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EVALUATION OF AUTOMOBILE DRIVETRAIN COMPONENTS TO IMPROVE FUEL ECONOMY

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16. Abstract

Wide ratio range automatic transmissions with lockup torque converters could be in production by the early 1980's. In order to evaluate their impact upon fuel economy, emissions, driveability, acceleration, and durability, four 1975 Chrysler automobiles with inertia weights and engine sizes typical of that time period were equipped with Multi-Purpose Test Transmissions. These transmissions could duplicate: current three-speed automatic transmissions; wide range three-speed automatic transmissions; and wide range four-speed automatic transmissions with or without torque converter lockup.

Each of the test cars were evaluated in seven different transmission modes for fuel economy, emissions, driveability, acceleration, and durability.

Fuel economy test results were compared to computer predicted fuel economies. Predicted values agreed with actual fuel economies within the resolution of the test method.

Composite fuel economy improvements of up to 14% were achieved with no change in acceleration and durability. Further development work is required to bring emissions and driveability to acceptable levels.

Maximum increases in fuel economy due to drivetrain improvements have not been demonstrated due to the possibility for further optimization of engine road load matching and the impacts of emission and driveability modifications.

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PREFACE

This work was performed for the U.S. Department of Transportation, Transportation Systems Center by Arthur D. Little, Inc., under contract DOT-TSC 1046. The Contract Technical Monitor was Ralph Colello and the Program Manager was Donald A. Hurter, assisted by Philip Gott.

We would like to take this opportunity to thank several individuals in various companies who were particularly helpful during this program.

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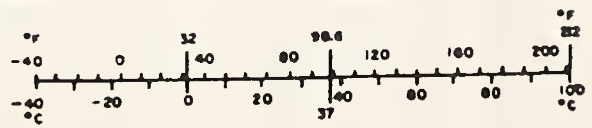
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. SUMMARY

This report describes the results of a program in which eight different transmission configurations were tested with a range of vehicle weights and engine sizes. This program was conducted in order to:

a. Validate the potential of improved fuel economy by better matching the engine to the road load;

b. Validate the potential of improved fuel economy by minimizing losses in the modern automatic transmission;

c. Establish the impact of these improved transmission configurations on exhaust emissions, driveability, acceptability, acceleration, engine and transmission life;

d. Compare the test results with computer simulation prediction using the "Veh Sim" program;

In this program four cars ranging in weight from 2250 to 3500 pounds in weight were tested with engine sizes ranging from 97 to 318 cubic inches. Each of six different modified transmission configurations were tested in each car and compared to the performance of the production automatic transmission. A seventh modified configuration was tested in one of the cars. The eighth configuration was the production (baseline) transmission. The transmission configurations (and their respective code names) tested in all cars were:

a. Production configurations (00);

b. Wide ratio three-speed (03);

c. Wide ratio three-speed with a lockup torque converter activated in third gear (33);

d. Wide ratio three-speed with lockup in second and third gear (23);

e. Wide ratio three-speed with lockup in second and third gear above 30 mph (23-30);

f. Wide ratio four-speed (04);

g. Wide ratio four-speed with lockup in fourth gear (44); and

h. Wide ratio four-speed with lockup in third and fourth gear (34);

The additional mode tested was:

i. Production configuration with torque converter lockup in second and third gears (20);

The test program consisted of:

a. Six EPA Urban tests of each car with a production transmission to determine baseline emissions and fuel economy;

b. Six EPA Highway tests of each car with a production transmission to establish baseline highway fuel economy;

c. Three replicate EPA Urban tests of each modified transmission in each car;

d. Three replicate EPA Highway tests of each modified transmission in each car;

e. Two Motor Vehicle Manufacturers Association Driveability tests of each transmission in each car;

f. Two Acceleration tests of the production and second gear lockup transmission in each car; and

g. One Acceptability test developed by Arthur D. Little of the wide range three speed with lockup in second and third.

Durability testing consisted of continuous monitoring of engine and transmission parameters throughout the program - approximately 12,000 miles were accumulated on each car.

Even though none of the transmissions were optimized for any specific vehicle, the test program indicates that most of the tested configurations can provide significant improvements in fuel economy without posing unsolvable problems in emissions and driveability. Furthermore, no 'exotic' transmission configurations are required in order to gain significant improvements in fuel economy. In general, transmission configurations which increased the total range of gear ratios available and/or which improved the efficiency of the transmission during a major portion of the driving cycle resulted in the most improved fuel economy.

During testing, there were several transmissions which performed equally well, resulting in fuel economy improvements which were statistically insignificant (not distinguishable) from one another. These transmissions can be grouped together as sets which provide equivalent improvements in fuel economy. These groupings are shown in Table 1.1. The differences in transmissions within each group are in driveability, the four-speed units being more driveable than the three-speed.

TABLE 1.1 TRANSMISSIONS YIELDING SIMILAR IMPROVEMENTS IN FUEL ECONOMY

Urban Cycle

Over 6% Improvements

318 Valiant	34,33,23,23-30
225 Valiant	34,23,33
122 Colt	20,23,33
97 Colt	03,23,33

No Significant Improvement

318 Valiant	03, 04,44
225 Valiant	03,04,44
122 Colt	04
97 Colt	34,04

Highway Cycle

Over 15% Improvement

318 Valiant	34,23,33,44,23-30
225 Valiant	None
122 Colt	44,23,33
97 Colt	None

5 to 15% Improvement

318 Valiant	None
225 Valiant	03,04,33,44
122 Colt	20,34,04,03
97 Colt	04,03,34,44,23,33

No Significant Improvement

318 Valiant	03,04
225 Valiant	None
122 Colt	None
95 Colt	None

As shown in Table 1.1 there is little difference in highway fuel economy improvements between either a wide-range three-speed or a wide-range four-speed. Over the urban driving cycle, the wide range three-speed transmission generally improved fuel economy more often than the four-speed because the fourth gear was not engaged below 40 or 45 mph. Fourth gear was, therefore, only rarely used in the urban cycle. The three-speed transmission, however, proved extremely poor in driveability, and modification to improve driveability reduced its urban fuel economy to the same range as the four-speed.

It is also interesting to note that reasonable improvements in fuel economy were obtained in the 122 Colt by simply adding a lockup clutch to the conventional three-speed automatic (20). This configuration performed as well as the 'best' wide range transmission in the urban cycle, and netted better than 5% improvement in the highway cycle.

Because none of the transmissions tested were refined to a production standpoint, these conclusions are preliminary. The process of improving driveability, reducing emissions, and optimizing the gear ratios in order to produce a fuel efficient, marketable car may alter these conclusions somewhat. Nonetheless, significant gains in fuel economy are possible with improved transmissions of the type tested in this program. Which transmission is the best overall compromise still remains a question.

Absolute values of the test results compared favorably with the absolute values developed by computer simulation when the hardware tested and simulated was closely matched. Production variations in torque converter characteristics can produce a significant error in simulation results, however.

The results of a three-replicate test program such as this have a variability which is potentially of the same order of magnitude as the differences in fuel economy obtainable with the transmissions tested. Therefore, there is a disparity between the relative rank ordering predicted by the computer and that determined by the tests. It is reasonable, however, to use statistical techniques to determine the relative differences in transmissions actually tested. Such analysis is not appropriate with computer modeling.

It may be concluded from the results of this program that significant improvements in fuel economy can be obtained through the use of more efficient transmission and better matching of the engine to the road load of the vehicle. Such improvements are accompanied by an increase in emissions which is in some cases acceptable and which in others requires further work to reduce them to acceptable levels. Driveability, acceptability, acceleration and durability need not be degraded due to the use of such transmissions. Such improvements may be predicted through the use of computer simulation, but not to the same degree of resolution as actual testing.

2. INTRODUCTION

2.1 BACKGROUND

The oil embargo of 1973-1974 served to catalyze the nation's awareness of the world's depleting fuel supply. The Transportation Systems Center of the Department of Transportation responded to this new awareness by conducting various programs aimed at determining all technological means which could be employed to reduce the fuel usage of the nation's transportation systems. One of these programs, "Technological Improvements of Automobile Fuel Consumption", identified by computer simulation many possible means of reducing automotive fuel consumption. One technique which was identified is the concept of an "overdrive" or wide-ratio range automatic transmission combined with a lockup clutch in the torque converter to eliminate slippage. The computer simulations in that study indicated that between a 5 and 16% increase in composite fuel economy could be obtained with this concept due to more efficient operation of the engine and transmission.

The program was undertaken in order to validate these computer predictions of the fuel economy benefits attributable to the use of automatic transmissions incorporating lockup torque converters and/or a range of gear ratios wider than is currently available. This report describes the program carried out under contract DOT/TSC-1046, by Arthur D. Little, Inc., for the U.S. Department of Transportation, Transportation Systems Center, in order to evaluate the impact of these concepts on emissions, driveability, acceleration, and engine life, as well as validate computer predictions of their impact on fuel economy.

2.2 PURPOSE

This program was initiated in order to validate the computer predictions of fuel economy benefits attributable to modified drivetrains. At the same time, it was desirable to determine the overall change in vehicle characteristics which would result from the use of a modified drivetrain. Only by hardware test can the impact of various drivetrains on various vehicle characteristics be determined. These characteristics include:

a. Emissions;

b. Driveability;

c. Acceleration;

d. Acceptability to the Marketplace; and

e. Durability;

as well as

f. Fuel Economy.

It is important to study driveability, acceleration, marketplace acceptability, and durability in order to be sure that the proposed modifications will be incorporated into the fleet. If the use of a vehicle modification significantly degrades one or more of these characteristics below current levels, the modification will not be useful in reducing the fuel consumption of the nation's vehicular fleet. These factors determine whether or not the driving public will purchase a vehicle. If a certain technological alteration degrades these factors, the public will not purchase the vehicle with this modification. If the modification does not sell, it cannot help reduce the nation's consumption of fuel.

2.3 SCOPE

The drivetrain modifications studies in this program require a relatively long lead time in order to bring them to the marketplace on an economical mass production basis. Therefore, it was deemed appropriate to test these modifications in vehicles which had weight and performance characteristics which would approximate those of the vehicles in which they could be expected to be installed. Assuming that a lead time of five years is reasonable and appropriate, the tests should be carried out on vehicles characteristic of the early 1980's. Therefore, vehicles with characteristics expected of the early 1980's were chosen for the tests. The test vehicles had curb weights ranging from 2250 to 3300 pounds, and engine displacements from 97 to 318 cubic inches.

With the early 1980's time frame in mind, it made sense to also consider emission levels appropriate for that decade. However, during the program's conception in 1975 no acceptably performing vehicle powered by an Otto-cycle engine which would meet the emission levels of the early 1980's was readily available. The development of such a vehicle and the required emissions control system was beyond the scope of a drivetrain investigation. Therefore, vehicles available at the onset of the program were utilized. These vehicles were designed to meet the 1975 Federal emission standards.

The number of drivetrain modifications possible is almost limitless. The types of drivetrains with fuel conservation potential range from hydrostatic and infinitely variable transmissions to multi-speed manual gear boxes. The concepts chosen for study in this program were three and four-speed automatic transmissions identical to current automatics except for an "overdrive" top gear ratio and a lockup torque converter. These units were chosen because they:

a. Are capable of production with minimal tooling change;

b. Alter vehicle characteristics negligibly;

c. Are acceptable to the mass market and will therefore be readily incorporated into the fleet; and

d. Anticipate minimal change in vehicle performance (acceleration).

The transmission modes tested were:

a. Baseline or production three-speed automatic;

b. Baseline automatic with lockup in second and third gear;

c. Wide ratio three-speed automatic;

d. Wide ratio three-speed automatic with lockup in third;

e. Wide ratio three-speed automatic with lockup in second and third with and without lockup below 30 mph;

f. Wide ratio four-speed automatic;

g. Wide ratio four-speed automatic with lockup in fourth; and

h. Wide ratio four-speed automatic with lockup in third and fourth.

3. TEST HARDWARE

3.1 INTRODUCTION

The units tested were built in order to validate the concept of wide ratio automatic transmissions with and without torque converter lockup. As such, the transmissions were constructed from available, off-the-shelf hardware wherever possible. No attempt was made to optimize these transmissions for fuel economy, emissions, driveability, or durability.

3.2 TRANSMISSIONS

Four Multi-Purpose Test Transmissions were built, one for each of the test vehicles. These transmissions were designed so that they could be operated as any one of the types of transmissions which the Transportation Systems Center desired to study. These units were basically a production Chrysler Torque-Flite automatic transmission to which a specially built lockup torque converter and a J-type Laycock de Normanville overdrive were added. Figures 3.1 and 3.2 are detailed illustrations of the Multi-Purpose Test Transmissions built for this program by B&M Automotive Products of Chatsworth, California. These transmissions are modifications of two A-727 and two A-904 Torque-Flite units.

3.2.1 Lockup Torque Converter

A torque converter transmits rotary motion by pumping hydraulic fluid from an impeller to a turbine, past a stator, and back to the impeller. Torque is multiplied by redirecting the hydraulic fluid from the turbine back onto the impeller via the stator in such a way that it assists the movement of the impeller.

This is accomplished at the expense of some efficiency. Because of the losses associated with the transmission of mechanical power through a fluid, the power output of the torque converter is always less than the input. This is true even when torque multiplication is neither needed nor desired, such as during normal highway cruising. The normal input/output efficiency of a typical production torque converter rarely exceeds 95%.

The lost power can be recovered if the torque converter is bypassed when it is not needed. This can be accomplished by locking the input portion of the converter to its output.

Figures 3.3 and 3.4 illustrate the lockup torque converters used in this program. All four torque converters are modified versions of the production torque converters supplied with the test vehicles.

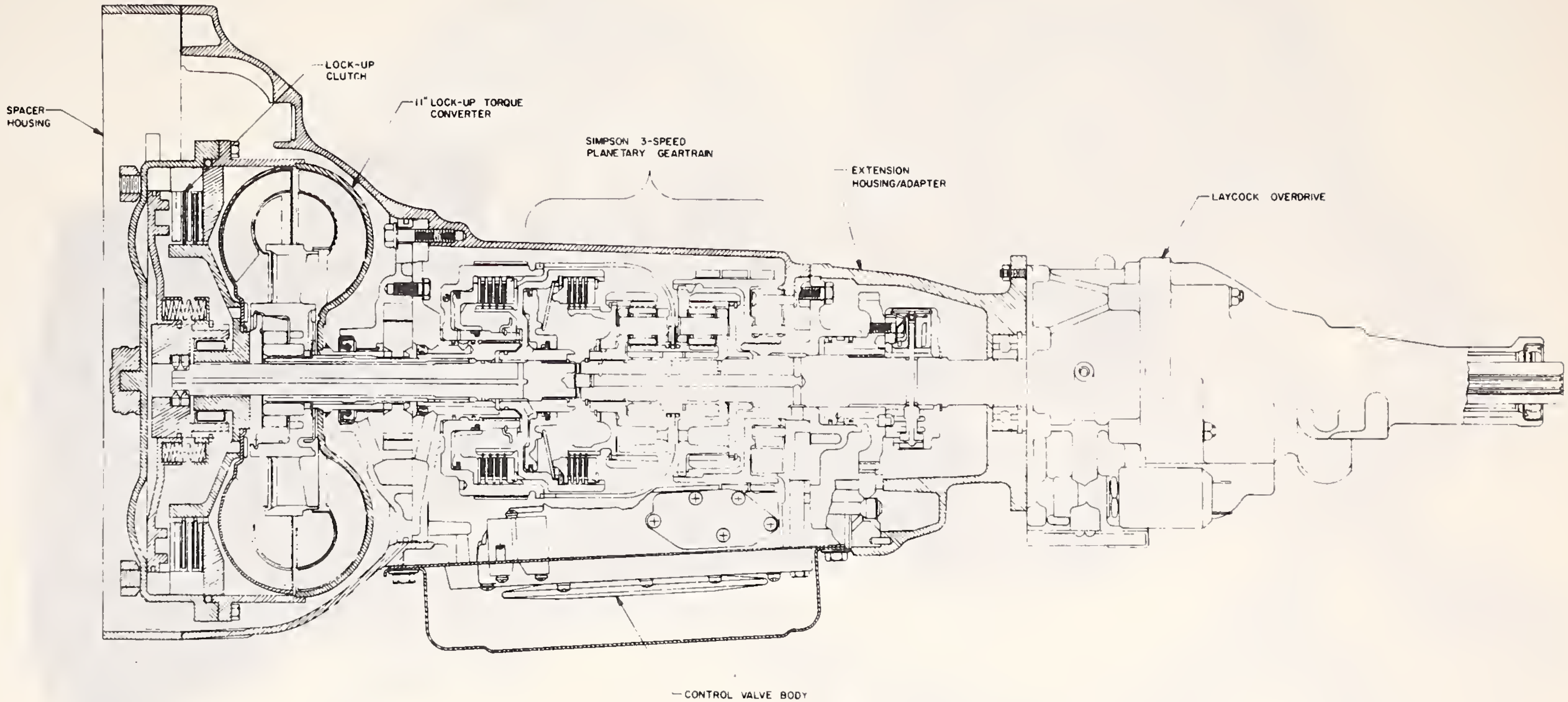


FIGURE 3–1 MODIFIED TRANSMISSION, SECTIONAL VIEW

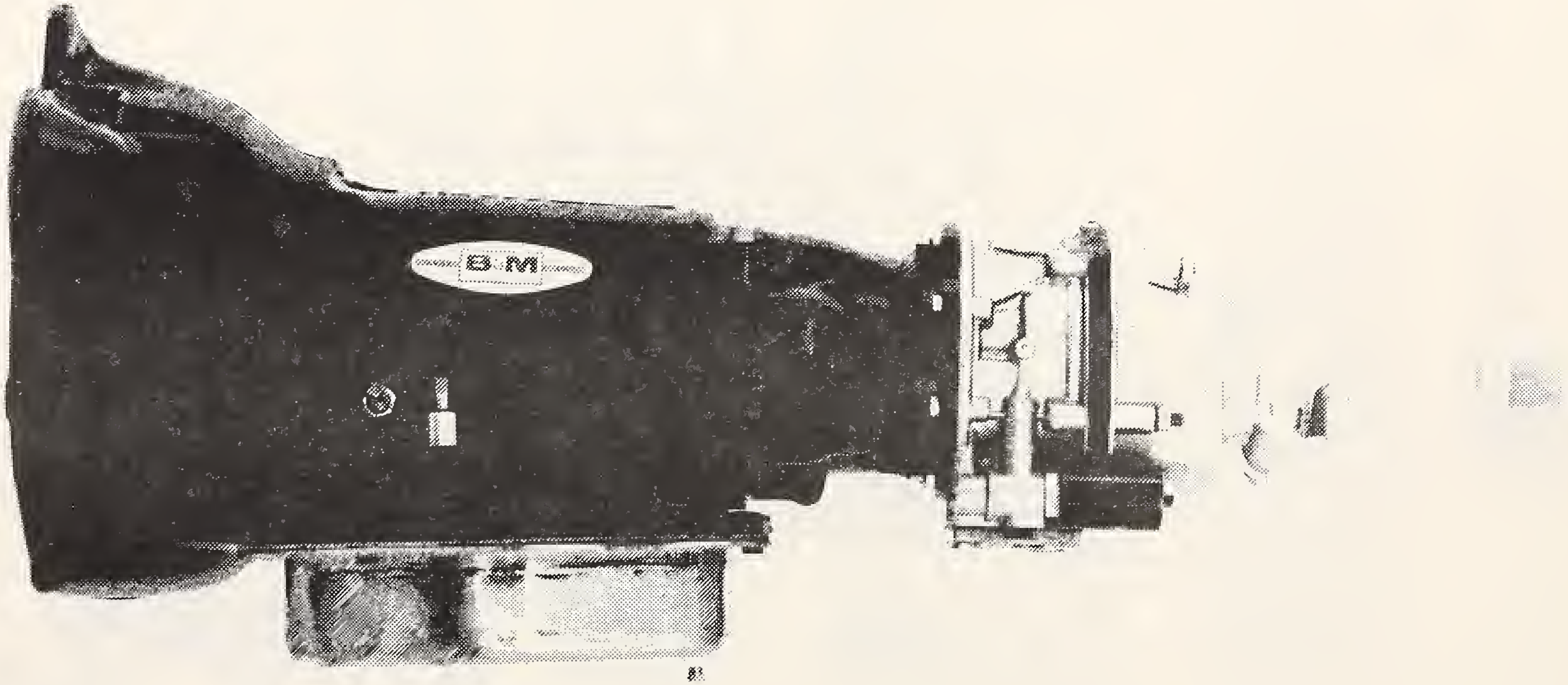


FIGURE 3.2 VIEW OF ASSEMBLED A-904 TRANSMISSION WITH OVERDRIVE UNIT AND SPECIAL PAN

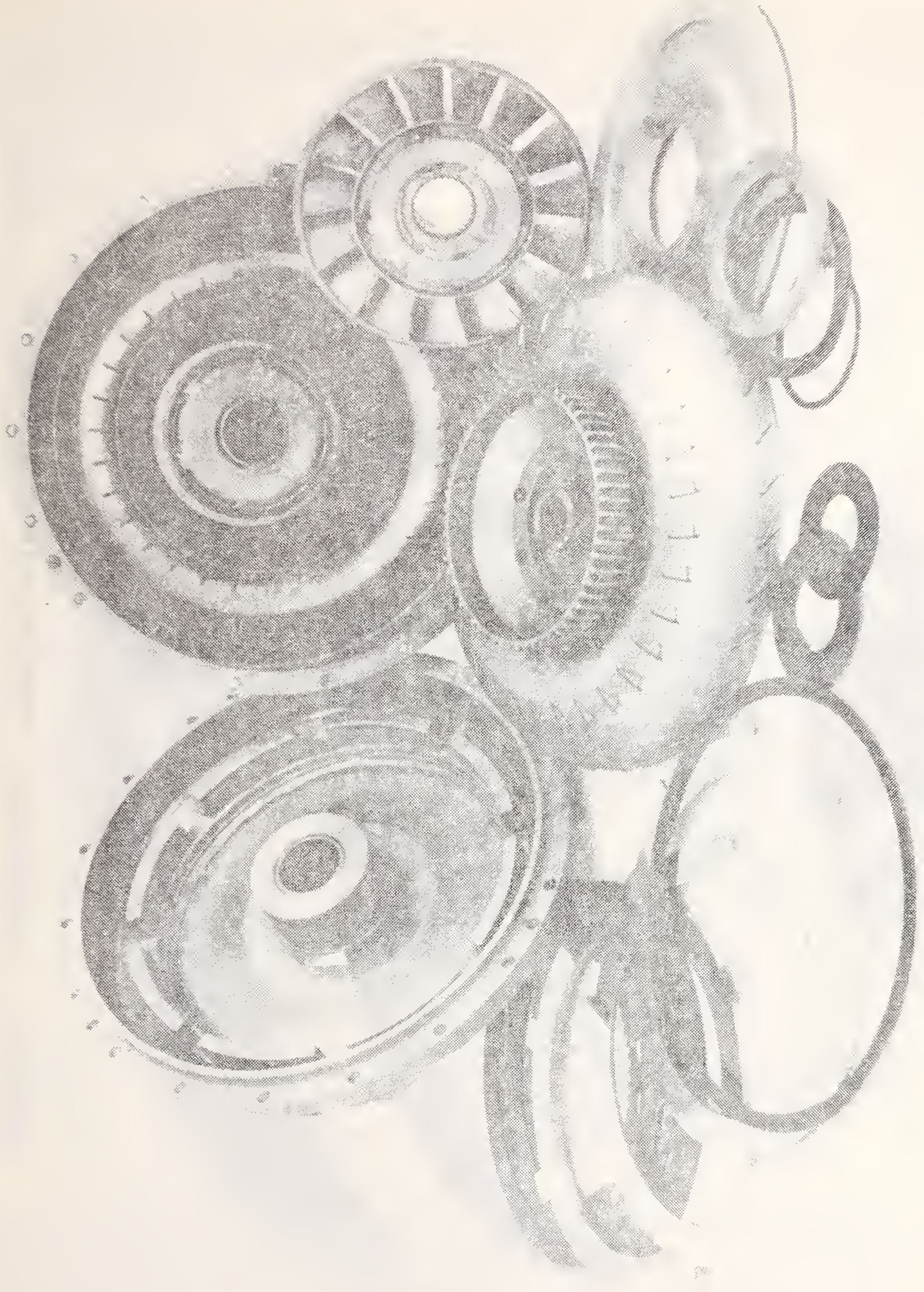


FIGURE 3.3 COMPONENT PARTS OF 9-½" DIAMETER B&M LOCK-UP CONVERTER

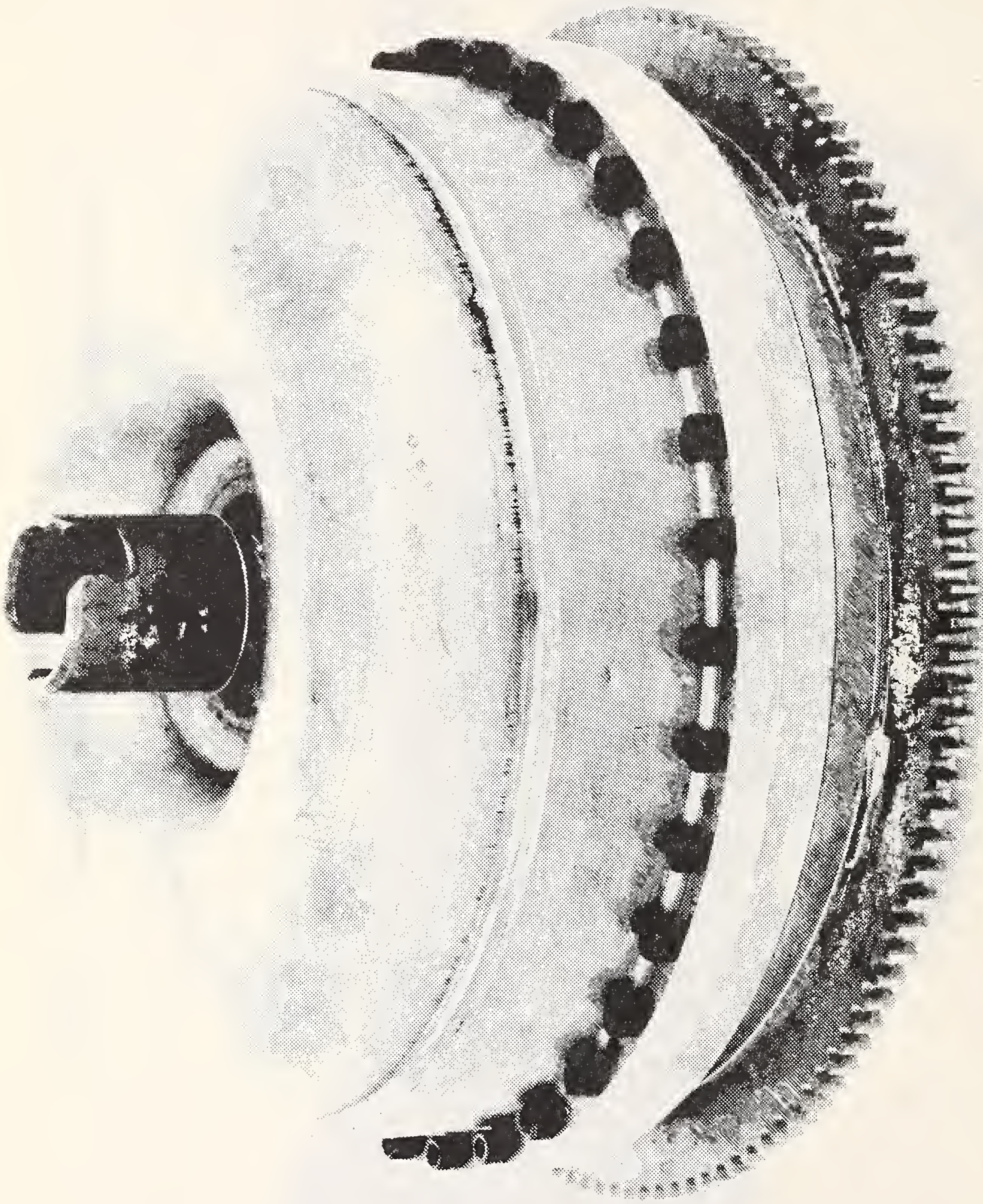


FIGURE 3.4 ASSEMBLED 10-3/4" DIAMETER B&M LOCK-UP CONVERTER

The production torque converter casing has been cut open just behind the ring gear and extended to accommodate a multi-disc wet plate clutch, a pressure diaphragm, and some actuating springs. The springs normally hold the clutch disengaged. When hydraulic pressure is applied through the drilling in the transmission input shaft (see Figure 3.1) to the pressure diaphragm, the spring pressure is overcome and the clutch is engaged. This action locks the torque converter casing to the large externally splined hub bolted to the turbine. Since the turbine is splined to the transmission input shaft, the torque converter is "locked-up". The engine driven torque converter casing is locked, via the clutch, to the transmission input shaft. When hydraulic pressure is released, the springs force the clutches apart and the torque converter functions normally.

This design allows the modified torque converter to function as a production unit with production characteristics until it is locked up. This has been verified by dynamometer tests of a production and a modified unit. See Sections 4.6 and 5.6.

3.2.2 Wide Ratio Gearing

The reason for a wide range of gear ratios in a transmission is to provide a given vehicle and engine with enough drivetrain torque at low vehicle speeds to allow rapid acceleration, if desired, and to operate the engine at its most efficient speed during cruise operation. In general, this requires gearing which allows the engine to run at relatively high speeds when the vehicle is moving slowly and which also allows the engine to run at relatively low speeds while the vehicle is moving rapidly.

This may be accomplished in a variety of ways. These range from a numerically high rear axle ratio and substantial top gear overdrive gear ratio or ratios in the transmission to a numerically low rear axle ratio and a very high reduction in the first few gears of the transmission. Modern domestic vehicles utilize a compromise between these extremes which yields "adequate" acceleration and reasonably comfortable cruising at 60 miles per hour with "adequate" power reserve at cruise for high speed passing acceleration. "Adequate" levels of acceleration and power reserve have become defined by the marketplace as those minimum levels which people expect in a given class or category of vehicle.

Since adequate power reserves do not come at the same relationship of engine speed (N) to vehicle speed (V), as optimum fuel economy, and since fuel has historically been inexpensive in the United States, the automotive marketplace has forced the contemporary vehicle to be designed with the N/V ratio favoring acceleration and reserve power rather than fuel economy.

Since it was desired to test a transmission configuration which would provide vehicle performance acceptable to the marketplace, it was decided to reduce the N/V ratio in the top gear only. In this way, low vehicle speed acceleration would be maintained at its current level because production N/V ratios would be maintained in the lower gears.

If the current production practice of three-speed automatic transmissions were to be retained for reasons of production and tooling costs, however, two marketplace problems could be anticipated.

(1) The change in ratio between the intermediate (second) and top (third) gear may be too great and produce an unacceptable, sudden change in vehicle acceleration during the gear shift because of a great and sudden change in N/V.

(2) Top gear acceleration may be degraded to unacceptable levels due to a too low N/V ratio.

Therefore, it was desirable to also test a four-speed unit. Such a unit would provide current "top gear" performance in third gear with a corresponding reduction in the magnitude of the change in N/V ratio so that change in vehicle acceleration during shifts would not be greater than current levels. Top gear would provide the desired reduction in N/V and a corresponding improvement in fuel consumption.

The desired top gear reduction in N/V was accomplished with an off-the-shelf overdrive unit. The particular unit used was a J-type Laycock de Normanville overdrive unit manufactured by GKN of Sheffield, England. This unit provided an overdrive top gear ratio when engaged and was attached to the transmission in place of the normal tail shaft (see Figures 3.1 and 3.2). By engaging it simultaneously with the engagement of third gear or after third gear is engaged, this unit allowed the transmission to become either a wide ratio three-speed or a wide ratio four-speed, respectively.

The J-type Laycock de Normanville overdrive unit is basically a planetary gear train which is hydraulically shifted. When providing a direct drive, the planet gear carrier is locked through a cone clutch to the annular gear. The cone clutch is kept engaged by four powerful springs. When overdrive mode is desired, hydraulic pressure is applied to a series of pistons which force the cone clutches apart and lock the planet carrier to the stationary housing of the overdrive unit through another cone clutch. Power is then transmitted from the input shaft and sun gear, through the planet gears, to the annular gear. The annular gear is connected to the output shaft.

Hydraulic pressure for the clutch engagement is supplied by a piston type pump housed within the overdrive unit and driven by the input shaft. The output of this pump, which runs continuously, is controlled by an electrically operated solenoid valve. When the valve is activated the pump output is directed to the piston which activates the clutch. When no electric power is applied to this solenoid, the pump output flows through a relief valve back into the sump. There is always some bleed-off from the pump to lubricate the unit.

Examination of Figures 3.1 and 3.2 will indicate that the overdrive unit is the last component of the transmission. As such, the output of the overdrive is directly fed to the driveshaft. Normally, the Torque-Flite tail shaft is used to feed the driveshaft.

The transmission governor, located at the forward-most end of the extension housing, senses tail shaft speed and hence provides a vehicle speed signal to transmissions. This speed signal determines the time at which the transmission is to shift.

With the addition of the overdrive, the governor no longer sensed vehicle speed. Instead it sensed the speed of the overdrive input shaft (the Torque Flite tail shaft). When the overdrive was disengaged (ratio of 1 to 1), sensing the overdrive input speed was equivalent to sensing the vehicle speed. However, when the overdrive was engaged, the governor sensed only 77.8% of the vehicle speed (overdrive ratio was .778 to 1). Therefore, the governor sent signals to the transmission which indicated that the car was travelling at speeds of only 77.8% of the true speed. This in turn changed the shift points and caused unnecessary downshifting.

To alleviate this problem, new governors were built in their own separate housing. These new governors were mounted to the underside of the floorpan of the cars just ahead of the rear axle. A flexible shaft was used to drive the governors. These shafts were in turn driven by a toothed belt and pulley arrangement running off of the slip yoke at the forward end of the driveshaft. Hence, the governors ran at driveshaft speed at all times. Hydraulic oil lines were run from the transmission back to the governors to provide the necessary governor input/output oil supply.

3.2.3 Transmission Controls

It was desired to activate the lockup clutch automatically in second and third gears as well as to activate the overdrive automatically in third gear. It was also desired to be able to manually activate both units at any time for use in a fourth gear or any other mode.

Since the overdrive unit was already activated electrically, it was desirable to operate the lockup clutch electrically also. A solenoid valve was placed in series between the main pump of the transmission and the clutch diaphragm. Energization of the solenoid sent transmission fluid through the drilling in the input shaft under full pump pressure (approximately 100 psi) to the lockup clutch diaphragm, thereby locking the torque converter. (See Figure 3.1).

In order to achieve automatic operation, all that was necessary was to energize either the lockup clutch solenoid, the overdrive solenoid, or both, at the appropriate time. Electrical signals were generated by tapping hydraulically activated electric switches ("pressure switches") into the oil ways which feed the front clutch and front band of the production transmission. When hydraulic pressure is supplied to these oil passages, the switches would close. Since the front clutch is activated only when the top gear is engaged, and the front band only when second gear is engaged, these electric signals are used to automatically engage either the lockup, or the overdrive, or both, during second and/or third gear operation. Figure 3.5 illustrates the internal modifications to the transmission which were made to accommodate the switches and solenoids.

After the initial series of tests were completed, an inhibitor switch was installed on one of the transmissions. This switch could be set to prevent torque converter lockup operation below any chosen road speed. It sensed vehicle road speed from the pressure output of the governor. After driveability tests were performed, this switch was set to prevent lockup below 30 mph in order to improve driveability.

Electric toggle switches were mounted on the dashboard of each car. These switches could be set to activate either the lockup clutch or the overdrive, or both, automatically in second and/or third gear. A manual override was also provided which was used to engage the overdrive and/or lockup clutch for fourth gear operation. The manual override was only effective, however, when third gear was engaged. This ensured the progressive engagement of fourth gear only after third gear had been engaged.

3.2.4 Gear Ratios and Shift Points

The modifications described above did not alter the normal operation or internal configuration of the Torque-Flite transmissions. The production gear ratios and shift points were maintained. The wider ratio transmission is obtained entirely through the engagement of the Laycock de Normanville overdrive either simultaneously with third gear or some time after third gear is engaged in order to produce either a wide ratio three-speed or a wide ratio four-speed, whichever is desired.

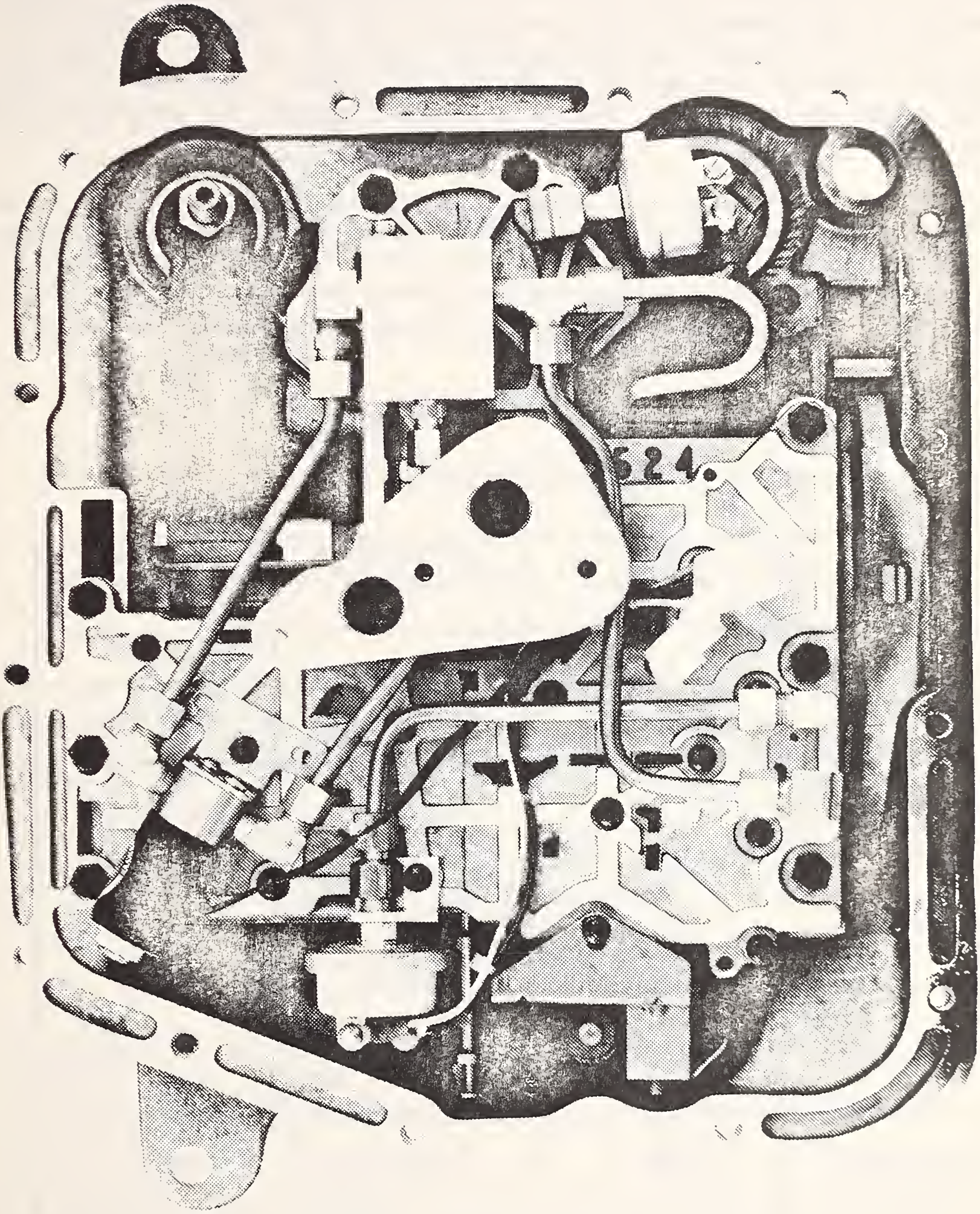


FIGURE 3.5 VIEW OF SPECIAL VALVE BODY IN A-904 TRANSMISSION

Table 3.1 presents the combinations of gear ratios and torque converter lockup available and evaluated in this program. In order to maintain "acceptable" performance, only the top gear was modified through the use of the overdrive unit. Greater improvements in fuel economy may be possible by engagement of the overdrive while the transmission is in second gear and altering the shift points to provide a lower N/V ratio throughout a greater proportion of the driving cycle. This was not done in order to maintain the low speed acceleration capability demanded by the marketplace.

For the same reason, the production shift points for the first three gears were maintained. The possible improvement in fuel economy attainable by an alteration in shift points only was judged to be minimal as computer simulation by the Transportation Systems Center has shown that the effect of shift point alteration is negligible within a reasonable bandwidth[2].

TABLE 3.1 DRIVETRAIN MODIFICATIONS

	Standard 3-Speed	Wide Range 3-Speed	Wide Range 4-Speed
Lockup Converter	2, 3 or not at all	2, 3 or not at all	2, 3, 4 or not at all
Gear Ratio			
First	2.45:1	2.45:1	2.45:1
Second	1.45:1	1.45:1	1.45:1
Third	1.00:1	.778:1	1.00:1
Fourth	-	-	.778:1
Ratio Range Increase	1.00	1.28	1.28

The four-speed transmission was included in the test program because it may be the only acceptable compromise between fuel economy and marketable driveability. The shift point for the fourth gear was therefore selected on the basis of driveability. In the four-speed, the overdrive was manually engaged at the minimum vehicle speed which would avoid lugging and/or surging. The torque converter was locked up at this same speed when it was desired to do so. It is important to note that the fourth gear shift could be affected only after third gear was engaged regardless of the signals from the driver. This assured that under conditions of rapid acceleration the overdrive would not become engaged before third gear, guaranteeing progressive engagement of all four gears.

The shift points are detailed in Table 3.2.

TABLE 3.2 SHIFT POINTS FOR MULTI-PURPOSE

AUTOMATIC TRANSMISSION

318 CID PLYMOUTH VALIANT

Shift	Road Speed at Minimum Throttle	Road Speed at Wide Open Throttle
1-2 Upshift	12 mph Approximate	45 mph Approximate
2-3 Upshift	20 mph "	88 mph "
3-4 Upshift	40 mph "	89 mph "
4-3 Downshift	40 mph "	N.A.
3-1 Downshift	12 mph "	N.A.

225 CID PLYMOUTH VALIANT

97 CID AND 122 CID DODGE COLTS

Shift	Road Speed at Minimum Throttle	Road Speed at Wide Open Throttle
1-2 Upshift	12 mph Approximate	35 mph Approximate
2-3 Upshift	20 mph "	69 mph "
3-4 Upshift	45 mph "	70 mph "
4-3 Downshift	45 mph "	N.A.
3-1 Downshift	11 mph "	N.A.

3.2.5 Increased Mass of the Multi-Purpose Transmission

The additions to the Torque-Flite automatic transmissions caused a significant increase in the mass of the transmission components. The added mass of the torque converter increased the rotational inertia of the drivetrain as well as increasing the total vehicle weight. These increased weights have a small but possibly measurable effect upon the fuel consumption of the test cars. However, since these masses are present in all tests, the change or difference in fuel economy between different transmission modes should not be affected.

The increased weight and mass of units can be significantly reduced in production design. It should be noted that these were exceptionally overweight because they were "one off" experimental designs which were designed for low volume production and serviceability in lieu of minimum weight. It is important to note that the 1978 Chrysler Corporation lockup torque converter is only 7 lbs. heavier than the production unit we used, rather than our 35 lbs. extra weight.

3.2.5.1 Increased Inertia

Table 3.3 presents the results of inertia calculations of the lockup torque converter and its components. Also included are the results of dynamometer measurements of the actual inertias of production torque converters. This data was provided by B&M Automotive Products.

The increase in the moment of inertia of the torque converters manifests itself as an increase in engine loading during acceleration and brake loading upon deceleration. The effects can best be evaluated if the increases in moments of inertia are considered to be similar to adding an equivalent weight to the mass of the car. The magnitude of the equivalent weight depends upon the rotational speed of the torque converter and is therefore dependent upon the gear ratio of the transmission and rear axles. Table 3.4 presents the equivalent weights of the torque converters used in this program.

3.2.5.2 Component Weight

In addition to the increased rotational inertia of the experimental units, they are, quite simply, heavier than the production transmissions. Table 3.5 presents the weights of the various units.

3.3 TEST VEHICLES

The type of drivetrain modifications studied in this program, especially the lockup torque converter, require a relatively long lead time in order to bring them to the marketplace on an economical mass production basis. Therefore, it was deemed appropriate to test these

TABLE 3.3 TORQUE CONVERTER MOMENTS OF INERTIA
(Pounds Mass - Inch Squared)

Description	Stock Torque Converter (From Chrysler Data)	Stock Cover Only (Calculated)	Lockup Components (Calculated)	Lockup Converter
9-1/2" Dodge Colt Unit	263 $lb_m - in^2$	110 $lb_m - in^2$	398 $lb_m - in^2$	661 $lb_m - in^2$
10-3/4" Plymouth Valiant Unit	585 $lb_m - in^2$	318 $lb_m - in^2$	1252 $lb_m - in^2$	1837 $lb_m - in^2$

TABLE 3.4 EQUIVALENT WEIGHTS OF TORQUE CONVERTERS

$$\text{Eq. Wt.} = I \frac{G^2}{R^2} \text{ lbs}$$

I = Moment of Inertia (lb-in^2)

R = Radius of Wheels

$$G = \frac{\text{No. of Revolutions of Torque Converter}}{\text{No. of Revolutions of Wheels}}$$

Gear	Production	Lockup	Δ
	1600 cc Colt (2500 lb Inertia Weight)		
First	194 lbs.	487 lbs.	203 lbs.
Second	68	171	103
Third	32	81	49
	2000 cc Colt (2500 lb Inertia Weight)		
First	161	404	243
Second	56	141	85
Third	27	67	40
	318 Plymouth (4000 lb Inertia Weight)		
First	142	445	303
Second	50	156	106
Third	24	74	50
	225 Plymouth (3500 lb Inertia Weight)		
First	180	565	385
Second	63	198	135
Third	30	94	65

TABLE 3.5 TRANSMISSION WEIGHT COMPARISON

Transmission	Weight: Supplied With Car (lbs)	Weight: Modified Unit Installed in Car (lbs)
A727 (Valiant)	136	230
A904 (Colt)	125	172

modifications in vehicles which had weight and performance characteristics which would approximate those of the vehicles in which they could be expected to be installed. Assuming that a lead time of five years is reasonable and appropriate, vehicle characteristics of the early 1980's were chosen for the tests. These characteristics would indicate that test vehicles weighing between 2000 and 3500 pounds and engines ranging from 90 to 320 CID would be desirable.

The modified drivetrain technology available to this program was based upon transmissions built by Chrysler Corporation. Therefore, cars built by Chrysler Corporation were prime candidates for this program. Fortunately, the Chrysler Torque-Flite transmission is available in the full line of cars sold by Chrysler, and the Dodge Colt met the criteria for the lightest cars with the smallest engines. The upper range of vehicle weights was met by the Dodge Dart/Plymouth Valiant line. Therefore, two Dodge Colts and two Plymouth Valiants were chosen as test vehicles. Table 3.6 presents a full description of each of the test cars as delivered to Arthur D. Little. With the exception of some structural changes and relocation of engine and/or transmission mounts to accommodate the new transmissions and the addition of a full set of engine instrumentation, the cars remained essentially stock except as noted in Section 3.3.1.

3.3.1 Modifications of Test Vehicles

3.3.1.1. Installation of "Mapped" 225 CID Engine

Since one of the primary goals of this program was to validate computer simulation techniques, it was desirable to eliminate as much as possible any differences between the computer inputs and the test vehicles. One major source of error could be between the characteristics of the engine in the vehicle being tested and the characteristics of the engine as fed into the computer.

In an attempt to eliminate this source of error, the 225 CID engine which was mapped for the computer simulation was installed into the 6-cylinder Plymouth Valiant. It was hoped that the engine tested would be identical to that used in the simulation.

Unfortunately, it was found after the engine was installed in the test car that it did not meet the 1975 Federal Emissions Standards for carbon monoxide. Subsequent investigation found that the carburetor was providing an over-rich mixture at high speeds. The carburetor was replaced with the one which was on the engine moved from the car and the emissions fell to acceptable levels.

TABLE 3.6 TEST VEHICLES

Vehicle	Curb Weight (lbs)	Inertia Weight (lbs)	Engine Size In^3	Horsepower at RPM	Rear Axle Ratio	Tire Size/Type	Catalytic Converter	Air Pump	EGR?
Plymouth Val.	3,265	4000	318	145 @ 4000	2.45:1	D-78x14 Bias Ply	Yes	No	Yes
Plymouth Val.	3,100	3500	225	95 @ 3600	2.76:1	6.95x14 Bias Ply	Yes	No	Yes
Dodge Colt	2,250	2500	97.6	79 @ 5200	3.89	BR70x13 Radial	No	Yes	Yes
Dodge Colt	2,425	2500	122	89 @ 5200	3.55	BR70x13 Radial	No	Yes	Yes

3.3.1.2 Modifications Required to the Dodge Colts in Order to Meet Emission Standards

The 122 CID Dodge Colt was tested over the EPA urban cycle before it was modified. In this test the car was found to be in compliance with the 1975 Federal Emission Standards.

After both Colts were modified, it was found that neither one met the 1975 Federal standards for carbon monoxide. This was due to the increased inertia of the lockup torque converter which effectively increased the apparent weight of the car by as much as 13% (see Section 3.2.5.1).

A great deal of experimentation followed in an effort to solve the problem of high carbon monoxide emissions. The addition of a thermal reactor and appropriate controls designed to allow the car to meet the 1975 California emission standards and elimination of exhaust gas recirculation (EGR) and retuning of the carburetor brought the 122 CID Colt down to acceptable levels of emission performance when tested in a production (baseline) transmission mode.

Interestingly enough, the car still did not meet "California" standards even though it was now equipped to do so - probably still due to the increased inertia of the transmission. It had emission outputs approximately the same as the car in "as delivered" form.

The 97 CID Colt required the addition of a similar thermal reactor with the appropriate controls, elimination of EGR, as well as retarding the timing from manufacturers' specifications by 4^{o} and retuning the carburetor until it performed in an acceptable manner from an emissions standpoint in the baseline mode.

In later over-the-road driving, it was noted (albeit qualitatively) that the fuel consumption, acceleration, and top speed of these cars was seriously degraded by these modifications.

As noted above, the modifications were due to the increased inertia of the lockup torque converter. As previously noted the high enertia of these test units should not be expected in a production design, and the problems created by the increased inertia should not be encountered.

4. TEST PROCEDURES

4.1 EMISSIONS AND FUEL ECONOMY

The two major goals of this test program were to:

a. Determine differences in fuel economy and emissions resulting from the use of alternative transmissions; and

b. Compare the results of hardware tests with the computer simulation of those tests and to determine if the computers were sufficiently sensitive to changes in hardware configurations to allow its use as a research tool.

4.1.1 Procedures

The 1975 Federal Test Procedures[3, 4] were used to determine the emissions and urban, highway, and composite fuel economy of the test cars in the various transmission modes. Evaporative emissions were not affected by transmission modifications, and therefore not tested.

In addition to the fuel consumption determinations made by the federally promulgated carbon balance test method, the fuel consumption was also determined by direct weight measurements of the fuel. The mass of the test tank and fuel was continuously monitored by an electronic strain gauge with digital readout. The mass of the tank and fuel was noted before and after each test. The mass of fuel consumed was referred to the standard mass of a gallon of the test fuel at 60°F and the fuel consumption calculated accordingly. An electric fuel pump was used to purge the fuel system of all air. The fuel system for each test consisted of the test tank, the car's own fuel pump, the car's carburetor, and the connecting feed line (and return lines in the Dodge Colts). The cars' fuel tanks and the lines to the fuel pumps were not utilized.

The test fuel was Indolene clear in the two Plymouth Valiants and Indolene HO in the Dodge Colts.

During the early stages of this program, tests were conducted at Olson Laboratories, Inc., of Livonia, Michigan. Most of the testing, however, was conducted at the laboratories of the Ethyl Corporation in Ferndale, Michigan.

It was originally planned to conduct three replicate tests of each transmission mode. Three baseline tests would be run in the beginning of the test program to establish the baseline fuel consumption and emission performance. The remainder of the transmissions were to be tested in a random sequence.

As a control, a baseline highway test was planned to be run at the end of each day's testing in order to determine whether or not any changes had taken place in the car or test apparatus.

After the first car, the 318 CID Valiant, had completed its testing, it was decided that a more rigorous comparison could be made between the modified and baseline transmission modes if the baseline tests were scattered throughout the test program. Therefore, three baseline tests were conducted in a semi-random pattern throughout the test programs for the remaining cars. In order to confirm that the car, in test trim, met the 1975 Federal Emission Standards, it was also decided to continue to conduct three baseline tests at the beginning of the test series. All six baseline tests would be used for a comparison.

The baseline highway control tests were dropped in favor of a check of the percentage carbon monoxide in the pre-catalyst exhaust gas under idle conditions at the end of each day's testing. Since this parameter is sensitive to vehicle tune, it was felt that this would provide an adequate and cost effective indication of the state-of-tune of the vehicle. The weight measurement of fuel mileage would provide an adequate check of the performance of the test apparatus.

Data was recorded on data sheets such as those illustrated in Figure 4.1.

4.1.2 Acceptance Criteria

Because of the relatively small differences in fuel economy expected between the various transmission modes, it was necessary to establish criteria for test result variability which would allow reasonable transmission to transmission comparisons to be made without demanding an unobtainable degree of precision from the test procedure. Work done by the EPA and reported by Milks and Matula[5] indicates that a coefficient of variance [standard deviation (s)/mean (x)] of 2.6% (CV = 2.6%) could be expected from 30 urban tests of the same vehicle tested on the same apparatus. Such precision can not be reported with any sort of reasonable confidence with a sample population of three as we planned to use in these tests.

However, it is possible to statistically compare the variance obtainable with the same level of confidence in two sample populations of different sizes for the same test procedures. The necessary technique used is called the "F" test. "F" is simply the ratio of two estimates of variance. If the two populations were of the same size, F would equal 1. However, when the populations are of different size, F is a function of the population sizes. From Juran[7] F = 2.92 for a comparison of the variances of two samples with populations of 3 and 30 at a 95% confidence level.

FIGURE 4.1 TYPICAL DATA SHEET USED FOR EMISSIONS AND FUEL ECONOMY TEST DATA RECORDING

Sheet ________ of ________

SUMMARY DYNAMOMETER TEST SHEET FOR ____________________

Line No.	Transmission		Scheduled Date		Run Date		Urban Cycle												
							Carbon Balance							Weight Method					
							CO	HC	NO_x	CO_2	MPG	Humidity Correction Factor	Atm. Press	Start Wt.	End Wt.	Fuel Used	S.G. @ Temp.		MPG
	L–U	OD	Urb.	Hwy	Urb/Seq.	Hwy/Seq.	gm/mi	gm/mi	gm/mi	gm/mi			In. Hg.	Grams	Grams	Grams	$\frac{gm}{ml}$	^{o}F	
1	OFF	OFF																	
2	OFF	OFF																	
3	OFF	OFF																	
4																			
5	OFF	3																	
6	OFF	3																	
7	OFF	3																	
8																			
9	3	3																	
10	3	3																	
11	3	3																	
12																			
13	2	3																	
14	2	3																	
15	2	3																	
16																			
17	OFF	4																	
18	OFF	4																	
19	OFF	4																	
20																			
21	4	4																	
22	4	4																	
23	4	4																	
24																			
25	3	4																	
26	3	4																	
27	3	4																	
28																			

FIGURE 4.1 (Continued)

Highway Cycle															
Carbon Balance						Weight Method									
CO	HC	NO_x	CO_2	MPG	Atm. Press	Start Wt.	End Wt.	Fuel Used	S.G. @ Temp.		MPG	Idle Co.	$\frac{MPG_{Wt} - MPG_{CB}}{MPG_{CB}}$		Remarks
gm/mi	gm/mi	gm/mi	gm/mi		In.Hg	Grams	Grams	Grams	$\frac{gm}{ml}$	°F		%	Urban	Highway	

Therefore, since

$$F = \frac{S_1^2}{S_2^2} = 2.92$$

and

$$CV = \frac{S}{mean} \times 100$$

$$\frac{CV_1}{CV_2} = F$$

$$CV_1 = 2.6\ F$$

$$CV_1 = 2.6 \times 2.92 = 4.4$$

data sets with a coefficient of variance of 4.44% of less would be acceptable for three replicate tests.

4.2 PERFORMANCE

A major concern surrounding the adoption of the lockup torque converter is that the corresponding loss of torque multiplication may noticeably degrade acceleration. Performance tests were therefore conducted in order to study the impact of torque converter lockup on acceleration.

4.2.1 Procedure

It was desired to determine whether or not the use of the overdrive top gear ratio and/or the lockup torque converter would degrade the acceleration capabilities of the vehicles. Therefore, it was originally planned to conduct two replicate wide open throttle (WOT) tests from 0 miles per hour (mph), 25 mph, and 50 mph for thirty seconds in each transmission mode. The top speed attainable under each condition was to be predetermined and the speed range covered from test start to the top speed was to be divided by three. The time to reach each third of the speed range was to be recorded.

On the day of testing, this test plan was modified in the interests of time and safety. Because of the degradation in performance caused by the additional emission control hardware, neither of the Dodge Colts would exceed 70 mph under WOT conditions in any transmission mode, and top speed was reached in less time than 30 seconds. Therefore, it became obvious that tests from 25 mph and 50 mph for 30 seconds would produce no different results than tests from 0 mph, and these tests were aborted in those cars.

Furthermore, none of the Torque-Flite transmissions shifted out of second gear at speeds significantly below 70 mph. Thus the only non-production transmission mode which would impact below 70 mph performance was torque converter lockup in second gear. Therefore, this was the only non-production transmission mode tested below 70 mph.

As the performance testing progressed, the weather turned foul and the test track became wet. Because hard braking was required at the end of the straightaway used for test purposes, it was decided to postpone the 25 and 50 mph tests in the two Valiants. Later on, we decided to abort these tests also, as the important 50 to 70 mph "passing gear" data was included in the 0 mph tests, and we did not relish driving at high speeds on the bumpy track available to us.

4.2.2 Equipment

The tests took place on the main straightaway of the Thompson Speedway road course in East Thompson, Connecticut.

Timing was performed with two manually operated Heuer 1006-BCD electronic timers and a stopwatch. All three timers were started simultaneously at the start of the test. The Heuers were stopped at the intermediate, predetermined speeds. The stopwatch was stopped as soon as 70 mph was reached.

The cars' speedometers were used for speed measurement.

We recognize that the techniques used in these particular tests were not as sophisticated as they might have been. However, they were sufficiently precise to determine any significant impact of the transmission modes on vehicle performance. Any errors introduced by the methodology were judged to be irrelevant in terms of the vehicle's performance.

4.3 DRIVEABILITY

"Driveability" is used in the automotive industry to describe the subjective operating characteristics of a vehicle. The choice of the word "driveability" may be unfortunate, but it does have a special meaning within the industry. Such operating defects as frequent stalling at stops or continuous engine knocking if inherent in a model and not correctable, would make that model completely unsaleable. These would constitute an obvious "driveability" failure. The engineers have recognized "driveability" defects as the passenger car has been developed and these undesirable characteristics have been constantly improved and are now virtually eliminated.

"In the development of ...vehicle features, "driveability" is included as a normal development item. No two manufacturers define all parameters involved in "driveability" in quite the same way. However, all manufacturers do go to great lengths to minimize "driveability" defects from prototype vehicles during the development period prior to release for production".[8]

Because degradation in driveability caused by any change in a vehicle could discourage sales, it is important to identify the impact of that change on driveability. The impact of the various transmission modes upon vehicle driveability are important to this program for two reasons:

1) If driveability is adversely affected, the adoption of one or more of these concepts may not take place because the driveability of vehicles so equipped may be unacceptable to the marketplace

2) It is important to determine how these transmissions affect driveability in order to correct or minimize any driveability defects which may deter sales and which may affect fuel economy.

During the initial design and installation of the test transmissions, no attempt was made to minimize the impact of these transmissions on driveability. Therefore, these tests must be considered as:

1) A first step in determining the worst case impact of these transmission concepts on vehicle driveability, and

2) A means of identifying corrective measures which must be taken to alleviate driveability problems.

At the conclusion of these tests, one of the test cars was selected for further work in the elimination of the driveability problems in one of the modified transmission modes.

4.3.1 Procedure

The procedure used was a modified form of a test developed by the Automobile Manufacturers Association (AMA), now the Motor Vehicle Manufacturers Association (MVMA), as an industry-wide test to determine the impact of emission controls on vehicle driveability[8]. This test evaluated drivetrain performance only, and numerically scored performance defects according to a demerit system. While it was originally designed to determine the relative impact of emission controls on driveability we found that it lent itself, with slight modifications, to evaluation of the relative impact of various transmissions as well.

It was possible to adapt the test to an evaluation of transmissions because any driveability defects associated with the drivetrain, manifest themselves as vehicle motions transmitted to the vehicle's occupants through the frame, body, and seats of the car. By adding a method of rating shift quality and scoring vehicle "lugging" or roughness, we found that this test was suitable for evaluating these transmissions.

As originally developed and refined, the test was a two-part test consisting of cold start and warm vehicle test sequences. The former sequence was developed to ascertain the impact of emission controls on cold vehicle driveability and, we felt, would yield little or no additional information concerning the transmissions over the warm vehicle portion. The cold start sequence would also add considerable time and cost to the driveability tests. Therefore, we chose to conduct only warm vehicle tests.

Warm vehicle driveability was determined by drivers and passengers using the procedure based upon the "AMA Driveability Procedure", Revision 2, dated 13 September 1971, developed by the Automobile Manufacturers Association, 320 New Center Building, Detroit, Michigan[8]. Each car had a driver and observer making independent evaluations of each transmission. Two replicate tests of each unit were made. None of the evaluators knew which transmission they were evaluating. All evaluators, however, had sufficient automotive knowledge and experience to properly implement the test. See Figure 4.2 and Table 4.1 for driveability evaluation sheets and weighting factors.

This test was developed as a comparative evaluation technique. The comparisons, in this case, were made between the baseline transmission and each of the modified modes.

The warm vehicle (minimum 5 miles driving) procedure is as follows:

1. Warm up vehicle for approximately 10 miles at freeway speeds

2. Road load operation from 20 to 70 mph

3. With automatic transmission vehicle, make the indicated wide open throttle (WOT) from 0 through 30 mph. With manual transmission vehicle, accelerate in high gear from 20 through 30 at WOT.

WARM VEHICLE DRIVEABILITY EVALUATION

VEHICLE NO. ____________ LICENSE NO. ____________

DATE: ________ TIME: START ________ FINISH ________ ODO. START ________ FINISH ________

TEMP.: START ________ °F FINISH ________ °F ROAD CONDITION: WET ________ DRY ________

HUMIDITY ________

REMARKS: ____

	RPM	VAC	IDLE: SATISFACTORY	IDLE: ROUGH*	IDLE: STALL	DRIVE MODES: SATISFACTORY	DETONATION*	SURGE*	HESITATION	STRETCHINESS	BACKFIRE	SHIFT FEEL
Curb Idle												
Road Load 20 MPH												
30												
40												
50												
60												
70												
WOT Accel)20–30 Manual Trans)0–30 Auto Trans												
Sudden Throttle Opening												
Moderate Throttle Opening												
Slow Throttle Opening												
PT Accel)20–30 Manual Trans)0–30 Auto Trans												
1/4 Throttle												
1/2 Throttle												
3/4 Throttle												
PT Crowd 20–40												
15 In. Hg												
10 In. Hg												
5 In. Hg												
PT Tip-In												
From 20 MPH 1												
2												
From 30 MPH 1												
2												

Soak	Start Time		Attempts:
Idle	N ______ RPM ______ VAC ______ D RPM VAC	After-Run	Yes ______ No
Acceleration Time 0—60 MPH (Sec.)			
Deceleration Time 70—40 MPH (Sec.)			Backfire

*T — Trace; M — Moderate; H — Heavy

FIGURE 4.2 TYPICAL DRIVEABILITY DATA SHEET

TABLE 4.1 DRIVEABILITY EVALUATION SCALE

Malfunction Rated	Demerits				Weighting Factor
	Trace	Moderate	Heavy	Yes	
Roughness*	1	3	6	-	1
Hesitation	1	3	6	-	4
Stretchiness	1	3	6	-	4
Stumble	1	3	6	-	4
Surge	1	2	3	-	3
Stall at Start	-	-	-	6	2
Stall-Driving	-	-	-	6	6
Backfire	1	2	3	-	3
Detonation	1	3	6	-	2
Transmission Shift Feel**	1	2	3	-	2

*Roughness in this case referred to lugging under load rather than idle roughness as noted on the data sheets

**Added to the AMA Test procedure

All tests were conducted on June 9, 1977, on the Thompson Speedway Road Course in East Thompson, Connecticut. During the tests the data was recorded on data sheets such as shown in Figure 4.2.

4. With automatic transmission vehicle, make the indicated accelerations from 0 through 30 mph at various constant throttle positons from very light to nearly WOT. With manual tranmsission vehicle, these part throttle (PT) accelerations are to be made from 20 through 30 mph.

5. "Crowds" are evaluated in high gear from 20 mph through 70 mph by accelerating at a continually increasing throttle opening. Several runs should be made varying the rate of throttle opening.

6. Evaluate the "tip-in" characteristcs by making several PT accelerations from 20 and 30 mph. Do not accelerate at a load which will cause the automatic transmission to downshift.

Definitions of Terms Applicable to Driveability Procedure

Road Load - A fixed throttle position which maintains a constant vehicle speed on a level road.

Coast - Deceleration at closed (curb idle) throttle.

Wide Open Throttle Acceleration (WOT) - An acceleration made entirely at wide open throttle (from any speed).

Part Throttle Acceleration (PT) - An acceleration made at any fixed throttle position less than WOT.

Tip-In - Vehicle response (up to two seconds in duration), to the initial opening of the throttle.

Crowd - An acceleration made at a continually increasing throttle opening.

Idle Quality - An evaluation of vehicle smoothness, with the engine at curbe idle in drive, as judged from the driver's seat.

Backfire - An explosion in the induction or exhaust system.

Hesitation - A temporary lack of initial response in acceleration rate.

Stumble - A short, sharp reduction in acceleration rate.

Lean Operation - This condition, depending on its severity, can manifest itself as outlined in the following categories:

-- Stretchiness - A lack of anticipated response to throttle movement. This may occur on slight movement from road load or during light to moderate accelerations.

-- Surging - A condition of leanness, resulting in short, sharp fluctuations. These may be cyclic or random and can occur at any speed and/or load.

After-run - A condition where the engine continues to run after the ignition has been shut off.

Detonation (Spark Knock) - A knock or ping which is recurrent or repeatable in terms of audibility.

Laymen's Nomenclature

Performance Factor	Performance Defects
Acceleration	Acceleration defects are usually associated with lack of proportional response of the vehicle to a movement of the accelerator pedal (gas pedal). This lack of response will vary depending on the type of defect, for example: Stumble - A short, sharp reduction in acceleration. Hesitation - A temporary lack of vehicle response to the initial movement of the accelerator pedal. Stretchiness - A lack of expected response of the vehicle to a slight movement of the accelerator pedal that is intended to produce a slight acceleration. Surging - An uneven, fluctuation response of the vehicle to a slight response of the vehicle to a slight movement of the accelerator that is intended to produce a slow acceleration. Infrequently, surging will occur with a greater accelerator movement.
Constant Speed Driving	Surging - An uneven, fluctuating sensation resulting from erratic changes in vehicle velocity. This defect is most easily

Performance Factor	Performance Defects
	detected on smooth roads and is usually masked by uneven roads.
Engine Starting	Delayed Start - An engine start that is longer than the anticipated starting time or exceeding the capacity of the engine cranking system and battery.
	Partial Start (Stalling) - One or more engine stalls occurring immediately or shortly after the initial start.
	Backfire - May occur during the starting operation.
Deceleration (Slow Down)	Surging - May also occur on deceleration when the accelerator pedal is still slightly depressed.
	Backfire - May occur with the foot entirely removed from the accelerator.
	Stalling - Complete stoppage of the engine may occur just prior to or at the time the vehicle comes to a stop.
Engine Noise	Detonation (Spark Knock) - An abnormal noise in the engine resembling a series of sharp raps, knocks, or pings - may occur at constant speed, or when accelerating or when climbing hills.
Vehicle Shutdown	After Run - A condition where the engine continues to run after the key is turned off.

4.4 ACCEPTABILITY

Many criteria contribute to the consumer's acceptance of an automobile. Probably the most important in the long run, however, is the way the vehicle performs on the road in a variety of situations. To develop a method for evaluating vehicle acceptability, therefore, we conducted tests under conditions that would at least approximate those that might be encountered by customers.

The vehicle used for acceptability testing was the 318 CID Plymouth Valiant V-8. Since it was possible to select either the stock configuration of the transmission or the transmission modification, any perceived difference was believed to be caused by the difference in the transmission configuration used and not to any other aspect of the vehicle.

4.4.1 Procedure

The profile approach to sensory evaluation was used to assess the acceptability of the automobile. This approach utilizing a profile panel of 4 or 5 people, was developed at Arthur D. Little, Inc., as a means of describing and quantifying those properties of a product that affect the senses. It has been applied to a wide range of products including the flavor of foods, the smoothness of faces after shaving with various devices, the softness of hair treated with shampoos, and the brightness or shine of polishes and cleaners. The profile approach was used as the basis for the evaluation of the acceptability of the test transmission.

A panel of five people who were trained to make perceptual judgments performed the evaluation. The members of this particular panel have been making objective evaluations of a variety of products by reporting their pertinent sensations and perceptions for many years. The panel familiarized itself with the test car, developed the test techniques that were relevant to an evaluation of the transmissions, the characteristics that were to be evaluated, and the terminology that was to be used to communicate the pertinent sensations and perceptions. Orientation of the panel to the automobile, development of techniques and terminology, and selection of a test route were carried out simultaneously. There were seven orientation test drives during which both transmission configurations were employed. During this period the panel became aware of the differences that were to show up during the formal testing.

Reference was made to the driveability procedure developed by the Motor Vehicle Manufacturers Association[8] and portions of that procedure which were pertinent to the consumer's mode of operation were incorporated into the acceptability test. Whenever appropriate, wide open throttle accelerations, part throttle tip-ins, crowds and road loads from 20 through 70 mph were made. Since the route included hills or grades, that aspect of performance was added to the evaluation. Likewise, the performance of the vehicle in a passing situation was considered essential to the test. Although similar to a part throttle tip-in, this sudden lane changing maneuver was carried out at highway speeds. It was felt that the test route should, in a reasonable distance, provide most of the conditions of traffic and terrain that a customer might be expected to encounter. A 27 mile route was devised that would provide the following sequence: six miles of stop and go traffic, nine miles of highway driving, eight miles of stop and go traffic, and four miles of highway driving. This route furnished an opportunity to test the vehicle on the level, on grades or hills, on straightaways, and on curves.

Each panel member rated the car as a driver and also as a passenger during the tests, using a rating sheet that is shown in Figure 4.3. Four panel members participated in each test run. The rating sheet listed the observations to be made at each stage of operation and provided space for a commentary on the way the vehicle performed the maneuvers. A total score was given for each stage rather than for the observations made during that stage. The scale had seven points ranging from no apparent defect (score of 1) to high defect level (score of 7).

Two runs were made each day of the test, and a total of five days of testing were performed. Each day both the baseline mode and the modified transmission mode were evaluated, one mode on each run. In order to avoid biasing the overall results, half of the test days started out with the baseline mode, the other half started out with the modified transmission in order to equalize any effects of vehicle operating temperatures, driver fatigue, passenger discomfort, etc.

Observations were made during seven stages of vehicle operation. These stages were:

1. Start-up
2. Warm up (five minutes)
3. Reverse and forward
4. "Cold" traffic driving
5. Highway driving
6. "Warm" traffic driving
7. Engine shut-down

Name:________________________ Date:_________

Weather Condition_____________ Temp.:________

Configuration:______________________________

Odometer:________________ Time:_______________

I. Start-Up — Score:_________

Observations	Notations
Delayed start	
Partial start (stall)	
Other	

II. Warm-Up — Score:_________

Observations	Notations
Idle quality	
Detonation (ping)	
Stall	
Other	

III. Back-Up and Forward — Score:_________

Observations	Notations
Shift ease	
Shift quality	
Stalling	
Other	

IV. Traffic Driving - Cold — Score:______

Observations	Notations
Shift quality	
Downshift	
WOT acceleration 0-25	
slow throttle	
moderate throttle	
sudden throttle	
P.T. tip-in 20-30	
Crowds 20-30	
30-40	
Road load @ 20	
Road load @ 30	
Road load @ 40	
Hill handling	
shifting	
strain	
ping	
Other	

FIGURE 4.3 ACCEPTABILITY RATING SHEET

V. Highway Driving — Score: ______

Observations	Notations
Shift quality	
Downshift	
Ping or knock	
Strain	
P.T. tip-in 20-30	
Crowds 20-30	
30-40	
40-50	
50-60	
60-70	
Road load @ 30	
Road load @ 40	
Road load @ 50	
Road load @ 60	
Road load @ 70	
Passing response	
Other	

VI. Traffic Driving - Warm — Score: ______

Observations	Notations
Shift quality	
Crowds 20-30	
30-40	
Road load @ 20	
Road load @ 30	
Road load @ 40	
WOT acceleration 0-25	
slow throttle	
moderate throttle	
sudden throttle	
Other	

VII. Engine Shutdown — Score: ______

Observations	Notations
Dieseling	
Other	

Odometer: ____________________ Time: ________________

Scale:
1 = none
2 = barely perceptible
3 = low
4 = low-moderate
5 = moderate
6 = moderate-high
7 = high

FIGURE 4.3 ACCEPTABILITY RATING SHEET (cont'd)

4.5 VEHICLE DURABILITY

Because of the higher engine loads associated with the use of an overdrive top gear ratio and a lockup torque converter there is a possibility that engine and catalyst durability may be degraded. A full fledged program to determine any change in drivetrain component life involves extensive dynamometer and over-the-road testing followed by complete teardowns of several different drivetrains after many thousands of miles and would cost more than this entire program. However, changes in certain basic operating parameters, if observed, may qualitatively and sometimes quantitatively predict changes in engine, catalyst, or drivetrain component life.

4.5.1 Procedure

Durability was determined by monitoring critical operating parameters before and after drivetrain modification. Any adverse change in these parameters that resulted with the use of a modified transmission will be expected to reduce the life of the affected components. Therefore, we monitored:

- Engine oil temperature
- Engine oil pressure
- Engine coolant temperature
- Transmission oil temperature
- Manifold vacuum
- Catalyst exhaust temperature (where applicable)

Engine oil temperature and pressure are closely related. A reduction in pressure at constant temperature and engine speed in indicative of wear in the lubrication system, usually the bearings. Since the capacity of the oil pump exceeds the flow requirements of even a worn engine running at high speeds, a pressure reduction caused by wear is most apt to show up under idle conditions. On the other hand, increased engine loads increase the internal engine temperatures and produce greater bearing loads. The resultant increased oil temperature reduces the viscosity of the oil and thereby the ability of the oil to protect the engine. Any significant increase in oil temperature under similar operating conditions, therefore, is indicative of shortened engine life. Reduced oil pressure at constant idle speed and temperature is indicative of advanced bearing wear.

Engine coolant temperatures at steady state operating conditions is indicative of the engine load. The coolant flow rate through the block is constant for a given engine speed. The volume flow through the radiator is controlled by the thermostat. By measuring the coolant temperature in the block, one may be able to measure the relative rate of waste heat output: the higher the engine load, the higher the rate of waste heat generation.

A significant increase in coolant temperature is therefore indicative of increased engine load. Higher coolant temperatures also mean that the rate of heat transfer away from critical engine parts such as valves and cylinder walls is reduced, and their life may be expected to be shortened as a result

Of all the drivetrain parameters that can be measured on an over-the-road car, perhaps the most critical is the transmission oil temperature. This fluid is subject to tremendous heat sources as it passes through high pressure pumps, around clutches, and through the torque converter. The operating temperature of this oil is normally 160 to 200°F. Temperatures only 50° higher tend to break down the oil. As the oil breaks down it loses its lubricity and ability to protect the clutch facings. At 300°F the rate of fluid breakdown is such that transmission damage and failure results within a few miles.[9] Table 4.2 illustrates the impact of transmission oil temperature on the useful life of that oil.

TABLE 4.2 LIFE EXPECTANCY OF TRANSMISSION OIL AS A FUNCTION OF TEMPERATURE

Temperature °F	Life Expectancy Miles
175	100,000
195	50,000
212	25,000
235	12,500
255	6,250
275	3,000
295	1,500
315	750
335	325
375	160
395	40
410	30 (minutes)

Source: Automotive Service Council[10]

The engine manifold vacuum gauge indicates the efficiency of the induction system. Valve damage, manifold leaks, and gross piston/cylinder defects are easily detected by an increase or fluctuation in manifold pressure. A manifold vacuum gauge is also a useful indicator of engine load. At a given speed, the higher the load the more open the throttle, and hence the higher the manifold pressure.

Catalyst temperature is proportional to the flow of unburned hydrocarbons and carbon monoxide leaving the engine. As engine load increases the combustion efficiency may drop, the engine airflow will increase, and more hydrocarbons and carbon monixide must be burned by the catalytic unit. The catalyst will be forced to work more and its operating temperature is expected to rise. The normal operating temperature range of a catalytic converter is between 400 and 1200°F with occasional excursions to 1600°F. Continued steady state operation at temperatures above 1200°F are known to seriously reduce the useful life of the catalyst. Degradation of the catalyst with increasing temperature is quite pronounced. The two Valiants which are equipped with catalysts were instrumented with pryometers having a range of 800°F to 1800°F to determine if abnormal peak and steady state temperatures resulted from the modified transmissions.

In order to correlate the above operational parameters with engine operating conditions, engine speed tachometers were also installed in the vehicles.

Both before and after installation of the modified transmissions, the cars were run in daily, "normal" service by members of the Arthur D. Little Automotive Technology Group. At the beginning and end of each trip the drivers were required to fill out a vehicle log and record:

a. Date

b. Odometer Reading

c. Transmission Mode Used

d. Idle Speed (in gear)

e. Engine Oil Temperature

f. Engine Oil Pressure

g. Ambient Temperature

During their trip, drivers were asked to record:

a. Peak Coolant Temperature

b. Peak Transmission Oil Temperature

c. Cruise Manifold Pressure at 30 and 55 mph

d. Peak Catalyst Temperature

e. Any unusual occurrences coincidental with recording of peak temperature

Drivers were also requested to record fuel and oil purchases and the mileage at which they were made.

A typical sample log sheet is shown in Figure 4.4.

4.6 COMPONENT TESTS

The multi-purpose test transmissions and their components were tested for:

a. Proper function

b. Torque converter characteristics

c. Spin losses

These tests were required in order to quantify any differences between production transmissions and the experimental units in terms of torque converter characteristics, shift points, shift time, main pump output, and spin losses. This information was necessary to be sure that the test units were as close as possible to production units in every respect except for the lockup and overdrive gear ratio, and to quantify the differences for the purpose of the computer simulation which was based upon production unit specifications.

4.6.1 Equipment and Procedure

4.6.1.1 Proper Function

Each multi-purpose test transmission was tested on the B&M Automotive Products' Inertia Dynamometer in order to ascertain its functional characteristics.

The dynamometer consists of a 455 CID high torque output automobile engine, a transmission test stand, a variable mass inertia wheel and suitable adapters for connecting the transmission to the engine and the inertia wheel. Torque transducers are located at the engine crankshaft flange and on the inertia wheel shaft to provide input and output data, respectively, of the transmission under test. Tachometer readings are taken from the engine crankshaft and inertia wheel. Six hydraulic pressure sensors can be used to monitor internal transmissions oil pressures. The oil flow rate through the torque converter/oil cooler/lubrication circuit can also be monitored.

DRIVING LOG

DATE	MILEAGE START / STOP	TRANS. MODE LOCKUP GEAR	TRANS. MODE OVERDRIVE GEAR	IDLE RPM*	ENGINE OIL TEMPERATURE	ENGINE OIL PRESSURE	WATER TEMP. PEAK TEMP. (TEMP / MPH)	TRAN. TEMP. PEAK TEMP. (TEMP / MPH)	CRUISE MAN. PRESS. 55 MPH	CRUISE MAN. PRESS. 30 MPH	CATALYST TEMPERATURE	COMMENTS AND TRIP DESCRIPTION	DRIVER'S INITIALS

*Record immediately after starting at idle and just before stop, also at idle.

FIGURE 4.4 **SAMPLE VEHICLE LOG SHEET**

All the desired data can be visually monitored on the dynamometer control panel. Eight specific parameters can be permanently recorded as a function of time on an eight-channel Offner Type 4 Dynograph. A Wiancho Type 2-1027-12 demodulator unit is used to couple the sensor outputs to the dynograph input.

Data which is reducible from this package are:

a. Shift point activation
b. Shift reaction time
c. Shift response time
d. Shift point speed
e. Shift speed lag
f. Transmission response time
g. Transmission shift torque capacity
h. Torque converter input torque
i. Transmission output torque
j. Torque converter input speed
k. Transmission output speed
l. Stall speed
m. Stall torque ratio } at zero output rpm
n. Capacity factor
o. Oil pressure (0-600 psi)
p. Oil temperature
q. Oil flow rate
r. Elapsed time acceleration

Data recorded for functional checks of the transmissions were:

a. Torque converter input torque
b. Transmission output torque
c. Shift control pressure (governor and throttle position)
d. Torque converter oil pressure
e. Lubrication oil flow
f. Torque converter input speed
g. Transmission output speed

Each transmission was cycled up and down through the gears at various input speeds. The measured parameters were compared to production specifications to ensure that the transmission performed as Chrysler meant.

4.6.1.2 <u>Torque Converter Characteristics</u>

In order to determine the torque converter characteristics (speed ratio, torque ratio, and capacity factor) over the operational speed range, a special absorbtion type dynamometer is required. Such units allow the input shaft to be run at different speeds while the transmission (torque converter) output shaft is held at a constant speed. In addition, a special "frictionless" transmission is required to connect the torque converter to the dynamometer without introducing extraneous variables. As far as we have been able to determine, such units are available only at the major automaker and transmission company research laboratories. The dynamometer that was available to this program is an inertia type unit which must be accelerated in order to yield data.

A 10-3/4 inch (A727) lockup torque converter was installed on the test stand. The dynamometer was accelerated at an input load of 200 ft/lbs using a special transmission locked into top gear for the entire speed range. The input and output speed and torque information developed during this test was used to develop a torque ratio, speed ratio, and capacity factor versus rpm curve which approximated that which would be developed during a true absorbtion dynamometer test.

This test was repeated with a production torque converter.

Torque converter efficiency, torque ratio, and input speed were determined as a function of speed ratio for both units tested. A comparison of the results would determine whether or not the lockup units performed in a manner identical to the production unit.

4.6.1.3 Spin Losses

The additional power needed to spin the overdrive unit was of interest in order to determine the impact of the additional power requirements on baseline fuel economy. It could be expected that if the additional power requirement were significant, the potential fuel economy benefit could be reduced or even offset by the additional power requirements of the overdrive unit. Furthermore, it was desirable to quantify these losses for use in the computer simulation work. This could allow further resolution of differences occurring between the test and simulation predictions of fuel economy improvements.

There are two types of loss in a gearset: "windage" or "spin" loss and power transmission loss. Spin losses are those losses incurred in overcoming bearing friction, oil pumping, lubricant drag, and gear tooth friction. Spin losses are normally only a function of speed and oil temperature.

Power transmission losses are those additional losses which are a function of the power being transmitted by the device. These are usually due to increased bearing friction and gear tooth friction and, to some extent, component deflection and misalignment caused by loading.

The tests which we conducted were designed only to determine the spin losses of the multi-purpose transmission as compared to the production unit. To determine the power transmission losses, which are a function of both speed and load, would have required a test program requiring a significant portion of the total program budget. The data obtained from such a program would have also required extensive revision of the simulation program to allow its use in the DOT/TSC modeling. While it would unquestionably add a great deal more sophistication to this program, it is our opinion that there are other sources of error in computer modeling techniques which introduce far greater discrepancies in such simulation work. Therefore, the relative benefits gained by the acquisition of such data did not justify, to this program at least, the relative cost of obtaining and using the information.

The test equipment consisted of a Lebow torque indicator Model 7518 and a torque sensor Model TVDT 1404-200. A General Radio Model 1531 AB STROBOTAC was used to allow measurement of both the input and output shaft speeds with the same instrument. Power was supplied by a Westinghouse 7 horsepower variable speed drive system. Oil temperatures were measured by an immersion Type J thermocouple reading out on an API meter. Figure 4.5 presents a schematic of the test fixtures.

Two replicate runs of each transmission were made. A production A904 unit and a modified A904 transmission were tested. The modified unit was tested both with the overdrive unit engaged and disengaged.

Because the oil temperature could not be raised to "normal" operating temperature without connection of a significant load to the output of the transmission, an infrared heater was directed at the oil pan to warm the oil of both units to the desired level.

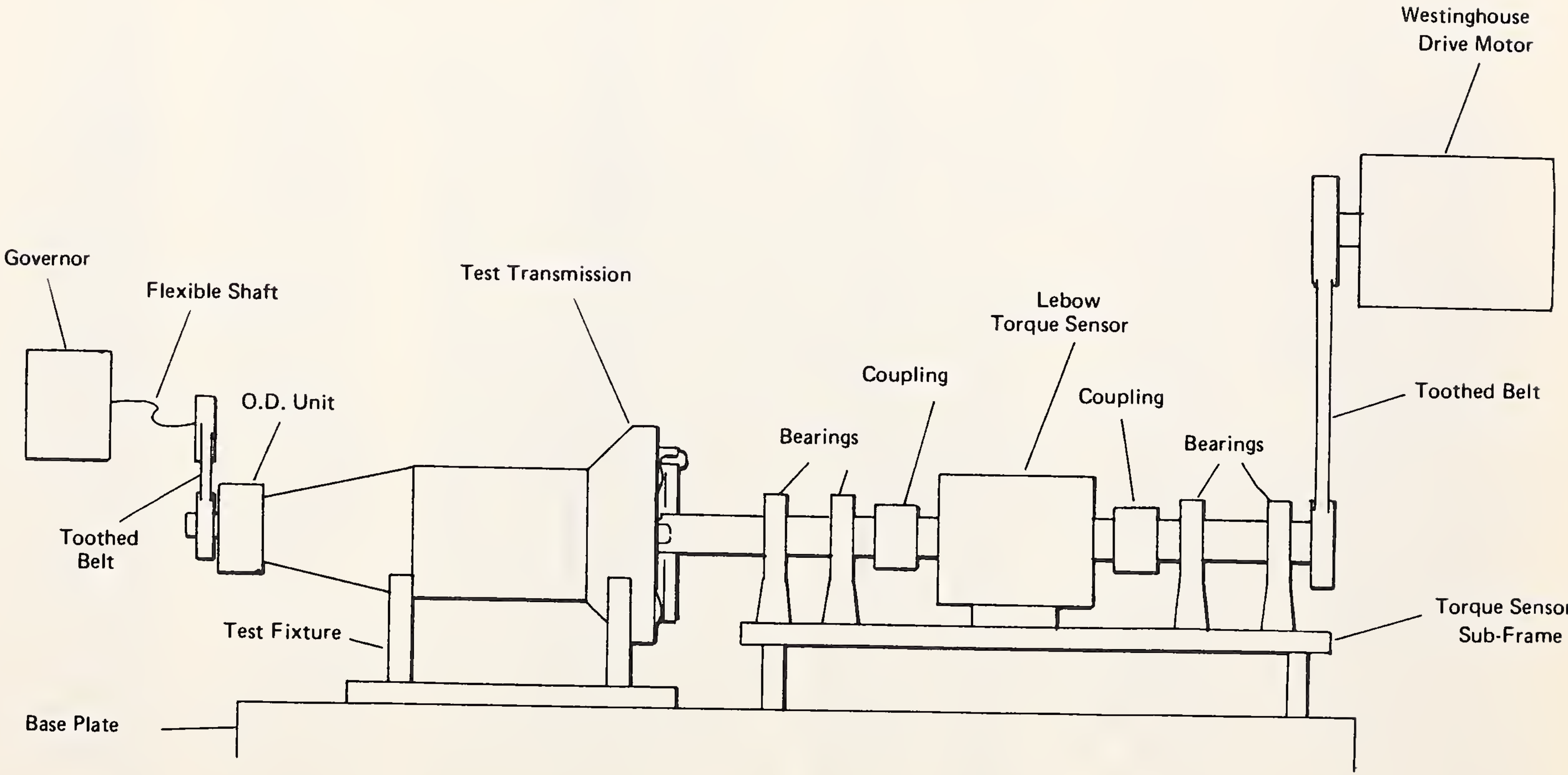


FIGURE 4.5 **SCHEMATIC SPIN LOSS TEST APPARATUS**

5. TEST RESULTS

5.1 EMISSIONS AND FUEL ECONOMY

Tables 5.1 through 5.4, 5.11 and 5.12 present summaries of the results of the urban and highway tests of each of the four cars operated in all transmission modes. The contract scope of work required tests of:

a. Baseline

b. Wide range 3-speed

c. Wide range 3-speed with lockup in third

d. Wide range 3-speed with lockup in second and third

e. Wide range 4-speed

f. Wide range 4-speed with lockup in fourth

g. Wide range 4-speed with lockup in third and fourth

h. Wide range 3-speed with lockup in second and third above 30 mph.

With the recent announcement that Chrysler Corporation will produce cars with current gear ratios combined with a lockup torque converter, we felt it was desirable to also evaluate a baseline transmission with lockup in second and third. The timing of this announcement allowed us to test only one car, the 122 CID Dodge Colt, in this mode.

5.1.1 Discussion of Tests

5.1.1.1 318 Plymouth Valiant

This car was unique to this program in three ways:

1) It was the only car to be tested at two different laboratories

2) It was the only car from which both carbon balance and fuel weighed measurement data could be combined

3) It was the only car which was fitted with the lockup inhibitor

This vehicle may also be considered to be the "trial" car which tested the effectiveness of our test sequencing and control test methodology, and experience with this car resulted in a more streamlined test program. (Section 4.1.1)

TABLE 5.1 1975 318 CID PLYMOUTH VALIANT

4000 LB INERTIA WEIGHT

Transmission Configuration	EMISSIONS						FUEL ECONOMY					
	CO		HC		NO_x		URBAN		HIGHWAY		COMPOSITE	
	Gm/Mi	Δ	Gm/Mi	Δ	GM/Mi	Δ	MPG	Δ	MPG	Δ	MPG	Δ
Baseline	10.6	-	0.73	-	1.8	-	12.8	-	20.7	-	15.5	-
WR3 SPD	11.9	+12%	0.62	-15%	2.6	+45%	12.3	-3.9%*	see note below	+4.0%*	15.1	-2.6
WR3 SPD, 3 LU	15.1	+42%	0.99	+36%	1.9	+5.6%	13.9	+8.6%	25.0	+21%	17.4	+12%
WR3 SPD, 2, 3LU	16.0	+51%	1.30	+78%	1.6	-11%	14.2	+11%	24.6	+19%	17.6	+14%
WR4 SPD	9.2	-13%	0.52	-28%	2.0	+11%	12.9	+0.8%*	21.2	+2.4%*	15.7	+1.2%
WR4 SPD, 4 LU	10.8	+1.9%	0.59	-20%	1.9	+5.6%	13.0	+1.5%	25.1	+21%	16.6	+7.2%
WR4 SPD, 3, 4LU	12.9	+22%	0.90	+23%	1.6	-11%	13.6	+6.2%	24.3	+17%	17.0	+9.7%

*NOTE: Due to a large coefficient of variance (5.23%) of the Carbon Balance data for this one test sequence, this one data point is based upon weight method results only (21.0 MPG vs. 20.2).

TABLE 5.2 1975 225 CID

3500 LB INERTIA WEIGHT

PLYMOUTH VALIANT

Transmission Configuration	EMISSIONS CO Gm/Mi	CO Δ	HC Gm/Mi	HC Δ	NOx Gm/Mi	NOx Δ	FUEL ECONOMY URBAN MPG	URBAN Δ	HIGHWAY MPG	HIGHWAY Δ	COMPOSITE MPG	COMPOSITE Δ
Baseline	9.6	-	0.57	-	2.1	-	17.5	-	27.6	-	21.0	-
WR 3 SPD	12.9	34%	0.78	37%	2.2	4.8%	17.6*	+0.6%*	30.0	+8.7%	21.6*	+2.9%
WR 3 SPD: 3LU	16.5	72%	1.0	75%	2.0	-4.8%	18.50	+5.7%	30.5	+10%	22.5	+7.1%
WR 3 SPD: 2,3LU	18.9	+97%	1.0	75%	1.8	-14%	18.4	+5.1%	29.3	+6.2%	22.1	+5.2%
WR 4 SPD	11.4	+19%	0.64	12%	2.2	+4.8%	17.7*	+1.1%*	30.3	+9.8%	21.8*	+3.8%
WR 4 SPD: 4LU	12.6	+31%	0.73	28%	2.0	-4.8%	17.7*	+1.1%*	30.7	+11%	21.9*	+4.3%
WR 4 SPD: 3,4LU	13.7	+43%	0.72	26%	1.9	-9.5%	18.2	+4.0%	29.5	+6.9%	22.0*	+4.3%

*Not significantly different from baseline

TABLE 5.3 1975 DODGE COLT

2500 LB INERTIA WEIGHT

122 CID

Transmission Configuration	EMISSIONS						FUEL ECONOMY					
	CO		HC		NO_x		Urban		Highway		Composite	
	Gm/Mi	Δ%	Gm/Mi	Δ%	Gm/Mi	Δ%	MPG	Δ%	MPG	Δ%	MPG	Δ%
Baseline	10.2	-	.44	-	2.3	-	20.7	-	31.0	-	24.4	-
Baseline Ratios with 2-3 Lock-up	10.8	+5.9	.48	+9.1	1.9	-17	22.6	+9.2	33.0	+6.5	26.4	+8.2
WR-3-Speed	11.3	+11	.44	0	2.0	-13	21.4	+3.4	34.0	+9.7	25.9	+6.1
WR-3-Speed 3 Lock-up	12.8	+25	.46	+4.5	1.6	-30	23.0	+11	36.4	+17	27.6	+13
WR-3-Speed 2-3 Lock-up	12.8	+25	.46	+4.5	1.6	-30	23.0	+11	35.8	+15	27.4	+12
WR-4-Speed	10.4	+2.0	.44	0	2.1	-8.7	21.2	+2.4*	33.5	+8.1	25.4	+4.1
WR-4-Speed 4 Lock-up	10.1	-1.0	.41	-6.8	1.9	-17	21.7	+4.8	35.8	+15	26.4	+8.2
WR-4-Speed 3,4 Lock-up	11.2	+9.8	.44	0	1.7	-26	21.7	+4.8	33.3	+7.4	25.8	+5.7

*Not significantly different from baseline

TABLE 5.4 1975 DODGE COLT

2500 POUND INERTIA WEIGHT

97 CID

Transmission Configuration	EMISSIONS						FUEL ECONOMY					
	CO		HC		NO_x		Urban		Highway		Composite	
	Gm/Mi	Δ%	Gm/Mi	Δ%	Gm/Mi	Δ%	MPG	Δ%	MPG	Δ%	MPG	Δ%
Baseline	10.3	-	.30	-	1.7	-	21.7	-	30.1	-	24.8	-
WR-3-Speed	11.5	+12	.28	-6.6	1.7	0.0	23.1	6.5	33.3	11	26.8	8.1
WR-3-Speed 3 Lockup	13.6	+32	.36	+20	1.5	-12	24.3	12	35.2	17	28.3	14
WR-3-Speed 2-3 Lockup	15.8	+53	.42	+40	1.5	-12	23.6	8.8	34.0	13	27.3	10
WR-4-Speed	10.0	-2.9	.31	+3.3	1.7	0.0	22.7*	4.6*	33.3	11	26.5*	6.9*
WR-4-Speed 4 Lockup	10.0	-2.9	.28	-6.7	1.6	-5.9	23.0	6.0	33.8	12	26.9	8.5
WR-4-Speed 3, 4 Lockup	12.7	+23	.34	+13	1.6	-5.9	22.1*	1.8*	33.4	11	26.1	5.2*

*Not Significantly Different from Baseline

5.1.1.1.1 Laboratories

This car completed its initial series of tests at the Livonia, Michigan, facilities of Olson Laboratories, Inc. Analysis of the data indicates that five data sets had coefficients of variance which exceeded the established limit of 4.44% (see Section 4.1.2). In order to test the validity of this limit and to determine whether the variability was in the car or the test facility, we desired to re-run these deviant data sets at another laboratory. Ethyl Corporation's laboratory in Ferndale, Michigan, was selected for these comparison tests.

In these tests, three each of the baseline, wide range three-speed with lockup in second and third, and the wide range four-speed with lockup in third and fourth, urban and highway tests were run. Statistical analysis of the data showed that data from both facilities were comparable in mean value, but that the replication accuracy of Ethyl's facility was somewhat better than that of Olson (see Table 5.5) but the difference in variance was not felt to be statistically significant.

Nevertheless, the improved replication variance combined with some scheduling conflicts caused us to decide to complete the remainder of the test program at Ethyl Corporation.

TABLE 5.5 REPLICATION VARIANCES OF TWO LABORATORIES TESTING THE SAME CAR

Method	Olson Variance	(D.F.)	Ethyl Variance	(D.F.)	F-Test	α
Urban-Carbon Balance	.11	(14)	.05	(6)	2.2	α=.25
Urban-Weight Method	.08	(14)	.01	(6)	8.0	α=.01
Highway-Carbon Balance	.84	(14)	.19	(6)	4.4	α=.05
Highway-Weight Method	.39	(14)	.26	(6)	1.5	α=.50

where α = significant level (confidence level = 1 -α)
and D.F. = Degrees of Freedom

The tests at Ethyl Corporation confirmed the validity of our acceptance criteria of a coefficient of variance limit of 4.44%.

A comparison of the 95% confidence intervals for mean line composite (the average of three line composites) for the retested transmission configurations are presented in Table 5.6. This indicates that there are no significant differences in mean mile per gallon estimates between the two labs. Therefore, the Olson data sets with deviant data points were replaced with the data sets obtained at Ethyl Corporation. Ethyl baseline tests were used as a basis for comparison of all the data.

TABLE 5.6 COMPARISON OF MEAN MPG ESTIMATES FROM EACH OF TWO LABORATORIES

Transmission	Olson	Ethyl	Cycle
Baseline	(20.22, 21.70)	(20.18, 21.20)	Highway
Wide-Range 3,2, 3 Lockup	(23.68, 26.36)	(24.30, 24.94)	Highway
Wide-Range 4,3 4 Lockup	(22.98, 24,86)	(23.57, 25.09)	Highway
Baseline	(12.52, 13.20)	(12.65, 13.07)	Urban
Wide Range 3,2, 3 Lockup	(14.18, 14.37)	(14.11, 14.37)	Urban
Wide Range 4,3 4 Lockup	(13.17, 13.61)	(13.48, 13.76)	Urban
Baseline	(15.11, 16.02)	(15.20, 15.80)	Composite
Wide Range 3,2, 3 Lockup	(17.30, 18.46)	(17.39, 17.76)	Composite
Wide Range 4,3 4 Lockup	(16.29, 17.09)	(16.70, 17.27)	Composite

5.1.1.1.2 Weight Method versus Carbon Balance

In the data obtained from the highway cycle tests of this car, the carbon balance technique yielded consistently greater mpg figures than did the weight method. The average difference was .66 mpg.

No statistically different results were detected in a comparison of the urban cycle data.

Therefore, since the methods yielded virtually identical results in the urban tests and exhibited a rather consistent difference in the highway tests, the test results from the two methods were combined. This resulted in a total of six data points for each transmission which allows a more confident comparison between the modified and baseline transmissions. We recognize that only three of the six data points for each transmission are truly independent, however.

For some reason yet unexplained, this car, the 318 CID Valiant, was the only car for which such a comparison of carbon balance and weight measurements was possible. In the tests of the other cars, the weight method yielded inconsistently different results from the carbon balance technique. These differences could have influenced the comparison of transmissions; therefore, only the carbon balance method was used to compare test results of the other three cars.

5.1.1.2 Discussion of 225CID Valiant Tests

This was the first car tested to utilize the more streamlined test procedure. Three baseline tests were conducted consecutively in order to establish that the car met the 1975 Federal Emission Standards within a reasonable margin. The wide ratio 3 and 4 speed transmissions with lockup in the top two gears were then alternately tested back to back until three replicates of each had been tested. This was done in an effort to supply data to DOT on the expected "best" transmission as rapidly as possible. Another, single, baseline test was run and then the remaining transmissions and two more baseline transmissions were tested in a semi-random sequence. All six baseline tests were to be used to compare the relative performance of the modified transmission modes.

Such a comparison was not possible with this car in this case, however. After the fourth baseline test, a growing disparity between the carbon balance and weight method fuel mileage figure was noticed, and the idle carbon monoxide readings were dropping, indicating that the car was deteriorating. The car was retuned and the gas analysis bench was examined. A plugged carbon dioxide sensor was found and repaired. In later data analysis it was uncertain as to just when these problems first developed and it was, therefore, decided to scrap the first four baseline tests and the tests of the wide ratio 3 and 4 speed transmissions with lockup in the top two gears. The fourth baseline test and the three replicates of each of the first two modified modes were re-tested. The first three baseline tests were not re-run in the interest of time and funds. This decision did not compromise the validity of the test program.

5.1.1.3 Discussion of 122CID Dodge Colt Tests

After the emissions were brought under control, the test program for this car followed the program planned for the 225 CID Plymouth Valiant.

The idle CO remained relatively constant throughout the test program and no problems were experienced with the laboratory equipment.

Analysis of the data indicated that only two re-tests were required. These were single "highway" tests of the 3 speed and 4 speed transmissions without lockup. No technical reason could be found which would explain the reason why these tests needed to be re-run; yet these single tests caused the coefficient of variance of their respective three-test data sets to exceed the previously established acceptable limit of 4.44%.

5.1.1.4 Discussion of 97CID Dodge Colt Tests

This car followed the same test sequence as the other Dodge Colt and the 225CID Plymouth Valiant.

There were no problems encountered in testing this car and no re-tests were required.

5.1.2 Analysis of Test Results

The test results were examined in two different ways. Comparisons were made:

1) Between hardware tests and computer simulation.

2) Between different transmission modes.

5.1.2.1 Comparison of Computer Predictions vs. Hardware Tests

Steady-state engine maps were made for the Chrysler Corporation 318 CID V-8 and 225 CID in-line 6-cylinder engines. These were then used by the Transportation Systems Center "Veh Sim" computer modeling program to predict the performance of these engines combined with the various transmissions in the Plymouth Valiant chassis.

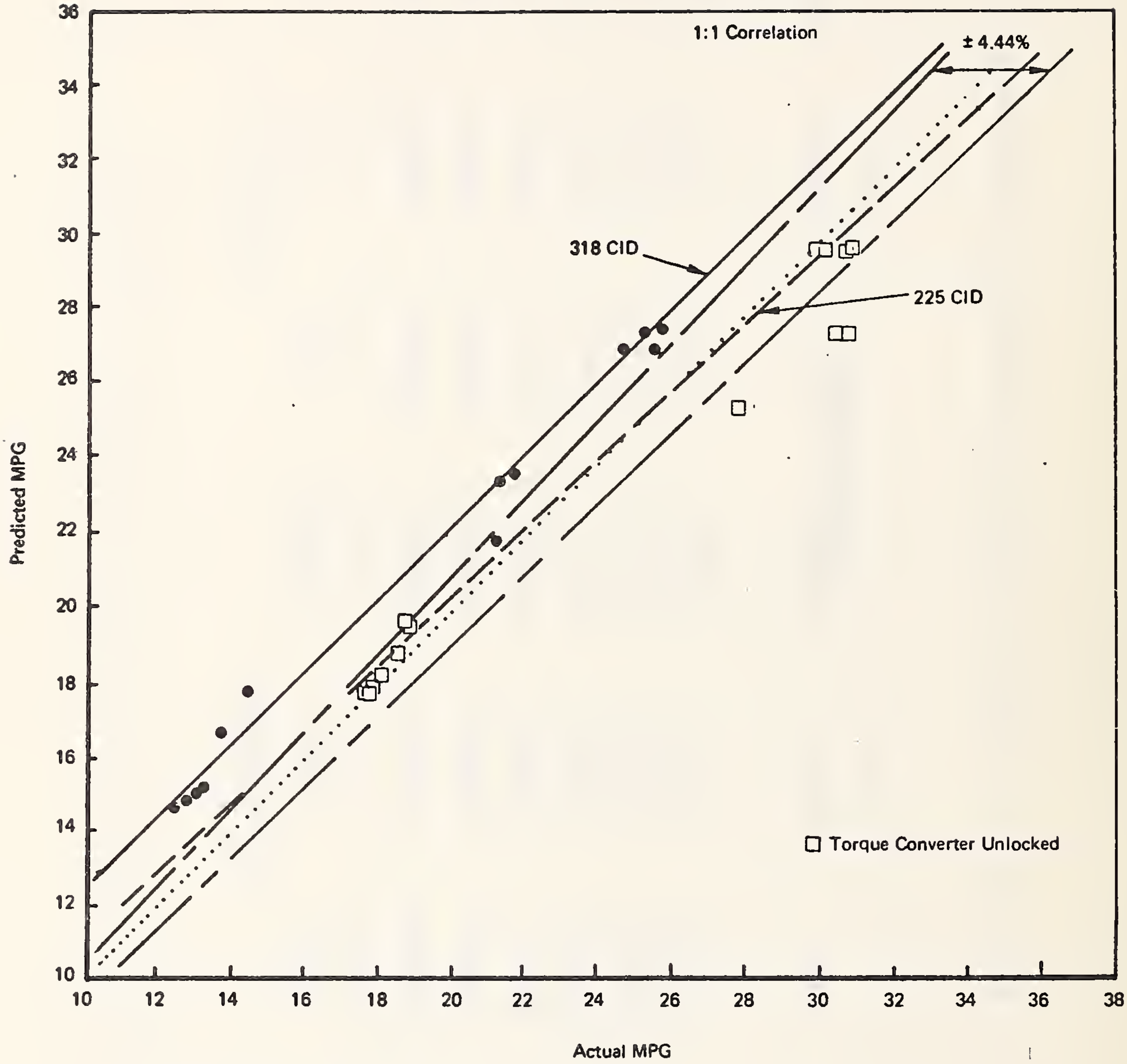
Tables 5-7 and 5-8 and Figures 5.1 and 5.2 show a comparison of the actual test and simulation results.

TABLE 5.7 COMPARISON OF ACTUAL AND PREDICTED FUEL ECONOMY

	318 CID Actual/Predicted			225 CID Actual/Predicted		
Transmission	Urban	Highway	Composite	Urban	Highway	Composite
Baseline	12.8/14.5	20.7/21.4	15.5/17.0	17.5/17.4	27.6/25.4	21.0/20.3
WR 3 SPD;	12.3/14.6	21.0/23.0	15.1/17.5	17.6/17.6	30.0/27.0	21.6/20.9
WR 3 SPD; 3 L.U.	13.9/16.6	25.0/26.3	17.4/19.9	18.5/19.2	30.5/29.3	22.5/22.7
WR 3 SPD; 2, 3 L.U.	14.2/17.1	24.6/26.4	17.6/20.3	18.4/19.6	29.3/29.3	22.1/23.1
WR 4 SPD;	12.9/14.6	21.2/23.1	15.7/17.5	17.7/17.6	30.3/27.0	21.8/20.9
WR 4 SPD; 4 L.U.	13.0/15.1	25.1/26.1	16.6/18.6	17.7/17.9	30.7/29.2	21.9/21.7
WR 4 SPD; 3, 4 L.U.	13.6/16.3	24.3/26.2	17.0/19.7	18.2/18.6	29.5/29.3	22.0/22.3

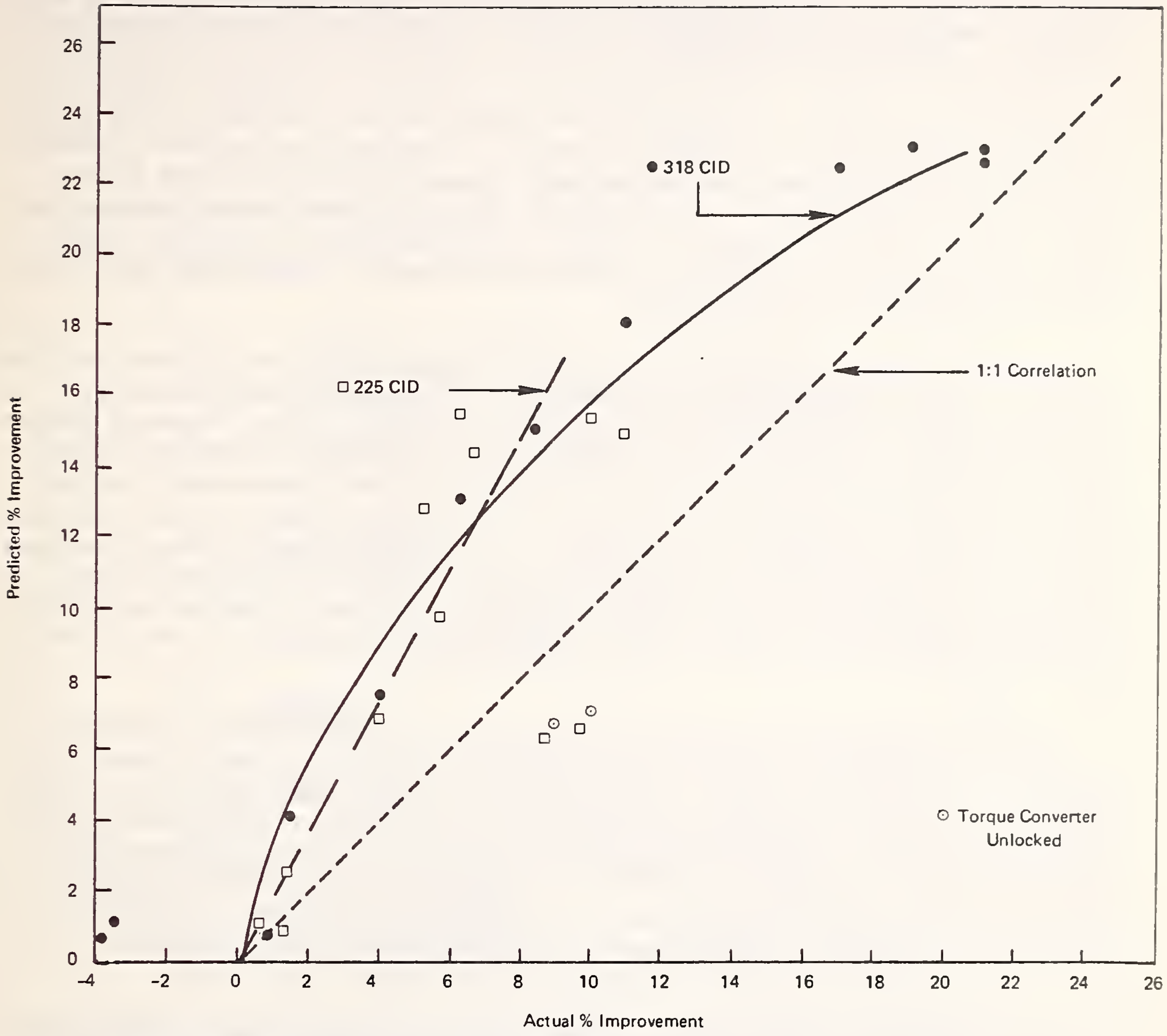
TABLE 5.8 COMPARISON OF ACTUAL AND PREDICTED INCREMENTAL IMPROVEMENTS, %

	318 CID			225 CID		
			Actual/Predicted			
Transmission	Urban	Highway	Composite	Urban	Highway	Composite
Baseline	-	-	-	-	-	-
WR 3 SPD;	-3.9/.7%	4.0/7.5	-2.6/2.9	.6/1.1	8.7/6.3	2.9/2.9
WR 3 SPD; 3 L.U.	8.6/ 14.5	21/22.9	12/17.1	5.7/9.9	10/15.3	7.1/11.8
WR 3 SPD; 2, 3 L.U.	11/17.9	19/23.4	14/19.4	5.1/12.7	6.2/15.5	5.2/13.7
WR 4 SPD;	.8/.7	2.4/8.0	1.2/2.9	1.1/.9	9.8/6.4	3.8/2.9
WR 4 SPD; 4 L.U.	1.5/4.1	21/22.0	7.2/9.4	1.1/2.6	11/14.9	4.3/6.7
WR 4 SPD; 3, 4 L.U.	6.2/12.4	17/22.4	9.7/15.9	4.0/6.9	6.9/15.3	4.3/9.8



Note: Lines drawn ignoring torque converter unlocked points.

FIGURE 5.1 COMPARISON OF ACTUAL AND PREDICTED FUEL CONSUMPTION



Note: Lines drawn ignoring torque converter unlocked points.

FIGURE 5.2 COMPARISON OF ACTUAL AND PREDICTED IMPROVEMENTS (PERCENTAGE)

A review of those tables and figures, expecially Figure 5.1 indicates that the DOT-TSC computer simulation predicts vehicle performance with very good precision provided that the simulated and actual hardware is identical. Figure 5.1 illustrates that the data for the 318 CID engine is offset from a 1 to 1 correlation by a fairly consistent factor. With the exception of three data points, the 225 CID data is, for all intents and purposes, a perfect correlation.

Figure 5.1 is the most significant chart to be considered, for it presents a comparison of absolute values of simulated versus test results. The data for both of the cars which were simulated are presented in the figure. Also presented is the "perfect" line of a one-to-one correlation. This "perfect" line is bounded by lines representing an allowable coefficient of variance of 4.44% in actual test results, reflecting the allowable variability of the test data.

In the 318C1D simulations, the only hardware which was mapped and then actually tested was the torque converter. The actual torque converter characteristics illustrated in Figure 5.9 were used in the computer simulation. The engine mapped for the simulation was different than the engine tested. All of the data points for this vehicle are consistent, and appear to vary from a perfect correlation by the same amount. This indicates that some factor, perhaps in the engine, is consistently different between the vehicle simulated and the vehicle tested. Factors which could most readily influence this are probably production engine to engine variation in engine compression ratio, fuel air ratio, valve timing or overlap and spark timing.

In the simulation of the 225 CID vehicle, except for the carburetor, the engine mapped and used by the computer was the same engine tested in the car. The torque converter characteristics used were those which were obtained from B&M automotive products for the torque converter used with the 318C1D engine. If only the points where the torque converter was locked-up are considered, the 225 CID results are essentially the same for both the actual and simulated tests. Locking-up the torque converter, essentially eliminates differences in real and simulated performance due to different characteristics of simulated and actual test units.

All the lock-up data points shown for this vehicle are within 4.44% of the one-to-one correlation line in Figure 5.1. This indicates that the computer simulation can predict fuel economy test results within the accuracy of the actual EPA test procedure, provided all the hardware tested is identical to the hardware simulated.

The predictions of incremental improvements presented in Figure 5.2 are not as consistent as Figure 5.1 would at first suggest. The differences of the simulated and actual test results are not as hopeless as they at first appear, however. Each datum point representing the real tests is actually a mean value of three test results. This mean value has a coefficient of variance associated with it of approximately 4.44%. This means that the value of each data point could be off from its true value as much as ± 4.44%. This value is of the same order of magnitude as some of the improvements which were calculated and presented in Tables 5.1 and 5.2 and plotted in Figure 5.2. Each data point in that figure, can, therefore, be off by as much as 9.3% of the MPG of the modified transmission mode divided by the MPG of the baseline mode. This is determined as follows:

If the true improvement in the modified transmission over the baseline is expressed as $\bar{\Delta}$, and,

X = the reported baseline transmission performance

$\bar{X}$ = the true baseline transmission performance

Y = the reported modified transmission performance

$\bar{Y}$ = the true modified transmission performance

$$\bar{\Delta} = \frac{\bar{Y} - \bar{X}}{\bar{X}} = \frac{\bar{Y}}{\bar{X}} - 1$$

$$\bar{\Delta} \text{ could equal } \frac{(Y + 4.44\%)}{(X - 4.44\%)} - 1$$

$$\bar{\Delta} = \frac{1.0444Y}{0.9556X} - 1$$

$$\bar{\Delta} = 1.0929\,\frac{Y}{X} - 1$$

If $\bar{X}$ = 20 MPG and $\bar{Y}$ = 25 MPG, $\bar{\Delta}$ would actually be 25%. However, if the full error of 4.44% were present,

$$\bar{\Delta} \text{ could be } (1.0929\,\frac{25}{20}) - 1 = 36.6\%$$

At 20 MPG, the error in $\bar{\Delta}$ could be 11.6 actual percentage points as plotted in Figure 5.2. Similarly, with no improvement, the error could be 9.29% actual percentage points.

Considering the potential for a stack-up of test errors, the data presented in the figures indicates a relatively good correlation.

The real problem does not involve a comparison of computer vs. actual data, but a great degree of variation in the test procedure itself.

5.1.2.2 Comparison of Transmission Modes

5.1.2.2.1 Statistical Analysis

The relative advantages of the modified transmission modes over the baseline modes, or the relative merits of one transmission or another, cannot be readily determined from a brief review of the data. Test variability may influence the results of tests in which only a limited number of replications (less than 10) are conducted. This is especially true when the difference between transmissions is of the same magnitude as the variability of the test itself.

In order to obtain a finer resolution between the results of the various transmission modes, we performed Duncan's Multiple Comparison Test. This test allows one to discern with some degree of certainty (in this case, 95%) whether or not differences between the mean values of two different groups of test results are a function of the test variability, or are truly indicative of differences in items being tested. (For a detailed discussion, see Reference 11.) The customary way of presenting the results of Duncan's Test is to arrange the means of the data sets in ascending order and underline those groups of means which are not significantly different. In other words, if several values are connected by the same underline, the difference between those means may be as much a function of test variability as of actual differences in the items being measured. Only those transmissions not connected by the same underline can be judged to provide fuel economy different from each other.

Tables 5.9 and 5.10 present the results of Duncan's Comparison Tests for the urban and highway cycles. In these tables, each configuration is represented by a pair of numbers. The first number represents the lower gear in which lock-up occurs. The second number indicates by an "0" the baseline gear ratios, by a "3" the wide ratio 3 speed, and the 4 speed is indicated by a "4". For example, 00 represents the baseline transmission and 34 represents the 4 speed with lock-up in third and fourth gears.

5.1.2.2.2 Discussion of Transmission Capabilities

Some general conclusions may be drawn from a review of Tables 5.9 and 5.10. These tables indicate that only those transmissions which provide improvements in transmission efficiency (lock-up) and/or low N/V ratios at low vehicle speed, provide significant advantages in fuel economy over a production transmission in the urban cycle. With the exception of the most powerful vehicle, all transmissions provide a significant improvement in fuel consumption in the highway cycle.

Also, in general, the transmission configuration which consistently provides the best improvement in fuel economy of both cycles is the wide range 3 speed with lock-up in third. This is confirmed by the calculation

TABLE 5.9 TRANSMISSION CONFIGURATIONS WHICH ARE NOT SIGNIFICANTLY DIFFERENT FROM EACH OTHER IN THE URBAN CYCLE AS INDICATED BY UNDERLINES

318 CID Valiant

Transmission	03	00	04	44	34	33	23
Mean MPG	12.3	12.9	12.9	13.0	13.6	13.9	14.2

225 CID Valiant

Transmission	00	03	04	44	34	23	33
Mean MPG	17.5	17.6	17.7	17.7	18.2	18.4	18.5

122 CID Colt

Transmission	00	04	03	44	34	20	23	33
Mean MPG	20.7	21.2	21.7	21.7	21.7	22.6	23.0	23.0

97 CID Colt

Transmission	00	34	04	44	03	23	33
Mean MPG	21.7	22.1	22.7	23.0	23.1	23.6	24.3

TABLE 5.10 TRANSMISSION CONFIGURATIONS WHICH ARE NOT SIGNIFICANTLY DIFFERENT FROM EACH OTHER IN THE HIGHWAY CYCLE INDICATED BY UNDERLINES

318 CID Valiant

Transmission	00	03	04	34	23	33	44
Mean MPG	20.7	20.8	21.2	24.3	24.6	25.1	25.1

225 CID Valiant

Transmission	00	23	34	03	04	33	44
Mean MPG	27.6	29.3	29.5	30.0	30.3	30.5	30.7

122 CID Colt

Transmission	00	20	34	04	03	44	23	33
Mean MPG	31.0	33.0	33.3	33.5	34.0	35.8	35.8	36.4

97 CID Colt

Transmission	00	04	03	34	44	23	33
Mean MPG	30.1	32.3	33.3	33.4	33.8	34.0	35.2

of the composite cycle in Tables 5.1 through 5.4. With only one exception, however, the wide range 3 speed with lockup in second and third is essentially identical in performance to the "33" configuration, and it is significantly better with the largest engine in the urban cycle while being significantly worse in the 225 CID Valiant over the highway cycle.

A potentially important finding of this program is that significant improvements in fuel mileage can be obtained by simply locking up the torque converter in an otherwise conventional automatic. As the "20" configuration in the 122 CID Colt indicates significant highway cycle improvements can be obtained. In the urban cycle, this transmission performs as well as the best of the more "exotic" units.

The changes in vehicle fuel economy and emissions resulting from a wide range three speed with lockup in second and third gear above 30 mph are shown in Table 5.11. Table 5.12 presents a comparison of this same transmission configuration with and without lockup below 30 mph. Since the car was driven approximately 5,000 miles between the first series of fuel economy tests and the test with lockup inhibition, and since a major tune-up was conducted during the 5,000 miles, it is not prudent to compare the absolute fuel economy figures of the two series of tests. However, the test results of the modified transmissions can be compared to their respective baseline values. The changes relative to the baseline can then be compared.

As shown in Table 5.12, there was a dramatic reduction in HC and CO emissions from the full lock-up configuration and a corresponding reduction in fuel economy improvement in the urban cycle. It is significant that the decrease in HC and CO emissions was greater than the decrease in urban fuel economy. This suggests that a simple and cost-effective, regulatory trade off could be made between emissions and fuel economy. Highway fuel economy was little affected as only a small portion of the total highway driving cycle is below 30 mph.

More specific findings are evident if each car is examined in detail.

5.1.2.2.2.1 318 CID Plymouth Valiant

The results of the test on this car are the most easily explained because they follow intuitive logic more closely than the tests of the other cars. Those transmission configurations which provide no increase in transmission efficiency yielded no significant changes in fuel consumption under any driving cycle.

TABLE 5.11 1975 PLYMOUTH VALIANT

4000 LB INERTIA WT

318CID & LOCK-UP INHIBITION BELOW 30 MPH

Transmission Configuration	EMISSIONS						FUEL ECONOMY*					
	CO		HC		NO_x		Urban		Highway		Composite	
	Gm/Mi	Δ%	Gm/Mi	Δ%	Gm/Mi	Δ%	MPG	Δ%	MPG	Δ%	MPG	Δ%
Baseline	11.9	--	1.10	--	1.86	--	13.3	--	20.8	--	15.9	--
WR 3-speed 2-3 Lock-up except below 30 mph	13.1	+10%	1.22	+11%	1.63	-12%	13.9	+4.5%	24.4	+17%	17.2	+8.2%

*Carbon Balance Method

TABLE 5.12 COMPARISON OF WIDE RANGE 3-SPEED
WITH LOCK-UP IN SECOND AND THIRD
WITH AND WITHOUT LOCK-UP BELOW 30 MPH
RELATIVE TO BASELINE TRANSMISSION

	EMISSIONS (% Change from Baseline)			FUEL ECONOMY (% Change from Baseline)		
	CO	HC	NO_x	Urban	Highway	Composite
With Lock-up Below 30 MPH	+51%	+78%	-11%	+11%	+19%	+14%
Without Lock-up Below 30 MPH	+10%	+11%	-12%	+4.5%	+17%	+8.2%

In the urban cycle, those transmissions which eliminate torque converter losses below 40 miles per hour (and therefore were active for a significant portion of the driving cycle) and which lowered the N/V ratio provided significant gains in fuel mileage. The transmission which eliminates torque converter losses over most of the cycle (lockup in second gear) and which also lowered the N/V ratio for a major portion of the driving cycle (wide ratio 3 speed) provided the greatest improvement in fuel economy.

In the highway cycle, all the transmissions which lowered the N/V ratio and eliminated slippage in the torque converter performed equally well. This is because the major portion of the highway cycle is above speeds of 40 MPH, the fourth gear shift point for this car.

5.1.2.2.2.2 225 CID Plymouth Valiant

In the urban cycle, the transmissions performed in a manner identical to that of the 318 CID Valiant. Those transmission modes which did not improve the driveline efficiency or which were not in effect for a significant portion of the driving cycle performed essentially no better than the production unit. All these transmissions which did decrease driveline losses and which lowered the N/V ratio provided comparable improvements in fuel economy.

In the highway cycle, however, the transmissions which performed well for 318 CID vehicle did not necessarily yield equivalent improvements in the 225 CID car. The entire range of fuel economy of all modified configurations varies by ± 2.3%, and the range of the configuration showing an improvement for the 318 is ± 1.5%. Thus, the overall performance of the transmissions offering gains in fuel economy are comparable. However, the individual configurations yielding improvements in the 225 CID car are rank ordered differently than with the 318 CID engine.

The unlocked transmissions coupled with the 225 CID Engine yielded a much better improvement than they did when driven by the larger 318 CID engine in the heavier car. This was because the more powerful engine and lower (numerical) rear axle ratio of the 318 CID Valiant caused the torque converter to slip more than in the less powerful 225 CID car with a more advantageous rear axle ratio and a lower inertia weight. The torque converter characteristics were identical. Therefore, the wider ratio on the 225 CID Valiant gearing without lockup had a more significant effect than in the 318 CID car under identical conditions because losses in the torque converter were reduced.

5.1.2.2.2.3 Dodge Colts

The same general trends hold for the Dodge Colts as for the 225 CID Plymouth Valiant at least to the degree of resolution available from these tests.

A significant finding of the Dodge Colt data is that significant improvements in fuel economy can still be obtained through driveline improvements with relatively heavily loaded engines which are characteristic of most subcompact automobiles.

5.1.3 Impact Upon Emissions

Almost without exception, the improvements in fuel economy obtained with the various transmission configurations were accompanied by increases in emissions of carbon monoxide (CO) and hydrocarbons (HC) and corresponding decreases in nitrogen oxide (NO_x) emissions.

The reduction in nitrogen oxides observed is, we feel, a significant finding because it indicates that even though the production of NO_x per power stroke probably increased, as would be expected under high loads, the reduction in the N/V ratio was enough to offset this increase and decrease the total mass output of NO_x. It is probably not possible to maintain this reduced NO_x output while simultaneously reducing the increased CO and HC emissions. However, this does indicate that there is some increased room for a tradeoff between NO_x and CO and HC in that the reduced NO_x output allows increased latitude for modifications aimed at reducing CO and HC at the expense of NO_x.

Of course, it is also true that modifications aimed at reducing the higher output of CO and HC may also reduce or negate the fuel economy benefits obtainable with any or all of these transmissions.

The increase in emissions experienced in the program may also not be representative of the increase in emissions which would be experienced if production rather than one-off manufacturing techniques had been used in constructing the experimental transmissions. As discussed in Section 4.6.1.2 and Section 3.3.1.2, the added inertia of the experimental torque converter increased the engine loading sufficiently to cause a severe increase in CO and HC output of the Dodge Colts. Even after the addition of "California" Emission Control equipment, the output of CO in the baseline mode was greater than that allowable by California standards after 50,000 miles. It may very well be that if the lock-up torque converters on all the test cars were closer to the weight of current production torque converters, the increases in carbon monoxide and hydrocarbon would not have been as great and may not have indicated that further efforts at reducing their output would be required to meet federal standards.

There is also a question of an impact of emissions upon fuel economy. It has been mentioned by many people that the incremental gains in fuel economy experienced with these transmissions in this program may not be obtainable with engines tuned to meet more stringent emission standards. It is unlikely, however, that drivetrain modifications such as these will not provide some improvement. Further testing is required before the precise effects of emission controls can be quantified.

5.2 PERFORMANCE TESTS

Figures 5.3 thru 5.6 show a comparison of the baseline and second gear lockup transmission in each car. Study of these graphs shows that there is no significant difference in the performance of the car whether or not the torque converter is locked up. If the lockup converter has any affect, it seems to provide a very slight advantage over the production torque converter for all but the most powerful car.

5.3 DRIVEABILITY TESTS

The driveability tests result in a numerical score which can be used to quantitatively compare occupants' subjective impressions of an automobile's behavior. The "perfect" car will receive zero driveability score. The higher the score, the greater the amplitude of various sensations transmitted to the occupants. Since few, if any cars, can be expected to receive perfect scores, these tests can be used to compare modified vehicles with baseline or production vehicles. Vehicles receiving driveability scores of the same bandwidth (Figure 5.7) as production cars can be expected to be equally as marketable as the production car, provided all else (including price) is equal.

It is important to note that these tests provide only a relative measure of driveability as compared to a production vehicle. There is no score which draws the line between driveable and undriveable vehicles. The closer a score is to zero, the more "perfect" the car. The "perfect" car is that a vehicle which performs as marketing research indicates the majority of buyers' desire.

Tables 5.13 through 5.19 present:

- The driveability score of each transmission by vehicle and evaluator

- The average driveability score of each transmission

- The number of demerits received under each behavioral category by drivers and observers

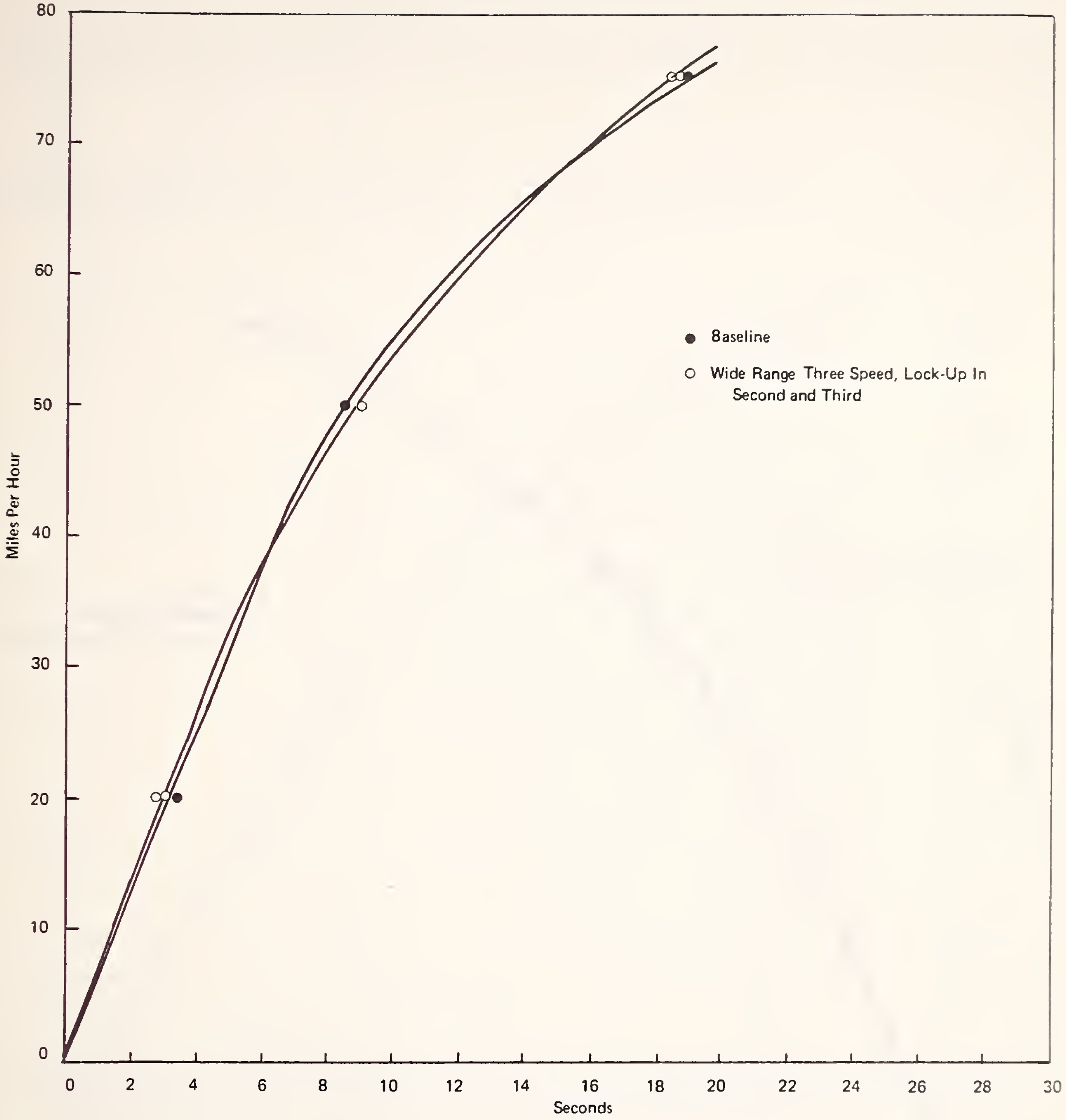


FIGURE 5.3 ACCELERATION TESTS 318 CID PLYMOUTH VALIANT

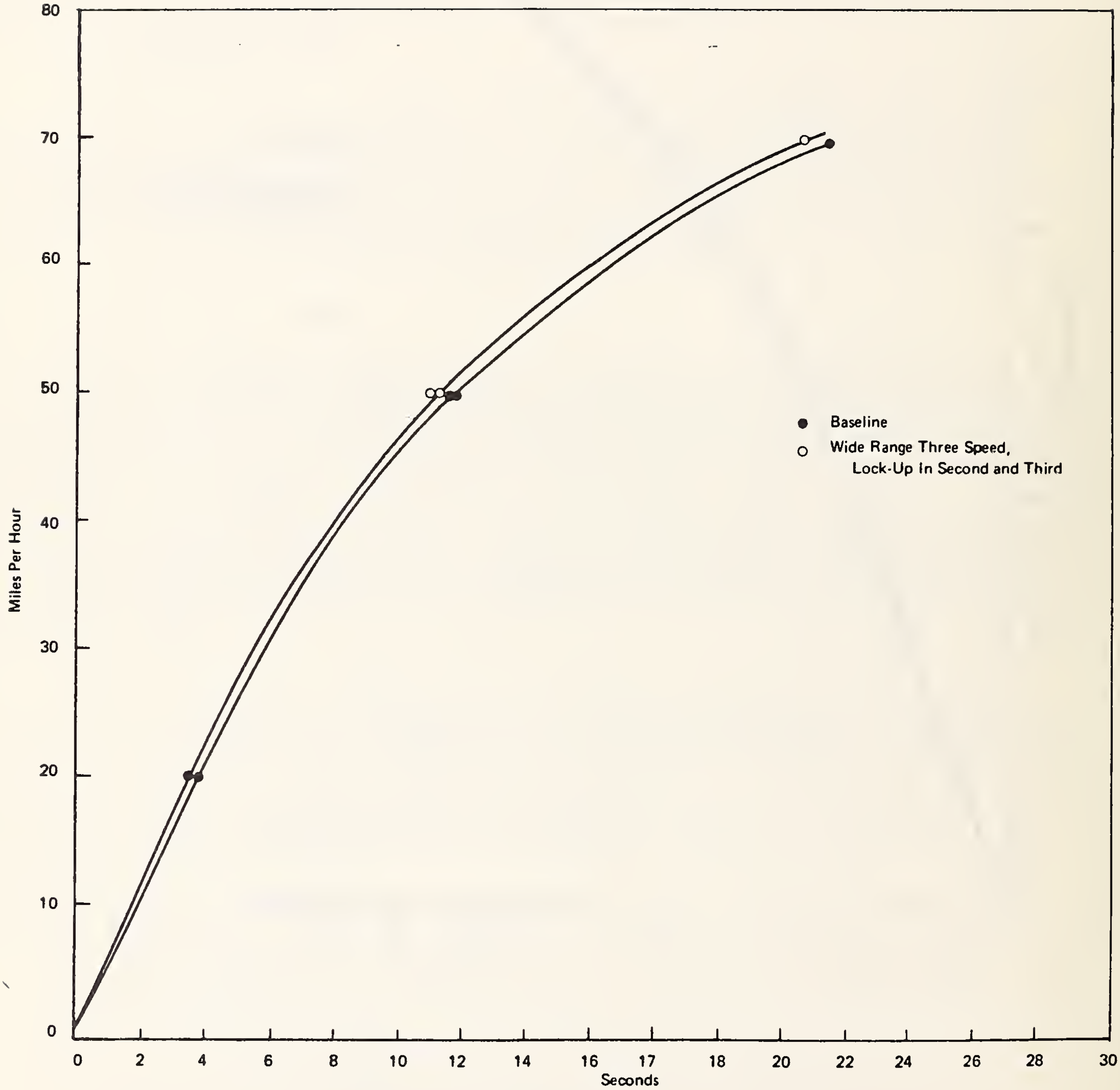


FIGURE 5.4 ACCELERATION TESTS 225 CID PLYMOUTH VALIANT

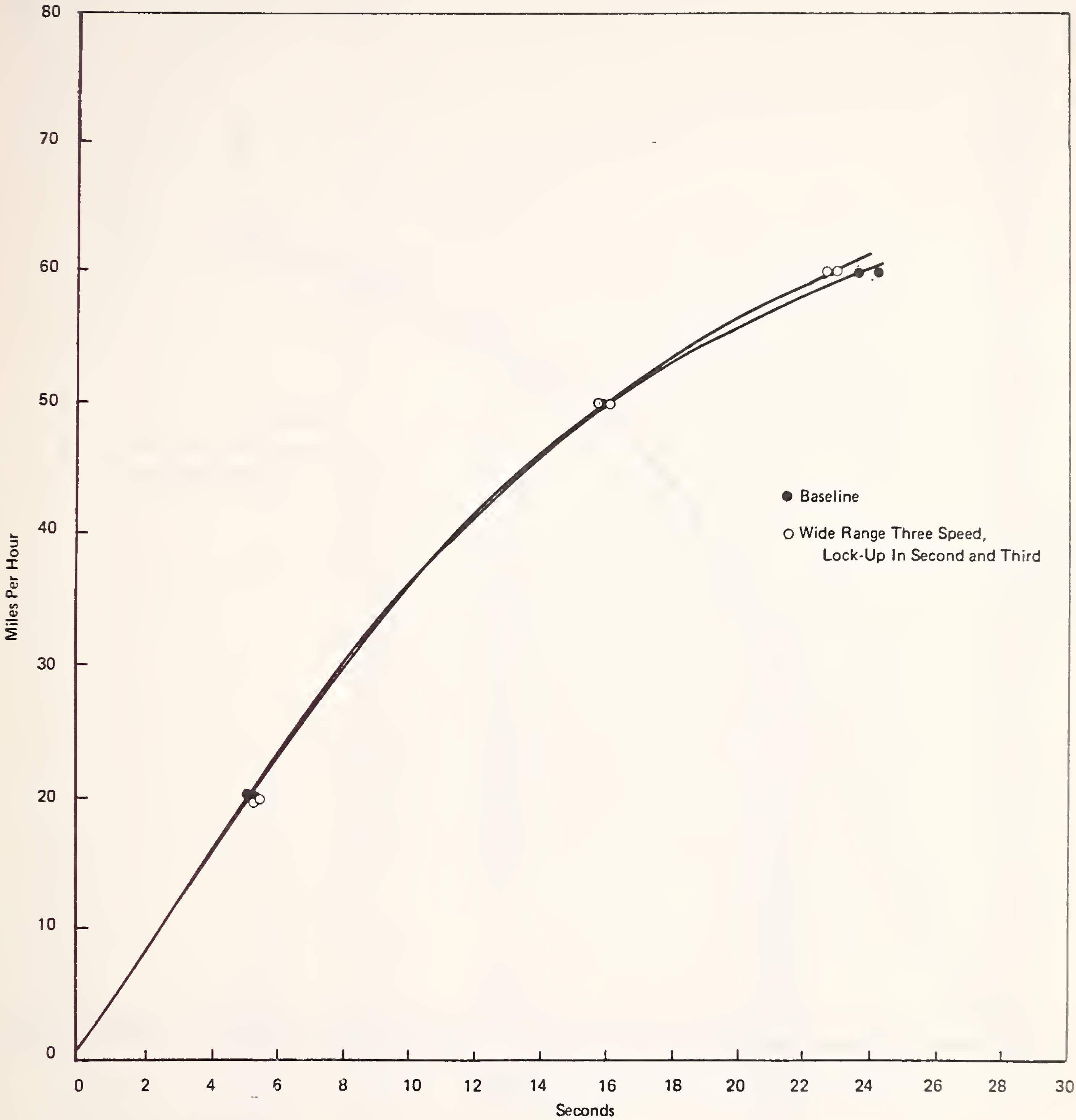


FIGURE 5.5 ACCELERATION TESTS 122 CID DODGE COLT

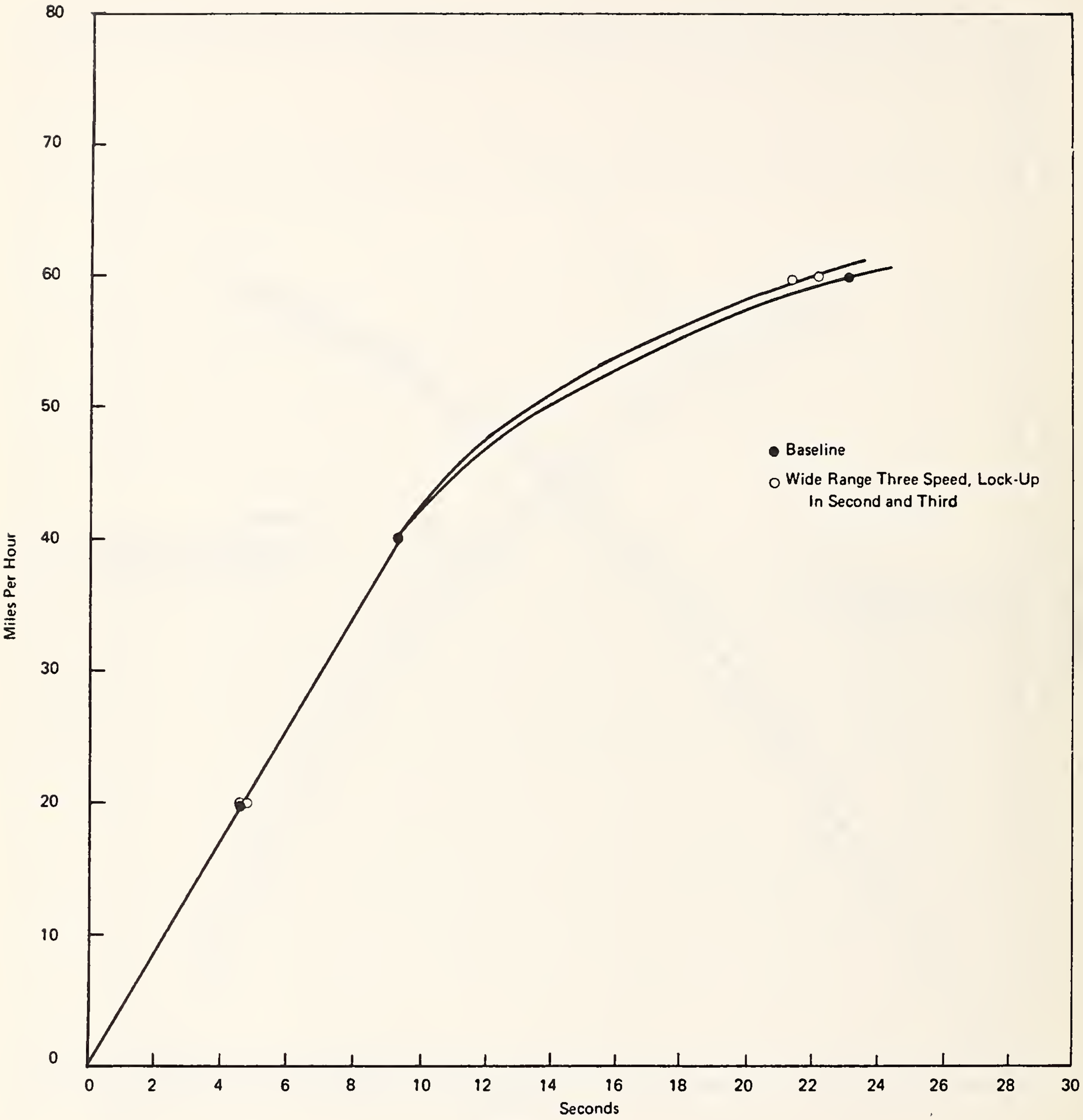


FIGURE 5.6 ACCELERATION TESTS 97 CID DODGE COLT

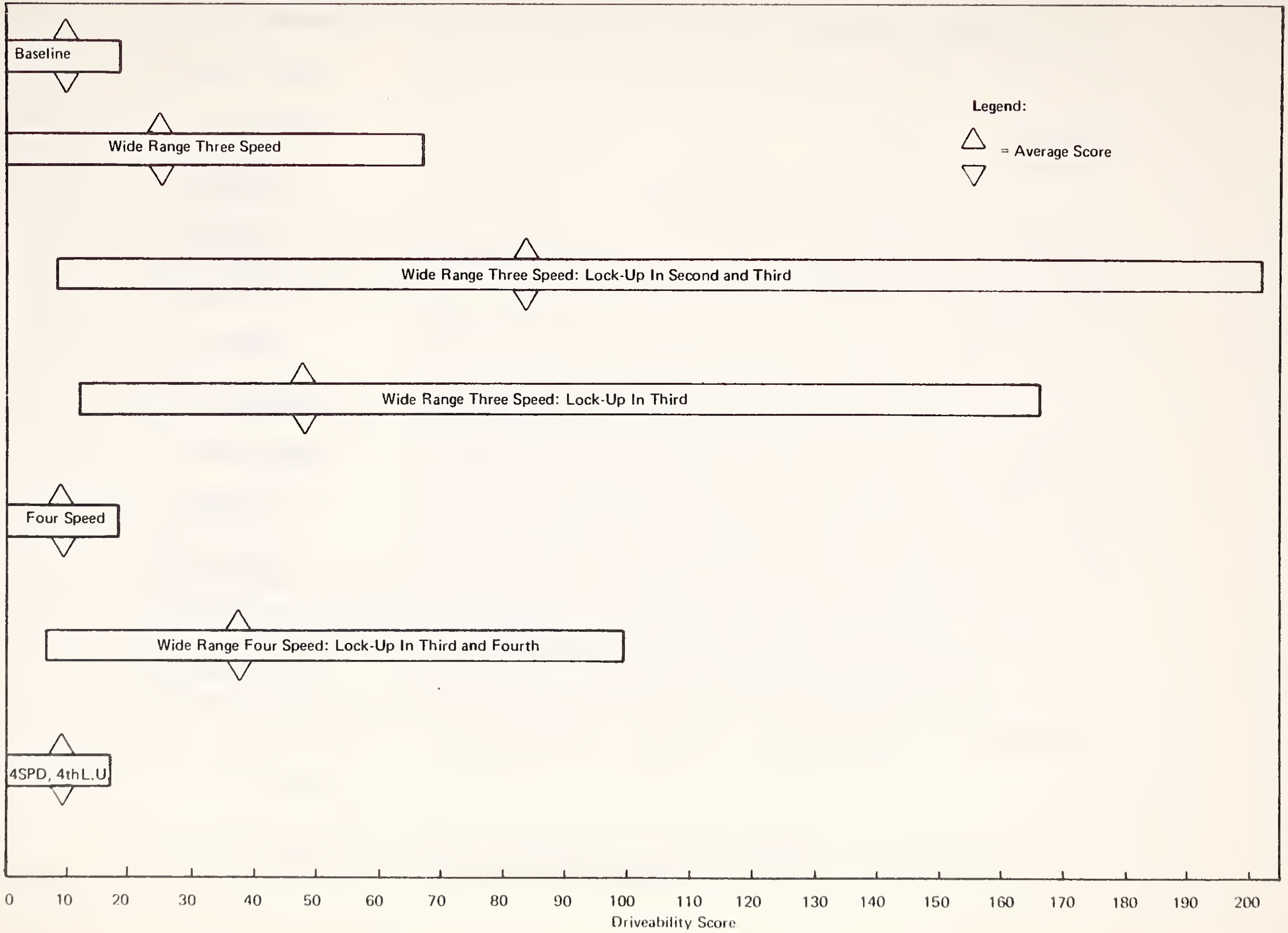


FIGURE 5.7 COMPARISON OF DRIVEABILITY SCORES

TABLE 5.13 BASELINE TRANSMISSION DRIVEABILITY RATING

	Driver				Observer				Average
Vehicle	318	225	122	97	318	225	122	97	
Driveability Score	0	13.5	17	7.5	0	18	15	8	9.9
Demerits:									
Rough	0	1.5	0	0	0	1	0	0	3.1
Hesitation	0	0	1.5	0	0	.5	1	.5	4.4
Stretchy	0	.5	1	0	0	1.5	1	0	.50
Stumble	0	0	0	0	0	0	0	0	0
Surge	0	0	0	2.5	0	0	0	2	.56
Stall	0	0	0	0	0	0	0	0	0
Backfire	0	0	0	0	0	0	0	0	0
Detonation	0	2	0	0	0	2	0	0	.50
Shift Feel	0	3	3.5	0	0	1.5	3.5	0	1.44
Total Demerits	0	7	6	2.5	0	6.5	5.5	2.5	3.75

TABLE 5.14 WIDE RANGE THREE SPEED DRIVEABILITY RATING

	Driver				Observer				Average
Vehicle	318	225	122	97	318	225	122	97	
Driveability Score	52	67	0	5	50	19.5	0	14	25.9375
Demerits:									
Rough	0	1	0	0	0	.5	0	0	.19
Hesitation	2	0	0	0	0	0	0	.5	.31
Stretchy	10.5	11	0	0	9	2	0	0	4.0
Stumble	0	0	0	0	1	0	0	0	.12
Surge	2	5	0	0	1	0	0	0	1.0
Stall	0	0	0	0	0	0	0	0	0
Backfire	0	0	0	0	0	0	0	0	0
Detonation	0	1	0	0	0	3	0	.5	.56
Shift Feel	0	2.5	0	2.5	3.5	2.5	0	5.5	2.0
Total Demerits	14.5	20.5	0	2.5	14.5	8	0	6.5	8.3

TABLE 5.15 WIDE RANGE THREE SPEED

DRIVEABILITY RATING

WITH LOCK-UP IN SECOND AND THIRD

	Driver				Observer				Average
Vehicle	318	225	122	97	318	225	122	97	
Driveability Score	95	14.5	25.5	212	98	8.0	16	202	83.9
Demerits:									
Rough	0	0	13.5	52	0	0	12	52	16.9
Hesitation	1	.5	1	0	0	.5	0	0	.38
Stretchy	2	1	.5	36	4	0	0	36	9.9
Stumble	9	0	.5	0	7.5	0	.5	0	2.2
Surge	3	1.5	0	0	5	0	0	0	1.2
Stall	0	0	0	0	0	0	0	0	0
Backfire	0	0	0	0	0	0	0	0	0
Detonation	0	0	0	0	0	.5	0	0	.06
Shift Feel	19	2	2	4	20.5	2.5	1	3	6.75
Total Demerits	35	5	17.5	92	37	3.5	13.5	91	36.8

TABLE 5.16 WIDE RANGE THREE SPEED

DRIVEABILITY RATING WITH LOCK-UP IN THIRD

	Driver				Observer				Average
Vehicle	318	225	122	97	318	225	122	97	
Driveability Score	12	18.5	18.5	166	16	25	13	108	47.125
Demerits:									
Rough	0	0	9.5	46	0	0	9	46	13.8
Hesitation	0	.5	0	0	0	0	0	0	.06
Stretchy	1	1.5	0	27	2	0	0	12	5.4
Stumble	1	0	0	0	1	0	.5	0	.31
Surge	0	2.5	0	0	0	5	0	0	.94
Stall	0	0	0	0	0	0	0	0	0
Backfire	0	0	0	0	0	0	0	0	0
Detonation	0	0	0	0	0	0	0	0	0
Shift Feel	2	1.5	4.5	6	2	5	1	7	3.6
Total Demerits	4	6	14	79	5	10	10.5	65	24.2

TABLE 5.17 WIDE RANGE FOUR SPEED

DRIVEABILITY RATING

	Driver				Observer				Average
Vehicle	318	225	122	97	318	225	122	97	
Driveability Score:	0	13.5	17	1.5	0	18	15	3.5	8.56
Demerits:									
Rough	0	1.5	0	0	0	1	0	0	.31
Hesitation	0	0	1.5	0	0	.5	1	.5	.44
Stretchy	0	.5	1	0	0	1.5	1	0	.5
Stumble	0	0	0	0	0	0	0	0	0
Surge	0	0	0	.5	0	0	0	.5	.12
Stall	0	0	0	0	0	0	0	0	0
Backfire	0	0	0	0	0	0	0	0	0
Detonation	0	2	0	0	0	2	0	0	.5
Shift Feel	0	3	3.5	0	0	1.5	3.5	0	1.44
Total Demerits	0	7	6	.5	0	6.5	5.5	1.0	3.31

TABLE 5.18 WIDE RANGE FOUR SPEED

DRIVEABILITY RATING LOCK-UP IN THIRD & FOURTH

	Driver				Observer				Average
Vehicle	318	225	122	97	318	225	122	97	
Driveability Score:	12	99	61	10.5	12	62.5	44.5	7	38.56
Demerits:									
Rough	0	16	0	10.5	0	13.5	0	7	5.9
Hesitation	0	1.5	2	0	0	.5	1.5	0	.6875
Stretchy	0	16.5	10	0	0	9.5	6.5	0	5.3125
Stumble	0	0	0	0	0	0	0	0	0
Surge	0	2	1	0	0	1	.5	0	.56
Stall	0	0	0	0	0	0	0	0	0
Backfire	0	0	0	0	0	0	0	0	0
Detonation	0	.5	0	0	0	1	0	0	.19
Shift Feel	6	2	5	0	6	2	11	0	4.0
Total Demerits	6	38.5	18	10.5	6	27.5	19.5	7	16.6

TABLE 5.19 WIDE RANGE FOUR SPEED

DRIVEABILITY RATING LOCK-UP IN FOURTH

	Driver				Observer				Average
Vehicle	318	225	122	97	318	225	122	97	
Driveability Score:	6	17.5	17	1.5	0	15	15	3.5	9.4
Demerits:									
Rough	0	1.5	0	0	0	1	0	0	.31
Hesitation	0	0	1.5	0	0	.5	1	.5	.44
Stretchy	0	1.5	1	0	0	1.5	1	0	.62
Stumble	0	0	0	0	0	0	0	0	0
Surge	2	0	0	.5	0	0	0	.5	.38
Stall	0	0	0	0	0	0	0	0	0
Backfire	0	0	0	0	0	0	0	0	0
Detonation	0	2	0	0	0	2	0	0	.50
Shift Feel	0	3	3.5	0	0	1.5	3.5	0	1.4
Total Demerits	0	8	6	.5	0	6.5	5.5	1.0	3.7

- The average number of categorized demerits

- The average of the total demerits.

In reviewing these tables, it is perhaps most important to observe ranges of values rather than absolute scores. In this way, transmissions can be compared to be within acceptable (baseline ranges) or entirely out of the driveability limits of these production vehicles. Figure 5.7 presents a comparison of the range and scores of each transmission.

Figure 5.7 indicates that none of the transmissions were completely outside of the baseline driveability range. However, only two of the transmissions, the wide range 4 speed without lockup and with lockup in fourth gear only, had driveability which was completely within the range of the baseline. The average driveability scores indicated by the pointers on each band in Figure 5.7 show that the other transmission did not favorably compare with the baseline transmissions.

A review of Tables 5.14, 5.15, 5.16, 5.17, and 5.18 and comparing them to 5.13 indicates that the modified transmissions received most of their demerits for:

- Roughness

- Stretchiness

- Shift Feel

with some degree of Stumble and Surge. A rigorous examination of this data is misleading because of the different ways in which the various testers evaluated their various subjective feelings. Some general findings are in order, however.

Roughness indicated what many manual transmission drivers would refer to as "lugging". This occurred because the torque converter was locked up at low engine speeds where the individual power strokes of the engine could be felt in the form of a "shock" transmitted through the drivetrain and into the chassis. The number of roughness demerits increased as the engine displacement and number of cylinders went down, indicating that the lower frequencies (fewer power strokes per engine revolution) were more objectionable. Unlocking the torque converter under these conditions so that the converter can provide the necessary damping, and allow an increase in engine speed, or causing a downshift to a lower gear while the converter remains locked and thereby increasing the frequency to less objectionable levels are the only practical solutions to this problem. These solutions would be expected to have a detrimental effect upon fuel economy, however.

Stretchiness is usually caused by an overly lean carburetion calibration for a particular engine speed and load condition. This undoubtedly occurred in some experimental transmission modes because of the lower engine speeds encountered with the overdrive gearing. Richer fuel-air ratios under the appropriate engine speed and load conditions, or a downshift, may be required to mitigate the stretchiness. Recalibration of the carburetor is bound to increase emissions, however. Downshifting upon such demand may have a detrimental effect upon fuel economy.

Transmission shift feel manifested itself in two different ways. The large ratio change between second and third gear in the wide ratio three-speed was undoubtedly responsible for a certain amount of jerkiness and unexpectedly noticeable changes in engine speed during shifts. The fact that under lockup conditions all shifts were power shifts (lockup clutch engaged during the shift) also contributed to jerks as the transmission changed gears. The large ratio change can be minimized by closer spacing of second and third gears, or by adding an intermediate ratio. This latter reason is undoubtedly why the two four speeds outperformed the comparable three speed units in this area. Jerky shifting under lockup conditions can be mitigated by momentarily unlocking the torque converter, which in itself generates shift feel demerits, or by modulating the rate of ratio change in the transmission itself. This last solution is probably why the four speed with lockup in fourth gear did so well. Even though the shift from third to fourth gear was a power shift, the ratio change occurred over an extended period (1-2 seconds). Hence, there was no jerkiness associated with this shift.

Stumble and surge are both due to overly lean air-fuel ratios under certain engine speed and load conditions. Again, however, recalibration of the carburetor for improved driveability may have to be traded off against increased emissions.

In summary, all of the significant driveability "problem areas" associated with these transmissions are solvable. The only considerations are the tradeoffs between driveability, fuel economy, and emissions. To demonstrate the impact of these tradeoffs, the 318 CID Valiant was modified to alleviate the most serious driveability problems of low speed lugging. In addition to the acceptability tests run on this modified car (see Section 4.4 and 5.4) emissions and fuel economy tests were also conducted.

5.4 ACCEPTABILITY

The objective of this phase of the program was to judge the acceptability of the baseline transmission with the wide range 3 speed with lockup in 2nd and 3rd but with lockup occurring only at road speeds over 30 mph.

In the numerical rating scale used, a score of one was given when no defects were noted and a score of seven was given when the defects were many, hence, a lower score indicates greater acceptability.

The average score of all tests for the standard configuration was 20.9 and for the modification it was 33.5, indicating that the modification was less acceptable. Of the seven stages that were selected for evaluation, the ones that contributed most heavily to the difference in acceptability were the driving stages. This is illustrated by the Table 5.20.

Table 5-20 indicates not only the differences in transmission performance, but the sensitivity of the profile procedure as well. The profile panel was unaware that the transmission mode does not in any way affect the start-up, warm-up, reverse and forward, or the shutdown stages. All else being equal, the scores for these four stages should be identical for either transmission. The differences in the scores for each transmission at each stage are an indication of the precision or significance of the test results. Of these four stages, the greatest difference appears for the engine start-up stage. This difference, 1.2, can be considered the maximum variation in score, for this series of tests, at least, which carries no significance. In other words, differences in scores greater than 1.2 are an indication of a change in vehicle acceptability due to the transmission configuration. Such differences in vehicle scores could have been due to differences in the weather, which could affect starting and warm-up, as well as variability in the profile procedure itself.

In the driving stages, the most frequent complaint was that of poor shift quality associated with the modified transmission mode. Shift quality was perceived as both a physical sensation of an instantaneous acceleration spike and also as an audible noise. This was diagnosed as the sudden release of sticking cone clutches in the overdrive unit. (In all fairness to the manufacturer, it must be stated that the overdrive as installed was underrated for the torque output of this car's engine and transmission. The cone clutches were literally being jammed into place by the torque being transmitted.) The instantaneous acceleration perceived by the panel occurred during most upshifts and downshifts under moderate to full throttle openings wherein the lock-up unit was engaged (speeds above 30 mph).

Because of the poor shift quality, automatic part throttle downshifts which normally occur with minimal perception became objectionable. This was most apparent in traffic driving during crowds from 20 to 30 mph. The occurrence frequency and hence objectionability of such downshifting may also have been increased due to the wider throttle openings required for low speed acceleration with the lockup torque converter and overdrive gearing. It is interesting to note that the panel profile did not indicate a reduction in vehicle response, but only a reduction in shift quality and perhaps an increase in the number of automatic downshifts.

Other factors which contribute to the differences in acceptability scores of the two transmission modes were pinging on hills or grades and a slight increase in the normal vehicle vibrations at speeds over 50 mph. The pinging is no doubt due to spark advance curve which has been optimized for normal torque converter operation and could probably be cured with the usage of spark timing which has been optimized for a manual transmission.

The increase in normal road vibration was, we feel, due to the addition of a fore and aft component to the normal vertical vehicle movement when the wheels go over a bump. When only one rear wheel goes over a bump at any given moment in time, two things happen: 1.) the wheel negotiating the bump travels further than the other wheel, and 2.) the entire rear axle is rotated transversely about the wheel which is not going over the bump. Both of these factors tend to generate a momentary force called "bump torque" on the driveshaft. With a conventional automatic transmission, the torque converter absorbs this bump torque by allowing the drivehsaft to momentarily change its angular velocity without noticeably affecting the progress of the vehicle over the road. If the torque converter is locked up, or replaced by a manual clutch, the bump torque will create a momentary twisting of the engine and transmission on their mounts, while simultaneously changing the instantaneous angular velocity of all the drivetrain components, including the rear wheels. This instantaneous change in rear wheel angular velocity will, of course, also instantaneously change the speed of the car over the road.

TABLE 5.20 ACCEPTABILITY SCORES

Operating Stage	Standard	Modification	Difference
Engine start-up	1.8	3.0	1.2
Engine warm-up	2.8	3.3	.5
Reverse and forward	3.4	4.3	.9
Cold traffic driving	3.5	6.7	3.2
Warm highway driving	3.1	6.7	3.6
Warm traffic driving	3.3	6.3	3.0
Engine shut-down	2.8	2.7	.1

It would be interesting to compare the effect of bump torque on vehicle vibration in a car with a conventional manual transmission and a conventional automatic to determine if the difference perceived by the panel are the same as those perceived by the panel in this series of tests. The effects should be similar between a manual transmission and the lock-up torque converter used in these tests.

In summary, it may be concluded that the effect in improving the driveability of this car did not go far enough to improve shift quality in highway driving, the least acceptable stage. In the traffic driving stages, apparently the driver of the car commanded greater acceleration than had been thought necessary when the lockup inhibitor was installed, and the corresponding wide throttle openings caused shifts to occur under lockup conditions (above 30 mph).

The inhibition of lockup below 30 mph did, however, eliminate any perception of the other faults detected in the earlier driveability tests (see Table 5.13). While the acceptability profile test indicates the intermittent occurrence of hesitation at highway speeds, there were no indications of reduced acceptability due to stretchiness, stumble, or surge.

The recent introduction of a lockup torque converter by Chrysler indicates that it is possible to modulate the rate of gear changes and torque converter lockup to improve high speed shift quality. Since this is the only significant problem responsible for the reduced acceptability of the tested transmission, it is reasonable to conclude that the introduction of a unit with overdrive gearing and a lockup torque converter will not cause a reduction in the acceptability of a passenger car as long as the shift quality of conventional transmissions is maintained.

5.5 DURABILITY

In reviewing the voluminous data contained in the original vehicle log sheets, it became apparent that ambient temperature and driving conditions had a much greater effect upon all measured parameters except for transmission oil temperature, catalyst temperature, and manifold vacuum, than did the transmission mode. It therefore may be stated that there were no unusual excursions in the measured parameters, with the noted exceptions, which would indicate a gross degradation in engine life expectancy.

5.5.1 Transmission Oil Temperature

Transmission oil temperatures generally decreased when the torque converters were locked up. This would be expected, since a main generator of heat in the transmission is the shearing of the oil in the torque converter when it slips. While somewhat affected by ambient temperature, a drop in transmission oil temperature of up to $50^{\circ}F$ ($200^{\circ}F$ to $150^{\circ}F$) was noted when, halfway through a trip, the torque converter was locked up in the 318 CID Plymouth Valiant. Referring to Table 4.2, such a reduction in temperature could significantly increase the life expectancy of the transmission oil and possibly other parts as well.

5.5.2 Catalyst Temperature

The pyrometer used to monitor catalyst temperature (actually catalyst exhaust gas temperature immediately downstream of the catalytic converter) had a temperature range of 800 to $1800^{\circ}F$. Much to our surprise, the units in both cars rarely registered temperatures over $800^{\circ}F$, regardless of transmission mode.

The highest temperature ever reached, $1250^{\circ}F$, occurred just after the "mapped" engine was installed in the 225 CID Valiant and when the engine was running too lean. The next highest temperature excursion occurred in the 318 CID Valiant at the end of a mile long climb up a relatively steep upgrade at high speed in baseline mode. This resulted in a temperature of $1200^{\circ}F$ being achieved, the highest recorded with a properly tuned engine.

Since the catalyst temperatures observed in these cars were all within the normal operating range of catalysts (400°-$1200^{\circ}F$) we expect that the use of lockup torque converters and lower N/V ratio will not adversely affect catalyst life.

5.5.3 Manifold Vacuum

The manifold vacuum gauges were intended to indicate any abnormalities in the induction system which might develop during the test program. None were indicated by unusual gauge readings.

The manifold vacuum gauges did indicate an increase in manifold pressure whenever the engine N/V ratio was reduced. This would occur with engagement of either torque converter lockup or the overdrive, or both. Such increases in pressure would be expected and are an indication that the pumping losses in the engine are reduced as the engine speed slows down and/or the throttle is opened.

5.6 COMPONENT TESTS

Component tests were conducted on a torque converter and a multipurpose test transmission in order to quantify any operational characteristics which may be different from those of production units. A lockup torque converter was tested for:

- Efficiency
- Torque Ratio
- Capacity Factor
- Input Speed

all as a function of input/output speed ratio. A transmission was tested for spin losses and compared to the spin losses of a production unit. All transmissions were tested for proper function and compared to manufacturers' specifications.

5.6.1 Proper Function

Each transmission was run through a typical operational cycle and various operational parameters were monitored on an oscillograph as illustrated in Figure 5.8. The traces generated were compared to equivalent traces of production transmissions. All transmissions were found to operate within production specifications.

The final adjustment of shift points was performed after the units were installed in the cars. The position of the throttle linkage was adjusted until the shifts occurred at the approximate center of the range specified for each car.

5.6.2 Torque Converter Characteristics

The techniques described in Section 4.6.1.2 were used to compare a production 10-3/4 inch torque converter to a lockup 10-3/4 inch unit.

The lockup torque converter characteristics compared favorably with those of the production unit as shown in Figure 5.9. In all cars, the lockup unit appears slightly "stiffer" than the production unit. This is undoubtedly due to the drag of the clutch plates which can be expected to decrease with wear. This test shows that the differences between the production unit and the lockup unit are minor, and that the differences can be expected to decrease with wear.

5.6.3 Spin Loss Tests

The Spin Losses of a production A904 (Dodge Colt) transmission and a modified A904 transmission were determined by Scientific Energy Systems, Inc. (SES). Table 5.21 and Figure 5.10 present the results of these tests as reported by SES.

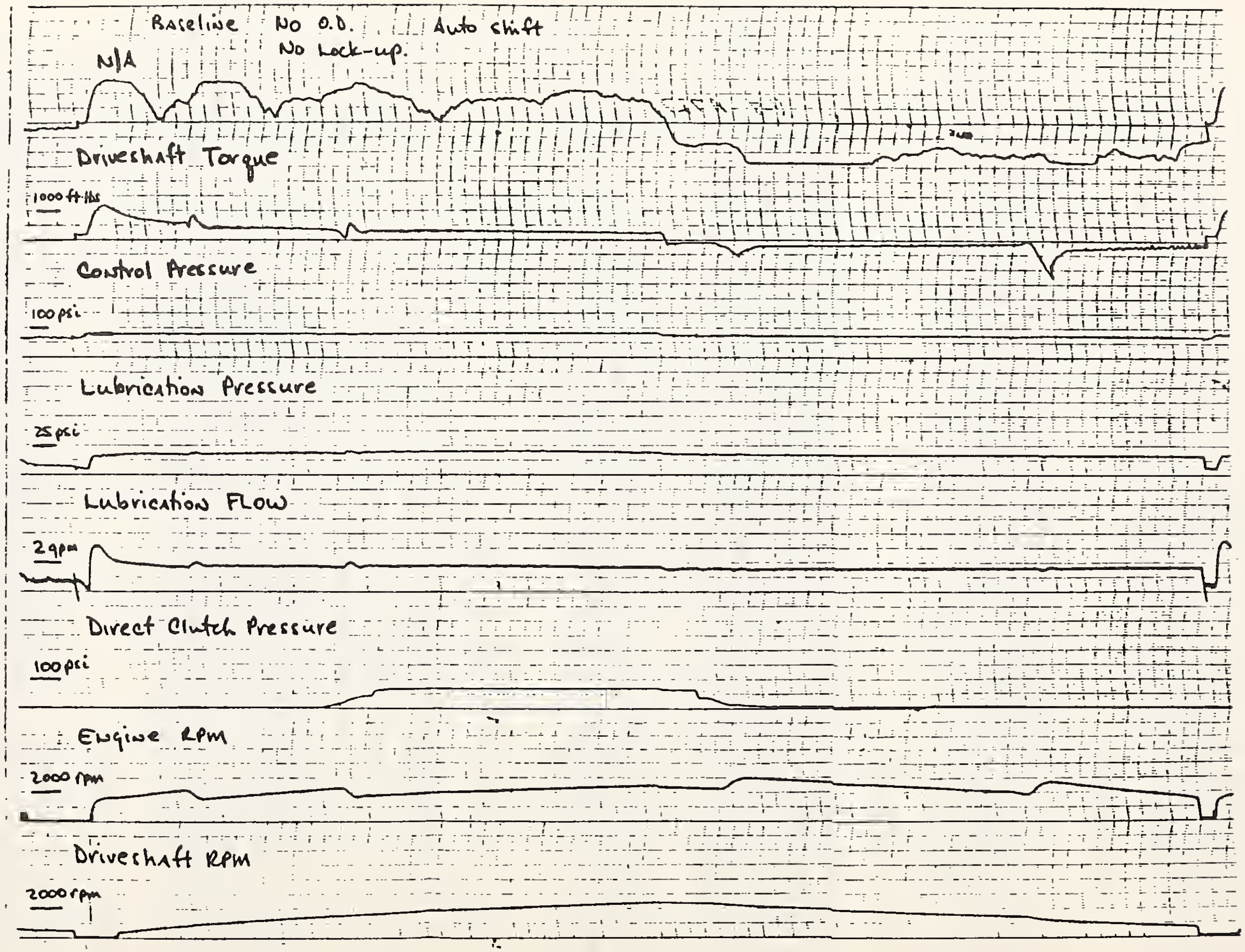
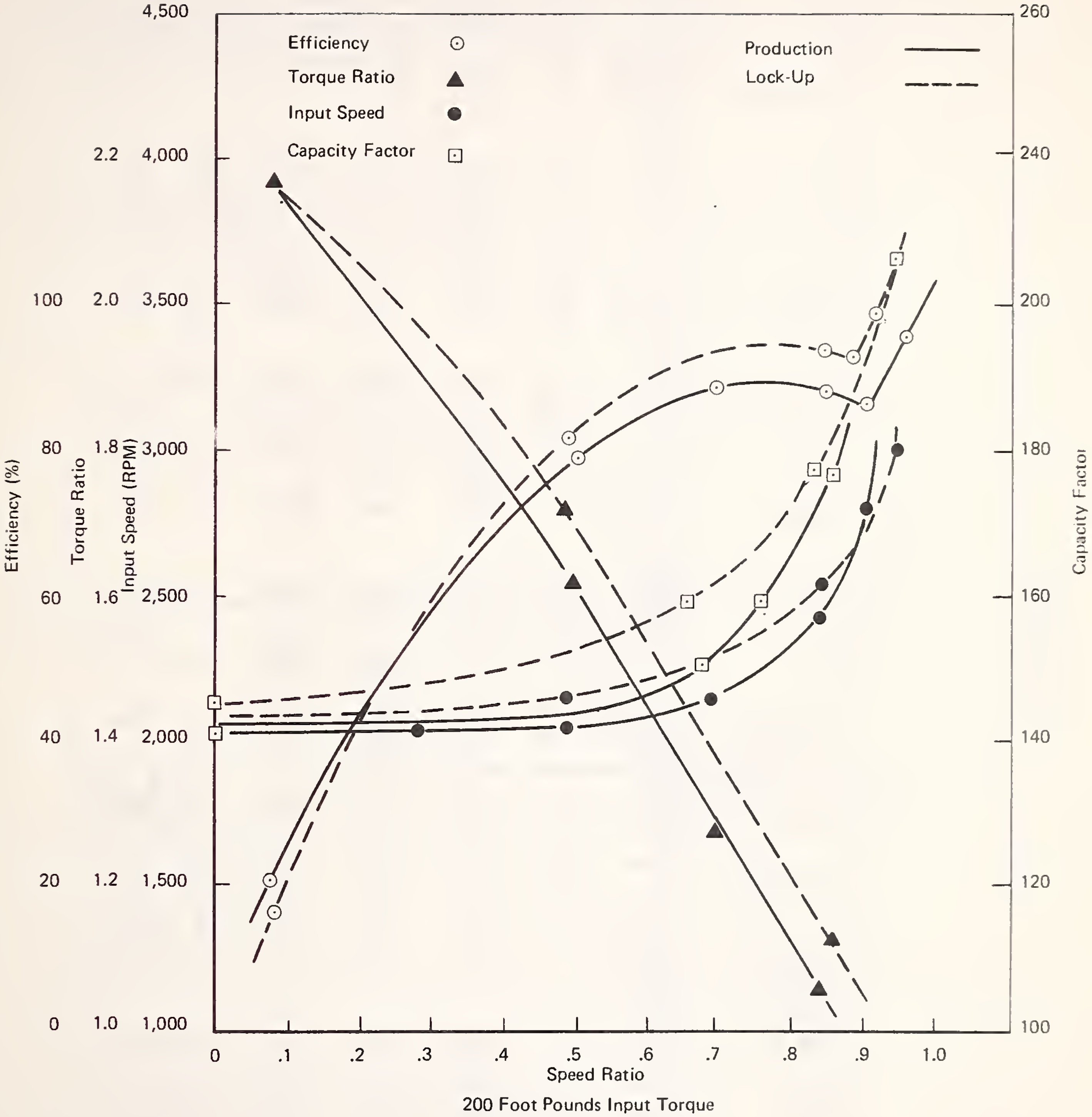


FIGURE 5.8 TYPICAL TRACES GENERATED FOR FUNCTIONAL TESTS OF MULTI-PURPOSE TEST TRANSMISSIONS



Source: B&M Automotive Products.

FIGURE 5.9 TORQUE CONVERTER CHARACTERISTICS

TABLE 5.21 CHRYSLER A904 AUTOMATIC TRANSMISSION SPIN-LOSS TESTS

TESTED IN "DRIVE" TORQUE IN INCH-POUNDS TEMP IN °F

Run 1	Input R.P.M.	485	1000	1500	2020	2500	3040
	Torque	44	53	65	72	76	81
O.D.	HP	.339	.841	1.55	2.31	3.02	3.91
	Oil T °F	163	160	160	162	166	167
Disengaged	Tailshaft R.P.M.	-	-	-	-	-	-
Run 2	Input R.P.M.	485	1000	1480	2000	2520	3020
	Torque	45	56	72	78	84	86-88
O.D.	HP	.346	.889	1.69	2.48	3.33	4.17
	Oil T °F	162	159	160	163	166	171
Engaged	Tailshaft R.P.M.	310	870	1910	2560	3250	3900
Run 3	Input R.P.M.	490	1000	1480	2000	2540	3010
	Torque	42	52	64	72-74	80	82-83
O.D.	HP	.327	.825	1.50	2.32	3.22	3.94
	Oil T °F	166	163	163	165	168	171
Engaged	Tailshaft R.P.M.	415	880	1910	2585	3280	3880
Run 4	Input R.P.M.	480	1000	1480	2020	2560	3020
	Torque	38	47	55	73-74	70	70-72
O.D.	HP	.289	.746	1.29	2.36	2.84	3.40
	Oil T °F	169	166	166	168	169	170
Disengaged	Tailshaft R.P.M.	340	680	1480	2020	2560	3020
Run 1	Input R.P.M.	490	1000	1490	2020	2520	3000
	Torque	32	34-35	44-45	48-50	54	56
Stock	HP	.249	.577	1.05	1.57	2.16	2.67
	Oil T °F	142	141	140	140	142	143
	Tailshaft R.P.M.	325	680	1480	2000	2520	3000
Run 2	Input R.P.M.	515	1020	1520	2010	2500	3000
	Torque	33	35	42-44	46-50	51-52	54-60
Stock	HP	.270	.566	1.04	1.53	2.04	2.71
	Oil T °F	154	149	155	150	153	156
	Tailshift R.P.M.	340	700	1500	2000	2500	3000

98

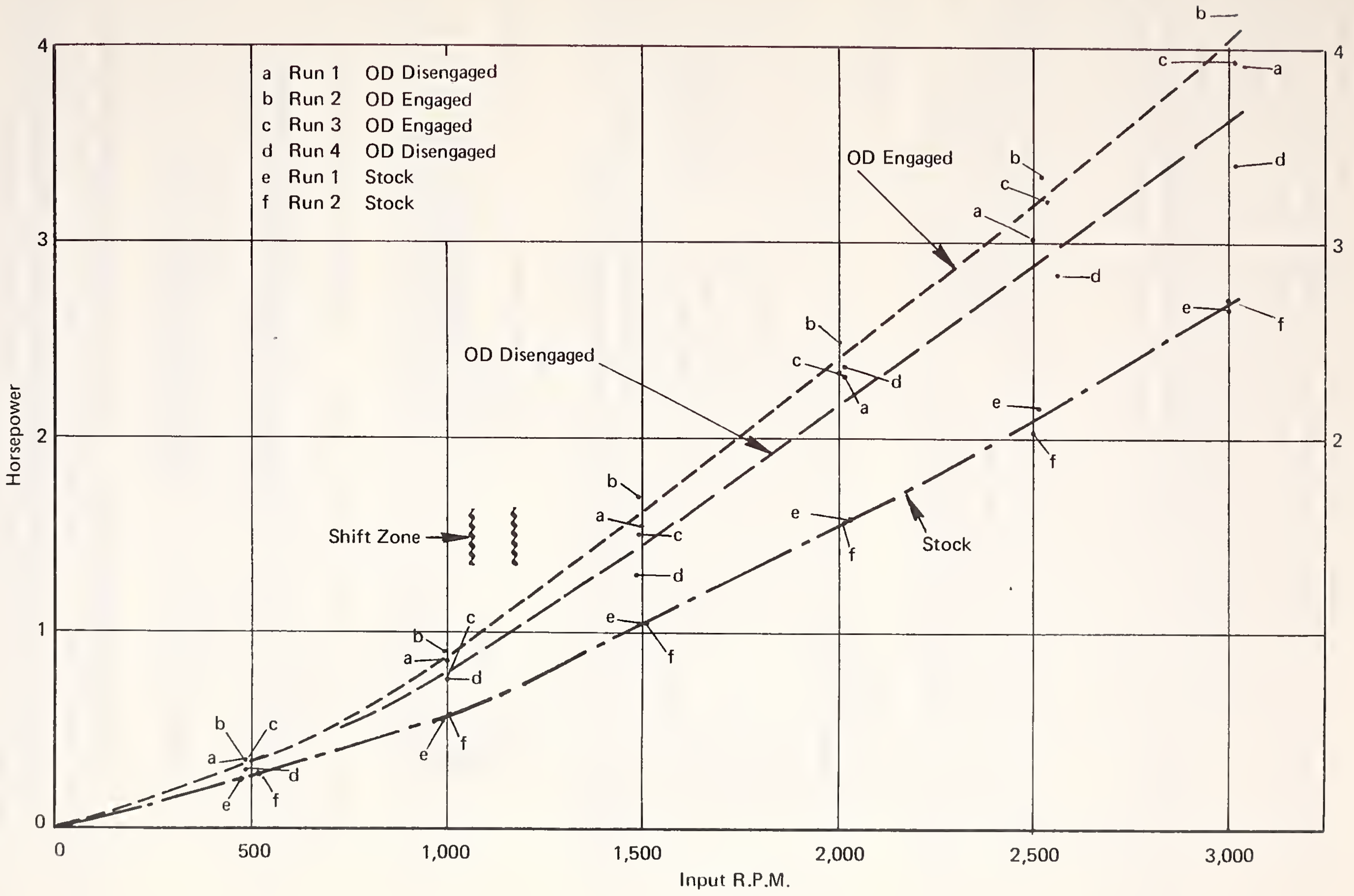


FIGURE 5.10 SPIN LOSSES OF PRODUCTION AND MODIFIED A904 TRANSMISSION

These tests on the A904 indicate that the experimental transmission absorbs approximately 1.5 times the power of a production unit, or an additional 0.82 horsepower at 2000 rpm. Since the shaft rpm data indicates that very little slippage occurred in the torque converter during any of these tests, it is safe to say that the additional power required by the experimental unit is absorbed in the overdrive unit. These results are applicable, therefore, to any of the transmissions equipped with overdrives, i.e., the Laycock overdrive unit will absorb approximately 0.8 horsepower at 2000 rpm.

In order to put the spin loss into proper perspective it is convenient to study the effect that a loss of 0.8 horsepower would have on the 318 Valiant for which we have an engine map and accumulated engine/vehicle operational data. Under level road cruise conditions in this car, equipped with a production transmission, the following conditions exist:

Road Speed	55 mph	(Accumulated data)
Manifold Vacuum	15 in Hg	
Engine Speed	2000 rpm	
BMEP	32.5 psi	(Map data)
BSFC	0.62 lbs/BHP-hr	
Power	26.09 horsepower	(Calculated from above data)
Fuel Consumption	16.2 lbs/hr	

If an additional 0.8 horsepower is required of the engine in order to run the overdrive, the following conditions are postulated:

Road Speed	55 mph
Power	26.09 horsepower (given)
Engine Speed	2000 rpm
BMEP	33.5 psi (calculated)
BSFC	0.61 lb/BHP-hr (map data)
Fuel Consumption	16.4 lb/hr (calculated)

The following formulae were used in the above analysis:

$$\text{Engine Horsepower} = \frac{\text{Engine rpm} \times \text{Engine Torque (ft lbs)}}{5252}$$

$$\text{Engine BMEP (psi)} = \frac{150.8 \times \text{Engine Torque (ft lb)}}{\text{Engine Displacement (in}^3\text{)}}$$

$$\text{Fuel Consumption (lbs/hr)} = \text{BSFC (lbs/hp-hr)} \times \text{Engine Horsepower}$$

It is reasonable to conclude from the above that the additional spin losses in the multi-purpose test transmissions have a measurable but insignificant effect on the fuel consumption of the test cars.

6. CONCLUSIONS AND RECOMMENDATIONS

There is good correlation between the fuel economy predicted by computer simulation and that obtained in actual test by the Federal Test Procedures when there is a reasonable degree of similarity between the hardware data used by the computer and the actual hardware tested.

Conclusion

Production differences in torque converter characteristics can cause a significant variation between simulated and actual test results.

Conclusion

In this program, between 7.5% and 15% improvements in composite fuel economy were realized with advanced transmissions. From this, it may be concluded that significant improvements in fuel economy can be obtained with the use of lockup torque converters either alone or with wider ratio gearing which reduces the top gear ratio of engine speed to vehicle speed. The improvements in fuel economy demonstrated in this program were accompanied by increases in carbon monoxide and hydrocarbon emissions, and general decreases in nitrogen oxide emissions. The degree to which these fuel economy improvements will be reduced when the carbon monoxide is controlled to more acceptable levels is unknown.

Recommendation

Conduct further testing in order to establish the improvements obtainable with modified drivetrains while maintaining acceptable levels of emissions.

Conclusion

Furthermore, it is unclear that the degree of improvement experienced in this program with vehicles meeting 1975 Federal Emission Standards will be obtainable with vehicles meeting future standards.

Recommendation

Conduct further tests in order to determine the degree of fuel economy improvements obtainable with drivetrain modifications on vehicles meeting more stringent emission standards.

Recommendation

Conduct further testing in order to establish the tradeoff between improvements in fuel economy and increases in emissions due to drivetrain modifications.

Conclusion

The testing indicated that statistical techniques can be applied to replicate results in order to discern differences in fuel economy of 5% or more. Such analysis is not appropriate to computer simulation.

Conclusion

The use of a lockup torque converter does not degrade vehicle acceleration.

Conclusion

Wide ratio four speed automatic transmissions without torque converter lockup or with lockup in fourth gear only do not degrade driveability from present levels in the cars tested. Driveability is degraded by the other transmissions primarily due to harsh shifting and low speed lugging. The acceptability of these problem characteristics can be improved through modulation of the various clutches and bands during shifts as well as elimination of lockup during low speed operation.

Conclusion

Testing of a car with a wide range three speed transmission with lockup in second and third at speeds over 30 mph resulted in improved driveability, only minor increases in HC and CO emissions, significant highway fuel economy improvements, and an overall composite fuel economy improvement of over 8%. In this configuration, however, the car was still not optimized nor was it acceptable to the average driver.

Recommendation

Conduct further testing to determine the impact of driveability modifications on fuel economy and emissions.

Conclusion

The use of modified drivetrain does not appear to degrade vehicle durability.

Recommendation

Conduct a 100,000 mile drivetrain durability test to more conclusively establish the impact of these drivetrains on engine life.

Conclusion

The modified transmission which yielded significant fuel economy improvements and which had the least impact on emissions was the addition of a lockup torque converter to a production transmission. This was only tested in one car, however.

Recommendation

Conduct a test program to establish the impact of a lockup torque converter and current gear ratios on fuel economy and emissions when used in a wide range of vehicles.

APPENDIX A

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