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THIRD QUARTERLY
PROGRESS REPORT

STUDY ON REDUCTION OF ACCESSORY-✓
HORSEPOWER REQUIREMENTS

74-310860(9)

April 23, 1975

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April 23, 1975

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REPORT NO. 74-310860(9)

TOTAL PAGES 40

ATTACHMENTS: Appendix I (21 pages)

REV	BY	APPROVED	DATE	PAGES AND/OR PARAGRAPHS AFFECTED
N/C	RJH	See Title Page	4-23-75	Initial Issue

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THIRD QUARTERLY
PROGRESS REPORT
STUDY ON REDUCTION OF ACCESSORY-
HORSEPOWER REQUIREMENTS

1.0 INTRODUCTION

This is the third quarterly technical progress report submitted in accordance with requirements outlined in Attachment B, Reports and Reviews, Environmental Protection Agency Contract 68-03-2119. This report covers the period from January 18, 1975 through March 31, 1975.

The objective of this study program is to minimize automotive accessory horsepower consumption, and thereby maximize overall vehicle fuel economy, by utilizing continuously variable speed drives or auxiliary power units (APUs) in a standard passenger automobile.

As an aid to definitizing accessory performance, load requirements and fuel economy, a baseline vehicle has been established. This vehicle is a conventional intermediate size 5- or 6-passenger automobile with a 4.1 to 5.7 liter (250-350 cubic inch) displacement, spark ignition engine. Accessories to be considered are the alternator, power steering system, power brakes, air conditioner, cooling fan, water pump and emission control air pump.

Although the primary goal of the study is to minimize power consumption of the accessory system, this must be accomplished in a manner acceptable to both manufacturers and customers.

Factors such as first cost, complexity, maintainability, and durability, will be significant considerations in the selection process.

The study includes the following considerations which will result in accessory drive systems that minimize power consumption:

- o Power consumed by present day accessories and drives
- o Power required to supply the load demands
- o Effectively matching individual accessory outputs to load requirements
- o Drive techniques to run accessories at peak efficiencies
- o Redesign of certain accessories to better match load characteristics and integrate with promising drives
- o Determine what power savings could be expected if optimizing drive/accessories were implemented by design modifications on a typical vehicle
- o Translate power savings into fuel economy

1.1 Content

The third quarterly report presents a program summary of major accomplishments.

- o Accessory drive devices analyses
 - (a) Single-ended, split-torque hydromechanical
 - (b) Electronic-controlled, variable-ratio belt
- o Vehicle computer model fuel economy analyses
- o Improved accessory efficiency analysis
- o Resized engine fuel economy analysis

- o Accessory evaluation matrix completed
- o Drive-systems trade-study completed and the prime concept presented
- o Variable-speed belt-drive concepts reviewed

The Accessory Data Sheets, included herein as Appendix I, have been developed for use in a manufacturer survey. The survey will be directed to approximately thirty sources. The data will be used to confirm analyses and provide information required for improving accessory performance.

1.2 Trip Summary

During this quarter, the following meetings were held for the purpose of establishing technical information and program status interchanges.

- o SAE Conference; Detroit, Michigan
- o General Motor Technical Center; Warren, Michigan
- o Environmental Protection Agency; Ann Arbor, Michigan
- o Precision Automated Machine Company; Orange, California

1.3 Fourth Quarter Tasks

Tasks to be pursued during the fourth quarter of the program are:

- o Complete 350 CID, Chevrolet engine accessory and drive envelope drawing

- o Complete sizing and preliminary layout of selected drive system
- o Complete detail drive designs
- o Expand accessories analyses in following areas:
 - o Analysis of efficiency trends and improvements resulting from reduced accessory speeds
 - o Cooling system load matching analysis required for reduced speed pump and fan
 - o Evaluation of electric cooling fans

2.0 ACCESSORY DRIVES

2.1 Single-Ended-Hydromechanical Drive

The functional design of this drive is identical to the hydro-mechanical split-path drive presented in the third monthly progress report (74-310860-3) except:

- o Input and output shafts are co-axial
- o Slightly increased pump and motor displacement
- o Straight-through-drive operation reduced from 2400 to 1900 input rpm
- o Designed for peak overloads of 200 percent

Both drive designs are shown in Figures 1 and 2.

The original drive design was an attempt to produce a package small enough to be driven directly by the engine crank and occupy the volume between the crank torsional damper and the radiator. Interface studies have shown that the drive will not fit in the baseline vehicle; therefore, the single-ended design was developed to permit remote drive mounting.

The pump and motor elements were resized to meet the power and duty cycle requirements of the Accessory Drive Specification, 75-311125 (Appendix II of 74-310860-6). This factor did not effect the overall size of the drive.

To more closely balance the pump and motor displacement, the controlled output speed and straight-through-drive speed were reduced to 1900 rpm. This modification has the effect of shifting the best

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HYDROMECHANICAL SPLIT-PATH DRIVE
BALL PISTON TYPE

FIGURE 1

HYDROMECHANICAL SPLIT-PATH
DRIVE-BALL PISTON TYPE
SINGLE ENDED

FIGURE 2

operating efficiency into the most used portion of engine speed (60 percent operation at 1500 to 2000 rpm). Accessory drive efficiencies for 100, 50 and 25 percent load are shown in Figure 3.

The peak-system loads of 200-percent rated power are accommodated by allowing system pressure to raise during the transient condition. This will cause a momentary drive-output speed-droop related to increased volumetric losses and lags in the control system. Since these peak loads are of short duration, total effect on endurance life of the drive is negligible.

2.2 Electronically-Controlled Belt-Drive

This is a variable-ratio belt-type drive with electronic sensing of both speed and adjustable sheave location. A functional section view of the drive is shown in Figure 4.

Drive control is effected through two interlinked systems: (1) Voltage generations based on operating rpm and (2) axial shift of pulley face monitored by optical scanning of integral geometric pattern which signals the percentage of shift as dictated by the programmed requirements of the accessory torque-horsepower curve. The result of the optical ratio scanning is a second voltage control which, with the rpm signal, dictates activation or deactivation of a hysteresis brake ball-screw axial-drive control. Low ratio downshift automatically occurs due to spring loading of the moveable face as the brake-screw control is deactivated.

Driven pulley operation maintains system tension by either cam-activated or spring-activated sheave-loading against the standard variable-speed belt. Total ratio changes of 8:1 and torque efficiencies of 90 to 95 percent are possible with this configuration drive.

EFFICIENCY
VS INPUT RPM

FIGURE 3

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VARIABLE RATIO BELT DRIVE WITH ELECTRONIC CONTROL

FIGURE 4

3.0 Computer Model Fuel Economy Analysis

The fuel economy analysis for the baseline vehicle, with and without the optimum accessory drive system, was completed and the results compiled in Table I. These results represent an in-depth study that considered a variety of total vehicle operating envelopes. The operating envelopes include various apportionments of two major variables:

- o Driving Mode
- o Accessory Loading

The driving modes or cycles are defined in detail in Table II. The selected driving cycles are currently in use throughout the automotive industry and governmental testing agencies. The driving cycles may be divided into three discrete groups that are not necessarily comparable but represent nationwide driving conditions.

- o Federal city and EPA highway cycles
- o SAE urban, suburban and interstate cycles
- o Constant velocity segments

Accessory load conditions for each driving cycle, air conditioning mode and accessory drive type are presented in Table III. All driving cycle fuel economy results are obtained for "ON" and "OFF" air conditioning modes of operation. The air conditioning load profile used in the Federal and SAE urban driving cycles represents the power required to achieve heat-soaked vehicle cooling or slow-speed operation in heavy traffic. For the EPA highway, SAE suburban and constant velocity segments, the air conditioning is matching the steady-state cooling requirements imposed by vehicle velocity. The stock engine cooling system fan is modulated via a thermostatically controlled clutch to represent cycle cooling demands and air conditioning load. The constant-speed

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TABLE I

FUEL ECONOMY ANALYSIS

Driving Cycle		FUEL ECONOMY - MPG				Percent Improvement With CSD	
		Standard Accessory Drive		Constant Speed Accessory Drive			
		A/C OFF	A/C ON	A/C OFF	A/C ON	A/C OFF	A/C ON
Federal (FDC)		10.31	9.42	10.43	9.72	1.16	3.18
EPA Highway Fuel Economy Test (HWFET)		16.33	15.09	16.93	16.05	3.67	6.36
SAE Urban		9.00	8.17	9.07	8.33	0.78	1.96
SAE Suburban		14.43	13.42	14.89	14.11	3.19	5.14
SAE Interstate (55 mph)		16.47	15.06	17.25	16.30	4.74	8.23
SAE Interstate (70 mph)		13.73	12.64	14.85	14.20	8.16	12.34
Constant Velocity Segments (mph)	30		15.30		15.38		0.52
	40		15.88		16.42		3.40
	50		16.07		16.98		5.66
	60		14.84		16.05		8.15
	70		13.36		14.65		9.66

TABLE II
DRIVING MODES

DRIVING CYCLE	GRAPHIC DISPLAY	AVERAGE SPEED MPH	CYCLE LENGTH MILE	STOPS PER MILE	PERCENT TIME @ DRIVING CONDITIONS				MAXIMUM ACCEL. RATE (Ft/Sec ²)
					IDLE	ACCEL.	DECEL.	CRUISING	
FEDERAL DRIVING CYCLE (FDC LA-4)		19.6	7.45	2.01	14.7	29.9	24.9	30.5	4.84
EPA HIGHWAY FUEL ECONOMY TEST (HWFET)		48.5	10.242	0.098	1.0	23.7	14.5	60.8	4.69
SAE URBAN		15.6	2.01	3.98	13.2	11.7	15.5	59.6	7.00
SAE SUBURBAN		41.1	5.195	0.38	2.6	11.9	10.6	74.9	7.00
SAE 55 MPH INTERSTATE		55.0	4.70	0	0	17.8	17.8	64.4	1.00
SAE 70 MPH INTERSTATE		70.0	4.70	0	0	17.8	17.8	64.4	1.00

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TABLE III
ACCESSORY SYSTEM SIMULATION CONDITIONS

Model Code No.	Type of Accessory Drive System	Driving Cycle	A/C Mode	A/C Drive Ratio	Fan Mode	Alternator Output (amps)	Total Accessory Power Consumption - Horsepower				
							Engine Speed - rpm				
							Idle	1000	1500	2000	3000
1	Stock	All	Off	1.4	40% Clutched	20	1.23	2.13	3.64	5.40	10.77
2	Stock	FDC Urban	Maximum pull down	1.4	75% Clutched	30	3.87	6.25	9.79	14.19	24.87
3	Stock	HWFET Suburban Interstate	Match steady state load	1.4	60% Clutched	30	3.39	5.25	7.89	10.94	18.47
4	Speed limited	All	Off	1.6	Direct drive	20	1.34	2.40	2.40	2.40	2.40
5	Speed limited	FDC Urban	Maximum pull down	1.6	Direct drive	30	4.14	6.75	6.75	6.75	6.75
6	Speed limited	HWFET Suburban Interstate	Match steady state load	1.6	Direct drive	30	3.59	5.60	5.70	5.75	5.80

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accessory-drive system fan does not require a clutch because fan-speed and power is controlled by the drive. Air conditioning "ON" operation requires an additional 10-ampere alternator load caused by the air conditioning blower motor and electric clutch operation. The air conditioning compressor for the constant-speed accessory-drive system must be driven at a slightly higher speed ratio than the stock system (1.6 vs 1.4) to achieve equivalent cooling capacity.

Data presented in Table I shows fuel economy for each particular driving cycle but is not sufficient to determine a gross, yearly average. SAE report 750003 contains current, nationwide, experimental data on driving speeds and conditions and presents a relationship between "miles driven" and driving speeds. The data, reproduced in Figure 5, may be used in conjunction with SAE driving cycles shown in Table II to establish a composite driving cycle that represents all driving conditions for a 10,000 mile vehicle year. Distribution of driving conditions on a yearly basis is:

- o 18.2 percent - Urban
- o 35.5 percent - Suburban
- o 40.7 percent - Interstate (55 mph)
- o 5.6 percent - Interstate (70 mph)

Air conditioning usage for the entire year has previously been established at 50 percent in Progress Report 74-310860(7). The nationwide, composite, fuel economy for the baseline vehicle, with and without the optimum accessory drive system is shown in Figure 6. The yearly savings in gallons of fuel is 33 or 4.31 percent while the increase in fuel economy is 4.54 percent. Additional increases associated with improving accessory operating efficiency and reduced engine size are also presented in this quarterly.

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DATA SOURCE: SAE REPORT NO. 750003

PERCENT MILES IN SPEED BANDS-NATIONWIDE

FIGURE 5

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FUEL CONSUMPTION ~ A/C OFF

YEARLY NATIONWIDE AVERAGE

4.54%

FUEL CONSUMPTION ~ A/C ON

YEARLY COMPOSITE 50% A/C OPERATION

COMPOSITE DISTRIBUTION

- 18.2% URBAN
- 35.5% SUBURBAN
- 40.7% INTERSTATE 55
- 5.6% INTERSTATE 70

NATIONWIDE COMPOSITE FUEL ECONOMY

FIGURE 6

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4.0 IMPROVED ACCESSORIES

The loads imposed on accessories are usually most severe at engine idle or low speed operation; therefore, accessories must be designed to meet these conditions. The standard accessory system must also be capable of surviving extreme overspeed operation at high engine speeds. This particular combination of design requirements necessitates a compromise in performance, efficiency and configuration.

Addition of an accessory drive device that limits maximum accessory speed would also allow accessory modifications or redesigns to improve the overall designs and performance characteristics. The standard accessory speed range is approximately 6.5:1 while the recommended constant speed accessory speed range is only 2.5:1 with constant speed operation occurring from 1000 to 3000 engine rpm. The overall effect is to drive the accessories at a maximum of 1.5 times idle speed over the conventional range of engine operation (95 percent operation at 650 to 3000 rpm).

A parametric study was performed to determine the effect of improved accessory efficiency on the baseline vehicle steady-state fuel economy. The results are presented in Figure 7 showing the percent increase in fuel economy vs vehicle speed for the baseline vehicle equipped with a constant speed accessory drive and accessories with 15, 20, 30 and 40 percent improved efficiencies.

4.1 Accessory Efficiency

A preliminary evaluation of how accessory efficiency improvements could be achieved at constant speed was performed, and the results are shown in Table IV. Improvement in the following areas were included in the analysis.

FIGURE 7

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TABLE IV
IMPROVED CONSTANT SPEED ACCESSORY EFFICIENCY

ACCESSORY	STOCK AVERAGE HP		IMPROVED AVERAGE HP	
	LOW SPEED	HIGH SPEED	LOW SPEED	HIGH SPEED
Air Conditioning	3.05	3.05	2.75	2.75
Alternator	0.95	1.20	0.69	0.72
Fan	0.40	0.60	0.25	0.37
Power Steering	0.45	0.64	0.39	0.51
Water Pump	0.20	0.25	0.20	0.25
Air Pump	0.10	0.11	0.10	0.10
TOTALS	5.15	5.85	4.38	4.70

Low Speed Improvement = 15 percent (Urban and Suburban Driving)

High Speed Improvement = 20 percent (Suburban and Interstate Driving)

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Air Conditioning - Reduced pumping losses by improving valves and porting (10 percent). Additional gains, not considered in this analysis, could be made by using a temperature cycling compressor.

Alternator - Reduced losses by lowering windage, bearing and brush effect and improving electrical losses (27 percent low speed, 40 percent high speed).

Fan - Fan geometry changed to air-foil shape and shroud fixed to fan center-line with 0.2 inch tip clearance (38 percent).

Power Steering - Remove or reduce effect of flow control orifice (14 percent low speed, 20 percent high speed).

Water Pump - Improved geometry and efficiency to achieve needed flow increase at low constant speed without increasing required input power (0 percent).

Air Pump - Improve mechanical efficiency with lighter bearings and rotating mass (0 percent low speed, 10 percent high speed).

Results of this preliminary study indicate that overall accessory power consumption may be reduced by 15 to 20 percent with reasonable efficiency improvements. Detailed analysis and testing is expected to confirm a minimum attainable improvement of 15 percent; therefore, this value will be used for fuel economy predictions.

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5.0 ENGINE RESIZING

The addition of an accessory drive device effects the baseline engine performance by:

- o Reducing accessory power requirements
- o Increasing available engine power for other uses
- o Increasing BSFC (Brake Specific Fuel Consumption-
lbs Fuel/Hour/HP)

Vehicle performance has been increased by adding significant, available power to the acceleration margin. Therefore, if the baseline vehicle performance was satisfactory, the accessory drive equipped vehicle could achieve "equal performance" with a smaller engine.

5.1 Power Savings

The power saved by the accessory drive at any engine speed is considered available for acceleration; therefore, the wide-open-throttle (W.O.T.) engine power may be reduced by an amount equal to the savings without affecting vehicle performance.

5.2 Equal Performance Engine

The difference in W.O.T. power between the baseline and equal performance engines is approximately 10 percent; therefore, the engine may be resized by this factor. Engine power is directly proportional to:

Mean Cylinder Pressure (BMEP)

Displacement

Speed

Engine speed cannot be modified without involving changes to the vehicle drive line. BMEP cannot be directly effected without changing various parameters as compression ratio or volumetric efficiency. Changes to engine speed and BMEP may produce adverse effects that cannot be accounted for in this elementary analysis. The single, most isolated, engine parameter that can easily be modified is displacement. Engine bore and/or stroke may be modified to effect a 10 percent decrease in W.O.T. power. A 10 percent decrease in engine displacement would produce a like change in W.O.T. power which would fulfill the definition of "equal performance" but the effect on part throttle operation is expected to be less than 10 percent. The relationships between small changes in engine displacement and part-throttle fuel economy are complicated and must be evaluated for mechanical and volumetric efficiency and BMEP effects. Until further analyses can be conducted, this study will assume a 10 percent decrease in engine displacement produces a 5 percent decrease in part-throttle power.

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5.3 Resized Engine Fuel Economy

The baseline vehicle BSFC vs HP engine map was modified by shifting the HP scale 5 percent. In effect, this produces a smaller engine and regains a major percentage of the BSFC lost by adding the accessory drive without affecting vehicle performance.

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5.4 Computer Model Fuel Economy

The computer model was modified to predict fuel economy for the baseline vehicle equipped with the optimum accessory drive, 15 percent efficiency improved accessories and 10 percent decreased engine displacement. Figure 8 shows the percent improvement in fuel economy for the above accessory and engine modifications. The fuel economy analysis presented in Section 3.0 of this report was repeated and the results are shown in Table V and Figure 9. Figure 9 shows a nationwide, yearly increase in fuel economy of 7.9 percent, which is nearly twice the savings for the baseline vehicle with accessory drive only. The yearly savings in gallons of fuel is 56 or 7.3 percent. It should be reiterated that the introduction of an accessory drive into the system allows fuel economy savings to be introduced in an incremental manner as the hardware becomes available for production. The drive itself will produce the initial savings without requiring changes to current accessories or engines. As individual accessory improvements are introduced the fuel savings increase. Finally the engine resizing could be introduced to realize the full potential in fuel economy associated with this concept.

FUEL ECONOMY IMPROVEMENT DUE TO ACCESSORY DRIVE,
IMPROVED ACCESSORIES, RESIZED ENGINE

FIGURE 8

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TABLE V
RESIZED ENGINE
FUEL ECONOMY ANALYSIS

Driving Cycle		FUEL ECONOMY - MPG				Percent Improvement	
		Standard Accessory Drive		Accessory Drive Resized Engine Improved Accessories			
		A/C OFF	A/C ON	A/C OFF	A/C ON	A/C OFF	A/C ON
Federal (FDC)		10.31	9.42	10.69	10.27	3.66	8.97
EPA Highway Fuel Economy Test (HWFET)		16.33	15.09	17.46	16.72	6.90	10.77
SAE Urban		9.00	8.17	9.17	8.75	1.91	7.06
SAE Suburban		14.43	13.42	15.21	19.56	5.41	8.46
SAE Interstate (55 mph)		16.47	15.06	17.80	17.00	8.08	12.90
SAE Interstate (70 mph)		13.73	12.64	15.41	14.87	12.23	17.67
Constant Velocity Segments (mph)	30		15.30		16.04		4.84
	40		15.88		17.03		7.56
	50		16.07		17.63		9.71
	60		14.84		16.70		12.53
	70		13.36		15.18		13.62

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FUEL CONSUMPTION ~ A/C OFF

YEARLY NATIONWIDE AVERAGE

7.90%

FUEL CONSUMPTION ~ A/C ON

YEARLY COMPOSITE 50% A/C OPERATION

COMPOSITE DISTRIBUTION

- 18.2% URBAN
- 35.5% SUBURBAN
- 40.7% INTERSTATE 55
- 5.6% INTERSTATE 70

RESIZED ENGINE
NATIONWIDE COMPOSITE FUEL ECONOMY

FIGURE 9

6.0 Accessory Evaluation Matrix

The accessory evaluation chart presented in Table VI is a collection of known data for conventional accessories. Also included is a tabulation of possible accessory modifications, and the resultant impact that could be expected from implementation of a speed limiting accessory drive scheme. Chart comments are brief and general for the purpose of exposing both critical and high-payoff areas where study efforts should be concentrated. The detail accessory data used to compile the chart is extensive and will be included in the final report as data books for each accessory.

TABLE VI
ACCESSORY EVALUATION MATRIX

EXISTING EQUIPMENT					
ACCESSORY	DOMESTIC PRODUCERS	RATIO TO ENGINE SPEED	LOAD DATA	LOAD CONTROL	LOSSES
ALTERNATOR	DELCO AUTO LITE MOTOROLA	2.7 TO 1 3.1 TO 1	MAX OUTPUT = 50-90A @ 13 V EQUIV OUTPUT = 1 TO 2 HP AVG $\approx$ 1/3 MAX OVERALL CONVERSION EFF $\approx$ 50-70%	DIRECT OUTPUT CONTROL PROPORTIONAL LOAD MATCHED OUTPUT AS PRESENTLY DESIGNED	BRG DRAG FAN AND ROTOR WINDAGE ELECTRICAL LOSSES IN IRON & CU.
WATER PUMP	INDIVIDUAL AUTO PRODUCERS	1 TO 1 1.25 TO 1	1/4 TO 4 HP PROPORTIONAL TO SPEED CUBED	NONE ON PUMP THERMOSTAT IN SYSTEM	EXCESS FLOW Δ P AT LOW COOLING LOADS
COOLING FAN	INDIVIDUAL AUTO PRODUCERS	1 TO 1 1.25 TO 1	1/8 TO 8 HP RELATED TO THE CUBE OF SHAFT SPEED, MAX COOLING REQ AT LOW SPEEDS	LOAD LIMITING WITH FLEX BLADES AND FLUID COUPLINGS	AERODYNAMIC
POWER STEERING PUMP	SAGINAW VICKERS THOMPSON	1.2 TO 1	$\approx$ 2 GPM @ IDLE FLOW PROP TO PUMP SPEED PRESSURE 50-1000 PSI DEPENDENT ON STEERING LOAD	OPEN CTR CONTROL VALVE DEMAND MATCH SYSTEM	FLUID PUMPING LOSSES AT SPEEDS ABOVE IDLE
AIR COND COMPRESSOR	FRIGIDAIRE CHRYSLER YORK TECUMSEH	1 TO 1 1.6 TO 1	1/2 TO 3 TON OUTPUT AND 2 TO 8 HP INPUT DEPENDENT ON ENGINE SPEED AND AMBIENT COND	ON-OFF AND SUCTION THROTTLING	VOL EFF POOR @ HIGH RPM WIDE RANGE SUCTION THROTTLING
AIR PUMP	SAGINAW	1.2 TO 1 1.3 TO 1	.04 TO 2 HP	ANTI BACKFIRE AND DISTRIBUTION VALVE	INTERNAL LEAKAGE BRG DRAG

*TBD = TO BE DETERMINED

ADVANCED ACCESSORIES AND DRIVE						
TYPE OF MODIFICATION	OPTIMUM SPEED	POWER SAVINGS POSSIBLE @ 55 MPH	FAVORABLE FEATURES	UNFAVORABLE FEATURES	COST IMPACT TO CONSUMER	CAN ACCESSORY IMPROVEMENTS BE TIME PHASED INTO SELECTED DRIVE CONCEPT
MAX SPEED LIMITED TO OPTIMUM EFFICIENCY OR HIGH PERCENTAGE OF MAX OUTPUT REDUCE LOSSES	3000/4000 RPM ALTERNATOR SHAFT SPEED	APPROX 1 to 1-1/2 HP	REDUCED STRESS IN ROTOR • LIGHTER & SMALLER REDUCED BRUSH & BRG WEAR	NONE	$\approx$ 25% LESS COST BY REDESIGN TO TAKE ADVANTAGE OF REDUCED MAX SPEED	YES
CONTROL SPEED ON COOLING DEMAND	VARIABLE	1/2 TO 2 HP	REDUCED CAVITATION DAMAGE LONGER BRG LIFE OPTIMUM POWER MATCH FASTER WARM UP	REQ TEMP SENSING LOAD CONTROL	TBD*	NO
CLIP SPEED ABOVE MAX LOAD REQ IMPROVE FLOW EFF.	EQUIVALENT TO CAR SPEED OF 30 TO 40 MPH	1 to 1-1/2 HP		REQ CAREFUL EVALUATION OF HIGH SPEED, HIGH LOAD COOLING CHARACTERISTICS	POSSIBLE SMALL INCREASE FOR MORE EFFICIENT PUMP	YES
ON/OFF BASED ON COOLANT TEMP (ELECTRIC)	DEPENDENT ON BLADE DESIGN	2-3 HP	IMPROVE EFF - NO W/P BRG LOADS - LESS NOISE OPT POWER MATCH FASTER WARM UP FREEDOM ON LOCATION	REQ ELECTRIC MOTOR AND TEMP SENSING CONTROL	$\approx$ 150% INCREASE COST FOR MOTOR AND CONTROLS (+ \$40.00 NET)	NO
LIMITED MAX SPEED. CONTROL BLADE AND SHROUD GEOMETRY	LOW = 1000 RPM			NONE	ELIMINATION OF VISCIOUS FAN CLUTCH (APPROX \$20.00)	YES
CLIP SPEED JUST ABOVE IDLE RPM REDUCE FLOW Δ P RESTRICTION	LOW $\approx$ 1000 RPM	1/2 TO 1 HP	CAN ELIMINATE P/S OIL COOLER - LESS WEAR LOWER SHOCK LOAD IN BELT ELIMINATE OR SIMPLIFY FLOW LIMITING CONTROL	NONE	SAME AS ALTERNATOR	YES
LIMIT MAX COMP SPEED TO VALUE REQ TO GENERATE WORST CASE COOLING CAPACITY CONSIDER COMPRESSOR TEMP. CYCLING	1000-2000 RPM	2-3 HP	REDUCED CENT STRESS LONGER BRG LIFE IMPROVED LUBE INCREASED VALVE LIFE CAN BE CONFIGURED FOR IMPROVED OUTPUT AT LOW ENGINE SPEEDS	WILL TRADE REDUCED HP ABOVE 30 MPH FOR SLIGHT INC BELOW 30 MPH	30-40% LESS INITIAL COST	YES
LIMIT MAX SPEED	1000-2000 RPM	APPROX 1/3 HP	REDUCED BRG AND VANE STRESSES. LONGER PUMP LIFE	NONE	NONE	NOT APPLICABLE

7.0 Drive System Trade Study

The accessory drive system trade study was concluded with the selection of variable-ratio-belt type devices. Candidate drive systems for the trade study were categorized in order of selection as follows:

- o Variable ratio belt
- o Variable ratio traction
- o Split path - hydromechanical
- o Variable electric
- o Two-speed gear transmission
- o Constant and variable speed hydrostatic
- o Friction clutch
- o Conventional belt or gear
- o Auxiliary power unit

The trade study evaluation matrix included the following criteria and weighting factors:

Fuel economy - 50 percent
Initial cost - 15 percent
Complexity - 10 percent
Maintenance cost - 10 percent
Noise - 5 percent
Installation flexibility - 5 percent
Weight - 5 percent

7.1 Fuel Economy

A design performance analysis of the candidate drive systems was conducted to substantiate applicability of each candidate with respect to conservation of required accessory power consumption. The systems were mechanized to control accessory input speed and torque using load-matching or speed-limiting techniques to provide minimum possible

accessory power consumption while maintaining sufficient performance over the total vehicle operating range. The drive system overall efficiency was calculated for the above operating conditions and used to determine the net effect on vehicle fuel economy.

The vehicle computer model was used to perform a parametric study of drive system efficiency effect on fuel economy. Results of that study, presented in Figure 10, show drive efficiency to be the single most important factor concerning drive system fuel economy.

Various industrial and recreational vehicle applications of the Variable Speed Belt Drive have shown that minimum drive efficiencies of 90 percent may be obtained with accurate and well executed designs. The overall drive efficiency is within the range of normal fixed-ratio belt drives which indicates that an accessory system employing a variable-ratio belt drive in place of an existing belt could operate with no efficiency degradation.

7.2 Initial Cost

Initial consumer cost for the optimum drive-system design was specified at \$50.00⁽¹⁾. The cost was based on one-half the amortization cost to the consumer in fuel savings over a three-year period at 15,000 miles/year, \$0.60/gallon and a 5-percent net increase in fuel economy due to the drive.

Computer-predicted fuel-economy increases for the variable-ratio belt-drive system have shown that one and one-half year amortization may be obtained with initial consumer cost set at \$44.55.

⁽¹⁾ See Design Specification for An Accessory Drive System, Specification No. 75-311125.

SENSITIVITY OF FUEL ECONOMY TO DRIVE EFFICIENCY

FIGURE 10

The leading manufacturer of variable-ratio belt-drives quoted distributor prices of \$25.00 to \$35.00 for existing drives within the required torque transmission range.

7.3 Complexity

Transmission hardware of the variable-ratio belt-drive is simple and well within the production capability of a modern machine shop. Complexity of the control system varies in proportion to the required degree of speed control. The accessory-drive-required speed-control is approximately ± 5 percent at 1000 rpm to ± 10 percent at 3000 rpm with a control response time-constant of $1/2$ second. Existing drive-types currently meet these control requirements.

7.4 Maintenance Cost

The variable-ratio belt-drive should require only light maintenance of the type given stock belt-drive systems with the possible exception of maintaining lubrication and/or external adjustments. The average cost of maintenance over a three-year period is estimated to be \$7.00 to \$10.00.

7.5 Noise

The noise level generated by a variable-ratio belt-drive system will not exceed acceptable subjective limits applied to current-day vehicles. A reduction in overall vehicle noise may be achievable due to reduced accessory speeds.

7.6 Installation Flexibility

The variable-ratio belt-drive can be designed to bolt on existing engines. Modifications in accessory bracketry and a possible, minor,

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relocation of the radiator should be expected. The concept is adaptable to installation of improved efficiency accessories that could follow initial drive system introduction.

7.7 Weight

The variable-ratio belt-drive deletes the existing fan-clutch requirements and possibly eliminates the need for power-steering fluid heat-exchangers and flow-limiting devices. The net-weight increase for adding the drive should not exceed 8 pounds. Further redesign of accessories to take advantage of constant-speed operation could produce a net decrease in accessory system weight.

8.0 Variable Speed Belt Drives

Figure 11 shows the types of variable ratio belt drives and control schemes applicable to automotive accessory systems. The three configurations presented in Figure 12 through 14 are currently being analyzed for the baseline vehicle application and one or more of these configurations will be selected for detail design.

TYPES OF VARIABLE-SPEED BELT-DRIVES

FIGURE 11

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"FEATURES"

- (1) RATIO CHANGE RESULTS FROM TRANSLATION OF DUAL GROOVE PULLEY MOUNTING SHAFT
- (2) INPUT AND OUTPUT PULLEYS ARE STANDARD FIXED GEOMETRY
- (3) LARGE RATIO CHANGES POSSIBLE WITH SMALL INPUT MOTIONS
- (4) CAN BE INSTALLED WITH MINIMAL CHANGES TO CONVENTIONAL ACCESSORY CONFIGURATIONS
- (5) SPEED SENSING AND ACTUATION ALTERNATES
 - (a) POWER STEERING PUMP FLOW
 - (b) ALTERNATOR FREQUENCY-ELECTROMECHANICAL ACTUATOR
 - (c) CENTRIFUGAL

DUAL GROOVE VARIABLE RATIO BELT CONCEPT
FIGURE 12

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- (1) SYSTEM CONSISTS OF 2 SPLIT FLANGE PULLEYS, ONE ON-CRANK WITH POSITION CONTROLLED AS A FUNCTION OF INPUT RPM AND ONE ON-OUTPUT SHAFT, SPRING LOADED FOR TAKE-UP
- (2) CONTROL MECHANIZATIONS
 - (a) CENTRIFUGAL DIRECT OPERATED
 - (b) CENTRIFUGAL SERVOED WITH CRANK-FED LUBE OIL
 - (c) CENTRIFUGAL SERVOED WITH BALL-SCREW ACTUATOR

SPLIT-PULLEY-PROGRAMMED
INPUT POSITION CONTROL
FIGURE 13

- (1) SYSTEM CONSISTS OF 1 SPLIT FLANGE PULLEY ON CRANK WITH POSITION CONTROLLED AS A FUNCTION OF CRANK SPEED WITH IDLER BELT TAKE UP
- (2) CONTROL MECHANICATION
 - (a) POWER STEERING PUMP FLOW ACTUATOR
 - (b) ELECTROMECHANICAL ACTUATOR-SPEED OR ALTERNATOR FREQUENCY CONTROLLED

SINGLE SPLIT PULLEY-IDLER TAKE UP

FIGURE 14

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APPENDIX I

ACCESSORY DATA SHEETS
(21 pages)

74-310860(9)
Appendix I

ENGINE COOLING FAN DATA SHEET

Assumptions: 1974 Intermediate or Compact Sedan
3000-4000 lbs. curb weight class
140 to 350 CID Engine (100-150HP)
3-speed Automatic w/2.7 to 3.5:1 axle ratio
Accessories include: Fan, Alternator, P/S
P/B, A/C, W/P and A/P

Specific Data:

- (1) Show flow vs. static ΔP and speed characteristics for fan on attached Figure 1 (Clutch locked-up).
- (a) Data represents vehicle installation: YES ☐ NO ☐
- (b) Fan shroud tip clearance: _____
- (c) Fan efficiency: _____
- (d) Engine Type _____, Displacement _____ CID,
Rated _____ HP @ _____ RPM.
- (2) The vehicle installed fan is driven at a ratio of _____ to _____ with respect to the engine crank speed (clutch lock-up).
- (a) Type of fan clutch used:
Torque Control ☐ Thermal Control ☐ Both ☐ None ☐
- (b) Show fan/clutch speed relationships on Figure 2.

General Data:

- (1) The fan sizing criteria is based on cooling requirements at:
- ☐ Engine Idle
- ☐ Max Engine Load (Explain loaded conditions: _____

_____) .

☐ Most Critical Condition (Explain: _____

_____.)

(2) Vehicle velocity effects required fan power as follows:

- ☐ No effect
☐ Reduces required power
☐ Increases required power

Explain graphically on plot below

NOTE: SHOW EFFECT IN % POWER
@ VARIOUS SPEEDS

(3) A radiator air flow of approximately _____ CFM (Minimum) would be sufficient to meet the most critical cooling requirements for the assumed vehicle.

- (4) Comment on electric motor driven, thermally controlled fans:
(Discuss cost, noise, power, warm-up, load matching, efficiency,
packaging, etc.)

FIGURE 2

ALTERNATOR DATA SHEET

The data requested is for the 55 ampere size alternator currently used in intermediate and compact automobiles.

- (1) Complete the Figure 1 alternator performance map or attach comparable data.
- (2) The distribution of alternator losses is as follows:

TYPE LOSS	LOSS DISTRIBUTION @ RPM		
	4000	6000	8000
Electrical*	%	%	%
Mechanical	%	%	%
Aerodynamic	%	%	%

*Assume max current load

- (3) If alternator speed could be held constant in the 3000 to 5000 RPM range, what improvements would be made to better efficiency and lower cost?

INPUT POWER IP

4
3
2
1
0

0 2000 4000 6000 8000 10000

ALTERNATOR SPEED - RPM

FIGURE 1

ENGINE WATER PUMP DATA SHEET

Assumptions: 1974 Intermediate or Compact Sedan
3000-4000 lbs. Curb Weight Class
140 to 350 CID Engine (100-150HP)
3-speed Automatic w/2.7 to 3.5:1 axle ratio
Accessories include: Fan, Alternator, P/S, P/B,
A/C, W/P and A/P.

Specific Data:

- (1) Complete the water pump performance map shown in Figure 1 or attach comparable data.

(a) Data represents ☐ Bench Test ☐ Vehicle Test
(b) If vehicle test, thermostat is ☐ OPEN ☐ CLOSED
☐ REMOVED. Engine type _____, Displacement
_____ CID, Rated _____ HP @ _____ RPM.

- (2) The vehicle installed water pump is driven at a ratio of _____ to _____ with respect to the engine crank speed.

Complete the Figure 2, water pump speed plot, for fully warmed-up vehicle operation.

General Data:

- (1) The most critical engine cooling condition considered in a water pump design is:

☐ hot day idle
☐ engine lugging
☐ max vehicle speed
☐ max vehicle load @ low speed
☐ other

Explain design condition:

- (2) A water pump flow of approximately _____ PPM (minimum) would be sufficient to meet the most critical cooling requirements for the assumed vehicle (Engine type _____, Displacement _____ CID, Rated _____ HP @ _____ RPM).

- (3) Discuss water pump design changes to improve operating efficiency:

- (4) Is the engine cooling fan load on the water pump shaft a significant design consideration? ☐ YES ☐ NO

What is cost impact if fan could be removed from water pump shaft?

- (5) Discuss merits and problems of driving the water pump at constant speed throughout all or part of the engine speed range:

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ΔP

EXAMPLE

FLOW

NOTE: PROVIDE
SUITABLE
SCALE

FIGURE 11

FIGURE 2

POWER STEERING SYSTEM DATA SHEET

Assumptions: 1974 Intermediate or Compact Sedan
3000-4000 lbs. curb weight class
140 to 350 CID Engine (100-150HP)
3-speed Automatic w/2.7 to 3.5:1 axle ratio
Accessories include: Fan, Alternator, P/S, P/B,
A/C, W/P, and A/P

Specific Data:

- (1) Complete the power steering pump performance map shown in Figure 1 or attach comparable data. Also, show total pump and steering gear flow vs RPM for null control valve position.
- (2) Complete the following chart of pump output pressures for the stated driving condition assuming the Figure 1 pump and vehicle.

DRIVING CONDITIONS	PUMP PRESSURE @ ENGINE SPEEDS				
	600 OR IDLE	800 OR 20 MPH	1000 OR 30 MPH	1500 OR 40 MPH	2000 OR 55 MPH
Parking Manuvers					
Hard Cornering					
90° Steering Wheel Turn					
Straight Road, Corrective Steering					
Straight Road, Null Steering					

- (a) Pump to engine speed ratio for above data is _____ to 1.

Engine type _____, Displacement _____ CID,
Rated _____ HP @ _____ RPM, Vehicle weight _____ lbs.

- (3) The vehicle power steering system contains a programmed flow limiting device ☐ YES ☐ NO Reason:

General Data:

- (1) Some P/S systems contain an oil cooler. What are the parameters that establish the need for a cooler and their magnitude at the threshold of need? _____

- (2) A P/S pump operating at _____ RPM minimum would be sufficient to meet all of the assumed vehicle steering requirements.

- (a) Would a constant speed P/S pump eliminate the need for flow limiting? ☐ YES ☐ NO
Explain: _____

- (b) Could cost and efficiency improvements be made if P/S pump were operated at constant speed? ☐ YES ☐ NO
Explain: _____

P/S PUMP DISPLACEMENT= _____ IN $\frac{3}{4}$ REV

INPUT POWER IP

12
10
8
6
4
2
0

0 1000 2000 3000 4000 5000

POWER STEERING PUMP SPEED ~ RPM

CONSTANT ΔP LINES
CONSTANT EFFICIENCY
LINES

IP

RPM

EXAMPLE

FIGURE 1

FIGURE 2

EMISSION CONTROL AIR PUMP DATA SHEET

Assumptions:

1974 Intermediate or Compact Sedan
3000-4000 lbs. curb weight class
140 to 350 CID Engine (100-150HP)
3-speed Automatic w/2.7 to 3.5:1 axle ratio
Accessories include: Fan, Alternator, P/S, P/B,
A/C, W/P, and A/P

Specific Data:

- (1) Complete the air pump performance map shown in Figure 1 or attach comparable data.
- (2) The vehicle installed air pump is driven at a ratio of _____ to _____ with respect to the engine crank speed.

Complete Figure 2 showing the required relationship of air pump flow and pressure to engine speed. Please note engine size and power rating.

General Data:

- (1) What is criteria for matching air pump output to engine operation?

This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are approximately 20 lines visible. The paper has a slightly textured appearance and some minor discoloration or shadows, suggesting it might be a scan of a physical document. There is no handwriting or other markings on the page.

Explain criticality of matching for optimum emission control:

- (2) If air pump speed were held constant at approximately _____ RPM minimum, effective emission control could be maintained by:

AIR PUMP
INPUT POWER IP

3
2
1

1000 2000 3000 4000 5000

AIR PUMP SPEED - RPM

FIGURE I

FIGURE 2