MA-06-0048-79-6

ORS CONTRIBUTING TO THE RETENTION OF SEATED PASSENGERS DURING EMERGENCY STOPS

MARCH 1980

DEPARTMENT OF TRANSPORTATION ★ UNITED STATES OF AMERICA ★

AUTOMATED GUIDEWAY TRANSIT TECHNOLOGY PROGRAM

U.S. DEPARTMENT OF TRANSPORTATION
Urban Mass Transportation Administration
Office of Technology Development and Deployment
Washington DC 20590

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16. Abstract

A series of seven experiments was conducted to examine the variables that could contribute to a safe emergency stop on an automated guideway transit system. Sixty subjects, conforming to a desired range, experienced emergency decelerations in a test vehicle controlled by an automated braking system. The independent variables examined were seat contour and covering, seat orientation and tilt, footrests and armrests, and rate of change of deceleration (jerk). The dependent variables were the deceleration level at which subjects moved from sensors that were imbedded in the experimental seat and subject comfort ratings.

The major results indicated that forward-facing subjects sustained higher deceleration levels without being dislodged than subjects sitting at small orientation angles of 15° and 30°. A footrest contributed to greater retention of forward-facing subjects as did a seat tilted back 12°. The maximum deceleration level for retention of 84 percent of the forward-facing passengers sitting on the tilted seat and using a footrest was 0.36 g.

Jerk was shown not to be a factor in dislodging subjects during the onset of the emergency stop. It was, however, a factor in the perception of comfort. Subjects reported being more uncomfortable at higher jerk levels.

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16. Abstract
In order to examine specific Automated Guideway Transit (AGT) developments and concepts, the Urban Mass Transportation Administration has undertaken a new program of studies and technology investigations known as the Automated Guideway Transit Technology (AGTT) Program. The objective of one segment of the AGTT program, the Systems Safety and Passenger Security (SS&PS) study, is the development of guidelines for the assurance of actual and perceived passenger safety and security in AGT systems. The prime objective of this deceleration and jerk research study was to provide AGT system planners, designers, and operators with guideline information on the acceleration levels at which seated AGT passengers might be expected to be thrown from their seats during emergency stops. A series of seven experiments was conducted to examine the variables that could contribute to a safe emergency stop on an AGT system. Sixty subjects, conforming to a desired range, experienced emergency decelerations in a test vehicle controlled by an automated braking system. The independent variables examined were seat contour and covering, seat orientation and tilt, footrests and armrests, and rate of change of deceleration (jerk). The dependent variables were the deceleration level at which subjects moved from sensors that were imbedded in the experimental seat and subject ratings. The major results indicated that forward-facing subjects sustained higher deceleration levels without being dislodged than subjects sitting at small orientation angles of 15° and 30°. A footrest contributed to greater retention of forward-facing subjects as did a seat tilted back 12°. The maximum deceleration level for retention of 84 percent of the forward-facing passengers sitting on the tilted seat and using a footrest was 0.36 g. Jerk was shown not to be a factor in disloding subjects during the onset of the emergency stop. It was, however, a factor in the perception of comfort. Subjects reports being more uncomfortable at higher jerk levels.

17. Key Words
AGT; Automated Guideway Transit; Deceleration; Emergency Deceleration; Jerk; Safety; Seated Passengers; Security

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PREFACE

The U.S. Department of Transportation's Urban Mass Transportation Administration (UMTA), in order to examine specific Automated Guideway Transit (AGT) developments and concepts, has undertaken a new program of studies and technology investigations called the Automated Guideway Transit Technology (AGTT) program.

The objective of one segment of the AGTT program, the Systems Safety and Passenger Security Study (SS&PS), is the development of guidelines for the assurance of actual and perceived passenger safety and security in AGT systems. This work was contracted, through the Transportation Systems Center (TSC), to a team composed of Dunlap and Associates, Inc., the University of Virginia, and the Vought Corporation.

The Systems Safety and Passenger Security (SS&PS) study has involved six related but separate tasks. Three were concerned with the development of guidebooks dealing with: 1) passenger security, 2) evacuation and rescue, and 3) passenger safety and convenience services. A fourth task required the development of a passenger value structure model; a fifth involved research on the retention of seated passengers during emergency stops; and a sixth involved the conduct of a joint Government and industry workshop to review and revise the three guidebooks.

The prime objective of this deceleration and jerk research study was to provide AGT system planners, designers and operators with guideline information on the acceleration levels at which seated AGT passengers might be expected to be thrown from their seats during emergency stops. This information is essential for the establishment of realistic vehicle headway specifications and overall AGT system performance, and traffic flow standards. A secondary objective was to develop design guidelines for high retention seats for AGT systems' passengers. Dunlap was responsible for the emergency deceleration and jerk study with assistance from the Vought Corporation. The Responsible Officer for Dunlap and Associates, Inc., was Dr. Richard D. Pepler. The project leader was Dr. Harold H. Jacobs. Mr. William Onifer assisted in the planning, execution and analysis of the experiments. Mr. J.R. Hanking of the Vought Corporation surveyed the available seat information, assisted in selecting the experimental seat, and provided the inputs to Section 5.0: Design Guidelines for High Retention AGT Passenger Seats. Dr. J. Karl Hedrick of M.I.T. served as consultant in the area of system dynamics.

The author gratefully acknowledges the cooperation of Dr. Duncan MacKinnan and Mr. R. Hoyler of the Urban Mass Transportation Administration and the following members of the professional staff of the Transportation Systems Center: Dr. C.N. Abernethy, Dr. E.D. Sussman, Dr. Janis Stoklosa, Mr. Gordon Plank, and Dr. Walter Hawkins, for their assistance in the planning, performance and documentation of this research study.

Finally, a special thanks is due to the subjects who participated in this research.

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METRIC CONVERSION FACTORS

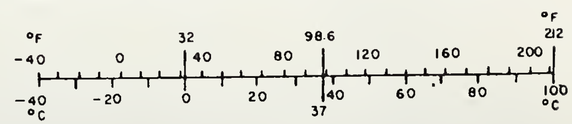
Approximate Conversions to Metric Measures

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

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

Approximate Conversions from Metric Measures

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



1. INTRODUCTION AND SUMMARY

1.1 Introduction

A primary concern in the design and development of Automated Guideway Transit (AGT) systems is the safety of public transit passengers during emergency stops. This concern is expressed in the requirement to use safe levels of deceleration and to provide seats and supports that can aid in the retention of passengers during deceleration. Known safe levels of deceleration determine directly the allowable headway between independent vehicles and indirectly the passenger-carrying capacities of the system. The goal is to establish deceleration and jerk levels that will minimize injuries, but will maximize the passenger flow rate of the system.

Several approaches have been used in previous studies to determine the requirements for a safe emergency stop. These included the use of subjective estimates by passengers on what they consider a "safe" stop (summarized by Gebhard, 1970), measurements of the movements of cadavers in very abrupt stops (Hodgson, Lissner and Patrick, 1963), and actual measurements of body movements in simulated transit situations (Abernethy, Plank, Sussman and Jacobs, 1977). While providing valuable background information, the first two of the above approaches did not provide empirical data on seated humans in emergency stop situations. Only the Abernethy et al. study directly addressed the problem. That study provided data on the effects of emergency deceleration for two extremes of the population: males larger than 95 percent of the male population, and females smaller than all but 5 percent of the female population.

The present study was undertaken to extend Abernethy et al.'s work through the use of a broader sample of test subjects in order to thoroughly study the effects of jerk and to investigate various seat configurations that might contribute to greater passenger retention. The independent variables investigated in the present study were: 1) jerk, which is defined as the rate of change of deceleration; 2) seat configuration including different coverings and contours, various angles of seat tilt, and the use of a footrest and armrests; and 3) seat orientation angle including forward- and side-facing. These variables were evaluated for their usefulness in enhancing passenger retention during emergency deceleration. The dependent variables were: 1) the deceleration level (measured in g*) attained when the subject moved off a seat sensor; and 2) subject comfort ratings.

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*g = acceleration due to force of gravity.

1.2 Purpose

The purpose of the present series of experiments was to:

- Establish accurate estimates of safe emergency deceleration levels for AGT vehicles carrying seated passengers.
- Determine the effects of jerk on the dislodgement and comfort of seated passengers.
- Investigate seat characteristics that could contribute to greater passenger retention such as seat coverings and contours.
- Identify passenger aids such as armrests and footrests that are practical for use in AGT systems.
- Identify a seat configuration that provides optimum retention for AGT passengers.

To meet these objectives, experiments were performed to investigate relevant variables that would aid in the retention of passengers in an emergency stop.

1.3 Summary of Results

These experiments showed that passenger retention was highest in a fabric covered contoured seat. Jerk was only found to affect passenger comfort, not retention. Higher decelerations were sustained by forward-facing passengers than those sitting at small orientation angles of 15^o and 30^o to the left. The retention of forward-facing passengers was enhanced by a backward tilt of the seat and the use of a footrest. The maximum deceleration level for the retention of 84 percent of forward-facing passengers sitting on a seat with a 12^o backward tilt and using a footrest was 0.36 g.

Armrests were important for the retention of side-facing passengers, although they did not restrict passengers' initial movement or slipping on the seat.

2. EXPERIMENTS

2.1 Background

2.1.1 Deceleration

The experimental research to date on emergency deceleration in public transit employed several methods for measuring safe deceleration levels. These methods included: sensing loss of balance of standees or seat dislodgement of seated passengers, using observers to rate passengers' movement, measuring the movement of dummies, and developing biomechanical computer models. The following paragraphs review the research employing these methods, and the major findings are summarized in Table 2-1.

Hirshfeld (1932) accelerated standing subjects at constant jerk rates of between 0.03 and 0.33 g/sec.* The dependent measure was foot movement that resulted in the opening of a sensor switch due to loss of balance. For the forward-facing position, the average value of acceleration at which subjects experience loss of equilibrium was 0.17 g. For side-facing subjects, the average value was 0.19 g. When forward-facing subjects held a vertical stanchion, the average value was 0.27 g.

Browning (1972) also measured standees. In his experiment, observers rated movement of subjects due to acceleration forces as: 'no relative movement,' 'slight relative movement,' and 'moderate relative movement.' Browning suggests that the 'moderate relative movement' criteria be used to define a maximum emergency deceleration. For unsupported standees in the general public, which included children and disabled, the observers rated 0.07 g as the maximum emergency deceleration. When instructed to use a handhold, 0.20 g was rated as the maximum.

Both of the above researchers studied only standees. Seated passengers present a different dynamic problem. American Seating (1975) measured the static force required to dislodge a buttock form from contoured seats covered with barley-cloth vinyl. A static force of 0.94 g was required to dislodge the form from a forward-facing seat and 0.97 g from a side-facing seat. An analytical study by Fox and Dryden (1975) utilized a biomechanical computer model to simulate a 95 percentile male in weight and height. A force calculated at 0.559 g was required for dislodgement. Neither this result nor the American Seating results were dynamically validated.

It was found that 84 percent (mean plus one standard deviation) of the passengers began to feel slightly uncomfortable at a 0.14 g deceleration level and very uncomfortable at a 0.22 g deceleration level. The 0.14 g deceleration level (slightly uncomfortable rating) was considered the maximum allowable deceleration for ordinary train braking situations, and the

*Jerk is measured in g's per second.

TABLE 2-1. SUMMARY OF RESULTS OF PRIOR RESEARCH

Researcher	Relevant Conditions	Criterion	Estimates of Deceleration Level
A. Objective Estimate			
Hirshfeld (1932)	Standees--forward-facing, unsupported	Loss of balance; measured by sensors	0.17 g (from acceleration data)
	Standees--side facing, unsupported	Loss of balance; measured by sensors	0.19 g (from acceleration data)
	Standees--holding vertical stanchion	Loss of balance; measured by sensors	0.27 g (from acceleration data)
Browning (1972)	Standees--unsupported	Moderate relative movement; rated by observers	0.07 g (from acceleration data)
	Standees--holding hand rail	Moderate relative movement; rated by observers	0.20 g (from acceleration data)
American Seating (1975)	Seated dummies--forward-facing, contoured seat covered with barley-cloth vinyl	Static force required to dislodge dummy; measured by spring scale	0.94 g
	Seated dummies--side-facing, contoured seat covered with barley-cloth vinyl	Static force required to dislodge dummy; measured by spring scale	0.97 g
Fox & Dryden (1975)	Biomechanical computer model of 95th percentile seated male, forward-facing	Dislodgement estimated by computer simulation of static and dynamic forces	0.559 g
Abernethy, Plank, Sussman and Jacobs (1977)	Seated--forward-facing, untilted	Dislodgement; measured by seat sensors	0.47 g (for 84% of population)
Abernethy et al. (continued)	Seated--forward-facing, tilted	Dislodgement; measured by seat sensors	0.52 g (for 84% of population)
	Seated--side-facing	Dislodgement; measured by seat sensors	0.41 g (for 84% of population)
B. Subjective Estimate			
Matsudaira (1961) and Matsui (1962)	Seated passengers--forward-facing	Comfort ratings by 84% of passengers:	
		- slightly uncomfortable	0.14 g
		- very uncomfortable	0.22 g
Urabe & Nomura (1964)	Seated passengers--(uncrowded)	Allowable limit; ratings by 90% of passengers	0.22 g

0.22 g level (very uncomfortable rating) for emergency braking situations. A study by Urabe and Nomura (1964) on a test train found that 90 percent of the passengers sitting at ease in an uncrowded condition rated 0.22 g as the allowable limit for deceleration. The acceptable deceleration levels obtained in these subjective estimate studies are much lower than those obtained with dummies or with a computer model.

The one study which actually tested seated passengers (Abernethy et al.) revealed permissible deceleration levels in a range similar to that obtained with the computer model. The authors reported that the mean maximum deceleration level at which forward-facing subjects were dislodged was 0.55 g. When the seat was tilted 5 degrees back, the mean value increased to 0.59 g. For the retention of 84 percent of the population, the permissible emergency deceleration level was estimated to be 0.47 g for forward-facing untilted passengers, and 0.52 g for passengers tilted back 5 degrees. For side-facing subjects, the mean deceleration was 0.49 g for retaining 50 percent of the population, and 0.41 g for 84 percent of the population. A re-examination of these results in the present study indicated the deceleration levels attained were artifically high due to the presence of an instrumentation lag in the system. This problem is discussed in Section 4.0.

Another method used in deceleration research was subjective estimates by passengers of the degree of comfort (or discomfort) experienced during deceleration (Table 2-1). Studies by Matsudaira (1961) and Matsui (1962) on a test train used a five-point scale that ranged from "insensible" (rating of zero) through "very uncomfortable" (rating of 5).

The actual emergency deceleration levels in use on electric rapid-transit vehicles throughout the U.S. ranges from 0.14 g to 0.30 g (Gebhard, 1970). The emergency braking levels in present automated transit systems range from 0.11 g to 0.37 g. These are listed in Table 2-2. On European railroads, the maximum decelerations range from 0.09 g to 0.12 g, with Belgium an exception, where 0.15 g is the extreme limit (Gebhard, 1970).

2.1.2 Jerk

Another aspect of the deceleration experience is the rate of change of deceleration, referred to as jerk. A basic question in this research is whether jerk has any effect on passenger retention, or whether retention is strictly a function of the deceleration levels--regardless of how the level was attained.

Matsui (1962), using the previously mentioned rating scale, found that in general passengers reported being more uncomfortable as jerk is increased up to a level of 0.09 g/sec. Urabe and Nomura (1964), using a similar comfort scale, found that the maximum allowable jerk for 50 percent of the passengers sitting in an uncrowded condition was 0.19 g/sec. This value represents the jerk at the final phase of the braking, just prior to the stop. Jerk at the first phase of the braking was reported to have little influence on comfort.

TABLE 2-2. EMERGENCY BRAKING LEVELS IN EXISTING AGT SYSTEMS

System	Deceleration Level	Reference
Tampa	0.11 g	Yen et al. 1977
Fairlane	0.19 g	Yen et al. 1977
King's Dominion	0.20 g	Yen et al. 1977
Sea-Tac	0.13 g	Yen et al. 1977
Houston Tunnel Train	0.15 g	Yen et al. 1977
Wedway	0.16 g	Yen et al. 1977
AIRTRANS	0.16 g - 0.22 g	Kangas et al. 1976
Val	0.18 g - 0.25 g	Anon. 1978
Morgantown	0.31 g - 0.37 g	Elms et al. 1979

In Hirshfeld's study of standees, jerk levels ranging from 0.03 g/sec to 0.31 g/sec were used. Up to approximately 0.09 g deceleration, no major differences were found in the passengers' ability to retain their balance as a function of the jerk level. Between deceleration levels of 0.09 g and 0.22 g, more passengers retained their balance at higher jerk levels (Hirshfeld's analysis of data at jerk levels of 0.08, 0.14 and 0.20 g/sec). Beyond 0.25 g deceleration, everyone lost their balance regardless of jerk level. Hirshfeld suggests that the reason for the counterintuitive results between 0.09 g and 0.22 g is that people sense the rapidly changing acceleration and adjust their posture accordingly. Easier stops are more casually accepted, leaving the rider unprepared. A more compelling explanation for this finding was that it was due to a constant bias characteristic of the sensor system. Any lag in the sensor system will increase the level of acceleration reached prior to an indication of dislodgement, but the effect will be most pronounced at high levels of jerk due to the rapid rise in deceleration. Such a lag could account for the counterintuitive results.

Browning (1972) reported that the upsetting effect of acceleration (or deceleration) on standees, riding on conveyors, as measured by the amount of staggering was due not only to acceleration, but also to the time taken to reach this level. Very rapid changes of acceleration, that reach a given level in less than half a second, have a greater upsetting effect than do changes that reach the same level in a second or longer. However, in Browning's study, the passengers' loss of balance was neither recorded nor even achieved, and his results are based on estimates of the subjects' response to the acceleration.

Abernethy et al. (1977) found that there were no significant differences in the deceleration level at which a sample of six subjects left their seats as a result of using a high jerk rate (1.5 g/sec to 2.0 g/sec). The authors, however, indicated these results to be tentative because of the limited number of subjects and the lack of precise control over the jerk levels.

In summary, the previous research indicates that jerk is a factor in determining the comfort aspects of deceleration. In terms of safety, the previous research on standees had differing findings on the effects of jerk. The only study directly applicable to the seated passenger in AGT systems is the Abernethy study, which found that jerk may not be a factor in actual passenger retention.

2.2 General Approach

These experiments were performed to investigate the variables that enhance the retention of passengers during emergency stops in transit vehicles. These variables were identified through literature review and through consultations with experts in the transit field. The variables were: 1) seat configuration including different coverings and contours, various angles of seat tilt, and the use of armrests or a footrest; 2) seat orientation angle including forward- and side-facing; and 3) level of jerk.

A series of seven experiments were performed. The experiments were similar in approach to the study by Abernethy et al., in which candidate decelerations for automated transit systems were simulated in a test vehicle. The vehicle containing the experimental seat was operated on an unused airport taxiway; and upon signal from the driver, the brakes were applied. The deceleration caused the subject to move off a seat sensor, simulating dislodgement from the seat. This movement was automatically noted on a deceleration record. A loose fitting safety harness prevented the subject from actually being dislodged from the seat. In the present study, the application of the brakes was automatically controlled by a hydraulic closed-loop feedback system initiated by a signal from the driver which provided accurate and repeatable decelerations (see Section 2.1.3.2). The deceleration levels were uniformly increased ("ramped") up to levels of 0.8 g.*
In selected experiments, movies were made of the subject's movements during the stops.

The experiments were initially conducted on an airport taxiway at Hanscom Field, Bedford, Massachusetts, starting in November 1977. During December 1977, the test location was moved to Otis Air Force Base on Cape Cod, Massachusetts, because the weather there was milder. The

*In selected experiments, the levels attained were as high as 0.9 g.

final three experiments were again conducted at Hanscom Field and were completed in July 1978. The test sites were selected to provide smooth flat surfaces ensuring maximum repeatability of the deceleration levels and to eliminate the possibility of collision with other traffic or obstacles.

2.2.1 Variables Investigated

The independent variables examined in the seven experiments are listed in Table 2-3. These are grouped as seat configuration, seat orientation and level of jerk.

Various seat configurations were investigated to determine the characteristics for greatest passenger retention. The seat configuration variables were covering, contour, seat tilt and use of armrests and a footrest. The two types of seat coverings used in the investigation were a vinyl covering (low coefficient of friction) and a fabric covering (high coefficient of friction). The high coefficient of friction fabric was assumed to provide higher retention properties.

Two types of seat cushions were used: flat and contoured. The contoured cushion was assumed to have the higher retention properties.

Four seat tilt angles were investigated: 0^{o} (flat), 3^{o}, 9^{o} and 12^{o}.* These were obtained by lowering the rear of the seat pan on its frame. It was assumed that passenger retention would increase with increasing seat tilt.

Two accessories, a footrest and armrests were examined. Both of these accessories were assumed to enhance passenger retention.

Another variable investigated was seat orientation which included both small and large angles. The small orientation angles were 0^{o} (forward-facing), 15^{o} and 30^{o} to the left. The large orientation angles were 45^{o}, 90^{o} (side-facing) and 135^{o}. These angles were selected as they have potential application in AGT systems.

The third category of variable investigated was jerk. Three levels of jerk were selected: 0.25 g/sec (defined as low jerk), 0.75 g/sec (medium jerk) and 1.25 g/sec (high jerk). Because previous research findings were anomalous, no assumptions about the effects of jerk on retention were made.

Two dependent variables were measured in the experiments (Table 2-3). These were: 1) the deceleration level attained when the subject moved off one of two seat sensors indicating dislodgement and 2) comfort ratings of the stops ranging from "very comfortable" to "very uncomfortable."

*Seat tilt was measured in one plane from front to rear, down the center of the seat.

TABLE 2-3. EXPERIMENTAL VARIABLES

Variable	Studied in:
A. Independent Variable	
1. Seat Configuration	
a) Covering	Experiment 1
1) Vinyl (low coefficient of friction)	
2) Fabric (high coefficient of friction)	
b) Contour	Experiment 1
1) Flat	
2) Contoured	
c) Tilt Angle	Experiments 4 and 5
1) 0° (flat)	
2) 3° back	
3) 9° back	
4) 12° back	
d) Accessories	
1) Footrest	Experiments 3, 4 and 5
a) With footrest	
b) Without footrest	
2) Armrests	Experiments 3, 4 and 6
a) With armrests	
b) Without armrests	
2. Seat Orientation Angle	
a) Small Angles	Experiment 4
1) 0° (forward-facing)	
2) 15° left of forward	
3) 30° left of forward	
b) Large Angles	Experiment 3
1) 45° left of forward	
2) 90° (side-facing)	
3) 135° left of forward	
3. Level of Jerk	Experiment 2
a) 0.25 g/sec (low jerk)	
b) 0.75 g/sec (medium jerk)	
c) 1.25 g/sec (high jerk)	
B. Dependent Variable	
1. Deceleration Level at Time of Subject Dislodgement	Experiments 1-7
2. Subject Comfort Ratings	Experiment 2

Legend:

Experiment 1: To Identify Seat Characteristics
Experiment 2: To Determine Effects of Jerk
Experiment 3: To Determine Effects of Large Seat Orientation Angles
Experiment 4: To Determine Effects of Small Seat Orientation Angles
Experiment 5: To Evaluate High Retention Seat Characteristics of Forward-Facing Passengers
Experiment 6: To Evaluate High Retention Seat Characteristics of Side-Facing Passengers
Experiment 7: Exploratory Study to Examine Effects of Preparation

2.2.2 Subjects

Sixty individuals participated in the seven experiments. Where possible, the experiments were run sequentially so that many of the subjects participated in more than one experiment. Recruitment was accomplished primarily through newspaper advertisements in the area of Bedford, Massachusetts, for the Hanscom tests; and in the area of Falmouth, Massachusetts, for the Otis tests. Each subject was given a medical examination by a licensed physician and was required to sign a statement of informed consent before participating in the experiments. Copies of these three forms are included in Appendix A. Each subject received $25 for his or her participation.

Subjects were selected as representative of the general population in terms of sex, height and weight. For both sexes, subjects were divided into three categories based on height and weight. These categories represented the smallest 15 percent of the population, the mid 15 percent and the largest 15 percent of the population in both height and weight (Morgan et al. 1963). The mean weight, height and age for each category are listed in Table 2-4.

TABLE 2-4. SUBJECT CHARACTERISTICS

Sex	Mean Weight		Mean Height		Mean Age
	lbs	kg	inches	cm	years
Male					
Small	133.1	60.4	64.6	164.1	24.7
Intermediate	160.6	72.8	68.4	173.7	37.0
Large	208.6	94.6	72.8	184.9	24.6
Female					
Small	103.0	46.7	60.6	153.9	28.4
Intermediate	131.2	59.5	63.5	151.3	35.5
Large	171.0	77.6	67.4	171.2	36.8

2.2.3 Instrumentation

The three major items of equipment were the test vehicle, the automatic braking system and the experimental seat.

2.2.3.1 Test Vehicle

The test vehicle was a new 14-foot Ford parcel van, rented from a local rental agency (see Figure 2-1). It had disc-brakes on the front wheels and dual wheels with drum brakes on the rear. Approximately 150 lbs. of lead was added to the rear bumper for increased braking force of the rear wheels.

2.2.3.2 Braking System

The brakes were controlled by a Lebow Associates Model 7610-112 Brake Test Instrument (Figure 2-2). This device consisted of a hydraulic power supply and brake pedal actuator which physically depressed the brake pedal on command, and an electronic programmer/controller with a built-in decelerometer. The programmer/controller was set to provide a uniformly increasing rate of deceleration up to the maximum deceleration attained by the test vehicle (over 0.9 g in Experiments 5 and 6). The driver initiated the stop with a remote switch; and, if required, could abort the stop at any time by releasing the switch. The accuracy of the Lebow decelerometer was checked against an independent decelerometer and also against deceleration levels calculated from velocity measurements of a fifth wheel mounted at the rear of the test vehicle.

2.2.3.3 Experimental Seat

A brief survey of seat manufacturers was conducted* to determine if a stock seat could be used for the experiments. A seat was required that could be adjusted for the study of the various seat retention properties. The American Seating Company Model 6318A Driver/Operator seat (Figure 2-3) met the requirements with some modifications.

The test seat characteristics are listed in Table 2-5. The seat pan angle was adjustable from a 0° (flat) position to tilts of 3°, 9° and 12° back. The seat back was always adjusted so as to maintain an approximate angle of 97° with the seat pan. The entire seat pedestal could be rotated and locked at 0°, 15°, 30°, 45°, 90° and 135° from forward-facing.

The seat cushions were specially fabricated for the study. The flat seat was constructed of two 2.54 cm (1 in) layers of 31.8 kg (70 lbs) compression foam.** The contoured seat was constructed of one layer of

---

* By the Vought Corporation.

** A 31.8 kg (70 lbs) weight placed on a 22.9 cm (9 in) disc depressed the foam by 25 percent.

FIGURE 2-1. TEST VEHICLE

FIGURE 2-2. BRAKE INSTRUMENT

(Brake pedal actuator--beneath steering column; electronic programmer/controller--on floor; recorder--on seat)

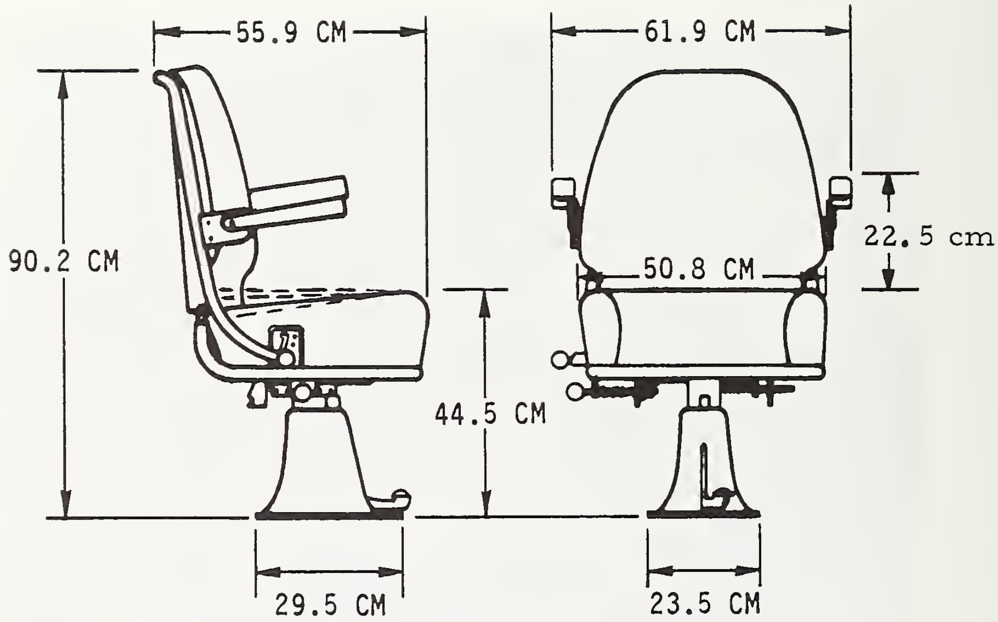


FIGURE 2-3. EXPERIMENTAL SEAT

TABLE 2-5. EXPERIMENTAL SEAT CHARACTERISTICS

<u>Seat Pan Angle</u> Adjustable Locked at 0°, 3°, 9°, 12° from horizontal <u>Seat Back Angle</u> Angle between pan and back was constant at 97° <u>Seat Pedestal</u> Rotatable Locked at 0°, 15°, 30°, 45°, 90°, 135° <u>Seat Cushion</u> Fabric: 1. Standard vinyl fabric flat cushion 2. Standard vinyl fabric with contoured cushioning 3. Fabric having a high coefficient of friction with flat cushioning 4. Fabric having a high coefficient of friction with contoured cushioning <u>Armrest</u> Folded away when not used <u>Footrest</u> Removable Continuously adjustable for passengers from 5th to 95th percentile in height

this foam with a second layer contoured along the front and sides to duplicate a sample of a high retention seat provided by the American Seating Company (Figure 2-4). The coverings were either a standard vinyl with a low coefficient of friction (General Tire Sentinel Vinyl) or a nylon and wool coarse weave fabric with a high coefficient of friction (Craftex K12924N).

The seat was equipped with fold-down armrests that lowered into position at the sides of the seat back. A footrest accessory with a 60° slope from the vertical was bolted to the floor in front of the experimental seat. The distance of the footrest from the seat could be adjusted for each subject so that the heels of the shoes rested on the floor and the soles rested fully against the footrest.

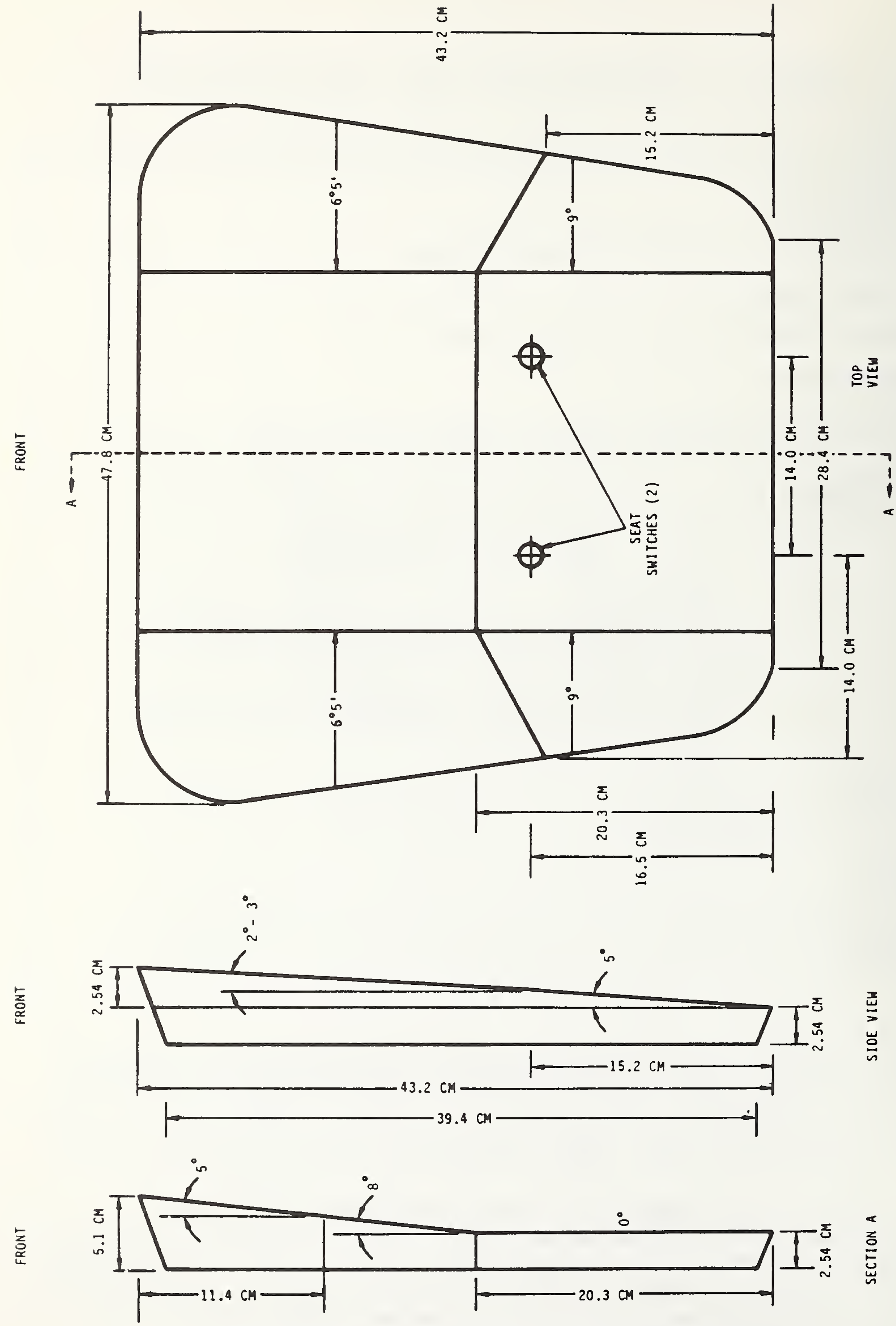


FIGURE 2-4. CONTOURED SEAT CUSHION

Two sensors were installed in the seat cushion and were wired in series to a recorder and to a lamp that signalled when the subject moved off the sensors. A five-point racing-type safety harness was loosely fastened around the subject and adjusted to allow sufficient movement to activate the seat sensors.

2.2.3.4 Recording Equipment

The deceleration levels and the status of the seat sensors were continuously recorded on a Brush Model 222 two-channel strip chart recorder.

Two Bolex Paillard movie cameras were employed during several experiments to record the movement of the subjects during stops. The cameras were set for a speed of 64 frames per second to produce slow motion pictures for analysis. In several experiments, the films were analyzed and correction factors for lags in the instrumentation were calculated (see Experiment 2: Effects of Jerk).

2.2.4 General Procedures

Essentially the same procedures were employed during all experiments. Subjects were told to report to the test site, either Hanscom or Otis, where they first were given a medical examination. They then signed a "Statement of Informed Consent" (Appendix A), and received a briefing on the purpose of the test and the procedure to be followed. Once in the experimental seat, the safety harness and footrest (if used in the experiment) were adjusted to fit the individual subject. The harness adjustment was sufficiently loose to permit enough movement for triggering the seat switches, but secure enough to ensure that the subject did not actually leave the seat.

The subjects wore rubber soled shoes and denim overalls to reduce the effects of frictional differences in personal clothing. They also wore a baseball catcher's chest protector and a helmet for safety.

The subjects were told to imagine that they were riding in a transit vehicle such as the Metropolitan Transit System. They were asked to react to the decelerations as if they were riding in an actual transit system and not to anticipate the stops. They were also asked not to become limp and simply "fall" into the safety harness. Subjects were also cautioned not to grab the seat or seat belt during stops.

When seated, the subject could see through the front window of the vehicle. However, the brake pedal actuator could not be seen so that the subject could not determine when the driver initiated the stop. The hydraulics of the automated braking system made a loud sound during warmup and activation. This sound was explained to the subject as being normal. To prevent the sound from serving as a cue to initiation of a stop, the braking system was turned on during most of the run.

A primary concern in conducting these experiments was the safety of the subjects. During the runs, the subjects wore a chest protector and a DOT-approved helmet. Emergency medical procedures were established at the test site in case of an accident. The entire test vehicle and procedures were reviewed and approved for safety by a committee of three human factors engineers who had no previous knowledge of or prior involvement with the study. The checklist used by the committee as well as their report are included in Appendix A. There were no accidents or injuries during the study.

During most runs, the driver accelerated the vehicle until a uniform velocity of 64 km/h (40 mph) was attained. During Experiments 5 and 6: High Retention Characteristics, the speed was 48 km/h (30 mph). The driver then triggered the braking system and the vehicle was allowed to decelerate until just before coming to a stop. At this point, the braking system was released allowing the vehicle to coast before actually stopping. This procedure provided the required deceleration data, yet avoided throwing the subject back against the seat.

In Experiments 5 and 6, the subjects were given magazines and were asked to read during the runs. This procedure was employed as a further attempt to establish a natural transit system environment.

Movies were made of the subjects' movements during selected experiments. These films enabled a detailed examination of the subjects' reactions to the deceleration and provided a visual record of when the subject began to be dislodged. This record was compared with the seat sensor information and a deceleration level was calculated that "corrected" for lags in the seat sensor recordings. (See Experiment 2: Effects of Jerk, for the detailed technique.)

As part of the analysis of each experiment, statistical tests were made to detect the presence of any order effects. No order effects were found.

Although some of the distribution of the experimental data was slightly skewed, the analysis of variance was employed to detect significant differences since this statistical test was considered sufficiently robust to accommodate the data.

Data on the effect of subject size were analyzed for each experiment and subsequently pooled across several experiments. No uniform pattern of results due to subject size was found in the statistical analysis. This data is available in Appendix C.

Throughout these experiments, the assumption was made that once the subject activated the seat switches, his/her movements from the seat would proceed inevitably as long as the deceleration persisted. There is strong evidence supporting this assumption in the motion picture recordings.

2.3 Experiment 1: Seat Characteristics

The purpose of this experiment was to identify the seat contour and covering with the best retention characteristics. The selected seat would then be used in all subsequent experiments. The variables considered were the seat shape, either flat or contoured, and the seat covering, either vinyl or high coefficient of friction fabric. Thus, the retention effects of four seat types were studied: vinyl flat, vinyl contour, fabric flat and fabric contour.

2.3.1 Specific Method

Twelve subjects participated in the experiment, two from each subject category. Each subject received four deceleration runs on each of the four seats. The order of presentation was counterbalanced to control for any order or sequence effects.

The experiment was performed using a forward-facing seat (0° orientation) with no seat tilt. No footrests or armrests were used during the runs. Jerk level was maintained at 0.25 g/sec.

2.3.2 Results

The mean deceleration level and standard deviation recorded when the subject lifted off the seat sensors for each of the four seat types tested are listed in Table 2-6. The listed values are not corrected for instrumentation lag because only relative values of maximum deceleration were required to discriminate between the seat characteristics. An analysis on this data indicated that the differences due to seat type were statistically significant (i.e., the probability of the differences being due to random variation was less than 1 in 1,000) (Table B-1, Appendix B).

TABLE 2-6. DECELERATION LEVELS ATTAINED WHEN SUBJECT DISLODGEMENT OCCURRED WITH THE FOUR TEST SEATS (UNCORRECTED)

Test Seat	Mean Deceleration	Standard Deviation
Vinyl Contour	0.300 g	0.067 g
Fabric Flat	0.302 g	0.061 g
Vinyl Flat	0.329 g	0.048 g
Fabric	0.334 g	0.053 g

The application of Tukey's HSD Multiple Comparison Test (Kirk, 1969) indicated that the retention characteristics of the fabric contour and vinyl flat were superior to the other two seat types ($p < .05$), but were not significantly different from each other. Although these results indicate that either seat could be used, the fabric contour seat was selected as a standard for use in the subsequent experiments.

2.4 Experiment 2: Effects of Jerk

This experiment was conducted to determine if jerk (i.e., rate of change of deceleration) is a factor in dislodging passengers from their seats. Three jerk levels, 0.25 g/sec, 0.75 g/sec and 1.25 g/sec, were employed.

2.4.1 Specific Method

Twelve subjects, two from each subject category, participated in the experiment. Each subject was tested three times at each condition of jerk in a counterbalanced order. The subjects were only tested in a forward-facing, untilted seat position using the fabric covered contoured seat. No footrest or armrests were used.

In addition to using the seat sensors to measure the deceleration level at which people came off their seats, movies were taken during each of the runs. These movies were used to determine the magnitude of any delay in the mechanical seat switches. Such a delay would give artificially high deceleration readings, and the effects would be more pronounced at high jerk levels. Side-view films were taken at 64 frames per second to record subjects' movements. A lamp attached to the side of the seat was also in view in each frame. This lamp indicated if the subject was on or off the seat sensors.

The film analysis consisted of viewing the frames one at a time and determining for each run:

1. When the subject began to move forward

2. When the seat sensors were triggered--as indicated by the lamp in view in each frame

The time delay between these two events was calculated from the film speed and this delay was subtracted from the seat sensor indication point on the strip chart recordings of the deceleration levels. This process enabled the calculation of a true dislodgement deceleration value. Figure 2-5 shows selected frames from a typical dislodgement sequence.

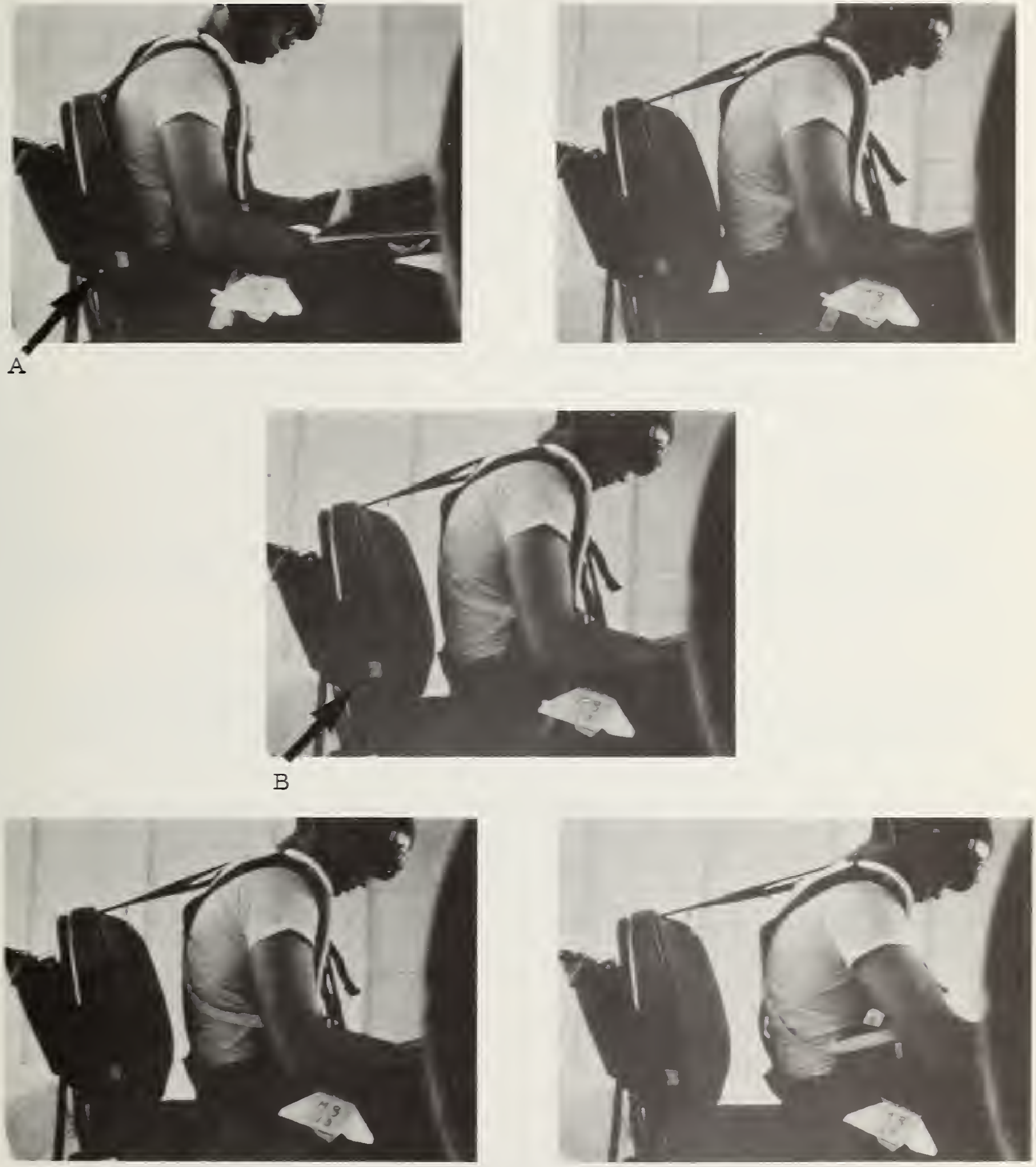


FIGURE 2-5. SUBJECT MOVEMENT
IN TYPICAL DISLODGEMENT SEQUENCE

Arrow A is pointing to an indicator light that extinguished (see Arrow B) when the subject moved off the seat sensors.

Subjective estimates of comfort were also solicited from the participants. On the fourth through ninth run, each subject was requested to rate the comfort of the stop, by answering the following question: "How would you rate the stop just experienced"? (Check One)

_______ Very Comfortable

_______ Comfortable

_______ Somewhat Comfortable

_______ Neutral

_______ Somewhat Uncomfortable

_______ Uncomfortable

_______ Very Uncomfortable

2.4.2 Results

The mean deceleration for each level of jerk is reported in Table 2-7. The initially measured or "raw" deceleration data and the corrected deceleration levels are both listed.

TABLE 2-7. DECELERATION LEVELS ATTAINED WHEN SUBJECT DISLODGEMENT OCCURRED WITH THREE CONDITIONS OF JERK

	Raw Deceleration Measured from Seat Sensors		Deceleration Corrected for Instrumentation Lag	
Jerk Condition	Mean	S.D.	Mean	S.D.
Low Jerk (0.25 g/sec)	0.383 g	0.104	0.29 g	0.10
Medium Jerk (0.75 g/sec)	0.429 g	0.070	0.29 g	0.06
High Jerk	0.491 g	0.077	0.30 g	0.07

The raw deceleration data indicated that the higher jerk conditions result in the passenger sustaining higher deceleration levels prior to dislodgement. The corrected deceleration data, however, indicated no systematic difference due to jerk. An analysis of variance of the corrected data confirmed the absence of this effect (Appendix B, Table B-2a).

In addition to revealing exactly when the subjects began to move during dislodgement, the film analysis permitted an examination of the range of body movements during a stop. In almost all cases, the subjects' shoulders moved forward followed by the forward movement of the buttocks. Movement of the buttocks was taken as the point at which the dislodgement began and was, therefore, used in all of the above calculations (Figure 2-5).

The timing of shoulder movements was calculated from the films and also analyzed for differences due to jerk levels. No differences were found (Appendix B, Table B-2b). The mean values for the deceleration levels at which the shoulders began to move forward were: 0.212 g for low jerk, 0.197 g for medium jerk, and 0.217 g for high jerk.

The relationship between the deceleration and jerk levels for each of the above three measures (i.e., raw dislodgement deceleration data, corrected dislodgement deceleration and calculated shoulder movement) are plotted in Figure 2-6. The figure shows the linear regression and correlation coefficient for each of the three measures. The curve for the uncorrected data indicates that deceleration level increases with higher jerk levels. The curves for the corrected deceleration and shoulder movement, however, are practically flat indicating the absence of the effect of jerk.

The subjective estimates of comfort were analyzed using a seven-point scale. A rating of "Very Comfortable" was assigned a value of one, and a rating of "Very Uncomfortable" was assigned a value of seven. The mean comfort ratings for each of the three jerk levels are listed in Table 2-8. The low jerk condition with a mean value of 3.5 was significantly more comfortable than both the medium jerk ($p \leq .01$), which had a mean value of 3.5, and the high jerk ($p \leq .001$) which had a mean value of 5.2 ($t = 2.95$, 4.49 respectively, $df = 21$). The difference between the mean ratings for medium and high jerk were not significant ($t = 1.44$, $df = 21$). These results indicate that while jerk had no effect on the deceleration levels at which people were dislodged, there was an effect on perceived comfort, i.e., as the jerk level increased, people reported increased discomfort.

TABLE 2-8. MEAN COMFORT RATINGS AS A FUNCTION OF JERK

Jerk Level	Comfort Rating
Low (0.25 g/sec)	3.5
Medium (0.75 g/sec)	4.6
High (1.25 g/sec)	5.2

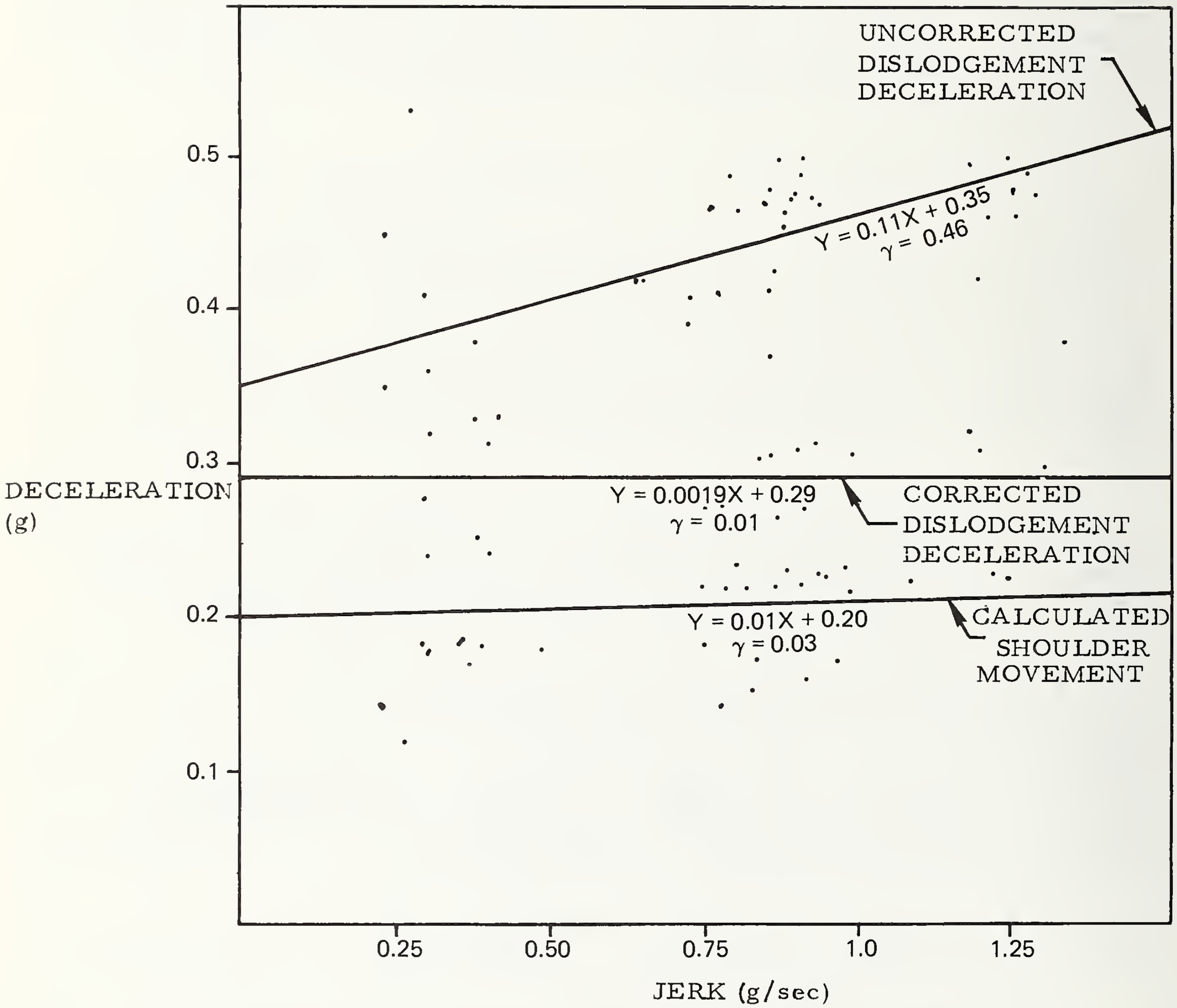


FIGURE 2-6. DECELERATION LEVELS AS A FUNCTION OF JERK

2.5 Experiments to Determine Effects of Seat Orientation

Two experiments were performed to investigate the effects of the orientation angle of the passenger's seat on retention. Forward-facing was defined as 0^{o} orientation. The first experiment examined large orientation angles of 45^{o}, 90^{o} and 135^{o}, rotated to the left of forward-facing. The second experiment examined small orientation angles of 0^{o}, 15^{o} and 30^{o}, also rotated to the left of forward (Figure 2-7).

Rear-facing (180^{o}) was not investigated. This position is considered to be the safest, yet probably least acceptable orientation for transit riders. Obviously, rear-facing would not have produced dislodgement or movement data.

2.5.1 Experiment 3: Large Seat Orientation Angles

The purpose of this experiment was to determine maximum deceleration levels for passengers riding at orientation angles of 45^{o}, 90^{o} and 135^{o} left of forward-facing. This experiment also examined the interaction of these angles with the use of a footrest and armrests. The fabric covered contoured seat without tilt was used, and the jerk level was maintained at 0.25 g/sec.

2.5.1.1 Specific Method

Six subjects, one from each subject category, participated in this study. Each received two runs at each of the three orientation angles and at each of four support conditions (armrests, footrest, both armrests and footrest, and no supports) for a total of 24 runs.

2.5.1.2 Results

The range of deceleration values at which the subjects moved off the seat sensors was quite large and positively skewed. Due to this, the measure of central tendency used was the median and the measure of dispersion used was the percentile. Table 2-9 contains the maximum deceleration levels at which 50 percent and 84 percent of the subjects remained on the seat. It should be noted that in the 90^{o} (side-facing) and the 135^{o} positions, the values represent subject movement and not necessarily dislodgement. A more detailed examination of the 90^{o} position was subsequently performed in Experiment 6.

The highest deceleration levels listed in Table 2-9 were obtained with the armrests and with the armrests/footrest combination. However, since the values in these two conditions were similar, the footrest did not interact with the armrests to produce greater retention than was due to the armrests alone. These results, therefore, indicate the importance of armrests at large orientation angles.

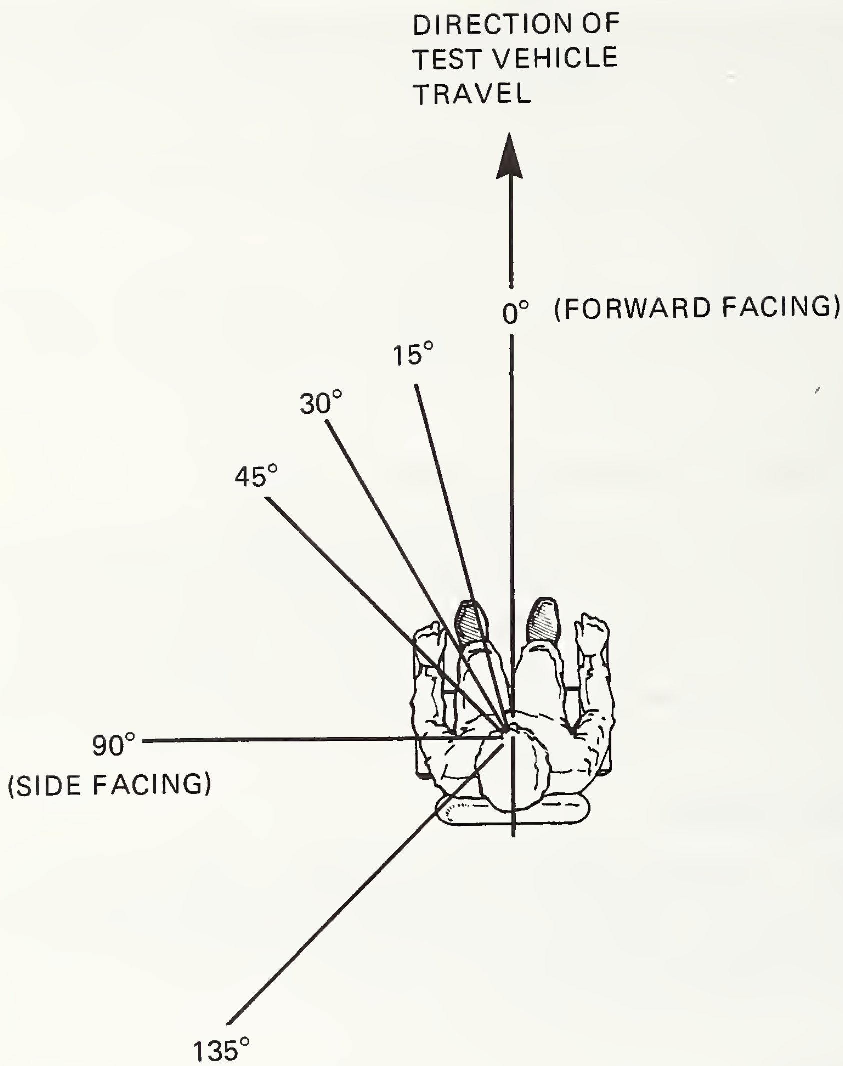


FIGURE 2-7. SEAT ORIENTATION ANGLES

TABLE 2-9. DECELERATION LEVELS AT WHICH 50% and 84% OF SUBJECTS WERE RETAINED AT LARGE ORIENTATION ANGLES (UNCORRECTED)

	45^{o} (To Left Side)		90^{o} (To Left Side)*		135^{o} (To Left Side)*	
	50% (Median)	84%	50% (Median)	84%	50% (Median)	84%
No Supports	0.255 g	0.205 g	0.250 g	0.158 g	0.380 g	0.220 g
Armrests	0.305 g	0.208 g	0.295 g	0.158 g	0.520 g	0.270 g
Footrest	0.250 g	0.190 g	0.220 g	0.135 g	0.390 g	0.233 g
Armrests & Footrest	0.295 g	0.208 g	0.310 g	0.235 g	0.550 g	0.258 g

*Represents movement, not necessarily dislodgement.

2.5.2 Experiment 4: Small Seat Orientation Angles

The purpose of this limited experiment was to determine if small orientation angles (15^{o} and 30^{o} to the left of forward) would aid retention when compared to forward-facing (0^{o}). The results indicated that there was a significant difference in the deceleration levels at which subjects were dislodged between the three seat orientation angles ($F = 31.9$, $df = 2, 333$, $p < .01$) with zero degrees having the highest retention value (0.52 g). Tukey's HSD Test (Kirk, 1969) of the mean deceleration dislodgement values indicated that the zero degree value (0.52 g) was significantly different from 15^{o} (0.42 g) and 30^{o} (0.38 g) values. The larger the orientation angle (0^{o} - 30^{o}), the lower the safe deceleration level.

2.6 Experiments to Evaluate High Retention Seat Characteristics

Two experiments were conducted to identify those characteristics that contribute to high retention of passengers during emergency decelerations. One experiment was conducted for forward-facing passengers and another for side-facing passengers. The fabric covered contoured seat was used. To attain deceleration levels of over 0.9 g, the jerk level was increased to 0.5 g/sec, and the speed of the test vehicle was decreased to 48 km/h (30 mph). To further simulate an actual transit situation, the subjects in the experiment were asked to read a magazine of their choice. These experiments was analyzed using the film technique described in Experiment 2. This approach provided dislodgement deceleration levels that were corrected for instrumentation lag.

2.6.1 Experiment 5: High Retention Seat Characteristics for Forward-Facing Passengers

This experiment was designed based on the results of Experiments 1 and 4 to produce a combination of characteristics that would enhance high retention of forward-facing (0° orientation) passengers. The variables examined were seat tilt (0°, 3°, 9° and 12° back) and footrest (present or absent).

2.6.1.1 Specific Method

Twelve subjects participated in the study, two from each subject category. All subjects received four runs at each of the four tilt angles, half of them with a footrest and half without, making a total of 16 runs per subject.

2.6.1.2 Results

The deceleration levels corrected for instrumentation lag at which different percentages of subjects were retained for the four seat tilt positions are listed in Table 2-10.

TABLE 2-10. DECELERATION LEVELS AT WHICH 50% AND 84% OF THE SUBJECTS WERE RETAINED FOR FOUR SEAT TILT ANGLES

Backward Seat Tilt	Deceleration Levels (Corrected)	
	50% of Subjects (Median)*	84% of Subjects
0°	0.36 g	0.31 g
3°	0.36 g	0.30 g
9°	0.37 g	0.33 g
12°	0.44 g	0.36 g

*Median is appropriate measure of central tendency due to skewed distribution of data.

An analysis of variance on the corrected dislodgement deceleration levels for those four conditions found that there was a significant difference among the seat tilt angles ($p = .001$) (Appendix B, Table B-3). Tukey's HSD Test (Kirk, 1969) indicated that the 12° seat tilt position had significantly higher retention ($p < .05$) than the other positions. No other significant differences were found among the seat positions.

There was also a significant difference in the dislodgement deceleration levels attained with and without a footrest ($p = .004$) (Appendix B, Table B-3). With a footrest, the corrected dislodgement deceleration was 0.442 g and without, 0.377 g.

Figure 2-8 shows the percentage of passengers retained at different deceleration levels in the forward-facing seat position for all seat tilt angles combined. Figure 2-9 is a similar presentation of the precentages of passengers retained at different deceleration levels in the forward-facing seat at the 12° backward tilt angle. Inspection of these two figures shows that with a footrest the distribution of dislodgement deceleration values is shifted toward the higher 'g' levels. It can also be seen that in Figure 2-9 there is a similar shift in the distributions of the dislodgement values toward the higher 'g' levels at the 12° seat tilt angle compared with the values in Figure 2-8 for all seat tilt positions combined.

2.6.2 Experiment 6: High Retention Seat Characteristics for Side-Facing Passengers

This experiment investigated dislodgement deceleration levels for side-facing (90° orientation) passengers with and without the use of armrests. Seat tilt angle was constant at 3° back and no footrest was used.

2.6.2.1 Specific Method

A total of 11 subjects were run in this experiment. All of the subject categories were represented. Each subject was tested three times with armrests and three times without.

2.6.2.2 Results

The mean deceleration levels indicating significant body movement likely to cause dislodgement were 0.379 g where the subjects had armrests, and 0.361 g where they did not. An analysis of variance indicated that these differences were not significant (Appendix B, Table B-4). No correction was necessary for instrumentation lag for this experiment as the switch opening occurred at the same time as significant body movement.

Figure 2-10 illustrates the precentages of passengers showing no significant movement off the side-facing seat at different deceleration levels. While there was no statistically significant difference between the mean dislodgement deceleration levels with or without armrests, there appears to be more of a 'tail' to the distribution at the higher 'g' values for the armrest condition. However, it is clear from the film analysis that while initial movement off the seat occurred at a similar deceleration level for both conditions, the armrests did provide a physical barrier that tended to prevent further movement beyond the initial movement off the seat and thus the armrests acted as a physical barrier to actual dislodgement.

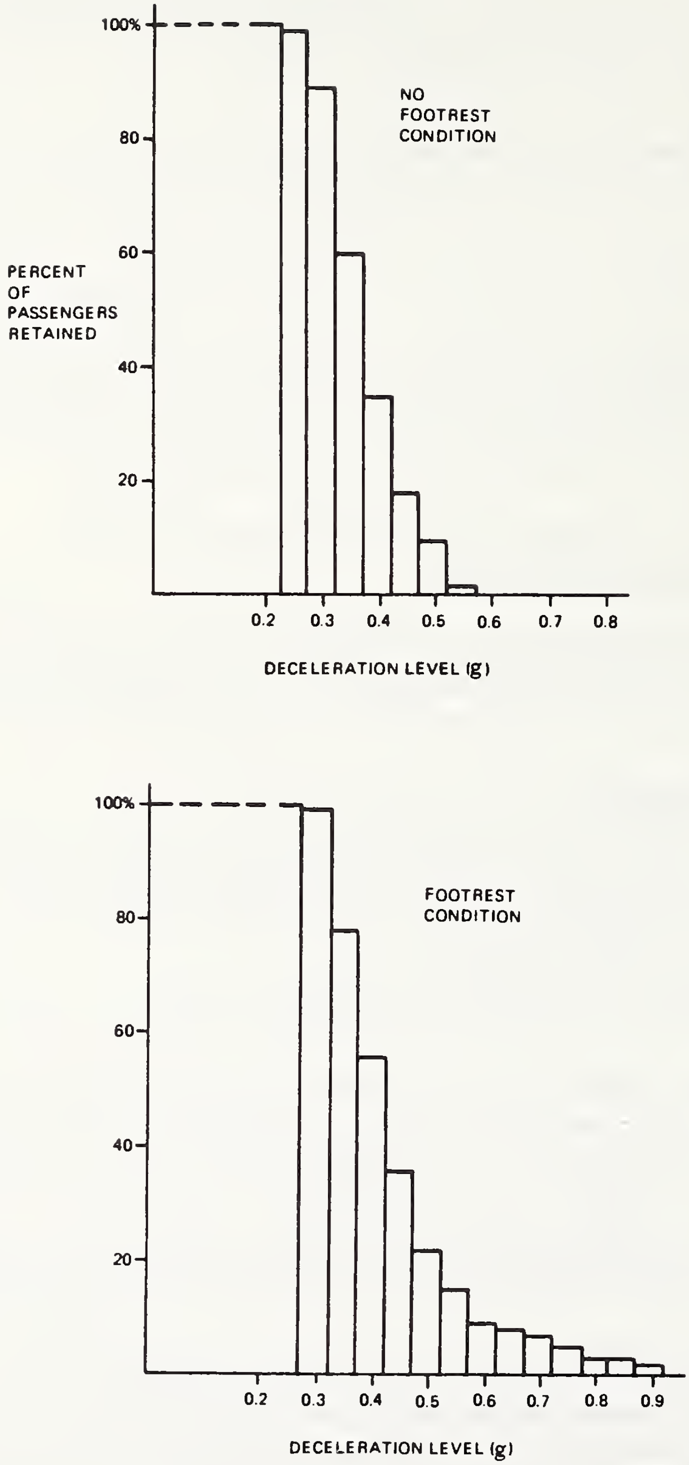


FIGURE 2-8. PERCENT OF PASSENGERS RETAINED
IN FORWARD-FACING POSITION
FOR ALL SEAT TILT CONDITIONS (CORRECTED DATA)

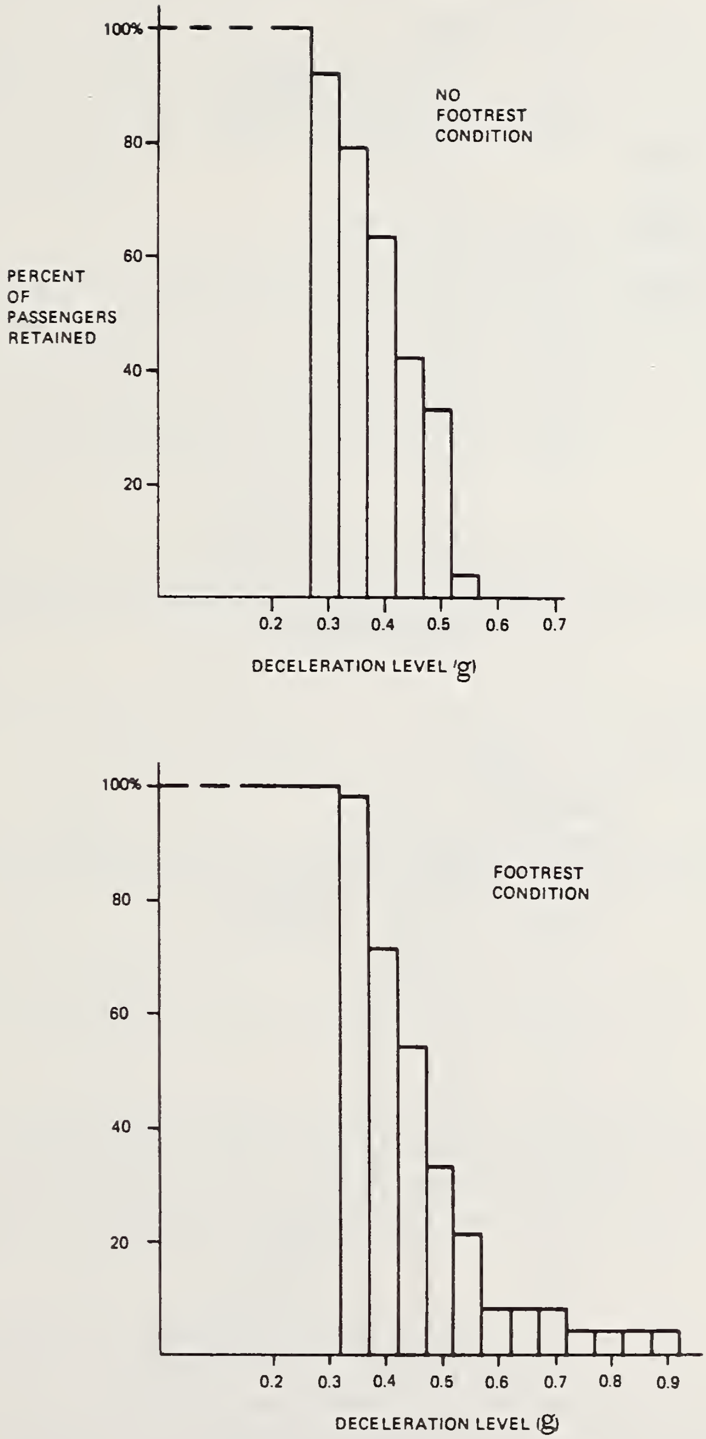
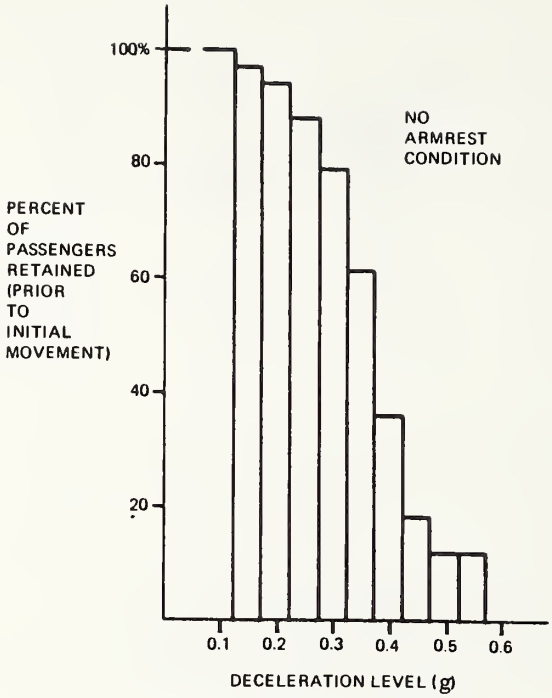


FIGURE 2-9. PERCENT OF PASSENGERS RETAINED IN FORWARD-FACING POSITION FOR 12° SEAT TILT CONDITION (CORRECTED DATA)



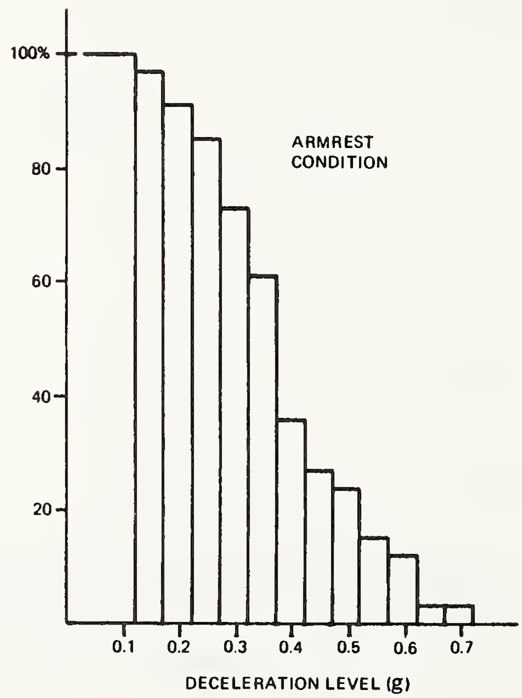


FIGURE 2-10. PERCENT OF PASSENGERS SHOWING
NO SIGNIFICANT BODY MOVEMENT IN SIDE-FACING SEATS

2.6.3 Summary of High Retention Experiments

The major findings of these two high retention seat characteristics experiments were that a footrest and a 12° seat tilt improved retention for forward-facing subjects; and that armrests, while not preventing initial movement, did provide a physical barrier preventing dislodgement for side-facing subjects.

For forward-facing passengers, the advantages of a footrest and a 12° seat tilt are illustrated in Figure 2-11. In general, these conditions are reflected in the curves for 12° tilt and for footrests lying to the right (and thus higher deceleration values) of the curves for the other conditions (0°-9° tilt and no footrests). Table 2-11 lists the corrected deceleration levels at which 50 percent and 84 percent of the population will be retained in an emergency stop with and without a footrest.

TABLE 2-11. DECELERATION LEVELS AT WHICH FORWARD-FACING PASSENGERS WILL BE RETAINED IN AN EMERGENCY STOP

Seat Tilt	Forward-Facing Passengers			
	50%		84%	
	With Footrest	Without Footrest	With Footrest	Without Footrest
12°	0.46 g	0.43 g	0.36 g	0.33 g
Less Then 12°	0.40 g	0.35 g	0.33 g	0.30 g

For side-facing passengers, Figure 2-12 illustrates the percent of passengers retained prior to initial movement at the various deceleration levels. The similarity of the curves illustrates that armrests do not impact initial movement; observations indicate however that they do provide a physical barrier to dislodgement.

2.7 Experiment 7: Effects of Preparation

A brief pilot study was conducted to determine if prior warning of an impending stop had an effect on maximum safe deceleration levels. In one condition, the subject was informed that "we are about to stop." In the other condition, the subject was not given any preparatory warning. Half of the tests were run with a footrest and half without. The fabric covered contoured seat was used in the forward-facing, untilted position. The jerk level was 0.50 g/sec.

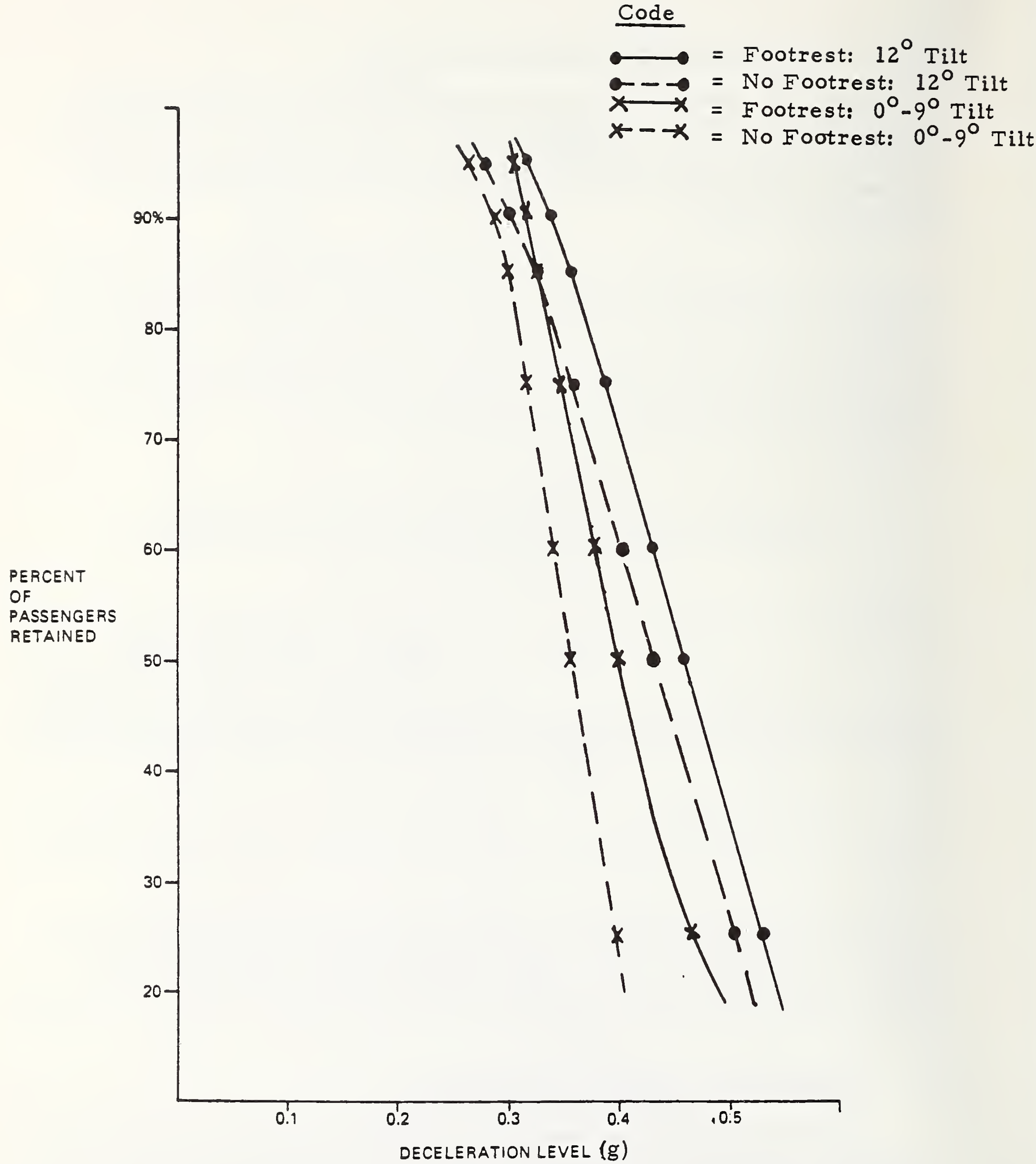


FIGURE 2-11. ESTIMATES OF PASSENGERS RETAINED IN FORWARD-FACING SEATS (CORRECTED DATA)

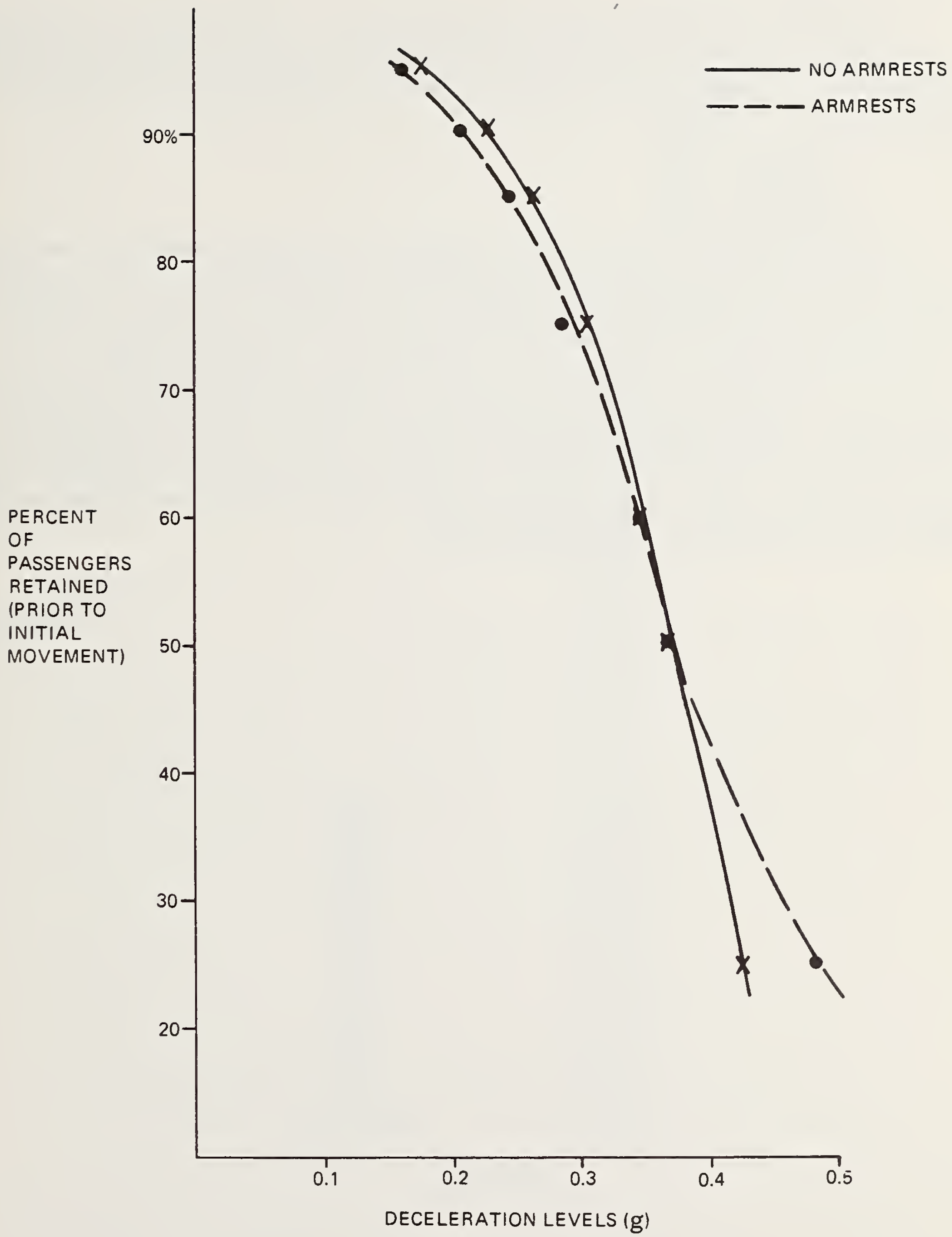


FIGURE 2-12. ESTIMATES OF PASSENGERS RETAINED PRIOR TO INITIAL MOVEMENT IN SIDE-FACING SEATS (CORRECTED DATA)

2.7.1 Specific Method

Two project staff members (as opposed to paid subjects) participated in this experiment and were given four runs at each of the four conditions: prepared--no support; prepared--footrest; unprepared--no support; and unprepared--footrest.

2.7.2 Results

The results of the pilot study indicated that both footrests and preparation were significant factors in stopping ($p < 0.0001$ for both) (Appendix B, Table B-5). The interaction of these two factors was also significant. When no footrest was used, there was no difference in deceleration level whether or not the subject was prepared for the stop (t test: $t = 1.75$, N.S.). With a footrest, however, subjects who were warned of the forthcoming stop sustained a significantly greater deceleration level than subjects who were not warned ($t = 17.9$, $p < 0.0001$) (Figure 2-13). The combination of being prepared and using a footrest provided a higher degree of retention than any other condition in this experiment.

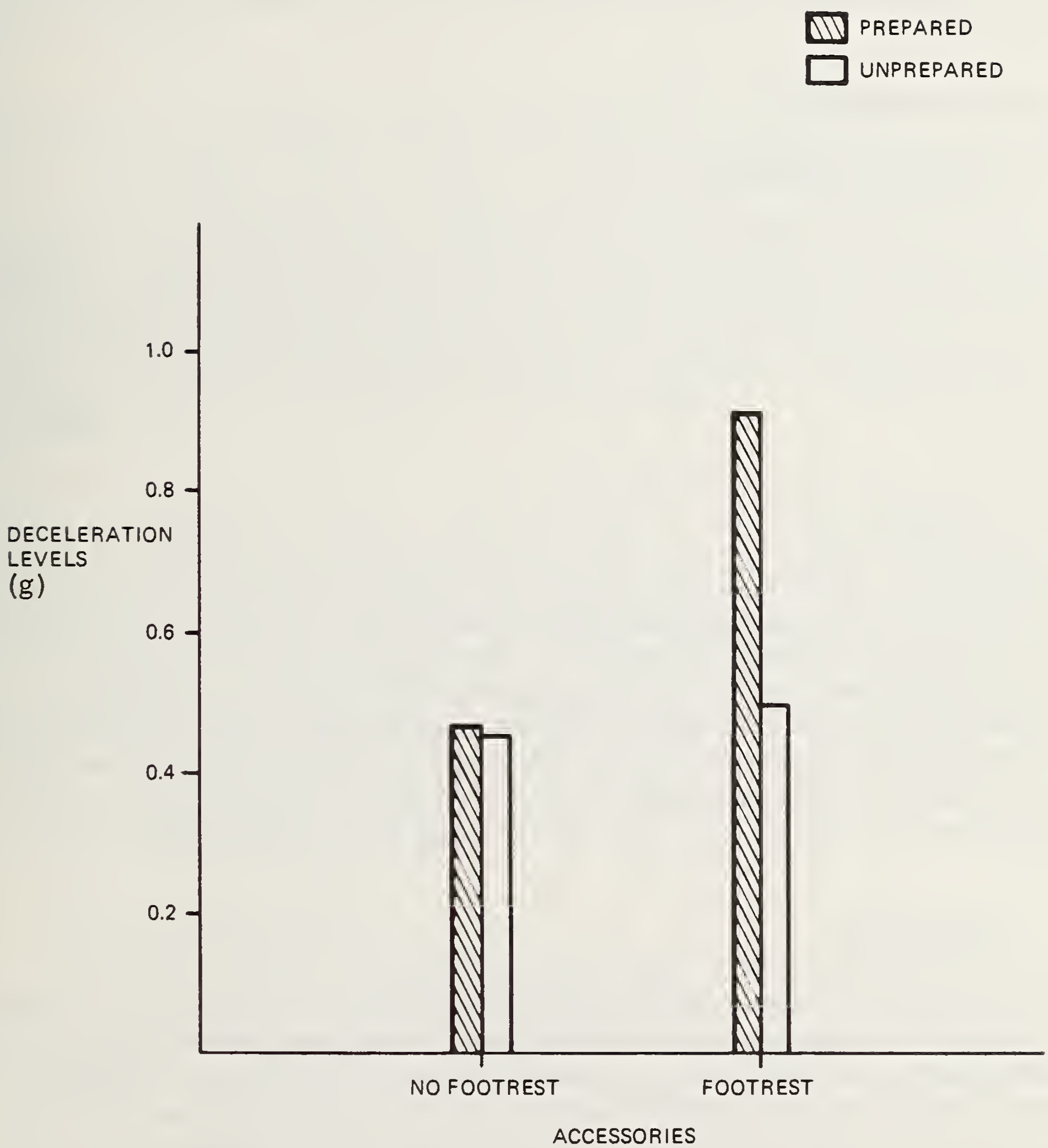


FIGURE 2-13. DECELERATION LEVELS
FOR PREPARED VERSUS UNPREPARED SUBJECTS
(UNCORRECTED DATA)

3. DISCUSSION

The results of these experiments provide data on the elements affecting passenger retention during emergency stops. These include seat configuration (covering, contour, tilt and accessories), seat orientation and jerk level employed.

3.1 Seat Configuration

3.1.1 Covering and Contour

The statistical results indicate that of the four seat types tested the two best types were the vinyl flat and the fabric contour. There were no differences between these two seat types. In addition, comments by subjects during their debriefing indicated that they did not find any differences between the seat types. Therefore, the choice between these two seat types should be made based on conditions of use, expected wear and the likelihood of vandalism.

3.1.2 Seat Tilt

Seat tilt was examined in one of the experiments. It was found that a pitch of 12° back provided a significant improvement in retention over the smaller pitch angles for forward-facing passengers. This finding is in accord with Abernethy et al. (1977), who found that tilting a standard transit seat back provided higher retention. For vehicles where high levels of deceleration are expected, a seat tilt of approximately 12° should be used for forward-facing passengers. Tilts in excess of 12° may be considered where the seat design is such that easy ingress and egress are possible.

3.1.3 Accessories

The results of several of the experiments indicated the value of a footrest in retaining forward-facing passengers. With sufficient warnings, forward-facing passengers can successfully use a footrest to maintain their position at high levels of deceleration. Armrests are important for side-facing passengers. They provide a physical barrier preventing large excursions during abrupt stops. Footrests and armrests, however, have to be properly integrated within the passenger compartment as they can be the cause of injuries; for example, tripping accidents.

3.2 Seat Orientation

One hypothesis expressed during the planning of this research was that a small orientation angle of a seat may provide some assistance in retaining passengers in an abrupt stop. The results, however, indicated that facing directly forward was better than being seated at a small angle of orientation. This finding was anecdotally substantiated by some subjects who reported that they had greater "control" in the forward-facing position. Since the feet provide the greatest force impeding dislodgement, it follows that having the feet positioned directly in front of the direction of body movement provides the best retention.

Large seat orientation angles such as 135° and 90° with armrests provided excellent protection against dislodgement. While it is true that armrests on side-facing seats prevent the dislodgement of passengers, they do not prevent passengers from sliding on their seats. It is unlikely the deceleration levels used in these experiments could have led to actual dislodgement with the armrests tested. If armrests are to be incorporated in AGT system passenger seats as barriers to dislodgement, they should be designed to withstand appropriate stress tests.

3.3 Jerk

Jerk was not found to be a factor in dislodging passengers during the onset of an emergency stop. It does, however, affect passengers' ratings of comfort. Subjects felt more uncomfortable at the higher jerk levels. This result is in accord with the previous findings of Abernethy et al. (1977) who also showed that increases in the rate of deceleration do not increase the possibility of being dislodged. It should be noted, however, that in research efforts, unless controlled for, the use of high jerk levels has resulted in overestimates of the deceleration level attained prior to dislodgement. Jerk is a factor in the perception of comfort, but not a factor in safety consideration and need not be specified therefore in setting emergency deceleration standards.

3.4 Deceleration Levels

The present research indicates that to retain 84 percent of the passengers in an emergency stop, the deceleration level should not exceed 0.36 g--where footrests are used and 0.33 g without footrests (assuming 12° seat tilt). The deceleration levels reported by Abernethy et al. (1977) are higher than those found in the present study. For example, the mean dislodgement deceleration level for an untilted forward-facing subject without a footrest was reported to be 0.55 g. However, the data in the present study were corrected for an instrumentation lag. For comparison purposes, a time lag correction factor was determined from Experiments 1-7 that most closely resembled conditions of the Abernethy et al. study. The mean time lag correction factors from these runs was calculated to be 0.16 seconds. When this time lag was applied to the mean deceleration of 0.55 g, obtained in the Abernethy et al. study, the "corrected" deceleration value in that case was 0.29 g (estimating the jerk level to be 1.75 g/sec). Another difference between the Abernethy et al. study and the present one was that in Experiments 5 and 6 (used for comparison), the subjects were reading magazines. They were, therefore, less prepared for the stop than were the subjects in the Abernethy et al. study. As seen in the pilot study of preparedness, the degree of preparation prior to the stop can be a significant factor if footrests are available.

3.5 Application of Results

A note of caution must accompany any application of the results of these experiments to Automated Guideway Transit systems. Although every attempt was made to simulate a natural riding situation, including the reading of magazines in several of the experiments, it must be realized that the subjects were expecting the stops to occur. The dislodgement deceleration levels that would be obtained with truly unprepared passengers might be less than measured in the present series of experiments. A further caution to applying the results of these experiments to AGT system seat design concerns the need for further research on the ease of ingress and egress for seats with a 12^{o} backward tilt.

It must also be noted that the present series of experiments were conducted with only seated adult subjects who were not handicapped. The results, therefore are not applicable to standing passengers, children, people carrying packages, the elderly nor the handicapped. But it could be hypothesized that deceleration levels for the retention of the general population (i.e., including representatives of the aforementioned categories) and standees would be even lower than found in the present study.

Finally, injury to passengers when a vehicle is decelerating is a very real problem in current transit systems. A recent study of Transbus Safety and Human Factors noted that most bus accidents occur during deceleration, and passenger injuries due to deceleration effects are the second most expensive type of accident (Booz Allen, Hamilton and Company, 1977). Therefore, the use of acceptable deceleration levels in transit systems, including AGT, is not only important in providing safe public transportation, but also in reducing operating costs of the system.

4. CONCLUSIONS

It can be concluded from the present series of experiments that during an emergency stop, forward-facing passengers can sustain higher deceleration levels than passengers sitting at orientation angles of 15° and 30°. For these forward-facing passengers, use of a simple footrest can enhance retention and safety. A seat, tilted back approximately 12°, also provides higher retention than a seat with less tilt. The use of armrests for side-facing passengers can serve as a barrier to restrict passenger movement.

Two seats were found to be superior: fabric contoured and vinyl flat. Choices between these seats should be governed by system environment and cost.

The maximum deceleration level for retention of 84 percent of the forward-facing passengers sitting on a seat of 12° tilt using a footrest was 0.36 g. To safely achieve significantly higher deceleration levels, for forward-facing passengers, redesign of the compartment would be required.

The jerk level employed in reaching these deceleration levels is not a factor affecting retention and, therefore, safety. Jerk is only a factor in the perceived comfort of passengers.

The results of the pilot study on preparedness suggest that additional research is needed to establish the value of providing a warning signal to passengers prior to an emergency stop. A warning signal coupled with appropriate assists, such as a footrest for the forward position, may increase the percentage of passengers retained in their seats during emergency stops.

Further studies should also examine alternative restraint systems, including air bags, seat belts and 180° orientation seating, which could safely accommodate secondary collisions between passengers and vehicle interior at higher deceleration levels.

5. DESIGN GUIDELINES FOR HIGH RETENTION AGT PASSENGER SEATS*

5.1 Introduction

The experiments in this study have identified several design changes that contribute to high retention during an emergency deceleration for forward-facing and side-facing passengers.

5.2 Major Elements Affecting Passenger Retention for Forward-Facing Seating

The presence of footrests and seat rearward tilt are the major elements affecting passenger retention for forward-facing seating.

5.2.1 Footrests

Footrests appear to be the major element in enhancing high retention for forward-facing seating. However, to have a significant effect on retention, the passengers' feet must be on the footrest. In addition, passengers who have their feet on the footrest but are unprepared for the stop can withstand only moderately higher deceleration levels than without a footrest. But, passengers who use a footrest and are alerted to an impending stop can withstand significantly higher deceleration levels. Footrests allow use of both legs to force the body against the seat back to counteract tumbling and sliding in the direction of vehicle forward motion.

The design and location of the footrest should accommodate the full range of potential users. However, emphasis should be directed toward accommodating a wide range of passengers to ensure usage and comfort. Other desirable footrest features include:

a. A footrest adjustable in distance and angle to accommodate the anthropometric range.

b. Heel rests to prevent feet from slipping off the footrest.

5.2.2 Seat Tilt

Seat rearward tilt is the other important factor affecting high retention seat design. Passenger retention increases as the angle of the seat pan is increased, i.e., the back of the seat pan is lowered. At the same

*This section was authored by J.R. Hanking, Vought Corporation.

time, the seat back should be adjusted to maintain a constant angle (nominally 103° - 115°) between the seat pan and the seat back. This has the effect of tilting the entire seat while maintaining a constant distance between the lower forward edge of the seat and the floor.

Twelve-degree seat pan tilt is currently considered a limit from the standpoint of comfort and ease of ingress and egress. Twelve-degree tilt offers a significant retention improvement over seat pan tilts of under 9°.

5.2.3 Seat Cushion Contour and Covering

The fabric covered contoured cushion and the vinyl flat seat cushion exhibited significantly better passenger retention than fabric covered flat and vinyl covered contoured cushions. No statement could be made from the cests as to the relative benefit of either cushion shape or covering. The selection of seat characteristics, therefore, must reflect individual system location, environment and economic constraints.

5.3 Major Elements Affecting Passenger Retention for Side-Facing Seating

Armrests are the major element affecting passenger retention for side-facing seating.

5.3.1 Armrests

Armrests offer the major benefit for passenger retention for side-facing seating, particularly when seating is individualized. Armrests do not prevent passenger movement but mechanically restrain dislodgement.

Individualized seating is required for passenger retention under high deceleration conditions to prevent passengers from tumbling into or leaning on other passengers.

During high deceleration stops where seat orientation angles are large (45° - 135°), passengers are apt to be pressed against the armrest unless they are well prepared and braced, which is unlikely. Under these conditions, care should be exercised in the armrest design and material selection to preclude possible injury.

5.3.2 Orientation Angles

Seat orientation angles between forward (0°) and side-facing (90°) result in progressively lower passenger retention values as angles increase. Forward-facing passenger seating allows the full use of feet and legs to counteract deceleration forces. Other orientation angles render feet and legs less effective against deceleration forces.

Test orientation angles beyond side-facing (90°) should show increasing passenger retention until a rear-facing (180°) orientation is reached. As the orientation angle increases beyond 90°, the seat back becomes the primary passenger retention element.

5.4 Recommended Seat Design Characteristics for AGT Passenger Seating

The following recommendations for AGE passenger seating are based in part on the results of this series of deceleration experiments, and on a review of the literature and discussions with seat design experts and manufacturers.

5.4.1 Forward-Facing Seating

Seat design features relevant to passenger retention in forward-facing seats do not compromise existing safety requirements. The addition of an associated footrest and tilting the seat rearward are the major factors affecting passenger retention. This study has shown that tilting the seat rearward 12° yields significant retention benefits over 9° or less. Twelve degrees is currently considered an upper limit because of difficulty entering and leaving seats with high tilt angles.

Table 5-1 presents a summary of current state-of-the-art recommendations on selected design parameters for forward-facing AGT passenger seats. The data are derived from this series of deceleration experiments and from the published sources listed. These recommendations are reflected in the illustration of a candidate design for a forward-facing AGT passenger seat shown in Figure 5-1.

5.4.2 Side-Facing Seating

Side-facing seating is not recommended for systems where high deceleration levels are part of routine operations. Passengers will withstand only lower deceleration levels in side-facing as compared to forward-facing seats. Armrests are the primary aid for counteracting passenger dislodgement in side-facing seating. However, armrests act as a barrier and do not prevent body movement and slipping. These parameters are reflected in the illustration of a candidate side-facing seat design shown in Figure 5-2.

Table 5-2 presents a summary of state-of-the-art recommendations for selected seat design parameters for side-facing seats, derived from the listed sources and the results of these experiments. These recommendations are reflected in the candidate design for a side-facing seat shown in Figure 5-2.

TABLE 5-1. RECOMMENDED VALUES FOR SELECTED DESIGN PARAMETERS OF FORWARD-FACING AGT PASSENGER SEATS

Parameter	Value
Seat Cushion Height (Front Edge, Uncompressed, from Floor)	38.1-43.2 cm (15-17 in)
Seat Cushion Length	40.6-43.2 cm (16-17 in)
Seat Cushion Width (Individual Seat)	45.7-50.8 cm (18-20 in)
Seat Cushion Tilt (Front to Back)	12°
Seat Cushion Compression	2.5-5.1 cm (1-2 in)
Angle Between Seat Cushion and Seat Back	103°-115°
Footrest Height	7.6-12.7 cm (3-5 in)
Footrest Location (from Seat Front)	25.4-30.5 cm (10-12 in)
Footrest Inclination	30°-50°

Sources: Damon, Stoudt, McFarland, 1966; Dreyfuss, 1960; Rensselaer Research Corporation, 1970; Woodson, Conover, 1964.

5.4.3 Other Seat Orientation Angles

Seat orientation angles between 0° (forward-facing) and 90° (side-facing) result in lower retention levels than forward-facing seating; even if equipped with both armrests and footrests.

Seat orientation angles beyond 90° prevent passenger dislodgement if equipped with armrests. As the orientation angle increases beyond 90°, the seat back is the primary element in passenger retention.

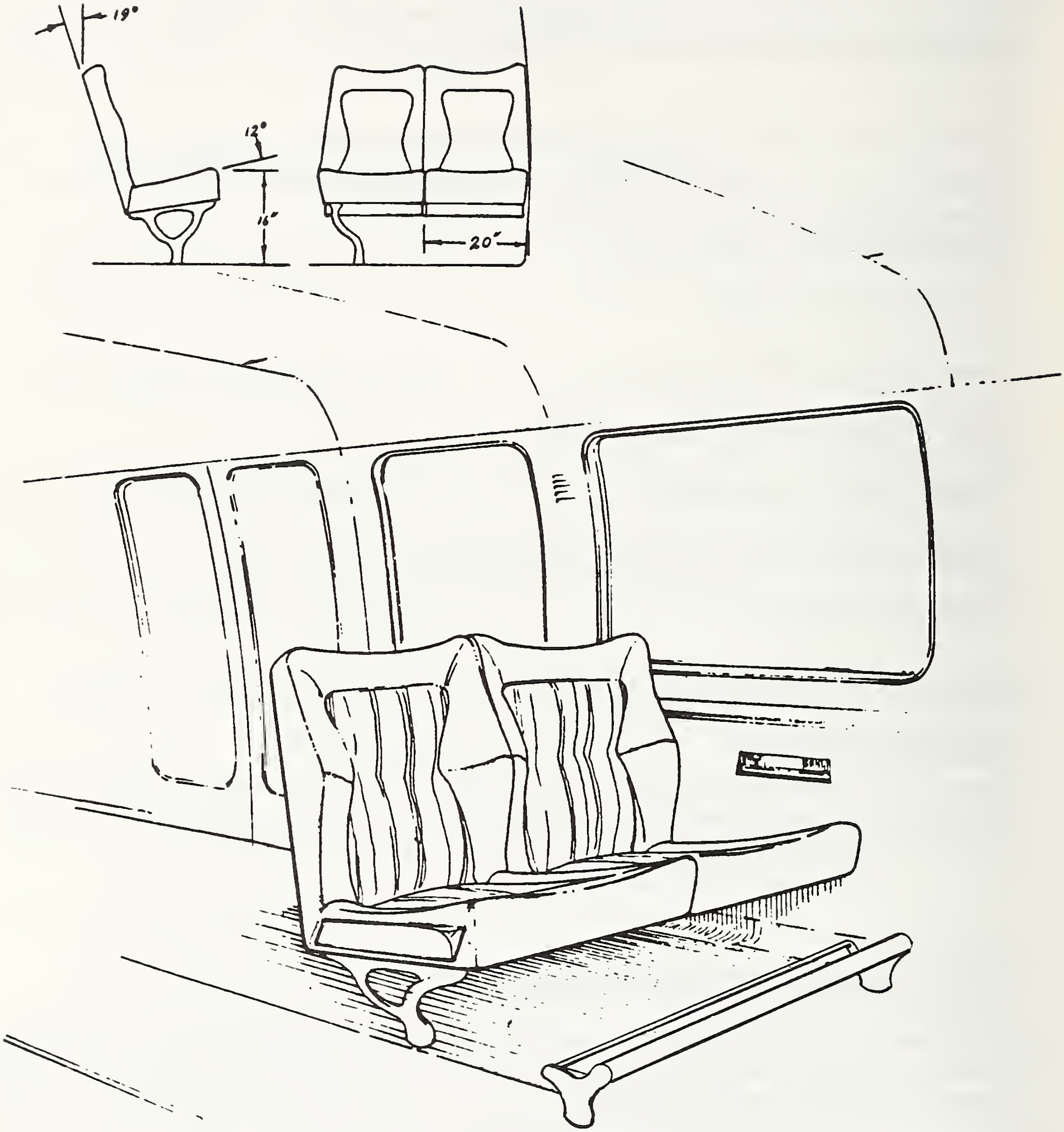


FIGURE 5-1. ILLUSTRATION OF A CANDIDATE DESIGN FOR FORWARD-FACING AGT PASSENGER SEATS

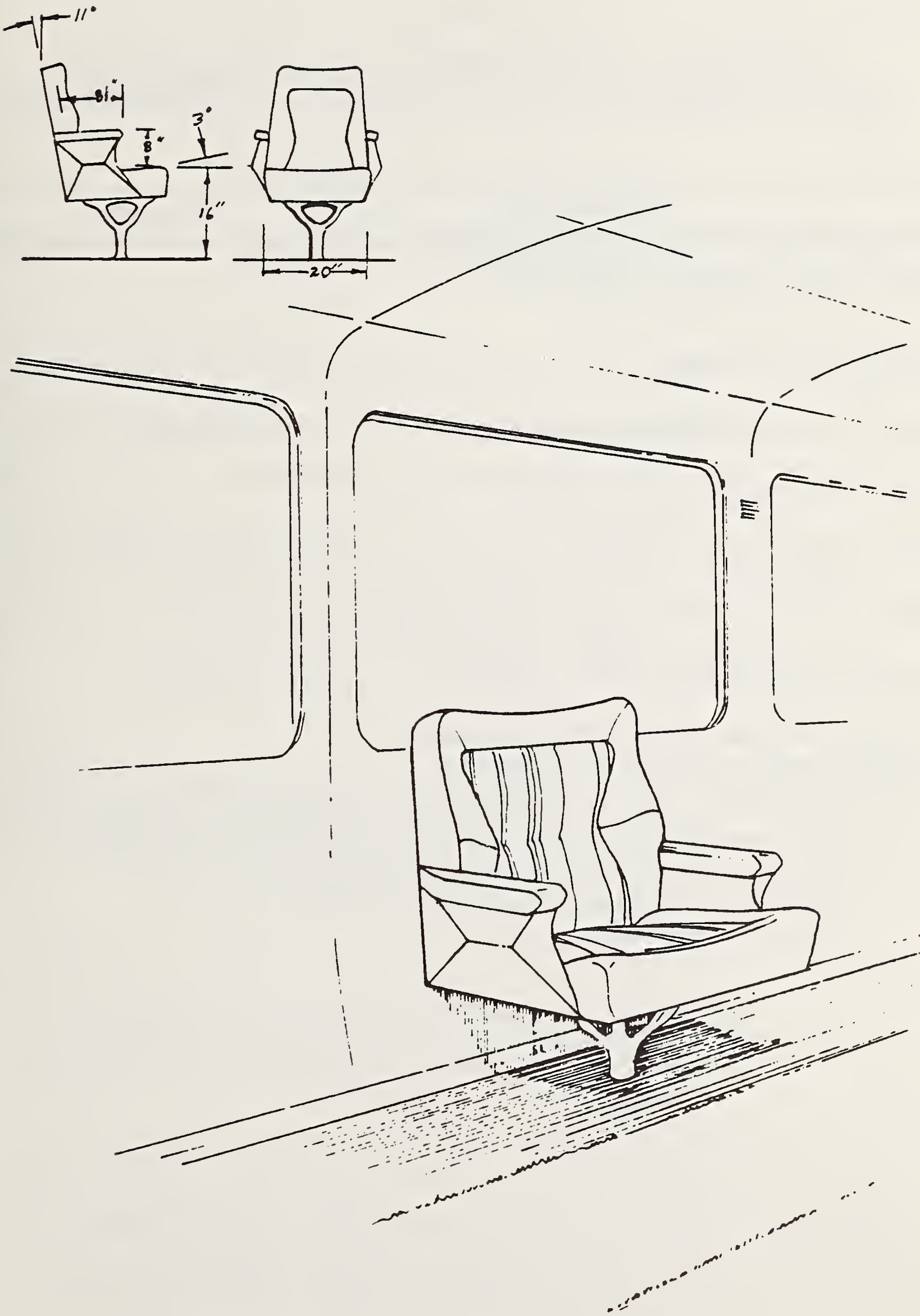


FIGURE 5-2. ILLUSTRATION OF A CANDIDATE DESIGN FOR SIDE-FACING AGT PASSENGER SEATS

TABLE 5-2. RECOMMENDED VALUES FOR SELECTED DESIGN PARAMETERS OF SIDE-FACING AGT PASSENGER SEATS

Parameters	Values
Seat Cushion Height (Front Edge, Uncompressed, from Floor)	38.1-43.2 cm (15-17 in)
Seat Cushion Length	40.6-43.2 cm (16-17 in)
Seat Cushion Width (Individual Seat)	45.7-50.8 cm (18-20 in)
Seat Cushion Tilt (Front to Back)	5^{o}-7^{o}
Seat Cushion Compression	2.5-5.1 cm)1-2 in)
Angle Between Seat Cushion and Seat Back	98^{o}-108^{o}
Armrest Height (Above Seat Cushion)	20.3 cm (8 in)
Armrest Length (From a Vertical Line Through Intersection of Seat Cushion and Seat Back)	15.2-21.6 cm (6-8.5 in)

Sources: Damon, Stoudt, McFarland, 1966; Dreyfuss, 1960;
Rensselaer Research Corporation, 1970;
Woodscn, Conover, 1964.

APPENDIX A.

ADMINISTRATIVE FORMS AND SAFETY REPORT

SUBJECT RECRUITMENT FORM

$25 -- IF YOU MEASURE UP!

If you are the sized person we are looking for, you can make $25 in a morning or afternoon by participating in a Deceleration Safety Study being conducted at Otis Air Force Base for the U.S. Department of Transportation.

We are looking for a limited number of the following sized people (between 18 and 59 years of age):

MALES

I. Up to 5'6" tall and weighing up to 138 lbs.
II. Between 5'7" and 5'9" and between 158 to 167 lbs.
III. Over 5'11" and over 187 lbs.

FEMALES

IV. Up to 5'1" tall and weighing up to 109 lbs.
V. Between 5'3" and 5'4" and between 128 to 138 lbs.
VI. Over 5'6" and over 157 lbs.

For details, please call Dunlap & Associates, Inc., at 548-2137 leaving name, telephone number and weight and height with answering service. We will return you call.

Thanks

SUBJECT'S STATEMENT OF INFORMED CONSENT

NAME: ____

ADDRESS: ____

____

The undersigned hereby agrees to participate in a Federally sponsored Deceleration Safety Study. Dunlap and Associates, Inc., has fully explained to me the nature, purpose and procedures of the program. I fully understand that I will voluntarily ride in a test vehicle wearing a slack safety restraint system and a suitable helmet. The vehicles will decelerate from an initial velocity of approximately 40 miles per hour in such a manner that I will experience up to 0.7 or 0.8 "g's" (equivalent to a short stop in a passenger vehicle) while seated in a standard transit type seat. The seat may be in the normal transit mounting position, tilted back, or rotated. I understand that the "g's" to be experienced are well below the human tolerance levels for gravitational forces, but they will be sufficient to slide me forward to the limits of the restraint harness.

With my knowledge, movies or videotapes may be made of me during a deceleration stop. These movies or tapes will be used only for research purposes.

I understand further that the tests will be so conducted to ensure, to the maximum extent possible, the health, safety and welfare of the subjects and that I will be at liberty at any time to withdraw from participation in the tests. I represent that I am over 18 years of age and have been advised by my physician that I am in good physical and mental health and have no history of health problems that would indicate that I should not participate in this test program. To the best of my knowledge, I am not pregnant. Further, I agree to subject myself to an examination by a licensed physician, chosen by Dunlap and Associates, Inc., prior to participation in the tests.

There has been no coercion or adverse pressure brought to bear in my volunteering for this project. I have done so of my own free will, completely aware of the possible hazards, rewards or recognition involved.

I understand that if I am selected for the tests, I will be paid twenty-five dollars ($25.00) for participation. My relationship to Dunlap and Associates, Inc., shall be that of an independent contractor and nothing contained herein shall be construed as creating any other relationship. Therefore, I will accept in connection with the services called for hereby exclusive liability for the payment of any withholding taxes or contributions for social security, unemployment insurance, old age payments, annuities or retirement benefits.

____

Signature

______________________________ ______________________________

Witness Date

MEDICAL EXAMINATION

for participation in

DECELERATION SAFETY STUDY

Name ______________________________ Weight __________

Age __________ Height __________

Sex __________

Heart __________

Lungs __________

Blood Pressure __________

Abdomen ______________

Back ______________

Medications ______________

Other (Specify) ________________

PHYSICIAN ________________________________

(Sign if o.k. to participate)

DATE ________________________________

DECELERATION SAFETY STUDY

CHECKLIST FOR SAFETY REVIEW COMMITTEE

Date ________________ Reviewer __________________________

Check Each Item: A - Adequate
I - Inadequate (Please Comment)
N - Not Able to Determine

Vehicle: Comments:

Tires _______
Brake Pedal Travel _______
Suspension ______
Brakes _______
Steering _______

Ingress & Egress Safely _______

Rear Door Security _______

Steel Mounting Plate Security _______

Seat:

Orientation & Security at

0° _______
15° _______
30° _______
45° _______
90° _______
135° _______

Seat Tilt Security at Position 1 _______
2 _______
3 _______
4 _______

Arm and Foot Rest Security

Seat Belts

Security at 0^{o} ________
15^{o} ________
30^{o} ________
45^{o} ________
90^{o} ________
135^{o} ________

Release Capability ________

Helmets ________

Consequences of Malfunctions

Electrical ________
Vehicle ________
Seat Support ________
Seat Belt ________
Other (specify) ________

____

Road Surface ________

Availability of Emergency Medical Service ________

Documentation

Subject's Statement ________
Medical Questionnaire ________

Other Items (specify)

____
____
____
____
____
____

Memorandum

12 October 1977

TO: Dr. Richard D. Pepler

FROM: Committee of Professional Peers

J. F. Oates, Jr.
R. J. Eckenrode
C. A. Goransson

SUBJECT: Safety Review of Experimental Procedures/Material Relating to Project 186, Task 5--Deceleration and Jerk

A safety committee composed of the above mentioned members, none of whom had previous knowledge of or prior involvement with the study, was formed to evaluate the measures undertaken to ensure the safety of subjects and test personnel who would participate in Task 5 testing. The committee reviewed test equipment and experimental procedures on Friday 10/7/77 at the Bedford, Massachusetts test site.

After a thorough review it is the considered opinion of the committee that the study has been well designed to minimize risk to the safety and well being of test subjects and test personnel. However, the committee discovered some minor potential safety hazards. Recommendations to avert these hazards were made to the project director, and are discussed below.

- A thorough inspection of the test vehicle (tires, brakes, suspension, steering, etc.) must be made by a professional mechanic immediately prior to commencement of testing to ensure that the vehicle is in proper working order.

- A formal, comprehensive checklist should be devised for use prior to each test "run." This checklist must include notations for each procedural step undertaken in preparation for a run, e.g.,

  -- Seat properly secured
  -- Restraining belts properly fastened
  -- Foreign objects removed from vehicle interior
  -- Etc.

  The primary purpose of the checklist will be to ensure verification that all such preparatory steps have been taken before the run commences. The checklist should include space for entering the subject's identification, test date and time, and the staff member conducting the inspection.

- The protective helmet to be worn by subjects should be put on and adjusted before the subject enters the test vehicle. The helmet must not be removed until the subject has exited the vehicle at the completion of the run.

- All protruding metal posts (such as the anchor points for seat belts) as well as the steel mounting plate and bolts must be padded.

- A padded chest and shoulder protector should be worn by the subject to guard against possible abrasions from the belts and harnesses.

- The restraining belt junction should be strapped to the subject's waist to firmly affix it in position against the chest protector.

- During several high deceleration test trials, the committee members discovered that the potential for whip-lash type effects existed if the test vehicle were brought to a complete stop. It was determined that the automatic braking mechanism could be released before the vehicle came to a complete stop, thereby eliminating the potential for a whip-lash effect. Further, it was found that this procedure in no way interfered with the data collection. Thus experimental procedures must preclude bringing the vehicle to a complete halt during automatic deceleration.

- During some test runs, experimental procedures call for leaving the arm rests in an upright position. At such times, the arm rests must be secured in that position to prevent them from rotating forward during deceleration. A bungee cord fastened to the seat back and both arm rests will suffice for this purpose.

- A portable, skid-resistant step must be provided to facilitate the subject's entry into and exit from the vehicle.

Memo To: R.D. Pepler
12 October 1977
Page Three

The committee feels that compliance with these recommendations will better ensure protection of all personnel involved in the study.

Signed:

John F. Oates, Jr.

Richard J. Eckenrode

Charles A. Goransson

APPENDIX B.

ANALYSIS OF VARIANCE SUMMARY TABLES

TABLE B-1. EXPERIMENT 1: SEAT CHARACTERISTICS - UNCORRECTED DECELERATION DATA

Source	DF1/ DF2	F	P Value	Mean Square	Sum of Squares
Seat Type	3/15	6.11	.001	0.0148	0.044
Subject Type	5/15	15.47	.001	0.0374	0.187
Interaction	15/168	1.17	N.S.	0.0028	0.042
Error	168	--	--	0.0024	0.406

TABLE B-2a. EXPERIMENT 2: EFFECTS OF JERK - CORRECTED DECELERATION DATA BASED ON BUTTOCK MOVEMENT

Source	DF1/DF2	Mean Square	F	P Value
Subject Kind	5/90	0.01356	2.65	N.S.
Jerk	2/90	0.00159	0.310	N.S.
Interaction	10/90	0.00898	1.75	N.S.
Error	90	0.00512	--	--

TABLE B-2b. EXPERIMENT 2: EFFECTS OF JERK - CORRECTED DECELERATION DATA BASED ON SHOULDER MOVEMENT

Source	DF1/ DF2	F	P Value	Mean Square	Sum of Squares
SK	5/30	0.96	.455	0.0108	0.0541
JK	2/60	0.82	.445	0.0035	0.0071
SK JK	10/60	1.27	.268	0.0055	0.0549
SK RP	30	--	--	0.0112	0.3368
SK RP JK	60	--	--	0.0043	0.2591

Key: SK = Subject Kind (small, intermediate and large--males and females)
JK = Jerk Level (low, medium, high)
RP = Replication Trials
N.S. = Not Significant

TABLE B-3. EXPERIMENT 5: HIGH RETENTION CHARACTERISTICS OF FORWARD-FACING PASSENGERS - CORRECTED DECELERATION DATA

Source	DF1/ DF2	F	P Value	Mean Square	Sum of Squares
SK	5/18	4.97	.005	0.0943	0.4715
FR	1/18	11.24	.004	0.2022	0.2022
SK FR	5/18	1.78	.168	0.0320	0.1599
SA	3/54	5.94	.001	0.0417	0.1252
SK SA	15/34	0.62	.850	0.0043	0.0648
FR SA	3/54	1.10	.357	0.0055	0.0164
SK FR SA	15/34	0.88	.588	0.0044	0.0658
SK RP	18	--	--	0.0190	0.3417
SK RP FR	18	--	--	0.0180	0.3237
SK RP SA	54	--	--	0.0070	0.3793
SK RP FR SA	54	--	--	0.0050	0.2687

Key: SK = Subject Kind (small, intermediate and large--male and female)
FR = Footrest (present, absent)
SA = Seat Tilt Angle (0°, 3°, 9°, 12° pitched back)
RP = Replication Trials

TABLE B-4. EXPERIMENT 6: HIGH RETENTION CHARACTERISTICS OF SIDE-FACING PASSENGERS - CORRECTED DECELERATION DATA

Source	DF1/ DF2	F	P Value	Mean Square	Sum of Squares
SK	5/27	2.31	.072	0.0530	0.2650
AR	1/27	1.32	.261	0.0050	0.0050
SK AR	5/27	0.68	.642	0.0026	0.0130
SK RP	27	--	--	0.0230	0.6207
SK RP AR	27	--	--	0.0038	0.1030

Key: SK = Subject Kind (small, intermediate and large--males and females)
AR = Armrest (present, absent)
RP = Replication Trials

TABLE B-5. EXPERIMENT 7: EFFECTS OF PREPARATION – UNCORRECTED DECELERATION DATA

Source	DF1/ DF2	F	P Value	Mean Square	Sum of Squares
SJ	1/6	26.10	.002	0.0325	0.0325
FR	1/6	117.96	.000	0.4851	0.4851
SJ FR	1/6	1.61	.252	0.0066	0.0066
PR	1/6	177.40	.000	0.3570	0.3570
SJ PR	1/6	0.75	.419	0.0015	0.0015
FR PR	1/6	188.20	.000	0.3160	0.3160
SJ FR PR	1/6	4.65	.074	0.0078	0.0078
SJ RP	6	--	--	0.0012	0.0075
SJ RP FR	6	--	--	0.0041	0.0247
SJ RP PR	6	--	--	0.0020	0.0121
SJ RP FR PR	6	--	--	0.0017	0.0101

Key: SJ = Subjects (2)
FR = Footrest (present, absent)
PR = Prepared, Unprepared
RP = Replication Trials

APPENDIX C.

SUBJECT SIZE ANALYSIS

In many of the experiments, differences in results were found among the different sized subjects. In spite of these differences, no single group was found to be particularly vulnerable to emergency decelerations nor, conversely, particularly resistant to movement. Also, no uniform pattern of results was found as a function of subject size.

In an attempt to increase the sample and identify any underlying pattern, data from several experiments were pooled. Corrected dislodgement data from the experiments on the Effects of Jerk and High Retention Seat Characteristics were used. Also included were data on the contoured fabric seat from the Seat Characteristics experiment, corrected for instrumentation lag.

The group means were as follows:

Subject Size	Sex		Average
	Male	Female	
Small	0.335 g	0.345 g	0.340 g
Intermediate	0.323 g	0.362 g	0.343 g
Large	0.340 g	0.300 g	0.320 g

A one-way analysis of variance indicated the presence of significant differences among groups: $F(5.545) = 3.389$, $p < .05$. Tukey's HSD Test (Kirk, 1969) indicated the sole course of significant difference was between the intermediate and large females, with large females having the lowest retention threshold and intermediate females, the highest ($p < .05$). It can be concluded that different sex and size characteristics are not a major factor in retaining seated passengers.

APPENDIX D.

REPORT OF NEW TECHNOLOGY

The work performed under this contract, while leading to no new technology, has provided guidelines in the retention of seated passengers during emergency decelerations for use by Automated Guideway Transit planners and designers. Recommended values are presented for selected seat design parameters for AGT passenger seats. In addition, suggestions are made for further research into the value of warning signals before an emergency stop, and the feasibility of alternative restraint systems.

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