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IMPLICATIONS OF FUEL-EFFICIENT VEHICLES ON RIDE QUALITY AND PAS--ETC(U)

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REPORT NOS. DOT-TSC-RSPA-79-21

NASA-CP-2096

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**IMPLICATIONS OF FUEL-EFFICIENT VEHICLES ON
RIDE QUALITY AND PASSENGER ACCEPTANCE:
WORKSHOP PROCEEDINGS
WOODS HOLE, MASSACHUSETTS, SEPTEMBER 6-8, 1978.**

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A. R. Kuhlthau
(Editors)

U.S. DEPARTMENT OF TRANSPORTATION
RESEARCH AND SPECIAL PROGRAMS ADMINISTRATION
Transportation Systems Center
Cambridge MA 02142

AUGUST 1979

FINAL REPORT

DOCUMENT IS AVAILABLE TO THE PUBLIC
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VIRGINIA 22161

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
RESEARCH AND SPECIAL PROGRAMS ADMINISTRATION
Office of Systems Engineering
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Technical Report Documentation Page

1. Report No. DOT-TSC-RSPA-79-21 NASA CP-2096	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Implications of Fuel-Efficient Vehicles on Ride Quality and Passenger Acceptance: Workshop Proceedings Woods Hole, Massachusetts, September 6-8, 1978	5. Report Date August 1979	6. Performing Organization Code DTS-532
7. Author(s) Anna M. Wichansky and A.R. Kuhlthau* (Editors)	8. Performing Organization Report No. DOT-TSC-RSPA-79-21 NASA CP-2096	10. Work Unit No. (TRAIS) RS904/R9502
9. Performing Organization Name and Address U.S. Department of Transportation Research and Special Programs Administration Transportation Systems Center Cambridge MA 02142	11. Contract or Grant No.	13. Type of Report and Period Covered Final Report Sep 6-8, 1979
12. Sponsoring Agency Name and Address ** U.S. Department of Transportation Research and Special Programs Administration Office of Systems Engineering Washington DC 20590	14. Sponsoring Agency Code	
15. Supplementary Notes *Department of Civil Engineering University of Virginia Charlottesville VA 22901	**Also Sponsored by: National Aeronautics and Space Administration Langley Research Center Hampton VA 23665	
16. Abstract This report summarizes the proceedings of the 1978 workshops on passenger ride acceptance/fuel economy tradeoffs jointly funded by the U.S. Department of Transportation and the National Aeronautics and Space Administration. Four workshops were conducted under the auspices of the Transportation Research Board's Committee A3C11 on Ride Quality and Passenger Acceptance at the National Academy of Sciences Summer Study Center, Woods Hole, Massachusetts, from September 6-8, 1978. Topics of discussion included ride quality and passenger acceptance problems associated with enhanced fuel efficiency of automobiles (Group A) and aircraft (Group B); shifts in intermediate range (100-500 miles) travel from automobiles to public transit (Group C); and implications of increased size disparity for ground transport freight and passenger vehicles using shared guideways (Group D). In each group, major problem areas were identified and strategies for conducting pertinent research were outlined. A glossary of technical terms and a list of workshop participants are also included in the report.		
17. Key Words Ride Quality, Fuel Economy, Passenger Acceptance, Automotive Tech- nology, Aircraft Design, Modal Shift, Public Transit, Freight Railroads, Passenger Railroads, Trucks	18. Distribution Statement DOCUMENT IS AVAILABLE TO THE PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 118
		22. Price

Preface

As editors, we would like to exercise our prerogative to thank all our friends and colleagues whose efforts made this workshop successful and this report possible. We refer to the group leaders and group recorders whose names appear elsewhere in this report, to Don Sussman of DOT/TSC who so ably directed the conceptual organization of the workshop, to Ann Symmers and Ralph Stone of the University of Virginia who assisted in making the general arrangements for the meeting and in its daily operation, and to Connie Robinson and all the members of the staff of the National Academy of Science Summer Study Center at Woods Hole, whose untiring efforts made our stay so pleasant and enjoyable.

A special expression of gratitude on behalf of all the attendees is due to Jack Fearnside, Deputy Undersecretary of Transportation who, as he has at our past workshops, made a special effort to share an evening with us. It was most stimulating and profitable for all.

The workshop was funded in part by the U.S. Department of Transportation, through the Transportation Advanced Research Project of the Office of Systems Engineering, Research and Special Programs Administration, and by the Noise Effects Branch of the Acoustics and Noise Reduction Division of the NASA/Langley Research Center. Financial support was also indirectly obtained from the many organizations who provided the time and supported the expenses of their staff members who were in attendance. On behalf of the members of the TRB Committee A3C11, we wish to acknowledge our indebtedness and extend our thanks to all these organizations. Without their support, there would have been no workshop.

Finally, it should be emphasized that the reports of the specific groups are primarily the work of the recorders

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and chairmen of those groups. The recorders prepared the original drafts, which were then circulated to the group chairmen and selected members for comment. Additional drafts were reviewed by the editor and used as deemed appropriate.

No effort has been made to force the group reports into any particular style or format. The chairman and recorder had complete freedom to select the style of presentation that was most appropriate for their group. However, we have prevailed upon certain writers to provide a glossary of technical terms used in their respective presentations. They appear at the end of the appropriate sections. We hope that the glossaries will provide sufficient explanation of some of the more specific concepts which formed an integral part of the workshop discussions to make this report accessible to all who are interested in fuel economy/ride quality issues.

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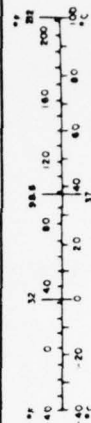
METRIC CONVERSION FACTORS

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				
sq in	square inches	6.5	square centimeters	cm ²
sq ft	square feet	0.09	square meters	m ²
sq yd	square yards	0.8	square meters	m ²
sq mi	square miles	2.6	square kilometers	km ²
ac	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				
tblsp	tablespoons	5	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cup	0.24	liters	l
pt	pint	0.47	liters	l
qt	quart	0.95	liters	l
gal	gallon	3.8	liters	l
cu ft	cubic feet	0.03	cubic meters	m ³
cu yd	cubic yards	0.76	cubic meters	m ³
TEMPERATURE (exact)				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
m	meters	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	sq in
m ²	square meters	1.2	square yards	sq yd
km ²	square kilometers	0.4	square miles	sq mi
ha	hectares (10,000 m ²)	2.5	acres	ac
MASS (weight)				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	st
VOLUME				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
m ³	cubic meters	0.26	gallons	gal
m ³	cubic meters	38	cubic feet	cu ft
m ³	cubic meters	1.3	cubic yards	cu yd
TEMPERATURE (exact)				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



1. INTRODUCTION

1.1 BACKGROUND AND OBJECTIVES

The transportation segment of our economy is a major user of energy and, in particular, petroleum fuels. Within this segment, there is considerable heterogeneity with regard to fuel efficiency both between transportation modes and between particular systems within modes. Choices of mode or system are not usually based on fuel considerations alone; however, the rising costs of energy and the predicted shortfall of petroleum fuels can be expected to increase profoundly the importance of fuel efficiency in the users' selection processes and directly influence the design of future systems.

Public acceptance of any mode is based on an interaction of factors beyond fuel efficiency; therefore, it is vital to understand the acceptability implications of planned or proposed changes in the features, design, and operations of transportation systems which are associated with increased efficiency.

To achieve optimum fuel efficiency while maintaining or improving on the existing level of service in transportation, two major areas must be addressed:

- a) development of the most energy-efficient vehicles and operating systems possible within each mode and,
- b) development of an improved understanding of the factors which will influence users to select transportation consistent with energy conservation for each trip or shipment.

Much work has already been done on the first issue. However, it has tended to focus on the technological aspects of improved energy efficiency and their effects on costs. Progress in the the second area is less obvious, although most certainly of equal, if not greater, importance.

Traditionally, mobility has been considered as a basic freedom of the individual, and our entire economic structure is based upon its availability. Thus, it would seem prudent

to attempt to find acceptable solutions to transportation energy problems while preserving this freedom, rather than imposing controls and limitations on it.

This leads to the inevitable conclusion that user choice is the key to progress in this area. While user choice certainly can be modified by influencing attitudes toward public responsibility, the major controlling factor is undoubtedly trip satisfaction, based on all of the decision parameters such as safety, dependability, convenience, time, comfort, cost, level of service, amenities, etc. In other words, user choice is largely based upon ride quality and service quality.

With these thoughts in mind, the members of the TRB Committee A3C11 felt that it was an appropriate time to bring together a group of individuals, actively working in all the various areas relating to the transportation energy problem, for an intensive discussion of all its aspects. Thus, the general purposes of the workshop were to examine the interaction between the user decision parameters and the technological and operational developments in transportation systems leading toward improved energy efficiency, and to define the issues and problems which result from this examination.

More specifically, the participants were asked to focus on the following set of five working objectives:

- (1) to identify the technological developments which will most probably contribute to improved energy efficiency in transportation vehicles and systems operations;
- (2) to predict the effects of technological advances on the parameters governing ride quality and service quality;

- (3) to estimate the impact on user acceptance which will result from changes in these parameters;
- (4) to define specific problem areas or policy issues which require further study, in order to improve the ability to predict the effects of technological and social developments on the use and manufacture of transportation systems;
- (5) to suggest possible approaches to the solution or investigation of these problem areas.

1.2 ORGANIZATION OF THE WORKSHOP

Rather than attempt to address the entire subject area, the Committee decided to form four working groups, each charged with a particular aspect of the overall transportation energy problem which was felt to be especially important. Group leaders were selected early in the spring and they, together with members of Committee A3C11, were responsible for selecting the individuals to be invited to participate. Although the basic format for the workshop called for the groups to work independently, ample opportunity was provided for interaction between the groups, both by regularly scheduled plenary sessions, as well as by informal consultation between groups.

As was the case with the most recent workshop held by the Committee,^{*} the University of Virginia was asked to serve as coordinator for the meeting. In addition to arranging for the meeting logistics, the University's School of Engineering and Applied Science agreed to provide a participant for each group who would serve as a recorder for

^{*}Kuhlthau, A. Robert (ed.), "Proceedings and Findings of the 1976 Workshop on Ride Quality," Lake Morey Inn, Fairlee, Vt., October 13-15, 1976. Report DOT-TST-77-38, NASA-CP-2006.

that group and prepare a digest of the group's activities and conclusions. The major body of this summary report is thus a collection of these group reports, with minor editing to provide continuity.

The four working groups and their membership are listed in the following section.*

1.3 INDIVIDUAL WORKSHOP ATTENDEES

Group A - Ride Quality and Passenger Acceptance Problems Associated with Enhancing Auto Fuel Efficiency

Chairman: Dr. Brian S. Repa
Engineering Mechanics Department
General Motors Research Laboratory

Recorder: Dr. Timothy C. Scott
Department of Mechanical and Aerospace Engineering
University of Virginia

Participants:

Mr. John Dinkel
Engineering Editor
Road and Track Magazine

Dr. Ricardo Dobson
Charles River Associates, Inc.

Mr. Paul Fancher
Highway Safety Research Institute
University of Michigan

Mr. James Heisler
Vice President
Market Facts, Inc.

Dr. Abraham D. Horowitz
Transportation & Urban Analysis
Department
General Motors Research Lab

Dr. Lorna Middendorf
Consulting Psychologist

Dr. Herbert Sachs
Department of Mechanical
Engineering
Wayne State University
(on sabbatical at U.S.
Department of Transportation,
Transportation Systems Center)

Mr. Nicholas Schaefer
Transportation Systems
Center
U.S. Department of Transportation

(continued)

*The names of all the participants are listed alphabetically in Appendix B along with their business addresses.

Group A - (Continued)

Dr. E. Donald Sussman	Dr. Larry M. Sweet
U.S. Department of Transportation	Aerospace & Mechanical
Transportation Systems Center	Sciences Department
	Princeton University

Group B - Ride Quality and Passenger Acceptance Problems
Associated With Aircraft Fuel Efficiency

Chairman: Dr. Ira D. Jacobson
Department of Mechanical and Aerospace Engineering
University of Virginia

Recorder: Dr. A. R. Kuhlthau
Department of Civil Engineering
University of Virginia

Participants:

Mr. D. William Conner
Aeronautical Systems Division
NASA/Langley Research Center

Mr. Donald Stark
Marine Division
Boeing Company

Mr. Brent Miller
Advanced Turboprop Office
NASA/Lewis Research Center

Mr. David G. Stephens
Acoustics and Noise
Reduction Division
NASA/Langley Research
Center

Professor Jan Roskam
Department of Aerospace
Engineering
University of Kansas

Mr. Ralph Stone
Department of Civil
Engineering
University of Virginia

Mr. George Scott
Air Traffic Control Systems
Research & Development
Federal Aviation Administration

Mr. L. F. Vosteen
Composite Primary Structures
Office
NASA/Langley Research Center

Group C - Shifts in Intermediate Range (100-500 miles)
Travel from Autos to Public Transit

Chairman: Dr. Joseph Dumas
Transportation Systems Center
U.S. Department of Transportation

Recorder: Dr. Larry G. Richards
Department of Civil Engineering
University of Virginia

Group C - (Continued)

Participants:

Mr. Brooks Bartholow
U.S. Department of Transportation
Research and Special Programs
Administration

Professor Dennis Gensch
School of Business Administration
University of Wisconsin-Milwaukee

Mr. Alan Grayson
U.S. Department of Transportation
Transportation Systems Center

Mr. Stanley E. Hindman
U.S. Department of Transportation
Urban Mass Transportation
Administration

Mr. Leon Jackson
Manager
Quantitative Market Analysis
AMTRAK

Mr. Barry Myers
Systems de Transport
Montreal, Quebec

Dr. Peter Stopher
Director of Research
Transportation Center
Northwestern University

Ms. Mary Lynn Tischer
U.S. Department of Transportation
Federal Highway
Administration

Dr. Anna Wichansky
U.S. Department of Transportation
Transportation Systems Center

Mr. Robert F. Wigmore
Staff Vice President
Piedmont Airlines

Group D - Implications of Increased Size Disparity for
Ground Transport Freight and Passenger Vehicles
Using Shared Guideways

Chairman: Dr. J. Karl Hedrick
Department of Mechanical Engineering
Massachusetts Institute of Technology

Recorder: Dr. Bradley Hargroves
Department of Civil Engineering
University of Virginia

Participants:

Mr. Glen G. Balmer
U.S. Department of Transportation
Federal Highway Administration

Mr. Timothy M. Barrows
U.S. Department of Transportation
Transportation Systems Center

Mr. Adrian Clary
Transportation Research Board
National Research Council

Mr. John Corbin
Ensco, Inc.

(continued)

Group D - (Continued)

Mr. Raymond Ehrenbeck
U.S. Department of Transportation
Transportation Systems
Center

Dr. John Jankovich
U.S. Department of Transportation
National Highway Traffic Safety
Administration

Mr. Chi-Tsieh Liu
U.S. Department of Transportation
Federal Highway Administration

Mr. Richard Scharr
U.S. Department of Transportation
Federal Railroad Administration

Dr. Leonard Segel
Highway Safety Research
Institute
University of Michigan

Dr. Robert J. Ravera
U.S. Department of Transportation
Research and Special Programs
Administration

Dr. David N. Wormley
Department of Mechanical
Engineering
Massachusetts Institute of
Technology

2. GROUP A

RIDE QUALITY AND PASSENGER ACCEPTANCE PROBLEMS ASSOCIATED WITH ENHANCED AUTO FUEL EFFICIENCY

2.1 GENERAL CONSIDERATIONS

2.1.1 Focus on Previous Workshops

The primary emphasis of previous workshops has been on achieving a better understanding of the nature of the ride quality problem in terms of the operational characteristics of existing vehicles. Problems related to the development of improved ride comfort standards and modeling of vehicle dynamics were more clearly defined and methods for their solutions proposed. This effort has resulted in a marked improvement in our ability to simulate vehicle behavior and passenger reaction to this behavior.

Until recently, passenger acceptance of vehicles could be related to factors such as performance and ride quality, and vehicle design changes could then be implemented in order to provide a better match between customer desires and vehicle behavior.

2.1.2 Effects of New Constraints

The effect of the need for improved fuel economy (whether real or imaginary) has been to introduce new factors of a psychological and sociological nature into the vehicle design problem. Customer preferences must now share the role of input status with regulatory requirements imposed by perceived long range fuel efficiency needs. These requirements are not always in harmony with customer desires, resulting in a situation in which industry must try to satisfy constraints which are often contradictory.

It became apparent quite early in the discussions that factors such as consumer attitudes about the existence of an energy shortage and the hierarchy of importance of vehicle attributes in the purchase decision cannot be overlooked. Such factors contribute new inputs to vehicle design criteria and complicate the problems facing industry.

2.1.3 Definition of the Group's Task

As a result of the above considerations, it was decided to split into two subgroups. The first subgroup concerned itself with the relationship between enhanced fuel economy and the technical problems facing the vehicle designer. The second subgroup addressed the subject of customer attitudes, not only toward vehicle ride quality and performance, but also on the overall perception of the general issues related to energy conservation.

In both cases the subgroups attempted to:

- . summarize the present status of increased automobile fuel efficiency efforts and indicate implications or trends for the future
- . identify specific problem areas
- . suggest future research needs.

The following report made by Group A is thus composed of a summary of the deliberations of the two subgroups.

2.2 TECHNICAL ASPECTS OF ENHANCED FUEL EFFICIENCY

2.2.1 Anticipated Engineering Changes

In order to meet requirements of enhanced automobile fuel efficiency, the following general engineering changes are anticipated:

1. Weight reduction:
 - a. Weight reduction with no size change through material substitution or other alterations.
 - b. Downsizing with similar or larger interior space.
 - c. Improved component design for higher efficiency with lower weight/size ratios.
2. Powertrain changes:
 - a. Improvements in conventional engines.
 - b. Switch to stratified charge and diesel engines.
 - c. Introduction of exotic systems.
3. Reducing horsepower capacity and requirements by reducing:
 - a. Aerodynamic drag.
 - b. Tire rolling resistance.
 - c. Engine accessory loads.

Some of these changes, such as downsizing and materials substitution, are currently being implemented by industry. Others such as major changes in powerplant type were felt to be of significance only in a longer range scenario which the group felt was beyond its capability to construct accurately at this time.

2.2.2 Resulting Technical Problems

Since most of the above items result in smaller vehicle size and/or weight, they have a direct influence on ride

quality. The group discussed and summarized the major technical problems involved as follows:

1. Material substitution often may lead to manufacturing cost savings because one part may replace a previous assembly. Conversely, from the standpoint of the customer, this may mean more costly accident damage repair.
2. Material substitution may introduce new corrosion problems from electro-chemical interaction of dissimilar metals.
3. Weight and size reduction may lead to new stability problems as vehicle mass centers change more drastically with engine and passenger placement.
4. Weight and size reductions influence vehicle ride, handling, and noise characteristics. This results in a greater need for integrated design methods using computer simulations to analyze and meet the constraints on design changes.
5. As unloaded (curb) weight drops, variable payload weight becomes a larger fraction of total weight. This increases problems of suspension travel, stiffness, and vehicle dynamics.
6. Present day vehicle designs provide relatively rigid body and frame structures having natural vibration frequencies that are much higher than those of the suspension and tire wheel-axle assemblies (unsprung masses), thereby removing the chance for dynamic interaction in the form of resonant vibration modes. If, in the course of weight reduction, the stiffness of body frame panels is substantially reduced, the sheet metal parts

may be excited by the low frequency vibrations of the suspension, resulting in vibration and noise. Weight reduction of the frame increases the chance for buckling and ultimate failure in collisions. In light of the above, weight reduction of body and frame is limited.

7. Material substitutions often cause customer acceptance problems because of reluctance to trust plastic and non-ferrous metals.
8. All things being equal, shorter wheelbase vehicles will have faster handling response but poorer ride quality and braking. Shorter vehicles also require more sophisticated techniques for collision energy management, as available crush distance decreases with body length.
9. The trend toward smaller engines introduces new noise problems often requiring increased sophistication in drive train design. However, European car designers have had to deal with these problems and have developed usable solutions.
10. Drivability, or the responsiveness of the engine to load and throttle changes, tends to decrease each time emission standards are upgraded, followed by a gradual recovery. Trade-offs between emissions and fuel economy will continue to cause drivability problems and will be important factors in driver acceptance.
11. Increased fuel efficiency will always be a function of tire design. The introduction of radial tires appears to be the best current technique for reducing rolling resistance, but there are cost

penalties and design problems which must be addressed in the use of these tires.

12. Downsizing of vehicles is not accompanied by reduced engine accessory loads in all areas. Electrical requirements, for example, remain essentially unchanged, as do passenger heating and air conditioning loads. Therefore, fuel economy gains will not be directly proportional to downsizing.

2.2.3 Status of Current Technology

It was generally conceded that most of the basic engineering technology for solving problems is available. Current needs involve the speed with which they can be brought to bear on the problems and a more concise definition of goals and criteria. For example, as references (3, 5-14) indicate, sophisticated computer models of vehicle dynamics are available but are not used or even available throughout the industry. Similarly, while composite materials are known to be of considerable value, the task of defining their properties through test and analysis is beyond the capabilities of industry alone in view of the urgency of incorporating them rapidly into vehicle designs. The short time frame also introduces the need for more generalized ride, safety, and performance standards which are flexible enough to encompass new design concepts without inhibiting innovation.

2.2.4 Proposed Research

The group identified nine areas where research is needed. These are summarized in Table 2-1* and discussed briefly below.

*In order to preserve continuity, Table 2-1 appears on Page 17

1. Properties of Lightweight Materials

Because of progress and rapid development of material technology, such as the introduction of high ultimate strength graphite and glass fibers and composite materials (combinations or laminates of metal and synthetic fibers), much design data which is required for various weight reduction schemes is not available. The support of research into the strength, wear, cost, and other properties of new materials would hasten their use in vehicle designs.

2. Consumer Acceptance of New Materials

It was noted that many consumers relate strength and safety with steel and will arbitrarily reject material substitutions in many areas. The group felt that a better understanding of this problem would be helpful in planning vehicle designs and marketing studies.

3. Aerodynamic Characteristics of Low Weight and Low Drag Vehicles

It is generally known that lighter vehicles are more subject to aerodynamic forces. While considerable work has been done towards understanding the nature of these forces, general design guidelines and cause-effect trends need to be summarized. The work of the many investigators should be brought together to form a more unified body of knowledge. The pay-off from such work would be high, since several safety and ride problems could be avoided. The group also felt that there may be sufficient gaps in the available data to warrant a high level of funding for more experimental work.

4. Effects of Downsizing and Associated Changes in Suspension Geometry on Ride, Handling, and Safety

This work might involve the use of existing computer models to perform generalized studies of the results of downsizing to give guidance for future vehicle designs. As was mentioned before, smaller vehicles require more careful attention to the interrelationships between suspension, aerodynamics and other factors (2). This increases the importance of integrated design techniques. A generalized vehicle simulator could be of great assistance in this area.

5. Technology Transfer of Advanced Vehicle Dynamics Analysis Techniques

The group recognized that technology transfer schemes are not always successful, but felt that the available knowledge of ride quality criteria, new materials, structural dynamics and advanced computer modeling needs to be better distributed throughout the industry. In terms of potential savings in time and effort, this project has a high pay-off if successful. While it was not clear exactly how much technology might be handled most effectively, a low level, long-term program implemented through professional societies was proposed.

6. Effect of Government Standards on Efficiency of Vehicle Designs

Several members of the group pointed out situations in which government standards conflict with the need for more fuel-efficient vehicles. It was indicated that current or proposed standards may be inappropriate for new design concepts or materials and may limit innovation. The potential

pay-off from a program to review and advise new standards, with testing done to study applicability, was felt to be high.

7. Driver-Related Ride Quality, Noise, and Handling Requirements

The group felt that there is enough difference between the driver (who has not been studied extensively) and the passenger (who has been the object of considerable study) to warrant research into driver ride quality requirements. Such research would be an extension of what has already been done for passengers and would provide required information in evaluating the ride and handling performance of proposed, new fuel-efficient vehicles.

8. Suspension System Optimization

As vehicle size decreases, the use of items such as independent rear suspension becomes more desirable. Since capital and operating cost penalties are associated with most such changes, an optimization study would be of considerable value. This could lead to improved ride and handling at minimal cost and weight. It could also indicate how small a vehicle could become before more advanced concepts such as active suspension controls would be necessary.

9. Determination of Vehicle Total Life Cost

A study of the relative importance of durability, initial cost, depreciation, fuel economy and other factors on vehicle total life cost was felt to be a low-cost, low-risk project with high pay-offs. Since these factors have changed so radically over the past few years, a clear picture of vehicle cost is no longer possible. Information in this area is vital to product planning and marketing.

TABLE 2-1. SUMMARY OF NEEDED RESEARCH ON VEHICLE ENGINEERING

RESEARCH ITEM	PAYOFF	RISK*	FUNDING**	PRIORITY
Properties of Lightweight materials (Strength, vibrations, manufacturability)	Very High - Large potential energy savings - Will reduce time to implement design changes	Very Low	Moderate to high (long term)	Very High
Consumer Acceptance of New Materials	High Helps understand and counteract rejection of beneficial improvements	Moderate	Low	High
Aerodynamic Properties of Low Weight and Low Drag Vehicles	High - Provide needed drag data - Avoid detrimental impacts on safety and handling	Low	High (long term)	High
Effects of Downsizing and Changes in Geometry on Ride, Handling, and Safety	Moderate - Establish downsizing trends and directions - Provide guidelines for future vehicle designs	Moderate	Moderate	Moderate
Technology Transfer of Advanced Vehicle Dynamics Analysis Techniques	High - Better distribution of existing knowledge - Speed up implementation	High	Low	Moderate
Effect of Government Standards on Efficiency of Vehicle Designs	High - Poorly defined standards may limit innovation - Standards may not match characteristics of new designs	Low	High	High
Ride Quality, Noise, and Handling Criteria for Drivers	Moderate - Leads to design improvements - Clarify differences between driver and passenger	Moderate	High (long term)	Moderate
Suspension System Optimization	High - Minimize cost, weight - Look at active control systems	Moderate	Moderate	Moderate
Determination of Vehicle Life Cost	High Determine relative influence of vehicle attributes	Low	Low	High

* Risk is defined as the probability that the project will not achieve its desired goals.

** Funding levels are defined as:

Low = Under \$100,000/year
Moderate = \$100,000 - \$300,000/year
High = Over \$300,000/year

2.3 BEHAVIORAL FACTORS AND THEIR IMPACT UPON REQUIRED RESEARCH

2.3.1 Customer Attitudes

It was noted that consumers generally do not believe in the existence of an energy shortage. This sentiment was felt to be strongest among those who drive vehicles with higher fuel consumption. When consumers acknowledge the possibility of an energy shortage, they frequently refer to American technology as a means of resolving it. Consumers consistently avoid the assumption that they will have to change their behavior in response to an energy shortage. When confronted with the possibility of having to conserve energy, they express a feeling of victimization by large institutions. That is, consumers believe that they are being taken advantage of by the government, the auto industry and the oil companies.

One consumer researcher at the meeting suggested the following order of importance for automobile attributes: comfort, safety, performance, and economy. Others noted that this order was not invariant across market segments. The notion of economy in the minds of consumers included a variety of components, such as fuel costs, repair costs, and monthly loan payments.

It was observed that most consumers do not actually seek out fuel economy. There are indications, however, that consumers may be willing to trade off performance and styling for fuel economy, if a trade-off is necessary. Presumably, other automobile attributes such as interior size and comfort should not be traded off in pursuit of improved fuel economy designs which are acceptable to customers.

2.3.2 Implications to the Vehicle Designer

If customers indeed rate comfort, safety, and performance above economy, then those changes implemented to meet regulatory

economy standards (vehicle and engine size reduction) are in direct opposition to the customer's perception of desirable vehicle characteristics. It is important to differentiate here between customer perceptions and actual fact, since size reduction does not necessarily imply degradation in comfort and safety. The vehicle designer is thus faced with the task of satisfying customer and regulatory demand simultaneously. To do so he must have a better understanding of how the customer will respond to various design changes from other than a rational viewpoint.

2.3.3 Impact on Required Research

The constellation of consumer beliefs relative to the energy shortage is not consistent with a massive move toward the purchase of fuel efficient vehicles. However, it was noted that the 1977 General Motors downsizing of its standard size cars is generally considered to be successful. Consumers bought the cars. In addition, it appears that the desire to obtain better fuel economy is a major motivating factor among those who purchase these downsized cars. Further research was called for to clarify the apparent inconsistency between consumer disbelief in the energy shortage and their purchase of fuel-efficient vehicles.

2.3.4 Approach to Research

It was emphasized that by and large, the research required is in the nature of marketing, and it is vital that this be very carefully structured. The marketing concept was summarized as having four principal components: (1) monitoring of consumers; (2) communicating to consumers; (3) monitoring the response of consumers to the communications and the products; (4) modifying products and communications to serve the needs of consumers better. The need to divide the consumers, such as future auto buyers, into market

segments prior to all other analyses was emphasized as an exceedingly important step.

2.3.5 Proposed Research

Five research approaches were suggested as appropriate for obtaining quantitative data on how consumer characteristics relate to the acceptance of fuel-efficient motor vehicles. These are summarized in Table 2-2* and discussed below.

1. Demographic Characteristics vs. the Auto Fleet

One panel member strongly urged the determination of correlations between demographic characteristics and ownership of the United States auto fleet. The workshop members generally acknowledged that this kind of research would result in a moderately high pay-off and that it involved a low risk. The research strategy involves correlations and cross-tabulations between demographic characteristics of people across the United States and the automobiles that they own in their households. Because of the way data is currently collected, it was suggested that this analysis be conducted at the county level. This analysis could identify the characteristics of who buys what kind of cars, what regions of the country they are from, and how weather affects auto ownership patterns. Because data on demographics and auto ownership may be collected over a substantial period of time, it is possible to monitor changes in the auto fleet on a long-term or longitudinal basis.

2. Consumer Survey Techniques

Consumer survey techniques were recommended as another methodology to assess consumer reaction

*See Page 24

to fuel-efficient vehicles. The group felt that this approach was complementary to the demographic analysis suggested in the previous paragraph. It was also felt that the pay-off from this approach would be high and the risk relatively low. Consumer survey techniques would result in the acquisition of both attitudinal and demographic data as well as auto ownership and usage patterns. By collecting data from individuals, it will be possible to perform analyses at a finer grain of detail than is possible in the county level of analysis suggested above. Through such methods as multidimensional scaling, causal analysis, and conjoint measurement, it will be possible to develop models which describe the process by which consumers come to own vehicles of different sizes. This process is important because it will help to design improved marketing strategies for the sale of fuel-efficient vehicles, and it will aid in the understanding of the impacts of Federal regulations on the automobile industry.

3. Travel Diaries

Travel diaries by vehicles at the household level were suggested as a third research approach. This research strategy was evaluated as having a high potential pay-off, but it was felt that there was a moderate risk of obtaining that pay-off. The panel members expressed concern over the validity of diary data. People who agree to fill out questionnaires over time are likely to be different from the general population who will avoid the onerous task. On the other hand, it was felt that the methodology could generate some highly useful information such as number of miles traveled by vehicle, fuel consumption by vehicle, occupancy by

vehicle, travel by time of day, and the function of different automobiles for household transportation.

4. Field Simulation

Field simulations, which involve the use of modified existing vehicles, were discussed as a fourth research approach. This fourth methodology was evaluated as having a high pay-off, but it involved some risk in the attainment of that pay-off. The research approach is attractive because it allows engineers to evaluate near-term design features in the form of simple modifications to existing vehicles which can then be developed as prototypes for limited consumer use. Such vehicles have been developed in the past, for example, by Gau (4). Consumers can then evaluate the vehicles, and these evaluations can be fed back into the designs before they are finally manufactured for the general public. Consumers having direct experience with the attributes of the prototype vehicle would probably be able to provide highly accurate data on its acceptability. On the other hand, consumers would only have access to these vehicles under unusual circumstances (i.e., the experimental evaluation period). Therefore, selection of the user/evaluators would have to be done very carefully, in order to minimize the bias associated with projecting consumer preferences from small groups of subjects.

5. Gaming Simulations

The last research methodology to be considered was simulation of consumer response to market choice through "gaming." This technique was considered to have high potential payoff with low

risk of failure. In gaming simulation, a set of procedural rules are developed which provide the subject/participant with feedback on the outcomes of his or her responses. The participant selects one type of vehicle from a choice set, and then uses it in various simulated situations. Vehicle use is constrained by rules dictated by the vehicle's hypothetical performance, capital maintenance costs, and other capacities. As the game progresses, the implications of the vehicle choice "feed back" and affect the player/participant's subsequent decision processes.

Gaming simulations are different from field simulations in that they require no hardware, and can be used to evaluate radical changes in the automobile and/or the overall transportation system in which the automobile is used. Proper design of the games can provide valuable insight into potential public response to automobile design and transportation systems use as a whole. Design of an appropriately sophisticated game requires extensive efforts by highly skilled researchers, but, once designed, the game can be readily and economically modified to examine numerous possibilities at low cost.

TABLE 2-2. SUMMARY OF NEEDED RESEARCH ON CUSTOMER CHARACTERISTICS

<u>ITEM</u>	<u>PAYOFF</u>	<u>RISK*</u>	<u>FUNDING**</u>	<u>PRIORITY</u>
Demographic Characteristics of Owners vs. Characteristics of Vehicle Fleet	(Moderate) - Market segmentation analysis - Relationships between geographical regions, weather, & auto ownership - Changes in auto fleet	Low	Moderate	High
Consumer Survey Techniques	(High) - Market segmentation analysis - Individual motives for car purchase - Marketing strategy - Ownership patterns - Differences among market car sizes, particularly new cars	Low	High	High
Travel Diaries	(High) - Vehicle miles traveled - Fuel consumption - Trip purpose and distribution - Occupancy - Time of day - The function of auto for personal travel	Moderate	High	Low
Field Simulations	(High) Evaluation of near term design features	Moderate	High	Moderate
Gaming Simulations	(High) - Consumer response to radical engineering innovations - Feedback on consumer choice	Low	Moderate	Moderate

* Risk is defined as the probability that the project will not achieve its desired goals.

** Funding levels are defined as:

Low = Under \$100,000/year
Moderate = \$100,000 - \$300,000/year
High = Over \$300,000/year

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3. GROUP B

RIDE QUALITY AND PASSENGER ACCEPTANCE PROBLEMS ASSOCIATED WITH AIRCRAFT FUEL EFFICIENCY

3.1 INTRODUCTION

As its first task, the group undertook the definition of the specific areas with which it should be concerned in discharging its responsibilities. These are areas in which technological advances leading to increased fuel economy are taking place or will occur in the future, and the means by which the impact of these technological advances on ride quality and acceptance will be evaluated.

In response to the former, the following general areas with specific developments within each were identified for further study:

1. Aerodynamics
 - . New airfoils
 - . Laminar boundary layer control
 - . Variable camber*
 - . High-lift devices
 - . Computational techniques
2. Propulsion
 - . Jet
 - . Propeller
 - . Types of fuel
 - . Blowing techniques* (V/STOL)
 - . Drive train (helicopter)
3. Structures
 - . Structural design
 - . New materials
 - composites
 - aluminum technology

*See Glossary at the end of this section.

4. Flight controls
 - . Fly by wire*
 - . Fly by light*
 - . Active controls*
 - ride smoothing
 - structural damping*
5. Operations
 - . Flight profiles or trajectories
 - terminal
 - enroute
 - . Spacing of aircraft
 - . Ground handling.

With respect to the evaluation of impacts, it was noted that several groups having many diverse interests would be involved. These include:

- . Passengers
- . Shippers or receivers of cargo
- . Pilots
- . Air traffic controllers
- . Airline operators
- . Airport managers
- . Community interests.

Furthermore, in reaching decisions concerning their acceptance of more energy-efficient aircraft or procedures, these groups will be concerned with one or more of the following factors:

- . Ride quality
- . Economics
 - cost
 - time savings

*See Glossary at the end of this section.

- . Performance of service
 - dependability
 - convenience of use
 - scheduling
- . Seating
 - accommodations
 - capacity
- . Amenities.

It was also noted that the elements of human factors involved in this process of acceptance evaluation are in themselves a discipline in which technological advances are occurring and likely to continue to occur. Thus it too must receive consideration in a manner similar to the five areas identified above.

Having defined the scope of the effort, a method of approach was next outlined as follows to conform with the general objectives of the workshop:

- (1) Examine the state-of-the-art in each technology area;
- (2) Define in more detail the fuel efficiency implications of the various specific developments in each area;
- (3) Estimate the probable impact that each will have on ride quality and acceptance;
- (4) Predict the time frame for possible implementation of these developments;
- (5) Identify future research needs.

The remainder of the report will summarize the application of the first four steps of this approach to each area in turn, and will conclude with sections which will illustrate the implications of fuel efficiency to the future development of aircraft types and summarize recommendations for the overall research needs which now exist.

3.2 AERODYNAMICS

Improvement in fuel consumption through developments in aerodynamics can be realized through any of the following phenomena:

- . Reduction in drag
- . Increases in lift-to-drag ratios (L/D)
- . Changes in lift curve slopes*
- . Changes in wing loading
- . Changes in operational speeds
- . Changes in operational altitudes.

Let us first examine the implications of each of these in general and then analyze some of the specific developments which are concerned with one or more of these areas.

Reductions in drag and increases in L/D ratios allow operations at a given speed and altitude with reductions in the required thrust. This reduces fuel consumption and also to some extent engine noise. The attendant improvement in ride quality would probably be small.

An increase in the lift curve slope will also increase response to gusts. The relationship with comfort is essentially inverse with an increase in lift curve decreasing the comfort.

Reductions in wing loading will relate directly to poorer ride quality, in as much as lighter wing loading results in more susceptibility to gusts.

Changes in operational speed also have a direct relationship to the gust response.

Changes in operational altitude will essentially change the gust environment in which the aircraft operates - the lower the altitude the more severe the gusts, and therefore the poorer the ride quality.

*See Glossary at the end of this section.

Let us now examine several specific designs which are either well tested and ready for application or in the research and development state.

3.2.1 Supercritical Wing

This device, which is currently in use on some types of aircraft, provides for a higher aspect ratio*, thicker wing which offers a marginal amount of fuel savings. The feeling is that future designs may have aspect ratios as high as 10 or 12 vs. the normal 7-8. A higher lift coefficient is obtained at maximum L/D, and hence an increased sensitivity to gusts. Some type of gust alleviation (sweep or active controls) will probably be required to maintain current standards of ride quality.

3.2.2 Variable Camber Wing

This is a new development under study at NASA/Langley. The concept is to be able to continually vary both the leading and trailing wing edges during flight. In this manner the wing may be optimized at every point in flight for the match between drag reduction and lift distribution on the wing. Resultant fuel savings should run about 2 or 3 percent. There will probably be little effect on ride quality, but the visual changes to the wing in flight may generate some image problems among certain types of passengers.

3.2.3 Other Drag Reduction Techniques

A major area for drag reduction is interference drag*, and improvements in fuel economy at a given speed may range from 2 or 3 percent in transports to somewhat higher values in general aviation aircraft. From the acceptance point of

*See Glossary at the end of this section.

view, a slight noise reduction should occur both from reduced engine noise and from flow. It is interesting to note that the airframe noise alone of a DC-10 in a landing environment (i.e., low altitude) is almost 80 EPNDB (Effective Perceived Noise)* which is the figure being used as a criterion for permissible levels after curfew at airports. Thus, the matter of reduction of airframe noise is quite important.

Summing over all the airfoil design type improvements discussed thus far, it should be possible to achieve a fuel savings of about 5-6 percent in transport aircraft and 10-15 percent in general aviation aircraft. An additional 2 or 3 percent is probably available to propeller-driven aircraft through proper aerodynamic design of the propeller blades.

3.2.4 Boundary Layer Control

Operating the wing in a laminar boundary layer (the layer of relatively smooth air flow adjacent to the wing) has an enormous potential for fuel economy. Estimates range anywhere from 20 to 40 percent. Not only is drag reduced, but there is a benefit in the fact that the angles of attack at which "stall" is induced are much higher than otherwise possible.

Almost certainly, the laminar regime will have to be produced by artificial means, such as active suction slots on the wing surface to remove the boundary layer. There will probably be marked effects in both ride motion and noise. In the former case, the designer will almost certainly wish to take advantage of the fact that the laminar boundary layer permits a greater aspect ratio, and less sweep, and results in lower wing loading. All of these tend toward poorer ride motion and, collectively, the degree of degradation could be serious (perhaps as great as 20-25 percent in some circumstances).

*See Glossary at the end of this section.

There are ways to compensate but, in general, they may lead to increased cost, complexity and even some reduction in the apparent fuel savings.

The implications on noise are not at all clear. The suction devices will generate noise, but it is quite likely that the net results will be less than a direct additive effect. The noise characteristics will probably change but the details of these changes and their effects are not yet well understood. The general feeling seems to be that there will not be any major effects on either interior or community noise.

3.2.5 High Lift Devices

High lift devices serve to increase the lift to drag (L/D) ratio, thereby potentially improving fuel economy. Generally, most conventional devices have been utilized as alternatives to simplification of wing designs, resulting in reduced maintenance costs. High lift devices have not traditionally been used to improve fuel economy. In fact, powered (as opposed to conventional) devices are poor in fuel efficiency and appear to have no real commercial potential.

3.2.6 Computational Techniques

Improved computational techniques for aerodynamic design will greatly enhance the ability to conduct more comprehensive analyses of system and component integration. A synergistic effect should result leading toward the inclusion of more new techniques into the early stages of configuration design. Thus all technologies can be combined toward common objectives of fuel efficiency and better understanding of human factor inputs such as noise and vibration.

The above considerations are summarized in tabular form in Table 3-1, which also includes estimates of the time frames on which the effects of the technologies might be evident. It is difficult to predict the acceptance of developments in airfoils because it depends on how they are used operationally, how they are combined in the configuration design, and whether or not new control practices are used.

3.3 PROPULSION

The discussions centered around five major technology areas:

- . Improvements in turbo fan engines
- . Improvements in turbo prop engines
- . New fuels
- . Blowing techniques
- . Helicopter drive trains.

3.3.1 Turbo Fan Engines

Improvements in fuel efficiency are seen in two types of developments, each occurring in a different time frame. In both cases, the changes are not expected to have any noticeable effect on ride quality or passenger acceptance.

- a. Near term improvements (within approximately the next five years)

Fuel consumption will be improved about 5 percent by a number of small improvements in components. It will be possible to incorporate these improvements in existing engines by retrofitting.

- b. Far term improvements (5 to 10 years)

A new generation of higher by-pass ratio*

*See Glossary at the end of this section.

TABLE 3-1. THE EFFECTS OF ADVANCES IN AERODYNAMICS TECHNOLOGY

	<u>TIME FRAME</u>	<u>RQ</u>	<u>PA</u>	<u>CA</u>	<u>FS</u>
AIRFOILS	MED	U	U	-	M
LAMINAR BOUNDARY LAYER CONTROL	FAR	N	N	-	P
HIGH-LIFT DEVICES	NEAR	P	P	-	-
VARIABLE CAMBER	FAR	-	-	-	M
COMPUTATIONAL TECHNIQUES	NEAR	P	P	P	M
DRAG REDUCTION TECHNIQUES	MED	P	P	-	M

P - POSITIVE
 N - NEGATIVE
 - - NIL
 M - MARGINAL
 U - UNCERTAIN

RQ - RIDE QUALITY
 PA - PASSENGER ACCEPTANCE
 CA - COMMUNITY ACCEPTANCE
 FS - FUEL SAVINGS

(8-10) engines appears likely which would incorporate a fuel use reduction of about 15 percent over the best designs of today. These improvements will be obtained through an increase in engine operating temperatures, increase in pressure, and through changes in internal designs. An example of the latter would be reduced clearance at the blade tips.

3.3.2 Turboprop Aircraft

The potential for fuel savings here is very great, but there are also potential ride quality and acceptance problems. The current research on turboprop design is aimed at producing aircraft up to a 250,000 lb. weight with load capacity of 50-250 passengers and capable of operating in the Mach 0.8 range. Thus, they would be comparable in speed, range and capacity with all but the very largest of today's turbofan aircraft.

a. Fuel savings

Studies by all the major airframe manufacturers have shown that the potential exists for a 15-20 percent fuel savings over the most advanced design turbofans discussed above. In comparison with a current technology aircraft such as the DC-9, the potential for fuel savings is between 40-50 percent even though the turboprop engines probably will carry a weight penalty. The fuel savings is also dependent on the mission. For example, turboprops excel at the shorter ranges.

b. Ride quality and acceptance

The basic problems are those of noise, both interior and exterior, and vibration. It is interesting to note that the airframe manufacturers

have included the problem of cabin environment in a list of four major technology requirements before they will seriously consider the turbo-prop engines for advanced high speed commercial aircraft. Thus, the largest potential for fuel efficiency in commercial aircraft may hinge on the ability to provide a cabin environment that is as good as the present turbofan aircraft.

The basic problem stems from the fact that the propeller tip speeds will probably be supersonic in order to achieve the cruise speeds desired. Thus, there will be tip shocks against the fuselage and pure tone noises and "beating" are anticipated in the cabin. At the present time we have very little information for the design of fuselages or cabins to attenuate pure tone noise, nor do we understand the passenger reactions to pure noise in the range of 100-200 Hz. The answers to these questions will certainly govern the acoustic weight penalty that must be imposed on the aircraft, and may even determine the ultimate viability of the aircraft for passenger service.

In the terminal areas, the noise of turbo-prop aircraft on the ground should cause no problem. Current technology is already much quieter in this regard than the DC-10. However, there may be some problems from the propagation of weak shocks from the blade tips on take-off and landing.

It is anticipated that the operating characteristics of the turboprop engines will be similar to the turbofans and so flight profiles, sensitivity to gusts, etc., should be about the same for equivalent missions.

3.3.3 Blowing Techniques

Neither upper nor lower surface blowing systems seem to have much future in the commercial passenger market in the next ten years. They have many ride quality problems and offer no advantages in fuel reduction, in fact, they will probably carry fuel penalties.

3.3.4 Helicopters

A major problem is noise in the gear train. Gear train research is receiving considerable attention throughout the industry, but the ability to solve problems of long-term exposure to noise, both interior and exterior, is not clear.

3.3.5 New Fuels

The objective here is to replace petroleum based fuel with something that can be derived from coal. There are three current favorites, but the potential of all of them is limited to a very long-range.

a. Synthetic jet fuel

Would have little effect on the aircraft configuration or operation and hence ride quality.

b. Methane

The production process would lead to the least expensive of the alternate fuels, and it would have little effect on the configuration design of current aircraft.

c. Hydrogen

There are lots of problems associated with the use of H_2 as an aircraft fuel. First and foremost are the safety and image problems as

they impact on user acceptance. It is extremely expensive to produce and handle. Also, since it must be carried in the aircraft as a liquid, it causes high volume requirements for storage. This also calls for a wider fuselage which could cause poorer ride quality, particularly in the lateral mode.

3.3.6 Summary

The effects of advances in propulsion technology are summarized in Table 3-2.

3.4 STRUCTURES

3.4.1 Materials

New materials for use in the structural design of aircraft generally fall into two main classes, composites and advanced metals.

a. Composites

- . Provide weight reductions of 25-35 percent per part
- . Reduce mass required for balancing on balanced surfaces
- . Improve response of control surfaces - due to reduced mass
- . Stiffness will have to be tailored (perhaps with some weight and size penalties) to meet the requirements of aeroelasticity and aerodynamic deflections.

b. New metals

- . Advance aluminum alloys show promise of a 10-12 percent weight reduction

TABLE 3-2. THE EFFECTS OF ADVANCES IN PROPULSION TECHNOLOGY

	<u>TIME FRAME</u>	<u>RQ</u>	<u>PA</u>	<u>CA</u>	<u>FS</u>
TURBOFAN ENGINES	NEAR	-	-	-	P
TURBOPROP	MED	?	?	?	P
UPPER/LOWER SURFACE BLOWING	?	N	N	N	N
HIGH BYPASS SMALL ENGINE	NEAR-MED	P	P	-	P
HELICOPTERS	?	M	?	?	?
NEW FUELS	VERY FAR	?	N	N	?

P - POSITIVE
 N - NEGATIVE
 - - NIL
 M - MARGINAL

RQ - RIDE QUALITY
 PA - PASSENGER ACCEPTANCE
 CA - COMMUNITY ACCEPTANCE
 FS - FUEL SAVINGS

- . Super plastic-formed-diffusion-bonded titanium is also a possibility
- . Both of the above could lead to higher allowable operating stresses.

3.4.2 Applications

The introduction of new materials into production will depend upon the component being replaced. Some examples are:

- . Aerodynamic fairings* (now being done)
- . Primary structure (approximately 1990 time frame)
Emphasis will be on tailored stiffness rings to bolster flimsy aircraft members and on use in high aspect-ratio wings. Also fuselage applications
- . Engine cowlings, nacelles*, etc.

3.4.3 Fuel Saving

The potential saving in fuel due to new materials is, of course, directly related to weight reduction. However, the problem here is that many manufacturers and customers are currently interested in seeing this weight reduction translated into improved performance characteristics such as increased payload, range, etc., resulting in little change in the gross weight of the aircraft.

3.4.4 Acceptance

There are several groups influenced, each with their own concerns.

a. Builder

- . There is a general lack of experience with the new materials; this leads to development costs to acquire a data base, develop design methods, determine certification procedures, etc. - e.g., fatigue.

*See Glossary at the end of this section.

- . Uncertainties over manufacturing costs.
- . Lack of maintenance experience leading to uncertainties over structural warranties.
- b. User (airline)
 - . Uncertainties over inspection requirements.
 - . Maintenance costs including personnel selection, training, etc., are not well understood.
- c. Customer (passenger)
 - . General image - will it be regarded as a new advanced aircraft - or as a "plastic airplane?"
 - . Noise - noise transmission may be a factor because of thinner sections in panels; may have to pay some penalty for noise suppression.
 - . Vibration - could be somewhat higher because integrated fabrication with composites offers fewer joints for potential damping.

3.4.5 Implementation

Implementation will depend upon the ability to supply these new materials in a cost-effective manner.

To a degree, broad-based usage of new materials will depend upon the abilities to improve structural design techniques, such as :

- . Automated methods to permit evaluation of more parameters early in the design stages.
- . Multidisciplinary programs which will permit preliminary design trade-off studies.
- . Reducing composite structural design to "handbook" methods so that aircraft companies can apply them extensively.

The question of the vehicles to which new materials might be applied depends upon the applications. There are

three major classes.

a. Retro-fit aircraft

Very limited. On current aircraft, it is usually too costly to change materials in an existing design.

b. Derivative aircraft

Some potential exists for special applications.

- . Lockheed is changing from a mix of aluminum and fiberglass to Kevlar/epoxy on leading edge and trailing edge panels, and some fairings on long range L-1011-500 aircraft.
- . Douglas is considering applications in control surfaces for derivative DC-10.

c. New aircraft

Potential is good. For example, proposals for the Boeing 767 call for about 4,200 lbs, of composites.

3.4.6 Summary

A summary of the effects in structures is shown in Table 3-3.

3.5 FLIGHT CONTROLS

In the context of today's proven applications and future potential, flight controls offer both a possibility for increased fuel efficiency and a definite improvement in the motion components of ride quality. These benefits can accrue either directly, through such means as motion and vibration alleviation to improve ride quality, or through energy management systems. Flight controls can also help in an indirect sense by compensating for ride quality deficiencies

TABLE 3-3. THE EFFECT OF NEW DEVELOPMENTS IN STRUCTURES

	<u>TIME FRAME</u>	<u>RQ</u>	<u>PA</u>	<u>CA</u>	<u>FS</u>
COMPOSITIES FOR SECONDARY STRUCTURE	NEAR	-	-	-	P
COMPOSITES FOR PRIMARY STRUCTURE	MED-FAR	-	-	-	P
NEW METALS	FAR	-	-	-	P
STRUCTURAL ANALYSIS	MED-FAR	-	-	-	P

P - POSITIVE
 N - NEGATIVE
 - - UNKNOWN
 M - MARGINAL

R - RIDE QUALITY
 PA - PASSENGER ACCEPTANCE
 CA - COMMUNITY ACCEPTANCE
 FS - FUEL SAVINGS

generated by other fuel-saving devices or techniques. Common, or routine, application of flight controls will also encourage other technological developments such as boundary layer control, structural weight reduction through load alleviation, etc. Load alleviation systems can be used to improve fatigue life.

Flight controls fall basically in three categories: reversible, separate surface, and irreversible. An indication of what might be expected in each is outlined below.

3.5.1 Reversible Controls

Examples: Cessna C 172

Learjet 35/36

Ride quality: Auto pilot loops with inner damping loops can provide some ride improvement.

Fuel economy: Nil.

Problem: Feedback of surface motions to pilot and/or to pedals and wheel.

3.5.2 Reversible Controls with Parallel Separate Surface Automatic Controls

Examples: U. Kansas/NASA/Beech M99

Learavia "Futura"

Ride quality: Significant improvement attainable

Fuel economy: Significant load alleviation is possible and reduction in overall empty weight of about 5 percent is expected. These could be reflected in either increase in operating performance or in fuel economy. Also, there should be a reduction in induced drag.

3.5.3 Irreversible Controls

Examples: Boeing 747

Examples: (Continued)

Boeing 767

Lockheed L-1011

- a. Near-term - Addition of active controls for load alleviation.

Examples: L-1011 wing control

Qantas use of lateral ride stability augmentation system in Boeing 747.

Ride quality: Definite improvement

Fuel economy: Not at present but may make some contribution in the future as refinements are incorporated.

- b. Far-term - Use of "hard" stability augmentation systems* and flutter*-suppression capability. These systems are currently under development, and may be used in 1995 time frame.

Ride quality: Definite improvement

Fuel economy: Can reduce empty weight by $\approx$ 8 percent and drag by $\approx$ 5 percent, both of which can improve fuel economy.

Problems: There are several problems associated with "hard stability" and flutter suppression systems including:

- . Redundancy management* is not yet generally accepted state-of-the-art.
- . Design criteria still not available.
- . Existing computational methods are inadequate for flutter suppression analyses.

- c. Fly-by-wire

Example: F-16

*See Glossary at the end of this section.

Ride quality: No effect
Fuel economy: Will reduce system weight by
eliminating direct mechanical
links to control surfaces.
Problem: Acceptance by civilian users and
authorities must be secured.

d. Fly-by-light

Example: Under development, but has been flight-
tested on the YC-14.

Ride quality: No effect
Fuel economy: Will reduce system weight even
more than fly-by-wire, and is more
reliable.

3.5.4 Summary

The results are summarized in Table 3-4. Essentially, the use of flight controls requires little energy for their own operation but can cause significant savings in aircraft weight, which could be translated into fuel economy. They also offer significant economies in the areas of maintenance and aircraft life through applications in load alleviation and flutter suppression. Flight controls can be used to automatically optimize operational parameters and thus provide direct energy management which should have a significant effect on fuel economy. Reductions in vibrations and motions could be improved by a factor of 10, leading to much better ride quality.

Most techniques are available today to design the flight control systems, but increased application is dependent on the availability of advanced computational techniques involving multi-technology or inter-technology applications to overall aircraft design. Most of the major advances will take 10-15 years to implement in fleet aircraft.

TABLE 3-4. EFFECTS OF NEW DEVELOPMENTS IN CONTROLS

	<u>TIME FRAME</u>	<u>RQ</u>	<u>PA</u>	<u>CA</u>	<u>FS</u>
REVERSIBLE CONTROLS	NEAR	P	P	-	-
SEPARATE SURFACE CONTROLS	NEAR	P	P	-	M
IRREVERSIBLE CONTROLS	FAR	P	P	-	P
ENERGY MANAGEMENT	NEAR	-	P	-	P

P - POSITIVE
 N - NEGATIVE
 - - NIL
 M - MARGINAL

RQ - RIDE QUALITY
 PA - PASSENGER ACCEPTANCE
 CA - COMMUNITY ACCEPTANCE
 FS - FUEL SAVINGS

3.6 OPERATIONS

This is a highly complex area involving all the activities of the aircraft from the time of engine start at the origin gate to engine cut-off at the destination gate. There is no doubt that fuel economies can be realized by minimizing delays encountered at each activity and also by providing the best possible flight trajectories and profiles from take-off to landing. However, at this time, there is insufficient data generally available to make any quantitative predictions of the potential fuel savings.

Ride quality and acceptance enter the picture both from the viewpoints of the passenger and the community. Generally speaking, delays frustrate the passenger and represent serious impacts on the convenience and dependability of the service, in addition to the direct time element which is of utmost importance. The passenger comfort aspect of ride quality suffers when aircraft are required to operate at low altitudes or in adverse weather situations for extended periods of time. Low altitude as well as ground activities have an adverse effect on the community through both noise and pollution.

From this brief introduction it is clear that there are considerable contributions which can be made in both fuel economy and passenger/community acceptance through improvements in operating procedures. There is much work being done in certain sectors, but the important point is that the whole area of operations is subject to a rather severe set of constraints. Some are natural, such as weather, terrain, winds, shear, human fatigue, etc.; some are economic, such as existing runway configurations, need for highest possible capacity utilization, availability of gates and ramps, etc. Some are technical such as runway spacing, approach paths and spacing, touchdown points, etc.;

some are institutional such as noise abatement, pollution control, land use, etc. Perhaps the best way to approach the ride quality and fuel economy issues associated with operations is to examine what is being done to improve performance within the various constraints.

3.6.1 Wake Vortex Avoidance

The strong wake vortices generated by the large, heavy jet aircraft require increased separation of aircraft in the approach, landing and take-off patterns, particularly when a diverse mix of vehicle sizes is involved. This reduces airport capacity, causing delays which result in adverse acceptance features and increased fuel consumption.

A task force studying eight major airports recently found that the capacity loss due to the increasing number of large, heavy jets in the mix may reach as much as 17 percent if present day separation standards as established by the FAA are not reduced.

It is hoped that reductions in the separation distance can soon be routinely achieved through improved technology for detecting and predicting the presence of high-energy wake vortices.

3.6.2 Airport Design

Terminal airspace capacity is limited by the physical layout of the airport, and by the ability of the Air Traffic Control (ATC) system to meter and space aircraft for safe operations. Several modeling techniques are currently being investigated to determine the maximum number of aircraft that can be handled by a given facility during specified time periods under conditions of peak demand. These techniques will predict delay times under varying runway and taxiway configurations, and provide planners with reliable

means for the measurement of acceptance rates.

The models permit computer analysis of improvements to existing facilities to achieve higher site capacity.

Possible improvements include:

- . dual-lane runway operations
- . separation between operations on parallel runways
- . reducing longitudinal separation standards
- . construction changes to satisfy all-weather operating requirements
- . high-speed turnoffs

3.6.3 Weather

It is necessary to provide accurate, timely, and operationally meaningful weather information to the users. Special emphasis should be placed on the identification and description of hazardous weather situations. Major improvements to today's system will include:

- a. Improved radar detection, identification and tracking
- b. Increase in the number and frequency of surface observations
- c. Automated collection, processing and distribution of pilot reports
- d. Reduction in delivery time of operationally critical weather reports to pilots and controllers
- e. Tailoring of weather data to render it more suitable for the user
- f. Presentation of real time hazardous weather to the controller
- g. Improvements to accuracy of aviation weather forecasts through quality control.

3.6.4 Noise Abatement

Aircraft noise and sonic boom impose critical constraints on the growth of civil aviation. Community objection to aircraft noise has brought on airport restrictions involving night curfews, aircraft types usage, preferential runway usage and limitations on expansion of existing airports. These restrictions result in the increased "stacking up" of aircraft and general congestion on airport runways during the day, wasting valuable fuel. General objectives of the Federal Aviation Administration (FAA) are to minimize the environmental impact of aircraft noise and to develop prediction, reduction and certification criteria for all aircraft.

3.6.5 Communications

The Discrete Address Beacon System (DABS) data link will provide a high capacity, ground/air/ground data link between Air Traffic Control (ATC) facilities and properly equipped aircraft. This productivity-oriented communications link would be used for delivery of ATC clearances, information and advisories. An improvement in area navigation (RNAV) capability should result.

3.6.6 Terminal Area Navigation

Two major improvements in ATC in the terminal area are possible through the expanded use of the area navigation system (RNAV) and the microwave landing system (MLS). Both should improve safety and reduce delays and hence contribute to improved acceptance and fuel economy.

a. RNAV

This is expected to improve the efficiency of ATC operations. It will reduce the controllers' work-load by relieving them of the need to provide

radar vector commands. The integral subsystems of RNAV will provide the aircraft with sufficient information to fly from one designated way-point to another within the terminal area without being told by the controller when to turn. It will also relieve the controller of part of his tracking requirement because of the improved behavior of the aircraft.

b. MLS

This system can be installed anywhere, but is particularly helpful in locations where the currently used instrument landing system (ILS) will not operate. Improved performance of this system will be available in the form of an infinitely variable multiple glide slope and a curved-approach capability. These features will reduce the need for maneuvering to obtain position in the landing sequence and permit utilization of approach paths with minimal noise impact. Use of runways previously closed because of noise abatement restrictions may be possible.

3.6.7 Wind Shear

Three potential near-term solutions to aviation problems created by hazardous low level wind shear are being investigated. They include: development of a ground-based Low Level Wind Shear Alert System to detect shear in the terminal area, development of a Hazardous Wind Shear Advisory Service (in cooperation with the National Weather Service) to alert pilots when strong wind shear conditions are going to affect airport operations, and the development of avionic displays to assist pilots in coping with shear during approaches to the airport.

3.6.8 Scheduling

Two major ground derived advances are underway which should reduce the airborne delays of aircraft. The first is a central flow control system which will manage the overall pattern of air traffic flow. The other, which will contribute to the first, but which can be used separately, is a terminal area metering and spacing capability.

a. Central Flow Control System

The objective is to balance the volume of traffic with the available capacity of the traffic-handling resources in a way which enables the aircraft to reach its destination with minimum delay. When demand on air traffic control resources exceeds the capacity to handle the demand, the flow control function can be invoked to achieve parity in the mass movement of aircraft. The system is being developed as an automated air traffic prediction/management system. It will regulate the flow of air traffic to and from airports on an origin-destination basis, allow for ground holding delays, and minimize airborne delays. In other words, it will predict proper take-off times for aircraft at a specific origin to go to specific destinations with minimum airborne delays.

b. Terminal Area Metering and Spacing (M & S)

This is an automation program designed to increase the airport capacity without impairing safety. The increase will be achieved by providing more consistent inter-arrival spacing of aircraft, thus assuring an increase in runway utilization. The automated M & S function may also prove beneficial in other areas such as overall reduction in arrival delays, equitable distribution of delays,

and absorption of delays.

Specifically, M & S will perform the following functions:

- (1) Control the flow of traffic into the terminal
- (2) Determine landing order based on the nominal landing time of the aircraft types in the mix
- (3) Establish schedule times at various check points to assure proper spacing
- (4) Aid the controller by generating recommended commands to satisfy the established schedules.

3.6.9 Ground Control at the Terminals

Currently, the ground control of aircraft at terminals is handled separately from the ATC. Thus, when the pilot gets clearance from ATC for departure to his intended destination (e.g., from the flow control system discussed above), his access from gate to runway is controlled separately. Large taxi queues during peak hours at busy airports are common experiences. These not only result in wasted fuel and inconvenience, or discomfort to the passenger, but also can introduce unwelcome perturbations into the flow control system, thus compounding its problems and reducing its effectiveness.

Little work is currently being done in this area. One problem is that it is at the interface between traffic control functions and airline/passenger interactions, which are controlled by the airlines. However, it is recommended as an area for further study regarding both the severity of the fuel diseconomies involved and for the development of procedures to eliminate ground queues. The latter will undoubtedly impinge upon passenger boarding strategies.

3.6.10 Summary

The results of the discussion of this topic are summarized in Table 3-5.

3.7 HUMAN FACTORS

As evidenced by the report of previous workshops conducted by this committee, there is a large body of knowledge available concerning the passenger's response to trip characteristics. It is well known that overall acceptance is based upon response to several parameters, generally in the following order of priority:

- . Safety
- . Dependability
- . Time
- . Convenience
- . Comfort
- . Cost
- . Amenities
- . Aesthetics.

There can be interchange depending upon the specifics of the situation.

It is also known that decisions of passenger acceptance are influenced by such attributes as

- . Expectations
- . Attitude
- . Marketing
- . Competition
- . Image.

Qualitatively, the sign of the effect (positive or negative) is known but much more work needs to be done to develop quantitative relationships.

Returning to the parameters, those which are involved with the physical interaction between the passenger and the vehicle are generally referred to as the ride quality

TABLE 3-5. EFFECTS OF NEW DEVELOPMENTS IN OPERATIONS

	<u>TIME FRAME</u>	<u>PQ</u>	<u>PA</u>	<u>CA</u>	<u>FS</u>
WAKE VORTICES	MED	-	-	N	P
AIRPORT DESIGN	NEAR	-	-	-	P
WEATHER	NEAR-MED	P	P	-	P
NOISE ABATEMENT	MED-FAR	-	-	P	M
COMMUNICATIONS	FAR	-	-	-	P
TERMINAL AREA NAVIGATION	MED	-	-	P	M
AIRPORT SURVEILLANCE	MED	-	-	-	P
WIND SHEAR	NEAR	P	P	-	-
SCHEDULING	NEAR-MED	?	?	-	M
TERMINAL GROUND CONTROL	MED-FAR	-	?	-	P

P - POSITIVE

N - NEGATIVE

- - NIL

M - MARGINAL

RQ - RIDE QUALITY

PA - PASSENGER ACCEPTANCE

CA - COMMUNITY ACCEPTANCE

FS - FUEL SAVINGS

of the vehicle. These imply consideration, either singly or in combination, of such factors as

- . Vibrations
- . Noise
- . Temperature
- . Pressure
- . Seating
- . Space, etc.

Extensive work has been done in this area and quantitative models relating the physical environment and subjective responses are available for assessment, design and trade-offs. In general, responses seem to be keyed toward three separate sets of stimuli: seating, motion and noise. The factor with the poorest characteristics for a given ride environment completely dominates the acceptance judgment.

Guidelines for the acceptable levels of motion and noise stimuli are well in hand, but the effects of specific seating or space characteristics are not as well understood. For example, in those cases where vertical accelerations are critical, an rms acceleration change of 0.05g will cause a unit shift on a 7 digit scale of ride quality. A similar figure for the transverse case is 0.025g. Interior noise changes of 10 to 15 dB A above 65 dB A usually cause a unit shift in the 7 digit scale.

Much less is known about community acceptance. There are no quantitative models which have been demonstrated to be reliable. Among the factors which must be considered are:

- . Noise level
- . Air pollution
- . Increased traffic congestion
- . Fear of crashes
- . Time and duration of exposure
- . Activity at time of exposure
- . Frequency of occurrence.

It is clear that the implications of the community acceptance problem will likely generate circumstances which are not entirely compatible with improved ride quality and fuel economy, e.g., flight profiles which are considerably longer and more intricate. Also, land use controls and basic economics will probably restrict the number of new airports constructed, while at the same time increased air travel demand will cause congestion both in the air and on the ground at the existing airports. Thus, the problems of passenger acceptance and fuel economy will only be compounded. On the brighter side, the quest for quieter aircraft is bound to have positive effects on passenger acceptance.

As discussed at the beginning of this section, the questions of acceptance must be addressed to several groups of participants in the air transportation systems. Although the time constraints of the workshop would permit detailed consideration only for the passenger and community sectors, an attempt was made to examine the compatibility of the goals and objectives of the various groups. The results are shown in Figure 3-1. Perhaps the most interesting conclusion is the complete lack of agreement between the community perspective and the desires of the human components of the air transportation system.

3.8 FUTURE AIRCRAFT CONFIGURATIONS

Throughout its deliberations the group found it essential to discuss the potential for fuel savings (FS) and ride quality (RQ) to be derived from various technologies in terms of the configurations and missions of the aircraft that would be likely to result. The consensus of the group on this subject was expressed in tabular form which is included here as Table 3-6.

TABLE 3-6. FUTURE AIRCRAFT

TYPE	1990	2000*
<u>COMMUTER</u>		
PAX: 50	- LOW INITIAL COST	- AIR CUSHION LANDING GEAR
SPEED: 200 KNOTS	- CLOSE SEAT SPACING	
RANGE: 300 MI	- ADVANCED STRUCTURES	
FIELD LENGTH: 4000 FT	- TURBOPROP ENGINES	
	FS SUBSTANTIAL	FS UNAFFECTED
	RQ A PROBLEM	RQ UNKNOWN
<u>SHORT HAUL</u>		
PAX: 80 - 500	- STEEP CLIMB/DESCENT	- ADVANCED POWER PLANTS
SPEED: M = .65 - .8	- CLOSE SEAT SPACING	- CONFIGURED FOR QUICK INTERMODAL CHANGE
RANGE: 300 - 1200 MI	- ADVANCED AERODYNAMICS	- ALTERNATE FUEL
FIELD LENGTH: 400 - 6500 FT	- TURBOPROP ENGINES	
	- ADVANCED STRUCTURES	
	- ACTIVE CONTROLS	
	FS SUBSTANTIAL	FS SUBSTANTIAL
	RQ A SLIGHT PROBLEM	RQ UNKNOWN
<u>LONG HAUL</u>		
PAX: 50 - 800	- HIGH PRODUCTIVITY	- NEW CONFIGURATION
SPEED: M = .75 - 2+	- CONVENTIONAL DESIGN	- POSSIBLE USE OF LAMINAR FLOW
RANGE: 3500 - 6000 MI	- WIDE BODY FOR SUBSONIC FLIGHT	- NEW TURBOPROP ENGINES
FIELD LENGTH: 8500 - 10,000 FT	- ADVANCED STRUCTURES	- ALTERNATIVE FUEL
	- ADVANCED AERODYNAMICS	
	FS SUBSTANTIAL	FS SUBSTANTIAL
	RQ NOT A PROBLEM	RQ UNKNOWN
	FS: FUEL SAVINGS	
	RQ: RIDE QUALITY	

3.9 GENERAL SUMMARY

Since the preliminary focus of the workshop was on fuel-efficiency, Table 3-7 was prepared to summarize the major contributions to be made to fuel savings by technological advances, and to reflect their impact on acceptance. As in the previous table, a basic issue can be seen in that taken individually, only the improvements due to operations control technologies will have a positive effect on ride quality and acceptance. Clearly compensations and trade-offs may have to be made - and it is quite possible that these may detract from the maximum potential for fuel economy.

3.10 RESEARCH NEEDS

The group defined ten research areas which it felt were the most important for the potential achievement of the dual goals of increased fuel efficiency while not detracting from ride quality and acceptance. These are listed below. The reader should be reminded that these are not in rank order; all are judged to be of great importance to the issues under study.

- . Methodology and software for predicting noise transmission early in structural design
- . Collection and analysis of fuel use data to determine the savings potential to be realized by reducing the operating constraints
- . Identify methods of A/C fuselage design to attenuate propeller noise propagation into cabin
- . Define human response to low frequency (100-200 hz) noise
- . Determine limits of high density seating
- . Determine reaction of passengers to reintroduction of propeller aircraft instead of more jets
- . Understanding redundancy management for irreversible controls

TABLE 3-7. AREAS HAVING MAJOR POTENTIAL FOR FUEL SAVING

	<u>TIME FRAME</u>	<u>RQ</u>	<u>PA</u>	<u>CA</u>
LAMINAR FLOW CONTROL	FAR	N	N	-
PROFAN ENGINES	NEAR	N	N	?
COMPOSITES	NEAR-MED	-	-	-
FLIGHT PATH/GROUND OPERATIONS	NEAR	P	P	N

P - POSITIVE
N - NEGATIVE
- - NIL

RQ - RIDE QUALITY
PA - PASSENGER ACCEPTANCE
CA - COMMUNITY ACCEPTANCE

- . Development of better computational techniques for flutter suppression
- . Development of better computational techniques for synthesis of aerodynamics/propulsion/structure, etc., in the design process including impacts on noise/motion
- . Understanding of dimensions of choice to determine ability to "sell" fuel efficient modification.

3.11 GLOSSARY

Active control - A control system incorporating feedback (as opposed to passive control, which incorporates no feedback).

Aspect ratio - Ratio of the square of the span length of a wing to the area of the wing as seen from above.

Blowing - Forced movement of air over aircraft surfaces.

By-pass ratio - Ratio of the airflow through the engine fan to the airflow which actually passes through the turbine.

Camber - A measure of the vertical non-symmetry of the wing cross section; variable camber is the ability to change the wing cross section during flight.

EPNDB - Effective perceived noise (DB = decibel), a measure of noise annoyance.

Fairing - A surface, usually non-load-bearing, which smooths the contour of the aircraft.

Flutter - High frequency vibration of an aerodynamic structure.

Fly-by-light - A control system in which the links between the controller and the control surfaces are accomplished optically.

Fly-by-wire - A control system in which the links between the controller and the control surfaces are accomplished electrically.

"Hard" stability augmentation system - A control system which allows the aircraft to operate beyond its normal limits of performance.

Interference drag - The drag which results from the interaction of flows between the components of the aircraft.

Lift-curve slope - A measure of the variation of lift with angle of attack.

Nacelle - The housing of an aircraft engine.

Redundancy management - The processing of signals from redundant systems.

Structural damping - Decay of vibrations in the structure.

4. GROUP C

SHIFTS IN INTERMEDIATE RANGE (100-500 MILES) TRAVEL FROM AUTOS TO PUBLIC TRANSIT

4.1 INTRODUCTION

This group was concerned with developing a program of research to determine whether energy can be saved by diverting people who make 100-500 mile trips by auto to public transportation. This intermediate range trip length was chosen for analysis because the automobile dominates travel below 100 miles, while for distances above 500 miles the airplane predominates. Currently, about 85 percent of trips over 100 miles are made by private auto, another 10 percent by air, with the remaining 5 percent divided between bus and train. However, buses and trains are, to a large extent, being used by the elderly and young, the low income, and the carless. A major concern of Group C was the large class of relatively affluent, middle-aged travelers who dominate the auto driving sector. Much of the discussion focused on whether ways can be found to make buses and trains appeal to this group and whether a switch in mode would actually save energy.

The group identified three major areas where research is needed. First, data are needed to describe the travel behavior of people making intermediate length trips and also their decision process and awareness of travel alternatives. Second, research is needed to describe the characteristics of groups of users that are likely candidates for changing travel patterns. In addition, an effort to find effective promotional strategies to appeal to these groups is important. Finally, research is needed to make the design of new systems and modifications to existing systems appeal to a wider range of user groups.

The following sections describe the research areas in detail. For each there is a statement of the problem, a description of research projects, and, in some cases, an appropriate method to be used.

4.2 TRAVEL BEHAVIOR AND DECISION-MAKING

Problem.

One of the major difficulties that the group faced throughout the workshop was developing research ideas in an area where so little solid data is currently available. We do not know how people are making trips, especially trips in which more than one mode is used. In addition, there are virtually no data on how people make trip decisions and whether they are aware of travel alternatives. Finally, research to improve data gathering techniques to supplement questionnaires is needed.

4.2.1 Project 1: Taxonomy of Intermediate Length Travel Behavior

The most frequently cited source of data on intermediate range travel behavior is the National Travel Survey (NTS) of 1972 conducted by the Bureau of the Census (7). The NTS queried approximately 25,000 individuals about trips of more than 100 miles taken during the previous year. There are several problems with using the NTS to understand travel behavior:

1. Information is provided only about the longest segment of the trip. If someone walked to a subway station, took the subway to the airport, flew 200 miles, and then took a bus to his destination, the trip would be counted only as a trip by air.

2. Data about individuals or households cannot be extracted from NTS. Because of the restrictions of the Privacy Act, researchers are provided with data only about the state or county where the trip originated. This makes it impossible to accurately compute trip distance for individual trips.
3. The NTS sampling procedures make the projections to the whole population questionable. In addition, there are consistent discrepancies between NTS and industry surveys. For example, surveys of the number of trips taken by train almost always show a higher percentage than the NTS figures.
4. The quality control of the NTS data is poor. For example, in one subsample including about 15 percent of the data, there are 13 cases of children under ten years old traveling alone by car.
5. The data base lacks information on many variables which are known to have a strong influence on mode choice. There is no information on auto ownership or accessibility to public transportation terminals. There is no information on the cost of travel or the time spent in transit.

Method.

The most realistic procedure would be to conduct a survey at the individual or household level. Because of the volume of information needed, data gathering should be restricted to a pair of cities or a corridor. The survey must include questions about the following:

1. All of the segments of the trip and the transfers between them
2. Party size, trip purpose, length and cost of trip

of the fuel diseconomies involved and for the development of procedures to eliminate ground queues. The latter will undoubtedly impinge upon passenger boarding strategies.

3. Demographic characteristics of travelers such as income, age, type of employment, and availability of autos.

4.2.2 Project II: Analysis of Traveler Decision-Making and Awareness of Alternatives

Of the work that has been funded by DOT over the past ten years, there has been only one nationwide survey of the attitudes of intermediate range travelers. This recently completed study was conducted for the Office of Transportation Economic Analysis (5) and consisted of a home interview that focused on the respondent's last automobile trip of more than 100 miles. The respondents were also asked about their knowledge of travel alternatives, and why they did not use those alternatives. The results of the survey showed that, in general, the respondents were knowledgeable about travel alternatives. Over 90 percent knew where the nearest bus station was located and 70 percent knew where the train station was. When asked why they did not use the bus or train, over 45 percent cited inconvenience in several forms as the reason, including increased trip time, poor location of stations, unsatisfactory schedules, and the requirement to transfer between vehicles. These results are consistent with a recent nationwide telephone survey conducted by AMTRAK which showed that travelers who used their autos to make trips rated convenience as the most important factor. The survey also indicated the importance of economy to bus users and the ability to relax during the trip to train users. We clearly need more of this type of data in order to understand trip decision-making.

Method.

A survey to obtain decision-making and awareness data could be combined with the survey on basic travel behavior. Although a questionnaire is often not the best tool for

probing underlying attitudes or the details of decision making, some useful information can be obtained. The methods to be described below can be used to supplement the survey data.

4.2.3 Project III: Use of Non-Survey Techniques

While interviews and questionnaires can be very useful tools for gathering data on travel behavior and demographic characteristics of travelers, they are not particularly effective at revealing underlying emotional responses. Moreover, it is difficult with such techniques to predict people's responses to proposed new systems or modifications to existing systems. There are, however, gaming and simulation techniques which can be used in these areas. Having individuals or groups of individuals play travel decision games or participate in simulations of systems can often provoke them into revealing their attitudes and decision processes. These techniques can be particularly effective when they are used in combination with surveys. For example, observing the behavior of people playing a game can often provide information about what questions to ask in a survey and how to word them. In addition, this research is needed to validate survey results, since the relationship between people's stated intention and their subsequent behavior is less than perfect.

Method.

There are currently projects underway at the Transportation Systems Center and the General Motors Research Laboratories investigating the relationship between intentions and behavior. This type of research has long been needed to improve confidence in survey findings. In addition, one of the major problems for transportation planners is that people often have difficulty describing how they make

transportation decisions. Asking consumers to keep travel diaries can often provide insights into decision-making processes.

4.3 MARKETING AND PROMOTION OF TRAVEL ALTERNATIVES

Problem.

The group discussed at length methods to promote the use of public transportation in ways that would appeal to a wider range of travelers. It was agreed, however, that before promotional strategies are developed, marketing studies are needed to identify the groups that the promotions will be aimed at. For example, a family of five with a large van going on a 200 mile trip destined for a rural area is not likely to be influenced to use a train. Initial marketing studies are needed to separate or segment travelers into groups that are more or less likely to change modes. Special appeals can then be targeted to groups that have the greatest likelihood of switching.

4.3.1 Project IV: Identification of the Market for Public Transportation

Can users be segmented into groups that are likely to change modes versus those that are unlikely to change? If so, what are the relevant variables involved in market segmentation? Possible bases for segmentation include:

1. Availability of alternatives
2. Frequency of travel
3. Prior use of common carrier
4. Demographic characteristics such as income and auto ownership.

Method.

While marketing information is essential before promotional strategies can be developed, it will not be cheap or easy to obtain since it requires a large scale survey and some kind of follow-up study to see who has switched modes. A cheaper but less useful research strategy would be to identify groups of users who are not likely to switch and then eliminate appeals aimed toward them.

4.3.2 Project V: Development of Strategies to Promote Use of Public Transportation

While there is a large research literature on promotion and advertising, little of it is relevant to transportation. Once it is determined which groups to appeal to, it is still not clear how best to appeal to them. Is it effective to try to enhance the image of a mode to potential users? How important is it to provide potential users with information on services and schedules? This is one research area for which funds may be difficult to obtain. Since intercity transportation systems tend to be privately owned, federal monies cannot be used to promote competing modes on an unequal basis. These funding and management problems will have to be overcome before projects can be initiated. Perhaps TRB or some other non-government agency can fund research into the effectiveness of promotional techniques and encourage competing modes to cooperate in a project that will benefit all parties.

4.4 USER-ORIENTED DESIGN

Problem.

The group spent a considerable amount of time analyzing the impediments to increased use of public transportation for intermediate range travel. It was agreed that there are at

least three areas where research projects or demonstrations are needed:

1. Improving the availability of public transit
2. Providing more service alternatives and
3. Making current systems easier for consumers to use.

The technologies needed for these changes have already been developed. What is needed are not new technologies but systems that meet travelers' needs better.

4.4.1 Project VI: Methods to Improve Availability

It was noted that buses and trains capture their largest share of the market in intercity travel between large urban areas that are 100-300 miles apart. For example, bus and rail combined account for about 25 percent of trips between New York and Washington but only about 5 percent of trips between Washington and Boston. When trips do not begin or end in a major city, virtually all trips are made by auto. Furthermore as noted above, auto users reported that they did not use public transportation because it was inconvenient. It would appear, then, that there is a market for public transit for intermediate length trips if public transit were available to a larger number of people.

Method.

One obvious research possibility here is to investigate the use of feeder services to main line systems. The short takeoff and landing (STOL) commuter airline demonstration between Montreal and Ottawa is an example.

The purpose of the demonstration was to show that STOL aircraft are acceptable to business travelers. The service was designed to allow business people to split their working

day between the two cities. At the end of the demonstration period, the STOL was operating at 60 percent capacity, and 35 percent of the users had previously used their cars for the trip. The interesting aspect of this service for the present discussion, however, is that it included a dedicated ground link. Mini-buses running from downtown locations to the STOL-ports were coordinated with plane departures such that the plane always waited for the bus before it left. A single fare covered both the flight and ground links. Thus, the users knew that once they made it to the bus, they were guaranteed a seat on the plane. This feature turned out to be one of the most attractive aspects of the service.

Another example of a service for improving availability that was discussed by the group was the "rendezvous railroad." This concept involves a train moving along a route without making all station stops. Feeder cars would be dispatched to and from the station to link with the moving train and transfer people and cargo, without decreasing the operational speed of the main vehicle by stopping the entire train to load and unload small numbers of passengers. Less populated areas receiving infrequent train service under the present system might become accessible to more frequent service via the feeder vehicles, resulting in a potential increase in ridership without loss of speed or energy. The distribution of demand for rail service would determine whether this or a more conventional style of operation is appropriate.

4.4.2 Project VII: Service Segmentation

The 1972 NTS showed that the most frequent trip makers were people between the ages of 35 and 55, and that the number of trips increased directly with income. Projections of population figures indicate that the biggest increase over the next 20 years will be in the number of people who are

35 to 55. These are the people who are now using their autos to make trips. Unless public transit can be modified to appeal to these people, the proportion of travelers using their autos will increase even more. Multiclass service may provide a means of increasing the use of public modes. Research and demonstration in this area should be encouraged.

Method.

An example of this type of service is currently being demonstrated in Canada. A "luxury" bus has been introduced between Montreal and Quebec City, featuring a hostess, meal service, three abreast seating, a telephone, and a reservation system. Four buses a day run in each direction. Use of the service has been good, especially by business travelers. The bus company has purchased two more buses and expects ridership to continue to increase. Funding needs to be provided for similar demonstrations in the United States.

4.4.3 Project VIII: Service Management

In the past, our understanding and data regarding travel choice have been derived from responses to transportation improvements such as the interstate highway system, which have enlarged the area within which individuals could travel to obtain benefits at the trip's end. The transportation alternatives now being considered, however, have as their objective improving service to existing developed areas and saving energy. Therefore, we need to increase the quality of service of existing transportation systems. One obvious area where research could have an immediate payoff is in the improvement of passenger communication and information aids such as providing scheduling, routing, transfer and fare information. The form of information can be as simple as higher quality printed matter and better signage, or as

complex as a computer terminal which can provide an individualized briefing to a passenger. Improvements in micro-computers would make the latter feasible. In addition to providing passengers with needed information, automated terminals could also reduce personnel costs.

4.5 REFERENCES

The following references have been selected as being appropriate for readers interested in the topics addressed by Group C.

1. Bennett, J., R. Ellis, and J. Prokopy, "A Comparative Evaluation of Intercity Modal Split Models," Transportation Research Board; Research Record No. 526, 1974. Pages 83-92.
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5. GROUP D

IMPLICATIONS OF INCREASED SIZE DISPARITY FOR GROUND TRANSPORT FREIGHT AND PASSENGER VEHICLES USING SHARED GUIDEWAYS

5.1 INTRODUCTION

Since ground transport modes represent a varied group of vehicles and surface types, it was agreed by the members of Group D that three subgroups should be formed:

Subgroup D-1: Rail

Subgroup D-2: Highways

Subgroup D-3: Advanced Concepts*

Both the rail and highway groups focused on conventional transport services; the advanced concepts group confined itself to technologies that are not yet in revenue service.

Because of the obvious differences between the three subgroups, most of the time was spent in independent meetings. They did, however, coordinate their activities through short joint sessions and interchanges between the subgroup chairmen throughout the conference.

Although the report of each subgroup is presented separately, the general objective of each group was the same. Specifically the goals of group D were to:

1. Identify the motivating factors leading to increased vehicle size disparity,
2. Identify the effects of vehicle size disparity on vehicle guideway maintenance,
3. Identify the resulting ride quality and level of service changes,
4. Identify the resulting technological trends (e.g., the design of lightweight/high-speed passenger

* The members of each subgroup are shown in Section 5.6.

rail cars vs. heavy axle load locomotives and freight cars; the increasing use of heavy axle load tractor trailer and double bottom trucks vs. lightweight passenger vehicles; the design of advanced concept vehicles to reduce guideway stress loads; rail and highway maintenance standards and costs, etc.).

In addition to these common goals, eleven specific areas of mutual concern were identified. These acted as a starting point for the discussions of each of the three subgroups in their separate meetings:

1. Safety
2. Cost accounting
3. Unit loading discrepancies
4. Failure criteria and material research
5. Regulation and enforcement
6. Trade-offs between vehicle and guideway specifications
7. Vehicle and guideway maintainability
8. Operating vs. initial costs
9. Passenger acceptance of shared traffic
10. Signaling and operations (and communications with operators)
11. Transport of hazardous materials.

An attempt was made to establish a systematic relationship between these factors as shown in Figure 5-1.

The reports of each subgroup follow. They consist of the description of a series of research areas which are generally presented in the following format:

Statement of problem
Research area goals
State-of-the-art
Evaluation of pay-off vs. risk
Proposed approach

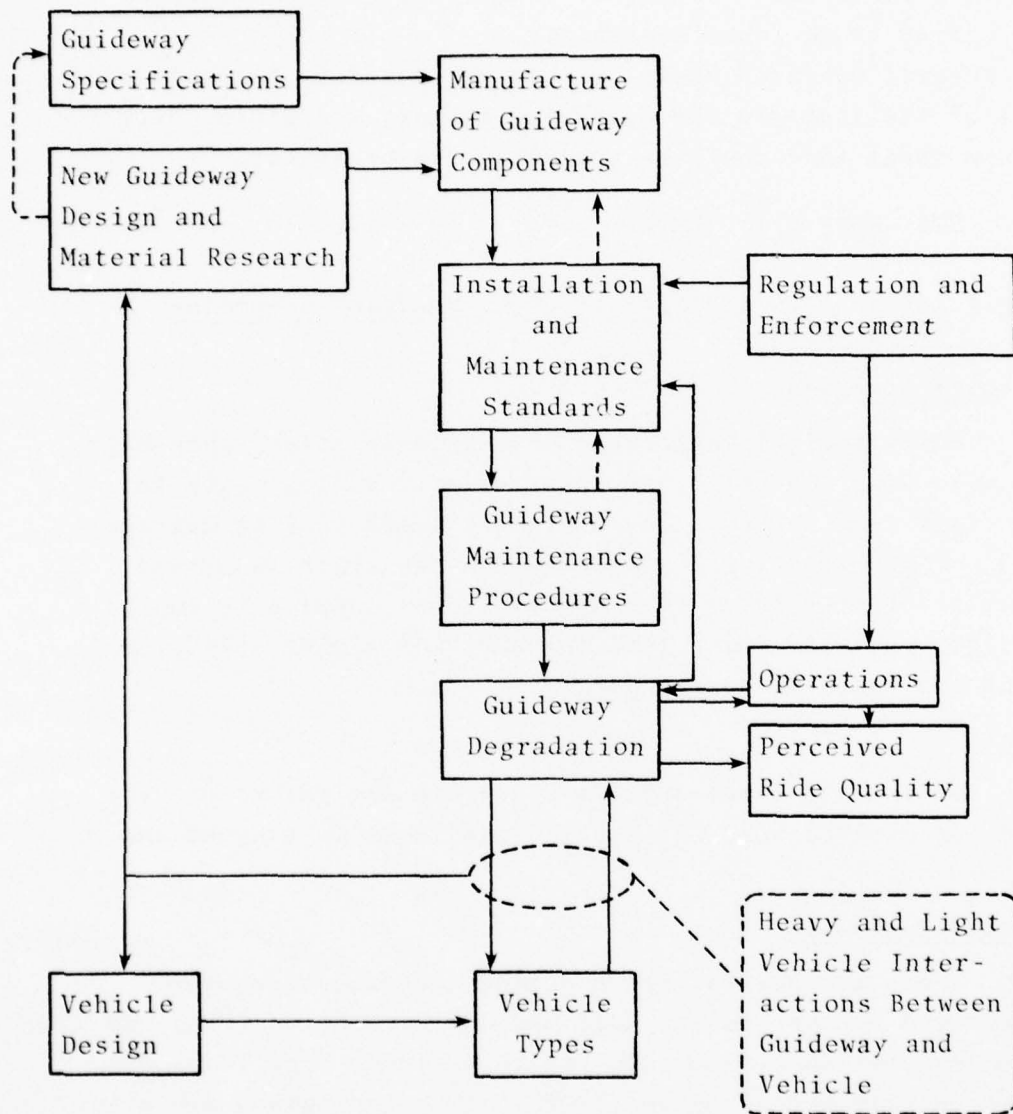


FIGURE 5-1. RELATIONSHIP BETWEEN FACTORS DISCUSSED

Probable level of effort (when possible)

Time frame (when possible) .

In several research areas, it was not possible to evaluate all of the items in the preceding format; therefore, only those items that could be evaluated are presented.

5.2 SUB-GROUP D-1: RAIL

5.2.1 Research Area D-1.1: Freight Vehicle/Locomotive Truck Design

Problem Statement

Heavy freight vehicles with high axle loads cause high dynamic loads on the track, particularly during entry to and exit from curves. These dynamic loads lead to degradation of both the track structure and the track alignment. Similar effects occur from dynamic loads imposed by empty freight vehicles which tend to "hunt" at higher speeds, and rock and roll* at lower speeds.

Goals

To improve wheel profile and truck designs to provide reduced dynamic vertical and lateral loads on tangent and curved track.

State-of-the-Art

There are several truck design programs currently sponsored by the Federal Railroad Administration (FRA) and the Association of American Railroads (AAR, e.g. Truck Design Optimization Program (TDOP)).* These programs are aimed primarily at improving dynamic performance and maintainability and have not stressed the reduction of track loads. They have also concentrated on freight vehicle trucks as opposed to locomotive trucks. For example, the radial truck designs proposed to date are exclusively for freight cars.

* See Glossary at the end of this section.

Pay-off vs. Risk

The pay-off is reduced vehicle and track maintenance costs, higher speeds, increased safety and increased operating efficiency; i.e., the pay-off is very high. The technical risks are moderate; some fundamental theoretical work is required. The major risk in implementation is economic; i.e., will the railroads perceive the benefits to warrant the costs?

Proposed Approach

The recommended approach is a combined wheel/track suspension design program aimed at reducing wheel/track dynamic loads. This will involve testing combined with improved predictive analytical tools.

Level of Effort

30 labor-years.

Time Frame

3 years.

5.2.2 Research Area D-1.2: Track Research

Problem Statement

The great disparity due to differences in design, loading and operations which exists between passenger and freight systems has created the need for new maintenance requirements for track.

Goals

1. Establish limits for the loads imposed on the track due to the dynamic interaction between vehicle and track.
2. Develop design requirements for vehicles and tracks which incorporate the interaction that one imposes on the other.

3. Limit vehicle operations which impose greater loads than allowed by the economics of track structure maintenance.

State-of-the-Art

The following activities related to this research area are currently in progress at various stages of completion:

1. TDOP (Truck Design Optimization Program)
2. Vehicle modeling efforts
 - Model development
 - Vehicle typing
 - Characterization of the track as a vehicle input
3. Maintenance-of-way studies
4. Improved track structure
 - Fast testing*
 - Track stiffness and impedance measurement
 - Evaluation of new structures and components
 - Lime slurry and the soft stabilization methods
5. FRA Office of Safety evaluation
 - Geometry
 - Rail flaw.

Pay-off vs. Risk

The expected pay-offs are high, particularly as new track maintenance standards are established. Due to the variation in vehicles and track life cycles, the risk is considered moderate.

Proposed Approach

1. Inventory the state of the track as a function of its maintenance cycle.
2. Develop methodologies that permit inventory by inspection.
3. Improve cost accounting methodologies for track rehabilitation.

4. Develop proper cost accounting for track degradation induced by vehicle loading cycles.
5. Restrict vehicle dynamic loads.
6. Develop new track materials.
7. Expand components research.
8. Improve designs for weak areas of track
 - Spirals (entry and exit)
 - Turnouts and other track work areas
 - Bridge approaches.

5.2.3 Research Area D-1.3: Rail Passenger Vehicles

Problem Statement

Real world economic limitations demand that rail systems run on less than ideal track. Lateral lurching as experienced today is unacceptable. Maintainability is not currently included in design goals. Regulations currently restrict the use of certain technological developments (e.g., tilt systems).

Goals

To provide improved ride quality and level of service with existing track.

State-of-the-Art

Passive suspension systems provide reasonable ride vibration environment with longer trip times. Tilt systems are available which provide higher speeds on curves and hence reduced trip times; however, current regulations restrict the use of these systems.

Pay-off vs. Risk

Higher passenger acceptance and lower maintenance costs should provide a good pay-off.

The risk of technical development is low. However, the uncertainty of benefit (from increased utilization) vs. the

cost makes the risk of actually achieving implementation high.

Proposed Approach

1. Develop innovative suspension designs, e.g., radial axle truck, etc.
2. Remove technical and institutional barriers to higher speeds on curves.
3. Reduce life-cycle costs by developing analytical tools and techniques to assist in control of maintenance and by improving the specification language for cars and trains.

5.3 SUB-GROUP D-2: HIGHWAYS

5.3.1 Research Area D-2.1: Establishment of a National Road Performance Standard

Problem Statement

Currently, the motor vehicle manufacturer must design vehicles in the absence of specific roadway performance criteria, e.g., roughness, surface reflectance, surface texture, level of maintenance effort, level of traffic service, etc. On the other hand, roadway builders have little assurance that vehicle manufacturers will not introduce new vehicles which will cause the roadway to become obsolete in a relatively short period of time. The effect of vehicle characteristics on roadway performance, other than axle weight, has not been established.

Vehicle limitations have traditionally been established on the basis of economic constraints other than roadway condition and, most likely, will be set by similar criteria in the future. Attempts to establish performance standards for roadways, (specifically, maintenance quality levels) have been sporadic and non-uniform.

An appraisal of the condition of the nation's road system has not been made and highway authorities are not in a position to predict the likely state of repair of the nation's road system at any future date, or the effect of any incremental increase or decrease in maintenance expenditure.

Goals:

Conduct research leading to the establishment of road performance standards.

State-of-the-Art

Measuring instruments are available (e.g., roughometers, deflectometers, photographic survey vehicles, skid trailers, weighing-in-motion scales) to conduct surveys of the quality of highways. However, the techniques have been proven on less than a national scale and not in a combined program. Consequently, vital data is not available. A mathematical simulation of a small maintenance division was attempted, unsuccessfully, by the National Bureau of Standards. A similar endeavor is currently underway, for an even smaller maintenance division, at Louisiana State University.

The sampling concept has been tested on a limited basis: (1) in the KAB* Study (conducted by cooperating states and the Transportation Research Board), (2) by the Ohio Department of Transportation for the purpose of allocating maintenance funds, and (3) by the Pennsylvania Department of Transportation when it established a maintenance management system.

Proposed Approach

PHASE I

A research team, equipped with measuring instruments, will develop a stratified sample of roadway segments to

*See Glossary at the end of this section.

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IMPLICATIONS OF FUEL-EFFICIENT VEHICLES ON RIDE QUALITY AND PAS--ETC(U)

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establish measurement sites and will train state teams to assist in data acquisition. (Although state teams will be involved, an assessment of the relative maintenance quality levels between states is not the objective of this phase.)

Level of Effect

At the national level - 10 labor-years.

Time Frame (Near Term)

Less than five years: two years preparation and soliciting state cooperation, two years to conduct the study.

PHASE II

The data developed in Phase I program will be used to model system performance and evaluate different strategies for operating the nation's highway system. Such items as the effect on highway maintenance of different vehicle mixes (large vs. small); incremental levels of investment; different maintenance strategies, (e.g., breakdown vs. preventive maintenance and the differential costs in terms of energy consumption); different vehicle configurations; different service levels; (e.g., requiring trucks to park under some storm conditions or limiting the number of vehicles entering the traffic stream) would be studied.

Levels of Effort

100 labor-years?

Time Frame

Medium term - five to ten years.

Pay-off vs. Risk

An appraisal of the state of the nation's highway system can almost certainly be accomplished, and periodic measurements, on a sampling basis, will almost certainly provide information on whether conditions are improving or

An appraisal of the condition of the nation's road system has not been made and highway authorities are not in a position to predict the likely state of repair of the nation's road system at any future date, or the effect of any incremental increase or decrease in maintenance expenditure.

Goals:

Conduct research leading to the establishment of road performance standards.

State-of-the-Art

Measuring instruments are available (e.g., roughometers, deflectometers, photographic survey vehicles, skid trailers, weighing-in-motion scales) to conduct surveys of the quality of highways. However, the techniques have been proven on less than a national scale and not in a combined program. Consequently, vital data is not available. A mathematical simulation of a small maintenance division was attempted, unsuccessfully, by the National Bureau of Standards. A similar endeavor is currently underway, for an even smaller maintenance division, at Louisiana State University.

The sampling concept has been tested on a limited basis: (1) in the KAB* Study (conducted by cooperating states and the Transportation Research Board), (2) by the Ohio Department of Transportation for the purpose of allocating maintenance funds, and (3) by the Pennsylvania Department of Transportation when it established a maintenance management system.

Proposed Approach

PHASE I

A research team, equipped with measuring instruments, will develop a stratified sample of roadway segments to

*See Glossary at the end of this section.

declining. This information would aid vehicle designers in providing vehicles which will perform adequately on the nation's road system.

Transportation authorities will also be in a position to establish funding levels and establish maintenance regulations with confidence.

The pay-off is high and the risk of failure is low for Phase I, but the objectives of Phase II may not be attainable.

5.3.2 Research Area D-2.2: Performance Standards and Use Restrictions for Large Freight-Carrying Vehicles

Problem Statement

The economic pressures for increases in the labor and capital productivity of highway transport, in conjunction with height and width constraints on cargo compartments, mean that productivity increases are synonymous with increases in the number of trailers hauled by a single tractor. In other words, substantial motivation exists for developing and authorizing the use of "highway trains." Since the physics of articulated, pneumatic-tired tractor-trailer systems dictates that the damping of the oscillatory modes of motion of these systems decreases with an increase in the number of linked articulated masses and with increased speed, it follows that road-use laws and performance standards in directional stability and rollover immunity must be developed and coordinated so as to preserve the operational integrity of highway transportation. Experience shows that the "highway trains" in common use today account for a disproportionate share of traffic blockage, even on the highest quality portions of the road network. The existence of the jackknifing phenomenon, together with the lower levels of rollover immunity exhibited by large tractor-trailer systems, constitutes an increased potential for upset, a traffic disruption which is further aggravated by the difficulty of removing large, upset vehicles from the travelled way.

Goals

Investigate the trade-offs between vehicle design and use restrictions as a means of preserving a minimum standard of traffic integrity and highway safety.

State-of-the-Art

The physics underlying the braking and steering behavior of commercial freight-carrying vehicles is becoming increasingly well understood. In addition, the vehicle dynamics literature dealing with the problem of roll stability and rollover is growing and, in the not too distant future, it can be anticipated that the mechanics of the single- and multi-unit freight-carrying motor vehicle will be reasonably well in hand. On the other hand, both accident data and exposure data are generally not available to indicate the extent to which freight-carrying vehicles of different designs and configurations are over-involved in incidents that cause property damage, personal injury, and the disruption of traffic. In particular, data are not available which reveal how much traffic disruption results from incidents in which large commercial vehicles block the travelled way prior to their removal.

Proposed Approach

Research Tasks:

1. Develop an appropriate sampling scheme for observing the movement and disruption of traffic as a result of accidents, in general, and trucking accidents, in particular.
2. Implement this scheme and collect data defining the losses in mobility and transportation output that result.
3. Develop a scheme for transforming the observed interruption of traffic (containing both freight and personal transportation vehicles) into dollar costs.

4. Identify the manner in which road-use laws promulgated by the various states determine the final configuration of large freight-carrying vehicles without simultaneously requiring that these configurations meet certain minimum performance standards.
5. On the basis of hypothetical performance standards for (a) directional stability and control, (b) braking, (c) rollover immunity, determine the alternative methods for achieving these performance standards and evaluate their relative cost-effectiveness and the resulting benefit/cost ratio to highway freight movement.

5.3.3 Research Area D-2.3: Impact of an Increased Size and Weight Disparity on the Safety of Highway Operations

Problem Statement

The desire to conserve fuel and to increase the productivity of freight transport leads to a growing disparity in size and weight of the vehicle population using the existing highway network. On the basis of current experience, it seems reasonable to hypothesize that the safety level of highway transport will be negatively affected by this size and weight trend. Accordingly, studies should be undertaken to identify and quantify the various ways in which these size and weight differences make demands on highway design, traffic control, and vehicle design.

Goals

Identify the various mechanisms by which a large variation in size and weight leads to a greater potential for loss of control or a greater probability of injury (or fatality) in the event of a collision or crash. Analyze the mechanisms in order to develop guidelines for vehicle and highway

designers and traffic controllers desirous of mitigating the negative safety consequences of increased variation in size and weight.

State-of-the-Art

It is known that the interactions between large and small vehicles sharing a common roadway cause the smaller vehicle to be at a disadvantage with respect to controllability and vision. Examples are the aerodynamic disturbance imposed on the smaller car by the large freight vehicle, the temporary shielding of cross winds, and the splash and spray created by large vehicles traversing wet road surfaces. Whether these interactions are sufficiently strong to influence the accident record to a significant extent is not known.

Previous research has demonstrated that highway appurtenances (e.g., guard rails, median barriers, bridge railings, etc.) designed to prevent departures from the roadway or encroachment of the opposite lane of travel are compromised in that they cannot be designed to perform equally well with all sizes and weights of vehicles. Although, it would appear that a size and weight disparity of increased magnitude will seriously aggravate this situation, data do not exist which will enable accurate predictions of the consequences (property damage, injuries, fatalities) deriving from prospective size and weight changes in the motor vehicle fleet. In a similar vein, it is known that trucks have geometries which seriously compromise the occupants of motor cars if they should collide with the rear end of a truck. Although the significance of present-day levels of this particular hazard is hotly contested, the question must be raised as to whether the prospective growth in vehicle size variability will aggravate this phenomenon such that "truck underride" will become a significant contributor to the accident record and the cost of accidents.

Proposed Approach

1. Given a specific level of road roughness (as produced by traffic and environmental causes), are smaller passenger vehicles (at the low end of the size and weight spectrum) likely to suffer significantly in their road-holding capability? Can this decrease be quantified and calculated on the basis of physics and is it possible to confirm this calculation by means of accident data?
2. Will the increased sensitivity of small, light cars to road roughness (resulting in reduced ride quality) produce a significant impact on the safety record by causing increased operator fatigue with a corollary loss in performance control and alertness? Will the vehicle configurations that evolve from the objective of making trucking more productive result in a degraded environment for the freight-vehicle operator such that his control performance is reduced? If so, how can this trend be offset by design practice and what are the dollar investments required to recoup losses in truck ride quality caused by design for increased productivity?
3. What are the relationships between increased vehicle size and weight and the increased potential for rutting and subsequent increase in the splash and spray generated during set road conditions?
4. How will a traffic mix consisting of a vehicle population characterized by a broader distribution of (a) sizes and weights and (b) acceleration performance levels, influence highway operations (headway maintenance, passing, entry into the traffic stream, etc.)? Will this influence on operations be negative from a safety point of view and, if so, can this influence be quantified for the

benefit of traffic controllers and those personnel charged with the task of establishing operational constraints and policies?

5. To what degree are the crashworthiness of the smallest cars in the vehicle population and the design of highway appurtenances as intended to constrain errant vehicles compromised by a growing size disparity and growing weight disparity? To what extent do prospective growth in size and weight disparity and its impact on collision consequences present arguments and justification for segregating the movement of freight- and passenger-carrying vehicles?

5.3.4 Research Area D-2.4: Develop Equitable Formulas for User Costs, Enforcement Costs, and Speed Constraints

Problem Statement

Funds for the construction and maintenance of highways derive from the charges that are imposed upon highway users. As the size and weight disparity of highway vehicles continues to increase, questions of equitability arise. Should user charges reflect the degree to which using the vehicle depreciates the existing capital investment in highways, or should these charges also reflect the difference in capital investment necessary to accommodate the vehicles?

Also, to what extent should the costs of regulating and enforcing traffic rules and operations be considered from the standpoint of equitability as well as safety and transport productivity?

Goals

Develop equitable formulas for user charges to reflect the extent to which vehicles (differing in size, weight, and performance characteristics) influence the initial investment,

the rate at which the investment is depreciated, and the costs associated with traffic regulation and enforcement.

5.3.5 Research Area D-2.5: Overload Detection and Enforcement

Problem Statement

Accurate and comprehensive measurement of truck weights is essential to (1) establishing the influence of loads on pavements, (2) conducting pavement management programs, and (3) insuring that highway costs are fairly apportioned to highway users and nonusers. However, current measurement and enforcement techniques, e.g., weighing "vehicles in motion," portable scales, fixed scales, and the use of bridges as scales are not adequate to the task at hand.

Accordingly, this workshop fully supports current efforts by state and federal authorities to improve overload measurement techniques and enforcement efforts. Workshop personnel, however, believe that the problem is well-known and is currently receiving adequate attention.* Inclusion of this item in the report serves to indicate our support for the research that is going on in this area.

5.4 SUB-GROUP D-3: ADVANCED CONCEPTS

5.4.1 Research Area D-3.1: Operational and Economic Considerations for Dedicated Lanes for Common Carrier Passenger and Freight Traffic

Problem Statement

One solution to the problem of heavy trucks and buses mixed with smaller cars is to restrict these vehicles to a dedicated lane. This gives rise to a host of questions:

1. How do you restrain drivers from changing lanes?

*DOT Cost Allocation Study, Public Law 95-599, Nov. 6, 1978, Federal Aid Highway Act of 1978, Section 161.

2. Is there any advantage in prohibiting cars from the truck lanes?
3. Should there be a separating barrier between the truck lane and the other lanes?
4. Could the exclusive lane be used for high-speed buses during the day and large trucks at night?

Research is required to provide rational answers to these questions.

State-of-the-Art

Many of the problems of barrier-separated lanes have been unveiled by the Federal Highway Administration (FHWA) in their studies of automated highway lanes for the use of specially equipped private cars. A major difficulty is that in the formation of a single lane by a barrier, there is no opportunity to pass a stalled vehicle. Reliability and inspection requirements increase dramatically with the volume of traffic flow. Adding additional lanes in each direction for passing becomes prohibitively expensive and difficult in terms of land use.

The FHWA efforts were primarily focused on passenger requirements. A more recent study by the Transportation Systems Center investigated exclusive lanes for the use of multiple-bottom trucks. It was found that the reliability problem (e.g., stalled vehicles) was not as severe as that for passenger vehicles for two reasons:

1. Fewer vehicles are involved
2. There is more control over these vehicles since they are operated by a limited number of companies.

Some of the economic pay-offs for the trucker in terms of increased productivity were discussed in the TSC study.

A dedicated guideway which is used to carry freight at night at moderate speeds (55 m.p.h.) could be used for high-speed buses (80-100 m.p.h.) during the day. Through

the use of a noncontact suspension, such buses could operate at even higher speeds.

Goals

1. Determine reliability levels for large truck combinations operating on single-lane guideways.
2. Determine acceptability to the trucking industry of operation in restricted guideways and/or line-haul operation at night only.
3. Explore various lane-configuration options (i.e., barriers, buried cables) for electronic guidance, trucks and buses operating throughout the day, one-way operations, etc.
4. Construct an overall cost-accounting procedure whereby desirability of the above alternatives could be assessed. This accounting should examine the costs associated with providing designated lanes capable of supporting these heavier vehicles.

Pay-offs

1. A presentation of the costs and benefits of various alternatives for restricting trucks and buses to exclusive lanes.
2. A determination of the most likely lane-configuration alternatives which would lead to greater focus for future research.

Priority

Various members of the transportation community, including the Secretary of Transportation, have brought up the notion of restricting large trucks to certain lanes or corridors. It is essential that the broadest possible range of options for accomplishing this with the least harm and/or maximum benefit to the nation be explored.

Level of Effort

This research task is estimated to be a 5 labor-year effort.

Time Frame

Two years.

5.4.2 Research Area D-3.2: Evaluation of Levitation Ground Transportation System Performance Characteristics for Freight-Passenger Shared Guideway Service

Problem Statement

Noncontact suspension-propulsion systems, which may employ fluid or magnetic forces for levitation, guidance and/or propulsion have a number of operational characteristics which make them potentially attractive for application to shared guideway freight-passenger operations. However, a number of potential problems exist with respect to the shared-mode aspect, including the effect of vehicle load on the power-efficiency of levitation, and the effect on freight distribution imposed by the requirements for relatively expensive fixed guideways which will undoubtedly constrain the extent of the network. Additional research should be directed toward these issues.

State-of-the-Art

A large body of literature exists on the design of levitation and propulsion devices for fixed guideway systems. The work on shared systems, while less extensive, has led to the identification of several characteristics favorable to such use. These include:

1. Low loadings per unit area on guideway structures because of the inherent distribution of the suspension and propulsion forces. These loads per unit area are an order of magnitude lower than pneumatic-tired wheels, and two orders of magnitude lower than rail wheels.
2. The capability of the guideway to contain the vehicle, thus preventing derailment and enhancing safety.

3. The capability for negotiating curves at increased speed relative to rail and highway systems, thus providing the potential for increased productivity.
4. The capability to use non-petroleum-based fuels.
5. The potential for low noise and pollution.
6. The potential to produce low vibration levels and accommodate guideway irregularities.
7. The potential for reduction in maintenance costs.

Goals

The research objectives are:

1. To assess the requirements for shared guideways passenger-freight service using advanced systems, e.g. -
 - . Vehicle design
 - . Guideway design
 - . System operation.
2. To determine the potential for operational characteristics of these advanced systems to influence the productivity and cost of passenger and freight service.
3. To identify and evaluate what kinds and types of freight services mate well with advanced system characteristics, e.g. -
 - . The effect of positive retention of the vehicle in the guideway on various safety issues
 - . The ability to handle fragile freight
 - . The potential advantages for handling hazardous materials.

Pay-Offs

This research will provide the basic information required to assess the potential of advanced systems for providing freight-passenger service, and will identify the specific applications which show the most promise.

Level of Effort

About 3 labor-years.

Time Frame

The study could probably be completed in about 18 months.

5.4.3 Research Area D-3.3: Potential for Levitated Ground Transport Systems to Reduce Guideway/Vehicle Maintenance Requirements

Problem Statement

Several important ride quality and acceptance issues relating to freight and passenger vehicles using shared guideways can be attributed to disparities in vehicle unit axle loads. These issues directly impact the maintenance requirements of shared guideways systems. While analysis indicates that advanced suspension systems (maglev, air cushion) can reduce unit loadings by orders of magnitude (absolutely) over conventional systems and also reduce the disparity between freight and passenger unit loadings, there are no studies based on actual data.

Goals

To identify and assess maintenance requirements from actual experience with several advanced systems and to project and compare these requirements to comparable conventional systems.

State-of-the-Art

At least five experimental advanced systems might be used for case studies: the Aerotrain* (France), KOMET,* (Germany), HSST* (Japan), ML-500* (Japan), and PTACV* (United States). Data in some form exists for all these systems. Existing and proposed cooperative interchange programs can be used to obtain data on the foreign systems.

*See Glossary at the end of this section.

Before and after guideway profile data for the PTACV have been collected by the Federal Railroad Administration and maintenance records for the vehicle exist.

Pay-off vs. Risk

This is a medium pay-off, low risk project. The direct pay-off is only medium because the analytical results are logically consistent. Nevertheless, results based on actual data might provide needed confirmation for policy decisions. There is a high indirect pay-off in cooperating with foreign programs which are aggressively pursuing levitated system technology - e.g. \$50 million annually.

Level of Effort

Two labor-years.

Time Frame

One year.

5.4.4 Research Area D-3.4: Automated Intercity Rubber-Tired Freight and Passenger Guideway Systems

Problem Statement

The Urban Mass Transportation Administration (UMTA) has done a considerable amount of research on automated vehicles for urban applications. However, there are numerous advantages to be seen for intercity application, particularly for shared passenger/freight operations on exclusive lanes. The potential for this technology for the moderate speed range applicable to the intercity market should be assessed.

Pay-off and Risk

Technological risk is very low since it would represent an extrapolation of technology which is currently being developed. Pay-off would be moderate in that it would increase the understanding of intercity transportation options.

Subtask

A subtask under this problem would be the development of a high-speed rubber tire for use on buses. This would represent a low technological risk for speeds below 130 m.p.h. and an increasing risk for higher speeds.

5.5 GLOSSARY

Rock and Roll - a combined vertical and rolling motion of the freight car caused by the staggered 39 ft. bolted rail in the U.S. This motion is accentuated at low speeds (approximately 15-20 m.p.h.) and can lead to freight damage and derailment.

TDOP - Freight car Truck Design Optimization Program sponsored by the Federal Railroad Administration. The project is currently in Phase II and is being performed by Wiley Laboratories.

FAST - Freight Accelerated Safety and Testing facility at Pueblo CO, test site used for evaluation of freight rail car and truck.

KAB - Keep America Beautiful study on ways of reducing littering.

Aerotrain - French air cushion supported vehicle powered by an aircraft type turbofan engine. Successfully operated for many years, currently not in use.

KOMET - German magnetically levitated vehicle propelled by hot-water rockets used for testing magnetic suspension components at speeds to 400km/hr.

HSST - Japanese High Speed Surface Transport system using vehicles with electromagnetics for lift and single sided linear induction motor for propulsion.

ML-500 - Japanese Magnetically Levitated vehicle employing superconducting magnetics and designed for 500km/hr speed.

PTACV - United States Protolyon Tracked Air Cushion Vehicle
tested at Pueblo CO, test track.

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