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16. Abstract

This research report deals with the Energy Intensity of Intercity Rail Passenger Systems. Included in the energy evaluation are the impacts of operating conditions (speed, load factor) and train consists. The report also documents an extensive list of data used for evaluation purposes. Impact of track on energy intensity is also documented. Several trains are simulated along the New York City to Buffalo Corridor. Increases in energy efficiency due to modernization of rolling stock and improvements of track and service conditions are also analyzed to insure equitable comparison among the competitive modes. The study concludes that: Presently the energy intensity figures are high because the load factor is low; there is a considerable potential for improving values by improving the attractiveness (reduced trip time) of the trains and also by using contemporary rolling stock. It is also concluded that presently, because of the poor track conditions, the maximum potential of the trains (in terms of speed, etc.) cannot be realized. Improved track conditions will enhance block speed which would result in increased rail patronage (consequently higher load factor) and reduced energy intensity. Electric trains were also studied (along NYC to Washington, D.C.) and are quite favorable from an energy intensity viewpoint. The study provides guidelines for energy conservation; will serve the railroad industry, and has a potential for nationwide application. This report represents a comprehensive study in the subject area.

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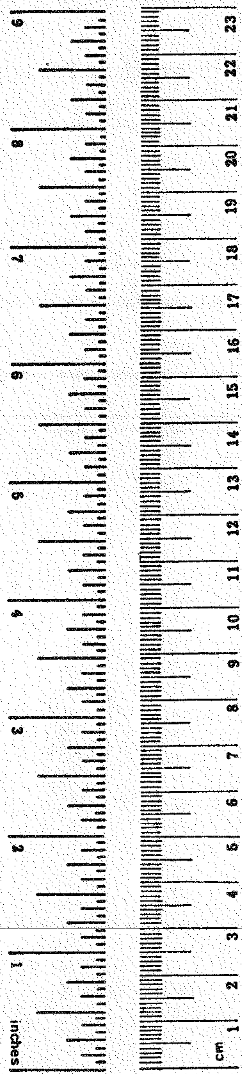
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

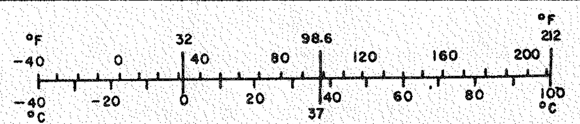
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	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

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



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



METRIC CONVERSION FACTORS

ENERGY INTENSITY OF INTERCITY
PASSENGER RAIL

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EXECUTIVE SUMMARY

This report summarizes findings related to "Energy Intensity of Intercity Passenger Trains". This work is being completed in partial fulfillment of DOT-OS-60124 contract entitled, "Intercity Rail Energy Efficiency for Passenger and Freight Movement". The major objective of the contract is to develop a "Passenger Train Performance Model and a Rail Passenger Demand Model". The Buffalo/New York City Corridor is being considered for modeling and evaluation purposes. The major tasks of the research are outlined as follows:

Task 1. Data Base. Establish a data base to support the construction of the Passenger Train Performance Model, the Rail Passenger Demand Model, and the energy analysis required in this research effort. This shall include, but not be limited to, the following:

(a) Review and document the results of existing train performance models and rail passenger demand models.

(b) Update the state-of-the-art (SOA) and document the results of the rail rolling stock equipment being developed in various parts of the world.

(c) Update to 1975, the 1968 data on intercity travel in New York State for all transportation modes with concentration on the Buffalo-New York City route.

(d) Update SOA and document energy studies related to energy efficiency for intercity passenger and freight movements for various transportation modes.

(e) Update SOA and document train resistance equations.

(f) Collect data on the quality of passenger service provided by various railroads in the New York State region.

(g) Collect data on railroad operating characteristics within the state of New York with particular emphasis on the Buffalo to New York City route.

Task 2. Passenger Train Performance Mathematical Model

Develop a passenger train performance mathematical model using the Buffalo/New York City route as the scenario for the development.

Task 3. Systems Analysis

Develop a quantitative understanding of the impact on trip time and energy efficiency due to the modernization of rolling stock.

Task 4. Rail Passenger Demand Model

Improvements to the rail passenger system which would result in decreased trip times, lower fares, increased trip frequency and improved passenger amenities could result in increased patronage levels. Therefore, a passenger demand analysis model shall be constructed to assess the increased rail passenger demand which may be realized as a result of the improvements which could come about under service changes, or changes in operating characteristics that result in service improvements.

The Buffalo/New York City route shall be used to construct this model.

Task 5. Passenger Energy Efficiency

Using the demand and performance models from Work Tasks 2 through 4, the contractor shall determine and evaluate the passenger energy efficiency of train service in the New York City to Buffalo Corridor.

This report is being prepared in response to Tasks 3 and 5.

Figure i shows the flow of activities for the accomplishment of the aforementioned tasks. This figure also describes the role played by the New York State Department of Transportation (NYSDOT). The major task handled by the NYSDOT was Task 4 which pertained to the development of

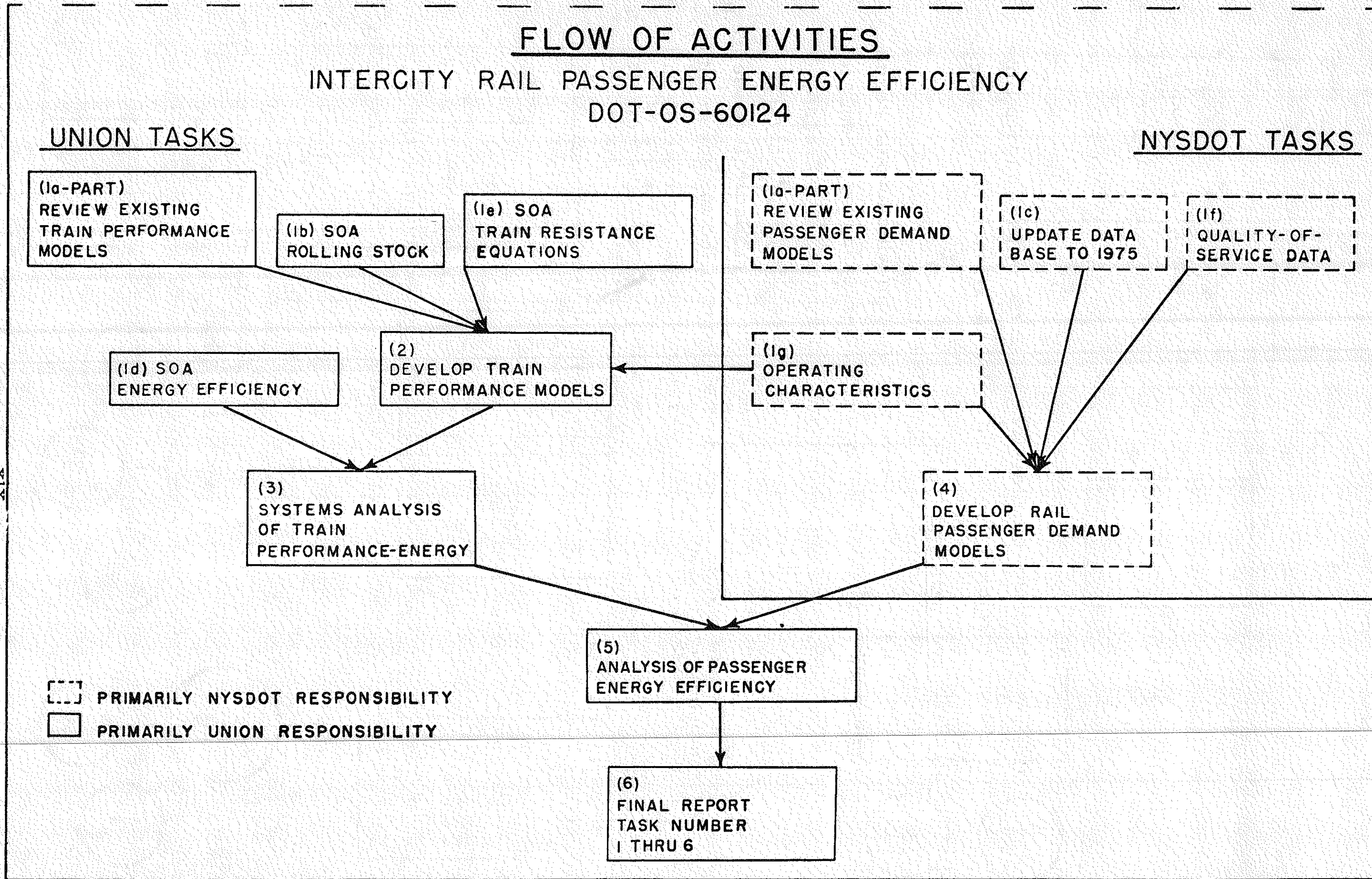
FLOW OF ACTIVITIES
INTERCITY RAIL PASSENGER ENERGY EFFICIENCY
DOT-OS-60124
UNION TASKS
NYSDOT TASKS
(1a-PART) REVIEW EXISTING TRAIN PERFORMANCE MODELS
(1b) SOA ROLLING STOCK
(1e) SOA TRAIN RESISTANCE EQUATIONS
(1a-PART) REVIEW EXISTING PASSENGER DEMAND MODELS
(1c) UPDATE DATA BASE TO 1975
(1f) QUALITY-OF-SERVICE DATA
(1d) SOA ENERGY EFFICIENCY
(2) DEVELOP TRAIN PERFORMANCE MODELS
(1g) OPERATING CHARACTERISTICS
(3) SYSTEMS ANALYSIS OF TRAIN PERFORMANCE-ENERGY
(4) DEVELOP RAIL PASSENGER DEMAND MODELS
(5) ANALYSIS OF PASSENGER ENERGY EFFICIENCY
(6) FINAL REPORT TASK NUMBER 1 THRU 6
PRIMARILY NYSDOT RESPONSIBILITY
PRIMARILY UNION RESPONSIBILITY

FIGURE i

SYSTEMS ANALYSIS INTERCITY PASSENGER RAIL OPERATION NYC TO BUFFALO CORRIDOR
DOT—OS—60124

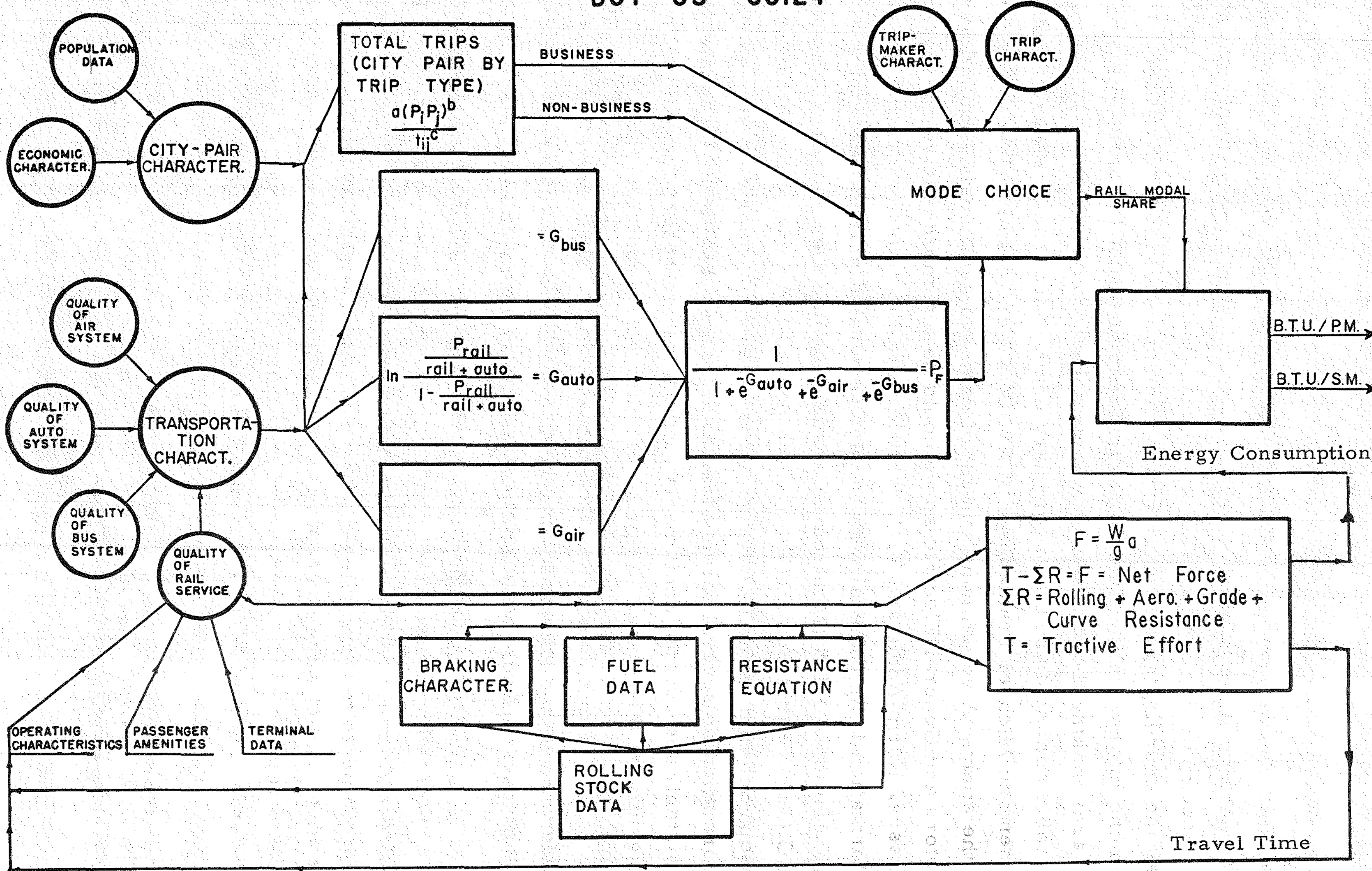

FIGURE ii

the 'Rail Passenger Demand Model'. Subtasks 1(a), 1(c), 1(f), and 1(g) were also accomplished by the NYSDOT. Figure ii shows the methodology utilized for accomplishing the goals of the study. Dr. David Hartgen, of NYSDOT, was the coordinator of research activities on behalf of the NYSDOT. His genuine interest in the Union College Transportation Program was a key factor towards making these research efforts a real success. Dr. Hartgen provided valuable comments on the preliminary draft. Messrs. Nathan Erlbaum, Gary Cohen and Michael Trentacoste of NYSDOT were also involved in certain facets of the study. A voluminous amount of data was generously supplied by General Motors and General Electric so we could do a comprehensive energy analysis. Messrs. Norm Addie and T. C. Whittle were the coordinators for the source information from General Motors, and General Electric, respectively. Mr. L. Y. Smith of MLW (Montreal, Canada) supplied the necessary information on LRC (Light Rapid Comfortable) which proved to be useful for the study. Mr. Joseph Schmidt of AMTRAK also helped greatly by supplying us with the detailed information on several foreign trains. Messrs. Axel Rose (graduate research assistant) and Joseph Santamaria (undergraduate research assistant) worked diligently on this study. Their contributions are appreciated.

The author would like to thank ERDA* for supporting the summer conference on the Effects of Energy Constraints on Transportation Systems. The discussions held were intellectually stimulating and also aided in this study.

Last but not least, considerable help, guidance, and encouragement were rendered by the contract monitor, Mr. Alexander Lampros of the Federal Railroad Administration. Mr. Lampros provided valuable suggestions for improvements to the earlier drafts. His patience and cooperation throughout the study period were of great help. He also supplied us with copies of recent related reports which were funded by FRA. The Office of the University Research (Federal DOT) supplied the funding for the project.

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*The U.S. Energy, Research and Development Administration which is now the U.S. Department of Energy.

CHAPTER 1.00

1.00 INTRODUCTION

Presently, the transportation sector accounts for nearly 53 percent of the total petroleum consumption in the U. S., nearly 40% of which is imported. This could well lead to untenable situations such as a deficit in our balance of payments, political unrest, and instability in our economic structure. For the U. S. alone, the cost of imported oil was roughly $7.3 billion in 1973 and approximately $45 billion in 1977. The long term impacts of such importation could be devastating. Several factors have contributed toward the high use of petroleum in the U. S. One factor is that transportation demand (in miles or passenger miles) has been increasing at a faster rate and the second factor is that there has been a considerable modal shift towards inefficient modes from an energy intensity viewpoint, since the post-World War II era. Mass transit and railroads have been losing their share of the market, while autos and planes have seen considerable growth. These factors have resulted in a tremendous increase in the use of petroleum which is a limited resource. For the near term, our strategies must be toward conservation and shifts to energy efficient modes. The crude analysis done on the subject of energy efficiency of passenger rail systems shows that rails are 2 to 5 times more efficient than the competing modes. Unfortunately, energy efficiency figures available so far vary from author to author because of the assumptions, methodology, and analysis of techniques by which they are derived. To give an added impetus toward the rehabilitation and modernization of the intercity rail system and to make it a national priority, credible data on energy efficiency must be made available to planners, engineers, federal and state officials and the general public. Revitalization of our railroads must be one of our national priorities because railroads offer economic and environmental advantages with respect to land use, air pollution, noise levels, energy efficiency and conservation, resource allocation, safety and cost per passenger mile of movement. The major goal of this study is to establish ground rules, document data sources and compare energy efficiency figures under various service and operating conditions. Since much of the present equipment on the rail system is outdated, it is important to study the impacts of current existing technology on energy efficiency figures for comparison purposes.

1.10 GOALS OF THE STUDY

Our main goal relating to the current research is the estimation of the present and foreseeable energy intensity figures for intercity passenger systems under variable service and operating conditions.

By energy intensity, we mean the amount of energy expended in moving a unit person-mile. Only the operational parts of the energy are considered here. The other parts such as maintenance and construction are not considered in this study. Energy intensity depends upon a host of factors which can be categorized among the following two subcategories:

- Technological Factors
  - Type of power plant, electric, diesel-electric, horsepower, tractive effort characteristics, weight to power ratio, etc.
- Operational Characteristics
  - No. of speed changes, average speed, maximum speed, dwell time, load factor, trip length, etc.

Our goal is to understand, in a quantitative matter, the impact of technological and operational characteristics upon EI values. It is hoped this will provide us with some insights regarding the EI values along certain corridors of the U.S. Our goal is to provide answers to the following questions:

A. What is the impact of railroad technology upon EI values?
By keeping load factor and trip configuration (level of acceleration and deceleration, cruising velocity, % time spent in each mode) constant, how do the EI values vary from one train consist to another? What kind of improvements could be expected in the EI values if we modernize the current rolling stock? Various types of contemporary rolling stock (Swedish RC4A locomotive hauling Amfleet cars, French CC 14500 locomotive hauling Amfleet cars) are being tested for possible deployment in the Northeast corridor, Before these systems are deployed, it is important to understand their energy performance characteristics.

B. What is the impact of operating characteristics upon EI values? Our goal is to derive credible EI values. Hence, the impact of the real environment must be brought into the picture. Inclusion of operating characteristics (speed characteristics, dwell time, load factor, trip length, acceleration and deceleration characteristics) will help us come up with realistic EI values. At the same time, we could learn some lessons on conserving energy. Speed characteristics are partially dictated by the quality of the track so it is important to study what impact the improvements of track would have upon EI values.

C. What is the energy intensity of competing intercity passenger transportation modes? It is important to understand EI values under current operating conditions. Speed, load factor and the description of the current fleet mix (No. and type of airplanes presently in use, No. and types of automobiles) are the major factors which influence the EI values. The goal of this section is to tabulate EI values under the existing conditions.

D. What are the potential areas for further research directed toward improving the EI values of intercity passenger rail systems? Here, we are concerned with improving the state of the art in areas related to 'Energy Intensity' of intercity passenger rail systems.

1.20 ORGANIZATION OF THE REPORT

This report is divided into a total of 10 chapters which are organized in the manner shown in Figure 1.10. Following is a brief description of each of the chapters.

Chapter 2 deals with the methodology on the energy intensity for various train consists. Energy Intensity (EI) is defined by the following expression:

$$EI\ (B.T.U./P.M.) = \frac{\text{Energy used in B.T.U.}}{\text{Passenger miles (PM)}}$$

Two types of approaches are discussed: the first relates to the statistical approach in which one has information on the yearly fuel consumed over a given route (or corridor) and data on passenger-miles; the second approach relates to calculating energy based upon engineering relationships while the passenger miles are predetermined based upon load factor and seating capacity information. Presently, both methods are in use and the purpose of this chapter is to discuss the pros and cons of each approach. This report utilizes the engineering approach (Chapters 4, 5, 6, 7, and 8) in greater depth.

For the deployment of the engineering approach, data related to technological characteristics of various trains are needed. These are described in Chapter 3. This section deals with the following train consists:

- F-40PH/Amfleet
- SDP-40F/Amfleet
- P30CH/Amfleet
- Turboliner
- E-8/Refurbished
- LRC
- French CC 14500/Amfleet

Physical, mechanical and performance characteristics are provided for the above trains. Data on various train configurations (No. of cars being hauled) are also provided. These trains differ in type of service (parlor cars, cafe cars, dining cars, luggage accommodation, etc.) and also the type of locomotive utilized for propulsion purposes.

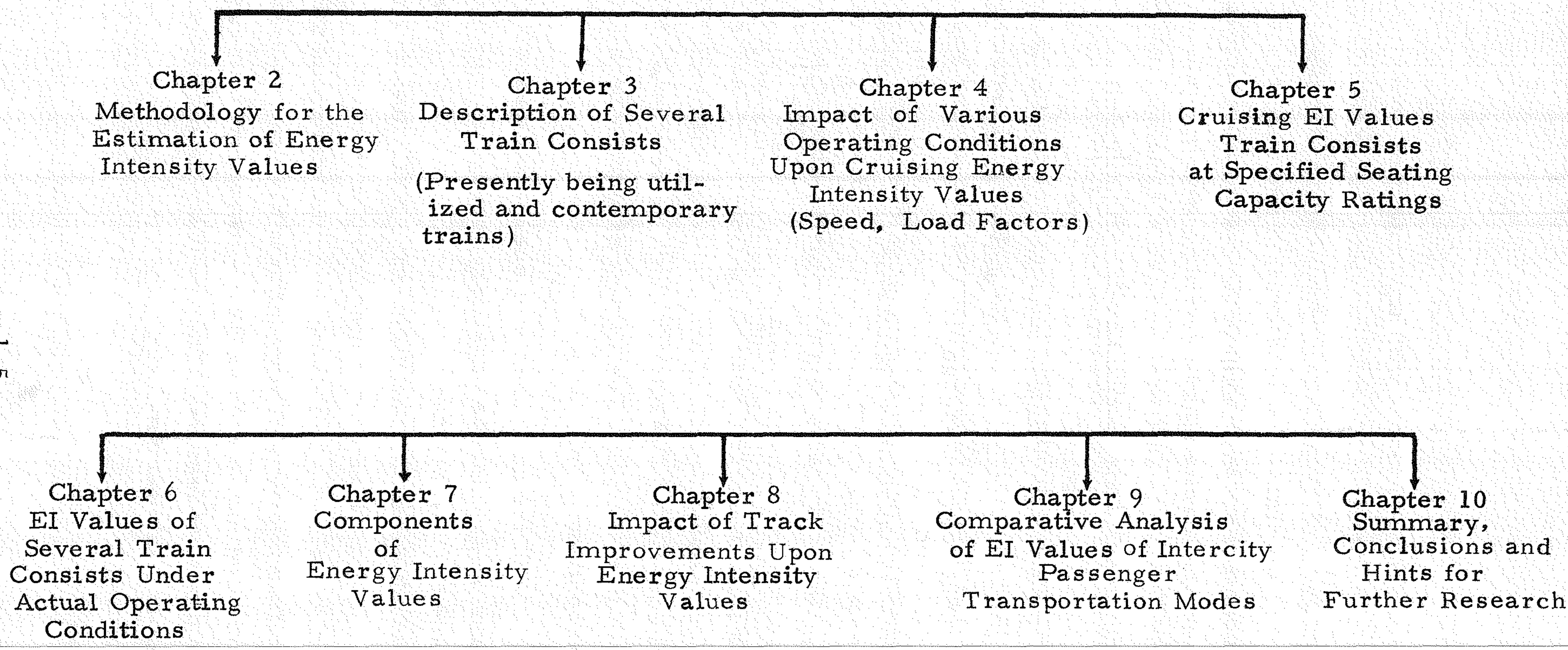

Figure 1.10. Organization of the Report

Chapters 4, 5, 6, 7, and 8 deal with the impact of operational characteristics upon EI values for several train consists. Speed and load factor are the major influencing factors upon EI values which are discussed in Chapters 4 and 5. By neglecting the impact of acceleration and deceleration, we can assume the trip of constant speed profile (cruising mode) which is varied. The relationship between EI values and cruising speed is documented in graphical and tabular form. Load factor and train consists are varied for several trains and the results are documented. Chapter 4 deals basically with the impact of cruising speed upon EI values for several trains estimated under various load-factor conditions. Chapter 5 deals with the same analysis but considers a specified seating capacity rating which varies from 200 to 350 passengers in increments of 50 passengers.

Chapter 6 is meant to provide us with EI values under actual operating conditions (speed restrictions, dwell time, actual No. of accelerations and decelerations, etc.). Several trains were simulated along the NYC-Buffalo and NYC-Washington routes. These trains were simulated using the existing operating conditions (speed restrictions, dwell time, load factor). Similar results were also documented for EI values for cases with load factors of 50 and 100 percent. Comparison of results of cruising versus actual operations are also discussed in this section. The impact of actual operating conditions upon EI values is expounded upon.

Chapter 7 deals with the components of energy such as acceleration, thermal losses, transmission losses, auxiliary losses, aerodynamic drag, rolling resistance and track resistance. Again, these components were studied for several trains which were simulated along the NYC-Buffalo and NYC-Washington routes. Our goal here is to discover the impacts of various conservation options on EI values. One of the technological options relates to the improvement of the drag coefficient which affects the drag resistance of the train. The operational option relates to the improvement in the load factor which depends upon a host of factors. The results relating to components of energy are provided in a tabular form.

Chapter 8 deals with the impact of track characteristics upon EI values. Track affects the allowable speed for the given train which in turn influences the demand and the load factor. The impact of track improvements upon EI values is documented for several trains.

Chapter 9 deals with a comparative analysis of EI values for several intercity passenger modes of transportation. Efforts are made to document the ground rules (load factor, speed) wherever possible. The key output of this chapter is a table which documents the EI values for several transportation modes under current and full load factor conditions. An attempt is also made to document an historical variation in EI values for each mode.

Chapter 10 contains a summary and concluding remarks. It also deals with future research needs.

Various appendices are also included to document the data base and the background information utilized for this study.

2.00 METHODOLOGY FOR THE ESTIMATION OF ENERGY INTENSITY VALUES

2.00 METHODOLOGY FOR THE ESTIMATION OF ENERGY INTENSITY VALUES

In this chapter, an explanation of methods for estimating energy intensity figures is provided. The data related to each method are also indicated. An attempt is also made to explain the pros and cons of the methods presently being employed.

Section 2.10 explains the definition of energy efficiency as it relates to various transportation systems. Section 2.20 explains the methodology for estimating energy intensity (EI) values. Section 2.30 deals with the comparative analysis of two methodologies (statistical and engineering approach) generally utilized for estimating EI values. Subsection 2.35 deals with the cruising analysis which is a subset of the engineering approach. Section 2.40 highlights the findings of this chapter.

2.10 Energy Efficiency of Transportation Modes - Definition

Efficiency in a general manner is defined as follows:

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}}$$

$$\text{Energy Efficiency}^{*} = \frac{\text{Transportation Output}}{\text{Energy Input}} = \frac{\text{Passenger Miles}}{\text{Energy Input (in B.T.U.)}}$$

Energy intensity is the inverse of energy efficiency and is defined in the following manner.

$$\text{Energy Intensity} = \frac{\text{Energy Input}}{\text{Passenger Miles}}$$

One way to define transportation output is by means of passenger-miles for passenger operation, and ton-miles for freight operation.

*Serious questions have been raised by proponents of airlines and trucking associations regarding this measure because it does not take into account the quality of service parameters such as travel time, convenience, reliability, etc. A ton of coal shipped through barges at a speed of 5 miles per hour is not equivalent to a ton of flowers moved across the country in a controlled environment from Los Angeles to New York. These are real issues which are important but cannot be addressed within the scope of this study.

Energy input is defined as the energy (converted into British Thermal Units) used by the particular modes for moving people and/or freight. On an aggregate level, the energy used may be the total amount of energy used in a year for moving a certain number of passenger miles for the rail operation. On the other hand, at a micro level, the energy expended may be the amount of fuel utilized to run a given type of train between a certain city pair under certain operating conditions such as load factor and speed. *It is important to note that the energy in the above equation is only the 'operational energy' which is usually accounted for the efficiency purposes. Other energy utilizations for purposes such as maintenance and construction (or indirect energy)* are also important but cannot be treated adequately at the present time because of the limitation of the resources. The transportation output would be

$$\begin{pmatrix}\text{Transportation}\\ \text{Output}\end{pmatrix} = (\text{no. of passengers}) \times (\text{route distance})^{\#}$$

Both the micro and macro approaches are valid and will be discussed in subsequent sections.

Another point which needs to be made relates to the fact that certain propulsion plants use electric energy (Metroliners, E-60-CP-General Electric Locomotive) and under those conditions, the energy (fuel, nuclear power, coal, etc., converted to B. T. U.) is measured at the input of the power plant which may be nearly two and a half times* the energy (electrical) needed for the given transportation propulsion system. It is recognized that the source energy (input to the power plant) may not necessarily be petroleum based.

2.20 Methodology for the Estimation of Energy Intensity Figures

There are basically two methods by which the energy intensity values (for any mode) can be estimated. The following paragraphs summarize some of the pros and cons of each method.

---

* For the analysis of this research, the efficiency of power plant and transmission is estimated at 35% and 95% respectively.

\# Varies from mode to mode. Planes usually fly direct whereas barges have high circuity.

A. Statistical Method

In this method, the gross figures are used for fuel and passenger miles (or ton miles) for the particular mode. For example, the American Public Transit Association maintains yearly data on passenger miles and energy utilized (KWH or gallons of diesel and gasoline) for its member transit organizations. Given these data, energy intensity can then be calculated as follows:

$$EI = \frac{\text{(Fuel Used in B. T. U. for a particular year)}}{\text{(Passenger Miles for the same year)}} \qquad (2\text{-}1)$$

The data on passenger miles are usually not directly available, but can be calculated in the following manner:

$$\text{Passenger Miles} = \text{(No. of Passenger Trips)} \times \text{(Average Trip Length)} \qquad (2\text{-}2)$$

or

$$\text{Passenger Miles} = \text{(Vehicular Miles)} \times \text{(Average Load Factor)} \times \text{(Average No. of seats)} \qquad (2\text{-}3)$$

In equation (2-2), trip length is an unknown, while in the third equation, (2-3), the load factor is an unknown parameter. Depending upon the assumptions of these parameters, passenger miles can be estimated.

For statistical purposes, we need the data base as mentioned in the preceding paragraph. The Interstate Commerce Commission and the individual railroad companies such as AMTRAK and Southern Railway are the major sources of required data needs. Also, the Transportation Association of America publishes a report entitled "Transportation Facts and Trends", which may serve the purpose of our data needs.

Most of the data mentioned earlier are on a national basis (gross statistics) and provide us with energy intensity values for a mixed fleet (for example, different types of train consists over different trip lengths with varying load factors and varying operating conditions). The quality of the data rests somewhat upon the particular organization depending upon the accuracy of the accounting procedures.

B. Engineering Methodology

This approach is based upon transportation mode characteristics (type of vehicle), operating characteristics (speed, dwell time, number of speed changes) and trip characteristics (trip length, load factor). The vehicles are simulated over a given trip and the energy demand is estimated from engineering relationships. Figure 2.10 shows the engineering methodology utilized for evaluating trains from an energy intensity viewpoint. The list of symbols used in the figure is as follows:

F = Net tractive effort = $T - R_t$

W = Total weight (including rotational) of the vehicles (including locomotive) (or a system of vehicles) in pounds = $\sum_{i=1}^{n} W_i$

a = Acceleration in ft/sec^2

T = Tractive effort (applied) at the wheels in pounds

R_t = Net resistance in pounds

W_i = Weight of the i-th vehicle

n = No. of vehicles (No. of cars + caboose + no. of locomotives)

V = linear velocity of the transportation system in miles per hour

Given the velocity profile of a given trip, we can calculate the rail horsepower in the following manner.

$$\text{Rail horsepower} = \frac{(T)\ (V)}{375} \qquad (2\text{-}4)$$

Given the rail-horsepower, and the operating velocity, the input fuel rate* can be calculated as shown in Figure 2.20. The energy intensity can then be calculated from the following equation.

$$\text{B.T.U./P.M.} = \frac{(\text{Fuel rate in gallons/hr}) \times (\text{B.T.U./gallon})}{(\text{Speed in miles/hr}) \times (\text{No. of seats}) \times (\text{Load Factor})} \qquad (2\text{-}5)$$

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*Most of these data are supplied by the manufacturers. For complete details see Reference 28.

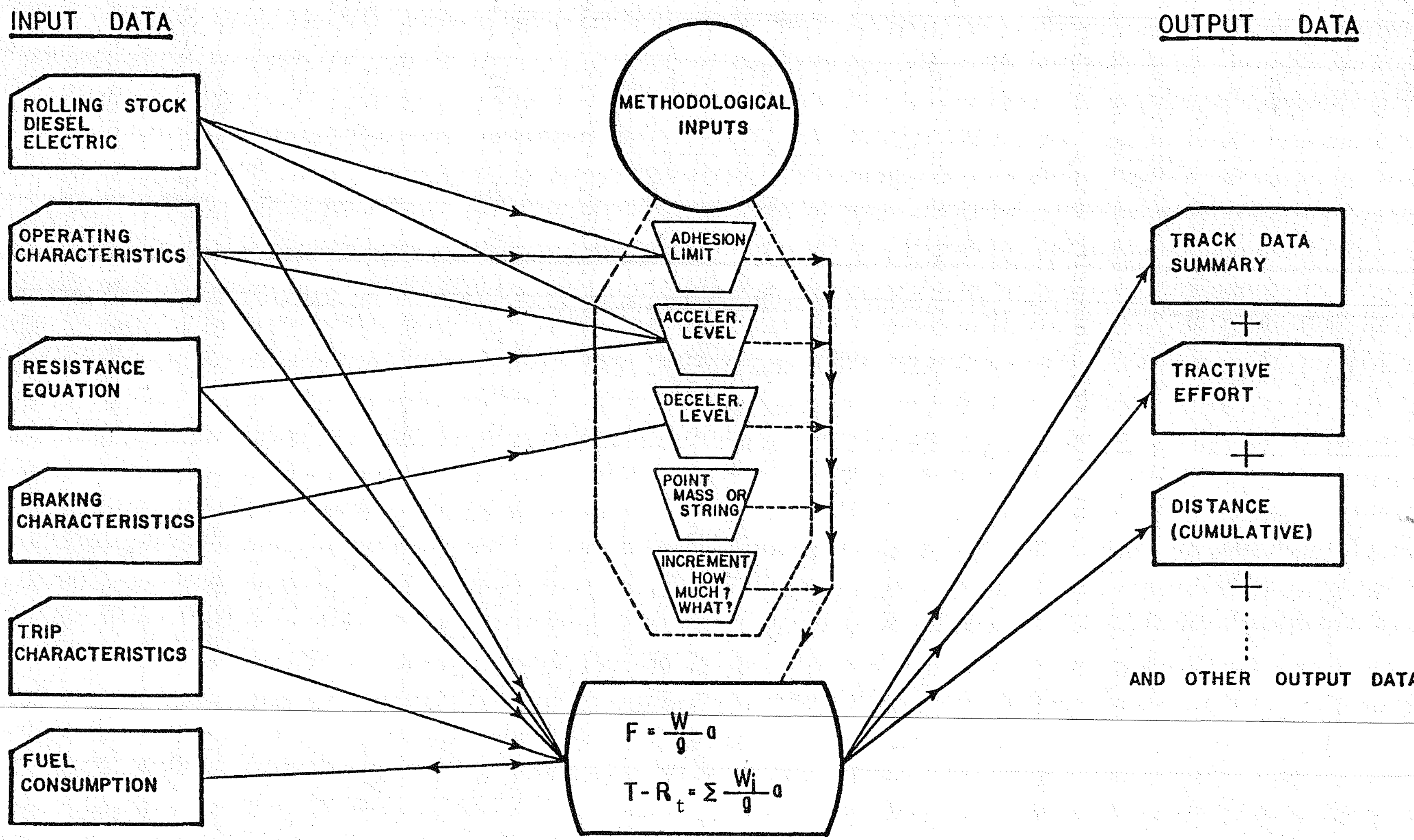
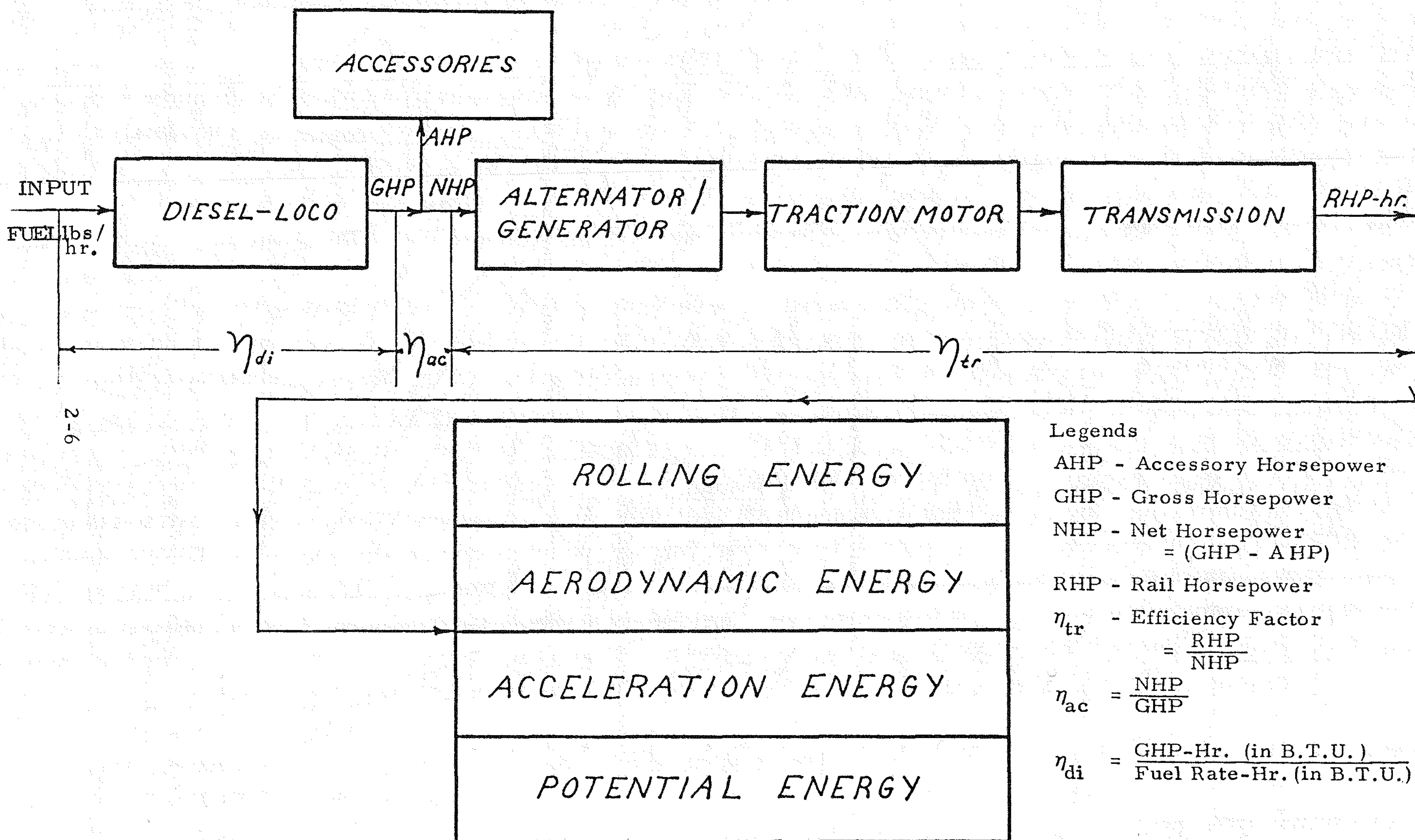


FIGURE 2.10
UNION COLLEGE TRAIN PERFORMANCE CALCULATOR



Legends

AHP - Accessory Horsepower

GHP - Gross Horsepower

NHP - Net Horsepower = (GHP - AHP)

RHP - Rail Horsepower

η_{tr} - Efficiency Factor $= \frac{RHP}{NHP}$

$\eta_{ac} = \frac{NHP}{GHP}$

$\eta_{di} = \frac{\text{GHP-Hr. (in B.T.U.)}}{\text{Fuel Rate-Hr. (in B.T.U.)}}$

FIGURE 2.20

COMPONENTS OF ENERGY (ACCELERATION OR CRUISING)

The above equation provides an instantaneous EI value which could be accumulated over the given trip and then the trip average EI* values could be established. This method is highly data-intensive and a considerable amount of labor is needed for obtaining the necessary data base and analyzing it for attaining the estimates of energy intensity figures for passenger and/or freight movement. The representative kinds of data needs follow:

(1) Vehicle Physical Characteristics

- Length
- Weight
- Height
- Width
- Number of seats

(2) Vehicle Mechanical Characteristics

- Type of propulsion system
- Max. gross horsepower
- Types of brakes
- Axle arrangement
- Type of transmission

(3) Vehicle Performance Characteristics

- Maximum speed
- Fuel rate at various output levels including idling
- Transmission efficiency
- Tractive effort characteristics

Chapter 3.00 and Appendix IV contain the pertinent information related to technical and performance characteristics of the passenger train consists. Readers who are interested in further details should refer to Reference [28].

*The trip average EI values do take into account the impact of idling due to station stops. The fuel consumption rates due to idling are usually provided by the manufacturers. For details see Reference [28].

2.30 COMPARATIVE ANALYSIS OF STATISTICAL AND ENGINEERING APPROACHES

A comparative chart on the pros and cons of utilizing the statistical or engineering approach follows.

Statistical Approach	Engineering Approach
1. Gross national estimates for energy intensity values are obtained.	1. Micro energy intensity values for the particular environment (trip, type of vehicle, load factor, speed) can be estimated.
2. Takes into account unknown non-quantifiable inefficiencies due to idling, circuitous routes, empty vehicle movement, etc.	2. Considerable amounts of data are needed to account for inefficiencies due to idling, circuitous route, empty vehicle movement, etc.
3. Input data can be established with some effort.	3. Input data are labor intensive and require considerable time and effort.
4. Energy intensity figures are not generally applicable for a particular situation (city-pair).	4. Energy intensity values can be estimated precisely to suit the given environment.
5. Energy intensity values are not explicitly affected by the aerodynamic and rolling characteristics of the vehicle.	5. Energy intensity values are sensitive to the aerodynamic and rolling characteristics of the vehicle (input to the calculations).
6. No meaningful analysis can be performed to study the impact of improved technology upon energy intensity values.	6. Impact of improved technology (reduced weight, lower aerodynamic drag, etc.) can be evaluated quantitatively.
7. Models do not have to be validated.	7. For real life purposes, engineering models should be validated by collecting relevant fuel data and comparing them with the mathematical models.
8. Effect of trip length and load factors cannot be evaluated explicitly.	8. Trip length and load factors are independent input parameters rather than inherent parameters in the model.

A somewhat simpler method for estimating energy intensity is the cruising energy intensity method which is a subset of the engineering methodology. A brief description of the method follows.

2.35 Cruising Energy Intensity Analysis

In this method, the vehicle is simulated such that it is moving at a constant speed on a level tangent track. No acceleration or deceleration is considered.

In order to illustrate the above method, let us assume that the resistance* of a given transportation system (i.e., locomotive pulling a set of cars) is given by the following equation:

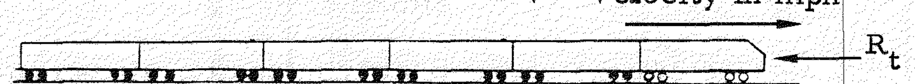


Figure 2.30 Resistance to a Given Set of Train Consist (2-6)

$$R_t = \text{Resistance in pounds}$$
$$= A_1W + A_2V + A_3VW + A_4V^2$$

where A_1, A_2, A_3, and A_4 are constants, V is the velocity in miles per hour and W is the weight of the system (usually in tons). Let us assume that the tractive effort supplied by the power plant (locomotive) is T, then

$$T = R_t \text{ (for equilibrium -- no acceleration)}$$

or

$$T = A_1W + A_2V + A_3WV + A_4V^2$$

$$RHP = \text{Rail horsepower} = \frac{(T)\ (V)}{375}$$

---

*The resistance equation was first published by Davis and has since been updated. For details refer to Appendix IV.

Knowing the RHP, fuel rates can be estimated. Let the fuel rate be Q gallon/hr. Then the energy intensity is given by

$$\text{B.T.U./P.M.} = \frac{(\text{Q in gallon/hr}) \text{x} (\text{EC in B.T.U./gallon})}{(\text{No. of Pass.}) \text{ x } (\text{V})}$$

$$= \frac{(\text{Q}) \text{ x } (\text{EC})}{(\text{No. of Seats}) \text{ x } (\text{Load Factor}) \text{ x } (\text{V})}$$

where

EC = energy content of the fuel being utilized by the power plant (in B.T.U./gallon)

= 138,700 B.T.U. for diesel engine

= 125,000 B.T.U. for gasoline engine

In the above equation, velocity V is varied and Q is obtained accordingly which allows us to plot B.T.U./P.M. as a function of cruising velocity V expressed in miles per hour.

For longer distance trips, cruising energy intensity provides a close approximation to the actual conditions. In order to get a more accurate energy intensity value, we need to know the number of accelerations and decelerations, dwell time, allowable speed, for the given trip. To obtain a crude approximation, this method is the best available. Chapters 4.00 and 5.00 provide the results of the cruising analysis. Chapter 6.00 deals with the estimation of EI values under actual operating conditions and compares the results with those for the cruising mode.

2.40 SUMMARY

Energy intensity values can be calculated easily by knowing the total energy usage and passenger-miles over a given period of time. This methodology is defined as the statistical approach which provides us with gross information on EI values (either on a route by route basis or on a national basis depending upon the input parameters) under the current operating and design characteristics. The statistical approach fails to provide us with any quantitative information on EI values on a micro level especially when one is interested in a variety of design (rolling stock) and operating characteristics. The engineering approach can help us learn the impact of various characteristics upon EI values in a quantitative fashion, but this method requires a large data base. A cruising analysis, which is a subset of the engineering approach, requires much less effort to compute, but provides approximate results. How close the cruising results are in comparison with the actual operating conditions is the basis for discussion in Chapters 4, 5 and 6.

3.00 DESCRIPTION OF SEVERAL TRAIN CONSISTS

3.00 DESCRIPTION OF SEVERAL TRAIN CONSISTS

In this chapter, descriptions of the several train consists which are presently being utilized for intercity passengers or which are being contemplated for utilization in the near future are provided. Each train consist is divided into the following three subcategories:

- Physical Parameters
- Mechanical Parameters
- Performance Parameters

Physical parameter characterization entails the following:

- Train Configuration - This parameter characterizes the arrangement of the train with regard to number and types of locomotives and cars. Snack cars, parlor cars, and dining cars are well documented. For example, 1-2C-S means one locomotive pulling two coach cars and one snack car. The type of the locomotive is mentioned in each heading.
- Train length
- Locomotive length
- Car length
- Train weight
- Maximum width
- Locomotive height
- Car height

Mechanical characteristics entail the description of the following:

- Axle arrangement
- Type of propulsion systems
- Maximum gross horsepower
- Maximum net horsepower
- Types of brakes
- Body tilt capability
- Service power

Performance characteristics entail quantification of the following parameters:

- Maximum speed - on level tangent track
- Fuel consumption at rated horsepower
- Power transmission efficiency
- Train resistance
- Maximum tractive effort
- Revenue seats
- Availability of first class accommodations
- Pounds/revenue seat

Sections 3.10 and 3.20 deal with the description of the above characteristics in tabular form.

3.10 DESCRIPTION OF A REPRESENTATIVE SET OF DIESEL/ELECTRIC AND GAS TURBINE TRAIN CONSISTS PRESENTLY BEING USED

- E-8 Refurbished
- F-40/Amfleet
- P30CH/Amfleet
- LRC Consist
- Turboliner

TABLE 3.10a

TRAIN CONSISTS

E-8 Consists

Task I(b)
DOT-OS-60124

	Consist	PR-1	PR-2	PR-3	PR-4	REMARKS
PHYSICAL	Train Configuration	1-2C-1S	1-3C-1S	1-4C-1S	1-5-1S	1-2C-1S, means 1 Loco, 2 coaches, 1 snack
	Train Length	325'3"	410'3"	495'3"	580'3"	
	Loco length	70'3"	70'3"	70'3"	70'3"	
	Car Length	85'	85'	85'	85'	
	Train Weight (loaded) tons	361.05	427.85	494.65	561.45	
	(empty) tons	344.95	406.07	467.11	528.15	
	Max. width	10'8"	10'8"	10'8"	10'8"	
	Loco Height	13'11"	13'11"	13'11"	13'11"	
	Car Height	13'6"	13'6"	13'6"	13'6"	
MECHANICAL	Axle arrangement - loco	A1A-A1A	A1A-A1A	A1A-A1A	A1A-A1A	
	- cars	2-2	2-2	2-2	2-2	
	Propulsion System	DE	DE	DE	DE	D.E. = Diesel Electric
	Max gross Horsepower	2 x1300	2 x 1300	2 x 1300	2 x 1300	
	Max. Net Horsepower	2 x 1125	2 x 1125	2 x 1125	2 x 1125	
	Brakes - loco - car	A(Tr)	A(Tr)	A(Tr)	A(Tr)	A - Pneumatic Powered Braking (Tread Brakes)
	Body Tilt capacity angle -	No	No	No	No	
	Service Power (Kw)	-	-	-	-	
PERFORMANCE	Max Speed m.p.h.	98	98	98	98	
	Max. Fuel consumption gal/hr	141.26	141.26	141.26	141.26	
	Power Trans efficiency @70	87%	87%	87%	87%	Efficiency at 70 mph
	Total Train resistance @70	4515	5144	5773	6402	Resistance at 70 mph
	Max. Tractive effort in lbs	29300	29300	29300	29300	
	# revenue seats	178	242	306	370	
	cafe car	Yes	Yes	Yes	Yes	
	1st Class accomodation	No	No	No	No	
	lb/revenue seat	3875.8	3355.95	3053	2854.9	
	Picture	No	No	No	No	No - Not Available

TABLE 3.10b

TRAIN CONSISTS

F40PH Consits

Task I(b)
DOT-OS-60124

	Consist	F-1	F-2	F-3	F-4	F-5	REMARKS
PHYSICAL	Train Configuration	1-2C-S	1-2C-S-P	1-3C-5	1-3C-S-P	1-4C-S	
	Train Length	311'6"	395'10"	395'10"	482'2"	482'2"	
	Loco length	56'2"	56'2"	56'2"	56'2"	56'2"	
	Car Length	85'4"	85'4"	85'4"	85'4"	85'4"	
	Train Weight (loaded)	311.02 tons	368.52 tons	371.58 tons	429.08 tons	432.14 tons	
	(empty)	290.5 tons	343.5 tons	343.5 tons	396.5 tons	396.5 tons	
	Max. width	10' 8 7/8"	10'8 7/8"	10'8 7/8"	10'8 7/8"	10'8 7/8"	
	Loco Height	15'5 1/4"	15'5 1/4"	15'5 1/4"	15'5 1/4"	15'5 1/4"	
	Car Height	12'8"	12'8"	12'8"	12'8"	12'8"	
MECHANICAL	Axle arrangement - loco	Bo-Bo	Bo-Bo	Bo-Bo	Bo-Bo	Bo-Bo	
	- cars	2-2	2-2	2-2 .	2-2	2-2	
	Propulsion System	DE	DE	DE	DE	DE	
	Max gross Horsepower	3250	3250	3250	3250	3250	
	Max. Net Horsepower	2290	2290	2290	2290	2290	
	Brakes - loco	Dy-A(Tr)	Dy-A(Tr)	Dy-A(Tr)	Dy-A(Tr)	Dy-A(Tr)	Dy-Electric Dynamic Braking A(Tr)-Pneumatic Powered Braking (Tread Brakes) EL - Electric Iniated System A(DK) - Pneumatic Powered Braking (Disc Brakes)
	- car	EL-A(DK)	EL-A(DK)	EL-A(DK)	EL-A(DK)	EL-A(DK)	
	Body Tilt capacity angle -	No	No	No	No	No	
	Service Power (Kw)	500	500	500	500	500	
PERFORMANCE	Max Speed m.p.h.	101	101	101	101	101	
	Max. Fuel consumption gal/hr	127.15	127.15	127.15	127.15	127.15	
	Power Trans efficiency @70	90.48%	90.48%	90.48%	90.48%	90.48%	
	Total Train resistance @70	5065.7	5713.3	5729.9	6377.45	6388.1	
	Max. Tractive effort lbs.	70,000	70,000	70,000	70,000	70,000	
	# revenue seats	228	278	312	362	396	
	cafe car	Yes	Yes	Yes	Yes	Yes	
	1st Class accomodation	No	Yes	No	Yes	No	
	lb/revenue seat	2548	2471.2	2201.9	2190.6	2002.5	
	Picture	No	No	No	No	No	

TABLE 3.10c

TRAIN CONSISTS

P30CH Consists

Task I(b)
DOT-OS-60124

	Consist	AM-1	AM-2	AM-3	AM-4	AM-5	AM-6	REMARKS
PHYSICAL	Train Configuration	1-2c-S	1-3c	1-2c-S-P	1-3c-S	1-3c-S-P	1-4c-S	
	Train Length	328'11"	328'11"	414'3"	414'3"	499'7"	499'7"	
	Loco length	72'4"	72'4"	72'4"	72'4"	72'4"	72'4"	
	Car Length	85'4"	85'4"	85'4"	85'4"	85'4"	85'4"	
	Train Weight (loaded) ton (empty) ton	374.52 354	374.68 352	432.02 407	435.08 406.7	492.58 460	495.64 460	
	Max. width	10'8 7/8"	10'8 7/8"	10'8 7/8"	10'8 7/8"	10'8 7/8"	10'8 7/8"	
	Loco Height	15'4 1/2"	15'4 1/2"	15'4 1/2"	15'4 1/2"	15'4 1/2"	15'4 1/2"	
	Car Height	12'8"	12'8"	12'8"	12'8"	12'8"	12'8"	
MECHANICAL	Axle arrangement - loco - cars	C-C 2-2	C-C 2-2	C-C 2-2	C-C 2-2	C-C 2-2	C-C 2-2	
	Propulsion System	DE	DE	DE	DE	DE	DE	
	Max gross Horsepower	3320	3320	3320	3320	3320	3320	
	Max. Net Horsepower	3000	3000	3000	3000	3000	3000	
	Brakes - loco - car	Dy-A(Tr) EL-A(DK)	Dy-A(Tr) EL-A(DK)	Dy-A(Tr) EL-A(DK)	Dy-A(Tr) EL-A(DK)	Dy-A(Tr) EL-A(DK)	Dy-A(Tr) EL-A(DK)	Dy - Electric Dynamic Braking A(Tr) - Pneumatic Powered Braking (Tread Brake) EL - Electric Iniated System A-(DK)-Pneumatic Powered Braking (Tread Brake)
	Body Tilt Cap. Angle-	No	No	No	No	No	No	
	Service Power (Kw)	750	750	750	750	750	750	
PERFORMANCE	Max Speed m.p.h.	103	103	103	103	103	103	
	Max. Fuel consumption gal/hr	155.95	155.95	155.95	155.95	155.95	155.95	
	Power Trans efficiency @70	86.2%	86.2%	86.2%	86.2%	86.2%	86.2%	
	Total Train resistance @70	4639	4640	5165	5178	5705	5719	
	Max. Tractive effort lbs.	97500	97500	97500	97500	97500	97500	
	# revenue seats	228	252	278	312	362	396	
	cafe car	Yes	No	Yes	Yes	Yes	Yes	
	1st Class accomodation	No	No	Yes	No	Yes	No	
	lb/revenue seat	3105.26	2793.7	2928.1	2602.1	2541.4	2323.2	
	Picture	No	No	No	No	No		

TRAIN CONSISTS

TABLE 3.10d

LRC Consists

Task I(b)
DOT-OS-60124

	Consist	LRC-1	LRC-2	LRC-3	LRC-4	LRC-5	LRC-6	REMARKS
PHYSICAL	Train Configuration	1-2C-S	1-3C-S	1-2C-S-P	1-3C-S-P	1-4C-S	1-2C-S-P	1-2C-S-P means 1 Loco, 2 Coaches, 1 Snack & 1 Parlor Car
	Train Length	322'11"	407'11"	407'11"	492'11"	492'11"		
	Loco length	67'11"	67'11"	67'11"	67'11"	67'11"	67'11"	
	Car Length	85'	85'	85'	85'	85'	85'	
	Train Weight (loaded) Tons (empty) tons	264 244.2	316.5 289.1	313.5 289.2	366.1 334.24	369. 334.	311.	
	Max. width	10'5"	10'5"	10'5"	10'5"	10'5"	10'5"	
	Loco Height	11'9"	11'9"	11'9"	11'9"	11'9"	11'9"	
	Car Height	11'9"	11'9"	11'9"	11'9"	11'9"	11'9"	
MECHANICAL	Axle arrangement - loco - cars	B-B 2-2	B-B 2-2	B-B 2-2	B-B 2-2	B-B 2-2	B-B 2-2	
	Propulsion System	DE	DE	DE	DE	DE	DE	
	Max gross Horsepower	3700	3700	3700	3700	3700	3700	
	Max. Net Horsepower	2700	2700	2700	2700	2700	2700	
	Brakes - loco - car	Dy-A(DK) A(Tr)	Dy-A(DK) A(Tr)	Dy-A(DK) A(Tr)	Dy-A(DK) A(Tr)	Dy-A(DK) A(Tr)	Dy-A(DK) A(Tr)	Dy-A(DK)-Electric Dynamic Braking-Pneumatic Powered Braking (Disc Brakes) A(Tr)-Pneumatic Powered Braking (Tread Brakes)
	Body Tilt capacity angle -	Yes 10°	Yes 10°	Yes 10°	Yes 10°	Yes 10°	Yes 10°	
	Service Power (Kw)	400 KW	400 KW	400 KW	400 KW	400 KW	400 KW	
PERFORMANCE	Max Speed m.p.h.	120	120	120	120	120	120	
	Max. Fuel consumption gal/hr	194.54	194.54	194.54	194.54	194.54	194.54	
	Power Trans efficiency @90	87%	87%	87%	87%	87%	87%	
	Total Train resistance @90	369 lbs.	4339 lbs.	4322 lbs.	4970 lbs.	4986 lbs.	4313 lbs.	
	Max. Tractive effort lbs	29,300	29,300	29,300	29,300	29,300	29,300	
	# revenue seats	220	304	270	354	388	250	
	cafe car	Yes	Yes	Yes	Yes	Yes	Yes	
	1st Class accomodation	No	No	Yes	No	No	Yes	
	lb/revenue seat	2220	1902.6	2142.2	1888.4	1722.7		
	Picture	Yes	Yes	Yes	Yes	Yes	Yes	

NOTE: LRC-3 is similar to LRC-6, except the no. of passengers.

TABLE 3.10e

Turboliner Consists

	Consist	RT-1	RT-3	RT-4	RT-5	RT-6	REMARKS
PHYSICAL	Train Configuration	2-2C-S-P	2-2C-S	2-3C-S	2-3C-S-P	2-3C-S	Turbo cars can be converted either to coach cars (capacity 40 seats) or parlor cars (capacity 27 seats)
	Train Length	424'9"	424'9"	424'9"	508'5 1/2"	508'5 1/2"	
	Loco length	86' 9 3/4"	86'9 3/4"	86'9 3/4"	86'9 3/4"	86'9 3/4"	
	Car Length	83'8 1/2"	83'8 1/2"	83'8 1/2"	83'8 1/2"	83'8 1/2"	
	Train Weight (loaded) tons (empty) tons	334.67 311	335.84 311	333.14 306.5	392.65 362.5	393.82 362.5	
	Max. width	10'	10'	10'	10'	10'	
	Loco Height	12'10"	12'10"	12'10"	12'10"	12'10"	
	Car Height	12'10"	12'10"	12'10"	12'10"	12'10"	
MECHANICAL	Axle arrangement - loco - cars	B-2 B-B	B-2 B-B	B-2 B-B	B-2 B-B	B-2 B-B	
	Propulsion System	THy	THy	THy	THy	THy	Turbine-Hydraulic
	Max gross Horsepower	NA	NA	NA	NA	NA	
	Max. Net Horsepower	1140 x 2	1140 x 2	1140 x 2	1140 x2	1140 x2	
	Brakes - loco - car	Hydy A(DK & Tr)	Hydy A(DK & Tr)	Hydy A(DK & Tr)	Hydy A(DK & Tr)	Hydy A(DK &Tr)	Hydy-Hydrodynamic Braking A(DK & Tr) - Pneumatic Powered (Disc Brakes-Tread Brakes)
	Body Tilt capacity angle -	No	No	No	No	No	
	Service Power (Kw)	320	320	320	320	320	
PERFORMANCE	Max Speed m.p.h.	110	110	110	110	110	
	Max. Fuel consumption	207.42	207.42	207.42	207.42	207.42	
	Power Trans efficiency @70	83.5	83.5	83.5	83.5	83.5	
	Total Train resistance @70	3004	3998	3982	4527	4531	
	Max. Tractive effort lbs.	42,000	42,000	42,000	42,000	42,000	
	# revenue seats	263	276	296	335	348	
	cafe car	Yes	Yes	No	Yes	Yes	
	1st Class accomodation	Yes	No	No	Yes	No	
	lb/revenue seat	2365	2253.6	2070.9	2164	2083.3	
	Picture	Yes	Yes	Yes	No	No	

3.20 REPRESENTATIVE - CONTEMPORARY TRAIN CONSIST ELECTRIFIED

- CC14500/Amfleet Cars

TABLE 3.20

TRAIN CONSISTS

French 14500 Consists (Alsthom)

Task I(b)
DOT-OS-60124

	Consist	FR-1	FR-2	FR-3	FR-4	FR-5	REMARKS
PHYSICAL	Train Configuration	1-2C-S	1-2C-S-P	1-3C-S	1-3C-S-P	1-4C-S	
	Train Length	322'9 1/16"	407'1 1/16"	407' 1 1/16"	493'5 1/16"	493'5 1/16"	
	Loco length	67'5 1/16'	67'5 1/16"	67'5 1/16"	67'5 1/16"	67'5 1/16"	
	Car Length	85'4"	85'4"	85'4"	85'4"	85'4"	
	Train Weight (loaded) (tons) (empty) (tons)	334.12 313.6	391.62 366.6	394.68 366.6	452.18 419.6	455.24 419.6	
	Max. width	10'6"	10'6"	10'6"	10'6"	10'6"	
	Loco Height (pantograph down)	14'8"	14'8"	14'8"	14'8"	14'8"	
	Car Height	12'8"	12'8"	12'8"	12'8"	12'8"	
MECHANICAL	Axle arrangement - loco - cars	Co-Co 2-2	Co-Co 2-2	Co-Co 2-2	Co-Co 2-2	Co-Co 2-2	
	Propulsion System	Elec.	Elec.	Elec.	Elec.	Elec.	
	Max gross Horsepower	-	-	-	-	-	
	Max. Net Horsepower	7,725	7,725	7,725	7,725	7,725	
	Brakes - loco - car	Dy - A(Tr) El A(DK)	Dy - A(Tr) El A(DK)	Dy - A(Tr) El A(DK)	Dy - A(Tr) El A(DK)	Dy - A(Tr) El A(DK)	Dy-Electric Dynamic Braking A(Tr)-Pneumatic Powered Braking (Tread Brakes) El-Electric Iniated System A(DK)-Pneumatic Powered Braking (Disc Brakes)
	Body Tilt capacity angle -	No	No	No	No	No	
	Service Power (Kw)	300	300	300	300	300	
PERFORMANCE	Max Speed m.p.h.	120	120	120	120	120	
	Max. Fuel consumption	-	-	-	-	-	
	Power Trans efficiency	85%	85%	85%	85%	85%	Assumed Constant
	Total Train resistance (lbs)						
	Max. Tractive effort (lbs)	68,000	68,000	68,000	68,000	68,000	
	# revenue seats	228	278	312	362	396	
	cafe car	Yes	Yes	Yes	Yes	Yes	
	1st Class accomodation	No	Yes	No	Yes	No	
	lb/revenue seat	2750.9	2637.4	2350	2318.2	2119.2	
	Picture	No	No	No	No	No	

3.30 SUMMARY

There are several types of trains which are either presently being used or are being planned for usage in the near future. These trains differ considerably in the performance characteristics (max. speed, fuel rates, weight in lbs/seat, etc.). This chapter has definitely provided some useful information which help us towards estimating the speed and fuel usage under various operating conditions.

4.00 IMPACT OF VARIOUS OPERATING CONDITIONS (SPEED, LOAD-FACTOR) UPON CRUISING ENERGY INTENSITY VALUES

4.00 IMPACT OF VARIOUS OPERATING CONDITIONS (SPEED, LOAD-FACTOR) UPON CRUISING ENERGY INTENSITY VALUES

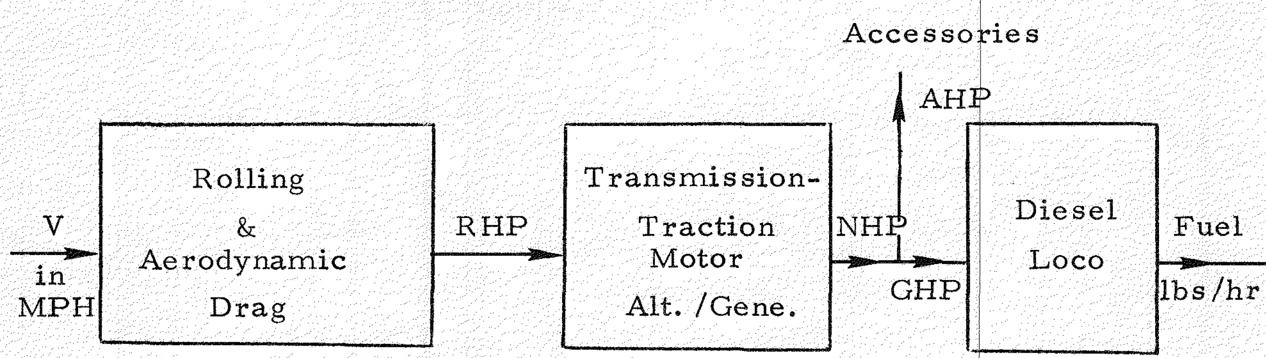
In this section, the impact of the following operating conditions upon energy intensity are evaluated

- Speed
- Load Factor

Details on the impact of each parameter follow:

SPEED: As mentioned in Chapter 2, speed has a profound impact on the energy intensity for the following reasons:

- Aerodynamic drag increases proportional to the velocity squared term; hence, more force is needed to overcome aerodynamic drag at higher velocities.
- Rolling resistance is affected by the velocity component.
- Thermal efficiency and transmission efficiences are also affected by the speed so the input energy components (B. T. U.) are affected.



RHP = Rail Horsepower
NHP = Net Horsepower
AHP = Auxiliary Horsepower
GHP = Gross Horsepower

Methodology for the Estimation of Fuel Rate Under Cruising Condition

In order to study the impact of velocity upon energy intensity, we are going to simulate various train consists at various speeds and then move backward to estimate the fuel consumption at each particular operating speed. The basic equation used is the following:

Tractive Effort Required = Net Resistance to motion

Net Resistance to motion is composed of the following parameters:

- Rolling Resistance
- Aerodynamic Drag
- Grade Resistance
- Curve Resistance
- Acceleration Resistance

For our analysis, only rolling and aerodynamic components are taken into consideration. For a specific cruising velocity, resistance is calculated and then the rail horsepower is computed as follows:

$$\text{Rail Horsepower}^{*} = \frac{(\text{Resistance in lbs.})\,(\text{Velocity in m.p.h.})}{375}$$

From the above rail horsepower equation, fuel rate can be calculated according to the above block diagram.

Results are documented in a graphical form for the following trains:

a. Diesel Electric Train Consists
   - E-8/Refurbished (Fig. 4.10)
   - P-30CH/Amfleet (Fig. 4.20a, b, c)
   - F-40PH/Amfleet (Fig. 4.30a, b, c)
   - SDP-40F/Amfleet (Fig. 4.40a, b, c)
   - LRC Train (Fig. 4.50a, b. c, d, e)

b. Gas-Turbine Train Consist
   - Rohr Turboliner (Fig. 4.60a, b, c)

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*See Appendix IV for further details.

c. Electric Train Consists

- Metroliners (Fig. 4.70a, b)
- E-60CP Locomotive pulling Amfleet cars (Fig. 4.70c)
- ASEA RC4a Locomotive pulling Amfleet cars (Fig. 4.70e)
- French CC14500 Locomotive pulling Amfleet cars (Fig. 4.70d)

LOAD FACTOR: Load factor is defined as the ratio of seats occupied by total occupied divided by total no. of seats. Given the train consist and seating capacity of each car, the total no. of seats can be easily estimated. Increasing the load factor increases the weight of the car which results in higher resistance* and consequently higher fuel consumption. Since the dead load constitutes a major portion of the train weight, hence increasing load factor does not result in appreciable increase in fuel consumption, i.e., the fuel consumption rates per train-mile are approximately constant. Under the above assumption, it is safe to say that doubling the load factor (say from 50% to 100%) would result in reducing the energy intensity values by half. For lighter trains just as LRC, the above assumption does not hold good because the live load is an appreciate amount of the total train weight. The subsequent section of this chapter deals with the impact of load factor and speed upon the EI values. Finally, section 4.80 deals with the chapter summary.

*See Appendix IV for further details.

4.10 E-8 TRAIN CONSISTS

Figure 4.10a shows the relationship between energy intensity and speed which has been derived by using the methodology outlined in Chapter 2. Load factor, number and types of cars are varied to get an estimate for the energy intensity. PR-1* has 3 cars while PR-4 has 6 cars. Three observations are obvious from the graph.

- There is a considerable decrease in the energy intensity values with increase in the number of cars. (There is an optimum number of cars which will result in the least EI value. Obviously there are travel time penalties with the increase in the number of cars.).
- For 50% load factor, energy intensity is nearly double as compared to the fully loaded train. This implies that the incremental fuel penalty due to the weight of the passengers is negligible.
- From a minimum energy intensity viewpoint, E-8 trains should be operating around 20 m.p.h. What this statement implies is that a fully loaded train (E-8 train having refurbished cars) will consume minimum energy if it were moving at a speed of 20 m.p.h. In practice, the lower speed will result in reduced rail demand and hence higher EI values (under similar train consist). These relationships are complex and have been presented in this report in Chapters 6 and 8.

*For complete descriptions of these train consists, refer to Chapter 3.

CRUISING ENERGY EFFICIENCY E-8
LOCOMOTIVE AND 2, 3, 4, 5 and 6 CAR CONSISTS

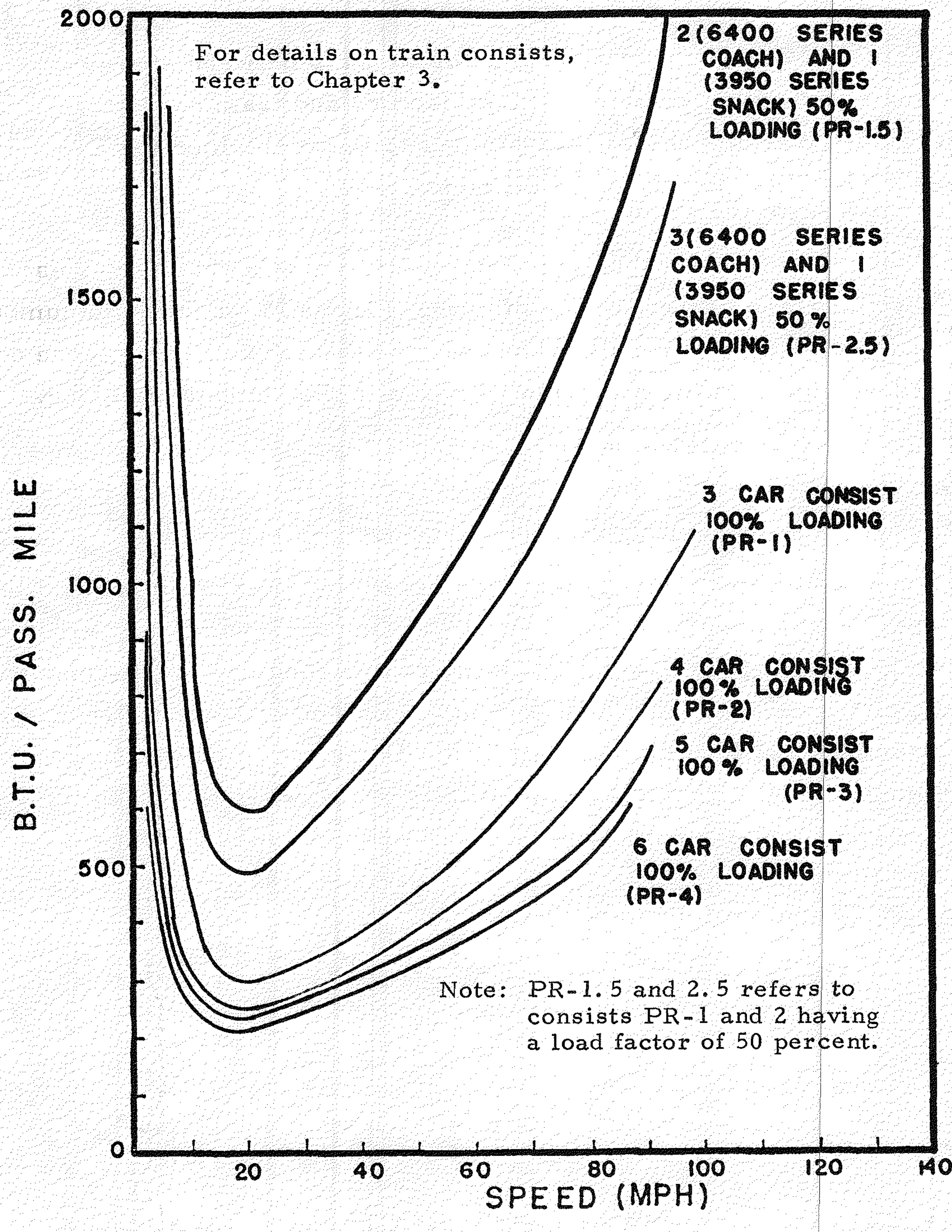


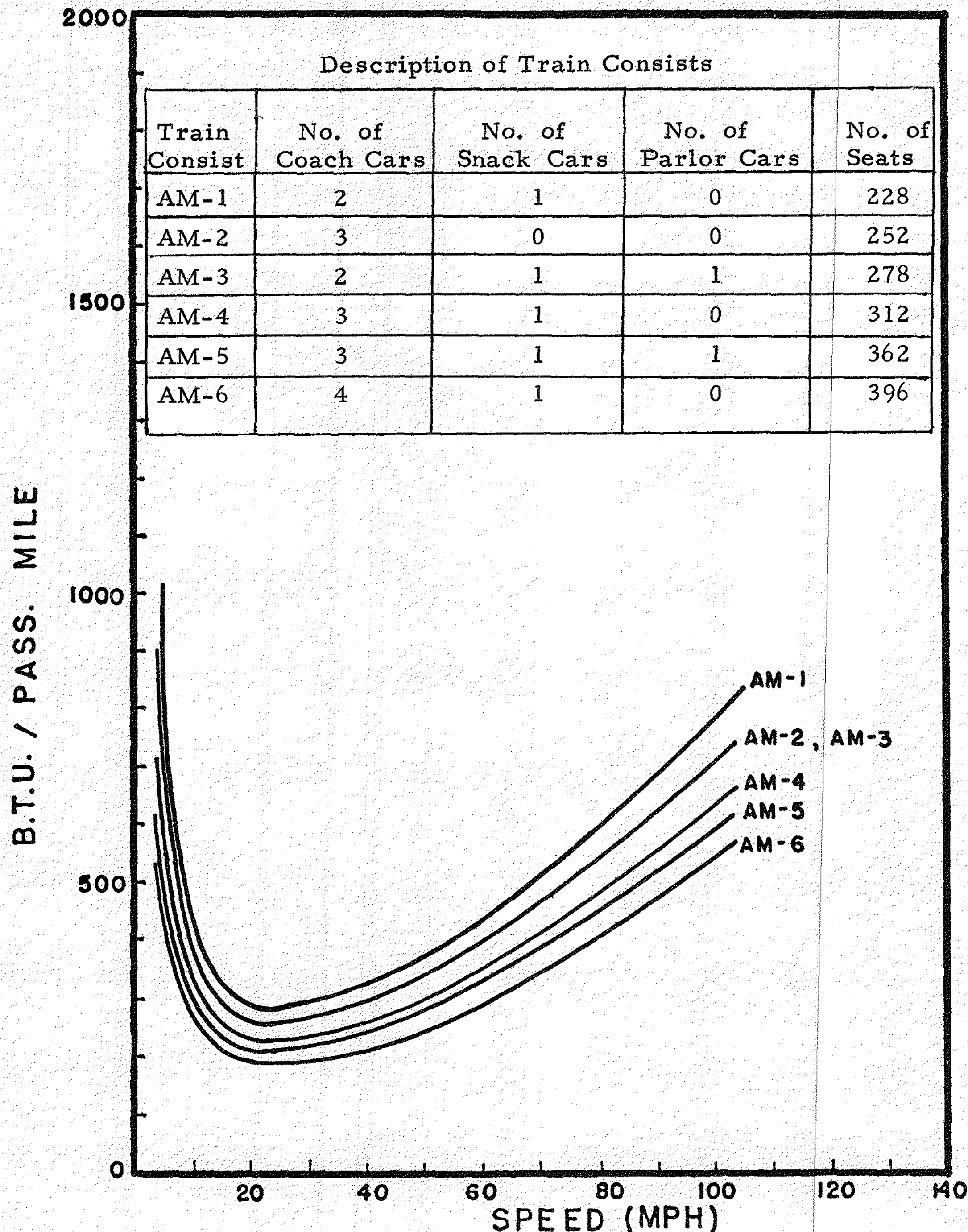
FIGURE 4.10

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

4.20 P30-CH TRAIN CONSISTS

Figs. 4.20a, b and c show the relationship between energy intensity and speed under a variety of load factors and train consists. Results of P30-CH train consists are similar to those obtained for E-8 except that P30-CH is slightly more efficient.

CRUISING ENERGY EFFICIENCY P-30 CH CONSISTS FULLY LOADED



Description of Train Consists

Train Consist	No. of Coach Cars	No. of Snack Cars	No. of Parlor Cars	No. of Seats
AM-1	2	1	0	228
AM-2	3	0	0	252
AM-3	2	1	1	278
AM-4	3	1	0	312
AM-5	3	1	1	362
AM-6	4	1	0	396

FIGURE 4.20a

CRUISING ENERGY EFFICIENCY P-30 CH CONSISTS 10 % LOAD

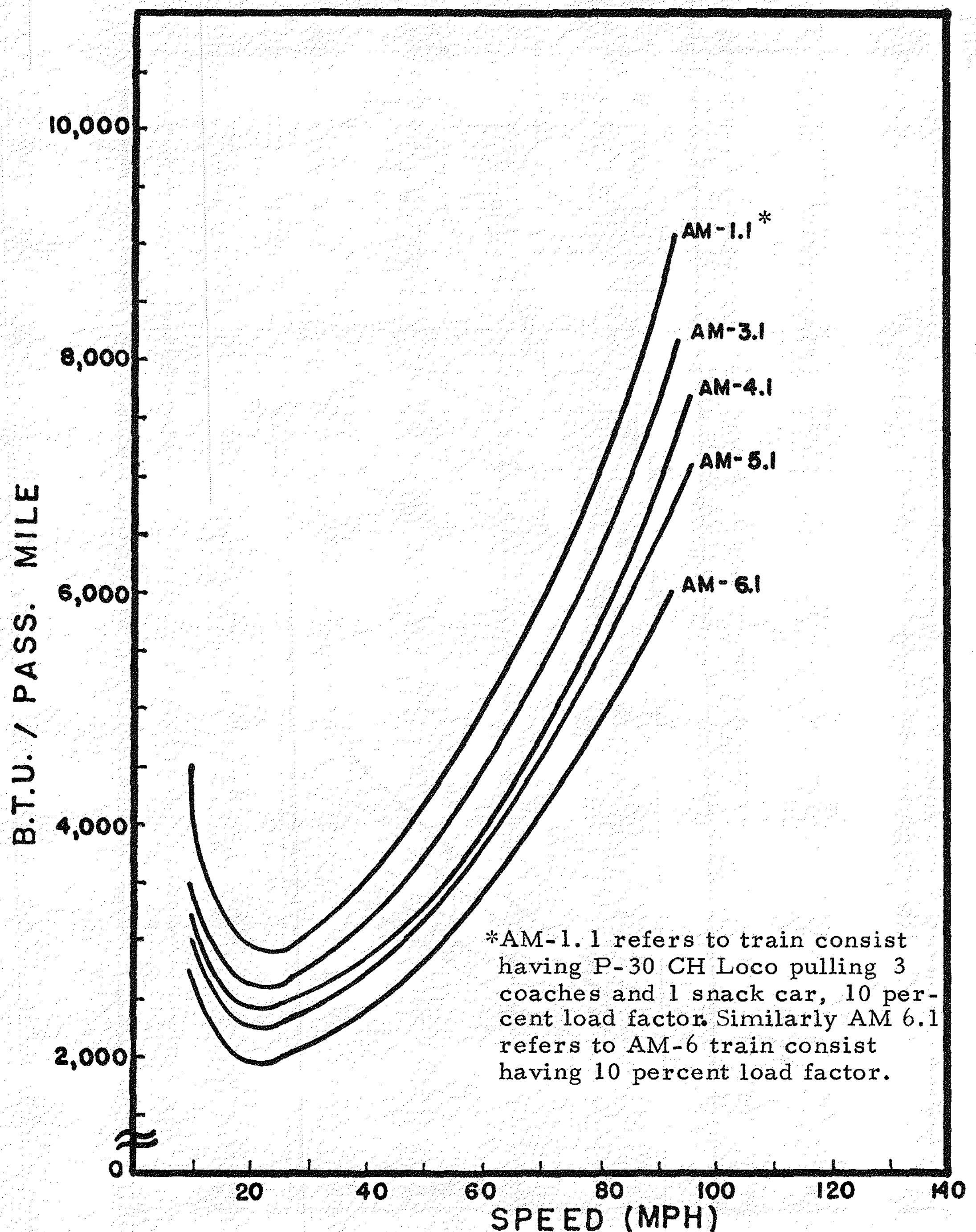


FIGURE 4.20b

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

CRUISING ENERGY EFFICIENCY P 30 CH CONSISTS 50% LOAD

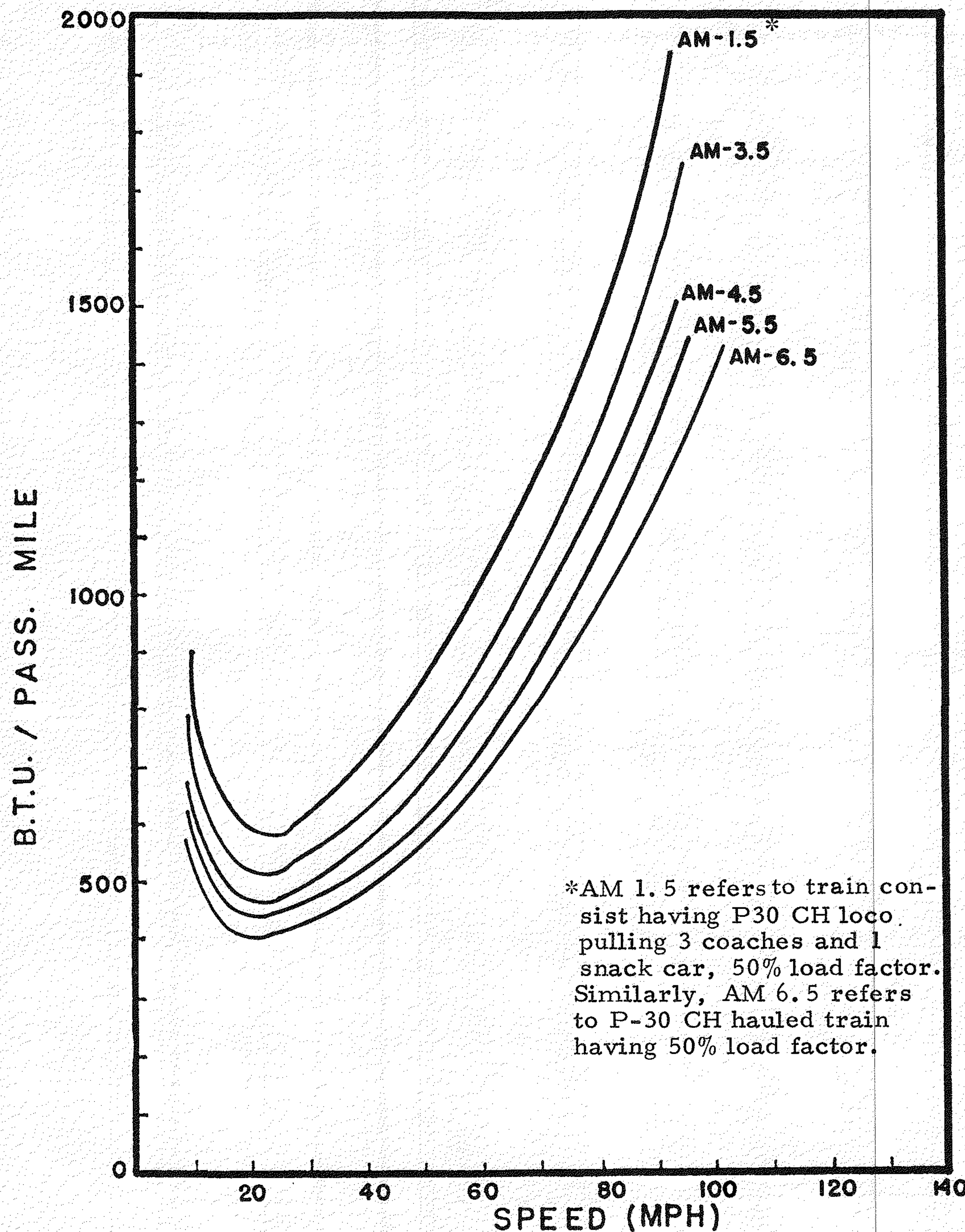


FIGURE 4.20c

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

4.30 F-40 PH TRAIN CONSISTS

Figures 4.30 a, b and c show the impact of speed upon energy intensity under a variety of load factors and train consists. The shape of the curves is similar to those previously studied for diesel/electric locomotives. Energy intensity values are lower, i.e., more fuel efficient, as compared to those for E-8 and P-30 CH.

CRUISING ENERGY EFFICIENCY F 40 PH CONSISTS

100 % LOAD

Description of Train Consists

Train Consist	No. of Coach Cars	No. of Snack Cars	No. of Parlor Cars	No. of Seats
F-1	2	1	0	228
F-2	2	1	1	278
F-3	3	1	0	312
F-4	3	1	1	362
F-5	4	1	0	396

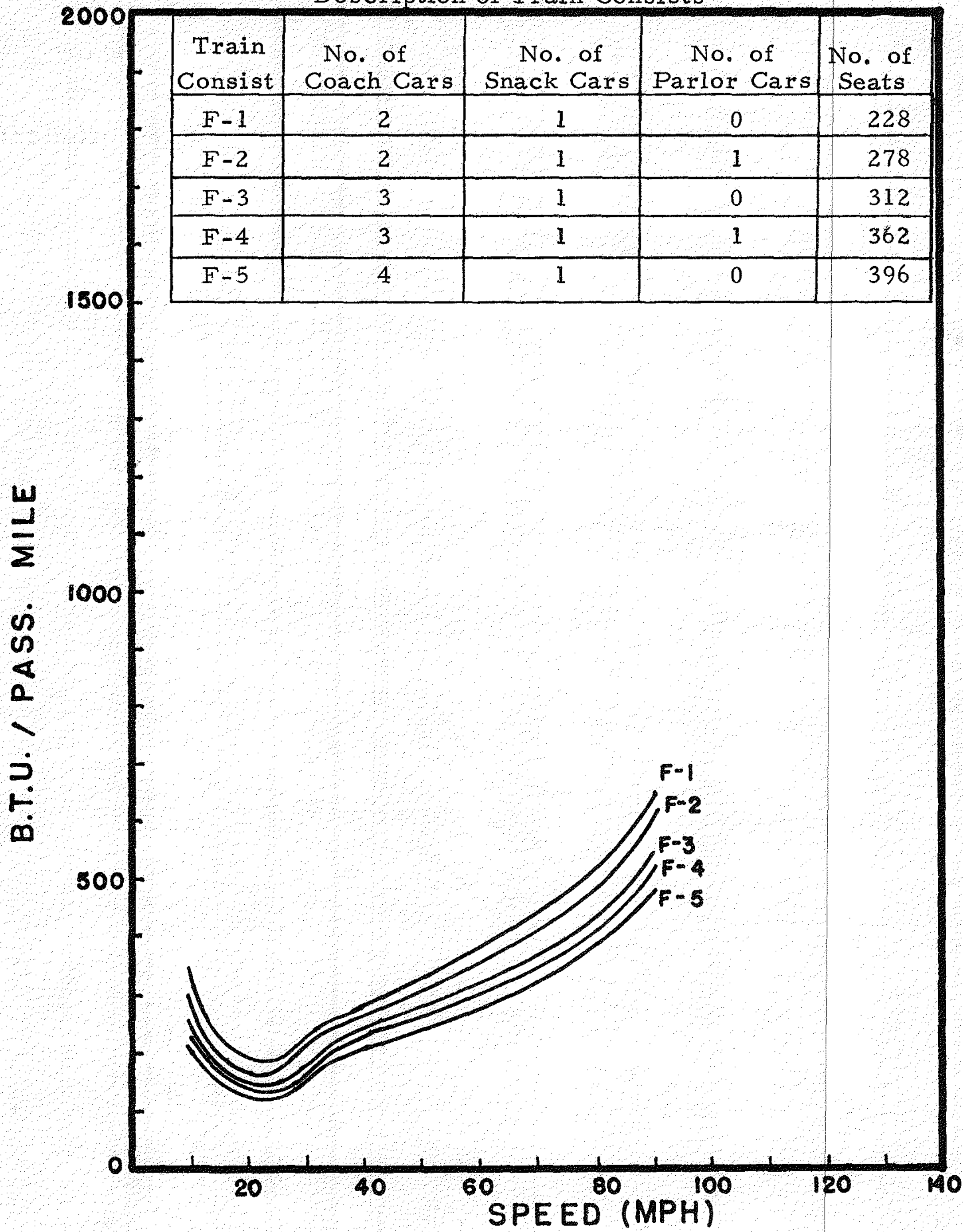


FIGURE 4. 30a

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

CRUISING ENERGY EFFICIENCY F40PH CONSISTS 10 % LOAD

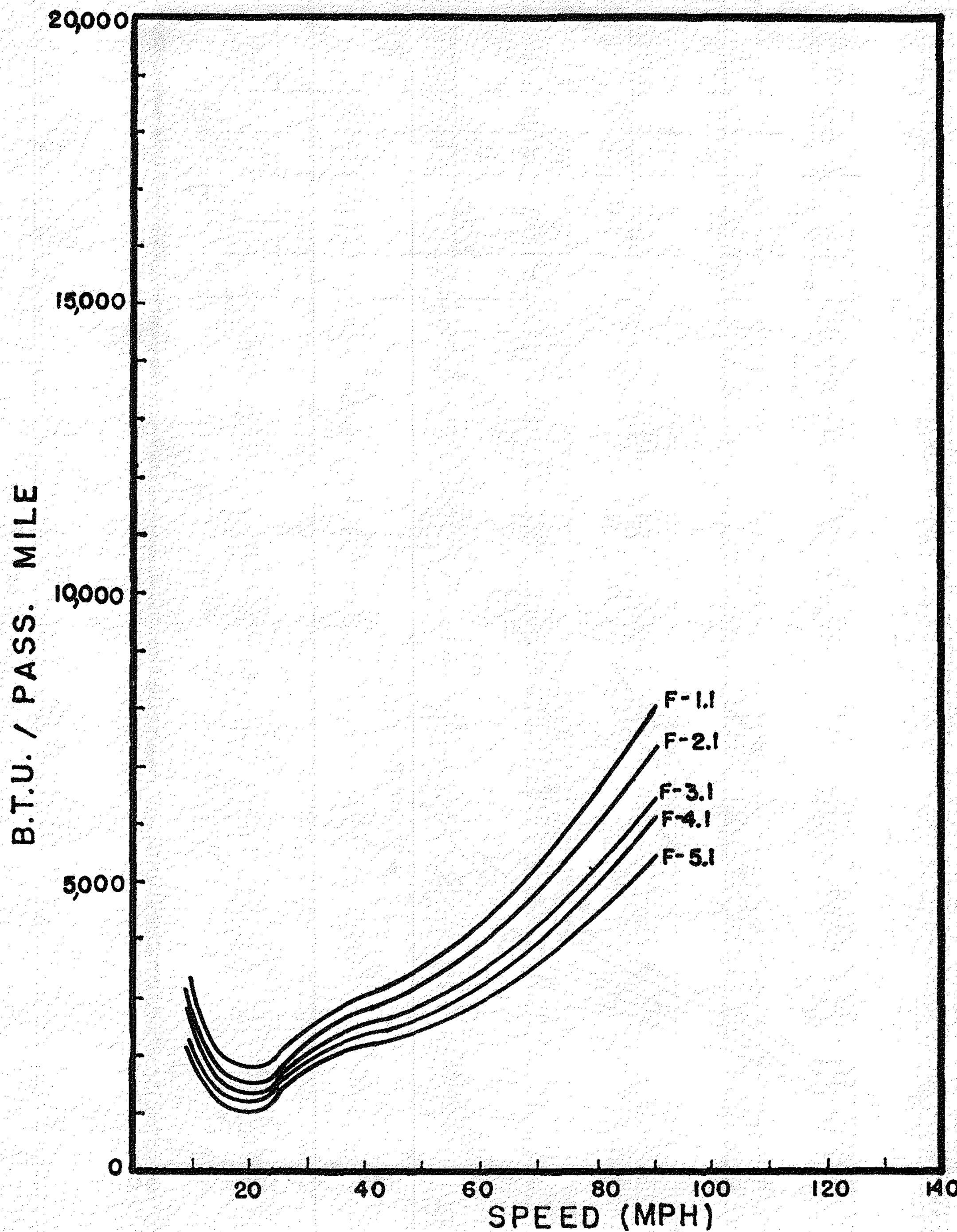


FIGURE 4.30b

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

CRUISING ENERGY EFFICIENCY F40 PH CONSISTS 50 % LOAD

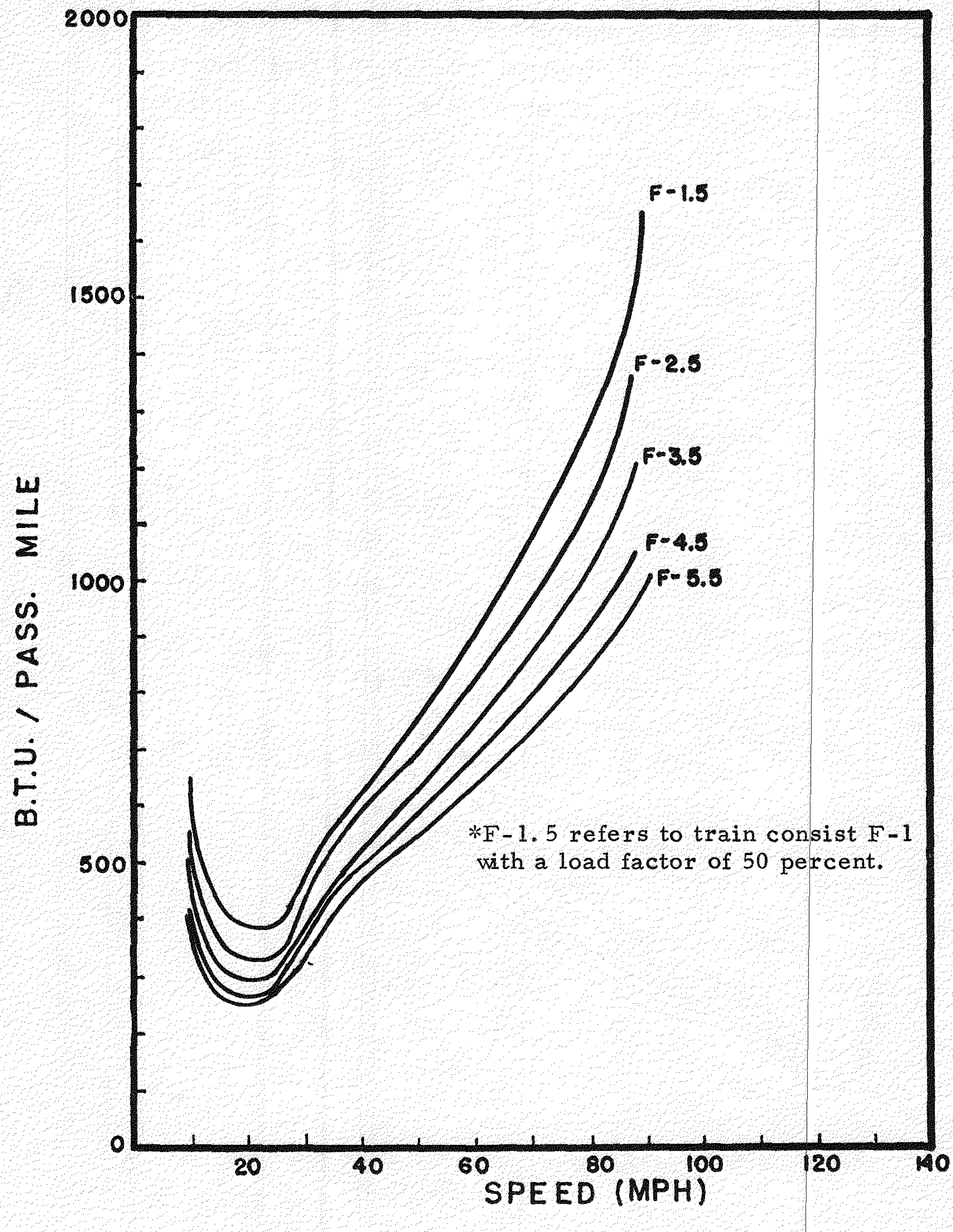


FIGURE 4.30c

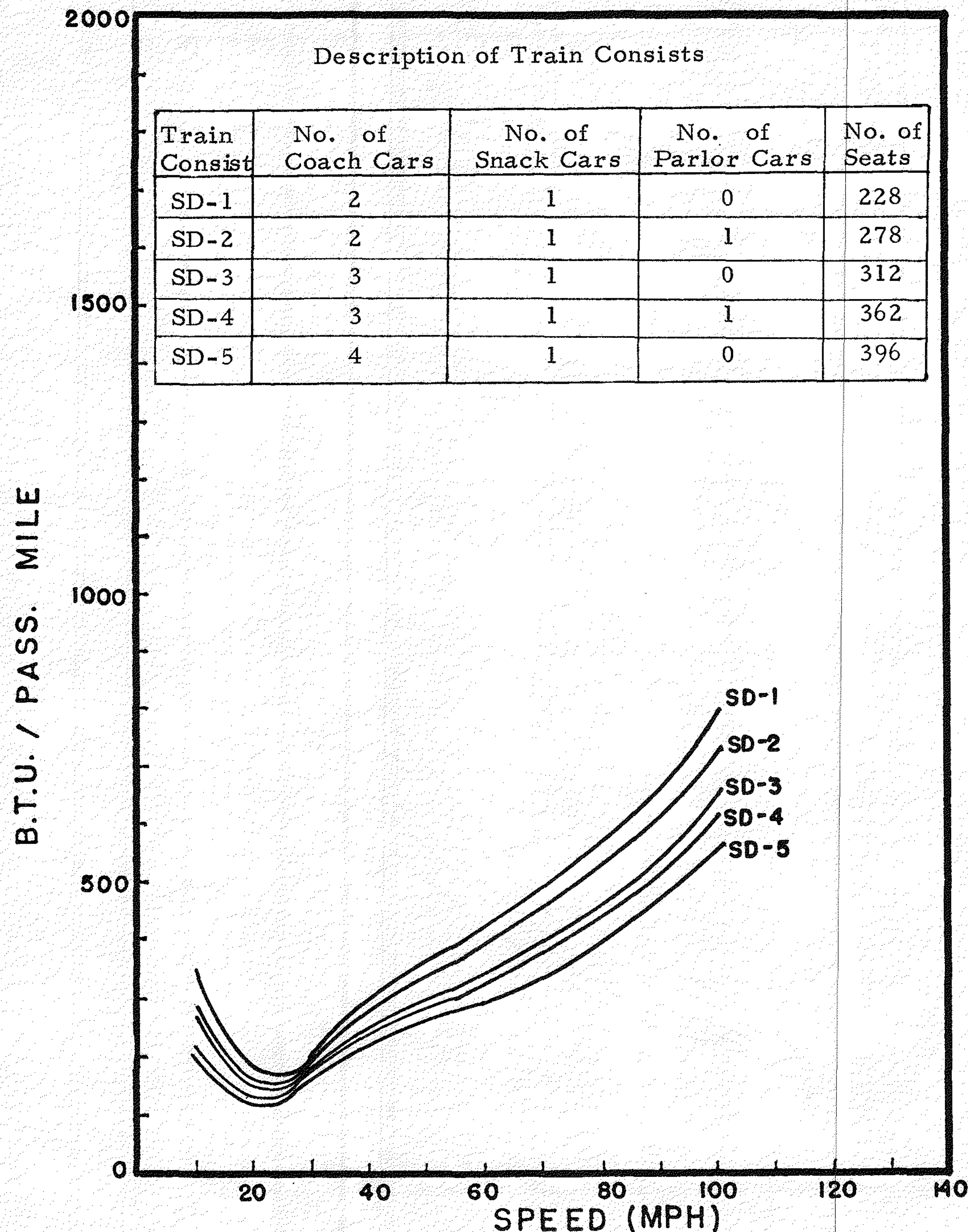
UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

4.40 SDP-40F TRAIN CONSISTS

Figures 4.40 a, b and c show the relationship between speed and energy intensity under a variety of load factors and train consists. The efficiency curves are similar to those of P-30 CH train consists.

CRUISING ENERGY EFFICIENCY SDP 40 F CONSISTS

100 % LOAD



Description of Train Consists

Train Consist	No. of Coach Cars	No. of Snack Cars	No. of Parlor Cars	No. of Seats
SD-1	2	1	0	228
SD-2	2	1	1	278
SD-3	3	1	0	312
SD-4	3	1	1	362
SD-5	4	1	0	396

FIGURE 4.40a

CRUISING ENERGY EFFICIENCY SDP 40 F CONSISTS

10% LOAD

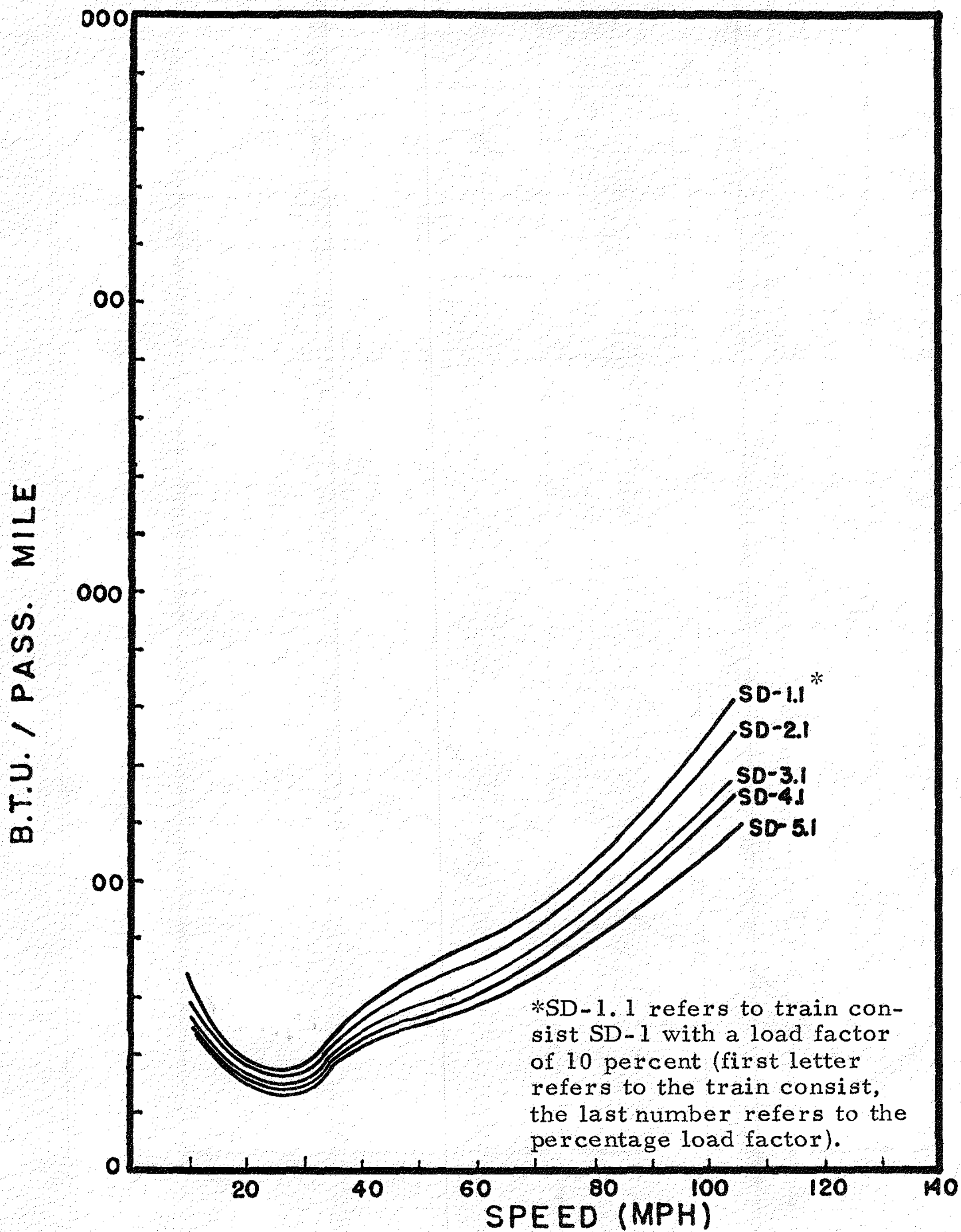


FIGURE 4.40b

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

CRUISING ENERGY EFFICIENCY SDP 40 F CONSISTS

50% LOAD

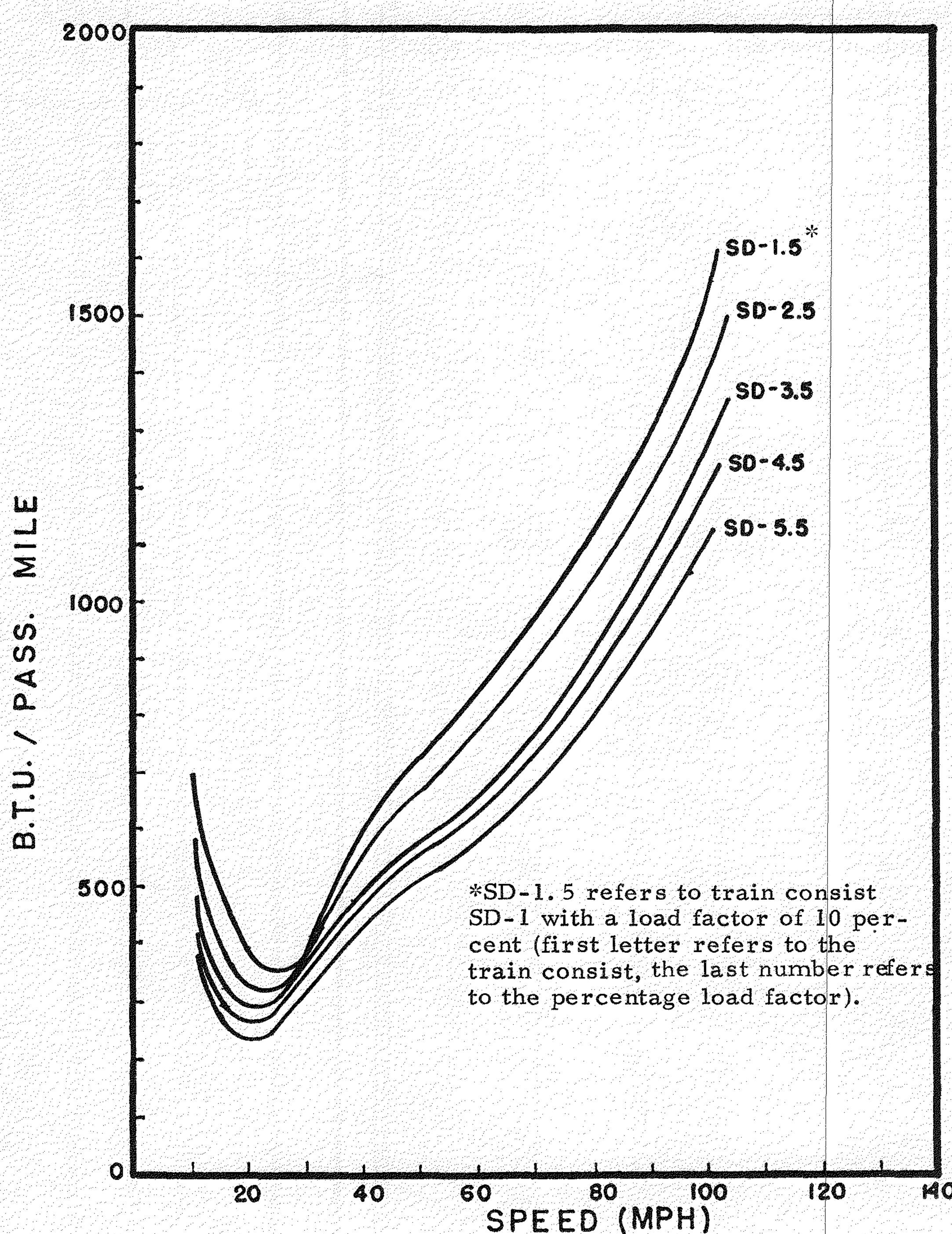


FIGURE 4.40c

4.50 LRC TRAIN CONSISTS

Figures 4.50 a, a-1, b, c, and c-1 show the relationship between energy intensity and speed. Various load factors (10, 50 and 100 percent) are considered for evaluation purposes. Different types of train consists are examined for comparison purposes. These train consists vary in passenger capacity from 220 to 388. All of these train consists have a cafe car. From the energy intensity viewpoint, LRC appears to be lowest.

CRUISING ENERGY EFFICIENCY LRC CONSISTS

100% LOAD

Description of Train Consists

Train Consist	No. of Coach Cars	No. of Snack Cars	No. of Parlor Cars	No. of Seats
LRC 1	2	1	0	220
LRC 3	2	1	1	270
LRC 5	4	1	0	388
LRC 6	2	1	1	250

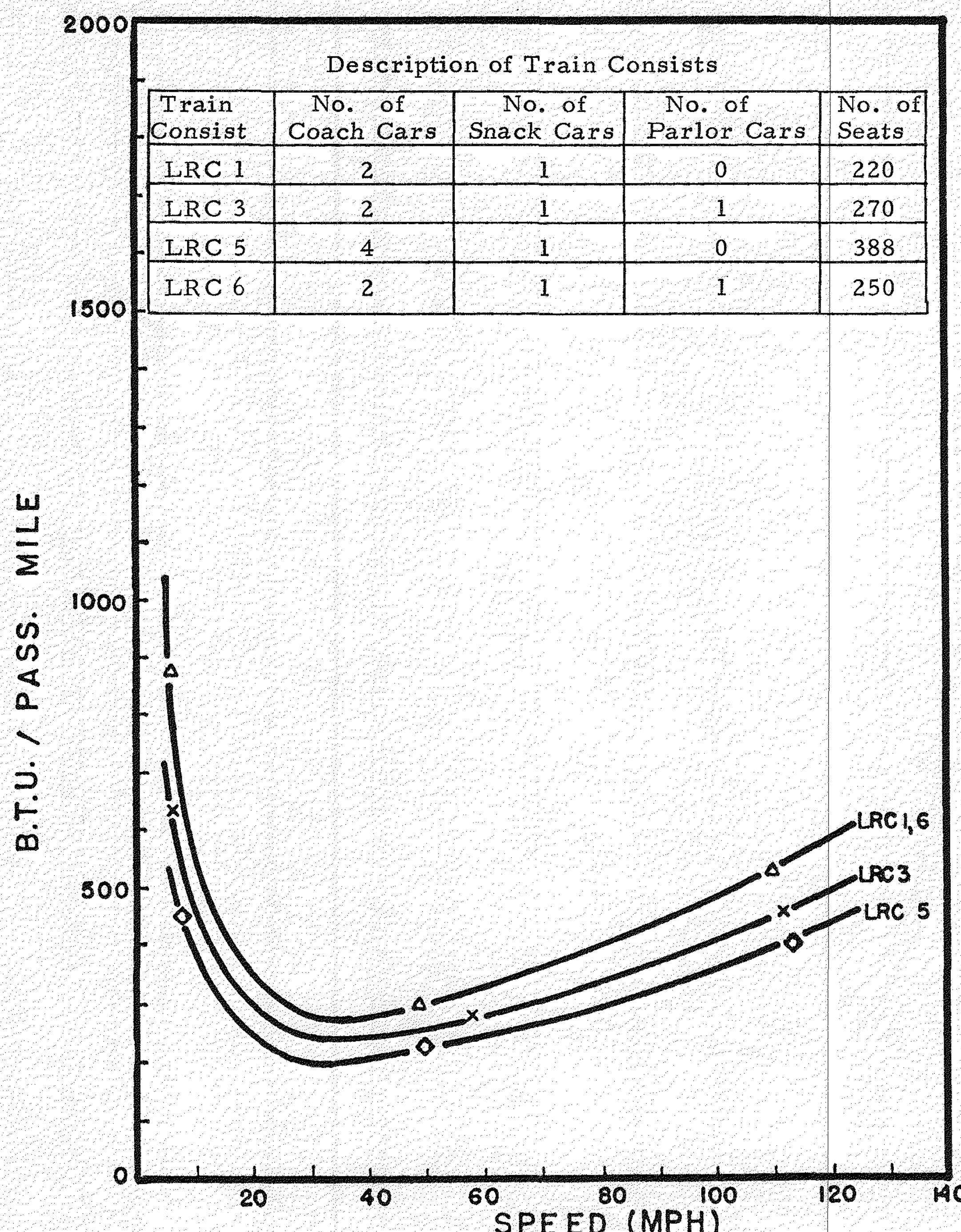


FIGURE 4.50a

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

CRUISING ENERGY EFFICIENCY LRC CONSISTS

100% LOAD

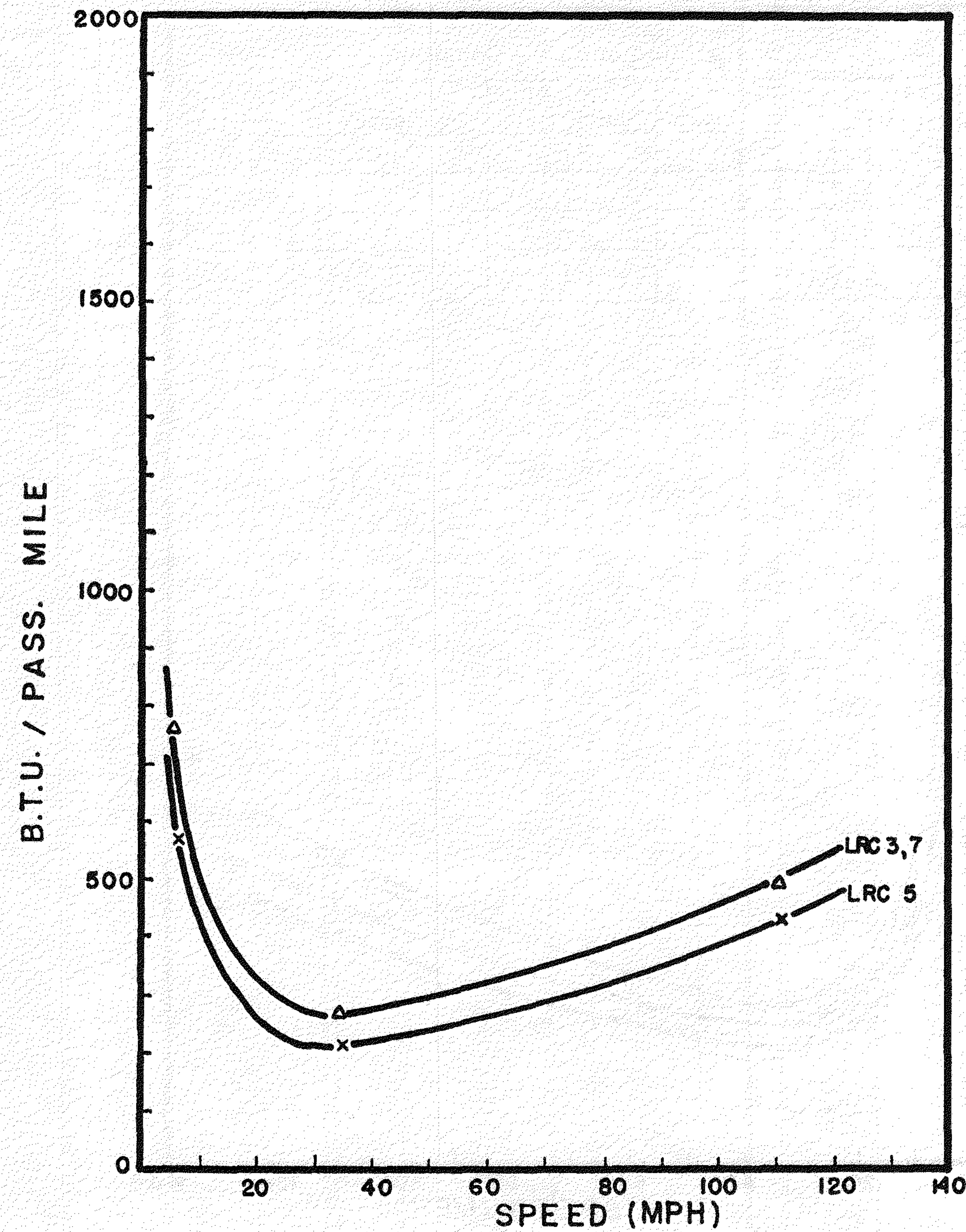


FIGURE 4.50a-1

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

CRUISING ENERGY EFFICIENCY LRC CONSISTS

10% LOAD

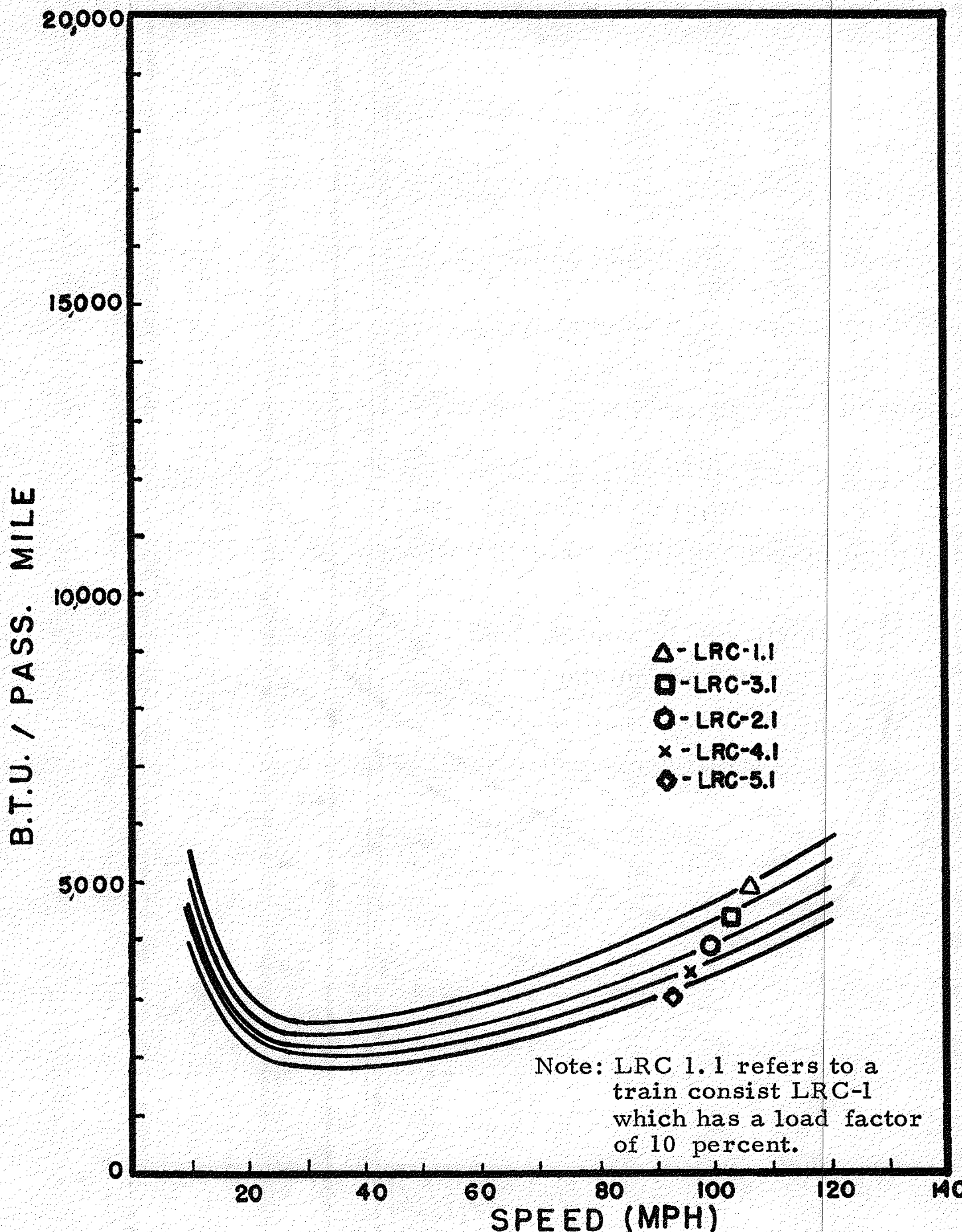


FIGURE 4.50b

CRUISING ENERGY EFFICIENCY LRC CONSISTS

50% LOAD

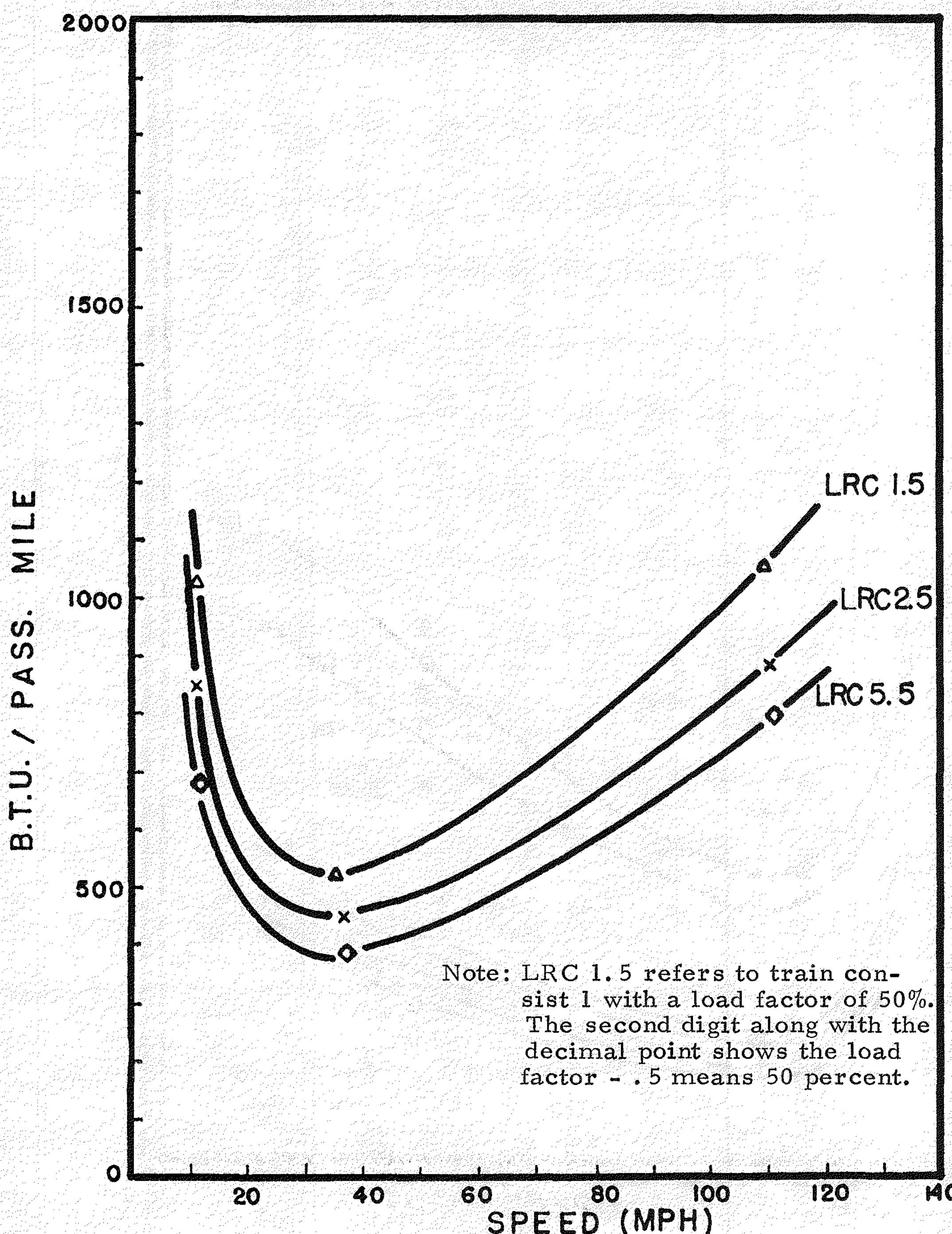
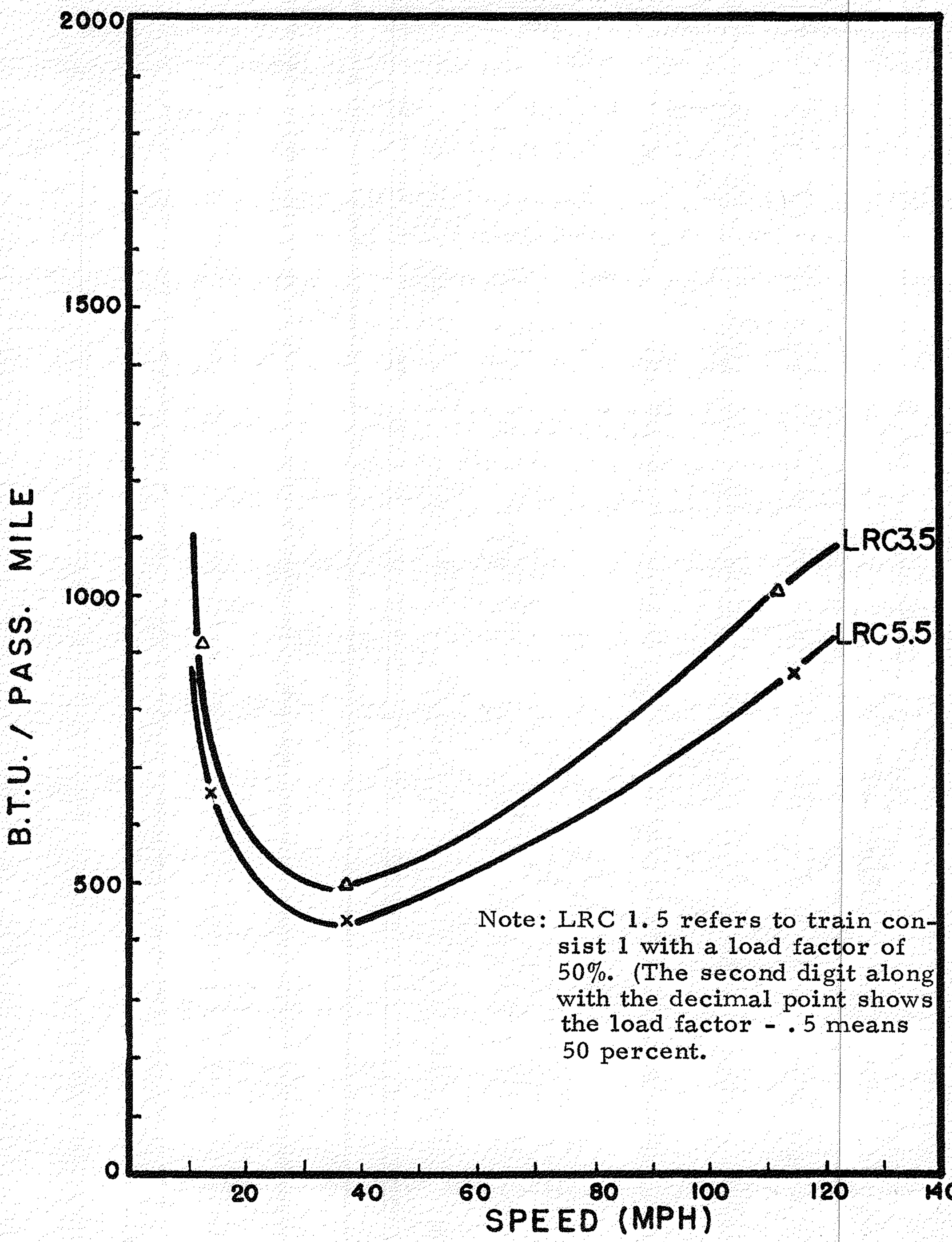


FIGURE 4.50c

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

CRUISING ENERGY EFFICIENCY LRC CONSISTS

50% LOAD



Note: LRC 1.5 refers to train consist 1 with a load factor of 50%. (The second digit along with the decimal point shows the load factor - .5 means 50 percent.

FIGURE 4.50c-1

4.60 ROHR-TURBOLINER TRAIN CONSISTS

Figures 4.60 a, b and c show the relationship between energy intensity and speed. Five different types of trains are evaluated which vary in passenger capacity from 263 to 348. All of these train consists except one (TR-4)* have a cafe car. Figure 4.60 a shows the impact of shutting down one turbine upon energy intensity. Figure 4.60 b shows the impact of various types of train consists upon speed. Figure 4.60 c shows the impact of various load factors upon energy intensity and speed. The behavior of the turboliner is quite different from diesel/electric trains. The following observations can be made with respect to energy intensity of the turboliner.

- Energy intensity decreases with increase in speed except at the far end of the operation.
- The turboliner is roughly two and a half times more energy intensive than a standard diesel train.

*For details on the train consist refer to Chapter 3.

CRUISING ENERGY EFFICIENCY ROHR TURBOLINER

1-3-1 CONSIST*

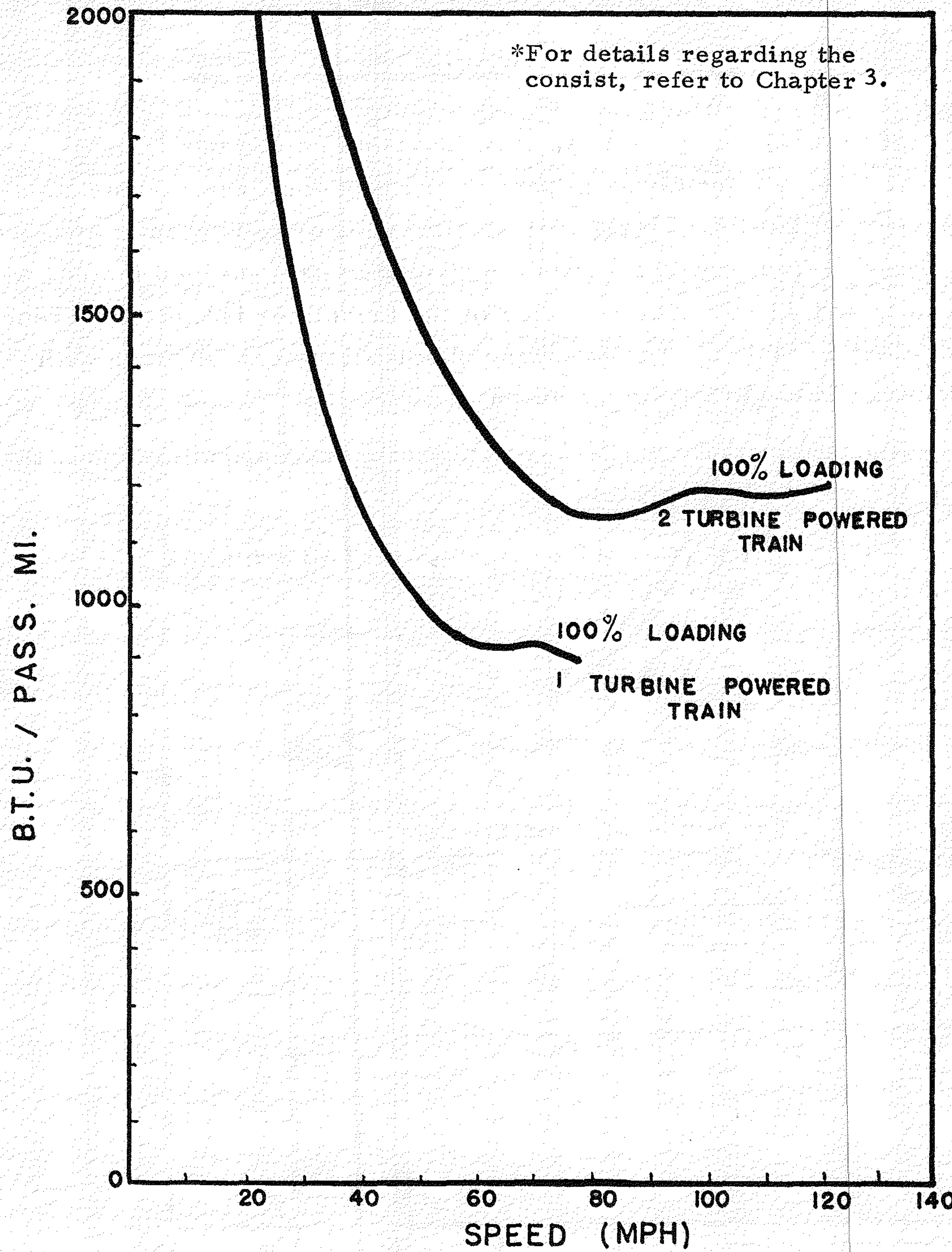
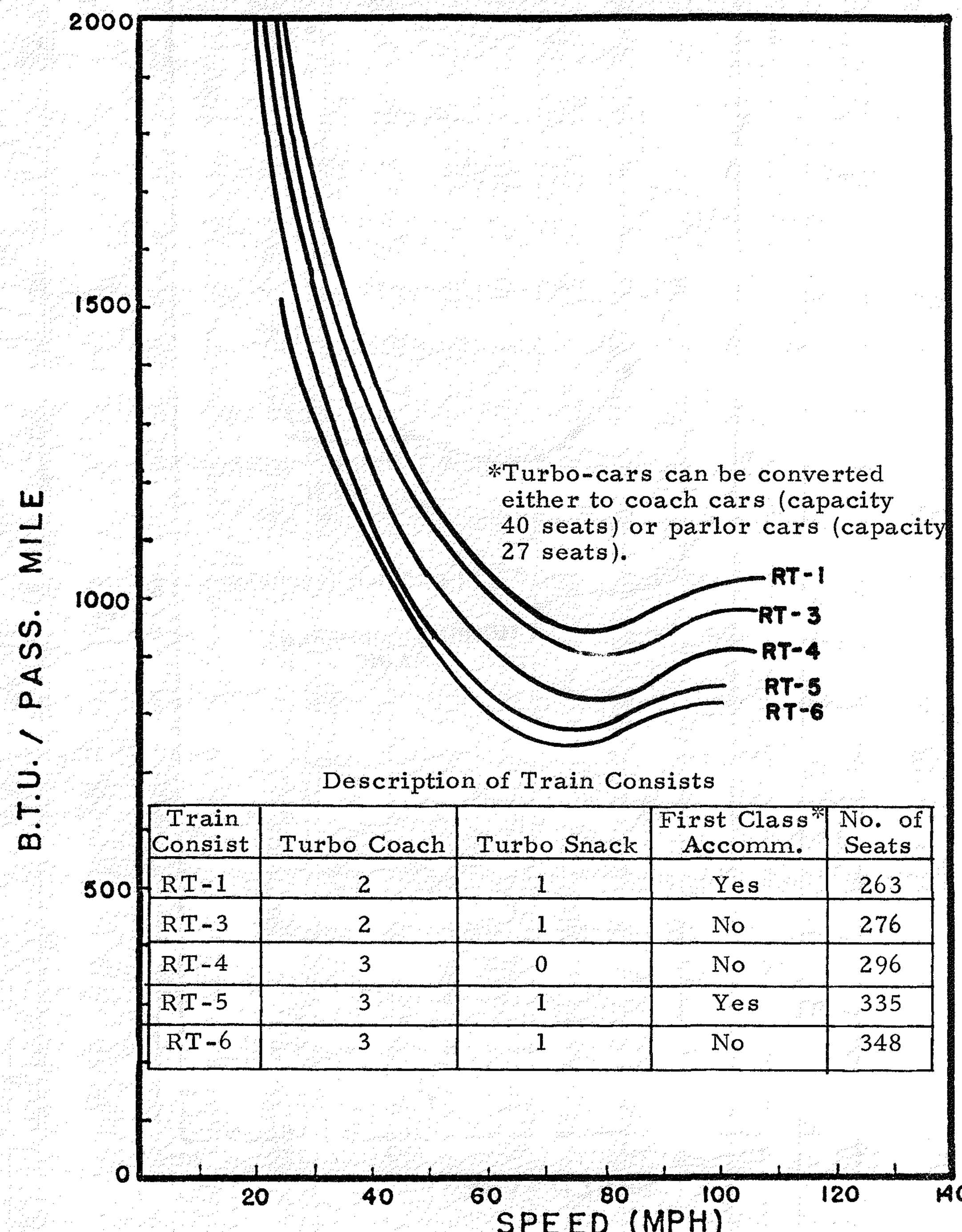


FIGURE 4.60-a

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

CRUISING ENERGY EFFICIENCY ROHR TURBOLINER CONSISTS FULLY LOADED



Description of Train Consists

Train Consist	Turbo Coach	Turbo Snack	First Class* Accomm.	No. of Seats
RT-1	2	1	Yes	263
RT-3	2	1	No	276
RT-4	3	0	No	296
RT-5	3	1	Yes	335
RT-6	3	1	No	348

FIGURE 4.60b

CRUISING ENERGY EFFICIENCY STANDARD

TURBOLINER RT-1, RT-5

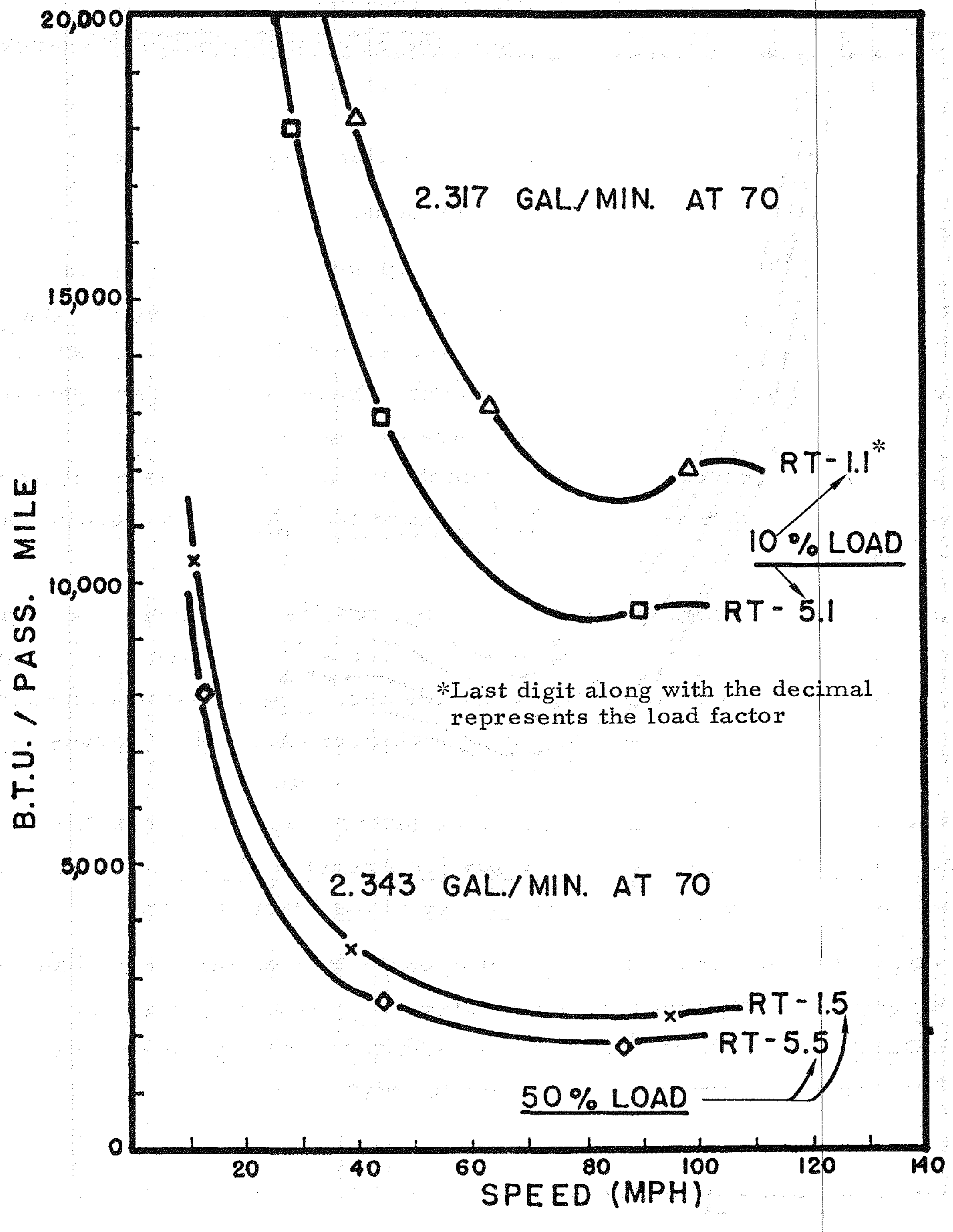


FIGURE 4.60c

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

CRUISING ENERGY INTENSITY OF STANDARD METROLINER (4 CARS)

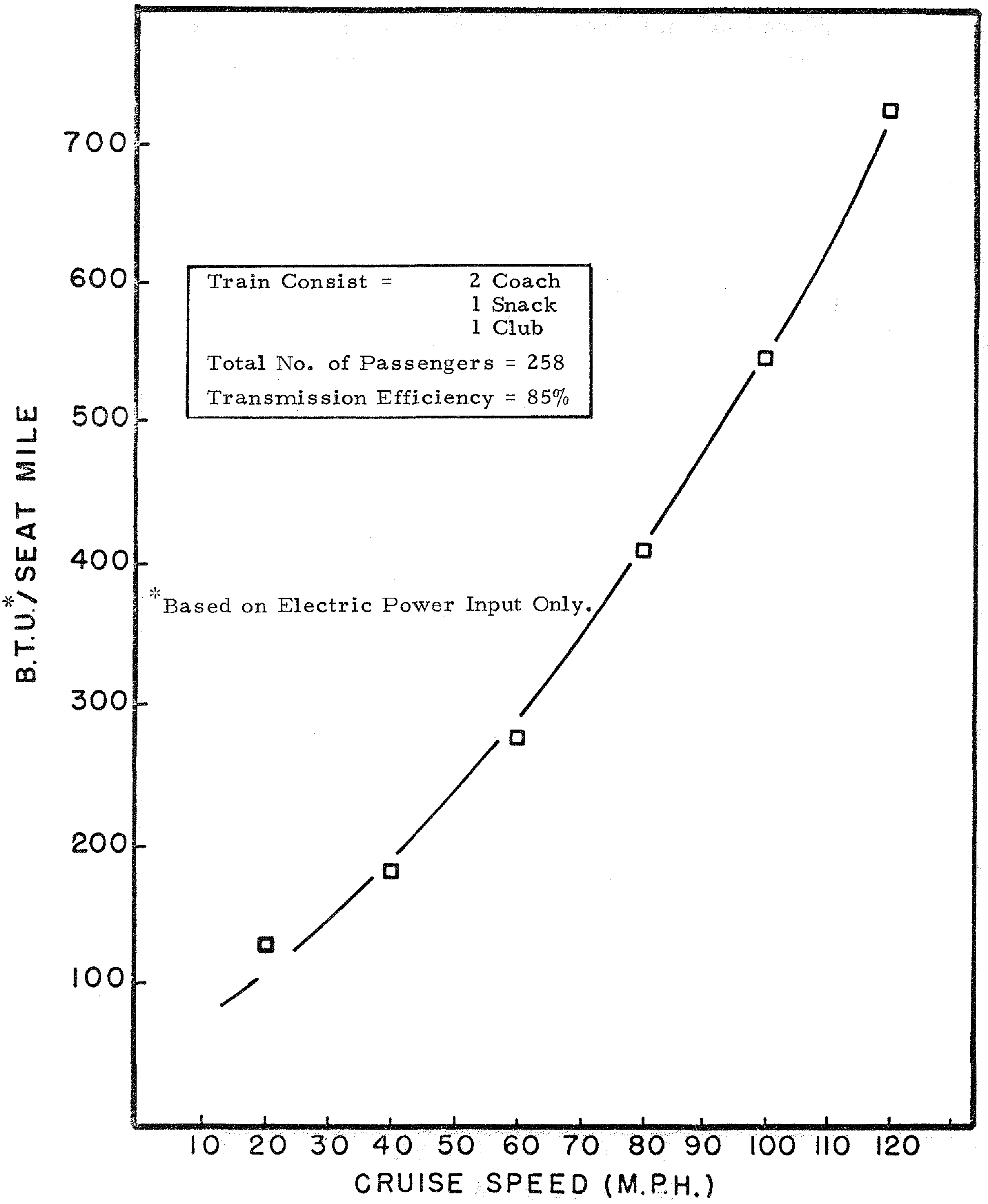


FIGURE 4.70b

CRUISING ENERGY EFFICIENCY E60 CP (ELECTRIC) + 4 AMFLEET CONSIST (1 AMCLUB, 1 AMCAFE, 2 AMCOACH)

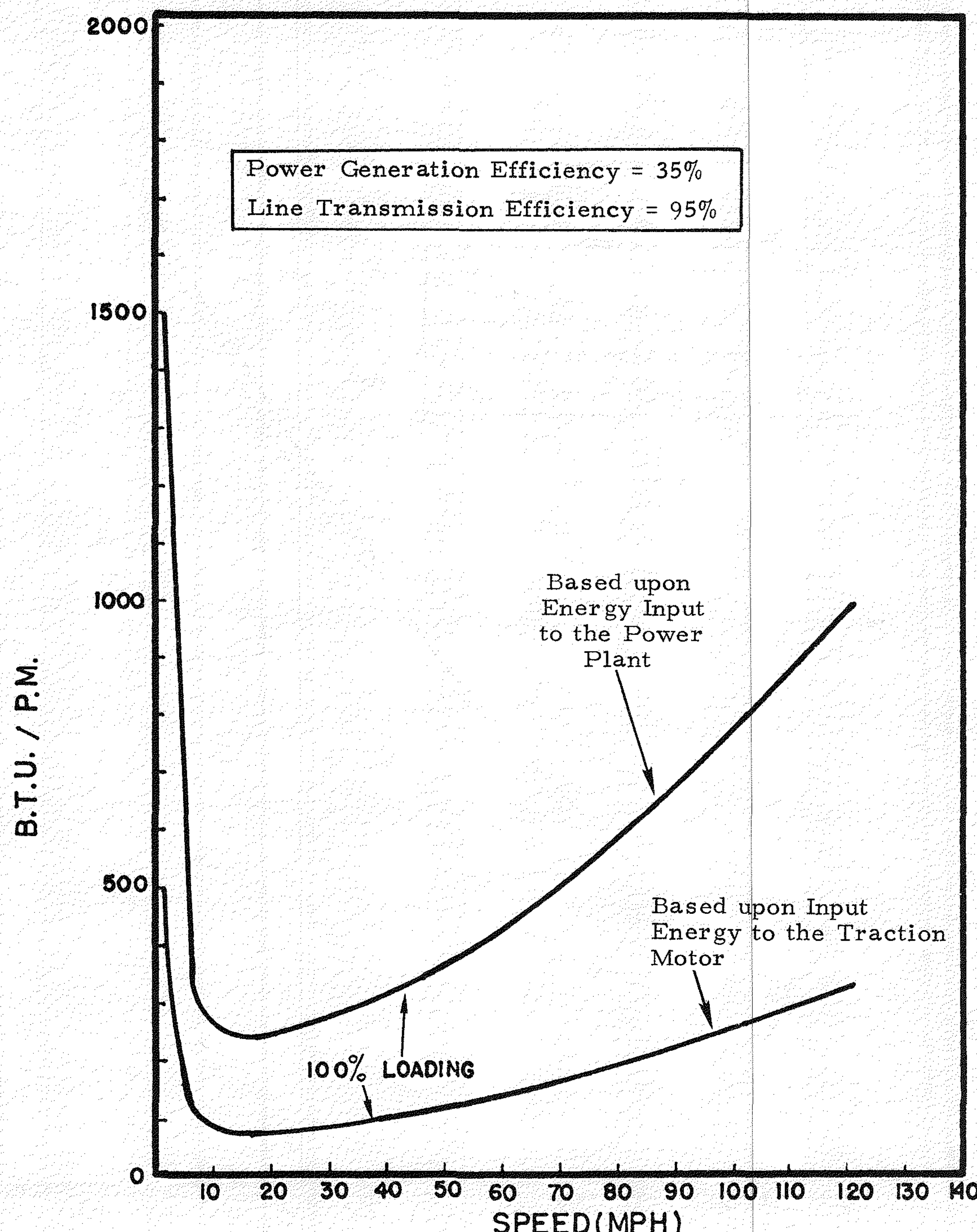


FIGURE 4.70c

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

CRUISING ENERGY INTENSITY OF FRENCH CC14500 LOCO HAULING 6 AMFLEET CARS

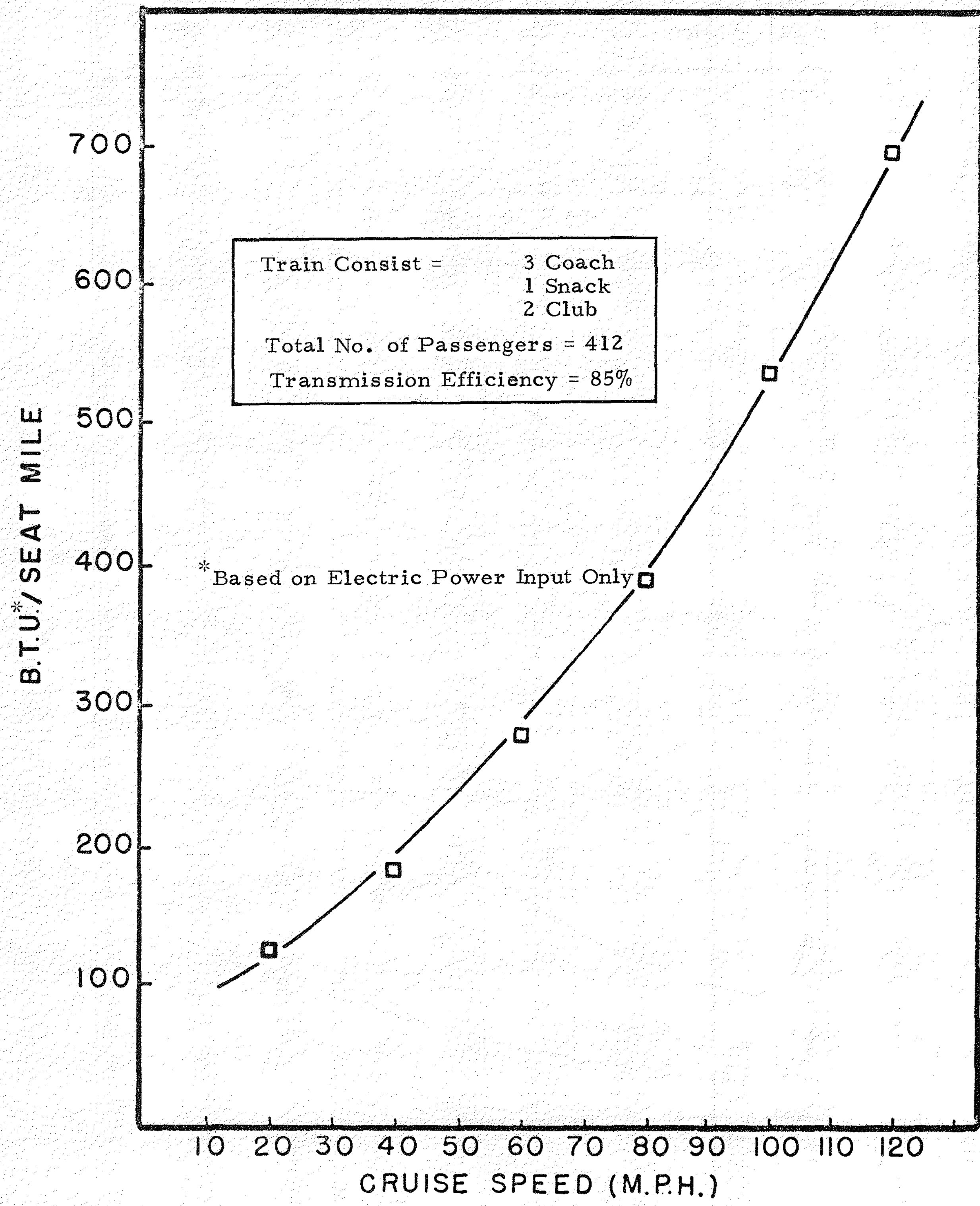


FIGURE 4.70d

UNION COLLEGE TRANSPORTATION PROGRAM	MAY 1977

CRUISING ENERGY INTENSITY OF SWEDISH RC4a LOCO HAULING 6 AMFLEET CARS

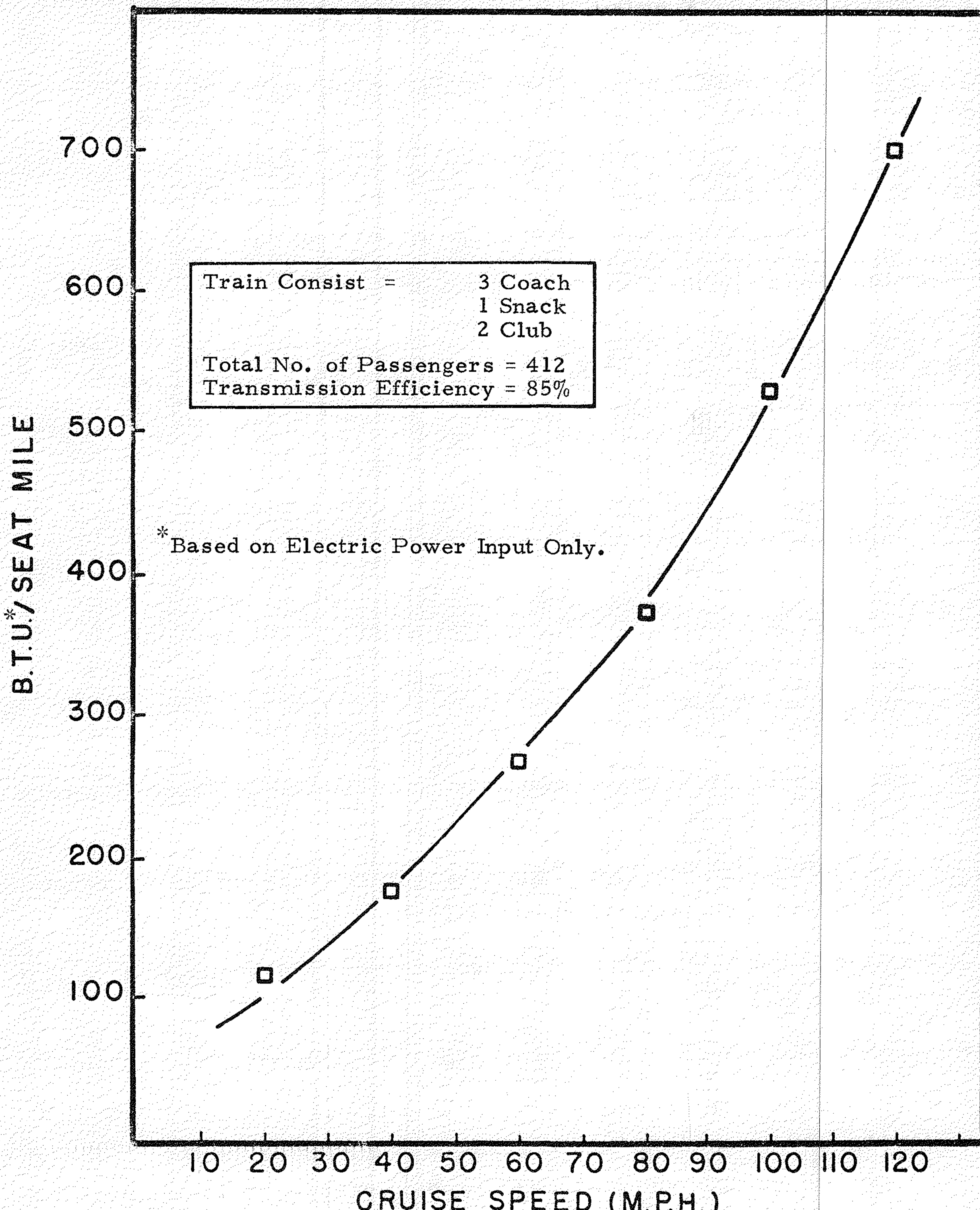


FIGURE 4.70e

4.80 SUMMARY

Table 4.80 provides a summary of the EI values calculated for various train consists cruising at a speed of 65 m.p.h. For diesel/electric train consists, the EI values were in the range of 289 to 443 B.T.U./S.M. The turboliner had an EI value of 881 B.T.U./S.M.. The electrified train consists (French CC14500, Metroliners) had an average EI value of 337 B.T.U./S.M.

The following observations can be made in regard to the diesel-electric train consists:

- B.T.U./S.M. is a nonlinear function of speed with first negative and then positive slopes. In most of the cases, the minimum exists around 25 m.p.h.
- Energy intensity is sensitive to the train consists (ratio of coach to parlor cars or snack cars, etc.) and load factor.
- Among the train consists analyzed, the LRC train appears to be the most energy efficient (least EI) while the E-8 train consist appears to be least efficient (see comparison mode at 65 m.p.h.).

For the turboliner, the following comments are made:

- Energy intensity decreases with increase in speed except at the far end of the operation.
- A turboliner is roughly two and a half times more energy intensive than a standard diesel/electric train.

In the case of the electric trains (metroliners or loco-hauled trains), the following observations are made:

- Metroliners are the most energy efficient modes of transportation.
- Loco-hauled train consists have an EI value of around 365 B.T.U./S.M. This value is based upon the input energy to the power-plants. It is important to note that considerable energy savings are possible if the train length (no. of cars) can be increased. It is also important to mention that the electric trains have a potential for use of non-petroleum sources of energy.

TABLE 4.80a

CRUISING EI ANALYSIS FOR DIESEL ELECTRIC, GAS TURBINE AND ELECTRIFIED TRAIN CONSISTS (65 m.p.h.)

Type of Power Plant	Train-Consist	No. of Passengers	B.T.U./S.M.
Diesel/Electric Train Consists	E-8 1-4-1-0	306	443
	P-30CH 1-3-1-0	312	378
	F-40PH 1-2-1-0	278	383
	SDP-40F 1-2-1-1	278	412
	LRC 1-3-1-0	304	289
Gas - Turbine	Rohr - Turboliner	296	881
Electrified	French CC 14500 1-2-1-1	278	365
	Metroliners 2-1-1	258	310

Table 4.80b shows the impact of load factor (for various train consists) upon EI values. In columns 5 and 7 are presented the ratios of EI values which are calculated at 10% and 50% load factors and compare with the full load conditions. For the diesel/electric train consists, it was found that these ratio are nearly equal (9.89 for SDP 40F) to the ratio between the successive load factors (100% vs. 10%) which indicates that
=10

- Marginal fuel penalty due to the increased patronage (from 10% load factor) is positive but small.

In the case of the turboliner, the marginal fuel penalty is negative which indicates that the train is more efficient at higher loads.

TABLE 4.80b

COMPARISON OF EI VALUES UNDER VARIOUS

5.00 CRUISING ENERGY INTENSITY VALUES OF SEVERAL TRAIN CONSISTS AT SPECIFIED SEATING CAPACITY RATING

In this chapter efforts are made to compare cruising energy intensity figures for several trains under specified seating capacity ratings. The following capacity ratings are evaluated.

- 200 passengers
- 250 passengers
- 300 passengers
- 350 passengers

In order to evaluate and document the impact of service characteristics such as the availability of luggage cars, dining or snack cars the consists are divided into two categories:

- Snack car consists - consists which have at least one snack car.
- Full service consists - consists which have parlor and club cars.

Tables 5.10 a and b show the details of the train consists and their performance characteristics. The extreme right column has data on the energy intensity at a cruising speed of 65 miles per hour. These tables also have information on the types of cars such as coach cars, club cars or snack cars. The first column represents the type and number of locomotives (or power-plants, 2 in the case of turboliner) and load factors. For example, RT-2-98-0 means two traction units of turbo-power-plant with a load factor of 98 percent. The EI values (under cruising mode only) for snack bar vary from 376 to 1279 B.T.U./S.M. The range for full service train consists was from 442 to 1204 B.T.U./P.M. It is important to note that the EI values decreased for the full-service turbo-consist. Figure 5.10-a graphically shows the impact of cruising speed upon EI values for the SD-1-87.7 train consist. Figures 5.10-b and c show the relationship between energy intensity and speed for various types of trains. Figure 5.10-b is interesting because it compares the EI figures for several trains in gallons/mile. For example, if turbo and E-8 trains (each carrying 200 people) were cruising at 60 miles per hour, then the turbo would be consuming 1 gallon more fuel over a stretch of 1 mile.

For the Buffalo-NYC Corridor, this amounts to a total of 440 gallons. Another point which needs to be made is that in case the trains were operating at 40 miles per hour, the differential would be higher and would amount to 2 gallons per mile.

The remaining charts and figures document the results for several train consists having seating capacity ratings of 250, 300 and 350 passengers.

CONSIST DESCRIPTION

(ENERGY INTENSITY OF SEVERAL TRAIN CONSISTS)

SNACK BAR CONSISTS

No. OF PASS. = 200

CONSIST TYPE**	# of Traction Units	# of Coach Cars	# of Club Cars	# of Snack Cars	COACH SECTION		CLUB SECTION		SNACK SECTION		TOT # Seats / % Load	Tons per Pass	HP per TON	SPEED after 10 miles	EI* at 65mph (cruising)
					# of Seats	FT^2 per Pass	# of Seats	FT^2 per Pass (b)	# of Seats	FT^2 per Pass					
AM-1-87.7 P30-CH Drawing Amfleet	1	2	-	1	168	6.5	-	-	60	6.6	228 (a) / 87.72	1.86	8.065	102	532
LRC-1-90.9 LRC-1-3-0	1	2	-	1	168	5.6	-	-	52	6.5	220 / 90.91	1.311	10.297	120	376
RT-2-98.0 ROHR Turbo-liner Shortened by coach	2	3	-	1	152	6.6	-	-	52	6.8	204 / 98.04	1.388	8.216	99	1279
PR-1-112.4 Refurbished E-8 drawing series 6400	1	2	-	1	128	8.1	-	-	50	9.25	178 / 112.36	1.815	6.198	90	536

**For consist description, refer to Chapter 3.

(b) Square foot of space per seat basis.

*Energy Intensity

(a) Numerator denotes the total no. of seats, Denominator refers to the percentage load factor.

TABLE NO. 5.10-a

UNION COLLEGE Transportation Program	DOT-OS-60124	May, 1977

CONSIST DESCRIPTION

SNACK BAR CONSIST | 200 PASSENGERS

CONSIST TYPE**	# of Traction Units	# of Coach Cars	# of Club Cars	# of Snack Cars	COACH SECTION # of Seats	COACH SECTION FT^2 per Pass	CLUB SECTION # of Seats	CLUB SECTION FT^2 per Pass (c)	SNACK SECTION # of Seats	SNACK SECTION FT^2 per Pass	TOT # Seats / % Load	Tons per Pass	HP per TON	SPEED after 10 miles	EI* at 65mph (cruising)
PR-2-82.7 Refurbished E-8 drawing series 6400	1	3	-	1	192	8.1	-	-	50	9.25	242(b) / 82.64	2.120	5.306	90.0	603
F-1-877 F40PH Drawing 2 Amcoach & 1 Amcafe	1	2	-	1	168	6.5	-	-	60	6.6	228 / 87.72	1.543	7.42	98.5	456
FR-1-87.7 cc14500 Amfleet Alsthom-Budd	1	2	-	1	168	6.5	-	-	60	6.6	228 / 87.72	1.66	23.3	120@ 1.9m(a)	491
SD-1-87.7 SDP40F Amfleet GM-Budd	1	2	-	1	168	6.5	-	-	60	6.6	228 / 87.72	1.885	7.96	103@ 7m	497

**For consist description, refer to Chapter 3.

(c) Square foot of space per seat basis.

*Energy Intensity

(a) 120 miles per hour speed is attained in 1.9 minutes

(b) Numerator denotes the total no. of seats, Denominator refers to the percentage load factor.

TABLE NO. 5.10-a (continued)

C O N S I S T   D E S C R I P T I O N

FULL SERVICE CONSISTS — 200 PASSENGERS

CONSIST TYPE**	# of Traction Units	# of Coach Cars	# of Club Cars	# of Snack Cars	COACH SECTION # of Seats	COACH SECTION FT^2 per Pass	CLUB SECTION # of Seats	CLUB SECTION FT^2 per Pass (b)	SNACK SECTION # of Seats	SNACK SECTION FT^2 per Pass	TOT # Seats / % Load	Tons per Pass	HP per TON	SPEED after 10 miles	EI* at 65mph (cruising)
F40PH drawing AMFLEET	1	2	1	1	168	6.5	50	10.9	60	6.6	278[a] / 71.9	1.87		88.3	584
CC14500 drawing AMFLEET	1	2	1	1	168	6.5	50	10.9	60	6.6	278 / 71.9	1.93		120@ 2.25 m	499
SDP40F drawing AMFLEET	1	2	1	1	168	6.5	50	10.9	60	6.6	278 / 71.9	2.16		100	545

**For consist description, refer to Chapter 3.

(b) Square foot of space per seat basis.

*Energy Intensity

(a) Numerator denotes the total no. of seats, Denominator refers to percentage load factor.

TABLE NO. 5.10-b

CONSIST DESCRIPTION

FULL SERVICE CONSISTS — 200 PASSENGERS

CONSIST TYPE**	# of Traction Units	# of Coach Cars	# of Club Cars	# of Snack Cars	COACH SECTION		CLUB SECTION		SNACK SECTION		TOT # Seats % Load	Tons per Pass	HP per TON	SPEED after 10 miles	EI* at 65mph (cruising)
					# of Seats	FT^2 per Pass	# of Seats	FT^2 per Pass (b)	# of Seats	FT^2 per Pass					
ROHR TURBO-LINER	2	1	2	1	112	6.6	54	8.5	52	6.8	$\frac{218}{91.7}$ (a)	1.76		75.2	1204
P30CH drawing AMFLEET	1	2	1	1	168	6.5	50	10.9	60	6.6	$\frac{278}{71.9}$	2.12		97.8	593
LRC	1	2	1	1	168	5.6	50	9.3	52	6.5	$\frac{270}{74}$	1.53		115.7	442

**For consist description, refer to Chapter 3.

(b) Square foot of space per seat basis.

*Energy Intensity

(a) Numerator denotes the total no. of seats, Denominator refers to percentage load factor.

TABLE NO. 5.10-b (continued)

CRUISING ENERGY EFFICIENCY SNACK BAR
CONSISTS 200 PASSENGERS - SDP 40F LOCO

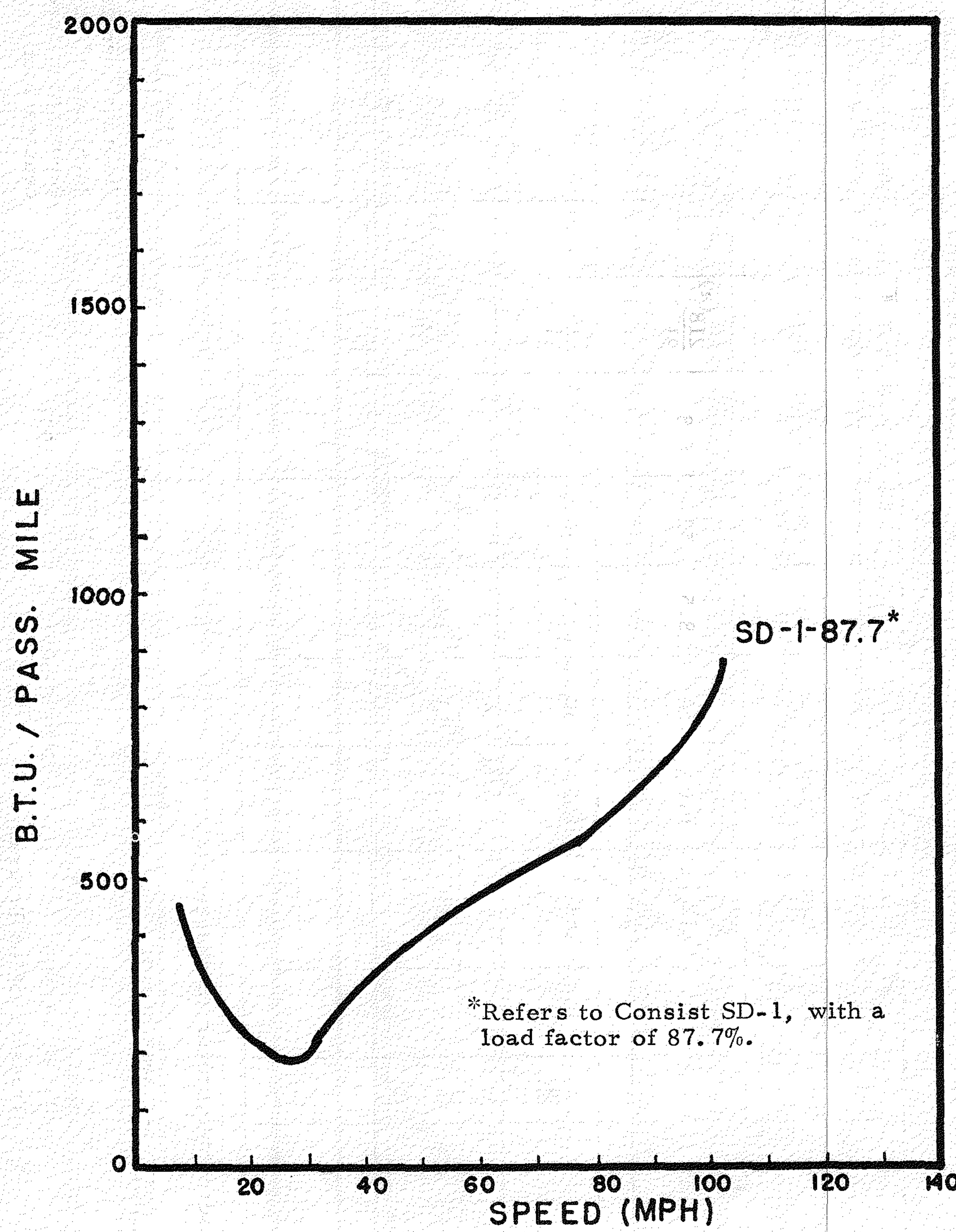


FIGURE 5.10-a

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

CRUISING ENERGY EFFICIENCY SNACK BAR
CONSISTS 200 PASSENGERS

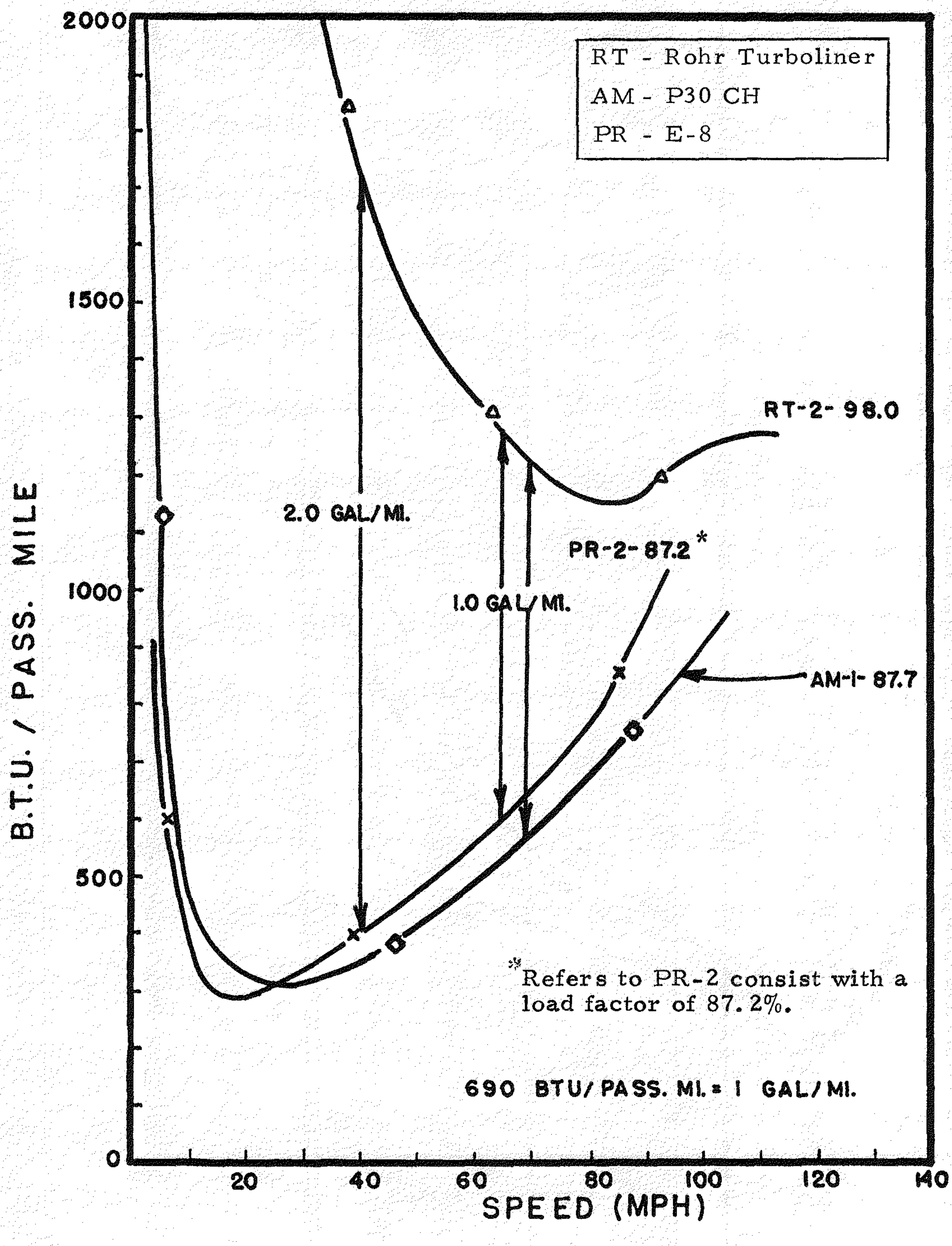


FIGURE 5.10-b

UNION COLLEGE TRANSPORTATION PROGRAM	DOT - OS - 60124 MAY 1977

CRUISING ENERGY EFFICIENCY SNACK BAR CONSISTS 200 PASSENGER

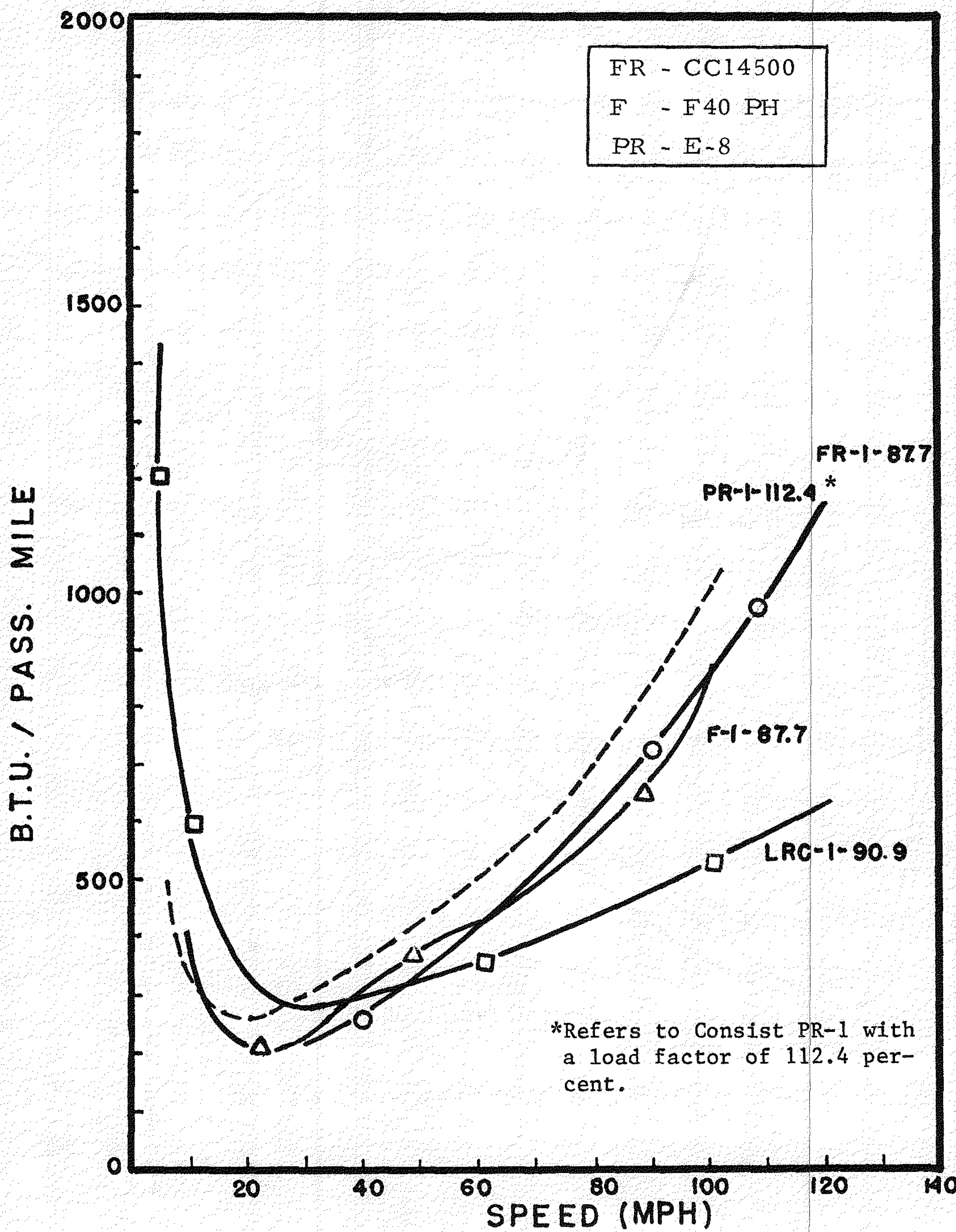


FIGURE 5.10-c

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

CONSIST DESCRIPTION

SNACK BAR CONSISTS — 250 PASSENGERS

CONSIST** TYPE	# of Traction Units	# of Coach Cars	# of Club Cars	# of Snack Cars	COACH SECTION		CLUB SECTION		SNACK SECTION		TOT # Seats % Load	Tons per Pass	HP per TON	SPEED after 10 miles	EI* at 65mph (cruising)
					# of Seats	FT^2 per Pass	# of Seats	FT^2 per Pass (b)	# of Seats	FT^2 per Pass					
RT-3-90.6 Standard Rohr turbo Snack Bar	2	4	0	1	224	6.6	-	-	52	6.8	276 (a) / 90.6%	1.334	6.75	99	1047
AM-1-109.6 P30CH drawing Amcoach &Amcafe	1	2	0	1	168	6.5	-	-	60	6.6	228 / 109.6%	1.51	7.97	102	427
AM-4-80.1 P30CH drawing Amcoach & Amcafe	1	3	0	1	252	6.5	-	-	60	6.6	312 / 80.1%	1.72	6.98	98	470
LRC-1-113.6 1-3-0 LRC consist	1	2	0	1	168	5.6	-	-	52	6.5	220 / 113.6%	1.07	10.1	120	303

**For consist description, refer to Chapter 3.

(b) Square foot of space per seat basis.

*Energy Intensity

(a) Numerator denotes the total no. of seats, Denominator refers to the percentage load factor.

TABLE NO. 5.20-a

UNION COLLEGE Transportation Program	DOT-OS-60124	May, 1977

C O N S I S T   D E S C R I P T I O N

SNACK BAR CONSISTS 250 PASSENGERS

CONSIST** TYPE	# of Traction Units	# of Coach Cars	# of Club Cars	# of Snack Cars	COACH SECTION		CLUB SECTION		SNACK SECTION		TOT # Seats % Load	Tons per Pass	HP per TON	SPEED after 10 miles	EI* at 65mph (cruising)
					# of Seats	FT^2 per Pass	# of Seats	FT^2 per Pass (b)	# of Seats	FT^2 per Pass					
F-3-80.1 F40PH Drawing Amcoach & Amcafe	1	3	0	1	252	6.5	-	-	60	6.6	312 (a) / 80.1 %	1.46	6.27	94.5	400
FR-1-109.6 CC 14500 Amfleet Alsthom-Budd	1	2	0	1	168	6.5	-	-	60	6.6	228 / 109.6%	1.34	22.3	120 @ 1.93m	348
FR-3-80.1 CC14500 Amfleet Alsthom-Budd	1	3	0	1	252	6.5	-	-	60	6.6	312 / 80.1%	1.56	19.85	120 @ 2.3 m	400
SD-1-109.6 SDP40F drawing Amfleet GM-Budd	1	3	0	1	168	6.5	-	-	60	6.6	228 / 109.6%	1.53	7.86	103 @ 7.1 m	399

**For consist description, refer to Chapter 3.

*Energy Intensity

(b) Square foot of space per seat basis.

(a) Numerator denotes the total no. of seats, Denominator refers to the percentage load factor.

TABLE NO. 5.20-a (continued)

UNION COLLEGE Transportation Program	DOT-OS-60124	May, 1977

CONSIST DESCRIPTION

SNACK BAR CONSISTS 250 PASSENGERS

CONSIST TYPE**	# of Traction Units	# of Coach Cars	# of Club Cars	# of Snack Cars	COACH SECTION		CLUB SECTION		SNACK SECTION		TOT # Seats % Load	Tons per Pass	HP per TON	SPEED after 10 miles	EI* at 65mph (cruising)
					# of Seats	FT^2 per Pass	# of Seats	FT^2 per Pass (b)	# of Seats	FT^2 per Pass					
SD-3-80.1 SDP40F drawn Amfleet consist	1	3	-	1	252	6.5	-	-	60	6.6	$\frac{312}{80.1}$ (a)	1.738	6.9	103 9.6	433

**For consist description, refer to Chapter 3.

(b) Square foot of space per seat basis.

*Energy Intensity

(a) Numerator denotes the total no. of seats, Denominator refers to the percentage load factor.

TABLE NO. 5.20-a (continued)

CONSIST DESCRIPTION

FULL SERVICE CONSISTS 250 PASSENGERS

CONSIST TYPE**	# of Traction Units	# of Coach Cars	# of Club Cars	# of Snack Cars	COACH SECTION		CLUB SECTION		SNACK SECTION		TOT # Seats / % Load	Tons per Pass	HP per TON	SPEED after 10 miles	EI* at 65mph (cruising)
					# of Seats	FT^2 per Pass	# of Seats	FT^2 per Pass (b)	# of Seats	FT^2 per Pass					
F-2-89.9% F40PH drawing Amfleet cars	1	2	1	1	168	6.5	50	10.9	60	6.6	278[a] / 89.92	1.47	6.25	94.5	400
FR-2-89.9 CC14500 Amfleet Alsthom-Budd	1	2	1	1	168	6.5	50	10.9	60	6.6	278 / 89.92	1.55	19.87	120 @2.3m	400
SD-2-89.9 SPP40F Amfleet GM-Budd	1	2	1	1	168	6.5	50	10.9	60	6.6	278 / 89.92	1.74	6.9	103 @9.6m	433

**For consist description, refer to Chapter 3.

(b) Square foot of space per seat basis.

*Energy Intensity

(a) Numerator denotes the total no. of seats, Denominator refers to the percentage load factor.

TABLE NO. 5.20-b

CONSIST DESCRIPTION

FULL SERVICE CONSISTS — 250 PASSENGERS

CONSIST TYPE**	# of Traction Units	# of Coach Cars	# of Club Cars	# of Snack Cars	COACH SECTION		CLUB SECTION		SNACK SECTION		TOT # Seats / % Load	Tons per Pass	HP per TON	SPEED after 10 miles	EI* at 65mph (cruising)
					# of Seats	FT^2 per Pass	# of Seats	FT^2 per Pass (b)	# of Seats	FT^2 per Pass					
RT-1-95.1 Standard ROHR Turbo-lines Conf.	2	3	1	1	184	6.6	27	8.5	52	6.8	263 (a) / 95.06	1.334	6.837	99.4	1039
AM-3-89.9 P30CH Drawn AMFLEET consist	1	2	1	1	168	6.5	50	10.9	60	6.6	278 / 89.92	1.793	6.979	98.3	470
LRC-3-92.6 LRC in a 1-4-0 configura.	1	2	1	1	168	5.6	50	9.3	52	6.5	270 / 92.59	1.247	8.662	115.8	350

**For consist description, refer to Chapter 3.

(b) Square foot of space per seat basis.

*Energy Intensity

(a) Numerator denotes the total no. of seats, Denominator refers to the percentage load factor.

TABLE NO. 5.20-b (continued)

CRUISING ENERGY EFFICIENCY SNACK BAR
CONSISTS 250 PASSENGERS

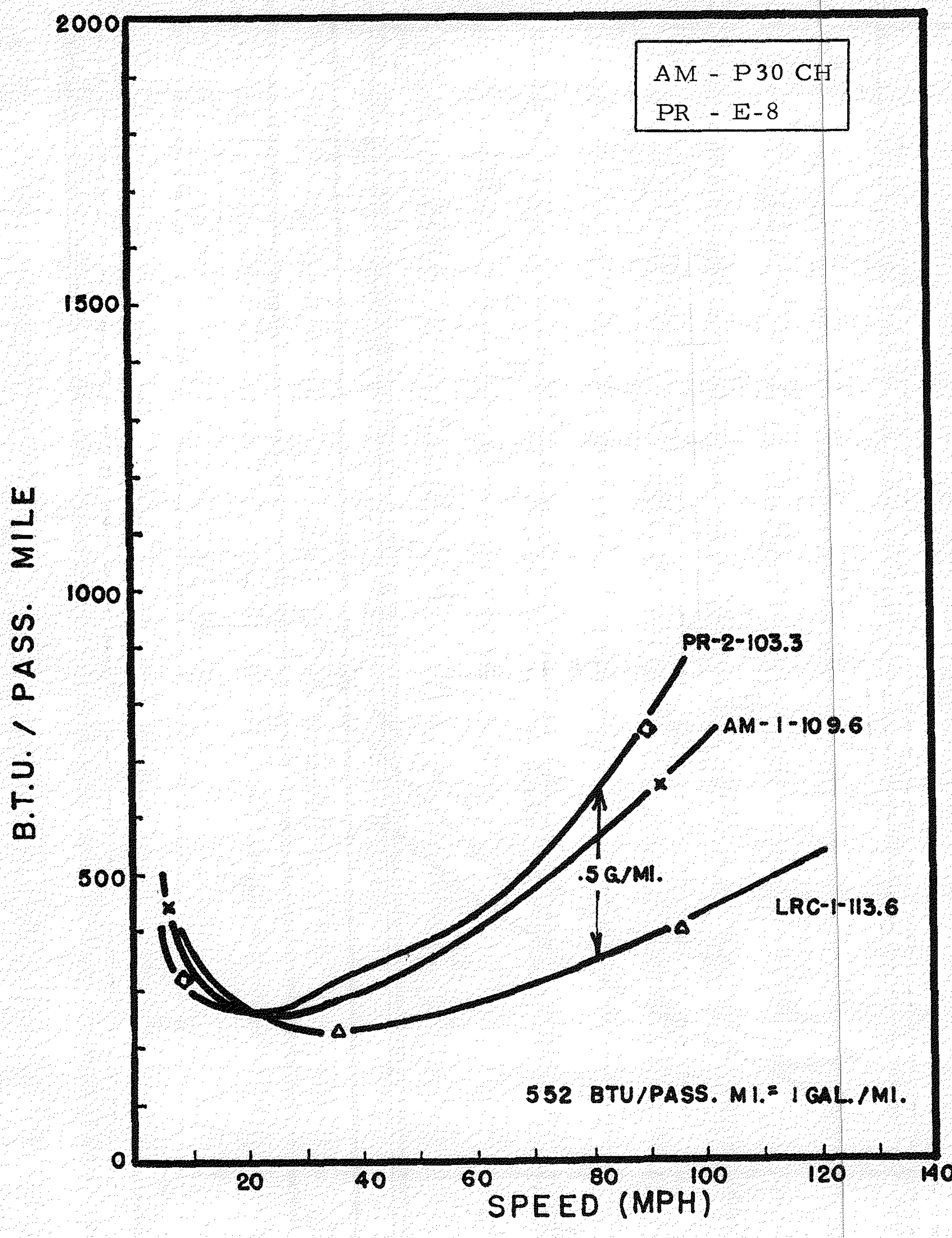


FIGURE 5.20-a

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

CRUISING ENERGY EFFICIENCY SNACK BAR

CONSISTS 250 PASSENGERS

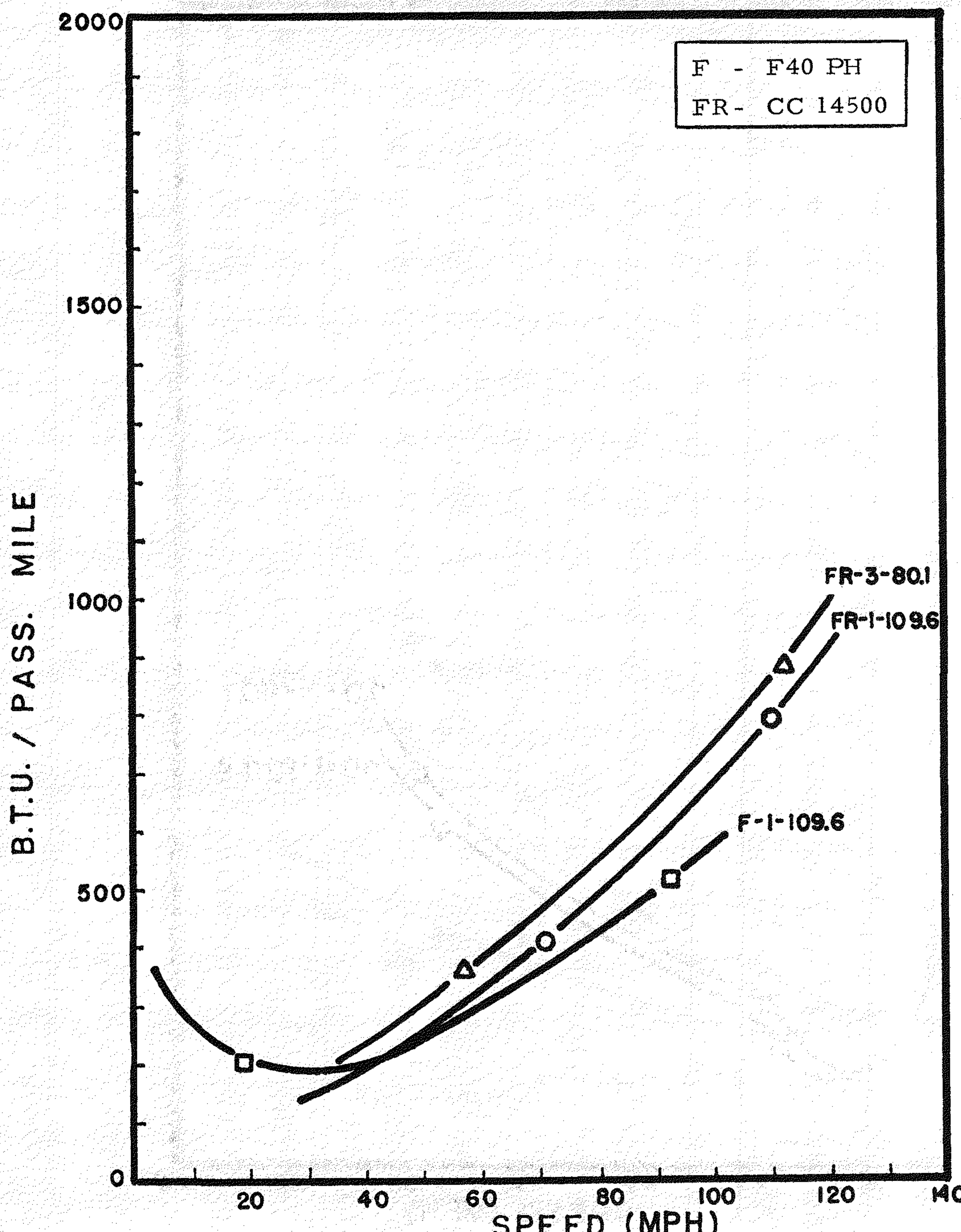


FIGURE 5.20-b

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

CRUISING ENERGY EFFICIENCY SNACK BAR CONSISTS 250 PASSENGERS - SDP 40F LOCO

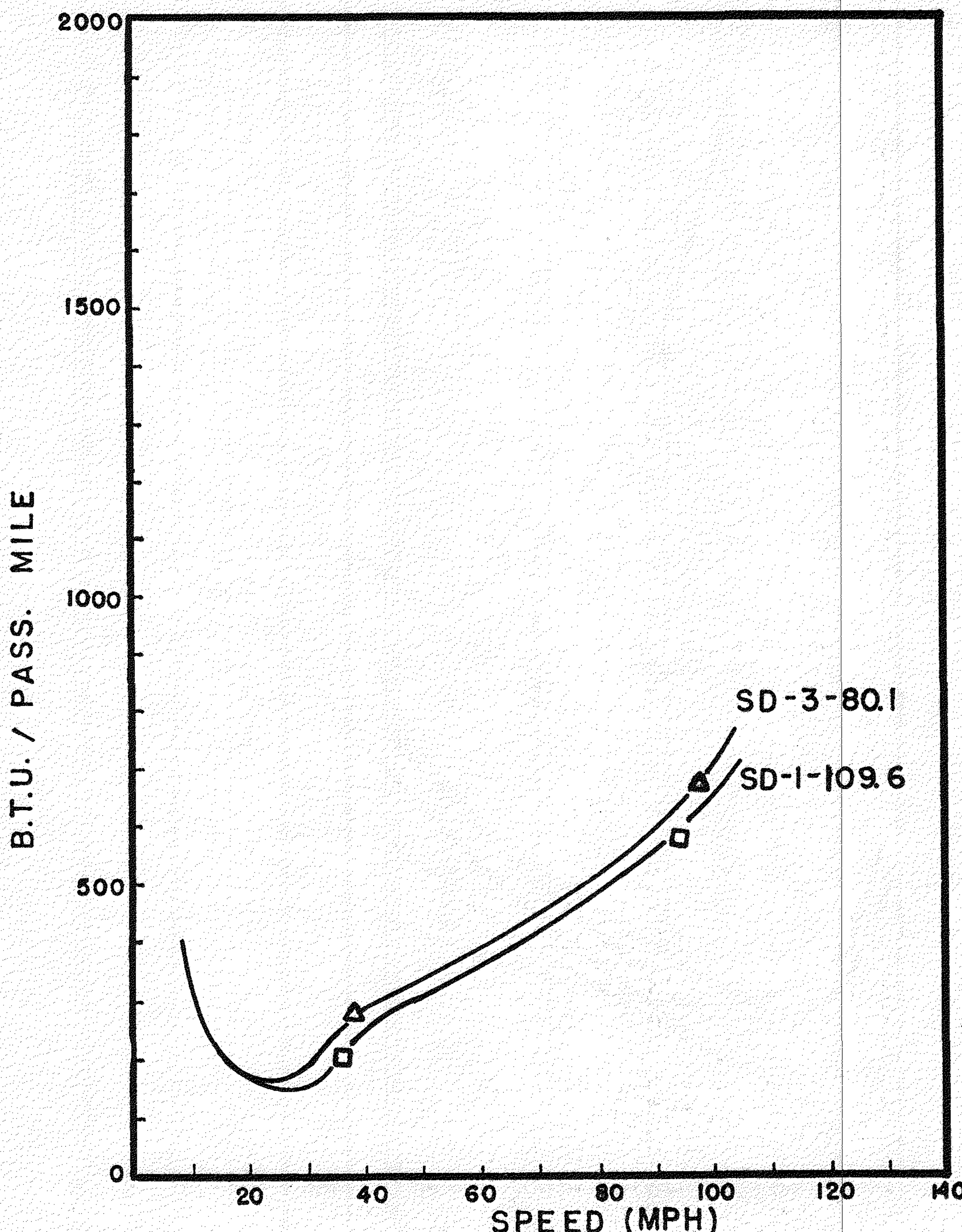


FIGURE 5.20-c

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

CRUISING ENERGY EFFICIENCY SNACK BAR CONSISTS 250 PASSENGERS

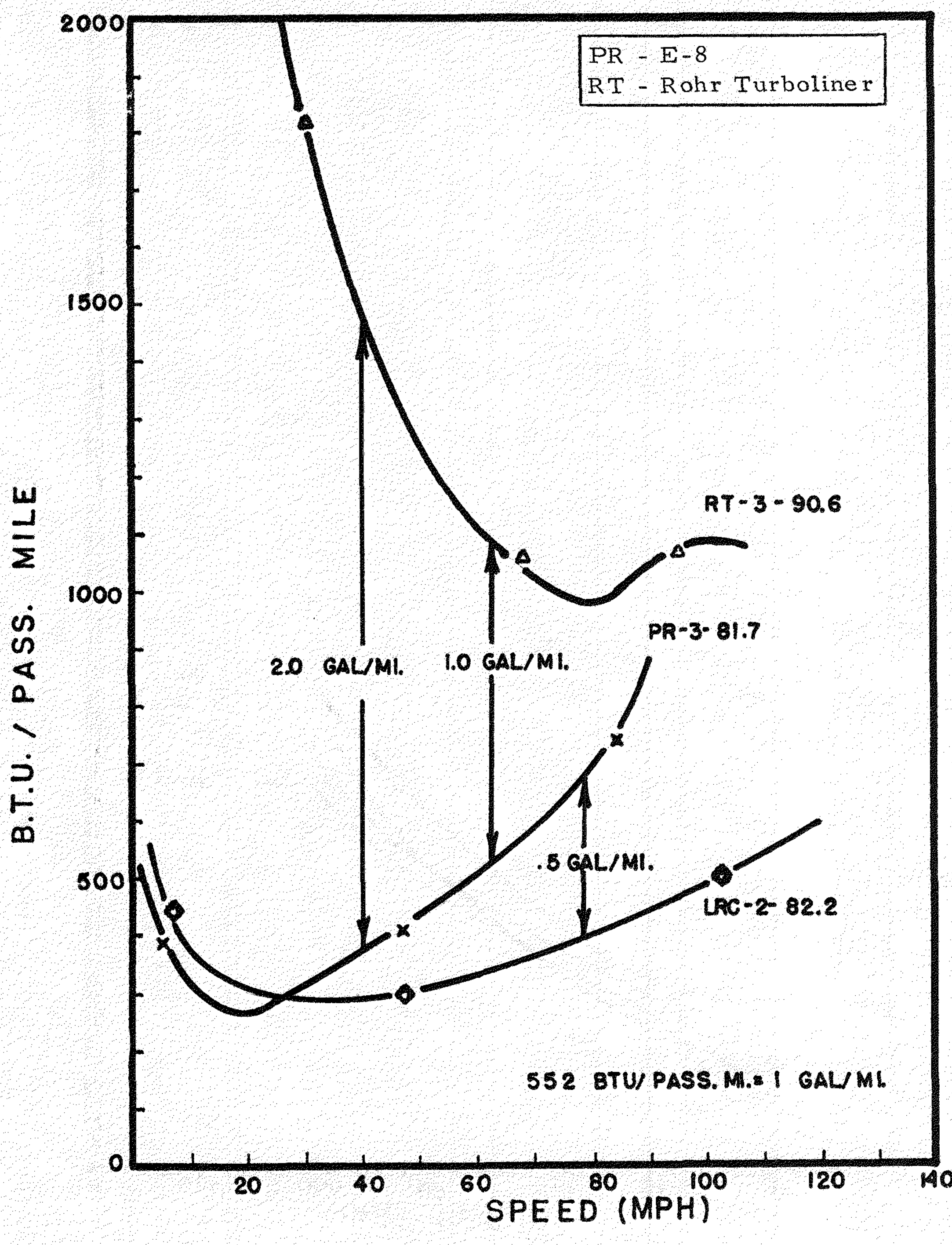


FIGURE 5.20-d

CRUISING ENERGY EFFICIENCY SNACK BAR CONSISTS 250 PASSENGERS

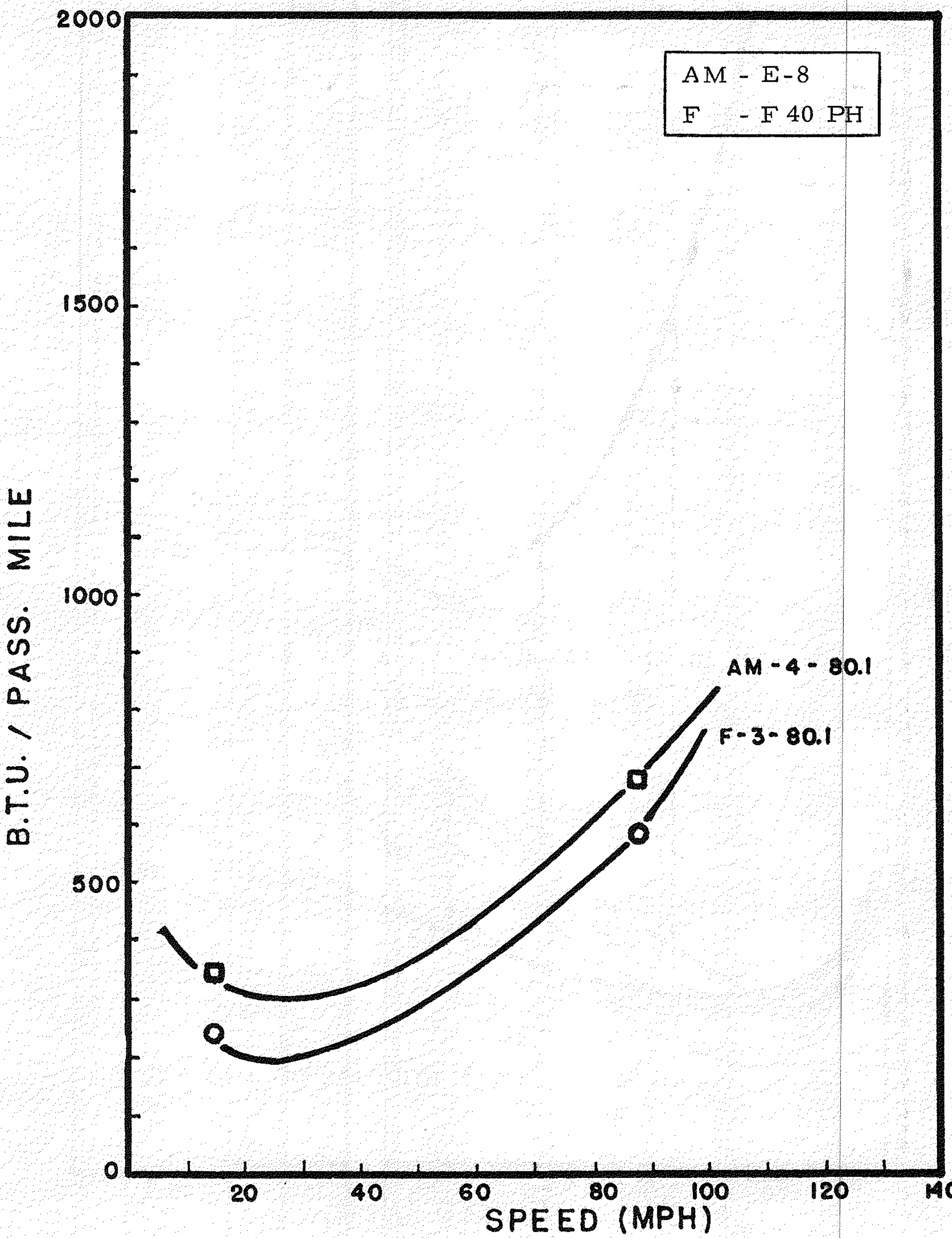


FIGURE 5.20-e

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

CRUISING ENERGY EFFICIENCY

SNACK BAR CONSISTS 250 PASSENGERS

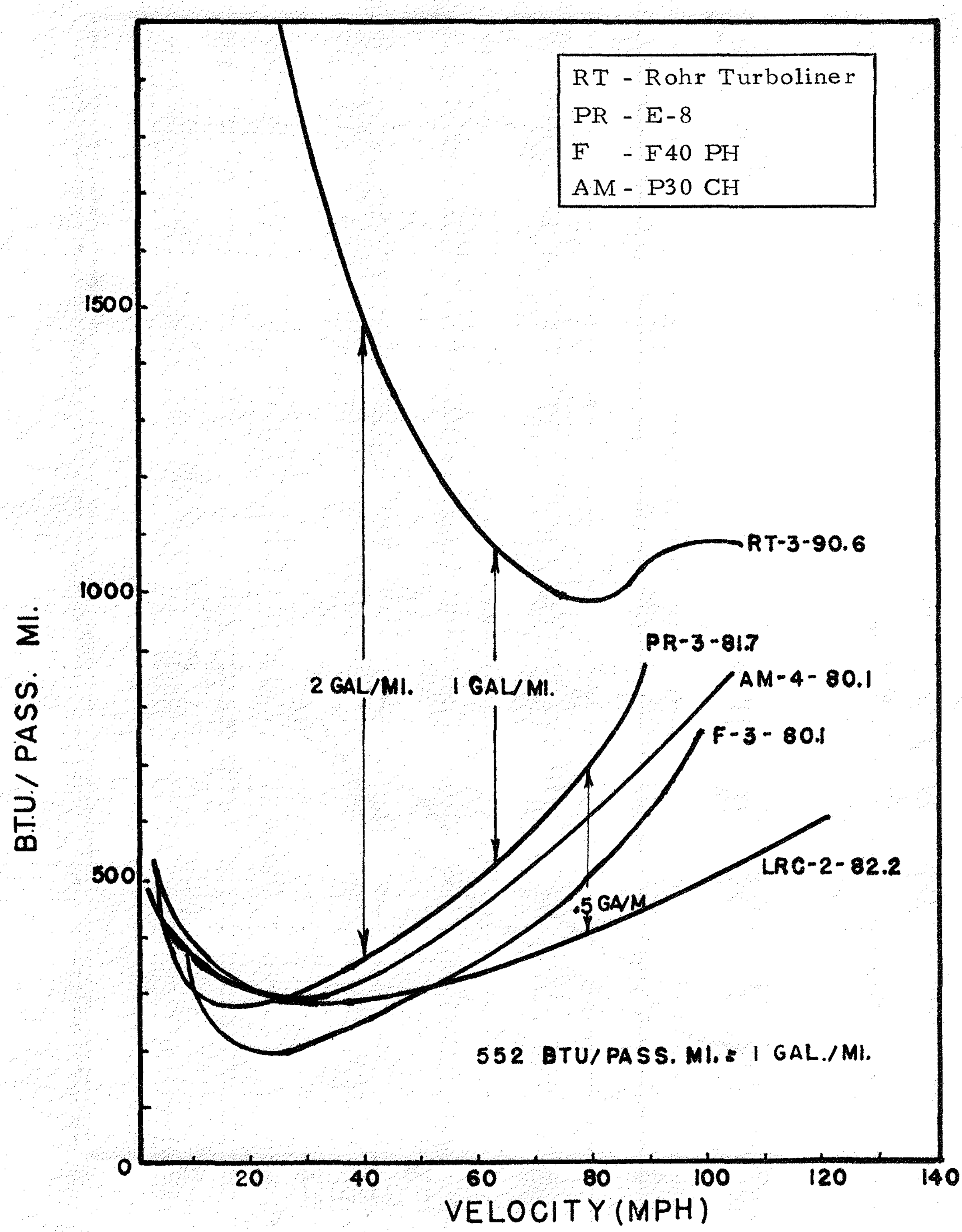


FIGURE 5.20-f

CRUISING ENERGY EFFICIENCY FULL SERVICE

CONSIST 250 PASSENGERS

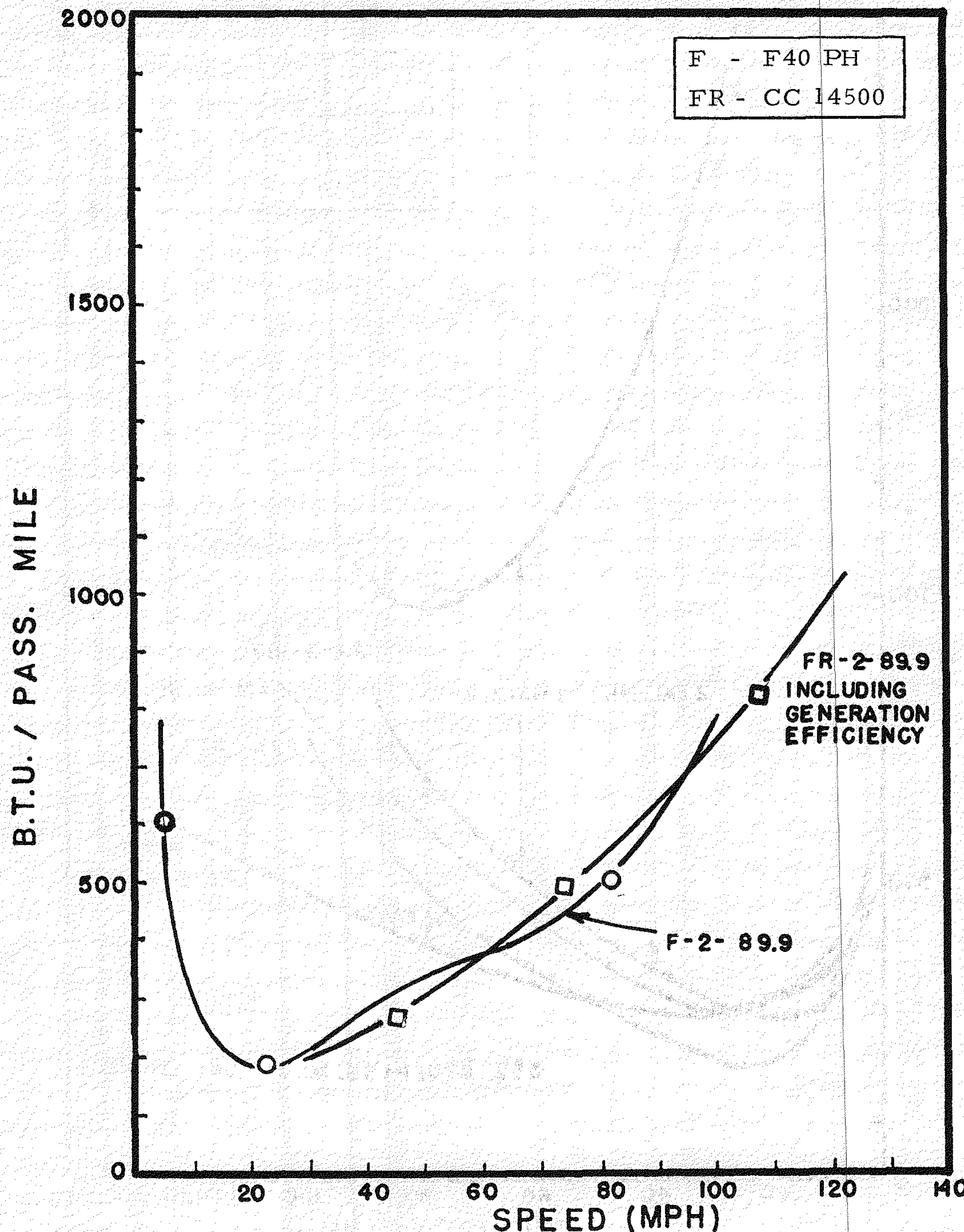


FIGURE 5.20-g

CRUISING ENERGY EFFICIENCY FULL SERVICE CONSISTS 250 PASSENGERS

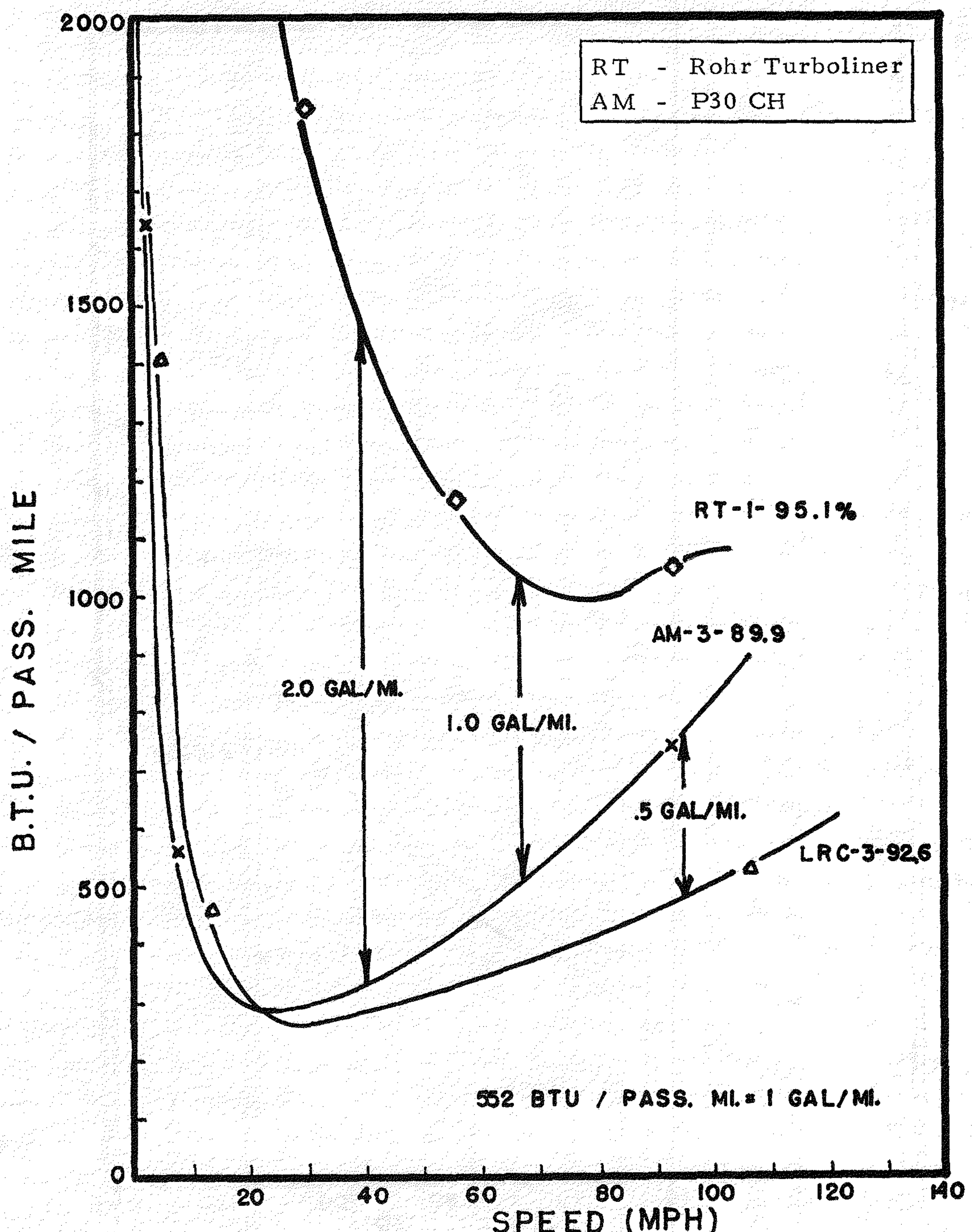


FIGURE 5.20-h

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

CRUISING ENERGY EFFICIENCY FULL SERVICE

CONSISTS 250 PASSENGERS

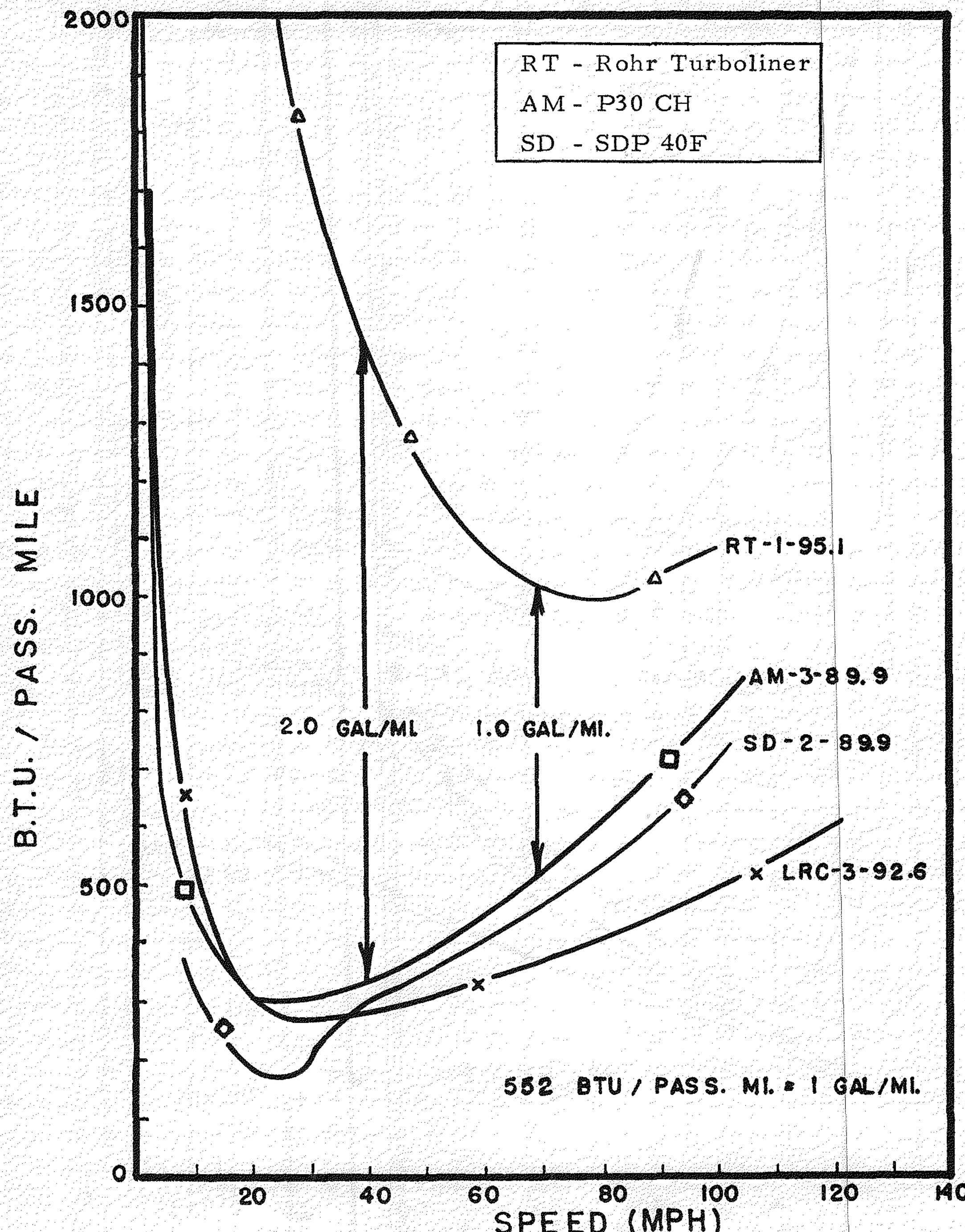


FIGURE 5.20-i

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

CRUISING ENERGY EFFICIENCY FULL SERVICE CONSISTS 250 PASSENGERS

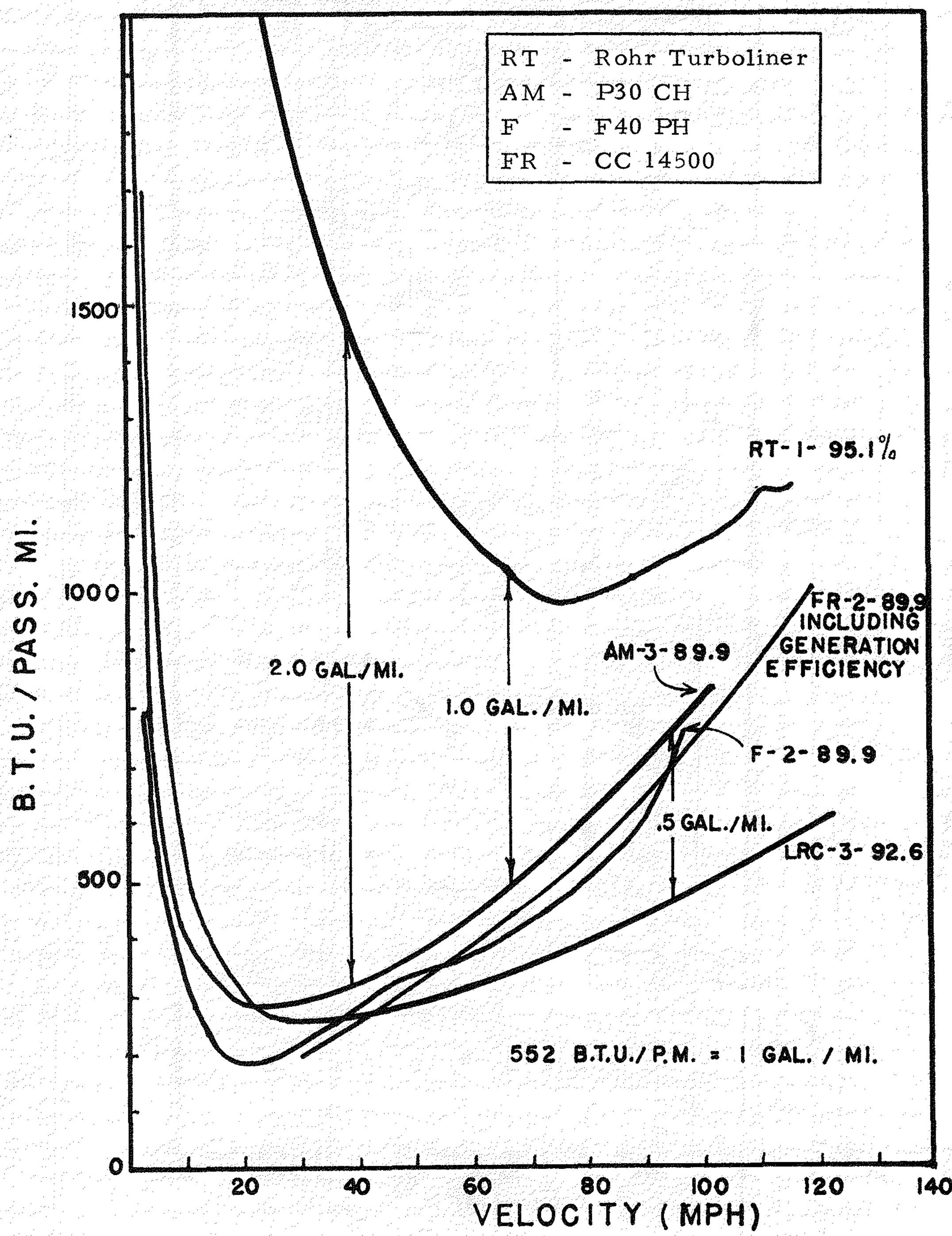


FIGURE 5.20-j

CONSIST DESCRIPTION

SNACK BAR CONSISTS — 300 PASSENGERS

CONSIST TYPE**	# of Traction Units	# of Coach Cars	# of Club Cars	# of Snack Cars	COACH SECTION # of Seats	COACH SECTION FT^2 per Pass	CLUB SECTION # of Seats	CLUB SECTION FT^2 per Pass (b)	SNACK SECTION # of Seats	SNACK SECTION FT^2 per Pass	TOT # Seats / % Load	Tons per Pass	HP per TON	SPEED after 10 miles	EI* at 65mph (cruising)
AM-4-96.2 P30-CH Drawn Amfleet consist	1	3	-	1	252	6.5	-	-	60	6.6	312 (a) / 96.15	1.447	6.912	98.0	393
LRC-2-98.7 LRC 1-4-0 configuration	1	3	-	1	252	5.6	-	-	52	6.5	304 / 98.68	1.054	8.539	115.2	293
RT-3-108.7 Standard (1-3-1) ROHR Turbo	2	4	-	1	224	6.6	-	-	52	6.8	276 / 108.69	1.127	6.746	99.1	876
RT-6-86.2 "Stretched (1-4-1) Rohr Turboliner	2	5	-	1	296	6.6	-	-	52	6.8	348 / 86.21	1.298	5.854	94.5	890

**For consist description, refer to Chapter 3.

*Energy Intensity

(b) Square foot of space per seat basis.

(a) Numerator denotes the total no. of seats, Denominator refers to the percentage load factor.

TABLE NO. 5.30-a

CONSIST DESCRIPTION

SNACK BAR CONSISTS   300 PASSENGERS

CONSIST** TYPE	# of Traction Units	# of Coach Cars	# of Club Cars	# of Snack Cars	COACH SECTION		CLUB SECTION		SNACK SECTION		TOT # Seats % Load	Tons per Pass	HP per TON	SPEED after 10 miles	EI* at 65mph (cruising)
					# of Seats	FT^2 per Pass	# of Seats	FT^2 per Pass (c)	# of Seats	FT^2 per Pass					
PR-3-98.0 Refurbished E-8 series 6400 &1 Amtrak	1	4	-	1	256	8.1	-	-	50	9.3	306 (a) / 98.04	1.647	4.554	86.0	452
F-3-96.2 F40PH drawing 3 Amcoach & 1 Amtrak	1	3	-	1	252	6.5	-	-	60	6.6	312 / 96.15	1.235	6.18	94.5	334
FR-3-96.2 CC14500 drawing Amfleet Alsthom-Budd	1	3	-	1	252	6.5	-	-	60	6.6	312 / 96.15	1.65	15.65	120@ 2.9m (b)	333
SD-3-96.2 SDP40F drawing Amfleet GM-Budd	1	3	-	1	252	6.5	-	-	60	6.6	312 / 96.15	1.4	6.8	103 @ 9.7 m	362

** For consist description, refer to Chapter 3.

(c) Square foot of space per seat basis.

*Energy Intensity

(a) Numerator denotes total no. of seats, Denominator refers to percentage load factor.

(b) Speed 120 miles attained at the end of 10 miles or 2.9 minutes.

TABLE NO. 5.30-a (continued)

CONSIST DESCRIPTION

FULL SERVICE CONSISTS 300 PASSENGERS

CONSIST** TYPE	# of Traction Units	# of Coach Cars	# of Club Cars	# of Snack Cars	COACH SECTION		CLUB SECTION		SNACK SECTION		TOT # Seats % Load	Tons per Pass	HP per TON	SPEED after 10 miles	EI* at 65mph (cruising)
					# of Seats	FT^2 per Pass	# of Seats	FT^2 per Pass (b)	# of Seats	FT^2 per Pass					
F-4-82.9 F40PH drawing Amfleet GM-Budd	1	3	1	1	252	6.5	50	10.9	60	6.6	362 (a) / 82.87	1.41	5.41	91.3	362
FR-4-82.9 CC14500 Amfleet Alsthom -Budd	1	3	1	1	252	6.5	50	10.9	60	6.6	362 / 82.87	1.49	17.3	120	376
SD-4-82.9 SDP40F drawing Amfleet GM-Budd	1	3	1	1	252	6.5	50	10.9	60	6.6	362 / 82.87	1.64	6.1	99.5	390

** For consist description, refer to Chapter 3.

(b) Square foot of space per seat basis.

*Energy Intensity

(a) Numerator denotes the total no. of seats, Denominator refers to percentage load factor.

TABLE NO. 5.30-b

UNION COLLEGE Transportation Program	DOT-OS-60124	May, 1977

CONSIST DESCRIPTION

FULL SERVICE CONSIST — 300 PASSENGERS

CONSIST TYPE**	# of Traction Units	# of Coach Cars	# of Club Cars	# of Snack Cars	COACH SECTION		CLUB SECTION		SNACK SECTION		TOT # Seats / % Load	Tons per Pass	HP per TON	SPEED after 10 miles	EI* at 65mph (cruising)
					# of Seats	FT^2 per Pass	# of Seats	FT^2 per Pass (b)	# of Seats	FT^2 per Pass					
RT-5-89.5 ROHR Turbo add. coach car	2	4	1	1	256	6.6	27	8.5	52	6.8	(a) 335 / 89.55	1.298	5.854	94.7	898
AM-5-82.9 P30CH Drawn Amfleet consist	1	3	1	1	252	6.5	50	10.9	60	6.6	362 / 82.87	1.623	6.160	94.9	426
LRC-4-84.7 LRC in 1-5-0 configura.	1	3	1	1	252	5.6	50	9.3	52	6.5	354 / 84.75	1.204	7.475	109.9	332

**For consist description, refer to Chapter 3.

(b) Square foot of space per seat basis.

*Energy Intensity

(a) Numerator denotes the total no. of seats, Denominator refers to percentage load factor.

TABLE NO. 5.30-b (continued)

UNION COLLEGE Transportation Program	DOT-OS-60124	May, 1977

CRUISING ENERGY EFFICIENCY SNACK BAR CONSISTS 300 PASSENGERS - SDP 40F LOCO

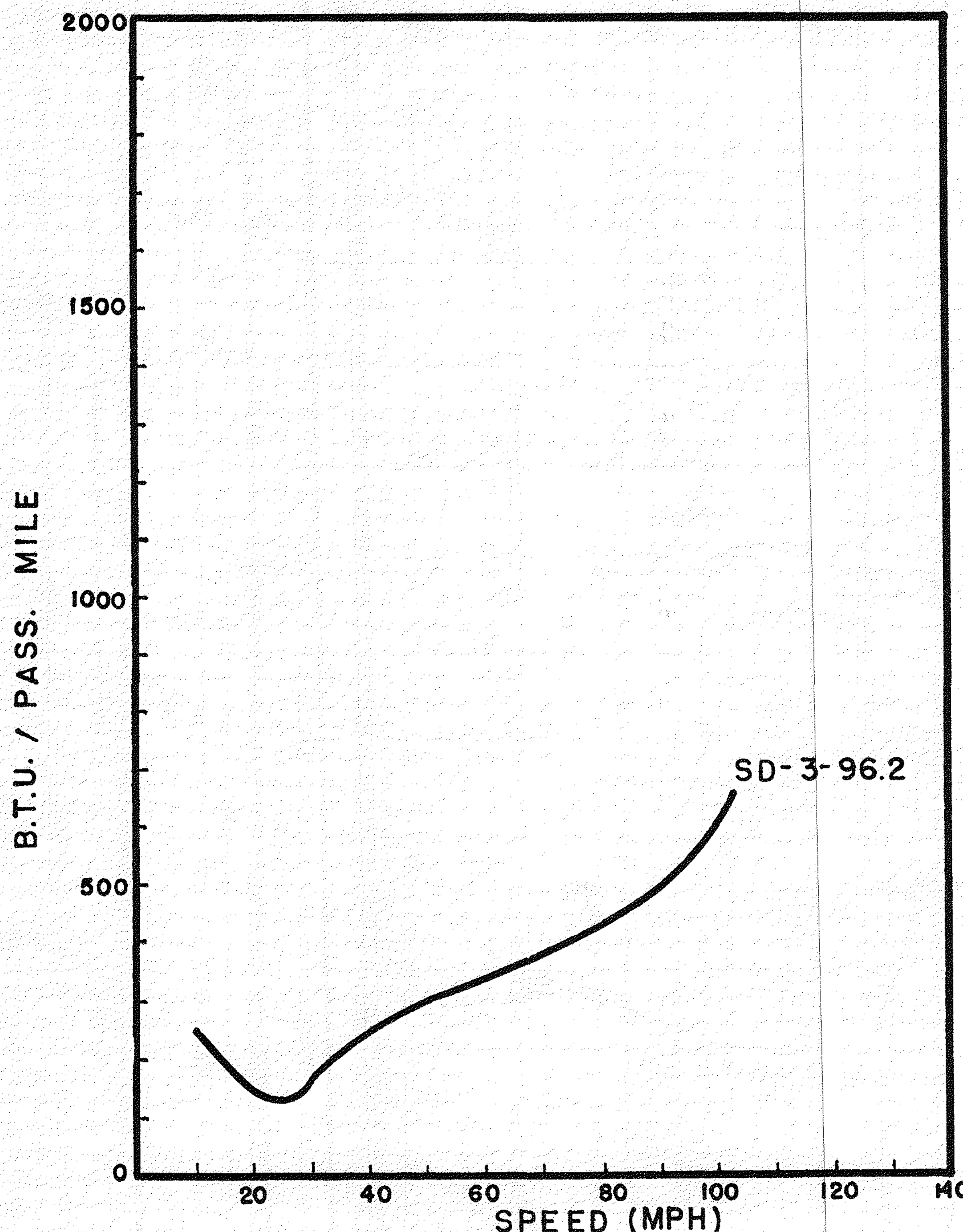


FIGURE 5.30-a

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

CRUISING ENERGY EFFICIENCY SNACK BAR CONSISTS 300 PASSENGERS

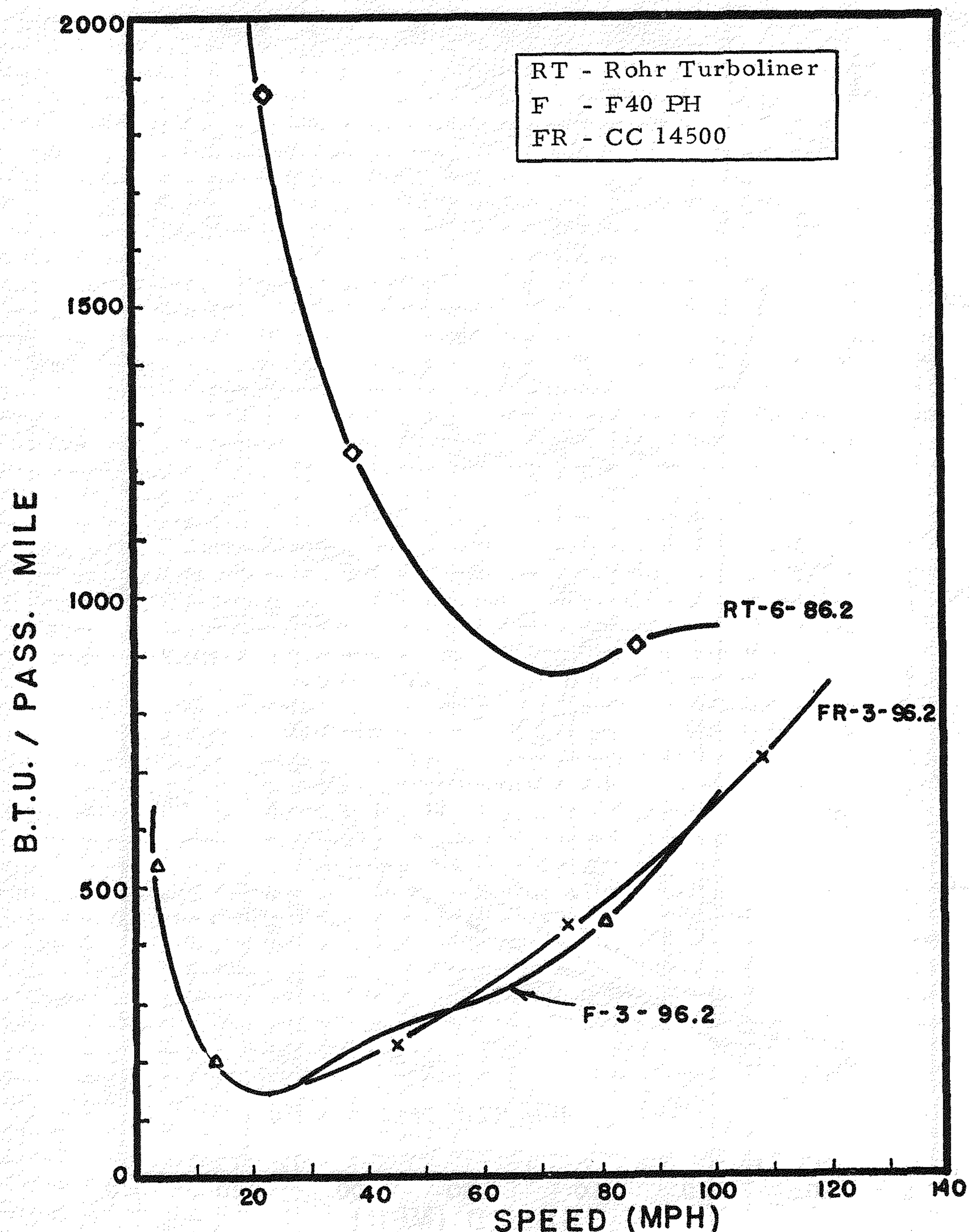


FIGURE 5.30-b

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

CRUISING ENERGY EFFICIENCY SNACK BAR
CONSISTS 300 PASSENGERS

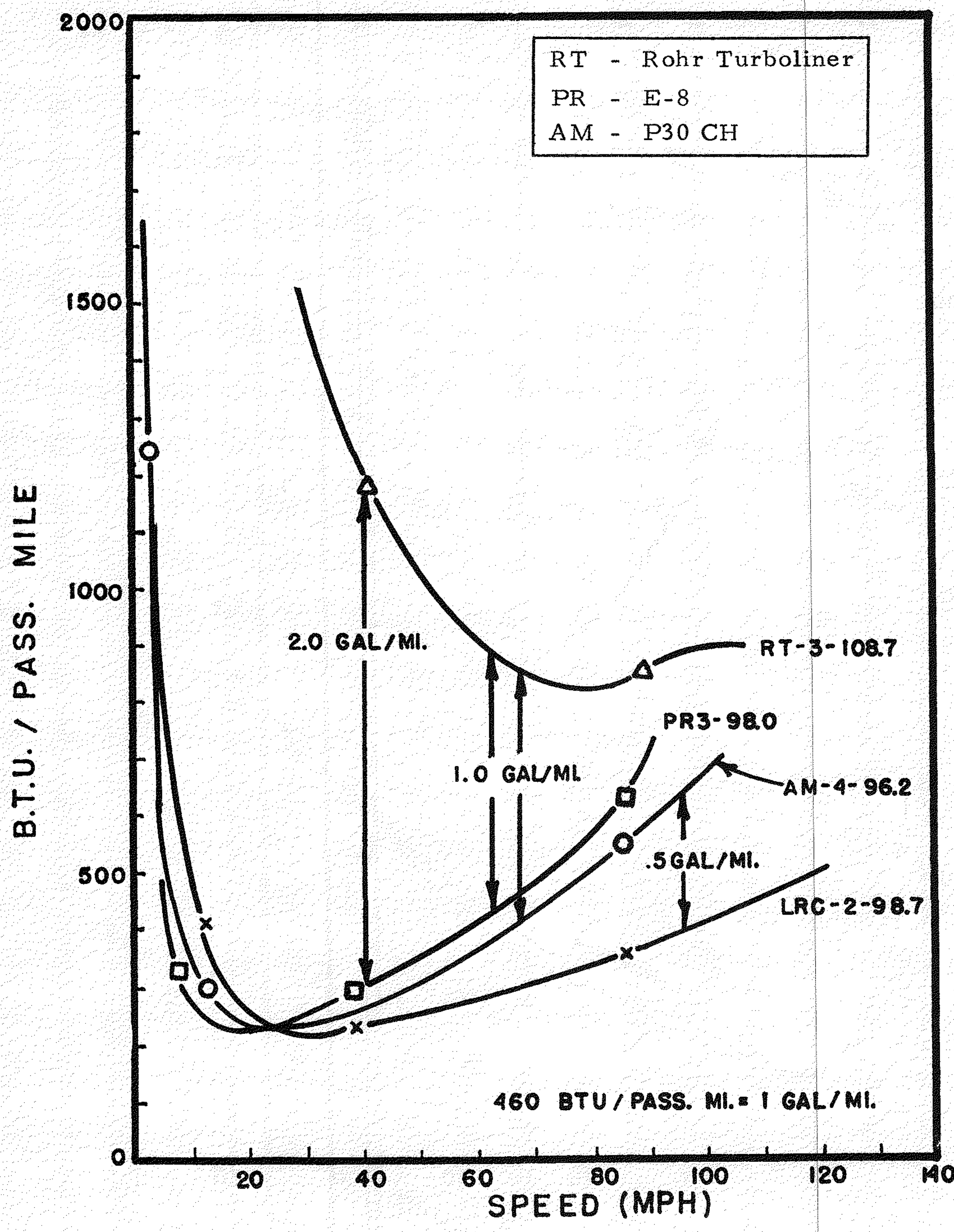


FIGURE 5.30-c

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

CRUISING ENERGY EFFICIENCY FULL SERVICE CONSISTS 300 PASSENGERS - SDP 40F LOCO

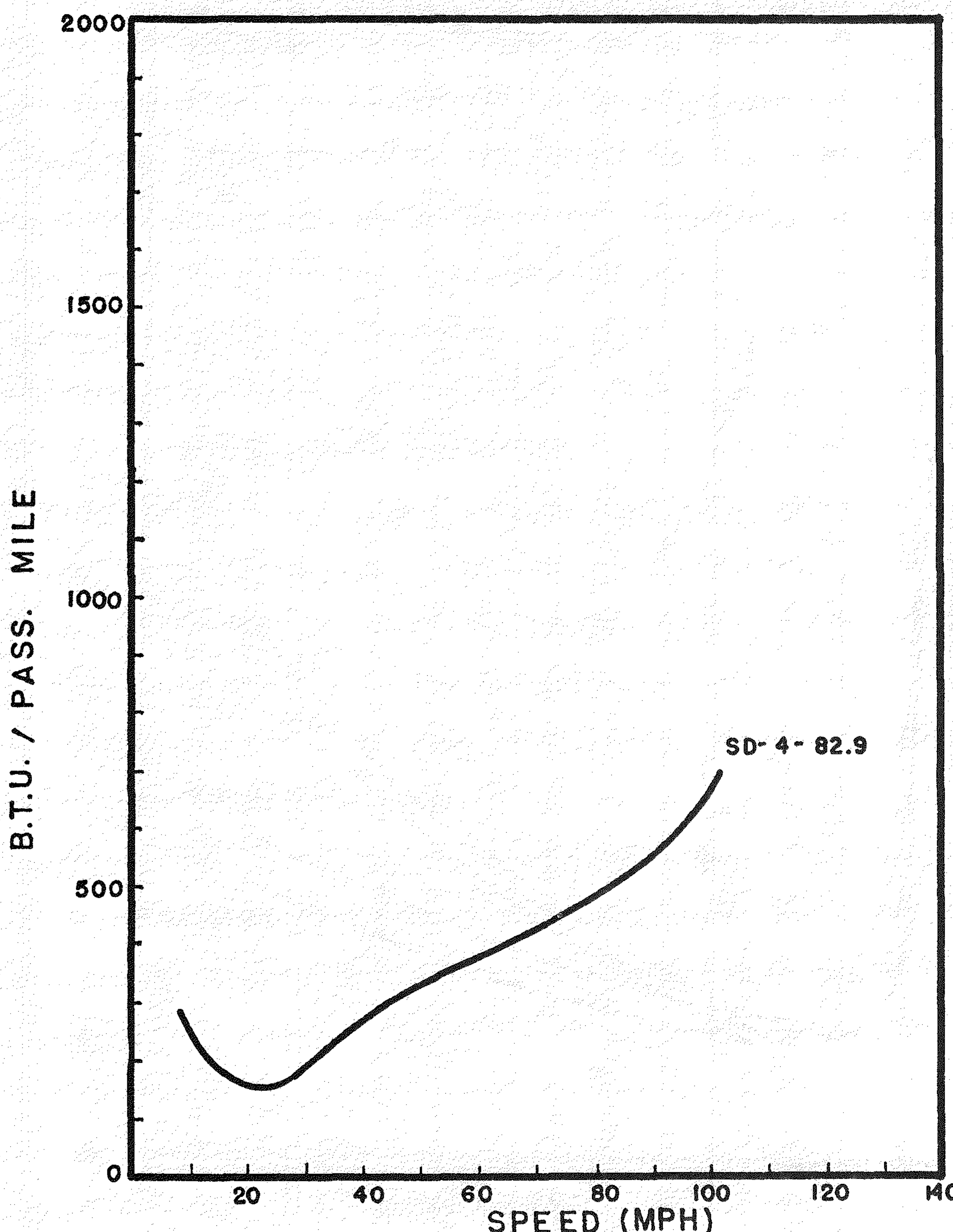


FIGURE 5.30-d

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

CRUISING ENERGY EFFICIENCY FULL SERVICE CONSISTS 300 PASSENGERS

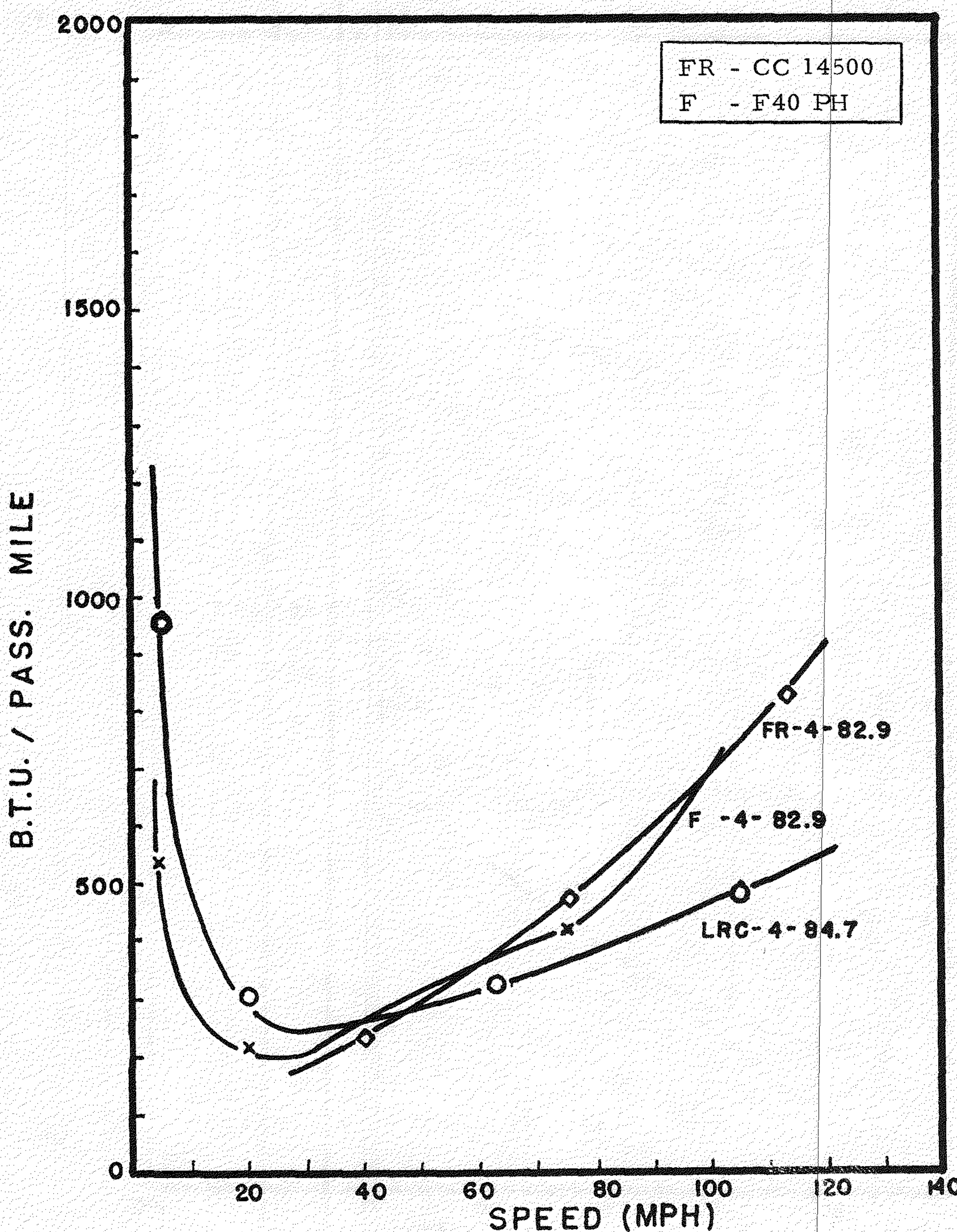


FIGURE 5.30-e

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

CRUISING ENERGY EFFICIENCY FULL SERVICE CONSISTS 300 PASSENGERS

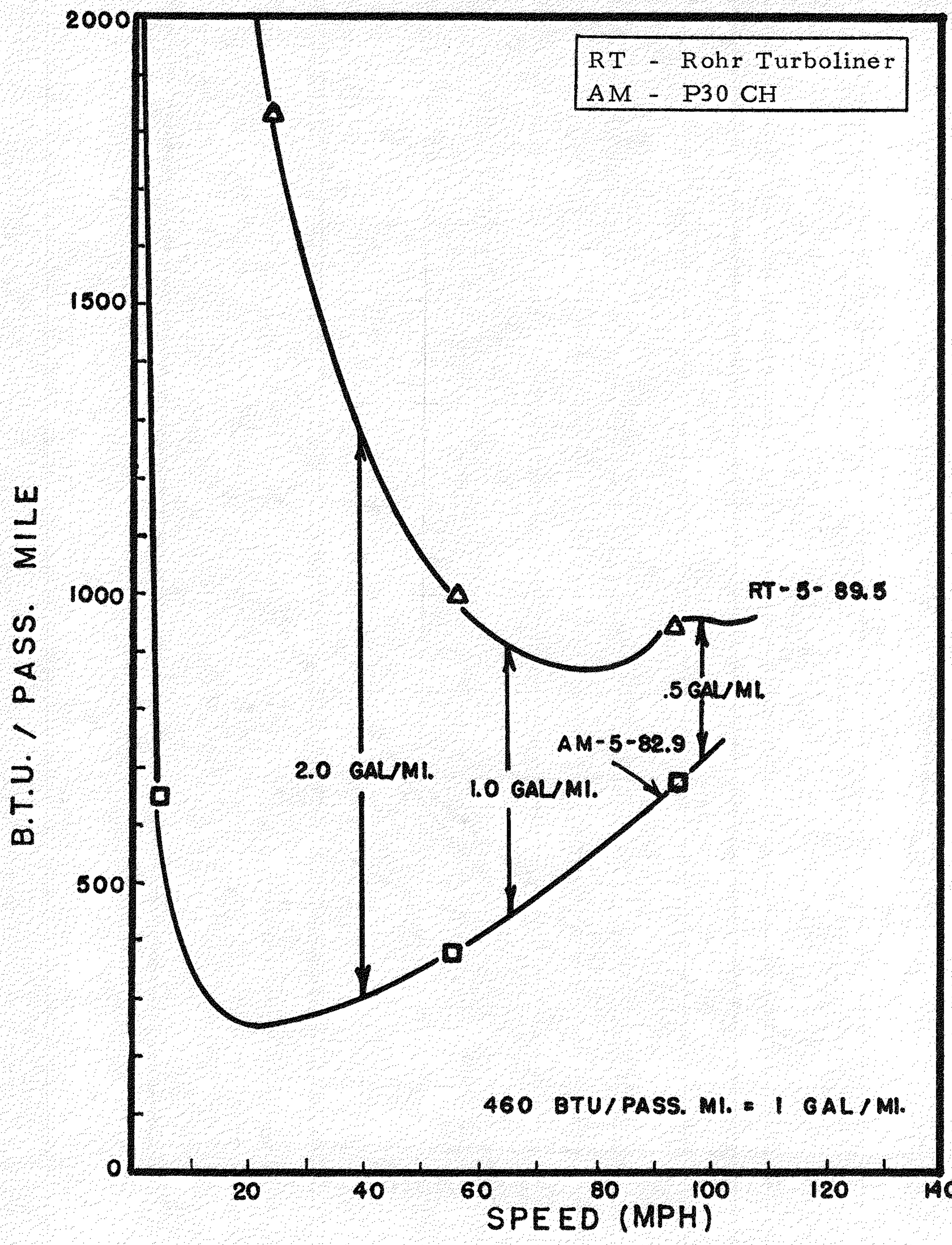


FIGURE 5.30-f

CONSIST DESCRIPTION

SNACK BAR CONSISTS 350 PASSENGERS

CONSIST TYPE **	# of Traction Units	# of Coach Cars	# of Club Cars	# of Snack Cars	COACH SECTION		CLUB SECTION		SNACK SECTION		TOT # Seats % Load	Tons per Pass	HP per TON	SPEED after 10 miles	EI* at 65 mph (cruising)
					# of Seats	FT^2 per Pass	# of Seats	FT^2 per Pass (b)	# of Seats	FT^2 per Pass					
F5-88.4 F40PH+4x Amcoach + 1 Amcafe	1	4	0	1	336	6.5	-	-	60	6.6	396(a) / 88.4	1.22	5.35	91	311
FR-5-88.4 CC14500 Amfleet Alsthom + Budd	1	4	0	1	336	6.5	-	-	60	6.6	396 / 88.4	1.29	17.12	120 @ 2.75m	323
SD-5-88.4 SDP40F drawing Amfleet GM-Budd	1	4	0	1	336	6.5	-	-	60	6.6	396 / 88.4	1.13	6.04	100	336

** For consist description, refer to Chapter 3.

(b) Square foot of space per seat basis.

*Energy Intensity

(a) Numerator denotes total no. of seats. Denominator refers to percentage load factor.

TABLE NO. 5.40-a

CONSIST DESCRIPTION

SNACK BAR CONSISTS 350 PASSENGERS

CONSIST TYPE**	# of Traction Units	# of Coach Cars	# of Club Cars	# of Snack Cars	COACH SECTION		CLUB SECTION		SNACK SECTION		TOT # Seats % Load	Tons per Pass	HP per TON	SPEED after 10 miles	EI* at 65mph (cruising)
					# of Seats	FT^2 per Pass	# of Seats	FT^2 per Pass (b)	# of Seats	FT^2 per Pass					
RT6-100.5 Rohr Turbo with an add. coach	2	5	0	1	296	6.6	-	-	52	6.8	348/100.5 (a)	1.126	5.84	94	770
LRC4-90.2 1-4-0 consist	1	4	0	1	336	5.6	-	-	52	6.5	388/90.2	1.05	7.38	109	286
PR4-94.6 E8+5 (6400 series coach) +1 snack car (3950 series)	1	5	0	1	320	8.1	-	-	50	9.3	370/94.6	1.599	4.02	82.5	430
AM6-88.4 P30CH +4 x Amcoach + Amcafe	1	4	0	1	336	6.5	-	-	60	6.6	396/88.4	1.4	6.1	94.5	367

**For consist description, refer to Chapter 3.

*Energy Intensity

(b) Square foot of space per seat basis.

(a) Numerator denotes the total no. of seats, Denominator refers to percenage load factor.

TABLE NO. 5.40-a (continued)

CONSIST DESCRIPTION

FULL SERVICE CONSISTS — 350 PASSENGERS

CONSIST TYPE**	# of Traction Units	# of Coach Cars	# of Club Cars	# of Snack Cars	COACH SECTION		CLUB SECTION		SNACK SECTION		TOT # Seats / % Load	Tons per Pass	HP per TON	SPEED after 10 miles	EI* at 65mph (cruising)
					# of Seats	FT^2 per Pass	# of Seats	FT^2 per Pass (b)	# of Seats	FT^2 per Pass					
RT-5-104.5 Rohr Turbo-liner with add. coach	2	4	1	1	256	6.6	27	8.5	52	6.8	335 (a) / 104.48	1.126	5.787	94.2	770
AM-5-96.7 P30CH Drawn Amfleet Consist	1	3	1	1	252	6.5	50	10.9	60	6.6	362 / 96.68	1.404	6.104	94.2	367
LRC-4-98.9 LRC 1-5-0	1	3	1	1	252	5.6	50	9.3	52	6.5	354 / 98.87	1.045	7.383	109.3	286

**For consist description, refer to Chapter 3.

(b) Square foot of space per seat basis.

*Energy Intensity

(a) Numerator denotes the total no. of seats, Denominator refers to percentage load factor.

TABLE NO. 5.40-b

UNION COLLEGE Transportation Program	DOT-OS-60124	May, 1977

CONSIST DESCRIPTION

FULL SERVICE CONSIST 350 PASSENGERS

CONSIST TYPE**	# of Traction Units	# of Coach Cars	# of Club Cars	# of Snack Cars	COACH SECTION		CLUB SECTION		SNACK SECTION		TOT # Seats % Load	Tons per Pass	HP per TON	SPEED after 10 miles	EI* at 65mph (cruising)
					# of Seats	FT^2 per Pass	# of Seats	FT^2 per Pass (b)	# of Seats	FT^2 per Pass					
F-4-96.7 F40PH Amfleet GM-Budd	1	3	1	1	252	6.5	50	10.9	60	6.6	362 (a) / 96.68	1.22	5.36	91	311
FR-4-96.7 CC14500 Amfleet Alsthom-Budd	1	3	1	1	252	6.5	50	10.9	60	6.6	362 / 96.68	1.29	17.12	120@ 2.75m	322
SD-4-96.7 SDP40F drawing Amfleet GM-Budd	1	3	1	1	252	6.5	50	10.9	60	6.6	362 / 96.68	1.42	6.04	99.5	336

**For consist description, refer to Chapter 3.

(b) Square foot of space per seat basis.

*Energy Intensity

(a) Numerator denotes the total no. of seats, Denominator refers to percentage load factor.

TABLE NO. 5.40-b (continued)

CRUISING ENERGY EFFICIENCY SNACK BAR CONSISTS 350 PASSENGERS - SDP 40F LOCO

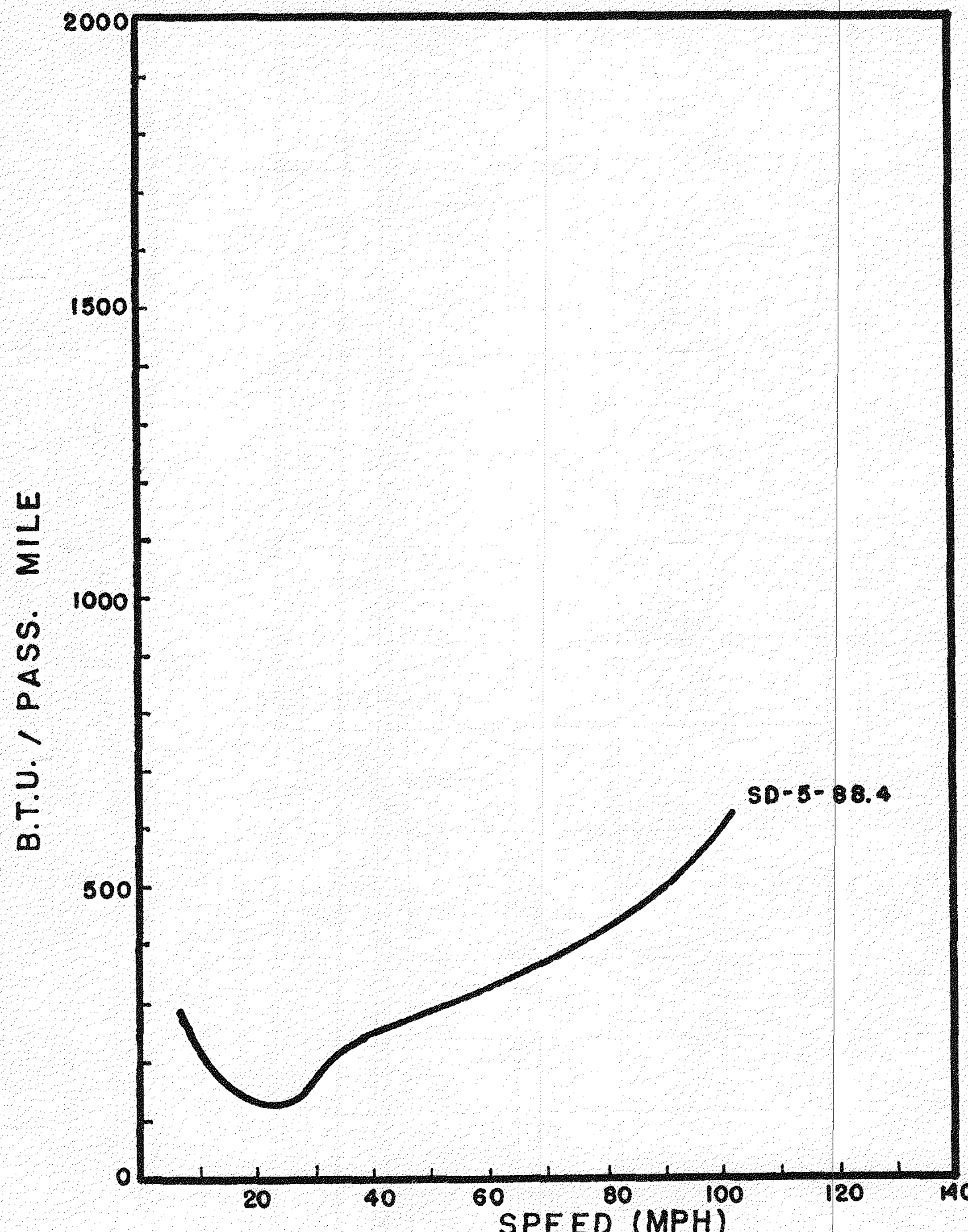


FIGURE 5.40-a

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

CRUISING ENERGY EFFICIENCY SNACK BAR CONSIST 350 PASSENGERS

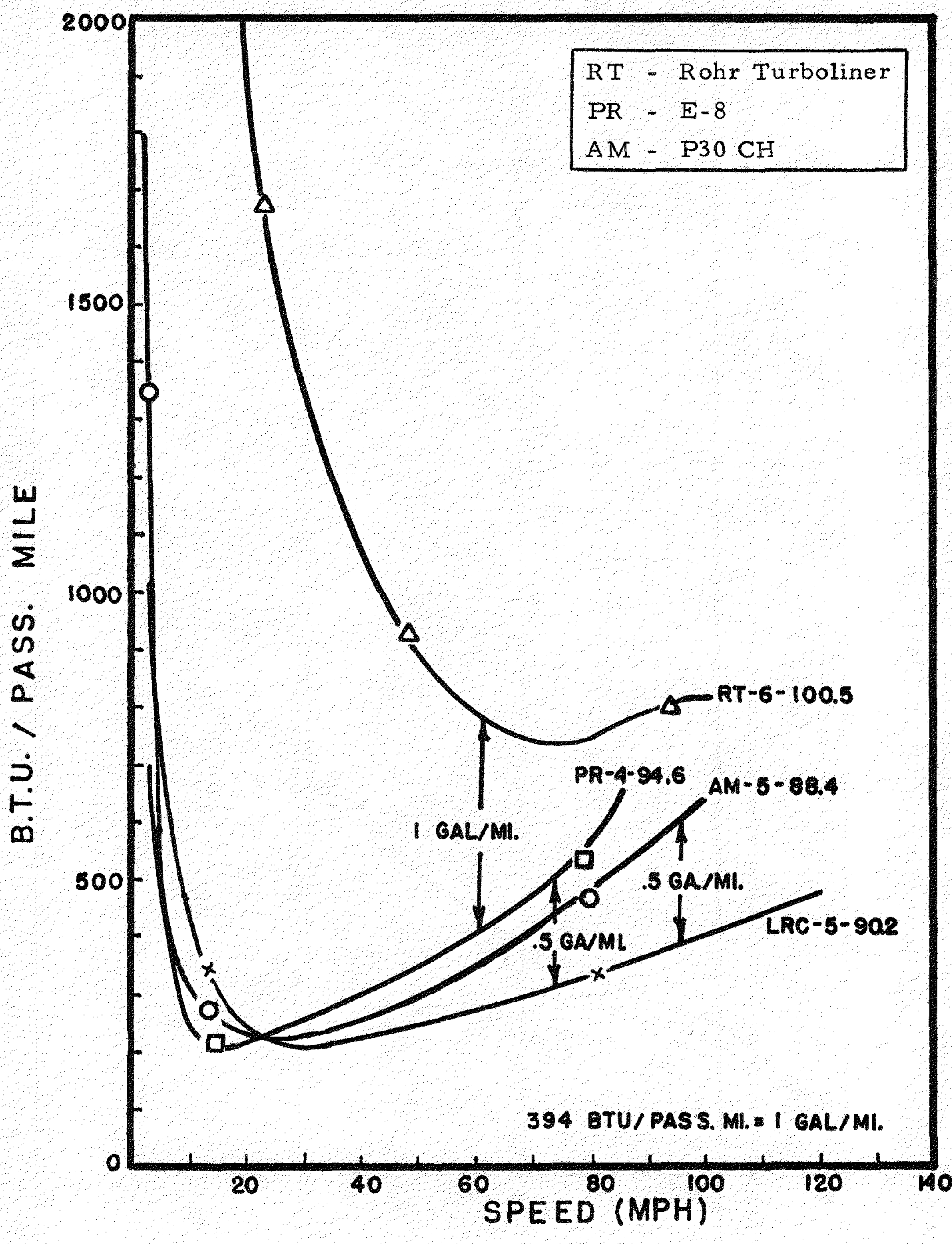


FIGURE 5.40-b

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

CRUISING ENERGY EFFICIENCY SNACK BAR CONSISTS 350 PASSENGERS

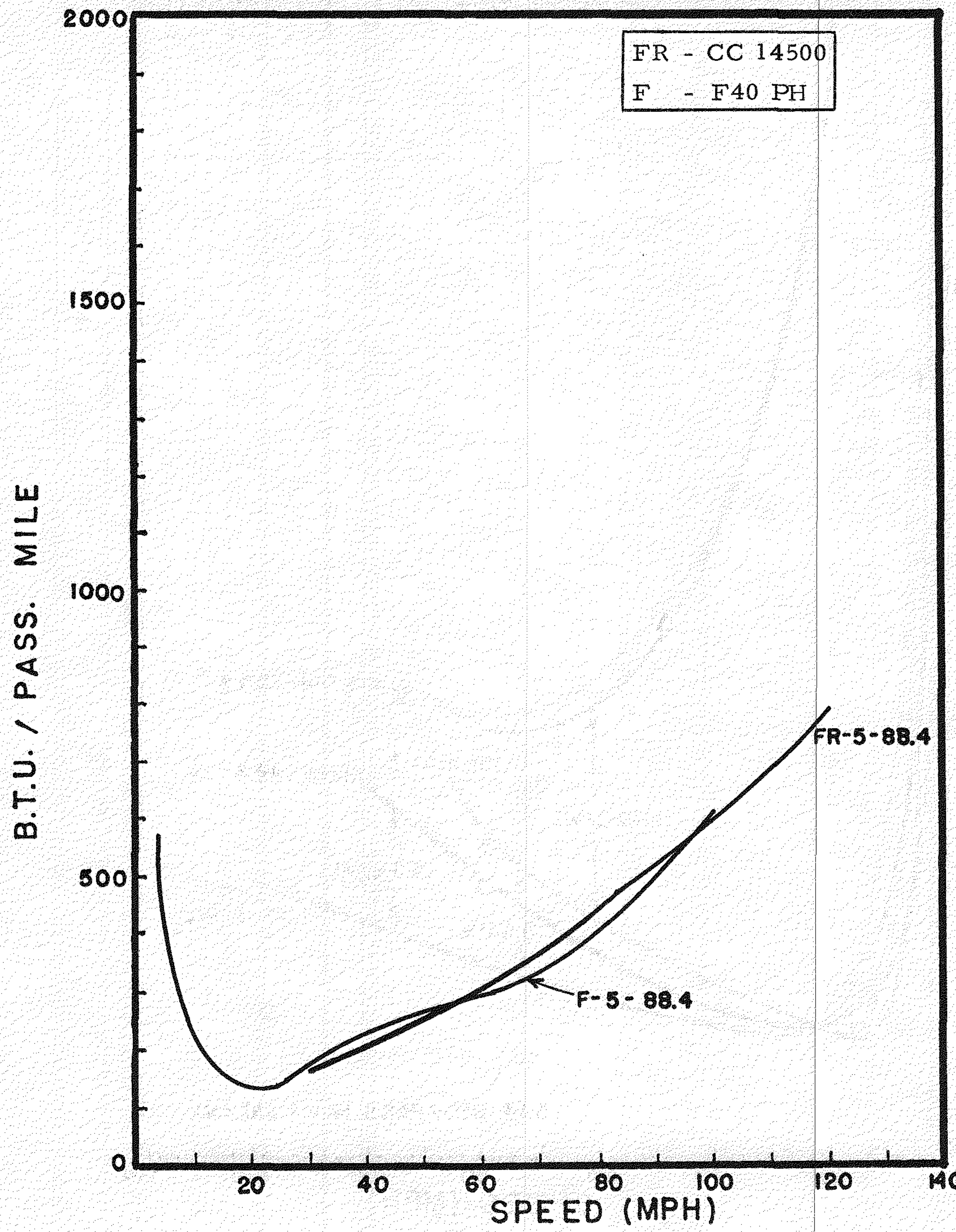


FIGURE 5.40-c

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

CRUISING ENERGY EFFICIENCY FULL SERVICE CONSISTS 350 PASSENGERS

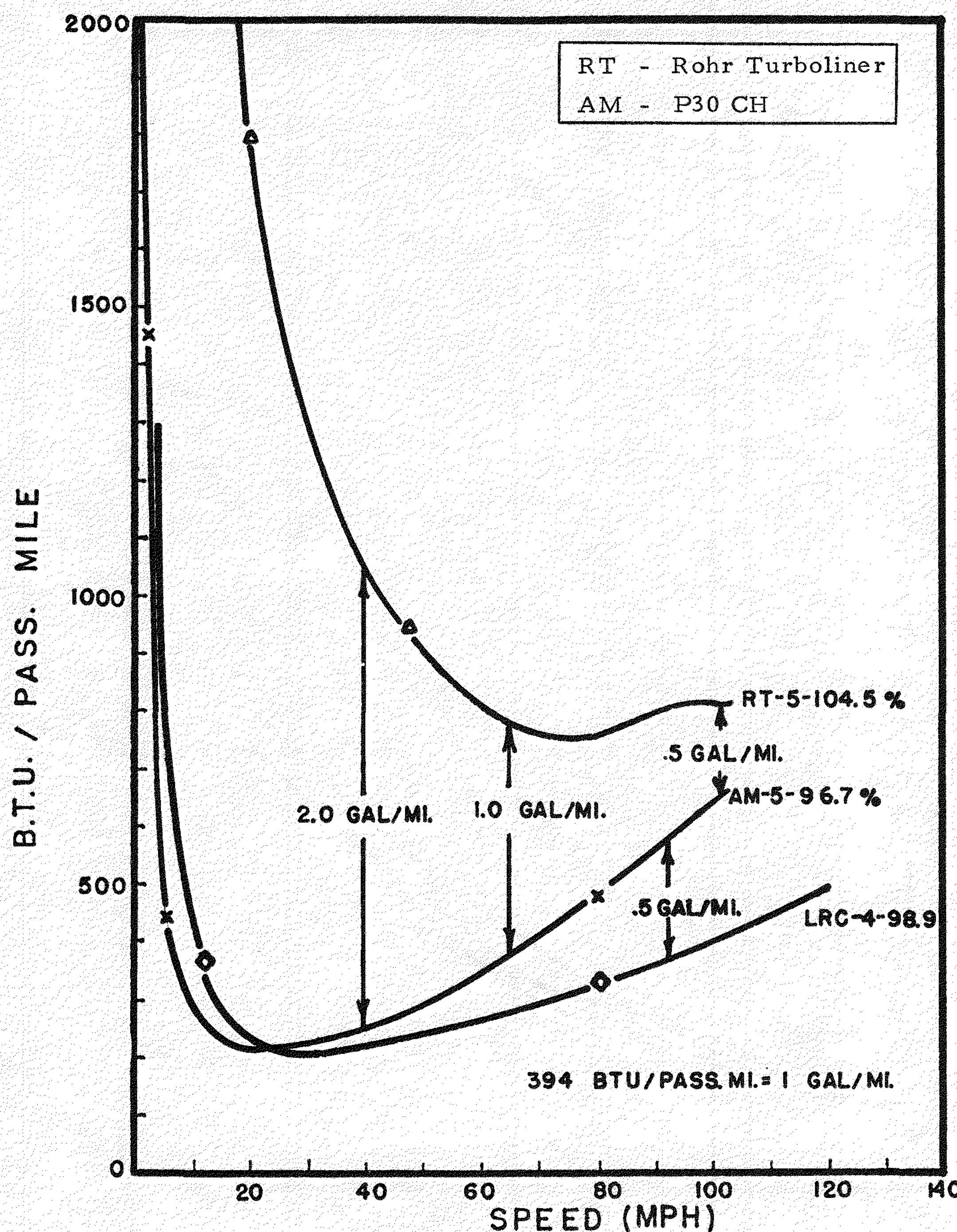


FIGURE 5.40-d

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

CRUISING ENERGY EFFICIENCY FULL SERVICE CONSISTS 350 PASSENGERS

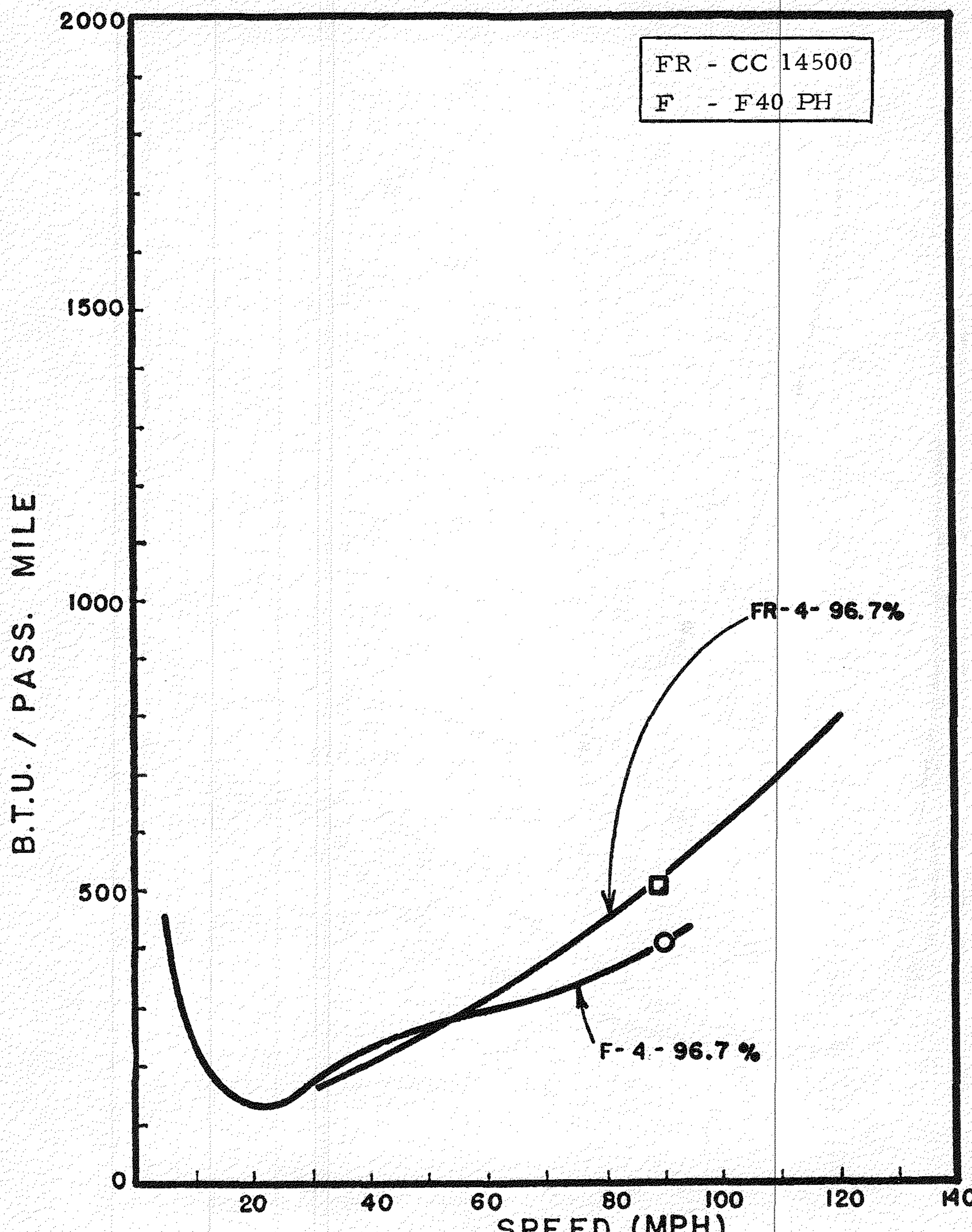


FIGURE 5.40-e

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

CRUISING ENERGY EFFICIENCY FULL SERVICE CONSISTS 350 PASSENGERS - SDP 40F LOCO

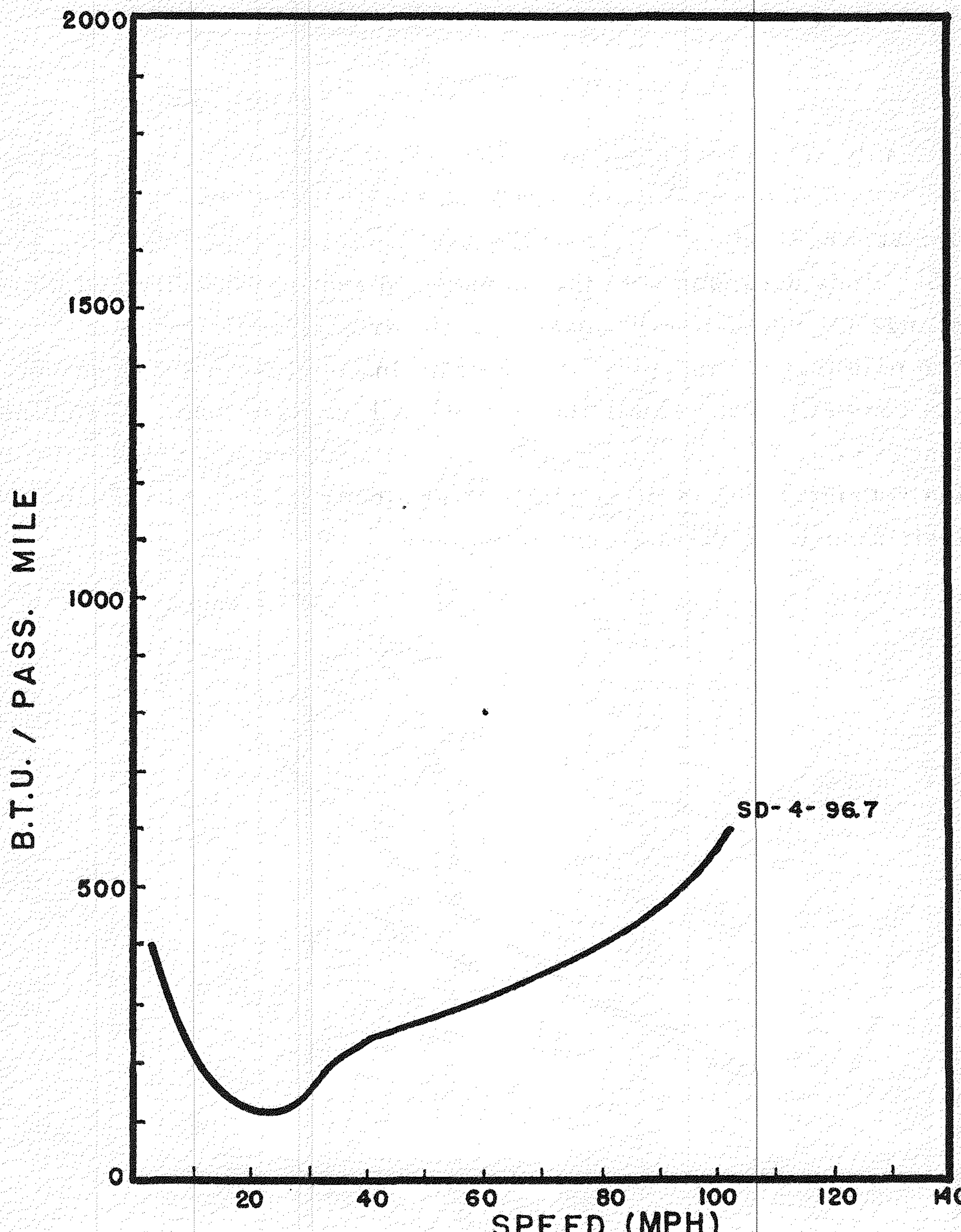


FIGURE 5.40-f

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

5.50 SUMMARY

Table 5.50 provides a quick look at the EI results for snack bar v/s full service consists estimated for several train consists. EI values are provided for several train consists with a seating capacity of 200, 250, 300 and 350. EI values decrease with the increase in seating capacity and increase when we change the consist from snack to full-service consists. It is important to note that the marginal fuel penalty in going from snack bar to full-service consist is very small because of the high base load. Turboliner behaves abnormally, EI values decrease with the shift from snack consist to full-service consist; turbo is more efficient at higher loads. LRC is the most efficient train among the diesel/electric trains.

TABLE 5.50

IMPACT OF CHANGE OF SEATING CAPACITY UPON EI VALUES (CRUISING)

Train Consist	Snack Bar Consists ←No. of Seats→ 200	250	300	350	Full Service Consists ←No. of Seats→ 200	250	300	350
P-30 CH	532	427	393	367	593	470	426	367
LRC	376	303	293	286	442	350	332	286
Rohr-Turbo	1279	1047	876	770	1204	1039	898	770
F-40 PH	456	366	334	311	584	400	362	311
SDP40 F	497	399	362	336	545	433	390	336
French CC 14500	491	348	333	323	499	400	376	322

6.00 ENERGY INTENSITY VALUES OF SEVERAL TRAIN CONSISTS UNDER ACTUAL OPERATING CONDITIONS

6.00 ENERGY INTENSITY VALUES OF SEVERAL TRAIN CONSISTS UNDER ACTUAL OPERATING CONDITIONS

Chapters 4 and 5 dealt with the impact of cruising speed upon energy intensity values. Under actual operating conditions, the driving cycle consists of the following modes:

- Idling (during station stops)
- Accelerating mode (starting or increasing speed)
- Constant velocity mode (cruising)
- Decelerating mode (decreasing speed or stopping)

Figure 6.10 shows the configuration of a typical trip structure which consists of several acceleration modes, braking modes and cruising part. Idling, which adds to the EI values, occurs at each of the station stops.

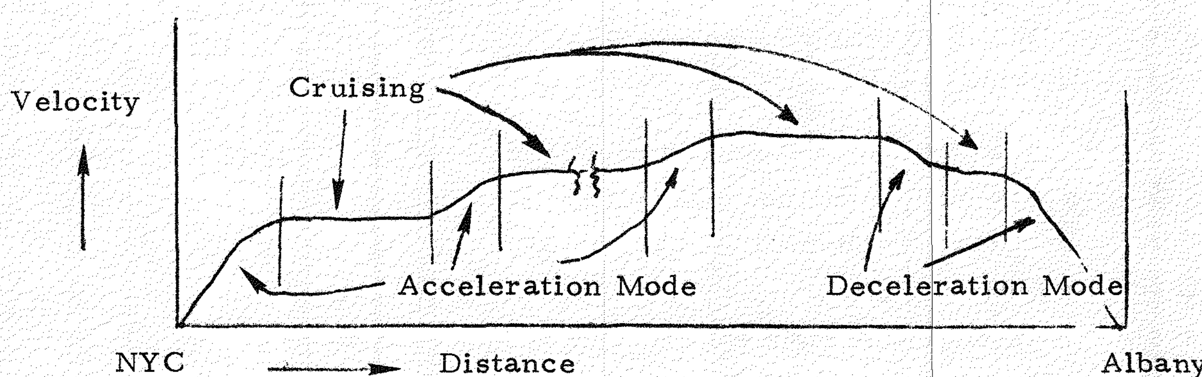


Figure 6.10 Configuration of a Typical Trip-Structure

During each trip, the train is likely to be in each mode several times. During each mode, the energy consumption rates are different, e.g., the accelerating mode usually requires high power because in addition to overcoming the aerodynamic, rolling and track resistance, the train has to overcome the accelerating force.

In order to understand and document the results of the energy intensity figures, several trains were simulated either along the NYC-Buffalo Corridor or the NYC-Washington route.

This chapter is divided into five sections. Sections 6.10, 6.20, and 6.30 deal with the EI results of diesel/electric, all electric, and turboliner train-consists. The results are tabulated for full load, half load and actual load conditions. Section 6.40 compares the results of EI values estimated earlier (in Chapter 4 and 5) with the EI results estimated under actual operating environments (speed restrictions, dwell time, No. of accelerations and decelerations). The main goal of this section is to examine in a quantitative way the impact of actual operating cycles versus the cruising mode. Section 6.50 provides a look at the chapter summary.

6.10 EI Values of Diesel/Electric Train Consists

Table 6.10a shows the results of the EI values estimated for diesel/electric train-consists. These results were simulated for the NYC-Albany route. It is important to reiterate that the EI values are based upon the operational energy only. The following concluding remarks need to be made with regard to the EI values for diesel/electric trains.

- For a 1-3-1-0 configuration and under full load conditions, the LRC appears to be the most efficient train (528 B.T.U./S.M.) from an energy intensity viewpoint. The SDP-40F train consist is second, the P-30CH train consist third and the E-8 train consist the fourth on an energy efficiency scale. It is also important that EI values are extremely sensitive to the type of the train consist (No. of locos, No. and types of cars--parlor, snack, etc.). For example, for the SDP-40-F train configuration 2-8-2-1 (2 locos, 8 coach cars, 2 snack cars and 1 club car), the EI value under full load condition is only 462 B.T.U./S.M. Those kinds of consists are possible only for the high-density routes such as NYC-Washington. For application to other routes, these values should be used only as a guide. For the cases discussed, EI values varied from 462 to 820 B.T.U./S.M. The average speed (including dwell time)[**] was around 50 mph.

[*] 1 Loco, 2 coach cars, 1 snack car and 0 club car.

[**] Dwell-Times are given in Table 6.10c.

TABLE 6.10a

ENERGY INTENSITY OF DIESEL/ELECTRIC TRAIN-CONSISTS ALONG NYC TO ALBANY ROUTE

S. N.	Type of Locomotive	EI Values Under			Average Speed	Train Configuration	No. of People	Remarks
		50% Load Factor	100% Load Factor	Actual Load Factor				
1a	E-8	1627			49.66	1-3-1-0*	121	Hauling Refurbished Cars
1b	E-8		820		49.34	1-3-1-0	242	
1c	E-8			4974	49.91	1-3-1-0	38.	
1d	E-8	1430			49.33	2-8-2-1	306	
1e	E-8		723		49.27	2-8-2-1	612	
1f	E-8	1555			49.96	3-8-2-1	306	
1g	E-8		786		49.93	3-8-2-1	612	
2a	P-30 CH	1151			50.49	1-3-1-0	156	Amfleet Cars
2b	P-30 CH		582		50.46	1-3-1-0	312	
2c	P-30 CH			4578	50.59	1-3-1-0	38.	
3a	SDP-40F	1100			50.90	1-3-1-0	156	Amfleet Cars
3b	SDP-40F		555		50.50	1-3-1-0	312	
3c	SDP-40F	911			50.25	2-8-2-1	421	

*1-3-1-0 means 1 loco, 3 coaches, 1 snack and 0 club car.

TABLE 6.10a (Continued)

ENERGY INTENSITY OF DIESEL/ELECTRIC TRAIN-CONSISTS ALONG NYC TO ALBANY ROUTE

S. N.	Type of Locomotive	EI Values Under 50% Load Factor	EI Values Under 100% Load Factor	EI Values Under Actual Load Factor	Average Speed	Train Configuration	No. of People	Remarks
3d	SDP-40-F		462		48.92	2-8-2-1	842	Amfleet Cars
3e	SDP-40-F	1035			50.44	3-8-2-1	421	
3f	SDP-40-F		524		50.42	3-8-2-1	842	
4a	LRC	1041			50.48	1-3-1-0	152	LRC-Car Consists
4b	LRC		528		50.43	1-3-1-0	304	
4c	LRC			3922	50.51	1-3-1-0	38.	

- Under 50% load factor, the EI values are nearly double as compared to 100% load factor, which implies that the incremental fuel penalty (on a vehicle-mile basis) in going from 50% to 100% load factor is negligible. This is because of the fact that for intercity trains, passenger weight is very small in comparison with the overall train weight. Table 6.10b shows the ratio of EI values calculated at 50% and 100% load factors. This ratio varies from 1.970 (LRC)* to 1.984. Hence, we are safe in assuming that the energy consumption rates on a per train-mile under fully loaded and half loaded conditions are nearly the same.

- Table 6.10a also documents the results of EI values estimated under the prevailing load-conditions and train-consists. LRC is not presently used along the route basis, but the results are presented just for comparison

Table 6.10b
Ratio of EI Values Calculated at 50% and 100% Load Factors

S. No. (for train consist identification)**		Calculated at a ratio of EI Values at 50% and 100% load factors
1a, b	E-8	1.984
1d, e	E-8	1.977
1f, g	E-8	1.978
2a, b	P-30 CH	1.977
3a, b	SDP-40F	1.981
3c, d	SDP-40F	1.971
3e, f	SDP-40F	1.975
4a, b	LRC	1.971

Average = 1.976

*LRC train is lighter and hence has more pronounced impact due to the added weight of the passengers.

**Refer to Table 6.10a for complete train-consist description.

purposes. For the cases studied, the EI values ranged from 3922 to 4974 B.T.U./P.M. which represents an average load factor* of 12.46 and 16.06%, respectively. *These EI numbers appear to be high in comparison with the national averages.*

TABLE 6.10c

Dwell Times NYC-Buffalo

Croton-Harmon	7 min.
Poughkeepsie	1 min.
Rhinecliff	1 min.
Hudson	54 sec.
Albany-Rensselaer	5 min. 24 sec.
Amsterdam	3 min. 30 sec.
Utica	5 min. 30 sec.
Rome	1 min.
Syracuse	5 min. 30 sec.
Rochester	6 min. 30 sec.

* The average load factor is calculated as follows:

$$= \frac{\text{Yearly patronage}}{\left(\text{Average weekly frequency}\right) \times \left(\begin{array}{c}\text{No. of Weeks} \\ \text{per year}\end{array}\right) \times \left(\begin{array}{c}\text{No. of Seats} \\ \text{per train}\end{array}\right)}$$

6.20 EI VALUES OF METROLINERS AND ELECTRIC LOCO-HAULED AMFLEET CONSISTS

Table6.20 shows the EI results estimated for metroliners and electric loco-hauled train consists. The EI values are based upon the input energy to the power plant. All of these results were simulated for the NYC-Washington route using existing track. Three types of locos (French CC 14500, Swedish RC4a and General Electric E-60 CP) were tested for our evaluation purposes.

Concluding remarks regarding EI values for metroliners and electric loco-hauled Amfleet train-consists.

- Under full load conditions, the EI values varied from 585 (RC4a, hauling 12 cars) to 688 (General Electric E-60 CP) B.T.U./S.M. These EI values correspond to a seating capacity of 950 people. As the seating capacity goes down, the EI values go up. Several factors contribute to the higher efficiency at increased capacity: reduced aerodynamic drag, increased motor and transmission efficiency. The average velocity is higher in comparison with the diesel/electric train-consists. It is interesting to compare the results of electric trains with those of the diesel/electric trains. On the whole, the diesel/electric trains appear to consume less energy on a per seat-mile basis. Admittedly, these results are based upon the two different operating conditions (track, speed, dwell time, etc.), and hence further analysis is needed to make general statements in regard to the EI values for diesel/electric and all electric trains.

- Under 50% load factor, the EI values varied from 1804 to 2364 B.T.U./P.M.

TABLE 6.20

ENERGY INTENSITY OF METROLINERS AND ELECTRIC LOCO-HAULED AMFLEET CONSISTS (SIMULATED ALONG NYC-WASHINGTON ROUTE)

S.N.	Type of Locomotive	EI Values Under 50% Load Factor	EI Values Under 100% Load Factor	EI Values Under Actual Load Factor	Average Speed	Train Configuration*	No. of People	General Remarks
1a	RC4a	2196			68.67	1-2-1-1	139	Assuming 35.74% generation + transmission + catenary efficiency (Hauling Amfleet consists)
1b	RC4a	1804			66.76	1-3-1-2	206	
1c	RC4a		859		67.56	1-4-1-1	446	
1d	RC4a		729		65.86	1-6-1-1	614	
1e	RC4a		645		64.26	1-8-1-1	782	
1f	RC4a		585		62.81	1-10-1-1	950	
2a	CC14500	2021			68.54	1-2-1-1	139	(Hauling Amfleet consists)
2b	CC14500		963		68.34	1-4-1-1	446	
2c	CC14500		825		67.66	1-6-1-1	614	
2d	CC14500		737		66.37	1-8-1-1	782	
2e	CC14500		677		65.11	1-10-1-1	950	
3a	E-60CP	2147			67.97	1-3-1-2	206	(Hauling Amfleet Consists)
3b	E-60CP	2364			69.68	1-3-1-0	156	
3c	E-60CP		1015		68.19	1-4-1-1	446	
3d	E-60CP		855		66.80	1-6-1-1	614	
3e	E-60CP		758		65.48	1-8-1-1	782	
3f	E-60CP		688		64.25	1-10-1-1	950	

*1-2-1-1 means 1 loco, 2 coaches, 1 snack and 1 parlor car.

TABLE 6.20 (Continued)

ENERGY INTENSITY OF METROLINERS AND ELECTRIC LOCO-HAULED AMFLEET CONSISTS (SIMULATED ALONG NYC-WASHINGTON ROUTE)

S. N.	Type of Locomotive	EI Values Under			Average Speed	Train Configuration	No. of People	General Remarks
		50% Load Factor	100% Load Factor	Actual Load Factor				
4a	Metroliners		887		78. 30	4-1-1*	418	(Hauling Amfleet consists)
4b	"		1019		78. 37	2-1-1	258	

*4 coaches, 1 snack and 1 club car.

6.30 EI VALUES FOR TURBOLINERS

Table 6.30 shows the results of the EI values for turboliners which were simulated for the NYC-Albany route.

- Under full load conditions, the energy intensity value for the standard turboliner (2-3-1-1)* is 1956 B.T.U./S.M.

- Under 50% loading, the energy intensity is 3930 B.T.U./P.M. which is again twice the value under full load conditions.

- Under the estimated route load factor of 14.78%, the energy intensity is 13,140 B.T.U./P.M.

The above remarks clearly indicate that turboliners are inefficient modes of transportation from the energy intensity viewpoint.

*Two powered cars, 3 coach cars, 1 snack car and 1 parlor car.

TABLE 6.30

ENERGY INTENSITY OF TURBOLINER
(SIMULATED ALONG NYC TO ALBANY ROUTE)

S. N.	Type of Locomotive	EI Values Under			Average Speed**	Train Configuration	No. of People
		50% Load Factor	100% Load Factor	Actual Load Factor			
1a	Standard-Turboliner	3930			49.78	2-3-1-1*	131.
1b	"		1956		50.31	2-3-1-1	263
1c	"			13,140	50.38	2-3-1-1	38.

*Means two powered cars, 3 coach cars, 1 snack car and 1 parlor car.

**Includes station dwell.

6.40 COMPARISON OF EI VALUES BETWEEN CRUISING MODE AND THE ACTUAL OPERATING CYCLE MODE

The goal of this chapter was to learn the impact of real operating environments (allowable speeds, number and levels of accelerations and decelerations, dwell times etc.) on the EI values. The cruising EI values were studied in Chapters 4 and 5. For comparative analysis purposes, Table 6.40 is prepared to document the EI values for cruising and the actual operating cycle. The cruising speed was 65 m.p.h. The average speed (including dwell time) for the diesel/electric and gas-turbine train consists was around 50* m.p.h. (Simulated along NYC-Buffalo Corridor). For the electrified train consists, the average speed was 73 m.p.h. (Simulated along NYC-Washington route). Ratio of EI values between actual operating cycle and cruising mode are given in the following table.

TABLE 6.40b

RATIO OF EI VALUES BETWEEN ACTUAL OPERATING CYCLE AND CRUISING MODE

Type of Train Consist	RATIO** = EI Values Under Actual Operating Cycle / Cruising - Mode
E-8	1.85
P-30 CH	1.53
SDP-40F	1.34
LRC	1.82
Rohr-Turboliner	2.22
French CC 14500	2.63
Metroliners	3.28

* Excluding dwell times, this amounts to roughly 54 m.p.h.

** One should be cautious in the interpretation of these data. This is not a one to one comparison because of the changes in train-consists, speeds etc. Hence, these ratios ought to be used only as a guide.

TABLE 6.40a

COMPARISON OF EI VALUES BETWEEN CRUISING MODE AND THE ACTUAL OPERATING CYCLE MODE: (FULLY LOADED)

Type of Power Plant	Type of Locomotive	Cruising Mode			Actual Operating Cycle*		
		No. of Passengers	B.T.U./S.M.	Cruising Speed (mph)	No. of Passengers	B.T.U./S.M.	Average** Speed (mph)
Diesel/Electric Train Consists	E-8	306	443	65	242	820	49.34
	P-30CH	312	378	65	312	582	50.46
	SDP-40F	278	412	65	312	555	50.50
	LRC	304	289	65	304	528	50.43
Gas Turbine	Rohr - Turboliner	296	881	65	263	1956	50.3
Electrified	French CC14500	278	365	65	446	963	68.34
	Metro-liners	258	310	65	258	1019	78.37

*Using NYC-Albany route for diesel/electric and gas turbine trains; NYC-Washington route for electric trains.

**Includes current dwell times and operating strategies.

6.50 SUMMARY

The results of this chapter are extremely interesting because they reveal the impact of real operating environments upon the EI values. For the NYC-Buffalo Corridor above, there are 56 accelerations, 80 decelerations and the average allowable speed is 57.82 m.p.h. These high numbers of accelerations and decelerations result in higher EI values. The low value of the average speed result in lower demand and consequently the lower load factor and higher EI values. For full load conditions, the crude analysis shows that the ratio of EI values calculated under actual operating conditions and cruising mode differ by a range of 1.34 to 3.28. Under actual load factors, the EI values were in the range of 3922 B.T.U./P.M. (LRC) to 13,140 B.T.U./P.M. (Turboliner) which are higher by a factor of 10 when compared with the cruising mode conditions. Hence, in conclusion, the EI values for intercity trains have a wide range because of sensitivity to the design (LRC, Turboliner, French 14500) and operating conditions (dwell times, number of accelerations and decelerations). For each route, depending upon the load factor, track conditions and train consists, one should estimate the EI values.

7.0 COMPONENTS OF ENERGY INTENSITY VALUES

7.0 COMPONENTS OF ENERGY INTENSITY VALUES

This chapter deals with the components of energy expended for intercity passenger train operation. Only the operational aspects of energy are considered. The goals of this chapter are to:

- Study and document the components of energy for various trains
- Discuss the conservation measures for intercity rail operations

Section 7.10 deals with the components of energy expended. Diesel/electric, gas turbine and electric trains were evaluated along certain routes. Section 7.20 deals with the conservation measures directed towards rail operation. Section 7.30 provides a chapter summary and some concluding remarks.

7.10 Components of Energy Intensity Values

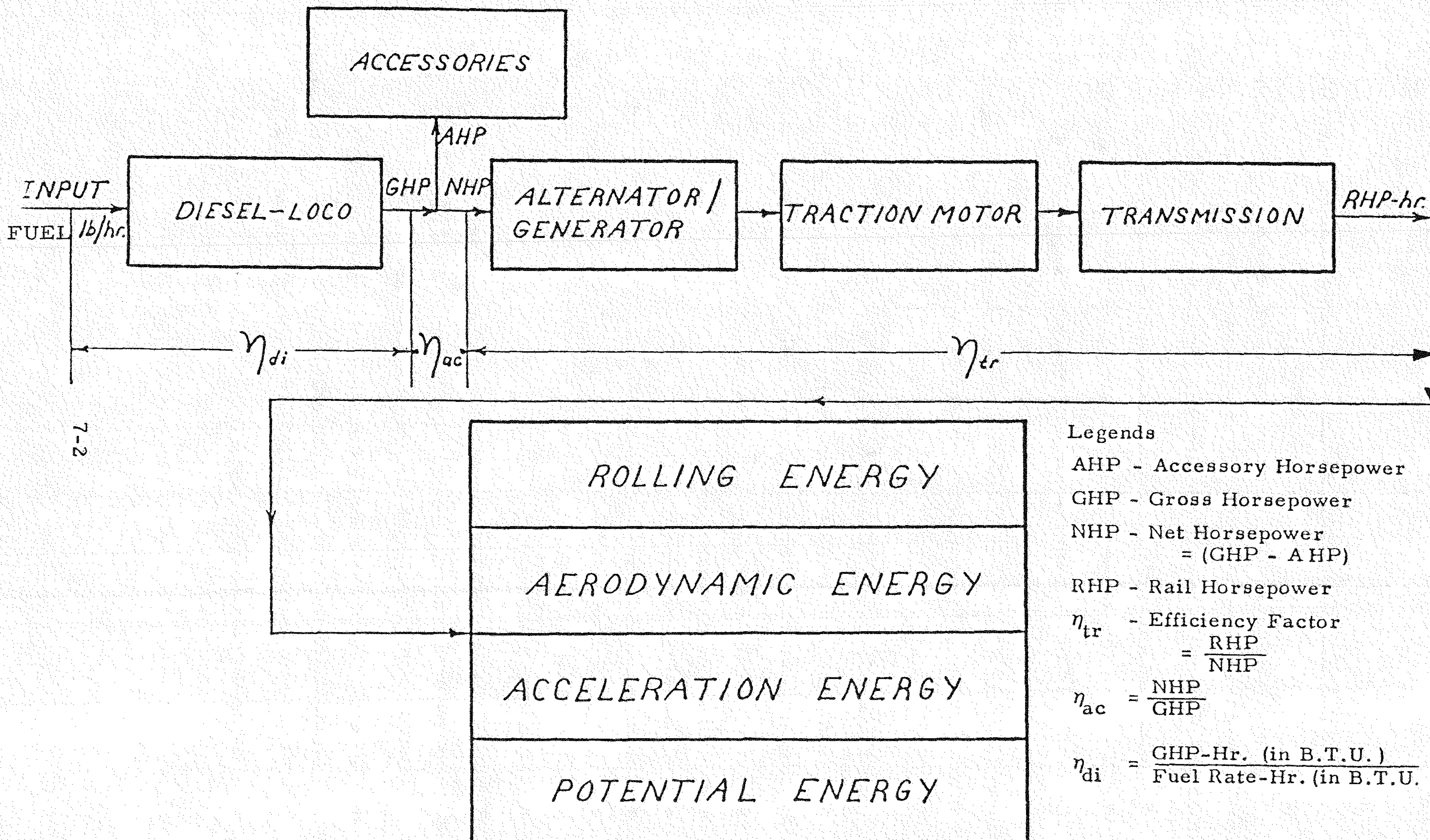
The energy utilized for interecity train operation can be divided into the following subcategories (Figure 7.10):

- Aerodynamic Losses
- Rolling Resistance Losses
- Transmission Losses
- Auxiliary Losses
- Track Losses
- Acceleration Losses
- Thermal Losses

Tables 7.10a, and b show the results of the components of energy expended for several trains. The following concluding remarks can be made in regard to the results of the above analysis:

- Nearly 70% of the energy for diesel/electric trains; 65% for the electric trains (including metroliners); and 89% for turboliners went towards the thermal losses within the power plant.

- Transmission losses range from 1.6% to 6.4%.



Legends

AHP - Accessory Horsepower

GHP - Gross Horsepower

NHP - Net Horsepower $= (GHP - AHP)$

RHP - Rail Horsepower

η_{tr} - Efficiency Factor $= \frac{RHP}{NHP}$

$\eta_{ac} = \frac{NHP}{GHP}$

$\eta_{di} = \frac{\text{GHP-Hr. (in B.T.U.)}}{\text{Fuel Rate-Hr. (in B.T.U.}}$

FIGURE 7.10

COMPONENTS OF ENERGY (ACCELERATION OR CRUISING)

TABLE 7.10a

COMPONENTS OF ENERGY FOR SEVERAL TRAIN CONSISTS

TRAIN CONSISTS ↓ / COMPONENTS OF ENERGY →	THERMAL LOSSES	AUX.	TRANS. LOSSES	TRACK RESIS.	ROLL. RESIS.	AERO. DRAG	ACCEL-ERATION	TOTAL
E-8	70.3	6.0	4.5	1.9	6.5	5.5	6.1	100%
P-30 CH	66.3	6.2	4.5	2.2	7.2	6.3	7.3	100%
TURBOLINER	88.9	2.5	1.6	0.7	2.3	1.8	2.2	100%
LRC	70.0	7.3	4.2	1.9	6.6	3.6	6.4	100%

ACTUAL TRACK, FULLY LOADED, 1977 N.Y.C.–ALBANY CORRIDOR

TABLE 7.10b

COMPONENTS OF ENERGY - ELECTRIC TRAIN CONSISTS

Components of Energy / Train Consists	Thermal Losses	Auxiliaries	Trans. Losses	Track Resistance	Rolling Resistance	Aero. Drag	Acceleration	Total
Standard Metroliners 4-1-1*	63.5	4.1	4.8	0.8	6.1	7.4	13.20	100%
E60 CP 1-4-1-1**	64.3	3.3	6.4	0.9	4.7	6.4	14.0	100%
CC 14500 1-4-1-1**	64.3	3.5	4.8	0.9	4.7	6.5	15.30	100%
RC4a 1-4-1-1**	64.3	4.0	4.8	0.8	4.9	7.20	14.10	100%

*4 coaches, 1 snack and 1 club car.

**Means 1 loco, 4 coach cars, 1 snack car and 1 parlor car.

ACTUAL TRACK, FULLY LOADED, NYC-WASHINGTON CORRIDOR

TABLE 7.20

PERCENTAGE CHANGE IN EI VALUES DUE TO CHANGES IN THE DRAG COEFFICIENT

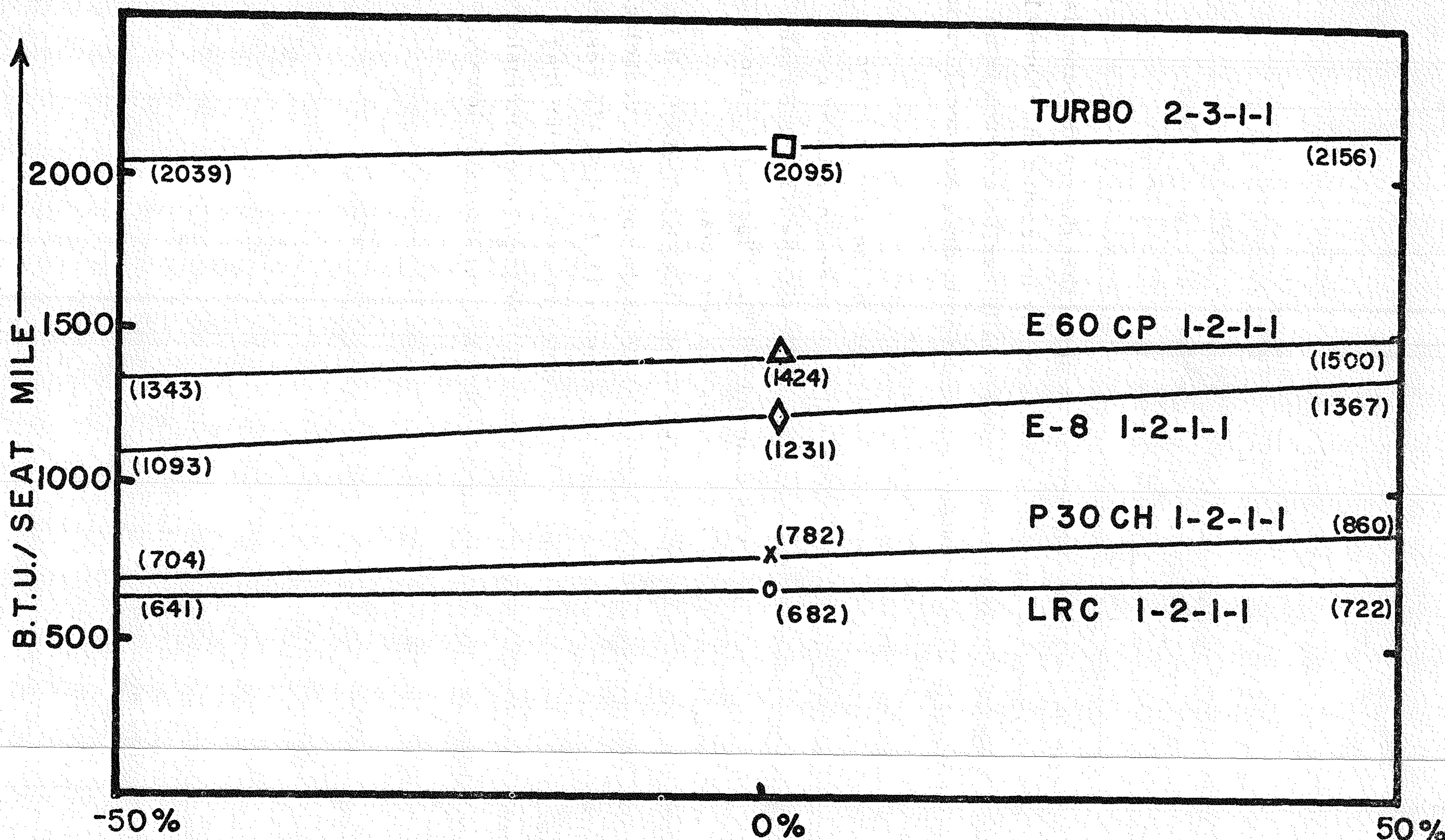
	Train Consist	% Change in Drag Coefficient	% Change in EI Value
a)	Turboliner	0	0
	2-3-1-1	-50	-2.67
		50	2.90
b)	E-60 CP	0	0
	1-2-1-1	-50	-5.68
		50	5.33
c)	E-8	0	0
	1-2-1-1	-50	-11.21
		50	11.04
d)	P30 CH	0	0
	1-2-1-1	-50	-9.97
		50	8.97
e)	LRC	0	0
	1-2-1-1	-50	-6.01
		50	5.86

- Auxiliary losses varied from 3.3% to 7.3%.
- Useful power (rail tractive effort--sum of track, rolling, aerodynamic and acceleration losses) varied from 7% (turboliners) to 27.4% (French CC 14500).

7.20 Conservation Potential

Results of the preceding section indicate that the major potential for conservation lies with the power plant itself (by improving the thermal efficiency of the engine). The gains, though small, can be accrued from the improvements of rolling resistance, aerodynamic drag and acceleration losses (by reducing the number of speed changes).

To quantitatively understand the impact of the change in the aerodynamic drag coefficient upon the EI values, several computer runs representing varied drag coefficients were made for the NYC to Buffalo Corridor. The drag coefficient was changed ± 50%. Figure 7.20 shows the results of such analysis. Table 7.20 shows the percentage change in EI value as a result of the change in the drag coefficient. It is concluded that in the case of the E-8 and P30 CH train consists, reducing aerodynamic drag by 50% would reduce EI value by 11.2 and 9.97% respectively. Figure 7.20 shows the impact of % change in aerodynamic drag coefficient upon EI values. It is important to add that the above conclusions are based upon the existing speed limits which are considerably lower.



% CHANGE IN AERODYNAMIC DRAG COEFFICIENT

NY TO BUFFALO B.T.U./PASSENGER MILE, ACTUAL TRACK, FULLY LOADED

FIGURE 7.20

Study of the Impact of Change in Aerodynamic Drag Coefficient Upon the EI Value

7.30 CONCLUSIONS

The study concludes that the major component of the energy is the thermal loss which accounts for over 60% of the total energy. Rolling and aerodynamic drag constitute roughly 10% (except turboliner) of the energy consumption. Acceleration loss constitutes roughly 6% for the diesel/electric and 14% for electric trains. The major potential for energy conservation lies with the improvements in the load factor* which depends upon a host of factors one of which is the improvements in the existing track conditions. Chapter 8 deals with the impact of track improvements upon EI values.

*Under the assumption of current technology--no major improvements in thermal efficiency, etc.

8.00 IMPACT OF TRACK IMPROVEMENTS UPON ENERGY INTENSITY VALUES

8.00 IMPACT OF TRACK IMPROVEMENTS UPON ENERGY INTENSITY VALUES

Chapter 6.00 dealt with the impact of actual operating conditions upon EI values. It was noted that the average was around 50 m.p.h.* which indicates that the present track conditions are a deterrent to the higher speeds which the trains are capable of attaining. The purpose of this chapter is to study and document:

- The impact of improved track upon EI values
- The impact of planned track improvements (which the New York State DOT plans to undertake) upon the EI values

This chapter is divided into three sections. Section 8.10 deals with the impact of various track improvements upon EI values (Constant Demand). Section 8.20 deals with the impact of planned track improvements (which are contemplated by the NYSDOT) upon EI values (including the changes in demand) in the near future. Section 8.30 provides a look at the chapter summary.

8.10 Impact of Several Levels of Track Improvements Upon EI Values

In order to evaluate the impact of improved track upon EI values, the following types of computer runs were made.

- Base-Line Runs: These are the cases in which actual track configuration, allowable speed limits and presently scheduled dwell times were utilized. Four sets of different train-sets (E-8, P-30 CH, Turboliner and LRC) were simulated along the NYC-Buffalo Corridor. These runs are similar to the runs described in Chapter 6 except that the results presented herein are for the entire corridor (NYC-Buffalo) rather than the subset (NYC-Albany) of the corridor.
- Actual Speed Runs: These runs obey the allowable speed limits similar to the base-line cases except that the track configuration has been simplified to the following format.

*The speed is considerably below the potential realizable speed of the trains. Allowable speed is constrained in several ways: adhesion and safety are the major factors.

- Zero Grade: In this case the corridor is assumed to have no curves or grades. In other words, the whole track is assumed to be a level tangent track.

- Average Corridor Grade: For simulation purposes, the actual corridor track is assumed to be having a constant uniform grade of value equal to the average corridor grade which is calculated in the following manner.

$$\text{Average Corridor Grade} = \frac{\left(\begin{array}{l}\text{Change in Elevation} \\ \text{between the 1st \&} \\ \text{last city of the} \\ \text{corridor}\end{array} + \begin{array}{l}\text{Equivalent Curve} \\ \text{Resistance expressed} \\ \text{in Elevation}\end{array}\right)}{\text{Corridor Route Distance}} \times 100$$

- Average City Pair Grade: Average city pair grade is calculated in the same manner as above except it is between particular cities.

- High Speed Runs: In these runs, the grades and curves throughout the corridor have been averaged in three categories: 0 grade, average corridor grade, average city pair grade; similar to the actual speed runs. These two sets of runs differ because in the case of the high speed runs, the vehicles are allowed to run to their maximum speeds after assuming a constant level of acceleration (with a maximum value of 2 m.p.h./sec.).

Figure 8.10 shows the velocity and track profile for various types of computer runs.

Subsection 8.11 illustrates the results of the above computer runs.

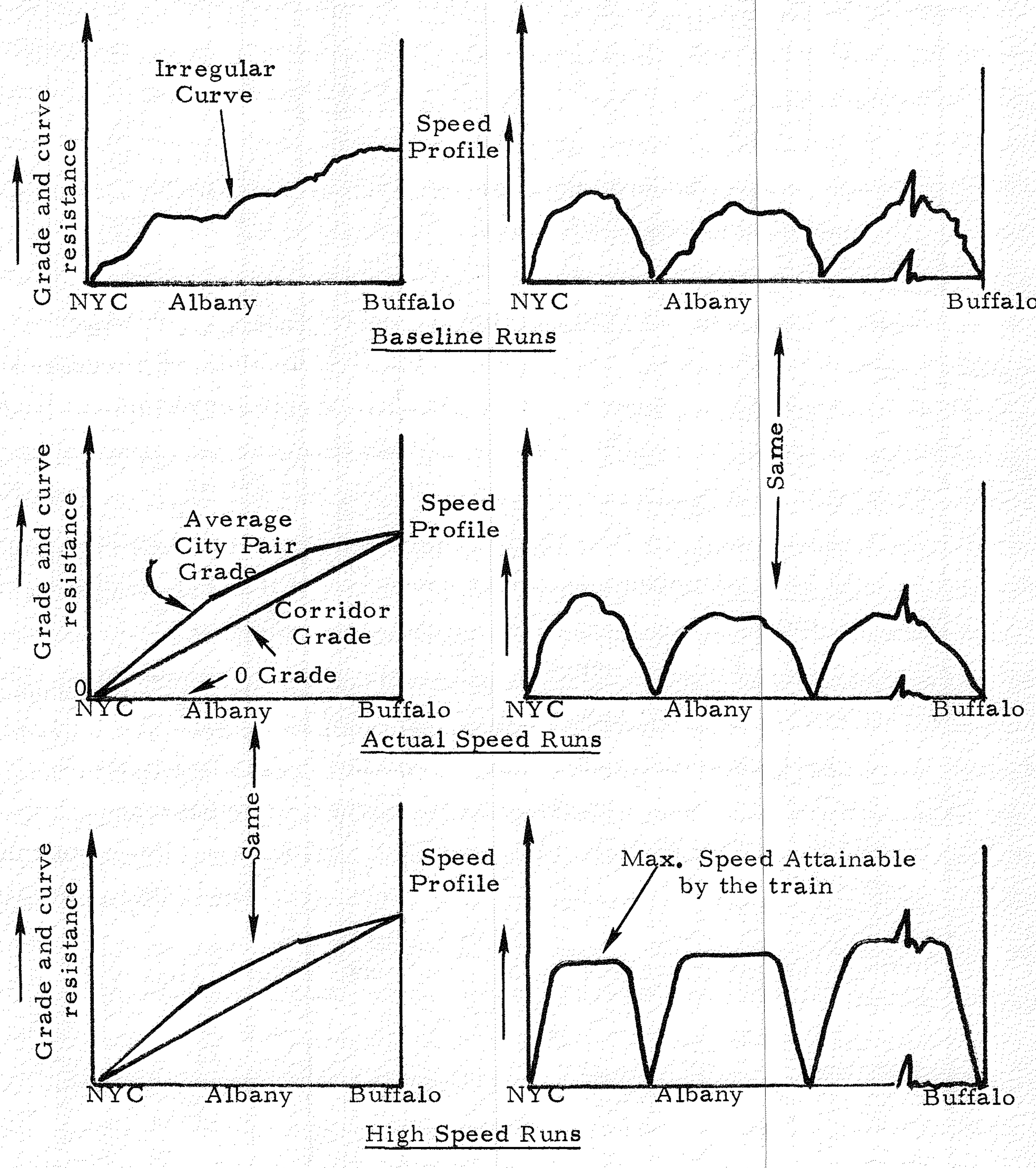
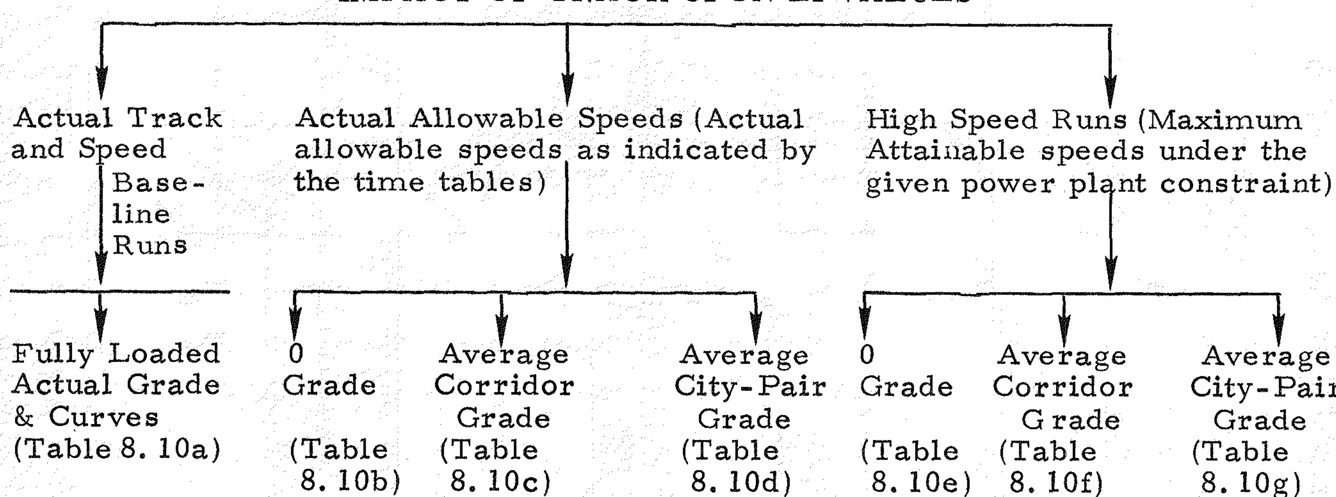


Figure 8.10 Velocity Profiles Under Various Track Conditions

8.11 Discussion of Results Related to "Impact of Several Levels of Track Improvements Upon EI Values"

IMPACT OF TRACK UPON EI VALUES



8.11a Results of Base-Line Runs:

Table 8.10a shows the results of the computer simulation for several trains along the NYC-Buffalo Corridor. The last column shows the data on average velocity which includes the station dwell times.*

8.11b Results of Actual Speed Runs:

Tables 8.10 b, c and d show the results of the similar train sets which obey the actual speeds but the actual grades and curves have been averaged over the whole corridor. The difference between the actual EI values (Table 8.10a) and those derived by averaging grade (Tables 8.10 b, c and d) appears to be small. Table 8.10e provides the differences as percentages of the actual values.

*Dwell times (NYC-Buffalo Corridor) are provided on Table 6.10c, page 6-6.

TABLE 8.10a

EI VALUES UNDER ACTUAL OPERATING CONDITIONS* - BASE-LINE RUNS

Train Consist	No. of Passengers	Fully Loaded Actual Grades & Curves		Average Speed (M.P.H.)
		Time H-Min-Sec	Energy Efficiency B.T.U./S.M.	
E-8 1-3-1-0	242	8-57-54	984	48.91
P-30 CH 1-3-1-0	312	8-43-47	699	50.25
Turboliner 2-3-1-1	263	8-46-3	2079	50.02
LRC 1-3-1-0	304	8-41-51	609	50.48

* Along NYC-Buffalo route.

TABLE 8.10b, c & d

ACTUAL SPEEDS (FULLY LOADED)

Train Consists	PASS.	8.10b O GRADE TIME H-MIN-SEC	8.10b O GRADE ENERGY EFFICIENCY BTU/S.M.	8.10c CORRIDOR GRADE TIME H-MIN-SEC	8.10c CORRIDOR GRADE ENERGY EFFICIENCY BTU/S.M.	8.10d CITY PAIR GRADE TIME H-MIN-SEC	8.10d CITY PAIR GRADE ENERGY EFFICIENCY BTU/S.M.
E-8	242	8-54-9	922	8-56-8	991	8-56-36	989
P-30CH	312	8-42-51	654	8-43-34	702	8-43-44	701
TURBO-LINER	263	8-44-59	2030	8-45-48	2071	8-45-48	2075
LRC	304	8-41-20	573	8-41-50	611	8-41-56	611

TABLE 8.10e

PERCENTAGE ERROR* IN EI VALUES BETWEEN BASE-LINE RUNS AND ACTUAL SPEED RUNS

Train Consist	0 Grade	Corridor Grade	City-Pair Grade
E-8	6.3	-.71	-.50
P-30 CH	6.4	-.42	-.286
Turboliner	2.3	.38	.192
LRC	5.9	-.32	-.32

8.11c <u>Results of High Speed Runs:</u>

Tables 8.10 f, g and h show the results of high speed runs upon EI values which also include the average speed. It is noted that the EI results of corridor grade v/s city pair grades differ by only a small amount. The following Table 8.10i provides the percentage error in EI values between the high speed runs and the base-line cases.

TABLE 8.10i

PERCENTAGE ERROR IN EI VALUES BETWEEN HIGH SPEED RUNS AND BASE-LINE RUNS

Train Consist	0 Grade	Corridor Grade	City-Pair Grade
E-8 1-3-1-0	.4	9	3.9
P30 CH 1-3-1-0	13.8	17.9	17.5
Turboliner 2-3-1-1	-20	-17.7	-17.7
LRC 1-3-1-0	5.4	11.6	12.1

*Calculated as follows: for O grade and E-8 train consist, base line EI value = 984, Actual speed run EI value = 922; hence % error with respect to base line

$$\frac{984 - 922}{984} \simeq 6.3\%$$

TABLE 8.10 f, g & h

HIGH SPEED RUNS

Train Consists	8.10f O GRADE TIME H-MIN-SEC	8.10f O GRADE ENERGY EFFICIENCY BTU/S.M.	8.10g CORRIDOR GRADE TIME H-MIN-SEC	8.10g CORRIDOR GRADE ENERGY EFFICIENCY BTU/S.M.	8.10h CITY PAIR GRADE TIME H-MIN-SEC	8.10h CITY PAIR GRADE ENERGY EFFICIENCY BTU/S.M.
E-8 *	6-23-50	988	6-35-14	1024	6-35-12	1024
P-30CH	5-38-20	796	5-46-13	821	5-46-22	822
TURBO-LINER	5-39-48	1662	5-48-6	1709	5-48-18	1710
LRC	5-04-35	642	5-06-25	680	5-06-06	683

*Train Consist explained on page 8-5.

Interestingly enough, the EI values have decreased at high speeds showing that it is more efficient when operating at higher speeds with fewer speed changes. Also it is important to note that the E-8 train consist had little change in EI values as a result of higher speeds. It is likely that the energy lost in the higher number of speed changes (in the case of actual track) has compensated for the higher energy required for overcoming the increased aerodynamic drag. Because of the positive grade, the EI values are higher for corridor grade and city-pair grades.

8.20 Impact of Planned Track Improvements Upon Demand and EI Values

This section is meant to evaluate the impact of planned track improvements* upon rail demand and subsequently the EI values. Subsection 8.21 provides details on the methodology for the estimation of EI values under improved track conditions. Subsection 8.22 discusses the results.

8.21 Methodology For Estimating EI Value Under Improved Demand Resulting Due to the Improved Track Conditions

Figure 8.20 provides the flow chart needed towards the estimation of increased demand and the resultant EI values. Box a provides the existing data on track in terms of allowable speed. With the availability of extra resources, the track can be improved (or bridges can be rebuilt) which result in higher speed limits as shown by the output of box b. This information is fed into the train performance calculator which calculates trip time and energy efficiency which are shown by boxes e and f. The improved trip-times were fed into the New York State DOT's demand** model which estimates the new demand. By assuming a present frequency and train consist, the unit energy consumption rates (B. T. U. /P. M.) were recalculated.

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*Readers who are interested in knowing details should refer to Reference No. 27.

**See Reference No. 12.

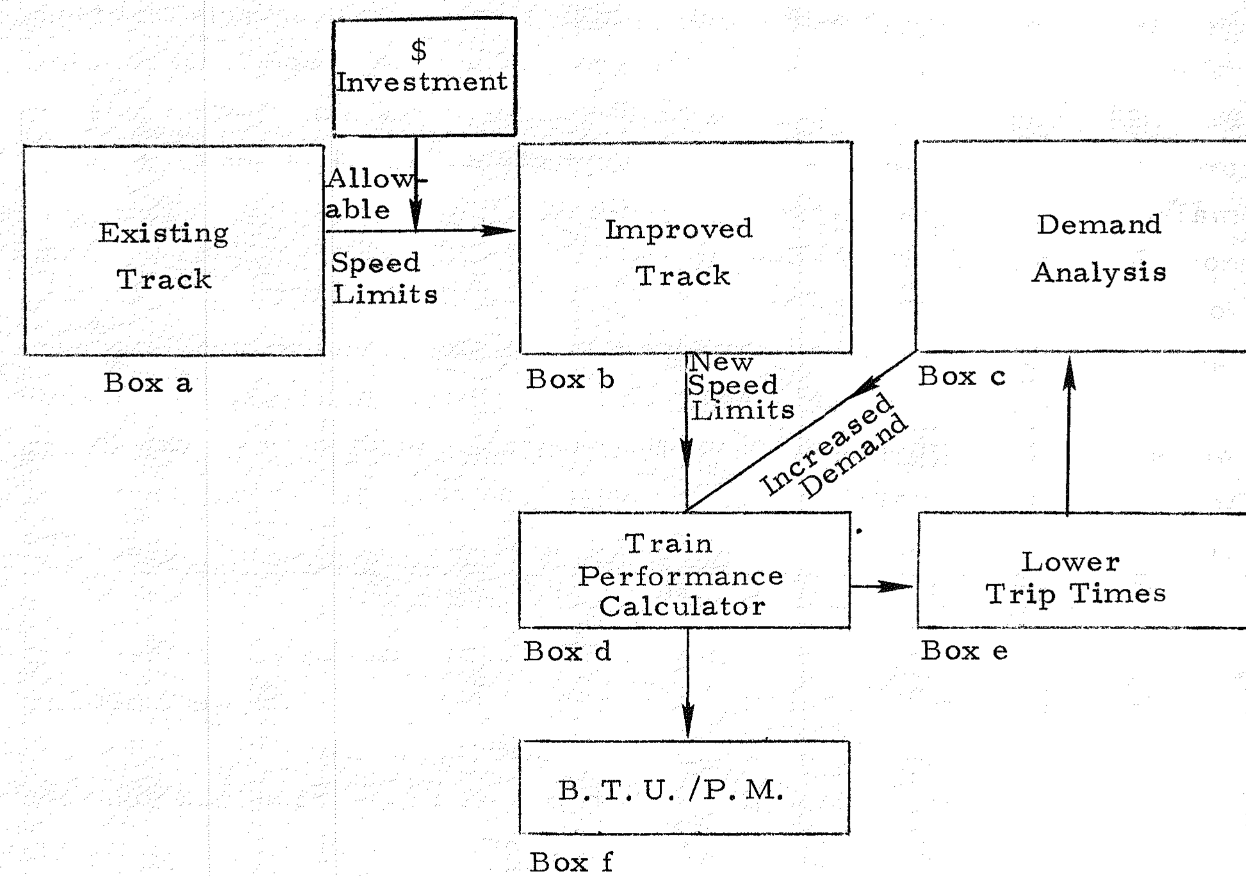

Figure 8.20. Flow Chart for Methodology Towards Analyzing the Impact of Improved Track Upon Rail Patronage

8.22 Discussion of Results

The train consists are the same as discussed in the preceding sections. Figures 8.20 a, b, c, and d present the results of the analysis. Results are presented for full load conditions and for actual load conditions. Each figure has 3 curves. The top curve shows the relationship between EI and average speed. The improved average speed is due to the improvement program which the New York State DOT plans to follow. On each curve is marked the year when that improvement is going to happen. The time period considered was from 1977 through 1980.* The load factor is kept constant for the top curve. The second line shows the impact of increased demand upon EI values. As discussed earlier, the increased speed would tend to increase demand (lower trip time) and hence increase the load factor which would reduce the EI values. The third, bottom, curve shows the variation in EI as a function of track improvements (and hence speed), under full load conditions. After careful examination of the figures, the following conclusions are made.

(a) Conclusions regarding the top curve (impact of track upon EI-under constant demand).

- Under constant demand conditions, the EI values for the diesel/ electric trains are in the range of 6000-8000 B.T.U. / P.M. The E-8 train consist having the highest EI values with the LRC train consist on the lower end of the range (more efficient). These values are the average EI values based upon the NYC-Buffalo Corridor. The Rohr Turboliner has a range of 16,000 to 18,000 B.T.U./P.M.

- In almost all the cases, the EI values first showed a decreasing and then an increasing trend as a function of the track improvements. Usually, the increased speed results in higher EI values (because of increased aerodynamic drag) which would

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*The E-8 train consist will not be utilized beyond 1979 so results for 1980 are not discussed.

have moved the curve upward right from the start but a second factor which is not shown in the diagram is the number of reduced speed changes which can help reduce the acceleration energy. It is contended that the downward movement of the curve is because initially the energy gain due to the fewer number of speed changes overcomes the energy loss due to the higher speeds.

(b) Conclusion regarding second curve - In all the cases, the second curve appears to be a linear curve with a negative slope. For the diesel/electric train consists, the EI values range from 2000 to 7000 B.T.U./P.M. For the turboliner, the EI value had a range from 7000 to 17,000 B.T.U./P.M. The improvements in track had an appreciable impact upon reducing the EI values.

(c) Conclusions regarding the third curve - EI v/s track improvements, under full load conditions. The diesel/electric trains have an approximate range of 600 - 750 B.T.U./S.M., whereas the turboliner has EI values in the neighborhood of 2000 B.T.U./S.M. The curve provides us with a potential EI value as a result of the improved track conditions.

IMPACT OF TRACK IMPROVEMENTS AND DEMAND (IMPROVED LOAD FACTOR) UPON ENERGY INTENSITY FIGURES. NYC TO BUFFALO

E-8

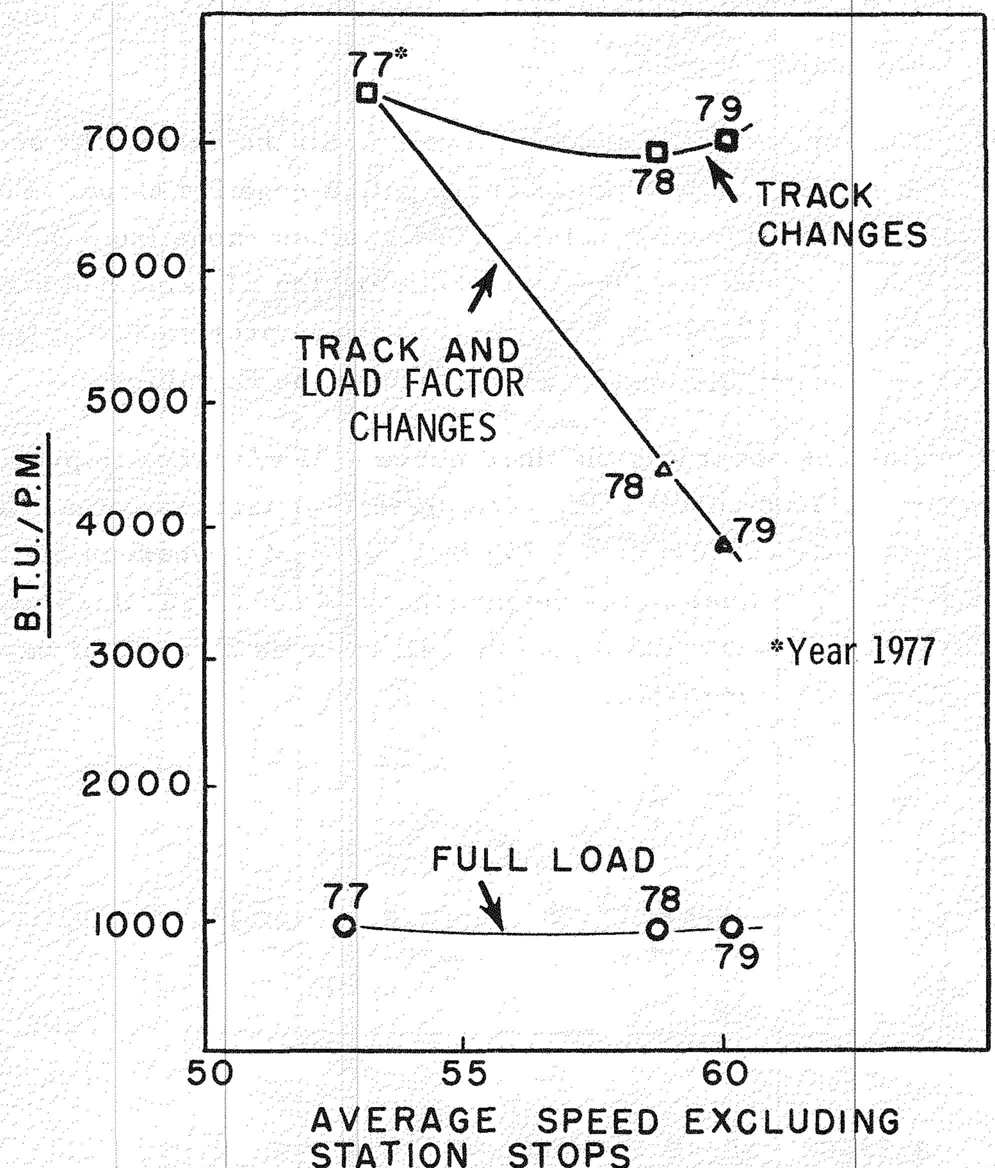

FIGURE 8.20a

IMPACT OF TRACK IMPROVEMENTS AND DEMAND (IMPROVED LOAD FACTOR) UPON ENERGY INTENSITY FIGURES. NYC TO BUFFALO

P30 CH

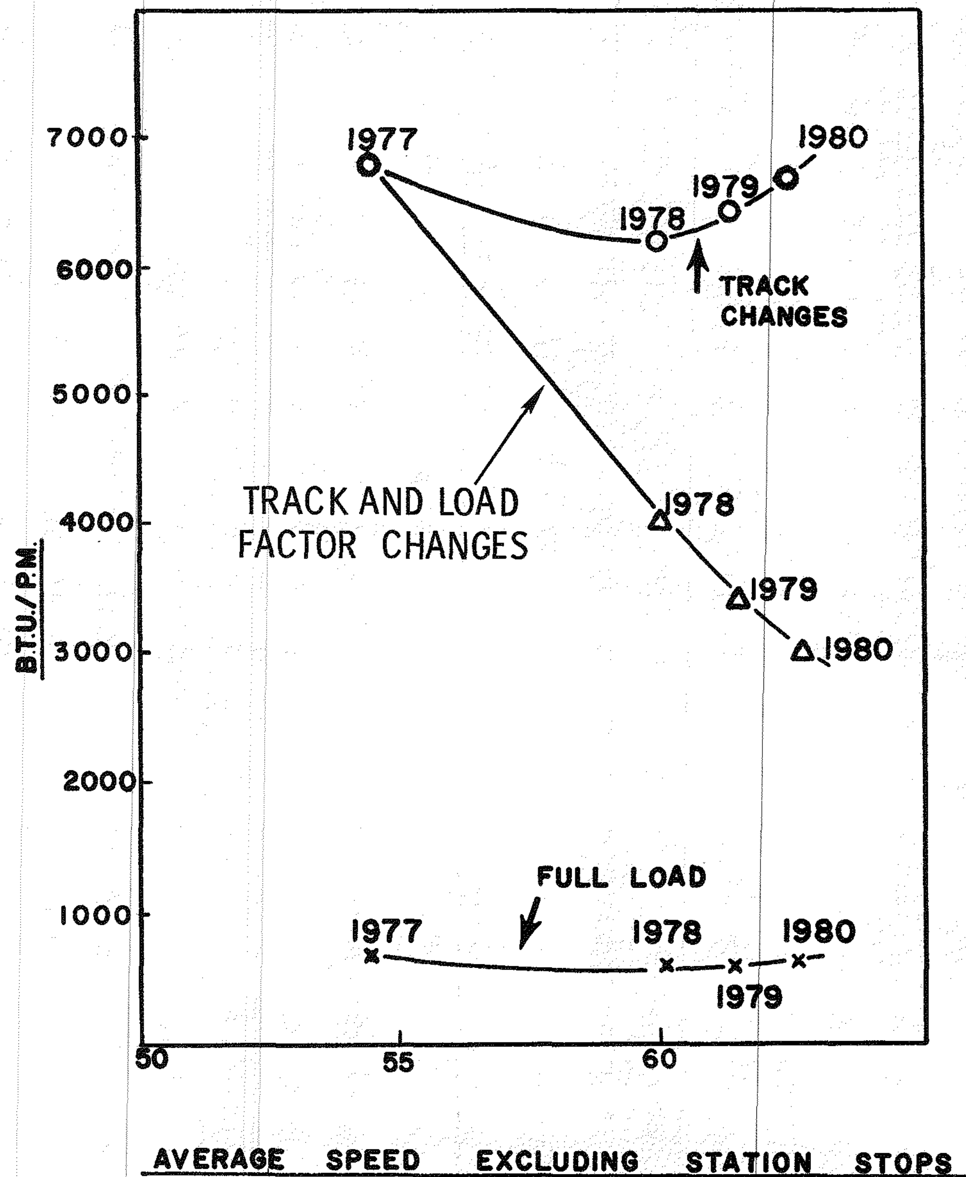

FIGURE 8.20b

UNION COLLEGE TRANSPORTATION PROGRAM	DOT-OS-60124 MAY 1977

IMPACT OF TRACK IMPROVEMENTS AND DEMAND (IMPROVED LOAD FACTOR) UPON ENERGY INTENSITY FIGURES. NYC TO BUFFALO

LRC

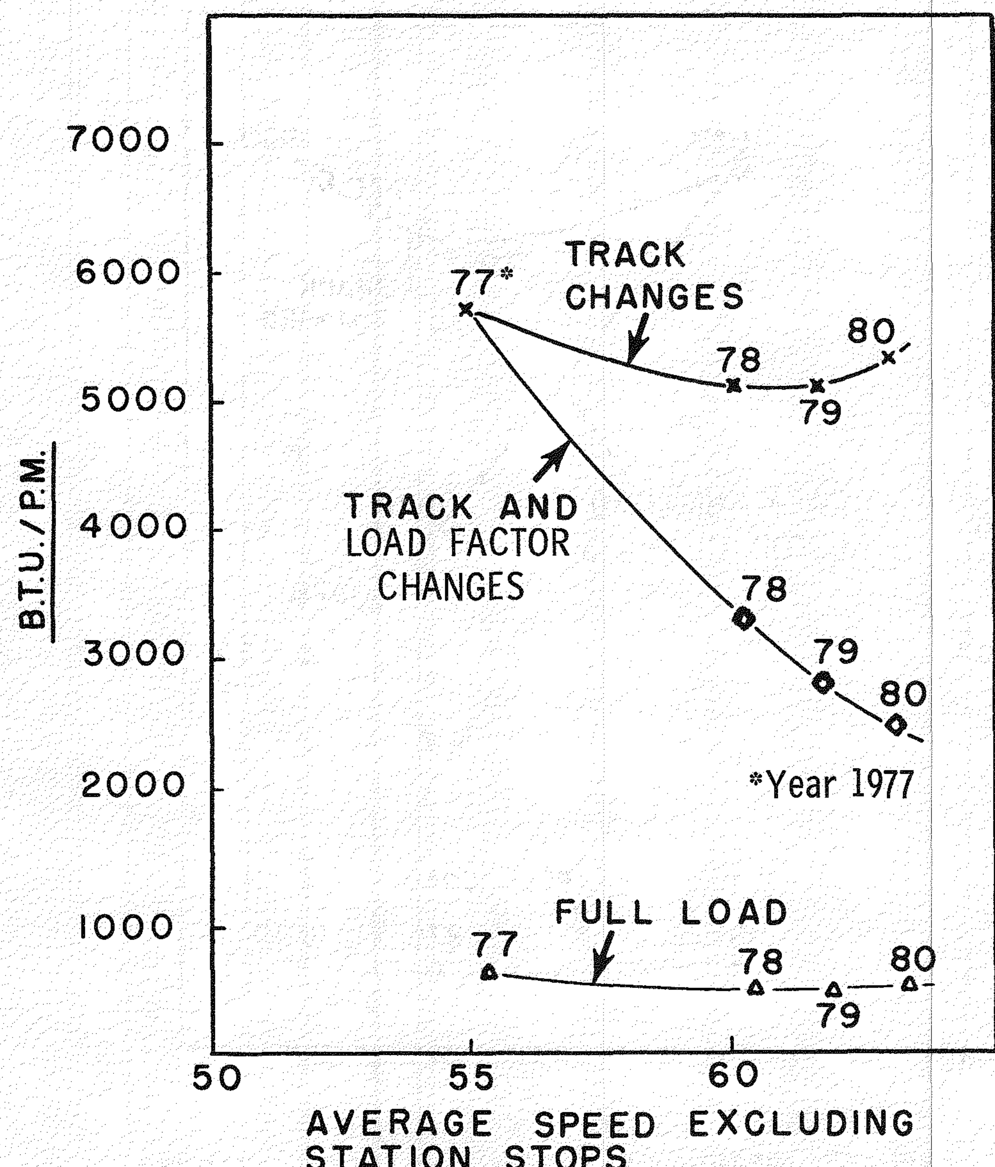

FIGURE 8.20c

IMPACT OF TRACK IMPROVEMENTS AND DEMAND (IMPROVED LOAD FACTOR) UPON ENERGY INTENSITY FIGURES. NYC TO BUFFALO

ROHR TURBOLINER

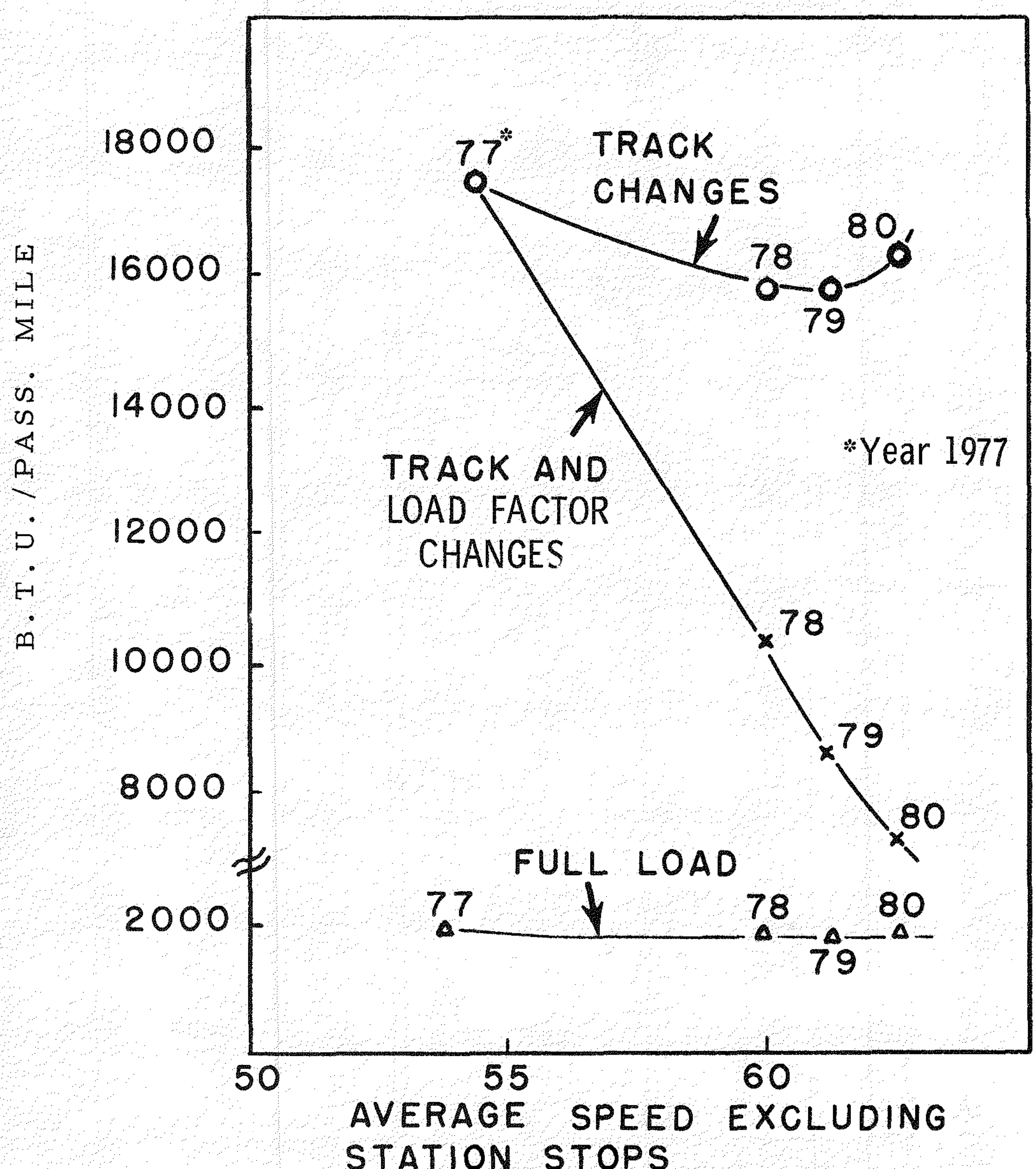

FIGURE 8.20d

8.30 SUMMARY

The results of this chapter can be summarized in the following manner.

- Track plays a major role in the estimation of energy intensity figures. For estimation purposes, one does not need detailed point by point track data; rather, average corridor grades or city-pair grades will suffice for fairly accurate results.
- Under constant load conditions, (demand is kept constant), the variation in EI values resulting from improved track is quite negligible* and would result in higher EI values if the allowable speeds were changed appreciably (top and 3rd curve in Figures 8.20 a, b, c and d).
- The impact of track improvements resulted in increased demand and hence decreased the EI values by an appreciable amount. (Second line in Figures 8.20 a, b, c and d).
- Diesel/Electric trains (E-8, LRC, P30 CH), behaved alike under the changes of track with minor variation existing amongst the trains analyzed. The slope of the curves for the turboliner was similar to those for diesel/electric trains except for the range.

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*This is true only under the conditions (range of speed) which were analyzed.

**One point needs to be made regarding the turboliners - On talking to AMTRAK marketing personnel, it was noted that rail passengers prefer the turboliner in comparison with the other diesel/electric trains which means that under similar conditions we could have higher load factors with the turboliners and hence reduce EI values. This is a modeling question which was not addressed in the current research. Inclusion of the above factor could lead to reducing EI Figures for turbo trains.

9.00 COMPARATIVE ANALYSIS OF ENERGY INTENSITY VALUES FOR INTERCITY PASSENGER TRANSPORTATION MODES

9.00 COMPARATIVE ANALYSIS OF ENERGY INTENSITY VALUES FOR INTERCITY PASSENGER TRANSPORTATION MODES

In this chapter, an attempt is made to compare the EI values of several intercity passenger modes of transportation. This is done to gain a better perspective on the overall issue of energy intensity for intercity passenger movement. Also, an attempt is made to document the historical variation in EI values over the last 10-15 years. An attempt is also made to document the EI values under current load factors as well as under full-load conditions. The statistical and engineering approaches have been utilized for gaining a better understanding of the EI values. An attempt has also been made to provide a suggested "EI" value for the major intercity transportation modes. It is also important to mention that the present analysis is based solely on the operational energy which is a subset of the overall energy needed to move people via various modes. Other elements of energy such as maintenance, construction, etc., are important, but an adequate job is not possible because of limitations on the available resources. Another point which needs to be made relates to the quality of ride offered by individual modes; e.g., travel time, cost, reliability, access, egress, frequency, convenience, etc., are all facets of the quality index which varies for each mode and also within modes. Also, the modes may not necessarily be competitive in nature but rather complementary to each other; e.g., use of an auto for gaining access to the airport, etc. Finally, another point needs to be made relative to the energy savings as a result of mode shift strategies. The energy savings resulting from the mode shifts depend upon a host of factors, only one of which is the EI values. This chapter can certainly provide some guidelines, but more work is needed before some conclusions can be made in regard to the energy savings.

This chapter is divided into 5 sections which are arranged in the following manner

9.00
Comparative Analysis of EI Values for Intercity Passenger Transportation Modes

- 9.10 Intercity Plane
- 9.20 Auto
- 9.30 Bus
- 9.40 Train
- 9.50 Comparative Analysis of EI Values for several Intercity Passenger Modes

In the subsequent sections, an attempt is made to expound upon the EI variations for various modes. Current relevant literature is also presented. It is hoped that this material will provide some stimulus towards gaining better insight into the subject of energy intensity.

9.10 INTERCITY PASSENGER PLANES

Figure 9.10a shows the historical variation in EI value over the time period of 1955 through 1976. These data pertain to the certificated air-lines. The data points are obtained by dividing the total energy consumption by the passenger miles flown. Two things need to be noted in regard to these EI values: these values are based upon the great circle miles which are smaller than the route-miles; passenger/cargo planes carry nearly 96% of the total ton-miles. Both of these factors tend to raise the actual EI values. Based upon this chart, it appears that the EI value for intercity passenger planes is around 6500 B.T.U./passenger mile. The major drawback of this chart is that it does not describe in a quantitative manner the impact of various types of equipment groups such as turbofan, turbojet, turbo-prop, piston, etc. In order to understand the impact of several equipment groups, Figure 9.10b has been derived from data provided in Reference 11. Load factors are also mentioned for each equipment group. Turbofan (3 and 4 engine, wide bodied) aircraft are most efficient under the current load factors. This figure also compares the results of 1974 operations which appear to be close to those of 1975. This figure provides us with the good estimates of the EI value for various equipment groups, e.g., turbofan (4 engine, wide bodied) aircrafts have an average EI value of 5542 B.T.U./P.M. while turbo-prop, 4 engine have an average EI value of 10188 B.T.U./P.M.

Figure 9.10c was prepared for understanding the EI value for intercity planes as a function of equipment type (B-747, B-707, B-727, DC-10, etc.). Current load-factors are also indicated. B-747, DC-10 and L-1011 are the most energy efficient aircrafts at the established load-factors.

The following conservation strategies have helped to attain the reduction.

- Fewer flights carrying more passengers
- Operational measures - altitude and speed combinations which result in minimum time with reduced consumption since speed has also been reduced
- New improved technology

OPERATING ENERGY INTENSITY

OF INTERCITY PLANES - HISTORICAL VARIATION IN EI VALUES

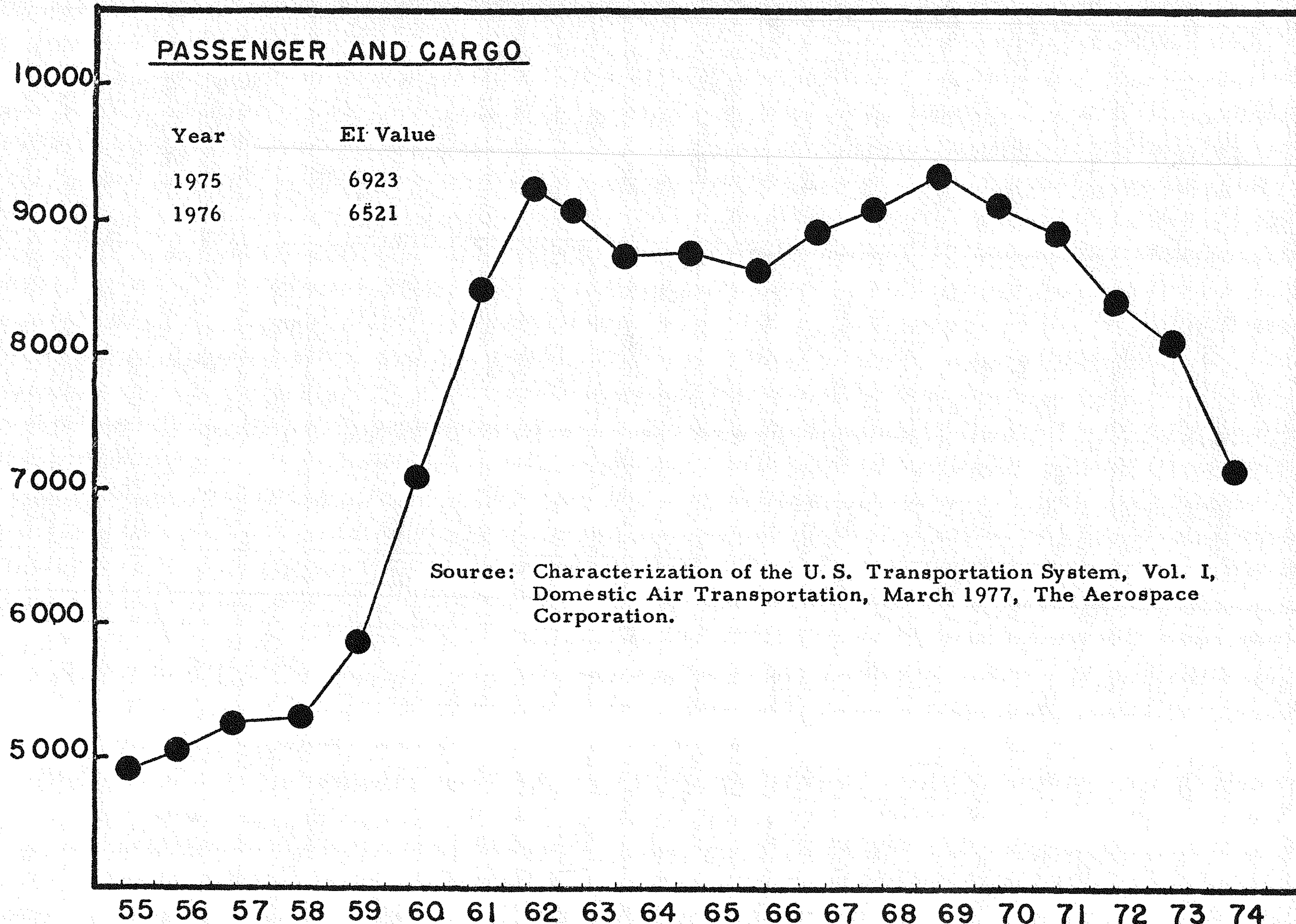
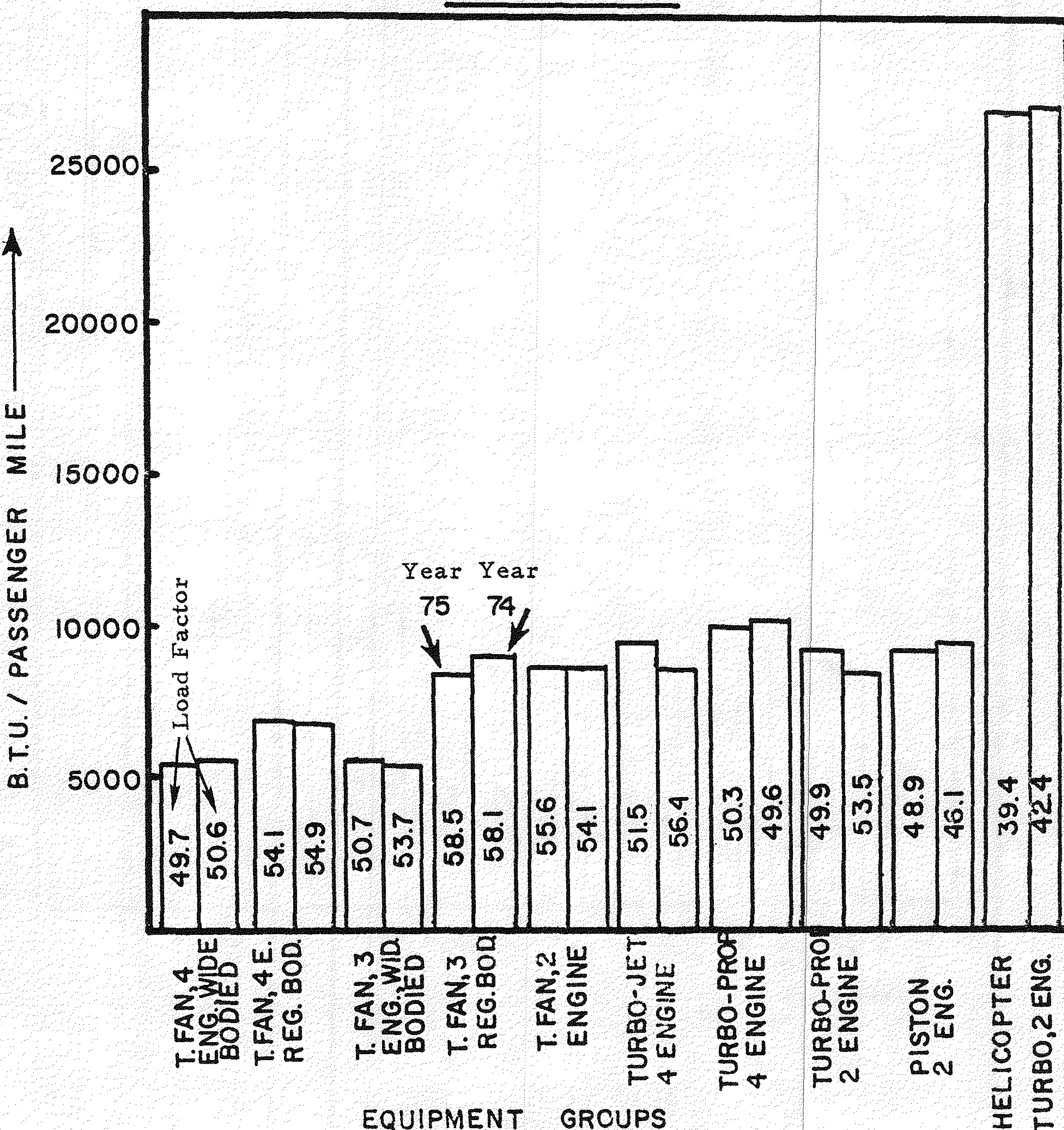


FIGURE 9.10a

ENERGY INTENSITY FOR INTERCITY PLANES (DIVIDED BY EQUIPMENTS GROUPS) PASSENGER

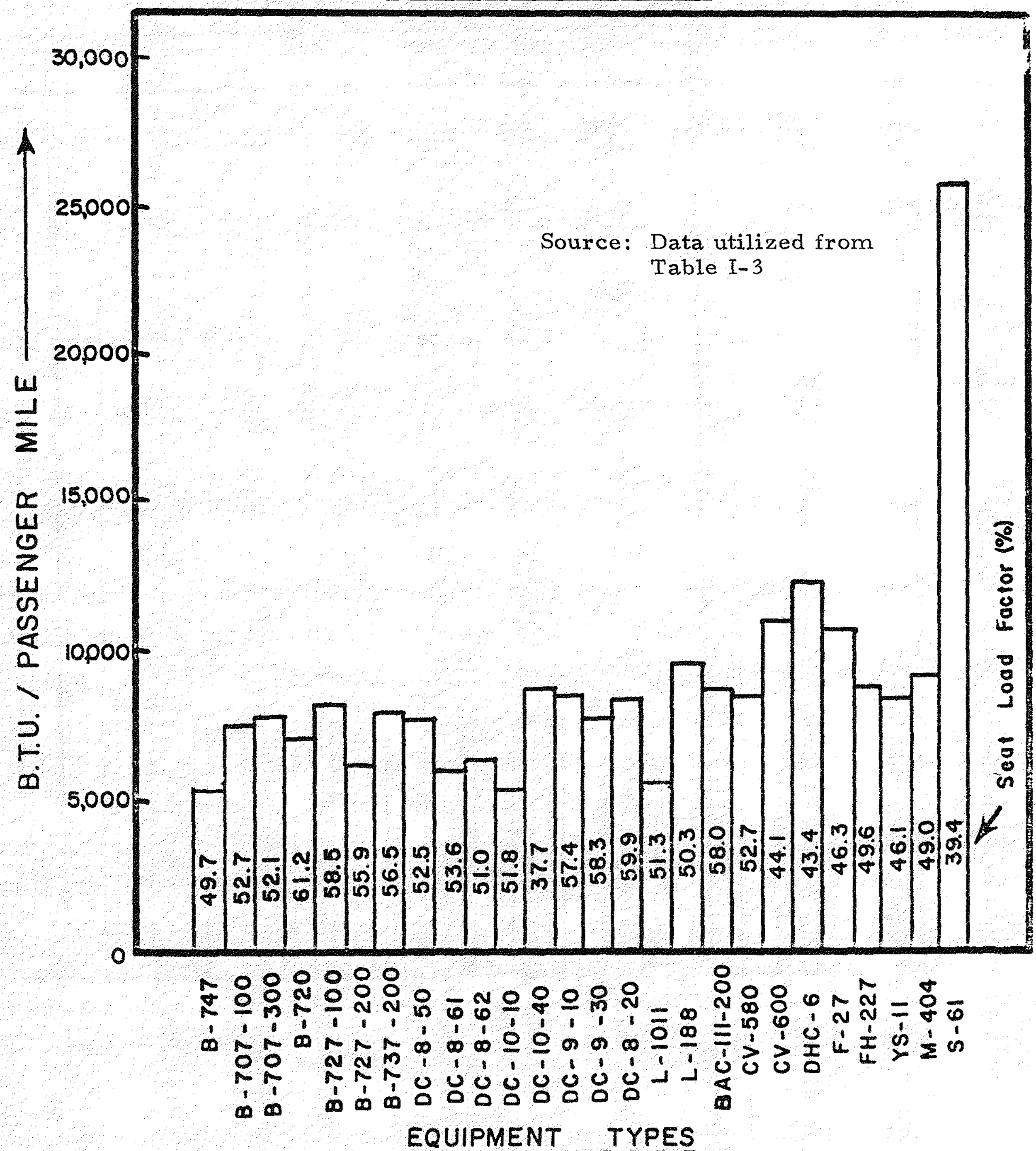


Source: Data utilized from Table I. 4

FIGURE 9.10b

UNION COLLEGE TRANSPORTATION PROGRAM

ENERGY INTENSITY FOR INTERCITY PLANES (DIVIDED BY EQUIPMENT TYPES) PASSENGER 1975



UNION COLLEGE TRANSPORTATION PROGRAM

FIGURE 9.10c

9.11 Engineering Approach

Section 9.10 dealt with the gross statistics for the certificated route carriers. These data were based upon yearly operations. In order to get a better perspective on the variation of EI values as a function of operating and design parameters, subsection 9.11 is presented. Firstly, the major factors which affect the EI values are listed as follows:

- Stage Length
- Type of Aircraft
- Operational strategies (altitude, ascent and descent procedures, etc.)
- Passenger and cargo load factor
- Seating density

In order to quantitatively understand the impact of the above factors, comprehensive data were needed. In spite of intensive efforts, the engineering data on several planes were not available except for B-727-100, B-727-200 and DC-10. These data have been supplied by the manufacturers and include information on fuel consumption and travel time under the given operating conditions (speed, altitude, weight of the plane).

Figure 9.10d provides the results of the energy intensity study (no cargo penalty) under the specified operating conditions (Altitude = 29,000 ft, Passenger load factor = 100%, Cargo load factor = 50%). Because of the assumptions inherent in the calculation,* these results should be taken only as a guide. These figures do provide us some insight as to the lower-bound values for the given airplane. It is important to note the variation among various aircraft as a function of stage-length. The DC-10 appears to be highly efficient in the range of 1500-2000 miles while the Boeing 727-100 and 727-200 appear to be more efficient (compared to DC-10) in the neighborhood of 500 miles stage-length.

In order to show the more equitable distribution of fuel between cargo and passenger, Figure 9.10e was presented. As expected, the EI values for passenger movements are lower in comparison with the previous figure.

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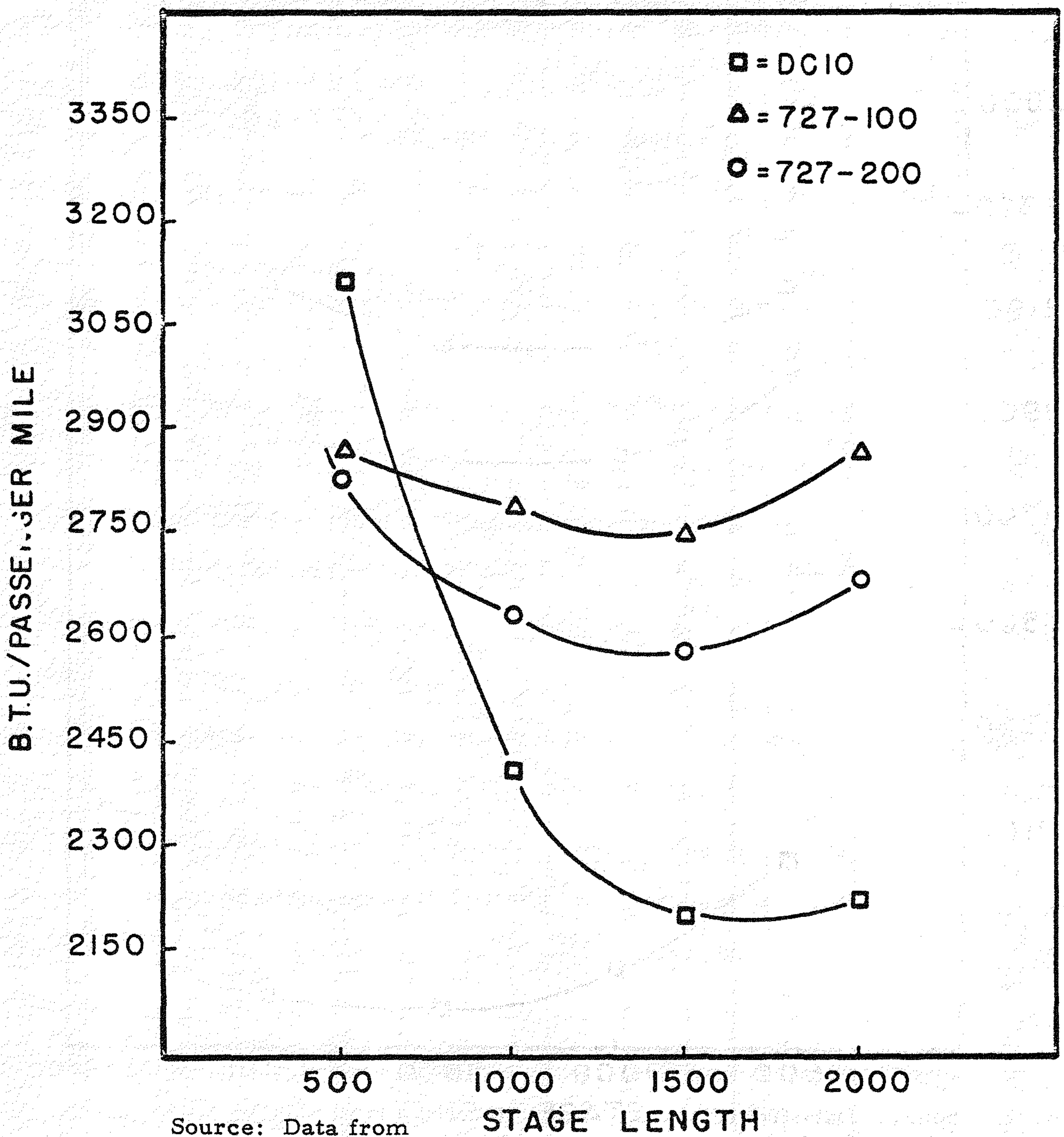
*Refer to Appendix I for further details.

ENERGY INTENSITY OF INTERCITY PLANES

NO CARGO PENALTY   100% PASS. LOAD FACTOR

ALTITUDE = 29000 FT.   50% CARGO LOAD FACTOR



Source: Data from Table I-6.

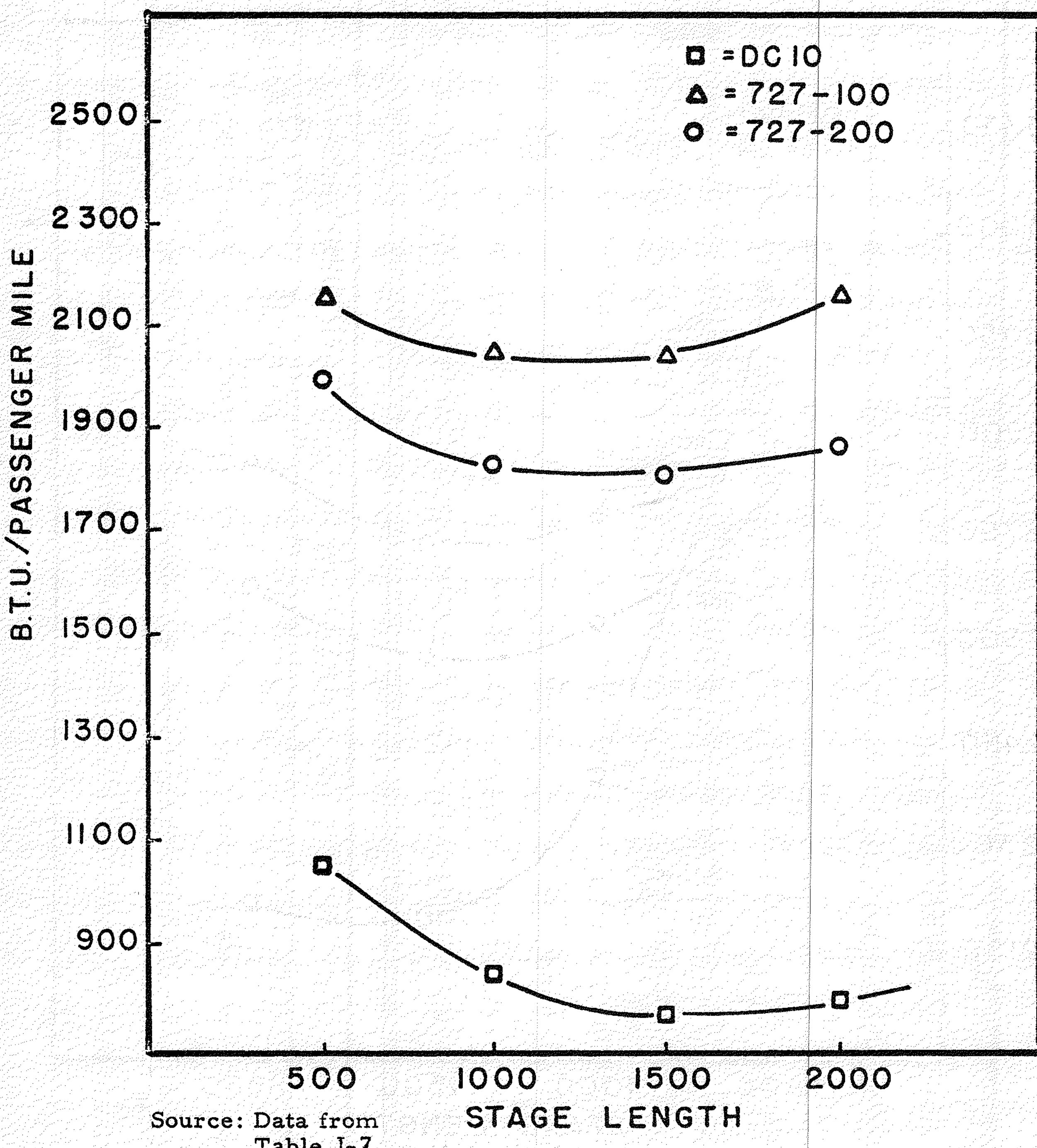
FIGURE 9.10d

UNION COLLEGE TRANSPORTATION PROGRAM	JULY 1977

ENERGY INTENSITY OF INTERCITY PLANES

FUEL PROPORTIONED ACCORDING TO WEIGHT

ALTITUDE = 29000 FT.   100% PASS. LOAD FACTOR
50% CARGO LOAD FACTOR



Source: Data from Table I-7.

FIGURE 9.10e

UNION COLLEGE TRANSPORTATION PROGRAM	JULY 1977

9.12 Concluding Comments Regarding EI Study for Intercity Passenger Planes

- Based upon the literature survey and the data presented in the preceding section, a reasonable estimate of EI value is around 6500 B.T.U./P.M. (at current load factor). This is just a gross number and for a particular situation, the actual EI number may be off ± 30%.
- Based upon the 1974 and 1975 airlines statistics, the following EI estimates may be listed at the current load factors.

Equipment Group	EI = B.T.U./P.M.
a) Turbo Fan 4 engine, wide bodied	5586
b) Turbo Fan, 3 engine, wide bodied	5725
c) Turbo Fan, 3 engine, regular bodied	9000
d) Turbo Jet, 4 engine	9163
e) Turbo-Prop, 4 engine	10250

These numbers can be updated each year after the latest CAB reports are available.

- Passenger planes carry most of the air cargo (96% or better) and hence a better fuel allocation methodology (which accounts for the marginal fuel penalty due to the added cargo weight) should be applied when calculating the EI value for intercity passenger aircraft.

- Considerable potential exists for improving the energy efficiency of intercity planes. Factors such as improved load factor, reduced speed, improved ascent and descent procedures, improved technology (turbo fan), and use of fewer engines during taxiing operation, can have a substantial impact on reducing the overall energy intensity of inter-city air operation.

- It is important to add that the airplane EI values usually quoted in the literature and also mentioned in this section are based upon the great circle miles while the competing modes have their EI values based upon the route-miles. This strategy results in higher EI values for the airplanes.

9.20 INTERCITY AUTO

Energy intensity of intercity auto depends upon a host of factors, most importantly:

- weight of the car, size and model year
- load factor
- rural vs urban driving

In the subsequent section, an attempt shall be made to expound upon the impact of the above factors upon EI values. Table 9.20a shows the historical variations in EI (B. T. U. /vehicle mile) over the period 1950 to 1974. The value varies from 8534 to 9055 (B. T. U. /V. M.). The miles traveled by the automobiles are over both rural and urban areas. It is important to note that the EI value has gone up since 1950. The higher curb weight, more accessories and the installation of pollution equipment may have resulted in the higher energy intensity figures.

Recently, the new car fleet has improved in energy efficiency as documented in Table 9.20b. These results provide fuel energy figures (miles per gallon) by model year (1957 through 1976) and weight class. These results were obtained by EPA through the chassis dynamometer testing. In order to understand the impact of highway driving upon EI value, Table 9.20c is presented. This table shows the relationship between curb weight and fuel economy (B. T. U. /Vehicle Mile). These results are converted to B. T. U. /P. M. at 50% and 100% load factors. The EI value (at 100% load factor) varies from 696 to 1570 B. T. U. /P. M. These numbers should be used with care, because of the assumptions inherent in the study, but they do provide us with the potential EI value for the intercity autos. Table 9.20d shows the results of fuel economy for the U. S. current and projected auto fleet. The last column has been converted to B. T. U. /P. M. based upon the current load factor. Table 9.20e shows the occupancy rate used by various authors.

TABLE 9.20a

PASSENGER CAR FUEL ECONOMY AND ENERGY INTENSITY

Year	Vehicle-mile (10^9) Urban	Rural	Gasoline Consumed(1) (10^9 gal)	Average fuel economy(2) (mi/gal)	Average energy intensity B.T.U./veh-mi
1950	182.5	181.1			
1955	233.6	259.0	25.0	14.53	8534
1960	284.8	303.3	41.2	14.27	8690
1965	378.2	333.4	50.3	14.15	8765
1966	400.4	351.4	53.3	14.11	8791
1967	415.0	359.2	55.1	14.05	8826
1968	438.7	375.3	58.5	13.91	8912
1969	466.0	392.8	62.4	13.76	9010
1970	494.5	406.5	65.8	13.69	9055
1971	525.2	428.9	69.1	13.81	8981
1972	567.5	436.0	73.5	13.65	9084
1973	592.2	444.3	78.0	13.29	9330
1974	589.8	428.1	74.2	13.71	9044

(1) Consumed for passenger cars and motorcycles.

(2) Average fuel economy is total miles divided by gallons of gasoline consumed.

Highway Statistics, 1965 through 1974 annual editions, U.S. Department of Transportation, Federal Highway Administration.

TABLE 9.20b

CITY/HIGHWAY COMBINED FUEL ECONOMY
BY MODEL YEAR AND WEIGHT CLASS

Model Year	Inertia Weight Class									
	2000	2250	2500	2750	3000	3500	4000	4500	5000	5500
'57-'67 avg.	27.8	26.3	23.1	20.7	18.5	16.3	15.2	14.0	13.1	12.7
1968	23.3	24.7	22.3	23.8	18.8	16.0	14.5	13.6	11.2	10.7
1969	26.9	24.5	22.7	20.3	18.6	16.0	14.4	13.6	11.0	13.0
1970	28.2	23.3	21.1	22.3	19.2	16.0	14.5	13.1	12.2	11.9
1971	27.3	25.8	23.3	22.1	17.8	14.7	14.1	12.9	11.6	13.1
1972	27.7	26.4	23.6	24.1	17.4	16.0	13.4	12.9	11.6	11.2
1973	28.7	26.4	23.8	21.1	18.8	16.8	13.0	12.2	11.2	10.4
1974	31.2	25.7	23.6	22.5	20.6	18.3	13.5	11.8	10.8	9.9
1975	31.3	28.1	24.5	22.4	21.6	17.6	15.5	14.6	12.8	12.0
1976	29.3	28.8	26.7	24.6	23.6	19.2	17.4	15.7	14.6	13.3

Source: Passenger Car Fuel Economy Trends Through 1976, SAE.
Selected SAE papers1965 - 1975. Automotive Fuel Economy, 1976.

TABLE 9.20c

ENERGY INTENSITY OF INTERCITY AUTO (HIGHWAY-CYCLE ONLY)

S. No.	Car Type	Engine Size/ Cylinder	Trans-mission	Curb* Weight in lbs.	B.T.U.* / Vehicle Miles	B.T.U.# / P.M. 50% Load Factor	B.T.U.# / P.M. 100% Load Factor
1.	Toyota Corolla	71/4	M	2015	2346	1246	696
2.	Volkswagen Rabbit	97/4	M	1860	2675	1430	808
3.	Datsun B-210	85/4	A	1975	3484	1857	1043
4.	Pontiac Sunbird	231/6	M	2740	3965	2080	1138
5.	Ford Mustang II	302/8	M	2755	5476	2877	1570
6.	Plymouth Volare	225/6	M	3630	3965	1677	914
7.	Buick Skylark	231/6	M	3425	4423	1876	1027
8.	Ford Granada	302/8	M	3525	4791	2029	1108
9.	Ford Thunderbird	351/8	A	4385	5750	2410	1297
10.	Dodge Aspen S. E.	360/8	A	3651	6764	2859	1558
11.	Oldsmobile Cutless Supreme	231/6	M	3790	4423	1582	872
12.	Chevrolet Malibu	250/6	A	3841	4600	1644	905

Source: EPA/gas mileage guide 1977
Consumer Reports 1976 and 1977
Ward's Automotive Yearbook 1977

* May differ somewhat depending upon the sources and assumptions.

\# Passenger weight = 150 lbs.

TABLE 9.20c (continued)

ENERGY INTENSITY OF INTERCITY AUTO

S. No.	Car Type	Engine Size/ Cylinder	Transmission	Curb Weight in lbs.	B.T.U. / Vehicle Miles	B.T.U. / P.M. 50% Load Factor	B.T.U. / P.M. 100% Load Factor
13.	Dodge Monaco	225/6	A	3770	5227	1870	1031
14.	Lincoln-Mercury Cougar	351/8	A	4295	5750	2041	1093
15.	Chrysler Cordoba	318/8	A	4180	6388	2272	1165
16.	Buick Lesabre	231/6	A	3893	4600	1432	798
17.	AM Matador	258/6	A	4124	5476	1697	941
18.	Plymouth Gran Fury	318/8	A	4390	6389	1971	1088
19.	Dodge Royal Monaco	440/8	A	4410	7352	2086	1151
20.	Lincoln Continental	460/8	A	5052	7812	2197	1200

1 - 5 Subcompact Cars of 4 Seats

6 - 10 Compact Cars of 5 Seats

11 - 15 Standard Cars of 6 Seats

16 - 20 Luxury Cars of 7 Seats

Gasoline: 115,000 B.T.U./gallon

TABLE 9.20d

ENERGY INTENSITY OF INTERCITY AUTO
(HIGHWAY CYCLE ONLY)

Year	Highway Driving Cycle	B.T.U. / V.M.	B.T.U.* / P.M.
1975	18.41**	6247	2603
1977	19.05	6037	2515
1982	22.30	5157	2149
1985	25.69	4476	1865
1990	30.28	3798	1582

Source: Issues Affecting Northeast Corridor Transportation Interim Report, June 1977; Prepared for FRA.

* Occupancy Rate = 2.4

** Aerospace Corp. estimates that the current U.S. fleet has a highway fuel efficiency of 18.41 m.p.g. whereas the Federal Task Force Report (Reference 14) assumes a combined fuel economy of 14.9 m.p.g. which when converted to Highway Cycle comes to 18.58 m.p.g. This discrepancy can't be settled and for subsequent discussions, a value of 18.41 m.p.g. (Highway Cycle) is utilized.

TABLE 9.20e

OCCUPANCY RATE FOR INTERCITY AUTO

Occupancy Rate	2.6	2.5	2.1
Author	Pollard	Fraize	Goss
Reference No.	33	17	20

9.22 Concluding Comments Regarding EI Study Related to Intercity Automobile

- Given the model year and type of trip (urban vs highway), a reasonable estimate of the EI values can be made from reports published either by EPA or Consumer Reports. The EPA testing methodology makes use of the chassis dynamometer. Consumer reports results are actual on the road tests and differ a bit from the EPA ratings.

- The professionals strongly disagree in regard to the load-factor (Table 9.20e). The load-factor is usually higher for the intercity trips. The best suggested number, based upon the literature survey, is around 2.4* persons per car. Using this occupancy rate, the EI value for a intercity trip is 2650 B.T.U./P.M. It is also important to mention that the auto can be competitive with other modes if the occupancy rates are increased.

- It is expected that the fuel economy of the intercity auto will keep on improving at a reasonable pace at least until 1995,** after which date there has to be a technology breakthrough for further gain in fuel economy.

- Based upon the present load factor conditions, the current auto consumes nearly double the energy consumed by the bus. It is also important to note that presently the plane consumes more than double the energy consumed by the auto (per passenger-mile basis).

- There is a considerable variation in EI value for the intercity automobile. A few of the important factors which contribute towards its variation, are as follows:

    - Load factor - depends upon the length of the trip, type of the vehicle and purpose of the trip.

---

*The national personal transportation study shows a higher load factor which is unsatisfactory because of the sample size for trips greater than 100 miles. Boeing report has documented (based upon N.E. Corridor and Kansas State) that a figure of 2.4 is more appropriate to use. (Reference 8.)

**Based upon new car standards in the law up to 1985 and permeating the fleet for 10 more years.

- Type of the vehicle - subcompact, compact, standard, luxury.
- Percentage urban driving - total urban mileage divided by the trip length multiplied by 100. The higher the percentage urban driving - the higher the average EI value.
- Length of the trip.
- Average speed and the distribution of the speed.
- Temperature, humidity, road conditions, etc.

9.30 INTERCITY BUSES

Table 9.30a provides energy intensity data as derived by The Aerospace Corporation using data supplied by carriers to the Interstate Commerce Commission. These EI figures are calculated after excluding the charter and special services.

Greyhound Lines, Inc., was contacted to get their input to this study. Mr. A.N. Ransom, Director of Research, made available to Union College data on passenger miles and fuel usage for the years 1973 through 1976. After analyzing these data, the results of the EI values are presented in Table 9.30b. The top line represents gross intercity operations. After eliminating the charter and local services, the remaining two rows were obtained. The EI figures tend to be in the range of 1000 - 1100 B.T.U. The national load factor for the year 1976 is 44% which is on the decline side. By comparing the results of Tables 9.30a and b, it is noted that the EI values are in close agreement which shows the high reliability of the input data used for the estimation purposes.

TABLE 9.30a

ENERGY INTENSITY OF RECENT REGULAR ROUTE INTERCITY BUS SERVICE

Year	Energy Intensity* B.T.U./P.M.	Load Factor
1975	1,157	44.9%**
1974	1,093	45.12%***

*Reference: Aerospace characterization of the U.S. Transportation System Vol. II, page 4-44, Aerospace Corp.

**Reference: TAA - Facts & Trends, July 1977.

***Reference: Linear interpolation between the year 1970 and 1975.

TABLE 9.30b

ENERGY INTENSITY OF INTERCITY BUS SYSTEM

(Greyhound Operation)

Type of Operation	1973	1974	1975	1976
1) Regular Route Intercity Miles only	1204	1126	1193	1183
2) Intercity Route After Eliminating Charter Service	1073	1003	1049	1116
3) Intercity Route After Eliminating Charter and Local Service	1041	975	1025	1099

Source: Greyhound, see Appendix III for further details.

9.31 Engineering Approach

In order to put more confidence into the EI study pertaining to the intercity buses, the engineering approach (cruising only) was utilized. The results are shown on Figure 9.30 c which is based upon 100% load factor. The preliminary results of this study indicate that:

- For MCI intercity bus, the EI value at 55 mph is around 400 B.T.U./S.M.
- For Standard intercity bus, the EI value at 55 mph is around 475 B.T.U./S.M.

The approximate value for MCI intercity bus and standard intercity* bus at the current load factors can be estimated as follows:

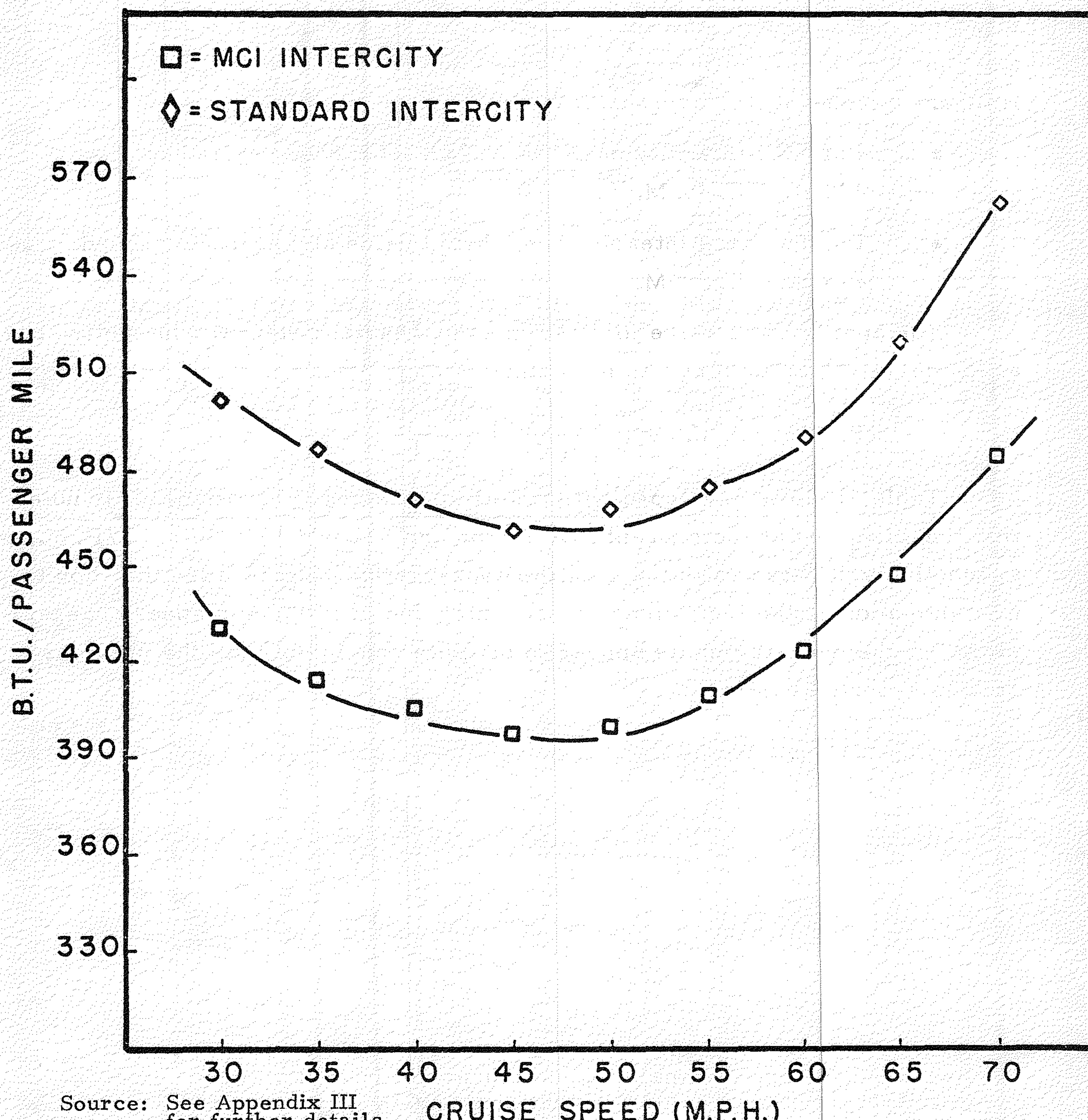
$$\text{B.T.U./P.M.} = \left(\frac{\text{B.T.U.}}{\text{S.M.}}\right)\left(\frac{1}{\text{L.F.}}\right)$$

Table 9.30d is developed with the use of the above equation. It is noted that the EI values at the current load factor are 876 and 1026 B.T.U./P.M., respectively. These values are on the conservative side because they don't take into account the inefficiencies occurring due to idling and speed changes, etc. But the overall results appear to be quite consistent with the previous studies reported earlier.

*Presently there are two main manufacturers of intercity buses: General Motors (standard) and Eagle International (MCI).

INTERCITY BUS ENERGY INTENSITY

100% LOAD FACTOR



Source: See Appendix III for further details.

FIGURE 9.30

UNION COLLEGE TRANSPORTATION PROGRAM	JULY 1977

TABLE 9.30c

ENERGY INTENSITY OF INTERCITY BUS
RESULTS OF ENGINEERING ANALYSIS

	B.T.U./P.M. at 50% Load Factor	B.T.U./P.M. at 100% Load Factor	B.T.U./P.M. at Current Load Factor*
MCI	789	398	876
Standard	974	475	1026

*Assumed Load-Factor = 45%

9.32 Concluding Remarks Regarding EI Study Related to Intercity Bus Operations

After reviewing the literature and performing our own calculations, the following concluding remarks are made with regard to the EI study related to intercity bus operation.

- It appears that we are in a good position to provide reasonable EI estimates under the current load factors. The suggested number is around 1100 B. T. U. /P. M., estimated at 45% load factor.
- Data upon which these numbers are based appear to be reliable because of the requirements imposed by the I. C. C.
- Intercity bus is the most efficient mode of intercity passenger transportation under the current operating conditions (load factor, speed, etc.).
- Under full load conditions, suggested EI value is around 500 B. T. U. /S. M.
- There is an 18% increase in EI value (for MCI bus) if the speed is changed from 55 mph to 70 mph.
- Based upon the literature survey, it appears that there is little potential for decreasing the EI values based upon per seat-mile basis.

9.40 INTERCITY PASSENGER RAIL SYSTEM

Table 9.40a shows the historical variation in EI values for the period 1964 to 1974. Data are provided for passenger trains with locomotives, including the electric locos and self propelled cars. These EI values are obtained by dividing total energy by passenger miles (commutation miles are excluded). These data are reported by the rail roads of class I to the Interstate Commerce Commission. The range of EI values is from 3931 to 6392 B. T. U. /P. M. The load factor for intercity rail is given in Table 9.40b. The total energy does include electric energy input to metroliners (1 KWH = 10,000 B. T. U.). The lower EI value for the year 1974 may be attributed to the higher load factor.

During the course of this study, Greyhound was contacted for energy related data for buses. The Research Department of Greyhound Lines, Inc., provided us with useful information not only for buses but also for trains. Table 9.40c is drawn from the information supplied by Greyhound to Union College. Based upon this information, the following EI values were developed for intercity rail passenger operation.

It is interesting to compare these numbers with those of Table 9.40a because: these numbers are for the latest years and these EI values are lower than those reported in Table 9.40a.

Stanford Research Institute is under contract to ERDA to do a study entitled "Railroad Energy Study". This study consists of four tasks. Table 9.40d provides data on the energy intensity of several trains. This table also provides data on Amtrak Routes, consists, load factor and Energy Intensity figures.

Boeing has recently completed a study entitled, "Intercity Passenger Transportation Data". As a part of this study several trains were simulated over different routes. The results pertaining to our present discussion are provided on Table 9.40e. These results are for 100 percent load factor and have been developed using the present rolling stock and speed limits. These EI numbers appear to be high because circuity has been taken into consideration.

During the course of this study, Southern Railway System was contacted for any relevant information related to energy efficiency of intercity passenger trains. In 1974, Southern Railway conducted controlled tests of their passenger trains between Washington, D.C. and Atlanta, Ga. The tests were conducted on six round trips. Each trip was 633.3 miles each way. The actual passenger miles per gallon were 47.8. If their train had 100% capacity, the seat mile per gallon would have been 81.7. These results are presented in Table 9.40f which shows the variation of EI values under actual load conditions and full load conditions.

9.41 EI Results of Engineering Analysis

The results of the computer simulated runs are given in Chapter 6, so are not repeated here.

TABLE 9.40a

OPERATING ENERGY INTENSITY
OF PASSENGER RAILROADS
(Historical Variation)

Passenger Trains with Locomotives

Year	B. T. U. Passenger-Miles
1964	5895
1965	5995
1966	5991
1967	6392
1968	5837
1969	5483
1970	5632
1971	4996
1972	5380
1973	4433
1974	3931

Source: "Characterization of the U.S. Transportation System," Vol. IV Railroads, The Aerospace Corporation, March 1977

TABLE 9.40b

INTERCITY RAIL PASSENGER LOAD FACTORS

Year	1960	1965	1970	1972	1975
Load Factor	29.8	34.1	36.7	38.7	35.0

Source: TAA, Transportation Facts and Trends, Thirteenth Edition, July 1977.

TABLE 9.40c

ENERGY INTENSITY OF INTERCITY PASSENGER RAIL

Year	Energy Intensity Value B.T.U./P.M.
1973	3556
1974	3015
1975	3962
1976	3152

Average = 3421 B.T.U./P.M.

TABLE 9.40d

SAMPLE OF AMTRAK ROUTES, CONSISTS, AND LOAD FACTORS

No.	Route	Miles	Consist	Seats	Notes	Load Factor	B.T.U. / P.M.
1.	St. Louis to Laredo	1,167	2 E-8 locomotives			51.3%	6,750
			2 coaches (@ 48 seats)	96			
			1 sleeper	22			
			1 diner				
			1 baggage dorm				
				118			
2.	Chicago to New Orleans	923	2 P-30CH locomotives			50.0%	3,550
			4 coaches	260			
			3 sleepers	34			
			1 diner				
			1 lounge car				
			1 baggage car				
			1 heater car				
				294			
3.	Chicago to Los Angeles	911	2 SDP-40 locomotives		Chicago to La Junta, CO.	63.4%	2,560
		1,332	3 SDP-40 locomotives		La Junta, CO. to Los Angeles, CA.		
		450	5 coaches	352	Summer consist: Chicago to Kansas City		
			3 sleepers (@ 22 seats)	66			
			2 diners				
			2 lounges				
			2 baggage cars				
				418			
		1,873	1 sleeper*	22	Kansas City to Los Angeles		
			1 mail car*				
				440			

Source: Railroad Energy Study: Description of Rail Transportation in the United States, Vol. II: Rail Passenger Transportation, Jan. 1977. Stanford Research Institute, California.

TABLE 9.40d (continued)

No.	Route	Miles	Consist	Seats	Notes	Load Factor	B.T.U. / P.M.
4.	New York to Albany	141	1 E-8†			47.7%	1,780
	Buffalo,	438					
	Detroit* (the "Empire")	676	3 coaches (@ 64 seats)	192			
			1 snack car	50			
				242			
5.	Chicago to St. Louis	282	1 F40PH				
			4 coaches (@ 84 seats)	336		47.7%	1,250
			1 Amcafe	56			
				392			

Note: These are the consists as of October 1976. However, four out of five routes are expected to have changed consists beginning October 31.

*This train terminates at different points.
†One FL-9 locomotive is used for 33 miles from Grand Central to Harmon.

Source: Railroad Energy Study: Description of Rail Transportation in the United States, Vol. II: Rail Passenger Transportation, Jan. 1977. Stanford Research Institute, California.

TABLE 9.40e

BOEING - PASSENGER TRAIN - ENERGY INTENSITY

City Pairs	Distance(1)	Circuitry(2)	Equipment	Empty Weight/ Seat	100% Load Factor Passenger-mile/gallon	100% Load Factor Btu/Passenger-Mile
Los Angeles - San Diego	109	1.174	Diesel-Elec.	4000	95	1421
New York - Washington	213	1.066	Electric	2600	60	2250
Chicago - St. Louis	251	1.131	Turbo-train	1700	88	1534
Portland - San Francisco	550	1.289	Diesel-Elec.	9400	62	2117
New York - Chicago	738	1.229	Diesel-Elec.	7800	75	1800
New York - Miami	1092	1.285	Diesel-Elec.	7400	82	1646
Seattle - Denver	1019	2.238	Diesel-Elec.	8500	38	3553
Minneapolis - San Francisco	1586	1.763	Diesel-Elec.	8000	55	2454
Atlanta - Los Angeles	1942	1.318	Diesel-Elec.	8500	70	1928
Miami - Los Angeles	2338	1.407	Diesel-Elec.	8500	65	2077

(1) Great circle distance in statute miles.

(2) Circuity is the ratio of actual distance traveled to great circle distance between two points.

Source: "Intercity Passenger Transportation Data - Energy Comparisons", Boeing Airplane Company, D6-41814, May 1975.

TABLE 9.40f

EI RESULTS OF SOUTHERN RAILWAY SYSTEM

Route	Actual Load B.T.U./P.M.	Full Load B.T.U./S.M.
Washington, D. C. to Atlanta	2901	1698

Note: Southern Railway Uses E-8 Loco, built by EMD

Source: Private communication with Mr. W. W. Simson, Vice President, Southern Railway System, Washington, D. C. (April 27, 1977)

9.42 Concluding Comments Regarding EI Study for Intercity Passenger Trains

Based upon the literature survey and the data base presented in the aforementioned paragraphs, the following concluding remarks are made with respect to the EI study for intercity passenger trains.

- There is a considerable variation in the EI values for intercity passenger rail operation. The differences in EI values stem from several factors such as:
    - Type of the rolling stock. Specific fuel consumption varies according to the type of the propulsion plant - gas turbine, diesel, diesel-electric, electric etc. (see Figure IV-3e, 4c contained in Appendix IV.)
    - Train Consists: Long distance trains usually have an extra load due to sleeper cars, baggage cars, lounge cars, mail car, etc.
    - Type of track. Quality of track dictates the allowable speed and number of slow orders. Curves and grades also affect the performance of the system.
    - Trip characteristics - load factor, stage length, and dwell time affect the energy efficiency of the system.
    - Methodology utilized for estimating the EI values. The data base for statistical and engineering approaches may not be consistent.
    - For Metroliners or electric hauled Amfleet consists, the energy intensity is around 1000 B.T.U./S.M. This energy is based upon the input to the generating station (nuclear, coal, oil fired). For getting the approximate EI value under a certain load factor, the following equation may be used:

$$EI/P.M. = \left(\frac{B.T.U.}{S.M.}\right)\left(\frac{1}{L.F.}\right)$$

where L.F. represents the actual load factor.

For diesel-electric trains (short to medium haul), the realistic EI estimate is around 750* B.T.U./S.M; for cross-country trains, the best EI estimate is 1000* B.T.U./S.M.

- The national average EI value for the intercity rail passenger operation is 3500 B.T.U./P.M., under the actual operating conditions. This number is based upon the literature survey presented in this chapter.

- The EI value for intercity rail passenger operation for a particular route cannot be easily estimated without knowing more information including:

    - Type of train consist - no. of parlor cars, snack cars, coach cars and the density of seating, baggage cars.

    - Type of the power-plant - LRC and SDP-40F are more efficient than E-8, Turboliner is least efficient at low outputs.

    - Length of the trip.

Once the above information is known then the EI values can be estimated with some confidence by looking at Tables 8.10, 20, and 30. These values are on the low side because they don't account for circuity and other losses such as yard-switching, maintenance, etc. It must be admitted that considerably more work is needed to come up with reasonably accurate EI values under actual working environments. The work presented here should be considered a stepping stone towards a comprehensive work (model validation) needed to arrive at accurate EI values.

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*Table 9.40d shows the sensitivity of train consist, route and load factor upon EI values.

9.50 COMPARATIVE ENERGY INTENSITY ANALYSIS FOR INTERCITY PASSENGER MOVEMENT

This section deals with the comparative EI values for several intercity passenger transportation modes which are presented on Table 9.50a. Energy intensity values are provided for current load factors and are also based upon the maximum seating capacity. As expected, authors differ in the resultant EI figure for each mode. Without dwelling on the assumptions adopted by each author, the following section is meant to provide a general overview regarding the reasons for variations in EI values within each mode.

- Physical and mechanical characteristics of the transportation mode. Each mode has a variety of equipment characteristics which result in different EI values, e.g., autos differ in size and power-plant; trains differ in size and type of power-plant (diesel, diesel/electric, gas turbine, electric); planes differ in size and thrust characteristics, etc.
- Traffic characteristics - length of trip, load factor, frequency of operation are some of the parameters which affect the EI values. Length of the trip has a definite impact upon the EI values of intercity planes.
- Fuel consumption data - assumptions regarding the fuel rate have a direct bearing upon the EI values. The fuel rates may be theoretical supplied by the manufacturers which may provide us with conservative EI estimates. On the other hand, actual fuel data obtained from yearly reports may be in error and hence may result in different EI values The actual fuel measurement data are usually on the high-side which may result in higher EI values. The other factor which affects the EI value relates to the components of fuel consumption which may consist of traction, maintenance, yard-switching, etc. Because of the accounting procedures in practice, it may not be possible to have data pertaining to the operational trip energy, thereby causing the variation in the estimated EI value.

- Methodology behind EI values - passenger planes carry most of the intercity air freight which causes extra fuel penalty. The methodology behind the distribution of fuel between passengers and freight affects the EI values for passenger as well as freight movement.

TABLE 9.50a
INTERCITY PASSENGER ENERGY INTENSITY FOR VARIOUS TRANSPORTATION MODES

Transportation Mode	B.T.U./P.M.										B.T.U./S.M.								
Automobile																			
Compact								2,738		1,900[2]		1,150	1,150	1,352	1,263	958	958	1,042	1,100
Average	2,400	3,800	3,800	3,600	3,000	3,800	4,600	7,600	2,883	2,650	1,796				1,475		1,976	1,167	1,600[1]
Intercity Bus	1,175	1,260	1,333	1,109	1,690	1,109	1,778	1,260	1,776	1,100	645	462	554	513		308	630	502	500
Train																			
Cross Country	3,852	2,774	924	1,733	3,015	1,733	2,774		2,965	3,500	963					352			1,000[3]
Metroliner								3,650		2,000[4]	1,850	660	660				1,850	436	1,000
Commuter						1,387		1,387	3,186		693						693	1,308	
Suburban						694					346							577	
Airplane																			
Wide Body						6,136		4,827		5,500	3,375					1,985-2,368	3,375	2,250-4,090	3,000[3]
Average	9,000	8,437	9,642	9,642	8,437	6,428	7,500	5,625	7,273 (Domestic) 5,980 (International)	6,500	3,970	2,596	2,596	6,136		3,292	3,970	2,647-5,000	3,600[3]
Reference	FEA	DOT/TSC	DOT/OTEP	Hirst (1973)	Hirst (1973)	National Commission on Materials Policy	Mooz	Goss	Pollard TSC	Mittal	Rice	DOT/OST	Fraise	Lieb	Austen	Flight	Goss	DOT/NASA	Mittal

(1) Occupancy Rate = 4

(2) Occupancy Rate = 2.4, mpg = 26.00

(3) Gross estimate - depends upon several factors

(4) Based upon 50% load factor.

10.00 SUMMARY, CONCLUSIONS AND HINTS FOR FURTHER RESEARCH

10.00 SUMMARY, CONCLUSIONS AND HINTS FOR FURTHER RESEARCH

This chapter is meant to provide an overview relating to the study. Firstly, it lists the accomplishments, then the conclusions and finally the research needs in regard to furthering the state of the art in the important area of energy intensity of intercity passenger rail systems.

10.10 Accomplishments

The following paragraphs expound upon the accomplishments relative to the goals of the study:

- Data Base: Considerable efforts were expended in trying to get an excellent data base which related to technical and performance characteristics of locomotives, cars and trains. A data base related to domestic as well as foreign rolling stock was collected and documented.

- Comparative Analysis of Energy Intensity Figures for Intercity Passenger Movement: A successful attempt was made to compare the EI values of the major intercity passenger transportation modes. This was done in order to gain some perspective on the issue of energy intensity for intercity passenger movement. The study also attempted to document the results of the previous studies germane to our domain of interest.

- Train Consists: Energy intensity depends not only upon the type of the locomotive utilized for hauling purposes but also depends upon the type of the cars: parlor, snack, coach, etc. The higher the seating density (number of seats/unit floor space), the lower the EI values; these results have been well documented. Amfleet andrefurbished train consists were evaluated and documented. The results of the EI values were put together in tabular and graphical form.

- Components of Energy: A successful attempt was made to list the components of energy expended towards the operation of the train. The goal was to examine and prioritize these components so they could be used as a tool towards policies directed towards conservation efforts. This was done for several trains such as E-8, P30CH, Turboliner, and LRC. Impact of variation due to the changes in the aerodynamic drag was also studied and documented. Data relating to operating conditions (traffic, track characteristics) were also documented.

- Methodology: This study uses the engineering approach and provides a good documentation behind the methodology utilized. The study also outlines the pros and cons of the statistical approach which has been previously utilized by many authors.

- Operating Conditions: The impacts of operating conditions such as speed, load factor, and track profiles have been fairly well documented. The impact of speed is well documented because it has a marked impact upon energy intensity figures. The quality of track determines the allowable speed which affects the demand and thereby the EI values.

10.20 CONCLUSIONS

Conclusions resulting from the study are summarized as follows:

- EI Values Under Actual Operating Conditions: Under the existing operating conditions (load factor), the trains are inefficient from an energy intensity viewpoint. The EI values for the corridor range from 4578 to 13140* B. T. U. /P. M. These values are way out of line compared to the national statistics which are around 3500 B. T. U. /P. M. The following factors may have contributed towards high EI values:
  - Low load factor for the corridor.
  - Use of turboliners which are considerably less efficient in comparison with the other trains in the corridor.
- Under Full Load Conditions: The EI values for trains under full load conditions vary from 462 to 820, with an average of 622 value for diesel/electric trains, 802 for electric trains (Metroliners or electric loco hauling Amfleet Consists). Among the diesel/electric train consists, LRC is the most efficient while E-8 is the least efficient train from energy viewpoint. SDP-40F and P30 CH have nearly the same efficiency. The EI values are also sensitive to the capacity of the train (no. of cars). A value of 482 B. T. U. /S. M. was estimated for a train (SDP-40F) carrying 842 people. Among the three electric locos which were studied (RC4a, CC14500, E-60 CP), RC4a was the most efficient and E-60 CP was the least efficient. The EI value for the turbo train under full load condition is around 1956 B. T. U. /S. M.
- Comparative Analysis of EI Values for Intercity Passenger Movement: The comparative EI values for planes, buses, autos and rail are as follows:

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*These EI numbers are for the NYC to Albany route which are lower than the NYC-Buffalo Corridor. (See Figures 8.20a through 8.20d, Pages 8-13 through 8.16).

Mode	B. T. U. /S. M.	Actual Load Factor*
Auto		
Compact (1)	1100	1900 (3)
Average (2)	1600	2650
Bus	500	1100 (4)
Air		
Wide Body	3000	5500 (8)
Current Fleet	3600	6500 (8)
Train		
Cross Country	1000	3500 (5)
Metroliner	1000 (7)	2000 (6)

(1) mpg = 26.0
(2) mpg = 18.0
(3) Occupancy Rate = 2.4
(4) 45% Load Factor Assumed
(5) Best estimate based upon the survey of current literature
(6) 50% Load Factor Assumed
(7) Best estimate based upon TPC runs and survey of current literature
(8) Estimated under the current operating conditions

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* Calculated on a nation-wide basis.

- Improving Energy Efficiency: Improving load factor is the key towards improving the energy efficiency of the intercity rail operation: load factor depends upon a host of factors, namely:
  - Travel time (track-conditions)
  - Frequency of operation
  - Cost of travel
  - Quality of service

This study# did not examine the factors which inclue nce lcad factor or patronage analysis. This was done by NYSDOT. Readers who are interested are encouraged to read the report* entitled, "Intercity Rail Patronage in the NYC-Buffalo Corridor." It was also concluded that presently, because of the poor track conditions, the maximum potential of the trains (in terms of speed, etc.) cannot be realized. The average velocity from NYC-Albany on the existing track is around 50 M.P.H. which is considerably below the potential realizable velocity of the current trains if the track conditions would allow it. Improving track conditions will certainly enhance block speed which would result in increased demand and reduced energy intensity.

- Impact of Actual Operating Environments: The ratio of EI values calculated under actual operating conditions and cruising mode differ by a range of 1.34 to 3.28 which again reinforces the fact that the existing track conditions result in unnecessary speed changes (higher no. of accelerations and decelerations) at the expense of increased energy consumption.

- It was concluded that the impact of added passengers had little impact upon the train fuel consumption rates. Hence, we are safe in assuming that the energy consumption rates on a per train-mile basis under fully loaded and partial loaded conditions are nearly the same.

The results of improved load factors (due to track improvements which resulted in higher patronage) upon EI value is documented in Chapter 8.0)

* Reference No. 12

- <u>Impact of Change in Aerodynamic Drag Coefficient Upon EI Value:</u> The study showed that reducing the aerodynamic drag coefficient by 50% would result in the reduction of EI value by only 9.97% (P30 CH train consist). Admittedly, the impact would be more pronounced if the allowable speeds were higher.

10.30 HINTS FOR FURTHER WORK

The following list of research topics is suggested as a guide for furthering the state of the art in areas related to "Energy Intensity of Intercity Passenger Rail Operation."

- Calibration of Train Performance Model: The train performance models utilized in this study were based upon theoretical resistance equations which have not been validated since 1926. These models need to be validated in view of the changing rolling stock and the operating conditions. Most of the data utilized for the study (tractive effort curves, fuel rate vs horsepower, transmission efficiency, etc.), were supplied by the manufacturers and need to be revalidated under the real operating environments. The data relating to auxiliary load were sketchy and need to be updated for further analysis. The idling fuel characteristics also need to be validated under the real operating environments.
- Train Evaluation Along Several Corridors: The results presented in the study pertain only to the NYC-Buffalo and NYC-Washington corridors. There is a need to analyze more corridors and examine the impact of grades and curves along several corridors. The impact of baggage cars, snack cars, parlor cars, etc., needs to be studied along each corridor.
- Energy Cost Effectiveness Models: There is a real need for studying the tradeoffs among various investment decisions, energy efficiency and amount of petroleum saved. This model should be dynamic in nature and should evaluate the impact of several policy issues on overall transportation energy efficiency in a comprehensive manner. The policy tradeoffs are not very well understood at the present time. Since the petroleum energy crunch is real, serious efforts ought to be made towards understanding such issues.

- The present study has examined only the operational aspects of energy; the remaining direct and indirect components such as station maintenance, track maintenance, maintenance of the vehicles, construction of the track, vehicles, etc., need to be examined over their life cycles and then compared with the competing modes on an equal basis, for fair EI comparisons.

- The present study contemplates one train consist from NYC-Buffalo, even though it is recognized that there is a patronage change at each station. Albany to NYC has the maximum number of patrons while Rochester to Buffalo has the lowest number of patrons, thereby resulting in lower load factor and higher EI values. It is worth looking into pros and cons of reducing the number of cars for the given city pairs when the patronage decreases. The advantage lies with the extra resources needed to handle the empty vehicles. It is likely that there is some optimum level of petroleum price above which it becomes more economical to have more yard stations.

- Speed, and Energy Consumption Tradeoffs: Higher speed results in more patronage and higher energy consumption. On the other hand, increased patronage should result in higher load factors which should reduce the energy intensity values. The tradeoffs between speed and energy intensity should be studied.

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APPENDICES

I. Intercity Planes
II. Automobile
III. Intercity Bus
IV. Intercity Passenger Train

APPENDIX I

INTERCITY PLANES

This appendix provides the data base and methodology utilized for estimating EI values of intercity planes. Use of aircraft performance manuals and latest available CAB reports are made. The performance manual lists travel time and fuel consumption data under a variety of altitudes and wind conditions. These charts are valid for a specific landing weight but corrections are also provided for any changes in weight due to additional cargo or passengers. The enroute profile is based upon certain altitude, cruise and descent procedures. The following data* were used for various planes.

Type of Aircraft	Empty Weight in Lbs.	Passenger Capacity	Cargo Capacity
DC-10-10	236,500	240	73,600
727-100	87,616	103	12,830
727-200	100,000	130	20,000

It must be noted that the passenger capacity varies depending upon the desire of the operating airlines. In the recent years, the seating density has been increasing.

By assuming data, passenger and cargo load factors, altitude, wind direction and speed, we are in a position to calculate energy intensity in the following manner:

$$EI = BTU/PM = \frac{(\text{Gallons of fuel used}) \times (\text{B.T.U./Gallon})}{(\text{Distance in Nautical Miles})\ (1.1508) \times \text{No. of Passengers}}$$

The above methodology carries cargo at no fuel penalty. In order to estimate BTU/ton mile for intercity planes, we calculated the incremental

*Civil Aeronautics Board Aircraft Operating Cost and Aviation Week and Space Technology, March 1977. Performance Report - 1976, Ref. 11.

fuel penalty for carrying cargo and then EI values were estimated from the following equation:

$$EI = BTU/\text{ton mile} = \frac{(\text{Incremental fuel in gallons}) \times (\text{B.T.U./gallon})}{(\text{Distance in miles}) \times (1.1508) \times (\text{Cargo Weight in tons})}$$

The third method for calculating energy intensity is by allocating fuel according to the weight of the cargo and passengers. Under these conditions, EI value is given as follows:

$$EI = BTU/PM = \frac{(\text{Fuel allocated to passengers in gallons}) \times (\text{B.T.U./gallon})}{(\text{Distance in miles}) \times (1.1508) \times (\text{No. of Passengers})}$$

The second source utilized for the aircraft EI study was the latest available report on "Aircraft Operating Cost and Performance Report." This report provides data related to aircraft capacity, speed, productivity, fuel and traffic. The key parameters which are of interest for our study are:

- Fuel Rate (in gallons/hr)
- Average Speed
- Seat Load Factor (and total no. of revenue seats)
- Cargo Load Factor (and total cargo capacity)

Table I-1 shows the equipment group by carrier group. Data are given for domestic and international carriers. The last column relates to the BTU/PM with no penalty for the cargo. Table I-2 provides a summary of equipment by group. For comparison purposes, data are given for the years 1974 and 1975.

Table I-3 provides data on the equipment type and the corresponding EI values. From this table, a summary (Table I-4) is prepared which describes the type of aircraft, seat load factor and average BTU/PM.

Table I-5 shows the flight planning data on B727-200, B727-100, and DC-10.

Tables I-6 and I-7 show the results of the EI study using the data from Table I-5. Table I-6 shows the results when the marginal fuel penalty, due to the weight of the cargo, is borne by the passengers alone which results in higher EI values. By penalizing cargo according to the distribution of the weight (between passengers and cargo), one gets lower EI values for passenger movement and higher EI values for freight movement.

TABLE I-1

EQUIPMENT TYPE BY CARRIER GROUP

PASSENGER

	Description	Yr	Gallon /Hr	Pass/ Mile	Speed (mph)	Seat L.F(%)	BTU /PM
1.	Trunks-Dom. Op. B-747	75:	3343	180.4	454	51.3	5306.2
		74:	3335	175.8	450	51.3	5480.3
2.	Trunks-Dom. Op. B-707-100B	75:	1591	69.7	399	53.4	7437.2
		74:	1607	69.8	399	54.1	7501.2
3.	Trunks-Dom. Op. B-707-300B	75:	1728	76.3	420	52.0	7010.0
		74:	1829	78.5	422	54.0	7177.5
4.	Trunks-Dom. Op. B-707-300C	75:	1753	77.7	419	55.4	7000.0
		74:	1675	78.0	411	55.1	6688.4
5.	Trunks-Dom. Op. B-720B	75:	1581	72.8	406	60.3	6953.7
		74:	1567	71.7	412	61.1	6896.0
6.	Trunks-Dom. Op. DC-8-50	75:	1774	77.7	391	58.6	7581.0
		74:	1769	81.3	395	61.8	7179.3
7.	Trunks-Dom. Op. DC-8-61	75:	1951	100.7	400	53.5	6296.7
		74:	1950	100.1	397	55.1	6379.0
8.	Trunks-Dom. Op. DC-8-62	75:	1642	80.5	441	56.0	6012.9
		74:	1648	79.9	434	59.7	6178.2
9.	Trunks-Dom. Op. DC-10-10	75:	2164	120.7	428	51.8	5445.6
		74:	2189	115.6	422	49.8	5833.4
10.	Trunks-Dom. Op. DC-10-40	75:	2342	89.0	380	37.7	9002.4
		74:	2363	86.2	377	36.5	9452.8
11.	Trunks-Dom. Op. L-1011	75:	2376	123.4	400	50.9	6257.7
		74:	2833	117.5	398	49.7	7875.3
12.	Trunks-Dom. Op. B-727-100	75:	1211	57.6	363	60.1	7529.4
		74:	1223	58.6	363	61.3	7474.2
13.	Trunks-Dom. Op. B-727-100C/QC	75:	1249	56.9	370	57.0	7712.4
		74:	1257	56.9	367	57.8	7825.3
14.	Trunks-Dom. Op. B-727-200	75:	1340	70.8	352	44.9	6990.0
		74:	1343	71.1	354	56.6	6936.6
15.	Trunks-Dom. Op. B-737-200	75:	864	58.0	303	60.6	6391.3
		74:	868	59.4	299	62.6	6353.4

TABLE I-1 (continued)

Description	Yr	Gallon /Hr	Pass/ Mile	Speed (mph)	Seat L. F(%)	BTU /PM
16. Trunks-Dom. Op. DC-9-10	75:	857	42.9	329	61.6	7893.5
	74:	898	45.7	321	64.7	7957.9
17. Trunks-Dom. Op. DC-9-30	75:	918	53.5	312	59.4	7149.5
	74:	915	57.7	308	64.0	6693.3
18. Trunks-Dom. Op. B-7.7-300	75:	2072	79.1	420	52.6	8107.9
	74:	2079	71.5	405	47.5	9333.3
19. Trunks-Dom. Op. DC-8-20	75:	2055	76.0	405	59.5	8679.3
	74:	2066	75.7	406	59.9	8738.8
20. Trunks-Dom. Op. L-188 (Electra)	75:	639	44.1	192	50.3	9810.8
	74:	630	43.4	190	49.6	9932.1
21. Local-SER-Dom. Op. BAC-111-200	75:	787	42.9	261	58.0	9.37.4
	74:	780	42.6	259	57.6	9190.3
22. Local-SER-Dom. Op. B-737-200	75:	863	51.0	310	54.0	7096.1
	74:	857	51.9	312	55.3	6880.2
23. Local-SER-Dom. Op. DC-9-10	75:	878	39.9	298	53.1	9600.0
	74:	865	50.5	29.7	54.0	9348.6
24. Local-SER-Dom. Op. DC-9-30	75:	916	49.3	288	49.5	8386.9
	74:	927	49.7	290	49.9	8361.2
25. Local-SER-Dom. Op. CV-580	75:	331	25.9	190	52.7	8744.2
	74:	334	26.8	192	54.4	8483.3
26. Local-SER-Dom. Op. CV-600	75:	278	17.6	175	44.1	11733.8
	74:	285	21.2	180	53.0	9709.1
27. Local-SER-Dom. Op. DHC-6	75:	78	9.0	130	47.7	8666.7
	74:	78	8.0	146	44.4	8681.5
28. Local-SER-Dom. Op. F-27	75:	240	18.4	174	46.0	9745.1
	74:	233	20.6	171	51.6	8598.8
29. Local-SER-Dom. Op. FH-227	75:	263	20.8	159	47.4	10338.1
	74:	264	23.1	163	52.4	9114.8
30. Local-SER-Dom. Op. YS-11	75:	306	26.7	171	46.1	8712.8
	74:	302	30.6	170	52.6	7547.1
31. Local-SER-Dom. Op. M-404	75:	200	19.6	139	49.0	9543.4
	74:	197	18.4	141	46.1	9871.3
32. Helicopter-Dom. Op. S-61	75:	172	9.8	86	39.4	26530.6
	74:	178	10.5	86	42.4	25625.7

TABLE I-1 (continued)

	Description	Yr	Gallon /Hr	Pass/ Mile	Speed (mph)	Seat L.F(%)	BTU /PM
33.	Alaskan-Dom. Op.	75:	1287	59.6	380	63.6	7450.0
	B-727-100	76:	1322	52.5	385	60.3	8502.7
34.	Alaskan-Dom. Op.	75:	944	32.4	343	44.8	11145.9
	B-737-2000/QC	74:	944	31.5	343	34.9	11358.2
35.	Alaskan-Dom. Op.	75:	1877	67.0	401	55.8	8082.1
	B-720	74:	1872	55.2	404	46.0	10912.6
36.	Alaskan-Dom. Op.	75:	78	5.0	126	39.1	16095.2
	DHC-6	74:	78	4.9	131	58.9	15796.9
37.	Alaskan-Dom. Op.	75:	223	11.5	198	46.6	12731.7
	F-27	74:	224	10.9	203	42.6	13160.4
38.	Alaskan-Dom. Op.	75:	225	20.0	192	51.8	7617.2
	FM-227	74:	224	18.5	200	49.8	7870.3
39.	Hawaiian Dom. Op.	75:	947	74.9	244	65.1	6745.3
	B-737-200	74:	949	73.5	247	64.2	6795.6
40.	Hawaiian Dom. Op.	75:	981	66.9	249	66.1	7655.7
	DC-9-30	74:	972	67.9	250	66.2	7635.0
41.	Trunks-Int/Ter Op.	75:	3577	177.3	476	48.0	5510.0
	B-747	74:	3577	182.8	474	49.8	5366.7
42.	Trunks-Int. Op.	75:	1583	69.0	402	51.9	7419.1
	B-707-100B	74:	1583	72.2	395	55.5	7215.9
43.	Trunks-Int. Op.	75:	1754	76.6	447	52.5	6659.4
	B-707-300B	74:	1769	77.3	448	53.0	6640.7
44.	Trunks-Int. Op.	75:	1716	80.4	431	55.7	6437.6
	B-707-300C	74:	1755	79.7	437	55.5	6550.6
45.	Trunks-Int. Op.	75:	1439	83.4	455	67.4	4929.8
	B-720B	74:	1605	80.1	459	67.1	5675.1
46.	Trunks-Int. Op.	75:	1713	66.2	429	46.4	7841.3
	DC-8-50	74:	1595	80.2	434	56.1	5957.2
47.	Trunks-Int/Op.	75:	2291	104.8	447	53.7	6357.7
	DC-8-61	74:	2242	90.3	450	46.3	7172.6
48.	Trunks-Int/Op.	75:	1860	75.3	440	46.0	7298.1
	DC-8-62	74:	1878	87.7	432	53.6	6444.0
49.	Trunks-Int/Op.	75:	2381	132.9	442	51.7	5269.3
	L-1011	74:	2403	153.0	441	60.0	4629.9

TABLE I-1 (continued)

	Description	Yr	Gallon /Hr	Pass/ Mile	Speed (mph)	Seat L.F(%)	BTU /PM
50.	Trunks-Int/Op.	75:	1354	67.6	337	62.0	7675.2
	B-727-100	74:	1382	65.3	334	59.0	8237.4
51.	Trunks-Int/Op.	75:	1191	55.8	399	54.5	6954.2
	B-727-150 c/QC	74:	1449	68.4	278	53.8	9906.3
52.	Trunks-Int/Op.	75:	1331	73.3	409	55.8	5771.6
	B-727-200	74:	1385	80.3	414	61.3	5416.0
53.	Trunks-Int/Op.	75:	2097	65.1	429	44.8	9761.2
	B-707-300	74:	2151	79.2	438	54.6	8060.9
54.	Trunks-Int/Op.	75:	1608	42.3	410	53.8	12053.3
	B-727-100	74:	1613	39.1	414	53.9	12953.9

Source: Aircraft operating cost and performance report, July 1976, Vol X, Civil Aeronautics Board

TABLE I-2

EQUIPMENT GROUP BY CARRIER GROUP

PASSENGER

		Yr	Gallon /Hr	Pass/ Mile	Speed (mph)	Seat L.F. (%)	BTU /PM
1.	Trunks-Dom. Op. T. Fan. 4-Eng, Wide-Bodied	75:	3343	180.4	454	51.3	5510.3
		74:	3335	175.8	450	51.3	5691.1
2.	Trunks-Dom. Op. T-Fan. 4-Eng, Reg-Bodied	75:	1705	77.4	404	54.6	7555.3
		74:	1714	78.2	404	56.1	7324.1
3.	Trunks-Dom. Op. T-Fan. 3-Eng, Wide-Bodied	75:	2257	117.6	412	49.8	6288.7
		74:	2270	112.6	409	48.1	6654.2
4.	Trunks-Dom. Op. T-Fan. 3-Eng, Reg-Bodied	75:	1283	64.4	358	57.4	7512.6
		74:	1285	64.5	359	58.4	7491.7
5.	Trunks-Dom. Op. T-Fan, 2-Eng	75:	898	53.7	311	59.9	7259.0
		74:	899	56.9	307	63.6	6947.7
6.	Trunks-Dom. Op. Turbo-Jet, 4-Eng	75:	2059	76.7	408	58.1	8882.5
		74:	2044	73.9	403	58.1	9265.4
7.	Trunks-Dom. Op. Turbo-Prop, 4-Eng	75:	639	44.1	182	50.3	10188.1
		74:	630	43.4	190	49.6	10314.1
8.	Local-Ser. Dom. Op. T-Fan, 2-Eng	75:	881	46.6	290	51.9	8800.9
		74:	879	46.9	291	52.6	8694.7
9.	Local-Ser. Dom. Op. Turbo-Prop, 2-Eng	75:	284	23.3	175	49.9	9402.8
		74:	301	25.6	181	53.5	8769.6
10.	Local-Ser. Dom. Op. Piston, 2-Eng	75:	176	18.8	135	48.9	9361.7
		74:	197	18.4	141	46.1	10251.0
11.	Helicopter-Dom. Op. Heli. Turb. 2-Eng	75:	172	8.8	86	39.4	27551.0
		74:	178	10.5	86	42.4	26611.3
12.	Alaskan-Dom. Op. T-Fan, 3-Eng, Reg-Bodied	75:	1287	59.6	380	63.6	7671.5
		74:	1322	52.5	385	60.3	8829.7

TABLE I-2 (continued)

		Yr	Gallon /Hr	Pass/ Mile	Speed (mph)	Seat L.F. (%)	BTU /PM
13.	Alaskan-Dom. Op.	75:	944	32.1	343	44.8	11574.6
	T-Fan, 2-Eng	74:	944	31.5	343	34.9	11795.1
14.	Alaskan-Dom. Op.	75:	1877	67.0	401	55.8	8431.5
	Turbo-Jet, 4-Eng	74:	1872	55.2	404	46.0	11332.3
15.	Alaskan-Dom. Op.	75:	175	13.7	173	49.0	9867.9
	Turbo-Prop. 2-Eng	74:	161	11.3	171	47.9	11248.3
16.	Hawaiian-Dom. Op.	75:	966	70.2	247	65.6	7521.0
	T-Fan, 2-Eng	74:	963	70.1	249	65.4	7448.1
17.	Trunks-Int/Ter Op.	75:	3577	177.3	476	48.0	5721.9
	T-Fan, 4-Eng,	74:	3577	182.8	474	49.8	5573.1
	Wide-Bodied						
18.	Trunks-Int/Ter Op.	75:	1757	77.4	443	52.4	6917.7
	T-Fan, 4-Eng,	74:	1763	78.9	444	53.6	6794.0
	Reg-Bodied						
19.	Trunks-Int/Ter Op.	75:	2310	130.9	440	51.6	5414.4
	T-Fan, 3-Eng,	74:	2197	149.4	437	59.2	4542.9
	Wide-Bodied						
20.	Trunks-Int/Ter Op.	75:	1333	68.3	363	59.0	7258.3
	T-Fan, 3-Eng,	74:	1387	71.6	361	59.8	7244.2
	Reg-Bodied						
21.	Trunks-Int/Ter Op.	75:	2097	65.1	429	44.8	10136.7
	Turbo-Jet, 4-Eng	74:	2151	79.2	438	54.6	8370.9
22.	Trunks-Int/Ter Op.	75:	1608	42.3	410	53.8	12516.9
	T-Fan, 3-Eng,	74:	1613	39.1	414	53.9	13452.1
	Reg-Bodied						

TABLE I-3

ENERGY INTENSITY OF VARIOUS TYPES OF PASSENGER PLANES

		Yr.	Seat Ave. L.F. (%)	Ave. BTU/PM
1.	B-747	75:	49.7	5408.1
		74:	50.6	5423.5
2.	B-707-100	75:	52.7	7428.2
	(100B)	74:	54.8	7358.6
3.	B-707-300	75:	52.1	7514.9
	(300B, 300C, 300)	74:	53.3	7474.6
4.	B-720	75:	61.2	6988.5
	(720B, 720)	74:	58.1	7827.9
5.	B-727-100	75:	58.5	8220.8
	(150, 160 C/QC, 100 (13)	74:	57.9	8936.1
6.	B-727-250	75:	55.9	6380.8
		74:	59.0	6176.3
7.	B-737-250	75:	56.5	7857.2
	(200, 200 C/QC)	74:	54.3	7846.9
8.	DC-8-50	75:	52.5	7716.2
		74:	58.9	6568.3
9.	DC-8-61	75:	53.6	6327.2
		74:	50.7	6775.8
10.	DC-8-62	75:	51	6655.5
		74:	56.7	6311.1
11.	DC-10-10	75:	51.8	5445.6
		74:	49.8	5833.4
12.	DC-10-40	75:	37.7	9002.4
		74:	36.5	9452.8
13.	DC-9-10	75:	57.4	8746.8
		74:	59.4	8653.3
14.	DC-9-30	75:	58.3	7730.7
		74:	60.0	7563.2
15.	DC-8-20	75:	59.9	8679.3
		74:	59.9	8738.8

TABLE I-3 (continued)

ENERGY INTENCITY OF VARIOUS TYPES OF PASSENGER PLANES

		Yr	Seat Ave. L. F. (%)	Ave. BTU/PM
16.	L-1011	75:	51.3	5763.5
		74:	54.9	6252.6
17.	L-188 (electra)	75:	50.3	9810.8
		74:	49.6	9932.1
18.	BAC-111-200	75:	58.0	9137.4
		74:	57.6	9190.3
19.	CV-580	75:	52.7	8744.2
		74:	54.4	8483.3
20.	CV-600	75:	44.1	11733.8
		74:	53.0	9709.1
21.	DMC-6	75:	43.4	12381.0
		74:	51.7	12239.2
22.	F-27	75:	46.3	11238.4
		74:	47.1	10879.6
23.	FM-227	75:	49.6	8977.7
		74:	51.1	8492.6
24.	YS-11	75:	46.1	8712.8
		74:	52.6	7547.1
25.	M-404	75:	49.0	9543.4
		74:	46.1	9871.3
26.	S-61	75:	39.4	26530.6
		74:	42.4	25625.7

TABLE I-4
ENERGY INTENSITY OF VARIOUS EQUIPMENT GROUPS (TURBOFAN, TURBO-JET)

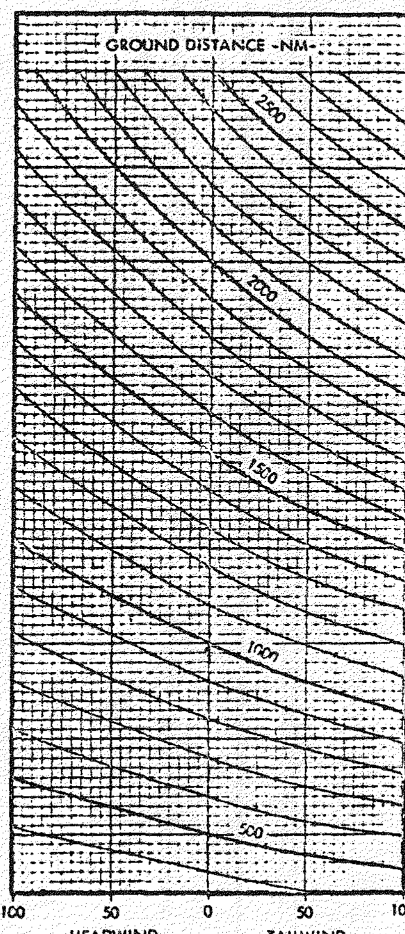
EQUIPMENT GROUP	YR	Ave. Seat L. F. (%)	BTU /PM
1. T-Fan, 4-Eng, Wide-Bodied	75:	49.7	5541.7
	74:	50.6	5632.1
2. T-Fan, 4-Eng, Reg-Bodied	75:	54.1	7236.5
	74:	54.9	7059.1
3. T-Fan, 3-Eng, Wide-Bodied	75:	50.7	5851.6
	74:	53.7	5598.6
4. T-Fan, 3-Eng, Reg-Bodied	75:	58.5	8739.8
	74:	58.1	9254.4
5. T-Fan, 2-Eng	75:	55.6	8788.9
	74:	54.1	8721.4
6. Turbo-Jet, 4-Eng.	75:	51.5	9509.6
	74:	56.4	8818.2
7. Turbo-Prop, 4-Eng.	75:	50.3	10188.1
	74:	49.6	10314.1
8. Turbo-Prop, 2-Eng.	75:	49.9	9402.8
	74:	53.5	8769.6
9. Piston, 2-Eng.	75:	48.9	8361
	74:	46.1	10251.0
10. Helicopter, Turb. 2-Eng	75:	39.4	27551.0
	74:	42.4	26611.3

TABLE I-5a
FLIGHT PLANNING

MACH .82 CRUISE

STD DAY*

29 - 35,000 FT.



TOTAL TRIP TIME AND TRIP FUEL REQUIRED

PRESSURE ALTITUDE	29,000 FT		31,000 FT		33,000 FT		35,000 FT		FL 290-310	FL 330-350
INDICATED AIRSPEED	318		305		292		279			
	TIME HR:MIN	FUEL 1000 LB	TIME HR:MIN	FUEL 1000 LB	TIME HR:MIN	FUEL 1000 LB	TIME HR:MIN	FUEL 1000 LB		
							4:57	41.1		
					4:44	40.5	4:46	39.1		1900
			4:30	40.3	4:31	38.7	4:32	37.3		
	4:13	40.2	4:15	38.4	4:17	36.9	4:19	35.5	1500	
	4:01	38.3	4:03	36.6	4:05	35.1	4:07	33.8		1700
	3:49	36.3	3:51	34.7	3:53	33.2	3:54	32.1	1400	
	3:37	34.3	3:39	32.8	3:41	31.4	3:42	30.3		
	3:24	32.3	3:26	30.9	3:28	29.6	3:29	28.6		1500
	3:12	30.3	3:14	29.0	3:15	27.8	3:16	26.8	1100	
	3:00	28.3	3:02	27.2	3:03	26.1	3:03	25.2		1300
	2:47	26.4	2:49	25.3	2:50	24.3	2:51	23.5	900	
	2:35	24.4	2:37	23.5	2:38	22.5	2:39	21.8		1100
	2:23	22.5	2:24	21.6	2:25	20.8	2:26	20.1	800	
	2:10	20.5	2:11	19.8	2:12	19.0	2:13	18.4		900
	1:57	18.6	1:58	18.9	1:59	17.3	2:00	16.8	700	
	1:45	16.7	1:45	16.1	1:46	15.6	1:47	15.1		700
	1:33	14.8	1:33	14.3	1:35	13.9	1:35	13.4	500	
	1:21	12.9	1:22	12.6	1:23	12.2	1:23	11.7		500
	1:09	11.0	1:10	10.8	1:10	10.5	1:10	10.2	400	
	:58	9.1	:58	9.0	:58	8.8	:58	8.7		

HOW TO USE THIS CHART:

1. Enter bottom left with reported enroute wind, proceed up to intercept ground distance. Proceed right to appropriate altitude column. Read trip Time and Fuel required.
2. Chart is based on a landing weight of 110,000 Lbs. For higher landing weights, ADD fuel correction for each 10,000 Lbs. above reference weight.

*3. For non standard temperatures: ADD 2 Min. to trip time for each 10°C below ISA. SUBTRACT 2 Min. from trip time for each 10°C above ISA. No correction to trip fuel required.

4. For maneuvering during climb-out: ADD 800 Lbs. to trip fuel required.
5. For an ILS approach: ADD 800 Lbs. to trip fuel required.

TABLE I-5b

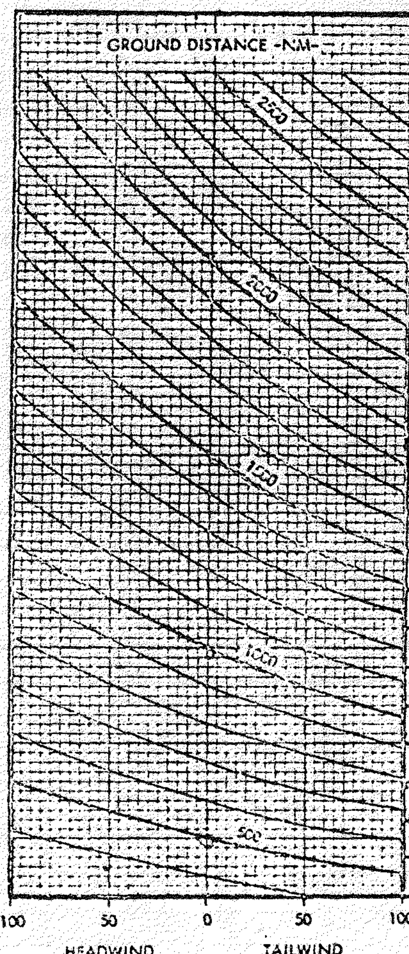
FLIGHT PLANNING

MACH .82 CRUISE

STD DAY *

29 - 35,000 FT.

	TOTAL FLIGHT TIME AND TRIP FUEL REQUIRED									
PRESSURE ALTITUDE	29,000 FEET		31,000 FEET		33,000 FEET		35,000 FEET			
INDICATED AIRSPEED	318		305		292		279			
	TIME HR:MIN	FUEL 1000 LB	TIME HR:MIN	FUEL 1000 LB	TIME HR:MIN	FUEL 1000 LB	TIME HR:MIN	FUEL 1000 LB	FL 290 - 310	FL 330 - 350
							5:07	33.9		
					4:52	38.4	4:54	37.2		1900
			4:36	38.0	4:33	36.6	4:40	35.5		
	4:21	37.3	4:23	35.1	4:25	34.8	4:27	33.8	1500	
	4:09	35.7	4:11	34.2	4:13	32.9	4:15	32.0		1700
	3:55	33.6	3:57	32.3	4:00	31.1	4:02	30.2	1400	
	3:44	31.6	3:46	30.5	3:48	29.5	3:50	28.6		1500
	3:30	29.8	3:31	28.7	3:32	27.7	3:33	26.8	1100	
	3:19	27.9	3:20	26.8	3:21	26.0	3:22	25.2		1300
	3:06	26.1	3:07	25.0	3:09	24.2	3:11	23.5	900	
	2:52	24.2	2:54	23.2	2:57	22.4	2:59	21.8		1100
	2:40	22.3	2:41	21.5	2:42	20.7	2:43	20.1	800	
	2:28	20.4	2:29	19.8	2:30	19.0	2:31	18.5		900
	2:15	18.7	2:16	18.2	2:18	17.3	2:20	16.8	700	
	2:02	16.9	2:03	16.4	2:05	15.6	2:07	15.2		700
	1:49	15.0	1:50	14.6	1:51	14.0	1:51	13.6	500	
	1:36	13.3	1:38	13.0	1:38	12.4	1:38	12.1		500
	1:22	11.5	1:24	11.2	1:26	10.8	1:28	10.5	400	
	1:11	9.7	1:12	9.6	1:13	9.3	1:13	8.9		
	:59	8.1	1:00	7.9	1:00	7.7	1:00	7.5		



HOW TO USE THIS CHART:

1. Enter bottom left with reported enroute wind, proceed up to intercept ground distance. Proceed right to appropriate altitude column. Read trip Time and Fuel required.
2. Chart is based on a landing weight of 110,000 Lbs. For higher landing weights, ADD fuel correction for each 10,000 Lbs. above reference weight.

*3. For non standard temperatures: ADD 2 Min. to trip time for each 10°C below ISA. SUBTRACT 2 Min. from trip time for each 10°C above ISA. No correction to trip fuel required.

4. For maneuvering during climb-out: ADD 800 Lbs. to trip fuel required.
5. For an ILS approach: ADD 800 Lbs. to trip fuel required.

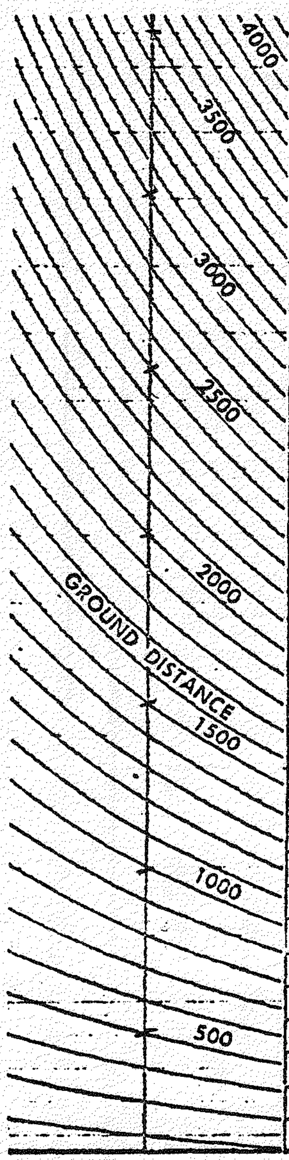
TABLE I-5c

FLIGHT PLANNING — CONSTANT ALTITUDE

MODEL DC-10 | M.82 | G.E. CF6-60 ENGINES

25,000 TO 31,000 FEET

NOTE:
Flight times are for Standard Day conditions.



TOTAL FLIGHT TIME AND TRIP FUEL								FUEL CORRECTION (LB)	
25,000 FT		27,000 FT		29,000 FT		31,000 FT			
TAS 492 KT		488 KT		484 KT		480 KT			
TIME HR:MIN	FUEL 1000 LB	TIME HR:MIN	FUEL 1000 LB	TIME HR:MIN	FUEL 1000 LB	TIME HR:MIN	FUEL 1000 LB	FL 250-270	290-310
		7:26	134.7	7:30	128.2	7:34	122.7		
7:11	138.1	7:12	130.7	7:18	124.4	7:21	119.0		
6:58	133.9	6:54	126.7	7:05	120.5	7:09	115.3		
6:46	129.8	6:35	122.7	6:53	116.6	6:56	111.6		
6:34	125.7	6:15	118.7	6:40	112.8	6:44	108.0	1800	
6:22	121.5	5:56	114.8	6:28	109.1	6:31	104.4		
6:09	117.4	5:39	110.8	6:16	105.4	6:19	100.8	1600	1800
5:57	113.2	5:30	106.9	6:03	101.7	6:06	97.2		
5:45	109.1	5:25	103.1	5:51	98.0	5:53	93.7		
5:33	105.1	5:19	99.2	5:38	94.3	5:41	90.1		1600
5:20	101.0	5:13	95.4	5:26	90.6	5:28	86.7	1400	
5:08	97.0	5:08	91.6	5:13	87.0	5:16	83.2		1400
4:56	93.0	4:58	87.8	5:01	83.5	5:03	79.7	1200	
4:43	89.0	4:46	84.0	4:48	79.9	4:50	76.3		
4:31	85.0	4:33	80.3	4:36	76.3	4:38	72.8		
4:19	81.0	4:21	76.5	4:23	72.7	4:25	69.4		1200
4:07	77.1	4:09	72.7	4:11	69.1	4:13	66.1	1000	
3:54	73.1	3:56	69.0	3:58	65.6	4:00	62.8		
3:42	69.2	3:44	65.3	3:46	62.0	3:48	59.4		1000
3:30	65.2	3:32	61.7	3:33	58.5	3:35	56.1	800	
3:18	61.3	3:19	58.0	3:21	55.1	3:22	52.7		800
3:05	57.4	3:07	54.4	3:08	51.6	3:10	49.4		
2:53	53.4	2:55	50.7	2:56	48.2	2:57	46.2		
2:41	49.5	2:42	47.1	2:44	44.8	2:45	43.0	600	
2:29	45.6	2:30	43.6	2:31	41.8	2:32	39.7		600
2:16	41.8	2:18	40.0	2:19	38.0	2:20	36.5		
2:04	37.9	2:05	36.4	2:06	34.6	2:07	33.3		
1:52	34.0	1:53	32.8	1:54	31.2	1:55	30.1	400	400
1:40	30.1	1:40	29.2	1:41	27.8	1:42	26.9		
1:27	26.2	1:28	25.6	1:29	24.4	1:29	23.7		
1:15	22.4	1:16	22.0	1:17	21.1	1:17	20.5		
1:03	18.6	1:03	18.3	1:04	17.7	1:04	17.3		
0:51	14.8	0:51	14.7	0:52	14.4	0:52	14.2		
0:38	11.1	0:39	11.1	0:39	11.0				

CHART VALID FOR A LANDING WEIGHT OF 300,000 LB AND LESS. FOR EACH 10,000 LB DEVIATION ABOVE 300,000 LB, CORRECT BY FUEL CORRECTION.

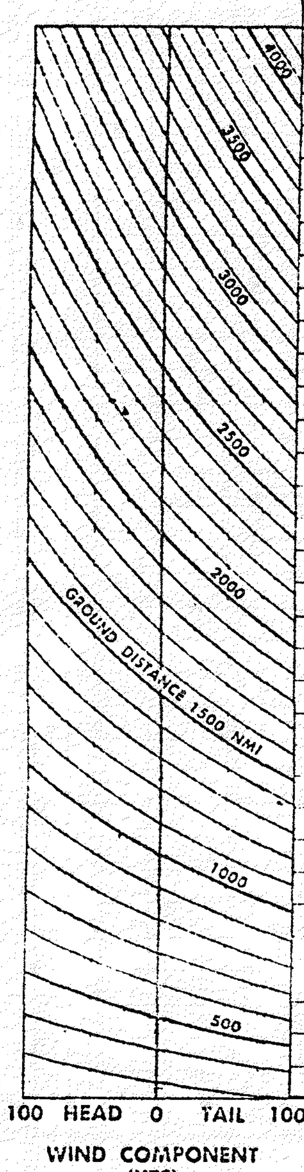
CA1-1117

TABLE I-5d

FLIGHT PLANNING—CONSTANT ALTITUDE

MODEL DC-10 | MACH 0.82 33,000 TO 39,000 FEET | G.E. CF6-6D ENGINES

NOTE: Flight times are for Standard Day conditions.



TOTAL FLIGHT TIME AND TRIP FUEL							
33,000 FT		35,000 FT		37,000 FT		39,000 FT	
TAS 475 KT		471 KT		469 KT		469 KT	
TIME HR:MIN	FUEL 1000 LB	TIME HR:MIN	FUEL 1000 LB	TIME HR:MIN	FUEL 1000 LB	TIME HR:MIN	FUEL 1000 LB
7:36	117.9						
7:23	114.3						
7:10	110.7	7:14	107.7				
6:58	107.2	7:01	104.2				
6:45	103.7	6:48	100.8				
6:32	100.1	6:36	97.3				
6:20	96.6	6:23	93.9				
6:07	93.2	6:10	90.5				
5:55	89.7	5:57	87.2				
5:42	86.4	5:44	83.9				
5:30	83.0	5:31	80.6				
5:17	79.6	5:19	77.3				
5:04	76.3	5:06	74.0	5:07	72.6		
4:52	72.9	4:53	70 8	4:55	69.4		
4:39	69.6	4:40	67 6	4:42	66.3		
4:27	66.3	4:28	64.4	4:29	63.2		
4:14	63.1	4:15	61.3	4:16	60.1		
4:01	59.9	4:02	58.1	4:03	57.0		
3:49	56.6	3:49	55.0	3:50	53.9		
3:36	53.4	3:37	51.8	3:38	50.8		
3:23	50.2	3:24	48.7	3:25	47.8		
3:10	47.1	3:11	45.7	3:12	44.9		
2:58	43.9	2:58	42.7	2:59	41.9		
2:45	40.8	2:46	39.7	2.46	38.9	2:47	38.4
2:32	37.7	2:33	36.6	2:33	36.0	2:34	35.5
2:19	34.6	2:20	33.6	2:20	33.0	2:21	32.6
2:07	31.4	2:07	30.6	2:08	30.0	2:08	29.7
1:54	28.4	1:54	27.7	1:55	27.2	1:55	27.0
1:41	25.3	1:42	24.8	1:42	24.4	1:42	24.2
1:28	22.3	1:29	21.9	1:29	21.6	1:30	21.4
1:16	19.3	1:16	19.0	1:16	18.7	1:17	18.6
1:03	16.3	1:03	16.0	1:04	15.9	1:04	15.9
0:50	13.3	0:51	13.1	0:51	13.1		

FUEL CORRECTION (LB)

FL 330	FL 350	FL 370 - 390
2600		
2400	2600	
2200	2400	
2000	2200	
1800	2000	
1600	1800	1800
1400	1600	1600
1200	1400	1400
1000	1200	1200
800	1000	1000
600	800	800
400	600	600
	400	

CHART VALID FOR A LANDING WEIGHT OF 300,000 LB AND LESS. FOR EACH 10,000 LB DEVIATION ABOVE 300,000 LB, CORRECT BY FUEL CORRECTION.

CA1-2553

TABLE I-6

ENERGY INTENSITY OF INTERCITY PLANES
NO CARGO PENALTY

Stage Length Dist.	Pass L.F.	Cargo L.F.	DC-10 B.T.U. / P.M.	B-727-200 B.T.U. / P.M.	B-727-100 B.T.U. / P.M.
500	0.5	0.5	5954.4	5466.4	5735.0
500	0.5	1.0	6856.6	5658.2	5735.0
500	1.0	0.5	3112.5	2829.1	2867.5
500	1.0	1.0	3518.5	2925.0	2985.8
1000	0.5	0.5	4691.4	5082.8	5528.1
1000	0.5	1.0	5300.3	5250.6	5528.1
1000	1.0	0.5	2413.3	2625.3	2764.0
1000	1.0	1.0	2751.7	2709.2	2867.5
1500	0.5	0.5	4240.3	5018.9	5498.5
1500	0.5	1.0	4781.6	5194.7	5498.5
1500	1.0	0.5	2180.3	2597.3	2749.3
1500	1.0	1.0	2481.0	2685.2	2857.7
2000	0.5	0.5	4234.6	4998.9	5513.3
2000	0.5	1.0	4798.5	5358.5	5513.3
2000	1.0	0.5	2201.9	2679.3	2867.5
2000	1.0	1.0	2455.6	2769.2	2867.5

Altitude = 29,000 Feet

TABLE I-7

ENERGY INTENSITY OF INTERCITY PLANES
FUEL PROPORTIONED ACCORDING TO WEIGHT

Stage Length Dist.	Pass L. F.	Cargo L. F.	DC-10		B-727-200		B-727-100	
			B.T.U. / P.M.	B.T.U. / T.M.	B.T.U. / P.M.	B.T.U. / T.M.	B.T.U. / P.M.	B.T.U. / T.M.
500	0.5	0.5	1233.5	13705.8	2915.6	32395.3	3389.5	37660.6
500	0.5	1.0	792.3	8803.1	2057.7	22863.2	2405.6	26728.8
500	1.0	0.5	1068.3	11869.9	1968.1	21868.3	2130.4	23670.8
500	1.0	1.0	728.9	8098.9	1560.1	17334.3	1764.6	19606.8
1000	0.5	0.5	971.9	10798.5	2711.0	30122.0	3267.2	36301.7
1000	0.5	1.0	612.5	6805.0	1909.5	21216.3	2318.8	25764.3
1000	1.0	0.5	823.3	9203.4	1826.4	20293.0	2053.5	22816.7
1000	1.0	1.0	570.0	6333.8	1445.0	16055.6	1694.7	18830.3
1500	0.5	0.5	878.4	9760.2	2676.9	29743.1	3249.7	36107.5
1500	0.5	1.0	552.5	6139.0	1889.1	20990.2	2306.4	25626.6
1500	1.0	0.5	748.3	8314.6	1806.9	20076.8	2042.5	22694.7
1500	1.0	1.0	514.0	5710.8	1432.2	15913.5	1688.9	18765.6
2000	0.5	0.5	877.3	9747.2	2666.2	29624.7	3258.4	36204.6
2000	0.5	1.0	554.5	6160.7	1948.7	21652.2	2312.6	25695.4
2000	1.0	0.5	755.7	8397.1	1863.9	20710.0	2130.4	23670.8
2000	1.0	1.0	508.7	5652.4	1477.0	16410.8	1694.7	18830.3

Altitude = 29,000 Feet

APPENDIX II

AUTOMOBILE

This appendix contains the necessary data base for the automobiles. Table II-1 provides the information on market class along with the representative vehicles. Five types of market classes are discussed. Most of the imports are classified in the sub-compact class. Tables II-2a, b and c provide the information on fuel economy (mpg) by model year, weight class and the type of the driving cycle (urban, combined and highway). Tables II-3a, b, c through f provide the data on fuel economy measures (B. T. U. /vehicle mile and MPG) categorized according to market class (standard, intermediate, compact, subcompact, specialty and total U. S. average) and model year (1958 through 1973). Figure II-1 provides the data in a graphical form for fuel economy measure (mpg - combined cycle) versus model year (1967 through 1976). This information is based upon the sales weighted average automobile.

TABLE II-1

AUTOMOBILE MARKET CLASSES

Market Class	Representative Vehicles (1973 Model Year)
Standard	AMC (Ambassador) Chevrolet (Caprice, Impala, Biscayne, Bel Air) Dodge (Polara, Monaco) Ford (LTD, Galaxie, Custom) Plymouth (Fury, Gran Sedan) Pontiac (Catalina, Bonneville, Grand Ville)
Specialty	AMC (Javelin) Chevrolet (Camaro, Corvette, Monte Carlo) Dodge (Challenger) Ford (Mustang, Thunderbird) Plymouth (Barracuda) Pontiac (Firebird, Grand Prix)
Intermediate[a]	AMC (Matador) Chevrolet (Chevelle) Dodge (Coronet, Charger) Ford (Torino) Plymouth (Satellite)
Compact[b]	AMC (Hornet) Chevrolet (Nova) Dodge (Dart) Ford (Maverick) Plymouth (Valiant)
Subcompact[c]	AMC (Gremlin) Chevrolet (Vega) Ford (Pinto)

[a] 1.4% of imports were in this class in 1973.

[b] 8.2% of imports were in this class in 1973.

[c] 90.4% of imports were in this class in 1973.

Source: • Mode Shift Strategies to Effect Energy Savings in Intercity Transportation April 1977, The Aerospace Corporation.

TABLE II-2a

FUEL ECONOMY (MPG) BY MODEL YEAR AND WEIGHT CLASS
1972 *FEDERAL TEST PROCEDURE (URBAN)*

YEAR	*INERTIA WEIGHT (LB)*									
	2000	2250	2500	2750	3000	3500	4000	4500	5000	5500
57-67*AV*	23.2	21.7	19.1	17.1	15.4	13.5	12.6	11.7	10.9	10.5
1968	19.3	20.5	18.5	19.7	15.6	13.3	12.0	11.3	9.5	9.5
1969	22.2	20.3	18.8	17.1	15.4	13.3	11.9	11.3	9.1	10.8
1970	23.4	19.3	17.5	18.5	15.9	13.3	12.0	10.9	10.1	9.9
1971	22.6	21.4	19.3	18.3	14.8	12.2	11.7	10.7	9.6	10.9
1972	23.0	21.9	19.6	20.0	14.4	13.3	11.1	10.7	9.6	9.3
1973	23.8	21.9	19.7	17.5	15.6	13.9	10.8	10.1	9.3	8.6

TABLE II-2b

FUEL ECONOMY (MPG) BY MODEL YEAR AND WEIGHT CLASS
1975 *FTP AND EPA HIGHWAY CYCLE (COMBINED URBAN/HIGHWAY)*

YEAR	*INERTIA WEIGHT (LB)*									
	2000	2250	2500	2750	3000	3500	4000	4500	5000	5500
57-67*AV*	27.8	26.3	23.1	20.7	18.5	16.3	15.2	14.0	13.1	12.7
1968	23.3	24.7	22.3	23.8	18.8	16.0	14.5	13.6	11.2	10.7
1969	26.9	24.5	22.7	20.3	18.6	16.0	14.4	13.6	11.0	13.0
1970	28.2	23.3	21.1	22.3	19.2	16.0	14.5	13.1	12.2	11.9
1971	27.3	25.8	23.3	22.1	17.8	14.7	14.1	12.9	11.6	13.1
1972	27.7	26.4	23.6	24.1	17.4	16.0	13.4	12.9	11.6	11.2
1973	28.7	26.4	23.8	21.1	18.8	16.8	13.0	12.2	11.2	10.4

TABLE II-2c

FUEL ECONOMY (MPG) BY MODEL YEAR AND WEIGHT CLASS
EPA HIGHWAY CYCLE (HIGHWAY)

YEAR	*INERTIA WEIGHT (LB)*									
	2000	2250	2500	2750	3000	3500	4000	4500	5000	5500
57-67*AV*	33.9	32.7	28.6	25.7	22.6	20.1	18.7	17.0	16.0	15.7
1968	28.8	30.4	27.4	29.4	23.1	19.6	17.9	16.7	13.3	11.8
1969	33.4	30.2	28.0	24.3	23.0	19.6	17.8	16.7	13.6	16.0
1970	34.7	28.8	26.0	27.4	23.7	19.6	17.9	16.0	15.1	14.6
1971	33.7	31.8	28.8	27.3	21.8	18.1	17.3	15.9	14.3	16.0
1972	34.0	32.5	29.0	29.6	21.5	19.6	16.5	15.9	14.3	13.8
1973	35.4	32.5	29.4	26.0	23.1	20.8	16.0	15.1	13.8	12.9

Sources:
- A Report on Automotive Fuel Economy, U.S. Environmental Protection Agency, February, 1974.
- Passenger Car Fuel Economy Trends through 1976, T. C. Austin, et. al., SAE paper 750957, October 1975.

TABLE II-3a

ALL MARKET CLASSES: TOTAL UNITED STATES SALES

Year	Curb Weight lb	Urban Intensity (BTU/V-Mi)	Urban Mileage (MPG)	Highway Intensity (BTU/V-Mi)	Highway Mileage (MPG)	Companies Intensity (BTU/V-Mi)	Companies Mileage (MPG)
1958	3714	9860	12.6	6630	18.7	8170	15.2
1959	3671	9800	12.7	6580	18.3	8110	15.3
1960	3563	9650	12.8	6490	19.1	8000	15.5
1961	3412	9450	13.1	6350	19.5	7820	15.6
1962	3451	9490	13.0	6380	19.4	7870	15.7
1963	3435	9470	13.1	6370	19.5	7860	15.8
1964	3442	9480	13.1	6373	19.5	7860	15.3
1965	3529	9600	12.9	6450	19.2	7950	15.6
1966	3579	9670	12.8	6500	19.1	8010	15.5
1967	3533	9680	12.8	6510	19.0	8030	15.4
1968	3591	10090	12.3	6780	18.3	8360	14.8
1969	3634	10260	12.1	6850	18.1	8430	14.6
1970	3570	10040	12.3	6250	18.4	8320	14.9
1971	3569	10480	11.8	7070	17.5	8700	14.3
1972	3650	10990	11.3	7360	16.8	9070	13.7
1973	3672	11320	11.0	7630	16.2	9380	13.2

TABLE II-3b

UNITED STATES TOTALS, MARKET CLASS: STANDARD

Year	Curb Weight lb	Urban Intensity (BTU/V-Mi)	Urban Mileage (MPG)	Highway Intensity (BTU/V-Mi)	Highway Mileage (MPG)	Companies Intensity (BTU/V-Mi)	Companies Mileage (MPG)
1958	3315	10000	12.4	6760	18.3	8310	14.9
1959	3973	10240	12.1	6960	17.8	8520	14.5
1960	4067	10380	11.9	7090	17.5	8650	14.8
1961	3975	10240	12.1	6960	17.8	8520	14.5
1962	3973	10240	12.1	6970	17.8	8520	14.5
1963	3923	10160	12.2	6900	18.0	8450	14.7
1964	3941	10190	12.2	6920	17.9	8480	14.6
1965	4005	10280	12.1	7000	17.7	8570	14.5
1966	4061	10370	12.0	7080	17.5	8640	14.3
1967	4125	10480	11.8	7180	17.3	8740	14.2
1968	4152	10890	11.4	7370	16.3	9050	13.7
1969	4248	11210	11.1	7550	16.4	9280	13.4
1970	4283	11531	10.8	7810	15.9	9580	12.9
1971	4408	12070	10.2	8140	15.2	10020	12.4
1972	4481	12290	10.1	8250	15.0	10190	12.2
1973	4807	13150	9.4	8850	14.0	10890	11.4

Sources:
- Passenger Car Weight Trend Analysis, The Aerospace Corp., ATR-74(7526-I, Vol. II, January 1974.
- A Report on Automotive Fuel Economy, U.S. Environmental Protection Agency, February, 1974.
- Passenger Car Fuel Economy Trends through 1976, T.C. Austin, et. al., SAE paper 750957, October, 1975.

TABLE II-3c

UNITED STATES TOTALS, MARKET CLASS: INTERMEDIATE

Year	Curb Weight lb	Urban Intensity (BTU/V-Mi)	Urban Mileage (MPG)	Highway Intensity (BTU/V-Mi)	Highway Mileage (MPG)	Companies Intensity (BTU/V-Mi)	Companies Mileage (MPG)
1958	3191	9160	13.5	6140	20.2	7590	16.3
1959	3776	9950	12.5	6700	18.5	8250	15.0
1960	3756	9920	12.5	6680	18.5	8220	15.1
1961	2937	8660	14.3	5850	21.2	7190	17.2
1962	2934	8550	14.5	5770	21.5	7090	17.5
1963	3045	8790	14.1	5930	20.9	7290	17.0
1964	3180	9130	13.6	6130	20.2	7560	16.4
1965	3318	9320	13.3	6260	19.8	7730	16.0
1966	3363	9390	13.2	6300	19.7	7770	15.9
1967	3450	9490	13.0	6380	19.4	7870	15.8
1968	3503	9900	12.5	6660	18.6	8210	15.1
1969	3505	9960	12.4	6680	18.5	8240	15.0
1970	3655	10230	12.1	6850	18.1	7930	14.6
1971	3632	10570	11.7	7130	17.4	8770	14.1
1972	3787	11214	11.0	7540	16.4	9310	13.3
1973	4000	11960	10.4	8040	15.4	9920	12.5

TABLE II-3d

UNITED STATES TOTALS, MARKET CLASS: COMPACT

Year	Curb Weight lb	Urban Intensity (BTU/V-Mi)	Urban Mileage (MPG)	Highway Intensity (BTU/V-Mi)	Highway Mileage (MPG)	Companies Intensity (BTU/V-Mi)	Companies Mileage (MPG)
1958	3041	8780	14.1	5930	20.9	7280	17.0
1959	2897	8460	14.7	5720	21.6	7030	17.6
1960	2679	7970	15.5	5410	22.9	6630	18.7
1961	2055	7890	15.7	5340	23.2	6560	18.9
1962	2723	8090	15.3	5510	22.5	6730	18.4
1963	2713	8070	15.4	5480	22.6	6720	18.4
1964	2721	8090	15.3	5490	22.5	6730	18.4
1965	2828	8310	14.9	5630	22.0	6910	17.9
1966	2823	8300	14.9	5620	22.0	6900	13.0
1967	2854	8360	14.8	5670	21.9	6950	17.8
1968	2941	8560	14.5	5770	21.4	7100	17.5
1969	2874	8450	14.7	5680	21.8	7000	17.7
1970	2874	8270	15.0	5560	22.3	6850	18.1
1971	2973	9280	13.4	6270	19.7	7700	16.1
1972	3027	9060	13.7	6110	20.3	7520	16.5
1973	3124	8750	14.2	5860	21.1	7240	17.1

Sources:
- Passenger Car Weight Trend Analysis, The Aerospace Corp., ATR-74(7326)-1, Vol. II, January 1974.
- A Report on Automotive Fuel Economy, U. S. Environmental Protection Agency, February, 1974.
- Passenger Car Fuel Economy Trends through 1976, T.C. Austin, et. al., SAE paper 750957, October, 1975.

TABLE II-3e

UNITED STATES TOTALS, MARKET CLASS: SUBCOMPACT

Year	Curb Weight lb	Urban Intensity (BTU/V-Mi)	Urban Mileage (MPG)	Highway Intensity (BTU/V-Mi)	Highway Mileage (MPG)	Companies Intensity (BTU/V-Mi)	Companies Mileage (MPG)
1958	1963	5760	21.5	3820	32.4	4750	26.1
1959	1969	5760	21.5	3820	32.4	4750	26.1
1960	2044	5980	20.7	3970	31.1	4930	25.1
1961	2039	6120	20.3	4070	30.4	5050	24.5
1962	2088	6110	20.3	4070	30.4	5050	24.5
1963	2041	5970	20.8	3970	31.2	4930	25.1
1964	1787	5460	22.7	3700	33.5	4550	27.3
1965	1798	5480	22.6	3700	33.4	4560	27.2
1966	1909	5650	21.9	3770	32.9	4660	26.5
1967	1943	5700	21.7	3790	32.7	4710	26.3
1968	2002	6170	20.1	3620	29.8	5120	24.2
1969	2023	6240	18.9	4190	29.6	5170	24.0
1970	2093	6780	18.3	4560	27.2	5620	22.0
1971	2139	6250	19.8	4200	29.5	5180	23.9
1972	2214	6310	19.6	4270	29.0	5250	23.6
1973	2289	6550	18.9	4390	28.2	5430	22.8

TABLE II-3f

UNITED STATES TOTALS, MARKET CLASS: SPECIALTY

Year	Curb Weight lb	Urban Intensity (BTU/V-Mi)	Urban Mileage (MPG)	Highway Intensity (BTU/V-Mi)	Highway Mileage (MPG)	Companies Intensity (BTU/V-Mi)	Companies Mileage (MPG)
1958	3945	10200	12.2	6930	17.9	8480	14.6
1959	3963	10220	12.1	6950	17.8	8500	14.6
1960	3930	10170	12.2	6910	17.9	8460	14.6
1961	3984	10250	12.1	6980	17.8	8530	14.5
1962	4168	10540	11.8	7230	17.1	8800	14.1
1963	4118	10460	11.8	7170	17.3	8730	14.2
1964	3300	9300	13.3	6240	19.8	7700	16.1
1965	3154	9060	13.7	6090	20.4	7510	16.5
1966	3208	9190	13.5	6160	20.1	7610	16.3
1967	3297	9300	13.3	6240	19.9	7700	16.1
1968	3445	9790	12.7	6590	18.8	8110	15.3
1969	3615	10210	12.1	6830	18.1	8450	14.7
1970	3639	10200	12.2	6830	18.1	8440	14.7
1971	3836	10890	11.4	7310	17.0	9000	13.8
1972	3953	11420	10.9	7650	16.2	9430	13.1
1973	4048	12070	10.3	8080	15.3	9960	12.4

Sources:
- Passenger Car Weight Trend Analysis, The Aerospace Corp., ATR-74(7326)-1, Vol. II, January 1974.
- A Report on Automotive Fuel Economy, U. S. Environmental Protection Agency, February, 1974.
- Passenger Car Fuel Economy Trends through 1976, T. C. Austin et. al., SAE paper 750957, October, 1975.

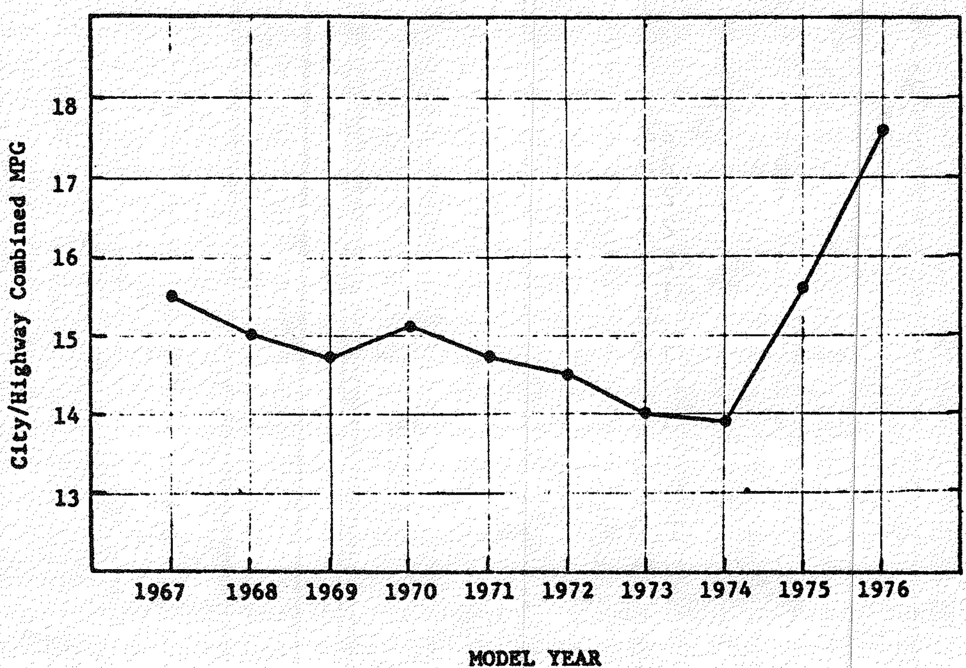


FIGURE II-1

SALES-WEIGHTED FUEL ECONOMY TRENDS - 1967 to 1976

Source: • Passenger Car Fuel Economy Trends Through 1976, T.C. Austin, et. al., Reference 36.

APPENDIX III

INTERCITY BUS

This appendix contains the data base and methodology for the estimation of EI values for the intercity bus. Firstly, a methodology for the resistance equation is provided which helps us to estimate fuel rate at various velocities. Equation III-2 is utilized for the calculation of EI values under various cruising conditions. Table III-2 provides design and performance specifications for the two kinds of buses which are commonly available in this country. Finally, statistical information regarding passenger miles and fuel used are provided for Greyhound operations.

RESISTANCE EQUATION

Resistance equation for a bus is assumed to be of the following form:

$$R = W\left(a + \frac{b}{p} + \frac{cV^2}{p}\right) + CV^2$$

where

R = Total resistance in lbs.

a, b, c = Rolling friction coefficients

p = tire pressure in psi

V = velocity in miles per hour

C = aerodynamic drag coefficient

W = loaded weight in tons

The following value of the coefficients are assumed for the analysis purposes:

$C = 0.139 \text{ lb}/(\text{mph})^2$

$a = 10 \text{ lb/ton}$

$b = 300 \text{ lb - psi/ton}$

$c = 0.07 \text{ lb - psi/ton-}(\text{mph})^2$

After the calculation of the drag resistance, brake horsepower can be estimated as follows:

$$BHP = \frac{(R)\ (V)}{375}$$

Most of these buses use Detroit Diesel 8V-71 engines. The fuel data for such engines are given as follows:

TABLE III-1

RELATIONSHIP BETWEEN FUEL CONSUMPTION RATES V/S BRAKE HORSE-POWER FOR DETROIT-DIESEL

B. H. P.	Fuel Consumption in Gal/Hr.
Idle 0	0.7
14	1.0
28	2.0
42	3.0
56	4.0
70	5.0
84	5.8
98	6.4
112	6.9
126	7.5
140	8.1
154	8.7
168	9.2
182	9.9
196	10.6
210	11.2
224	11.8
238	12.7
252	13.4
266	14.1
280	15.0

Once, the fuel rate is known, then energy intensity can be calculated as follows:

$$EI = BTU/PM = \frac{(\text{Fuel Rate in gallon/hr})\ (\text{B.T.U./gallon})}{(V)\ (\text{No. of seats})\ (\text{Load Factor})} \qquad \text{III-2}$$

Load factor, and speed are varied and energy intensity figures are obtained.

Two different types of intercity buses* were evaluated for the study.

*MCI buses are manufactured by Motor Coach Industries. GM buses are manufactured by GMC Truck & Coach Division, General Motors Corporation.

TABLE III-2

DESIGN AND PERFORMANCE CHARACTERISTICS
OF INTERCITY BUSES

Manufacturer	MCI	GM
Bus Type	Intercity	Intercity
Model	MC8	P8M-4905
Length (in.)	479.5	479.11
Width (in.)	96.0	95.76
Height (in.)	130.0	131.5
Frontal Area ($in.^2$)	10,752.0	10,868.76
Capacity (No. of seats)	53	44
GVWR (lbs)	26,760	29,740
No. of Axles	2	2
No. of Tires	6	6
Engine Type	Diesel	Diesel
Manufacturer	Detroit Diesel	Detroit Diesel
Model	8V-71N	8V-71N
No. of Cyl.	8	8
Displacement ($in.^3$)	567.4	567.4
Bore and Stroke (in.)	4.5x5.0	4.5x5
Compression Ratio	18.7 to 1	18.7 to 1
SAE NET HP @ RPM	285 @ 2150	285 @ 2150
SAE NET Torque @ RPM	770 @ 1200	770 @ 1200
Weight/Horsepower		
Braking	Air	Air
Type	Drum	Drum
Surface Area	1058 $in.^2$	1058 $in.^2$
Accessories		
Air Conditioning	Yes	Yes
Heater	Yes	Yes
Lavatory	Yes	Yes

Greyhound Lines, Inc.
Greyhound Tower Phoenix, Arizona 85077
Phone: (602) ~~248-5000~~ 248 - 6550

June 20, 1977

Mr. Ram K. Mittal, Ph.D., P.E.
Assistant Professor
Department of Mechanical Engineering
Union College
Schenectady, NY 12308

Dear Professor Mittal:

This will serve as response to your June 1 letter directed to this company, also your June 7 letter directed to Mr. Joseph G. Stieber, our Vice President - Engineering in Chicago, wherein you are soliciting information for your study related to "Energy Intensities of Intercity Bus Systems".

At present our company, through cooperation with other members of the intercity bus industry, is working with the U.S. Department of Transportation in its program to effect voluntary fuel economy.

We appreciate the interest you have expressed in our company and although we do not have the information available which you have requested we do believe that the enclosed Fuel Efficiency Comparison may be of interest to you. For your information, it has been developed through use of statistics taken from annual reports filed with the Interstate Commerce Commission for the years 1973 through 1976 inclusive.

Very sincerely yours,

A. N. Ransom

A. N. Ransom
Director of Research

Enclosure

cc: J. G. Stieber
Chicago

TABLE III-3

COMPARISON OF AMTRAK/GREYHOUND ACTUAL FUEL EFFICIENCY FOR YEARS 1973-1974-1975-1976

	AMTRAK				GREYHOUND			
	1973	1974	1975	1976	1973	1974	1975	1976
Passenger Miles/Gallon	39	46	35	44	133	142	135	126
Passenger Miles	#3,806,511,000	#4,258,805,811	#3,571,195,000	#4,268,231,042	a)8,960,496,000	9,216,767,000	8,131,495,000	7,464,742,000
Fuel Usage (gallons)								
Locomotives								
Passenger	*74,966,000	*69,458,248	*59,613,275	*66,211,422				
Yark Switching	* 623,000	* 802,328	* 853,729	* 836,135				
SUBTOTAL	*75,589,000	*70,260,576	*60,467,004	*67,047,557				
Rail Motorcars								
Passenger	*411,000	*658,722	*19,301,007	* 9,803,065				
Yard Switching	- -	- -	122,774	- -				
SUBTOTAL	*411,000	*658,722	*19,423,781	* 9,803,065				
Conv. Electric Energy (gal.)	#21,237,000	#21,445,000	#21,230,000	#20,968,000				
TOTAL FUEL USAGE (gal.)	*97,237,000	*92,364,298	*101,120,785	*97,818,622	b)77,788,087	75,197,717	70,229,672	69,439,359

	1973	1974	1975	1976
Passenger Miles/Gallon computed for total fuel consumption using regular route intercity passenger miles only.	c)115	123	116	117
Passenger Miles/Gallon after eliminating est. gallons of fuel used in charter service	d)129	138	132	124
Passenger Miles/Gallon after eliminating est. gallons of fuel used in charter and local service	e)133	142	135	126

#Passenger miles includes those accumulated by use of electric trains consuming power as follows (from AMTRAK annual report to ICC (A or R-1):
- 1973 - 274,378,000 Kilowatt hours (Equivalent to 21,237,000 gallons of fuel)
- 1974 - 277,070,000 Kilowatt hours (Equivalent to 21,445,000 gallons of fuel)
- 1975 - 274,322,779 Kilowatt hours (Equivalent to 21,230,000 gallons of fuel)
- 1976 - 270,897,024 Kilowatt hours (Equivalent to 20,968,000 gallons of fuel)

*Source: AMTRAK Annual Report to Interstate Commerce Commission (R-1) Schedules #531 and #571.

a)Source: Greyhound Report (D or MP-1) to Interstate Commerce Commission (Regular route intercity operations only--does not include charter and local service

b)Source: Greyhound Lines, Inc. (Eastern and Western Divisions) Financial Statements - Statement A, Page 2 (Includes fuel used in charter and local service.)

c)Passenger miles (regular route intercity service only) per gallon of fuel used in all revenue services (intercity, local and charter).

d)Passenger miles (regular route intercity service only) per gallon of fuel used in regular route intercity and local service. Fuel used in charter service eliminated on basis of charter bus miles operated at approximately 6.00 miles per gallon in 1973, 6.32 miles per gallon in 1974, 6.24 miles per gallon in 1975, and 6.10 miles per gallon in 1976.

e)Passenger miles (regular route intercity service) per gallon of fuel used in such service. Fuel used in charter and local service eliminated on basis of bus miles operated in such services at 6.00 MPG in 1973, 6.32 in 1974, 6.24 in 1975, and 6.10 in 1976.

5/10/77
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TABLE III-4

COMPUTATION OF ITEM (d) ELIMINATING FUEL USED IN CHARTER SERVICE

	1973	1974	1975	1976
1. Total Bus Miles	466,531,728	475,366,847	438,161,618	423,243,926
2. Total Fuel Used (gallons)	77,788,087	75,197,717	70,229,672	69,439,359
3. Bus Miles per Gallon	6.00	6.32	6.24	6.10
4. Total Charter Bus Miles	51,266,964	53,101,880	52,936,363	55,401,712
5. Fuel used in Charter Service (est.) (gallons)	8,544,494	8,402,196	8,483,392	9,082,248
6. Fuel used in regular route intercity and local service (excl. est. charter) (gallons)	69,243,593	66,795,521	61,746,280	60,357,111
7. Regular route intercity revenue passenger miles	8,960,496,000	9,216,767,000	8,131,495,000	7,464,742,000
8. Passenger mpg (excluding charter)	129	138	132	124

COMPUTATION OF ITEM (e) ELIMINATING FUEL USED IN CHARTER AND LOCAL SERVICE

	1973	1974	1975	1976
9. Local Service - Bus Miles	11,616,370	10,493,412	8,208,197	7,448,017
10. Bus Miles per Gallon	6.00	6.32	6.24	6.10
11. Fuel used in local service (est.) (gallons)	1,936,062	1,660,350	1,315,416	1,220,986
12. Fuel used in regular route intercity and local service (excl. est. charter) (gallons)	69,243,593	66,795,521	61,746,280	60,357,111
13. Fuel used in intercity service excl. charter and local (est.) (gallons)	67,307,531	65,135,171	60,430,864	59,136,125
14. Passenger mpg excl. charter & local service	133	142	135	126

APPENDIX IV

INTERCITY PASSENGER - TRAINS

This appendix contains the data base and background information needed for the estimation of the EI values for the intercity passenger trains. Firstly, a resistance equation is given which helps us to estimate the rail-horsepower. Knowing the rail-horsepower and various efficiencies of the system, we can calculate the fuel rates. Efficiency data are also provided in a tabular form for various types of train consists. Readers who are interested for further details should refer to Reference 28.

Figure IV-1 shows a string of vehicles moving at a velocity V on a level tangent track. Let us analyze the resistance to the i-th vehicle which is given by the following equation:*

$$r_i = 1.3 + \frac{29}{w_i} + b_i V + \frac{c_i A_i V^2}{w_i n_i} \qquad \text{IV-1}$$

where

w_i = weight in tons/axle (dead weight + line weight)

V = velocity in miles per hour

b_i = constant (also called flange coefficient)

A_i = projected area in sq. ft.

n_i = no. of axles

c_i = drage coefficient (see Table IV-1).

r_i = resistance in pounds per ton of weight

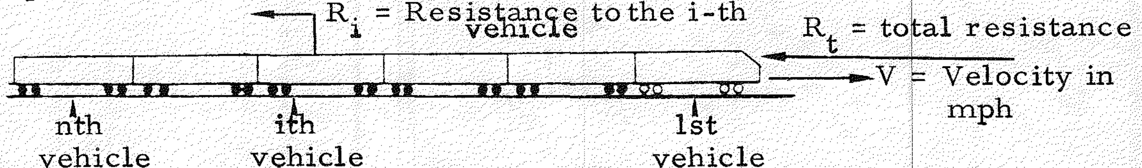


Figure IV-1. String of Vehicles Moving at a Velocity V

---

*Usually termed the "Davis Equation."

TABLE IV-1

VALUE OF AERODYNAMIC DRAG COEFFICIENT
FOR VARIOUS TRAIN CONSISTS

	Loco	Amclub	Amcoach	Amcafe
E-60 CP Pulling Amfleet	.0027	.0003	.0003	.0008
	Coach	Snack	Coach	Parlor
Conventional Metroliners	.0024	.0003	.0003	.0005
	Loco	Coach	Cafe	
E-8 Train Consist	.0025	.0004	.0009	
	Loco	Coach	Cafe	
Turboliner	Lead .002 Trail .0005	.0003	.0003	

Then the total resistance (being faced by the system - string of vehicles moving along a level tangent track) is given by the following equation:

$$R_t = \sum_{i=1}^{n} (r_i)(w_i)(n_i) = \sum_{i=1}^{n} R_i$$

For certain velocity V, the rail horsepower can be calculated by the use of the following equation:

$$\text{RHP (Rail Horsepower)} = \frac{(R_t)(V)}{375}$$

Various kinds of parameters (η_{di}, η_{ac}, η_{ty} , etc.) have to be known before one can estimate the fuel rates. Knowing the fuel rates, the instantaneous value of energy intensity can be calculated by the use of the following formula:

$$\text{EI} = \text{B.T.U./P.M.} = \frac{\text{(Fuel flow rate in gallon/hr) (B.T.U./gallon)}}{\text{(V) (No. of seats in the train) (Load-factor)}}$$

The average energy intensity over a given route (or a city pair) is given by the following equation:

$$\text{EI} = \text{B.T.U./P.M.} = \frac{\text{(Total fuel used in gallons) (B.T.U./gallon)}}{\text{Passenger Miles}}$$

whereas passenger miles = (Seat miles) (Average load factor).

Figures IV-3a through e provide the necessary data base for LRC train consists. Figures IV-4a through d provide the technical information on turboliners. Finally, Figures IV-5a and b provide the technical information on General Electric - E60CP locomotive. Figure IV-6a provides H. P. /ton ratings for several train consists which help us to estimate the acceleration and maximum speed capabilities of various trains. Figure IV-6b provides data on maximum cruising speed (on level tangent track and constant grade) capability for several train consists.

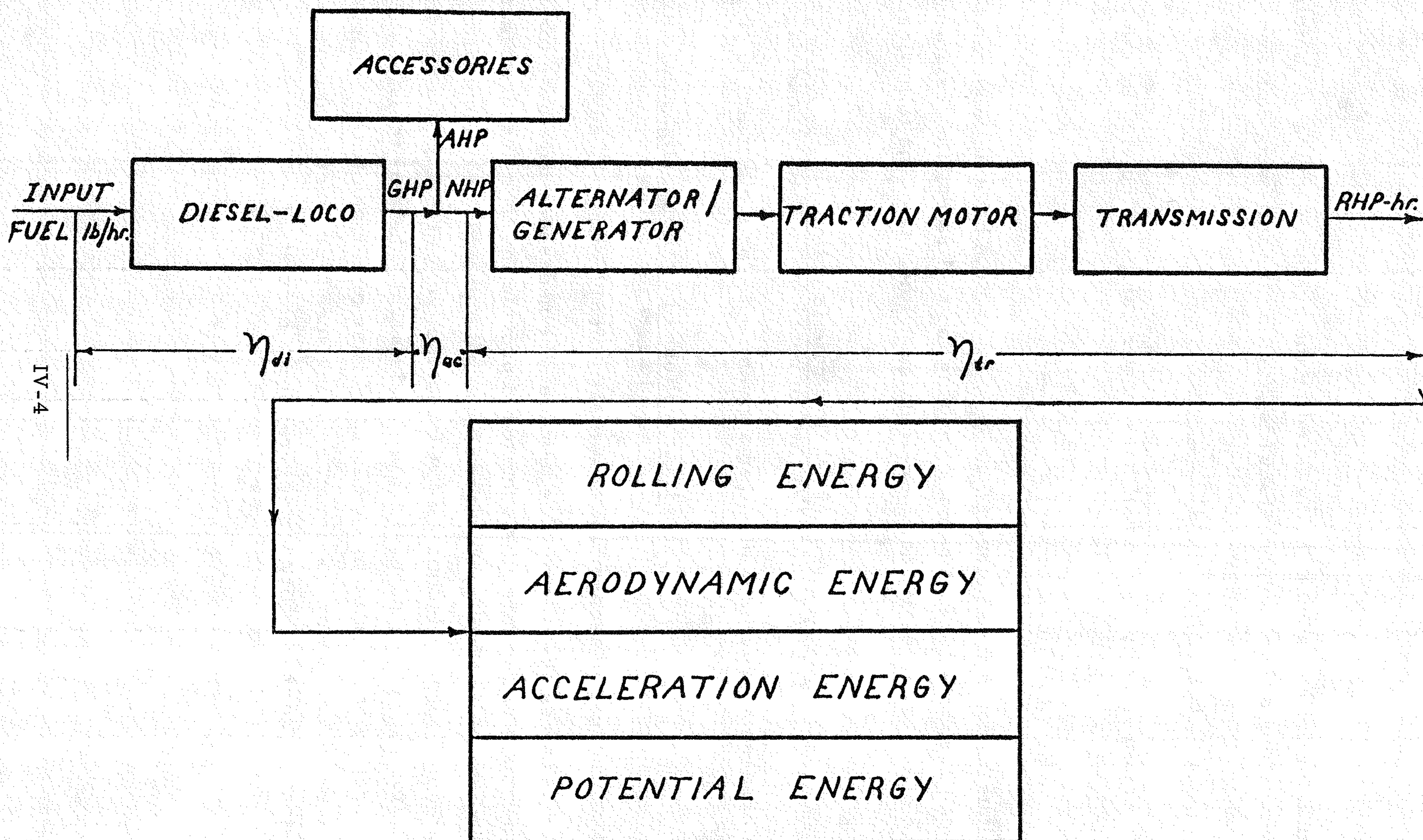
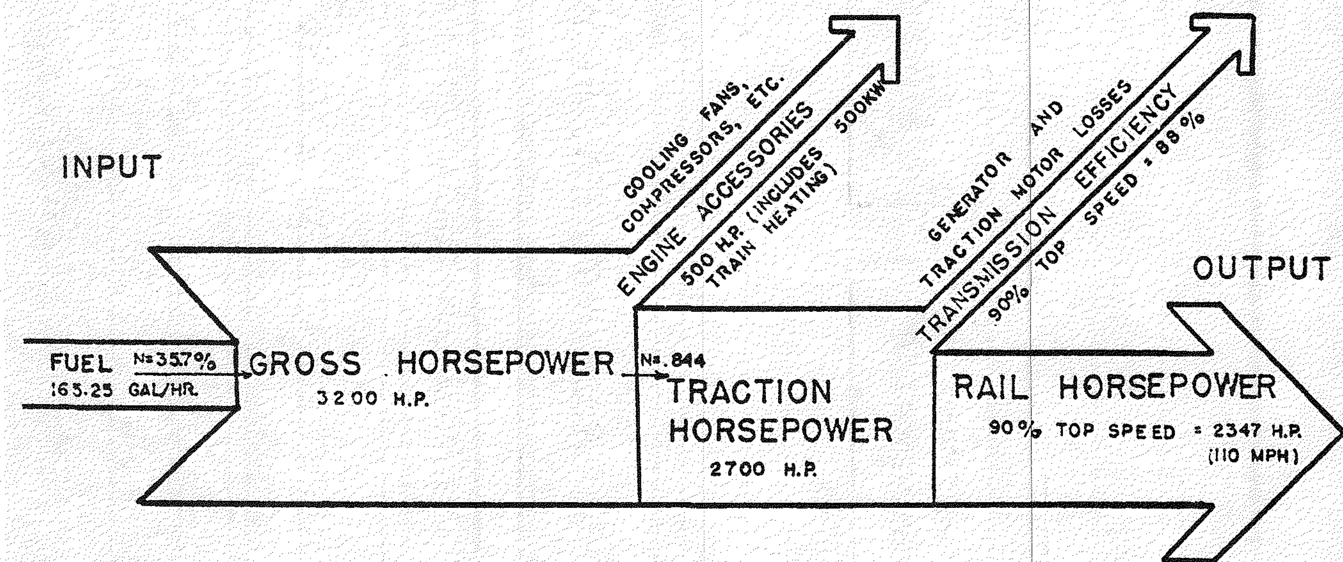


FIGURE IV-2
COMPONENTS OF ENERGY (ACCELERATION OR CRUISING)

LOCOMOTIVE EFFICIENCY DIAGRAM 8TH NOTCH PERFORMANCE



SPECIFICATIONS:
CANADIAN LRC POWER CAR
DIESEL ELECTRIC LOCOMOTIVE
2700 H.P.

ENGINE:
251 F DIESEL - 16 CYLINDER

TRANSMISSION:
ONE - GTA 17 ALT.
FOUR - GE TRACTION MOTORS
71-32 GEARS
40" DIAMETER WHEELS

FIGURE IV-3a

Transmission Efficiency Curve - LRC
Power Car

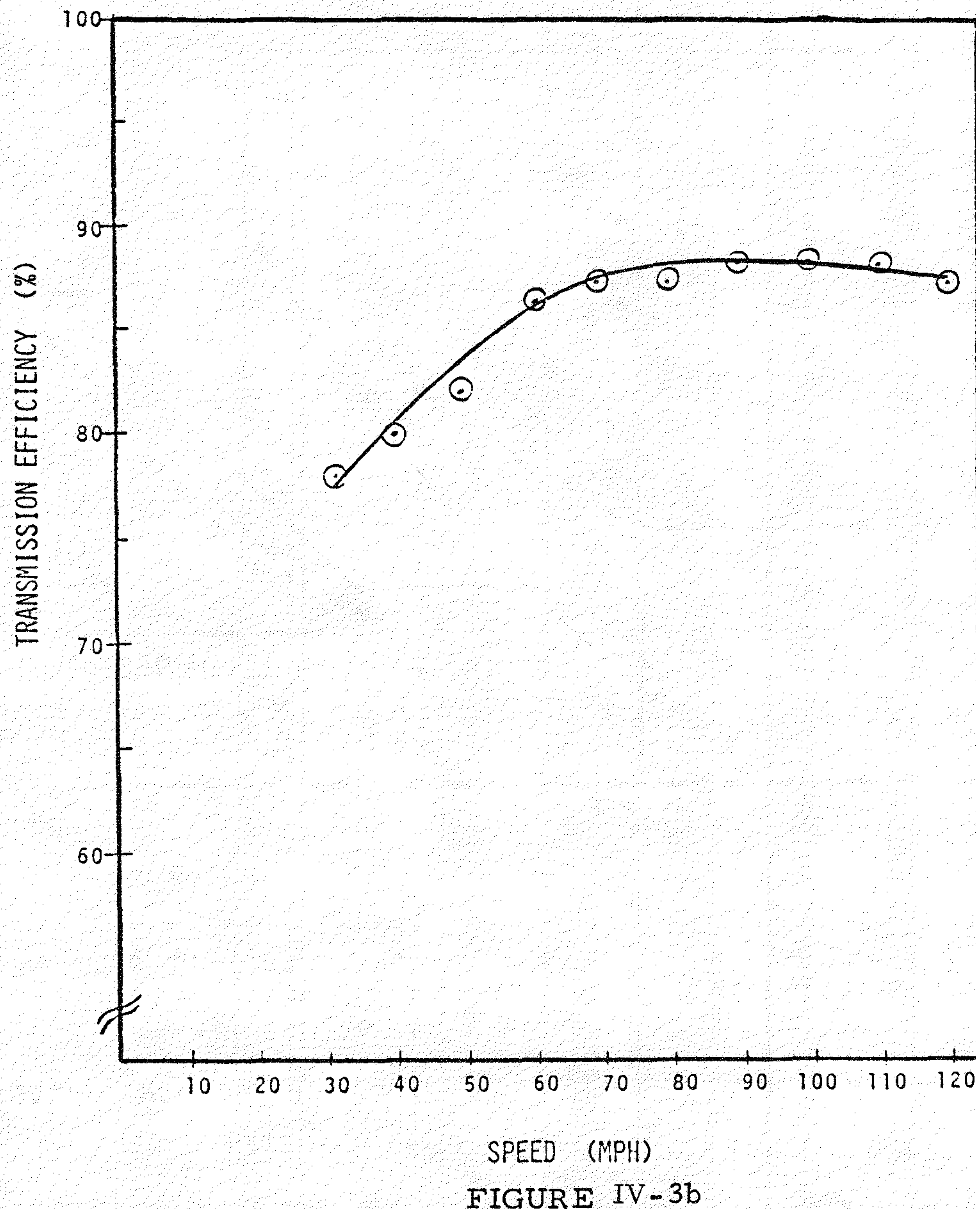


FIGURE IV-3b

Union College	DOT - OS - 60124	May 1977
Transportation Program		

Engine Thermal Efficiency vs. Gross HP Curve - LRC Power Car

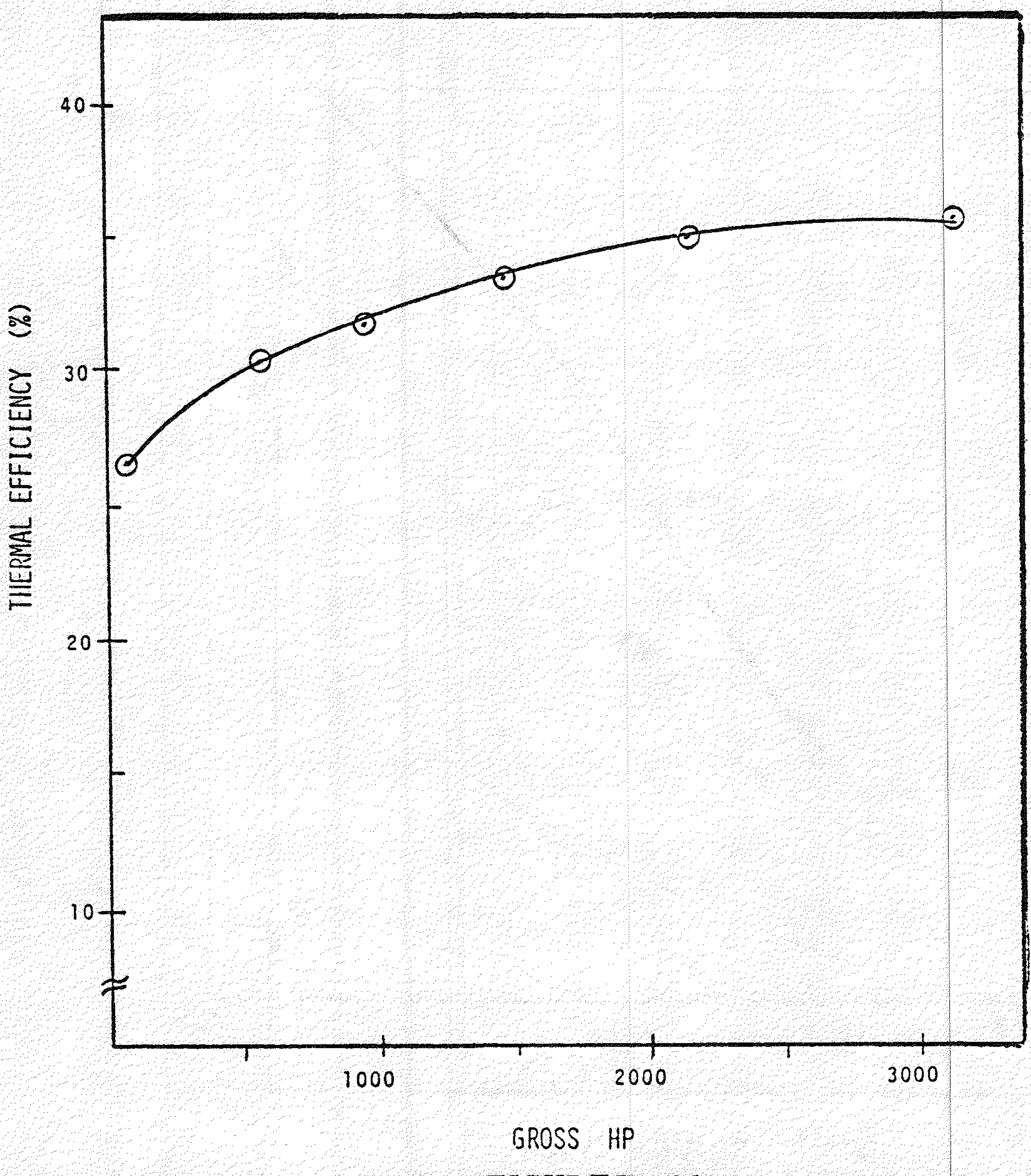


FIGURE IV-3d

Union College	DOT - OS - 60124	May 1977
Transportation Program		

Tractive Resistance Curve - LRC

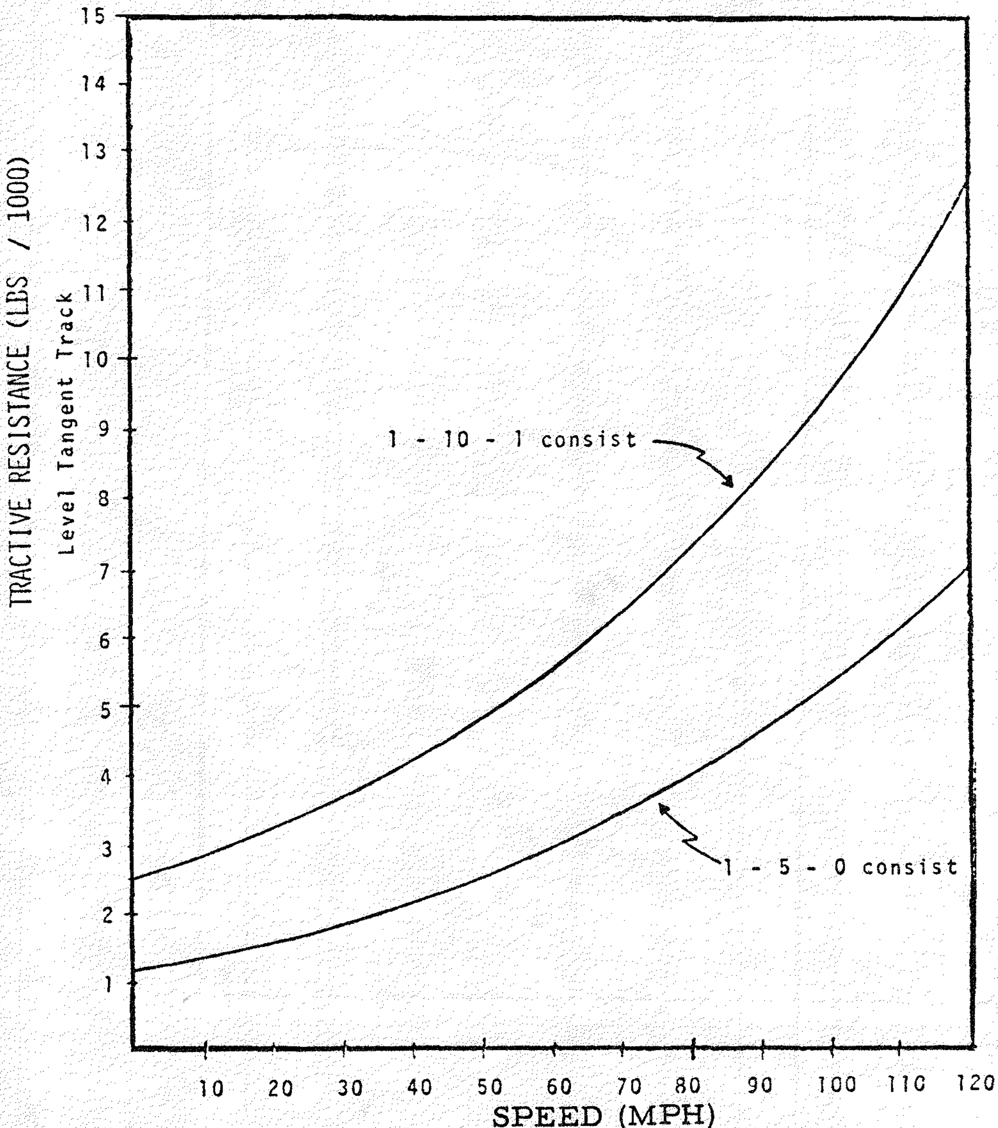


FIGURE IV-3c

Union College	DOT - OS - 60124	May 1977
Transportation Program		

FUEL CONSUMPTION VS. GROSS HP -

LRC POWER CAR

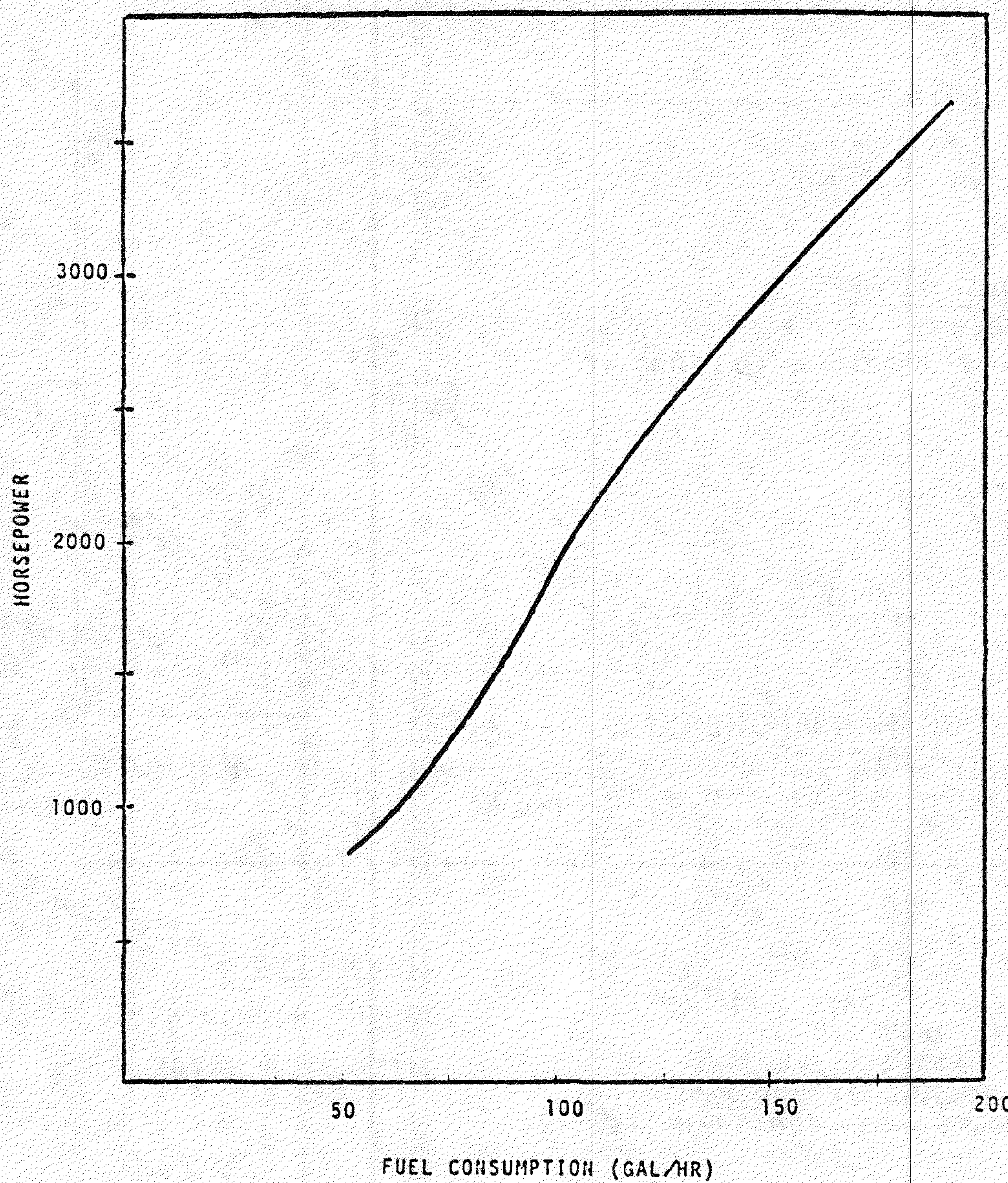


FIGURE IV-3e

UNION COLLEGE	DOT - OS - 60124	MAY 1977
TRANSPORTATION PROGRAM		

LOCOMOTIVE EFFICIENCY DIAGRAM

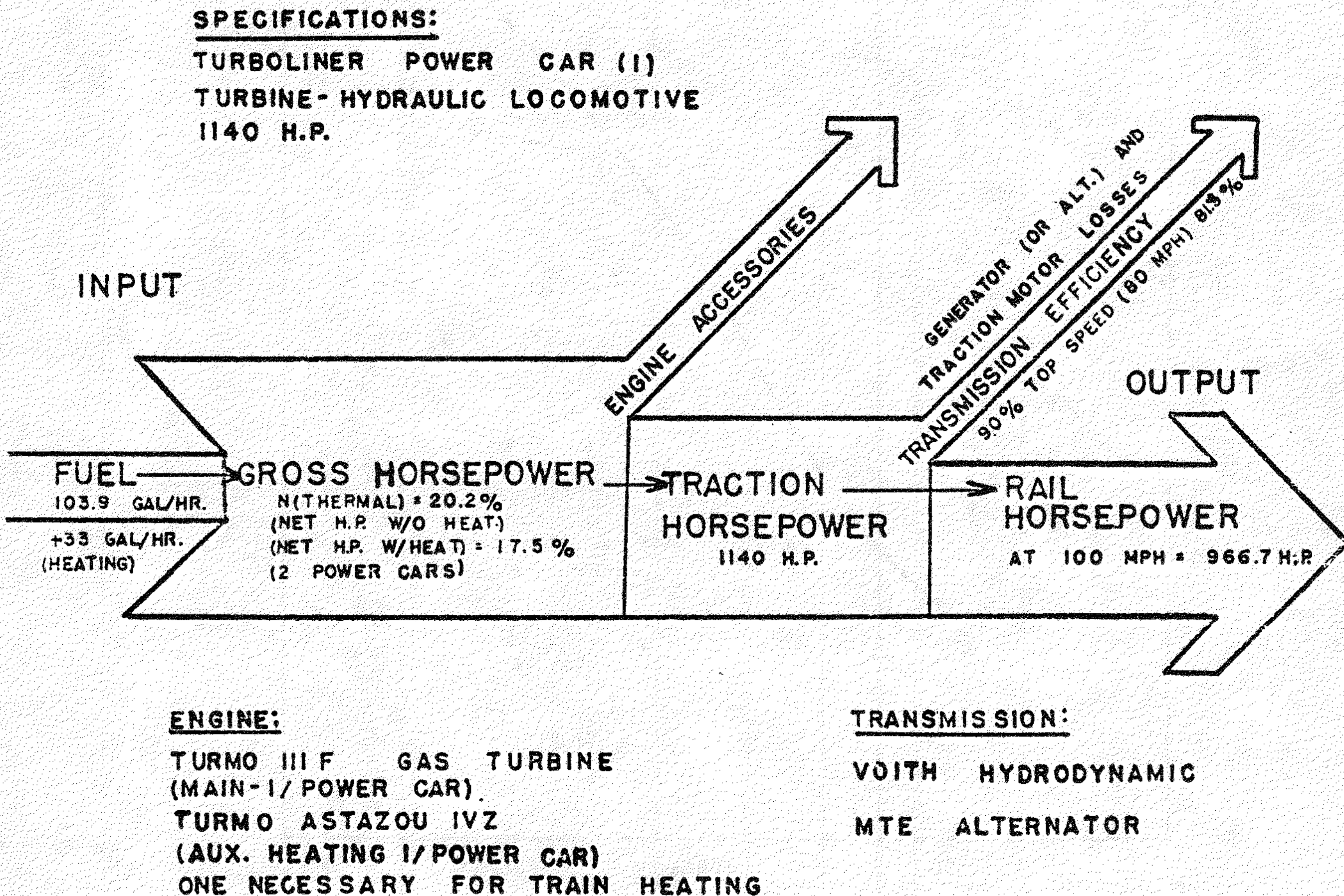


FIGURE IV-4a

TRANSMISSION EFFICIENCY CURVE - TURBOLINER

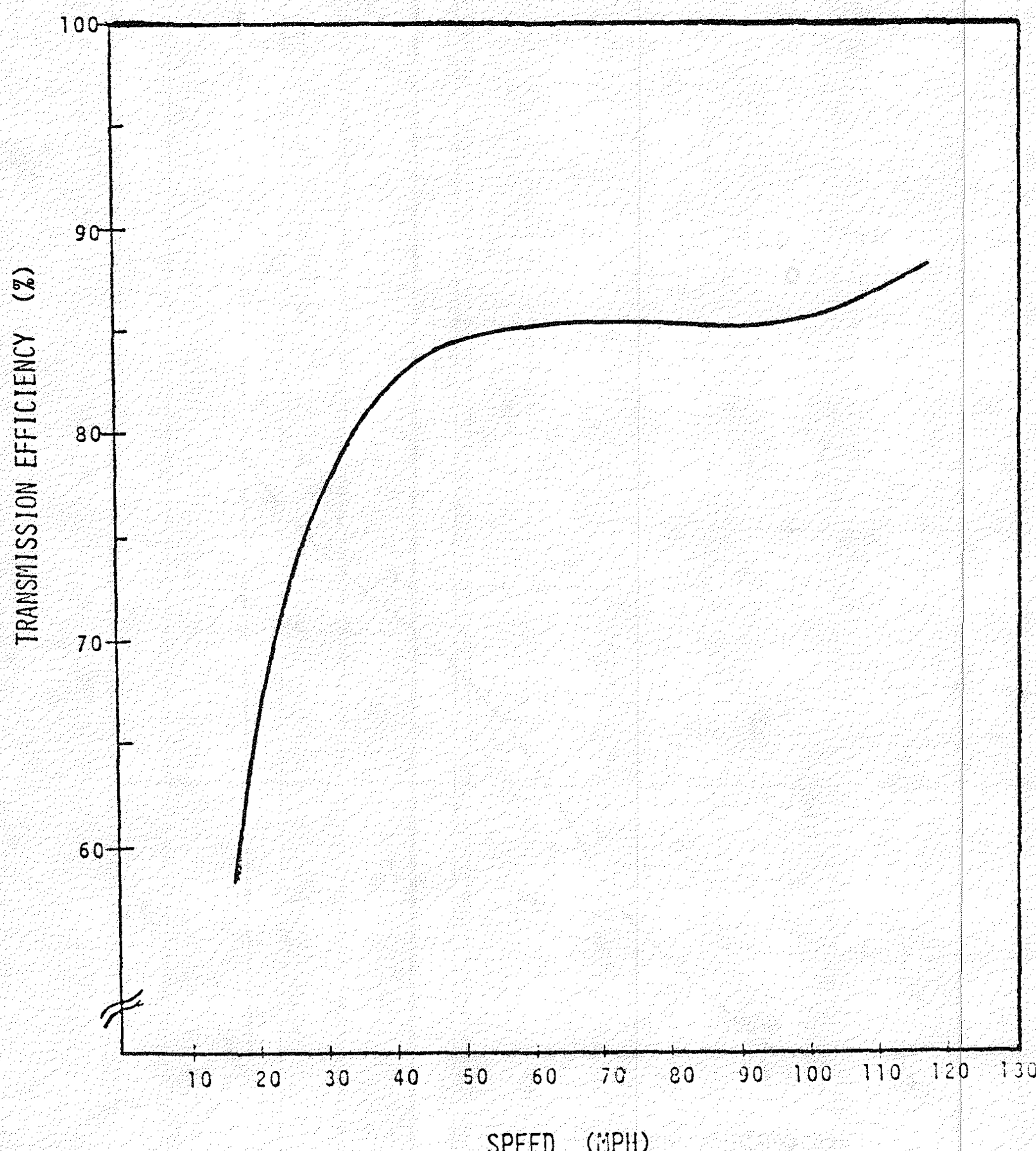


FIGURE IV-4b

UNION COLLEGE	DOT - OS - 60124	MAY 1977
TRANSPORTATION PROGRAM		

FUEL CONSUMPTION VS. TRACTION HP -

TURBOLINER (2 POWER CARS)

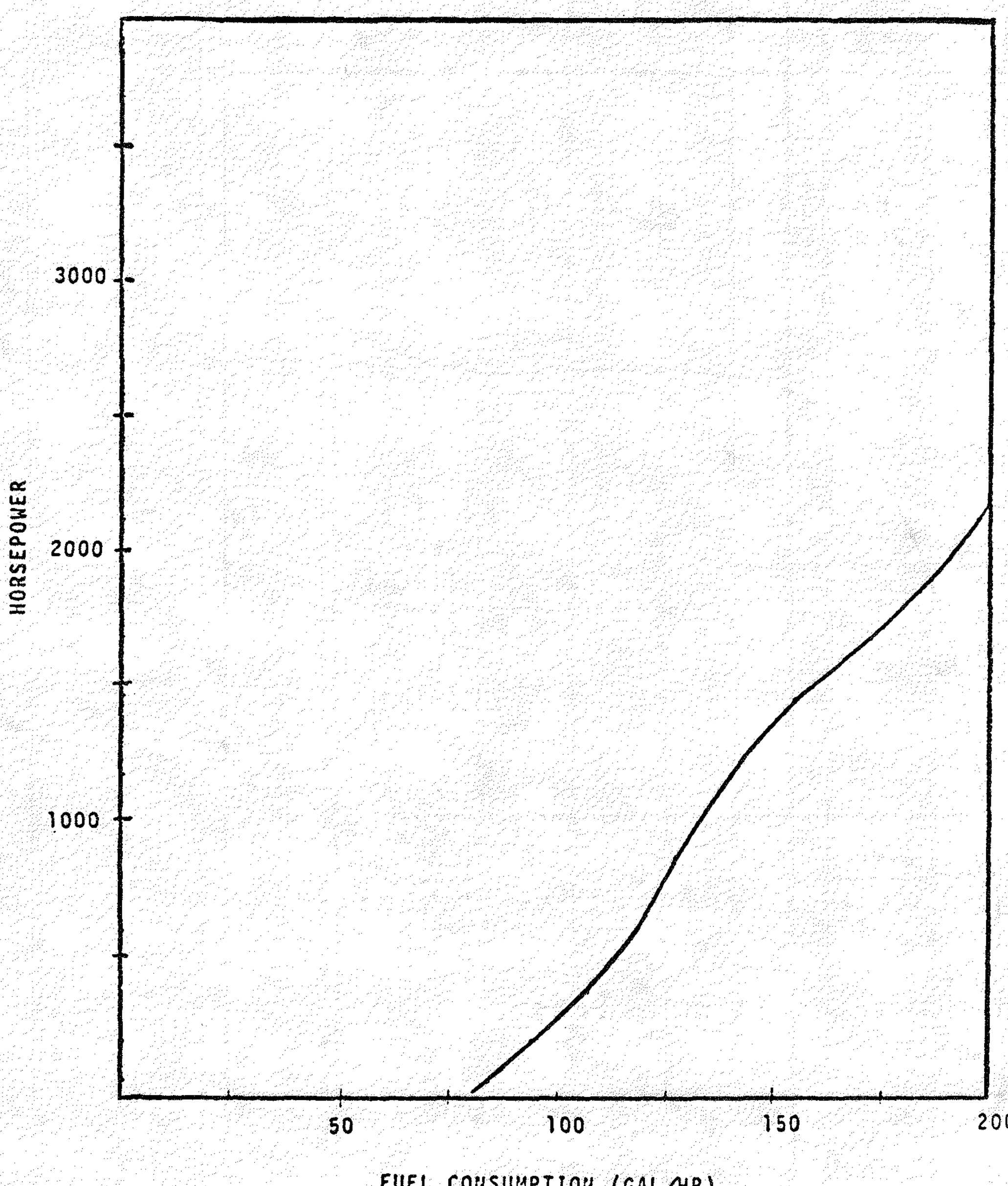


FIGURE IV-4c

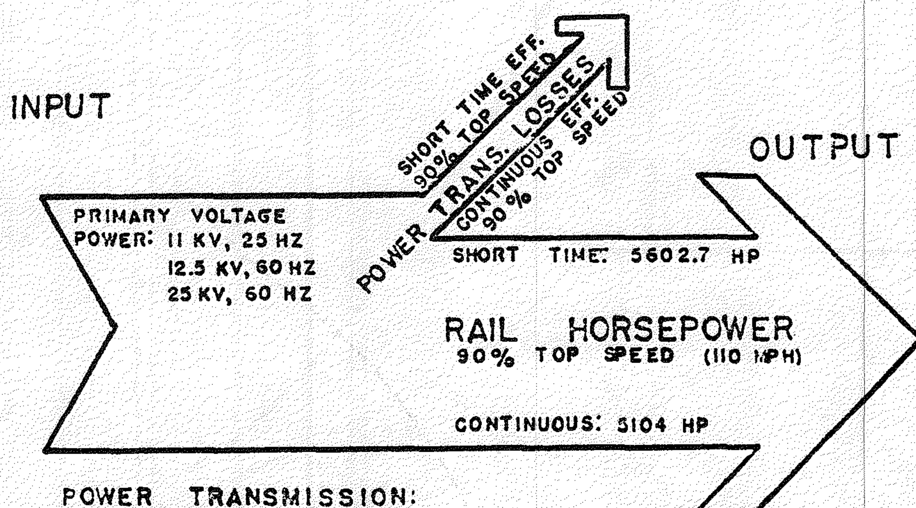
UNION COLLEGE	DOT - OS - 60124	MAY 1977
TRANSPORTATION PROGRAM		

LOCOMOTIVE EFFICIENCY DIAGRAM

SHORT TIME AND CONTINUOUS PERFORMANCE

SPECIFICATIONS:

GENERAL ELECTRIC - E60 CP
ALL ELECTRIC LOCO.
6000 H.P.



POWER TRANSMISSION:

1- GE CLASS FOA 7960 KVA TRANSFORMER
2- THYRISTOR GE RECTIFIERS
1- 17E X 57A1 SMOOTHING REACTOR
6- GE 730B1 TRACTION MOTORS
68/38 GEARS
40" DIA. WHEELS

FIGURE IV-5a

TRACTIVE EFFORT CURVE - E60CP LOCOMOTIVE

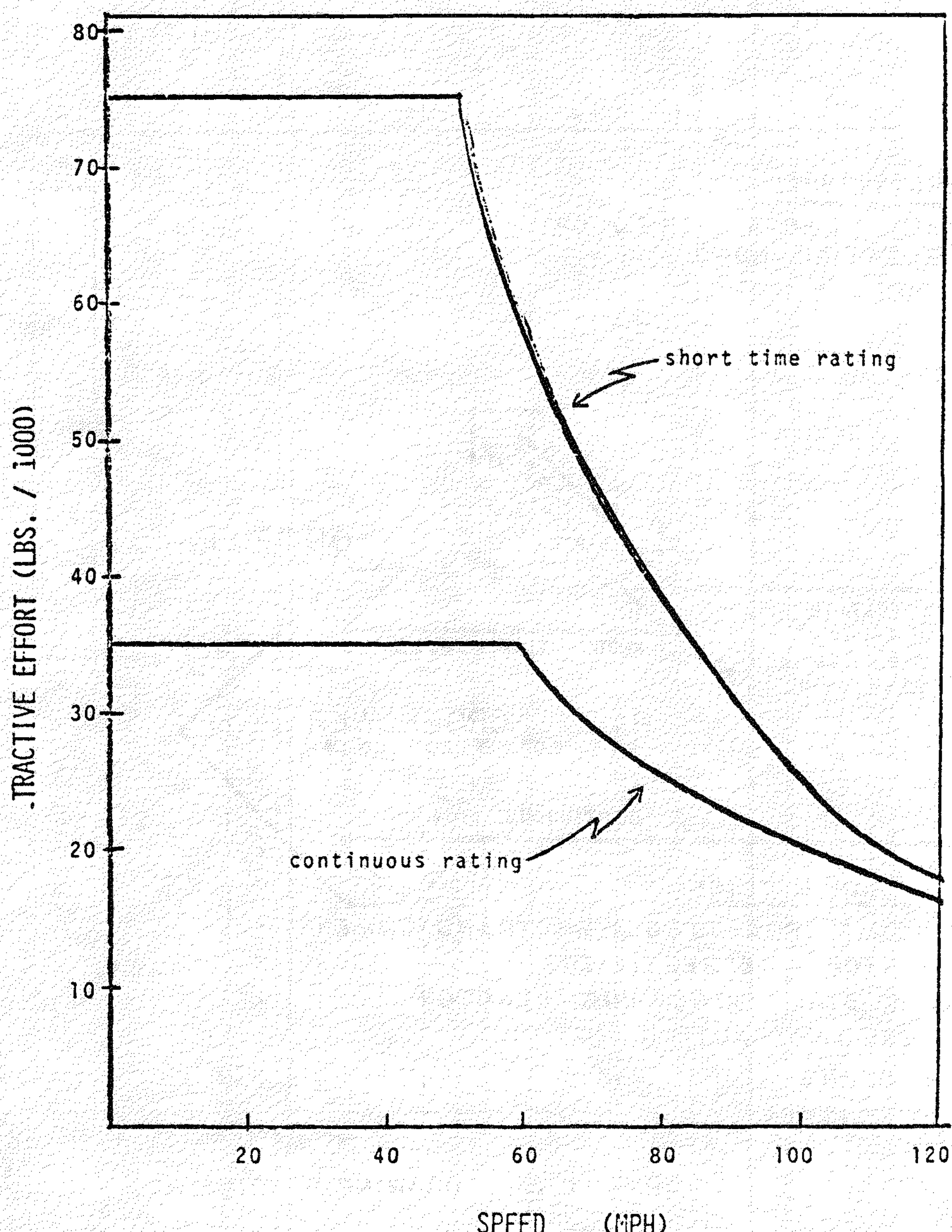


FIGURE IV-5b

UNION COLLEGE	DOT - OS - 60124	MAY 1977
TRANSPORTATION PROGRAM		

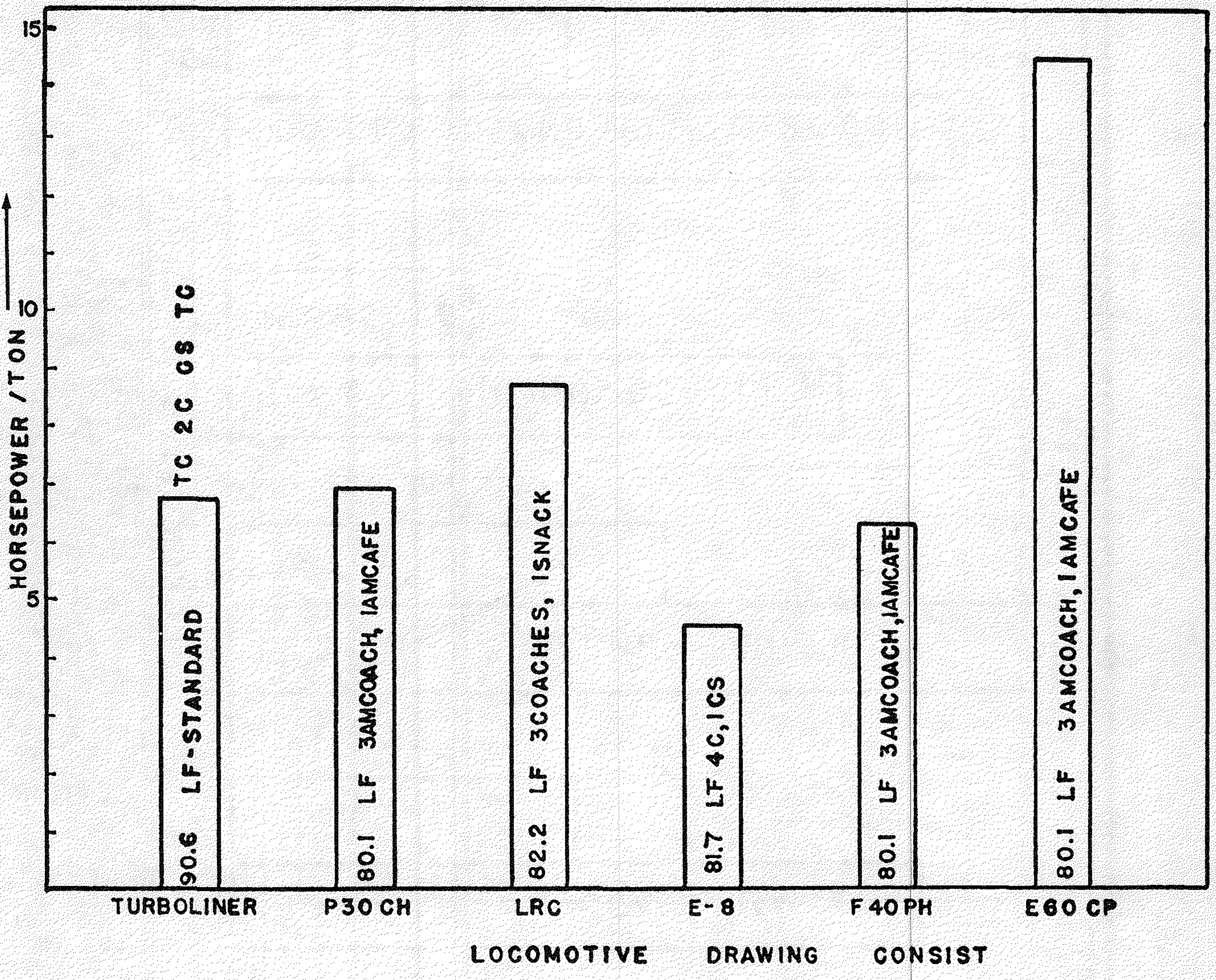


FIGURE IV-6a

HCRSEPOWER/TON RATINGS OF VARIOUS 250 PASSENGER SNACK BAR CONSISTS

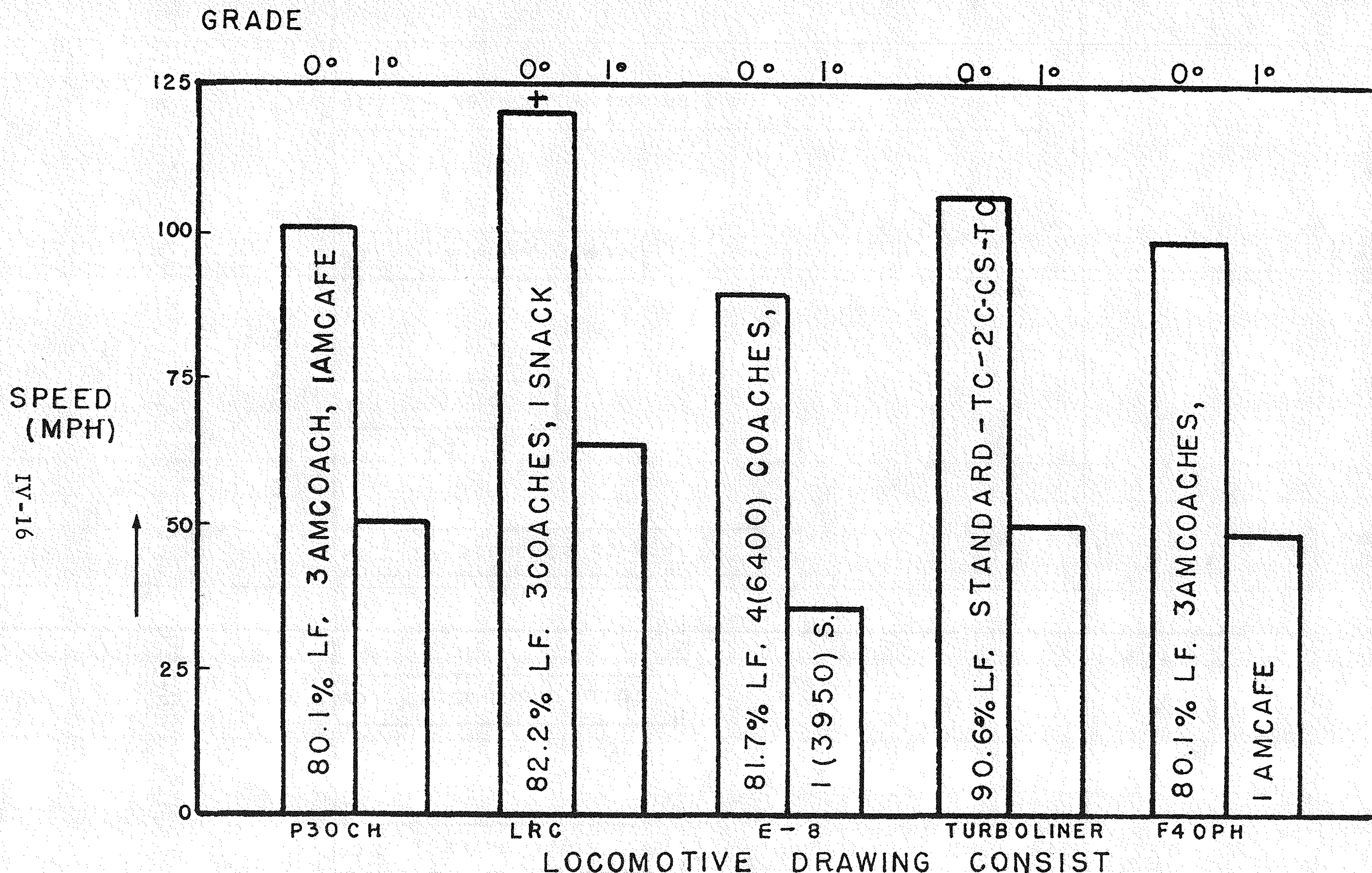


FIGURE IV-6b

Maximum Speed on Level Tangent Track and 1% Grade for Various Train Consists - 250 Seating Capacity (Snack Bar)

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