w/237 CID Diesel and:																		
2 Sp.Auto Trans, 2.79 Axle	373	22.00	35.7	34.8	32.6	28.7	25.0	21.4	59.8	78	60	59	48	48	59	0.85	0.93	1.24
" 2.55 Axle	374	22.41	36.8	36.2	34.0	30.0	26.3	22.6	62.7	83	66	66	54	55	67	0.79	0.81	1.08
3 Sp.Auto Trans, 2.79 Axle	377	22.60	36.3	35.5	33.0	29.0	25.3	21.7	64.1	81	63	61	50	49	60	0.84	0.93	1.26
" 2.55 Axle	378	22.68	37.4	36.6	34.4	30.3	26.6	22.8	64.7	86	68	68	56	57	69	0.78	0.81	1.09
4 Sp.w/Lock-Up Trans,2.55Axle	384	20.93	-	-	44.5	39.5	33.5	28.4	52.0	-	-	118	103	98	110	.48 (.71)	.40 (.77)	.42 (1.08)
" 2.30Axle	385	22.12	-	-	46.7	40.7	34.2	29.0	60.6	-	-	128	110	102	115	.42 (.63)	.34 (.66)	.26 (.90)
Continuously Variable Trans.	380	26.17	34.8	42.3	43.4	40.6	33.8	27.9	90.0	73	95	112	109	100	107	0.69**	0.28**	0.15**

*See pages 343 and 399.

** These Accel. values are without the downshift which is essential to CVT application.

TABLE 4-16

DIESEL ENGINE SUMMARY COMPANY Y-STANDARD SIZE VEHICLE, WITHOUT AIR CONDITIONING

CASE DESCRIPTION	COMP RUN NO.	FUEL ECONOMY - MPG FED'L DR.CYC	STEADY SPEED - MPH 20	30	40	50	60	70	% INCREASE OVER REF. VEH. CASE 401 FED'L DR.CYC	STEADY SPEED - MPH 20	30	40	50	60	70	RELATIVE WOT ACCELERATION CAPABILITY COMPARED WITH REFERENCE VEHICLE 30 MPH	50 MPH	70 MPH
Original Ref. Vehicle	401	10.4	15.7	18.6	18.5	17.3	15.4	14.0								(NUMBERS IN PARENTHESES REPRESENT ACCELERATION OBTAINED WITH DOWN-SHIFT TO 3RD GEAR)		
I Ref. Veh.w/326 Diesel and:																		
3 SP.Auto Trans, 3.08 Axle	521	13.79	20.4	22.2	21.6	19.8	17.2	14.8	32.6	30.	19.	17.	14.	12.	6.	1.01	0.98	0.90
" 2.73 Axle	522	14.18	20.8	23.0	22.5	20.7	18.3	15.9	36.3	33.	24.	22.	20.	19.	14.	0.88	0.84	0.76
" 2.50 Axle	523	14.36	21.0	23.6	23.1	21.2	18.9	16.5	38.1	34.	27.	25.	23.	23.	18.	0.84	0.75	0.84
4 SP.Lockup Trans#1,2.73Axle	527	14.58	-	-	29.7	26.4	23.1	19.3	40.1			61.	53.	50.	38.	.41 (.77)	.38 (.80)	.26 (.75)
2.50Axle	528	14.87			31.2	27.6	23.8	19.7	42.9			69.	60.	55.	41.	.37 (.68)	.31 (.70)	.18 (.63)
4 SP.Lockup Trans.#2,2.50Axle	531	14.05	-	-	31.2	27.6	23.8	19.7	35.1			69.	60.	55.	41.	.37 (.68)	.31 (.70)	.18 (.63)
Continuously Variable Trans.	534	16.10	19.9	25.3	28.1	27.4	23.1	18.7	54.8	27.	36.	52.	58.	50.	34.	0.75*	0.26*	0.17*
II Synthesized veh. w/reduced wt., area, drag & radial tires w/326 CID Diesel, and:																		
3 SP.Auto Trans., 2.73 Axle	524	15.28	22.3	25.4	25.2	23.5	21.1	18.3	47.0	42.	37.	36.	36.	37.	31.	1.02	1.03	1.03
" 2.50 Axle	525	15.54	-	26.0	26.0	24.3	22.0	19.2	49.4		40.	41.	40.	43.	37.	0.92	0.92	0.92
" 2.30 Axle	526	15.71	-	26.5	26.6	25.0	22.6	19.9	51.0		43.	44.	44.	47.	42.	0.89	0.83	0.80
4 SP.Lockup Trans#1,2.50Axle	529	16.06	-	-	34.2	31.5	27.8	24.2	54.3			85.	82.	81.	73.	.46 (.81)	.44 (.87)	.37 (.88)
" 2.30Axle	530	16.36	-	-	-	32.9	29.0	24.9	57.3				90.	88.	78.	.41 (.73)	.37 (.77)	.29 (.76)
4 SP.Lockup Trans#2,2.50Axle	532	15.08	-	-	34.2	31.5	27.8	24.2	45.0			85.	82.	81.	73.	.46 (.81)	.44 (.87)	.37 (.88)
" 2.30Axle	533	15.54	-	-	-	32.9	29.0	24.9	49.3				90.	88.	78.	.41 (.73)	.37 (.77)	.29 (.76)
Continuously Variable Trans.	535	17.37	20.7	27.4	30.9	31.8	29.2	24.1	67.0	32.	47.	67.	84.	90.	72.	0.90*	0.39*	0.16*

*These accel. levels are without the downshift which is essential to CVT application

(see pages 326 – 335)

TABLE 4-17

DIESEL ENGINE SUMMARY COMPANY X-STANDARD SIZE VEHICLE, WITH AIR CONDITIONING

CASE DESCRIPTION	COMP RUN NO.	FUEL ECONOMY - MPG FED'L DR.CYC	FUEL ECONOMY - MPG STEADY SPEED - MPH 20	30	40	50	60	70	% INCREASE OVER REF. VEH. CASE 451 FED'L DR.CYC	% INCREASE STEADY SPEED - MPH 20	30	40	50	60	70
Original Ref. Vehicle	451	9.66	14.5	16.6	16.7	15.7	14.3	12.9							
I Ref.Veh.w/326CID Diesel &:															
3 SP.Auto Trans,3.08 Axle	571	12.64	17.9	19.4	18.9	17.6	15.6	13.7	31.0	23.0	17.	13.	12.	9.	6.
" 2.73 Axle	572	13.04	18.4	20.3	20.0	18.6	16.6	14.7	35.1	27.	22.	20.	18.	16.	14.
" 2.50 Axle	573	13.24	18.6	20.9	20.6	19.2	17.2	15.3	37.1	28.	26.	23.	22.	20.	19.
4 SP.Lockup Trans#1,2.73Axle	577	13.26	-	-	26.8	24.0	21.0	17.7	37.2			60.	53.	47.	37.
" 2.50Axle	578	13.55	-	-	28.1	24.8	21.5	17.8	40.3			68.	58.	50.	38.
4 SP.Lockup Trans#2,2.50Axle	581	12.69	-	-	28.1	24.8	21.5	17.8	31.3			68.	58.	50.	38.
Continuously Variable Trans.	584	14.55	17.2	22.5	25.2	24.5	20.5	16.9	50.7	19.	36.	51.	56.	43.	31.
II Synthesized Veh. w/reduced wt, area, drag,&radial tires w/326 CID Diesel, and:															
3 SP.Auto Trans, 2.73 Axle	574	14.03	19.8	22.0	22.0	20.8	18.9	16.8	45.3	37.	33.	32.	32.	32.	50.
" 2.50 Axle	575	14.31	-	22.7	22.8	21.6	19.8	17.6	48.2		37.	37.	37.	38.	36.
2.30 Axle	576	14.51	-	23.3	23.7	22.3	20.5	18.3	50.2		40.	42.	42.	43.	42.
4 SP.Lockup Trans#1,2.50Axle	579	14.64	-	-	31.0	28.3	25.3	22.0	51.7			86.	80.	77.	71.
" 2.30Axle	580	14.94	-	-	-	29.6	26.2	22.4	54.7				88.	83.	74.
4 SP.Lockup Trans#2,2.50Axle	582	13.62	-	-	31.0	28.3	25.3	22.0	41.0			86.	80.	77.	71.
" 2.30 axle	583	14.06	-	-	-	29.6	26.2	22.4	45.6				88.	83.	74.
Continuously Variable Trans.	585	15.68	17.9	24.0	27.8	28.7	25.8	21.5	62.3	23.	44.	66.	83.	80.	67.

TABLE 4-18 SUMMARY OF FUEL ECONOMY IMPROVEMENTS

AVAILABLE FROM DIESEL ENGINE INSTALLATIONS

VEHICLE	TRANS. TYPE	RELATIVE ACCELERATION	% MPG FDC	INCREASE 40 MPH	INCREASE 70 MPH
Reference	3 Sp. Auto	1.0	30	15	5
"	3 Sp. Auto	0.9	33	20	15
"	4 Sp. Lock-up	.8 - .85	35	50	
"	CVT	1.0	50	50	
Synthesized	3 Sp. Auto	1.0	45	35-40	
"	3 Sp. Auto	.85 - .9	48	40-45	
"	4 Sp. Lock-up	0.85	52	80	
"	CVT	1.0	60	70-85	

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APPENDIX A

TITLE

Reference Vehicle - Co. X compact car

RUN NO(S)

601

PURPOSE

Determine baseline economy for Co. X compact car.

INPUT DATA SUMMARY

Co. X reference vehicle input data: test weight = 3351 lb.; 250 CID 6 cylinder engine; frontal area = 21.4 ft.^{2}; drag coefficient = 0.47; 3 speed automatic transmission with 11.25" torque converter; axle ratio = 2.79; bias ply tires; accessories - alter., P.S. and fan, no air conditioning.

SUMMARY OF RESULTS

		SIMULATION FUEL ECONOMY		MANUFACTURER'S DATA (MPG)	
		3351 lb.	3030 lb/run 602	1972/3059 lb	1973/3151 lb
steady	30	27.9	28.8	-	21.4
speed	40	27.1	27.6	-	23.0
(MPH)	50	23.8	24.3	-	22.1
	60	20.7	21.1	-	21.6
	70	17.8	18.1	17.9	18.3
Federal Drive Cycle		17.45	18.15	-	-
City/Suburban Drive Cycle		-	-	17.0	16.6

COMMENTS

Tire efficiency lumped into road load rolling resistance input data, rear axle efficiency of 95% used.
Engine and accessory data supplied by manufacturer is for 1972 engine.

CONCLUSIONS

1. Reasonably good agreement with manufacturer's data.
2. Substantially better economy than Co. Y compact due to a) lower weight, b) 3 speed transmission rather than 2 speed, c) lower axle ratio, d) lower drag coefficient, e) 1972 engine rather than 1973

TITLE

Reference Vehicle - CO X standard car

RUN NO(S).

701 (W/O A/C); 801 (W/A/C)

PURPOSE

Determine baseline economy for CO X standard car

INPUT DATA SUMMARY

CO X reference vehicle input data: Test weight = 5008 lb.; 400 CID V-8 engine; frontal area = 24.94 ft.^{2}; drag coefficient = 0.50; 3 speed automatic transmission; w/12.25" torque converter; axle ratio = 2.75; bias ply tires; accessories - alt., P.S., and fan; run 801 with air conditioning operating; run 701 w/A/C not operating.

SUMMARY OF RESULTS (air conditioning off)

		Simulation Fuel Economy (MPG)		Manufacturer's Data (MPG)	
		5008 lb.	4508 lb. (run 702)	1972 (4587 lb)	1973 (4808 lb)
steady speed (MPH)	30	19.0	19.3	18.9	17.9
	40	19.8	20.1	19.5	18.2
	50	18.6	19.0	18.3	16.3
	60	16.5	16.9	16.9	15.4
	70	14.5	14.8	14.9	14.2
Federal Drive Cycle		11.6	12.0	-	-
City/Suburban Cycle		-	-	12.6	11.4

COMMENTS

Engine and accessory data supplied by manufacturer is for 1972 engine. Rear axle efficiency and tire efficiency lumped into road load rolling resistance data.

CONCLUSIONS

1. Reasonably good agreement with manufacturer's data.

TITLE

Reference Vehicle - Co. Y - compact car

RUN NO(S)

302 (reference vehicle), 306*(2.73 axle and drag coefficient = .5), 311*(3760 lb., 2.73 axle)

PURPOSE

Determine baseline economy for Co. Y compact car - and compare with manufacturer's data.

INPUT DATA SUMMARY

Co. Y reference vehicle input data: test weight = 3877 lb.; 250 CID 6 cylinder engine; frontal area = 21.9 ft.^{2}; drag coefficient = 0.568; 2 speed automatic transmission with 11.0" torque converter; axle ratio = 3.08; bias ply tires; accessories - alt., P.S., fan.

SUMMARY OF RESULTS

		SIMULATION FUEL ECONOMY (MPG)			MANUFACTURER'S DATA
		run 302	run 311	run 306	3765 lb/2.73 axle
		3877 lb/3.08 axle	3760 lb/2.73 axle	C_D=.5	
steady	30	21.75	22.42	22.67	22.4
speed	40	20.46	21.18		-
(MPH)	50	19.41	19.59	20.37	20.9
	60	16.93	17.36		-
	70	13.50	14.02	15.09	15.9
Federal Drive Cycle		13.77		14.10	

COMMENTS

No manufacturer's data for drive cycle economy.
Fan included in engine map.
Manufacturer's data available for 2.73 axle ratio but not for reference Vehicle axle ratio of 3.08.
Drive train has allowance for 95% tire efficiency, and 96% rear axle efficiency.
*Run 311 corresponds to same weight and axle ratio as manufacturer's data.

*Run 306 corresponds to proper axle ratio for comparison to manufacturer's data - also drag coefficient is reduced 0.5 which seems like a more probable value for vehicle. (Vehicle weight = 3877 lb.)

CONCLUSIONS

1. Reasonable agreement is obtained between manufacturer's data and computer simulation for run 311 where vehicle weight and axle ratio were identical.

2. Substantially better agreement is obtained when drag coefficient is reduced to 0.50, a value which is more nearly in line with values for all other reference vehicles.

TITLE

Reference Vehicle - Co. Y - standard car

RUN(S)

401 (W/O - A/C), 451 (W/ - A/C)

PURPOSE

Determine baseline economy for Co. Y standard car - and compare with manufacturer's data

INPUT DATA SUMMARY

Company Y reference vehicle input data: test weight = 4856 lb.; 350 CID V-8 engine; frontal area = 23.6 ft.^{2}; drag coefficient = 0.50; 3 speed automatic transmission with torque converter; axle ratio = 2.73; bias ply tires; accessories - alt., P.S., fan. Run 401 with A/C not operating; run 451 with A/C operating.

SUMMARY OF RESULTS (air conditioning off)

		SIMULATION FUEL ECONOMY (MPG) run 401 - 4856 lb. - 2.73 axle	MANUFACTURER'S DATA (MPG) 4966 lb. - 2.73 axle
steady speed (MPH)	30	18.6	19.0
	40	18.5	-
	50	17.3	18.4
	60	15.4	-
	70	14.0	15.2
Federal Drive Cycle		10.36	-

COMMENTS

No manufacturer's data available for drive cycle economy.
Drive train has allowance of 93% tire efficiency, and 96% rear axle efficiency.

CONCLUSIONS

1. Reasonably good agreement with manufacturer's data.

TITLE

Single Parameter Changes in weight, drag, tires, axle ratio, and accessory load from CO X-compact reference car

RUN NO(S).

602, 603, 604, 605, 606, 607

PURPOSE

Determine the sensitivity of fuel economy to single parameter changes in vehicle weight, frontal area, drag, radial tires, axle ratio, and accessory loads

INPUT DATA SUMMARY

Same as CO X compact car (run 601) except as follows:
Run 602 - test weight = 3030 (10% reduction)
Run 603 - frontal area = 19.28 ft^2 (10% reduction)
Run 604 - drag coefficient = 0.423, (area = 19.28 ft^2, 20% aero drag reduction)
Run 605 - radial ply tires
Run 606 - axle ratio = 2.55 (9% reduction)
Run 607 - accessory load reduction to std. fan + const. 1.0 HP

SUMMARY OF RESULTS

Results are summarized in Table 4-1 which shows fuel economy in MPG for Federal Drive Cycle and steady speeds of 20, 30, 40, 50, 60, and 70 MPH. Also shown to right is a table of values listing percent increase in MPG over the reference vehicle (run 601) for the same operating conditions. This latter table shows the sensitivity of MPG to single parameter vehicle changes. These results are compared with similar results for CO X standard and CO Y compact and standard vehicles in Table 4-7.

COMMENTS

Constant accessory load case shows a 4 - 5% improvement in MPG for nearly all operating conditions.

CONCLUSIONS

Single parameter changes compare well with those from computer simulation on other reference vehicles and with information obtained from literature sources, shown in Table 4-7. Principal exception is somewhat larger effect of axle ratio reduction at 50 MPH and 70 MPH and lower effect of axle ratio reduction over Federal Cycle.

TITLE

Single parameter changes in weight, drag, tires, axle ratio, and accessory load from CO X - Standard car without A/C operating.

RUN NO.(s)

702, 703, 704, 705, 706, 707

PURPOSE

Determine the sensitivity of fuel economy to single parameter changes in vehicle weight, frontal area, drag, radial tires, axle ratio, and accessory loads.

INPUT DATA SUMMARY

Same as CO. X standard car (run 701) except as follows:

Run 702 - Test weight = 4508 lb. (10% reduction)
Run 703 - Frontal area= 22.45 Ft^2 (10% reduction)
Run 704 - Drag coeff= 0.45 (Area=22.45 Ft^2) (20% aero drag reduction)
Run 705 - Radial ply tires -
Run 706 - Axle Ratio= 2.50 (9% reduction)
Run 707 - Accessory load reduction to Std Fan + 1.5 HP

SUMMARY OF RESULTS

Results are summarized in Table 4-2 which shows fuel economy in MPG for Federal drive cycle and steady speeds of 20, 30, 40, 50, 60, and 70 MPH. Also shown to right is a table of values listing percent increase in MPG over the reference vehicle (Run 701) for the same operating conditions. This latter table shows the sensitivity of MPG to single parameter vehicle changes. These results are compared with similar results for Co X compact and Co Y compact and standard vehicles in Table 4-7.

COMMENTS

No attempt was made to explore the reasons for the anomolous results of zero improvement in drive cycle MPG for reduced axle ratio. All other reference vehicle cases show a small (~1%) improvement.

CONCLUSIONS

Single parameter changes compare well with those from computer simulation on other reference vehicles and with information obtained from literature sources as shown in Table 4-7 with the sole exception that axle ratio reduction has no effect on MPG over the Federal drive cycle.

The constant HP accessory load case improves drive cycle MPG by less than 1/2% and saves only 1 1/2-2% at high speed cruise. The savings is only 1/2 of that obtained when A/C is operating.

TITLE

Single parameter changes in weight, drag, tires, axle ratio, and accessory load from Co. X-standard car with A/C operating.

RUN NO.(s)

802, 803, 804, 805, 806, 807

PURPOSE

Determine the sensitivity of fuel economy to single parameter changes in vehicle weight, frontal area, drag, radial tires, axle ratio, and accessory loads.

INPUT DATA SUMMARY

Same as Co X standard car (Run 801) except as follows:

Run 802 - Test weight= 4508 lb. (10% reduction)
Run 803 - Frontal area = 22.45 ft^2(10% reduction)
Run 804 - Drag coeff= 0.45 (area=22.45Ft^2) (20% aero drag reduction)
Run 805 - Radial ply tires
Run 806 - Axle ratio = 2.50 (9% reduction)
Run 807 - Accessory load reduction to Std. fan + 3.7 HP

SUMMARY OF RESULTS

Results are summarized in Table 4-3 which shows fuel economy in MPG for Federal Drive Cycle and steady speeds of 20, 30, 40, 50, 60 and 70 MPH. Also shown to right is a table of values listing percent increase in MPG over the reference vehicle (Run 801) for the same operating conditions. This latter table shows the sensitivity of MPG to single parameter vehicle changes. These results are compared with similar results for Co X compact and Co. Y compact and standard vehicles in Table 4-7.

COMMENTS

No attempt was made to explore the reasons for the anomolous result of zero improvement in Drive cycle MPG for reduced axle ratio. All other reference vehicle cases show a small (~1%) improvement.

CONCLUSIONS

Single parameter changes compare well with those from computer simulation on other reference vehicles and with information obtained from literature sources as shown in Table 4-7 with the sole exception that axle ratio reduction has no effect on MPG over the Federal drive cycle.

The constant horsepower accessory load case improves driving cycle MPG by less than 1% but saves 3-4% at high speed cruise due mainly to reduced A/C load.

TITLE

Single parameter changes in weight, drag, tires, axle ratio, and accessory load from Co. Y - compact ref. car.

RUN NO.(s)

304, 305, 319′, 321′, 336, 310

PURPOSE

Determine the sensitivity of fuel economy to single parameter changes in vehicle weight, frontal area, drag, radial tires, axle ratio, and accessory loads.

INPUT DATA SUMMARY

Same as Co. Y compact car (Run 302) except as follows:

Run 304 - Test weight= 3477 (10% reduction)
Run 305′ - Frontal area= 19.71 FT^2 (10% reduction)
Run 319′ - Drag coeff = 0.50 (Area=19.71 FT^2) (22% Aero Drag Reduction)
Run 321′ - Radial Ply tires
Run 336 - Axle Ratio = 2.73 (11% reduction)
Run 310 - Accessory load reduction to Std. fan + 0.3 HP

SUMMARY OF RESULTS

Results are summarized in Table 4-4 which shows fuel economy in MPG for Federal Driving cycle and steady speeds of 20, 30, 40, 50, 60, and 70 MPH. Also shown to right is a table of values listing percent increase in MPG over the reference vehicle (run 302) for the same operating conditions. This latter table shows the sensitivity of MPG to single parameter vehicle changes. These results are compared with similar results for Co. Y standard and Co. X compact and standard vehicles in Table 4-7.

COMMENTS

The greater effect of reduced drag coeff at high speeds compared with the results for other reference vehicles is undoubtedly due to the high initial drag coeff. of this reference vehicle (0.568) compared with 0.50 or below for all other reference vehicles.

CONCLUSIONS

Single parameter changes compare well with those from computer simulation on other reference vehicles and with information obtained from literature sources as shown in Table 4-7. Principal exceptions are the lower effect of axle ratio at 50 MPH and the higher effect of drag reduction at 50 MPH and 70 MPH.

The constant accessory load case shows about 2% improvement in MPG over the entire operating range.

TITLE

Single parameter changes in weight, drag, tires, and axle ratio from CO Y standard car without A/C operating.

RUN NO.(s)

428, 402, 403, 413, 412

PURPOSE

Determine the sensitivity of fuel economy to single parameter changes in vehicle weight, frontal area, drag, radial tires, and axle ratio.

INPUT DATA SUMMARY

Same as CO Y standard car (run 401) except as follows:

Run 428 - test weight = 4356 lb (10% reduction)
Run 402 - frontal area = 21.3 ft^2 (10% reduction)
Run 403 - drag coeff. = 0.45 (area = 21.3 ft^2)(20% aero drag red.)
Run 413 - radial ply tires
Run 412 - axle ratio = 2.50 (9% reduction)

SUMMARY OF RESULTS

Results are summarized in Table 4-5 which shows fuel economy in MPG for Federal Driving Cycle and steady speeds of 20, 30, 40, 50, 60, and 70 MPH. Also shown to right is a table of values listing percent increase in MPG over the reference vehicle (run 401) for the same operating conditions. This latter table shows the sensitivity of MPG to the single parameter vehicle changes. These results are compared with similar results for CO Y compact and CO X compact and standard vehicles in Table 4-7.

COMMENTS

Constant speed assessory drive was not investigated as a single parameter change with this reference vehicle.

CONCLUSIONS

Single parameter changes compare well with those from computer simulation on other reference vehicles and with information obtained from literature sources shown in Table 4-7. Principal exception is somewhat lower effect of axle ratio reduction at 70 MPH. The cause of this descrepancy was not investigated.

TITLE

Single parameter changes in weight, drag, tires, and axle ratio from CO Y standard car with A/C operating.

RUN NO.(s)

479, 481, 452, 453, 463, 462

PURPOSE

Determine the sensitivity of fuel economy to single parameter changes in vehicle weight, frontal area, drag, radial tires and axle ratio.

INPUT DATA SUMMARY

Same as CO Y standard car (run 451) except as follows:
- Runs 479, 481 - test weight = 4256/4456 lb (8-12% reduction)
- Run 452 - frontal area = 21.3 ft^2 (10% reduction)
- Run 453 - drag coeff = 0.45 (area = 21.3 ft^2) (20% aero drag red.)
- Run 463 - radial ply tires
- Run 462 - axle ratio = 2.50 (9% reduction)

SUMMARY OF RESULTS

Results are summarized in Table 4-6 which shows fuel economy in MPG for Federal Driving Cycle and steady speeds of 20, 30, 40, 50, 60, and 70 MPH. Also shown to right is a table of values listing percent increase in MPG over the reference vehicle (run 451) for the same operating conditions. This latter table shows the sensitivity of MPG to the single parameter vehicle changes. These results are compared with similar results for CO Y compact and CO X compact and standard vehicles in Table 4-7.

COMMENTS

Constant speed assessory drive was not investigated as a single parameter change with this reference vehicle.

CONCLUSIONS

Single parameter changes compare well with those from computer simulation on other reference vehicles and with information obtained from literature sources shown in Table 4-7. This case shows no descrepancies from the general trend of single parameter effects.

TITLE

Cumulative changes to develop synthesized vehicle with reductions in frontal area, drag, weight and axle ratio and use of radial tires - Co. X compact car.

RUN NO.(s)

603, 603 1/2*, 611, 612, 613, 614, 615

PURPOSE

Determine the fuel economy of synthesized vehicle and the cumulative effect of changes in vehicle area, drag, weight, tires, axle ratio, and accessory power.

INPUT DATA SUMMARY

Same as Co. X compact car (run 601) except as follows:

Run 603-Like 601 with frontal area= 19.28FT^2 (10% reduction)
Run 603 1/2*-Like 603 with drag coeff.= 0.45 (4% reduction)
Run 611-Like 603 1/2* with weight= 3030 lb. (10% reduction)
Run 612-Like 611 with radial ply tires
Run 613-Like 612 with axle ratio= 2.55 (9% reduction)
Run 614-Like 613 with drag coeff.=0.423 (10% reduction over ref. vehicle)
Run 615-Like 613 with constant 1.0 H.P. access. load + std. fan

SUMMARY OF RESULTS

Results are summarized in Table 4-1 which shows fuel economy in MPG for federal driving cycle and steady speeds of 20, 30, 40, 50, 60 and 70 MPH. Also shown to right are tabulated values listing percent increase in MPG over the reference vehicle (Run 601) for the same operating conditions. These results are compared with those from runs on other reference cars in Table 4-8.

COMMENTS

The sequence of cumulative changes for this reference vehicle were based on a reduction of drag coefficient to 0.45, (a 4% reduction from the reference vehicle) rather than the usual 10% reduction since this vehicle has a lower than ordinary drag coefficient initially.

Run 614 represents a synthesized vehicle with the full 10% drag coeff. reduction.

* No computer run was made for the case identified as 603 1/2. This case falls nearly midway between cases 603 and 604 and results were estimated by interpolating between these two cases.

CONCLUSIONS

The total fuel economy improvement resulting from simultaneous application of all the above vehicle changes (synthesized vehicle - run 615) is about 12% for the FDC and about 20% for steady speed driving. Excluding the constant HP accessory drive feature (run 614) the improvement is 8% for FDC and 12-15% during steady speed.

TITLE

Cumulative changes to develop synthesized vehicle with reductions in frontal area, drag, weight, and axle ratio and use of radial tires - Co. X standard car without A/C operating.

RUN NO.(s)

703, 704, 711, 712, 713, 714

PURPOSE

Determine the fuel economy of synthesized vehicle and the cumulative effect of changes in vehicle area, drag, weight, tires, axle ratio, and accessory power.

INPUT DATA SUMMARY

Same as Co. X standard Car (Run 701) except as follows:

Run 703 - Like 701 with frontal area= 22.45FT^2 (10% reduction)
Run 704 - Like 703 with drag coeff.= 0.45 (10% reduction)
Run 711 - Like 704 with weight= 4508 lb. (10% reduction)
Run 712 - Like 711 with radial ply tires
Run 713 - Like 712 with axle ratio= 2.50 (9% reduction)
Run 714 - Like 713 with constant 1.5 HP access. Load + std. fan.

SUMMARY OF RESULTS

Results are summarized in Table 4-2 which shows fuel economy in MPG for federal drive cycle and steady speeds of 20, 30, 40, 50, 60 and 70 MPH. Also shown to right is a table of values listing percent increase in MPG over the reference vehicle (Run 701) for the same operating conditions.
The results from the above runs are compared with results from similar runs on the other reference cars in Table 4-8.

COMMENTS

Results for this reference vehicle are in generally good agreement with those for other reference vehicles as shown in Table 4-8.

CONCLUSIONS

The total fuel economy improvement resulting from simultaneous application of all of the above vehicle changes (synthesized vehicle - run 714) is about 12% for the FDC and about 20% for steady speed driving. Excluding the constant HP accessory drive feature (run 713) the improvement is 8-9% for FDC and 12-15% during steady speed.

TITLE

Cumulative Changes to develop synthesized vehicle with reductions in frontal area; drag, weight and axle ratio and use of radial tires - Co. X standard car with A/C operating.

RUN NO.(s)

803, 804, 811, 812, 813, 814

PURPOSE

Determine the fuel economy of synthesized vehicle and the cumulative effect of changes in vehicle area, drag, weight, tires, axle ratio, and accessory power.

INPUT DATA SUMMARY

Same as Co. X standard car (Run 801) except as follows:

Run 803 - Like 801 with frontal area= 22.45 FT^2 (10% reduction)
Run 804 - Like 803 with drag coeff= 0.45 (10% reduction)
Run 811 - Like 804 with weight= 4508 lb. (10% reduction)
Run 812 - Like 811 with radial ply tires
Run 813 - Like 812 with axle ratio= 2.50 (9% reduction)
Run 814 - Like 813 with constant 3.7 HP access. load + std. fan.

SUMMARY OF RESULTS

Results are summarized in Table 4-3 which shows fuel economy in MPG for federal driving cycle and steady speeds of 20, 30, 40, 50, 60 and 70 MPH. Also shown to right are tabulated values listing percent increase in MPG over the reference vehicle (Run 801) for the same operating conditions.
The results from the above runs are compared with results from similar runs on the other reference cars in Table 4-8.

COMMENTS

Results for this reference vehicle are in generally good agreement with those for other reference vehicles as shown in Table 4-8.

CONCLUSIONS

The total fuel economy improvement resulting from simultaneous application of all the above vehicle changes (synthesized vehicle - run 814) is about 7% for the FDC and about 15-20% for steady speed driving. Excluding the constant HP accessory drive feature (run 813) the improvement is 6.5% for FDC and 12-18% during steady speed.

TITLE

Cumulative changes to develop synthesized vehicle with reductions in frontal area, drag, weight and axle ratio and use of radial tires - Co. Y compact car.

RUN NO.(s)

305', 319', 320, 318', 309', 316'

PURPOSE

Determine the fuel economy of synthesized vehicle and the cumulative effect of changes in vehicle area, drag, weight, tires, axle ratio, and accessory power.

INPUT DATA SUMMARY

Same as Co. Y compact car (Run 302) except as follows:

Run 305' - Like 302' with frontal area= 19.71 FT^2 (10% reduction)
Run 319' - Like 305' with drag coeff.= 0.50 (12% reduction)
Run 320 - Like 319' with weight= 3477 lb. (10% reduction)
Run 318' - Like 320 with radial ply tires
Run 309' - Like 318' with axle ratio= 2.73 (11% reduction)
Run 316' - Like 309' with constant 0.3 HP access. load + std. fan.

SUMMARY OF RESULTS

Results are summarized in Table 4-4 which shows fuel economy in MPG for federal driving cycle and steady speeds of 20, 30, 40, 50, 60 and 70 MPH. Also shown to right are tabulated values listing percent increase in MPG over the reference vehicle (Run 302') for the same operating conditions. The results from the above runs are compared with results from similar runs on the other reference cars in Table 4-8.

COMMENTS

Results for this reference vehicle are in generally good agreement with those for other reference vehicles as shown in Table 4-8.

CONCLUSIONS

The total fuel economy improvement resulting from simultaneous application of all the above vehicle changes (synthesized vehicle - run 316) is about 13% for the FDC and about 20-30% for steady speed driving. Excluding the constant HP accessory drive feature (run 309) the improvement is 11% for FDC and 15-25% during steady speed.

TITLE

Cumulative changes to develop synthesized vehicle with reductions in frontal area, drag, weight and axle ratio and use of radial tires - Co. Y standard car without A/C operating.

RUN NO.(s)

402, 403, 429, 430, 436, 438

PURPOSE

Determine the fuel economy of synthesized vehicle and the cumulative effect of changes in vehicle area, drag, weight, tires, axle ratio, and accessory power.

INPUT DATA SUMMARY

Same as Co. Y standard car (Run 401) except as follows:

Run 402 - Like 401 with frontal area= 21.3FT^2 (10% reduction)
Run 403 - Like 402 with drag coeff.= 0.45 (10% reduction)
Run 429 - Like 403 with weight= 4356 lb. (10% reduction)
Run 430 - Like 429 with radial ply tires
Run 436 - Like 430 with axle ratio= 2.50 (9% reduction)
Run 438 - Like 436 with constant 0.5 HP access. load + std. fan

SUMMARY OF RESULTS

Results are summarized in Table 4-5 which shows fuel economy in MPG for federal driving cycle and steady speeds of 20, 30, 40, 50, 60 and 70 MPH. Also shown to right are tabulated values listing percent increase in MPG over the reference vehicle (Run 401) for the same operating conditions.
The results from the above runs are compared with results from similar runs on the other reference cars in Table 4-8.

COMMENTS

Results for this reference vehicle are in generally good agreement with those for other reference vehicles as shown in Table 4-8.

CONCLUSIONS

The total fuel economy improvement resulting from simultaneous application of all the above vehicle changes (synthesized vehicle - run 438) is about 9% for the FDC and about 15-20% for steady speed driving. Excluding the constant HP accessory drive feature (run 430) the improvement is 8.3% for FDC and 10-18% during steady speed.

TITLE

Cumulative changes to develop synthesized vehicle with reductions in frontal area, drag, weight and axle ratio and use of radial tires - Co. Y standard car with A/C operating.

RUN NO.(s)

452, 453, 482, 486, 487, 489

PURPOSE

Determine the fuel economy of synthesized vehicle and the cumulative effect of changes in vehicle area, drag, weight, tires, axle ratio, and accessory power.

INPUT DATA SUMMARY

Same as Co. Y standard car (Run 451) except as follows:

Run 452 - Like 451 with frontal area= 21.3 FT^2 (10% reduction)
Run 453 - Like 452 with drag coeff.= 0.45 (10% reduction)
Run 482 - Like 453 with weight= 4356 lb. (10% reduction)
Run 486 - Like 482 with radial ply tires
Run 487 - Like 486 with axle ratio= 2.50 (9% reduction)
Run 489 - Like 487 with constant 4.2 HP access. load + std. fan.

SUMMARY OF RESULTS

Results are summarized in Table 4-6 which shows fuel economy in MPG for federal driving cycle and steady speeds of 20, 30, 40, 50, 60 and 70 MPH. Also shown to right are tabulated values listing percent increase in MPG over the reference vehicle (Run 451) for the same operating conditions. The results from the above runs are compared with results from similar runs on the other reference cars in Table 4-8.

COMMENTS

Results for this reference vehicle are in generally good agreement with those for other reference vehicles as shown in Table 4-8.

CONCLUSIONS

The total fuel economy improvement resulting from simultaneous application of all the above vehicle changes (synthesized vehicle - run 489) is about 17% for the FDC and about 25-30% for steady speed driving. Excluding the constant HP accessory drive feature (run 487) the improvement is 9% for FDC and 15-20% during steady speed. The constant HP accessory drive provides a substantial economy improvement with A/C operating but not significant improvement with A/C off.

TITLE

Continuously variable transmission (CVT) - Co X compact

RUN NO.(s)

608, 616, 617

PURPOSE

Determine the improvement in fuel economy from the use of a CVT with reference vehicle and synthesized vehicle

INPUT DATA SUMMARY

Run 608 - same as ref. vehicle (run 601) except with CVT
Run 616 - same as synth. vehicle (run 613) except with CVT
Run 617 - same as synth. vehicle (run 614) except with CVT

CVT modeled as follows:

1. Transmission ratio always selected to allow engine to operate at best BSFC condition for required power level during both steady state and transient operation.
2. Transmission efficiency = 90% under all conditions.

SUMMARY OF RESULTS

Results are presented in Table 4-1 where fuel economy in MPG is tabulated for the Federal Drive Cycle and for steady speeds of 20, 30, 40, 50, 60, and 70 MPH. Percent increase in MPG over the reference vehicles is listed in the right hand table for the same vehicle operating conditions.
These results are compared with similar results for the Co. X standard and Co. Y compact and standard cars in Table4-10 which shows percent increase in MPG due to effect of CVT for both reference vehicles and synthesized vehicles.

COMMENTS

CVT computer model does not account for limited ratio range required in actual hardware. Therefore some clutch slippage must occur at low vehicle speeds. This will reduce MPG over the FDC somewhat.

CONCLUSIONS

CVT (90% efficient) appears to improve fuel economy by about 20-30%. Improvement is about 20% over federal driving cycle and about 20-40% during steady speed driving.

TITLE

Continuously variable transmission (CVT) - Co. X standard

RUN NO.(s)

708, 715, A/C not operating
808, 815, A/C operating

PURPOSE

Determine the improvement in fuel economy from the use of a CVT with reference vehicle and synthesized vehicle - with and without A/C operating.

INPUT DATA SUMMARY

Run 708 - Same as Ref. vehicle (Run 701) except with CVT
Run 715 - Same as Synth. vehicle (Run 712) except with CVT
Run 808 - Same as ref. vehicle (Run 801) except with CVT
Run 815 - Same as synth. vehicle (Run 812) except with CVT

CVT Modeled as follows:

1. Transmission ratio always selected to allow engine to operate at best BSFC condition for required power level during both steady state and transient operation.
2. Transmission efficiency = 90% under all conditions.

SUMMARY OF RESULTS

Results are presented in Tables 4-2 and 4-3 where fuel economy in MPG is tabulated for the federal drive cycle and for steady speeds of 20, 30, 40, 50, 60, and 70 MPH. Percent increase in MPG over the reference vehicles is listed in the right hand table for the same vehicle operating conditions.

These results are compared with similar results for the Co. X compact car and Co. Y compact and standard cars in Table 4-10which shows percent increase in MPG due to effect of CVT for both reference vehicles and synthesized vehicles.

COMMENTS

CVT computer model does not account for limited ratio range required in actual hardware. Therefore some clutch slippage must occur at low vehicle speeds. This will reduce MPG over the FDC somewhat.

CONCLUSIONS

CVT (90% efficient) appears to improve fuel economy by about 20-30%. Improvement is about 25% over federal driving cycle and about 10-40% during steady speed driving.

TITLE

Continuously variable transmission (CVT) - Co. Y compact

RUN NO.(s)

351, 352, 353

PURPOSE

Determine the improvement in fuel economy from the use of a CVT with reference vehicle and synthesized vehicle.

INPUT DATA SUMMARY

Run 351 - Same as ref. vehicle (Run 302) except with 100% CVT
Run 352 - Same as ref. vehicle (Run 302) except with 90% CVT
Run 353 - Same as synth. vehicle (Run 318) except with 90% CVT

CVT modeled as follows:

1. Transmission ratio always selected to allow engine to operate at best BSFC condition for required power level during both steady state and transient operation.
2. Transmisison efficiency = 90% under all conditions.

SUMMARY OF RESULTS

Results are presented in Table 4-4 where fuel economy in MPG is tabulated for the federal drive cycle and for steady speeds of 20, 30, 40, 50, 60, and 70 MPH. Percent increase in MPG over the reference vehicles is listed in the right hand table for the same vehicle operating conditions. These results are compared with similar results for the Co. X compact and standard cars and Co. Y standard in Table4-10which shows percent increase in MPG due to effect of CVT for both reference vehicles and synthesized vehicles.

COMMENTS

Run 351 was performed with 100% efficient CVT to show effect of ideal (or perfect) transmission.

Comparison of results from Runs 351 and 352 show effect of CVT inefficiency on fuel economy (Table 304).

Effect of CVT may be slightly greater with Co. Y compact than with other vehicles (especially over federal drive cycle) due to 2 speed transmission in ref. vehicle (all others have 3 speed).

CONCLUSIONS

CVT (90% efficient) appears to improve fuel economy by about 20-30%. Improvement is about 25% over federal driving cycle and about 20-40% during steady speed driving.

TITLE

Continuously variable transmission (CVT) - Co. Y standard

RUN NO(S)

442, 443, 444, A/C not operating
492, 493, 494, A/C operating

PURPOSE

Determine the improvement in fuel economy from the use of a CVT with reference vehicle and synthesized vehicle - with and without A/C operating. Also determine effect of const. HP access. drive with CVT.

INPUT DATA SUMMARY

Run 442 - same as ref. vehicle (run 401) except with 90% CVT
Run 443 - same as synth. vehicle (run 430) except with CVT
Run 444 - same as synth. vehicle (run 438) const acc HP) except with CVT
Run 492 - same as ref. vehicle (run 451) except with CVT
Run 493 - same as synth. vehicle (run 486) except with CVT
Run 494 - same as synth. vehicle (run 489) const. acc. HP) except with CVT
CVT modeled as follows:
1. Transmission ratio always selected to allow engine to operate at best BSFC condition for required power level during both steady state and transient operation.
2. Transmission efficiency = 90% under all conditions.

SUMMARY OF RESULTS

Results are presented in Tables 4-5 and 4-6 where fuel economy in MPG is tabulated for the Federal Drive Cycle and for steady speeds of 20, 30, 40, 50, 60, and 70 MPH. Percent increase in MPG over the reference vehicles is listed in the right hand table for the same vehicle operating conditions. These results are compared with similar results for the Co. X compact and standard and Co. Y compact cars in Table 4-10 which shows percent increase in MPG due to effect of CVT for both reference vehicles and synthesized vehicles.

COMMENTS

CVT computer model does not account for limited ratio range required in actual hardware. Therefore some clutch slippage must occur at low vehicle speeds. This will reduce MPG over the FDC somewhat.

CONCLUSIONS

CVT (90% efficient) appears to improve fuel economy by about 20-25%. Improvement is about 20% over federal driving cycle and about 10-40% during steady speed driving.

TITLE

4 speed automatic transmission with lock-up torque converter - on Co. Y compact and standard reference and synthesized vehicle

RUN NO(S)

361, 362, 511, 512, 561, 562

PURPOSE

Determine the fuel economy improvement available by application of 4 speed automatic transmission with torque converter lock-up - compared with conventional 3 speed (or 2 speed) automatic transmission.

INPUT DATA SUMMARY

Same as Co. Y reference vehicles, except 4 speed automatic transmission with reference torque converter for 1st gear, and fully locked-up TC in 2nd, 3rd, 4th gears. Gear ratios are: gear 1 = 2.0; gear 2 = 1.5; gear 3 = 1.0; gear 4 = 0.8. Rear axle ratio is 3.08. Shift logic used is: Compact (run 361, 362) - gear 1-2 @ 15 MPH, 2-3 @ 22 MPH, 3-4 @ 27 MPH; Standard (run 511, 512, 561, 562) - gear 1-2 @ 16 MPH, 2-3 @ 24 MPH, 3-4 @ 30 MPH.
Transmission data applied to following vehicles:
Run 361 - to Co. Y compact reference vehicle (run 302)
Run 362 - to Co. Y synthesized vehicle (run 318)
Run 511 - to Co. Y standard reference vehicle w/o A/C (run 401)
Run 512 - to Co. Y standard synthesized vehicle w/o A/C (run 430)
Run 561 - to Co. Y standard reference vehicle with A/C (run 451)
Run 562 - to Co. Y standard synthesized vehicle with A/C (run 486)

SUMMARY OF RESULTS

Results for MPG over Federal Drive Cycle and at steady speeds of 20, 30, 40, 50, 60, and 70 MPH are summarized in Table 4-11for the six cases listed above. Also tabulated to right in Table 4-11are values of percent improvement over the corresponding baseline cases employing the conventional 3 speed (or 2 speed) automatic transmission to illustrate the improvement due to the 4 speed lock-up transmission. In addition, for the synthesized vehicles a set of figures are included to illustrate the total percent improvement in MPG over the reference vehicle cases.

COMMENTS

The choice of transmission gear ratios, shift logic and axle ratio could have significant effect on fuel economy, and would also affect acceleration capability. These changes were not fully explored.

CONCLUSIONS

4 speed lock-up transmission shows about a 6-10% improvement in MPG (average) over the corresponding case with conventional 3 speed automatic. Synthesized standard car results show slightly less improvement.
A total improvement over reference vehicle of 20-25% is available in synthesized compact car whereas the total improvement is 15-20% for standard car.

TITLE

430 CID Ford stratified charge engine - with Co. Y standard reference vehicle - No A/C

RUN NO.(s)

501

PURPOSE

Determine fuel economy of standard size car with stratified charge engine and compare with reference vehicle.

INPUT DATA SUMMARY

Co. Y standard reference vehicle (Run 401) w/o-A/C operating except engine replaced with 430 CID-V-8 Ford FCP stratified charge engine described in SAE 680041 engine map taken from Fig. 35 of SAE 680041.

SUMMARY OF RESULTS

	FUEL ECONOMY - MPG					
	FDC	Steady Speed - MPH 30	40	50	60	70
Run 501 (FCP Engine)	12.33	24.3	22.6	19.7	17.0	14.5
Run 401 (Ref. Vehicle)	10.36	18.6	18.5	17.3	15.4	14.0
Percent increase in MPG Due to stratified charge engine in computer simulation	19	30.8	22.7	14.0	10.0	3.8
% Improvement from Ford Test Data (SAE 680041)		31	34	27	30	32

COMMENTS

1. The 430 CID stratified charge engine with a maximum power capability of 210 H.P. is compared with a 350 CID reference vehicle engine with a maximum power level of 150 HP. In order to make a fair comparison the stratified charge engine should have been sealed down to a comparable power level but time was not available for that study.

2. FCP Engine performance map used represents a stratified charge engine without emission controls. Effect of emission controls charges is unknown to authors.

3. Not clear whether FCP engine map included vehicle exhaust system and air cleaner.

CONCLUSIONS

1. These results indicate that the stratified charge engine can offer improvement in vehicle MPG on the order of 20 percent for urban driving and about 10% for highway driving. At high road speeds, or near full load the stratified charge engine economy becomes equal to a conventional engine.

2. Ford test results show somewhat greater economy improvement at higher speeds. This is undoubtedly due to the greater displacement of the FCP engine compared with Co. Y standard 350 CID-V8. Ford test data compared equal displacement engine.

TITLE

237 CID Diesel Engine in CoX compact reference vehicle - also with 4 speed lock-up automatic and continuously variable transmissions.

RUN NO(S)

621, 623, 625, 627, 630, 631

PURPOSE

Determine the improvement in fuel economy resulting from the substitution of a diesel engine for the gasoline engine - also examine effect of various transmissions and axle ratios with the diesel engine.

INPUT DATA SUMMARY

Same as CoX compact reference vehicle (Run 601) except w/237 CID Diesel engine and transmissions and axle ratios as follows:

Run No.	Transmission Type	Gear Ratios 1	2	3	4	Axle Ratio	Relative Accel. @ 50MPH
621	3 Sp. Auto	2.46	1.46	1.0	-	3.08	1.01
627	"	"	"	"	-	2.79	0.88
625	4 Sp. Lock-up Auto.	3.25	2.15	1.0	0.71	2.79	0.89*
630	"	"	"	"	"	2.55	0.76*
631	"	"	"	"	"	2.30	0.64*
623	90% eff. CVT	-	-	-	-	2.79	-

* These accelerations result from downshift into 3rd gear.

SUMMARY OF RESULTS

Results are summarized in Table 4-12 which shows fuel economy in MPG for Federal Drive Cycle and steady speeds of 20, 30, 40, 50, 60 and 70 MPH. Also shown to right is a table of values listing percent increase in MPG over the reference vehicle (run 601) for the same operating conditions. Since the various transmission and axle ratio options increase fuel mileage at the expense of performance, the WOT acceleration relative to the reference vehicle acceleration is shown for 30, 50 and 70 MPG at the extreme right of Table 4-12. Relative acceleration values at 50 MPH are also listed in input data table above.

COMMENTS

The 4 speed transmission with overdrive gear and the CVT both increase fuel mileage during cruise by allowing the engine to run at lower RPM. This severely degrades "direct gear" acceleration performance and makes downshifting necessary for acceptable acceleration.

Improvements due to diesel engine are less with this vehicle than for CoY compact and CoX and Y standard vehicles due principally to the relatively efficient gasoline engine installation of this reference vehicle.

4 speed lock-up transmission shows lower MPG over FDC due to higher average engine speeds caused by higher ratios in gears 1 & 2.

CONCLUSIONS

The diesel engine offers a substantial improvement in MPG at light load. The improvement is much less at high vehicle speeds unless acceleration performance is sacrificed or a downshifting transmission is employed.

1. At equal acceleration performance (run 621), the diesel engine alone increases MPG by 23% over the FDC and at 20 MPH but from 40-70 MPH the MPG increases only 3-4%.
2. By degrading acceleration performance about 8-10% (run 627) the MPG increase becomes 25% over the FDC and 12-13% from 30-70MPH.
3. Adding a 4 speed lock-up transmission (runs 625, 630) brings the MPG improvement to 45-53% for steady speeds of 40-70 MPH while degrading WOT acceleration by 10-20%. (FDC mileage decreased slightly because excessive step-up ratios were assumed for gears 1 and 2.)
4. Combining the CVT with a diesel boosts MPG improvement to 48% over the FDC while retaining a 45-55% improvement at 30-70 MPH.

TITLE

237 CID Diesel Engine in CoX compact synthesized vehicle - also with 4 speed lock-up automatic and continuously variable transmissions.

RUN NO(S)

622, 624, 626, 628, 629, 632

PURPOSE

Determine the improvement in fuel economy resulting from the substitution of a diesel engine for the gasoline engine --- Also examine effect of various transmissions and axle ratios with the diesel engine.

INPUT DATA SUMMARY

Same as CoX compact synthesized vehicle (Run 613) except w/237 CID diesel engine and transmissions and axle ratios as follows:

Run No.	Transmission Type	Gear Ratios 1	2	3	4	Axle Ratio	Relative Accel. @ 50 MPH
622	3 Sp. Auto	2.46	1.46	1.0	-	2.79	1.07
628	"	"	"	"	-	2.55	0.96
629	"	"	"	"	-	2.30	0.83
626	4 Sp. Lock-up Auto	3.25	2.15	1.0	0.71	2.55	0.941*
632	"	"	"	"	"	2.30	0.79 *
624	90% Eff. CVT	----------------------				2.55	-

* These accelerations result from downshift into 3rd gear.

SUMMARY OF RESULTS

Results are summarized in Table 4-12 which shows fuel economy in MPG for Federal Drive Cycle and steady speeds of 20, 30, 40, 50, 60 and 70 MPH. Also shown to right is a table of values listing percent increase in MPG over the reference vehicle (run 601) for the same operating conditions. Since the various transmission and axle ratio options increase fuel mileage at the expense of performance, the WOT acceleration relative to the reference vehicle acceleration is shown for 30, 50 and 70 MPG at the extreme right of Table 4-12. Relative acceleration values at 50 MPH are also listed in input data table above.

COMMENTS

4 Speed lock-up and CV transmissions. Both require downshifting to obtain acceptable acceleration performance.

4 speed lock-up transmission shows lower MPG over FDC due to higher average engine speeds caused by higher ratios in gears 1 & 2.

Improvements due to diesel engine are less with this vehicle than for CoY compact and CoX and Y standard vehicles due principally to the relatively efficeint gasoline engine installation of this reference vehicle.

CONCLUSIONS

The diesel engine in combination with about 10% reduction in vehicle weight, area, drag, axle ratio and rolling resistance provides a substantial increase in MPG over the entire operating range.

1. At equal acceleration performance (run 628) the diesel engine and synthesized vehicle increase MPG by 38% over the FDC and by about 30% at steady speed.

2. By degrading acceleration performance about 10-15% (run 629) the MPG increase becomes about 39% over the FDC and about 35% for steady speed driving.

3. Adding a 4 speed lock-up transmission (runs 626, 632) brings the MPG improvement to 70-80% for steady speed driving with 0-15% degradation in WOT acceleration from the reference vehicle. (FDC mileage decreased slightly because excessive step-up ratios were assumed for transmission gears 1 and 2.)

4. Combining the CVT with the diesel in the synthesized vehicle, the total increase in MPG is 60% over the FDC and about 70-85% at steady speed.

TITLE

326 CID diesel engine in CO X standard reference vehicle - also with 4 speed lock-up automatic and continuously variable transmissions

RUN NO(S)

721, 722, 732, 727, 728, 731, 734 (A/C-off)
821, 822, 823, 827, 828, 831, 834 (A/C-on)

PURPOSE

Determine the improvement in fuel economy resulting from the substitution of a diesel engine for the gasoline engine—also examine effect of various transmissions and axle ratios with the diesel engine.

INPUT DATA SUMMARY

Same as CO X standard reference vehicle (runs 701, 801) except w/326 CID diesel engine and transmissions and axle ratios as follows:

Run Nos.	Transmission Type	Gear Ratios 1	2	3	4	Axle Ratio	Relative Accel @ 50 MPH
721, 821	3 speed auto	2.46	1.46	1.0	-	3.05	0.76
722, 822	"	"	"	"	-	2.75	0.67
723, 823	"	"	"	"	-	2.50	0.59
727, 827	4 sp. lock-up auto #1	2.5	1.55	1.0	0.68	2.75	0.66*
728, 828	"	"	"	"	"	2.50	0.57*
731, 831	4 sp. lock-up auto #2	3.2	2.1	1.0	0.68	2.50	0.57*
734, 834	90% eff. CVT	-	-	-	-	2.50	-

*These accelerations result from downshift into 3rd gear.

SUMMARY OF RESULTS

Results are summarized in Tables 4-13 and 14 which shows fuel economy in MPG for Federal Drive Cycle and steady speeds of 20, 30, 40, 50, 60, and 70 MPH. Also shown to right is a table of values listing percent increase in MPG over the reference vehicle (runs 701, 801) for the same operating conditions. Since the various transmission and axle ratio options increase fuel mileage at the expense of performance, the WOT acceleration relative to the reference vehicle acceleration is shown for 30, 50, and 70 MPG at the extreme right of Tables 4-13 and 14. Relative acceleration values at 50 MPH are also listed in input data table above.

COMMENTS

The 4 speed transmission with overdrive gear and the CVT both increase fuel mileage during cruise by allowing the engine to run at lower RPM. This severely degrades "direct gear" acceleration performance and makes downshifting necessary for acceptable acceleration

Because of CO X standard reference car has a 14% higher power to weight ratio than any of the other reference vehicles, the 326 CID diesel installation provides substantially poorer relative acceleration. To make these results more comparable with the other reference vehicles the relative acceleration figures should be increased about 15%.

Acceleration performance was not calculated for cases with air conditioning "on".

CONCLUSIONS

The diesel engine offers a substantial improvement in MPG at light load. The improvement is much less at high vehicle speeds unless acceleration performance is sacrificed or a downshifting transmission is employed.

1. At 25% reduced acceleration* performance (run 721) the diesel engine alone increases MPG by 29% over the FDC and up to 25 MPH but at 70 MPH the MPG increases only 7%.
2. By degrading acceleration performance an additional 10% (run 722) the MPG increase becomes 30% over the FDC and increases another 5-7% for steady speed driving.
3. Adding a four speed lock-up transmission (run 727) brings the MPG improvement to 31% over the FDC and to about 50% for steady speed driving while degrading acceleration* about 35% from the reference vehicle (only 10% worse than basic diesel run 721).
4. Combining the CVT with a diesel boosts MPG improvement to 43% over the FDC while retaining an average 50% MPG improvement at steady speeds of 40-70 MPH.

TITLE

326 CID diesel engine in CO X standard synthesized vehicle - also with 4 speed lock-up automatic and continuously variable transmissions

RUN NO(S)

724, 725, 726, 729, 730, 732, 733, 735 (A/C-off)
824, 825, 826, 829, 830, 832, 833, 835 (A/C-on)

PURPOSE

Determine the improvement in fuel economy resulting from the substitution of a diesel engine for the gasoline engine--also examine effect of various transmissions and axle ratios with the diesel engine.

INPUT DATA SUMMARY

Same as CO X standard synthesized vehicle (runs 713, 813) except 2/ 326 CID diesel engine and transmissions and axle ratios as follows:

Run Nos.	Transmission Type	Gear Ratios 1	2	3	4	Axle Ratio	Relative Accel @ 50 MPH
724, 824	3 speed auto	2.46	1.46	1.0	-	2.75	0.79
725, 825	"	"	"	"	-	2.50	0.70
726, 826	"	"	"	"	-	2.30	0.64
729, 829	4 sp. lock-up auto #1	2.5	1.55	1.0	0.68	2.50	0.70*
730, 830	"	"	"	"	"	2.30	0.61*
732, 832	4 sp. lock-up auto #2	3.2	2.1	1.0	0.68	2.50	0.70*
733, 833	"	"	"	"	"	2.30	0.61*
735, 835	90% eff. CVT	-	-	-	-	2.5	-

*These accelerations result from downshift into 3rd gear.

SUMMARY OF RESULTS

Results are summarized in Tables 4-13 and 14 which shows fuel economy in MPG for Federal Drive Cycle and steady speeds of 20, 30, 40, 50, 60, and 70 MPH. Also shown to right is a table of values listing percent increase in MPG over the reference vehicle (runs 701, 801) for the same operating conditions. Since the various transmission and axle ratio options increase fuel mileage at the expense of performance, the WOT acceleration relative to the reference vehicle acceleration is shown for 30, 50, and 70 MPG at the extreme right of Tables 4-13 and 14. Relative acceleration values at 50 MPH are also listed in input data table above.

COMMENTS

4 speed lock-up and CV transmissions both require downshifting to obtain acceptable acceleration performance.

Because of CO X standard reference car has a 15% higher power to weight ratio than any of the other reference vehicles, the 326 CID diesel installation provides substantially poorer relative acceleration. To make these results more comparable with the other reference vehicles the relative acceleration figures should be increased about 15%.

Acceleration performance was not calculated for cases with air conditioning "on".

CONCLUSIONS

The diesel engine in combination with about 10% reduction in vehicle weight, area, drag, axle ratio and rolling resistance provides a substantial increase in MPG over the entire operating range.

1. With acceleration performance about 20% below this reference vehicle (but nearly equal to the other reference vehicles**) the diesel engine and synthesized vehicle increase MPG by 39% over the FDC and by about 32% at steady speed. (run 724)
2. By degrading acceleration about 10% (from run 724) the MPG increase becomes 40% over the FDC and about 38% for steady speed driving. (run 725)
3. Adding a 4 speed lock-up transmission (run 729) brings the MPG improvement to 43% over the FDC and about 75-80% for steady speed driving with about 10% performance degradation from the base case (run 724).
4. Combining the CVT with the diesel in the synthesized vehicle, the total increase in MPG is 52% over the FDC and about 60-80% at steady speed.

TITLE

237 CID Diesel engine in CoY compact reference vehicle - also with 4 speed lock-up automatic and continuously variable transmissions.

RUN NO(S)

371, 372, 375, 376, 379, 381, 382, 383

PURPOSE

Determine the improvement in fuel economy resulting from the substitution of a diesel engine for the gasoline engine --- Also examine effect of various transmissions and axle ratios with the diesel engine.

INPUT DATA SUMMARY

Same as CoY compact reference vehicle (run 302) except w/237 CID diesel engine and transmissions and axle ratios as follows:

Run No.	Transmission Type	Gear Ratios 1	2	3	4	Axle Ratio	Relative Accel. @ 50 MPH
371	2 Speed Auto	1.82	1.0	1.0	-	3.08	0.87
372	"	"	"	"	-	2.55	0.66
375	3 Speed Auto	2.46	1.46	1.0	-	3.08	0.88
376	"	"	"	"	-	2.79	0.77
381	4 Speed Auto	3.25	2.15	1.0	0.71	2.79	0.73*
382	"	"	"	"	"	2.55	0.62*
383	"	"	"	"	"	2.30	0.51*
379	90% Eff. CVT	----------				2.55	-

* These accelerations results from downshift into 3rd gear.

SUMMARY OF RESULTS

Results are summarized in Table 4-15 which shows fuel economy in MPG for Federal Drive Cycle and steady speeds of 20, 30, 40, 50, 60 and 70 MPH. Also shown to right is a table of values listing percent increase in MPG over the reference vehicle (run 302) for the same operating conditions. Since the various transmission and axle ratio options increase fuel mileage at the expense of performance, the WOT acceleration relative to the reference vehicle acceleration is shown for 30, 50 and 70 MPG at the extreme right of Table 4-15. Relative acceleration values at 50 MPH are also listed in input data table above.

COMMENTS

The 4 speed transmission with overdrive gear and the CVT both increase fuel mileage during cruise by allowing the engine to run at lower RPM. This severely degrades "direct gear" acceleration performance and makes downshifting necessary for acceptable acceleration.

4 speed lock-up transmission #2 shows lower MPG over FDC due to higher average engine speeds caused by higher ratios in gears 1 & 2.

This vehicle shows a greater improvement due to diesel engine at high vehicle speeds due mainly to the high initial axle ratio of the reference vehicle.

CONCLUSIONS

The diesel engine offers a substantial improvement in MPG at light load. The improvement is much less at high vehicle speeds unless acceleration performance is sacrificed or a downshifting transmission is employed.

1. At 10% reduced acceleration performance (runs 371, 375) the diesel engine alone increases MPG by 43-48% over the FDC and up to 25 MPH but from 40-70 MPH the MPG increases only 22-35%.

2. An additional 5-10% improvement is available by dropping acceleration performance to about 70-80% of reference vehicle performance (runs 372, 376).

3. Adding a 4 speed lock-up transmission (run 381) brings the MPG improvement to 60-70% at 40-70 MPH while degrading WOT acceleration by 25%. (FDC mileage decreased slightly because excessive step-up ratios were assumed for transmission gears 1 and 2.)

4. Combining the CVT with the diesel boosts MPG improvement to 73% over the FDC while retaining a 60-70% improvement during steady speed driving from 20 to 70MPH.

TITLE

237 CID Diesel Engine in CoY compact synthesized vehicle - also with 4 speed lock-up automatic and continuously variable transmissions.

RUN NO(S)

373, 374, 377, 378, 380, 384, 385

PURPOSE

Determine the improvement in fuel economy resulting from the substitution of a diesel engine for the gasoline engine --- Also examine effect of various transmissions and axle ratios with the diesel engine.

INPUT DATA SUMMARY

Same as CoY compact synthesized vehicle (run 309) except w/237 CID diesel engine and transmissions and axle ratios as follows:

Run No.	Transmission Type	Gear Ratios 1	2	3	4	Axle Ratio	Relative accel. @ 50 MPH
373	2 Speed Auto	1.82	1.0	1.0	-	2.79	0.93
374	"	"	"	"	-	2.55	0.81
377	3 Speed Auto	2.46	1.46	1.0	-	2.79	0.93
378	"	"	"	"	-	2.55	0.81
384	4 Speed Auto	3.25	2.15	1.0	0.71	2.55	0.77*
385	"	"	"	"	"	2.30	0.66*
380	90% Eff. CVT	-	-	-	-	2.55	-

* These accelerations result from downshift into 3rd gear.

SUMMARY OF RESULTS

Results are summarized in Table 4-15 which shows fuel economy in MPG for Federal Drive Cycle and steady speeds of 20, 30, 40, 50, 60 and 70 MPH. Also shown to right is a table of values listing percent increase in MPG over the reference vehicle (run 302) for the same operating conditions. Since the various transmission and axle ratio options increase fuel mileage at the expense of performance, the WOT acceleration relative to the reference vehicle acceleration is shown for 30, 50 and 70 MPG at the extreme right of Table 4-15. Relative acceleration values at 50 MPH are also listed in input data table above.

COMMENTS

4 Speed lock-up and CV transmissions. Both require downshifting to obtain acceptable acceleration performance.

This vehicle shows a greater improvement due to diesel engine at high vehicle speeds due mainly to the high initial axle ratio of the reference vehicle.

4 speed lock-up transmission #2 shows lower MPG over FDC due to higher average engine speeds caused by higher ratios in gears 1 & 2.

CONCLUSIONS

The diesel engine in combination with about 10% reduction in vehicle weight, area, drag, axle ratio and rolling resistance provides a substantial increase in MPG over the entire operating range.

1. At equal acceleration performance (run 373) the diesel engine and synthesized vehicle increase MPG by 60% over the FDC and by 50-60% at steady speed. Slightly better results are obtained when a 2 speed automatic transmission of the reference vehicle is replaced by a 3 speed automatic.

2. By degrading acceleration performance about 12% (runs 374, 378) the MPG increase becomes about 64% over the FDC and 55-68% for steady speed driving.

3. Adding a 4 speed lock-up transmission (run 384) brings the MPG improvement to 100-110% for steady speed driving while degrading WOT acceleration about 20% below reference vehicle. (FDC mileage decreased slightly because excessive step-up ratios were assumed for transmission gears 1 and 2.)

4. Combining the CVT with the diesel in the synthesized vehicle, the total increase in MPG is 90% over the FDC and about 100-110% at steady speed.

TITLE

326 CID Diesel Engine in CoY standard reference vehicle - also with 4 speed lock-up automatic and continuously variable transmissions.

RUN NO(S)

521, 522, 523, 527, 528, 531, 534 (A/C Off)
571, 572, 573, 577, 578, 581, 584 (A/C on)

PURPOSE

Determine the improvement in fuel economy resulting from the substitution of a diesel engine for the gasoline engine --- Also examine effect of various transmissions and axle ratios with the diesel engine.

INPUT DATA SUMMARY

Same as CoY standard reference vehicle (Runs 401, 451) except w/326 CID Diesel Engine and transmissions and axle ratios as follows:

Run Nos.	Transmission Type	Gear Ratios 1	2	3	4	Axle Ratio	Relative Accel. @ 50 MPH
521, 571	3 Speed Auto	2.52	1.52	1.0	-	3.08	0.98
522, 572	"	"	"	"	-	2.73	0.84
523, 573	"	"	"	"	-	2.50	0.75
527, 577	4 Speed Lock-Up Auto#1	2.50	1.55	1.0	0.68	2.73	0.80*
528, 578	"	"	"	"	"	2.50	0.70*
531, 581	4 Speed Lock-up Auto#2	3.2	2.1	1.0	0.68	2.50	0.70*
534, 584	90% Eff. CVT	-	-	-	-	3.08	-

* These accelerations result from downshift into 3rd gear.

SUMMARY OF RESULTS

Results are summarized in Tables 4-16 & 17 which show fuel economy in MPG for Federal Drive Cycle and steady speeds of 20, 30, 40, 50, 60 and 70 MPH. Also shown to right is a table of values listing percent increase in MPG over the reference vehicle (runs 401, 451) for the same operating conditions. Since the various transmission and axle ratio options increase fuel mileage at the expense of performance, the WOT acceleration relative to the reference vehicle acceleration is shown for 30, 50 and 70 MPG at the extreme right of Tables 4-16 & 17. Relative acceleration values at 50 MPH are also listed in input data table above.

COMMENTS

The 4 speed transmission with overdrive gear and the CVT both increase fuel mileage during cruise by allowing the engine to run at lower RPM. This severely degrades "direct gear" acceleration performance and makes downshifting necessary for acceptable acceleration.

Acceleration performance was not calculated for cases with air conditioning "on".

CONCLUSIONS

The diesel engine offers a substantial improvement in MPG at light load. The improvement is much less at high vehicle speeds unless acceleration performed is sacrificed or a downshifting transmission is employed.

1. At equal acceleration performance, (run 521) the diesel engine alone increases MPG by 33% over the FDC and at 20 MPH but at 70 MPH the MPG increases only 6%.

2. By degrading acceleration performance about 15% (run 522) the MPG increase becomes 37% over the FDC and 14% at 70 MPH.

3. Adding a 4 speed lock-up transmission (run 527) brings the MPG improvement to 40% over the FDC and 38% at 70 MPH while degrading WOT acceleration by 20%.

4. Combining the CVT with a diesel boosts MPG improvement to 55% over the FDC while retaining a 34% improvement at 70 MPH.

TITLE

326 CID Diesel Engine in CoY Standard synthesized vehicle - also with 4 speed lock-up automatic and continuously variable transmissions.

RUN NO(S)

524, 525, 526, 529, 530, 532, 533, 535 (A/C Off)
574, 575, 576, 579, 580, 582, 583, 585 (A/C On)

PURPOSE

Determine the improvement in fuel economy resulting from the substitution of a diesel engine for the gasoline engine --- Also examine effect of various transmissions and axle ratios with the diesel engine.

INPUT DATA SUMMARY

Same as CoY Standard synthesized vehicle (Runs 436, 487) except w/326 CID Diesel engine and transmissions and axle ratios as follows:

Run Nos.	Transmission Type	Gear Ratios 1	2	3	4	Axle Ratio	Relative Accel. @ 50 MPH
524, 574	3 Speed Auto	2.52	1.52	1.0	-	2.73	1.03
525, 575	"	"	"	"	-	2.50	0.92
526, 576	"	"	"	"	-	2.30	0.83
529, 579	4 Speed Lock-up Auto#1	2.50	1.55	1.0	0.68	2.50	0.87*
530, 580	"	"	"	"	"	2.30	0.77*
532, 582	4 Speed Lock-up Auto#2	3.2	2.1	1.0	0.68	2.50	0.87*
533, 583	"	"	"	"	"	2.30	0.77*
535, 585	90% Eff. CVT	-	-	-	-	3.08	-

* These accelerations results from downshift into 3rd gear.

SUMMARY OF RESULTS

Results are summarized in Tables 4-16 & 17 which shows fuel economy in MPG for Federal Drive Cycle and steady speeds of 20, 30, 40, 50, 60 and 70 MPH. Also shown to right is a table of values listing percent increase in MPG over the reference vehicle (runs 401, 451) for the same operating conditions. Since the various transmission and axle ratio options increase fuel mileage at the expense of performance, the WOT acceleration relative to the reference vehicle acceleration is shown for 30, 50 and 70 MPG at the extreme right of Tables 4-16 & 17. Relative acceleration values at 50 MPH are also listed in input data table above.

COMMENTS

4 Speed lock-up and CV transmissions. Both require downshifting to obtain acceptable acceleration performance.

Acceleration performance was not calculated for cases with air conditioning "on".

CONCLUSIONS

The diesel engine in combination with about 10% reduction in vehicle weight, area, drag, axle ratio, and rolling resistance provides a substantial increase in MPG over the entire operating range.

1. At equal acceleration performance (run 524) the diesel engine and synthesized vehicles increase MPG by 47% over the FDC and at low speed cruise whereas the improvement averages about 36% for steady driving at higher speeds.

2. By degrading acceleration performance about 8-15% (runs 525, 526) the MPG increase becomes about 50% over the FDC and 40-45% for steady speed driving.

3. Adding a 4 speed lock-up transmission (run 529) brings the MPG improvement to 55% over the FDC and about 80% at steady speed while degrading performance about 15% below the reference vehicle.

4. Combining the CVT with the diesel in the synthesized vehicle, the total increase in MPG is 67% over the FDC and about 70-80% at steady speed.

APPENDIX B

INDEX SHEET OF COMPUTER SIMULATION RUNS
CØ Y COMPACT

Computer Run No.	Test Weight	Frontal Area	Drag Coeff.	Tires	Axle Ratio	Access Load	Engine Type	Trans Type
302	3877	21.90	.568	Bias	3.08	Std.	Std.	2 sp. auto
303	3677	21.90	.568	Bias	3.08	Std.	Std.	2 sp. auto
304	3477	21.90	.568	Bias	3.08	Std.	Std.	2 sp. auto
305	3877	19.71	.568	Bias	3.08	Std.	Std.	2 sp. auto
306	3877	21.90	.50	Bias	2.73	Std.	Std.	2 sp. auto
309	3477	19.71	.50	Radial	2.73	Std.	Std.	2 sp. auto
310	3877	21.90	.568	Bias	3.08	Con .3 HP	Std.	2 sp. auto
311	3760	21.90	.568	Bias	2.73	Std.	Std.	2 sp. auto
315	3477	19.71	.50	Radial	3.08	Con .3 HP	Std.	2 sp. auto
316	3477	19.71	.50	Radial	2.73	Con .3 HP	Std.	2 sp. auto
318	3477	19.71	.50	Radial	3.08	Std.	Std.	2 sp. auto
319	3877	19.71	.50	Bias	3.08	Std.	Std.	2 sp. auto
320	3477	19.71	.50	Bias	3.08	Std.	Std.	2 sp. auto
321	3877	21.90	.568	Radial	3.08	Std.	Std.	2 sp. auto
336	3877	21.90	.568	Bias	2.73	Std.	Std.	2 sp. auto
351	3877	21.90	.568	Bias	3.08	Std.	Std.	CVT
352	3877	21.90	.568	Bias	3.08	Std.	Std.	CVT
353	3477	19.71	.50	Radial	3.08	Std.	Std.	CVT
361	3877	21.90	.568	Bias	3.08	Std.	Std.	4 sp. auto
362	3577	19.30	.50	Radial	3.08	Std.	Std.	4 sp. auto
371	3877	21.90	.568	Bias	3.08	Std.	Diesel	2 sp. auto
372	3877	21.90	.568	Bias	2.55	Std.	Diesel	2 sp. auto
373	3577	19.71	.50	Radial	2.79	Std.	Diesel	2 sp. auto
374	3577	19.71	.50	Radial	2.55	Std.	Diesel	2 sp. auto
375	3877	21.90	.568	Bias	3.08	Std.	Diesel	3 sp. auto
376	3877	21.90	.568	Bias	2.79	Std.	Diesel	3 sp. auto
377	3577	19.71	.50	Radial	2.79	Std.	Diesel	3 sp. auto
378	3577	19.71	.50	Radial	2.55	Std.	Diesel	3 sp. auto
379	3877	21.90	.568	Bias	2.55	Std.	Diesel	CVT
380	3577	19.71	.50	Radial	2.55	Std.	Diesel	CVT
381	3877	21.90	.568	Bias	2.79	Std.	Diesel	4 sp. auto
382	3877	21.90	.568	Bias	2.55	Std.	Diesel	4 sp. auto
383	3877	21.90	.568	Bias	2.30	Std.	Diesel	4 sp. auto
384	3577	19.71	.50	Radial	2.55	Std.	Diesel	4 sp. auto
385	3577	19.71	.50	Radial	2.30	Std.	Diesel	4 sp. auto

INDEX SHEET OF COMPUTER SIMULATION RUNS
CO Y STANDARD A/C OFF

Computer Run No.	Test Weight	Frontal Area	Drag Coeff.	Tires	Axle Ratio	Access Load	Engine Type	Trans Type
401	4856	23.60	.50	Bias	2.73	Std.	Std.	3 sp. auto
402	4856	21.30	.50	Bias	2.73	Std.	Std.	3 sp. auto
403	4856	21.30	.45	Bias	2.73	Std.	Std.	3 sp. auto
412	4856	23.60	.50	Bias	2.50	Std.	Std.	3 sp. auto
413	4856	23.60	.50	Radial	2.73	Std.	Std.	3 sp. auto
428	4356	23.60	.50	Bias	2.73	Std.	Std.	3 sp. auto
429	4356	21.30	.45	Bias	2.73	Std.	Std.	3 sp. auto
430	4356	21.30	.45	Radial	2.73	Std.	Std.	3 sp. auto
436	4356	21.30	.45	Radial	2.50	Std.	Std.	3 sp. auto
437	4356	21.30	.45	Radial	2.50	Std.	Std.	3 sp. auto
438	4356	21.30	.45	Radial	2.50	Con .5 HP	Std.	3 sp. auto
442	4856	23.60	.50	Bias	2.73	Std.	Std.	CVT
443	4356	21.30	.45	Radial	2.73	Std.	Std.	CVT
444	4356	21.30	.45	Radial	2.73	Con .5 HP	Std.	CVT
501	4856	23.60	.50	Bias	2.73	Std.	Std.	3 sp. auto
511	4856	23.60	.50	Bias	3.08	Std.	Std.	4 sp. auto
512	4356	21.30	.45	Radial	3.08	Std.	Std.	4 sp. auto
513	4856	23.60	.50	Bias	2.73	Std.	Std.	4 sp. auto
514	4856	23.60	.50	Bias	2.50	Std	Std.	4 sp. auto
515	4356	21.30	.45	Radial	2.73	Std.	Std.	4 sp. auto
516	4356	21.30	.45	Radial	2.50	Std.	Std.	4 sp. auto
517	4356	21.30	.45	Radial	2.30	Std.	Std.	4 sp. auto
521	4856	23.60	.50	Bias	3.08	Std.	Diesel	3 sp. auto
522	4856	23.60	.50	Bias	2.73	Std.	Diesel	3 sp. auto
523	4856	23.60	.50	Bias	2.50	Std.	Diesel	3 sp. auto
524	4356	21.30	.45	Radial	2.73	Std.	Diesel	3 sp. auto
525	4356	21.30	.45	Radial	2.50	Std.	Diesel	3 sp. auto
526	4356	21.30	.45	Radial	2.30	Std.	Deisel	3 sp. auto
527	4856	23.60	.50	Bias	2.73	Std.	Diesel	4 sp. auto
528	4856	23.60	.50	Bias	2.50	Std.	Diesel	4 sp. auto
529	4356	21.30	.45	Radial	2.50	Std.	Diesel	4 sp. auto
530	4356	21.30	.45	Radial	2.30	Std.	Diesel	4 sp. auto
531	4856	23.60	.50	Bias	2.50	Std.	Diesel	4 sp. auto
532	4356	21.30	.45	Radial	2.50	Std.	Diesel	4 sp. auto
533	4356	21.30	.45	Radial	2.30	Std.	Diesel	4 sp. auto
534	4856	23.60	.50	Bias	3.08	Std.	Diesel	CVT
535	4356	21.30	.45	Radial	3.08	Std.	Diesel	CVT

INDEX SHEET OF COMPUTER SIMULATION RUNS
CO Y STANDARD A/C ON

Computer Run No.	Test Weight	Frontal Area	Drag Coeff.	Tires	Axle Ratio	Access Load	Engine Type	Trans Type
451	4856	23.60	.50	Bias	2.73	Std.	Std.	3 sp. auto
452	4856	21.30	.50	Bias	2.73	Std.	Std.	3 sp. auto
453	4856	21.30	.45	Bias	2.73	Std.	Std.	3 sp. auto
458	4556	23.60	.50	Bias	2.73	Std.	Std.	3 sp. auto
462	4856	23.60	.50	Bias	2.50	Std.	Std.	3 sp. auto
463	4856	23.60	.50	Radial	2.73	Std.	Std.	3 sp. auto
479	4256	23.60	.50	Bias	2.73	Std.	Std.	3 sp. auto
481	4456	23.60	.50	Bias	2.73	Std.	Std.	3 sp. auto
482	4356	21.30	.45	Bias	2.73	Std.	Std.	3 sp. auto
483	4356	21.30	.45	Bias	2.50	Std.	Std.	3 sp. auto
485	4356	21.30	.45	Bias	2.50	Con 4.2 HP	Std.	3 sp. auto
486	4356	21.30	.45	Radial	2.73	Std.	Std.	3 sp. auto
487	4356	21.30	.45	Radial	2.50	Std.	Std.	3 sp. auto
489	4356	21.30	.45	Radial	2.50	Con 4.2 HP	Std.	3 sp. auto
491	4856	23.60	.50	Radial	2.73	Std.	Std.	CVT
492	4856	23.60	.50	Bias	2.73	Std.	Std.	CVT
493	4356	21.30	.45	Radial	2.73	Std.	Std.	CVT
494	4356	21.30	.45	Radial	2.73	Con 4.2 HP	Std.	CVT
561	4856	23.60	.50	Bias	3.08	Std.	Std.	4 sp. auto
562	4356	21.30	.45	Radial	3.08	Std.	Std.	4 sp. auto
563	4856	23.60	.50	Bias	2.73	Std.	Std.	4 sp. auto
564	4856	23.60	.50	Bias	2.50	Std.	Std.	4 sp. auto
565	4356	21.30	.45	Radial	2.73	Std.	Std.	4 sp. auto
566	4356	21.30	.45	Radial	2.50	Std.	Std.	4 sp. auto
567	4356	21.30	.45	Radial	2.30	Std.	Std.	4 sp. auto
571	4856	23.60	.50	Bias	3.08	Std.	Diesel	3 sp. auto
572	4856	23.60	.50	Bias	2.73	Std.	Diesel	3 sp. auto
573	4856	23.60	.50	Bias	2.50	Std.	Diesel	3 sp. auto
574	4356	21.30	.45	Radial	2.73	Std.	Diesel	3 sp. auto
575	4356	21.30	.45	Radial	2.50	Std.	Diesel	3 sp. auto
576	4356	21.30	.45	Radial	2.30	Std.	Diesel	3 sp. auto
577	4856	23.60	.50	Bias	2.73	Std.	Diesel	4 sp. auto
578	4856	23.60	.50	Bias	2.50	Std.	Diesel	4 sp. auto
579	4356	21.30	.45	Radial	2.50	Std.	Diesel	4 sp. auto
580	4356	21.30	.45	Radial	2.30	Std.	Diesel	4 sp. auto
581	4856	23.60	.50	Bias	2.50	Std.	Diesel	4 sp. auto
582	4356	21.30	.45	Radial	2.50	Std.	Diesel	4 sp. auto
583	4356	21.30	.45	Radial	2.30	Std.	Diesel	4 sp. auto
584	4856	23.60	.50	Bias	3.08	Std.	Diesel	CVT
585	4356	21.30	.45	Radial	3.08	Std.	Diesel	CVT

INDEX SHEET OF COMPUTER SIMULATION RUNS CoX COMPACT

Computer Run No.	Test Weight	Frontal Area	Drag Coeff	Tires	Axle Ratio	Access Load	Engine Type	Trans. Type
601	3351	21.42	.47	Bias	2.79	STD	STD	3 Sp Auto
602	3030	21.42	.47	Bias	2.79	STD	STD	3 Sp Auto
603	3351	19.28	.47	Bias	2.79	STD	STD	3 Sp Auto
604	3351	19.28	.423	Bias	2.79	STD	STD	3 Sp Auto
605	3351	21.42	.47	Radial	2.79	STD	STD	3 Sp Auto
606	3351	21.42	.47	Bias	2.55	STD	STD	3 Sp Auto
607	3351	21.42	.47	Bias	2.79	Con 1. HP	STD	3 Sp Auto
608	3351	21.42	.47	Bias	2.79	STD	STD	CVT
611	3030	19.28	.45	Bias	2.79	STD	STD	3 Sp Auto
612	3030	19.28	.45	Radial	2.79	STD	STD	3 Sp Auto
613	3030	19.28	.45	Radial	2.55	STD	STD	3 Sp Auto
614	3030	19.28	.423	Radial	2.55	STD	STD	3 Sp Auto
615	3030	19.28	.45	Radial	2.55	Con 1. HP	STD	3 Sp Auto
616	3030	19.28	.45	Radial	2.79	STD	STD	CVT
617	3030	19.28	.423	Radial	2.79	STD	STD	CVT
621	3351	21.42	.47	Bias	3.08	STD	Diesel	3 Sp Auto
622	3030	19.28	.45	Radial	2.79	STD	Diesel	3 Sp Auto
623	3351	21.42	.47	Bias	2.79	STD	Diesel	CVT
624	3030	19.28	.45	Radial	2.55	STD	Diesel	CVT
625	3351	21.42	.47	Bias	2.79	STD	Diesel	4 Sp Auto
626	3030	19.28	.45	Radial	2.55	STD	Diesel	4 Sp Auto
627	3351	21.42	.47	Bias	2.79	STD	Diesel	3 Sp Auto
628	3030	19.28	.45	Radial	2.55	STD	Diesel	3 Sp Auto
629	3030	19.28	.45	Radial	2.30	STD	Diesel	3 Sp Auto
630	3351	21.42	.47	Bias	2.55	STD	Diesel	4 Sp Auto
631	3351	21.42	.47	Bias	2.30	STD	Diesel	4 Sp Auto
632	3030	19.28	.45	Radial	2.30	STD	Diesel	4 Sp Auto

INDEX SHEET OF COMPUTER SIMULATION RUNS CoX STANDARD A/C OFF

Comp. Run	Test Weight	Frontal Area	Drag Coeff.	Tires	Axle Ratio	Access Load	Engine Type	Trans. Type
701	5008	24.94	.50	Bias	2.75	STD	STD	3 Sp Auto
702	4508	24.94	.50	Bias	2.75	STD	STD	3 Sp Auto
703	5008	22.45	.50	Bias	2.75	STD	STD	3 Sp Auto
704	5008	22.45	.45	Bias	2.75	STD	STD	3 Sp Auto
705	5008	24.94	.50	Radial	2.75	STD	STD	3 Sp Auto
706	5008	24.94	.50	Bias	2.50	STD	STD	3 Sp Auto
707	5008	24.94	.50	Bias	2.75	Const 1.5HP	STD	3 Sp Auto
708	5008	24.94	.50	Bias	2.75	STD	STD	CVT
711	4508	22.45	.45	Bias	2.75	STD	STD	3 Sp Auto
712	4508	22.45	.45	Radial	2.75	STD	STD	3 Sp Auto
713	4508	22.45	.45	Radial	2.50	STD	STD	3 Sp Auto
714	4508	22.45	.45	Radial	2.50	Con. 1.5HP	STD	3 Sp Auto
715	4508	22.45	.45	Radial	2.75	STD	STD	CVT
721	5008	24.94	.50	Bias	3.05	STD	Diesel	3 Sp Auto
722	5008	24.94	.50	Bias	2.75	STD	Diesel	3 Sp Auto
723	5008	24.94	.50	Bias	2.50	STD	Diesel	3 Sp Auto
724	4508	22.45	.45	Radial	2.75	STD	Diesel	3 Sp Auto
725	4508	22.45	.45	Radial	2.50	STD	Diesel	3 Sp Auto
726	4508	22.45	.45	Radial	2.30	STD	Diesel	3 Sp Auto
727	5008	24.94	.50	Bias	2.75	STD	Diesel	4 Sp Auto
728	5008	24.94	.50	Bias	2.50	STD	Diesel	4 Sp Auto
729	4508	22.45	.45	Radial	2.50	STD	Diesel	4 Sp Auto
730	4508	22.45	.45	Radial	2.30	STD	Diesel	4 Sp Auto
731	5008	24.94	.50	Bias	2.50	STD	Diesel	4 Sp Auto
732	4508	22.45	.45	Radial	2.50	STD	Diesel	4 Sp Auto
733	4508	22.45	.45	Radial	2.30	STD	Diesel	4 Sp Auto
734	5008	24.94	.50	Bias	2.50	STD	Diesel	CVT
735	4508	22.45	.45	Radial	2.50	STD	Diesel	CVT

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CO X STANDARD A/C ON

Computer Run No.	Test Weight	Frontal Area	Drag Coeff.	Tires	Axle Ratio	Access Loan	Engine Type	Trans Type
801	5008	24.94	.50	Bias	2.75	Std.	Std.	3 sp. auto
802	4508	24.94	.50	Bias	2.75	Std.	Std.	3 sp. auto
803	5008	22.45	.50	Bias	2.75	Std.	Std.	3 sp. auto
804	5008	22.45	.45	Bias	2.75	Std.	Std.	3 sp. auto
805	5008	24.94	.50	Radial	2.75	Std.	Std.	3 sp. auto
806	5008	24.94	.50	Bias	2.50	Std.	Std.	3 sp. auto
807	5008	24.94	.50	Bias	2.75	Con 3.7 HP	Std.	3 sp. auto
808	5008	24.94	.50	Bias	2.75	Std.	Std.	CVT
811	4508	22.45	.45	Bias	2.75	Std.	Std.	3 sp. auto
812	4508	22.45	.45	Radial	2.75	Std.	Std.	3 sp. auto
813	4508	22.45	.45	Radial	2.50	Std.	Std.	3 sp. auto
814	4508	22.45	.45	Radial	.250	Con 3.7 HP	Std.	3 sp. auto
815	4508	22.45	.45	Radial	2.75	Std.	Std.	CVT
821	5008	24.94	.50	Bias	3.05	Std.	Diesel	3 sp. auto
822	5008	24.94	.50	Bias	2.75	Std.	Diesel	3 sp. auto
823	5008	24.94	.50	Bias	2.50	Std.	Diesel	3 sp. auto
824	4508	22.45	.45	Radial	2.75	Std.	Diesel	3 sp. auto
825	4508	22.45	.45	Radial	2.50	Std.	Diesel	3 sp. auto
826	4508	22.45	.45	Radial	2.30	Std.	Diesel	3 sp. auto
827	5008	24.94	.50	Bias	2.75	Std.	Diesel	4 sp. auto
828	5008	24.94	.50	Bias	2.50	Std.	Diesel	4 sp. auto
829	4508	22.45	.45	Radial	2.50	Std.	Diesel	4 sp. auto
830	4508	22.45	.45	Radial	2.30	Std	Diesel	4 sp. auto
831	5008	24.94	.50	Bias	2.50	Std.	Diesel	4 sp. auto
832	4508	22.45	.45	Radial	2.50	Std.	Diesel	4 sp. auto
833	4508	22.45	.45	Radial	2.30	Std.	Diesel	4 sp. auto
834	5008	24.94	.50	Bias	2.50	Std	Diesel	CVT
835	4508	22.45	.45	Radial	2.50	Std.	Diesel	CVT

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APPENDIX VII

REPORT OF INVENTIONS

A diligent review of the work performed under this contract has revealed no new innovation, discovery, improvement or invention.