REPORT NO. DOT-TSC-OST-74-39.I

TECHNOLOGICAL IMPROVEMENTS TO AUTOMOBILE FUEL CONSUMPTION
Volume I: Executive Summary

C. W. Coon et al

DECEMBER 1974

FINAL REPORT

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Prepared for
U.S. DEPARTMENT OF TRANSPORTATION
OFFICE OF THE SECRETARY
Office of the Assistant Secretary for Systems Development and Technology
Washington DC 20590
and
U.S. ENVIRONMENTAL PROTECTION AGENCY
Ann Arbor MI 48105

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Technical Report Documentation Page

1. Report No. DOT-TSC-OST-74-39.I	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle TECHNOLOGICAL IMPROVEMENTS TO AUTOMOBILE FUEL CONSUMPTION Volume I: Executive Summary		5. Report Date December 1974
		6. Performing Organization Code
7. Author(s) C. W. Coon et al		8. Performing Organization Report No. DOT-TSC-OST-74-39.I
9. Performing Organization Name and Address Southwest Research Institute* Energy Conversion Systems Section Department of Automotive Research San Antonio TX 78284		10. Work Unit No. (TRAIS) OS514/R5523
		11. Contract or Grant No. DOT-TSC-628
12. JOINTLY SPONSORED BY- U.S. Department of Transportation Office of the Secretary Office of the Assistant Secretary for Systems Development and Technology Washington DC 20590 and U.S. Environmental Protection Agency Ann Arbor MI 48105		13. Type of Report and Period Covered Final Report June 1973-January 1974
		14. Sponsoring Agency Code
15. Supplementary Notes *Under Contract to: U.S. Department of Transportation Transportation Systems Center Kendall Square Cambridge MA 02142		

16. Abstract

This report is a preliminary survey of the technological feasibility of reducing the fuel consumption of automobiles. The study uses as a reference information derived from literature, automobile industry contacts, and testing conducted as part of the program requirements. The design changes, which are recommended for the purpose of maximizing fuel economy, have been derived after lengthy review against a series of constraints including regulatory requirements, technical feasibility, and cost effectiveness.

Several possible technological improvements are identified, documented, and evaluated with respect to fuel economy. Results are reported as percentage improvement in fuel economy by comparison with 1973 model year vehicles. The effect of vehicle emission control systems is considered in the evaluation procedure.

The most promising individual improvements are incorporated into three synthesized vehicle designs, and the projected fuel economy improvement for these vehicles is reported.

The status of the technology reported is that available in the time period of July 1973 to January 1974.

17. Key Words Automobiles, Fuel Economy, Powerplants, Transmissions, Drive Trains, Tires, Accessories, Aerodynamics, Weight, Fuel Consumption, Innovations		18. Distribution Statement DOCUMENT IS AVAILABLE TO THE PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 14	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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EXECUTIVE SUMMARY

Study Objective

The study described by this report was performed in order to assess the possible effectiveness of technological improvements as a means of increasing automotive fuel economy on a short-term basis. Specifically, only those devices or systems which could be demonstrated by 1976 and produced in quantities appropriate to 10 percent of the total automobile production by 1980 were accepted for consideration. The goal of the study was the specification of combinations of improvements that would result in a 30-percent reduction in fuel consumption; this goal was attained by a comprehensive evaluation of individual improvements followed by the synthesis of vehicle designs.

Throughout the study, considerations and constraints other than fuel economy improvement were observed. Foremost among the additional considerations was the subject of vehicular emissions; it was specified that the synthesized vehicles must meet the 1976 Interim Standards for gaseous emissions of:

0.41 g/mile unburned hydrocarbons

3.4 g/mile carbon monoxide

2.0 g/mile oxides of nitrogen

Individual improvements were examined with regard to the effect on emissions, and where possible, the calculated fuel economy benefits were biased to account for the effect of emission control on fuel economy. It was generally assumed that, when necessary, emissions of unburned hydrocarbons and carbon monoxide would be controlled by catalytic reactors in the exhaust over the time period covered by the study. Similarly, exhaust gas recirculation (EGR) was regarded as the primary means for control of oxides of nitrogen.

In addition to fuel economy benefits and emissions control features, all suggested individual improvements were evaluated with regard to safety, noise, reliability, effect on vehicle performance, and cost to the consumer.

Computation of Vehicle Fuel Economy

An analytical evaluation of the fuel economy benefit associated with a particular improvement was obtained on the basis of a composite driving schedule. There is, at present, no standard technique for this purpose; however, numerous procedures have been proposed. The schedule used in this study was based on an equal distribution of vehicle use between an urban driving pattern and steady-state road operation. The urban driving cycle was patterned after the LA-4 emission test driving cycle. For convenience, the cycle was interpreted in terms of acceleration, cruise, and combined deceleration and idle modes. The vehicle loading used in the analysis was approximately equal to observed road loads. The road load portion of the composite cycle was based on an equal distribution of speeds of 20, 30, 40, 50, 60, and 70 mph. The evaluation procedure made use of brake specific fuel economy data obtained from engine maps. Subsequent to the analysis, the results of the use of the driving schedule were compared with those from other suggested schedules, and the agreement was considered to be satisfactory.

The reference vehicle used throughout the study was a standard 1973 automobile having a 350 CID engine and a curb weight of 4300 lb (4600 lb loaded vehicle weight; 4500 lb EPA emission test inertia weight). For the various individual improvements, fuel economy comparisons were made with and without consideration of emission controls. When emission controls were included, a comparison was made between the fuel economy of an improved vehicle meeting the 0.41–3.4–2.0 emission standards and the fuel economy of the reference vehicle meeting the 1973 emission standards; it is this comparison, expressed in percentage improvement, that is reported throughout this summary. *It should be observed that the reference vehicle, without improvement, would suffer a 5-percent decrease in fuel economy as a result of the application of the correction procedure for emissions.* Thus, in the text, a decrease in fuel economy of 5 percent does not imply a penalty.

Although a single reference vehicle was used throughout the study for fuel economy comparison purposes, some consideration was given to smaller and lighter vehicles. Reductions in weight, rolling resistance, and aerodynamic drag were each treated as individual improvements, and the fuel economy benefits were evaluated. In addition, one of the synthesized designs incorporates these features, among others, in an analysis which includes the effects of the engine and drive train.

Cost of Automobile Ownership and Operation

Included in the report is a section devoted to the cost of owning and operating an automobile. The goal of such a discussion was a mechanism for predicting the

allowable incremental cost of an improvement based on the magnitude of the fuel economy benefit that could be expected. This information is presented in graphical form. A specific change in gasoline mileage can be used to obtain the allowable increase in purchase cost that would be justified by addition of the device. Moreover, a description of the industrial engineering process associated with automobile production is included. The time required for incorporation of an improvement on actual production vehicles is essential to the overall evaluation process.

Individual Improvements

The report contains comprehensive discussions of the proposed individual improvements together with sections that describe the general characteristics of vehicle operation and emission control. Since all facets of the investigation cannot be treated in detail, there is an inherent hazard in any attempt to summarize the results of the evaluation. In the following paragraphs the major results are outlined, and the intent is to provide a synopsis of the more detailed discussions in the main body of the report.

Turbocharged, Spark Ignited, Carbureted Engine

Turbocharging, or the use of a turbine in the engine exhaust to increase combustion chamber pressure, has been suggested as a means of improving fuel economy. It was found that a turbocharged, spark ignited, carbureted engine having a displacement of 250 CID could have a power output equivalent to that of the 350 CID reference vehicle engine. The fuel economy evaluation procedure predicted an improvement in fuel economy of 11 percent for this engine, but the engine analysis indicated an extreme sensitivity to knock. For successful operation, a water-alcohol injection system would be essential for knock control. In an attempt to decrease the knock limitation, a turbocharged engine equipped with an aftercooler and a reduced compression ratio was analyzed. It was found that a displacement of 280 CID would be required for power output equivalent to that of the reference vehicle. Although the engine could operate without knock, the predicted economy increase was only 4 percent. A third attempt, which was based on reduction of the compression ratio to prevent knock, resulted in an insignificant economy benefit since no appreciable reduction in engine displacement could be achieved by comparison with the reference vehicle. The only turbocharged engine which demonstrated a worthwhile economy improvement was the 250 CID version that required water-alcohol injection to prevent knock. It was believed that the mechanical complexity and owner maintenance requirements of such a system excluded it from further consideration.

Variable Displacement Engine

A variable displacement engine was also evaluated on the basis of fuel economy improvement. The engine was based on a conventional V-8 configuration; it was assumed that a mechanism could be designed to allow operation on four cylinders at light loads and eight cylinders at heavy loads. A fuel economy improvement of 7 percent was predicted, but a high degree of mechanical complexity would be required in the switching device. In addition, idle roughness and high loads on four cylinders would be encountered. This concept was not pursued to the synthesized vehicle design stage.

Reduction in Engine Friction

It has been suggested that a reduction in engine friction would provide an increase in fuel economy. In order to evaluate this hypothesis, an engine map was constructed on the basis of a reasonable reduction in mechanical friction. However, the total friction loss is divided between pumping losses and mechanical friction; in the usual engine operating regime the pumping losses dominate. The use of the fuel economy prediction procedure did not result in an increase in fuel economy associated with the reduction in mechanical friction.

Lean Mixture Engine

Considerable emphasis has been devoted to the operation of engines with lean mixtures as a means of fuel conservation. An analysis was presented allowing the prediction of the fuel/air mixture which would result in the best economy for any engine operating condition, and the results were used for the construction of an engine map. The resulting engine map data were used to predict fuel economy. It was estimated that an increase of 12 percent could be obtained if the engine operated only at the best economy mixture throughout the entire speed-load range. The estimate of a 12-percent improvement also assumes that no fuel penalty would be incurred in the attainment of the 0.41–3.4–2.0 emission standards. This 12-percent estimate is probably optimistic; therefore, an improvement on the order of 6 percent is more likely. It should be noted that it is possible to operate engines at fuel/air ratios much lower than those used in the best economy estimate outlined above. Several devices are presently being proposed for

that purpose. However, engines operated at very lean mixtures typically exhibit a sacrifice in the area of performance; if this compromise occurs, then the vehicles cannot be compared to the reference vehicle used in this study.

Intake Port Fuel Injection

Intake port fuel injection was considered as a means of improving fuel economy. Precise engine map data were not available, and a numerical comparison to the reference vehicle was not presented. However, the system is regarded as a worthwhile improvement on the basis of superior control of the fuel/air ratio and the possibility of improved distribution of the fuel among the cylinders. Improved mixture control and mixture distribution could have a favorable effect on vehicle emissions as well as fuel economy; injection systems are basic features of the three-way catalyst systems that are being investigated by several groups. Further investigation and direct comparison with carburetion systems should be encouraged.

Another feature of intake port fuel injection which deserves further study is the possibility of fuel shutoff during vehicle deceleration. From a fuel economy viewpoint, it appears that substantial benefits could accrue, but there is some uncertainty regarding the amount of fuel required to restart the engine. Another area of study involves the compatibility between fuel shutoff on deceleration and emission control catalysts. If the reactor cools while the vehicle is decelerating, then excessive emissions might occur after the engine starts.

Stratified Charge Engines

Stratified charge engines have been considered as a source of improved fuel economy. For this study, the engine configuration of primary interest was the open chamber design which employs spark ignition and direct cylinder fuel injection. Such engines exhibit their most favorable fuel economy when they are operated without a throttle, and load control is achieved by controlling the fuel supply. Most, however, require throttling at idle for stable operation.

For the purposes of this study, an engine map for an experimental stratified charge engine was used. The fuel economy benefit as a result of the application of the calculation procedure was 34 percent based on the 0.41–3.4–2.0 emission standards. It should be noted that some stratified charge engines incur a severe fuel penalty as emission standards for oxides of nitrogen become more severe than 2.0 g/mile. In addition, this engine design typically produces relatively high hydrocarbon emissions. Some experimental versions are throttled throughout the engine operating range in order to improve the compatibility with catalytic reactors. However, it would appear that the problems can be resolved and that the engine can be certified under the 0.41–3.4–2.0 standards with substantial fuel economy benefit.

Another reason for interest in the stratified charge design is the demonstrated ability of some of the engines to operate on a wide variety of fuels. The importance of this multifuel capability increases as fuel supplies become uncertain.

Diesel Engine

The diesel engine has been the object of much interest as an automobile power plant, but its use has been primarily restricted to heavy-duty vehicles. However, it does have advantages that cannot be overlooked in the treatment of fuel economy. Two diesel engine configurations were analyzed during the course of this study, and one was incorporated into a synthesized vehicle design. Using the fuel economy analysis procedure, it was predicted that a naturally aspirated diesel engine, having a displacement of 378 CID, would allow a fuel economy improvement of 26 percent after correction for the differing energy contents of diesel fuel and gasoline. The corresponding figure for a turbocharged engine of 260 CID displacement was 57 percent. In both cases, the 0.41–3.4–2.0 standards for gaseous emissions can be met without auxiliary devices.

Some problems are associated with the use of diesel engines in automobiles. The weight of the engine must be reduced; however, this objective can be met by means of a typical development program. In addition, diesel exhaust typically has an odor different from that of gasoline engine exhaust, and public acceptance of large numbers of diesel engines is unknown. Finally, some difficulty may be encountered with particulate emission standards. Diesel engines exhibit higher exhaust particulate levels than carbureted, spark ignited engines.

Drive Trains

The means by which power is transmitted from the engine to the wheels can have an appreciable effect on fuel economy. An inappropriate drive train can result either in excessive losses or in uneconomical operating conditions for the engine. For the purpose of this study, several alternate drive trains were examined, and their impact on fuel economy was assessed. In each case, a

comparison was made with the standard three-speed automatic transmission in the reference vehicle. The effect of the proposed transmission on engine emission control was considered.

It was found that a lock-up clutch that would operate in high gear when there was no need for torque multiplication would result in a fuel economy decrease of about 2 percent. This value is only slightly better than that which would be observed for the reference vehicle without the addition of any improvement, and the lack of positive results may be attributed to the driving cycle used in the evaluation procedure. However, a fuel economy benefit should be observed in the highway cruise modes (ref. Table 27).

The use of a manual transmission should result in a fuel economy improvement on the order of 2 percent. The difference between this result and that for the lock-up clutch lies in the complete separation of engine and transmission that occurs with a manual transmission at engine idle. Since a substantial amount of idle time is included in the urban cycle and since the load on the engine is decreased by clutch disengagement at idle, the manual transmission can be expected to allow a more substantial fuel economy improvement than would a lock-up clutch. Consumer acceptance of the manual transmission, however, was judged to be minimal.

The combination of an overdrive and a lock-up clutch was found to result in a fuel economy decrease of 3 percent. This represents some improvement by comparison with the reference vehicle, but the benefit is not of sufficient magnitude to overcome the effect of emission controls.

The type of lock-up clutch considered for the purpose of this study would operate only in high (direct) gear, and it would engage when the torque converter approached the coupling point. It would be possible to construct a lock-up device which would engage at any preset torque ratio in every gear. In this way, the economy benefit of the manual transmission could be approached. Such transmissions are used in some heavy-duty vehicles, but the application to passenger cars involves questions of cost and driveability that remain unanswered.

An object of particular interest is the continuously variable (or infinitely variable) transmission. Many such devices have been proposed, and two were considered during the present study. In principle, the continuously variable transmission, with an appropriate control system, is capable of selecting a gearing configuration that would allow the engine to operate near an optimum condition. There is some reason for concern since the optimum schedule would require engine operation at low speeds and high loads; however, the precise extent of necessary engine modifications has yet to be determined. Of the two drives considered, one was of the traction-type and the other was a combination planetary gear-hydrostatic drive. The quantity of test data available was minimal; however, the traction drive was evaluated through the use of the fuel economy prediction procedure. The results indicated a 3-percent improvement in feul economy over the combined urban and steady speed schedule. It should be noted that most of the benefits that accrue from the use of a continuously variable transmission occur during steady state driving. Furthermore, little is known about engine emissions at the speed and load conditions that would be dictated by this drive. Compensation of the fuel economy improvement for emission control is difficult.

An optimum vehicle drive train was selected for comparison purposes. The optimization process was biased toward fuel economy; speed and acceleration were maintained at acceptable levels. The drive train employed a four-speed automatic transmission in which the highest gear was in fact an overdrive. The use of the fuel economy evaluation procedure resulted in the prediction of a 4-percent increase in fuel economy that could be attributed to this system.

Tires

The tires with which an automobile is equipped dictate the rolling resistance, and therefore, a substantial influence is exerted by the tires on the overall road load. The report describes the major methods of tire construction and compares them on the basis of rolling resistance. It was found that a reduction of 30 percent in rolling resistance could be accomplished through the use of radial ply tires. In the analysis procedure, this reduction translates into a 4-percent increase in fuel economy.

Aerodynamics

Another method of reducing vehicle road load is through the reduction of aerodynamic drag. The various factors which influence drag were discussed, and an assessment of the possible drag reduction for the reference vehicle was made. In order to estimate the magnitude of the possible fuel economy benefit, it was assumed that the aerodynamic component of the road load could be reduced in the near term by 10 percent. Over the driving schedule used for the fuel

economy evaluation, this change resulted in a fuel economy benefit of 1.5 percent.

Weight

The weight of the vehicle is an important factor in any consideration of fuel economy. For the purpose of evaluating the influence of vehicle weight in the context of this report, it was assumed that the curb weight of the reference vehicle could be reduced from 4300 to 3600 lb. The resulting fuel economy benefit was found to be 7 percent for the driving schedule. Of the two methods examined for weight reduction, one involved a reduction in vehicle size and the other assumed a weight reduction without size reduction. The first option is essentially equivalent to a 1973 intermediate size vehicle. The second option, weight reduction for a vehicle of 1973 standard size, would be achieved only after a full-scale development program.

Air Conditioning Improvements

Air conditioning has become an accepted feature of automobiles in many parts of the country, and it does influence the fuel economy of a vehicle. No air conditioning system would result in a net improvement in fuel economy for the standard reference vehicle; however, the cost of air conditioning in terms of fuel economy was estimated to be 6 percent when the system is operating. Several modifications of existing systems were recommended as a means of decreasing the fuel economy penalty. Among the suggested changes were alterations of the control system, improvements in compressor efficiency, and changes in the method used for driving the compressor. With regard to the latter, it was recommended that the compressor be driven at a speed appropriate to the air conditioning system load. The use of a constant speed drive was not recommended due to the lack of availability and inconsistency with air conditioning system requirements.

Cooling Systems

The fuel economy for a cold vehicle is generally significantly lower than that for a warm vehicle; therefore, it is possible that modifications to the vehicle cooling system could have a positive effect on fuel economy by decreasing the time required for warmup. It was recommended that the ebullient cooling system be studied as a means of reducing the time required for attainment of warmed up economy.

Salient features of the individual improvements are summarized and compared in Table 1.

Synthesized Vehicle Design

The individual improvements were evaluated and assessed according to their potential in coordination with one another, and three vehicle designs were synthesized. The main features of each design are outlined in the following discussion with greater detail given in the body of the report.

Conventional Spark Ignition Engine Design

The characteristics of the proposed vehicle are as follows:

(1) Engine–260 CID V-8, aluminum block, spark ignition

(2) Engine accessories

  (a) Electronic fuel injection with fuel shutoff during deceleration

  (b) Catalytic reactor in exhaust system for control of HC, CO

  (c) Spark advance control

  (d) Exhaust gas recirculation

(3) Vehicle size–Intermediate; styling similar to 1973 models

(4) Tires–Radial ply, steel belted

(5) Vehicle weight–Curb, 3600 lb; loaded vehicle weight, 3900 lb; emission test inertia weight, 4000 lb

(6) Transmission–Coupling biased converter or lock-up clutch with planetary gearset; four-speed automatic, gear ratios 2.5:1, 1.5:1, 1:1, 0.7:1

(7) Rear axle ratio–3.23:1

The change from full to intermediate size will provide a reduction of approximately 10 percent in the aerodynamic drag, primarily due to the reduction in frontal area. The radial ply tires and reduced weight allow a substantial reduction in rolling resistance. The four-speed automatic transmission provides an overdrive capability which would function at speeds above approximately 30 mph.

TABLE 1. SALIENT FEATURES OF INDIVIDUAL IMPROVEMENTS

INDIVIDUAL IMPROVEMENT	UNCONTROLLED EMISSIONS	MODIFIED VEHICLE 0.41–3.4–2.0 STD VEHICLE–1973 STDS	ADDITIONAL COST PER VEHICLE $	VEHICLE PERFORMANCE CHANGE	VEHICLE NOISE CHANGE	WEIGHT AND SIZE CHANGE (REPLACED ITEM)	RELIABILITY CHANGE	OTHER DISADVANTAGES	OTHER ADVANTAGES	CONSUMER ACCEPTANCE	DEMONSTRATION BY 1976?	PRODUCTION BY 1980?
TURBOCHARGED CARBURETED ENGINE 250 CID; WATER-ALCOHOL INJECTION	17%	11%	75-150	TOP SPEED SAME SLIGHT LOSS OF ACCEL. PERFORM.	INCREASED	25% LESS WT. SAME BOX VOLUME	DECREASED	ENGINE MORE SENSITIVE TO FUEL QUALITY INLET AIR TEMP. PROPER WATER ALCOHOL INJECTION		DECREASED	YES	YES
TURBOCHARGED CARBURETED ENGINE 280 CID. AFTER COOLED	10%	4%	150-250	TOP SPEED SAME SLIGHT LOSS OF ACCEL. PERFORM.	INCREASED	10% LESS WT. 10% MORE BOX VOL.		SENSITIVE TO CONDITIONS ENHANCING KNOCK, BUT NOT TO EXTENT OF 250 CID ENGINE		SLIGHTLY DECREASED	YES	YES
VARIABLE DISPLACEMENT ENGINE	23%	7%	125-175	TOP SPEED SAME PROBABLE LOSS OF ACCEL.	NONE	NONE	DECREASED	COMPLEX VALVE GEAR-DIFFICULT CONTROL PROBLEM		SIGNIFICANTLY DECREASED	YES	YES
ENGINE WITH REDUCED FRICTION	0%	−5%	NOT EVALUATED	NONE	SIGNIFICANT INCREASE	NONE	DECREASED			SAME	YES	YES
LEAN MIXTURE ENGINE	8% MAX	12% MAX	NOT EVALUATED	NONE	NONE	NONE	DECREASED			SAME	NOT EVALUATED	NOT EVALUATED
NATURALLY ASPIRATED DIESEL-378 CID	24% (MPG) 16% (BTU)	36% (MPG) 26% (BTU)	180-270	NONE	SIGNIFICANT INCREASE	40% MORE WT. 20% MORE BOX VOL.	EQUAL OR BETTER	EXHAUST ODOR WEIGHT REDUCTION A MAJOR EFFORT EXHAUST PARTICULATES	POSSIBLE MULTI-FUEL CAPABILITY	DECREASED	NO	DOUBTFUL
TURBOCHARGED DIESEL 260 CID	55% (MPG) 44% (BTU)	69% (MPG) 57% (BTU)	200-300	REDUCED ACCEL PERFORM.	SIGNIFICANT INCREASE	10% MORE WT. SAME BOX VOL	EQUAL OR BETTER	EXHAUST ODOR, BUT LESS THAN NA DIESEL WEIGHT REDUCTION EXHAUST PARTICULATES	POSSIBLE MULTI-FUEL CAPABILITY	DECREASED	YES	YES, WITH MAJOR EFFORT
CONTINUOUSLY VARIABLE TRANSMISSION	21%	3%	NONE	NONE	UNKNOWN	NONE	UNKNOWN	CHANGES OPERATING MODE OF ENGINE, REQUIRES ENGINE REDESIGN	POTENTIAL EXISTS FOR REDUCTION IN ENGINE DISPLACEMENT	SAME	DOUBTFUL	NO
HYDROMECHANICAL TRANSMISSION	17%	0 ± 5%	NONE	NONE	INCREASED	NONE	UNKNOWN	CHANGES ENGINE OPERATING MODE TRANSMISSION HAS LOW EFFICIENCY	POTENTIAL EXISTS FOR REDUCTION IN ENGINE DISPLACEMENT	SAME	DOUBTFUL	NO
LOCK-UP CLUTCH	3%	−2%	20-30	NONE	NONE	25% INCREASE IN TORQUE CONVERTER WEIGHT	SLIGHT DECREASE		CAN BE USED WITH OVERDRIVE	SAME	YES	YES
OVERDRIVE	5%	−3%	50	NONE	ENGINE SPEED (AND NOISE) REDUCED	40 POUND INCREASE	SLIGHT DECREASE		POTENTIAL EXISTS FOR DISPLACEMENT REDUCTION WITH AXLE RATIO CHANGE	SAME	YES	YES
MANUAL TRANSMISSION	11%	2%	−100	SLIGHT LOSS OF ACCEL PERFORM.	NONE	REDUCED	SLIGHT DECREASE			DECREASED	YES	YES
4-SPEED AUTOMATIC TRANSMISSION	NOT EVALUATED SEPARATELY		50	IMPROVED	NONE	SLIGHT INCREASE	NONE			SAME	YES	YES
INTAKE PORT FUEL INJECTION	NOT EVALUATED SEPARATELY		75	SLIGHTLY IMPROVED	NONE	NONE	SLIGHT DECREASE		POTENTIAL FOR BETTER FUEL-AIR RATIO CONTROL FOR CATALYST SYSTEMS	SAME	YES	YES
STRATIFIED CHARGE ENGINE (NOT CARBURETED)	29%	34%	150-200	SAME OR SLIGHTLY IMPROVED	NONE	NONE	DECREASED UNLESS ENGINE IS MADE LESS SENSITIVE TO INJECT & TIMING	POSSIBLE EXHAUST ODOR PROBLEM; HIGH EXHAUST PARTICULATES, ENGINE SENSITIVE TO INJECTION & TIMING	POTENTIAL EXISTS FOR MULTI-FUEL OPERATION	SAME	YES	YES
AIR CONDITIONING IMPROVEMENTS	2-4% MAX		16	SLIGHTLY IMPROVED	DECREASED	NONE	NONE			SAME	YES	YES
STEEL BELTED RADIAL PLY TIRES	4%		75	NONE	NONE	NONE	INCREASED		RELIABILITY NOT DECREASED BY INCREASED TIRE PRESSURE	SAME	YES	YES
WEIGHT REDUCTION	7%		200-MATERIAL CHANGE 400-SIZE REDUCTION	NONE	NONE	-	NONE			SAME	DOUBTFUL FOR MAT'L CHANGE-YES FOR RED. SIZE	YES
AERODYNAMIC DRAG DECREASE C_DA REDUCED 10%	2%		NONE	NONE	NONE	SMALL CHANGE IN WEIGHT	NONE			SAME	YES	YES
REFERENCE VEHICLE	0%	−5%										

The engine displacement and rear axle gearing were selected to allow equal acceleration performance for the synthesized design and the 4300 lb reference vehicle. The power requirement is 115 hp at 4000 rpm.

The application of the fuel economy calculation procedure resulted in the prediction of a 30-percent fuel economy benefit. The effects of emission controls are included in this estimate.

It was concluded that the cost decrease as a result of the vehicle size change would be approximately equal to the cost of the added accessories. The cost, then, would be about equal to that of a 1973 reference vehicle constructed during the same year.

Consumer acceptance of the design should be good. Cold start capability and driveability should be enhanced, and the noise level at highway speeds should be reduced. The gearing will not accommodate the towing of heavy loads without operation in third gear.

The vehicle should exhibit the same reliability and maintainability characteristics as the reference vehicle. No difficulty is expected in meeting the 1973 safety standards because the vehicle is essentially a modification of the existing intermediate chassis.

The development of the engine and emission control system is straightforward, although testing and evaluation will be required. The design can be demonstrated by 1976 and produced by 1980; the longest lead time item will be the lightweight engine.

Stratified Charge Engine Design

A vehicle design was synthesized about the stratified charge engine. The primary characteristics of the vehicle are as follows:

(1) Engine—300 CID (open chamber, stratified charge) V-8, cast iron block

(2) Engine accessories (additional)

  (a) Vacuum pump for supply of functions presently produced by manifold vacuum; the engine will be throttled at idle only

  (b) Catalytic reactor in exhaust for control of HC, CO

  (c) Exhaust gas recirculation for control of NO_X (possibly)

(3) Vehicle size—Full; aerodynamic drag reduction of 10 percent

(4) Tires—Radial ply, steel belted

(5) Vehicle weight—Curb, 3800 lb; fuel and one occupant, 4100 lb; inertia test weight, 4000 lb

(6) Transmission—Conventional three-speed torque converter design with modified shifting controls (ratios are the same as the reference vehicle)

(7) Rear axle ratio—3.08:1

The characteristics of fuel consumption as a function of load for this engine make the four-speed transmission used in the previous design unnecessary. The power output of the engine will be approximately the same as that for the conventional spark ignition engine in the previous design, although some reduction may be necessary for control of smoke.

The vehicle is basically equivalent to a standard 1973 automobile except that the weight has been reduced. The radial ply tires and styling changes allow a reduction in road load of 10 percent by comparison with the reference vehicle.

It was predicted that an economy benefit of 55 percent by comparison with the reference vehicle, after correction for emission controls, could be obtained with this design. This estimate might be reduced by as much as 5 percent if it proves impossible to control emissions of oxides of nitrogen to the 2.0-g/mile level without exhaust gas recirculation. The combustion process is responsible for most of the control, and for some engines, the fuel penalty rises rapidly as the level decreases. Although present designs exhibit high hydrocarbon emissions even with aftertreatment, there is considerable optimism within the industry for compliance with the 0.41-g/mile standard through improved reactor design and operating schedule.

The usual procedure is to treat each change in stratified charge engine specifications, even a change in displacement, as a completely new design. With this philosophy, demonstration of the engine by 1976 would require an intense effort. Quantities on the order of one million should not be expected by 1980, although a pilot production should be possible by that time. The pilot production run would be used to resolve some production tolerance control problems.

The cost of the vehicle described above was estimated to be approximately $400 greater than that of the 1973 reference vehicle. According to the procedure for estimating the allowable incremented cost of improvements, this amount can be justified.

Consumer acceptance of the stratified charge engine is not regarded as a problem; therefore, vehicle characteristics would not be noticeably altered. From an overall viewpoint, it is worthwhile to reiterate the multifuel capability of the engine.

Turbocharged Diesel Engine Design

A vehicle based on the turbocharged diesel engine was specified as follows:

(1) Engine–230 CID turbocharged diesel, 4 cylinder, cast iron block (115 hp at 4000 rpm)

(2) Engine accessories

  (a) Vacuum pump

  (b) Clutch fan

(3) Vehicle size–Full; aerodynamic drag reduction 10 percent

(4) Tires–Radial ply, steel belted

(5) Vehicle weight–Curb weight, 3950 lb; loaded vehicle weight, 4250 lb; inertia test weight, 4000 lb

(6) Transmission–Four-speed torque converter type (ratios the same as those listed for the S.I. engine synthesized design)

(7) Rear axle ratio 3.23:1

This design is basically a full-size vehicle with reduced weight. The four-speed transmission has been specified as a means of increasing turbocharger energy input at road load, and the transition to third gear on demand will reduce the possibility of severe turbocharger lag.

Radial ply tires and aerodynamic improvements are also incorporated in this design. Road load horsepower requirements are reduced with respect to the reference vehicle but are the highest of any of the synthesized designs due to the increased rolling resistance.

In addition to the obvious need for power steering, a suitable vacuum pump would have to be driven to supply the various subsystems requiring vacuum power. Power requirements for this accessory were also assumed to be on the order of the power steering pump parasitic requirements.

On the basis of the fuel economy evaluation procedure, it was estimated that the fuel economy benefit for this design would be 70 percent by comparison with a 1973 reference vehicle. This figure includes an adjustment for the energy content of diesel fuel.

It was estimated that the cost increase would be approximately $425, and this increment is justified by the fuel savings.

The diesel engine meets the 0.41–3.4–2.0 emissions standards without auxiliary control devices, but extreme difficulty will be encountered if particulate emission standards are set at low levels.

The primary development risk involves reduction of engine weight or vehicle compatibility with a heavier engine. The development program would involve testing on engine dynamometers and chassis dynamometers, and it is expected that a prototype vehicle could be developed by 1976. As with the stratified charge engine, the first production would probably be on a pilot basis.

Test Program

During the period occupied by this study, several tests were performed on a small sample of vehicles. The series of tests involved two vehicles each (one standard and one intermediate size) from each of the three major manufacturers. The pair of vehicles from each manufacturer was nominally equipped with the same engine.

The tests were conducted in order to characterize the fuel consumption traits of the standard and intermediate vehicles. Each vehicle was operated on the chassis dynamometer using the LA-4 emission test procedure, and direct fuel consumption measurements were made for cold start and hot start test runs. In addition, each vehicle was operated on the road, and measurements of fuel consumption and road load were obtained. Finally, each engine was operated on a dynamometer in

order to obtain engine map data. The test procedures and the results are described in the body of the report.

The results of the tests indicated significant differences between the fuel consumption characteristics of the several vehicles. These differences were attributed to variation in engine operating condition and to the specific tuning used by each manufacturer for emission control.

In addition to the vehicle tests, power consumption measurements were made for each of the major accessories on each vehicle, and the effect of air conditioning was determined during the chassis dynamometer tests.