FRA
81-6

REPORT NO. FRA/ORD-81/42

AMTRAK FUEL CONSUMPTION STUDY

John S. Hitz

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

FEBRUARY 1981
FINAL REPORT

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION
Office of Research and Development
Washington DC 20590

Technical Report Documentation Page

1. Report No.
FRA/ORD-81/42

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
AMTRAK FUEL CONSUMPTION STUDY

5. Report Date
February 1981

6. Performing Organization Code

7. Author(s)
John Hitz

8. Performing Organization Report No.
DOT-TSC-FRA-81-6

9. Performing Organization Name and Address
U.S. Department of Transportation
Research and Special Programs Administration
Transportation Systems Center
Cambridge MA 02142

10. Work Unit No. (TRAIS)
RR132/R1313

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
Federal Railroad Administration
Office of Research and Development
Washington DC 20590

13. Type of Report and Period Covered
Final Report
May 1980 - September 1980

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This report documents a study of fuel consumption on National Railroad Passenger Corporation (Amtrak) trains and is part of an effort to determine effective ways of conserving fuel on the Amtrak system. The study was performed by the Transportation Systems Center (TSC) under the sponsorship of the Federal Railroad Administration and in cooperation with Amtrak.

A series of 26 test runs were conducted on Amtrak trains operating between Boston, Massachusetts, and New Haven, Connecticut, to measure fuel consumption, trip time and other fuel-use-related parameters. The test data were analyzed and compared with results of the TSC Train Performance Simulator replicating the same operations.

Results of the tests showed that the average fuel consumption for the 157.7 mile trip was 368 gallons and that the average fuel use efficiency was 277 ton-miles per gallon. Fuel consumption and fuel use efficiency were found to increase consistently with increasing train tonnage. One locomotive was also found to consume about 12 percent more fuel than the other locomotive tested. The fuel consumption and trip time results for individual runs varied between +8.0 to -9.5 and +5.4 and -10.7 percent, respectively, of the Train Performance Simulator results. However, when averaged over the ten test runs analyzed, the fuel consumption and trip time results were within 1.04 and 0.03 percent, respectively, of the simulator. Throttle notch settings and train speed profiles also agreed well with simulated results.

17. Key Words
Energy Conservation
Railroad Energy Use
Amtrak
Locomotive Fuel Use

18. Distribution Statement
DOCUMENT IS AVAILABLE TO THE PUBLIC
THROUGH THE NATIONAL TECHNICAL
INFORMATION SERVICE, SPRINGFIELD,
VIRGINIA 22161

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages

22. Price

Form DOT F 1700.7 (8-72)

Reproduction of completed page authorized

PREFACE

This report documents a study of fuel consumption on National Railroad Passenger Corporation (Amtrak) trains operating between Boston, Massachusetts, and New Haven, Connecticut. The study supports efforts to determine effective means of conserving locomotive diesel fuel on the Amtrak system. The study was performed by the Transportation Systems Center (TSC) under the sponsorship of the Federal Railroad Administration (FRA), Office of Research and Development, in cooperation with Amtrak.

The TSC project manager was Robert E. Coulombre and the principal investigator was John S. Hitz. Management and coordination of Amtrak participation was performed by C.E. (Gene) Inglett of Amtrak. The tests were performed by Robert M. Dorer and Anthony T. Newfell of TSC and Benjamin J. Cross of Amtrak. Reduction and analysis of the test data was performed by Stephen A. Cultrera, Cheryl J. Sanders, and Philip J. Ayvazian of TSC. Analysis of the tests using the TSC Train Performance Simulator was performed by Samuel W. Schiff of TSC, who also assisted in preparation of Section 5 of this report.

The author is indebted to all those TSC and Amtrak participants whose extraordinary efforts in performing and analyzing the fuel measurement tests were crucial to the timely completion of the project and to Richard A. Novotny, Chief of the Passenger Systems and Facilities Division, FRA, and Thomas P. Woll of FRA for their overall direction and guidance of the project.

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

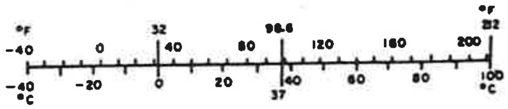


TABLE OF CONTENTS

Section Page

1. INTRODUCTION.. 1

1.1 Purpose.. 1
1.2 Background... 1
1.3 Approach... 2

2. FUEL CONSUMPTION TESTS.. 3

2.1 Data and Instrumentation................................... 3
2.2 Test Procedure... 6
2.3 Summary of Tests Performed................................. 7

3. REDUCTION OF TEST DATA.. 11

3.1 Data Reduction Assumptions................................. 11
3.2 Temperature Correction of Fuel Measurements................ 12
3.3 Resulting Test Data.. 15

4. ANALYSIS OF TEST RESULTS.. 18

4.1 Factors Affecting Fuel Consumption......................... 18
4.2 Empirical Fuel Consumption Formula......................... 26

5. TSC TRAIN PERFORMANCE SIMULATOR - ANALYSIS OF TESTS............. 29

5.1 Introducton to the TSC Train Performance Simulator......... 29
5.2 TPS Assumptions and Procedures for Modeling Amtrak Passenger Trains.. 30

5.2.1 Track Data Assumptions and Procedures................ 30
5.2.2 Train Data Assumptions and Procedures................ 31
5.2.3 Operational Data Assumptions and Procedures.......... 34

5.3 Comparisons of TPS and Test Results........................ 36

5.3.1 Fuel Consumption..................................... 37
5.3.2 Total Trip Time...................................... 39
5.3.3 Throttle Notch Distributions......................... 39
5.3.4 Speed Profiles....................................... 47

APPENDIX A - TEST PROCEDURES....................................... A-1

APPENDIX B - DATA ACQUISITION FORM................................. B-1

APPENDIX C - TEST DATA SAMPLES..................................... C-1

APPENDIX D - SAMPLE TRAIN PERFORMANCE SIMULATOR OUTPUT LISTING..... D-1

LIST OF ILLUSTRATIONS

Figure		Page
2-1	INSTRUMENTATION DIAGRAM	5
2-2	SUMMARY OF TESTS PERFORMED	9
3-1	FUEL SUPPLY-RETURN TEMPERATURE DIFFERENCE VERSUS TIME	14
4-1	TOTAL FUEL CONSUMED VERSUS TEST RUN	19
4-2	TOTAL FUEL CONSUMED VERSUS TOTAL GROSS TONS	20
4-3	TON-MILES PER GALLON VERSUS TOTAL GROSS TONS PER LOCOMOTIVE	22
5-1	COMPARISON OF TEST AND TPS THROTTLE PERFORMANCE TEST RUN #12	41
5-2	COMPARISON OF TEST AND TPS THROTTLE PERFORMANCE TEST RUN #14	42
5-3	COMPARISON OF TEST AND TPS THROTTLE PERFORMANCE TEST RUN #18	43
5-4	COMPARISON OF TEST AND TPS THROTTLE PERFORMANCE TEST RUN #20	44
5-5	COMPARISON OF TEST AND TPS THROTTLE PERFORMANCE TEST RUN #23	45
5-6	COMPARISON OF TEST AND TPS THROTTLE PERFORMANCE TEST RUN #26	46
5-7	COMPARISON OF TEST AND TPS SPEED-DISTANCE PROFILES TEST RUN #5	48
5-8	COMPARISON OF TEST AND TPS SPEED-DISTANCE PROFILES TEST RUN #3	49

LIST OF TABLES

Table		Page
2-1	TEST DATA AND INSTRUMENTATION	4
3-1	CAR WEIGHT CHARACTERISTICS	11
3-2	TRAIN WEIGHT COMPUTATION ASSUMPTIONS	12
3-3	SUMMARY OF TESTS CONDUCTED	16
3-4	SUMMARY OF SIGNIFICANT TEST PARAMETERS BY TEST RUN	17
4-1	THROTTLE NOTCH ANALYSIS, LOCOMOTIVE #212	24
4-2	THROTTLE NOTCH ANALYSIS, LOCOMOTIVE #205	25
4-3	FUEL CONSUMPTION REGRESSION FORMULAS	27
5-1	LOCOMOTIVE PHYSICAL CHARACTERISTICS FOR TSC-TPS	32
5-2	LOCOMOTIVE POWER CHARACTERISTICS FOR TSC-TPS	33
5-3	SAMPLE CONSIST CHARACTERISTICS FOR TSC-TPS	35
5-4	COMPARISON OF TOTAL FUEL CONSUMED BETWEEN TSC-TPS AND TEST	38
5-5	COMPARISON OF TOTAL TRIP TIME BETWEEN TSC-TPS AND TEST	40

EXECUTIVE SUMMARY

This report documents a study of fuel consumption on Amtrak trains. A series of 26 test runs were conducted on Amtrak trains operating between Boston and New Haven to measure fuel consumption, trip time, and other related parameters. The test data were analyzed and compared with results of the TSC Train Performance Simulator replicating the same operations.

Results of the tests showed the following average statistics for the 157.7 mile trip:

Average fuel consumption	368 gallons
Average gross train tonnage	649 tons
Average fuel use efficiency	277 ton-miles per gallon.

Fuel consumption across all tests ranged from 263 gallons for a 5-car, single locomotive train to 620 gallons for a 12-car, dual locomotive train. Fuel use efficiency, in ton-miles per gallon, ranged from 234 for a 488 gross ton train to 353 for a 1328 gross ton train.

The following factors were analyzed, using the test data, to determine their influence on fuel use: train tonnage, locomotive unit tested, head end power generated, trip time, ambient temperature, humidity, throttle notch distribution, and number of slowdowns. Fuel consumption and fuel use efficiency (ton-miles per gallon) were found to consistently increase with increasing train tonnage. In addition, locomotive #205, which appeared to be in better mechanical condition than locomotive #212, typically used about 40 gallons less fuel than #212 under the same conditions. None of the other factors

investigated were found to consistently influence fuel use, although more extensive fuel consumption-related data and the use of multivariate regression techniques will most likely yield additional correlations. Using all the test data, an empirical formula relating fuel consumption to train tonnage was developed with an r^2 statistic of 0.84.

Test results agreed very closely with results using the TSC Train Performance Simulator. While there were variances of about ±10 percent, the average difference for actual runs versus simulated runs, in fuel consumption and trip time, over the 10 test runs analyzed, was only 1.04 percent and 0.03 percent, respectively. A comparison of throttle notch distributions showed patterns much closer than expected, indicating that individual engineer train handling characteristics were close to theoretically optimum performance. Speed profiles were also very similar with the few minor differences partly explainable as attempts by engineers to provide a more comfortable ride for passengers. The results of this study are of immediate use in characterizing and evaluating fuel consumption. However, it must be understood that the limited nature of these tests did not permit a clear identification or evaluation of the effects of engine and operator performance on energy efficiency. This study will provide Amtrak with a basis to design future programs for identifying areas where improvements can be made in the energy efficiency of train operations.

1. INTRODUCTION

1.1 PURPOSE

This report describes the results of a study of fuel consumption on Amtrak trains performed by the Transportation Systems Center (TSC) under the sponsorship of the Federal Railroad Administration (FRA), Office of Research and Development, in cooperation with Amtrak, the National Railroad Passenger Corporation. The study objectives were to measure actual fuel consumption and trip time characteristics of Amtrak trains operating between Boston and New Haven and to compare the results with simulation analyses of the same trains using the TSC Train Performance Simulator (TPS).

1.2 BACKGROUND

The rising cost of locomotive diesel fuel has created a strong interest on the part of all railroads, and Amtrak in particular, in determining effective means of conserving fuel. One approach to achieving fuel conservation is to develop an information base of fuel consumption characteristics including data on related parameters that could possibly influence fuel use. With such baseline information, analytical tools can then be calibrated and utilized to evaluate and select options for conserving fuel. This study represents the first comprehensive attempt to move in this direction. Fuel consumption and related characteristics of Amtrak trains have been measured under controlled conditions. Simulations of the same trains operating under the same conditions were then performed with the TSC-TPS, and the results were compared with the tests. Analyses of factors affecting fuel consumption and differences between test and simulation results were also performed.

The results of this study are of immediate use in characterizing fuel consumption and evaluating fuel conservation options on Amtrak trains. The study will also be of longer-range use in designing more extensive tests and analyses that will lead to effective fuel conservation programs on the entire Amtrak system.

1.3 APPROACH

Data and instrumentation requirements for fuel consumption tests were developed. The instrumentation was then obtained and installed on two Amtrak F40PH locomotives, and a series of 26 tests was performed as described in Section 2. The test data were then reduced using a number of criteria developed jointly with Amtrak to yield fuel consumption related statistics as discussed in Section 3. Analyses of the data to characterize fuel consumption, to identify factors affecting fuel consumption, and to develop an empirical formula for fuel consumption is presented in Section 4. Analysis of selected test runs using the TSC-TPS and a comparison of TPS results with the tests is described in Section 5.

2. FUEL CONSUMPTION TESTS

2.1 DATA AND INSTRUMENTATION

The first task in planning for the fuel consumption tests was to develop data and instrumentation requirements. The two primary test data parameters, fuel consumed and trip time, were established by the project objectives. All other data requirements for the test were based on the need to measure as many parameters as possible which could influence either fuel consumed or trip time. Instrumentation required to measure the test data was determined on the basis of the following considerations: cost, ease of installation, short-term nature of tests, ability to manually acquire data, and accuracy of measurements.

The resulting data and instrumentation for the tests are summarized in Table 2-1. An instrumentation diagram is provided in Figure 2-1. Fuel consumed was measured with positive displacement flow meters on the engine fuel supply and return lines. Impulse switches were attached to the flow meters with a remote readout installed in the locomotive cab. The readout device automatically computed the difference between the supply and return flows to give the total fuel consumed by the engine in 1/10th gallon increments.

Power produced by the head end generator was measured by a watt meter and watt strip chart recorder mounted in the engine compartment under the head end generator console. The strip chart recorder provided a continuous monitoring of power generated to permit estimates of the average head end power requirements of the train.

TABLE 2-1. TEST DATA AND INSTRUMENTATION

DATA	INSTRUMENTATION
FUEL CONSUMED	FUEL METERS & TOTALIZER
HEAD END POWER	WATT METER & RECORDER
TOTAL TEST TIME	ELAPSED TIMER
TIME IN DYNAMIC BRAKE	ELAPSED TIMER
TIME IN LOW IDLE	ELAPSED TIMER
TIME IN IDLE	ELAPSED TIMER
TIME IN THROTTLE NOTCH	RECORDER
TIME IN BRAKE	RECORDER
SPEED AND DISTANCE	SPEED RECORDER
FUEL TEMPERATURE	PYROMETER
CONSIST TYPE	MANUAL
WEATHER DATA	MANUAL
TIME VS DISTANCE	MANUAL
SLOW ORDERS	MANUAL
UNUSUAL OCCURRENCES	MANUAL
FUEL SAMPLE	MANUAL

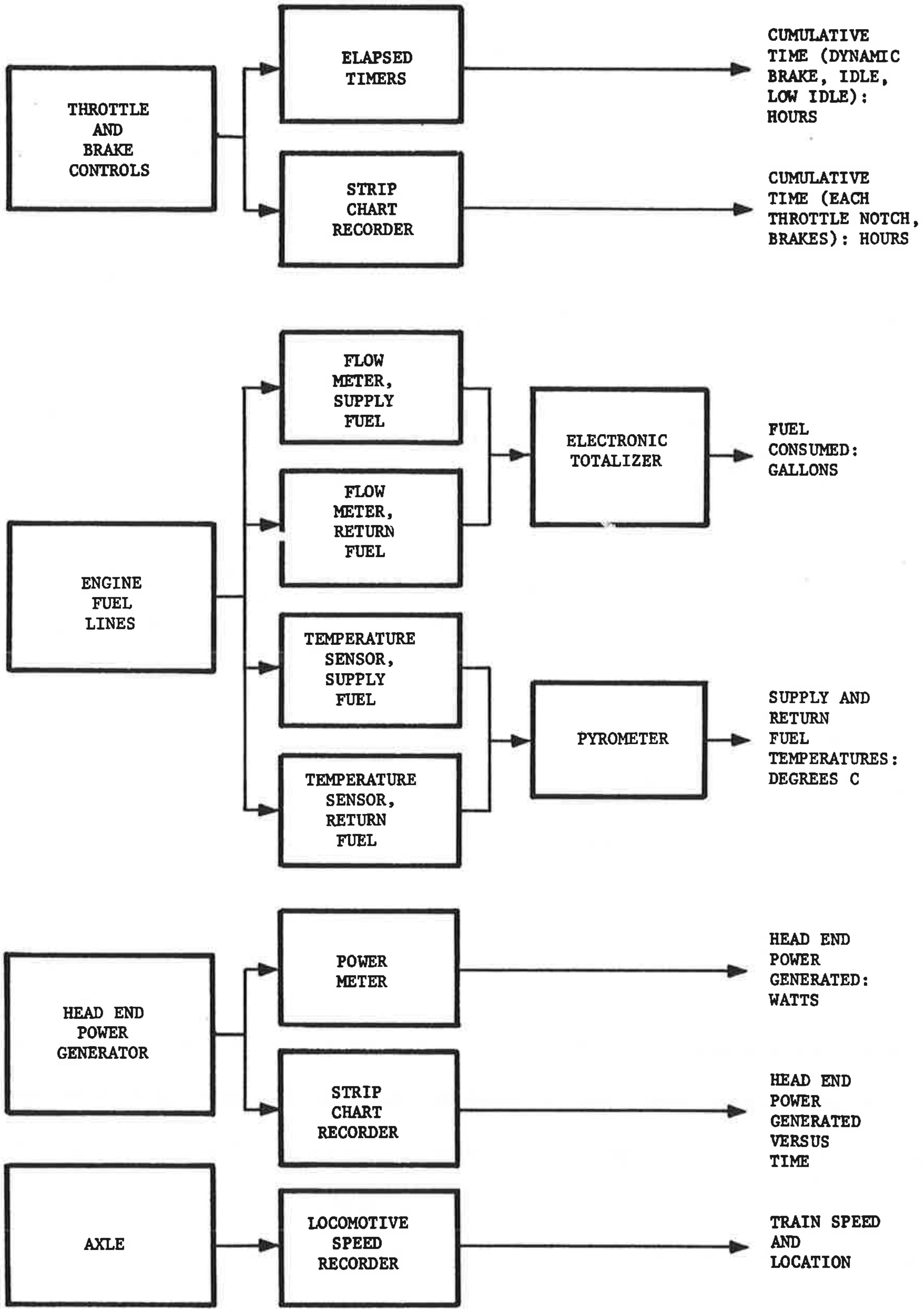


FIGURE 2-1. INSTRUMENTATION DIAGRAM

Elapsed timers, reading in 1/10th hours, were used to measure the total cumulative time in test, dynamic brake, low idle, and idle. Time in each of the eight throttle notches was obtained by monitoring, with a strip chart recorder, the time each of the A, B, C, and D throttle solenoids were activated. Similarly, a strip chart recorder and pressure transducer were used to monitor automatic brake application. The timers, throttle, and brake recorders were mounted in the locomotive cab.

Train speed and location on the route were measured using the locomotive speed recorder system.

The temperature of the fuel supplied and returned was monitored at the flow meters with a digital pyrometer reading in 1/100th degrees centigrade.

Train makeup, weather conditions (temperature, humidity, and wind), time versus location, slow orders, and other special conditions were recorded manually on a standard data form. Before each test, a sample of fuel was also obtained.

2.2 TEST PROCEDURE

Each fuel consumption test was conducted by a TSC and Amtrak test engineer. Prior to each test, the instrumentation was checked for proper operation, train consist information was recorded, strip charts were dated, and other pretest activities were performed according to standard procedures listed in Appendix A. All data recordings were made on a standard data acquisition form displayed in Appendix B. Whenever possible, fuel consumption and other data readings were started 30 minutes prior to scheduled departure and extended 30 minutes after arrival at the destination.

During the test, at 10-minute intervals, the train location (milepost), fuel consumed, and time in test, dynamic brake, low idle, and idle were recorded. At each station stop, these readings were also made in addition to the station dwell time and fuel consumed measured directly at the flow meters (independent of the totalizer readout device in the locomotive cab) to serve as a backup data source. At each 10-mile interval, an accurate recording of time, milepost, and speed was made to assist in correlating results with later simulation analyses. Any slow orders or other unusual occurrences during the test were noted on the data form. Samples of strip chart recordings obtained from the tests are displayed in Appendix C, including speed, throttle notch, brake application, and head end power tapes.

2.3 SUMMARY OF TESTS PERFORMED

Over the duration of the project, a series of 26 tests were conducted using various combinations of two F40 locomotives on trains operating between Boston and New Haven. A graphical summary of the tests performed is provided in Figure 2-2, which shows the locomotive and train make-up as well as the date and time of each test.

The project, in essence, consisted of three series of tests involving different locomotive combinations. Tests #1 through #18 were conducted using locomotive #212. It should be noted that test #15 was aborted prior to leaving New Haven due to severe flooding conditions in the area on July 29th. Locomotive #205 was used for tests #19 through #23, and tests #24 through #26 were performed with both locomotives #212 and #205 in the consist. As shown in Figure 2-2, a variety of different train conditions were tested. This was a desirable feature permitting a range of typical operating conditions to be encountered. The shortest train tested consisted of only five cars while the longest train consisted of 18 cars.

TEST #	TRAIN #	DATE	TIME BEGIN	TIME END	CONSIST*
1	169	7/16/80	5:56 a	8:51 a	212 CL C C C C B
2	168	7/16/80	2:02 p	5:20 p	212 CL C C C C C D C C B
3	195	7/16/80	6:35 p	9:29 p	212 C C C C CF
4	195	7/17/80	11:53 a	3:02 p	212 CL C C C C C
5	190	7/18/80	9:34 a	12:27 p	212 B C C C C C CL
6	195	7/18/80	5:00 p	7:46 p	212 C C C C C CL
7	174	7/22/80	6:59 p	9:56 p	212 B CL C CF C C C
8	169	7/25/80	6:00 a	8:57 a	212 CL C C C C B
9	192	7/23/80	12:13 p	3:22 p	212 CL C C C C C
10	195	7/23/80	6:35 p	9:28 p	212 CL C C C C C
11	172	7/24/80	5:37 p	9:02 p	212 CL C C C C C D C
12	169	7/28/80	6:00 a	8:41 a	212 CL C C CF C C B
13	172	7/28/80	5:37 p	8:37 p	212 CL C C C C C CF C C

* = Locomotive and unit number, CL = club car, C = coach car, B = baggage car, D = diner car, CF = cafe car, SL = sleeper car

FIGURE 2-2. SUMMARY OF TESTS PERFORMED

TEST #	TRAIN #	DATE	TIME BEGIN	TIME END	CONSIST
14	171	7/29/80	7:40 a	10:51 a	212 CL C C C C C CF C B
15	CANCELLED				
16	168	7/30/80	2:18 p	5:30 p	212 B CL C C C CF C C C
17	67	7/30/80	10:15 p	1:41 p	212 B C CF C C C SL B
18	174	8/1/80	2:15 p	5:40 p	212 CL C C CF C C C B
19	174	8/1/80	7:00 p	9:32 p	205 B CL C C C CF C
20	171	8/2/80	7:40 a	10:46 a	205 B C C CF C C C C C CL
21	168	8/2/80	2:25 p	5:31 p	205 C C C C C CF B C C CF
22	67	8/2/80	10:22 p	1:56 a	205 SL B SL C C CF C C B
23	170	8/5/80	3:42 p	6:31 p	205 CL C C C CF C C
24	171	8/6/80	7:25 a	10:39 a	205 212 C C C CL C C C C C CF C B
25	168	8/12/80	2:37 p	5:42 p	205 212 CL/CF C C C CF/CL C C C C C C B
26	67	8/12/80	10:00 p	1:20 a	205 212 C C C C C C C C C C C B CF/CL C C SL SL B

FIGURE 2-2. (CONTINUED)

3. REDUCTION OF TEST DATA

3.1 DATA REDUCTION ASSUMPTIONS

Prior to reduction of test data, a number of assumptions described in Tables 3-1 and 3-2 regarding train weights were developed jointly with Amtrak so that calculation of train tonnages could be performed on a uniform basis. Table 3-1 summarizes the weight characteristics assumed for the different cars encountered during the tests. Table 3-2 summarizes the assumptions made of other categories of weights included in the computation of train tonnages. The calculation of ton-miles was done on the basis of a 157.7-mile distance between Boston and New Haven. To provide a consistent basis for analysis of fuel consumption data, only the fuel consumed between the actual time of departure and arrival was considered in the calculation of statistics presented in the following sections. Fuel consumption data was typically obtained over a period from 30 minutes before departure until 30 minutes after arrival.

TABLE 3-1. CAR WEIGHT CHARACTERISTICS

CAR TYPE	WEIGHT, LBS.	NUMBER OF SEATS[1]
F40 PH Locomotive	259,000	NA
Coach	104,000	84, 60
Club	112,900	41, 33
Diner	112,900	23
Cafe	112,900	41, 53
Sleeper	140,500	21
Baggage, 50 ft.	85,000	NA
Baggage, 70 ft.	97,000	NA

[1] Most commonly encountered number of seats listed first.

TABLE 3-2. TRAIN WEIGHT COMPUTATION ASSUMPTIONS

WEIGHT CATEGORY	COMPUTATION ASSUMPTION
Passenger Weight	- 200 lbs. per passenger including carry-on luggage - 75% load factor in coaches - 85% load factor in food service cars
Crew Weight	- 200 lbs. per crew member - 5 crew members per train plus 1 per passenger car
Food Weight	- 3,000 lbs. per food service car
Baggage Weight	- 10,000 lbs. per baggage car - 30,000 lbs. mail per 50 ft. baggage car - 50,000 lbs. mail per 70 ft. baggage car
Fuel Weight	- Average gallons in tank over test run - 7.5 lbs. per gallon
Locomotive Oil Weight	- 240 gallons - 7.5 lbs. per gallon
Locomotive Water Weight	- 250 gallons - 8.3 lbs. per gallon

3.2 TEMPERATURE CORRECTION OF FUEL MEASUREMENTS

The measured fuel consumption data was corrected for an error caused by a difference in temperature between the supply and return fuel. Because the fuel that is returned to the tank has circulated through the engine, it is warmer than the supply fuel and less dense. The measured returned flow is therefore erroneously high by an amount proportional to the difference in density between the supply and return fuel. The formula for determining the correct fuel consumption as a function of the measured supply and return flows and their density difference is:

$$FC = MS - MR \times E \tag{3-1}$$

where: FC = fuel consumed

MS = measured supply flow

MR = measured return flow

E = fuel density at return temperature ÷ fuel density at supply temperature

The difference in supply and return fuel temperature was monitored over the duration of tests #25 and #26. The results, expressed as a plot of temperature difference, °F, versus time into test, are shown in Figure 3-1. The dashed line segments correspond to periods in the station before and after each run while the solid line segments correspond to running time. As soon as head end power is turned on in the station, the temperature difference begins to climb. (See Figure 3-1, 124 minutes into test for run #25 and at the start of test for run #26.) During running time, the temperature difference climbs to a peak of about 16°F.

To determine the error in measured fuel consumption caused by the temperature difference for a typical run, the data represented in Figure 3-1 were used with the temperature correction formula, Equation 3-1. To improve the accuracy of the calculation, the error was computed over each of the separate time intervals during the run for which temperature readings were made and then aggregated to yield the total error for the entire run. The underestimate in measured fuel consumption over the running portion of the test was

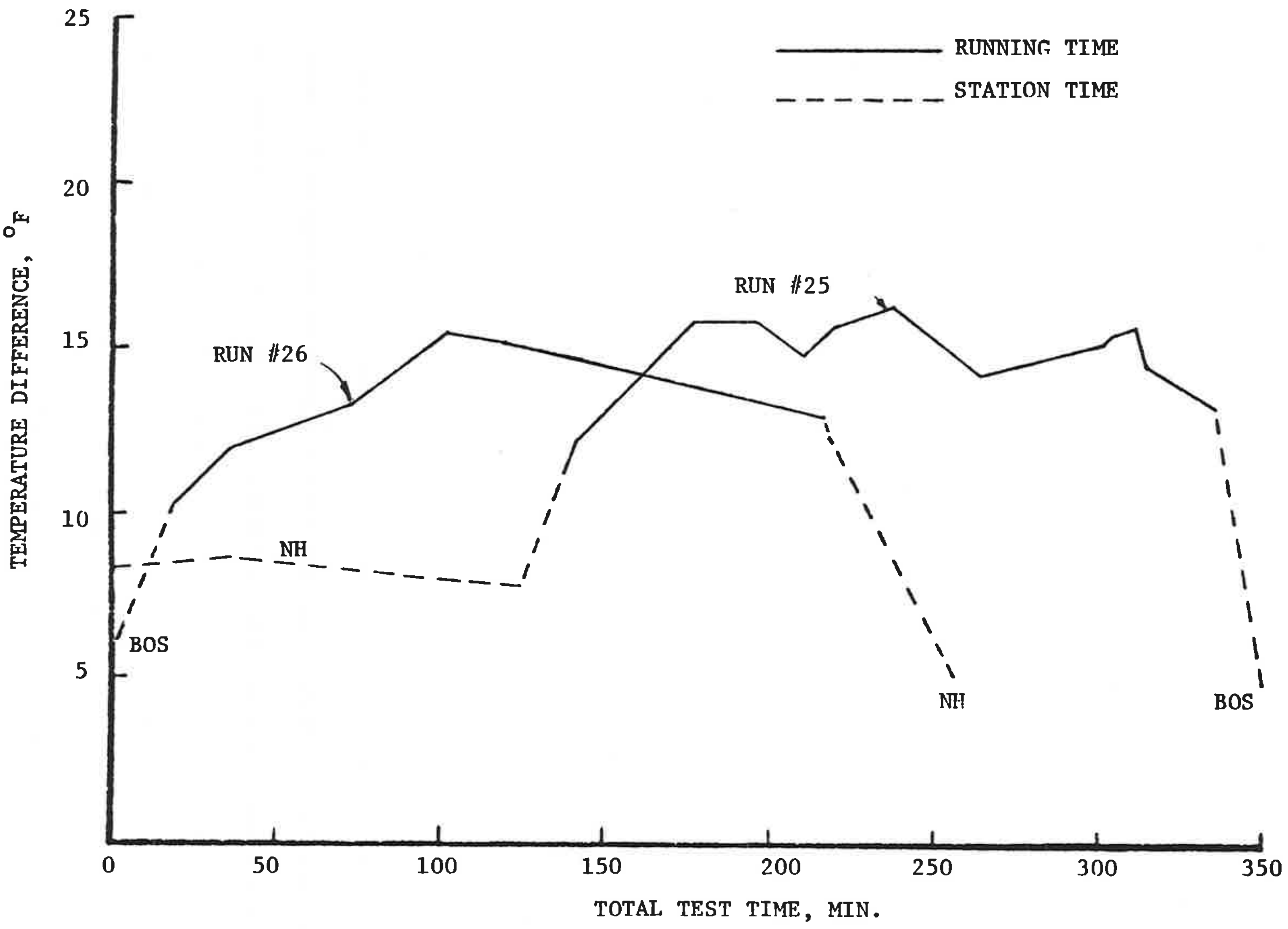


FIGURE 3-1. FUEL SUPPLY-RETURN TEMPERATURE DIFFERENCE VERSUS TIME

1.51 percent for run #25 and 1.37 percent for run #26. The average of these two results, 1.44 percent, was applied to the measured fuel consumption for all test runs.

3.3 RESULTING TEST DATA

The values of key test parameters averaged over the test series for each of the three locomotive combinations (locomotives #212 and #205 operating separately and together as a dual locomotive consist) are presented in Table 3-3. A comparison of the results between locomotives #212 and #205 indicates that locomotive #205 is more fuel-efficient. While locomotive #205 averaged more train tonnage than #212, it used less fuel. Its fuel efficiency as measured by ton-miles per gallon, or gallons per 1,000 ton-miles, is therefore better than locomotive #212. A possible contributing factor to locomotive #205's better performance is its mechanical condition. When the two locomotives were operated together, it was observed that locomotive #212 was smoking considerably more than #205.

The dual locomotive consist tests show results which would have been expected based on the performance characteristics of the individual locomotives. The fuel efficiency of locomotives #212 and #205 operating in tandem is between the performance of the locomotives operating individually.

A detailed summary of all significant test parameters for each test run is presented in Table 3-4. For the single locomotive tests, the gallons of fuel consumed per test ranged from 262.7 to 408.8. For the dual locomotive tests, the range was from 542.7 to 620.8 gallons. An analysis of factors contributing to this variation in fuel consumption is presented in the next section.

TABLE 3-3. SUMMARY OF TESTS CONDUCTED

PARAMETER	RUNS 1 TO 18	RUNS 19 TO 23	RUNS 24 TO 26
DATES	JULY 16-AUG 1	AUG 1-AUG 5	AUG 6-AUG 12
LOCOMOTIVE	212	205	212 & 205
AVERAGE TONS	566	658	1102
AVERAGE GALLONS	339	336	586
AVERAGE TON-MILES/GALLON	264	309	297
AVERAGE GALLONS/1000 TON-MILES	3.82	3.24	3.43
AVERAGE HEAD END POWER/PAX CAR, KW	36	53	57

TABLE 3-4. SUMMARY OF SIGNIFICANT TEST PARAMETERS BY TEST RUN

TEST NUMBER	TOTAL FUEL CONSUMED	TOTAL GROSS TONS	TON-MILES PER GALLON	TOTAL TRIP TIME, MIN.	TOTAL CARS IN CONSIST	TOTAL CARS REQUIRING HEAD END POWER	AVERAGE HEAD END POWER, KW	AVERAGE AMBIENT TEMPERATURE, °F	AVERAGE HUMIDITY, PERCENT
1	309.9	493.1	250.9	175	6	5	175	72	74
2	393.6	672.3	269.4	198	9	8	264	90	50
3	262.7	432.1	259.4	174	5	5	210	87	57
4	323.6	491.5	239.5	189	6	6	235	85	61
5	327.7	552.1	265.7	172	7	6	204	75	67
6	328.7	487.6	233.9	166	6	6	-	81	64
7	309.4	572.5	291.8	177	7	6	-	82	60
8	307.4	494.6	253.7	177	6	5	-	67	87
9	320.6	490.5	241.3	189	6	6	-	77	75
10	328.7	488.9	234.6	173	6	6	-	75	78
11	370.3	608.2	259.0	205	8	8	-	76	77
12	280.0	557.7	314.1	161	7	6	-	68	90
13	374.3	671.2	282.8	180	9	9	274	80	66
14	374.3	674.9	284.3	192	9	8	269	62	98
15	RUN CANCELED								
16	408.8	674.7	260.3	192	9	8	315	83	60
17	347.9	644.3	292.1	206	8	6	249	71	71
18	390.5	616.4	248.9	186	8	7	-	80	52
19	280.0	557.4	313.9	152	7	6	382	79	72
20	362.1	732.9	319.2	186	10	9	452	75	88
21	363.2	732.7	318.1	186	10	9	512	86	60
22	383.4	715.6	294.3	214	9	7	333	77	77
23	292.2	553.3	298.6	169	7	7	349	87	62
24	620.8	987.0	250.7	194	12	11	643	77	84
25	542.7	989.8	287.6	185	12	11	605	81	72
26	593.4	1328.1	353.0	200	18	10	406	70	70

4. ANALYSIS OF TEST RESULTS

4.1 FACTORS AFFECTING FUEL CONSUMPTION

A major concern of this study is to identify factors that affect fuel consumption to serve as a basis for future efforts to conserve fuel. If a simple graph of fuel consumed versus test run is made, as in Figure 4-1, it can be seen that there is considerable variation from one run to another. The fact that the dual locomotive runs (triangular symbols on Figure 4-1) consumed significantly more fuel than the single locomotive runs indicates that train tonnage may be affecting fuel use. The dual locomotive trains were significantly heavier than the single locomotive trains.

Figure 4-2 is a plot of gallons of fuel consumed versus total gross tons of the train. A consistent trend can be seen between increasing train tonnage and increased fuel use. To determine the strength of the linear relationship between these two variables, least squares linear regression lines were computed and superimposed on the plot. The regression lines were computed for the data points from all tests combined and for the two sets of data for the single locomotive tests. A regression line was not computed for the dual locomotive tests since there were too few data points for meaningful analysis.

The regression line for all data points yields a correlation coefficient of 0.93, indicating a strong linear relationship. The relatively high r^2 value of 0.86 also indicates that much of the variability in gallons consumed is explained by the linear relationship with train tonnage. Thus, reductions in train weight while maintaining the same passenger carrying capacity will improve fuel efficiency. For the typical train operating between Boston and

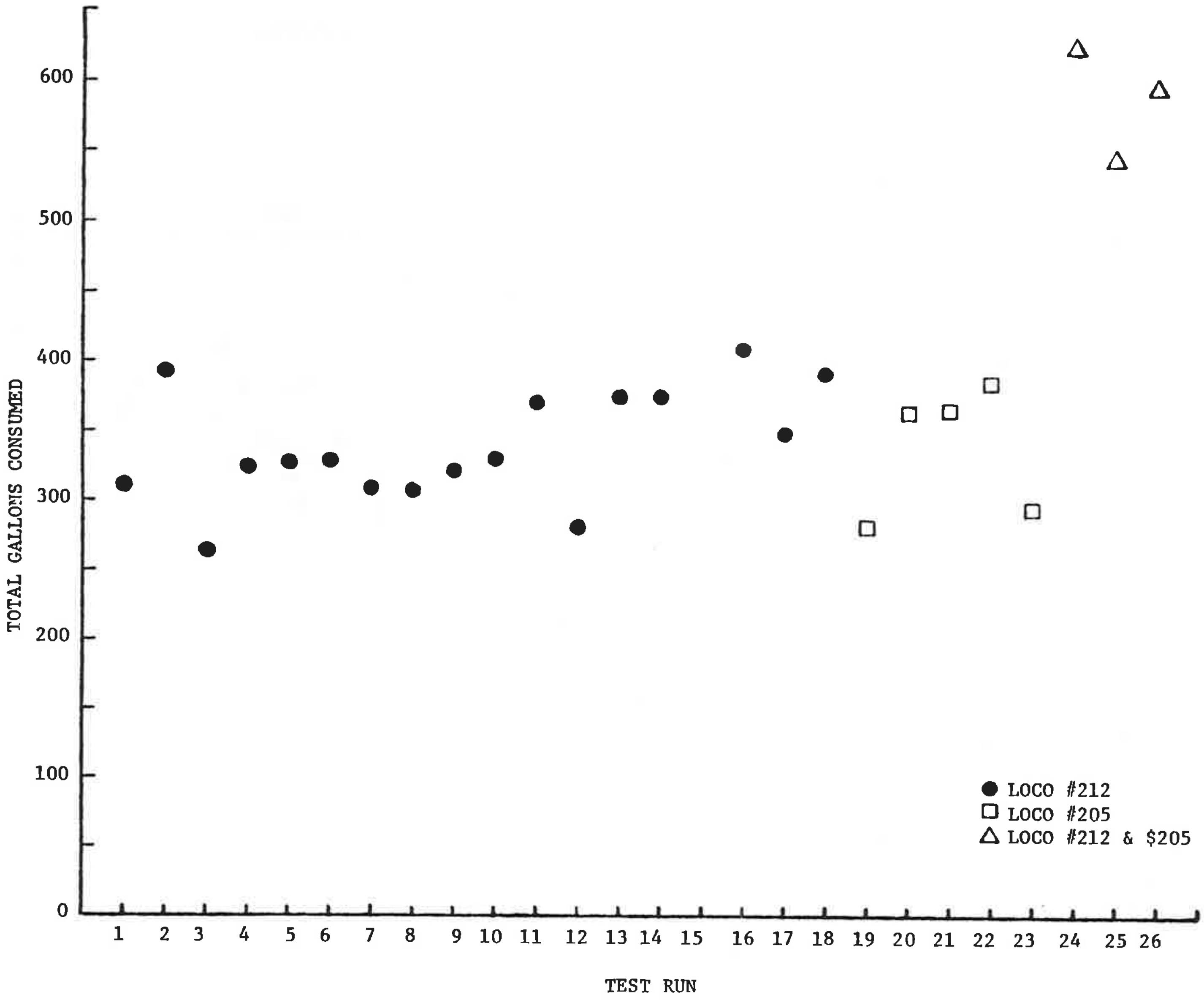


FIGURE 4-1. TOTAL FUEL CONSUMED VERSUS TEST RUN

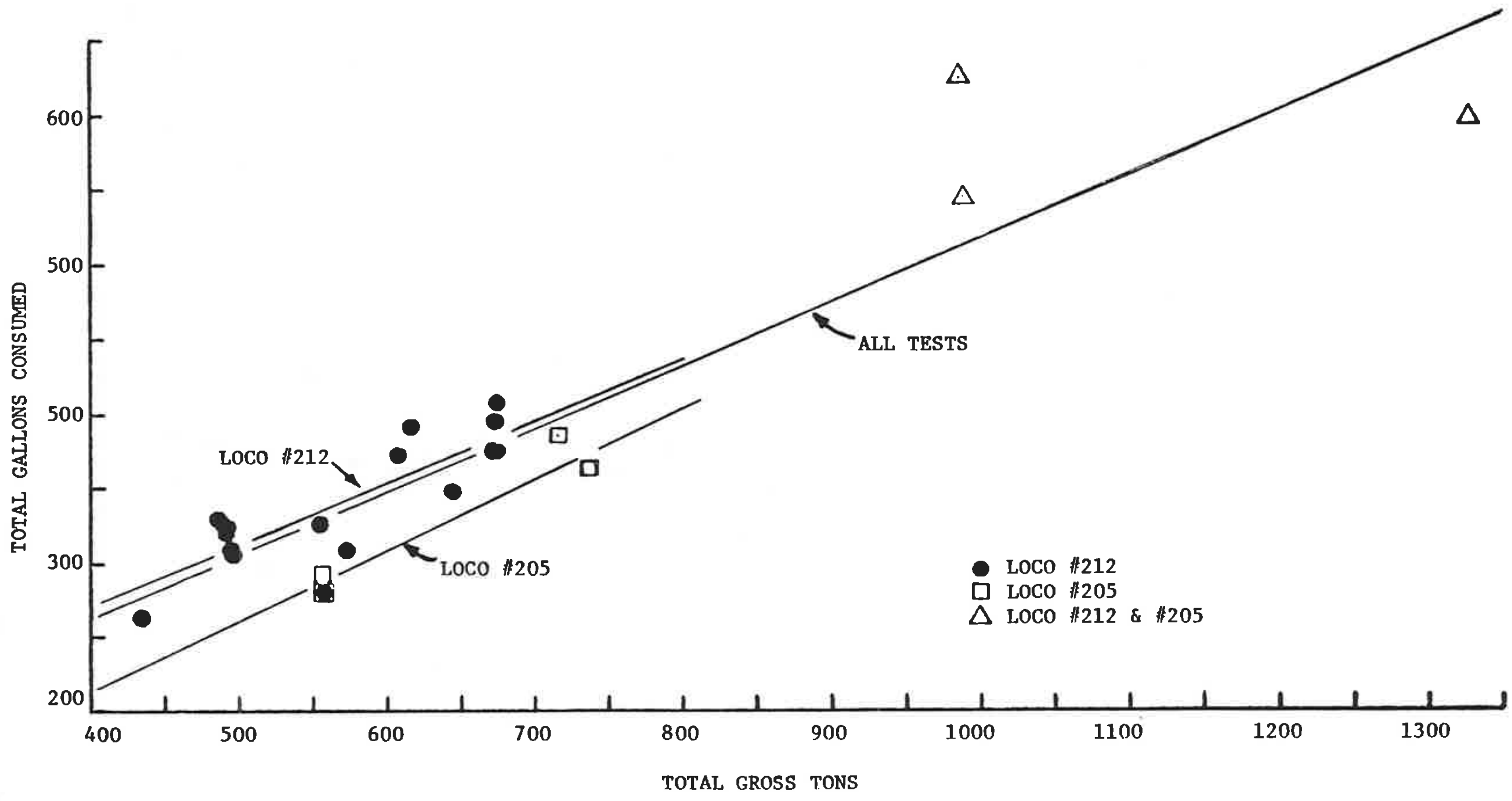


FIGURE 4-2. TOTAL FUEL CONSUMED VERSUS TOTAL GROSS TONS

New Haven (648.8 tons, test average), a 10 percent reduction in train weight would yield a 7.7 percent reduction in fuel consumption.

The regression lines for the two sets of single locomotive tests indicate that the influence of tonnage on fuel consumption is similar for both locomotives #212 and #205; i.e., the slopes of the curves are about equal. However, for any given tonnage level, the regression line for #205 is about 40 gallons lower than for #212. This provides another indication that locomotive #205 is more fuel-efficient than locomotive #212.

A measure of locomotive fuel use efficiency is ton-miles per gallon. This measure provides an indication of the useful work provided, ton-miles, per unit of input energy supplied, gallons of fuel. Figure 4-3 shows the ton-miles per gallon achieved for the tests plotted against gross train tonnage per locomotive. Although some scatter in the data is evident, there is a general trend of increasing fuel use efficiency with increased train tonnage. A linear regression line fitted to all the test data has been superimposed on the plot and verifies the fuel use effiency-train tonnage relationship. The correlation coefficient for the regression line, 0.59, indicated only a moderate linear relationship between fuel use efficiency and train tonnage. This, coupled with the scatter in data, suggests that other factors, as well as train tonnage, may be influencing fuel use.

The basic data summarized in Table 3-4 were analyzed to determine if any other factors could be identified that affect fuel consumption. The data were initially analyzed by grouping into test samples of similar tonnage so that this parameter would be controlled. Values for the factors of temperature,

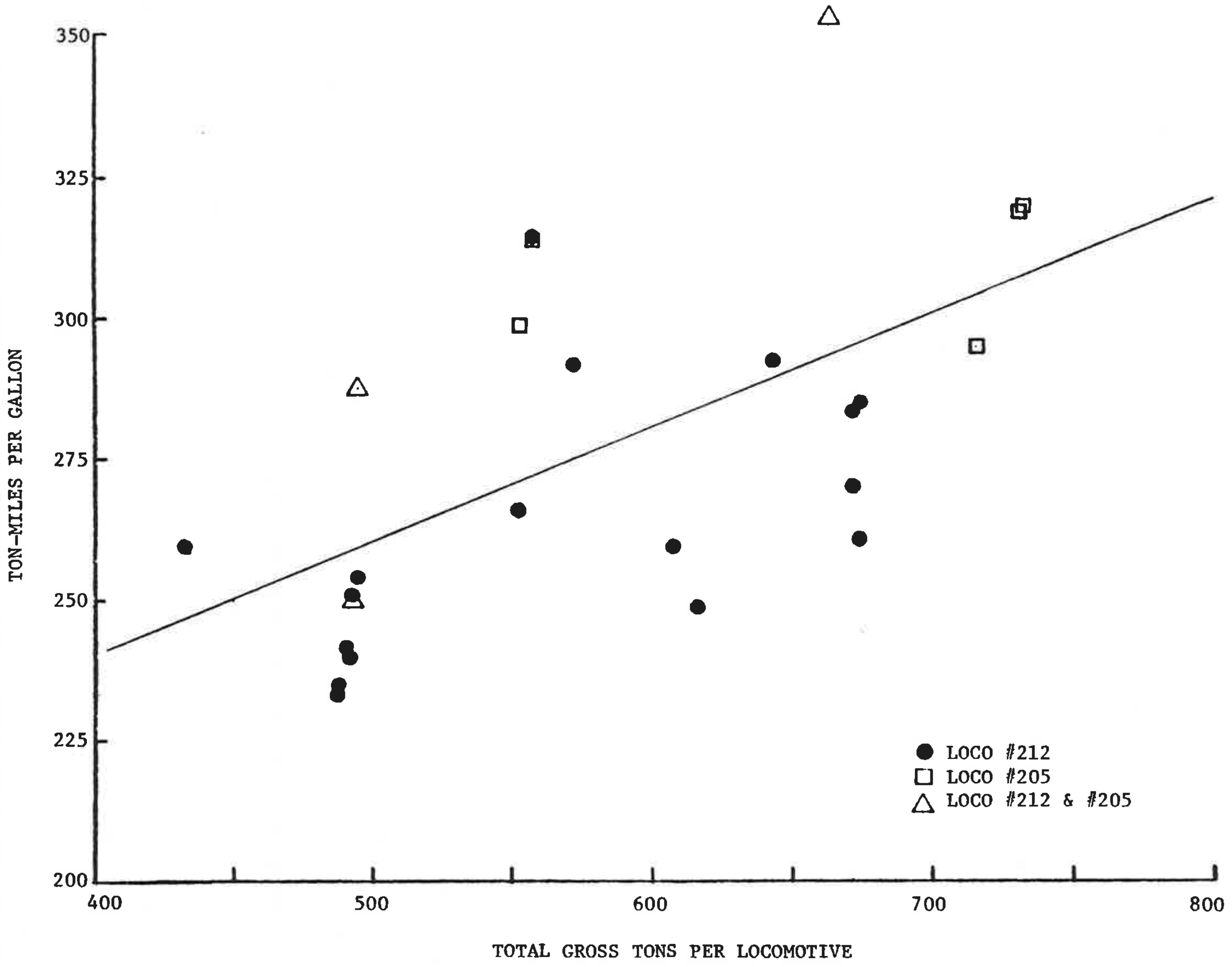


FIGURE 4-3. TON-MILES PER GALLON VERSUS TOTAL GROSS TONS PER LOCOMOTIVE

humidity, trip time, number of slowdowns to 20 mph or less, and head end power generated were then tabulated for each of the runs within these groups. These factor values were then reviewed to determine if there were any consistent correlations with variations in fuel consumption. No consistent patterns of correlation were found across all the groups. Within two of the three groups, a trend was observed between additional head end power generated per car and added fuel consumption. (See Table 3-4, tests #13, #14, and #18 and tests #1 and #4.)

The test data were also arranged by rank order of fuel efficiency (ton-miles per gallon). Again, no consistent correlations were found between fuel efficiency and the factors discussed above.

The distribution of time in the different throttle notches was also analyzed to determine its effect on fuel consumption for the tests for which this data was available. Tables 4-1 and 4-2 show the throttle notch distributions for several test runs, ranked by their fuel efficiency, for locomotives #212 and #205, respectively. The two tables indicate opposite trends in the influence of throttle notch distribution on fuel consumption. Table 4-1 indicates that less use of higher throttle notches improves fuel efficiency while Table 4-2 indicates the opposite. No consistent correlation can therefore be claimed between this factor and fuel consumption on the basis of the test results.

The lack of any detected correlation between factors discussed above, other than train tonnage and fuel consumption, can result for several reasons. The data may be too limited in quantity and/or too high in variability to

TABLE 4-1. THROTTLE NOTCH ANALYSIS, LOCOMOTIVE #212

TEST NUMBER	TON-MILES PER GALLON	GROSS TONS	PERCENT TIME IN THROTTLE NOTCH							
			8	7	6	5	4	3	2	1
#12	314	558	33	4	2	9	17	5	7	21
#14	284	675	47	2	4	3	12	2	2	26
#18	249	616	57	2	3	1	4	1	12	16

TABLE 4-2. THROTTLE NOTCH ANALYSIS, LOCOMOTIVE #205

TEST NUMBER	TON-MILES PER GALLON	GROSS TONS	PERCENT TIME IN THROTTLE NOTCH							
			8	7	6	5	4	3	2	1
#20	319	733	60	3	3	1	8	2	2	20
#23	299	553	48	0	7	1	12	2	2	27

permit any correlation to be detected. If the influence of factors is weak, a large amount of data with known variance would be required to establish the existence of a correlation with an acceptable degree of confidence. In addition, other factors not accounted for during the tests (e.g., engineer train handling characteristics and fuel quality) may influence fuel consumption to an extent that masks the effect of the factors investigated.

4.2 EMPIRICAL FUEL CONSUMPTION FORMULA

The strong relationship observed between fuel consumption and train tonnage led to the suggestion that an empirical formula relating fuel consumption to certain train parameters could be developed. Such a formula would be a useful tool for both operations and analysis applications where estimates of fuel use are required. A relatively simple empirical formula, while not as accurate as a train performance calculator, would permit quick and inexpensive results to be obtained.

A linear regression equation relating fuel consumption and train tonnage data appeared to be the simplest formula that could be developed. Three such formulas were developed for: (1) all the test data points, (2) locomotive #212 data points, and (3) locomotive #205 data points. The three curves produced by these formulas are the ones shown superimposed on the test data in Figure 4-2. The regression formulas and their corresponding r^2 statistics are shown in Table 4-3.

TABLE 4-3. FUEL CONSUMPTION REGRESSION FORMULAS

APPLICABLE DATA	FORMULA	r^2 STATISTIC
All Test Data	Fuel = .42 tons + 96	.84
Locomotive #212	Fuel = .41 tons + 105	.68
Locomotive #205	Fuel = .48 tons + 23	.92

Although the linear regression formulas produced good results as evidenced by the r^2 values, two additional attempts were made to develop alternative formulas. The first alternative was to construct a formula relating fuel consumed to the sum of several terms accounting for the energy needed to meet the following requirements: (1) acceleration, (2) grades, (3) velocity independent resistances, (4) velocity dependent resistances, and (5) head end power. The second approach was to take the basic regression formula and modify it by adding two additional terms reflective of the energy required for velocity dependent resistance and head end power. With the exception of train tonnage, these two factors were thought to have the most influence on fuel consumption.

The coefficients of the alternative formulas were determined on a trial and error basis. When the alternative formulas were compared with the simple regression formula, neither produced as good results. This supports the finding discussed in the previous section that no factors other than train tonnage could be identified that consistently correlated with fuel consumption.

The present effort to develop an empirical fuel consumption formula is considered preliminary. With additional test data on fuel consumption and other factors such as head end power, trip time, speed profile characteristics and throttle notch distribution, a more accurate formula can be developed. Such a formula will most likely contain several nontonnage terms which could not be found significant in this analysis. The use of multivariate regression analysis techniques will also be helpful in developing a more accurate formula.

5. TSC TRAIN PERFORMANCE SIMULATOR - ANALYSIS OF TESTS

5.1 INTRODUCTION TO THE TSC TRAIN PERFORMANCE SIMULATOR

The TSC-TPS is a computer program which simulates the operation of a train over a railroad route. The program, which was originally developed by the Missouri Pacific Railroad for its own use, has been extensively modified at TSC to expand its range of capabilities in simulating both rail freight and passenger service.

The output of the TPS consists primarily of tables or graphs that show the speed, time, distance, fuel consumption, and throttle notch positions of the train as it moves along the specified route. Additional information about the route (a series of track segments), such as mileposts, grades, elevations, curvature, and speed limits can also be shown in either tabular or graphic form.

The TPS is a useful tool which can be used to analyze the effects on fuel consumption and trip time of various parameters such as:

1. Locomotive power characteristics
2. Train tonnage
3. Number of station stops
4. Extent and frequency of slowdowns
5. Multiple unit throttle control devices
6. Use of different train resistance formulas

To simulate the running of a train, the TPS requires data on the route, the train, and operating conditions. The route data provides the model with a description of the physical characteristics of the track over which the train will run. A separate track record is coded for every occurrence and change of elevation (grade), curvature, speed, and station stops.

The train data includes: train consist type (passenger or freight), car type, car length and weight, number of loads and empties, number of axles per car, and resistance equation. Specific information about the power consist must also be specified including: locomotive type, number of locomotives, length and weight, number of axles, gross horsepower, derated horsepower, running and idling fuel rates, transmission efficiency, and tractive effort.

In addition to the above data, the following additions and/or variations can be made to a TPS run to accurately simulate normal operating conditions:

1. actual starting time of the train
2. alterations to the route (grade or curvature)
3. more or fewer stops and different dwell times
4. temporary changes in speed limits from those specified in the track data (e.g., slow orders)
5. changes in either the power or train consist (locomotives and/or cars) at stops enroute
6. wind velocity and direction
7. modifications of resistance characteristics to account for unusual cars or locomotives.

5.2 TPS ASSUMPTIONS AND PROCEDURES FOR MODELING AMTRAK PASSENGER TRAINS

The following three subsections outline the assumptions and procedures that were necessary to accurately represent the track, train, and operational characteristics of the Amtrak passenger trains analyzed in this study.

5.2.1 Track Data Assumptions and Procedures

First, an existing TPS track data base containing a file of the track records for the route segment between Boston and New Haven was updated with the latest Amtrak speed limits and restrictions (timetable as of 4-27-80). Secondly, elevations at each of the station stops were specified as follows:

- Boston - 5.0 ft.
- Providence - 20.0 ft.
- New London - 22.0 ft.
- New Haven - 20.0 ft.

5.2.2 Train Data Assumptions and Procedures

To accurately simulate the EMD F40PH locomotive used in Amtrak passenger service between New Haven and Boston, the following data was entered into a TPS input file for each run. Table 5-1 provides information on the physical dimensions of the F40 locomotive including weight, length, and number of axles. Table 5-2 provides data on the tractive effort, transmission efficiency, and energy consumption of the F40PH locomotive.

Since the current version of the TPS program did not have a provision for modeling head end power, several modifications were made in an effort to accurately estimate the fuel required to generate head end power. The first modification consisted of inputting data into the TPS which represented the actual tractive effort curve for an F40 locomotive generating an average load of 250 Kw of head end power. This, in effect, reduces the available horsepower of the locomotive to pull the train. In addition, actual brake-specific fuel consumption data for an F40 locomotive operating in the head end power mode was converted from pounds/brake-horsepower to gallons/hour and input into a TPS engine efficiency file. These two modifications provided the TPS program with the necessary data to calculate fuel consumption to run the train over the route. The last modification consisted of a separate manual calculation of fuel used to generate head end power, which was then added to the TPS

TABLE 5-1. LOCOMOTIVE PHYSICAL CHARACTERISTICS FOR TSC-TPS

```
---------------------------------------------------------------------------
Power consist beginning at BOSTON
---------------------------------------------------------------------------
LOCOMOTIVES  - - - - - - - - RESISTANCE COEFFICIENTS - - - - - - - -
NO. TYPE          ROLL    BRG  FLANGE  AIR DRAG     AREA   STRMLIN      EXP

 1 F40PH          1.30  29.00   0.030  0.002400    44.40   0.00210   0.3330

LOCOMOTIVES         TOTAL     DRIVEN  LENGTH  RATED  DERATED    RUN     IDLE
NO. TYPE           WT. XL     WT. XL   (FT.)     HP       HP  G/HPH      GPH

 1 F40PH          136.  4    136.  4     56.  3000.    2000. 0.0560    0.500

   Total          136.  4    136.  4     56.  3000.    2000. 0.0560    0.500

LOCOMOTIVES       TRANS   BREAKS    TE MAX   RESISTANCES  (POUNDS AT 1 MPH)
NO. TYPE           EFF  LOW HIGH   (LBS.)    ROLL   BRG.    FLANGE      AIR

 1 F40PH          82.1%             59800.   177.   116.      4.08   0.0899

   Total          82.1%             59800.   177.   116.      4.08   0.0899

 1 Diesel     unit:  F40

   Total length is    56. feet.    Total weight is   136. tons.

   Adhesion limit is 23.00 %.      Total power is   3000. hp.
---------------------------------------------------------------------------
```

TABLE 5-2. LOCOMOTIVE POWER CHARACTERISTICS FOR TSC-TPS

---- TRANSMISSION EFFICIENCY ----				-----ENERGY CONSUMPTION ------			
VEL (MPH)	TE MAX (LB)	EFF MULT	EFFICIENCY (%)	% OF MAX HP	HP	ENERGY MULT	GAL/HR
0	59800.	1.00	82.13	0	0.	0.14	30.00
5	59250.	1.00	82.13	5	150.	0.21	31.48
10	49000.	1.00	82.13	10	300.	0.27	33.68
15	39000.	1.00	82.13	15	450.	0.31	36.46
20	36500.	1.00	82.13	20	600.	0.35	39.66
25	33100.	1.00	82.13	25	750.	0.38	43.25
30	28500.	1.00	82.13	30	900.	0.42	47.43
35	24500.	1.00	82.13	35	1050.	0.46	52.07
40	21600.	1.00	82.13	40	1200.	0.49	57.27
45	19300.	1.00	82.13	45	1350.	0.53	62.98
50	17500.	1.00	82.13	50	1500.	0.57	69.05
55	16000.	1.00	82.13	55	1650.	0.60	75.84
60	14750.	1.00	82.13	60	1800.	0.65	83.49
65	13600.	1.00	82.13	65	1950.	0.68	91.35
70	12600.	1.00	82.13	70	2100.	0.73	100.32
75	11750.	1.00	82.13	75	2250.	0.77	109.49
80	11000.	1.00	82.13	80	2400.	0.81	119.76
85	10250.	1.00	82.13	85	2550.	0.86	130.53
90	9650.	1.00	82.13	90	2700.	0.90	142.15
95	9000.	1.00	82.13	95	2850.	0.95	154.15
100	8250.	1.00	82.13	100	3000.	1.00	168.00
105	0.	1.00	82.13				
110	0.	1.00	82.13				
115	0.	1.00	82.13				
120	0.	1.00	82.13				
125	0.	0.00	0.00				
130	0.	0.00	0.00				
135	0.	0.00	0.00				
140	0.	0.00	0.00				
145	0.	0.00	0.00				
150	0.	0.00	0.00				
155	0.	0.00	0.00				
160	0.	0.00	0.00				
165	0.	0.00	0.00				
170	0.	0.00	0.00				
175	0.	0.00	0.00				
180	0.	0.00	0.00				
185	0.	0.00	0.00				
190	0.	0.00	0.00				
195	0.	0.00	0.00				
200	0.	0.00	0.00				

results to yield total fuel consumption. This calculation was based upon a rate of 3.3 gallons per passenger car per hour, which represents an average of the head end power data collected from all the Amtrak fuel test runs. This coincides very closely with the rate used by Bechtel, Inc., of 3.4 gallons per passenger car per hour in their analysis of Amtrak operations.

The average train consist modeled included a combination of Amfleet passenger cars, club cars, food service cars, and baggage cars. The detailed weight characteristics for each car are provided in Tables 3-1 and 3-2 of this report. The TPS program requires only the specification of the average streamlined passenger car plus the total number of cars in the consist. Thus, all the individual car weights, lengths, etc., had to be accumulated and divided by the actual total number of cars in the consist. These average car lengths and weights were then used as input for each of the TPS runs. Table 5-3 contains a sample of these averages for one of the ten TPS runs.

5.2.3 Operational Data Assumptions and Procedures

Detailed data on the operation of each Amtrak train run was collected and recorded in order to permit accurate modeling with the TPS. The data used in the TPS program included the following:

1. station stop locations and dwell times
2. departure and arrival times
3. special speed restrictions and slow orders not contained in the TPS speed data base.

TABLE 5-3. SAMPLE CONSIST CHARACTERISTICS FOR TSC-TPS

```
Train consist beginning at BOSTON

For computation, train is considered as blocks of cars:
     7 blocks of  1 car  each.

BLK CAR                  - - - - - - - RESISTANCE COEFFICIENTS - - - - - -
 NO  NO CAR NAME         ROLL   BRG  FLANGE  AIR DRAG   AREA  STRELIN   EXP

  1   1                  1.30 29.00  0.045  0.001735   35.00 0.00050 0.8800
  2   1                  1.30 29.00  0.045  0.001735   35.00 0.00050 0.8800
  3   1                  1.30 29.00  0.045  0.001735   35.00 0.00050 0.8800
  4   1                  1.30 29.00  0.045  0.001735   35.00 0.00050 0.8800
  5   1                  1.30 29.00  0.045  0.001735   35.00 0.00050 0.8800
  6   1                  1.30 29.00  0.045  0.001735   35.00 0.00050 0.8800
  7   1                  1.30 29.00  0.045  0.001735   35.00 0.00050 0.8800

BLK CAR                   CAR   CAR     TARE  RESISTANCES (POUNDS AT 1 MPH)
 NO  NO CAR NAME          WT.  LGTH   XL  WT.    ROLL   BRG.   FLANGE   AIR

  1   1                   60.   80.    4   0.     78.   116.     2.70 0.0504
  2   1                   60.   80.    4   0.     78.   116.     2.70 0.0504
  3   1                   60.   80.    4   0.     78.   116.     2.70 0.0504
  4   1                   60.   80.    4   0.     78.   116.     2.70 0.0504
  5   1                   60.   80.    4   0.     78.   116.     2.70 0.0504
  6   1                   60.   80.    4   0.     78.   116.     2.70 0.0504
  7   1                   60.   80.    4   0.     78.   116.     2.70 0.0504

                         420.  560.   28   0.    546.   812.    18.90 0.3528

     7 cars total.

   420. trailing tons.  Horsepower-to-trailing-ton ratio is  7.143

   556. gross tons.  Train is    616. feet long.
```

5.3 COMPARISON OF TPS AND TEST RESULTS

Ten of the test runs were selected for analysis and comparison with the TPS. Seven of the runs were with locomotive #212, two with locomotive #205, and one with both in a dual locomotive consist. The two major considerations in selecting the runs were to obtain a sample of runs with a representative range of fuel efficiencies and to use those runs for which complete sets of data were available.

For each of the TPS samples selected, a complete set of detailed simulation outputs was produced. An example of an output listing for run #12 is shown in Appendix D. It should be noted that the fuel consumption results shown in Appendix D no not include the fuel required for head end power generation. This fuel is added to the TPS results at the rate of 3.3 gallons per passenger car per hour of running time. Each detailed output of the TPS contains the following reports:

1. Run Summary - trip time, average speed, and fuel consumed
2. Timetable
3. Elapsed Time in Each Throttle Notch Position
4. Elasped Time in Each Velocity Range
5. Energy Use Summary - energy consumed for various train resistances

For each of the TPS runs, the outputs were compared with test results on the basis of fuel consumed, total trip time, throttle notch distribution, and speed profiles.

5.3.1 Fuel Consumption

The comparison of fuel consumption results is shown in Table 5-4. The TPS results include the fuel consumed for head end power. The TPS produces results that are in good agreement with the tests. Compared on an individual run basis, the average difference in fuel consumption between the TPS and tests was 4.5 percent with a range from a minimum of 0.8 percent to a maximum of 9.5 percent. Because there are minor factors influencing fuel consumption that the TPS does not account for, e.g., differences in engineer train handling characteristics, it is to be expected that some differences will occur with individual runs. Averaged over a series of runs, however, the TPS should produce results in close agreement with the tests since any minor unaccounted for factors should tend to cancel out. On this basis, using the TPS to estimate the total fuel consumed over all ten test runs, the aggregate difference is only 1.04 percent.

The TPS performance was also evaluated by comparing its results averaged separately over the runs with locomotives #212 and #205. The TPS produces an average underestimate of fuel consumed for locomotive #212 of 3.6 percent and an average overestimate of 5.4 percent for locomotive #205. These results are consistent with the earlier observation that locomotive #212 showed relatively poor fuel efficiency, while locomotive #205 showed relatively good fuel efficiency. The TPS produced results which are between these two extremes. As would be expected, given this situation, the results for the dual locomotive consist, which included both locomotives, are almost equal with only 1.1 percent difference. If the TPS were "tuned" for the burn rates of each locomotive, even closer results could be expected for comparisons involving the individual locomotives.

TABLE 5-4. COMPARISON OF TOTAL FUEL CONSUMED BETWEEN TSC-TPS AND TEST

TEST NUMBER	TOTAL FUEL CONSUMED FROM SIMULATOR, GAL.	TOTAL FUEL CONSUMED FROM FIELD TEST, GAL.	PERCENT DIFFERENCE
2	375.3	393.6	-4.6
3	264.9	262.7	+0.8
5	301.2	327.7	-8.1
8	290.0	307.4	-5.7
12	285.8	280.0	+2.1
14	381.6	374.3	+2.0
18	353.0	390.1	-9.5
20	391.4	362.1	+8.0
23	298.1	292.2	+2.0
26	604.9	593.4	+1.9
Average	354.6	358.4	-1.04

5.3.2 Total Trip Time

A comparison of TPS and test results on the basis of total trip time is shown in Table 5-5. As with fuel consumption above, there is close agreement in results. On an individual run basis, the average difference was 3.7 percent with a range from a minimum of 1.0 percent to a maximum of 10.7 percent. Averaged over all ten runs, the aggregate difference in trip time was only 0.03 percent.

5.3.3 Throttle Notch Distributions

The distribution of time in each throttle notch position from the TPS is compared with results of six test runs in Figures 5-1 through 5-6. The test instrumentation recorded all time in idle and low idle as throttle notch 1. Hence, to create compatible results with the TPS, all TPS time in idle and brake was combined into throttle notch 1. (The TPS brakes only in idle.) There is relatively good agreement between TPS and test results. The general distributions are the same with 8th notch being used about 50 percent of the time and 1st notch about 25 percent of the time. The remainder of the time is spread among the other throttle notches. Considering that each test run represents the performance of different mixes of engineers and firemen, while the TPS represents a theoretical optimum use of power, the results are surprisingly close. It suggests that attempts to control engineers to yield optimum throttle notch performance may not produce significant changes in fuel consumption.

An analysis of differences in throttle notch distributions and corresponding differences in fuel consumption between the TPS and tests shows no consistent trend. For every run where the TPS has less time in 8th notch and

TABLE 5-5. COMPARISON OF TOTAL TRIP TIME BETWEEN TSC-TPS AND TEST

TEST NUMBER	TOTAL TRIP TIME FROM SIMULATOR, HRS.	TOTAL TRIP TIME FROM FIELD TEST, HRS.	PERCENT DIFFERENCE
2	3.23	3.30	-2.1
3	2.87	2.90	-1.0
5	2.95	2.88	+2.6
8	3.06	2.96	+3.4
12	2.81	2.69	+4.5
14	3.37	3.20	+5.4
18	3.03	3.10	-2.1
20	3.21	3.10	+3.5
23	2.78	2.82	-1.6
26	2.97	3.33	-10.7
Average	3.028	3.027	+0.03

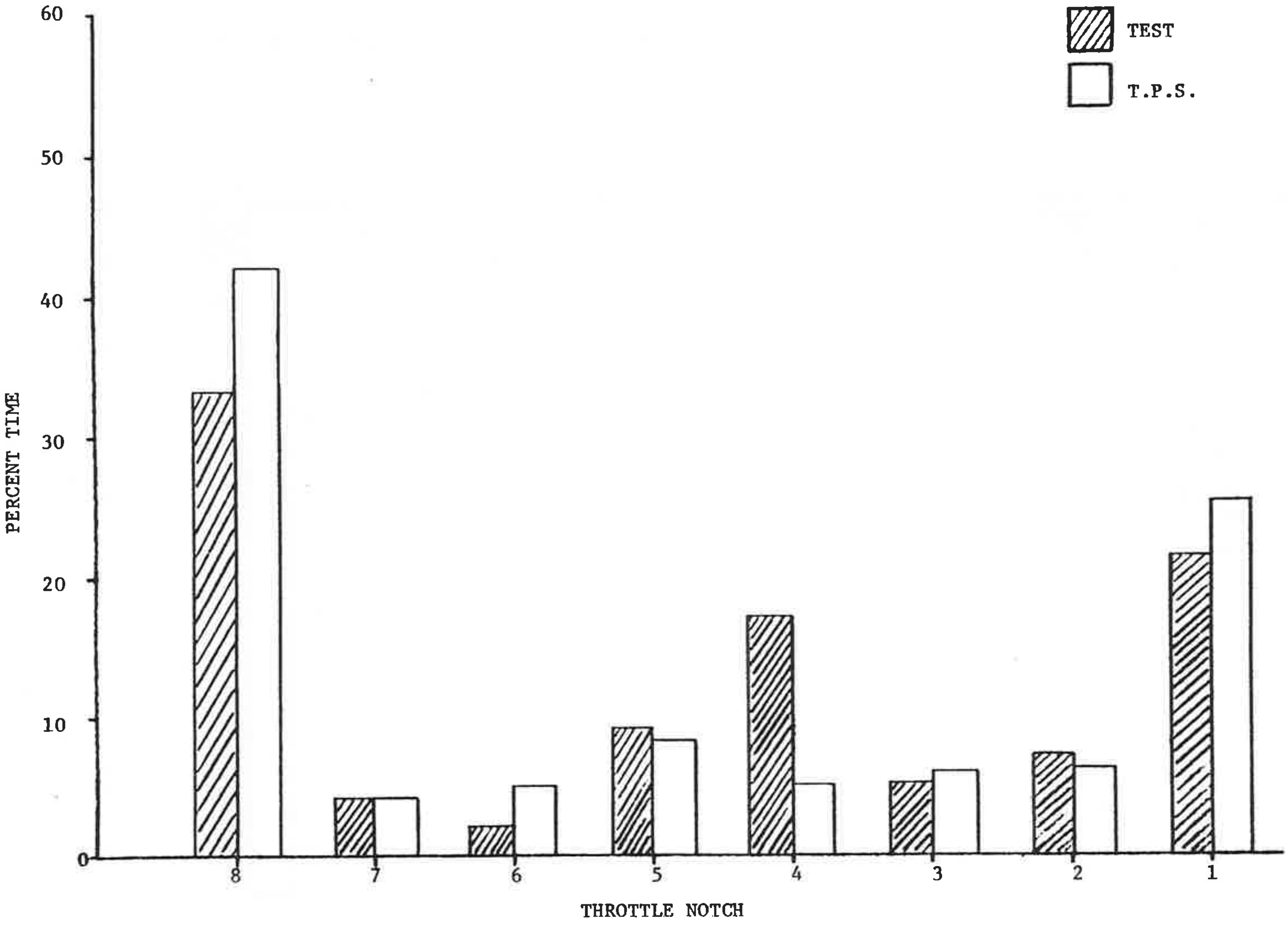


FIGURE 5-1. COMPARISON OF TEST AND TPS THROTTLE PERFORMANCE TEST RUN #12

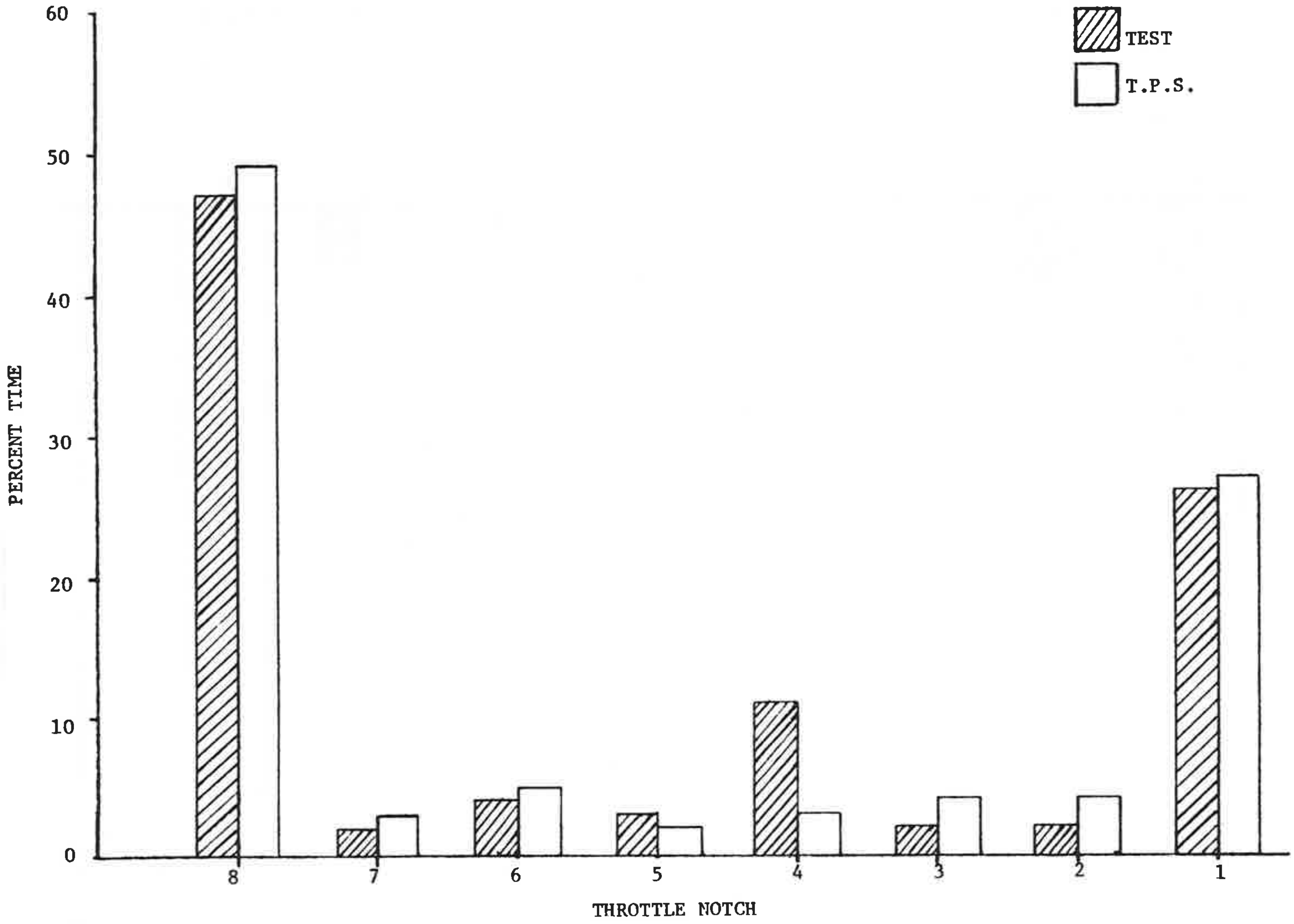


FIGURE 5-2. COMPARISON OF TEST AND TPS THROTTLE PERFORMANCE TEST RUN #14

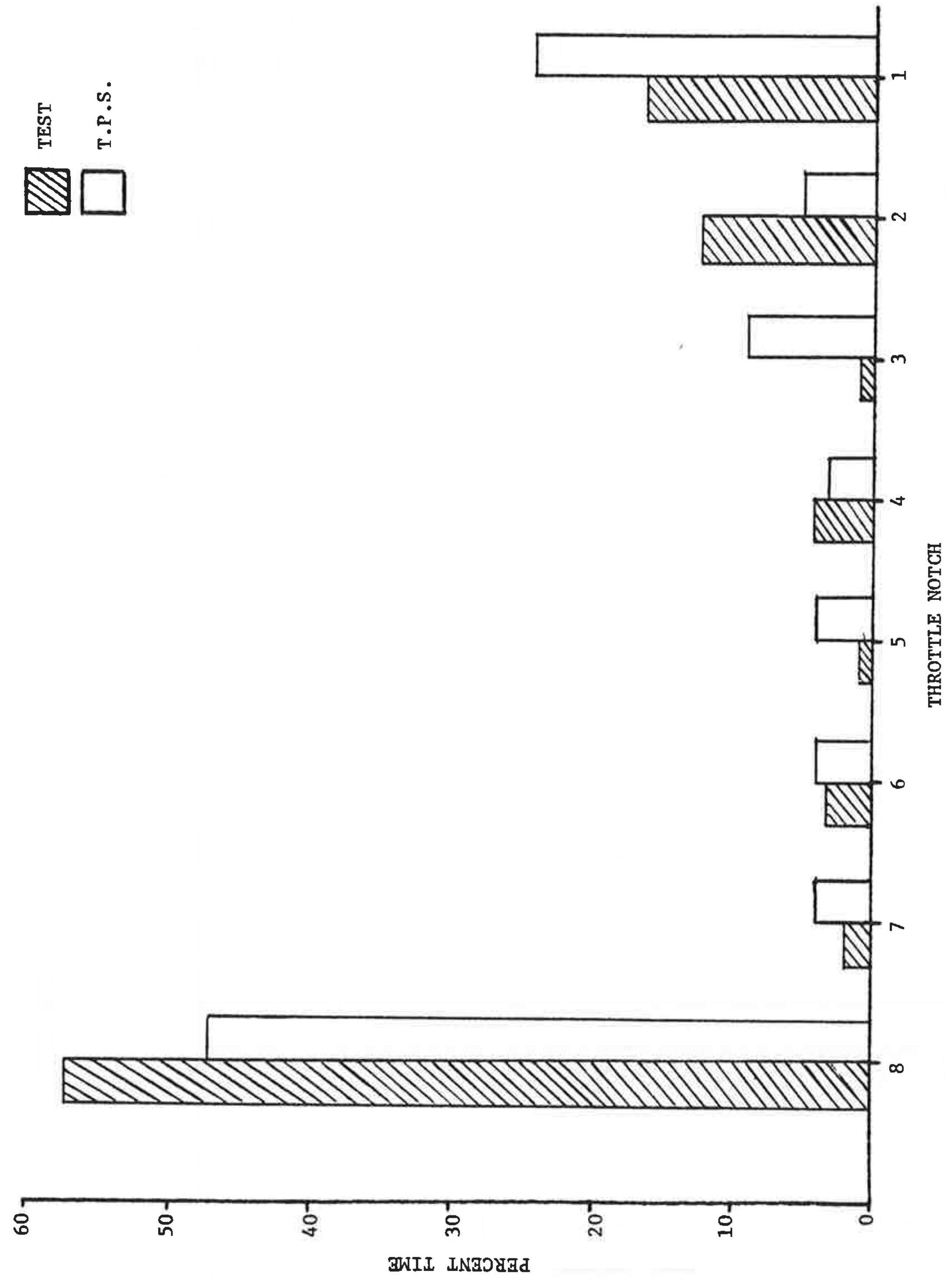


FIGURE 5-3. COMPARISON OF TEST AND TPS THROTTLE PERFORMANCE TEST RUN #18

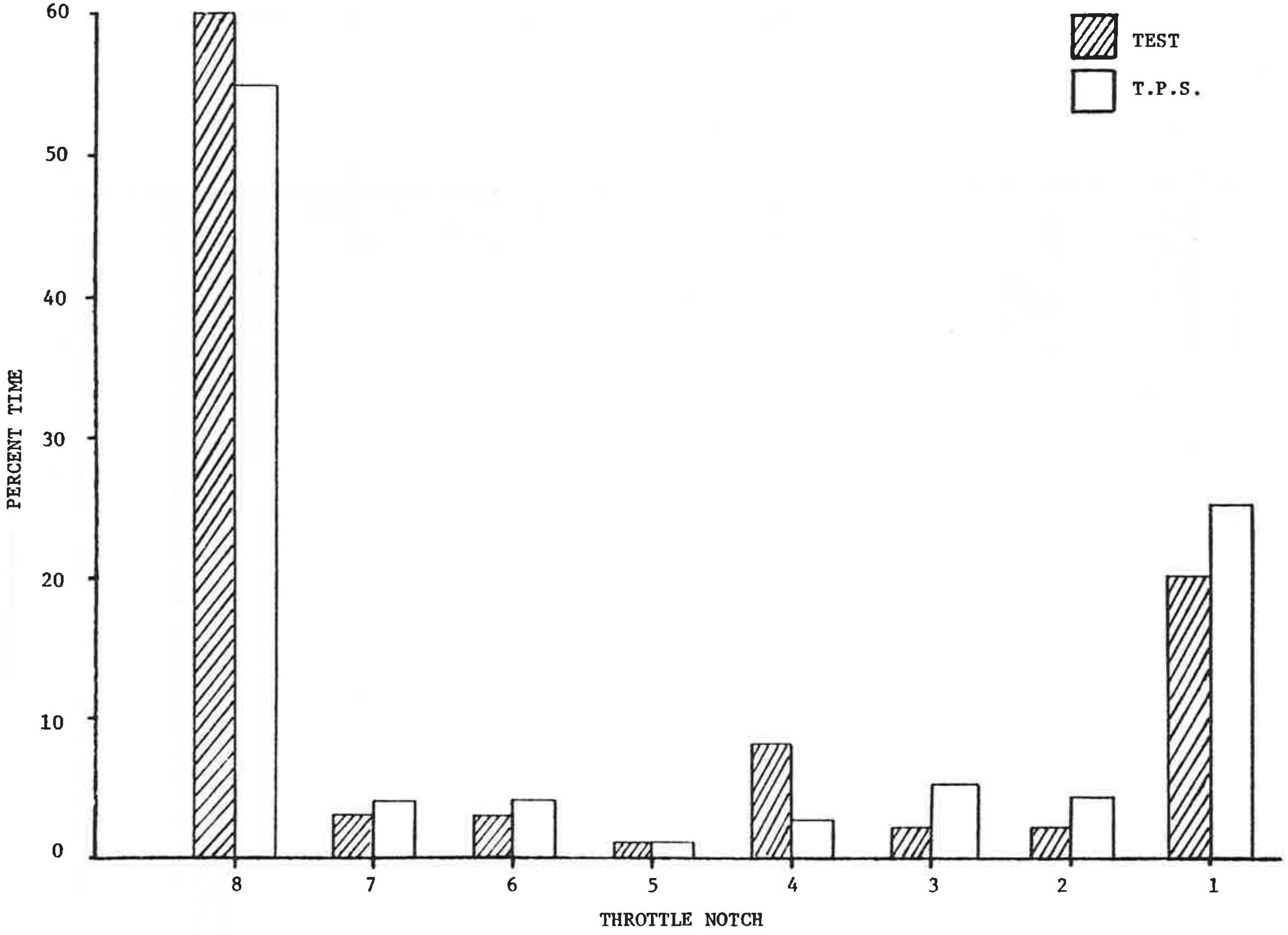


FIGURE 5-4. COMPARISON OF TEST AND TPS THROTTLE PERFORMANCE TEST RUN #20

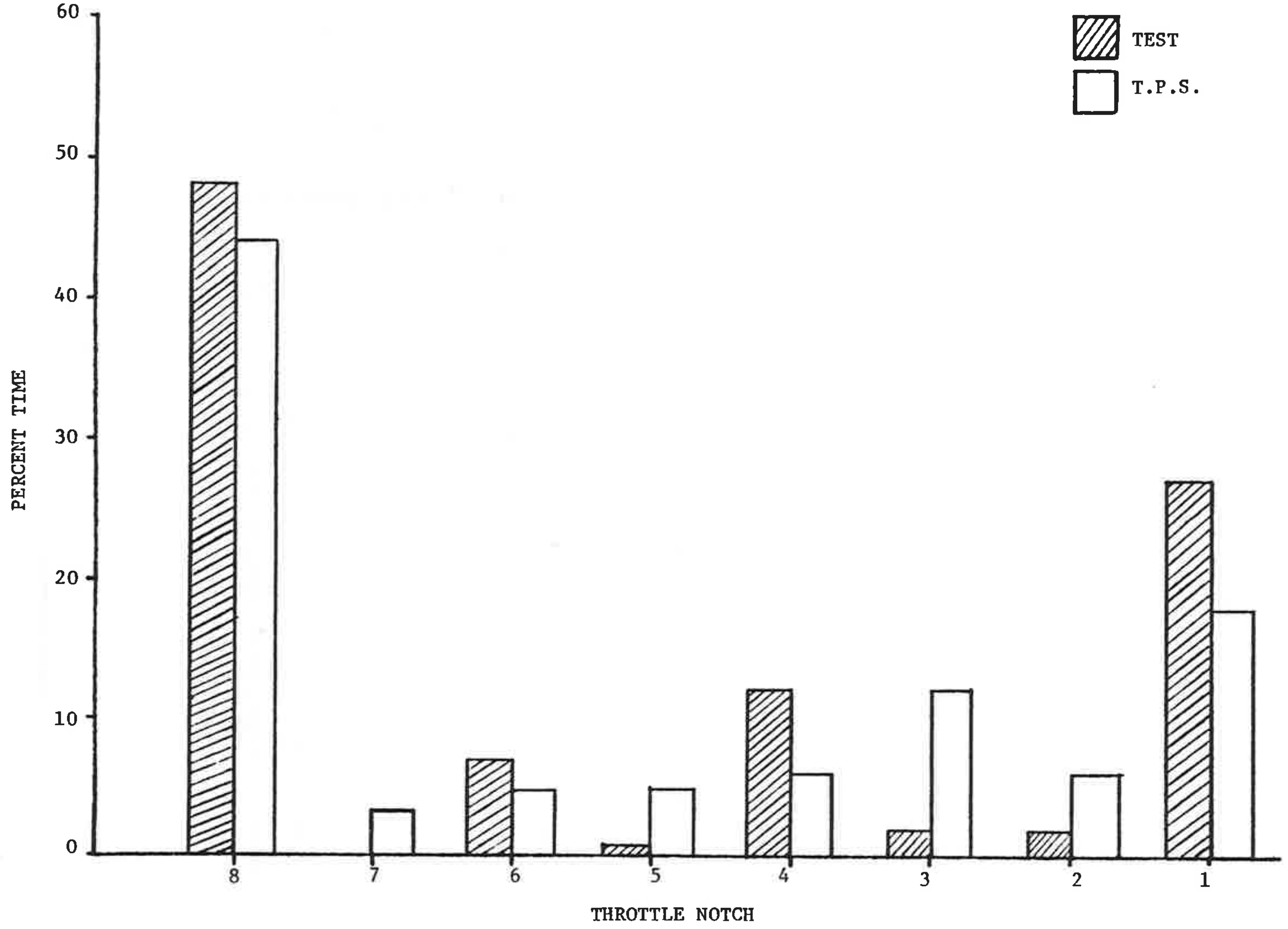


FIGURE 5-5. COMPARISON OF TEST AND TPS THROTTLE PERFORMANCE TEST RUN #23

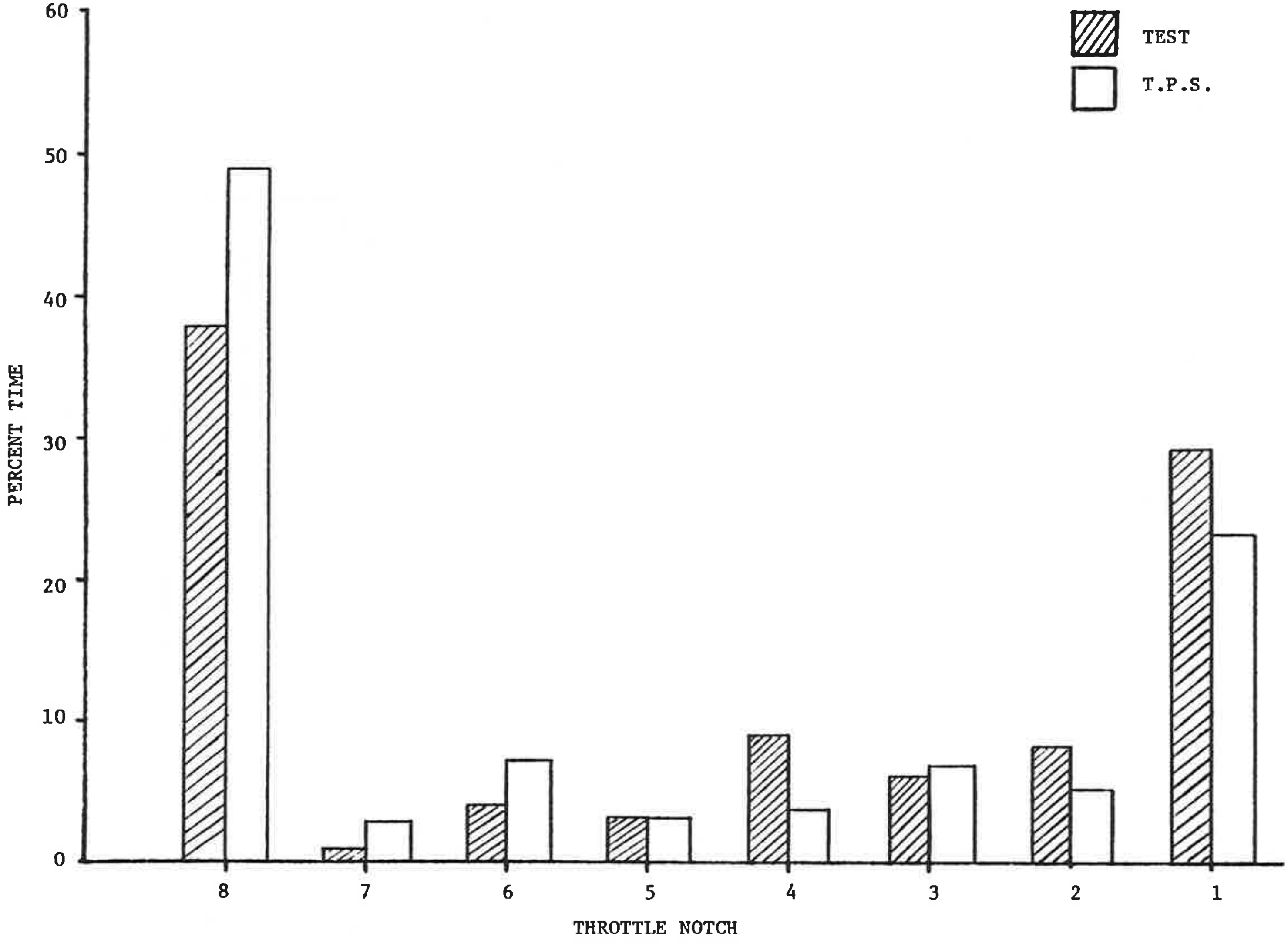
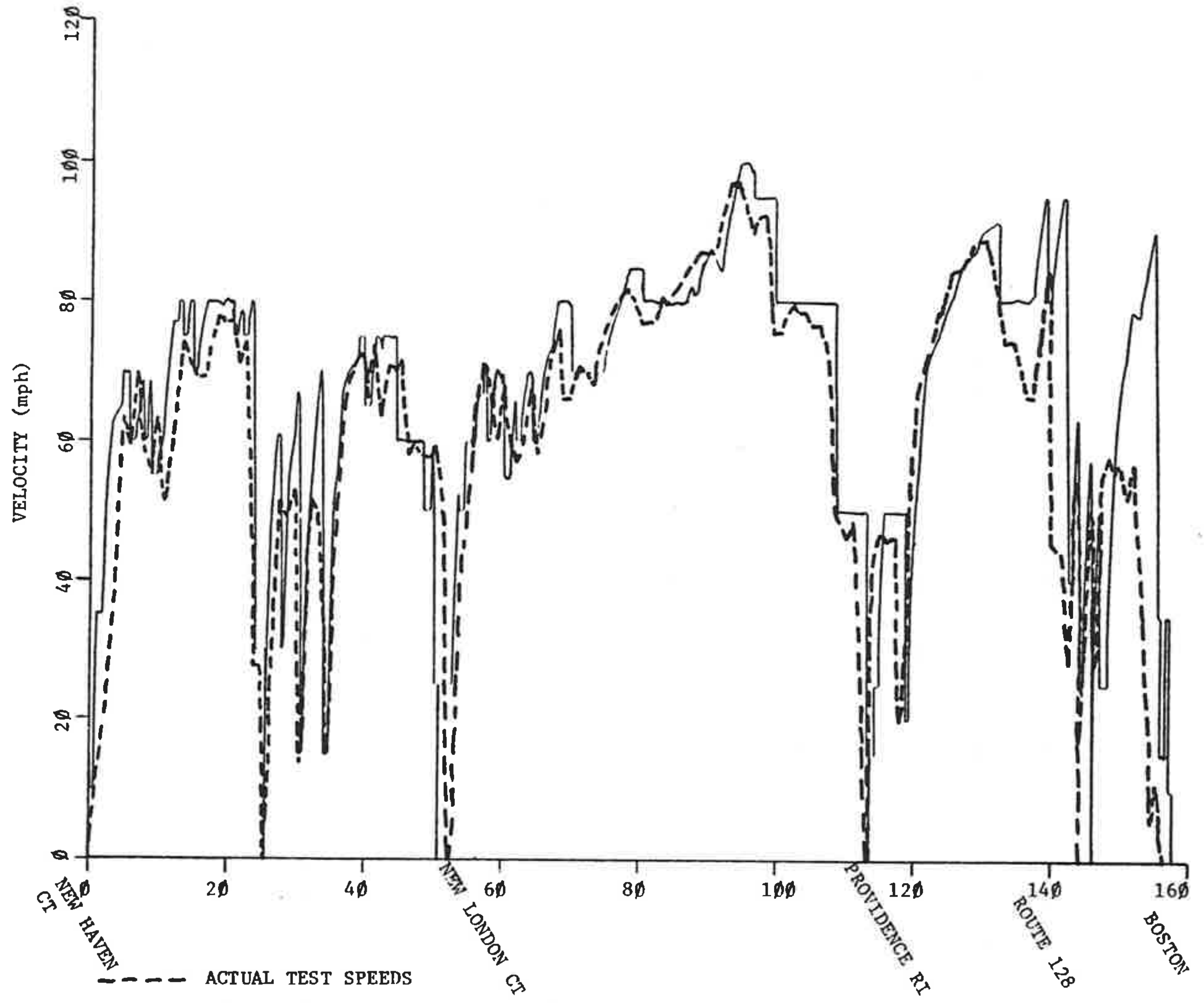


FIGURE 5-6. COMPARISON OF TEST AND TPS THROTTLE PERFORMANCE TEST RUN #26

less fuel consumption than the corresponding test, another run can be found with the opposite trend. For example, Run #12 shows the TPS with 8.7 percent greater time in notch 8 and greater fuel consumption than the test. However, run #26 shows the TPS with 10.4 percent greater time in notch 8 and less fuel consumption than the test.

5.3.4 Speed Profiles

A comparison of speed-distance profiles between TPS and test results for runs #3 and #5 are shown in Figures 5-7 and 5-8. In general, the agreement in speed profiles is excellent. The minor differences that occur seem to be due to several factors. Speed limit data input to the TPS may occasionally be in error. Slow orders often changed on a daily basis and may not always have been incorporated into the TPS. There also appears to be a slight calibration error in the track location data (either from the test or the TPS data file). For example, on run #5, several station stops are offset slightly between the TPS and test results. Finally, individual engineer operating characteristics are evident in some cases. The engineer, for example, can be seen to accelerate or decelerate at lower rates than the TPS so as to pass through some speed restrictions. This strategy would tend to produce a more comfortable ride for the passengers by eliminating several changes in speed.



Note: Sharp horizontal breaks in TPS speed correspond to track speed limits.

FIGURE 5-7. COMPARISON OF TEST AND TPS SPEED-DISTANCE PROFILES TEST RUN #5

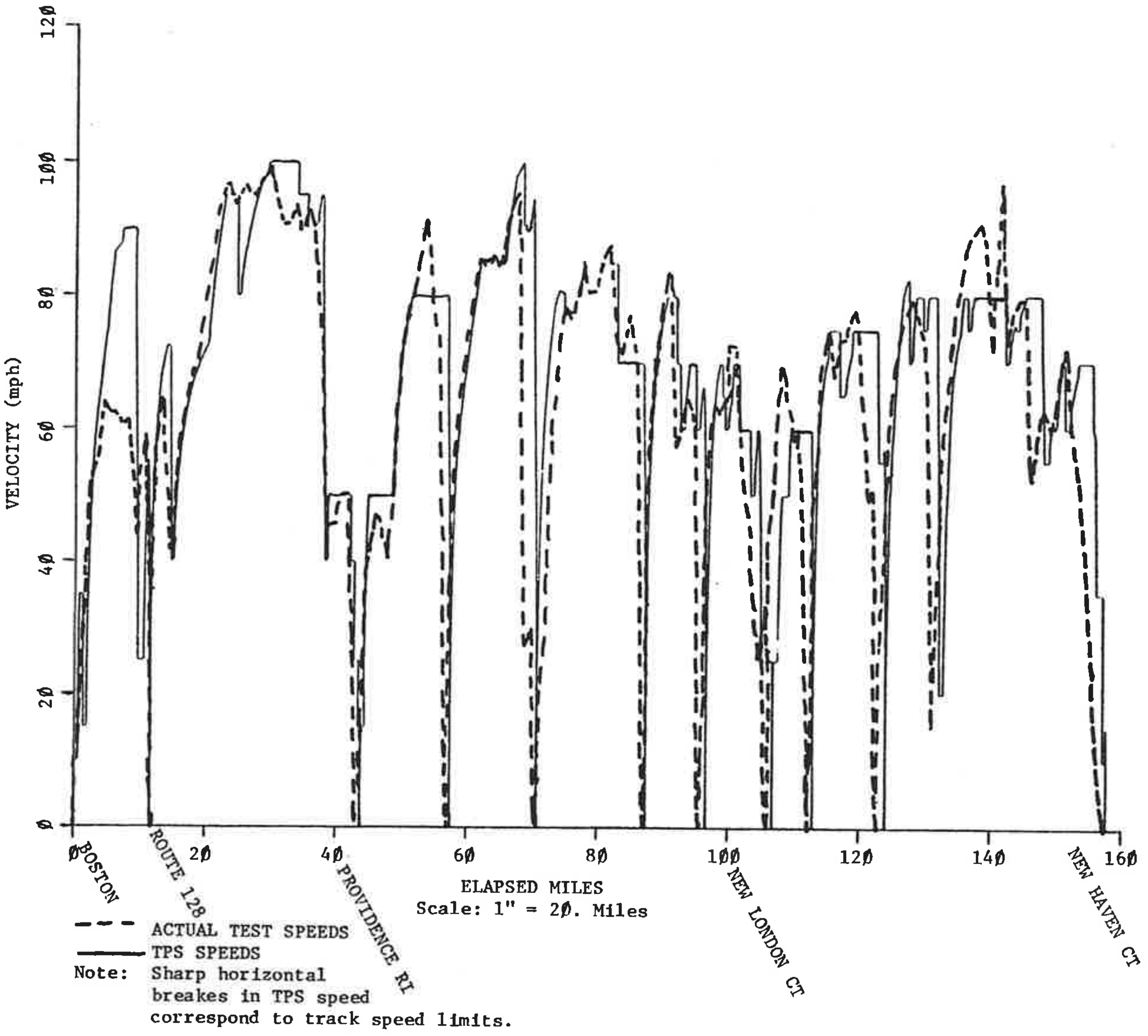


FIGURE 5-8. COMPARISON OF TEST AND TPS SPEED - DISTANCE PROFILES TEST RUN #3

APPENDIX A

TEST PROCEDURES

Test Procedure

Thirty minutes prior to scheduled departure

1. Check the speed, power meter, automatic brake, and throttle position recorders for adequate paper supply and mark all three tapes with the following information:
    1. Run #
    2. Train #
    3. Date
    4. Exact time (hour/min/sec)
    5. The notation "begun run," the location, and a "↓"
2. Record the elapsed time meters for low idle, idle, dynamic brake, and total time and record the time these readings are taken.
3. Record the fuel totalizer reading and the time the reading is taken.
4. Record the engine number.
5. Record the train number.
6. Record the consist information.
7. Record the moisture of the rail (wet or dry).
8. Record the reading on the fuel tank gauge.
9. Record the readings on the fuel flow meters and the time the readings are taken.
10. Check chart recorders for paper movement.

At departure

1. Record the departure time.
2. Record the elapsed time meters and fuel totalizer readings.

Every 10 minutes after departure

1. Record the time and location.
2. Record the elapsed time meters and fuel totalizer readings.

Every 10 miles

1. Record the location, exact time (hour/min/sec), and the speed of the train.

At all station stops

1. Record the arrival and departure times (hour/min/sec) and the station name.

At the destination

1. Record the arrival time, location, and the readings of the elapsed time meters and the fuel totalizer.

2. Mark the speed, power, automatic brake, and throttle chart recorders with the run #, train #, date and location, and by the notation "end" and "↑".

3. Record the fuel meter readings and the time these readings are taken.

4. Record the fuel in the tank.

New Haven only:

5. Obtain copies of the speed recorder tapes.

6. Obtain fuel sample for analysis, number and label by run #, train #, and date.

7. Record amount of fuel added to engine.

8. Remove all chart recorder tapes. (To be done at South Station also if time permits.)

During the test

1. Note any unscheduled delays as to location, time, duration and reason, if available.

2. Include movements against the current of traffic by times and locations.

3. Note any other comments, data exceptions, or the like.

APPENDIX B

DATA ACQUISITION FORM

Run number ________
Train number ________
Date ________

DATA FORM - Amtrak fuel test between New Haven and South Station

General Information Sheet

Data recorder's name ____________________________

Engine #(s) - Lead unit first ________ ________

Consist information (location behind engine consist) - Car number and type

1. ________________
2. ________________
3. ________________
4. ________________
5. ________________
6. ________________
7. ________________
8. ________________
9. ________________
10. ________________
11. ________________
12. ________________
13. ________________
14. ________________

Engineer's name ____________________

Fireman's name ____________________
put a check mark by the individual
who actually operates the engine

Fuel meter readings

_____ minutes prior to
departure __________ (supply)
__________ (return)

_____ after
arrival __________ (supply)
__________ (return)

Fuel in locomotive tank (gal.)

New Haven _______

South Station_______

Fuel added to locomotive tank after arrival at destination

New Haven _______

South Station_______

	Rail Moisture (wet-dry)	Temperature(f)*	Humidity(%)*
New Haven	________	________	________
New London	________	________	________
Providence	________	________	________
South Station	________	________	________

Train orders issued to train and crew	Number	Location delivered
	______	________________
	______	________________
	______	________________
	______	________________
	______	________________
	______	________________

* will be filled in later if information is unavailable to data recorder

Sheet #____

Run number ______
Train number ______
Date

DATA FORM - Amtrak fuel test between New Haven and South Station
meter readings and location and speed checks

	Fuel	Dynamic	Total	Low idle	Idle
Time- ________ Location- ________					
Time- ________ Location- ________					
Time- ________ Location- ________					
Time- ________ Location- ________					
Time- ________ Location- ________					
Time- ________ Location- ________					
Time- ________ Location- ________					
Time- ________ Location- ________					
Time- ________ Location- ________					
Time- ________ Location- ________					

Mile Post	Time	Speed

Comments - Special Events - Unusual Occurrences -

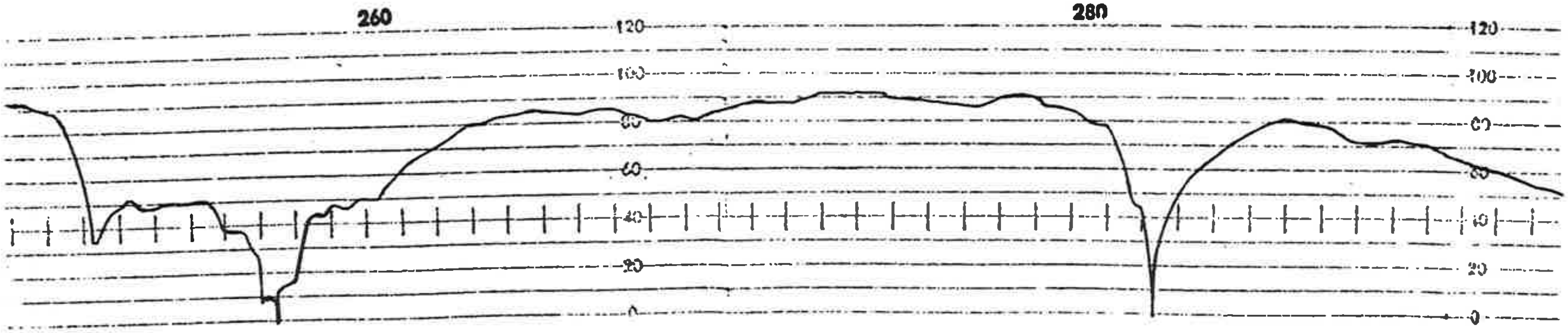
Fuel meter readings

		Supply	Return	KW load
Station	____________	____________	____________	____________
Station	____________	____________	____________	____________
Station	____________	____________	____________	____________
Station	____________	____________	____________	____________

APPENDIX C

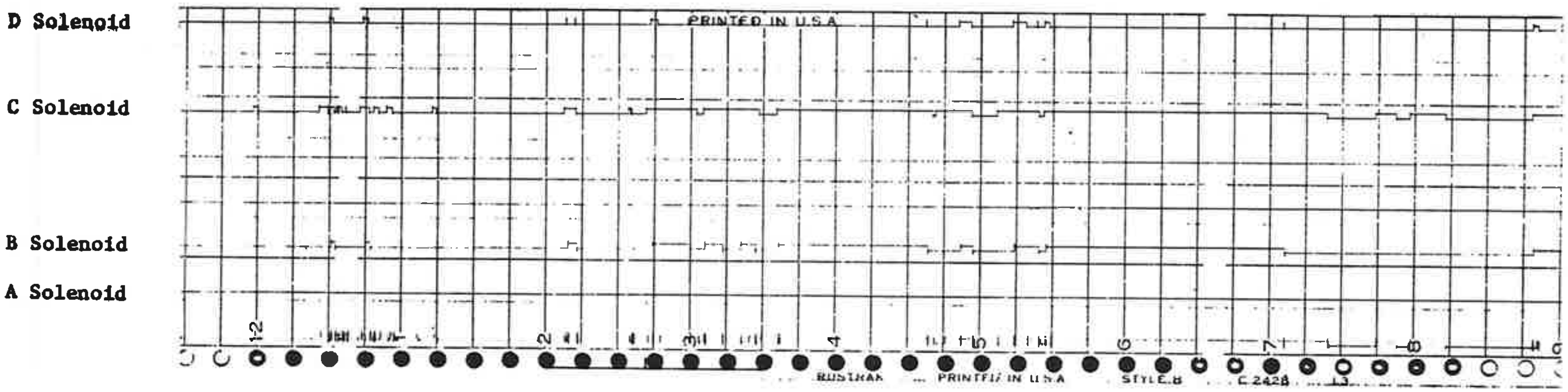
TEST DATA SAMPLES

SAMPLE SPEED RECORDER TAPE
Run No. 24
Train No. 171
Locomotive No. 205
Date: 8/6/80



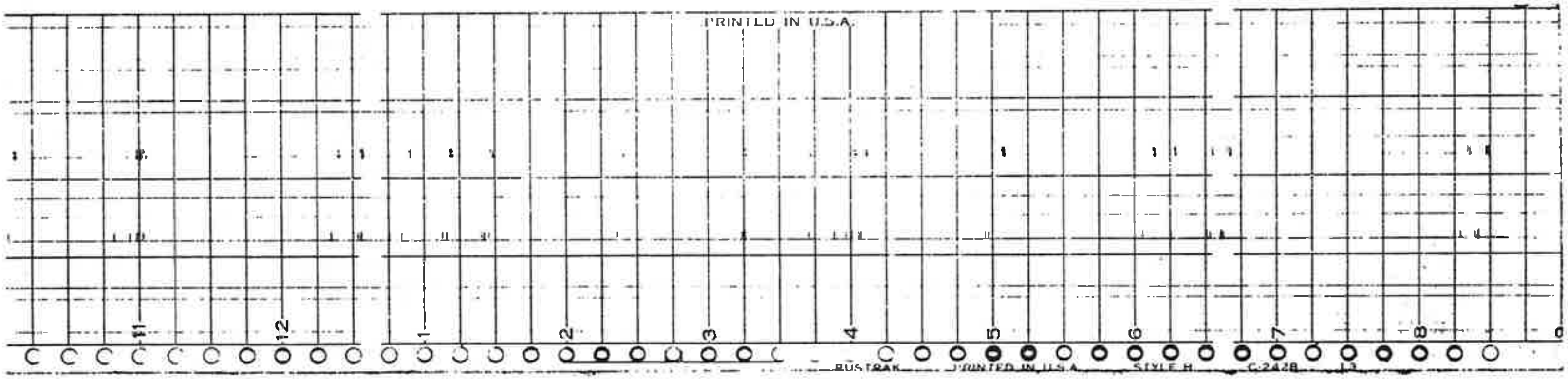
Scale: 1/4 inch per mile

SAMPLE THROTTLE NOTCH APPLICATION TAPE
Run No. 24
Train No. 171
Locomotive No. 205
Date: 8/6/80



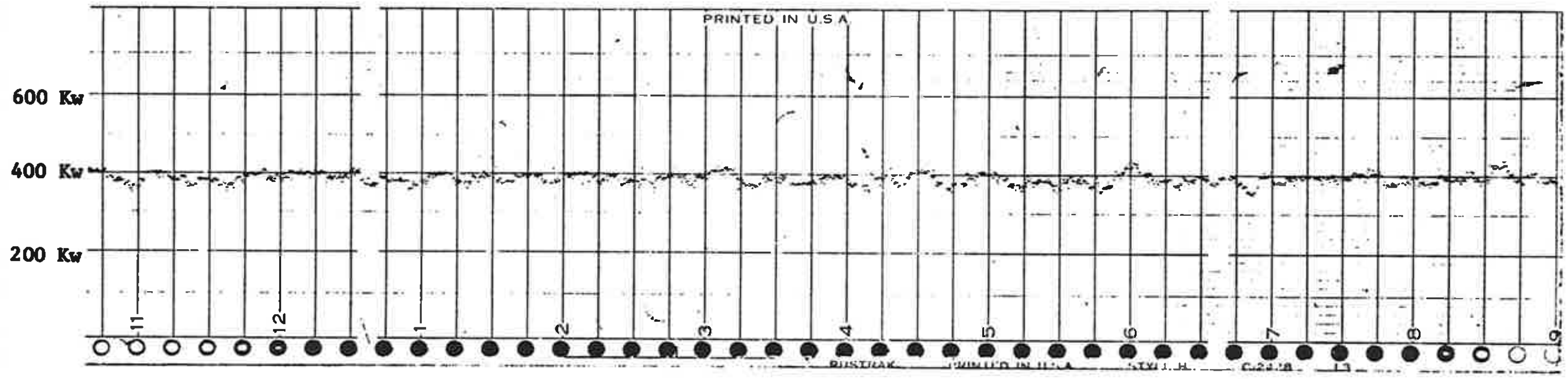
Scale: 12 inches per hour

SAMPLE BRAKE APPLICATION TAPE
Run No. 10
Train No. 195
Locomotive No. 212
Date: 7/23/80



Scale: 12 inches per hour

SAMPLE HEAD END POWER GENERATOR TAPE
Run No. 19
Train No. 174
Locomotive No. 205
Date: 8/1/80



Scale: 12 inches per hour

APPENDIX D

SAMPLE TRAIN PERFORMANCE SIMULATOR OUTPUT LISTING

```
                          RUN SUMMARY


From BOSTON       to NEW HAVEN C  via NORTHEAST CORR

Using Totten equation for streamlined cars

Power consist beginning at BOSTON
 1 Diesel    unit:  F40

Train consist beginning at BOSTON
      7 cars total.


 Elapsed time running: 02:38:52    Average running speed  59.56 mph.
              stopped: 00:09:36    Total miles: 157.70
                       --------
              total:   02:48:28    Average overall speed  56.17 mph.


 Fuel: gallons consumed running:  225.41
       Gallons consumed idling:     4.80
                                  -------
       Total gallons consumed:    230.21

       Cost at  80.00 cents per gallon: $  184.17
```

```
                         TIMETABLE

   From BOSTON        to NEW HAVEN C   via NORTHEAST CORR

   Using Totten equation for streamlined cars

                    CLOCK TIME           ELAPSED TIME    PASSING    TIME
STATION          HRS:MIN   HRS:MIN    HRS:MIN   HRS:MIN  SPEED   STOPPED

BOSTON                     LV 06:00             LV 00:00     0
ROUTE 128      AR 06:19   LV 06:20   AR 00:19  LV 00:20           00:01:06
PROVIDENCE R   AR 06:53   LV 06:57   AR 00:53  LV 00:57           00:04:20
NEW LONDON C   AR 07:55   LV 07:59   AR 01:55  LV 01:59           00:04:10
NEW HAVEN C    AR 08:48              AR 02:48

                    CLOCK TIME           ELAPSED TIME    PASSING    TIME
STATION          HRS:MIN   HRS:MIN    HRS:MIN   HRS:MIN  SPEED   STOPPED
```

ELAPSED TIME IN EACH THROTTLE POSITION

From BOSTON to NEW HAVEN C via NORTHEAST CORR

Locomotive consist F40

THROTTLE POSITION	% OF RATED H.P. AVAILABLE	ELAPSED TIME	% OF TOTAL TIME	FUEL USED
BRAKE	0.	0 hr 20.90 min	12.41%	10.45 gal
1	0.- 5.	0 hr 11.94 min	7.09%	6.08 gal
2	5.- 12.	0 hr 10.28 min	6.10%	5.57 gal
3	12.- 31.	0 hr 10.15 min	6.02%	6.61 gal
4	31.- 46.	0 hr 8.15 min	4.84%	7.00 gal
5	46.- 59.	0 hr 12.64 min	7.50%	13.60 gal
6	59.- 74.	0 hr 8.07 min	4.79%	10.99 gal
7	74.- 89.	0 hr 6.68 min	3.96%	11.73 gal
8	89.-100.	1 hr 10.04 min	41.58%	153.39 gal
IDLE	0.	0 hr 9.60 min	5.70%	4.80 gal
TOTAL		2 hr 48.46 min	100.00%	230.21 gal

ELAPSED TIME IN EACH VELOCITY RANGE

From BOSTON to NEW HAVEN C via NORTHEAST CORR

Locomotive consist F40

VELOCITY RANGE	ELAPSED TIME	% OF TOTAL TIME	FUEL USED
0 - 10 mph	0 hr 16.91 min	10.04%	8.68 gal
11 - 20 mph	0 hr 9.84 min	5.84%	6.05 gal
21 - 30 mph	0 hr 11.81 min	7.01%	9.22 gal
31 - 40 mph	0 hr 7.59 min	4.50%	8.79 gal
41 - 50 mph	0 hr 14.05 min	8.34%	17.69 gal
51 - 60 mph	0 hr 20.21 min	12.00%	30.32 gal
61 - 70 mph	0 hr 25.11 min	14.91%	44.07 gal
71 - 80 mph	0 hr 37.46 min	22.24%	56.78 gal
81 - 90 mph	0 hr 18.13 min	10.76%	34.54 gal
91 - 100 mph	0 hr 7.35 min	4.36%	14.06 gal
TOTAL	2 hr 48.46 min	100.00%	230.21 gal

ENERGY USE SUMMARY

From BOSTON to NEW HAVEN C via NORTHEAST CORR

Locomotive consist F40

Using Totten equation for streamlined cars

COMPONENT	% OF TOTAL FUEL	% OMITTING LOSSES	FUEL USED
Rolling and Bearing Resistance*	6.86%	13.17%	15.79 gal
Flange Resistance*	6.85%	13.15%	15.77 gal
Aerodynamic Resistance*	9.89%	19.00%	22.78 gal
Grade Resistance	10.38%	19.94%	23.90 gal
Curve Resistance	1.00%	1.93%	2.31 gal
Acceleration	17.09%	32.81%	39.34 gal
Transmission Losses	11.33%		26.08 gal
Engine Losses	34.50%		79.43 gal
Idle	2.09%		4.80 gal
TOTAL	100.00%	100.00%	230.21 gal

*"Rolling and Bearing Resistance" consists of the velocity-independent terms in the train resistance equation; "Flange Resistance" is the linear velocity-dependent term; "Aerodynamic Resistance" is the velocity-squared term. These names merely indicate the dominant physical mechanisms conventionally understood to underly each term.

175 copies