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PROCEEDINGS
OF THE
URBAN RAIL VEHICLE CRASHWORTHINESS WORKSHOP

APRIL 1978

Conducted at

U.S. DEPARTMENT OF TRANSPORTATION

RESEARCH AND SPECIAL PROGRAMS ADMINISTRATION
TRANSPORTATION SYSTEMS CENTER
CAMBRIDGE, MA. 02142

OCTOBER 1979
WORKSHOP PROCEEDINGS

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U.S. DEPARTMENT OF TRANSPORTATION
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16. Abstract

This document contains the proceedings of the Urban Rail Vehicle Crashworthiness Workshop held at the Transportation Systems Center, Cambridge, Massachusetts, April 13-14, 1978. The workshop brought together researchers, manufacturers, users, and government representatives to exchange information on crashworthiness, both to share knowledge and to provide input as to further research needs.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

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

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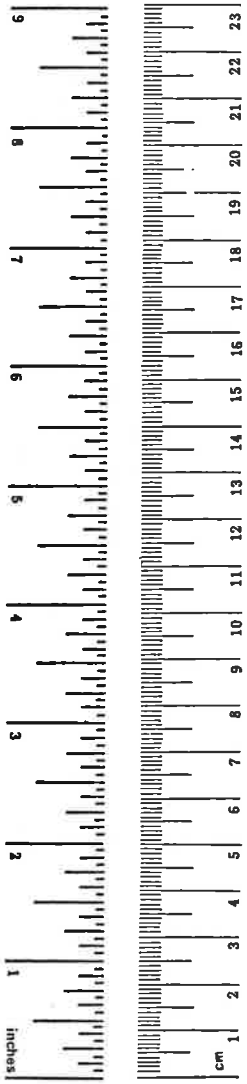
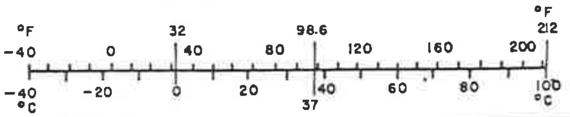
*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



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



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SUMMARY

The Urban Mass Transportation Administration (UMTA) has been actively engaged in crashworthiness research for urban rail transit cars over the past few years. This conference provided the opportunity for knowledgeable representatives from the Federal Government, properties, railcar manufacturers, researchers, and interested public for a review, exchange, critique, and open discussion of these urban rail vehicle crashworthiness activities. It is hoped that the ideas generated and recommendations contained in this document can be used for guiding future R&D activities and program development.

The first part of this document contains the research activities presented by the Calspan Corporation, Boeing Vertol Company, and Illinois Institute of Technology Research Institute; transit authority experience by Metropolitan Transportation Authority (MTA) of New York, Chicago Transit Authority (CTA), Metropolitan Atlanta Rapid Transit Authority (MARTA), and New York City Transit Authority (NYCTA); and the manufacturing industry experience by the Budd Company, Franco-Belge (France), and Boeing Vertol. The second part of this document contains the proceedings from the two workshops, namely, crashworthiness and rail car design and test and evaluation; and the concluding remarks from the Office of Safety and Product Qualification, UMTA, and from the Transit

System Branch at TSC.

The major recommendations from the group fell into two fairly broad categories:

1. The need for (industry-wide) vehicle design engineering guidelines including structural criteria and passenger compartment (containment) criteria;
2. The need for validating these criteria through programs of test and evaluation.

Other recommendations from the workshops are summarized by the chairmen on p 198-199 and p 241-242.

Appendix A contains pertinent publications relating to the subject matter; Appendix B presents the summaries of comments and meeting evaluations of the conference; and Appendix C lists the workshop attendees who registered.

The contributions from the authors, panel members, the numerous participants who provided to the general sessions,and workshops with their experiences, ideas, recommendations are gratefully acknowledged. Also, the professional conduct of Pacific Consultants is recognized in their efficient support to TSC in carrying out a highly successful meeting.

INTRODUCTORY REMARKS

Dr. Robert Whitford, Deputy Director, TSC

William Rhine, Director, Office of Safety and Product Qualification, UMTA

Ronald Madigan, Chief, Transit Systems Branch, TSC

Mr. Madigan: Good morning gentlemen. To start the proceedings off, I would like to first introduce you to the Deputy Director of the Transportations Systems Center, Dr. Robert Whitford.

Dr. Whitford: Thank you Ron. Welcome to TSC. I'm really appreciative of the kind of conference that we are holding because one of the most important things that we, the Government and all of you who are in the R & D community face is, "What do we do with the R & D?" The Federal Government tries to make its R & D relevant, but what is the best way to get the results out into the field where somebody can use it or react to it or provide some feedback so we can go to the next step of research or development that's needed?

It is good when the communities, the operators, the manufacturers take the opportunity to get together with us in the R & D sector. It's an opportunity for sharing and for having a better understanding. I'm particularly thankful to UMTA for their help in putting this conference together.

We need your input in assessing where we are and where we should be heading. So, I welcome you to TSC. Additionally, I might just say a couple of words about the Center. I don't know how many of you have been here before, but it's worth spending a couple of minutes to talk about it. TSC came into being in 1970, as a research and development arm for the Department of Transportation, to work across the board in multi-modal, if you will, transportation. The Department of Transportation includes very diverse agencies and administrations such as the the Federal Aviation Administration, Federal Railroad Administration, Federal Highway Administration, National Highway Traffic Safety Administration, U.S. Coast Guard, St. Lawrence Seaway Devleopment Corporation, and, of course, Urban Mass Transportation Administration.

TSC is in the unique position of doing research and development work for all of these administrations. Also, we are doing work in both the "hard sciences" technology, as some people would call it, and in the "soft sciences," such as social impact studies, economic impact studies; understanding the investment question from a variety of perspectives; analyzing the institutional barriers within the transportation industry; and doing other analyses that assist the Office of the Secretary and the various Administrators with their policy questions.

Dr. Whitford: continued. We have about a hundred and thirty different projects at TSC, and while you're here, you might take the opportunity to just walk through what we call the TIC, the Transportation Information Center. It's on the first floor, and as you come in, off to the right.

You can just conduct yourself through, and I think that the pictures and the displays will give you a good idea of the things we're doing for the department.

Our budget at TSC is about sixty million dollars, and we have about six hundred and thirty federal employees working on projects which include motor vehicle energy, air traffic control, airport safety, communications, urban systems including bus, rail, DPM, (Downtown People Mover), advanced guideway transit systems, track research and inspection for FRA and UMTA, and the like.

Finally, let me say a word about the sponsor of this conference, Bill Rhine, who's the Director of the Office of Safety and Product Qualification within UMTA. I first met Bill when this facility was the NASA Electronic Research Center back in the '68 and'69 era. I was with the TRW Company peddling guidance, control, and computer systems. Bill was on the government side at that time. Later, Bill stayed with the organization when it became the Transportation Systems Center but left shortly after I came, to work for the Bay Area Rapid Transit System as Director of Engineering. He has now after a few years in that position made the loop back to government and has the experience and understanding which can help us improve the operations, equipment, safety and services for urban transit, through R & D. So, without taking any more time, I would like to turn the proceedings over to Bill and wish you success in your endeavors over the next two days. Thank you.

Mr. Rhine: I'd like to start off by thanking TSC for all they've done in bringing about this conference. I'm sure we all appreciate that setting up the facilities, arranging for the speakers and attendees, transportation, and so forth, is no simple task.

I've been asked to give an overview of the program. I don't know exactly what that is but Bob Whitford pretty well summarized both what we want to do here in the next two days and what these sort of conferences mean to us. It's truly a workshop. It's a means for us to get feedback and interaction with the community. In this case, crashworthiness research, to see what's going on.

A lot of you know my boss, George Pastor, and his great concern with this question of delivery systems. How does the government or any organization deliver its product? And for R & D, it's of particular concern to us. In the past, I think we, the Federal Government, have not developed adequate means for this. But through such workshops and participation as this, better documentation, and closer contacts with people, we hope that we will have a delivery system which gets across our message.

We hope we will be delivering things that you people need and want and that we have your participation in carrying out these programs.

It's kind of strange coming back. As Bob said, I've been here before. I even was, in an offhand and somewhat underhanded way, reponsible for getting the Rail Program started at TSC.

In 1970 we had received certain monies from UMTA. I was here and on the Urban TACV (Tracked Air Cushion Vehicle) Program, which some of you may remember. At one time, Dr. Hemmes gave some marching orders up here to get a rail program started. And we said, "There's no money for it." And he said, "I gave you a lot of money; find it somewhere." I slid two hundred thousand dollars off in a corner, and Ron and several people were assigned to the program then. All of a sudden someone at TSC looked up and said, "Where are you getting that money?" "Off the Urban TACV V Program." They said, "You can't do that." We said, "We've already done it."

Well, here today is the monster come full bloom. The program's gone very successfully since then, and it's interesting for me to come back in 1978 and see all that's gone on from then, a small starting of two hundred thousand dollars in 1970.

I'll give it back now to Ron Madigan.

CRASHWORTHINESS RESEARCH ACTIVITIES

Calspan Corporation, David Segal

Boeing Vertol, Ed Widmayer

IITRI, Dr. Edward Hahn, Arne Wiedermann

CALSPAN - DAVID SEGAL

Mr. Madigan: Well, to start off, we'd like the Calspan people to tell you about the work that they've been doing for us. The original crashworthiness program started after that unfortunate accident in Chicago, when the Highliner was struck and penetrated, and about 44 people were killed. At that time, I think Secretary Volpe said, it's inevitable when a heavy car hits a light car, that that's going to happen. We thought, well, maybe it's not inevitable. Maybe there are things that can be done. And so with that, we started out. Dr. Bob Raab from TSC is here this morning. He worked with the Calspan people, and that was in 1973 we started that work under Bob's direction.

Then things evolved. So, I'd like Dave Segal this morning to tell you about the work that they started then and where it took them, and where they think we are today. Dave...

Mr. Segal: Thank you, Ron. As Ron mentioned, this work was started in late 1973 and finished in late 1975.

As shown in Figure 1, the objectives of this initial look at rail car crashworthiness were to provide engineering data for evaluation and planning purposes. Up until that point, very little was known about the situation that existed in car structures as related to occupant protection. So it was necessary to look into the information available and provide additional data for evaluation of crashworthiness of existing rail car designs.

TO PROVIDE THE ENGINEERING DATA REQUIRED FOR THE EVALUATION OF THE CRASHWORTHINESS OF EXISTING URBAN RAIL CARS (TASKS 1-6)

TO PROVIDE PRELIMINARY ENGINEERING DATA FOR PLANNING OF FUTURE CRASHWORTHINESS EFFORTS (TASKS 7-10)

FIGURE 1. CONTRACT OBJECTIVES

We also wanted to provide engineering data for planning future crashworthiness efforts and, hopefully, to provide data for establishing guide lines for improved structural standards.

The objective of any crashworthiness investigation is to provide a safe environment for passengers of a vehicle up to some established exposure level. Crashworthiness involves two general areas of study as shown in Figure 2. The first collision involved

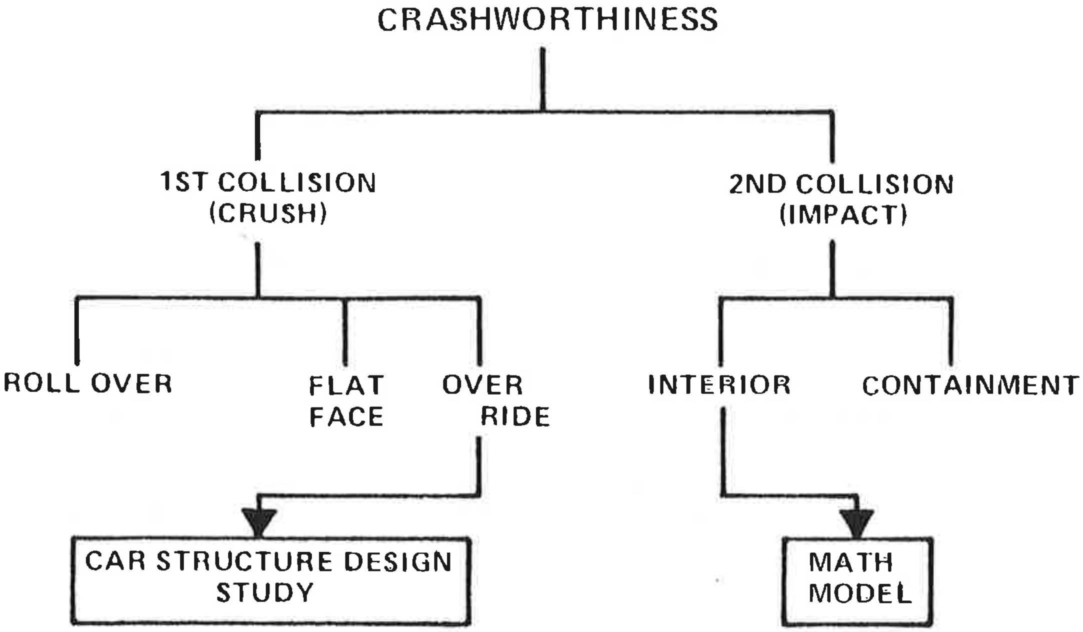

FIGURE 2. CRASHWORTHINESS STUDY

Mr. Segal: cont, structural properties of the vehicle which have a large role in determining the environment that the occupant is exposed to during a collision.

The second aspect of the problem is the collision between the occupant of a vehicle and the interior of that vehicle. The second collision is related to the structural end of the crashworthiness problem in that the deceleration experienced by the vehicle has a major effect on the relative velocity of impact between the occupant and the vehicle, and in fact, the optimum solution to the crashworthiness problem can only be accomplished through a trade off of first and second collision characteristics.

Summarizing the approach taken in the study, the first step was to review available biomechanics data in an attempt to establish relationships between injury and exposure. The next step was to develop a rather simplified train occupant collision model. The third was to select five existing rail cars for use in the study and estimate the structural force-deformation properties. Figure 3 lists the five cars that were chosen for the study.

PENN CENTRAL/READING - SILVERLINER
NYCTA - R-33
R-44
BARTD - A,B
MBTA - SILVERBIRD

FIGURE 3. CRASHWORTHINESS STUDY OF 5 EXISTING CARS

Mr. Segal: cont. Some of the biomechanical data that was investigated early in the program are summarized in Figure 4. As a result of that investigation, the GADD severity index, which has been used in the automotive community for quite some time, was chosen for use in this study. This index relates a severity number, determined by raising the acceleration experienced by an occupant to the 2.5 power and integrating over time to the liklihood of various injury levels.

If we assume that the acceleration that an occupant experiences during an impact is constant, then we can develop a chart as shown in Figure 5 which gives an indication of what has to be done in order to protect an occupant. This chart contains lines of impact speed varying between 10 and 60 mph and lines of the deformation that the impacted surface is assumed to undergo.

The intersection of any speed and deformation then gives the acceleration level and time at that level which can be related to the third set of curves, indicating the severity index for that event. A severity index of 1000 is indicative of concussion or the borderline between severe and moderate injuries.

A flow chart illustrating the procedure for determining the severity for a given event is shown in Figure 6. Given the crash velocity of a vehicle, the acceleration of that vehicle, and the spacing of an occupant from an interior surface, the velocity of that occupant at impact can be computed. Further, given the crush characteristics or crush distance of the interior surface, the occupant acceleration and severity index can be computed. Assuming a number of different conditions of spacing and crush distance, a weighting factor can be applied to come up with an overall vehicle injury rating for a car in a given collision.

AREA	TEST METHODS	SUBJECT	PARAMETER AND LEVEL	INJURY	REFERENCE
HEAD H_x	IMPACT FLAT PLATE	CADAVER	80 g's	CONCUSSION	↓
	↓ ↓ ↓	↓	40 g's	NONE	↓
H_y	SLED BELTS	HUMAN	46 g's	MINOR	5
α	ROTATION	ANIMALS	50 rad/sec.	50% CHANCE OF CONCUSSION	4
α	↓	↓	1800 rad/sec^2	↓ ↓ ↓ ↓	↓
HSI	CALCULATED	–	f(a, t) 1000	DEFINED AS NON INJURIOUS	9
HIC	↓	–	↓ ↓	↓ ↓ ↓	2
FACE FRONTAL	IMPACT, UNPADDED, 28 IN^2	HUMAN	400 lbs	NONE	1
(FOREHEAD)	PADDED, 28	↓	285	↓	↓
	↓ ↓ 5 ↓	CADAVER	2000	FRACTURE (THRESHOLD)	↓
	↓ ↓ 1 ↓	↓	900	↓	11
TEMPOROPARIETAL	↓ ↓ ↓	↓		↓	↓
(TEMPLE)	↓ ↓ 1 ↓	↓	450	↓	↓
ZYGOMATIC	↓ ↓ 5 ↓	↓	480	↓	1
(CHECK)	↓ ↓ 1 ↓	↓	250	↓	↓
	↓ ↓ 1 ↓	↓	200	↓	11
MAXILLA	↓ ↓ 1 ↓	↓	160	↓	1
(UPPER JAW)	↓ ↓ 1 ↓	↓	150	↓	11
MANDIBLE	↓ ↓ 5 ↓	↓	600	↓	1
(LOWER JAW)	↓ ↓ 1 ↓	↓	275	↓	↓
MANDIBLE, x	↓ ↓ 1 ↓	↓	400	↓	11
MANDIBLE, y	↓ ↓ 4 ↓	↓	200 ↓	↓	11
NECK HYPERTENSION	STATIC LOADING	CADAVER	42 ft lbs	LIGAMENTOUS DAMAGE	1
HYPERFLEXION	↓ ↓	↓	140 ↓ ↓	NONE	↓
CHEST C_x	FREE FALL, IMPACT PADDED	HUMAN	49 g's 10 sec	NONE	3
	SLED, BELTS	↓	45 4 g's 23 sec	MINOR	1
	IMPACT, 28 IN^2	CADAVER	1200 lbs	RIB FRACTURE	↓
	SLED, VEST, 140 ↓	HUMAN	3300 lbs	NONE	7
C_z	SEAT EJECTION TESTS	↓	25 g's	OCASSIONAL VERTEBRAL FRACTURE	5
C_R	CALCULATED	–	60 g's 3 msec	DEFINED AS NON INJURIOUS	2
CSI	↓	–	f(a, t) 1000	↓ ↓ ↓	↓
PELVIS	SLED BELTS	HUMAN	2800 lbs	NONE	1
	↓ ↓	↓	5000 ↓	↓	↓
LOWER EXTREMITIES					
FEMUR	CALCULATED	–	1700 lbs	DEFINED AS NON INJURIOUS	2
	IMPACT, PADDED 28 IN^2 AXIAL	HUMAN	1050	NONE	1
	↓ ↓	CADAVER	1700 ↓	FRACTURE	↓
	STATIC LOADING IN TORSION	↓	102 ft lbs	↓	12
PATELLA	IMPACT, UNPADDED, 28 IN^2	↓	1700 lbs	↓	1
TIBIA	STATIC LOADING IN TORSION	↓	50 ft lbs	↓	8
	↓ ↓ ↓ BENDING	↓	166 ↓ ↓	↓	↓
	↓ ↓ ↓ TORSION	↓	55 ↓ ↓	↓	12
FIBULA	↓ ↓ ↓ ↓	↓	7 ↓ ↓	↓	
UPPER EXTREMITIES					
HUMERUS	STATIC LOADING IN TORSION	CADAVER	46 ft lbs	FRACTURE	12
RADIUS	↓ ↓ ↓ ↓	↓	14 ↓ ↓	↓	↓
ULNA			9 ↓ ↓		
WHOLE BODY	SLED BELTS	HUMAN	45 4 g's 23 sec	MINOR	1
	RE ENTRY COUGH	↓	126 g's	NONE	10
	FREE FALL IMPACT PADDED	↓	49 g's 10 sec	↓	3
	SLED BELTS	↓	ONSET RATE	↓	6
			1000 g's/sec	↓	

FIGURE 4. INJURY CRITERIA

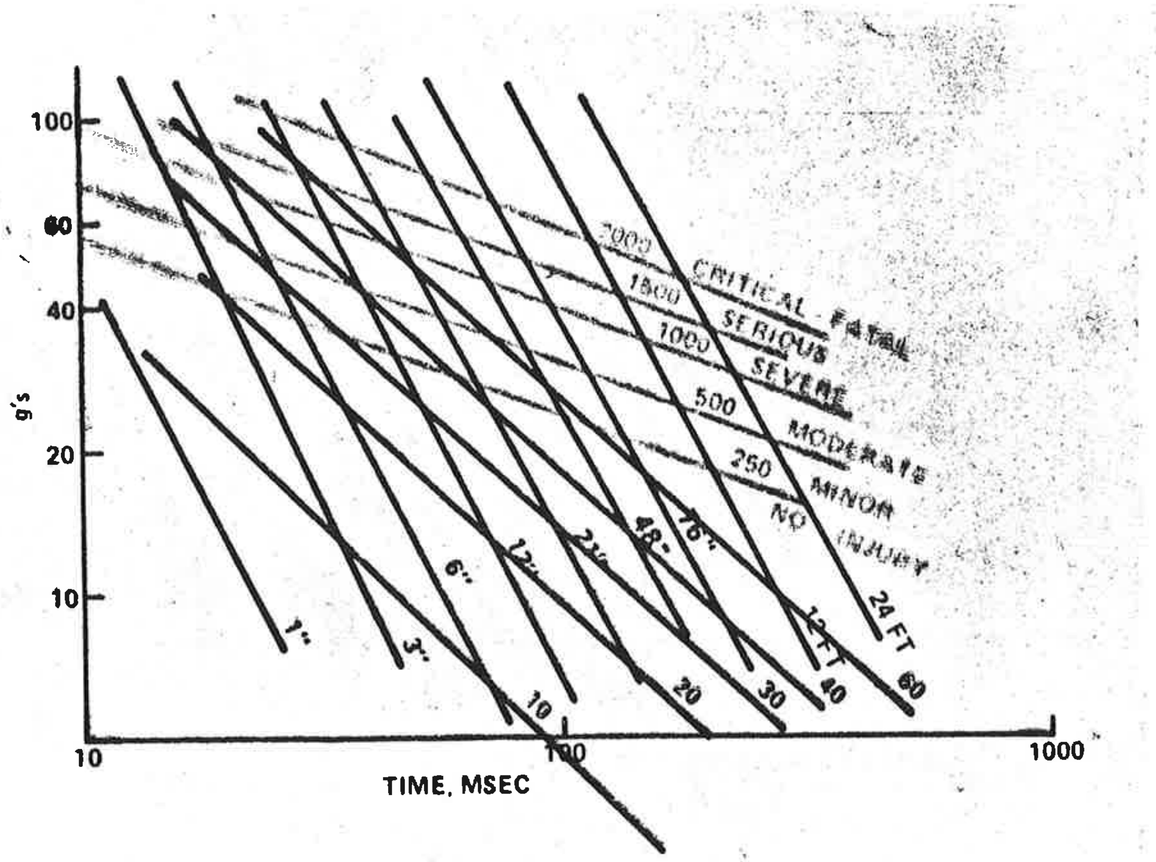

FIGURE 5. INJURY SEVERITY DETERMINATION

$$\left.\begin{array}{r}(V_c, a_c, S) \longrightarrow V_p \\ \\ d\end{array}\right\} \left.\begin{array}{c} a_p \longrightarrow SI \\ \\ \text{WEIGHTING}^{*} \end{array}\right\} R$$

WHERE

V_c = TRAIN CRASH VELOCITY

a_c = CAR DECELERATION

S = OCCUPANT SPACING WITH RESPECT TO INTERIOR CONFIGURATION

V_p = PASSENGER IMPACT VELOCITY

d = IMPACTED-OBJECT CRUSH DISTANCE

a_p = PASSENGER DECELERATION

SI = SEVERITY INDEX (BASED ON HSI, HIC, CSI et al.)

R = ABBREVIATED INJURY SCALE

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*WEIGHTING TO INCLUDE SUBJECTIVE, OR QUALITATIVE, EVALUATION OF INJURY COMPONENTS SUCH AS WINDOW GLASS, SHARP-CORNERED SEATS, ETC.

FIGURE 6. FLOW CHART, CRASH TO INJURY

Mr. Segal: cont. The next step in the analysis was to develop a train-occupant collision model and computer program. Figure 7 is a schematic of one option within that model. The rail cars themselves are representative rigid masses. The springs, as are shown in the figure, act between each of the cars as a barrier. Within the program the springs are really generalized force-deformation characteristics representing in this case the series combination of the structural properties of adjoining cars.

In operation the train contacts the barrier, and numerical integration determines car positions, accelerations, velocities, and the forces acting between the cars at each point in time. In parrallel with the train car calculations the position of the occupants relative to the car are also computed at each point in time. As the rail car decelerates, the occupant spacing decreases until contact with the interior occurs. Based on the relative velocity at impact and the properties of the interior surface, a deceleration and severity index is computed for the occupant.

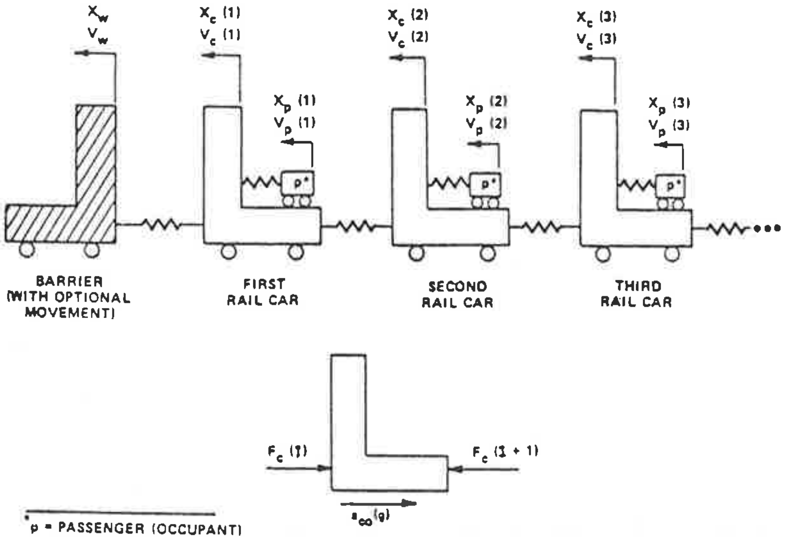
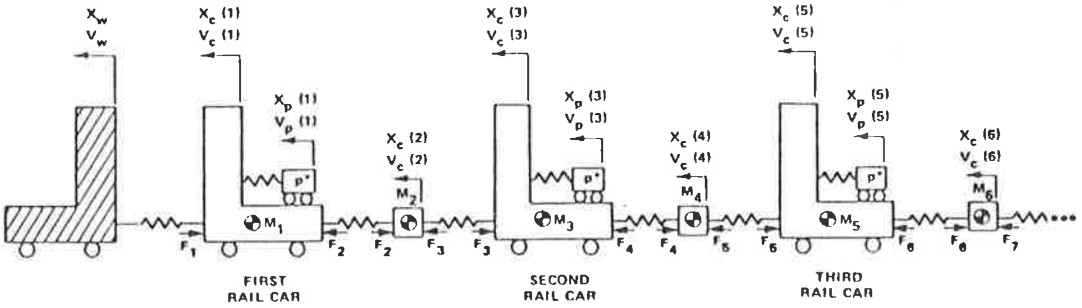


FIGURE 7. SIMPLIFIED SCHEMATIC DIAGRAM OF TYPICAL MODE 1 TRAIN CONFIGURATION

Another mode of operation of the computer simulation model is used to handle separate force-deformation properties of adjoining vehicles. This mode is used to study the effects of override of one car against another during the collision. As shown in Figure 8 separate force-deformation properties

Mr. Segal: cont. for each of the cars together with a mass acting between the force-deformation properties are input. The interface mass, which allows isolation of adjacent car structural properties, consists of that mass which is at a common velocity during a collision.



M_i = WEIGHT/g, i = 1,3,5, . . .

M_i = (WFACTR)·WEIGHT/g, j = 2,4,6, . . .

---

*p = PASSENGER (OCCUPANT)

FIGURE 8. SIMPLIFIED SCHEMATIC DIAGRAM OF TYPICAL MODE 2 TRAIN CONFIGURATION

One problem that was experienced during this initial study was the lack of available data in the area of structural characteristics of rail cars. As a result simplified structural analysis was performed to generate a representative curve for pure frontal loading of rail car structure as shown in Figure 9. In this case the full front of the rail car is engaged; there is no override. As is shown, about one and a half million pounds of force is developed at maximum. In contrast the analysis indicated that about half that value is reached when override occurs as can be seen in Figure 10.

These two curves are indicative of the representation of structural properties used to study the various rail cars. Although they are not confirmed by experimental data, they did provide a start toward establishing relationships between structural performance and injury.

Figure 11 summarizes the conditions that were simulated using the train occupant collision model. As is seen, up to ten cars in a train at impact speeds ranging from twenty to eighty miles per hour were simulated both with override and without override.

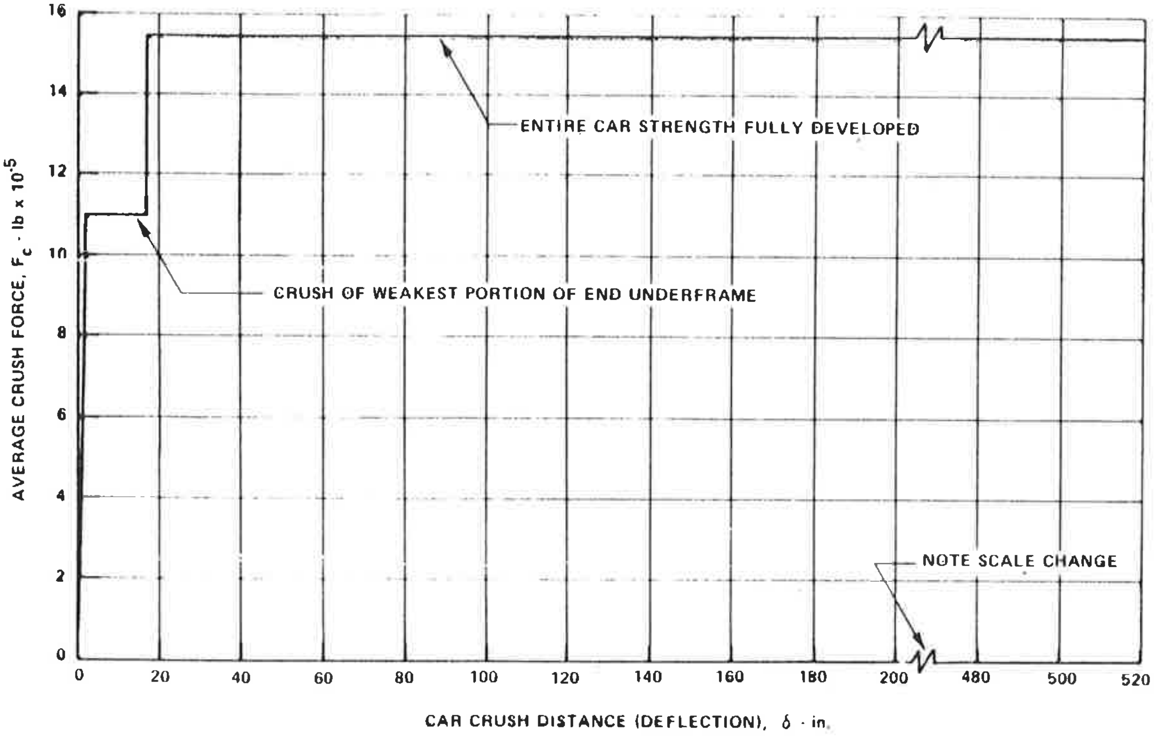


FIGURE 9. CRUSH FORCE VS DEFLECTION FOR SILVERLINER CAR - NO OVERRIDE

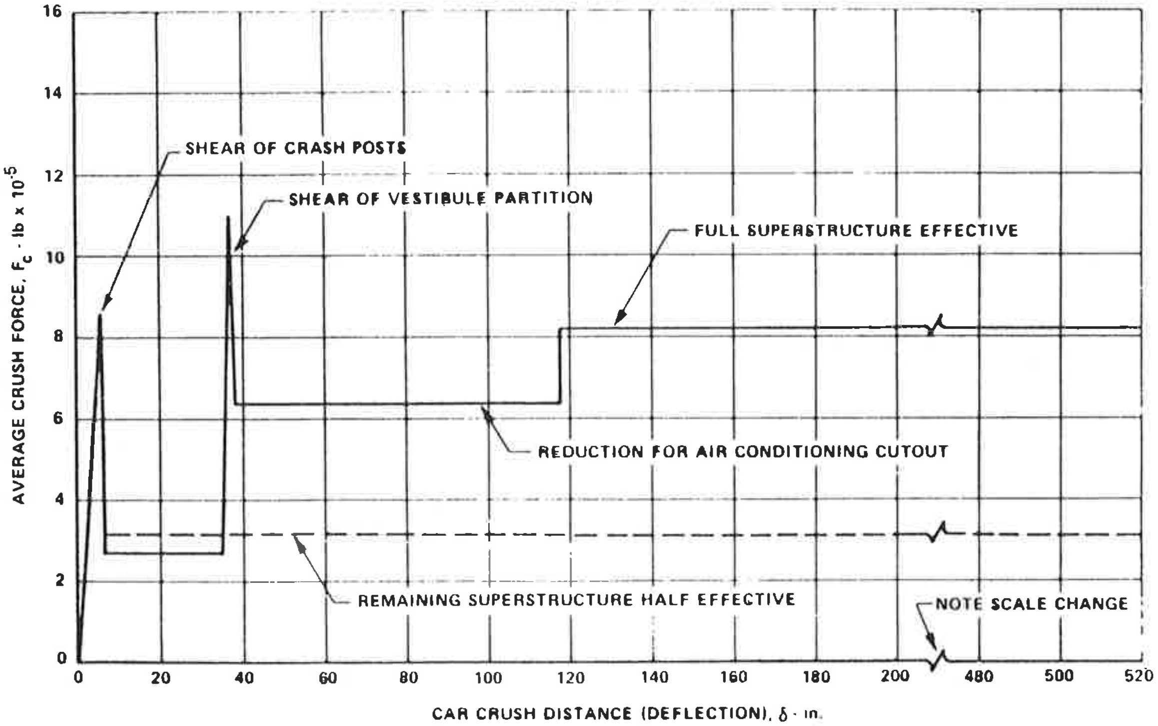


FIGURE 10. CRUSH FORCE VS DEFLECTION FOR SILVERLINER CAR - INITIAL OVERRIDE

CAR TYPE IN TRAIN	NO. OF CARS IN TRAIN	CRASH IMPACT VELOCITY (mph)	NO OVERRIDE	OVERRIDE 1	OVERRIDE 2
SILVERLINER	1, 2, 4, 6	20, 30, 40, 60	✓	✓	✓
R-33	4, 8	20, 30, 40, 60	✓	✓	--
R-44	4, 8	20, 30, 40, 60	✓	✓	--
BARTD	4, 6, 8, 10	20, 30, 40, 60, 80	✓	✓	--
SILVERBIRD	2, 4, 6	20, 30, 40, 60	✓	✓	--

FIGURE 11. RAIL CAR CONDITIONS SIMULATED

The next few figures illustrate some of the results obtained with the model. Figure 12 summarizes the effect of crash velocity on crush distance of the first car of a four-car train. And not surprisingly, as the crash velocity increases, the deformation of the first car increases substantially.

Figure 13 presents representative results of a car on crush distances in a four-car train at forty miles per hour impact velocity. As is seen, the model predicts that the first car is crushed approximately eleven feet while the second car is crushed only two feet. The third and fourth cars undergo a negligable deformation.

The effects of override on the crush of the first car of a train of four cars is shown in Figure 14. As would be expected from a comparison of the force-deformation properties shown in Figure 9 and 10, the initial override condition results in somewhat more than twice the crush of the no override condition.

The effect of the number of cars in a train on the crush of the first car is shown in Figure 15. As the number of cars increases, the crush of the first car increases, due to the fact that the first car must dissipate a substantial part of the increase in energy associated with the increase in mass of the train.

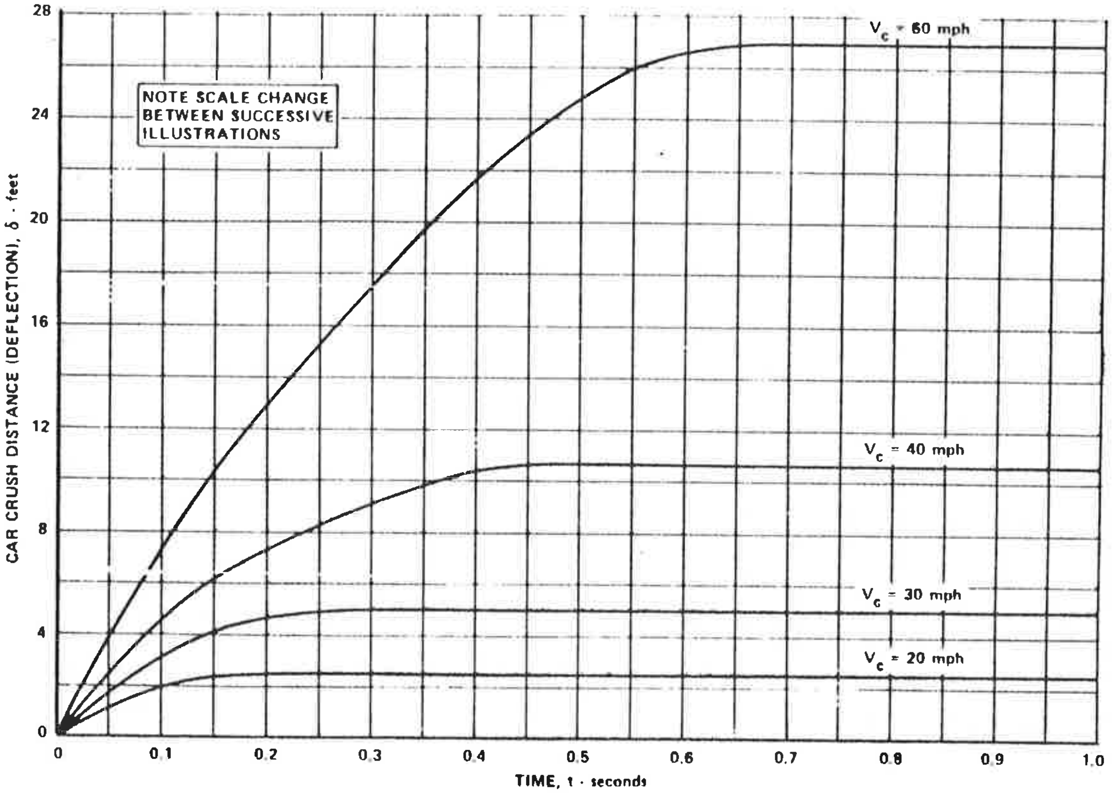


FIGURE 12. EFFECT OF CRASH VELOCITY, V_C' ON CRUSH DISTANCE OF FIRST CAR–TRAIN OF FOUR SILVERLINER CARS

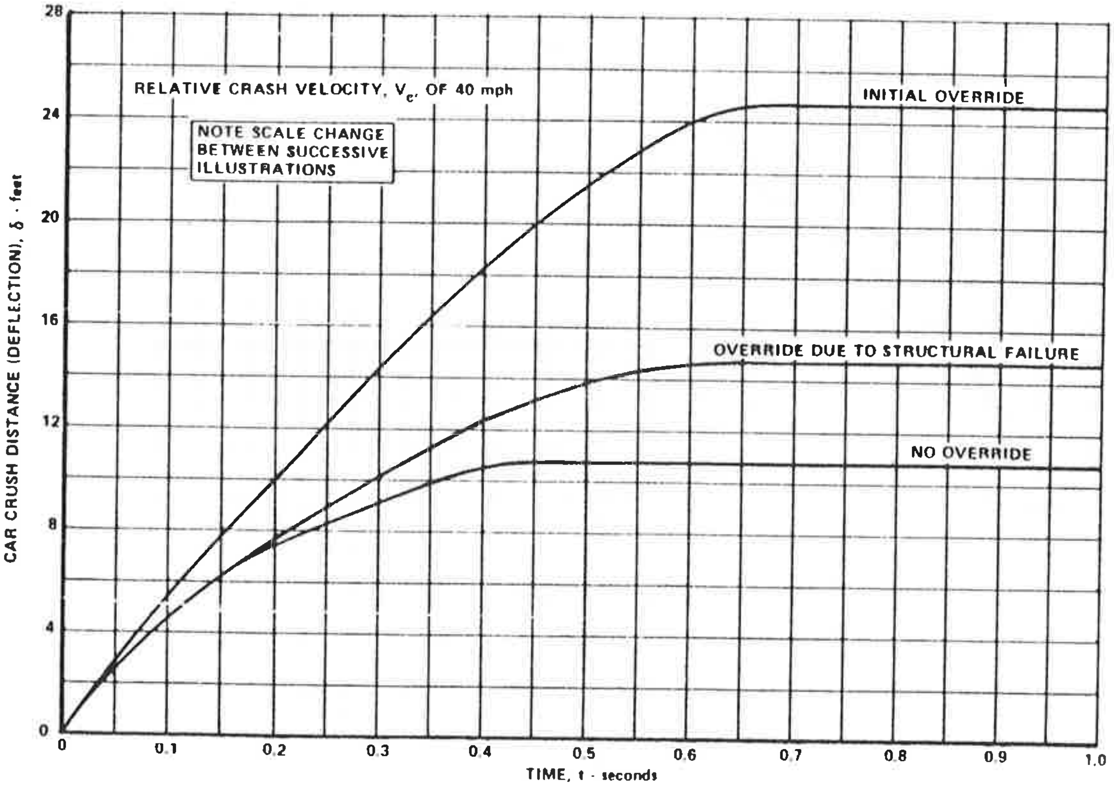


FIGURE 13. EFFECT OF OVERRIDE ON CRUSH DISTANCE OF FIRST CAR – TRAIN OF FOUR SILVERLINER CARS

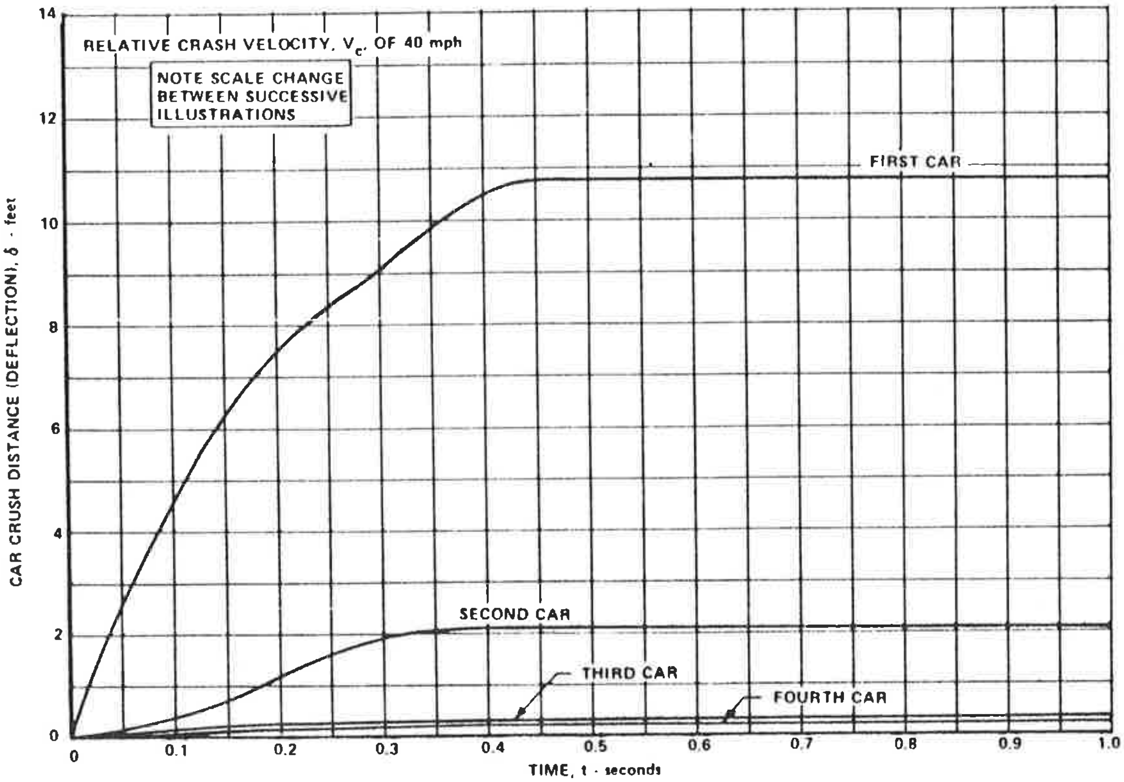


FIGURE 14. EFFECT OF CAR POSITION IN TRAIN ON CRUSH DISTANCE OF CAR - TRAIN OF FOUR SILVERLINER CARS

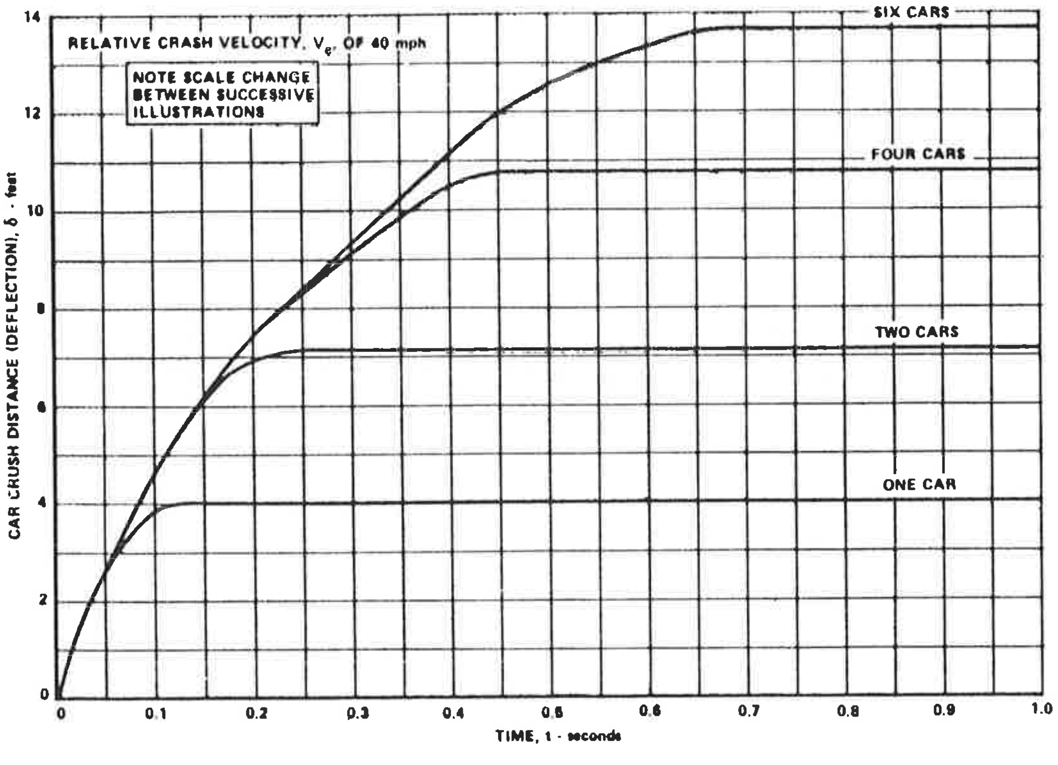


FIGURE 15. EFFECT OF NUMBER OF CARS IN TRAIN ON CRUSH DISTANCE OF FIRST CAR - TRAIN OF ALL SILVERLINER CARS

Mr. Segal: cont, We considered two kinds of injuries or fatalities in looking at the rail car crashworthiness problem: the first being a deceleration related injury associated with the severity index that was discussed above; the second kind of injury or fatality can be associated with an intrusion or crush injury or fatality. Figure 16 presents a look at these crush fatalities as a percent of full occupant loading, with a four car train, no override, as a function of closing velocity, strength to weight ratio, and unoccupied crush space. As would be expected, as the closing velocity or impact velocity between the two trains increases, the number of crush related fatalities is expected to increase due to the fact that more of the first car is being destroyed during the collision event. As the strength to weight ratio increases, crush fatalities are expected to decrease because of the decreased crush of the lead car. However, due to the higher car decelerations, an increase in second collision injuries may result.

The other approach that might be taken to reduce crush fatalities insures that there is sufficient unoccupied lead space in the first car of the train. As shown in the figure, an unoccupied lead space of 10 feet eliminates crush fatalities at a 40 mph closing velocity collision.

CAR CONFIGURATION		CLOSING VELOCITY		
UNOCCUPIED LEAD CAR CRUSH SPACE	S/W RATIO	40 MPH	60 MPH	80 MPH
0	5	4	8	14
	10	2	5	9
	15	1	2	4
5′	5	2	6	12
	10	1	3	6
	15	0	0	2
10′	5	0	3	10
	10	0	1	2
	15	0	0	0
20′	5	0	0	5
	10	0	0	0
	15	0	0	0

FIGURE 16. CRUSH FATALITIES IN PERCENT OF FULL OCCUPANT LOADING FOUR CAR TRAIN, NO OVERRIDE

Mr. Segal: cont. Figure 17 is representative of the second collision or index related injuries that were obtained with a number of different conditions. The severity indices shown on the last four columns are average values, intended to give an idea of the overall safety of a given car. The average values are computed from free occupant spacings of two and four feet and crush distances of the impacted object of one and two inches.

Of particular interest on this figure is the tendency for the severity index to increase toward the rear of the train. This is evidently due to the fact that different cars in a train have somewhat different deceleration versus time characteristics in a collision. Consider an example of a four car train in a collision at a 40 mph closing velocity with each car having a two plateau force-deflection characteristic consisting of a constant 1,100,000 lb for deformations between 0 and 0.3 feet and a constant 1,550,000 lb thereafter. Velocity-versus-time curves for the first and second cars of the train are plotted in Figure 18.

In the initial time regime (0 t 0.01 second) the entire train decelerates as a rigid body under a front-end force level of 1,100,000 lb. At t = 0.01 second, the force level at the front end of the train increases instantly to 1,550,000 lb, marking the start of the second time regime. At this time, the train attempts to decelerate as a rigid body at a higher rate corresponding to the increased force. However, this would require that the force level between the first and second cars be

$$F_{12} = 3/4\ (1,550,000) = 1,160,000 \text{ lb}$$

It should be noted that no information has yet been found to confirm this result from the simulation study. However, partial override generally occurs in severe frontal accidents thus lowering the effective strength to weight ratio of the first car and leading to a high incidence of crush fatalities with a low incidence of second collision injuries in the trailing cars. If car construction can be improved to eliminate override, the predictions of increasing severity index toward the rear of the train may be meaningful and should be further investigated.

Figure 19 provides a summary of things that can be done to improve rail car crashworthiness. Of primary importance is the mimimization of first collision or crush fatalities. This can be accomplished through override prevention, building stronger cars, or through provision of unoccupied crush space.

The second collision is more difficult to define in terms of specific recommendations, since it is really a rather random,

NO. OF CARS IN TRAIN, N	CAR IN WHICH PASSENGER IS RIDING	CAR CRUSH DISTANCE (DEFLECTION) IN FEET		PASSENGER SEVERITY INDEX*			
		20 mph CRASH VELOCITY	60 mph CRASH VELOCITY	20 mph CRASH VELOCITY	30 mph CRASH VELOCITY	40 mph CRASH VELOCITY	60 mph CRASH VELOCITY
1	FIRST	1.4	8.0	1,254	6,348	13,615	19,118
2	FIRST	2.0	15.2	1,254	3,762	3,753	3,702
	SECOND	--	0.5	1,254	4,281	4,995	5,580
4	FIRST	2.5	27.0	921	1,842	1,979	2,208
	SECOND	1.0	2.3	735	884	965	1,061
	THIRD	--	--	821	1,155	1,196	1,378
	FOURTH	--	--	855	1,491	1,539	1,568
6	FIRST	2.5	37.7	921	1,842	1,979	2,208
	SECOND	1.6	3.2	386	532	591	605
	THIRD	0.4	1.8	307	379	380	400
	FOURTH	--	0.5	383	445	509	448
	FIFTH	--	--	464	539	557	551
	SIXTH	--	--	532	645	663	629

*AVERAGE OF VALUES CALCULATED FOR PASSENGER SPACINGS, S, OF 2 ft AND 4 ft AND FOR IMPACTED OBJECT CRUSH DISTANCES (DEFLECTIONS), d, OF 1 in. AND 2 in. FROM TABLE 2-2:

SEVERITY INDEX	CATEGORY OF INJURY	SURVIVABILITY
LESS THAN 250	NO INJURY	NOT LIFE-THREATENING
250 TO 500	MINOR INJURY	
500 TO 1,000	MODERATE INJURY	
1,000 TO 1,500	SEVERE INJURY	
1,500 TO 2,000	SERIOUS INJURY	PROBABLE
OVER 2,000	CRITICAL INJURY OR FATALITY	UNCERTAIN TO NONE

FIGURE 17. CAR CRUSH DISTANCES AND PASSENGER SEVERITY INDICES FOR SILVERLINER TRAINS CRASHING UNDER DIFFERENT CONDITIONS

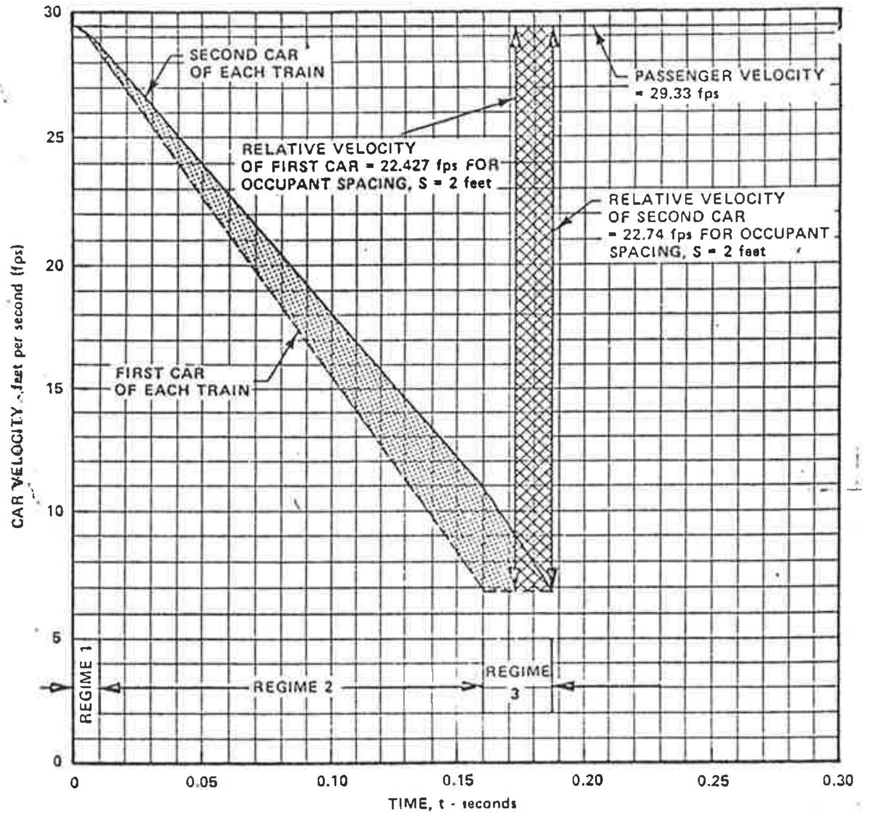


FIGURE 18. MINIMUM PASSENGER SEVERITY INDICES FOR FIRST AND SECOND CARS OF EACH TRAIN IN A COLLISION OF TWO FOUR-CAR SILVERLINER TRAINS AT A RELATIVE CLOSING VELOCITY OF 40 MPH

Mr. Segal: cont, unpredictable event. With people standing, seated, facing sideway, etc., the railcar interior presents a very uncontrolled atmosphere to provide protection for the occupants. But there certainly are some things that can be done. Elimination of small, hard, sharp objects, for example, partitions might be effective in this regard.

1. OVERRIDE PREVENTION
2. STRONGER CARS
3. PROVISION FOR UNOCCUPIED CRUSH SPACE
    - LEAD CAR
    - ADD-ON ENERGY ABSORBER
4. CONTROL OF INTERIOR DESIGN

FIGURE 19. IMPROVED RAILCAR CRASHWORTHINESS

From the Floor: Are they in the order of preference or rank?

Mr. Segal: No, I don't believe there's any particular ranking here.

From the Floor: Stronger? What do you mean by that? Is that the buff load?

Mr. Segal: We're looking at the crush load.

From the Floor: Do you have a value for that?

Mr. Segal: No, I don't. This study was based on simplified structural analyses without any real evidence that those analyses were valid in terms of actual load levels.

From the Floor: Did you make any attempt to tie this back into the natural crash?

Mr. Segal: No, we were unable to come up with any data to corroborate the model or structural characteristics that we used.

Mr. Tucker: Taking strength, did you just consider the load of the anticlimber or did you consider the whole car acting in compression?

Mr. Segal: (cont.) This is the whole car. We made no effort to take a look at the details of what happens as the collision is initiated. It's the whole car event.

Mr. Tucker: If you just loaded the anticlimber, you'd get a significant bending on the car even take the crushing of the skin through the whole length of the car, then as part of the energy absorption, is about what you're saying.

Mr. Segal: I believe that the skin was accounted for only in a column.

Mr. Tucker: But not as far as deflection of the car due to the eccentric load on the car?

Mr. Segal: Yes, I think that's correct.

Mr. Madigan: I think you'll hear more about plastic deformation.

Mr. Segal: Are there any other questions that I might try to answer?

From the Floor: Has there been any attempt to validate the model, get it through laboratory simulation or real accident reconstruction?

Mr. Segal: We have not been involved in this kind of work since this project ended in late '75, so we have done nothing in that regard. Thank you.

Mr. Madigan: Thanks, David.

BOEING VERTOL - EDWARD WIDMAYER

Mr. Madigan: Calspan was already started in this program when we had a very unfortunate accident with the State of the Art Car (SOAC) out at Pueblo. It struck a gondola car.

Now, while it wasn't a transit type accident, we did call on the Boeing people to come in and take a look at just what happened during that accident as best they could evaluate it.

How did the car develop the loads and so forth?

What happened, of course, the gondola car, its anticlimber was a very flimsy attachment. There was an override situation and penetration.

The motorman was killed in that accident and so we felt an obligation to take a look at the hard data that we had there. Namely, we had the vehicle, and we had the result of the gondola, and we had a pretty good measure of the forces that were developed.

Ed Widmayer, from Boeing, is here to talk about the kind of work that was done.

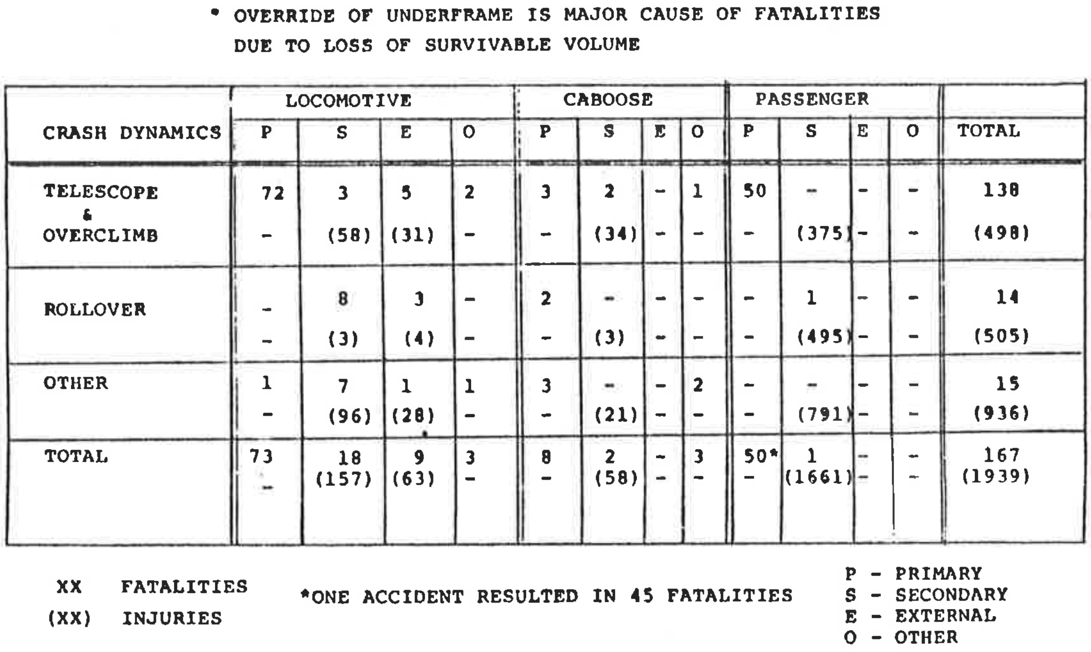
Mr. Widmayer: This morning I'm going to review the crashworthiness studies conducted under Contract DOT-TSC-691, and to touch briefly on some of the results that were obtained in Contract DOT-TSC-856. The first contract was done for UMTA and the second contract was done for the FRA, but the results of the studies are surprisingly similar, and certain findings from the second study are germane to the business at hand.

These studies treat the structural aspects of crashworthiness and only touch on the mechanisms of occupant injury. A companion study, DOT-TSC-821, conducted for the FRA treats in some detail the problems of delethalization of the interior of rail cars. If you are concerned with the interior problem, you might refer to Mr. Samuel Polcari of TSC.

Crashworthiness is the prevention of fatalities and injuries to the vehicle occupants in collisions. Some facts about crashworthiness to keep in mind are that most fatalities result from the loss of survivable volume, that is, crushing. The people are killed by being crushed by the intruding vehicle. Most of the loss of survivable volume results from overriding or telescoping. Most secondary injuries, that is, where people are injured and survive, are due to secondary impact where the occupant hits his surroundings. Contrary to the Calspan results, I find to the first order the two problems may be treated separately.

A central thesis that runs through my remarks this morning is the intrusion due to override must be prevented. That's a contrary

Mr. Widmayer: cont. goal for crashworthiness. These facts become apparent from an eight-year accident history study conducted under Contract DOT-TSC-856. A summary of the statistics are shown in Figure 1. These data included passenger vehicles, cabooses and locomotives as reported to the FRA. However, of interest here is what happened in the passenger vehicle. There were fifty people killed in passenger vehicles over this time span.



- OVERRIDE OF UNDERFRAME IS MAJOR CAUSE OF FATALITIES DUE TO LOSS OF SURVIVABLE VOLUME

CRASH DYNAMICS	LOCOMOTIVE				CABOOSE				PASSENGER				TOTAL
	P	S	E	O	P	S	E	O	P	S	E	O	
TELESCOPE & OVERCLIMB	72	3	5	2	3	2	-	1	50	-	-	-	138
	-	(58)	(31)	-	-	(34)	-	-	-	(375)	-	-	(498)
ROLLOVER	-	8	3	-	2	-	-	-	-	1	-	-	14
	-	(3)	(4)	-	-	(3)	-	-	-	(495)	-	-	(505)
OTHER	1	7	1	1	3	-	-	2	-	-	-	-	15
	-	(96)	(28)	-	-	(21)	-	-	-	(791)	-	-	(936)
TOTAL	73	18	9	3	8	2	-	3	50*	1	-	-	167
	-	(157)	(63)	-	-	(58)	-	-	-	(1661)	-	-	(1939)

XX FATALITIES
(XX) INJURIES

*ONE ACCIDENT RESULTED IN 45 FATALITIES

P - PRIMARY
S - SECONDARY
E - EXTERNAL
O - OTHER

FIGURE 1. FATALITY MECHANISMS -- COLLISIONS
DOT-TSC-856

The details of the statistical study are given in a report which will be published presently. However, for the passenger vehicles that are of concern here, the Chicago accident involving the ICG Highliner, forty-five people were killed and in the SOAC accident one person, the operator, was killed. There was another accident in Darien, Connecticut where a commuter train had a collision with another commuter train and four were killed. But in all instances the primary crush killed fifty of these people. We found that all the people that were killed were always in the first car. Those accidents were all characterized by telescoping, Mr. Widmayer: cont. override, or overclimb.

From the Floor: Are your studies limited to just the collision of one vehicle with another vehicle, or is there any crossing accidents involved?

Mr. Widmayer: No, no crossings. This study was concerned with a collision between the trains. However, there was an interesting accident up in Bucks County where a commuter train unfortunately hit a truck carrying coil steel in a grade crossing accident. One of the coils of steel sheared off the collision post next to the floor and proceeded to travel the length of the car to the last six seats killing the engineer and two passengers. In essence it's an overclimb situation in that the coil of steel rose above the underframe, impacted the collision posts, sheared them off, and travelled the length of the car to kill the people. In the same sense a rail vehicle would override underframe and kill people.

With respect to the injury shown in the parenthesis, in the accidents where we had telescoping and overclimb, there were 375 injuries; roll over had 495, and the other causes resulted in 791. If you look at the total, the secondary injuries are impressive, but they constitute both major and minor injuries. In the case of telescoping and overclimb we get about 25 percent of injuries.

From the Floor: What were the crushes associated with fatalities in the first car?

Mr. Widmayer: In the case of the Chicago car, the overriding train penetrated to the middle of the car. It was a terrible accident.

From the Floor: Can I ask two questions? First off, what are the dates of the periods?

Mr. Widmayer: 1966 to 1973.

From the Floor: Second, you're including intercity rail?

Mr. Widmayer: Yes, however, the accidents involving passenger vehicles, as I say, forty-six of them concerned the ICG Highliner and the SOAC accident which occurred out at Pueblo.

From the Floor: But the roll over occured primarily in intercity traffic?

Mr. Widmayer: Yes, I don't think we've ever had any on the urban cars.

Mr. Tucker: So what you're saying is that there have been no transit cars within this period that have had an overclimb, and they've all been intercity cars?

Mr. Widmayer: I won't say that. The accident history that we looked at was taken from the FRA files. It included the NTSB reports. For structural data we went to G.E. at Erie where Mr. Ginetti was very helpful and used Keith Hawthorne's work for the AAR -- I can't really support a statement that says nobody was killed on a trolly car. But this information shows that serious accidents are those when you have overclimb.

UMTA is concerned with crashworthiness and the SOAC accident presented a unique opportunity to study crashworthiness on an up-to-date vehicle. The accident occurred on the high speed test track at Pueblo in August 1973, while the SOAC was undergoing braking tests.

As background, they'd run all morning, went to lunch; during lunch the station keepers moved a locomotive and gondola from one position to another on the test track and left a switch set to a siding. After lunch, the test team got back on the car to resume the braking tests. at about 55 miles an hour, they were switched onto a siding where they proceeded to hit the gondola backed up by a locomotive.

Factors were present in this accident that are not usually available. These factors were, we had eyewitnesses in the test engineers that were observing the braking tests; we had known conditions as the operator had the car practically on speed, preparing to do his next brake test; and we know the track, where the brakes were applied and so forth. So we have a pretty good idea of the impact conditions.

In addition we knew the masses of the cars involved. We were able to determine a reasonable sequence of events for the collision, from what failed, when and where by the location of debris, and by the applications of some rational mechanics. We had documented damage because UMTA sent the car to Boeing for repairs, and we knew what we had to fix. We also had available engineering data on the car. We had the stress analysis, and the New York City Transportation Authority made static test results available to us. We had a lot of cooperation. (see Figures 2 & 3)

- EYE WITNESSES
- KNOW CONDITIONS
- SEQUENCE OF EVENTS DETERMINED
- DAMAGE DOCUMENTED
- ENGINEERING DATA AVAILABLE

FIGURE 2. SOAC ACCIDENT NTSB RAR-74-2

- ANALYZE ENERGY ABSORBING CAPACITY OF SOAC CARBODY
- ANALYZE ACCIDENT DAMAGE FOR FAILURE MODES TO SUBSTANTIAGE ANALYTICAL RESULTS
- APPLY COLLISION DYNAMICS ANALYZES TO ASSESS CRASHWORTHINESS
- DETERMINE EFFECT OF COLLISION CONDITIONS ON PASSENGER INJURY POTENTIAL
- RECOMMENDED STRUCTURAL MODIFICATIONS TO IMPROVE CRASHWORTHINESS

FIGURE 3. SOAC STUDY - AN ENGINEERING ASSESSMENT OF SOAC CRASHWORTHINESS

Mr. Widmayer: cont. Boeing conducted a study on this accident with Drs. Herbert Weinstock and Robert Raab of TSC as the program technical monitors.

The objective of the study was to provide an engineering assessment of the SOAC crashworthiness. The technical approach was to analyze the energy absorbing capability of the SOAC car body. This was done by postulating failure modes of primary structural elements and conducting standard stress type analysis to determine what a particular element could absorb in the way of energy.

Mr. Widmayer: cont. Next, the accident damage was assessed for the actual failure modes, and this was used to substantiate the analytical results. Then we used simple collision dynamics to assess the crashworthiness.

The next task was to determine the effect of collision conditions on the passenger injury potential, and finally we were to recommend structural modifications for the improvement of crashworthiness of SOAC.

The SOAC is a derivative of the R-44 Car that was built by the St. Louis Car Company. The major elements of the car are the underframe, the superstructure and the mechanical section underneath. In Figure 5 you see the car end. The anticlimber loads come back to the draft sill to the bolster and then are carried over the bolster to the side sills. There are also shear plates that transfer loads from the draft sill over to the side sills.

From the Floor: There's no continuous center sill?

Mr. Widmayer: That's correct. Between the bolsters the loads are carried in the side sills. This underframe is essentially, symmetrical about the car center.

To return to the superstructure, it was designed to demonstrate passenger comfort and is somewhat stylized. The forward windscreens span the front and collision posts were only able to extend up a short distance to just below the front sill.

The car end is molded fiberglass. The collision posts are cantilevered from the floor structure and extend to the windowsill. Corner posts support the roof, and the roof is of conventional construction. The underframe was designed to a 500,000 pound buff load requirement.

From the Floor: The discontinuous center sills, I would like to point out, are unique to the R-44 Car and to the SOAC Car; the other cars at NYCTA do have continuous center sills and a criteria of 500,000 pounds, that is, at the yield strength of materials.

Mr. Widmayer: That's correct.

From the Floor: Could you indicate where the collision posts are located?

Mr. Widmayer: Yes. They came in right about here. You'll see them in more detail when we get to the photographs.

Standard stress analysis procedures were applied to the SOAC structure, and the energy capacity was determined. The results of these analyses are shown in Figure 6.

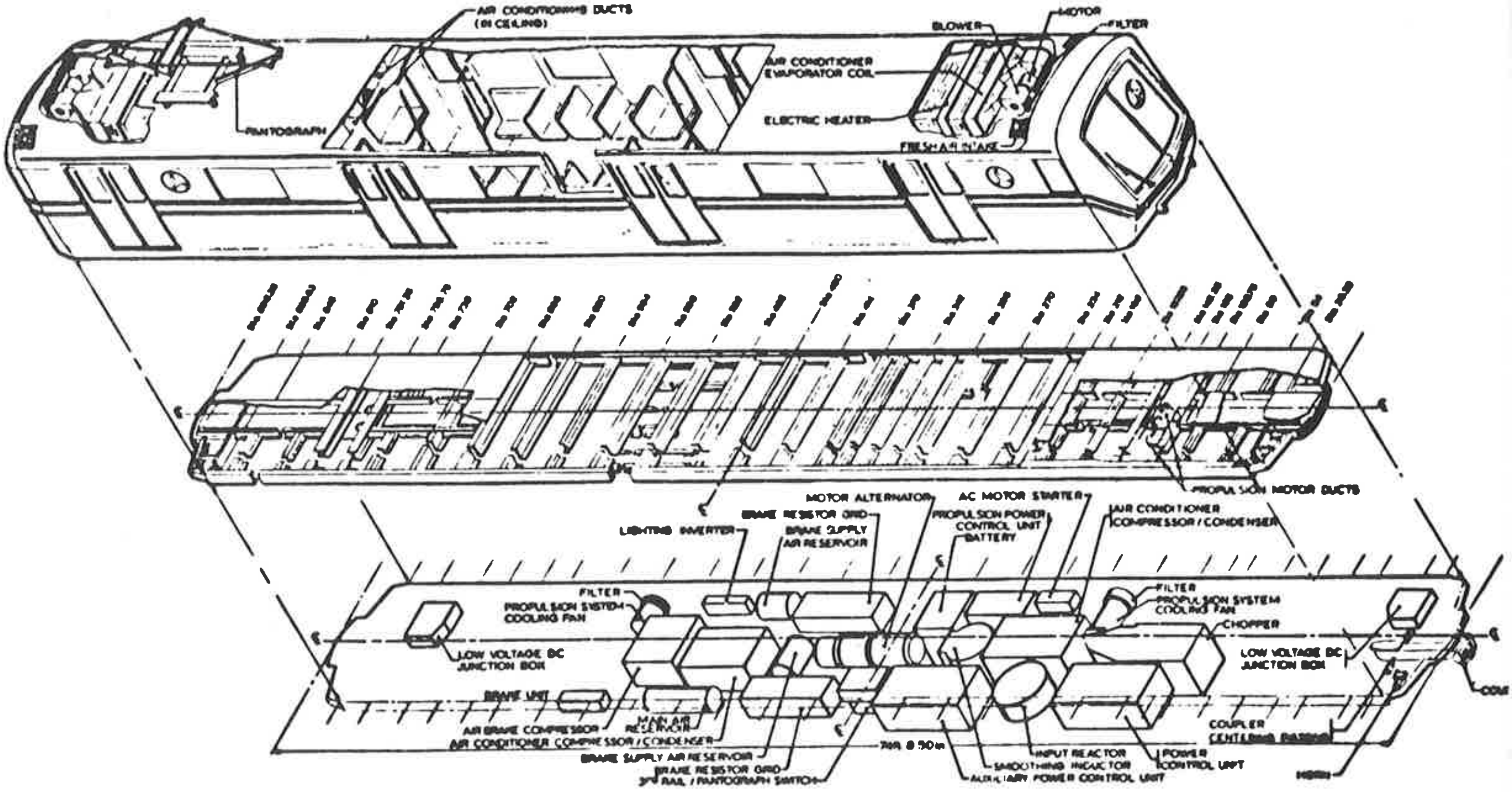


FIGURE 4. MAJOR ELEMENTS OF STATE-OF-THE-ART CAR

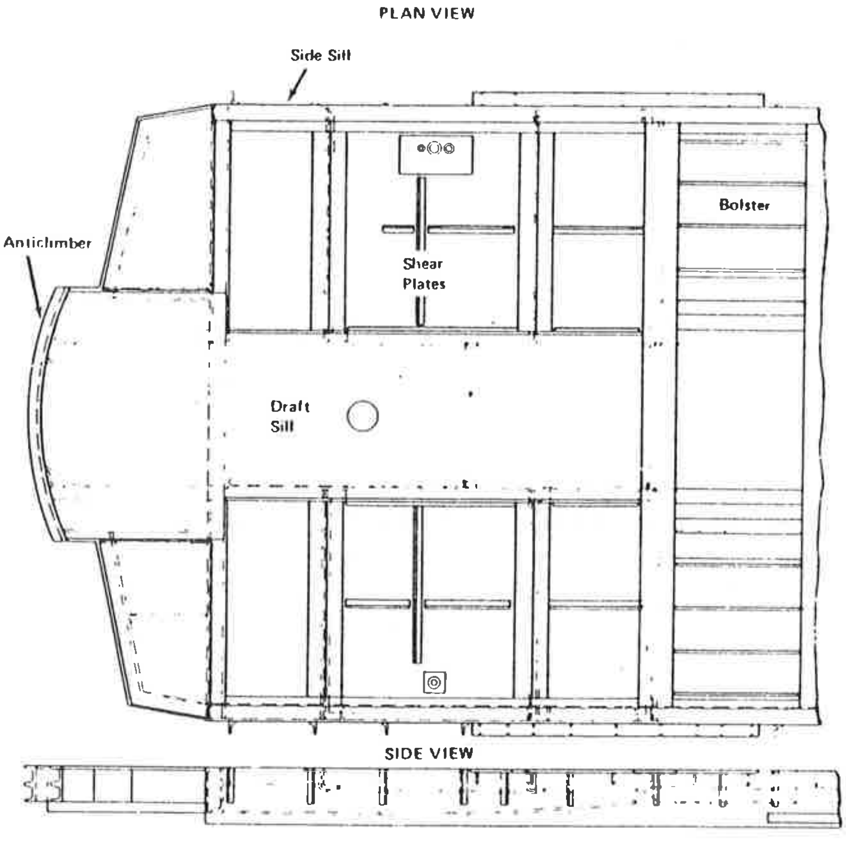


FIGURE 5. SOAC UNDERFRAME

Element	Failure Mode	Limit Load	Strain Energy
Collision post	Shear Bending	31,200 lb 614 lb	Small 1.7 in.-lb
Draft sill	Beam column Axial compression	500,000 lb 500,000 lb	14×10^6 in.-lb at $\theta = 45°$ 476,000 in.-lb/in.
Shear panel	Plate buckling & weld rupture	286,300 lb	3,552 in.-lb (elastic)
Bolster	Fore and aft bending	172,478 lb	1,097,080 in.-lb/rad (includes both sides)
Side sill	Column buckling Strong axis Weak axis	 352,600 lb 352,600 lb	 460,000 in.-lb at $\theta = 45°$ 60,000 in.-lb at $\theta = 45°$
Corner post (end)	Bending (plastic hinge)	10,945 in.-lb	47,000 in.-lb* 16,400 in.-lb/rad
Side wall	Sheet-stiffener	48,000 lb	80,000 in.-lb*
Cove	Local buckling	37,797 lb	64,000 in.-lb (estimated)*
Roof (1/2 section)	Local buckling	1,612 lb	4,000 in.-lb*

*4-inch midspan deflection

FIGURE 6. LOAD ENERGY TABLE

Mr. Widmayer: cont. Starting with the collision posts, the computed limit load and the strain energy was deemed small. This was primarily attributed to the weld strength that attached the posts to the floor structures. The posts themselves were made out of 3/8 steel plate and were relatively strong, but the welds limited the energy absorbing capability.

The draft sill, considered a beam column, had fourteen million inch pounds capacity, if we assume a forty-five degree plastic hinge develops. If you considered simply axial compression as a short column, we obtain 476,000 inch pounds per inch.

If we look at shear panels, they transfer the load from the draft sill over to the side sills. In the elastic range they absorb a miniscule amount of strain energy, and we only considered them to be elastic because the welds appeared to let go shortly after they entered the plastic region.

The bolster at 45 degree plastic bending has about a million inch pounds per radian energy absorbing capability. The side sills have a substantial amount. The corner posts, side wall, cove, and roof have as shown. The significant thing here is, if

Mr. Widmayer: cont. you compare the different amounts of the energy absorption for the various components, what you see is that the draft sill, the bolster, and the side sills should provide most of the protection. The rest of the structure doesn't provide much protection at all.

The rest of the structure is what is available to protect you in case of override. Once you get above the underframe, you're essentially sitting there naked. There's no structure up there of any substance to protect the passengers.

Using the energy absorbing data and postulating a senario of failures, it was possible to form a force deflection curve for the car. Figure 7. You've seen this type of curve. It was handsomely described by the Calspan presentation; our interpretation differs slightly from theirs and that's a point of interest. We'll talk about that a little more.

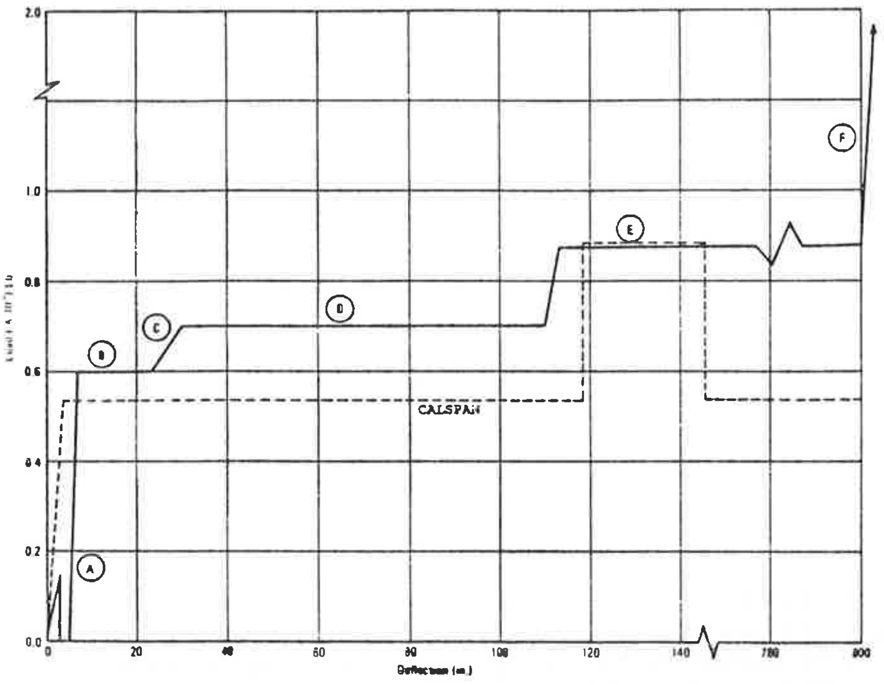


FIGURE 7. CRUSH FORCE VERSUS DEFLECTION FOR CAR SQUEEZE WITH NO OVERRIDING

This little spike, represents the energy absorption of the coupler, and then when the contact with the anticlimber (A) occurs, you get a rise like this. As you come back a little further in the car (B) some twenty-five or thirty inches, you begin to pick up the side sills (C) and then you have the crush of the car (D) as further crush occurs.

Mr. Widmayer: cont. The important aspect of this curve really is the energy absorbed that is, the area under the curve. That's a real measure. If the curve has any value at all, the area under the curve tells how much crush you'd get and what sort of penetration you'd have.

Calspan, I presume, applied the same type of procedures we did and got this kind of difference. I look on that as representative of the scatter that's inherent in the process. Two engineers sit down and look at a piece of structure, and one thinks it's going to do this and one thinks it's going to do that. That's about the kind of thing you would get out of this approach.

From the Floor: What's the "F" indicate on the end there?

Mr. Widmayer: Bulk compression. You've got all the material in a wad and there's no place left to go.

See what happens when we have override? In our scenario we take it from the point where the overriding vehicle has cleared the anticlimber. This is the sum total of all of those little parts that we showed you earlier in the energy absorption chart and you get very little until you get back 60 inches. At this point we assumed in our scenario that the trucks would start to make contact with the anticlimber, so the curve rises back to the previous level. Then you have something that carries load.

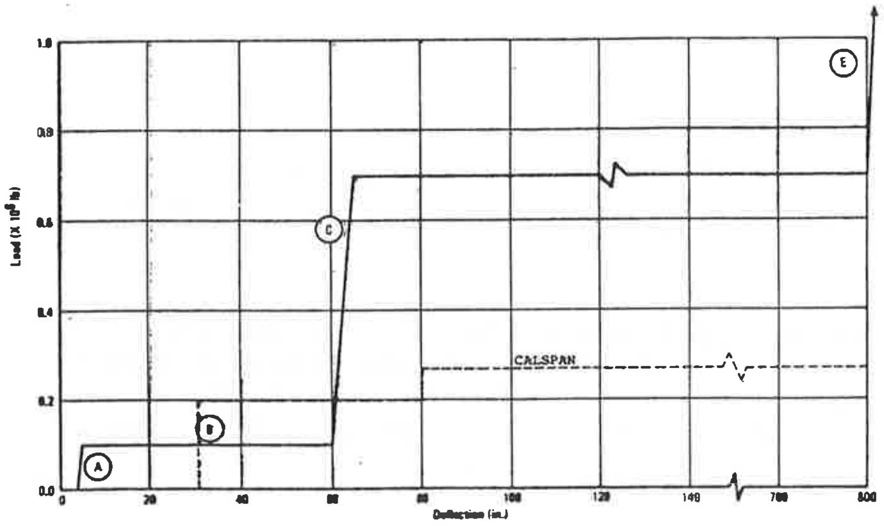


FIGURE 8. CRUSH FORCE VERSUS DEFLECTION WITH OVERRIDING

Mr. Widmayer: cont. One point to notice about this process is with a straight face we have to talk about the behavior of the structure after we have crushed it -- sixty feet -- sixty-five feet, almost the length of the car. What validity it has is only for relatively short crush distances, although we draw the curve from one end to the other.

Mr. Madigan: Ed, if you drop the truck in that process, the truck actually kicked off, would it fall down as in the Calspan data, say, where the low level is?

Mr. Widmayer: Yes, I would say it would, absolutely.

From the Floor: That was exactly what happened at the ICG accident. That's why the one car penetrated so far; it did not have locking center plate and just left its truck behind.

Mr. Widmayer: Yes, the old train, as I recall, did not have an anticlimber, and it also did not have truck retention.

Relating to the type of crush you'll get then, if the Calspan is the one that occurs, what you get is this much area under the curve in the form of strain energy.

From the Floor: In any of these cases, you're not assuming any coupling up of cars?

Mr. Widmayer: Well, in a previous figure we showed you what the draft gear contributed. That was that little spike down in the corner, and we'll talk about that later when we discuss the actual accident. In the accident there was coupling. Couplers did engage; they did lock. We'll get to that when we talk about the accident later. It's a very interesting accident.

From the Floor: The area under any one of these curves has to be the same for a given collision of given vehicles and speeds. So, could you explain a little bit better what you meant by your last statement?

Mr. Widmayer: If I were to superimpose the nonoverride case on here, what you'd get is a line that comes across here, it comes down here, and there's a little spike. What's missing is this much area in the override case. In other words, you don't have this much energy absorption working for you in the case of override. That's not there.

From the Floor: I'm sorry, I thought you were comparing those two curves.

Mr. Widmayer: No, no.

From the Floor: Something is missing somewhere because...

Mr. Widmayer: Well, at this point, we have a different hypothesis, we assumed a different scenario.

From the Floor: Yes, what I'm saying is that the lower curve then is going to have to go back three car lengths at the rate it's going because the area does have to be the same.

Mr. Widmayer: That's a good point. That's part of the central theme. We must prevent override.

From the Floor: I think you can prevent three-car override pretty well.

Mr. Widmayer: I hope they stop eventually. Figure 8 is the type forced deflection curve that goes into the simple dynamics model. The model that you saw in the Calspan presentation, just imagine you're looking at that. I didn't draw the full thing, but it's possible to put up a simple dynamics simulation with the non-linear force-deflection curves that you saw representing the spring conditions between the cars. You have multiple cars. The popular one that I've used in my approach is eight cars, that is, four moving and four standing still. You start the simulation at the instant of contact,and you're able to get the accelerations and the velocities and the displacements and the crush of the cars. How much these springs have deflected as a function of time From this you can get preditions of the crush, as I said.

To put things in context, our contract was following the Calspan studies. We were about twelve months behind them in time. So, we had a certain advantage in that we were learning from them. We did not have their program, unfortunately, but we put together a program which gave within the accuracy of hand plotting, the same results for simple crush cases.

At the time we were doing this simple dynamics model, we had some other studies going on at Vertol in which we were using a non-linear finite element model to simulate the crash of aircraft structures. We applied this program "Krash" to the railcar. The program is fairly versatile in that it's a rather powerful analytical instrument. It permits the computation of the dynamic response of a spring connected lump mass system. (see Figures 9 & 10)

- COMPUTATION OF THE DYNAMIC RESPONSE OF A SPRING-CONNECTED, LUMPED-MASS SYSTEM.
- SIX DEGREE-OF-FREEDOM MASSES
- FORCES INCLUDING GRAVITY, AERODYNAMICS, INTERNAL STRUCTURAL LOADS, AND EXTERNAL IMPACT LOADS
- LARGE DEFLECTIONS
- NONLINEAR INTERNAL AND EXTERNAL FORCES
- ELEMENT RUPTURE

FIGURE 9. KRASH FEATURES

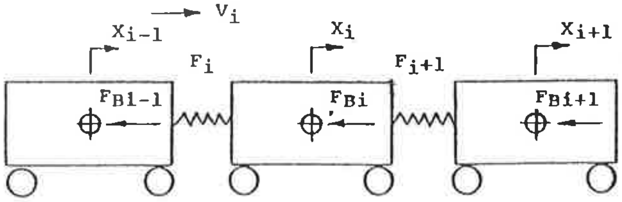


FIGURE 10. MULTI-CAR CONSIST IMPACT MODEL

<u>Mr. Widmayer</u>: cont. Each of the masses has six degrees-of-freedom, three translation and three rotation. You have options on the type of forces that you can put on your masses. The program does account for large deflections. That is, as your structure starts to deform, it keeps track of where the masses are and what's happening to the deformations in the beam and that sort of thing.

You have non-linear internal and external forces. You can put in elastic, prefectly plastic curves, you can put in collapse type of approximations, and you can treat element rupture. You can put in a deflection criteria, it says, if you have deformed to a

Mr. Widmayer: (cont.) certain point, and a weld lets go or you've pulled a tension member to 17 percent elongation and it's no longer there. It drops that out of the program, and it gives you a fairly powerful tool to look at what happens under a crash condition.

Figure 11 shows the SOAC accident model that we used, using the finite element program. The locomotive is represented as a single mass. The gondola is represented as a single point mass. The element between them represents the spring rate that you would get from CG to CG of the cars. And the gondola to the anticlimber, that's point four, represents the stiffness, the spring rate, that would be present in the gondola car.

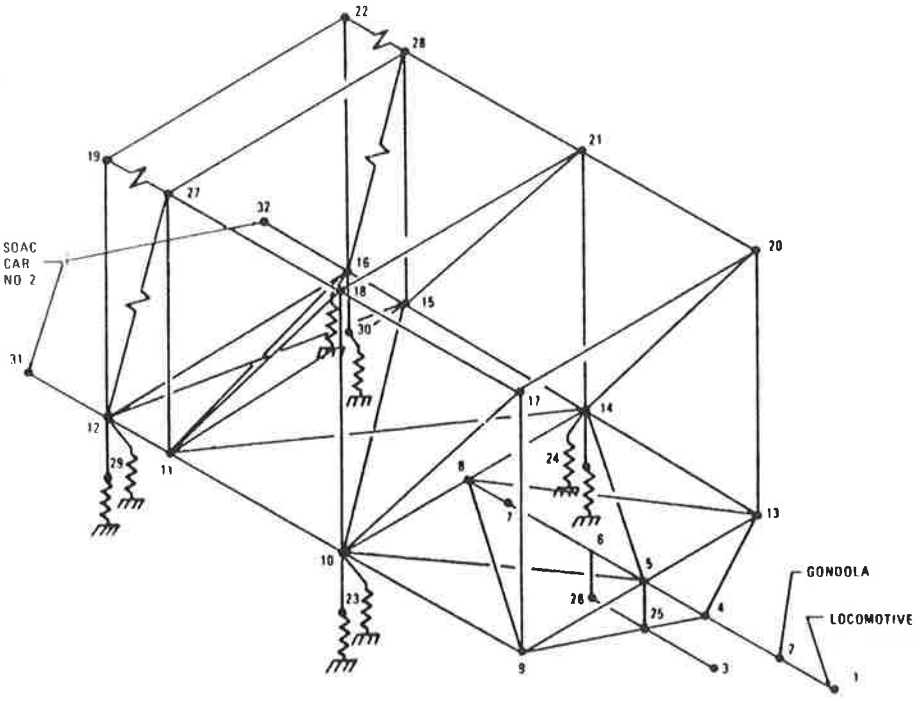


FIGURE 11. SOAC ACCIDENT MODEL

We represent the draft sill as the series of elements and masses. We have the bolster end, the side sills are shown on both cars, the corner posts, we did not bother to put the collision posts in.

Mr. Widmayer: cont, The collision posts go out of the analysis so fast that it wasn't worth the while to put them in the analysis.

We have this as the draft anchor pin and the coupler carrier.

These represent the suspension and back here we have taken the second SOAC. There were two cars, it was running as a married pair, and this was the second car. We've distributed the mass between these two points and applied into the side sills at that point. We did not bother to detail model the other end of the car.

The results of the simulation (Figure 12) showed reasonable agreement with the accident data. The draft sill has a large plastic hinge back at 8, and there are plastic--it is essentially in a plastic condition, it is exceeded yield, the yield allowable for the underframe.

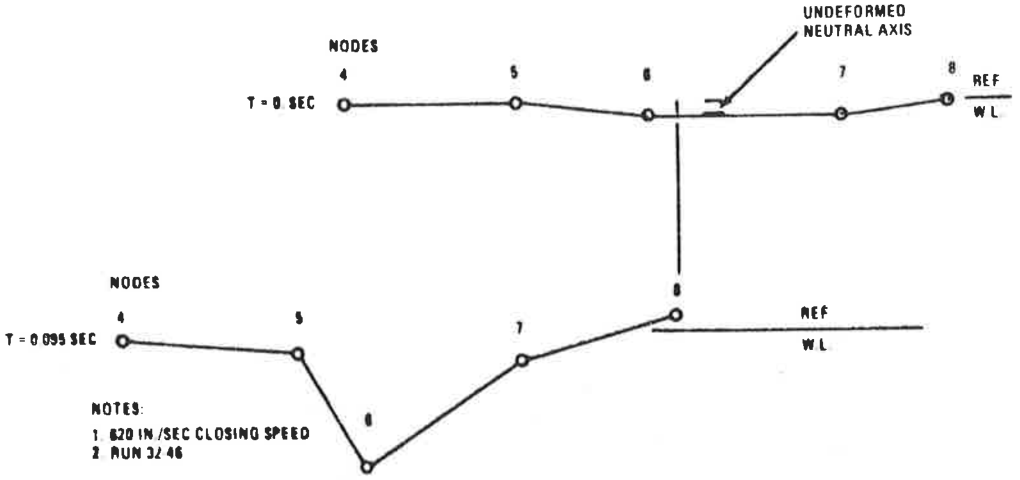


FIGURE 12. ACCIDENT RESULT SIMULATION

Mr. Widmayer: cont. A point to note, while I'm here, this is the underformed neutral axis of the draft sill. The designers started out with a couple of channels and they welded it up. And they remembered they needed a draft anchor plate, so they put something that looks like about a 3/4 inch plate which spans the section and pulls the neutral axis of the draft sill, considered as a beam column, down. They had to put a cut-out for the coupler carrier, and they went into the weld that supports the anticlimber, so you have the axis of this member moving all around. For the behavior, as a compression member, that's not really desirable. You're introducing eccentricities into your member.

While I don't show it up here, you get a tremendous amount of output from these models data, and it's quite difficult to represent it. But there was plastic set in the bolster, the loads and deformations in the major elements of the model were rational, and the simulation -- well we got ruptures where ruptures occurred in the car in the actual accident, and the simulation appears to be applicable through the major energy absorption stroke that took place in the accident.

This wasn't a part of the contract, but it's an appropriate time to put in.

From the Floor: What was the difference between the simulated final crush and the actual crush?

Mr. Widmayer: They were of the same order. They were close. I'd have to go back and look at the data to give you numbers. The problem with this type of simulation is the further you go in the time solution, the more you depart from reality. It's difficult to predict what's going to happen in a structure in the elastic range. It is very difficult to predict what is going to happen when you're mildly into the plastic region, and if you carry the process far enough, there comes a time when the accumulation of small errors in your assumptions and in your modeling begin to carry you where your simulations are no longer applicable.

What I'd like to do here is just compare the analytical procedures we used in the program. The energy analysis (Figure 13) identifies the elements that may provide you with protection. It is useful in comparing one car with another; that is, you can compare the draft sill with the draft sill, collision post with a collision post, and for it to be useful, all of your welds that hold this major structure together have to be examined for their rupturing strength.

ENERGY ANALYSIS
- * IDENTIFIES ELEMENTS THAT MAY PROVIDE PROTECTION
- * MAY BE USED TO COMPARE WITH OTHER CARS
- * MUST INCLUDE WELD RUPTURE CRITERIA TO BE TRACTABLE
- * USES SIMPLE LOAD CONDITIONS

SIMPLE COLLISION DYNAMICS
- * FORCE-DEFLECTION CURVE SUBJECTIVE TO CRASH SCENARIO
- * DYNAMIC LOAD DISTRIBUTION NOT PROPERLY TREATED

KRASH NON-LINEAR STRUCTURAL DYNAMICS SIMULATION
- * PROVIDES BETTER TREATMENT OF DYNAMIC LOADS
- * TREATS RUPTURES AND STRUCTURAL NONLINEARITIES
- * DESCRIBES FAILURE MODES
- * DIFFICULT AND EXPENSIVE TO USE

FIGURE 13. COMPARISON OF ANALYTICAL PROCEDURES

Mr. Widmayer: cont. It does use simple load conditions. It's also real easy to use. You can do it with a slide rule. You don't have to go to the computer. Formulas are relatively simple. You can knock it out fairly fast. In the simple collision dynamics using, say, the Calspan type model, you use all of this energy analysis. Your force-deflection curves are predicated on what you learned in the energy analysis. But the forced deflection curve is subjective to the crash scenario that you assumed.

Also, you haven't represented the dynamic loads properly in doing your energy type analysis. In fact, the dynamic loads distribution in a collision are more or less triangular in shape. They're high at the point of impact, and as you go back in the car, they drop off.

The type of load distribution we assume here has no cumulative inertia effects, unless you get real fancy. The Calspan model, I might say, is fairly easy to use. You can run quite a few cases and get quite a bit of information fairly rapidly out of that type of analysis.

Mr. Widmayer: cont. The Krash non-linear structural dynamics simulation gives a better treatment of the dynamic loads. You get the inertia relief as you go through the car. You get combined loads on the elements. You get the effect of rupture. And you take into account structural non-linearities. You get an insight into the failure modes of the elements. This is an iterative process in which you have to go back and modify your model because the loading is building up in a manner you hadn't anticipated nor provided for.

For instance, I may have to go back and put in combined bending and torsion into a given element. The program is difficult to use and it's expensive. You burn up a lot of computer time, and you can use a lot of engineering time using this type of solution. But you do get a real good insight as to what's going on in your collision.

I should probably emphasize here that the application of any of these, and preferably the further you go into it, the more you're going out of it, is well worthwhile. That's because it does focus attention of the designer on the crashworthiness problems of the structure, and it gets him thinking. When he makes his assumptions and selects his members and designs his joints and welds and thinks in terms of his load path, he goes further than just designing for loads. He's now designing for how is this thing going to fail? And in this process he can eliminate obvious poor design conditions. This, in itself, gives an intended increase in crashworthiness.

We're now going to the SOAC crash. What you're seeing here is the draft sill. (Figure 14-1) a big plastic hinge here. (14-2) It's a little more than forty-five degrees when folded back. The draft sill at the discontinuity due to the draft anchor plate has another big plastic hinge up here. Notice we didn't come out with a cutting torch this is where it broke off.

This where the end still was attached to the draft sill, and you can see that the weld let go. (Figure 14-3)

From the Floor: Were they continuously welded or skip welded?

Mr. Widmayer: I'm under the impression they were skip welded, and this comes from conversation with people who were involved in the design.

Here's the spot that the collision post was. You can see it just tore out. I think they just welded it to the floor structure which was 1/8 plate decking.

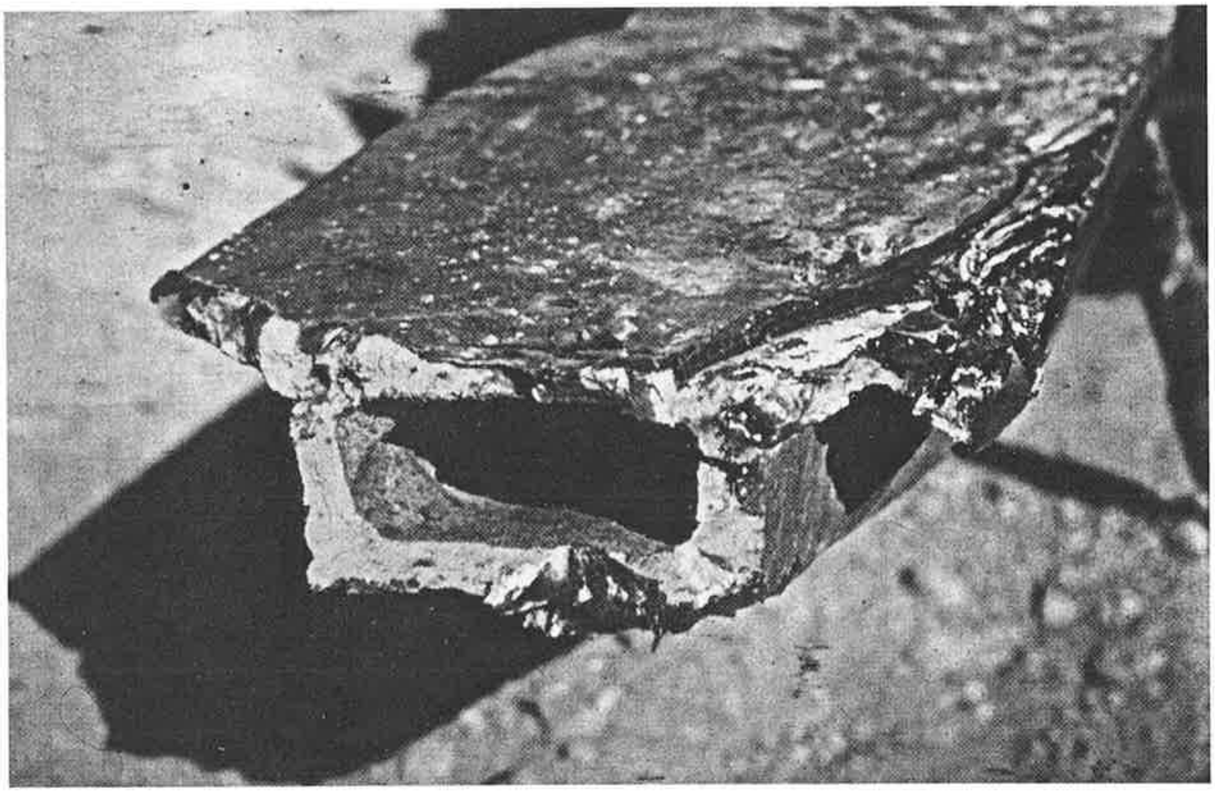


FIGURE 14-1. DRAFT SILL

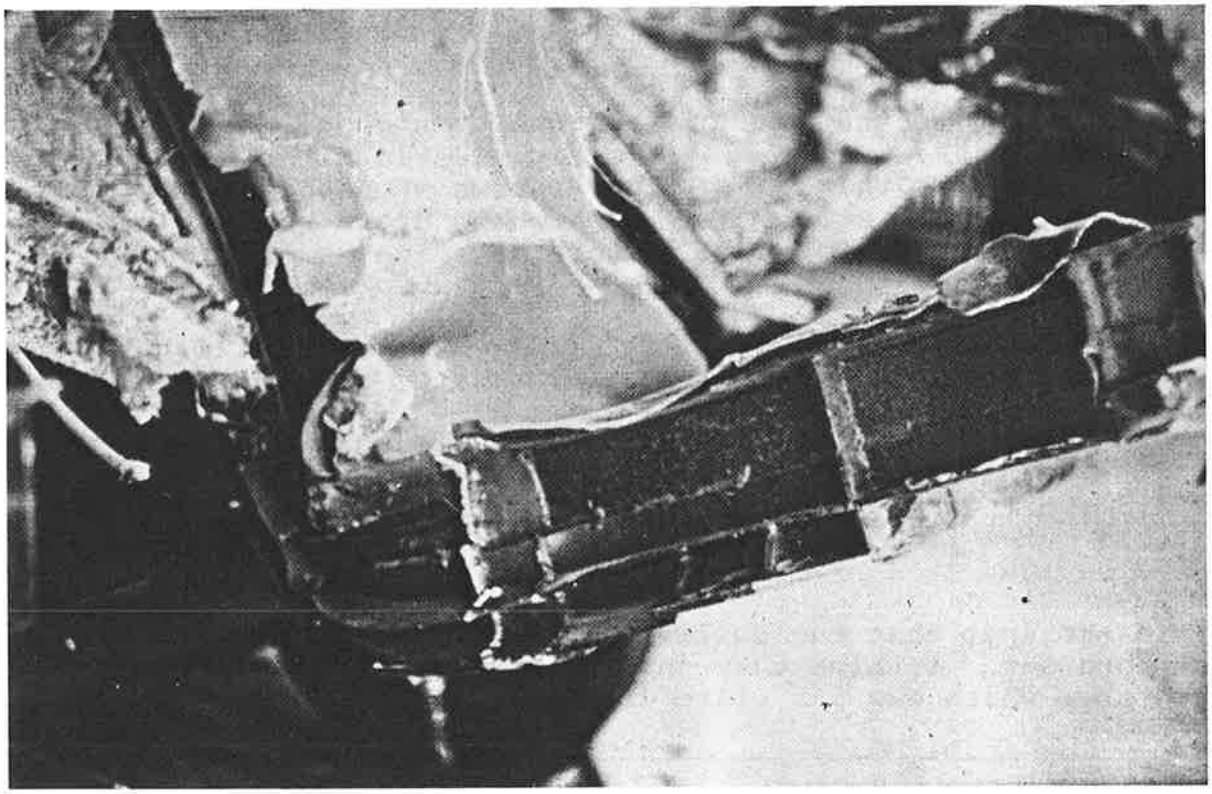


FIGURE 14-2. ANTI-CLIMBER

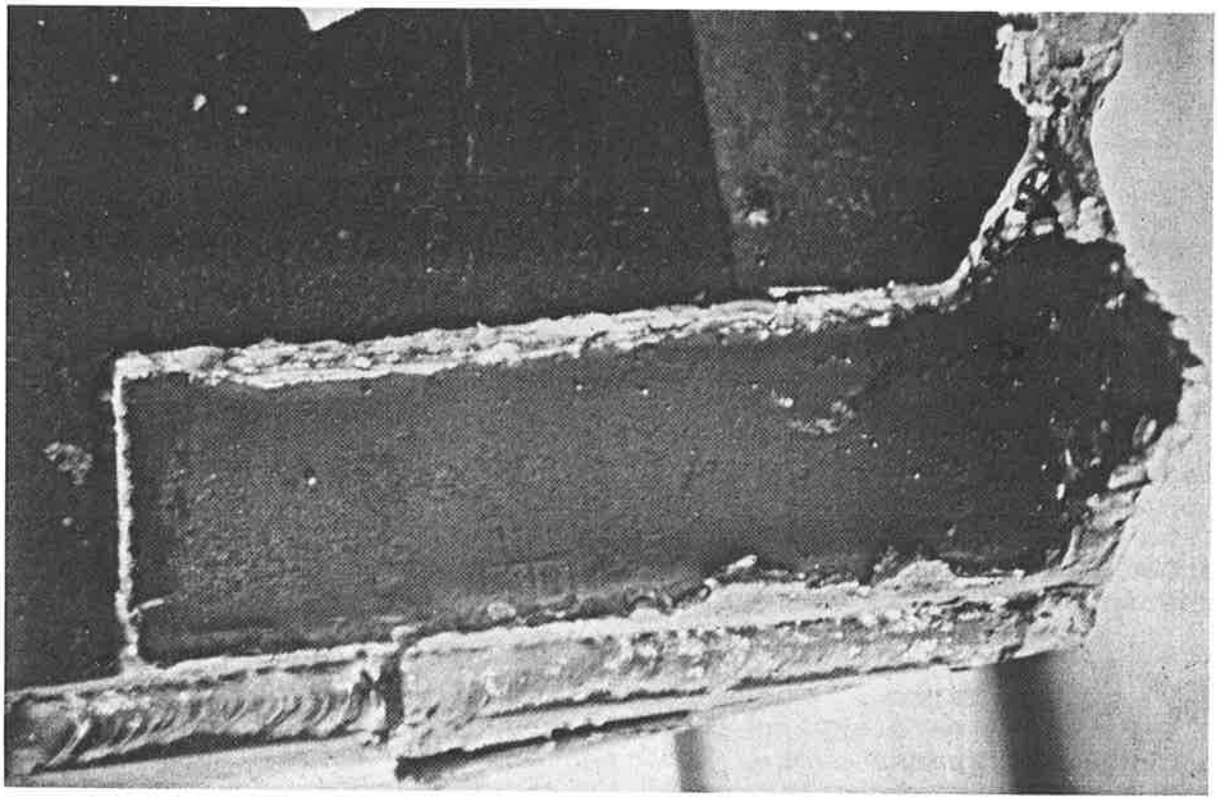


FIGURE 14-3. WELDMENT FAILURE

Mr. Widmayer: cont. This is a view of the car roof. (Figure 14-4.) It did take some energy, but not too much. You get the nice buckle

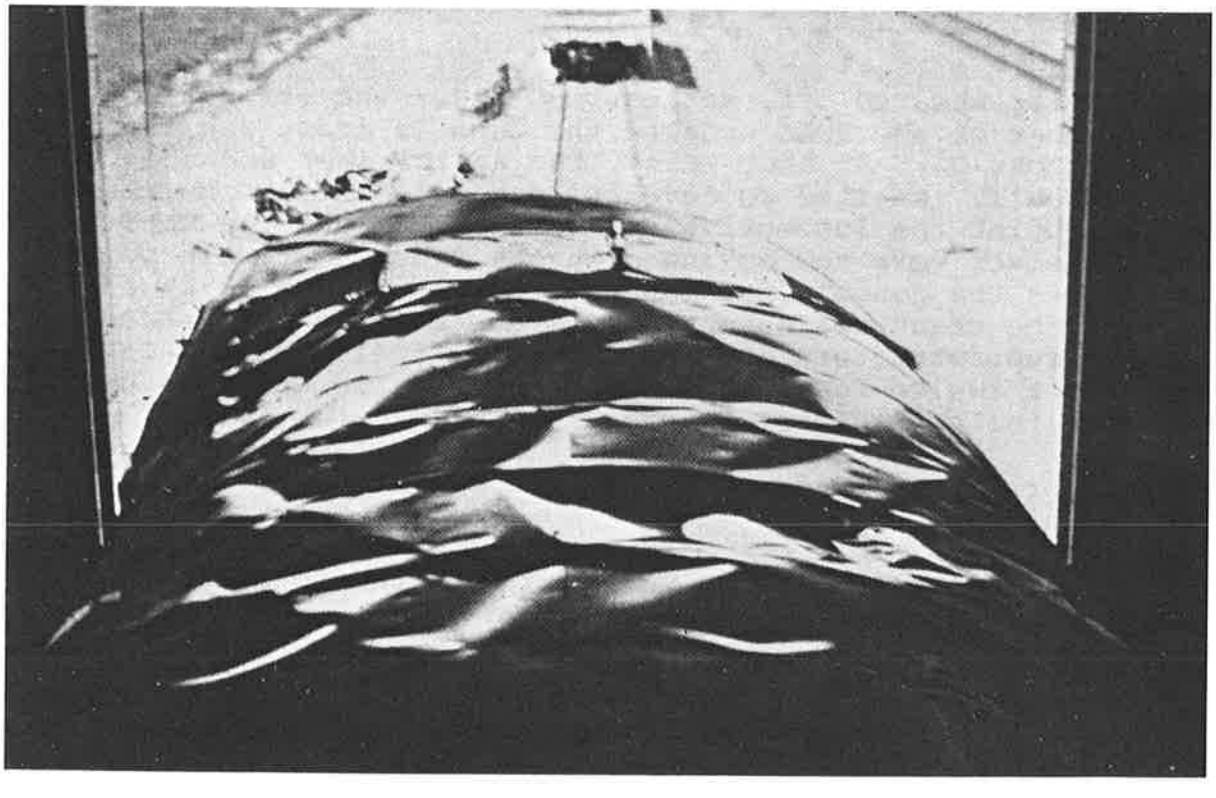


FIGURE 14-4. CAR ROOF

Mr. Widmayer: cont. pattern that you get on sheet metal when you load it in that manner.

This looks like the coupler of the gondola. It failed very early in the collision.

For an assessment of the collision damage, the first conclusion you come to here is that the collision post did not prevent the intrusion.

The second thing is that the rupture of the welds prevented the development of maximum energy absorption. The third thing is that the draft sill provided most of the energy absorption and it formed plastic hinges at locations where there were severe changes in the section properties.

The coupler locking did not prevent overriding because the shanks of the couplers failed. Those couplers did engage. We spent quite a bit of time studying it. The couplers engaged, they locked,and then the shanks broke. So the couplers themselves, at least somewhere between thirty and thirty-five miles an hour,did not provide protection against override.

The SOAC anticlimber appears to be strong enough. Now, it's difficult to describe this accident, but what happened, the couplers engaged; the shear pins and the couplers apparently broke. The anticlimbers came together. There was an anticlimber placed on the gondola car. However, I think it had a vertical load capability of something on the order of 10,000 pounds of shear.

The anticlimber sheared off, was carried under the car until the anticlimber of the SOAC engaged the gondola draft pin that holds the trucks on. At that point, the anticlimber and the draft sill really started to develop load, develop the buckles, and at this point the locomotive and the gondola and the whole crashing consists were now moving down the track. At some point in the process the gondola had managed to rise enough to free itself, and the crash was essentially over, and then it proceeded to bash the superstructure of the SOAC about twelve feet. It wrinkled about twelve feet; it took out side walls and tore up about twelve feet of superstructure.

From the Floor: Can you describe how the operator was fatally injured in this?

Mr. Widmayer: He stayed in his seat and when the gondola came through the fiberglass nose, he was killed.

From the Floor: What was the speed; were you saying fifty-five?

Mr. Widmayer: No, we were coming up on fifty-five miles an hour for the brake test when the operator saw the open switch. Brakes were applied and there was quite an analysis of what brakes were put on. It is estimated that the car was doing between thirty and thirty-five miles an hour at the time of impact. With respect to the type of impact conditions in the second car, we had an engineering team in the second car, and they wanted to know why the train had stopped. They felt a jolt. They wondered what that was, too. They went out and started looking for the motorman after everything came to a halt.

The simple collision dynamics analysis was used to assess the effect of crash parameters on the crashworthiness of the SOAC. Here you see a familiar curve (Figure 15). This is again for a four-car SOAC train, hitting another four car SOAC train, and we get this type of results.

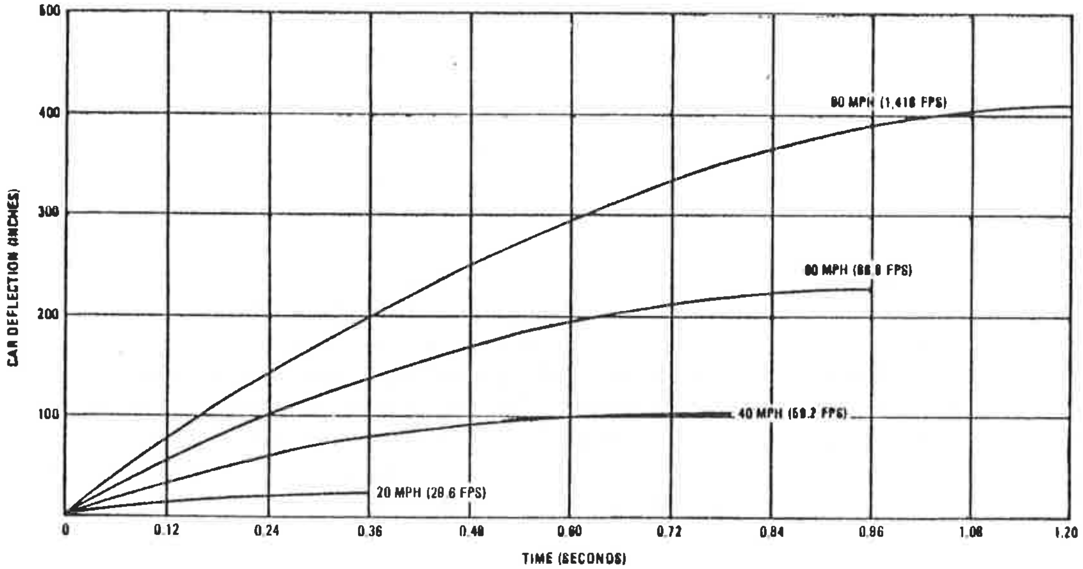


FIGURE 15. TOTAL CRASH DEFLECTION OF CAR NO. 5 VERSUS TIME (FOR TWO 4-CAR SOAC TRAINS)

Mr. Widmayer: cont, Unfortunately, I did not bring the slide that I really would like to show. But we did, using the simple collision dynamics, correlate the impact with the gondola, using again the simple conditions, and the resulting crash was of the order that you would expect.

If we had been told to do this analysis and then go out and have the accident, I'm not sure we would have gotten the kind of correcation we did get. But if you know what the final answer is, you can keep upgrading your assumptions until you've got enough to give you the crush and you can, in a sense, rationally predict the kind of crush you'd get.

From the Floor: Are these curves based on overriding?

Mr. Widmayer: No.

From the Floor: Does that assume that one car overrides the other, or does that assume that anticlimbers are engaged in standing?

Mr. Widmayer: No, this assumes just straight crush.

Mr. Tucker: Does it assume uniform loading on the car so it acts as a column or loading on the underframe?

Mr. Widmayer: It assumes it is a linear spring.

Mr. Tucker: You're not taking the deflection off the curve?

Mr. Widmayer: No. It was not assumes that an element had column stability problems in the formulation of the forced deflection curve; it's not in here. That forced deflection curve is an equivalent spring.

Now at forty miles per hour, we get about a hundred inches of crush on the car. That corresponds somewhat to the Calspan number. I think they said about eleven feet. We got eight and a half. Just in a matter of passing, we took the forced deflection curve; put a factor on it to see what would happen to the crush distances if you put this kind of factor on the car (Figure 16). Here is the hundred inches we were talking about for factor 1 on the forced deflection curve. If you double the stiffness (Factor 2) you get a reduction like so. If you double it again, and you get down to a point in here. I'm not quite sure why this curve overlaps here, but the final deflections look approximately correct.

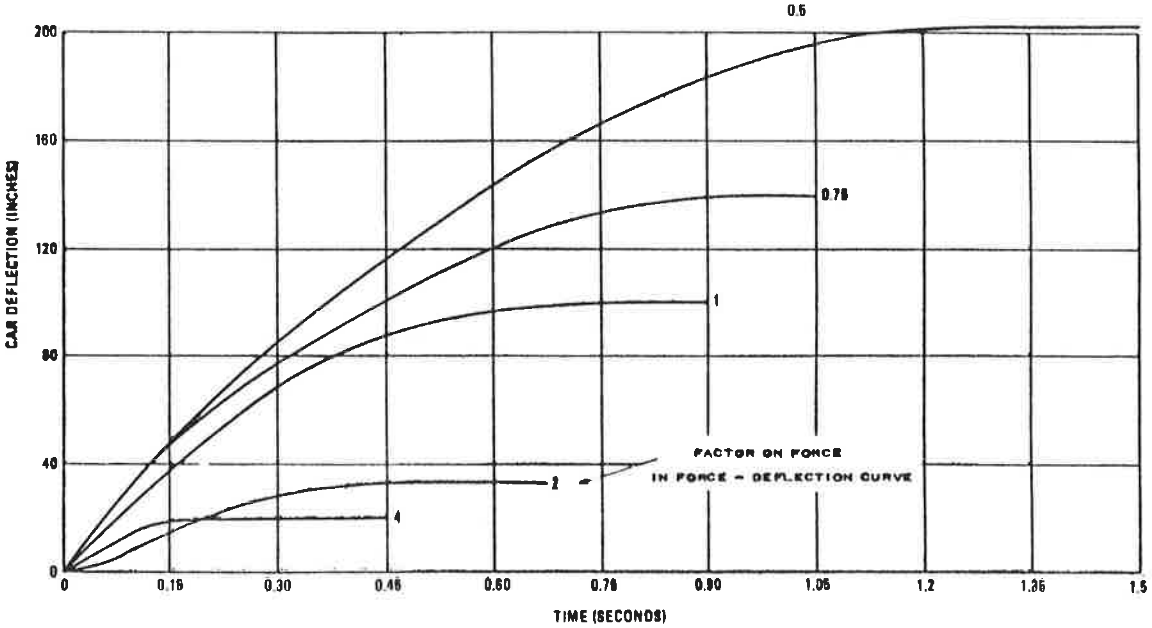


FIGURE 16. EFFECT OF CAR STRENGTH ON CRUSH DEFLECTION (CAR NO. 5, V_0 = 40 MPH)

Mr. Widmayer: cont. As can be seen, increse in the stiffness decreases the deflections, and this goes along with the idea that increase in the stiffness would increase the crashworthiness provided you prevent overriding intrusion.

The effect of the collision parameters on the injury potential to passengers may be studied using the Calspan severity index. (Figure 17)

$$AI = \int_0^T (A_P)^{2.5} DT$$

$$AI > 2000 \text{ SEC FATAL}$$

FIGURE 17 . ABBREVIATED INJURY INDEX

Mr. Widmayer: cont. Here's the index that was shown in the Calspan report. We used it. When this index is greater than 2,000 seconds, you have a fatality. The index is subjective but it is a reasonable type of criteria. This particular index is fairly easy to compute while you're doing your simple dynamics model, and we used it.

Now, at this point, we differ somewhat from the Calspan results. What I did here was I modified our program to account for the travel of a passenger into a barrier, and I had the program tell me how fast the passenger was going when he reached the barrier. (Figure 18)

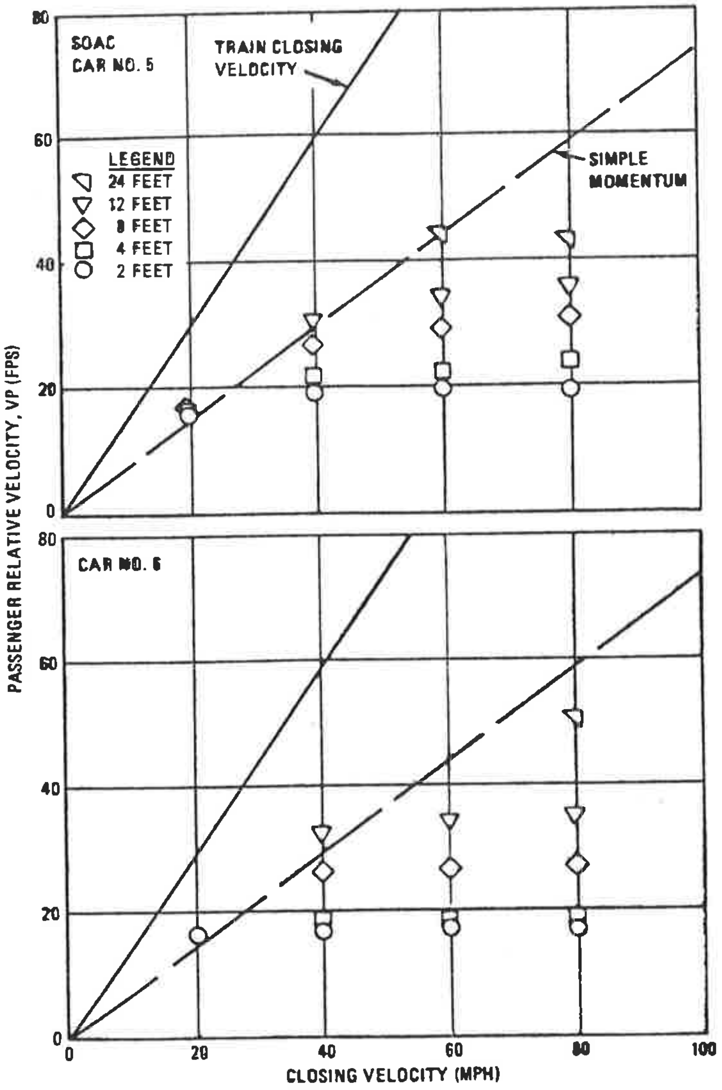


FIGURE 18. PASSENGER RELATIVE VELOCITY VERSUS TRAIN CLOSING VELOCITY

Mr. Widmayer: cont. For instance, if we were traveling at eighty miles an hour, and this is for a four-car train hitting a four-car train, but if we're going at eighty miles and we hit a four-car train and the barrier is two feet in front of you, like a seat back, what it says is you would hit the seat back with a relative velocity. You'd catch up with the seat back. We assume that the passenger has no friction on the seat of his pants. He's going to continue at eighty miles an hour while the car's stopping and he will hit that seat back with a velocity of about twenty feet a second.

If it were at sixty miles an hour, we'd get the same twenty feet a second. At forty miles an hour again we'd get twenty feet a second, and at twenty miles an hour, we're limited by the momentum relations and it gets a little bit less here.

If you increase the distance to the barrier, the relative velocity impact goes up this way. Now, what this indicates is that above a certain speed, the passenger impact problem is independent of the structural problem.

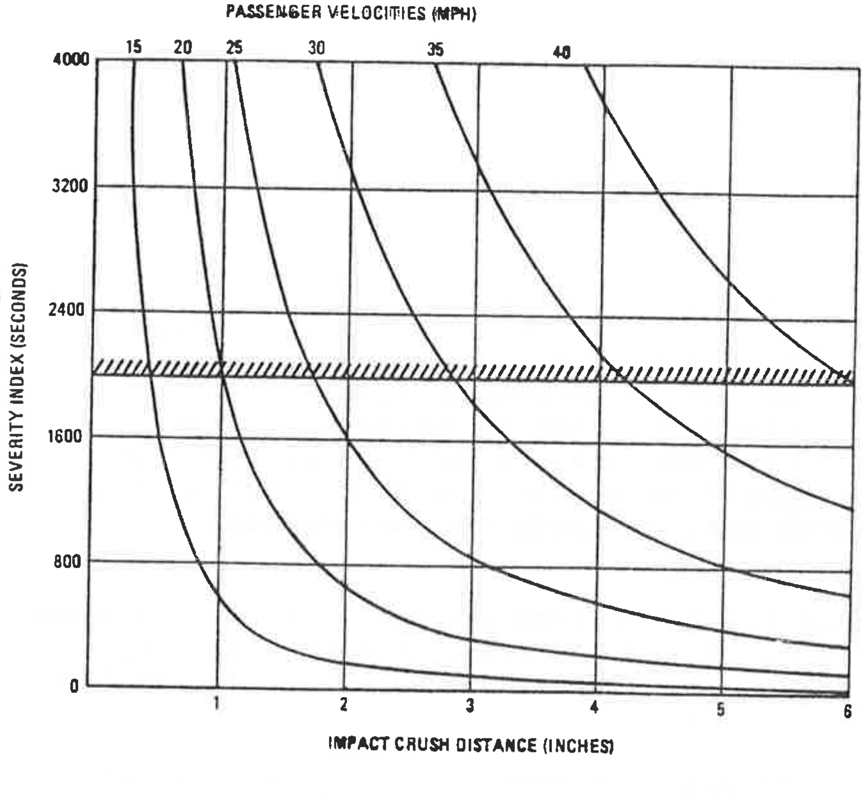


FIGURE 19. SEVERITY INDEX VERSUS IMPACT CRUSH DISTANCE FOR CONSTANT PASSENGER VELOCITIES

Mr. Widmayer: cont. Now here again, using the assumption of a constant deceleration, we took the passenger velocities and here we converted them to miles per hour. We're showing the severity index; we drew a line across here, the hatch line, anything above that's fatal in a crude sense. What it says is, if we have a padded seat or a padded bulkhead, which will give you one inch of deflection at a constant force. (I don't know how you get that spring, but assuming you have it, and you're coming at a relative impact speed of fifteen miles per hour) it says you're down in here around 600 severity index; Calspan has a table that relates the severity index to the types of injuries you would get. You would receive some injuries from it. For instance, if you have a half inch and you hit it at twenty miles per hour, you're going to be seriously injured. You have a good potential for a fatal accident. If you have a quarter of an inch crush, you have an excellent chance of being killed.

In other words, for hard surfaces, even fifteen miles per hour, according to the index, you have an excellent chance of being killed. Now, maybe the index isn't precise, but it's a good measure, I mean, within the rationale you might want to modify the index. But the general trend is there, and you will get this kind of result out of it.

For example, if I wanted to protect against a twenty mile an hour impact so that only minor injuries to my passengers in a four-car collision would result, I could provide softness where things would deform to about an inch. Then, instead of getting people being severely injured, they'd walk away with only bruises or contusions.

A significant result is that since the relative velocity has been shown to be independent of the collision velocity, but depends on the passenger distance from the constraint or the barrier, the passenger injury potential may be treated separately from the structural problem of preventing loss of survivable volume. Since there seems to be a difference of opinion, this probably should be studied further. But if you can separate the two problems, it leads to considerable simplification.

Thus, the injury problem may be treated by the internal arrangement of using padded surfaces and so forth, and the structural problem may be treated by strengthening collision posts, welds, buff strengths, and other items.

The next part of the study was to recommend structural modifications to improve the crashworthiness of the SOAC

Mr. Widmayer: cont. and to prevent override. Improved strength, full height, collision posts would be required. These posts would have to be firmly attached to the draft sill and into an anti-telescoping point in the roof. And, quite possible, we would want to make the roof a little stronger. The roof, itself, is not really a major load carrying pad.

The posts should be, most probably, thick wall structural tubes. And the reason I say this is that under collision conditions you get combined loads, so the structural tube gives you a good resistance to loadings in two directions, and the thick wall eliminates a local crippling type stability problem.

From the Floor: Would a rectangular tube still meet your need, meet your definition, or just a circular tube?

Mr. Widmayer: Rectangular tubes would be fine.

Improved weld strength between the anticlimber to the bolster of all major structural elements is required for structure such as the shear plates and the end sills. The attachments of those elements to the side sill were designed to meet the buff test requirements. That is to say, the welds were strong to carry their part of the buff test load and they were not made much stronger, at least not by intention.

The welds should be in the elastic region when the rest of the material would be in the plastic region, so that failures, such as ruptures and collapses, would take place in the members rather than in the joint. Column eccentricities in the draft sill should be avoided.

The basis objective of the crashworthiness improvement exercise is to fill in this override area to get back to the basic buff strength requirement of the underframe. Ideally, what we're saying is that the superstructure should develop the equivalent strength of the underframe. This might be achieved by a stronger roof and sides in conjunction with better collision posts.

When you configure the car, you should try to get strength into the sides and in the roof to carry the collision loads back down into the underframe where you've got some strength.

Mr. Tucker: What shear strength would you need in the collisio posts in order to do that?

Mr. Widmayer: It would be tremendous. There's also the possibility in some configurations to have a second set of posts. Where there is a vestibule, there is the opportunity to run a second set of collision posts.

The engineering assessment (Figure 20) of the crashworthiness was that the SOAC, as built, met the crashworthiness standards implied in the current practices that just specify buff strength. We went over the specifications for the SOAC, and it met all of the specifications.

- COLLISION POSTS DID NOT PREVENT INTRUSION
- RUPTURE OF WELDS PREVENTED DEVELOPMENT OF MAXIMUM ENERGY ABSORPTION
- DRAFT SILL PROVIDED MOST OF ENERGY ABSORPTION, PLASTIC HINGES FORMED AT SECTION CHANGES
- COUPLER LOCKING DID NOT PREVENT OVERRIDING AS SHANK FAILED
- ANTICLIMBER APPEARS STRONG ENOUGH

FIGURE 20. ENGINEERING ASSESSMENT

The penetration of the occupant areas by overriding must be reduced, and we would like, as a goal, to bring the superstructural contribution up to the buff specified strength, if possible. Provision for adequate vertical posts and truck retention also might be remedies to help provide for the override situation. We certainly can make the truck retention quite a bit stronger without much weight penalty.

Reduction of the first collision casualties may be achieved by increasing the buff strength requirements and by provision of adequate resistance in the superstructure.

And the last part of the assessment was that the reduction of secondary collision casualties may be most effectively achieved by providing a soft car interior. This may be treated independently of the first collision to the first order of things.

Now, in a follow-up study that took place after the SOAC, there are two or three things that we found that are very germane to this particular meeting.

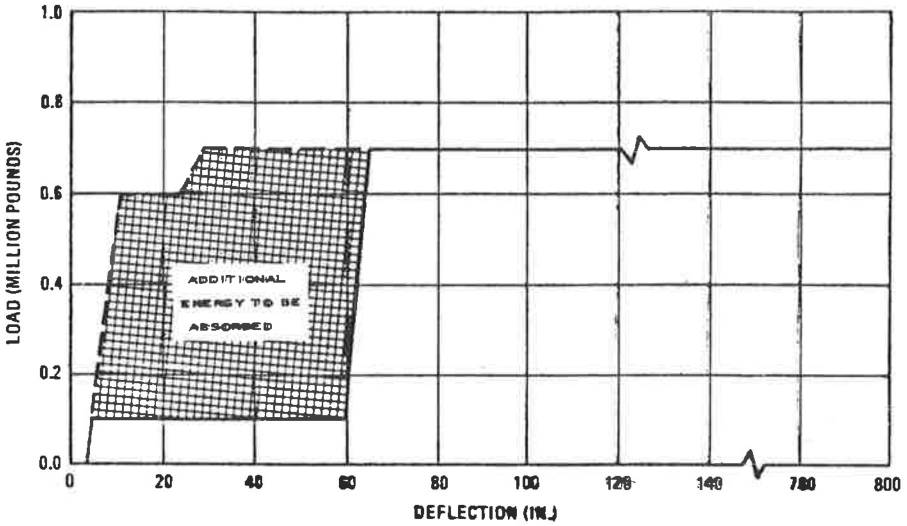


FIGURE 21. CRUSH FORCE VERSUS DEFLECTION TO PROVIDE BUFF REQUIRED STRENGTH

Mr. Widmayer: cont. What is shown here are the results of some weld impact tests. The tests were done by the Michigan Highway Department. They were interested in why some of the bridges were cracking at low temperature when they were hit by trucks and other miscellaneous missiles.

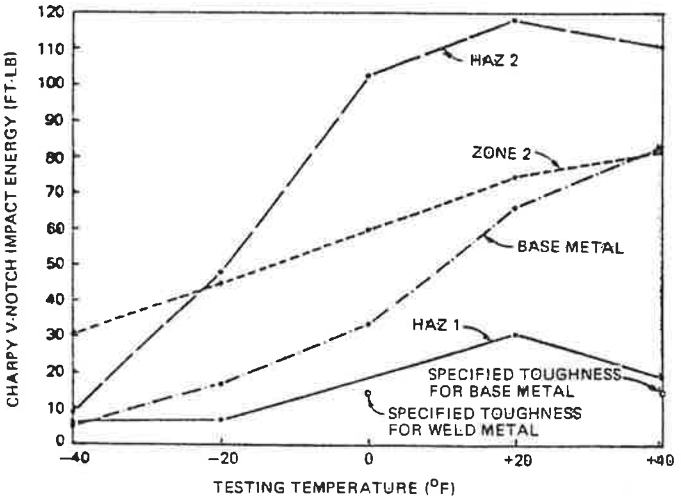
It's very informative. What they had was they had a Contractor A and a Contractor B. They provided them both with A558 steel. The difference between Figures 22 is in the first one they're using electroslag welding techniques, and in the second they're using submerged arc welding.

In one instance you obtain a CHARPY rating of seventy, and in the other you've got a chance of getting somewhere back in here, the weld metal would go about twenty.

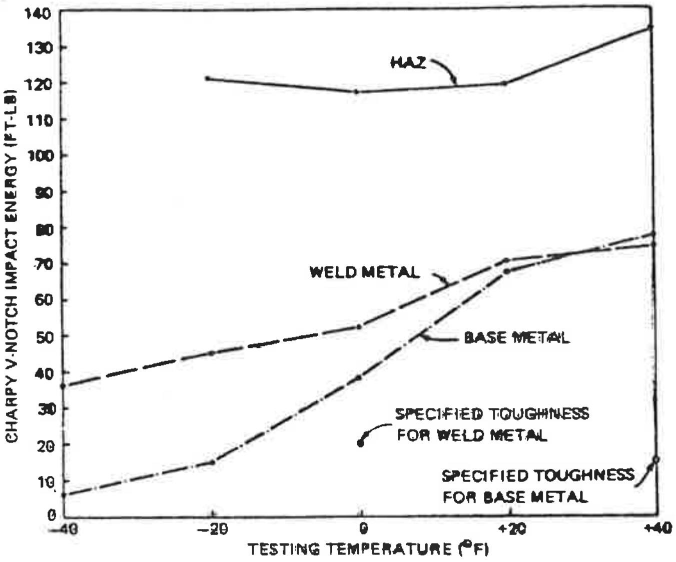
The significance of this is that there's been little emphasis on getting steels and welding processes that are going to give us good impact resistance. I'm not a metallurgist, but people in the labs back in Vertol tell me there are articles appearing on this subject with some regularity among the metallurgists.

It looks to me like it's a very fruitful area as to come up with a good understanding of what kind of welding processes to use and to find out what the effect of the welding process is on the impact resistance on the welds for use in the car end. With respect to the metals, I understand that there are ways of procuring impact resistant steel without paying through the nose for it.

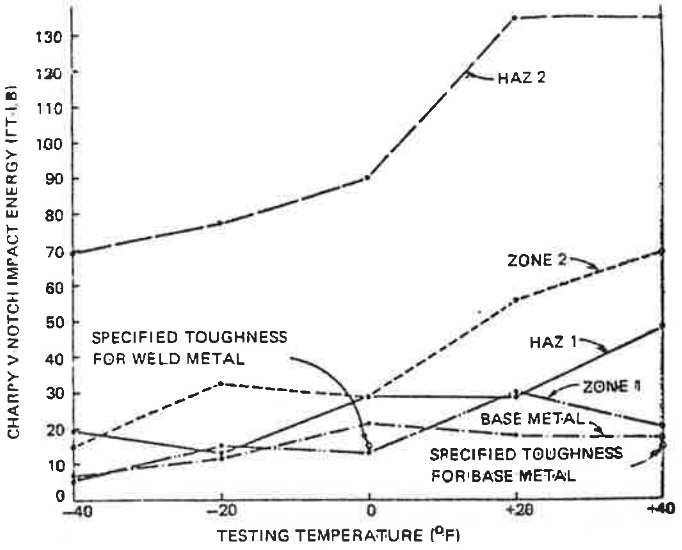
For instance, if you get your structural sections normalized after they're rolled, you're going to get better impact resistance.



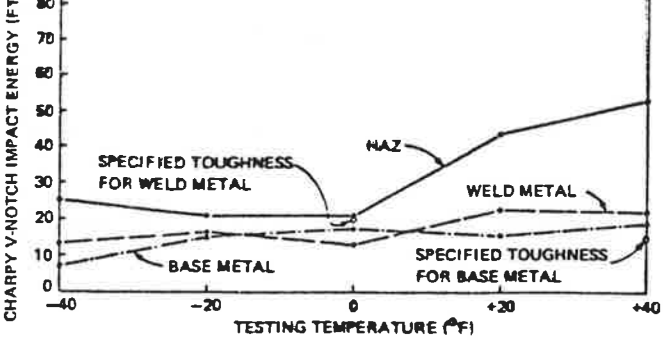
Energy Transition-Temperature Curves for a Dry Shoe Electroslag Weldment Made in 3-In. A 588 Steel (Weldment ES 588-B2).



Energy Transition-Temperature Curves for a Submerged Arc Weldment by Fabricator B in 3-In. A 588 Steel (Weldment SA 588-B2)



Energy Transition-Temperature Curves for a Cooled Shoe Electroslag Weldment Made in 3-In. A 588 Steel (Weldment ES 588-A2).



Energy Transition-Temperature Curves for a Submerged Arc Weldment by Fabricator A in 3-In. A 588 Steel (Weldment SA 588-A2).

FIGURE 22. WELD IMPACT TESTS

Mr. Widmayer: cont. This is an area that's of importance to the car buyer. If he knew how to specify a good process, a proven process for the steels that are used between the bolster and the car end, he would be getting better crash protection from his car end.

With respect to weld designs, there are procedures in use that are dear to the hearts of all civil engineers, for instance, designing for plastic conditions, rather than designing to the yield conditions.

In the plastic process, you make the welds so that the weld will not fail until after you reach full plasticity; you develop plastic hinges, mechanisms, I believe, they like to call them. This procedure could be extended to that critical area of the car, between the bolster and the car end, and would eliminate some of this weld rupture we keep seeing.

I think there's a requirement for some test programs. The object would be to develop a technology base. There are quite a few components that are used in the rail industry where you can find no evidence that they're consistently tested to failure. One of the simple ones is the car body itself. In the standard acceptance test the car body is loaded up to percentage of the yield strength, read the strain guages, extropolate the results, and if everything is okay, go.

You have no idea what's going to happen after you go past yield. I think I've heard of only one test where they tested to destruction, and Budd did that back in about '38 or so, after they had an unfortunate accident near Bryn Mawr.

The dynamic test of sections in a complete vehicle should be done to give us a better understanding of what's going on in the crash process. Collision tests are required to get the collision dynamics and get design loads. We don't really know what kind of design loads we should be using. Is it sufficient to put an anticlimber on there that will take 75,000 pounds shear, or take the jacking load, or is it necessary that we should be at 150,000 or 300,000 or whatever?

We don't know when have you got enough. The designer that did the gondola anticlimber thought he had it at about 10,000 pounds shear strength.

Develop materials, processes, and design procedures that are going to give us better crashworthiness. This may provide a basis for

Mr. Widmayer: cont. the development of industry standards and certainly be a tool for the properties and how to procure their cars and what kind of acceptance tests they are going to have.

Is there anything more? Oh, yes, specifications. I'm going to pass on that. (Figures 23 and 24)

Thank you.

- * DEVELOP TECHNOLOGY BASE
- * STATE TEST TO FAILURE OF COMPONENTS
- * DYNAMIC TEST OF SECTIONS AND OF COMPLETE VEHICLES
- * COLLISION TESTS TO DEVELOP COLLISION DYNAMICS AND DESIGN LOADS-SCALE AND FULL SIZE
- * DEVELOP MATERIAL, PROCESS AND DESIGN PROCEDURES
- * PROVIDE BASIS FOR INDUSTRY STANDARDS, VEHICLE SPECIFICATION, AND ACCEPTANCE TESTS

FIGURE 23. TEST PROGRAM

- * HIGH IMPACT RESISTANT WELD PROCESSES
- * HIGH IMPACT RESISTANT STEEL FOR CAR END STRUCTURES
- * UNDERFRAME TO ROOF COLLISION POSTS THAT DEVELOP THE STRENGTH OF THE UNDERFRAME
- * ANTICLIMBERS AND BACKUP STRUCTURAL
- * TRUCK RETENTION
- * PROOF OF DESIGN

FIGURE 24. SPECIFICATIONS

IITRI - DR. EDWARD HAHN

Mr. Madigan: Well, we've talked a lot this morning about the work that's gone on, with Ed stressing that the thing to avoid is overclimbing. The IIT Research Institute carried some of the work further and included the vertical plane through the car in their work. I'd like Ed Hahn to come up and talk about that.

Dr. Hahn: Our project was entitled "Increased Rail Transit Vehicle Crashworthiness in Head-On Collisions" and was done under contract with TSC. Arnie Wiedermann and I will tell you about it.

INCREASED RAIL TRANSIT VEHICLE CRASHWORTHINESS
IN HEAD-ON COLLISIONS

Contract DOT-TSC-1052

Edward E. Hahn
Arne H. Wiedermann

IIT RESEARCH INSTITUTE

A. Robert Raab
Fred Rutyna
Samuel Polcari
Ming Chen

TRANSPORTATION SYSTEMS CENTER

FIGURE 1. IITRI RESEARCH CONTRACT

We had considerable help from some of the people here at the Transportation Systems Center. Bob Raab, who was our project monitor at the start of the program; Fred Rutyna; our present project monitor, Sam Polcari; and Ming Chen all gave us a good bit of help.

The collision of two impacting trains or consists of transit cars (I'm only going to be talking about transit cars, not the intercity trains.) can be broken down into three separate, but really interdependent phenomena. We can seperate the collision into initial impact, which is just concerned with the mechanics of the initial impact of the leading cars of two consists; primary collision, where we consider the mechanics of the interaction of all the cars with each other; and secondary collisions, which is the interaction of passengers with seats, passengers with other passengers, Dr. Hahn: cont. and possible passengers with loose objects which might be flying about the car in an accident.

The objectives of our program were to study these three phenomena. The initial impact of two transit cars can be broken into three separate items, the cars may impact and purely crush; upon impact, one of the cars may jump up and override the second car which we've seen from the report earlier can be very bad; or there can be a combination of the two, crush with subsequent override.

In our program, we developed an analytical model of two cars in an impact situation. This model was in pretty good detail, but just in the vertical plane of the track. From results obtained from that analytical model, we were able to make some recommendations for future directions of design for impact control devices.

In TASK 2, we considered the primary collision of two impacting consists, again, using an analytical model which would simulate whether the cars merely crushed, overrode, or some combination of the two. We considered all the cars in the two impacting consists.

We were able to determine, with this model, all the accelerations of all the cars; vertical, horizontal, and any angular accelerations that might have occurred.

From study of the secondary collisions, we found out what happened to the passenger inside the car as a result of the accelerations that he felt from the impact, such as hitting his head on a seat, and other things such as that.

The first two tasks I talked to you about I'll cover right now, and then Arnie Wiedermann will cover this third task after I'm finished.

For TASK 1 and 2 we needed a computer code to carry out the calculations, so we developed a general purpose planar code, that's the vertical plane containing the track. It's a fairly general purpose hybrid code in that, you could consider lump parameter elements or finite elements.

IITRAIN COMPUTER CODE
Planar
General Purpose
Hybrid
(lumped parameter or finite element)
21 Deformable or Constraint Elements

FIGURE 2. IMPACT COMPUTER CODE

Dr. Hahn: cont. The code contains a considerable number of different elements that we can use to model the cars of the train, either deformable elements such as springs or beams, or what I call constraint elements, such as pin joints or hinge joints.

We needed to validate the code, we wanted to use some kind of train data, but there's very little available. Therefore we obtained test results from Pullman Standard. These results were actually for freight cars running into each other at a very low impact speed. We set up a model to check out how close we would come to the experimental results with our IITrain Computer Code. We matched extremely well out to the third peak. We still have the peak there at about the right time, however, it didn't go up to quite the proper force. But we were happy enough with these results that we went ahead with our analysis.

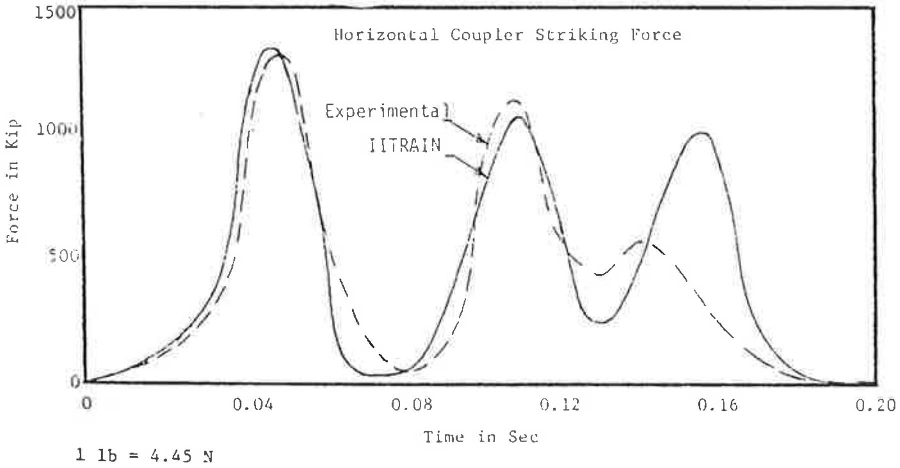


FIGURE 3. PULLMAN STANDARD TEST RESULTS, HORIZONTAL COUPLER STRIKING FORCE

This is the model of a single transit car that we used for our first analysis. We used beams, which allow large deformations, to model the roof structure; the floor structure and the side sills were modeled with another set of beams. The draft sill and end sill assembly with the anticlimbers were also modeled. We used a six mass representation of the entire car body, so we get the effect of the distribution of the mass throughout the length of the car body.

Also, we modeled the coupler and draft gear in rather great detail, with a three mass representation. The coupler leveler spring, draft gear, the draw bar, and the hanger holding it up, as well as possible contact of the coupler with the underframe of the car were all modeled. The truck was modeled with springs and dashpots in the main body of the truck with a seperate bolster mass. We did include

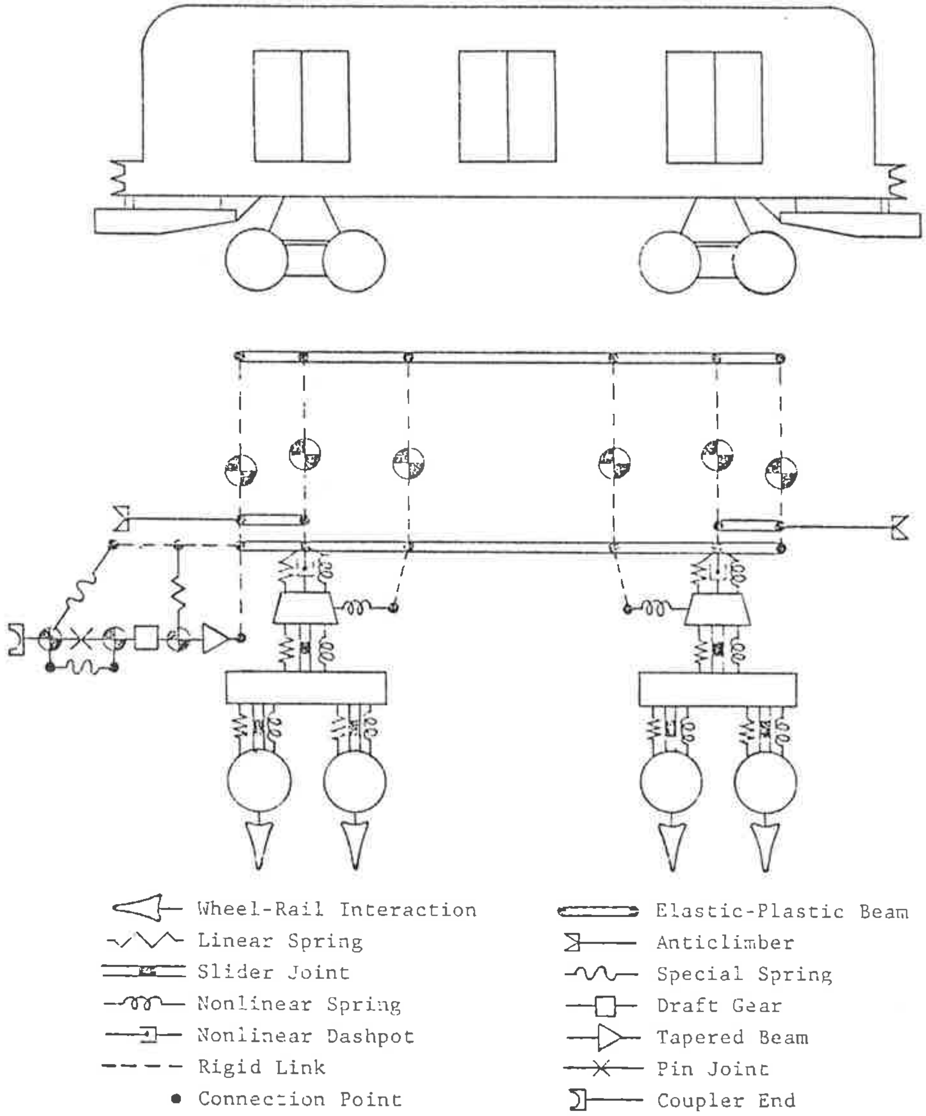


FIGURE 4. TRANSIT CAR MODEL

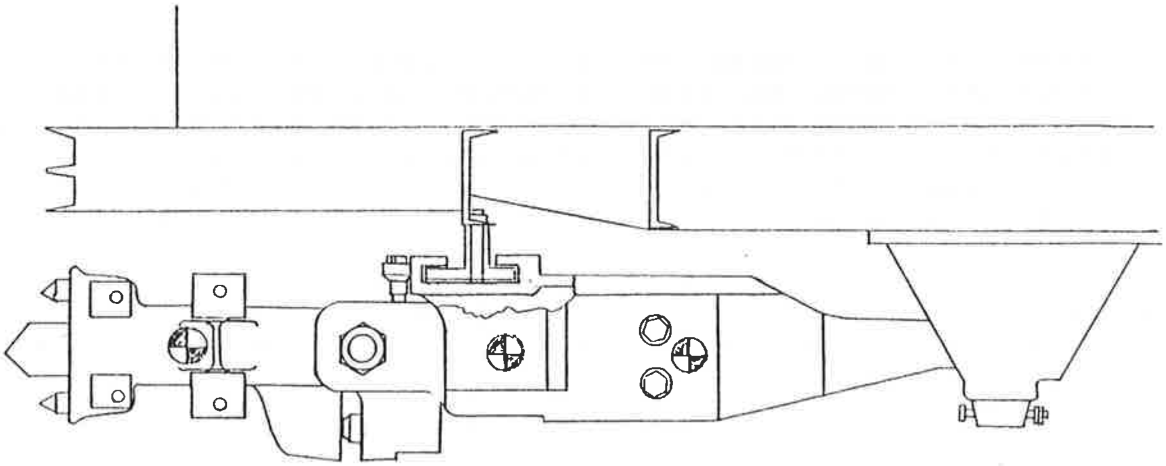


FIGURE 5. COUPLER ASSEMBLY MODEL

Dr. Hahn: cont. the effect of the flexibility of the rail in the wheel-rail interaction.

We formed a rather detailed model that we could use in the computer code. Using that model, we investigated the effects of the various parameters which describe the impact control devices on a car; the impact control devices that we considered were the anticlimber-end sill-draft sill arrangement, as well as the coupler and draft gear.

We included such things as the elastic spring constant of the anticlimber, the crushing spring constant, the spring constant during crushing, the load at which crush starts to occur, and the load at which complete failure may occur. These were considered in both the horizontal and in the vertical directions.

The depth of the engagement surface and the initial misalignment of the two cars, which could have a large effect, were also included in our investigation.

Insofar as the coupler and draft gear were concerned, we investigated the strength of the draw bar, the rail hanger (it's spring constant can have a big effect), the load at which rupture may occur for the rail hangers, spring constant for the draft gear, the shear pin failure loads for the draft gear, the travel before we engage the shear pins, the travel after the shear pins failed before bottoming out, the spring constant after that point, the coupler leveler spring constant, and the amount of pre-load in that spring.

We investigated the various parameters to see what effect they would have on override, on crush, and on crush with subsequent override.

We investigated the crush sensitivity to these various parameters that I described, and we found the largest effect on crush was due to the crush force for the anticlimber. A one hundred percent change in the anticlimber crush force caused something around twenty-three percent change in the amount of crush. The horizontal crushing spring constant had a fairly large effect, something like eighteen percent. The draft gear travel had a different effect depending on whether it was mounted on the car that was moving or the car that was sitting still.

One of the impacting cars was fully loaded with about 30,000 pounds of passengers and was stationary. It was impacted by a moving car that was essentially unloaded, with a very small number of passengers.

Most of the analyses were done for a twenty mile per hour crash.

The other physical parameters had very little effect insofar as crush was concerned. So far as override is concerned, the shear

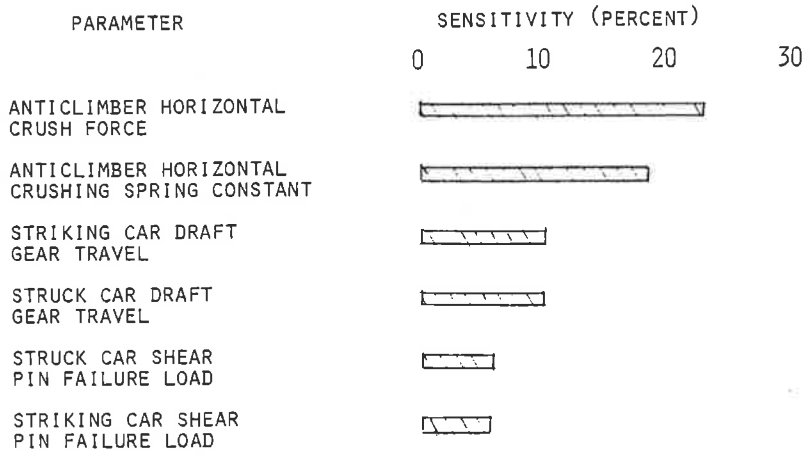


FIGURE 6. CRUSH SENSITIVITY

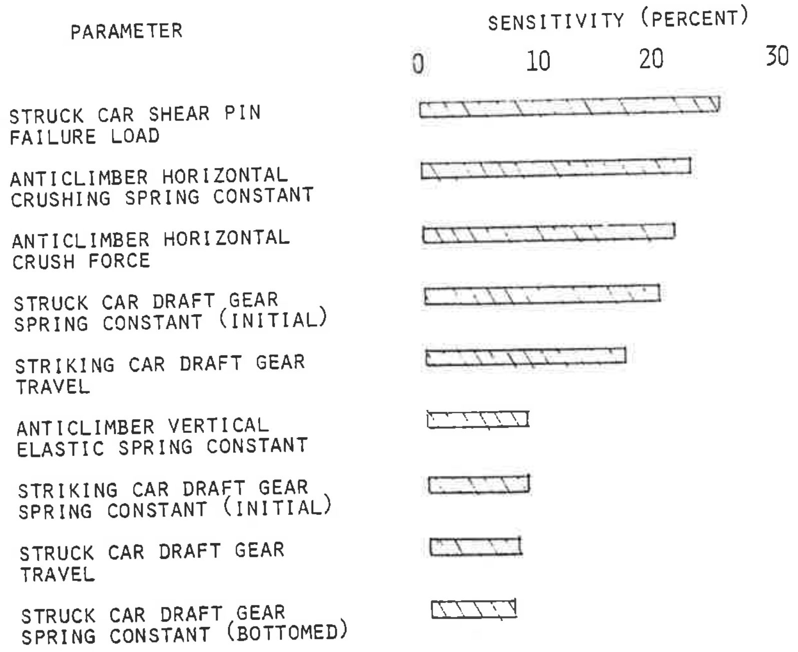


FIGURE 7. OVERRIDE SENSITIVITY

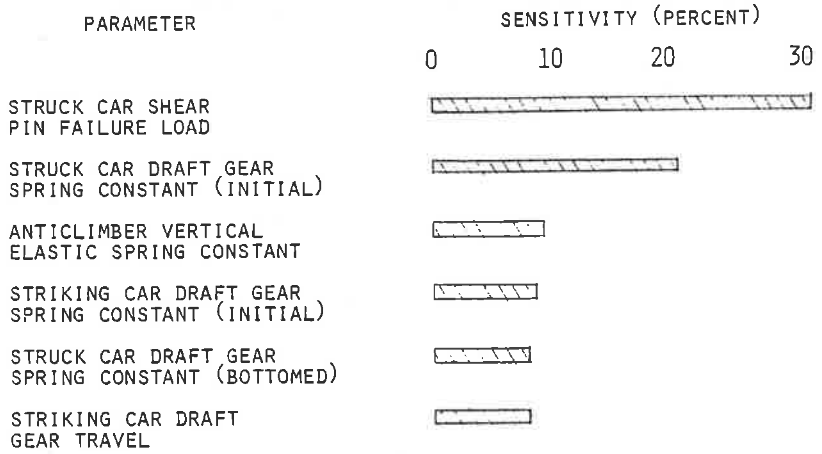


FIGURE 8. CRUSH WITH OVERRIDE SENSITIVITY

PARAMETER	CRUSH	OVERRIDE	CRUSH AND OVERRIDE
STRUCK CAR SHEAR PIN FAILURE LOAD	-6.0	-24.5	-30.5
STRIKING CAR SHEAR PIN FAILURE LOAD	-5.5	3.5	- 2.0
STRIKING CAR DRAFT GEAR SPRING CONSTANT (BOTTOMED)	-0.5	4.5	5.0
STRUCK CAR DRAFT GEAR SPRING CONSTANT (BOTTOMED)	-0.5	7.5	8.0
STRIKING CAR DRAFT GEAR SPRING CONSTANT (INITIAL)	-0.5	9.0	8.5
STRUCK CAR DRAFT GEAR SPRING CONSTANT (INITIAL)	-0.5	-20.0	-20.5
ANTICLIMBER ELASTIC VERTICAL SPRING CONSTANT	0.0	9.0	9.0

FIGURE 9. SENSITIVITY COMPARISON

Dr. Hahn: cont. pin failure load had the biggest effect.

The cars were lined up so the anticlimbers would engage, if they moved straight ahead. I didn't have enough misalignment so that they would initially jump over each other. In none of my computer runs did the anticlimbers fail, and we had override.

The shear pin failure load for the struck car was found to be an important paramater for override. The anticlimber crushing spring constant, again, had a fairly large effect, as well as did the crush force. The struck car draft gear spring constant, striking car, draft gear travel, and the rest of the paramaters had fairly negigible effects.

For the combination of override and crush, we found that the most important paramater was the shear pin failure load, with about a thirty percent change in crush with subsequent override for a hundred percent change in the struck car shear pin failure load.

The draft gear spring constant also had a fairly large effect, and after that, not much effect from the remaining parameters.

From the Floor: Execuse me, could I just get an interpretation of what it is that's on the chart? What I'm interpreting you're saying is that if you increase the shear pin failure load by a hundred percent, the probability of a crush with override will go down by thirty percent?

Dr. Hahn: Not the probability, but some measure of crush with override, the amount of crush and the amount of override, some measure of that will decrease by thirty percent. So I will crush

Dr. Hahn: cont. thirty percent less. Actually, crush and override, thirty percent less.

From the Floor: Severity of what results goes down by thirty percent for a hundred percent increase?

Dr. Hahn: Right.

From the Floor: Could you explain how you arrived at these, the sensitivity. What is it, a ratio of something?

Dr. Hahn: It is, in this case, decrease of override, the amount that one car overrode the other.

From the Floor: In feet or inches?

Dr. Hahn: The sensitivities were in terms of non-dimensional numbers. I set everything up in terms of a typical set of parameters for a railroad car, which were obtained from Pullman Standard. All data was normalized to non-dimensional numbers in terms of this typical data.

From the Floor: What's the mechanics of how you actually override; how does it override?

Dr. Hahn: In none of our models did we actually completely override. So the measure that I used was the tendency towards override, which was the vertical force felt at the anticlimbers, since as that force increased the tendency toward override, increases.

From the Floor: Is this force the one that you get from misalignment of the coupler?

Dr. Hahn: Well, misalignment of the coupler could force the one car up, and then when the anticlimbers engaged a vertical force would act at the webs of the anticlimbers, that's the force that I'm talking about.

From the Floor: Is there an explanation for the difference in the sensitivities related to the struck car and the striking car in the case of the shear pin failure load? Wouldn't they be the same?

Dr. Hahn: Not necessarily. If one car is moving and one car's is sitting still, the optimum designs may be different; unfortunately, we can't legislate which car is going to be sitting still.

From the Floor: Well, is this assuming a uniform design?

Dr. Hahn: This was assuming that the two cars were of similar designs.

From the Floor: It's not related to the fact that one is loaded and one isn't or something like that?

Dr. Hahn: Well, that, also; the one that was sitting still was loaded, so we had those two differences. It can be due to either the fact that it's loaded or to the fact that it's sitting still.

From the Floor: Did you ever run it without a dissimilar load?

Dr. Hahn: No, without dissimilar loads the event becomes symmetrical for designs of the striking and struck cars.

From the Floor: You're implying that there is a difference between the struck car and the striking car and intuition implies that that's not correct, at least, my intuition.

Dr. Hahn: I wouldn't say...

From the Floor: The difference is the mass and perhaps in the resistance of the wheels on the track. One is rolling.

From the Floor: One is slowing down, the other is quickening up.

Question From the Floor: Well, the masses in this case are definitely different.

Dr. Hahn: The masses were different, so we have two things that are different.

From the Floor: If they were the same, would the results be the same? If the masses of the two cars were identical...

Dr. Hahn: The results would be different than for the cars with dissimilar masses.

From the Floor: If the masses of the struck car and the striking car were identical, would your numbers there be the same?

Dr. Hahn: They wouldn't be exactly the same, no.

From the Floor: How close?

Dr. Hahn: I did not run any analysis to find out how close. I would expect that it would be fairly similar.

These results point out that there are some things about design that you could change, which would improve the car insofar as crush with override is concerned. We have parameters that we might want to look at insofar as design is concerned.

Dr. Hahn: cont. One thing that you may have noticed that didn't appear here was the effect of an override of the vertical crush force for the anticlimbers. The reason it didn't show up is we never did have any actual override. As long as that crush force is big enough that you don't have override, you're fairly safe.

From the Floor: Did you assume level tangent track for all of your analyses.

Dr. Hahn: Yes, level straight track.

From the Floor: On your struck train, you're assuming that it's staged there with the brakes applied, so the wheels would skid when it hit?

Dr. Hahn: The brakes were not applied on the struck train.

From the Floor: So, the wheels were rolling.

Dr. Hahn: Yes, it was free to roll.

Mr. Tucker: Did you assume a certain ultimate strength in the anticlimber in a vertical direction?

Dr. Hahn: Yes.

Mr. Tucker: Do you remember what that was and the weight of the car?

Dr. Hahn: I remember it was a very low percentage of the horizontal, on the order of ten percent or so.

From the Floor: Can I assume there are some typos in the chart? The numbers don't add up. The right hand column is full of inconsistencies.

Dr. Hahn: Crush sensitivity plus override sensitivity does not necessarily add up to crush with subsequent override sensitivity.

From the Floor: Why doesn't it.

Dr. Hahn: Because one is really a measure of crush, the other is a measure of override. Now, crush and override, the combination doesn't have to be the sum the way that we define it. It doesn't necessarily have to be the sum.

From the Floor: If you come up on the striking car shear pin failure load with a negative 5½ on crash and a positive 3½ on override, it sure is a long way to get to a negative 20.

From the Floor: Could you explain the significance of the negative numbers?

Dr. Hahn: If we increase the failure load, we will decrease the amount of crush, with a minus. With the plus sign as here, if we increase the failure load, we would increase the amount of override. So that's what the plus and minus is -- whether we increase or decrease. And as far as those numbers are concerned for the striking car shear pin failure load, there may be an error. There's a paper in your folder, which does not have an error on the charts for sure. And the figures are given in the back, not exactly this same form, but the same figures do appear.

Having investigated the initial impact, I looked at the primary collision using the same computer code. An eight-car train moving essentially unloaded, again, running into another eight-car train, which was fully loaded and sitting still without the brakes applied was analyzed.

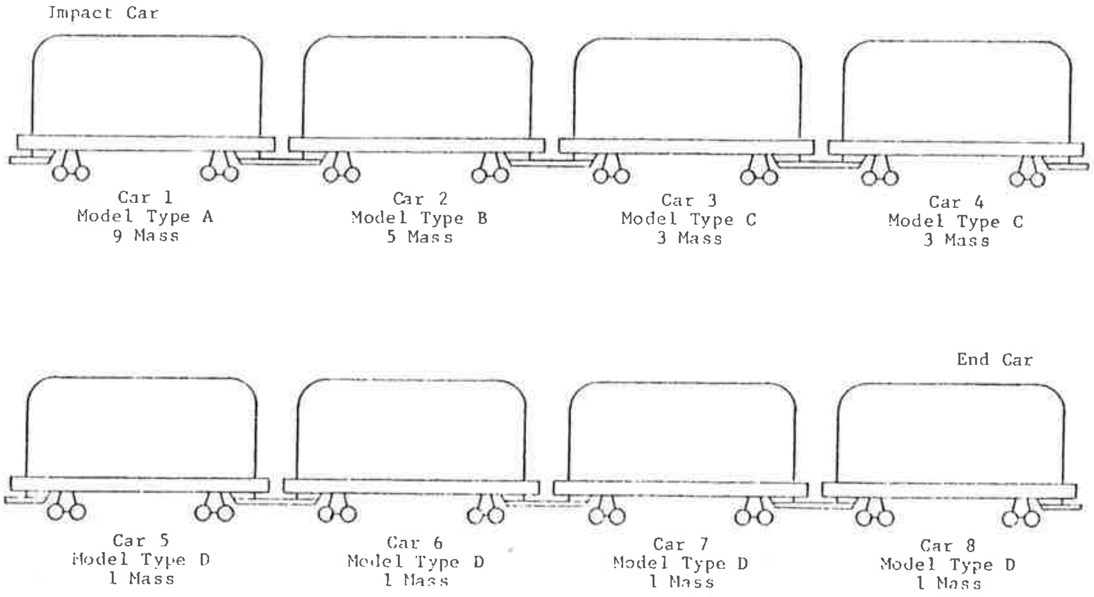


FIGURE 10. EIGHT CAR CONSIST MODEL

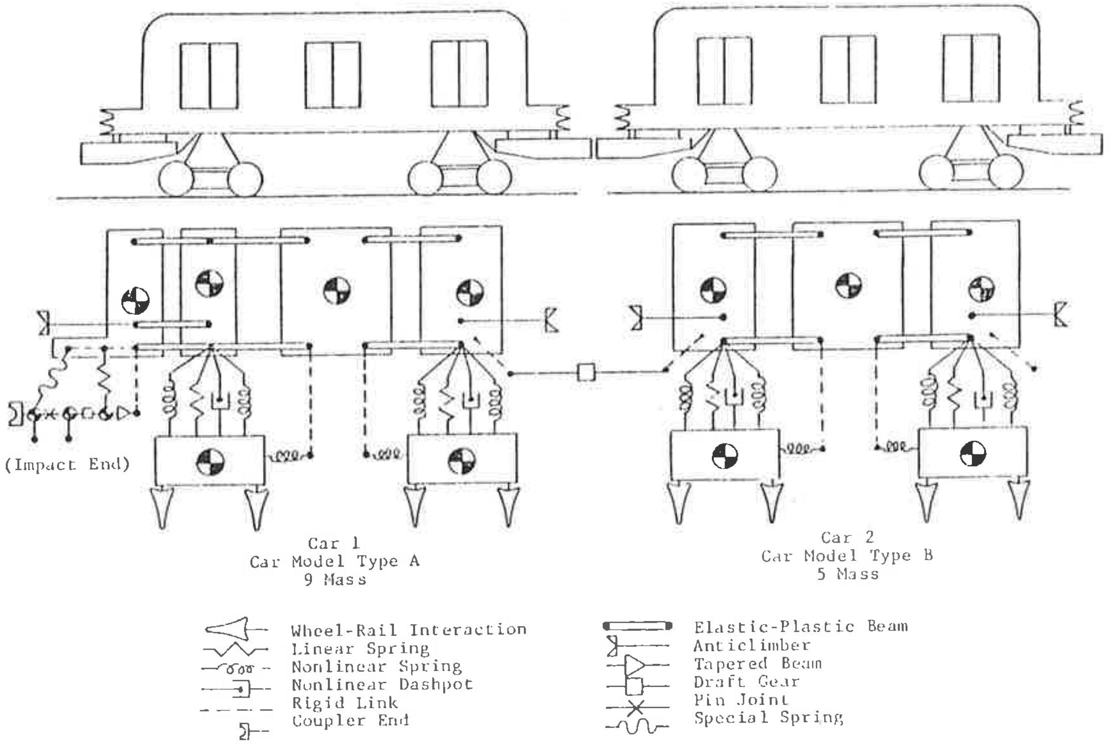


FIGURE 11. CAR MODEL TYPES A AND B

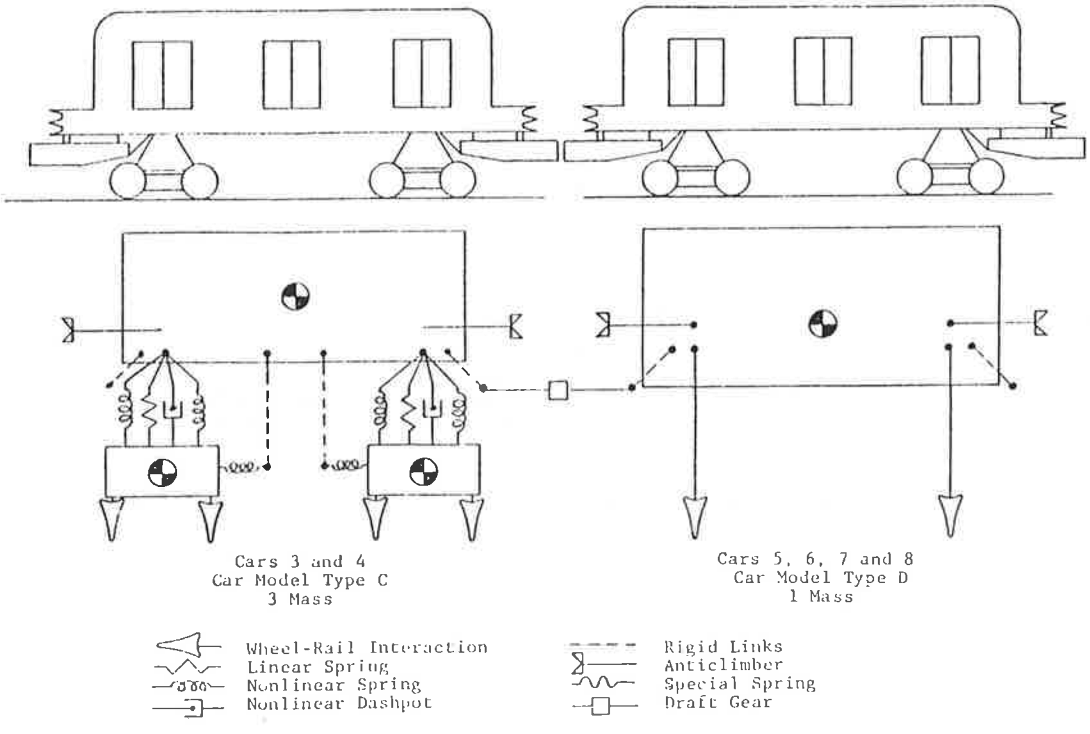


FIGURE 12. CAR MODEL TYPES C AND D

Dr. Hahn: cont. We started out using a fairly complex model of the first car, the cars which impact, a little less complex model of the second car, etc. The last few cars used a simple single mass representation.

I ran the computer code for this complex model, and then I tried one more time using for all eight cars, the very simple, single mass model. Running the entire train with the complicated model was costing something like a thousand dollars for one accident, and we couldn't afford to run that for many accidents.

This is the horizontal acceleration history for the first car for the very complex model, and here for the very simple model. (Figure 13) If you look at the acceleration traces, you see that they do match quite well; the peaks are slightly different, but the average 5 g's are right on. The struck car had about 3½ g's, the same thing here. The second car, again, matches well, maybe the peaks look a little bit different, the sharp points, but the rest of it is quite good.

So, from these results, I could conclude that I really didn't need the complex model to find out what the accelerations might be from the car.

I have here ten accelerations for the first car; this is the unloaded moving consist, the first car, second, third, fourth, fifth, and so on. We have about 5 g's and about seventy miliseconds, and essentially a square wave more or less. (Figure 14)

The second car looks almost exactly like the third, fourth, fifth, sixth, seventh, eighth. From the second on, we get essentially the same acceleration pulse. A higher one in the first car, a lower pulse in the second again, almost a square wave in the rest of the cars.

This, by the way, was run with the very complex model for a twenty mile an hour impact. This figure is for a thirty-five mile per hour impact. This was the simplified model, and about thirty-five miles per hour is as far as I could go with that simplified model, or we started seeing differences insofar as the accelerations are concerned. (Figure 15)

From the Floor: Excuse me, wouldn't you expect to see some continuation along the lengths of the car?

Dr. Hahn: I expected to, until I plotted the results, and then I could convince myself that maybe everything was okay. You see the little peak here, where the shear pin fails, and then we get the

Dr. Hahn: cont. immediate rise up to the crush force for the anticlimbers.

And then this anticlimber stays engaged. We're crushing, while we're accelerating or decelerating actually, our car, and as we decelerate that car, at this point, the car behind it brakes its shear pin and comes in contact.

Now, we have the crush force on both ends of the car are essentially equal, so our acceleration here drops down to zero. We have no net force left on that car. And we have the full crush force acting on our fourth car, and we just move that chain of events down the line until finally we get to the last car. So that's really what happens.

You see, we do have some cases of double impact and a lot more spurious acceleration signals as we get out in the event for the higher speed impact than we did with low speed.

But, again a square wave essentially, or a double square wave. The acceleration is like 3½ g's which is the same as it was at the twenty mile per hour impact. That's really just the anticlimber horizontal crush load divided by the weight of the car. That's essentially where everything is.

I don't have plots here of the vertical accelerations. They look like this, almost zero. And the angular accelerations were very low also. So, almost everything does take place in line, which should point out that there might be a little of validity, then in the results, which were carried out by Calspan and the Boeing results, where they did just use an in-line model.

I think, now, I pretty well covered my part of it. And Arnie will tell you what happens to the people inside the train.

From the Floor: The last graph which you showed and gave the impression that there was no -- I don't know if I'm using the right word -- but no damping in the system. In other words, crush from one car to the other.

Dr. Hahn: Not really, we have energy in all eight of the cars. We take out quite a bit of the energy out of the first car, then we start taking energy out of the second car, then the third car, fourth, and so on until we get all eight of them.

Dr. Chen: Do you have evidence to confirm this, from the point of view of the actual, let's say, crashes, where you could detect that your shear pin in the couplers would have sheared as far back in the train as that?

Dr. Hahn: cont. In the accident in Chicago that took place, what was that, a year ago at Addison Street. There, the shear pins in all of the cars of both consists did fail, and there was a small amount of crushing, a very small amount of crushing, of all the anticlimbers. All the anticlimbers did engage. So, it's not good evidence, but it's some evidence.

Dr. Chen: I would like to mention that that's exactly what happened last January on the MBTA Orange Line. The shear pins broke off in the same way in the eight-car consist. We don't know what the exact speed was, but the first car had a penetration, of possibly four feet. The second car had a slight, maybe a foot or two, penetration, whereas from the third car on there was no sign of damage although the couplers are quite different from what you have there.

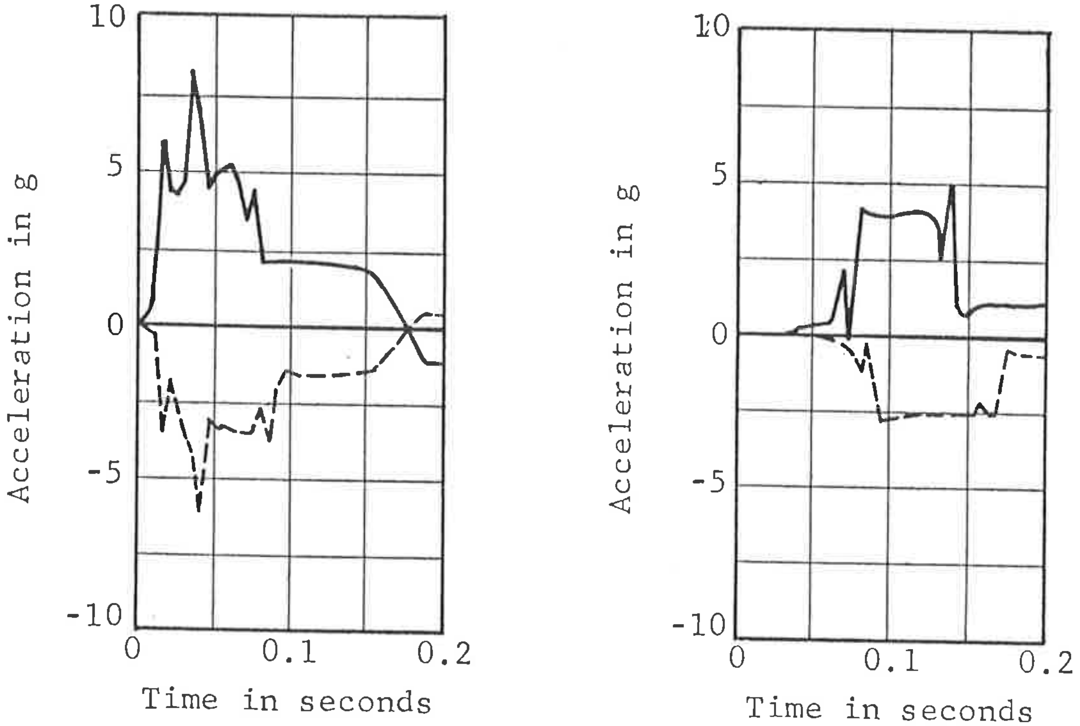
Dr. Hahn: Well, here, that didn't occur. Now, I don't know what would have happened had I gone beyond the thirty-five mile per hour. Beyond thirty-five miles per hour, perhaps something different.

From the Floor: We estimated our speed at twenty to twenty-five.

Dr. Hahn: That would be in the range where my results are valid, hopefully.

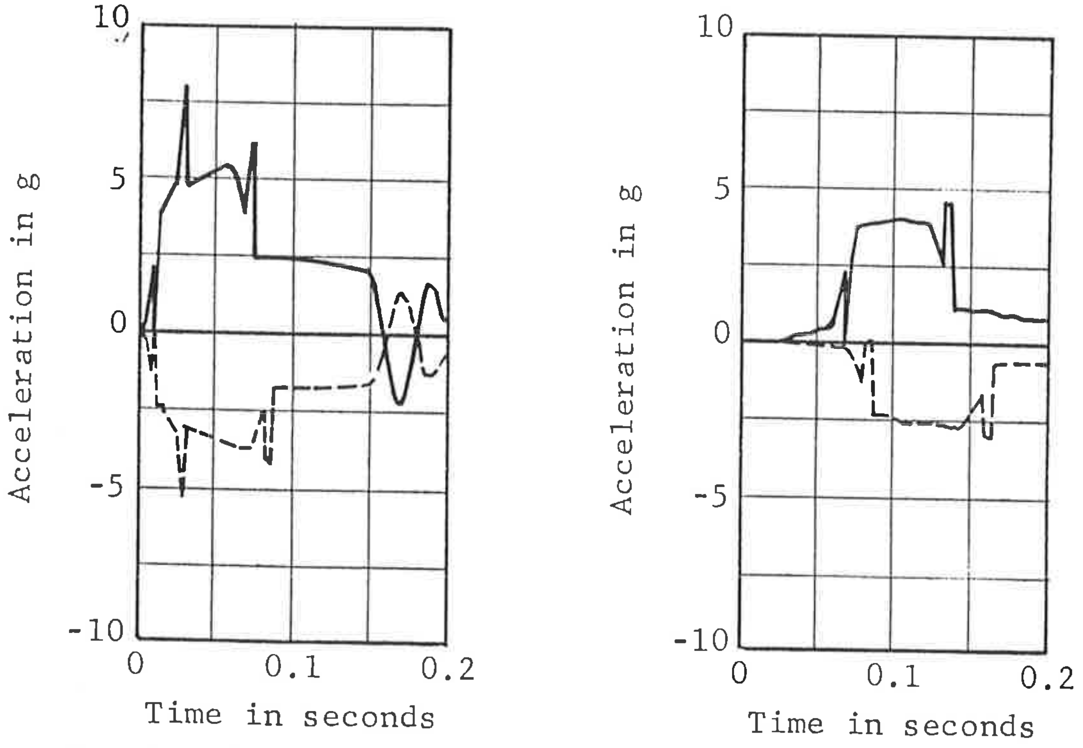
From the Floor: Excuse me, does your model include the crush in the first car?

Mr. Hahn: Yes, the complex model did. Now, the second results, which were run at thirty-five miles per hour, that did not include crushing of the first car up to the first body bolster. Just back to the body bolster.



Car 1 Initial Model

Car 2 Initial Model



Car 1 Simplified Model

Car 2 Simplified Model

FIGURE 13. COMPARISON OF HORIZONTAL ACCELERATIONS FOR INITIAL AND SIMPLIFIED CONSIST MODELS 32 km/h (20 mph collision)

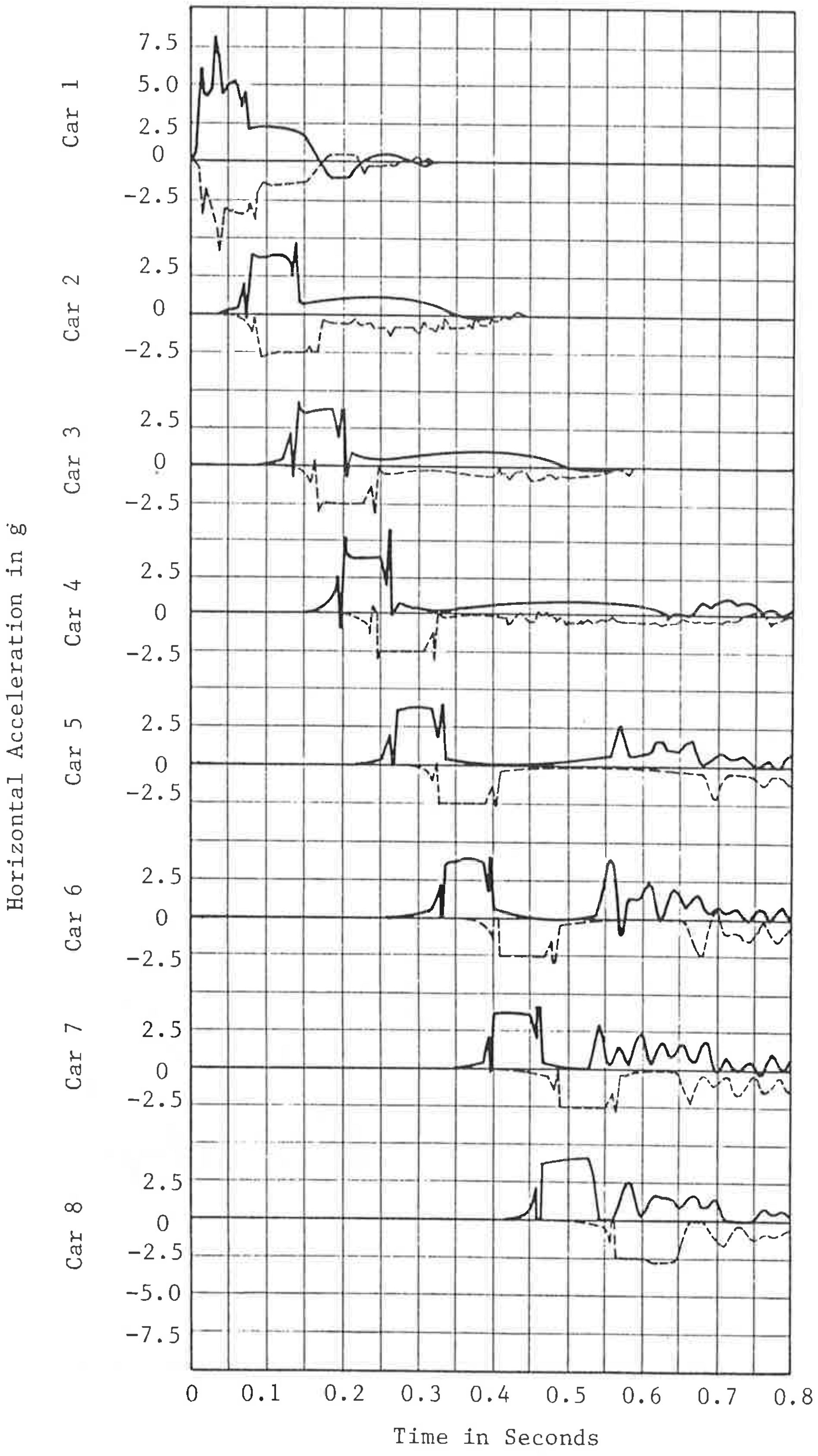


FIGURE 14. INITIAL MODEL HORIZONTAL ACCELERATIONS 32 km/h (20 mph collision)

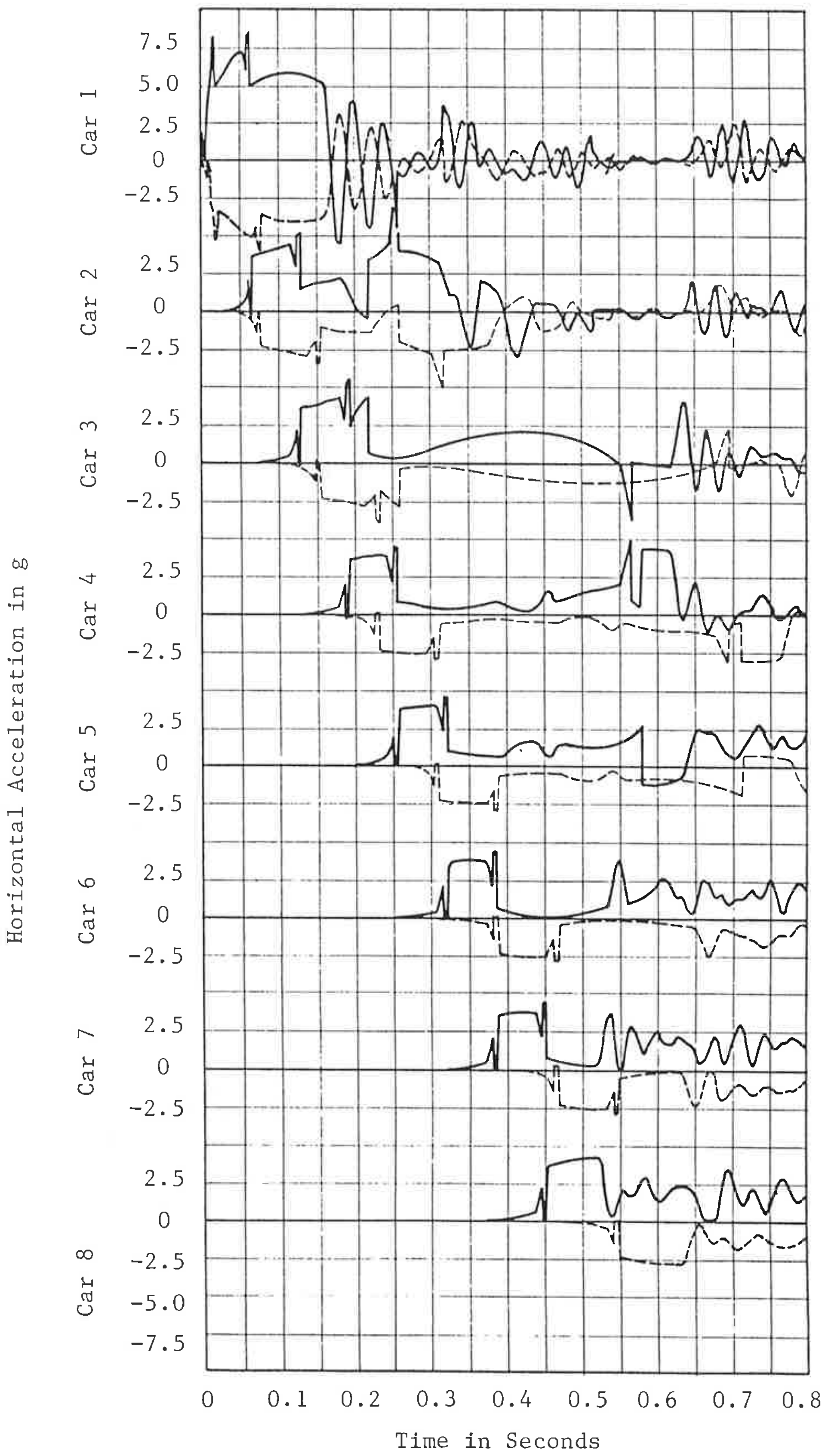


FIGURE 15. SIMPLIFIED MODEL HORIZONTAL ACCELERATIONS
56 km/h (35 mph collision)

IITRI - ARNE WIEDERMANN

Mr. Wiedermann: My portion of the talk will deal with the assessment of the nature and severity of the injury producing mechanisms relating to the secondary collision; that is, the interaction of the passenger being moved about in the passenger compartment.

To deal with this problem, we had to work in the following four areas. First of all, we had to examine and select pertinent injury fatality criteria.

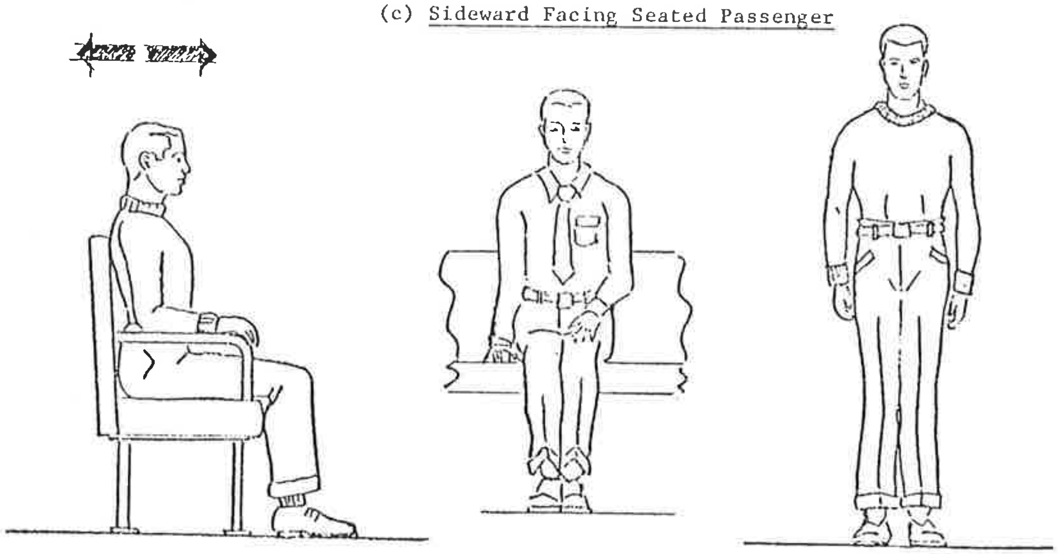
Secondly, we wanted to examine the influence that the response characteristics of the impacted surface or structure had upon that criteria.

Thirdly, we had to examine the passenger motion specifically. In order to do that, we first wanted to examine and characterize the acceleration pulses that the car frame or passenger compartment undergoes and to establish some equivalency between different pulse shapes.

We also had to consider the variability of anthropometric parameters as they affect the passenger population that we're concerned with. At that point, we're able to proceed with the examination of the motion of the passengers, per se.

And finally, we put all this together in a computer code, if you wish, an injury prediction methodology to provide some easy means of assessing the response of an entire consists car system.

(c) Sideward Facing Seated Passenger



(a) Forward Facing Seated Passenger

(b) Backward Facing Seated Passenger

(d) The Standing Passenger

FIGURE 1. PASSENGER CONFIGURATIONS

Mr. Wiedermann: cont. We're dealing, in this particular case, with four passenger configurations; (Figure 1) we have a standing passenger, we have a forward facing seated passenger, and a rearward facing seated passenger, where the forward and the rearward refers to the direction that the change in car velocity undergoes. And we also have a sideward facing seated passenger configuration that we're dealing with.

The first problem has been touched on already, namely the nature of the injury (Figure 2) and the selection of a injury and fatality criterion. We're concerned here with primarily the impact of the head, face, and chest as body components, and to a minor extent, the response of the neck in a flexion response mode.

NATURE OF INJURY

IMPACT - HEAD, FACE, AND CHEST
FLEXION - NECK

INJURY/FATALITY CRITERION

SEVERITY INDEX - IMPACT
PEAK ACCELERATION - IMPACT
ROTATION - FLEXION

INJURY SCALE

FATALITY
CRITICAL
SERIOUS
MODERATE
MINOR
NO INJURY

CONCLUSION:

FIGURE 2. NATURE OF INJURY

The criterion that are available have been mentioned. We, basically, were using the GADD severity index as the convenient tool for assessing the results of the crash environments. And, of course, we have to distribute these over some kind of injury scale. The point to be recognized here is that we are not dealing with an exact science. Nonetheless, we do have some approximate benchmarks and we know, roughly, in what direction to go. Perhaps we don't know exactly how far to go in some instances.

Mr. Wiedermann: cont. This just shows the severity index relationship with the injury scale that we have finally selected for the three body components shown. It's quite clear that the data was obtained on severity index for which that exponent 2.5 was used,

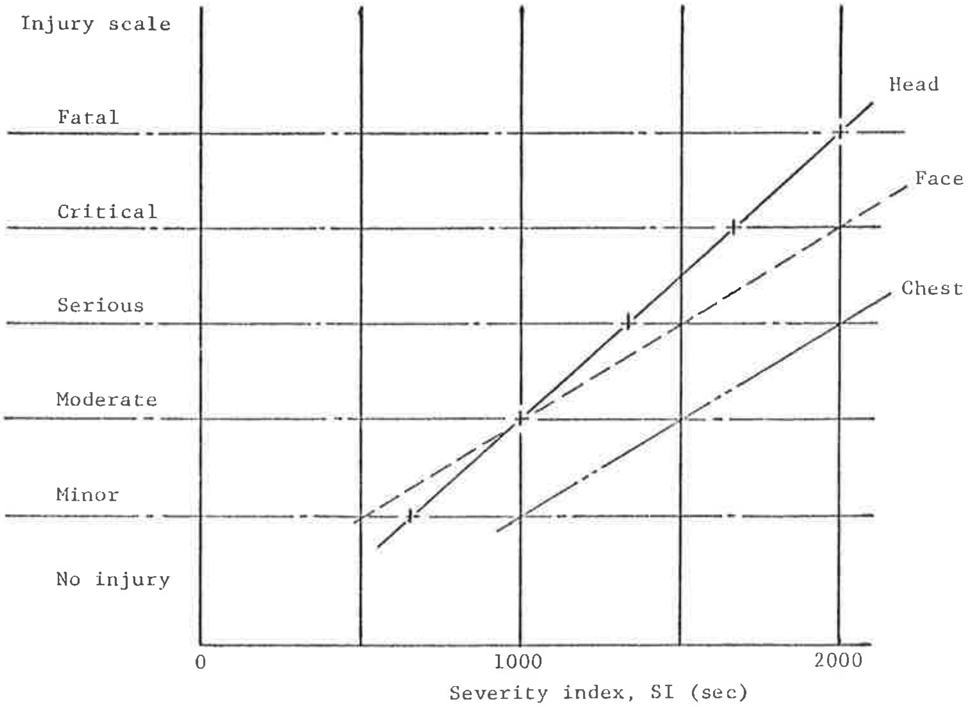


FIGURE 3. INJURY SCALE FOR IMPACT OF BODY COMPONENTS

was only well founded in cases of the impact of the head in a very prescribed type of impact situation, and on relatively firm surfaces.

PARAMETERS:

IMPACT VELOCITY OF BODY COMPONENT

MASS OF IMPACTING BODY COMPONENT

FAILURE (YIELDING) LOAD

EFFECTIVE STIFFNESS

- ELASTIC
- PLASTIC
- PERFECT ABSORBER

CONCLUSION:

STRONG DEPENDENCE OF SEVERITY INDEX UPON IMPACT VELOCITY

FIGURE 4. IMPACT SURFACE/STRUCTURE EFFECTIVENESS

Mr. Wiedermann: cont. We wanted to consider the influence, then, of the response of the impacted structure or the impacted surface. The parameters that we examined were the impact velocity of the body component, the mass of the impacting body component, the yielding or the failure strength of the surface, and to also include such things as the elastic and plastic yielding and finally end up with what was previously dealt with, something called the perfect absorber, which is a system which has a finite resistive force.

We looked at the sensitivity of these parameters to the severity index, and it was quite clear that the impacting velocity of the body component is by far the most important parameter. It's sensitivity depended upon the nature of the response of the impacted structure. For the perfect absorber the dependence was basically a linear dependence. For any structure that has some yielding character to it, the velocity dependence goes up to the 2.5 power.

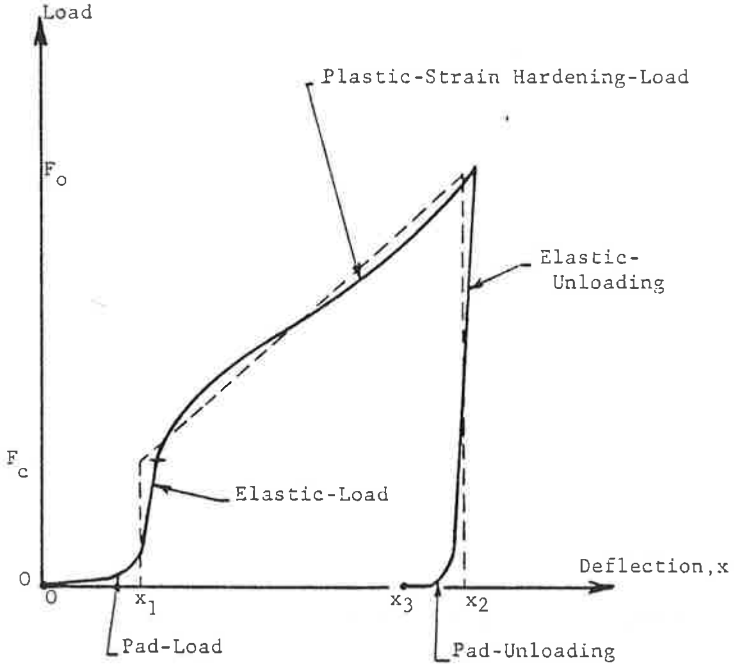


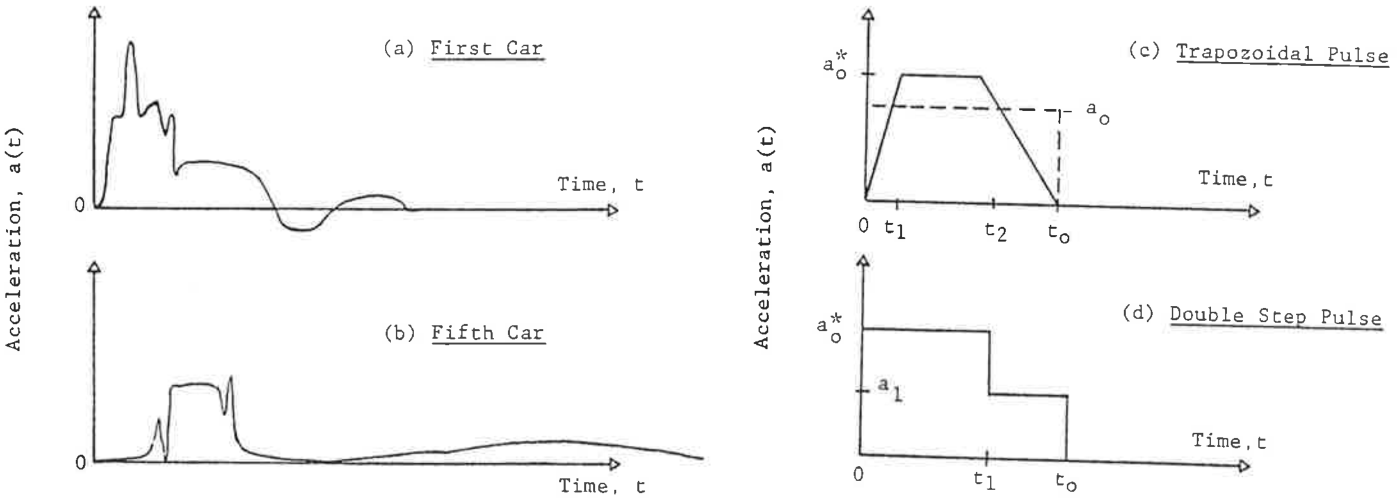
FIGURE 5. POTENTIAL LOAD-DEFLECTION RELATIONSHIP

Here, I've showed you briefly the generic load deflection relationships that we dealt with. Usually, we expect some sort of a rapid increase in force at the time of impact, a yielding, perhaps an increase in stiffness of the response as deflection is increased, and then some sort of an unloading characteristic.

Mr. Wiedermann: cont. The perfect absorber would be just a simple step pulse. The more general case is roughly as shown. This area represents basically the energy absorbed by the system and is equal to the kinetic energy of the incoming body component. When the system is elastic and we load and unload along a straight line, of course, there is no energy absorbed. There is merely a storage of the kinetic energy in the structural deformation, and then a reapplication of that energy back to the body components, so that it rebounds with an equal velocity or a velocity equal to the incoming velocity. Such a system is much more severe, of course, in producing an injury. It essentially doubles the severity index.

The next part of the problem deals with examining the motion characteristics, or acceleration characteristics, of the cars for use in the motion analysis of the passengers. Clearly, we have to deal with some simplified motion characteristics and most of the analysis was performed with simple step wave or constant acceleration impulses.

We treated, however, in the classification of these pulses, a trapezoidal pulse, which embodies in it, not only the step pulse, but also the full spectrum of triangular pulses. We examined a double step pulse. This range of pulse shapes, I think, gives us a good representation of what actually occurs in the various cars.



PEAK ACCELERATION
AVERAGE ACCELERATION
CHANGE IN VELOCITY
PULSE DURATION
STOPPING DISTANCE

SHAPE (TIME DETAILS OF ACCELERATION)
SQUARE (STEP) PULSE
TRAPEZOIDAL PULSE
DOUBLE STEP PULSE

FIGURE 6. ACCELERATION PULSE CLASSIFICATION

Mr. Wiedermann: (cont.) The spurious signals, here, are a fine structure of these acceleration pulses, I think, secondary importance in terms of the response of the passenger. In this case, we can neglect this late time slowly changing velocity, and acceleration, and just treat this simple step pulse.

This first car is a little more complex and we could treat it as either a double step or as a triangular pulse. It turns out that they give equivalent results.

These, then, are the characterizations that we used for the acceleration pulses: peak acceleration, average acceleration; the change in velocity (I will probably use the term just velocity or impact velocity; they are essentially the same parameter); pulse duration; and stopping distance. Now, stopping distance turns out to be a rather significant parameter. These are, of course, interrelated for different pulse shapes. There are basically four variables that we dealt with. With two relating equations, we can define the other two from any given two, and I'll go into that a little more later.

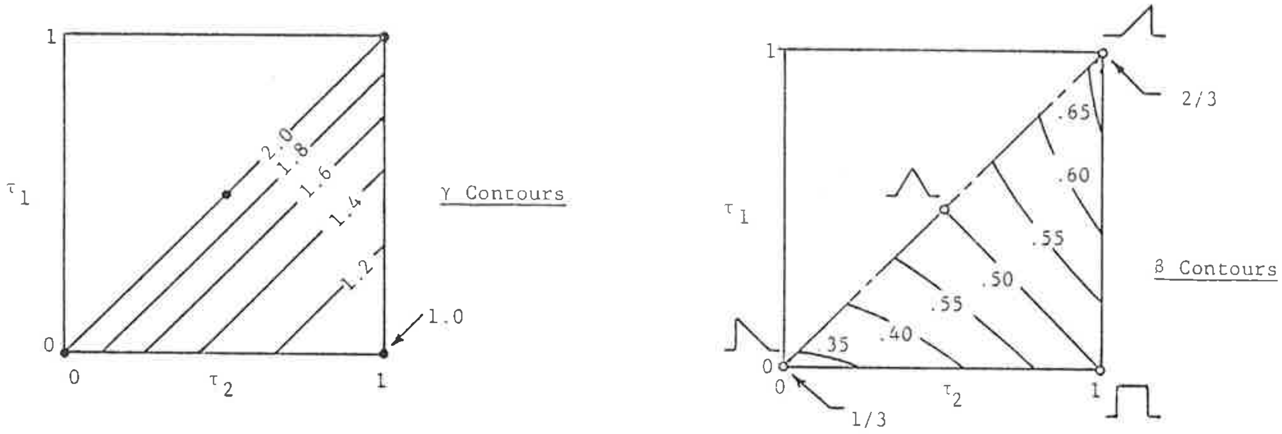


FIGURE 7. CHARACTERISTICS OF TRAPEZOIDAL ACCELERATION PULSE

I'll just show you this first curve here, beta, and you can't quite see the beta, but it's just the multiplier that you multiply the pulse duration and the change in velocity to obtain the stopping distance.

You see that in most cases that factor is like a half. When you go to some of the extreme pulses, it only varies from a third to two-thirds. With a double step pulse, that particular parameter

Mr. Wiedermann: cont. is also in the range of a half or for those pulse shapes or pulse parameter shapes of interest.

MEAN VALUES AND STANDARD DEVIATION OF:

HEIGHT OR CHARACTERISTIC BODY DIMENSION(S)
WEIGHT OF BODY COMPONENT(S)
MOMENT OF INERTIA
STIFFNESS (NECK ROTATION)

CONCLUSION:

STANDARD DEVIATIONS ARE LARGE
LIMITED AND BIASED DATA BASE

FIGURE 8. PASSENGER CHARACTERISTICS - ANTHROPOMETRIC DATA

Now, the first part of dealing with the passenger motion is to somehow find his weights, sizes, moments of inertia, and so forth. In the case of neck rotation, we have to say something about the stiffness, moment stiffness at that particular joint.

We find out first of all that the variations of these parameters for the population are in general very large, and furthermore, that the data base that we examined to obtain these relationships is rather limited and quite biased.

Large sample sizes are usually restricted to military groups, which means we're talking basically about the young, white adult.

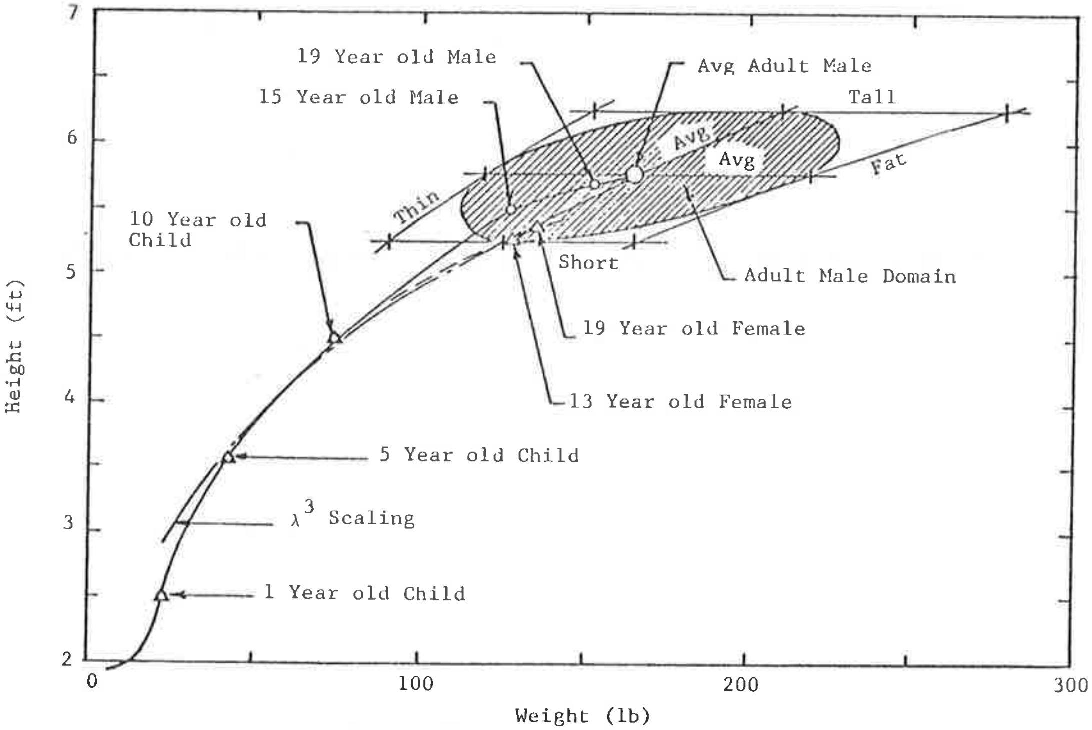


FIGURE 9. HEIGHT/WEIGHT DATA SUMMARY

Mr. Wiedermann: This (Figure 9) shows the relationship between body height and body weight for something we might call the average adult male and some data on a five-year-old, ten-year-old child, some young adults. The male of the species end up roughly at this point; the female species end up at a slightly lesser height and lesser weight.

We developed some parameters, multiplying factors in a sense, to establish something which we can call thin and fat, tall and short. This shaded area represents about ninety to ninety-five percent of the adult male population.

So, we have some idea of the spectrum of the anthropometric variables we're dealing with, and we establish some scaling laws so that we can get some useful numbers for carrying out the analysis.

Now, the first passenger motion I'd like to discuss is the standing passenger. It turns out that the sudden change in velocity of the floor of the car basically upsets the passenger so that his subsequent motion is independent of the change in velocity and the acceleration of the car.

TUMBLING MOTION RESULTS IN IMPACT (OF HEAD) ON:

VERTICAL BARRIER (PARTITION, STANCHION, ETC.)
FLOOR

SPECIFIC PARAMETERS INCLUDED--BARRIER SPACING

CONCLUSIONS:

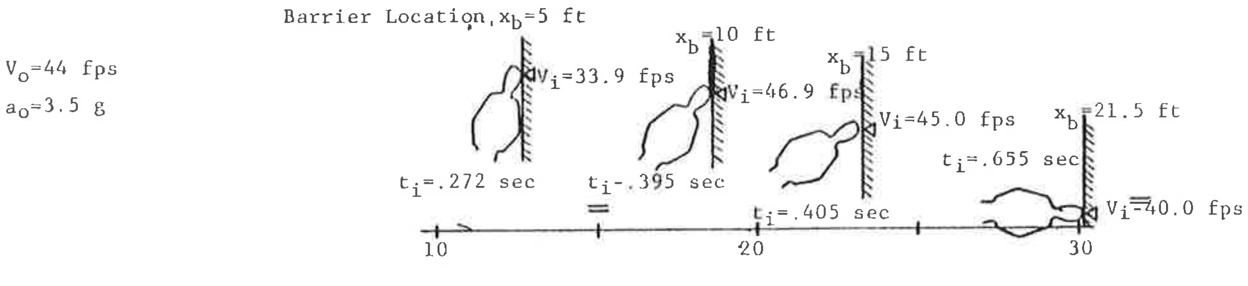
WEAK DEPENDENCE OF IMPACT VELOCITY UPON POPULATION CATEGORY.

IMPACT VELOCITY WITH BARRIER IS ROUGHLY EQUAL TO TRAM CAR VELOCITY CHANGE PLUS DISTANCE VARIATION CONTRIBUTION.

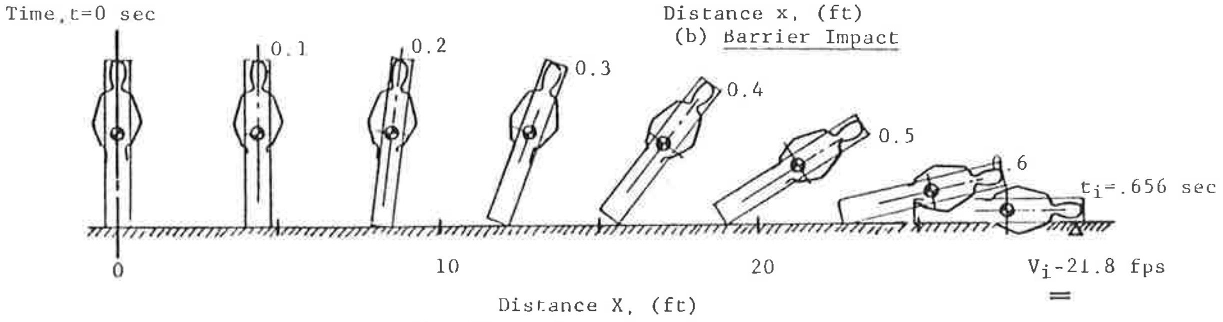
IMPACT VELOCITY WITH (HARD) FLOOR IS MODERATELY SEVERE.

FIGURE 10. STANDING PASSENGER

From the Floor: Sir, is the passenger holding on to anything?



Distance x, (ft)
(b) Barrier Impact



Distance X, (ft)
(a) Floor Impact

FIGURE 11. TUMBLING PASSENGER TRAJECTORIES

Mr. Wiedermann: No.

From the Floor: He's just free standing?

Mr. Wiedermann: He's free standing. Now, I could make other comments, but I don't want to take the time on that now. Perhaps we can discuss those things in the workshop.

As I say, the effect of the change in motion is basically to upset the passenger. He then undergoes a motion and depending upon the location of the nearby barriers, he will either strike a barrier with his head or impact his head on the floor.

Now, we find that this type of motion is very insensitive to the population category, that is to say, the anthropometric variables. All these passengers move in roughly the same kind of pattern. We find that the impact with a barrier, which in this case might be a stanchion or a bulkhead or something, is dependent upon, of course, the change in velocity of the car with some perturbations due to his rotation. And we finally see that when impact with the floor occurs, this is a head impact. If the floor is relatively hard, this is a relatively severe situation to be in.

Impact velocity is of the order of twenty feet per second or slightly greater, and again, that was a result that was independent of the population category.

Mr. Wiedermann: cont. This (Figure 11) just illustrates the nature of the model we used. It was a simple, tumbling block model. We had the capability of using more sophisticated linked mass models; the difficulty with those models is you have to specify connecting relationships. These relationships are poorly founded. So you end up with a more sophisticated model with additional uncertanties, and it's not clear that by going in that direction, you'll improve the results in any way at all.

This is the standing passenger. He begins to tilt, contact with the floor is lost very early, and he merely flips over and strikes his head here a little bit over on the floor at slightly over twenty feet per second. This takes about six and a half tenths of a second. If there is a barrier, then these are the barriers, then these are the locations of the separation distances between the passengers and the barrier. He will strike his head on the barrier at velocities which are of the order of the change in velocity of the car, which in this case, was thirty miles per hour.

From the Floor: Is there any information on which way a person should stand; sideway or frontway?

Mr. Wiedermann: No, no. Well, you see it's quite clear if we arrange the varied heights and sizes of the individuals, even treat five-year-old children, they respond very much the same. They would fall over, and if they hit the floor, and this is like a thirty foot distance in this particular case, the impact velocity of this corner is like twenty feet per second; if they strike a barrier, these numbers are not so much this one because you're still really in process, but once you get out to this intermediate range, you see you're up like this velocity, forty-four feet per second.

From the Floor: The distance, is that with respect to the ground or with respect to the car?

Mr. Wiedermann: This is with respect to the floor of the car. The floor stops, in this case, I think, the number ten, yes -- the stopping distance corresponds to these conditions is ten feet. So that if the barrier -- the passenger is basically moving through space thirty feet -- if the barrier is twenty feet away, the car stops in a fixed frame of reference ten feet further, thrity feet, so he just reaches the barrier when he hits the floor.

So, in this instance, then, the car itself stops in ten feet; the passenger who is some distance back from the end of the car, moves through a space a total of thirty feet before impact occurs. I might add, he does have some horizontal velocity still left there.

From the Floor: Are you saying here, that the passenger can get going faster than the vehicle was traveling?

Mr. Weidermann: No, he's basically standing still in space.

From the Floor: You've got 46.9 feet per second at ten feet.

Mr. Weidermann: That perturbation from the car velocity is due partly to his rotation, so he gets an additional increment of velocity there.

The next passenger configuration I'd like to talk about is the forward facing, seated passenger, and the backward facing, seated passenger -- all three of them, I guess, are on this slide. Here, we, of course, considered the train car crash parameters, that's the velocity, the acceleration pulse; variations in the anthropometric parameters; and in dealing with the forward facing seated passenger, we had basically two models; one we called the hip loft model, and the other is the pin hip mode. In the latter case, we also included slip, and I'll discuss that in a moment.

The other factors that are of concern are the spacing of the passenger from the, say in this case, the seat back or a partition immediately in front of him.

From the Floor: Is a pin hip a seat belt for the passenger?

PARAMETERS - TRAIN CAR CRASH PARAMETERS
ANTHROPOMETRIC PARAMETERS

FORWARD FACING:
- SPACING
- HIP LOFT (HIP LOFT & PINNED HIP MODEL)
- SLIP

BACKWARD FACING:
- FLEXION RESPONSE

SIDEWARD FACING:
- SPACING

CONCLUSIONS:

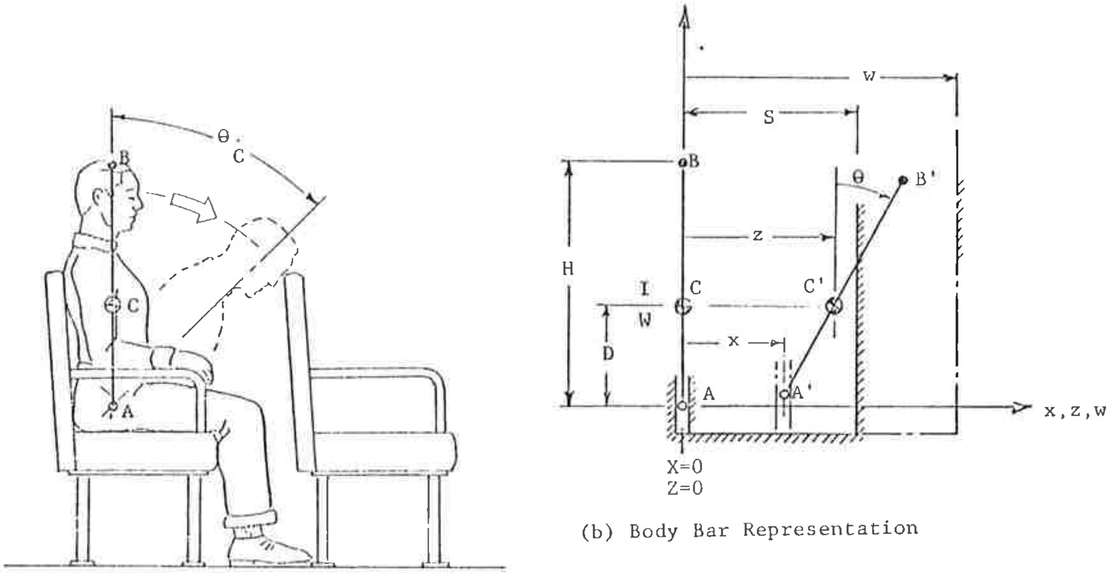
IMPACT VELOCITY IS DEPENDENT UPON IMPACT PHASE

IMPACT VELOCITY IS STRONGLY DEPENDENT UPON ANTHROPOMETRIC PARAMETERS AND SLIP

ACCELERATION PULSE SHAPE INFLUENCE IS NOT STRONG

NECK INJURIES ARE EXPECTED TO BE MINIMAL

FIGURE 12. THE SEATED PASSENGER



(a) Passenger Configuration

(b) Body Bar Representation

FIGURE 13. HIP LOFT MODEL FOR FORWARD FACING SEATED PASSENGER

Mr. Wiedermann: cont. Well, not really. I'm using it here, as I'll discuss in a moment, as a bounding solutions for the real practical case.

The rearward facing passenger just undergoes basically a whiplash type of experience. The sideward facing passenger essentially rolls over and if there is a seat back or a partition close enough, he will strike his head or shoulder on that object.

The results of this analysis shows that there is a rather strong dependence on the impact velocity on the impact phase, at what part of the train stopping phase the impact occurs. There's also a fairly strong dependence on the anthropometric parameters and on slip.

In general, if we have equivalent pulses, the acceleration pulse shape is not important, and we'll find out that the backward facing seated passenger who experiences whiplash is very unlikely to be injured. That's a minimum severity type of situation.

This illustrates the nature of the motion response model that we used for the forward facing seated passenger. We basically limit ourselves to what we felt was the gross response of the passenger, namely to roll over forward as in the manner shown. So we modeled the torso head combination as a single body bar with the center mass located here, and some kind of restraint at the hip point.

Mr. Wiedermann: (cont.) In the hip loft model there is no vertical resistance to this point, so that the CG move horizontally,

To compensate for the rotation, there must be a lofting of the hip point. Quite clearly, there is mass and of course, corresponding inertia. The upper legs, thighs, which would tend to not allow that upper part of the body or point A to loft.

To compensate for that, we pinned this joint. That would be equivalent to a seat belt restraint, or in part, it overcompensates for the inertia that this part of the body would have on the motion of this upper bar.

Finally, we included the factor slip. Mainly the fact is that there is little resistance at the seat point, so the passenger moves forward by some distance. That slip will terminate, however, when this space is consumed. There's impact of the hip with the seat back partition, here and at that point, there is a forward rotation of the body bar, and of course, the upper part of the passenger.

In this manner, we felt we had a reasonable bound on the response of the seated passenger. This diagram (Figure 14) shows, in a dimensional fashion, these velocities are just normalized by the change in velocity of the car.

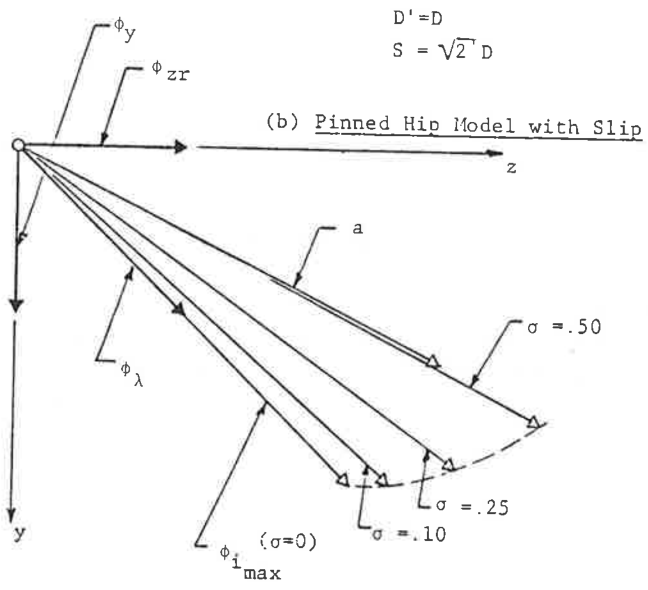


FIGURE 14. VECTOR DIAGRAMS FOR IMPACT VELOCITIES OF SEATED PASSENGER FACING FORWARD

Mr. Wiedermann: cont. We've got some reasonable values here for the body size. This is the distance above the CG to the impact point. This is a spacing point. D in this case, is an important anthropometric variable; it's the distance between the hip joint and the center of gravity of the body.

This is the vector, the impactor vector for the hip loft model. This is the corresponding vector for the pin model without slip, and these are the influences of slip, going from no slip to slip equal to half the body dimension there, which is about a foot. So this is like six inches of slip.

We see that the magnitude and direction of that impact velocity is not too strongly dependent on the model, per se. We will find here again by the change in velocity of the car, increases very rapidly -- I left off a parameter here; kappa, which is basiclly the inverse of the stopping distance. When it reaches a critical value there, then the impact velocity is relatively constant.

The varions curves in Figure 15 show the difference between the two models, the pin and the hip loft model, and these two sets shows the variation and the uncertainty in certain anthropometric parameters, this being basically the moment of inertia. We get the same kind of result when we consider the effects of slip, zero slip up to about fifty percent for that characteristic dimention.

So, we have then a pretty good idea of the magnitude of this impact velocity as a function of the parameters, and I might point out at this stage, that we really have a statistical problem here, when we introduce the variability of the anthropometric variables, when we introduce the variability of slip, or the uncertainty of slip.

But most importantly, we see that there is a kink in the curve here, which is dependent on the inverse of the stopping distance.

Before I talk about the lines shown in Figure 16, let me just talk about the variables that are shown here. With our square pulse, and if we define the pulses by an average acceleration, we have four unknowns, four variables, average acceleration, change in velocity or velocity of the car frame, the duration of the pulse, and the stopping distance. We have two equations relating to these; so given two, we can define the other two.

Mr. Wiedermann: cont. The pulse shape only influences this scale here. It slides it back and forth by a factor of like maybe a half or a quarter at most. So, that we can pretty well get a feeling for what is going to happen when we have slightly different pulse shapes.

I've shown here lines of constant impact velocity. Given a passenger and an impact on a given structure, this line of constant impact velocity basically is a line of constant injury. So, these then represent, for a given passenger and interior structure, lines of constant injury.

We see we have a bend in the curve. There are two definite regions. Now, this is the stopping distance of like that characteristic dimension. If the car stops in a very short distance, then the impact velocity is independent of the car velocity and is only a function of the acceleration level.

This scale here to 100 feet per second; that's equivalent to 60 mph. We're basically operating in the real world, in this domain, with accelerations and average accelerations. Here's ten, so we're basically in this operation, this range here. Here, the characterization is that the impact velocity -- the impact occurs after the car has stopped. In that situation then the impact velocity is dependent on the acceleration level and independent of the speed or change of speed of the car.

Now, what that means, of course, is we do not necessarily want to make the car any stronger. We need to limit the acceleration, so you want to limit the force that the end of the car sees, and you'd like to have it then crush. That force would just manifest itself as a crush distance, and obviously you have to exclude the passengers from that part of the car.

Furthermore, that distance increases with the square of the changing speed of the car. The backward seated passenger, using a very conservative injury criteria, is safe beyond accelerations of about 12 g's which is basically above what the environments we would anticipate we would encounter. So that passenger is generally quite safe in that passenger configuration.

Unfortunately, we don't know which end of the car or consist is going to be struck. Finally, we put all those features together into a little computer code, or prediction methodology in which one

Mr. Wiedermann: cont. can use a consist car interaction model to generate change in velocity for each car of each consist,or one could just use these as input parameters to study the remaining problem.

We have the capability of putting in a variety of passenger distributions in terms of the numbers in the train and each of the consists, in each of the cars and each of the passenger configurations. Central to this model is the recognition that the impact velocity of the body component on the structure is an important parameter. So we go directly to that, using mean values for the passenger configurations, and then we introduce some statistical variations to incorporate the uncertainties of the problem.

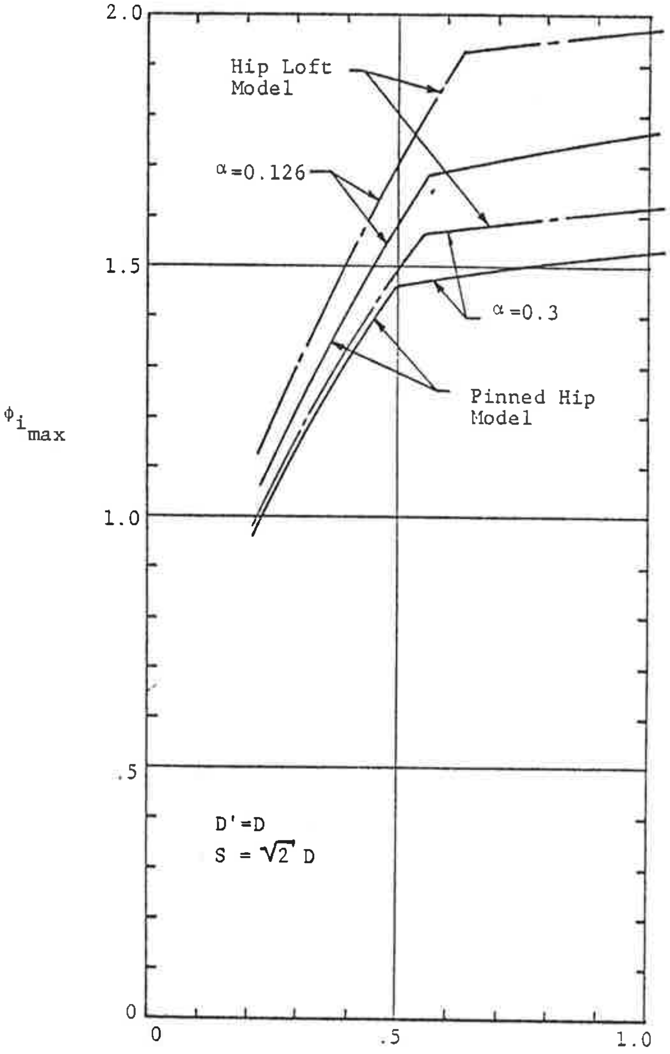
We have some spacing considerations. We have to feed in three or four parameters for the various types of response conditions that we use to idealize the interior conponent. We come up with a severity index,compare it with our criteria,and end up with a profile of injury. We've thrown in a few other little features to try to bring the model a little closer to reality.

Not all passengers that fall to the floor will impact their head, and they may be able to use their arms to break the fall. So, we put in a few factors of distributions to account for that kind of situation.

They are clearly not well founded.

I'd like to turn the talk back over to Dr. Hahn to make a few closing remarks.

FIGURE 15. IMPACT VELOCITY DEPENDENCE ON MODEL



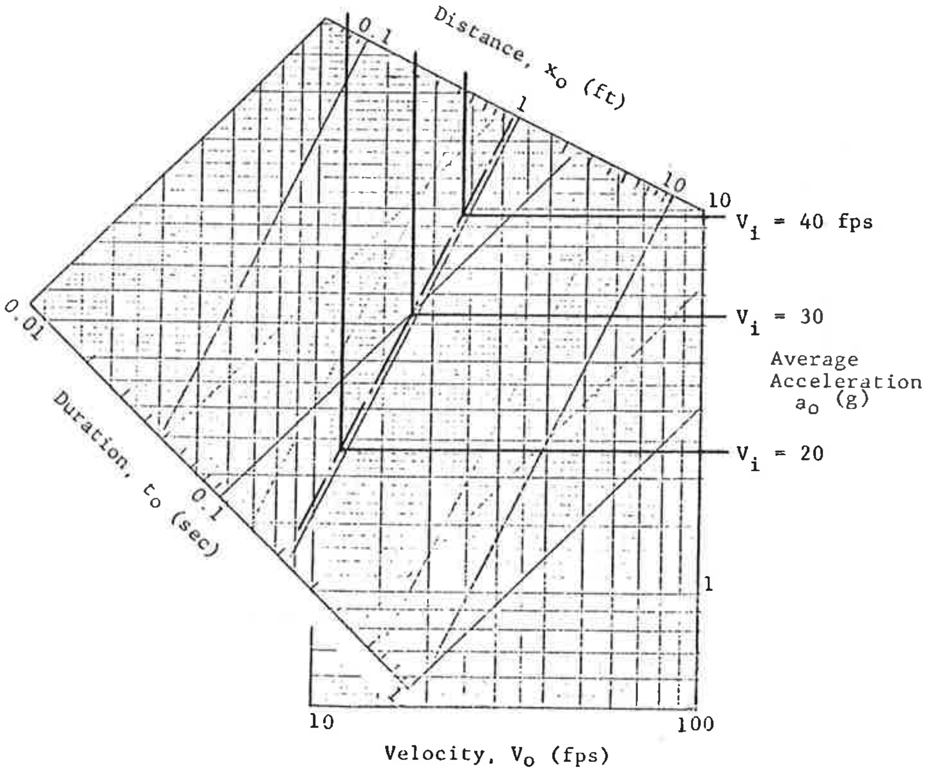


FIGURE 16. CONSTANT INJURY CONTOURS FOR FORWARD FACING SEATED PASSENGERS

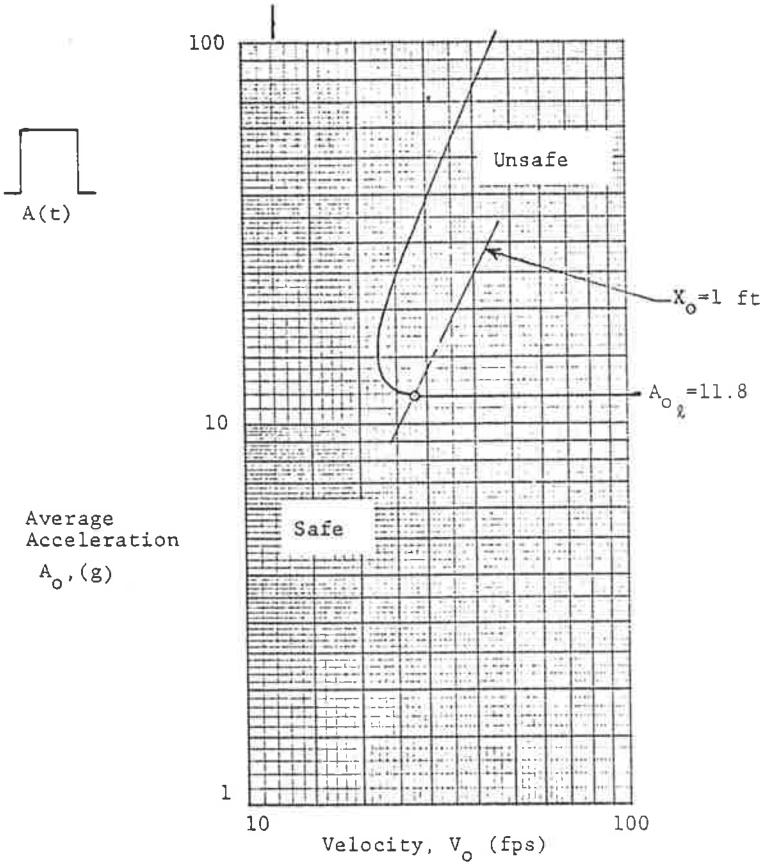


FIGURE 17. SAFE REGION IN TRAIN CRASH DOMAIN FOR BACKWARD FACING SEATED PASSENGERS

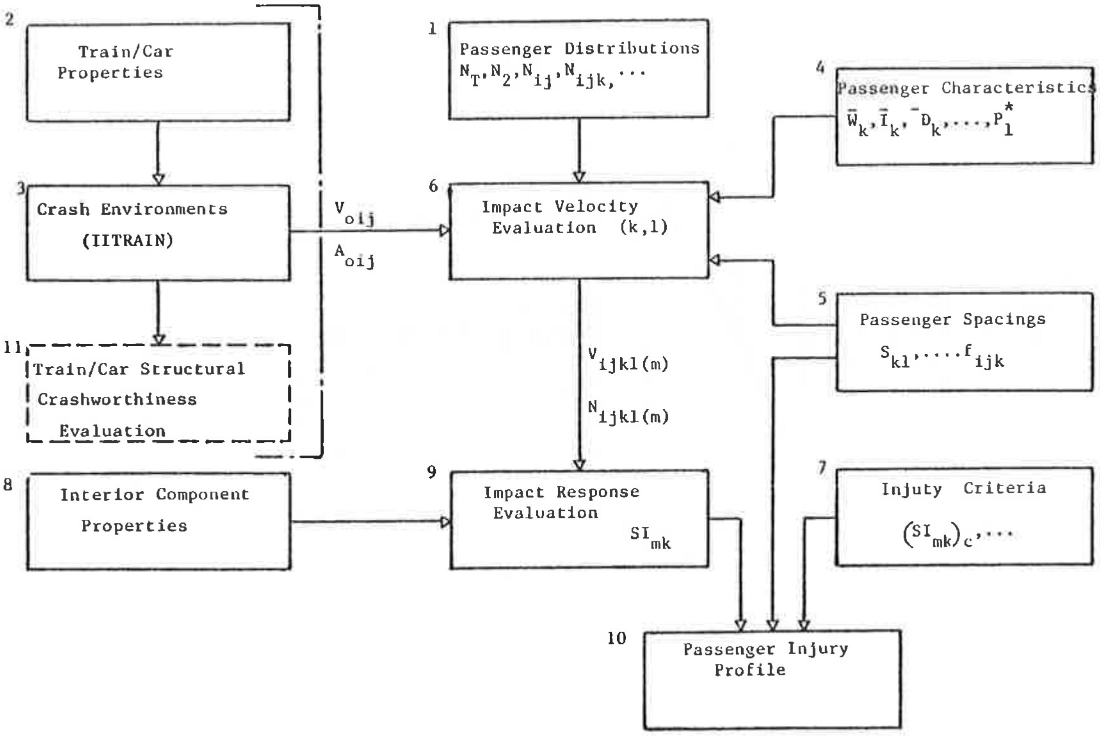


FIGURE 18. PASSENGER INJURY PREDICTION METHODOLOGY

IITRI - DR EDWARD HAHN

Dr. Hahn: We feel that with the work that's been done by various people,that we're now in a position where actually there's enough data available to start to prepare a set of tentative standards for safer urban rail car design. We just briefly laid out a program for such a project, and I can just go through it (Figure 19) real fast. I necessarily have to start out with a review phase, review what kind of standards and specifications may be set by properties now. Usually that's just a buff load as far as I know, and very little more insofar as what we've been talking about. The analytical work which has been done and the experimental work which has been done so far needs to be determined.

We also need to find out how people actually are injured and killed in transit car accidents. Boeing had some data, but most of that data was from one accident in Chicago, and we just don't really know how people are killed, and so we don't know which part of Arnie's work really applies. So, that could be done, either from existing accident reports (I don't think they're complete enough) or we'd probably have to look at new accidents. That might take some length of time waiting for the accidents to occur.

There is more work that needs to be done insofar as establishing analytical techniques. The model I have, for instance, is only good on straight level track. What happens if you're going up an incline, or if you're on curved tracks; there might be quite a bit of more things that would occur then. Also, we haven't considered derailment type accidents, and that may also occur in transit trains. For instance, one fell off the L structure in Chicago.

The analytical techniques need also to be validated with some kind of experimental results. You know, all of our transit computer results aren't worth too much until we're really sure that they do match what happens in the real world. So, we need some sort of validation, some sort of test program, full scale preferably. And then we would need to conduct more complete variation of parameters study to obtain the data that's necessary in preparing a set of standards. A set of tentative standards could then be prepared. It probably couldn't be very complete, but at least we could get something or other off the ground and get started. This set of standards would need to be validated. We would, at that time, prepare some sort of full scale test plan for evaluation of the standards, and then we'd need to actually carry out the full scale tests and to modify the standards to match what occurred in the tests.

1. REVIEW
2. PREPARE SENARIO OF RAPID TRANSIT ACCIDENTS
3. ESTABLISH ANALYTICAL TECHNIQUES
4. VALIDATION OF ANALYTICAL TECHNIQUES
5. CONDUCT VARIATION OF PARAMETER STUDY
6. DEVELOP CRASH SAFETY GUIDELINES
7. PREPARE TENTATIVE SAFETY STANDARDS
8. PREPARE TEST PLAN FOR FULL-SCALE EVALUATION OF STANDARDS
9. FULL-SCALE EVALUATION OF STANDARDS
10. PREPARE MODIFIED STANDARDS

FIGURE 19. STANDARDS FOR SAFE URBAN RAILCAR DESIGN

TRANSIT AUTHORITY EXPERIENCE

Dr. Donald Ruskin, MTA
Walter Keevil, CTA
John Tucker, MARTA
Joseph Sebastiano, NYCTA
Noel Marks, NYCTA

MTA - DR. DONALD RASKIN

Mr. Madigan: I'll turn it over to Frank Cihak, and Frank will introduce his panel of authority members.

Mr. Cihak: Good afternoon gentlemen. I'd like to very quickly introduce the members of the panel and explain how they'll speak. And then for my own benefit, I'd like to go through the audience and ask if you would all introduce yourselves, because I see all the names on the list that I don't know, and I think it might be beneficial for everyone. The first speaker this afternoon on the panel will be Dr. Raskin from the MTA, who's on my left. Second will be Walter Keevil, from the Chicago Transit Authority, who's next to him. Third will be John Tucker, from MARTA, who's on the far left, and finally the New York City Transit Authority, Joseph Sebastiano and Noel Marks, who'll both be participating. I am Frank Cihak, Manager of Technical Programs for the American Public Transit Association, and I formally had a long relationship with the Chicago Transit Authority, so some of you may have met me there at one time or another. If there are no objections, could you just go down the lines here and introduce yourselves.

INTRODUCTION OF AUDIENCE

Mr. Cihak: I should briefly explain how the panelists were selected today. I made the selection myself, and I tried to get the mix of experience that we have. Dr. Raskin will be representing the MTA with particular emphasis on the commuter type operation, relatively high speed and large cars.

CTA and NYCTA should be included in any discussion of this type just because of their size, and finally John Tucker, representing the newest property to come along.

Some of you may be aware that Dr. Raskin prepared a monograph some years ago, entitled "Physics of Collisions" for the Transit Development Corporation, which put forth most of the ideas that were expounded on this morning. Ed Widmayer mentioned that eight years of experience gave him his conclusions. Well, I could say there were eighty years of experience that arrived at the same thing, so we validated what we have heard before.

With that, I will call on Don.

Dr. Raskin: I'd like to start out by thanking those responsible for the meeting, UMTA and TSC. I hope that everyone understands that all of us are interested in technology transfer, and I'm hopeful that this sort of meeting will be one of the most fruitful ways of transferring people's knowledge about technology and hopefully advancing the state of the art in the most painless, most efficient way.

I will mention that back in January of '73 the Institute of Rapid Transit, which is now merged into APTA, held an internal symposium, somewhat similar to this one except that it was only the users that met at that point. There were no car builders nor any consultants at the meeting. The monograph that Frank just mentioned was prepared for that meeting, and those of you who are friends of Frank will be able to get a free copy from him. Otherwide, you can buy it from the government.

The thrust of that paper was to set down the framework for the kind of papers we heard this morning on a very simplistic but hopefully nontrivial level -- talking about very basic things in very simple terms. Clearly it did not have the depth or range that the kind of computations presented this morning have. However, it did deal with the basic fact, which is when you have a collision of some sort, there is an amount of energy that has to be dissipated in some way, the energy of moving cars.

One of the reasons that we held that seminar was that there had been a great deal of controversy resulting from the previous year's collision on the Illinois Central, which was a collision between two very dissimilar cars. Much of of the severity of that collision related to just that, that they were cars of very dissimilar designs.

However, one of the points that was expounded on at length in the official analysis of that collision, was the difference in weights of the cars. One of the attempts made in the "Physics of Collisions" paper was to point out that weight itself is not the critical item. That, in fact, for given closing velocities, the lighter the car weight, the less energy there is that has to be dissipated. Therefore, in this sense, you're better off with lightweight cars.

Of course, the kind of damage that is done after a collision occurs is not a function of the weight of the car, so much as it is a function of how that weight is used -- what is the internal structure of that car. That subject is fairly obvious and has already been discussed, but I'll just point out that cars built to the same 800,000 lb buff load standard vary in weight from 70,000 pounds up to 160,000 pounds. So to the extent that one standard can be used to support the claim that the structures were "just as strong," this results in a terribly wide range in car weight. If the structure is not being strengthened by the extra weight, Dr. Raskin: cont. then that extra weight is very much a handicap in a collision, simply because it increases the amount of energy that does have to be gotten rid of in one way or another.

Clearly what has been discussed this morning is how is that energy best dissipated, or more accurately, models of how it is actually dissipated without value judgments added.

Another point that has already been mentioned, especially by Ed Widmayer, is that it's not just the design of the structure but also the quality of the construction itself, particularly if a designer assumes a certain strength in the attachment of members to one another (the welding strength), then clearly if the welding is not done well or if it's not done exactly to the drawings, you're in really deep trouble. This was, in fact, one of the observations made on the Illinois Central collision. It seems fairly clear that it was also a problem in the SOAC collision.

But in any case, the basic problem, as I said, is to dissipate that energy. How you do it is, to some extent, a question of philosophy, and that's what the remaining members of the panel will be discussing.

You have many choices in designing a car or in writing the specifications of the car. You can range all the way from a very hard structure to a yielding structure. What you do on the one hand is to protect the car; what you do on the other hand, to some extent, is to protect the passengers (or certain passengers). That is a basic philosophical question. To some extent, you do have to protect the car. To some extent, however, you can sacrifice that to minimize certain kinds of injuries.

As Frank mentioned, I am the representative on the panel who speaks for the commuter users, and as you probably know, the commuter cars are designed to equal or exceed federally regulated construction standards.

I'd like to give just a little bit of history of where these standards came from. One thing you may be interested in knowing is that the first passenger car construction standard was, in a sense, developed by the government. It was for the Railway Post Office cars, in 1911, and required that the cars be able to withstand 400,000 lbs. of longitudinal load, with the load being taken up by the combination of the buffer and the draft gear. This was prior to the tight-lock coupler, so that these two items were of a very different configuration than they would be now.

In 1936, when the tight-lock coupler came along, at first some people felt that this was the answer to the maiden's prayer in terms of collision survivability. In fact, it didn't take too long before they found out that wasn't the case. But in any

Dr. Raskin: cont. case, it did require a revision of the RPO spec because of the very basic change in the nature of the construction. At the same time, or in parallel to that revision, the Association of American Railroads (in 1939) developed what they called at that time a "recommended practice", which evolved in 1945 to a standard, which is now referred to as "the AAR standard." It has subsequently been revised.

The AAR standards are, in a sense, a compromise between the hard structure and the soft structure. Basically, that is what you have to do; you can't go to either extreme. In some sense they must be somewhat arbitrary, and not all railroads build to the minimum requirements. For instance, there is one railroad that builds their cars to a 50% higher standard than the 800,000 lb buff strength which is one of the items in the AAR spec.

The AAR standards relate to five different things, the compression strength, which is the one that everyone always thinks of when you talk about AAR standards. They relate to the anticlimbing apparatus of the cars and the vertical strength of the coupling arrangement. They specify certain strength levels for structural elements commonly called "collision posts", and they also refer to the mechanism for locking the truck to the car body so that it doesn't run away.

I'll make a few comments in general, rather than regaling you with all the specifications as they stand. First of all, as you undoubtedly know, there are really two sets of standards. One relates to trains of greater than 600,000 pounds total empty weight, and one to trains weights less than that.

Another very important point is the fact that the AAR standards are not what's printed in the Federal Register. The AAR standards are much more extensive than those few items that do appear in the FRA's regulations. For instance, in addition to the requirement on collision posts (that the two collision posts have an ultimate shear strength of not less than 300,000 pounds), there are additional requirements on the fact that you can't use a material whose yield strength exceeds eight percent of tensile. In other words, when you do one of these tests and you find that it doesn't yield, you have to have some further reliance on the fact that you're not right at the edge of collapse.

Further, there are some requirements about how you go about calculating these various strengths. For instance, at the collision posts, strengths shall be based on the web. If you have an I-beam construction, the flanges don't enter in at all.

The other point that has to be acknowledged is the fact that the AAR standards are oriented toward the kind of passenger cars

Dr. Raskin: cont. that prevailed at the time and probably still prevail -- that is, cars that have steps leading down to a low level station platform. Therefore, with the exception of some cars that are very recent, all AAR cars do not have continuous side sills. Therefore, the design of an AAR car is concentrated towards a strong center sill structure. This is a basic conceptual difference, you might say, between an AAR car and a transit car.

I will mention that there seems to be a clear tendency of transit properties to move toward specifying what is called the "lightweight" AAR standard. However, there are very definite variations from it, in particular, with respect to the method of attachment of the truck to the car body, based on the fact that basically a transit operation is so very different from a mainline railroad.

Now a couple of general comments, and then I'll sit down and you'll get some real information. The first is that it was realized way back that no single element in the car structure is going to be able to absorb the energy of anything other than a very, very low speed collision. If you are talking about anything above five miles an hour closing speed, then you can't rely on any one of these members to avoid a catastrophe. Therefore, something like a "collision post" is a misleading term. It conjures up all kinds of feelings of security which are false security. In fact, the amount of energy that has to be absorbed is enormous. A twenty mile per hour collision represents an amount of energy which is equivalent to what it would take to lift the car sixteen feet in the air. This is not the sort of energy that you can absorb in any one particular structural member.

That is why, for instance, the AAR specs refer to so many different aspects of the car structure. It was understood even than that it was a cooperative effort between many different parts of the car structure that was going to help keep you out of trouble.

One comment I would make on the subject of modeling and of setting standards in general is the very obvious point which I'm sure we're all aware of, that the number of scenarios is simply too varied to ever really deal with. It's Murphy's Law run wild. Whatever car design you come up with to survive whatever kind of impact, you will find an impact eventually that doesn't meet your initial criteria, and you'll be in trouble. Basically, we're faced with the fact that the number of variables is high, and that in any case, the amount of energy is very high. So slight variations can cause a great deal of trouble.

Just to make the discussion somewhat more concrete, I will mention a collision between two of our New Haven cars on a seven and a half degree curve in New Canaan, Connecticut. I'll make a

Mr. Raskin: cont. general comment that this was a very well constructed car. It has held up very well in all sorts of situations, but this one was a terribly tragic situation in which collision occurred at a mimimum of about twenty-five miles an hour, but at such an angle that the end underframe was just pushed aside and folded up. One car did not override the other car, but simply pushed its way in for a distance of ten to fifteen feet, causing the death of two people who were sitting behind the cab of the car. They were sitting at least five feet back from the front of the car.

As I say, it was a terribly tragic situation, and one for which it's nearly inconceivable that practical structural design could really have forseen and withstood.

The other set of variables that we have to deal with is the passenger configuration at the time of impact. This has already been mentioned in the IITRI work and to some extent in all of the other work. One comment in the last paper was not really made clear enough in the presentation, so I'm going to emphasize the point. When the treatment of the standing person in the thirty mile an hour collision was related, it was not made clear enough (to me at least) that when that person hit the floor, the speed with which his head hit the floor was related solely to the fact that he had been standing and not to the forward motion of the car. In other words, his head hit with the same speed that mine would if I keeled over right now and hit the floor. My head would hit the floor at twenty-two feet per second. According to the experts, that can kill me. It has nothing to do with whether the car is moving or whether it's standing still.

The other thing that any transit operation will appreciate is the real magnitude of these G levels that we're hearing thrown around. One G is twenty-two miles per hour per second. When you think of what happens in a normal fairly heavily-loaded transit car, when the motorman puts the car in emergency and you get a breaking rate of three to four miles per hour per second and multiply that by seven or eight then clearly you're talking about people being tossed around. It's a very bad situation, and the question then is what can you do about it. I would like to bring up what I feel is a very important point.

The obvious thing that you do about it is that you soften the interior. But I would like to caution you at least to think twice about that path. First of all it ain't easy, especially in a transit car where you have a lot of accoutrements that people need to hold on to. But aside from that, softening the interior does increase other risks which may be, in a rail operation, much more real risks. Let's face it. Collisions

Mr. Raskin: cont. that do occur make the headlines, but they do not occur frequently enough to be our greatest risk or liability. On the other hand, one risk that we all do face is the danger of flammability, toxicity, and smoke. I don't mean to imply that this is a situation that is out of control, but it is certainly a situation that we don't want to see get worse. None of the materials that we could put in the car to soften it would be acceptable from this point of view.

To give a "real world" example, on Conrail's Harlem line in Westchester, there was a collision between two trains, a twenty mile an hour collision. There were a number of people who were thrown against seats and other hardware in the car. There was no real damage to the train. (That is, a lot of semi-expendable parts were bent. I'll also mention that sort of at random radius rods were bent throughout the train. Some were, some weren't, as you went back further to the end.) In any case, it was not what you would call a horrendous crash. There were, however, a number of relatively minor injuries: bruises, cuts, some broken limbs. As a result of that, we were essentially forced into putting padding in the cars.

Now, this padding which covers the backs of the seats was specified with our usual care with regard to flammability. This is a problem that we're aware of, and we know what the best materials are to use. We've used the best materials uniformly even though this has been more expensive than the other, easier-to-use materials would have been. Nonetheless, we are unhappy about having done it because of the fact that it's going to increase the amount of combustible material in the cars. (So that I don't mislead anyone, it's not combustible in the alarming sense; it's only combustible in the sense that the "fire load" in the car is increased by the addition of the pads.)

I will also make the point that the quality control on things like welding, which has already been mentioned, is such a critically important item. I suspect, speaking completely without any basis other than hunch, that difficulties in quality control will increase and will require even greater vigilance as quality of workmanship continues to move inexorably down. The only countervailing force may be the automation of welding operations, but nonetheless, that will require quality control and vigilance by the customer.

Finally, I'll make the point, which I will be just first of the panel members to say, and that is that the fundamental collision protection is in keeping the trains apart. That in fact, on a railway there's essentially no excuse for trains colliding. It's not, after all, like automobiles on a highway

Mr. Raskin: cont. where you don't have the kind of control over where they are that you do have for trains on a railway. Proper signaling systems are clearly the bulk of the answer to any of these "crashworthiness" questions. I would just add the further caution that this is where the investment should be made rather than in trying to beef up car structure or soften interiors which, to a large extent we must realize, a fairly hopeless approach.

Again, I will thank the people who set up the meeting, and I will thank the presenters of the talks this morning for adding an additional technical competence to the subject.

Mr. Rhine (UMTA): First of all, I agree with you that it would be impossible to increase crashworthiness for all possible crashes. But in today's world, there are a number of standards being set which do, essentially, the best you can. That is, for a given increase in investment which is not always done carefully, at least you've taken care of a significant number of problem areas. I think that's something to keep in mind, given that there's some crash scenario that nothing in the world can protect us.

So we talk about standards and whether they're the ones that the federal government inspired, as they do so often, or are those that the industries themselves think are appropriate. I think if you make a sort of best effort, that's about all we can do today in this world.

Also on your talk, your point about everybody can say it over again, but I think it's kind of a waste of time about keeping trains apart. The very reason is -- and I've looked at about every collision that's occured -- there's an element in there called a human being, the same one that's in the automobile. All of the signaling systems in the world, if you don't have automated backups and so forth, in themselves are not going to prevent collisions.

The major public involvement safety issue with rail transit is collisions. Like it or not -- I don't consider it unsafe conditions, and I don't think it's a bad situation, but that's the one the public sees; that's the one the public's exposed to. That's where these accidents -- and they are few and they are not serious -- do occur. They are collisions.

So you say we concentrate on something else, what other thing can we concentrate on besides better operators or helping operators act more safely or many more layers of automatic backups to safety systems?

Mr. Rhine: cont. I'm just saying I do think we have a duty to look at protecting people when accidents do occur if we can do something reasonable.

Dr. Raskin: I'll respond by saying, number one, I guess I didn't make clear enough that my feeling is essentially a quote of the Calspan Report which is, if you've got that weight in the car, make the best use of it. Let's build that structure just as good as we can, given what we are putting in in the way of metal.

The other point is that my feeling is that if you have a certain amount of money to invest, you invest it in the signal system. You don't invest it in going further in the car than you can in just proper design.

Mr. Stickel: So far the conference to me has appeared to be exclusively devoted to railcar to railcar collisions. That's very important, but as far as SEPTA is concerned, I'm sure that the MTA has the same problem. The highway crossing collisions are very serious. We experience a lot more of those collisions than we do railcar to railcar.

Now, have there been any work or studies concerned with improving the crashworthiness of that type of collision and the ensuing problems that occur after that collision, such as fires? Don't any members of the panel or anybody have any experience in that?

From the Floor: The FRA has had such a program going on now for several years. They did some train conspicuity work in the beginning. This is a psychological study. How big does a train look in order to avoid trying to beat it at a crossing. They did some crashworthiness quantitative testing at Pueblo Transportation Test Center. There is a gentleman here -- John Mirabella, would you like to take over?

Mr. Mirabella: Yes. The research being done now is more in avoiding the grade crossing accidents rather than just protecting the passenger car. There is some work being done in locomotive cab design which will be addressing the crashworthiness of the locomotive cab and will eventually include the grade crossing accidents, but we have not done anything specifically on the passenger car.

From the Floor: Well, we've had grade crossing accidents where, you know, the car has burned up after the first where you ignite the fuel on the truck or automobile, whichever you crash into, and there are several thousand dollars worth of damage, and we should be looking at that as well as the injuries that occur from the fire.

From the Floor: That's a big concern of a lot of engineers, especially with trucks.

From the Floor: Bill, could I throw out something here. The meeting we're having here and with what Mr. Stickel just brought up, I think illustrates clearly there is a policy -- there are two conflicting policies going on right now within UMTA that we are supposed to live by. One, make the cars better so they don't hurt people, then they are at the same time encouraging substitution of light rail and commuter rail for rapid transit, which you are encouraged to go that way rather than corporate separation. We're getting into the very thing that Mr. Stickel was pointing out.

We would better be advised to avoid the grade crossing. Now given where you've got them already, you got to deal with them, but I think UMTA's policies are to encourage more of this, not less, and I think that should get the meeting back to UMTA somehow.

From the Floor: You say there's a policy on our part to build safer cars. I don't think we've done anything in any way yet that's told anybody or given any idea, so I don't know where you get...

From the Floor: Well the meeting was called here to examine the worthiness of considering doing anything further in this area, but it's completely open as to whether it should be open or not. It's a R & D question -- that's open.

Now, the other policies, we can agree, that UMTA had people look at alternatives to the whole rapid transit and so forth.

From the Floor: To me, it's a downward looking alternative; they always want to make it cheaper, cheaper for obvious reasons. Then, we get into, what I think, are catastrophic consequences, not just super consequences.

From the Floor: I agree with you that UMTA encourages people to look at alternatives to rapid rail, including light rails, but I don't think anybody in UMTA adovcates mixed traffic light rails as some of the old systems do.

From the Floor: We're talking grade crossings, which Ed Stickel brought up. If you look at railroad division SEPTA which is a high-speed trolly system, they have lots of grade crossings, and it doesn't shake a rabbit -- most of them are minor -- the Red Arrow has several trolley cars that have been smashed up totally over the years.

From the Floor: I thought you were addressing new systems?

From the Floor: I am, but here again, there's an encouragement -- now we haven't built yet, but there's an encouragement to look at alternatives particularly those which are cheaper.

From the Floor: Well, Buffalo was told to go ahead on that basis. The only basis they got to go ahead was to run on the surface downtown.

Mr. Rhine: We have a number of goals, not just cars. Cost is one and perhaps the most prevalently published goals, but other goals include safety and national needs; such as environmental factors, and I agree with you that these are frequently in conflict and inevitably some conflicts would exist between safety, environment, and costs. You can't have it both ways.

From the Floor: Well, we do recommend that as an added safety thing that when people push these things, they must recognize what they're asking transit properties to take on, make sure people understand there are increased hazards, potential hazards or that configuration of the system that they do not neglect the fact that their policy is pushing toward a system which may have other problems.

Something like the other questions here, put added material in there to save from occasional accident, and you're carrying a fuel source around with you.

From the Floor: Probably at the risk of repeating what other people have said or anticipating what someone said, I do anticipate the need of federal involvement in determining by modeling and by physical testing that correct stress levels -- what best stress levels would be for a car design.

In our case, it has to be regulated by the FRA, and so we are in the 600,000 pound cars with 400,000 pound buff, all that kind of stuff. Much of it is arbitrary. It is my thought that they have to be "A" best design for the best utilization, and I think some parametric studies should be made along that line -- the suggestion is some parametric studies that would involve the thoretical work and the practical work that would actually determine "A" best or a matrix of stress levels with the various members of the car.

Mr. Cihak: I would like to thank Don for his comments and bring us up to speed on all these things I experienced in the history of the Railway Post Office in the AAR items myself.

CTA - WALTER KEEVIL

Mr. Cihak: Next will be Walter Keevil of the Chicago Transit Authority. Walter is Supervisor of Electric Vehicle Design, and Walter is a graduate of the Northwestern University and a very old and dear friend of mine. Walter...

Mr. Keevil: I have to start out by saying I was pleased at many of the comments this morning from the various research authorities and other speakers as to what would be the best items to insist upon in car design, because it just so happens that they are almost all in the present CTA specifications. I hope we got there first.

The CTA philosophy of car design has been developed since the late 1940's and has come now to be a very well thought out and complete specification for the car body structure. The basis of the design is what we call "controlled crush" whereby we take into account all of the features of this morning and say that we are going to sacrifice part of the car in a collision, but we insist upon the center of the car between body bolsters, being suitably strong so that it will not be crushed. We have in essence then a three-part car, the two ends and the center. The ends are further divided into the areas outside the coupler anchors and the area between the anchors and the body bolster.

We have also taken into consideration the level of stresses in the various members of the car under the load conditions that are specified, both horizontal and vertical. The load conditions are based upon AAR specifications. A lot of our specification has evolved from that source. The numbers are not the same, though, because we have a much lighter car. Our present cars weigh about 52,000 pounds while some of our 1950 era cars were as light as 44,000 pounds.

We do demand that certain stress levels not be exceeded in the car body structure and that certain section moduli be met for the center and corner posts. We also have a section that spells out the types of welds that are permitted and those that are not permitted and a definition of weld quality and technique to insure maximum weld strength.

We also insist that the center posts be complemented with two corner posts and that all of these be tied together with anti-telescoping plates, which is old-time railroad practice. The entire front end structure is tied to the roof, so that while the roof itself may not carry much of the load, it will not become detached from the posts. This helps us with the anti-telescoping provisions of the rest of the design.

The center and corner posts are carried completely through the end underframe so that they extend out the bottom and they are welded all the way around, top and bottom.

Mr. Keevil: cont. It seems that everything that has been mentioned as being good, except, perhaps, putting an airbag on the front end of the car has been incorporated in one way or another. We have details on the loads and deformation characteristics of interior items such as seats and stanchions to insure that they are not torn loose or collapse when subjected to the loadings during a collision.

As everyone has mentioned, the philosophy for controlled crush is very basic to rapid transit. You don't have a cornfield in which you can spread cars out as you do on the mainline railroads. You need to take out the tremendous energy of the collision without spreading things all over, without knocking cars off the elevated structure into the street, or without filling up the subway tube with crushed metal. So the controlled crush philosophy allows this and gives us a car that will deform and will not telescope and will, yes, destroy the very ends of the cars. Granted you could put vestibules or dead air spaces at the ends of the cars but with Chicago's 48-foot car there is very limited space for this. We would have to add extra cars to the trains to carry the same loading if we were to block off the first six feet in the car.

Our design has been proven in service and I think that the study of it and perhaps incorporation on other properties would be of benefit.

From the Floor: What's your buff load?

Mr. Keevil: Buff load is 200,000.

From the Floor: Did you ever contemplate specifying some speed of collision like five miles an hour or something like that in your specs?

Mr. Keevil: Specifying it and then demanding what at that speed, that nothing happen?

From the Floor: Yes.

Mr. Keevil: No, we have not. With that five miles an hour, however, very little does happen. We have bumped into bumping posts at that speed. We couple at five miles an hour too occasionally and shear the shear bolts.

From the Floor: I remember when you talked about developing the full strength of the members that you welded. How do you go through that manufacturing process? Do you test?

Mr. Keevil: We don't have the capability of verifying it. We specify it. We review the car builder's designs, the

Mr. Keevil: cont. types of welds that he's using, the material of the welds. We don't actually test the welds to insure that they do meet that, however.

Mr. Madigan: One of the things that came up this morning was the dissimilarity between equipment specifications and raw material.

Mr. Keevil: Right. We do not cover that.

From the Floor: At best, you could only approve a procedure, which I'm sure he does. You approve a procedure, get the welder certified, make sure for your quality control function that they remain certified, and then take sample sections for test. Chicago does all of that.

Mr. Keevil: We don't take sample sections.

Dr. Raskin: Can I mention one thing? There was some discussion this morning about non-continuous welding. I'd just like to make a point that in itself, there's nothing wrong with that. I'm sure the gentleman from Budd Company, if no one else, will defend the fact that you don't need a continuous bead of weld. But, again, it's matter of doing it properly. There's good design and there's bad design, and there's good work and there's bad.

Mr. Cihak: Thank you, Walter. My comments exactly.

MARTA - JOHN TUCKER

Mr. Cihak: Next, we're going to have John Tucker, and John is in the -- I'm not going to say enviable position, but at this point he is in receipt of two nice shiny new car bodies in Atlanta, and I am sure that at this point he has had the opportunity to involve himself in the design of that car and satisfy himself that it does meet and will be able to do exactly what he wants it to.

With that, John, I'll ask you to tell us what it will do.

Mr. Tucker: Thank you, Frank. You've gotten me off on a different subject than I planned to talk about.

The subject today really is the experience of operating properties. Since we have fortunately had no experience with collisions, I am not able to talk about that.

However, I am very much impressed with the concern of UMTA and George Pastor to deliver technology to the industry. I would like to address that subject primarily because in designing an entirely new transit system from a blank piece of paper that's a very pertinent part of the problem. I think our experience at MARTA in developing standards around which to design a completely new transit system could be of value to some people.

Therefore, rather than talk about specific cars and specific conditions, I would like to address that subject. I am a little sorry that the policy session was called off because I think that is probably the key to this whole issue. I'll try to address that. Most of us here this afternoon are talking about policy anyway, and maybe we are preempting it.

From the Floor: We may not need a separate session as such, but maybe the last half of the wrap-up session.

Mr. Tucker: I am very much impressed with the sessions this morning. The thing that impressed me the most is that everybody seemed to be saying the same thing. The numbers, from what I could tell, all demonstrated essentially the same thing. The work that has been done up until now on totally analytical programs, seems to indicate,without a detailed study of the data, that there was very good correlation from one study to the other.

Our friends at Alusuis did some work on our MARTA car, and I think the data that we have very much correlates with the data

Mr. Tucker: cont. that I saw here today. That tells me that we are probably reaching a point in time where we should get down to the next step, and that is to do something with it.

We have to recognize that there are two basically different cars. There are commuter cars, and there are transit cars. Since we are only involved in transit cars at this time, we think that at least as far as we're concerned, the problem is simplified quite a bit.

I appreciate the problems that people have operating passenger cars on the mainline, but I'll address my comments only to the transit car. People with new properties, like us, and with just a transit operation with a totally dedicated right of way are very fortunate. We don't have a mix of equipment on our system. We don't have vehicles with different strength characteristics. We don't have old and new equipment with significantly different weight.

So our safety problems with regard to car design are much simplified. We will have a few flat cars, and some cars will be used for maintenance, but we hope not to duplicate the experiment that was conducted out at Pueblo. The basic problems, as they are pointed out, are generally understood. We have to keep cars from penetrating. We have got to have good anticlimbing devices so that on frontal collisions we don't have cars that penetrate. I think that with designs that exist today, in transit applications, we can accomplish that. We have to look at rigidity and the weight to deflections ratios of some of these cars to minimize the secondary affects of collisions.

I've been hearing about deflection all day, and it just confuses me. I think of deflection as being elastic, and some of these deflections are obviously not. I believe the correct word is rigidity. But the weight to deflection (or rigidity) ratios are important.

At the same time, we should have some standards around in which we limit the deflection or rigidity of the car body so that we can control the acceleration that people in the car feel. We should also set some standards, for what is appropriate as far as interior linings and flexibility of interiors. We, like everyone else, have spent a lot of time and a lot of money over the last five years looking at the problems. Our friends responsible for flammibility would be very unhappy if we all of a sudden started loading a car with polyurethane foam or even

Mr. Tucker: cont. any other similar material. It may help crashworthiness, but could cause a disaster if a fire should occur. I would therefore like to introduce the premise that we should at this point in time go on from the studies that have been made. Although there are refinements and improvements in the analytical studies that can be made, I suggest that we proceed to develop standards for transit cars along the lines that the AAR developed for commuter cars. With the benefit of these studies which make us smarter than our grandfathers were when they developed the AAR standards and the better technology today, we should be able to do a better job of it.

What should we specify? What we should develop are standards for the industry so that everyone can specify essentially the same thing. It is really the first step in car standardization, and it eliminates a lot of problems for many people.

Let me just cite an example. When you start with a blank piece of paper, especially on safety issues, the conservative thing to do is to make sure you're at least as safe as everybody else. I am sure everybody does that. They look at all other standards and say, "Well everybody else has 200,000 pounds of buff strength. Maybe I should have 300,000 pounds because if we ever have an accident and are ever called before a regulatory body, I can at least say that I've been more conservative than everybody else.

Certainly that's an element in the thinking process. You've got to look at precedent when you're designing something to completely new standards, and unless some standards are developed that are accepted over the country, people are always forced to take a look at the standards that exist today and say, "By golly, we've got to be better than that even though it violates the whole concept of standardization."

Then, of course, if an accident should occur in an existing property, then the investigators can point to the new property and say, "Well look at these fellows, they are so much better than you."

National standards could save much time and money. They need not be federal standards. Perhaps industry standards would be most desirable. They would save much time and decision making and probably could result in shorter lead time and more cost effective development of new transit systems.

I'd like to very briefly touch upon some of the things that perhaps should be in these standards and hopefully get to a point where people can agree on these.

I think the standard, in addition to the usual buff strength, should have some definition of what the crashworthiness criteria

<u>Mr. Tucker:</u> cont. should be. There are limitations that you can set without drastic changes in the geometry of the car, but if the deflection to weight ratio could be specified, if the relative rigidity of the ends of the car compared to the center of the car (perhaps there should be three zones) the relative strength and the strength to weight ratio could be, included in the standard for those things.

If, as I advocate, a standard were to be developed, we should consider the longitudinal buff strength as we do today. We should consider collision post design and strength and methods of attachment. We should look at anti-telescoping plates which, as Walter Keevil points out, have been used for years. They really provide the upper support for the collision post and distribute a proportion of the load into the roof structure so that the designer can take better advantage of the total structure.

We should look at truck to body attachments and make sure that these meet certain standards. We should look at corner posts. I think people in the past have tended to not utilize corner posts to the extent that we could.

We should consider the distribution of load into the sides of the car and find a way to look at the buckling, the load carrying capacity and the energy-absorbing capacity in the side sheets of the car and the side posts.

This is not a criticism, but one thing that seemed to be missing from all of the analyses I have seen to date is the fact that the car does not fail as a column uniformly loaded; it fails as a column eccentrically loaded.

With medium to high speed collisions, a great deal of deflection goes into the car in bending, and I assume that a great deal of energy goes into shear failures in side panels.

When we talk about crashworthiness design, and if we do come out with a standard, we should look at seat designs so that seated passengers can have the maximum protection. We've been working at trying to find a way to make the hand grab in the seat a frangible device so that people will break it before breaking their heads.

We have a design in our car for doing that, but I'm not very proud of it, and I think the next fellow that comes along can improve on it.

We should look at vertical stanchions. We have put padding on all of them so that we do have cushioned vertical stanchions. The only trouble with them is that with my hands I can just about hold onto them. I don't know what my grandmother would do.

Mr. Tucker: cont. I'm sure she'd find them very difficult to hold. So you get into a situation where to protect people against hurting themselves in a collision, you may, to some extent, defeat the purpose of the device that you put in.

Seat spacing is another very important thing. We all have different standards on that, and perhaps it is something that can be looked at as far as what the optimum seat spacing and the cushioning on the back seat should be.

For new properties, anyway, you have the option of putting a full width cab on a car. Some of the older properties, I'm sure, would have trouble with that, but that should be given consideration in developing a standard, at least for new applications.

We should look at the strength of the materials and the ductility of materials. I think Walter said that in his specification, the ratio yield to the ultimate strength was specified. That's really an important property because it is a measure of ductility and, perhaps, one answer to the questions that were raised this morning about how to specify ductility. You could use the CHARPY specification or you could use the ratio of ultimate to yield strength.

Of course, quality control standards, test standards, and material certifications all fall into the same category.

To summarise I think the work that's been done today is very impressive. I'd advocate that even though people that are doing theoretical analytical work see a need for more work, Let's take the work that we have today, develop a standard that would at least apply to new properties so that the decision making process that goes into starting to build something new is reduced. To the extent possible, include standards that can be used by existing properties. I think that developing standards should be the next logical step in the crashworthiness program.

Thank you. I appreciate being invited.

From the Floor: John you are advocating structural standardization, not the kind of stuff we were talking about, car body design, the component design and stuff like that. For the moment, it's the load distribution, stress analysis.

Mr. Tucker: I'm advocating structural standards but structural standards in a broader sense than the usual thing. What's the appropriate buff load? What's the appropriate shear load

Mr. Tucker: cont. for collision posts? How should the collision post be fastened to the underframe and to the anticlimber? What's an appropriate standard for weight to relative strength in different parts of the body of the car?

From the Floor: Is your idea going towards the standard car?

Mr. Tucker: Well, that's a little optimistic, but it's certainly a step in that direction. If you are ever going to standardize, these are things that people who are coming out with new procurements can standardize on as long as the standard is not distinctly different than what we have today. It is a little bit like the AAR. The AAR makes an allowance for trains that are appreciably lighter than were originally anticipated when the standard was written. You can make allowances like that.

Most transit systems, with a few exceptions, have trains of appreciably equivalent weights. If there were standard buff strengths and standard collision posts and corner posts, why they'd be consistent with many of the systems that are in use today.

If you look at the numbers for some of these things, they don't vary by ten percent. So why not have a standard?

From the Floor: I don't want to talk too much, but I would suggest that you, in forming your standards for such things as collision posts and truck attachments, support it with some technical data base obtained by some testing.

Mr. Tucker: I agree with that.

Mr. Widmayer: Before you set up the numbers and the configurations of this sort of thing, build them and test them and maybe test a vareity.

Mr. Tucker: Yes, but by the same token, whatever's done, should be done quickly, I feel it's more important to do something than to do it perfectly. If we wait standardization will become more difficult.

From the Floor: The question was raised about car standardization. Some people may not be aware of this -- the desire of them to work towards something that is more standardized than we have today without forcing people to accept a car which is not useful to them or just for the sake of standardization.

We have a separate program, project, to develop what we call a standard rail car specification. It is not an absolute standard

From the Floor: cont. car, and the standardization is primarily aimed at the sub-system level for other such questions such as reliability and the continuing apparent degredation of reliability in operational vehicles. We do have this project underway; we hope and we intend to work with industries throughout to make sure it's a useful product for them. It's of no value to us whatsoever, but we feel that by taking the time and the investment and getting input from industry of this sort would be helpful too. We will do this, and some of the property representatives today here also know of another benevolent act on our part to ask them to join together in joint car buys which has the, if you will, the effect of standardization or at least working towards the miminum number of configurations and also getting hopefully some of the benefits of larger scale production and getting more and more things to work on.

So we do have the idea that there can be some standards, and I second the idea that it would be nice if the industry would develop some of these things, and as a federal employee I'm not pushing that it's the federal government's job to do these things.

Mr. Tucker: I think we could do a great job on that.

NYCTA - JOSEPH SEBASTIANO

Mr. Cihak: The concluding remarks will be presented by the operator who probably has the largest single influence in all of this, the New York City Transit Authority who operates more cars than everybody else put together.

So, Joe, as the guy with the biggest sledge hammer of all, and Noel, I'll let you guys go ahead.

Mr. Sebastiano: Being the last property to have its say puts us at a disadvantage because most of the things that need to be said have already been said. However, we may have some input in this conference.

First, and most important is that a rapid transit system must have an excellent and reliable signal system, as New York has. The reliability of the signal system, of course, depends very heavily on its design and its maintenance. The signal system determines the safety of the system and we rely very heavily on it.

Notwithstanding the excellence of our signal system, our car design does reflect some crashworthiness. We do this, not in specifying crashworthiness, but in the actual car design. Traditionally, New York has always specified crashworthiness by design in the following manner.

First, we specify the combination of loads and forces that must be used in calculating the fiber stresses both in the dynamic and in the static condition, and we state that the combination which governs the design of any member should be used. Then, steels that may be used are specified and we state that the design must not exceed half yield of the steels used.

Prior to 1948, the car specification was not a performance specification. It was actually a hardware specification wherein almost each nut, bolt, and screw was specified. There were no collision posts or any other posts specified for the car. The end frame details and the underframe details, however, detailed specifically what the requirements were. This produced a very sturdy but heavy car and adequate for our needs.

The post 1948 era brought about a different kind of thinking. Performance specification by this time had become popular throughout the industry. High strength steels were developed. A light weight car was emphasized. Formed plastic ends were required to enhance the exterior appearance of the car. Squeeze tests came into being and became quite popular.

Mr. Sebastiano: cont. Not all of these things occurred at one time but rather as an evolutionary process, and each subsequent car order was revised to reflect new developments.

Present specifications are combinations of performance specifications in certain areas and hardware specifications in other areas.

We now have a requirement for a stress analysis to be performed and submitted for approval. We require collision posts in accordance with current AAR practices. Incidentially, these collision posts are attached not only to underframe members but to the roof members as well.

We also specify squeeze tests to be performed to prove the adequacy of the design. There are no tests, however, for the override condition where one car will override the other. We've also gone to the shear pin concept in the drawbar.

We believe that the R-46 car, our latest car, is one of the finest cars in the country. It has certain crashworthiness properties, but I don't think any of us really know what they are. The only way to find out is by destructive testing and we're not about to go into any destructive testing. We believe we have an excellent car for our rapid transit system compatible with our excellent signal system.

Just as an aside, I guess you all heard about our recent accident with our R-46 cars on the F line at one of our Manhattan stations where a lightly loaded R-46 train collided into the rear end of another lightly loaded R-46 train. As I said, we have an excellent signal system and it should have prevented this accident except that we had a problem with the cars exceeding their maximum speed requirements. The emergency trip was effective, and at the time the trains collided, one train was traveling between seven to seven and a quarter miles per hour.

Well, the crashworthiness of this car proved itself in that only the shear pins on the drawbars sheared, and there was practically little or no damage to the anti-climbers and car.

From the Floor: Did you have any passenger injury?

Mr. Sebastiano: Yes, the trains were lightly loaded during the early morning hours and 22 passengers were treated at hospitals and were released.

Mr. Sebastiano: cont. Our car design has not stood still. We are looking at a future car buy which we call the R-55 procurement. We've asked our Civil Engineering and Architectural Division to study the strength requirements of the car including crashworthiness and come up with recommendations. That study was completed about a year and a half ago and the results were submitted to APTA as being the current thinking in New York City.

Noel Marks from our Civil Engineering and Architectural Division will outline the many changes that were recommended and accepted. Noel...

NYCTA - NOEL MARKS

Mr. Marks: Being the last speaker has one advantage. I heard the other presentations first, and being in that position, I can say that the pendulum has now swung from highly theoretical to practical considerations of car crashworthiness. The question which I'll address is: "What do we put into the specifications?"

My remarks are based on comments made by the NYCTA Engineering Department's Civil Engineering and Architectural Division on the R-55* draft specifications. These comments, which were transmitted to APTA in November, 1976, appear to be quite consistent with the presentations made this morning and will provide an overview of our latest thinking in New York on car crashworthiness.

In developing crashworthiness design criteria for rapid transit cars, there are various parameters and restraints in car design which must be considered.

1. Signal System - Safety

The first parameter results from a highly successful signal system, viz., crashes are rare events.

The main purpose of signaling is to provide safety and headway in rapid transit operations. This is accomplished by installing and interconnecting literally thousands of components of signal equipment into a coordinated functioning system that in all phases stresses safety.

The signals are so spaced that if a motorman attempts to pass a red signal, even at the maximum attainable speed at that point in the railroad, his train will be tripped by the automatic trainstop and brought to an emergency stop. In general a margin of safety of approximately 35 percent of the braking distance required, for the maximum speed that he could possibly be traveling at, is designed into the spacing of most signals.

The circuits and the signal equipment that they control are so interconnected as to prevent head-on collisions,

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* R-55 is the tentative designation of the NYCTA's next BMT-IND passenger car contract.

Mr. Marks: cont.

side collisions, derailments, and other accidents, in addition to providing protection against rear-end collisions. The safety record in New York throughout its 75 years of operation has been excellent.

Therefore, our first parameter in crashworthiness design is that we are designing for a rare event. If we had collisions every day, we'd be designing for a much different set of circumstances.

2. Evolutionary Change

The NYCTA has more than 6000 cars in operation. We don't want to suddenly place "super cars" in service which could demolish existing cars in a collision. Therefore, evolutionary change in crashworthiness design is required.

3. Car Weight

There are several primary factors that must be considered with respect to car weight. These are maximum allowable wheel loads, conservation of energy to operate, and minimizing the mass in a collision.

A. Maximum Allowable Wheel Loads

Cars operate on subway and elevated structures, which were designed for standard car loadings. In New York, these standard car loadings are based on cars which are now obsolete, i.e., the BMT "Articulated Car", IND R-1, and IRT "Fliver" Car.

These cars were selected as a design standard for the subway and elevated structures on which they operate with the intent of using a conservative design loading.

Therefore, one of the criteria for new car design must be a restraint on the magnitude and spacing of maximum wheel loads, such that the stresses produced by these loads in subway and elevated structures do not exceed those imposed by the standard design loadings.

Mr. Marks: cont.

B. Conservation of Energy to Operate

Energy use and cost of operation increase with an increase in car weight.

C. Minimizing the Mass in a Collision

The heavier a car, the greater will be the collision forces at a given velocity. Also, although a heavy car could minimize damage to the car structure in a collision, it could cause substantial injuries to passengers.

Therefore, restriction on car weight is a required restraint in car design.

4. Crashworthiness Factors

There are several primary factors related to car crashworthiness. These are longitudinal compressive strength of car structure, strength of vertical end members, vertical strength of end of car, and strength of shear mechanism.

A. Longitudinal Compressive Strength of Car Structure

For the R-46 Car, the equivalent of 500 kips (at yield) at the anticlimbers and 300 kips (at yield) at the couplers were specified. Loading tests were performed to verify the buff strength design.

It is anticipated that these design buff loads will be specified for the R-55 Car.

B. Strength of Vertical End Members

AAR requirements for the strength of vertical end members were specified for the R-46 Car. For the R-55 Car we intend to supplement the AAR requirements as follows:

Mr. Marks: cont.

(1) In addition to the forward collision posts and corner posts, aft collision posts and corner posts will be provided at the cab end only, located at the rear of the cab, to improve car crashworthiness by significantly reducing the possible penetration of occupant areas by overriding.

(2) A total bending resistance of forward and aft collision posts and corner posts at the cab end equal to the resistance of the car to buff load at the anticlimber, i.e., 500 kips at yield, will be specified.

C. Vertical Strength of End of Car

For the R-46 Car, the AAR requirement for design of the anticlimber arrangement and the coupler carrier arrangement was essentially followed, i.e., vertical load of 100 kips at yield.

It is anticipated that this vertical load will be specified for the R-55 car.

D. Strength of Shear Mechanism

The shear mechanism in the draft gear of the R-46 Car is designed to release at 150 kips plus or minus 5 kips, permitting the transfer of excess buff loads to the car's underframe by allowing the coupler and drawbar yoke to travel an additional distance before contacting the rear of the drawbar where the yoke is further cushioned by the rubber in the draft gear.

It is anticipated that this shear mechanism release load will be specified for the R-55 Car.

5. Crashworthiness Criteria

The car crashworthiness factors outlined above can be derived only from the results of a controlled dynamic test and evaluation program. The high cost of such a program precludes its incorporation into any NYCTA car contract. We recommend, however, with NYCTA approval of course, that cars scheduled to be retired be made available for structural modification using R-55 crashworthiness criteria, and for dynamic testing under a Federally sponsored test program. One of the purposes of this testing would be to verify the effectiveness of the R-55 crashworthiness criteria.

The results of any dynamic test program must be expressed in equivalent static terms for specification purposes. Specification of static criteria permits relatively inexpensive static load testing to be used to check whether the car builder has, in fact, met the specifications.

6. Car Standardization

The dynamic tests used to derive crashworthiness criteria should be consistent with APTA's car standardization program. We support car standardization, and believe that the R-55 Specification should be used as the basis for a standardized rapid transit car. This would result in procurement of cars meeting the most stringent crashworthiness criteria yet to be established.

7. Static Load Testing

A variety of physical load tests are required, in addition to structural calculations and computer analyses, to check the adequacy of the structural design of the various car components, i.e., carbody, trucks, coupler, and drawbar, due to the complex nature of these structures.

In general, in our load tests, we specify maximum loads corresponding to 80% of yield to provide sufficient load input to adequately check the structure, but yet remain in the nondestructive area of testing.

For the carbody, in addition to the traditional static load testing, e.g. buff load tests, performed under the R-46 contract, it is anticipated that two additional load tests related to car crashworthiness will be specified for the R-55. These tests will be used to check the vertical strength of end of car and strength of vertical end members.

Mr. Marks: cont.

I won't take the time now to discuss the details of these new loading tests, but will provide copies to our hosts so that this material may be included in the record.

Are there any questions?

Mr. Madigan: You may have mentioned it but what comes out of this morning's meeting is the question of preventing override and penetration. Number one, as the anticlimbers meet there should be enough engagement; and number two, there should be enough vertical stiffness to keep them from tearing. How do you view that?

Mr. Marks: We agree with that. We follow the AAR requirements of a vertical design load of 100 kips at the end of the car. The anticlimbers, which are six inches high, hopefully engage. If they don't, we have collision posts, and for the R-55 a double set of collision posts to prevent override penetration. We believe that we can take a great leap forward in crashworthiness design by introducing a second set of collision posts and having the four feet between forward and aft posts as the prime area for energy absorption.

Mr. Madigan: The other thing, Noel, is I'm not too sure that they would have to test whole cars, meaning, you could get some information and might be able to get into a smaller scale testing of anticlimbers, couplers, etc.

Mr. Marks: Scale tests have their place, but because of the scale factors and the amount of collision energy involved, I think that ultimately full-scale testing would be required.

From the Floor: Do you feel that these extensive crashworthiness factors that you've included in your specs will substantially raise the cost of the vehicle?

Mr. Marks: No. Overall, we've cut down other areas in the R-55 specifications as compared with the R-46, and the net result, we believe, will be a lighter car with no increase in cost, even though we are adding four posts per car.

From the Floor: Does the spec that you're developing for the R-55 car include any new treatments of the interior of the car?

From the Floor: cont. We've mentioned padding or not padding of seat backs and things of that sort.

Mr. Marks: New York has a vandalism problem, which precludes the use of any soft material in the car interior.

Mr. Sebastiano: In addition, New York believes that the use of flammable materials should be prohibited in subway construction. We believe that it has its place in buses and high speed rail lines on the surface, but not in the subway. We would like very much to limit the amount of flammable material in the car and all plastics, fabrics, floor materials are subject to close scrutiny. These materials, if used, must meet the highest standards of flammability and toxicity set by the NYCTA. So we are not in favor of the use of cushions unless they are fireproof.

From the Floor: I think we, in Boston, would agree with that.

From the Floor: Padding is not necessarily the best approach to making interiors soft. There are limitations with padding in terms of its thickness which has to be generally rather thick to be of any value. When the pad bottoms out, you transmit the force to the supporting structure. So when we talk about some kind of a softer interior, it doesn't necessarily have to mean a padding type of an approach, but can be a softer structural system, such as a panel to deform substantially. Therefore, we shouldn't necessarily think of a foam padding as being the answer to making the interior softer as there are many drawbacks.

Mr. Sebastiano: I believe someone mentioned that handholds, stanchions and the like could be made flexible, but this is not a good approach.

From the Floor: You can have a stiff bar with soft ends so that there's a certain amount of flexibility available, which is really what you're looking for in terms of the passenger-structure interaction.

Mr. Marks: Even if you use a soft material that is non-flammable and does not emit toxic fumes when burned, you still have the vandalism problem.

Mr. Wiedermann: The soft structure could be a metal structure.

Mr. Marks: My point is that if it's soft, it's subject to vandalism.

Mr. Wiedermann: Well, how soft is soft. We have to be careful of that.

Mr. Cihak: I suggest we carry on this discussion tomorrow at the workshop on crashworthiness and railcar design.

I'd like to thank the panel for helping me out on this subject, and with that, I'll turn it back to Ron.

Note: Following are excerpts from comments to the R-55 draft specifications, alluded to by Mr. Marks, covering the strength of vertical end members and vertical strength of end of car.

Vertical End Members

Car crashworthiness criteria includes longitudinal compressive strength of car structure, vertical strength of end of car and strength of vertical end members. This criteria can be developed only from the results of a controlled dynamic test and evaluation program.

The high cost of such a program precludes its incorporation into any Authority car contract.

However, based on the material in References 1 and 2, the AAR design requirements for Vertical End Members (which were specified for the R-46 car) can be supplemented as follows:

1. In addition to forward collision posts and corner posts, provide aft collision posts and corner posts, at the cab end only (located at rear of cab) to improve car crashworthiness by significantly reducing the possible penetration of occupant areas by overriding.

2. Specify a total bending resistance of forward and aft collision posts and corner posts at the cab end equal to the resistance of the car to buff load at the anti-climber, viz, 500,000 pounds at yield. Use load ratios of 3:1* between collision posts and corner posts and 2:1** between forward posts and aft posts. For collision posts and corner posts at all non-cab ends, specify the same ** bending loads used for the aft posts at the cab end.

* Based on AAR's specification of section moduli for vertical end members

** Based on CEAD's judgement.

Reference 1:	Department of Transportation, Urban Mass Transportation Administration, Washington, D.C., Edward Widmayer, A.E. Tanner and Robert Klump, "Crashworthiness Analysis of the UMTA State-of-the-Art Cars", October, 1975, Report No. UMTA-MA-06-0025-75-15
Reference 2:	Department of Transportation, Urban Mass Transportation Administration, Washington, D.C., R.J. Cassidy and D.J. Romeo, "An Assessment of the Crashworthiness of Existing Urban Rail Vehicles"., November 1975, Report No. UMTA-MA-06-0025-75-16.I and II

Therefore, include the the following criteria for Vertical End Members in the R-55 specifications:

3.5.3 ENDS OF CAR

The ends shall consist of a molded plastic shell over steel framing members consisting of 2 forward collision posts, one at each side of the end door opening, and 2 forward corner posts. In addition, for the cab end only, 2 aft collision posts, one at each side of the cab door opening, and 2 aft corner posts shall be provided at the rear of the cab. Each forward post shall span between the underframe structure and anti-telescoping plate, and each aft post shall span between the underframe structure and roof structure.

3.5.3.1 STRENGTH REQUIREMENTS - VERTICAL END MEMBERS

The car body end structures shall be designed in accordance with the requirements of Section 18, Vertical End Members, of the AAR "Specifications for the Construction of New Passenger Equipment Cars."

In addition to these requirements, the collision posts and corner posts, their attachments and supporting structures shall withstand the following static design loads without yielding or buckling:

Member	Design Load (pounds)
1. Cab End	
a. Forward Collision Post	126,000
b. Forward Corner Post	42,000
c. Aft Collision Post	63,000
d. Aft Corner Post	21,000

Member	Design Load (pounds)
2. Non-Cab End	
a. Forward Collision Post	63,000
b. Forward Corner Post	21,000

Each of the above loads shall be applied in a longitudinal direction, 18 inches above the top of the underframe, and shall bear over the front face of the post for a height of 6 inches.

Loading Test of Forward Collision Posts and Corner Posts

A loading test of the forward collision post and corner post structures at the cab end shall be performed by the contractor in the presence of the Director with the following requirements:

(1) The car shall be subjected to static loads of 100,000 pounds at each forward collision post and 33,000 pounds at each forward corner post (for a total static load of 266,000 pounds), with resistance at the opposite end of car to be at the centerline of end sills. These static loads shall be applied simultaneously.

  (a) Each load shall be applied in a longitudinal direction, 18 inches above the top of underframe, and shall bear over the front face of the post for a height of 6 inches.

(2) Each load shall be applied in at least five (5) increments, and removed in reverse order.

(3) Maximum stress in any material under the maximum above load shall not exceed 80% of the yield stress specified in Section 2.4.

(4) Strain gages shall be located as per drawing of car structure approved by the Authority, and readings of each gage at each load level shall be recorded. Approximately 50 strain gages shall be used. In addition, approximately 50 gages of those required under Section 17.3.3 __, "Car Body Compression Test at Anticlimber," will be utilized.

(5) There shall be no visual permanent deformation, fractures, cracks or separations in car structure.

  (a) Any broken welds shall be jointly examined by the Contractor and the Authority to determine if failure is the result of weld quality or stress.

Loading Test of End of Car

A loading test of the end of car structure at the cab end shall be performed by the Contractor in the presence of the Director with the following requirements:

(1) The car shall be subjected to a static vertical upward load of 80,000 pounds, applied on centerline of car at the anticlimber. This loading test may be combined with the "Car Body Vertical Load Test" of Section 17.3.3.__, to provide resistance to the applied load.

(2) Load shall be applied in at least five (5) increments, and removed in reverse order.

(3) Maximum stress in any material under the maximum above load shall not exceed 80% of the yield stress specified in Section 2.4.

(4) Approximately 50 strain gages of those required under Section 17.3.3__, "Car Body Vertical Load Test", will be utilized, and readings of each gage at each load level shall be recorded.

(5) There shall be no visual permanent deformation, fractures, cracks or separations in car structure.

    (a) Any broken welds shall be jointly examined by the Contractor and the Authority to determine if failure is the result of weld quality or stress.

MANUFACTURING INDUSTRY EXPERIENCE

Budd, William Dickhart

Franco-Belge, Jean Guy Marret, George Zehnder

Boeing Vertol, Michael Dennis

BUDD - WILLIAM DICKHART

Mr. Dickhart: To establish who we are, Budd builds rail cars. We have a reputation for strong rail cars, as this picture of an accident some years ago indicates. It was a little embarassing when one of the Budd trains backed into a locomotive. You can see the results. (Figure 1.)

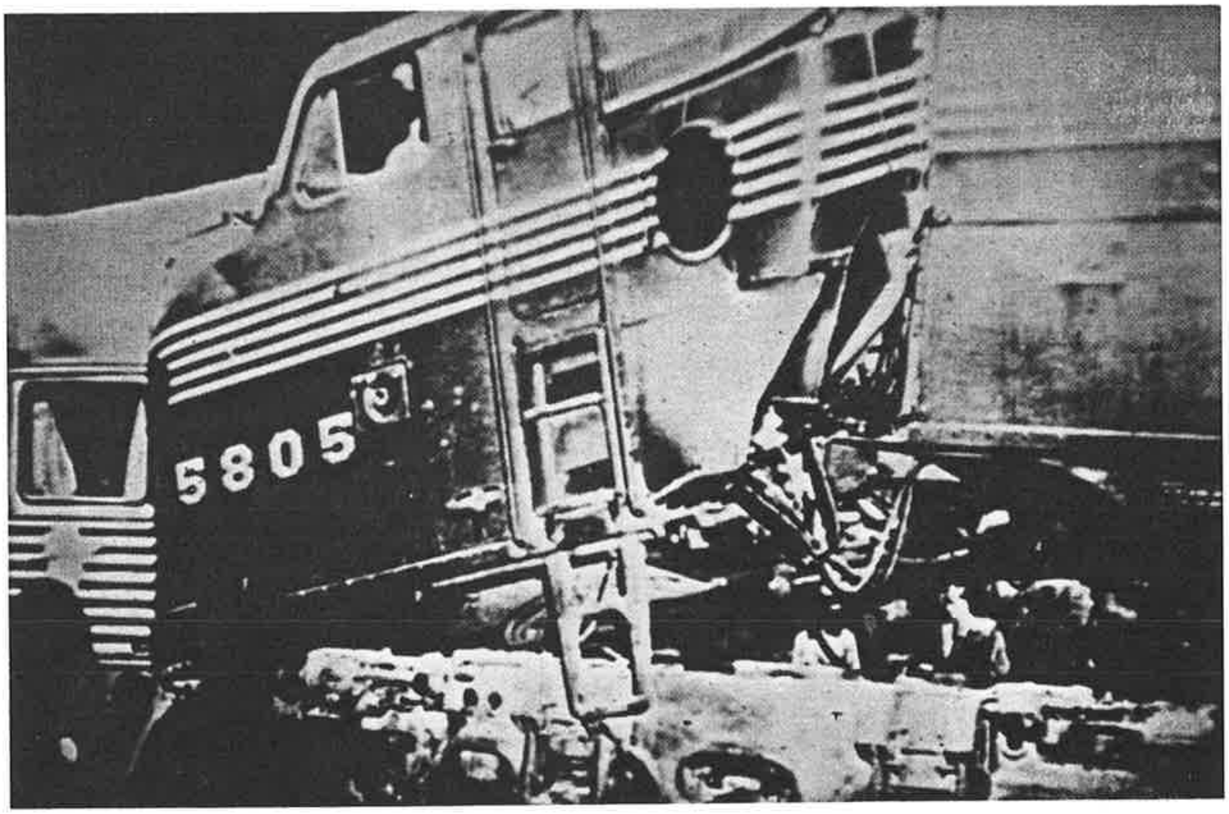


FIGURE 1.

Not only that, but we have been designing rail cars for controlled crush or controlled crippling for a number of years. I think you can see this slide of an early Zephyr that was in a crash how the crash was limited to the end of the car. A matter of fact, that car was subsequently repaired and went back into service. (Figure 2.)

Through the years The Budd Company has attained quite a collection of wreck pictures, not only for our own cars, but of the other cars. You do learn a lot from examining wreck pictures, and we certainly recommend it. And, don't limit the analysis to the last couple of years.

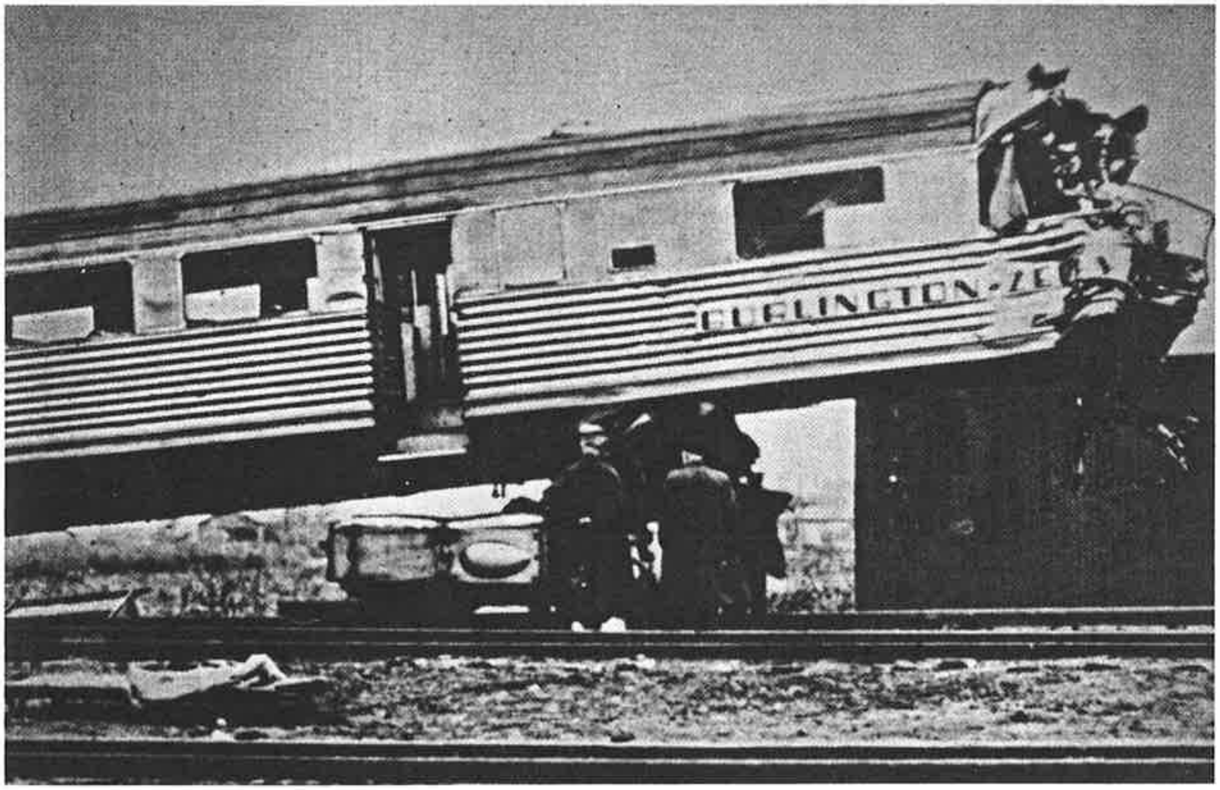


FIGURE 2.

Mr. Dickheart: cont. At the Technical Center, the man who follows up on wrecks now -- some of you have already met him -- is Mike Pavlick.

We do have a large and unique testing laboratory in Philadelphia as part of the Technical Center. This slide shows the two million pound test machine which is one element in the laboratory. As Ed said earlier, we did run a test to destruction on this machine. I believe the car subsequently became the Budd test car and then ultimately the AAR test car. (Figure 3.)

In addition to the compression test machine at the testing laboratory, we have an environmental chamber, a road and rail simulator, and a number of pieces of static and dynamic test equipment. This facility is used not only by Budd but by the industry -- GE, Pullman, Boeing and Rohr.

We did support Calspan in the study that was mentioned this morning on transit cars by providing them with technical details and estimates of the force-deflection curves. Then, these curves were subsequently normalized by Calspan. (Figure 4.)

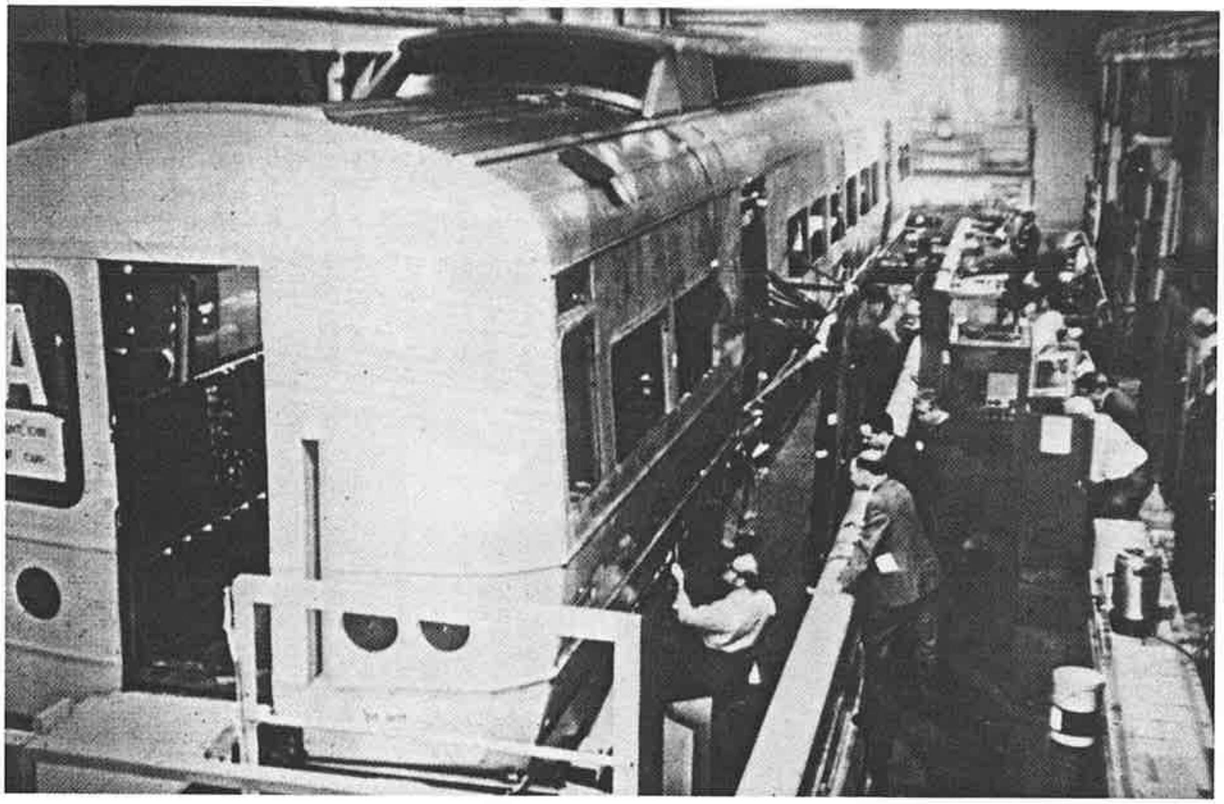


FIGURE 3. TWO MILLION POUND TEST MACHINE

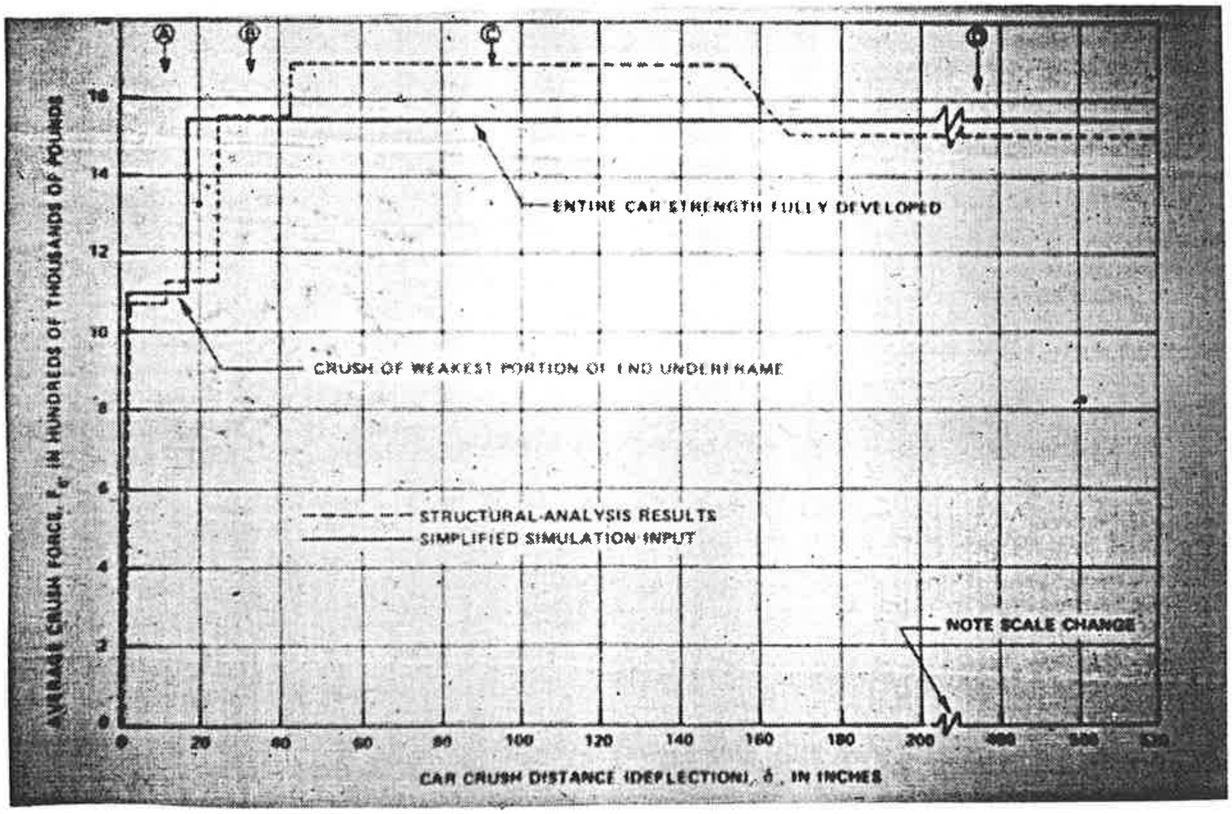


FIGURE 4. FORCE DEFLECTION CURVE

Mr. Dickhart: cont. What you see on the left is a full-size structural element, a chasis rail. To Dick Marvin's left, you see the scale element. Note that the mode of collapse is identical.

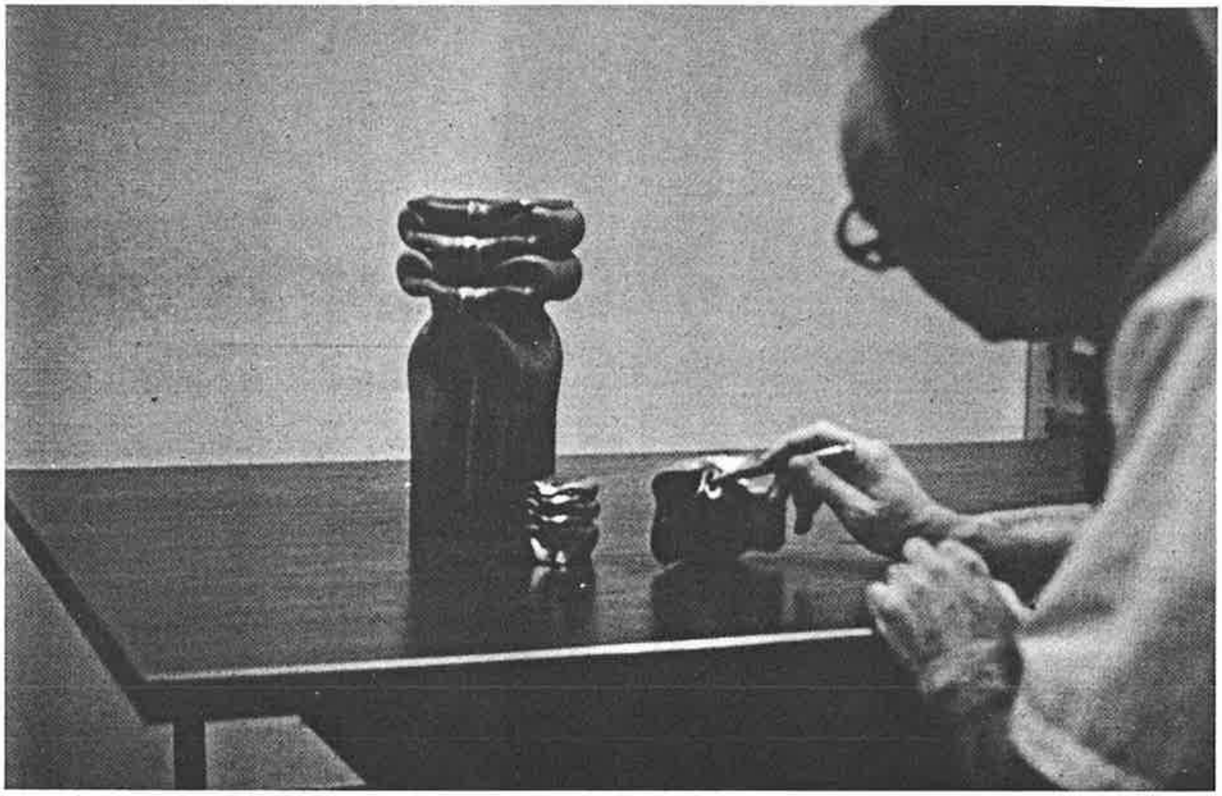


FIGURE 5. SCALE MODEL TESTING

This is the crash tower where this work is conducted. (Figure 6) It's a thirty-mile-an-hour crash tower. It was designed to take half scale automobiles or trucks. It has instrumentation, accelerometers, strain guages, force measurement, and high-speed photography.

This facility has been used to do programs for Ford and General Motors and American Motors. It's been very successful. We've developed quite a bit, and I just want to show you a few items that have been developed on it. Talk a little bit about structural elements.

This is a scale section of a van frame. You see the triggering device or the energy-absorbing mechanism that's in the forward portion, behind the simulated bumper. The concept was developed in the crash tower, and there it is in the actual production hardware that is now being produced. Figure 7., 8.

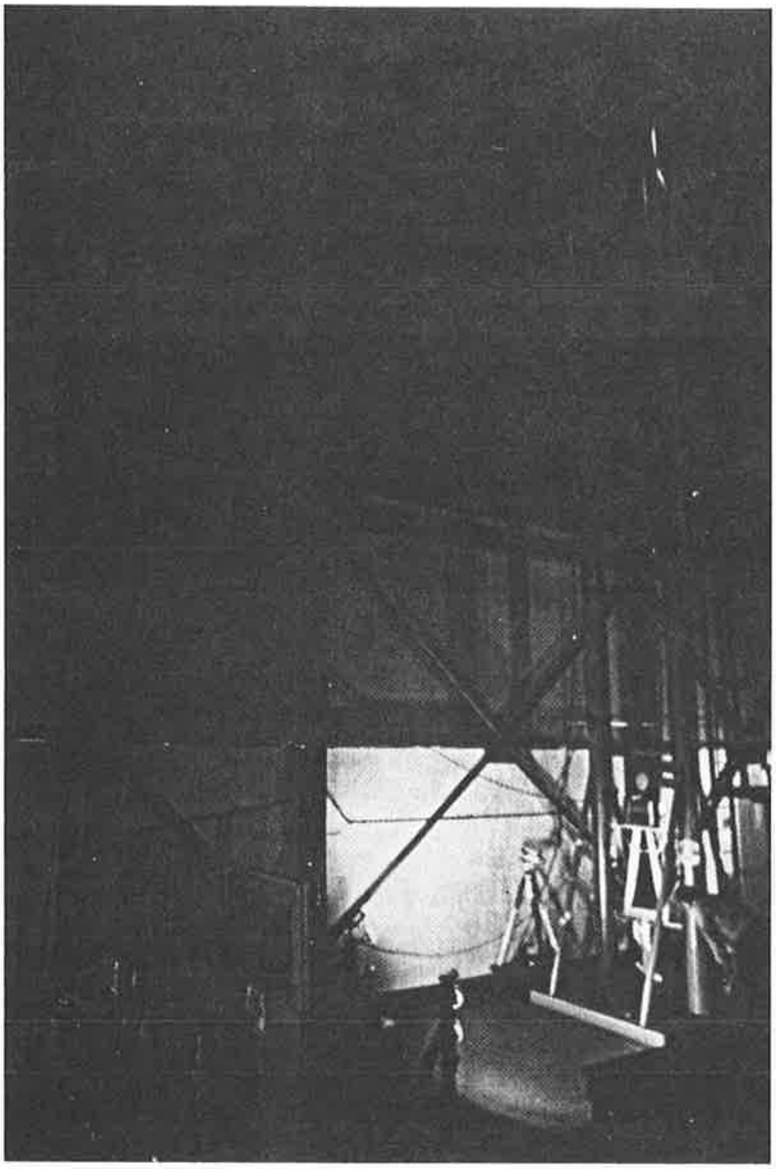
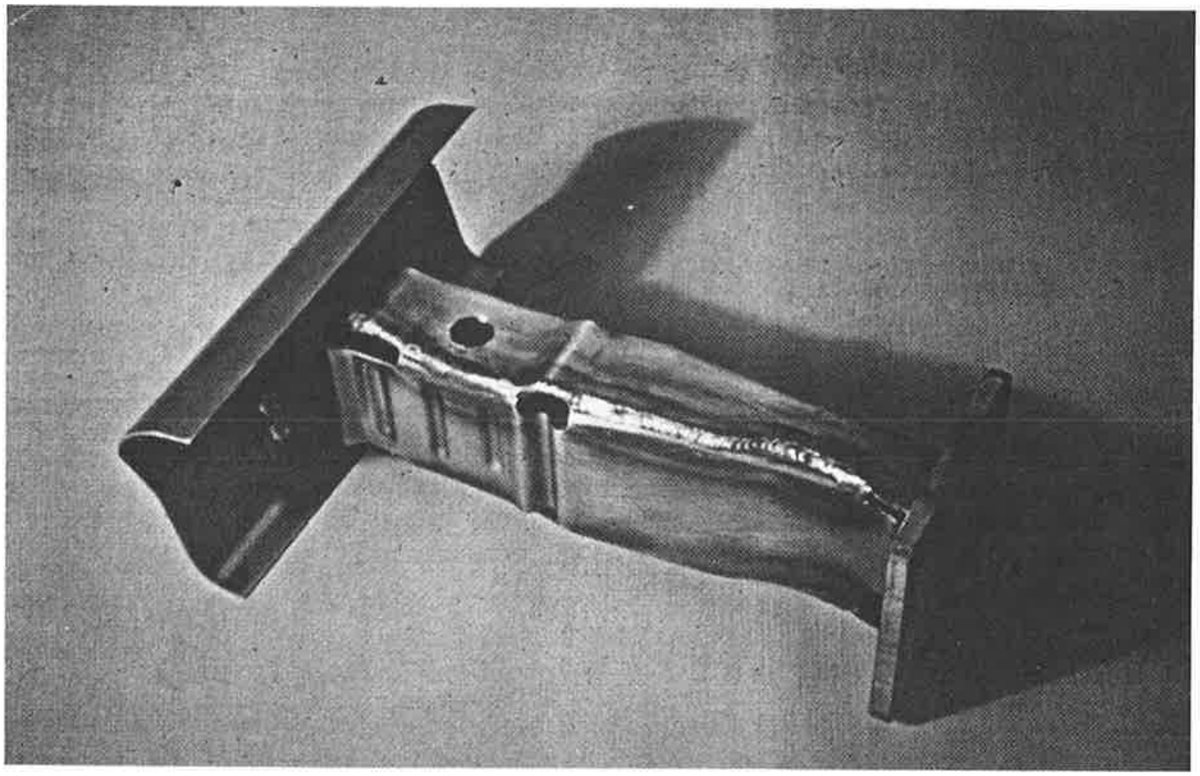


FIGURE 6. CRASH TOWER

FIGURE 7. SCALE FRAME



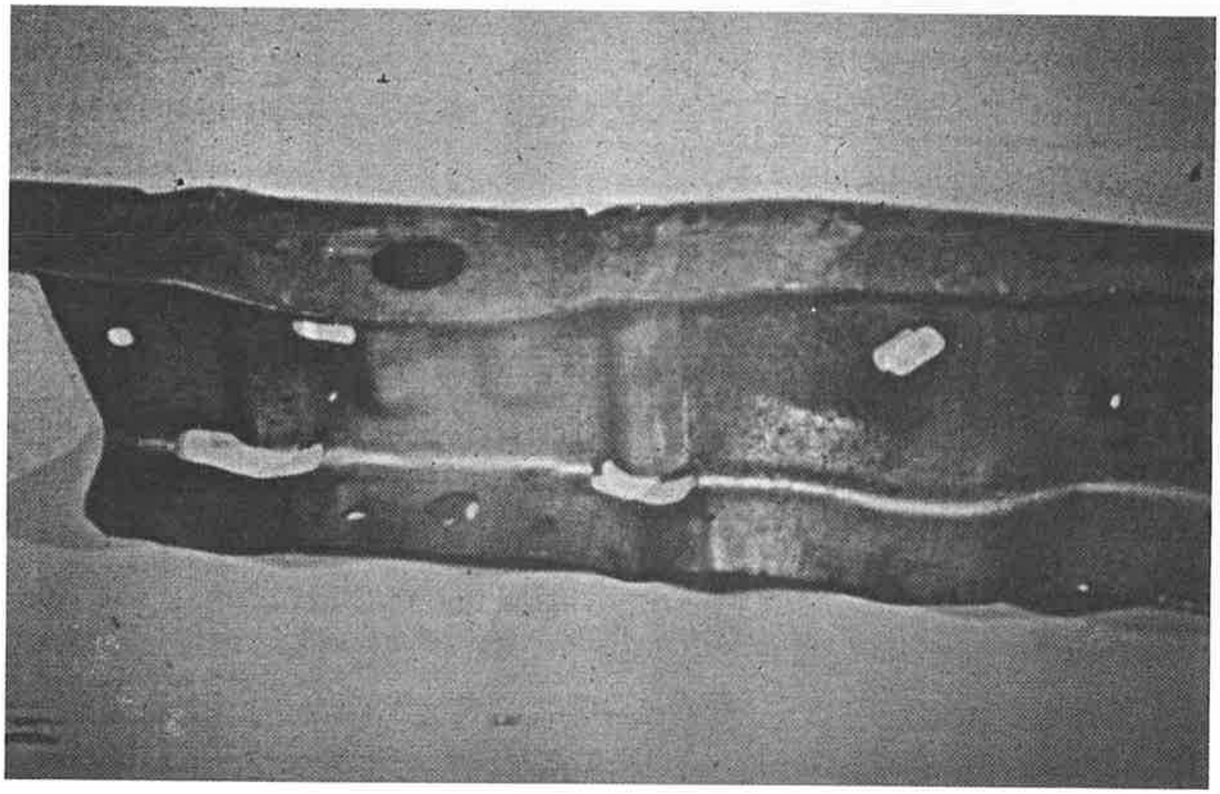


FIGURE 8. FULL SIZE FRAME

Mr. Dickhart: cont. In this particular program, we developed the characteristics to be used in the lumped mass modeling in addition to testing the frame back to the A post. The forward portion which was tested and the after portion. So that the scale modeling facility can give you real data which can be used in your lumped mass modeling.

This series of slides builds into a rather complex structure. We tested structural elements initially and then kept adding as the whole structure was developed.

Now you recognize the structure as being the forward portion of a small car with practically everything simulated within it. The instrumentation and the load cells are attached in the passenger compartment area.

The name of the game here is to keep the passenger compartment intact to provide living room within the vehicle during the crash. The important thing is, and let me point this out to you, this represents the passenger compartment portion. You see all the crush is taking place forward of the passenger compartment. (see Figures 9., 10)

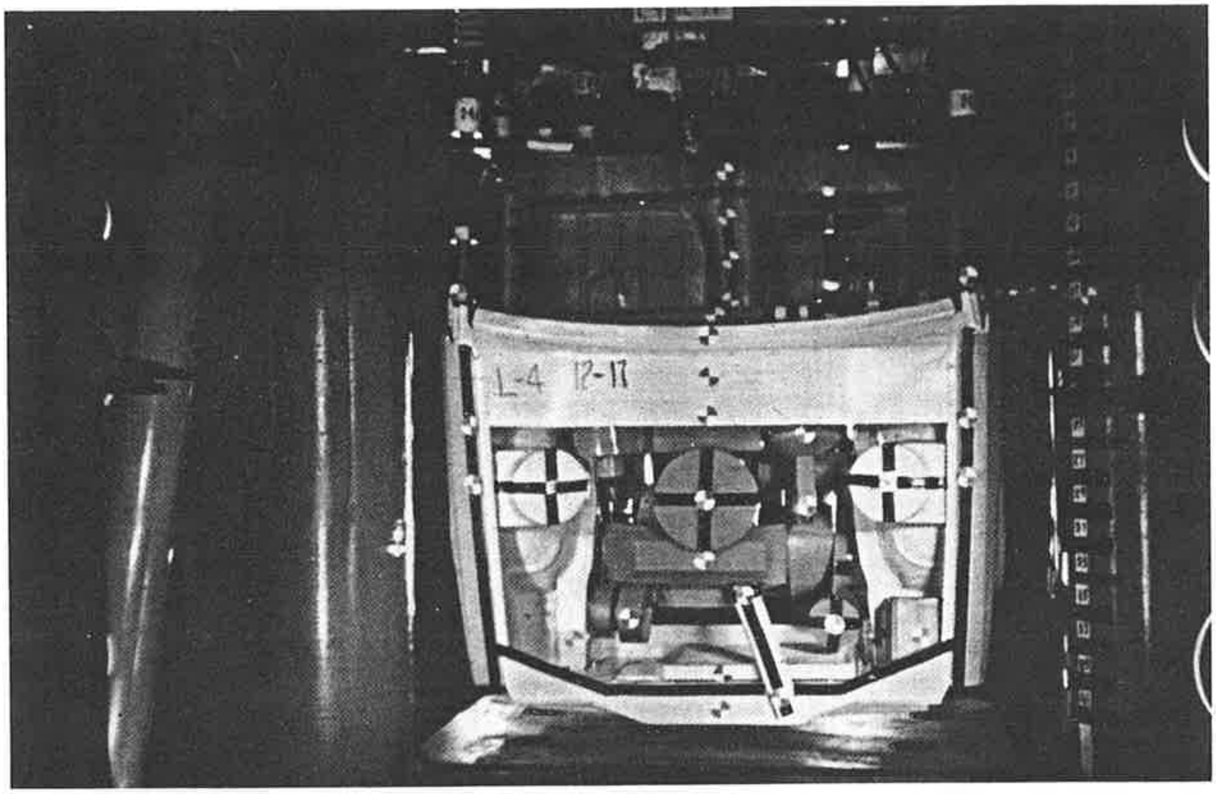


FIGURE 9. PASSENGER CAR FRONT END BEFORE CRASH

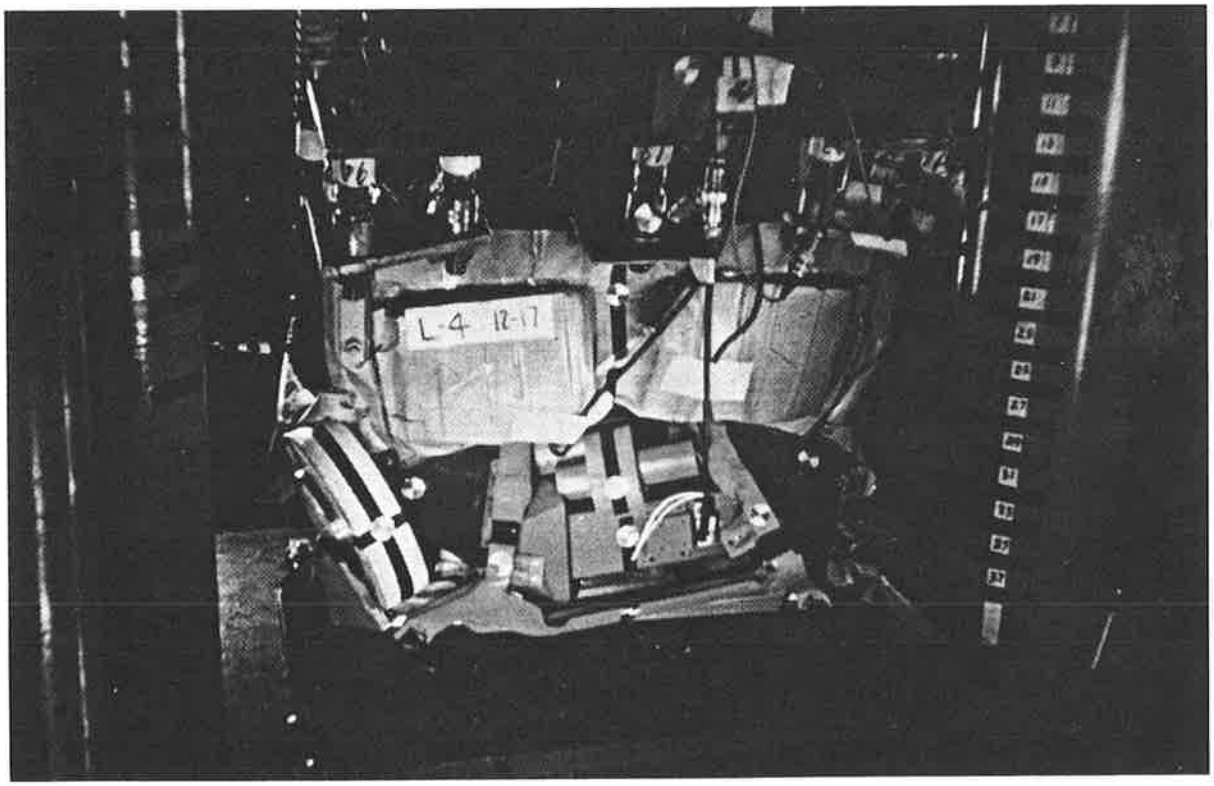


FIGURE 10. PASSENGER CAR FRONT END AFTER CRASH

Mr. Dickhart: cont. With that as background, I did want to comment about the things we heard this morning.

In principle we agree with most of the things that were said from an R & D standpoint this morning. I questioned some of the numbers in the IITRI presentation, and the difference between the striking and the struck. We are fortunate, at the Budd Technical Center, to be working in all the land transportation modes; auto, truck, trailer, rail and to transfer the technology. In the automotive work, it's generally assumed, and I think the tests conducted to date indicate, that there's not much difference between a striking and a struck vehicle.

The other work that was reported certainly seemed to be good work, and to corroborate that which we've been looking at.

The real question that we have is the practicability of applying some of the computer programs to specifications or standards and how the car builder and the property can really use this information. The question is based to a degree on the work that we're doing in connection with the Wrecker Program for NHTSA in the big-car-little-car problem. Attempts to apply the Wrecker Program, while unsuccessful to date, will probably result in a much more limited application than was originally expected.

With that introduction to the automotive area, I wanted to discuss some of the things that we learned that might be applied to rail. The big-car-little-car study, which was mentioned in Automotive News about a week or so ago, is aimed at enhancing the side structure to improve the safety of occupants in the small car. In this program, Calspan is conducting the tests and some other work for us and they're doing a very fine job.

One of the things I would like to recommend to you today is that since there is so much interest in crashworthiness in the automotive field, take a look at what's being done there. There's a lot of money being spent there, and I think there is an opportunity to transfer some of the learning from this into the rail car area.

One area that Budd is involved in is scale model testing and the development of automotive structure through the use of scale modeling.

I've heard a number of people today say that they'd like to see tests, they'd like to see full scale tests, and I hope in the next few minutes that I'll be able to convince you that it is not necessary to go full scale, and therefore, you can afford to do a lot of dynamic testing.

Of course, the whole principle here is the fact that inscale you get the same dynamic performance that you do with the less than full size.

Mr. Dickhart: cont. Now as I mentioned earlier, everything that we have shown you has been done with the flat barrier and there's no reason that this technique can't be used to make dynamic studies of rail cars.

Concerning the validity of scale model testing, at Budd we believe in keeping as large as possible-half scale, third scale, full scale structural elements, if it will fit in the facility. It's our opinion if you go to the very small scales that you begin to lose too much. We think this facility could be used to run dynamic tests on rail car models, and we think that subsequent to that, crush tests could be run on full scale cars previously tested in the field -- use the other end of it to validate the work. Of course, ultimately, the proof of the pudding would be -- I'm sure all of you would like to see a full scale dynamic test to validate the scale crash and crush tests.

We recommend you read General Motors SAE paper, number 780366. They refer to the work that's been done by The Budd Company, they built their own facility to do this, and they do show some very detailed correlation between scale model test and full scale tests.

You may have seen the announcement that we're developing an electric automobile with the Garrett Corporation, and the structure is all plastic. It was tested last week, and I'm pleased to say it does meet the NHTSA Standards for thirty-mile-an-hour crash with all of the crush forward of the passenger compartment. So you can use plastics as well in scale model work.

So my recommendation to you, for your consideration in the workshops and other areas where so many people say, "We'd like to see dynamic tests," consider scale dynamic tests.

The only other note that I have here that I wanted to mention for consideration was one that Dr. Raskin mentioned earlier and several others. We think that when you're talking crashworthiness that another item that bears on it is fire. Fire, not only from a standpoint of what the interior materials do, but also the effect it may have on the structure, and we hope that's something that can be looked into. Of course, TSC has specialists in the area.

Thank you for your attention.

From the Floor: How much would it cost you if you wanted to build a half scale?

Mr. Dickhart: We couldn't fit a half scale in there, it had to be more like a third scale. Well, let me answer it this way, Mr. Dickhart: cont. which is avoiding the answer, but gives you an idea. In the case of a prototype automobile, a full scale crash might cost a hundred to two hundred thousand dollars, and you could probably build something that would give you the same sort of information for between ten and maybe twenty thousand dollars.

From the Floor: Would it be appropriate before doing dynamic tests scale model to static tests and be a computer simulation with the lumped mass Model design your scale, train in this case, and you could also look at the override problem and then do the dynamic scale testing?

Mr. Dickhart: Yes, it will fit in a number of ways. I didn't emphasize the fact that we do a lot of static testing; in structural elements especially, we have two ways of checking what we're doing. One is to take a full scale element and run a static test on it and apply a dynamic factor; the other is to run a scale model statically and a scale model dynamically and determine the dynamic factor.

Any other comments?

Mr. Madigan: Thank you, Bill, that was very enlightening.

FRANCO-BELGE - JEAN GUY MARRET, GEORGE ZEHNDER

Mr. Madigan: Good morning. This morning we are going to have manufacturer presentations. After we will break for the workshops. The Crashworthiness and Railcar Design Workshop will be in Room 1120. John Tucker will be the Chairman. The other workshop will be chaired by Professor Chen in Room 519. So what we'll do when we break here is assemble outside very informally and Professor Chen will take his group to Room 519 and Mr. Tucker will take his group to Room 1120. Let's get the show on the road. Tommy Woods, you're the representative of RPI, would you take it over, please.

Mr. Woods: Good morning, gentlemen. We're going to try to be as brief as we can this morning and, we have two presentations as Ron said. The first one is going to be the Franco-Belge Company and they have a program showing what they're doing and what they've accomplished down at MARTA and, I think Mr. Marrett and Mr. Zehnder want to do this collectively, Jean Guy, do you want to start the proceedings?

Mr. Marret: Good morning, gentlemen. The film you are going to see now has been made by MARTA people. It doesn't concern the crashworthiness but, I think you will be interested to see our plant in France, the shipment of the cars and their arrival in Atlanta a few weeks ago. We plan to start the running tests the beginning of May and this film will be completed afterwards. We have to finish it with the advancement of the revenue service next December. Thank you. Film.

Mr. Zehnder: Gentlemen, after this introduction showing the MARTA car, I want to point out a few remarks about crashworthiness and, especially based on the experiences that have been gained in Europe about the subject. When we try to imagine what kind of vehicle failure can occur, we can distinguish three different modes of failure. The first slide, please. On the picture to the left, (Figure 1), you see now a type of buckling of vehicles after they get into contact with another rail car. Here is another type, (Figure 2); you see how far from the end this buckling goes into those welded steel vehicles. Another type of failure is bending of vehicles. (Figure 3) You see here a terrible crash. The train was powered by an electrical power car. The vehicle left on bottom, the second car was a trailer that had been bent by 180 degrees. This collision occurred at about 100 kilometers per hour and this was the result.

Member of the Audience: That one car on the left looks like---

Mr. Zehnder: This one (indicating) is the power car that crashed into another train with a heavy locomotive in front. The center of the power car is here (indicating) and this part was crushed and the rear end was almost untouched. The center of the second?

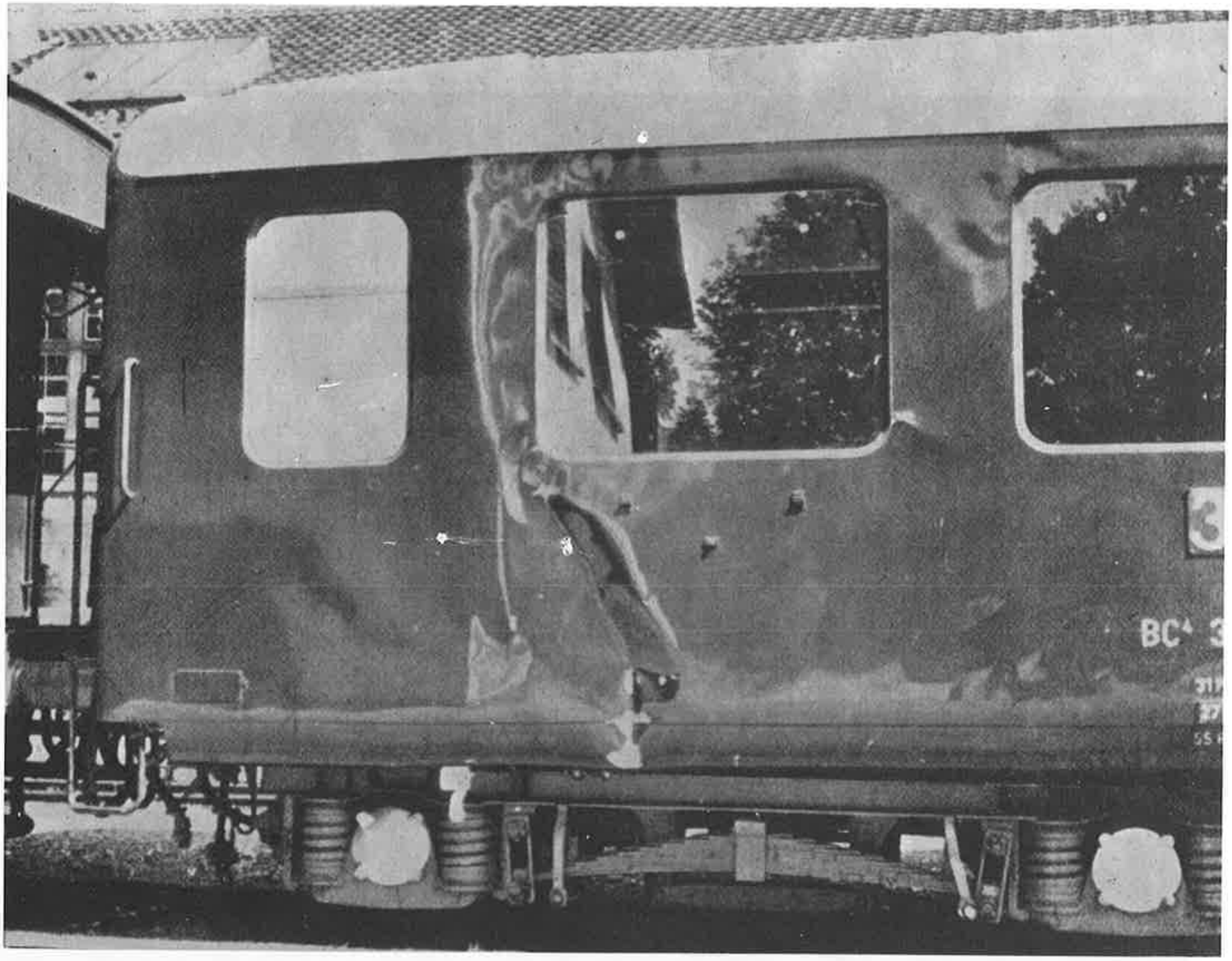


FIGURE 1.

FIGURE 2.

FIGURE 3.

Mr. Zehnder: cont. car is here and it is curved around. Now, the third mode of failure is shown in the next picture, (Figure 4.). You see here a collision, three rail cars got free on a high level station and ran down a gradient track without passengers in it and ran into an oncoming train. When you look closer at the picture, you can see that three cars are involved. The first one struck against the locomotive and made an override. The second one was just sheared off above the underframe and penetrated into the third one.

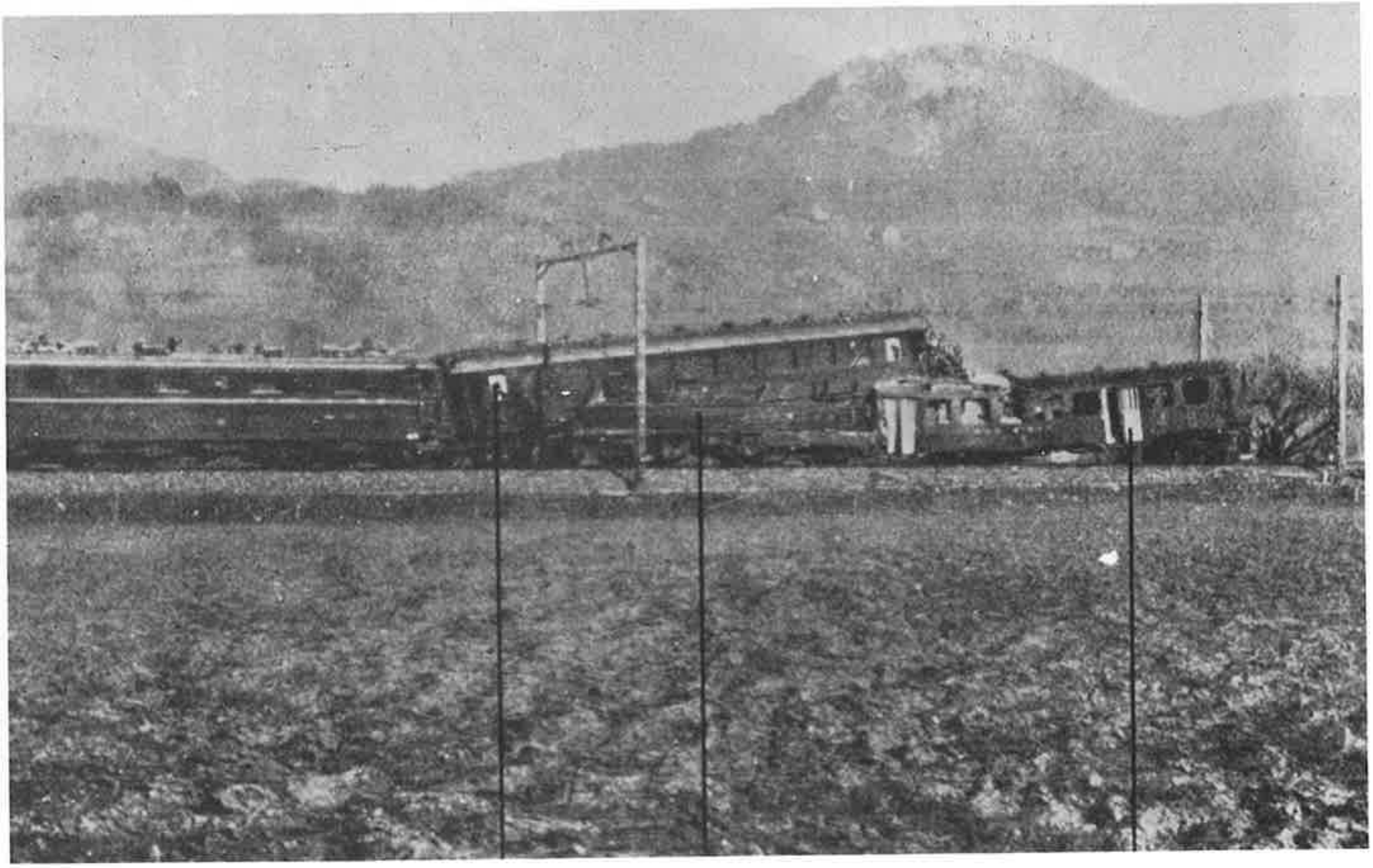


FIGURE 4.

Mr. Zehnder: cont. This is the end against the locomotive, (Figure 5.), and this shows the third car. (Figure 6.) You see down here the underframe of the second car and the first on top.

Now what can be done to prevent such dangerous accidents? A few theoretical remarks about that. On the picture to the right you see the energy content of moving trains and, according to

FIGURE 5.

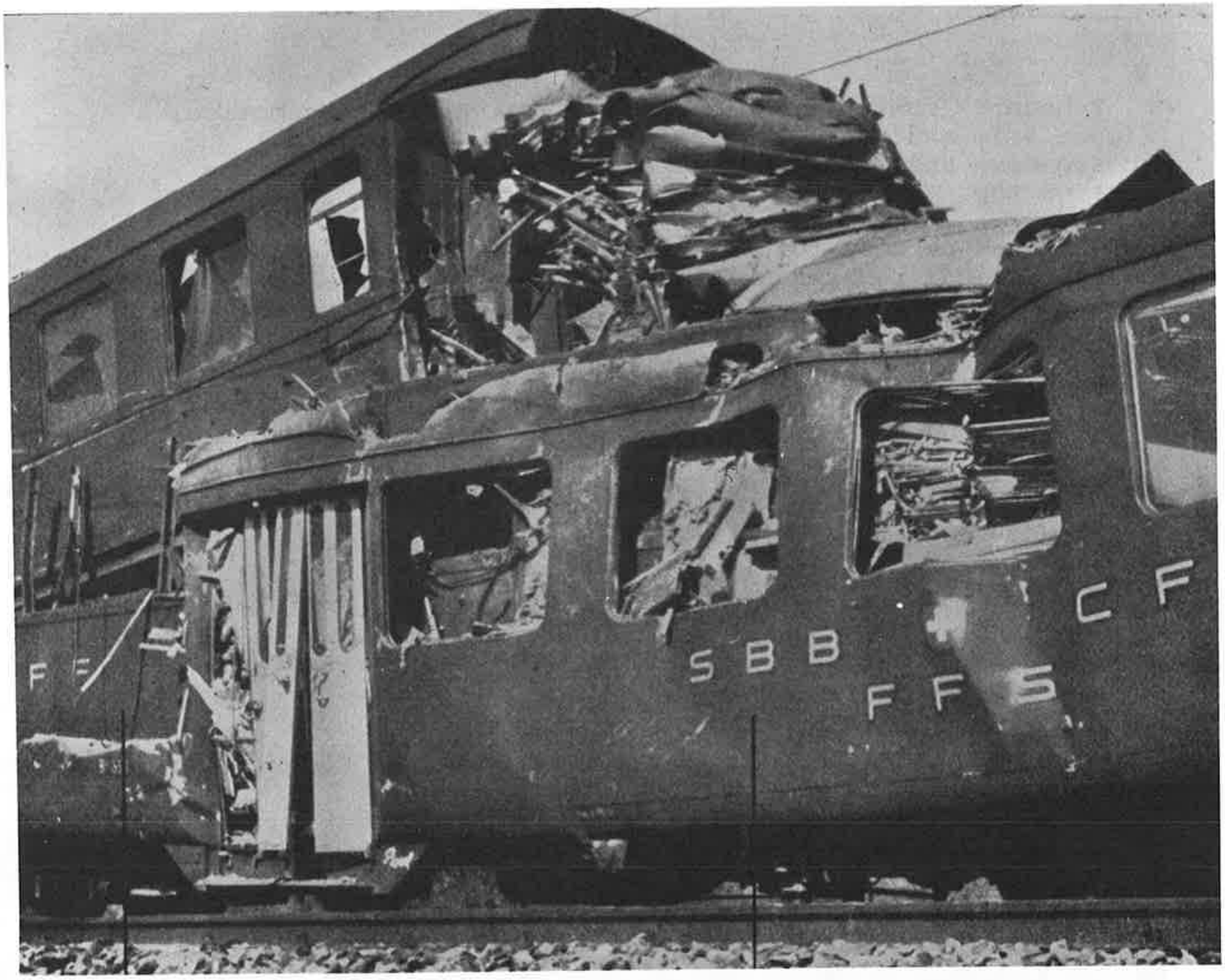


FIGURE 6.

Mr. Zehnder: cont. the mass of the train and the running speed, the energy content varies between 100 and 200,000 kilojoules (KJ). (Figure 7.) When you look, for instance, at rapid transit trains, two car consist, this is somewhere between fifty and one hundred tons and at the speed of perhaps, thirty miles per hour, you have then an energy content in that consist in the order of five thousand KJ. What energy can be dissipated within the elastic range of the car body made either of aluminum or of steel with the various yield strengths, 230 Newtons per sq. millimeter. Out of these 5000 KJ, a 20 meter car that is built for a buffing load of 2000 kilonewtons, (KN), that means about 450,000 pounds, can only take before yield 66 KJ, or in a steel design only 22 KJ. So we need other means to dissipate this energy.

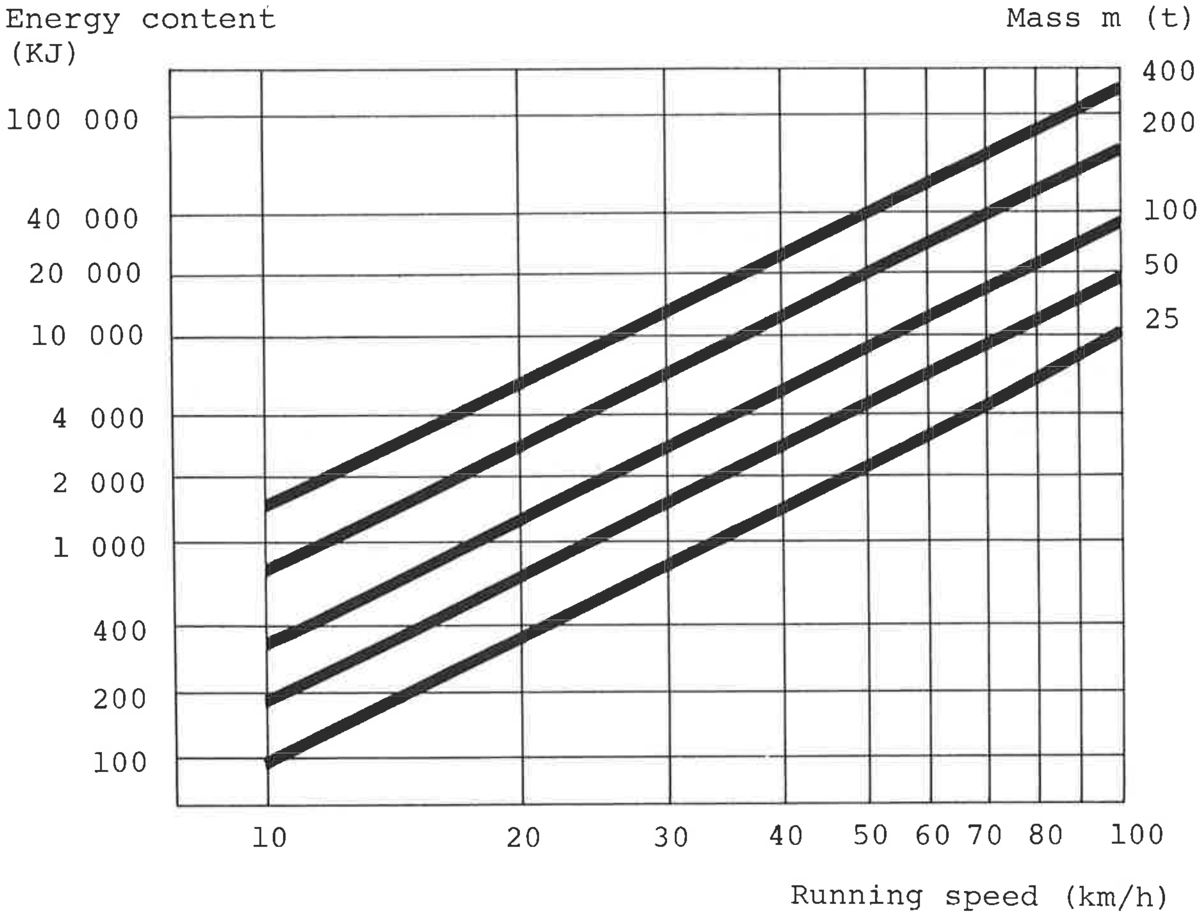


FIGURE 7. ENERGY CONTENT IN RUNNING TRAINS

Symmetric buffing load at yield of material	Construction, Material			
	Anticorodal-062 AA 6005 A	Unidur-100 AA 7005	St 37 mild steel	St 50 low alloy high tensile steel
(KN)	$\sigma_{0,2}$ 230 N/mm^2	$\sigma_{0,2}$ 280 N/mm^2	$\sigma_{0,2}$ 240 N/mm^2	$\sigma_{0,2}$ 360 N/mm^2
1000	33	40	11,4	17,1
2000	66	80	22,8	34,4
3000	99	120	34,2	51,3
4000	132	160	45,6	68,4

FIGURE 8. ENERGY CAPACITY IN KJ OF DIFFERENT COACHES OF 20 METERS LENGTH.

Mr. Zehnder: cont. In Europe we have buffers with about 100 millimeter stroke and each buffer, according to its equipment, take up to about 75 KJ. Four buffers in contact can take 300 KJ plus the cars another 60 to 100 KJ, so we have 400 KJ out of the 5000 KJ in a collision. Now what could be done is to add somewhere in contact, collapsible elements to take a certain amount of energy and such elements at an end effort of 1000 KN can take about 100, to 150 KJ and when we get back to this diagram, (Figure 9) we can find out at what speed we can prevent any damage and, for the 50 ton consist, this speed is close to 20 kilometers per hour. That makes about 12, 13 miles per hour without damaging the structure. Higher speeds will lead to damage on the structure.

Bumper rubber spring	105 mm stroke	1000 KN max-Effort	30 KJ
Bumper steel spring	105 mm stroke	1000 KN max-Effort	50 KJ
Bumper hydraulic	105 mm stroke	1000 KN max-Effort	75 KJ
Collapsible tube	105 mm stroke	1000 KN max-Effort	100 KJ
Collapsible tube	160 mm stroke	1000 KN max-Effort	150 KJ

FIGURE 9. ENERGY CAPACITY IN KJ OF DIFFERENT RAILWAYS BUMPERS OR SHOCK ABSORBING ELEMENTS

When you look at Figure 10, these are test results made with an 80 ton freight vehicle and various closing speeds. The yellow line shows the effort behind the buffers with buffers of 25 KJ capacity; the blue line, the same two cars with 70 KJ buffers. So you see the low investment protection of the vehicles is possible up to speeds of about 17, 18 kilometers per hour without damage on the vehicle. And, as soon as you exceed these speeds, either the end load on the car will increase or then, drastic deformation occurs.

All these reflections have found entrance into the specifications for cars and we must look now how various cars are built in Europe. I show you here, first of all, a typical steel car. (Figure 11) First of all, you will remark that?

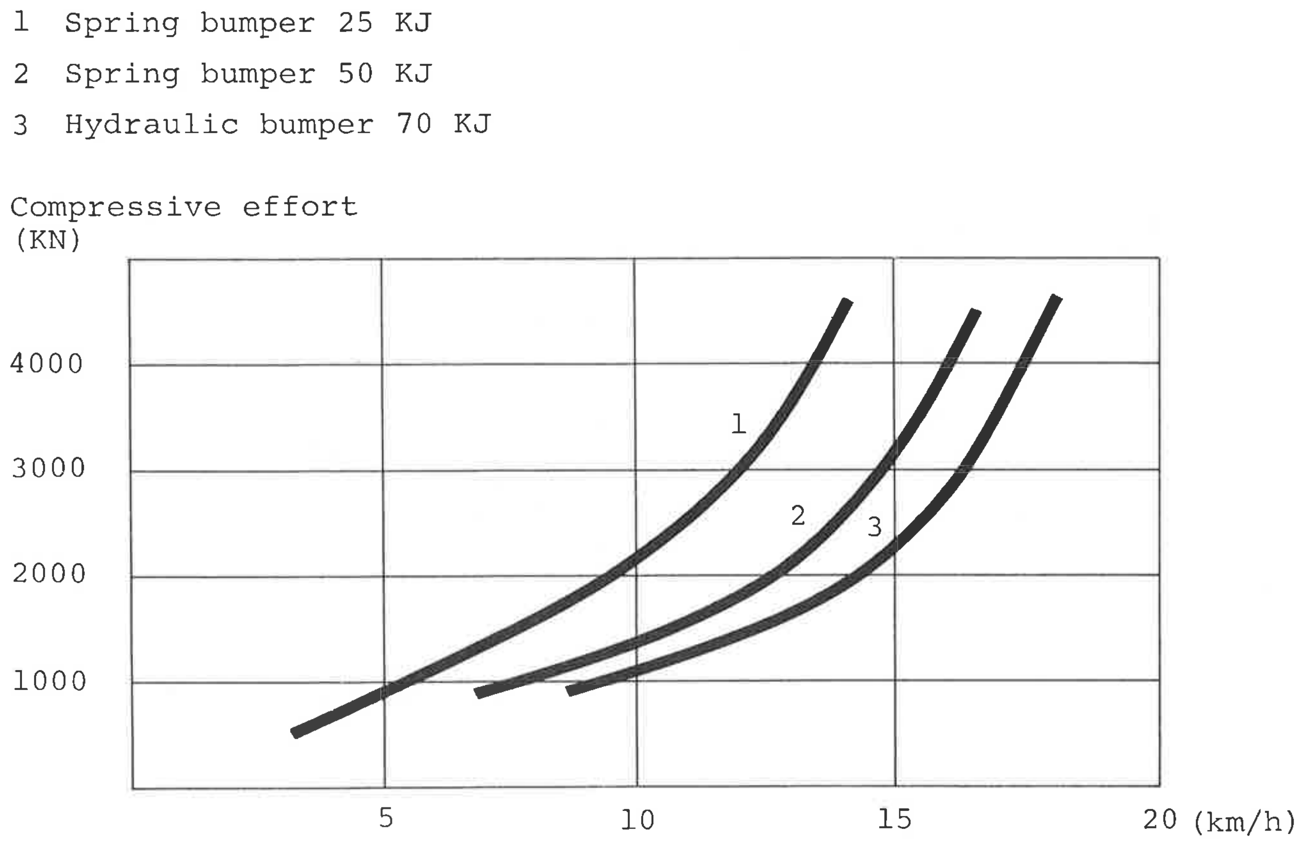


FIGURE 10. SHUNTING EFFORT BETWEEN TWO 80 t VEHICLES IN FUNCTION OF ENERGY CAPACITY OF BUMPERS

FIGURE 11. TYPICAL STEEL CAR

Mr. Zehnder: cont. the bulkhead of the vehicle is straight and that the intercar closure is a rubber tube. This helps in case of two cars running into each other. When the buffer stroke is completely at the end, then the rubber tubes prevent the cars from override. What is the behavior of the steel structure after the collision? You have relatively thick walls, side walls, side sill as rolled member, the roof has corrugated members. The mode of failure of such a vehicle is roughly like the first two pictures I showed; long wave buckling and, if we calculate the buffing load of this car taking the whole sidewall into account, we make an error because of the buckling. This vehicle cannot take the same load as in straight compression.

Another type of vehicle is shown here. It's more like an aircraft-type vehicle, thin skin with a great number of stiffeners, longitudinally and vertically, and joined together by spot welding and rivetting. (Figure 12.) Here when a collision

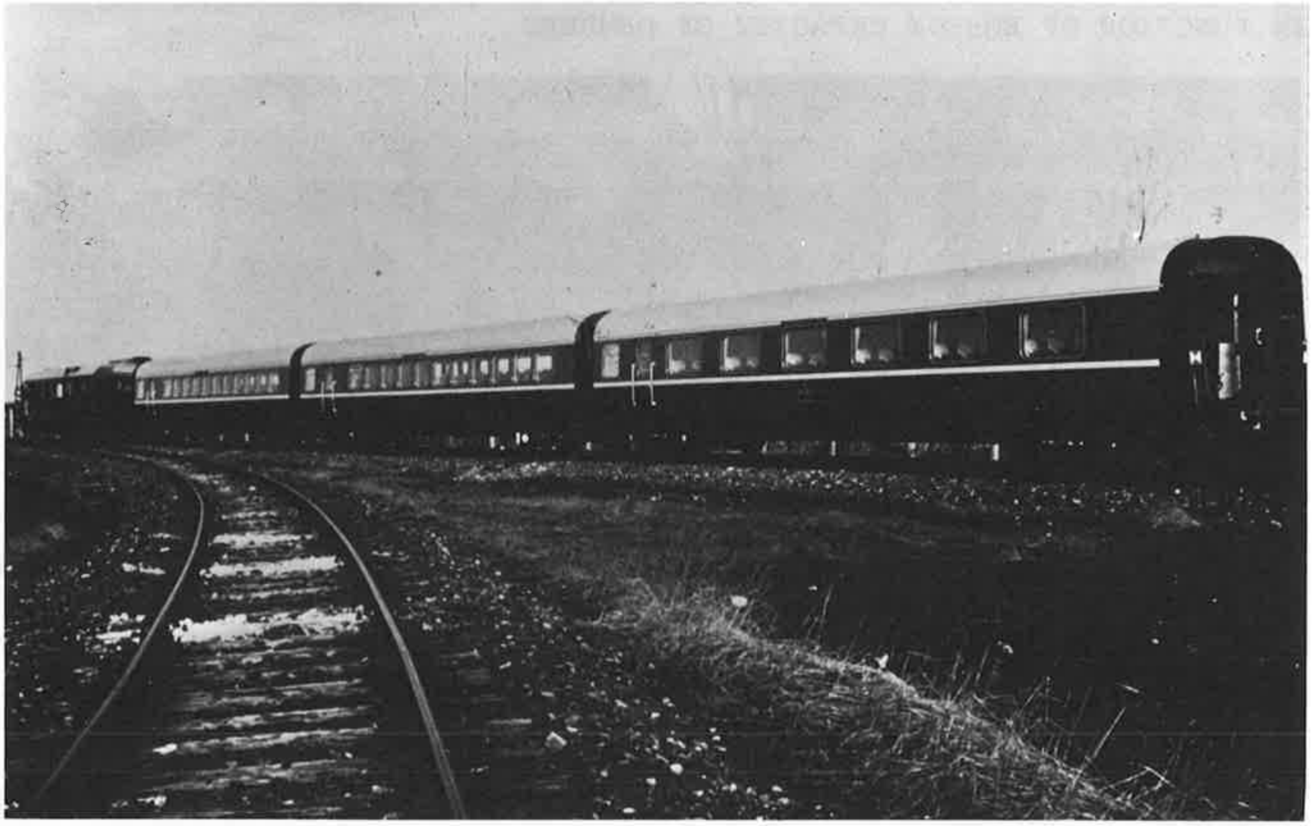


FIGURE 12A. AIRCRAFT TYPE VEHICLE

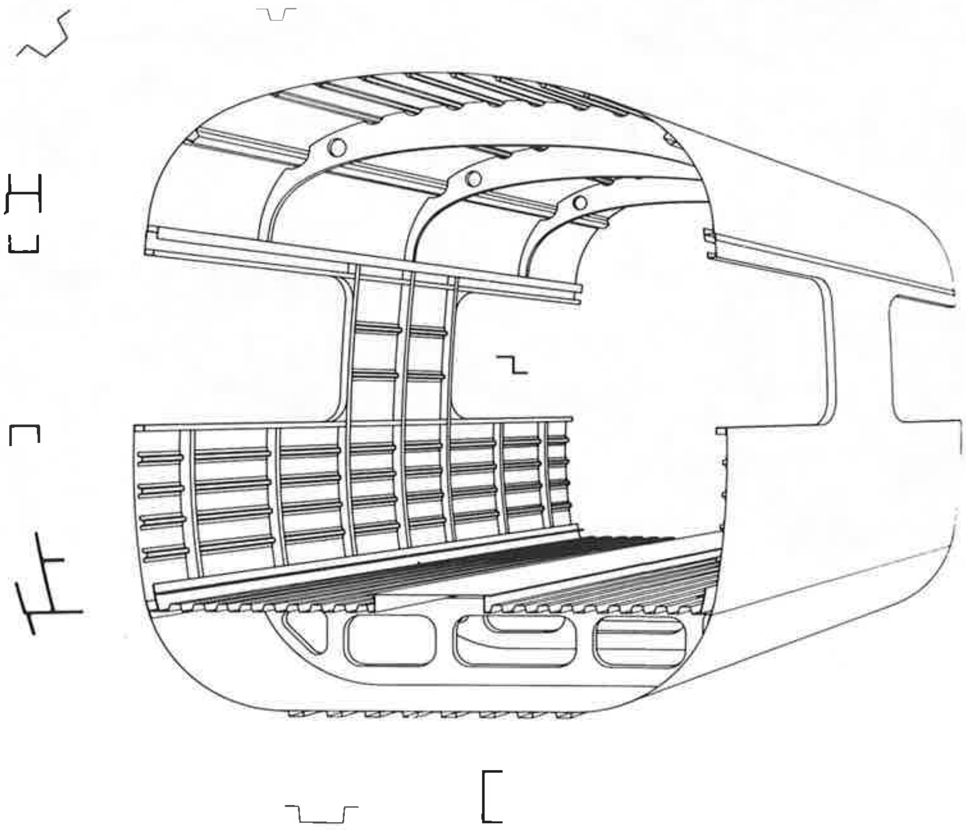


FIGURE 12B. AIRCRAFT TYPE VEHICLE

Mr. Zehnder: cont. with such a vehicle occurred in Denmark, everybody was a little astonished because of the bad behavior of the vehicle; all the fixtures between stiffening elements and the outer skin had failed. That means spot welds and rivets unbuttoned and the car opened as if it had a certain number of built-in zippers.

Member of the Audience: Do you have a picture of that?

Mr. Zehnder: No, unfortunately, the authorities are not so keen to show damaged cars. Now, another philosophy of car manufacturing is the use of longitudinally running extrusions. (Figure 13) Here now, in case of a collision, the members contain their own stiffeners so they cannot be desoliderized and even in the underframe structure, you can prevent buckling through built-in stiffeners. Another advantage of this type of design is that all those extrusions can also carry the transverse loads so that much more of the material is load carrying in the principal longitudinal direction, whereas, in traditional design, the crossmembers do not contribute to the buffing strength of the vehicle, only to the weight of it. So with such

FIGURE 13A. LONGITUDINAL EXTRUSION VEHICLE

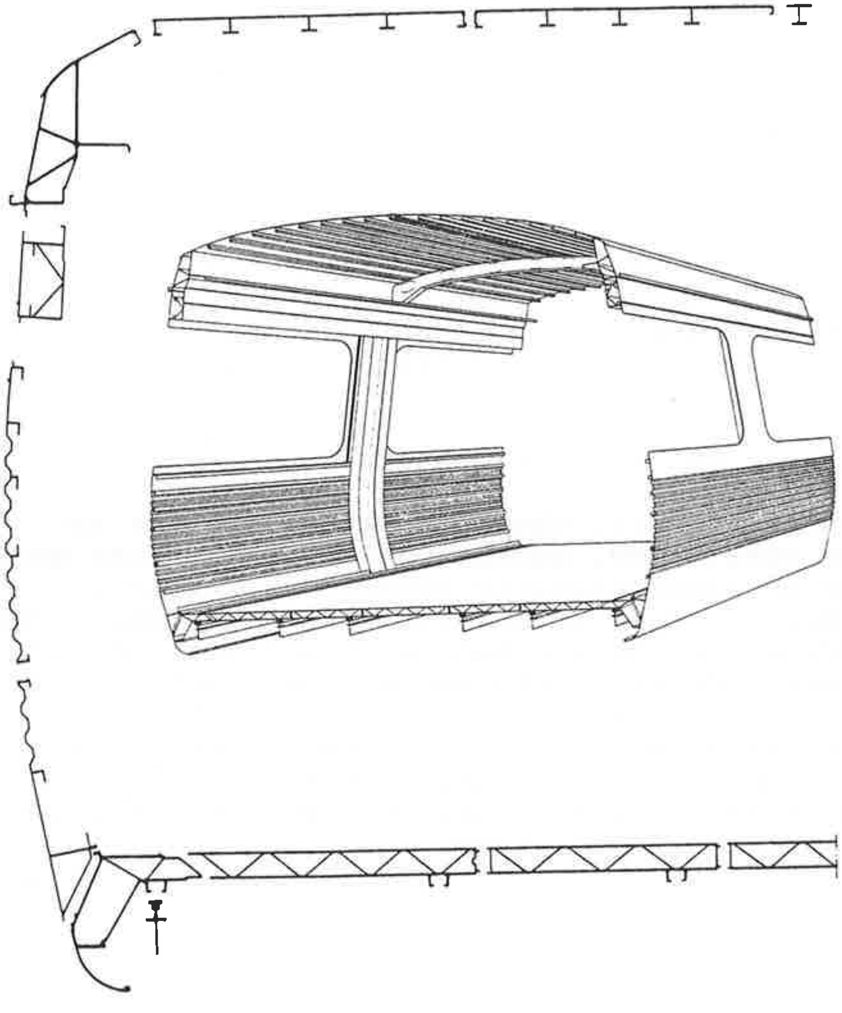


FIGURE 13B. LONGITUDINAL EXTRUSION VEHICLE

Mr. Zehnder: cont. a design, we supposed that the collision behavior would be much superior to that of traditional designs and in order not to have only assumptions, two different cars will be full-scale collision-tested and these tests will be run about September or October of this year in France.

Another point is, as in the UIC type coach I showed before, we should get contact with the full cross-section of the vehicle as soon as the draft gear has sheared off.

Here, now, these are high speed trains. (Figure 14) The inclined nose and the aerodynamic shape are just bad examples for

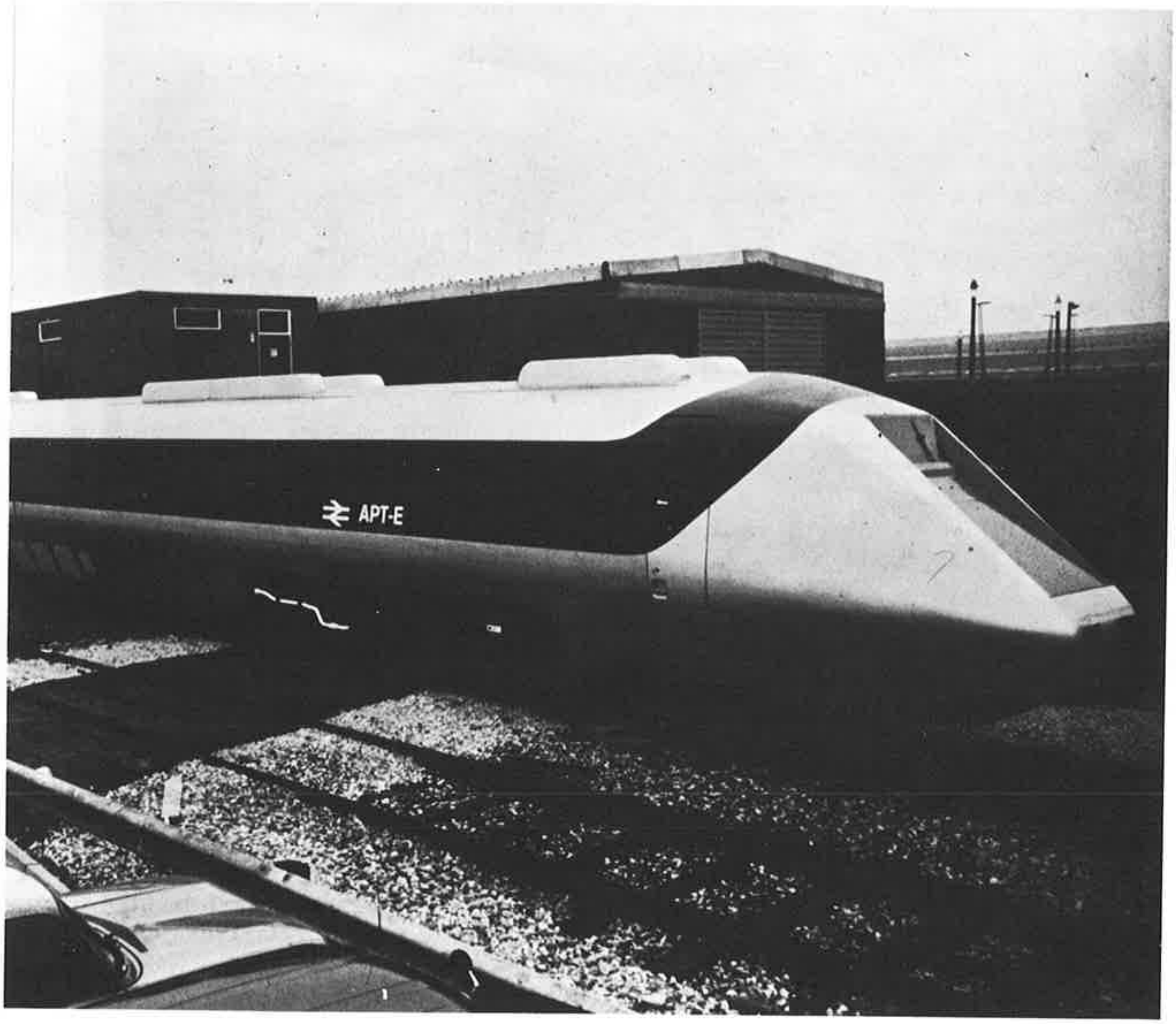


FIGURE 14. HIGH SPEED TRAIN

Mr. Zehnder: cont. for collision strength because they only get into contact with a small section of the vehicle in the first collision. Then the inclined collision posts start to buckle and a prebuckled shell has much less strength than a unbuckled shell that gets into contact.

To the right you see the Brussels subway car. (Figure 15.) I tried to get detailed information on two crashes they realized with their new cars, but the only thing I was allowed to do was to have a look at the vehicles but I couldn't take photographs, nor can I show you photographs taken by the authorities. Here, the interesting thing is that they have two types of vehicles of the same size built according to the same specifications. One type of vehicle is a rivetted aluminum design with high tensile steel end under-frame rivetted into the aluminum part. The other is an all-welded aluminum design.

FIGURE 15. BRUSSELS SUBWAY CAR

Mr. Zehnder: cont. In both head-on collisions, at about 30 to 40 kilometers per hour, the two fiberglass reinforced plastic bulkheads failed and the rivetted car had the buckling of the steel end under-frame and this part (indicating) was unbuttoned from the side whereas the the welded aluminum body itself had no failure at all. The result was that after replacement of the fiberglass Molding, the all-welded car entered into service eight days later and the two other trains, six months after the collision, are still in repair.

When you look at the BART car, here again, the inclined bulkhead, to my opinion, causes certain hazard in collisions due to the fact that the roof cannot develop its full stength because other parts buckle before. (Figure 16.)

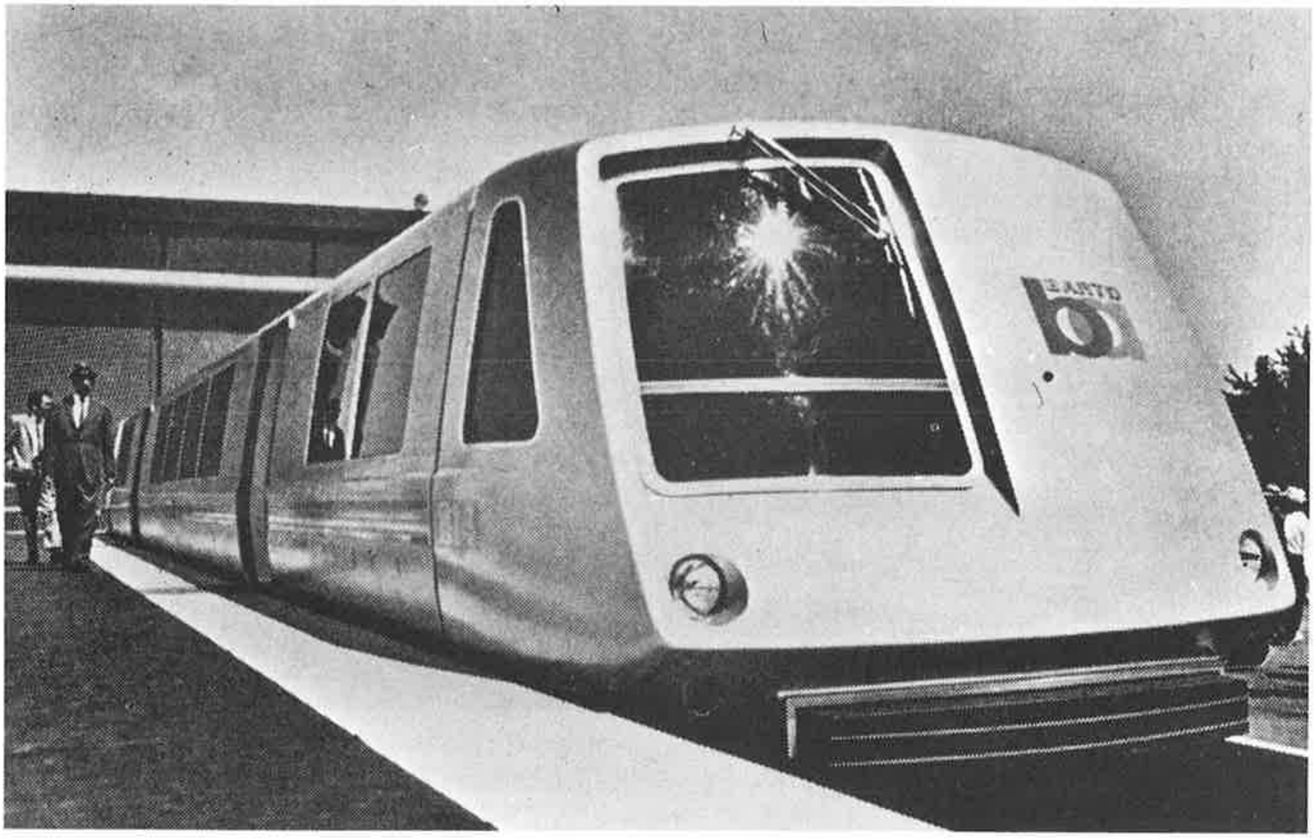


FIGURE 16. BART CAR

This here shows again how nicely vertical bulkheads prove in a collision even with over-ride. (Figure 17.)

The conclusions to be drawn from those pictures should be:

FIGURE 17.

Mr. Zehnder: cont. first of all, we think that specifications should contain a clause that low-speed collisions must not cause damages so, I suggest, a dynamic response of the car rather than pure strength requirements. Second, I think specifications for rapid transit vehicles should call for vertical bulkheads at the end. Third, collision posts are absolutely necessary and, fourth, it is advisable that the draft gear, which is eccentric to the floor, is not built for energy absorption but that the anti-climber can do a telescopic movement because the anti-climber is

Mr. Zehnder: cont. on the level of the underframe and, when it is cushioned with an energy-absorbing material, it can prevent damage to the cars running at low speed. Thank you very much for your attention.

Mr. Woods: Thank you. Are there any questions for this gentleman?

Member of the Audience: Sir, at what speed do you plan to conduct your speed crash test this fall?

Mr. Zehnder: Well, the highest speed that is planned is 55 kilometers per hour.

Member of the Audience: You mentioned in the end, cushioned anti-climbers?

Mr. Zehnder: Yes.

Member of the Audience: Did you operate with those?

Mr. Zehnder: Yes. Perhaps you remember Mr. Baker's presentation yesterday which showed, for instance, the collapsible under-frame members of the trucks, the rectangular tubes that collapse in a certain mode. I can imagine that you put a stiff bar behind the anti-climber and then collapsible tubes so that this anti-climber can, thanks to the collapsible tubes take energy over the full travel, move backwards without damage on the under-frame. The Lockheed Aircraft Corporation has made another study of shock-absorbing elements. They used circular tubes that are notched on one end and, they insert a ring that makes coil up the strips of that tube and takes energy in this way. These elements are quite cheap and easily replaceable.

Member of the Audience: You show us so many different kinds of constructions. Do you have any comparisons like strength or weight ratio, this kind of thing, whether one will yield better than the other, that's my first question. My second question is, could you propose when you talk about dynamic response, maybe you can elaborate a little bit.

Mr. Zehnder: Well, I showed you three different types of construction work. One is the stressed skin with heavy gauged sheet and a small number of stiffeners and there, I would say, the body shell made for a car, the size of MARTA, 75 feet long

Mr. Zehnder: cont. and about 10½ feet wide, will weight in aluminum roughly 7½ tons. The second type of design with thin-gauge skin and many, many stiffeners, will turn out with a shell weight of approximately 6 tons and the integral extrusion design will turn out at 6.6 tons. The latter is not an assumption, this is the measured weight, so the three designs with equivalent strength show that thick gauge sheet materials, are the heaviest, then comes the integral extrusion design. The typical aircraft design is the lightest car.

Member of the Audience: The second question, whether you propose to talk about dynamic response?

Mr. Zehnder: For dynamic response, I would suggest that specifications for rapid transit cars state clearly that damages due to low-speed collisions, as they occur mostly in the yards, have to be prevented. Up to a speed of 15 kilometers per hour, no permanent deformation should occur and then it's up to the manufacturer to design his shock-absorbing elements and the strength of the car to fulfill this specification. To prevent heavy damages in high-speed collisions, we should stay, again, with the end-buffing load as it has been specified yesterday.

Member of the Audience: Would you repeat those three relevant weights on those three designs?

Mr. Zehnder: The traditional sheet design is about 7.5 tons. The aircraft-like design is 6 tons and the actual MARTA design, 6.6 tons.

Member of the Audience: Are those metric tons?

Mr. Zehnder: Yes, metric tons.

Member of the Audience: What was the buff load requirement for that design?

Mr. Zehnder: For that design it was 200,000 pounds compressive load and on the collision posts again, 200,000 pounds plus 50,000 pounds in transversal direction, 6 inches above the under-frame.

Member of the Audience: Is that ideally?

Mr. Zehnder: Yes.

Mr. Woods: Thank you George. I think if you have any further questions in the workshop, the gentleman will be available.

BOEING VERTOL - MICHAEL DENNIS

Mr. Woods: Now the next presentation will be by Boeing Vertol, Mr. Mike Dennis, in charge of structures, design criteria on the new CTA cars and the light rail vehicles. Mike.

Mr. Dennis: Good morning, gentlemen. I think it is appropriate at this workshop to discuss the two cars presently being produced at Boeing Vertol in Philadelphia. It might give us some ideas for the workshop. They are two distinct types and you'll note that the specifications are quite diverse also. One of the problems I have is that yesterday, Walter Keevil covered a lot of ground I was going to cover this morning. However, I have done a little pruning and if I sound repetitious I hope you'll bear with me.

The first car that I'm going to discuss is the CTA car. It is running in Chicago at this time. This car weighs just under 50,000 pounds, it is 48 feet long, and travels up to 70 miles an hour. Here you see a married pair (See Figure 1.), the maximum unit on a train is five pairs. The body structure is basically 301 stainless steel, mostly quarter hard. There was a lot of talk yesterday about the collision posts. This is an important part of the crashworthiness structure. You cannot see them since they are buried inside of this fiberglass end fairing. In the bottom they are recessed through the underframe; the top has an anti-telescoping plate which ties the posts together. We have also longitudinal structure which takes that horizontal kick at the top into the roof. It also helps to tie the roof to the four end posts.

The end underframe on this car is made from a welded structure of lower alloy high tensile steel that is stress relieved.

The underframe itself does not utilize center sills. The side sills, as you see here, are quite deep and the load is transferred into the draft sill out of the end sills and into the two side sills, approximately here (indicating). Now we'll take a quick look at some of the criteria. (See Figure 2. for CTA design criteria) The first two slides are the common design and static test criteria, generally types of this appear in all specifications. The second one is the controlled crush criteria. Then we come into the criteria of the collision posts which, as Walter Keevil cleared up yesterday, have always thought, it is based on the AAR criteria.

Here we have more collision post criteria specifying very clearly what is required. Here is the common section modulus strength requirement. There is criteria on the anti-climber requiring quite a good level of vertical load plus end load.

Mr. Dennis: cont. Now this is an interesting one; we are getting into the inside of the car. We have a seat that will help to hold the people in position, especially in elevated structure crashes where the car might come off and, as it has happened in Chicago actually hung from elevated. These seats would stop the people from falling into the end. Stanchions are a very important item also. It is recognized that they will bend and the idea here is that they will not break free and form a lance to kill people. They will actually gain more strength as they bend because the roof is helping to hold them in tension.

Here we have some common coupler and draw-bar criteria. The one difference, which I haven't shown here, is the coupler has a double emergency release, the first one being 90,000 pounds the second emergency release at 110,000 pounds. It is very clear what the specifications required, we received positive direction from the CTA people, specifically Walter Keevil in detailed design area which permitted us a very rapid design and test phase.

The second car is the light rail vehicle which is presently running here in Boston on the M.B.T.A. (See Figure 3) Perhaps some of you have ridden on it. Let me just give you a few of the statistics. This car weighs just under 69,000 pounds. it is 71 feet long and travels 50 miles an hour and there are four cars in a train.. Here you see two in train. Now the structure on this car is almost exclusively manufactured from low alloy, high-tensile steel and it is entirely fusion welded. The roof sheets are made from 302 stainless steel. It has three trucks, the two end ones are powered. In the center, this is not a good photograph, but in here, there is an articulation section which allows the car to climb and make very sharp turns. The minimum turn is 42 feet. It has what we call plug doors and they drop clear to the bottom of the skirt, this adds quite a lot of complexity to the under-frame. The collision posts, as you can see in this view are very similar to those used on the SOAC vehicle. Both cars have very large windshields. The collision posts are in here (indicating) and here's the anti-climber. I may add that these collision posts are considerably stonger than the SOAC. We did learn very quickly from that incident but, even so, they are truncated and tied into a reasonable strength horizontal shelf under the windshield. This car, due to the doors, doesn't have side sills, it has what we call body sills, kind of split center sill as it goes through the cars past the center door area. (Figure 4 shows the LRV design criteria) You will note that the first two are the common static design and test requirements. It is not shown here but the test requirement was 90% yield. This car has what is termed, suggested guidelines for general crashworthiness; this was added after the SOAC incident.

Mr. Dennis: cont. One interesting feature is the energy absorbing coupler shank. It is an extruding tube that does cover impacts up to five miles an hour. We then have the coupler criteria and the truck retention is specified but, as you can see, it takes a little interpretation. This one (referring to 5.b) is not so important because the vehicle itself decelerates at 6 miles per sec. in any emergency situation, so, ten miles an hour isn't worth considering when you're talking of a crash or yield situation.

Here, (referring to 5a) you have to interpret what was meant and, I believe we took the two feet of the guideline; came up with a force of approximately 4g; decided that this appeared a little low and realised that maybe we should use 8g. With this approach and the fatigue design of the truck, we came up with a design that we feel holds the truck on quite adequately.

Mr. Madigan: If I'm not mistaken, with the track brake you can go up to sixteen miles an hour.

Mr. Dennis: What happens with the track brake is you get the peak deceleration the fraction before the car stops, it peaks to approximately twelve to thirteen, that is correct. I was quoting the specification level.

You then come to what I've termed general statements. In the collision posts you see the term adequate structure, in the anti-climbers, articulation section, things like minimum damage, no values attached, this all takes interpretation.

Now, I'd like to say a few words on how these cars were designed. For the overall body structure at Boeing, we used a computerized finite element analysis to optimize the weight, produce a structure of sufficient strength to meet the criteria and yet have stiffness in tune with the truck to ensure the ride quality and the way side vibration, if it is required. When we come to areas such as welds and joints and fatigue analysis, we use standard strength of material approaches. Now, obviously, somebody's going to ask, did we use a Krash program, which we heard a good discussion on yesterday, and the answer is, a simple no, we didn't, it wasn't developed at that time. And the next question, I presume, is would we have used it? I think we might have done it if it could have aligned itself with the schedule we were working to. Okay, now where does crashworthiness fit into all of this? Let me try to explain how our car structure evolves.

The largest constraint on any car is the dynamic envelope and with this I include the truck swing envelope. Things like equipment size, passenger flow and access and, by that I mean the steps and door location and esthetics also play a large part in determining the useable volume. In the remaining space we try to put the structure. Now crashworthiness directly affects structure. Yet, I know it is in conflict with the esthetics and, by that I mean, yesterday we heard about the need for good full-length

Mr. Dennis: cont. collision posts tied into a strong roof. Yet, on our one car we had the opposite.

I'd like to mention a couple of my ideas on crashworthiness and we've heard a lot about the energy involved and I think it is important to realize that the energy has to be dissipated. It cannot be converted and I think the best way to do it is the controlled crush method of having a structure that does permit dissipation due to crashing. Now, this morning we started getting into crushing structures and, I think, it is important to realize that probably a lot of the groundwork has already been done in this area. The moon lander, I believe, has crushing legs and I know that helicopters have crashworthy seats that employ extruding tubes and various other devices. I am sure this wealth of data is available. I think if it's a case that it is definitely needed we should look into it and try to reduce the cost.

Yesterday, there was a discussion of model testing. I think this probably is the logical way to go but I think that in the final analysis, full-size testing is mandatory. I believe there's always a question of the model factors that might be involved.

The other thought I had yesterday when I was listening to the various computerized approaches, and even the Krash program, was that I had a slight negative feeling myself when reality was mentioned. And, we at Boeing very successfully use a similar computerized finite element analysis for production design. We can accurately detune a car and truck for the ride quality and we know and understand the controlling factors on way-side vibration. I do not doubt that a program like the Krash, or one of the other programs that was mentioned yesterday, could be developed to be a very useful program. Possibly even tied directly into the type of program we are using.

My one final comment, it's my own personal view, it is that we have had a lot of discussion on standardization. I think it should lead to a standard car where large orders would assist in making a profit. We are in the business to make money as are most other people in their endeavors. I think it would be a very tough road, however, but it should be a goal. The one problem, with the standardization, though, we mustn't stiffle engineering ingenuity because any two engineers can come up with different designs for the same problem, both equally as good. We must also include manufacturing, engineering, and other disciplines of that type in the statement. Thank you gentlemen. Are there any questions?

Member of the Audience: I have one comment in regard to the design of the LRV. Esthetics, which you claim to be sort

Member of the Audience: cont. of a major factor, that we're not able to have full high collision posts, but in the case of the surface transit vehicle, streetcar, what dictated the big window, the big glass in the front of it, was the need for the operator to be able to see automobiles, small children and other objects.

Mr. Dennis: Certainly, I appreciate that but I was speaking as a structure's man and maybe I'm a little biased but, as crashworthiness does gain momentum, it has to come against these other factors that I discussed. One of the important items is when you start talking about collision posts. We'll have to work on that problem.

Member of the Audience: What happened on the LRV, of course, you have a very tapered end to fit in the subways but, that perhaps on the corner posts we have more work to do.

Mr. Dennis: Well, again, the basic problem is that you have a reasonable corner post on one side and on the other side you have a door which again drops right to within a foot of the ground. You could put a nice corner post in there but it wouldn't be backed up by anything. It is a function of what controls the design, how important are all these various parameters and how can they be melded together.

Mr. Wood: Thanks, Mike. Gentlemen, are there any questions for the Franco-Belge or Boeing people? If not, I think we're done. After the workshops, the chairman will bring you back here so we can give our summary comments.

Mr. Madigan: By the way, somebody I think ought to address the issue of esthetics of car design because, you know, all the people back home are going to force you to buy a fancy-shmancy car and a transit car is a transit car but, we're going to have to come to grips with that situation.

(ADJOURNED)

FIGURE 1.

C28186

CHICAGO TRANSIT AUTHORITY
RAPID TRANSIT CARS

Designed and Built by

BOEING VERTOL COMPANY

FIGURE 2.

CHICAGO TRANSIT AUTHORITY - 2400 SERIES

DESIGN CRITERIA

ITEM	COMPONENT	CONDITION	REQUIREMENT
1	CARBODY	COMPRESSIVE LOAD WITH VERTICAL LOAD	200,000 LB/71000 LB 48500 LB 90% YIELD
2	CARBODY	MAXIMUM VERTICAL	71,000 LB - 50% YIELD
3	CARBODY	LONGITUDINAL STRENGTH	ANTICLIMBER TO COUPLER - 100% COUPLER TO BOLSTER - 120% BOLSTER TO BOLSTER - 140%
4	COLLISION POST	STRENGTH COMPATABILITY (END UNDERFRAME)	DESIGN AND ATTACHMENT SHALL DEVELOP FULL STRENGTH OF END UNDERFRAME a) ANY LOCATION UP TO 6 INCHES ABOVE TOP OF UNDERFRAME b) ANY HORIZONTAL ANGLE UP TO 30° EITHER SIDE OF AXIS. c) POST ATTACHMENT TO RESIST TORSION.
5	CORNER POST	STRENGTH COMPATABILITY (END UNDERFRAME)	DESIGN AND ATTACHMENT SHALL DEVELOP SILL STRENGTH a) FORCE LOCATED AT TOP OF UNDERFRAME. b) AZIMUTH - ANY HORIZONTAL ANGLE UP TO 90° FROM LONGITUDINAL.

FIGURE 2.

CHICAGO TRANSIT AUTHORITY - 2400 SERIES

DESIGN CRITERIA

ITEM	COMPONENT	CONDITION	REQUIREMENT
6.	COLLISION/CORNER POSTS	STRENGTH COMPABABILITY (ANTI TELESCOPING PLATE)	POST ATTACHMENT AT TOP TO ANTI-TELESCOPING PLATE. a) RESIST WITHOUT FAILURE THE POST REACTIONS, SINGULARLY OR IN ANY COMBINATION, WHEN ASSUMED TO BE SIMPLE BEAMS (PIN ENDED) LOADED AT A POINT 18 INCHES ABOVE UNDERFRAME, WITH A LOAD SUFFICIENT TO DEVELOP POST YIELD. b) VERTICAL CONNECTION AT POST ENDS SHALL BE SUFFICIENT TO RESIST VERTICAL FORCES INDUCED BY POST YIELDING. c) ANTI-TELESCOPE PLATE SHALL BE ATTACHED TO POSTS AND ROOF SUCH THAT FULL VERTICAL ROOF STRENGTH IS ATTAINED ON YIELD OF POSTS.
7.	COLLISION/CORNER POSTS	SECTION MODULUS	ALL POST 30 IN^3 TOTAL. COLLISION POSTS ASSIGNED - 75% TOTAL
8.	ANTI-CLIMBER	STRENGTH CAPABILITY	THE ANTI-CLIMBER, ITS ATTACHMENTS AND THE END SILL TO WHICH IT IS ATTACHED SHALL BE ABLE TO RESIST WITHOUT DEFORMATION OR LOSS OF ENGAGEMENT, A VERTICAL LOAD OF 75,000 LB. AND A HORIZONTAL LOAD OF 200,000 LB APPLIED BY AN OPPOSING ANTI-CLIMBER WITH ANY POSSIBLE ENGAGEMENT, INCLUDING ONE RIB ENGAGEMENT.

FIGURE 2.

CHICAGO TRANSIT AUTHORITY - 2400 SERIES

DESIGN CRITERIA

ITEM	COMPONENT	CONDITION	REQUIREMENT
9.	BOLSTER	TRUCK RETENTION	THE CONNECTION BETWEEN CAR BODY AND TRUCKS SHALL BE CAPABLE OF RESISTING A VERTICAL LOAD OF 50,000 LB AND A HORIZONTAL SHEAR LOAD OF 150,000 LB IN ALL DIRECTIONS IN A PLANE LOCATED BETWEEN THE FINISHED FLOOR AND AXLE CENTERLINE
10.	SEAT	CRASH RESTRAINT	SEAT ATTACHMENT TO FLOOR AND SIDE STRUCTURE SHALL BE ADEQUATE TO RESIST LOAD RESULTING FROM TWO PASSENGERS BEING THROWN AGAINST THE SEAT WITH A LONGITUDINAL FORCE OF 4.0g. THE SEAT MAY DISTORT BUT NOT TEAR LOOSE.
11.	STANCHIONS	CRASH RESTRAINT	STANCHION ATTACHMENT TO FLOOR AND CEILING SHALL BE ADEQUATE TO RESIST THE LONGITUDINAL AND VERTICAL FORCES RESULTING WHEN THE STANCHION IS LOADED HORIZONTALLY WITH A LOAD SUFFICIENT TO CAUSE IT TO BEND. ALTERNATIVELY, THE STANCHION CAN BE FREE TO MOVE VERTICALLY IN THE CEILING BUT EXTEND AT LEAST FOUR INCHES ABOVE THE CEILING. A BOLT SHALL BE INSTALLED HORIZONTALLY THROUGH THE STANCHION NEAR THE END SO THAT THE CEILING WILL BE DISTORTED IF STANCHION BENDING PRODUCES MORE THAN THE ALLOWED VERTICAL MOVEMENT.

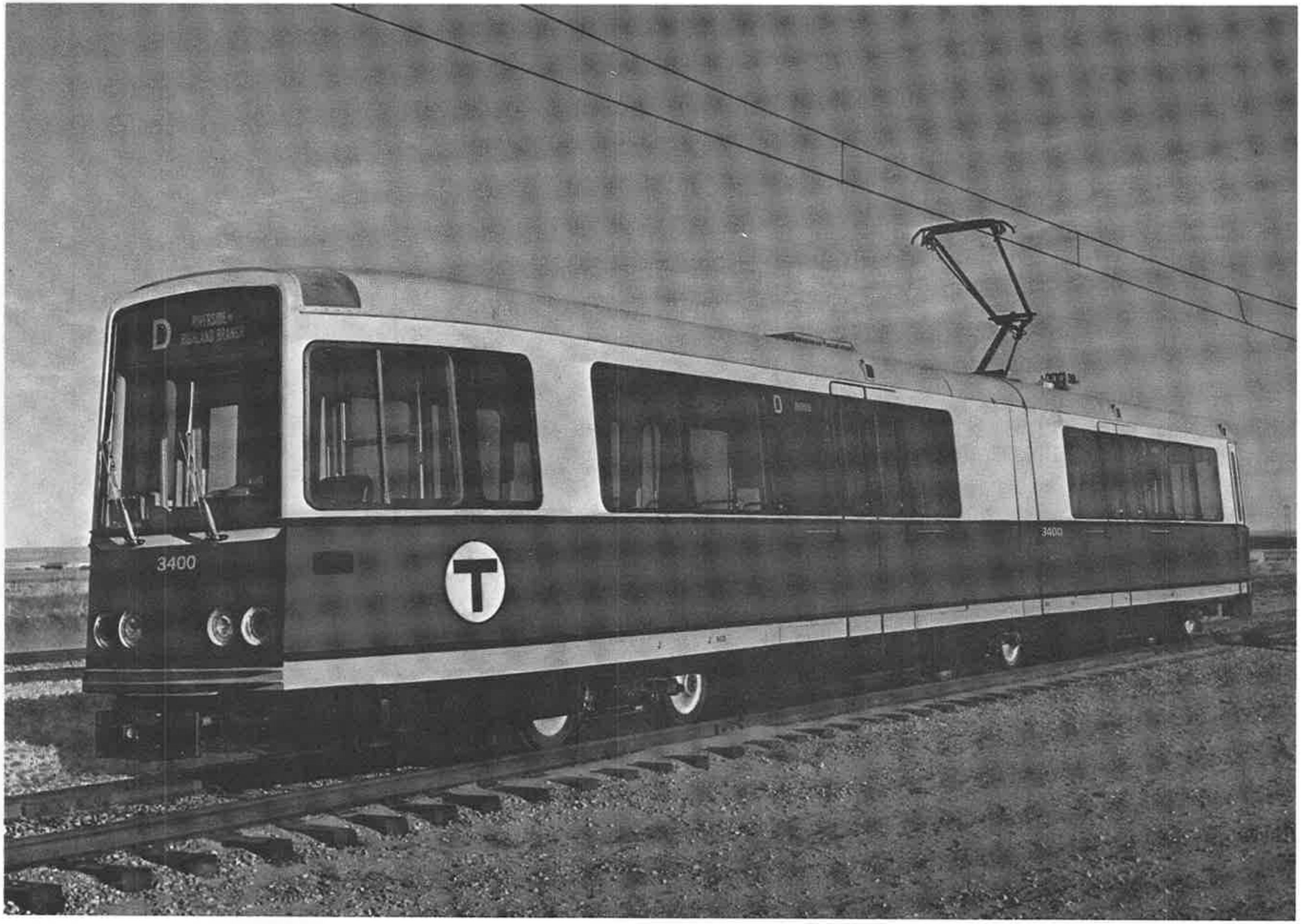
FIGURE 2.

CHICAGO TRANSIT AUTHORITY - 2400 SERIES

DESIGN CRITERIA

ITEM	COMPONENT	CONDITION	REQUIREMENT
12	COUPLER	ENERGY ABSORPTION FREE MOTION	DRAFT GEAR CAPABILITY 90,000 LB BUFF AT ONE INCH STROKE. 17 MILES OF TRAVEL AFTER EMERGENCY RELEASES.
13	DRAWBAR	ENERGY ABSORPTION FREE MOTION	90,000 LB DRAFT GEAR EMERGENCY RELEASE ALLOWS 31 INCHES OF TRAVEL.

FIGURE 3.



C 25656

LIGHT RAIL VEHICLE

Designed and Built for
MASSACHUSETTS BAY TRANSPORTATION AUTHORITY
By
BOEING VERTOL COMPANY

FIGURE 4.

LRV - DESIGN CRITERIA

ITEM	COMPONENT	CONDITION	REQUIREMENT
1	CARBODY	COMPRESSIVE END LOAD WITH VERTICAL LOAD	138,000 LB (2.09) WITH 69,000 LB. YIELD STRESS.
2	CARBODY	VERTICAL LOAD	102,945 LB - 50% YIELD.
3	CARBODY	CRASHWORTHINESS GUIDELINES	THE FOLLOWING GUIDELINES ARE SUGGESTED TO ACHIEVE CRASHWORTHY DESIGN GOALS FOR FRONT END COLLISIONS OF EMPTY CARS: (FOR THIS CONDITION THE COUPLER SHALL BE CONSIDERED TO BE IN THE STRAIGHT AHEAD POSITION AND SHALL MAKE THE INITIAL CONTACT IN THE COLLISION. oVEHICLE TO WITHSTAND 1.5 MPH IMPACT WITH SOLID OBJECT AND SUSTAIN ZERO DAMAGE. oVEHICLE TO WITHSTAND 5 MPH IMPACT WITH DAMAGE CONFINED TO DRAFT GEAR ASSEMBLY. oVEHICLE TO WITHSTAND 10 MPH IMPACT WITH SOLID OBJECT WITH DAMAGE CONFINED TO FORWARD TWO FEET OF VEHICLE, MEASURED FROM EXTREME END OF CAR, AND WITH NO HAZARDOUS ELECTRICAL DAMAGE. oVEHICLE TO WITHSTAND HIGHER THAN 10 MPH IMPACT SPEEDS WITH MODERATE DAMAGE TO VEHICLE STRUCTURE.

FIGURE 4.

LRV - DESIGN CRITERIA

ITEM	COMPONENT	CONDITION	REQUIREMENT
4	COUPLER	ENERGY ABSORPTION	75,000 LB 1.5 INCHES EMERGENCY RELEASE AT 75,000 LB.
5	TRUCK	RETENTION BY RADIUS RODS	a) LOAD IMPOSED BY COLLISION AT SPEED UP TO 15 MPH. b) LOAD DUE TO 10 MPHS DECELERATION NOTE: RADIUS ROD CAN DISTORT UNDER EXTREME LOADING CONDITIONS IN EXCESS OF ABOVE.

FIGURE 4.

LRV - DESIGN CRITERIA

ITEM	COMPONENT	CONDITION	GENERAL STATEMENT
a)	COLLISION POST	OPERATOR PROTECTION	ADEQUATE STRUCTURAL MEMBERS.
b)	ANTI-CLIMBER	ENERGY ABSORPTION	REMAIN FUNCTIONAL AFTER LOW SPEED IMPACTS AND ALLOW ENERGY DISTRIBUTION.
c)	ARTICULATION	END COLLISION	a) BUFFING LOADS TRANSMITTED WITH MINIMUM DAMAGE OF DEFORMATION. b) VERTICAL SHEAR STRENGTH VALUES ENSURE ANTI-CLIMBING AND ANTI-TELESCOPING.

Mr. Tucker: There are two subjects that have been suggested already. Jason Baker would like to introduce the subject of framing requirements and it's been suggested, and I think it's a good one, that we just talk a little bit about the influence of styling on structural design in crashworthiness, specifically. Does anyone have some other subjects that they'd like to introduce?

Mr. Cihak: I would like some discussion on the consideration of compatible design, meaning if you have a freight of x freight and x quality, weight, and so forth and if you vastly change cars that run together with those, no pun intended, but runs on the same railroad introduces a factor which frequently can be negative to old cars.

Mr. Tucker: Okay, we'll put that down as a subject. Does anyone else have anything they want to introduce?

Mr. Green: The subject raised yesterday of whether more stiff is better. I wonder if we could have discussion on that.

Mr. Tucker: Okay.

Mr. Vigrass: I'm curious that no one has addressed the degradation over time of some types of cars, particularly what I've observed about cars built out of ordinary steel, even the high tensile steel. They do corrode over time. I'd like to hear some discussion on that.

Mr. Tucker: Okay.

Member of the Audience: I'd like to hear a question be addressed to collision on curves.

Mr. Tucker: Okay, thank you. That gives us plenty of subjects to start our discussion. Pullman Standard expressed an interest in saying a few words in introduction and perhaps we could do that first and then we'll get into some of the other subjects that were suggested. May I introduce Joe Raidt of Pullman Standard.

Mr. Raidt: Yes, I'd like to just give an overview of Pullman Standard's activities in crashworthiness over the past three years. Originally, back in 1972, as got involved with a contract for tank car safety project and we developed a mathematical model for simulating the tank car collisions to prevent separation of the couplers. We did this and the mathematical model of the trailer cars showed how the couplers did override and cause puncture of the tank head. This was a preliminary study that proposed to do a more

Mr. Raidt: cont. advanced program taking into account the elasticity of the cars for the higher speed collision, and, also take a look at the sharp head coupler, but that's as for as that went. This was given to Washington University for further expansion on their crashworthiness program and also, it gave parameter data to IITRI for their program.

Further on for a Volvo passenger car contract, we looked at higher speed collisions using an energy absorbing device in the draft gear and, we developed a mathematical model to simulate a string of cars running into a string of cars, still maintaining the thrust throw limit of the car. It was 800,000 pounds. We were able to get collision speeds of 16 kilometers per hour and up to 20 kilometers per hour with it, the energy absorbing device and the draft gear and looked into further that this could still be increased by changing this crushable load capacity in the travel of it. We could even get higher impact speeds with this and still maintain the 800,000 pound thrust throw limit of the car. That's an overview of what Pullman is doing. Any questions?

Member of the Audience: Was this work all with tank car?

Mr. Raidt: No, the last study was with passenger cars.

Member of the Audience: Were the passengers considered in this?

Mr. Raidt: No, the passengers were not taken into consideration in this model. In the original tank car collision model there was lading with the spring friction models in there.

Mr. Tucker: Thank you. Now let's take the subjects in the order suggested. The first subject that was suggested was the effect of styling on crashworthiness. I assume that the intent of the people who suggested this subject wanted to discuss whether we should constrain the stylists, the architects, and the politicians and, if so, how should we do it. Is there anyone that would like to comment on this subject?

Member of the Audience: I was involved in a situation like this in Chicago. The designer, I'd say who drew the design but that's not correct, selected finishes and colors and drew an envelope around essentially what was specified, a shell, it was incorporated by the designer's features and I think the consultant in that particular case was quite cooperative and he saw our point of view. As a result,I don't think the design of the car was compromised in any way.

Mr. Tucker: Who was your designer?

Member of the Audience: Sundberg-Ferrar.

Mr. Tucker: In Atlanta, we sized the major structural components before going to Sundberg. We told them what size collision posts we had to have and the general size of the structured components. We required that he corrogate the sides because we had specification that was open for both aluminum and stainless steel. We had him design something that permitted a corrugated roof. To summarize, we tried to get the structural designer in a little bit before the stylists. I found from my experience, the stylists were always very willing to cooperate and have the engineers tell them what they need. Does anyone else have some other comments?

Mr. Vollmar: We've had a little bit of experience along that line. I think what was said here was true that where you make a cooperative effort, where the engineers and the designers get together before the designer offers something to the board, that's critical. If you let the designer get to the board before the engineer reviews the design, you're going to have problems. You have to get the sequence of the design established properly before both agree that you have something you want to present.

Mr. Tucker: You've got to realize the problem of the designer. He has to sell a unique design to the board, the Mayor, or the management of the Authority. He knows that the engineers are not the ultimate judges of his designs. You've got to get to him early.

Mr. Madigan: I think if you tell your Chairman that you can't build a nice, fancy-shaped car because of structural requirement or whatever you want to call it, he's going to say, "Well, who laid that on? Not me." There has to be some other backup there and everyone is subject to pressure unless, somebody comes up with some level of requirement you can point to.

Mr. Tucker: Yes, standards would make it easier. We found from experience that after Sundberg introduced the design in Atlanta, the Mayor was very unhappy because he expected to see a long nose on the car. Sundberg came down and defended the engineers very adaquately and convinced the mayor that his was a handsome design. So it works both ways.

Mr. Greene: I think the important thing is the emphasis on some kind of criteria in the way of strength and load distribution and stuff like that. Otherwise, you are kind of at the mercy of the decision-makers who don't really have the technical background. About five years back, I was privileged to, on very short notice, sit

Mr. Greene: cont. in at a design review that evaluated several proposals. It was a federally-sponsored job, just to point where the responsibility was, and three of the vendors went throught their flip-chart routine very sophisticatedly; it was very interesting. The fourth gentlemen did so likewise, but he was stopped midway by one of the executives present who said, "Oh, I don't like your nose," and the nose arrangement was rather straight-forward a slight slant to it, and up-to-date configuration, but basically, what we're used to. Of course the vendor said, "Well, sir, if you don't like my nose, I will come in with a new one tomorrow," and he did, and it was a bullet-shaped rocket-to-the-moon type thing. I do believe that the intention of today's and yesterday's meeting is to pinpoint this kind of problem area and kind of hope to prevent them from occurring in the future. I guess the offshoot of all this, in the positive, is that we do need some kind of criteria which will give the technicians a value base on which to defend the posture that they take.

Mr. Tucker: Fred's point is very well put. You've got to help the designer sell his design don't, he might run off in another direction. We had some Board members visit the designer's shop. We developed support for Sundberg on our Board before introducing the design to the public. I think that helps. Let's get on with the second subject then. Jason Baker would like to talk a little bit about framing construction requirements.

Mr. Baker: Fred did mention what I'm going to talk about, but I'll give it to you in a little more detail. I have made a survey of some of the framing structure requirements of recent orders, and I find that even for buff load it's all over the place. A lot of operating companies just don't require certain capacities for collision posts or anything relative to safety of the framing structure. What I think we ought to do, and possibly it was mentioned upstairs, that maybe the standardization people can pick it up, but I'd like to make it known that we should do something about standardizing the requirements. We have 400,000 pound buff loads in one company and 180,000 in another company and even some of the other requirements like ultimate shear strength in end collision posts, as one operating company had no requirement for. One thing more was brought out at the meetings yesterday. Only three companies have any requirements on the attachment of the truck to the car body. I think that's very important. If you lose the truck in a collision, you're going to penetrate. If you have some requirements for the truck attachment you may not lose the truck and you may not penetrate so we ought to have some sort of requirement for that, too. This is what I think we ought to discuss to some extent, John, and again, if they want to pick it up with this standardization, they can. I think it's very important

Mr. Baker: cont. we have criteria and then we should decide on what the figures should be and make it all one so we get the best figures and, possibly, we get the safest car.

Mr. Tucker: Does anyone else want to comment on that?

Dr. Raskin: I just want to emphasize a point that I made yesterday and that is, that some of the reasons behind all these various requirements relate to the thinking that went into the AAR specification, and I would like to emphasize the fact that there is a set of requirements. It's not a grab bag. It embodies a certain philosophy of how to build cars, and it is essentially a team approach to crashworthiness. There are five different requirements, all of them interrelated such that in a cooperative way the structure works to absorb the energy. It's not something where you can say, "Well, I don't need truck attachments, but I do need buff strength, I don't need collision posts, but I do need draft gear vertical load." You can't do that. It has to be clearly thought out of how the car is going to absorb the energy that it has to absorb.

Mr. Sebastiano: At yesterday's meeting, New York suggested that the specification that we are proposing for our new R55 car procurement be the basis of the standard for the industry. We firmly believe that we have a good design. But, we'd like to go further. What we would propose is that we first establish by test a maximum speed that results in a minimum of injury to passengers. Now, if that is established at say ten or eleven miles per hour, than this is the criteria that the cars should meet without any physical damage. We also propose that the R55 specifications require that a mock-up be build and tested at the Pueblo Test Track. We would even recommend to to our Authority to use some of our R9 cars that we are scraping to be used to run such a test. A second alternative would be, as the Budd Company pointed out yesterday, to develop a scale model for test. We firmly believe that standards should be established for all properties to meet the same requirement of crashworthiness. We, again, propose to recommend to our Authority, that some of our scrap cars be turned over to U.S. DOT to be rebuilt to this new criteria and tested to become the standard for the industry.

Mr. Tucker: Could you make copies of your standards?

Mr. Sebastiano: Yes, we will have copies distributed.

Mr. Tucker: Perhaps, as a tangential subject, we should discuss who should sponsor this activity. Should it be the Federal Government, or should it be APTA, or should there be some ad hoc group from transit agencies outside of APTA? Has anyone got a suggestion?

Mr. Greene: I'm not speaking for anybody but myself and I've had a kind of varied experience which included a temporary one-year assignment with APTA which lasted for five years. The APTA charter kind of included the representation of the transit industry. Part of the mechanism with which I was involved included direct representation by guys such as Mr. Tucker. I don't want to pinpoint everybody on the floor, but most of my colleagues in the field were members of what was called an advisory board. So again, speaking for myself, I would suggest that the mechnism for achieving the goal which we are describing is, yes, government funding, but, I think it should be through a management of APTA team which would include, by definition if you will, the input of the various properties integrated, assimilated or whatever, and made into a package by APTA.

Member of the Audience: Where does the manufacturing industry come in this?

Mr. Greene: Oh, I'm sorry, this is the big picture aspect but, certainly, and again, speaking for myself and not Mr. Chihak or anyone else, historically from my own experience, APTA did have or its predecessor, did run a program which I consider rather successful and included interface with industry. It's really a straightforward program management effort and it can be easily structured to include testing by whoever, the correct interfaces with industry. Certainly it has to be cooperative effort. But when you're laying these things contractually, it's, to my mind, a rather simple management process and I don't see any conflict.

Mr. Spencer: I'm Paul Spencer, with UMTA. Fred, we have programs now such as tunneling technology, noise abatement and smokeless cable, and we work very closely with APTA. We use them as advisory committees and they give us guidance on a real time basis in these areas and their input is weighted every bit as high as our own. I would like to ask you whether you had this sort of role in mind? Would you like to see a stronger role on the part of APTA or just what?

<u>Mr. Greene</u>: I'd like all there is and then some, so, obviously, I'd say that I would like myself, APTA, or whoever it is, to have the stronger role but that's really an incidental kind of thing. What you're saying is really correct. There has to be an interrelation and acceptance of the input from the properties and the exact mechanism for that must be worked out by others.

<u>Mr. Sebastiano</u>: Why not continue with this project under the existing ASDP program? We had the Act One, the Advanced Subsystem Development Program; why not a crashworthiness program to develop and prove the standards that will be proposed.

<u>Mr. Cihak</u>: I'm not in a position of setting up the policy, certainly, but I would like to offer the comment that basically what is requested here, a set of standards, should be addressed in the rail car standardization program which is presently funded. Now, it's not envisioned at present to fund large-scale testing of any kind, probably not any testing. However, if there is an impasse reached in that particular area of discussion, then certainly a recommendation in the rail car standardization project would be to move forth in this area. I fully agree that there should be a base-line requirement and then perhaps I could see some adjustment for various train sizes and/or car weights, modifying it some way to be, perhaps, more in tune with the physical requirements. I see it has to happen sooner or later and the exact method, I'm sure everyone would understand that APTA doesn't have funds to pursue this thing and the funding mechanism would very likely be through th Federal Government. Certainly, a cooperative effort in this area is well indicated.

<u>Mr. Baker</u>: Just to continue on the answer, Frank, I envision that the operating authorities would get together and come up with a set of criteria and a set of figures in conjunction with the car building industry because the car builders, they have their inputs too. And, between the two of them, they can come up with a standard set of framing structure criteria. Now, whether it be funded through APTA or UMTA, at the moment, it's immaterial as long as we can get that particular aspect of car building on the straight and narrow path.

<u>Mr. Spencer</u>: I would like to address Mr. Sebastiano's question, namely, why we don't put crashworthiness under the advance subsystem development program. Now, let me explain just briefly. We currently have two large turnkey types of operations within the office rail technology. One of them is urban rail supporting technology, and we use TSC as our primary system's manager in that program.

Mr. Spencer: cont. The other is the advanced subsystem development program its successor stars subsystem application for rail technology or something like that. The supporting technology activities include generic type activities, such as construction, noise abatement, and safety. When these technologies are developed to the point where they can be deployed through, or developed through specific subsystems which you can plug into a vehicle, then they fall under the second large, the ASDP type of activity which currently uses Boeing-Vertol as a prime contractor. So, I think for the time being, we would keep crashworthiness and other safety activities, in the urban rail supporting technology program and, if it developed to the point where we had specific configurations in mind that we could retrofit to one of the vehicles which you offer, for example, at that point then it would fall into the other categories of programs.

Mr. Tucker: I assume we're all talking about transit cars and we're not going to tackle AAR or light rail cars with this sort of an approach. Is that the general concensus?

Mr. Williams: One person in the front row who made a comment, it may have been this, and that was to do with the standards which might vary from property to property depending on train weight and, I think, another factor that may want to be considered is the train maximum speed because, as we saw in some of these diagrams, there's a lot of difference, the inertia or the energy to deal with is considerably different from the higher speed trains Now, what this goes directly against is the idea of standardization where everybody wants to build the same thing, or would like to have the same thing. So, somehow, that has to be ironed out and maybe a little research would be good to show what the different strength requirements might be, based on train weight and speed. Because those of us that maybe run short trains at low speeds, or want to try to save energy and save money in buying cars, and should have a chance to do that, if we don't lose too much money because of the smallness of our car order and the differentness of it.

Mr. Tucker: Don Raskin, when he talked about AAR yesterday, alluded to the fact that AAR permits derating the requirements based on car weight and train weight. That may be a way to go in that direction.

Mr. Schmidt: Pete Schmidt, Baltimore. I think that whoever actually writes the standards is going to have to do a lot of homework. The first step is to publish the homework in some kind of design handbook, some kind of list of things to consider, then from there work on the standards as a second phase. Just a collection of

Mr. Schmidt: cont. everybody's spec in that some kind of source document that lists everything, puts it together and gives a general overview of how to go about designing it as a function of train length or velocity would be the first step and that would lead eventually into standards.

Dr. Raskin: I just want to second that because I think if we have any other source of effort, it's going to be, well, we used 300,000 and we found that's okay, and 500,000 is what we used and that's okay. It's got to be better professionally.

Mr. Tucker: Okay, we will report back to the group on the output of this meeting. I read the concensus as being that people feel that it's desireable to have framing criteria, if we can use that expression, for transit cars and we'll suggest to our host that we pursue it further.

The next subject that was raised was the consideration of compatible designs between different cars. Perhaps Frank Cihak would like to introduce that subject.

Mr. Cihak: In reference to the ICG collision, one of the areas of much discussion at that time was the great dissimilarity between the two cars. There's like fifty years between them. The car weights were largely different. The striking car in that case had a one motor truck on one end and a trailer truck on the other end, and I think, the philosophy of the two cars was, in some ways, somewhat different. Certainly the sizes were. This brings up an area of when you have compatible cars in a fleet, you have at least some assurance that they will all act the same if they ever get involved. If you radically upgrade a new car and put it in a fleet with some other cars of lesser level of protection, then you now are, let's say, putting the burden on the old car. Now, it's obviously very difficult to segregate the cars in a fleet but some places it's possible to do it. At least in our discussion, that's something to be kept in mind.

Mr. Tucker; Any other comments on this subject?

Mr. Vollmar: The idea is certainly one that requires a lot of concern. What you find yourself faced with, what you really have to do if you want to improve and you have existing equipment is, you've got to go into improvements that are totally defensive in which you may make the new cars capable of defending themselves better, but not capable of inflicting anymore damage on the older ones than they already can inflict on each other. And, this precludes gross changes. For

Mr. Vollmar: cont. instance, if you have cars with 200,000 pound buff and you decide they ought to be 400,000, you're really setting up a rather unpleasant condition. On the other hand, you can say, well, my collision post sheer strength of 100,000 really isn't adequate. I want to go to 300,000. This will not damage the other car but it will certainly protect the new one so, this is a process that has to be done very carefully, very selectively, and you have to know what your existing cars are capable of withstanding. So, certainly, it's a problem that everybody with cars that are operating must look at and there's got to be some escape clause in a new set of standards to allow properties with cars that are not that good to adjust to avoid running torpedos around their system, basically. One other point, I guess there's been so much talk about ICG, and I think a few things ought to be straightened out, because it so happened we had the privilege of investigating that accident in 1972. There had been a lot of misconceptions thrown around and I'll just take a couple of minutes to straighten it out because it's very misleading.

One of the big ones has been talked is the weight of cars. The point of great interest here is that the car that did all the damage was much lighter than the car that it destroyed. The car destroyed was a Highlighter which weighed about 134,000 pounds. The car that did the damage was a trailer and Frank, it's a pure trailer because, one four motor car and a trailer. That trailer weighed about 80,000 pounds. So the problem isn't heavy and light, it's just exactly how they come together. The old car didn't have much in the way of collision posts and it didn't have its trucks attached and it didn't have any vertical strength on the couplers at all. They had radial carrier couplers with about 10,000 pounds vertical so, even though the coupler went under the frame of the Highliner, it simply disappeared. It didn't do a thing to solve the problem. Being a trailer, it had a relatively clean underside so it slid very nicely over the end of the Highliner with its end sill knifing through what structure existed. The only stucture that existed was what was required by AAR, end posts and, I really have to say this, AAR has never called end posts collision posts and we really ought to quit doing it because we mislead a lot of people into thinking we have something we don't. We have big numbers involved, at least they sound like big numbers, AAR has 800,000 pounds of shear and many transit properties are 200 or 300 or so, and that sounds like a lot. But, when you begin to look at what kind of energy that post can absorb and what kind of energy you have available, you find that they really aren't collision posts.

Mr. Vollmar: cont. For instance in the IC, we had 800,000 shear posts and, if you try to determine how much energy they can absorb, it's somewhere in the range of 25 or 30,000 foot pounds per post. In the collision which took place at 50 miles an hour, we had about 60,000,000 foot pounds available and there's just no comparision. The collision post is not a collision post, it's an end post and we'd all be well advised to refer to it as that. It's protection in low speed accidents, five, six, ten miles an hour. The whole structure is designed to provide protection to the passengers at restricted speed operations. The AAR approach was that we have signals and you always should have a train under control so the only condition that's permissible to operate with a motor train in a block is 15 miles an hour. At that speed we'll be all right. That's tne philosophy that got you there so, when you run into one of those at 50 or 60 miles an hour, you're just gonna have a big mess, which is exactly what happened.

Certainly, the lack of compatibility of equipment had a big impact in the IC accident. If they had been two Highliners, we would not see nearly the amount of destruction because, first of all, the couplers in those cars had the full vertical strength and had they gone under each other's end sills, there probably would not have been overriding and the damage would have been much less and, obviously, the number of fatalities. I think that probably clears up most of the things I was concerned about.

Mr. Tucker: If they were two Highliners, then they might have coupled.

Mr. Vollmar: That's correct. Oh, one other thing, our Secretary of Transportation at the time said you can't count on these aluminum cars to stand up.

Mr. Tucker: Any other comments on compatibility? It's a very interesting subject. If not, I'll summarize. I don't know if there's anything that we should bring back to our hosts on the compatibility issue except that compatibility should be considered in any standard. Does that summarize the discussion?

Since we're talking about that sort of thing, I'll jump to the last subject introduced which is that of collision on a curve. Harry Dorosh wanted to introduce this subject.

Mr. Dorosh: Harry Dorosh, with UTDC. I'm particularly interested in the question of collisions in other than a straight line, especially in its regard to having vehicles on an elevated guideway, which some of our development in Canada is directed toward. I see two particular problem areas in this. One is the problem that was brought up yesterday in an accident where it was pointed out that the structure, the superstructure tore loose from the underframe and this sheared away, and, of course, this didn't offer the occupants very much protection. The second aspect of the problem is when you're colliding on a curve, any possible overturning moment that might be produced and any tendency for the cars to be derailed and pushed off the guideway onto the ground. I was wondering if anybody has had experience, or at least thoughts in these two areas.

Mr. Vollmar: Was the collision you just referred to the one that I mentioned because, that was not a matter of a superstructure, the end frame just folded over and up, the end frame did what it normally could be expected to do in a sideways collision. It was not a matter of pieces of car tearing apart. It just folded up. It was a good structure, just inadequate for the kind of job. I don't see any way it could have been designed to do that.

Mr. Dorosh: If we're talking about a collision on a tight curve, what would be approximately the degradation in protection of the cars as opposed to the straight-on type of collision? How much more susceptible are they to damage when you're getting at an angle instead of straight on?

Mr. Vollmar: Well, I'll answer that by saying we've never seen any kind of damage like that because that was a fairly high-speed collision, 30-35 miles an hour and that shouldn't be happening.

Mr. Tucker: There's another consideration, of course, when you're on a curve, that is, you're more likely to cause a derailment maybe the secondary effects are worse than the primary effects. Would someone like to comment on that?

Mr. Keevil: I'm sure you're all aware of the last one that we had where we took some cars off the structure. The actual collision damage in that accident was minimal. It was a relatively low speed collision, 15 miles an hour or less, and the end sills and underframe and all experienced what you would consider normal damage from a collision at that speed. They performed excellently and, there was no cause to suspect any inadequacy of the designs in either car. So, as he says, the secondary damage, the derailment and the subsequent falling off the structure was what caused the major problems, not the actual collision.

Mr. Vogel: Erich Vogel, Washington Metro. I don't have any solutions or to add to anything Walter said. I have a question, though. Yesterday we went through all these analytical models that we're talking about straight level tangent tracks, rear end collision where we take into consideration the buff load of the coupler and all the other good stuff. Yet, in my experience, I have seen other than yard collisions, none on the main line, that ever happened on level transit tracks on transit cars. Most of them happened on a curve and the reason is poor visibility for one. So, my question is, I question some of the data and not from the point of view that it's not valid, but from the point of view, how does it help us in reality when we look at all the analytical data on a level tangent track and it doesn't mean anything when most collisions happen on a curve. We lose a lot of the areas and a lot of the factors that are plugged into the analytical models so, I have some problems in trying to take the pure numbers and put them out in the field and say live with it. What does it do for me? I don't know.

Mr. Tucker: Does anyone else have a comment on this subject?

Mr. Rhine: The IITRI people fully recognize this limitiation of the analysis they had done and one of the recommendations to follow on analysis was to look at the, say optimal, crash alignments and we have not yet seen fit to fund that. It is, though, recognized as not a shortcoming but as a limitation in the work that's been done.

Mr. Tucker: Of course the energy levels would be lower if you caused the other train to derail but, perhaps, we should talk a little bit about whether we should have standards for derailments, too.

Mr. Vollmar: A couple of things here. The ICG accident also occurred on a curve and I think I can say almost without question, that it didn't make any difference what kind of track that was on. It was a mess. It did leave standing the corner post on one end of the car and the car actually came out to the side of the Highliner and penetrated some forty feet and came out through the side. This was a result of the curve. Whether this helped to save some lives or lost some is hard to say but, there were some people in the rear section of that car who were on the inside of the curve who came out of it without a scratch. Those who were on the outside have problems. The accident that Don was talking about, I also had the

Mr. Vollmar: cont. privilege to investigate, and again, although the structure behaved a little differently than we had seen, it was no question that it did everything that it was supposed to do and then some. It was the most amazing mute evidence to the kind of evidence that exists in this kind of an accident where the basic draft sill, which is composed of high stength steel, 70,000 psi yield material, and two sections forming a box and about 12 inches deep was bent into a radius of about two feet. And, if you can begin to figure what it takes to do that, it sort of gives you an indication of what you run into.

We had another accident that we were involved with, earlier on Bill Vigrass' property, which also occurred on a curve, and again, the bar behaved exactly as we would expect them to. So that in the areas where you're likly to see relatively high speed accidents, the curves are gentle and it's unlikely that it will make much difference in the performance of the car. The National Transportation Safety Board in commenting on the Illinois Central accident did suggest that impact stresses up to 15 degrees from the longitudinal be considered in future designs and when you look at that, it does make some slight difference in the configuration of the post and the amount of material you have to put into it.

Mr. Dorosh: Did the couplers engage in these accidents?

Mr. Vollmar: In the ICG accident, they didn't obviously. One coupler simply never existed and I don't think they engaged in the New Canaan accident either. On the PATCO accident, they did, but the shear bolts and the couplers, of course, retreated and allowed the anti-climbers to do the job and, one car suffered a perfect imprint of the other's anti-climber. About a six-inch deep dent was about all it did. That was a 20-mile-an-hour accident. It was only two single cars so the mass was down and we didn't have a great deal of energy available to do damage.

Mr. Dorosh: Would you like to make some kind of comment on the gathering range of the coupler in the accident?

Mr. Vollmar: Well, the gathering range in the couplers, all these couplers, is very small in consideration of the amount of offset that you can get on a curve. On curves in higher speed territory, the couplers will, probably, normally gather provided they're centered and not all systems have guaranteed centering of couplers. The end two did and the DRPA cars both had centering devices. But, where the curvature is sufficiently sharp, as it was in New Canaan, those couplers will pass under those conditions. The normal gathering range that we expect for couplers is never more than about 5 minute offset so that you could do a little geometry and figure out at what point the end overhang of the car will get you out of that condition, and it's probably somewhere

Mr. Vollmar: cont. around two degrees of curvature, I'm guessing.

Mr. Zehnder: European specifications call, for that reason, for diagonal squeeze test in the underframe so that not only in the longitudinal sense, but also slightly out of the longitudinal, the underframe develops certain strengths and with that provision, I think, a great deal of this problem can be covered.

Mr. Greene: John, one comment. If you're going to write this up as a recommendation or something, most of the discussion on the subject has really been addressed to Highliner or to the commuter type operation and all I would recommend, is that your consideration also take into account the mass transit or the subway-type vehicles which are somewhat different and the accident severity is not the same as has been some of the experiences of the other cases.

Mr. Tucker: I'm not going to write this up. I will give a short oral report in the summary session.

Mr. Keevil: I think with the curve incident, one item that ought to be considered in the car design, is to make sure that your anti-climber goes far enough around that on your sharpest curve you still have anti-climber engagements. Some of your cars have very short anti-climbers that, on a sharp curve, will never engage and you'll be corner post to corner post without any anti-climber.

Member of the Audience: This may be somewhat out of place but I'd just like to make a couple of comments that relate to the New Canaan accident. One is that it was a perfect example of the application of the Chicago-style design philosophy in that all the damage was toward the end of the car from the bolster. Inboard of the bolster there wasn't a wrinkle in the car, not a thing. But, outboard of the bolster, it was just a complete mess and I have to underscore the implications of that philosophy. I'm not saying there's anything wrong with it, but when Walter said that that's a design which makes sense, however, you are in a sense sacrificing certain people, this was an example of that happening, and we have to understand that a good car structure is not going to protect all the lives of the people in the car. As I said yesterday, two people were killed in that crash because they happened to be sitting in the wrong place. From an engineering point of view, the structure did a terrific job, but two people did die.

Member of the Audience: cont. Now, what would have saved those people was a proper signaling system because this accident occurred because of man-failure, there's absolutely no question about that, and there was a signaling system in effect. But with a cab signaling system with override speed,the worst that we could have had in that case would have been a 15-mile-an-hour collision, as opposed to say, twice that speed which is what we, in fact, had. As I said, that is the protection of the passengers, not the structural design of the car. The point is that signaling systems will not guard against any collisions. There's no question about that. There still will be a possibility for man-failure but, the signaling system, if properly designed and applied, can guarantee at least that the worst collision you will have will be a low-speed collision that the car structure can deal with.

Member of the Audience: I would like to ask Mr. Zehnder, you mentioned European standards, if these are national standards of some sort or industry standards and if they are documented and, if so, could we get some copies of these?

Mr. Zehnder: Well, that standard I mentioned is the standard of UIC, the Union of International Railways and, it is documented in the report from the committee OREE 7, and there they specify the vertical loads to apply in passenger vehicles as well as the longitudinal loads. For the longitudinals I can mention that what they call for are 200 tons on buffers or central coupling, 50 tons on diagonal compression, 40 tons, about 15 inches above the buffers, and 40 tons on the waist level. These specifications are easily available from UIC.

Mr. Tucker: That's very interesting. They're much higher standars than we normally use on strength. Does UITP have a standard too, for car strengths and components like that?

Mr. Zehnder: They are not bound for transit cars. They are heavy rail standards but, on the other hand, the European rapid transit vehicles have roughly the same size and speed as European heavy rail.

Mr. Sebastiano: I'd like to expand a little bit more on what Don Raskin was trying to point out. We've seen some ugly pictures of the accidents in the last couple of days. Now in this discussion on crashworthiness, lets not lose sight of certain facts. All of us are capable of designing and producing a car that can withstand any mile-per-hour collision without damage and without any other effect, not even a wrinkling of the skin. I'm sure that's possible in today's

Mr. Sebastiano: cont. technology but, we certainly don't want to do that because we will injure more people by two cars impacting at high speed. If the cars are capable of sustaining high speed collision, everybody in the car would be thrown to one end of the car and spattered up against the end bulkhead. So, in this discussion on crashworthiness, in order to protect the maximum number of passengers in the car, there are certain things that we must do.

What we would like to do is to absorb as much energy as possible so as to injure the least number of passengers. That is why, in all our discussions on rapid transit, we're not talking about high speed, we're depending, as Don Raskin said, on excellent signal system. That is one of the primary things that we said yesterday.

Number one, you must have a good signal system and, number two, you must have a car that has crashworthiness in the low-speed range.

Mr. Tucker: Thank you. Are there any other comments? Joe's comments seem to lead into the question Fred Greene asked "Is more stiff more better?" That's the way you gave it to us. Fred, do you want to introduce the subject.

Mr. Greene: I posed it as a question. I don't know. My intuitive response is that more stiff is not more better and my experience on my property, where we did have a rear-ender around a curve and did everything wrong, the more stiff did not seem to be the solution, because the one particular car bent the center sill appreciably to the point where the car had to be scrapped. It did seem as if the car took the brunt of the energy and not the passengers. Yesterday's discussion did imply that more stiff was more better. I kind of question that because I just don't know and I would appreciate comments from the audience from people more knowledgeable as to what their thinking is.

Mr. Vollmar: I certainly have to agree with your speculation that more stiff isn't better. There's a cross-over point. I don't know if we're there yet, but certainly the stronger the car after a certain point, the more the likelihood of damage from what we called yesterday the secondary collision. I go back to the ICG accident again. There were forty-four people killed and all the deaths were in one car. Now the total train was impacted at fifty-miles-an-hour but there were only minor injuries in the other three Highliners, and in the other five of the older cars. Now, in the leading old car there were no deaths. There were several very serious injuries but, it indicates that, by the Highliner yielding as it did and allowing itself to be destroyed, Mr. Vollmar: cont. of course it took people with it, but it meant that the rest of the people in that train were protected.

The Safety Board, one of the members of the Board asked some questions at that hearing as to whether or not it would be possible to build a car that would stand up to that accident and, if such a car were built, would it be desirable. A couple of quick calculations, nothing very difficult about this, indicated that to stand up to that collision without damage to the car took 33,000,000 pounds of buff strength. Now, we're talking about 300 or 800 thousand and we really have to work hard to get that.

Now conceivably, you could put enough material in there to do that. I don't know whether there'd be any room left for people or not but, if you then go one step further and you say, if you repeated the accident with that car, what would happen, the whole train would hold up very nicely. The draft gears would give you a little bit of slack and the acceleration rate that the passengers experiences was in the range of 50g's. I kind of think, from what we said yesterday, that's a little hard one and my statement is, we would have killed the whole train. So, obviously, there's a cross-over point. I'm not sure that we're there now, but I think that our primary concern in all of this is energy absorption, not necessarily maintaining the car so that it looks, after a 20 mile collision, as though nothing had happened to it.

Mr. Tucker: Well, to take the same IC car. There were two that collided during tests. I don't know if you recall that one but, in that case, there was a lot of energy absorbed within the car. There was some nomi-nominal damage to the end. They hit at about 40 miles an hour, but there were only two cars involved. The sum total was that of the test people that were in the cars, we had two very serious brain concussions. That gives the other end of the spectrum as to how stiff the IC car is. I think the IIT fellow had a comment on that subject. Did you? Is more stiff more better?

Member of the Audience: Well, with regard to secondary impact, these would be the passengers in the second or third car. It's quite clear the acceleration level is a significant parameter so there is a question as to whether you want to. You can minimize that by allowing crush and, you've got to basically trade off how many people you're going to write off in the front end, the impact point versus saving the bulk of passengers in the remainder of the train. That's not an easy decision to make. That's really what it boils down to.

Mr. Cihak: I would like to make a comment about taking all the energy on the front end of the lead car, though. That leads to, obviously, a gross loss of space in the car, and I would put forth the concept that maybe you want to take a foot out of every car at the ends rather than ten or twenty feet out of the first car.

Mr. Zehnder: Another possibility to dissipate energy without making collapsing the passenger container would be that all under-floor equipment can slide along the vehicle at, let's say, an effort of about 4g and then it take a great amount of energy in sliding along the car's under-frame just with that effort that retains it at about 4g in longitudinal acceleration.

Mr. Tucker: That's another thought. Okay, I guess we've exhausted that subject since no one else has a comment to make. I'd like Bill Vigrass to have a chance to introduce his subject which is degradation over time.

Mr. Vigrass: This is based on personal observation and, let's say, maybe some concern and bias. My thing is car maintenance and not new car design and I've observed, in a number of public properties, fortunately not mine, a continuing severe problem by the maintenance departments to get adequately funded each year. Public boards will happily run empty buses up and down the streets in the suburbs, it's exceedingly hard for the maintenance people to get adequate funds to maintain their equipment properly. The result of this, at least in several places where I visited, is that on steel cars built in say the 40's and 50's, there is very serious corrosion and loss of integrity. I've observed, just as a passenger standing near the front of the car, I always stand by the cab so I can see ahead, and I look down and see the end posts, they're surely not collision posts in the cars I'm thinking of. They're just rotted away down at the floor level. There's just nothing left. The car envelope keeps the rain out of the inside, I think, and not a whole lot more of that.

So, going back to what Ray Vollmar mentioned about new cars and old cars, a mixture of the two, and you don't want to set up a damaging condition. But in this case it exists. You can't have the new car as weak as the old one because otherwise you'd have a bad situation. So, is there a way to enforce, somehow, public bodies to adequately fund maintenance so there isn't a loss of integrity of the car structure on cars which do corrode? Stainless steel cars don't so, I don't know about aluminum, I worked for a railroad, Union Pacific, and they had aluminum cars. They were retiring them in the late 40's and mid 50's when the Burlington cars had exactly the same age and they were running and running and running.

Mr. Cihak: They're still in good shape with Amtrak. There's a problem, therefore, and I think it ought to be addressed, and maybe, this is something where Federal standards might be helpful. The maintenance people could point to them and lean on them to demand and get proper funding because this is going to keep going on and on. The public bodies have always been this way. New York preserved the five cent fare, they preserved the ten cent fare and now they're trying to preserve the 50 cent fare. It's always the same. The cast of characters changes but the situation doesn't.

With the interest in crashworthiness, I must say, the Federal spotlight on it right now with the meetings here and the question, of course, from our sponsors was, should we keep going on here? What should we do? I would like to include something on the maintenance as well as the design of new equipment. I think this is crucial. At least, it has been in certain places.

Mr. Tucker: Any other comments on this?

Member of the Audience: UMTA does fund money for rehabilitation programs for their cars so that the major problem, I think, that can come up.

Mr. Tucker: We need more funds, I think. Anymore comments Well, we've covered all of the subjects that were on the agenda. I don't know how we're doing schedule-wise, but it's worthwhile to carry on if someone has some other observation or comment that they'd like to make.

Mr. Keevil: I'd like to raise, for consideration, the question of coupler shear-bolts, draft gear and other means of absorbing energy. Ordinarily, CTA cars have draft gear and shear pins which let loose at certain finite value that don't absorb very much energy over time. There are designs available that use extrusion tubes and various other devices to absorb energy over a longer span of time and distance. Would there be a benefit to including designs of this type, and does the experience of the Europeans, particulary, show that this type of design is any improvement over the shear-bolt design?

Mr. Tucker: Would you like to comment on that, Mr. Zehnder?

Mr. Zehnder: The only thing I can say about that subject is, that those vehicles that have a collapsible tube behind the coupler can withstand the collisions up to about 15 kilometers per hour without any damage on the structure. Only beyond that, when the energy capacity of this collapsible element is over, it enages, really, the structure. So, people who have introduced that are very happy with that element. The others have always slight damage on their structures.

Mr. Tucker: What is the travel normally on those devices?

Mr. Zehnder: The travel is roughly 100 millimeters, say 4 inches about and, all these elements develop the full strength over the whole travel. It's not a triangular diagram, but a rectangular one.

Mr. Tucker: Yes, they're very effective in absorbing the energy. As a matter of fact, the light rail car uses that. That's the only car in this country, that I know of that uses that principle.

Mr. Dennis: It has a very low energy capability now.

Mr. Tucker: Yes, that's because you don't have much stroke. Paul Spencer, do you have a comment?

Mr. Spencer: Mr. Zehnder, I was intrigued with your notion that you're going to go ahead this fall with full-scale crash testing and here we're still talking about it after a program that's been going on for years. This morning I heard things which lead me to believe that it would be more useful to get data on curved-track crashes. Is your planning firmed up to the extent where you've decided pretty much the crash conditions that you will undergo? If so, do you plan to do some testing on curves as well as tangent tracks?

Mr. Zehnder: I must say to this, all those tests are more or less out of our control because the authorities call for it and they set out the test conditions. So we have no influence on it and I guess they will use straight tangent tracks for having comparable results as they have carried out already a full-scale collision test with previous material. They want to see the improvements over the existing materials.

Mr. Tucker: Will these be RATP tests?

Mr. Zehnder: This and the interconnection tests.

Mr. Tucker: So there will be two, the RATP and the interconnect cars both?

Mr. Zehnder: Yes.

Mr. Tucker: Have they tested the RATP cars yet for collision.

Mr. Zehnder: Well, they have gone up to 10 kiometers per hour and just to the energy capacity of the buff element. They saw that it is not sufficient, they will

Mr. Zehnder: cont. study a new buff element and then go further with the collision speed.

Mr. Tucker: Okay, and will the other tests be sponsored by SNCF, the French National Railway?

Mr. Zehnder: Yes, and both high speed tests will be carried out about Septemeber or October of this year.

Mr. Tucker: By the way, the interconnect cars are very much of the same dimensions as one of our transit car, the MARTA car. I think the structure is essentially the same. Any other comments?

Mr. Dennis: The answer to the fascinating question, I think, is going to bounce back and forth until the speed is defined. In the low-speed areas, the stiff cars will probably perform but we're undoubtedly talking about something close to 10 miles an hour and the reason is that the energy involved is stored. It is not absorbed. The force is high and the deflection is comparatively low. What Mr. Zehnder is talking about is systems that truly absorb energy and here we're talking about plastic energy; that energy that is not returned after the crash incident, and you are talking of possible lower force levels but high deflection. That is where the energy capability is.

So until the body property, or whoever decides this, and we're going to protect up to 10, 20, 30 or whatever speed, then the engineer or the technicians, or whoever, can get involved and design the necessary systems.

Mr. Tucker: The one thing that wasn't discussed though, in the whole course of the meeting, when we talk about energy absorption, was the work that was done on the ACT 1 car. Some real serious efforts were made to increase the energy absorption. It takes a great amount of space. I think that was the reason that the original very ambitious program for energy absorption was modified. I don't remeber, how much energy is still being absorbed in that car. Does anybody have a better recollection than I do on the latest status of the energy absorption of the ACT 1 car.

Mr. Dennis: I think the device, I'm not too familiar with it, but I believe it's either a hydraulic or pneumatic pair of cylinders, but they do not have many feet of stroke. So I don't believe, and they cannot develop much more than what the underframe will carry, and here we're talking, I believe, in the 200, 300,000 pound range, so the amount of energy involved is still nothing like 30 or 40,000,000.

Mr. Tucker: When we talk about the energy of the train moving at any speed over 20 miles-an-hour, the numbers become fantastic. Even if you're going to crush metal, it takes an awful lot of metal to be deformed. It's been historically true that the people have chosen to deform the metal in the car body instead of adding additional frangible members. As I recall, on the Act-I, the device did not pick up until 5 miles-an-hour. Didn't they have shear pins that would have sheared at 5 miles-an-hour, or something?

Mr. Dennis: Yes, that is correct. They had a normal coupler with the emergency release and then the next step is to break pins that would allow the devices to stroke. I will add one thing. They are willing to accept the nice aerodynamic nose which is fiberglass.

Just one thing that I haven't heard discussed is that the BART car does have some kind of peeling energy absorber and I don't believe that was mentioned. That idea, I guess, is ten years old, but the anti-climber on the BART car, there is a device behind it and it is my understanding it literally peels the draft sill flanges off. That is another form of metal extrusion, metal deformation, which does absorb energy.

Mr. Tucker: Yes, the BART car did have some crashworthiness criteria on the specification but I don't recall precisely what it was.

Member of the Audience: I might mention, John, having looked at the BART car that hit the maintenance vehicle, the enery absorbing front-end structure did almost an engineering job for what it was supposed to do. It curled up very beautifully. Unfortunately that was the fatal accident for the man in the truck but it was a classic of a structure picking up a good deal of the energy. Of course at that speed, it was 70 miles-an-hour, it was almost academic.

Mr. Tucker: It was a very light-weight vehicle, too.

Member of the Audience: Yes.

Mr. Tucker: Any other comments or suggestions? Do we have any advice for UMTA as to what we've learned from the research that's been done? Perhaps that's a viable subject for discussion.

Member of the Audience: I was just going to ask George the difference in philosphy in preventing climbing and anti-climbing in Europe. I don't see a lot of anti-

Member of the Audience: cont. climbers on these rapid transit cars in Europe and I wondered whether there's a substitute or, am I correct, do they use anti-climbers?

Mr. Zehnder: Unfortunately, they haven't on the rapid transit cars. It's only on the heavy rail with the inter-car closure that prevents from over-climb.

Member of the Audience: Are you a believer in anti-climbers yourself?

Mr. Zehnder: I have no experience with it.

Mr. Vollmar: I'd like to make just one general observation that became obvious to me during Mr. Dickhart's presentation where they were simulating, or actually running scaled tests primarily on automobiles. He suggested the possibility of something like that for rail vehicles. The thought that crossed my mind was in testing the automobiles, that seemed very reasonable because we had that automobile out there on the road killing off people at the rate of two to three per hundred million passenger miles. And, I think, something really has to be done because there's a major problem. Then I looked further and I said, why do we have the same concern with rail transit vehicles where the fatality rate is down below .01 per hundred million passenger miles and we really are in excellent shape now in spite of the problem we have. We know we have man-failure problems, we now have structures that are less than a lot of people consider ideal, we know we're under maintained, and yet, in spite of all that, the number of people that have been killed in transit vehicles collisions is unbelievably small.

One of the things that I think we do ourselves an injustice is in not bringing this story forward to the attention of the general public, elected officials and so forth. Every time there's an accident, there's a great outcry of concern and I never hear anybody say, "Okay, we had a problem, but just remember we're one hundred times safer than any other way you can travel, at least with the alternative which is the automobile."

Mr. Vollmar: cont. This is a real condition because I have heard people who use transit systems, or railroad commuter service say, "Boy, if you just had an accident, I'm gonna drive from here on." This is ridiculuous because they're putting themselves in an environment with one hundred times the risk because they don't know any better. I think that one of things that we need to do is let people know how good a job we're doing right now. When you listened to the discussion yesterday, you could almost assume you were hearing a discussion of the most dangerous mode instead of the safest, and I think, we do have to keep all this in proportion.

One other observation, and some people have alluded to it and so have I, of the great deal of energy, and you're really talking huge numbers, it quickly gets into the millions of foot pounds in accidents with big trains at any significant speed, 20, 25, 30 miles an hour. The real prevention has to be in the signal train control system and the operator training, maintenance training and things of that area which, I think the industry has done a reasonably good job in. That's where the improvements really have come because, again, as you look at the energy that's available and you can play with various things, but you're only nibbling at the edge of the problem, and it's simply beyond resolution within the vehicle itself.

Mr. Rhine: Ray, I do appreciate that people don't know that just this week the Secretary of Transportation designated UMTA as having prime responsibility for all rapid rail and light rail transit safety instead of the previous designation of the FRA so this gives me an added concern in this area. We do know that this is probably, almost undoubtedly the safest form of mass transit available in public. I'm sure you all know that you can never get enough safety and we have the same problem you have in responding to the people that say, "Well, why aren't you doing something about that accient, or this accident, or that accident", the tombstone philosophy, which is very unfortunate.

Part of the purpose of this meeting, and we'll get to it again,is a balance again between priorities for work in this area, priorities for work in other areas. We recognize our financial limitations and yours and that's why we want to. But it's just a question, as we said, we have to take a deliberate look at safety in the absolute sense in this form of transportation. So we are trying to keep it in focus and in context also but it's always a political issue and you also have to recognize the realism of politics in this world and, particularly, in Washington, D.C.

Mr. Tucker: That's a very good point that Ray made, though. We've got to be careful how we talk. Engineers always focus on problems, politicians always focus on nonproblems so, when engineers talk to politicians, why they quite often get a completely distorted view of things. We are generally problem-solvers and we think in terms of problems.

Mr. Greene: I guess maybe to oversimplify it but why we rapidly come to a point where the energy builds up so quickly is, just remember, that the energy is equal to the function in the square of the velocity and it doesn't take very long, by squaring those numbers, to get tremendous values. I really think that crossover points should be determined where the actual number of miles is because it's unfeasible to think beyond that point. So maybe it's a suggestion again for you, to determine just what that cross-over point is.

Mr. Tucker: It may be one that's indeterminable because it's also a function of mass and it varies quite a bit. Any other comments for the good of the clan?

Well, we might as well have a cup of coffee then. Thank you very much for coming.

CRASHWORTHINESS AND RAILCAR DESIGN - SUMMARY

Mr. Tucker: In the session on car design this morning, we had a very stimulating discussion as to what to do with the information that we received in the course of these meetings. There were very broad points of view in some of these subjects, but I sensed a general consensus among the people in the room on a few points, I'll talk about those and try to express the consensus of the group.

For the benefit of the people that weren't here, I'll very briefly go over the subjects that were discussed.

At first, we talked about whether there should be some effort to standardize on what Jason Baker described as framing and construction requirements for transit cars. There was quite a bit of discussion as to how it might be done and who should sponsor the work, but the consensus was that it was desirable to standardize and that there should probably be three different standards; one for mainline and commuter cars, one for transit, and one for light rail.

In the course of the discussion we learned that they do have such standardization in Europe just as AAR has similar standards for mainline commuter cars.

We also discussed who should develop the standard and how it should be done. I sensed that nobody in the APTA group was in a position to make a commitment but it appeared that most people would prefer to work through APTA with the support of the federal government. It was suggested that this could be worked into the standard railcar program that consultants, suppliers and the transit operating people are involved in. The actual stimulus for pursuing this further must come from the federal people and APTA, I personally would like to see the users and the manufacturers develop the standards with the advise of some qualified consultants so that we can reach industry-wide consensus, with adequate participation we may come up with something that hopefully will last as long as the AAR standards.

The next subject that was brought up was the subject of compatibility between new cars on a property and whatever cars are designed and built to a higher level of crashworthiness. This is certainly a consideration that deserves further study. In many cases, participants felt that it is not inconsistent to build more crashworthy cars and mix them with currently existing cars. I think New York is a good example of this. The crashworthiness requirements won't necessarily change the requirements because we'll still have compatible anticlimbers and end posts.

If we can make these cars a little better without appreciably changing the mass or the end configuration, they should be

Mr. Tucker: cont. compatible. I'd say that was the way I read the consensus on that.

Fred Greene asked the question (and I have to read this to understand it) "Is more stiff more better?" That resulted in a discussion which got back into the issue of the effect of high accelerations (due to a stiff car) on the occupants, that certainly must be a consideration in any crashworthiness activity.

The next discussion involved collisions on curves. It was pointed out that the Europeans call for a diagonal squeeze test, which is new to me and sounds like a worthwhile consideration. It was also suggested that when we consider impact, we look at the impact strength at 15 degrees each side of the center line. The general consensus seemed to be that high speed collisions have to occur on high speed track and the angular displacement between the two cars on a high speed track can't be much.

It was discussed that in considering accidents on curves that we have to be most concerned about couplers. There is less chance of couplers gathering and engaging while on a curve. Therefore the standard should consider coupler centering devices and gathering range to see if we can optimize the probability of coupling. Generally, if couplers and anticlimbers engage, the effects of a collision are minimized. It was suggested that the width of the anticlimbers as well as the configuration location relative to the coupler be considered. I think that's a good suggestion.

The other subject that was discussed and the one in which we had a really spirited discussion was the subject of what happens with time. "Should maintenance be considered in crashworthiness?" Since it's possible that some of the features that are built into cars to make them more crashworthy may deteriorate with time. I don't know that this should be considered in the same light as the standards that were discussed. Perhaps maintenance is more a question of funding and safety regulations than of standards. However, it certainly is something that should be addressed and looked at further.

That summarizes the discussion. We stayed away from the test subject because it was being discussed in the other workshop, but I think the sense that I had was that people are in favor of more tests. They were in favor of full scale tests, if possible, and we look forward to hearing the report of the session on testing.

Thank you very much for your help and cooperation. I found this a very interesting and worthwhile session. I hope you did, too.

TEST AND EVALUATION - WORKSHOP

Dr. Chen: I have prepared a list of topics (see attached) to be discussed in which I have stated some of the purposes for having a test and evaluation workshop. The second part lists what kind of testing should be performed. There are three areas. One area is scale model testing, the second, laboratory testing and the third field testing.

For example, yesterday we talked about simulation by mini-computer models. We would like to know how good these simulations are and in which direction they are going. We would like to verify and assess them.

Another important role of the test would be to identify the critical parameters. We may want to set more parameters like car weight, spacing, speed, and other vertical constraints. What kind of critical parameters will be useful? Only test and evaluation can provide the answer.

Studies have proposed some kind of improved impact devices, some of them are cylinders, and others are different configurations. We want to know how effective these devices are. We'll have to rely on testing. A force-deflection curve for a rail car which includes coupler, collision posts, anticlimber, and front sill is an important feature. To establish these curves, we would rely on some kind of tests, laboratory tests, or something like that to verify the results. Mr. Zehnder from Franco Belge says that they are going to make a two-car collision test some time, and I think it will be worthwhile. When this is carried out, we can put some instrumentation in there and get some results other than seeing the movies.

Finally, we would like to set limiting speeds for different rail cars. We would like to know the behavior of each crash -- override, derailment, etc. Many things which cannot be analyzed theoretically we can do by testing. So tests are really the backbone of engineering. All the analyses and computations have to be verified through tests.

So with this background, for the test and evaluation session the floor is open.

Mr. Marks: We should add the bottom line purpose to the list of topics, that is, to establish a workable specification.

Mr. Pritz: That is exactly right. What goes into the specification?

Mr. Widmayer: Well, that is certainly a part of it, but there should also be investigative -- that is, for instance, into the crash dynamics -- tests aimed at just trying to find out what goes on. Never mind what we have put into the spec. Let's see if we can understand what the problem is. Everything you've got here is certainly valid, but there should be another side. There should be some activity to investigate collision dynamics, more of the time force type stuff. The zooming pinhead isn't really solved at all. Yet the dynamics of couplers needs to be explored. Can you really make a coupler lock at high speeds? This sort of testing is exploratory. There should be a part to just getting the understanding as distinguished from qualification type stuff. We're going to get the loads in a fifty mile an hour crash, what happens when the coupler breaks, when are the times when an anticlimber lets go and that sort of testing. There should be a research side to any program that you provide in addition to the qualification type stuff.

Dr. Chen: You are thinking about using these test techniques to explore and understand existing and new phenomena.

Mr. Widmayer: Yes, new concepts, or to understand old concepts.

Mr. Mirabella: You say not only are we validating the design, we're validating the techniques.

Mr. Widmayer: No, I'm saying -- the techniques are good. Dynamic Sciences knows how to crash trains, Stanford Research has done some real good dynamic modeling tests.

Mr. Mirabella: When you say the techniques -- using them to predict when the coupler will engage and when it will override, then you compare --

Mr. Widmayer: Yes, to understand the phenomenon is what I am talking about. To go back a little bit, when we started talking about override, there were all sorts of wild concepts as to how come when you hit a car, it goes up in the air instead of back. Well, it goes off on a diagonal, but it wasn't understood and various people postulated various ways this thing could happen. Then you have to do tests and observe it.

Dr. Chen: Okay, you are talking two things. One, you want a new technique on testing. The other one is you would really like to know what would be the outcome behavior that results from the test.

Mr. Widmayer: Yes, I like the words research as distinguished from development. With the development side, you're going to end up with the stuff that you can use in specifications. With the research side, you're looking at concepts, phenomenological activities.

Mr. Marks: Research is necessary, but it is a long-term activity. We need a quick, first-order check of the specifications developed, to date, from the experiences and judgements of the various transit authorities. The first phase of a testing program could result in the data needed to verify or modify existing specifications for early use.

Mr. Widmayer: There would have to be some prioritization after you get the total program together. This is what you are saying.

Mr. Marks: Right.

Mr. Widmayer: Yes. No argument there.

Mr. Pritz: Along with that comment of getting results quickly, Franco Belge is going to crash some railcars.

Dr. Chen: That's what Mr. Zehnder of Franco Belge said.

Mr. Pritz: So maybe we ought to consider what information we would obtain from that test. I was thinking that it would seem reasonable to put some dummies inside the car and monitor their crash dynamics. All of this crashworthiness is really related to what happens to the people inside.

Dr. Chen: TSC has some experience on dummies. Did any of of you people do those before? Dynamic Science did.

Mr. Widmayer: Dynamic Science has had dummies in the locomotive cab.

Dr. Chen: Do we have anybody from Dynamic Science in this session.

Mr. Kochis: Yes, right here.

Mr. Chen: Can you elaborate on those?

Mr. Kochis: Unfortunately, that was before my time and I don't have the information with me. I know that we did have some dummies in the locomotive.

Dr. Chen: We saw some movies on collision tests -- FRA work.

Mr. Mirabella: There were also some dummies in the car there.

Mr. Kochis: Franco Belge is going to crash those new cars, as I understood it, in September or October.

Dr. Chen: So, we have to do it pretty quick. We have to make some plans and we have to decide what kind of instrumentation will be going in. We might be able to do that because we are buying their cars.

Mr. Widmayer: Where are they going to have the collision test?

Mr. Marks: France.

Mr. Widmayer: Then it will be a good test to go and watch.

Dr. Chen: That's the real thing.

Mr. Kochis: Certainly putting dummies in would be a great idea.

Mr. Pritz: We ought to have a whole sequence of dummies - somebody standing up, child dummies, everything. You ought to have the room to look at the whole spectrum there.

Mr. Pugliese: I was under the impression that the French government is paying for the whole thing, that they are requiring it, and that Franco Belge isn't specifying the test. The government is going to come in and say, "Well, you have to crash these two cars." In speaking to him, I was talking to him about instrumenting it and my interpretation of what he said was that they may not

Mr. Pugliese: cont. even get any of the data, and the data that will be available may be, at most, films.

Mr. Marks: I'm not sure of what participation, if any, we're going to have in that test.

Dr. Chen: Maybe we should try to negotiate it somehow. If it is September, it is a very quick order.

Mr. Marks: That's right.

Dr. Chen: We can get the most out of it. In that case, what information would we like to know.

Mr. Widmayer: Accelerations.

Mr. Spons: We will be conducting a test at the Test Center. I haven't heard that one mentioned during these two days, but that does have a crash attenuator system on the anticlimber, and in about three weeks -- or maybe four weeks -- we'll be crashing that car into a barrier. This is very low speed, though, and it's a device, and we will be instrumenting the car and checking it. They want to run it to five miles an hour. I believe it is designed for 10 mph without any damage to the front end of the car.

Mr. Pritz: Do you have occupants in that?

Mr. Spons: We are proposing to run it with a man on board at five miles an hour. We don't expect any damage to the car. It will be manned. It's a hydraulic piston that will go back into the car once you break the shear pin.

Mr. Pritz: So you're talking about a volunteer sitting there? Is it a real person or a dummy?

Mr. Widmayer: It might be both.

Dr. Chen: Who is doing that? Dynamic Science?

Mr. Spons: No, this is at the Transportation Test Center. It's funded by UMTA.

Mr. Widmayer: Garret probably is doing it, isn't it?

Mr. Spons: Well, Boeing is the systems manager, and Garrett is supporting the test. They built the car.

Dr. Chen: When do you expect this to happen?

Mr. Spons: We're planning it right now. I anticipate in three or four weeks.

Mr. Marks: Is the purpose of this test to check the hydraulic energy absorption, or not the car structure itself in a collision?

Mr. Spons: No, it will be low speed to check the hydraulic system, anticlimber, etc.

Mr. Mirabella: So, it's tangent track?

Mr. Spons: Yes.

Mr. Mirabella: Has any work been done on curved track which is where a lot of these accidents occur?

Mr. Spons: Yes. We had one at the Test Center for Monocars. The car was on a straight track, but there was a side track next to it and it was parked too close in the intersection, and two hopper cars and a locomotive hit the corner and pushed the two monocars and a locomotive, I'd say about 20 feet. It hit the corner post which is about a five by five inch diameter aluminum corner post, and we broke that, and that was the only damage to the car other than the fiberglass front and we repaired that. It was running again in three days.

Mr. Mirabella: If all the testing's done on tangent track and designers are optimizing for the lowest weight and most crashworthiness, we may have significant increases on that tangent track or the simulations, which are also tangent, and find out once you're off the design situation, you may have a very poor situation.

Mr. Marks: From previous tests, can we obtain a first-cut magnitude of the lowest speed at which passengers could become injured?

Mr. Pugliese: Well, automotive experience that I've been involved in with airbags --. GM's airbags won't go off at speeds before 11 miles an hour, so based on the dummy data -- now I've done some driver airbag non-deploy tests -- I ran one a few weeks ago -- at 17 miles an hour, and that was acceptable in terms of our present injury criteria.

Mr. Pritz: Well, what would the vehicle decleration peak look like compared to a train crash?

Mr. Pugliese: Oh, that was -- let me think --

Mr. Pritz: The deceleration for a train has got to be much lower.

Mr. Pugliese: Yes, we're only talking about 4 Gs, 4 or 5 ten G range as opposed to the low speed cases, we're only talking something in the order of less than 10 Gs also so that would be comparable, I think.

Mr. Kochis: The interior of the vehicles are far from comparable.

Mr. Pugliese: Yes, that's true.

Dr. Chen: Since we are on this topic, we should establish limiting speed. Do you think we could come up with some kind of suggested number, including no damage to the car, or with a crushable car, no injury to the passengers or crew members?

We can dream up some of these numbers, and then carry out tests. Then we will suggest that they should do it. Turning back, we should be testing components to be sure these numbers will be good. Are we going to address this?

Mr. Marks: AAR specifies a buff load at the anticlimber of 800 kip at yield for design of intercity cars. NYCTA specifies 500 kip at yield for its new 75/ft cars (R-44 and R-46). Other transit authorities specify values substantially less than 500 kip, e.g., 200 kip. We need dynamic tests, including full-scale tests, to get a handle on what these buff loads mean in terms of car crashworthiness, speeds of collision, and degree of protection to passengers in a collision.

Mr. Pugliese: I think that you brought up something indirectly which hasn't been impressed that should be included. That is you're talking about France having a 200,000 buff load, your 500 and another car is 400, and that's compatibility of these cars with other cars on the line and if any aggressivity effects that might be present. You're thinking of your 400 kip car as a good car. That may be good compared to another car of that same design, so that's one thing I think that should be addressed. What are the aggressivity effects of any recommendations that come out regarding the population that is presently on the track.

Mr. Marks: We discussed evolutionary change in crashworthiness design during our presentation, namely, that we don't want to suddenly place "super cars" in service which could demolish existing cars in a collision. Prior to the R-44 and R-46 car contracts, the NYCTA specified a design buff load of 400 kip at yield for its BMT-IND cars. The R-44 and R-46 cars were designed to 500 kip at yield. Therefore, the cars within our transit system are compatible with respect to buff load.

Mr. Pritz: Is there a rationale for wanting the buff load up as high as that viewed from damage or your accident data?

Mr. Marks: These loads were chosen from experience.

Mr. Pritz: But you're trying to avoid deformation of the train? Well, that ties in with it.

Mr. Marks: We're trying to avoid deformation of the train at low speeds and allow some crushability to avoid injury to the passengers at higher speeds.

Mr. Pritz: But by taking up the buff load, you're increasing the deceleration of the vehicle in a crash which could make it worse for the occupants.

Mr. Marks: That's why we need dynamic tests. We must relate design buff loads to car crashworthiness, speeds of collisions, and degree of protection to passengers in a collision.

Mr. Widmayer: I still maintain that the relationship between buff load and passenger injury are independent.

Mr. Pugliese: I looked over your view graph, and I could not see how you could come to the conclusion based upon the data that you presented unless you did a number of simulations, where you varied the force deflection characteristics of the trains. You were only using one force deflection characteristics, so I can't see how you can come to that conclusion.

Mr. Pritz: It's not true in automobiles.

Mr. Widmayer: No, but you have different ride-down characteristics.

Mr. Pugliese: What you're saying could be exactly right, but did you look at it in terms of varying the frontal stiffness of the trains?

Mr. Widmayer: Yes.

Mr. Pugliese: Oh, you did then.

Mr. Widmayer: You multiply them by two, four, eight, whatever you want. The relative velocity of the passengers to the constraint doesn't change. That's something different. Let's get on to the testing part.

Dr. Chen: We'll discuss it, then we can come to some conclusions we all agree on.

Mr. Marks: The parameters we outlined in our presentation of car buff strength, strength of collision posts and corner posts, vertical strength of end of car, and capacity of the shear mechanism in the draft gear are all factors relating to car crashworthiness. We need to establish these factors from a dynamic testing program.

Mr. Widmayer: The idea, though, of what is a proper buff strength to specify is a good one, that should be part of your --.

Dr. Chen: Yes, that was one in the Part "B," the laboratory tests -- B-2.

Mr. Pritz: Along with that, I was thinking back to the Franco Belge direction. Maybe you could at least monitor the decelerations along the floor, and then you could reproduce the deceleration trace in the laboratory and measure some dummy decelerations. But that could be done pretty simply, must to put a series of them periodically down on the floor.

Dr. Chen: Excuse me. So we all agree on the Franco Belge test. We'd like to put instrumentation on the car floor to measure the deceleration. We want this test to be done.

Mr. Marks: Let's ask for a plan of their test program for our review and comments.

Dr. Chen: Well, in September, I don't know if we will have time really to have a full bite, but I think we can try. There's probably not enough time. Maybe we can get major things we wanted, like a piggyback ride test. We just hang onto it.

Mr. Pritz: Certainly. Accelerometers ought to be pretty easy to walk in on.

Dr. Chen: Is there anything else you can suggest?

Mr. Pugliese: On the bolster, all along the main components of the cab that would be used in any modeling effort. You'd definitely want accelerometers there.

Mr, Pritz: I was thinking from the point of view of reproducing the dynamic situation that the occupants are going to experience. Then you'd set up a lab and reproduce that with your set-up or anybody's.

Dr. Chen: That's more or less like yesterday's presentation on the collision of leading cars. It shows how they collide at different speed and some kind of responses. This will be a verification of what he said.

Mr. Pritz: Yes, I would also tie it back in to this discussion of whether the buff load is independent of the occupant. I assume they would measure the buff load. I would certainly think so.

Mr. Nelson: Well, I think that's one of the reasons why you want to see what is available in their test plan. In other words, what instrumentation, where it's located. I think that's the sort of information we need to even review. Find out what is available, what is going to be, what results are there, and then, if you were allowed to participate, you could put in the additional information or instrumentation and we gain additional data which can be used back to correlate your model studies.

Mr. Pritz: What was the speed they were going to crash -- 25 miles an hour

Mr. Pugliese: 55 kilometers, which is about 30 miles an hour.

Mr. Pritz: Is that going to destroy the train?

Mr. Nelson: I would think, yes.

Mr. Pugliese: Is that a closing velocity or a velocity of each car?

Dr. Chen: I would say closing velocity. That's usually the way it works.

Mr. Pritz: You told me just a few minutes ago that it's 600,000 dollars for one of those cars? I assume it's not going to be a totally finished car.

Mr. Nelson: Well, that would not necessarily be finished. That is just the structure. The structure -- I don't know -- one car I've seen -- probably 15 to 20 percent. What would a structure cost?

Mr. Pritz: I was just trying to get a feel for the cost of the test that they are going to do.

Mr. Widmayer: You'd have to put in, if you wanted to get a good crash simulation, you'd have to put in probably dummy trucks that are weighted for motors, you'd have to put a dummy air conditioning system in, weights or an attachment and to the attachment points, and other heavy pieces of equipment would have to be in place in the car in order for it to be valid.

Mr. Nelson: Well, you'd have to put in not only the weight, but also at CG if possible.

Mr. Widmayer: Oh, yes. You'd want the mass properties duplicated.

Mr. Marks: Plus simulated passenger load in addition to the dummies.

Mr. Widmayer: The passenger load is sometimes loose in terms of not being firmly attached to the car.

Dr. Chen: I think as detailed techniques go UMTA will probably get some companies to take care of that. One thing, we should discuss here from a practical point of view, is whether we want something now or we could get some contractors to do the same later.

Mr. Widmayer: In addition to the accelerations, we want deformations, not necessarily time analogue trace.

Dr. Chen: Yes, just like your last SOAC accident.

Mr. Widmayer: Yes, that's the minimum you would want.

Mr. Pritz: Can we come up with an estimate of what it would cost to do this test?

Mr. Widmayer: That makes no difference anyhow. When they go to the company, they'll get a response that means something. We would waste our time this morning if we tried to estimate the

Mr. Widmayer: cont. cost of the testing. The question is really what data do we want?

Mr. Pritz: It seems to be eliminated that the government would support any testing themselves and that we're trying to piggyback into the Franco Belge thing, and if it's only a quarter of a million dollars to do a full scale test, I don't think that's prohibitive at all.

Dr. Chen: Well, we would think of it that way too. That's because this is coming up.

Mr. Widmayer: To take advantage of the opportunity.

Mr. Pritz: Right. Absolutely. We should take advantage of that.

Dr. Chen: We were planning the details ourseleves. Okay, on the Franco Belge test, we'd like to tack on measurement of decelerations and buff load and measurement of the structure destruction.

Mr. Widmayer: And there was mentioned an anthropomorphic dummy. At least one. How many channels of instrumentation you want to spend on dummies?

Mr. Kochis: Well, if you're going to put one, you may as well cover all four categories that we were talking about yesterday.

Dr. Chen: Dummy as passenger?

Mr. Widmayer: Yes, but I'll tell you. A dummy takes like what -- five or six channels of data?

Mr. Pugliese: No, more than that. You've got three, head; three, chest; you've got pelvis, femurs. So that's eight. You've got time channel, that's nine.

Mr. Widmayer: That's a recorder. Then there is some multiply. You want analog data. You want the frequency response.

Mr. Pugliese: That's the current practice.

Mr. Pritz: The current practice is to use nonaccelerometers in the head so they can calculate angular accelerations as well as translational. So you're talking about a lot of channels.

Mr. Kochis: You could talk about a lot of channels.

Mr. Widmayer: Well, the question there again is, are these research type things, or on the behavior of the dummy itself, trying to simulate it as an occupant or what kind of damage does the dummy undergo?

Mr. Kochis: We also don't know the car, whether it has any side facing seats to begin with. That may be a moot point. You may not want any but there you may not have it. You may not have any rear facing. I don't know what the car configuration is.

Mr. Nelson: You have both forward facing and side facing. I can answer both questions.

Mr. Kochis: In their cars.

Mr. Nelson: Yes.

Dr. Chen: That means we need at least two dummies.

Mr. Widmayer: Well, put down the possibility of four dummies, and when you get to the cost factor for the instrumentation you'll come to whatever facts come up. They're talking nine channels -- nine or more channels of data per dummy. Your instrumentation is proliferating at an alarming rate.

Mr. Kochis: You may be able to backtrack on the rear facing. You may not want to do any leg or chest instrumentation on the standing passengers. You may just want the head.

Mr. Widmayer: Yes, but from these details you can determine when you get further into it. So we said dummies.

Mr. Pritz: That's why I was thinking if you had the deceleration trace for the floor, then you could reproduce these things in whatever configuration you want in a laboratory setup that is set up for a multiple channel operation. You can run different sort of tests.

Dr. Chen: So we'll just say dummies. We don't have to say up to four dummies. We'll say dummies -- more than one.

Mr. Pugliese: And if you're going to have dummies, the dummy size should be included in there also.

Mr. Widmayer: Now you're getting into a real big program again.

Dr. Chen: That's too detailed, I guess. We'll let somebody else worry about that.

Mr. Marks: We should also add some strain gages on the underframe to relate static design buff loads to the dynamic buff loads obtained at various speeds.

Mr. Widmayer: I've never gotten any useful information out of the strain gauge in a crash test. That's the top line. The problem is that where it gets into the area you're interested in, the strain gauge is failing just the way the structure is. You lose your instrumentation and you have whole channels of information where this thing is getting interested, and this is all going blank. Your screen is blank on that instrument. The strain gauges ruptured, the wires ruptured that connect to them. You've got to have the strain gauge right where the plastic hinge is. The distribution in a member of the loads -- the strain gauge is very sensitive to that. What the strain guage actually shows you is the average strain in the gauge and you've got it right on a little point, and if you look in here and the problem's four inches away, you miss it. It's very difficult, in the post test, to go back and do this. We've looked at the -- NASA and the Army have dropped two CH47 helicopters and God knows how many had those things loaded with strain gauges -- 1500 channels of strain gauges -- and I haven't seen one channel of strain gauge data that's been analyzed and correlated with what the structural properties are and what the loads are. It's very difficult.

Mr. Marks: That's true for the plastic region, but within the elastic range at low speeds...

Mr. Widmayer: But you're talking about the Belge test.

Mr. Marks: Correct.

Mr. Widmayer: And they are going to be in the plastic region. On the test you're talking about where you want the low speed stuff, yes. Strain gauges.

Dr. Chen: We're going to plan that ourselves. Okay. You're talking about buff load of the Franco Belge car. They have the buff load test anyway, so why should we ask for that.

Mr. Marks: They have a buff load test, but I'm trying to relate speed of collision to their design buff load.

Dr. Chen: Can you tell that from the dynamic crash test? It's very difficult.

Mr. Widmayer: You tell it from the accelerometers and knowing the mass properties.

Dr. Chen: We cannot tell. It seems we don't measure the force in there, so we really cannot tell, unless they figure out some other way.

Mr. Pritz: It would seem reasonable to expect some difference between dynamic buff load and a static buff load.

Mr. Pugliese: But not so much for aluminum, though.

Mr. Widmayer: It depends again on the mass distribution behind it. You've got a heavy coupler mounted on the draft sill and decelerate it, you've got your load distribution in a crash is triangular. Here's your car, the load distribution looks like this along the car, and how much it tapers down, there's another car. The front of the car can be failing and the back end doesn't know the car's been hit. If you've got a car that's 75 feet long and the speed of sound is 15,000 feet a second, you can figure out the time, and if you're talking thousands of seconds, you've gone into the plastic region or right in the vicinity of the anticlimber and the area right behind it -- the back end hasn't got the signal yet.

Dr. Chen: Can we conclude that we just want three things; deceleration, structure destruction, and dummies.

Mr. Palmer: I'd like to suggest, if we are going to be including an active dummy, maybe it would be appropriate to throw in a few passive dummies just for their mass properties. Put them behind the seats or next to the stanchions or in front of the plate glass

Mr. Palmer: cont. cab window or something like that and see how the different structures respond to impacts. No instrument in the dummies, but just sort of observing the results of their mass after the crash. That would be inexpensive.

Dr. Chen: That would conclude the issue of dummies.

Mr. Palmer: But passive dummies.

Mr. Pritz: That brings up the point of high speed movies then, doesn't it, to observe what they're doing.

Dr. Chen: They do that anyway.

Mr. Kochis: Well, if they do internal.

Mr. Pritz: Yes, I'm sure they do internals.

Mr. Kochis: If you're using the dummies without the movies, it's not going to do you any good.

Mr. Palmer: Well, you can see if they knock the stanchion down. I agree, it would be much better to have movies with that.

Dr. Chen: Why don't we just leave it there. Time is getting short. Are we going back to limiting speed issues? Is there anything to suggest in there? We're up to seven miles, running tests on all those three.

Mr. Marks: It is not practical to specify destructive dynamic tests in car contracts to determine whether or not the car builder has met the specifications. Non-destructive static tests, such as standard squeeze tests, are used to determine acceptability of the car. The problem is to derive the static loading specified in car contracts from dynamic tests.

Dr. Chen: Okay, it seems we have squeeze tests already. The issue is now, how do we make use or correlate this squeeze test into a dynamic test?

Mr. Widmayer: His problem is a good one. The approach is -- you use low speed tests, 5, 10 miles an hour -- some low speeds - -- you instrument it with accelerometers and strain gauges in this case because you're going to test dynamically in the elastic range, and you take and get the strains for the particular impact speed and for the acceleration. Then you can relate those to the strength properties of the members and with the stuff of three or four low speed impacts, you will be able to extrapolate to the point of damage, and that would be where you could set it. By non-destructive testing you can determine the speed at which you would get damage using these techniques, and there your strain gauges would be valid. You'd tack then on the draft sill in the vicinity of the anticlimbers, back by the draft anchor and so forth. Where you're stressing this -- this is the point where we're going to get a big stress and extrapolate those to the answer that you really want as to whether the car is good for that speed or not, that whatever threshholds of damage speed you set, you can determine whether the car will do it.

Mr. Marks: In addition, speed must be related to passenger injury. We don't want to build a car that's too stiff.

Mr. Nelson: That's right.

Dr. Chen: Now what is the threshhold?

Mr. Nelson: What is the threshhold of passenger injury is right. You should set up at least some level using standard and mobile dummies which would correspond to the severity index. Something should be set up along that line which would be able to present a useful end result of all of your tests. Not just your structural design, but what does it have in the human element.

Mr. Pritz: The problem is that most of that criteria is set up for the severe and fatal injuries, particularly in the automotive field. We're down here, we're talking about little or no injury, and there's very little data to use.

Mr. Pugliese: Well, you still can -- that was based on relating the AIS injury scales to come up with a number. Going back, for example, on that we're using 2000 for a fatal. Now, the reason they came up with that criteria is because all the models used were just single mass occupants.

Mr. Widmayer: The severity index is a measure and GAD is another number. There's a different number for the sternum and something else. You go through and there's a whole range of them.

Mr. Pritz: I'm saying that even if you put a dummy in and measured knee loading or anything, there's no number that relates to no injury. There are numbers that are up there where the breakage starts to occur. They say 1500 pounds in the femurs, fractures are likely. Well, that's way beyond where he's talking about no injuries. There's no numbers down at the bottom such as 100, 200 and 300 pounds.

Dr. Chen: So, there are two issues here. We're trying to suggest dynamic tests at low speeds and to extrapolate to some kind of threshold that's related to buff load. This is what we want to know. The second part is how are these tests related to injuries. These two thresholds are entirely different.

Mr. Pugliese: Well, if Ed's contention is right, you can separate the two problems. Then it becomes simply a matter of interior design on the one hand and a structural upgrading on the other to prevent intrusion.

Dr. Chen: Yes, that's not what we are looking for. We are looking for what kind of test which will tell us how these dynamics are related to buff load. Buff load is a standard test, so we want to know whether this buff load will be any good. We want to run dynamic tests to verify it. The other thing is to run dynamic tests to verify the injuries.

Mr. Marks: In addition to buff load, we have to obtain static loads for the other crashworthiness parameters previously mentioned. For example, the R-55 draft specifications specifies the total bending resistance of eight forward and aft collision posts and corner posts at the cab end to be equal to the resistance of the car to buff load at the anticlimbers, i.e., 500 kip at yield. Should we make the total bending resistance of the posts equal to, smaller than, or larger than the buff resistance of the car?

Dr. Chen: Yes, we're trying to correlate these tests into different specs.

Mr. Widmayer: That's in the research realm. How do you make eight posts work together?

Mr. Marks: They're not working together. In fact, in a collision, you may engage two posts or one post depending on the angle of the collision.

Mr. Widmayer: Do you want them to work together? Would you want them connected with some sort of a framework that would transfer bending loads from the top of the post to the forward post into the back posts? Why would you have them sitting independently, and you shear this off like the Gillette ad where you cut one whisker at a time? You want to tie them together? It might be stronger.

Mr. Marks: It might be stronger, but it might be too stiff which may have damaging effects on the passengers.

Mr. Widmayer: Yes, but what I am saying is that there is a research area into how to use eight posts. The car end concept that you've got is a good concept. We're going to have a double layer of posts. Then the question is do I connect the posts this way. Suppose I've got them in relation to shear panels. Essentially what I've got is girders then.

Dr. Chen: Okay, these will be the parameters that will be involved under this big heading. You could have five versions, three versions--that's a good way to find our which is the best. Am I right?

Mr. Widmayer: Yes.

Dr. Chen: Okay, we should relate it to the buff load, buff strength and/or any other strength. Are we set on that? Do we want to propose that they should do dynamic nondestructive tests at low speeds? We should extrapolate these results to find out how they are related to the buff load and other specs like vertical posts and other things.

Mr. Pugliese: The thing that bothers me about that is that you're trying to relate something on an elastic slope to dynamic response of the entire vehicle, and depending on where the plastic hinges are formed in that car, you can go 20 times the same buff load that will respond differently with the same weight.

Dr. Chen: Yes, but we do establish, from Calspan's study where we pick up five typical cars, the force deflection curves. We'll get some kind of idea with research to prove it.

Mr. Pugliese: I guess that what I'm trying to say is my feeling is that you can use the buff load criteria to establish low speed damageability performance and I go along with that.

Dr. Chen: It's the same.

Mr. Pugliese: But nothing more than that. I really don't think you can use the buff load itself to relate that to crush, for example.

Mr. Widmayer: There's a certain innate property. A 500,000 buff load car is not going to deform as much as a 200,000 pound buff load car if both of them are hit by an eight-car train going 70 miles an hour.

Mr. Pugliese: If they are both constructed the same way, I would say yes. But I saw three or four different designs today in all different weights, all different buff load designs from the French presentation. I'm not sure you can just generalize. Maybe you're right, but inherently in my mind, I don't see it. It doesn't fall in. You could be right.

Mr. Widmayer: Well, to the first order of things, a 200,000 pound buff load car being hit by a -- or say you run him into a barrier at a certain velocity -- and a 500,000 pound buff load car -- these things don't vary in weight by a factor of two. The masses are different, but, to the first order of things, you're better off in the stiffer car as far as getting yourself crushed. So there is some innate crashworthiness associated with the magnitude of the buff load. You go up to the intercity cars where they are 800,000 pound buff load, and compare it back to the 200,000 pound buff load and the comparison becomes obvious. So there is some innate measure to the buff load as involving crashworthiness.

Mr. Pritz: At two levels. At the low level where you're talking about fatalities and crush distance.

Mr. Marks: Car crashworthiness criteria should be developed in connection with a car standardization program. This program could result in two or more standardized cars because each transit system has different requirements and restraints, such as tunnel sizes. Therefore, two or more sets of crashworthiness criteria may be required.

Dr. Chen: Now, let's talk about standard cars. We can characterize the standard car in different ways. I think in this discussion we probably can classify them as 200K, 300K, 500K. Maybe this way, our problem will be simplified because you can design a car through buff load. As long as we have 200K, 300K, etc., that's what we worry about. Otherwise, it's too complicated. Try to relate this to buff load. That's the issue.

Okay, we just say a parameter and test all these different buff loads. Is that okay? So we're through with this issue. We have two. How do we want to do it? I think I'd like some discussion on the scale model versus full scale lab models, and the pro and cons. This should probably be discussed in terms of economics and time. How much information can we get from the scale model testing? If we can get quicker results from the scale test that's fine, but probably we won't to the extent that we would like to have.

Mr. Widmayer: I think that if you're talking about the behavior of the collision posts, a third scale model or something like that might be where you'd want to find out how the posts would behave.

Dr. Chen: This is Al Brown.

Mr. Brown: I'm sorry I'm late.

Mr. Chen: We were discussing scale model versus laboratory models.

Mr. Widmayer: Ming, you're going at specific tests that should be done. Is that right?

Dr. Chen: We're going to do both and also the philosophical part. The first thing we talked about was the Franco Belge test because it's just coming out.

Mr. Widmayer: Yes, but that was a side issue. If you'd never heard of Franco Belge, we'd have a different meeting.

Dr. Chen: The second part is the limiting speed part and the buff load relation. We have a chance to do this. Now, we'll talk about other items that were listed on this sheet of paper.

Mr. Widmayer: What about the hardware attached to the crashworthiness testing of such things as anticlimbers?

Dr. Chen: Yes, that should be in there.

Mr. Widmayer: In where?

Dr. Chen: In scale tests or lab tests.

Mr. Widmayer: No, that's just a technique. The question is... Go ahead.

Dr. Chen: That means components, component tests. We'll talk about them, like coupler, draft gear, collision posts -- each component.

Mr. Widmayer: I think it would help you if the properties could say what they think should be tested. What would they want tested? Would they want to see tests done on anticlimbers, tests done on couplers, tests done on collision posts, tests done on what?

Dr. Chen: The issue would be whether we would need tests on these components.

Mr. Widmayer: Yes, this would put you all in a stronger position. If they said they wanted to see tests done on a specific item.

Dr. Chen: Should tests be done on each individual components - major components?

Mr. Marks: The major components related to crashworthiness should be statically tested, such as the shear mechanism in the draft gear, the end of the car (vertical strength), the collision posts and corner posts. The anticlimber is tested as part of the squeeze test.

Mr. Pritz: Well, you want destructive testing.

Mr. Pugliese: Yes, right. You put it on the crusher and get the force deflection characteristics and then use that in your modeling efforts to determine...

Mr. Pritz: You want to go beyond the testing that you're doing now on into the plastic region to see the contribution of each element in the total energy abosrbed.

Mr. Widmayer: And your anticlimber is loaded normal -- this way, not this way. What's the capability to resist shear of an anticlimber? Are the tines really good? Some clown went out and picked up two channels and welded them together and that became the standard anticlimber. I'm willing to bet you that's exactly the way it was done. A guy says, "Put one on", and the mechanic went and grabbed two pieces that looked right, and he probably did a good job, but we really don't know whether the tines should be this wide or this wide or this wide, and how much should it take? It just happens to be the way the thing came out.

Dr. Chen: So we will recommend static component tests, which may include draft hear, coupler, anticlimber, shear pin, collision posts?

Anything else?

Mr. Nelson: Telescopic lens. But then, what you want to do is start to tie the individual components togehter into the system.

Dr. Chen: Okay, but that's subsystems. We should talk about components first.

Mr. Nelson: Destructive components.

Dr. Chen: Yes, these are related. Draft hear, coupler, shear pins, anticlimber, and collision posts.

Mr. Widmayer: Static and dynamic tests where dynamics would affect their properties.

Dr. Chen: You want static and dynamic tests right?

Mr. Widmayer: We had a coupler that failed on the SOAC in the SOAC accident, a big shank and it just broke off nice and clean.

Dr. Chen: What kind of tests do you want to achieve?

Mr. Widmayer: To destruction.

Dr. Chen: Just drop tests?

Mr. Widmayer: All of these tests should be to destruction.

Dr. Chen: I know. Say we apply force statically and then, dynamically. What kind of dynamic force do you want to apply?

Mr. Widmayer: What do you want, ram? You could use a ram. I think that's a detail that the guy designing the test could figure out. I don't think we should really take the time here.

Dr. Chen: So we recommend static and dynamic tests -- component tests -- related to crashworthiness.

Mr. Nelson: I think that the point is that even though you're testing dynamically, you want to simulate the closing speeds that you're considering. In order words, just don't look at it as a drop test.

Mr. Pugliese: I don't necessarily think that you ought to test the same speed that you're going at. Your static crush test should determine what your speed is. You don't want to smack something into a wall at initial impact energy which is much, much greater in an order of magnitude greater than what the component could take. For example, if one of your components in here will go at 50,000 pounds or 2 g's and the rest of the train is taking 4 g's. You don't necessarily want to subject that component to a specific component test.

Mr. Nelson: That's correct, but I'd have simulated closing speeds. Where does it fit in the system -- the overall system? Check is right there. I think that's what you're saying. You're talking about a simulated closing speed.

Dr. Chen: Like a draft gear in dynamic tests. I think it never failed.

Mr. Widmayer: We've failed them. We broke the coupler off the gondola and we broke the coupler off -- I mean we broke the shanks of those couplers. They were both broken in that 35 mile an hour collision.

Dr. Chen: No, I'm just talking about component tests.

Mr. Widmayer: Yes, I'm saying I'm interested in what -- under dynamic impact conditions, where does the draft gear from the draft anchor to the -- right out to the hook -- where does that system fail. Pin Tong is saying that he's going to prevent

Mr. Widmayer: cont. override by having shelf lock couplers. If the shank fails at 35 miles an hour, he isn't going to prevent override above 35 miles an hour.

Dr. Chen: In addition, we need to talk about the subsystems, and do the same thing. We should put everything together.

Mr. Widmayer: And then there's the system.

Dr. Chen: Okay. Static and dynamic tests of the subsystems hich include...

Mr. Marks: Are we limiting ourselves to rapid transit cars?

Dr. Chen: Yes.

Mr. Marks: Some of the ideas you've mentioned are for intercity cars, aren't they?

Mr. Widmayer: Yes, but the same idea is going to carry over and help prevent override. They're going to want to say that they are going to rely on the coupler. We'll have this coupler centere and we get the couplers engaged, and that helps to prevent override. That is a concept.
And you'd like to know if you've got a coupler that will fail on a 25 mile an hour impact or a 35 or a 55 mile an hour impact. The item--but you really don't know. I mean, statically it's doing great, and under service conditions they're doing great, but in the accident condition, it may not be as great as we think it is or it may be fine.

Mr. Marks: Wouldn't we adequately check the various components in full scale dynamic tests?

Mr. Widmayer: Only if you're lucky. On a component test, you have more control over the conditions you put on a specific component. On a subassembly test, you have less, and on a system test, you have even less control over what an individual component will see.

Mr. Mirabella: Even if you did get it on a final test, it might be too late, you may have lost a lot of your test by not having a strong enough coupler or whatever.

On the component tests on the coupler, I'm sure you'd wnat to do it in full scale. It's hard to get them small scale.

Mr. Chen: We can recommend on the components test that it should be full scale test for all components.

Mr. Mirabella: If you're trying to design a new component, is it possible to get a lot more information faster small scale, and then once you've got what you want, do it full scale.

Mr. Marks: Are we trying to design and test new components, or are we testing only existing components?

Mr. Pritz: I think at this point, we're trying to stick it to what is the real world now. That's the way I see it.

Mr. Mirabella: So you're talking about baseline.

Mr. Pritz: Yes.

Dr. Chen: We recommend full scale tests on components. How about the subassembly?

Mr. Widmayer: On that, it would be a question of facility availability. If you take an old car and build a front end on it, and let's say we want to attach the New York City eight collision posts, you stick those eight collision posts and then run the car into a barrier or a ram of some kind of simulated override, see how it goes, bring the thing back, turn it around, have another one put on and hit it again. That may be cheaper than building the dynamically scaled model of that end. This is something that you guys can determine.

Dr. Chen: Anybody want to say anything?

Mr. Widmayer: I don't know that you want to recommend whether it be dynamically scaled or a full scale model at this point. I think you really ought to determine what you want to test.

Mr. Pugliese: Some information should be generated out to the baseline theory which would be directly applicable to where you are now.

Dr. Chen: Okay, on the sub-assembly part, we'll just recommend that we make static and dynamic tests. Whether they should be scaled or full scale that will depend on the cars. What else do we want to talk about?

Mr. Widmayer: Along this destructive testing, I would like to see a full scale car tested to destruction -- one or more underframe type concepts or structural concepts.

Dr. Chen: Is this a mock-up?

Mr. Widmayer: No this is a structural shell. You just go to static test and test to ultimate.

Dr. Chen: So you're talking about testing real cars, not a mock-up. You mentioned underframes.

Mr. Widmayer: Yes. You buy some existing cars -- demis and old ones even -- and statically test them to destruction just to determine what happens if we -- we all know what happens when we go up to eighty percent load, eighty percent of yield or fifty percent yield -- because that's what all the cars have been qualified to. Nowhere do we know how the car fails once you go past yield. What happens to the car when you go past yield? Even statically, we don't know that.

Mr. Nelson: Is there any good measure of what happens to the material strength with age?

Mr. Widmayer: I'm sure that's around. You talk in terms of corrosion and fatigue cracks and that sort of thing. That's all that really deteriorates the stuff.

Mr. Nelson: If you tested all the cars to destruction, yes, you would see the phenomena of what happens to those two cars. Do you think if you bought another car and performed the same test that you would get the same results?

Mr. Widmayer: They wouldn't be identical because there are differences in the cars.

Mr. Nelson: No, the same series cars.

Mr. Widmayer: No, I'm talking about even the same series cars. The welder didn't feel so good today and he was almost finished the weld when it was lunch time, so that weld is a little short. There are all sorts of idiosyncracies that get in but, actually, the acquisition of a structural shell -- for instance, if you were to go down to Budd or to Pullman or to Boeing Vertol and say, "Provide us with a structural shell", you might be getting something that the test specimen may cost you somewhere between thirty and fifty thousand dollars, and you could bet a brand new item that had never been on the road -- if you wanted to test one. Once they start stuffing them, the price goes out of sight, but you could buy structural shells fairly cheap.

Dr. Chen: Are you thinking about those five typical cars in Calspan's study?

Mr. Wdmayer: Yes.

Dr. Chen: Maybe we can test two or three of them to see how they behave.

Mr. Widmayer: Yes, there's no data around other than -- there's only been one destructive test -- static test -- that I've been able to find. Budd did it in 1939 or 1938, somewhere like that. There is no data on what happens to these designs when you go past yield other than the crash test, and that's a different thing.

Dr. Chen: Maybe we should recommend this test and use two or three typical cars.

Mr. Widmayer: Yes, and I say what you would like to get are different concepts, where you have the center sill and the side sill, load carrying capability, maybe somebody's got a monocot fuselage.

Dr. Chen: We should also include new concept like Franco Belge's.

Mr. Widmayer: Sure. Why not? You have to establish a technological base for some of this stuff that's to go on.

Dr. Chen: Any more discussion on that? If not, we would recommend to test full size cars to destruction, and also this would include new design, new concept on the shell structure.

Mr. Widmayer: Put in parentheses "structural shell." A new car is $700,000. A structural shell, you may be able to get for $35,000 or $40,000, somewhere in that range. Or you can get some old ones.

Dr. Chen: Are we through with this full car test? Maybe we'll go on the field test, and see what we can do there. We'll talk about consists and see whether they are going to override, etc.

Mr. Widmayer: Okay, that's collision dynamics and ultimate performance.

Dr. Chen: We have to get into this before we quit. On the field test, what do we want to do?

Mr. Spons: Are you talking single car or a consist?

Dr. Chen: Whatever. Just our ideas.

Mr. Spons: The facility there -- you can run a single car or multiple car on curved track or a straight track. We can do it remotely for you, and the area is instrumented with places for high speed cameras. It's just whatever the consist is that you're looking for - the type of test center.

Dr. Chen: What do we want, say on the field test, whether it's a single car or a consist of cars.

Mr. Widmayer: What you're talking about is a field test program, and why limit yourself? I mean, you may do it with single cars in the near future and build up, or you start at the top with the big consist and build down. One of the things that a lot of people were talking about is what happens in the curve crash. Where would you get design loads for the side posts and the side sills? How much do you shear the cars sideways if you hit on a curve? What happens when two cars collide on a curve? This is an area for both research and to get data for specifications.

Dr. Chen: We don't even have very much study on this.

Mr. Widmayer: And we're fighting about that. But this area is open to you.

Mr. Marks: High buff loads could develop in collisions on tangent track. However, collisions on sharp curves would probably result in derailments before high buff forces could be realized.

Mr. Mirabella: It's a much more different mode.

Mr. Widmayer: Maybe we should know what that is. Maybe you should know as a property operator.

Mr. Mirabella: Maybe you should design one for rollover.

Mr. Chen: I think one thing we can do for single cars that we talk about so much is the controlled crash. So, it should be tested. Hit into the bumper or into the wall, something like that. That should be worthwhile doing. What kind of controlled crash could we do for single cars? We could study other failure modes, override or things like that. I think we could do either scale model, which would be cheaper, or field tests, like we saw it on the movie of a tank car crash.

Mr. Pugliese: What about the analytical studies? With the static crush data generated out of this, you can refine the models such that you could use those to handle a number of considerations which you won't be able to test from a cost standpoint, and you'll be able to validate the models now, if any analytical study was part of this.

Mr. Chen: I don't really understand it. Put it another way.

Mr. Pugliese: Well, is there going to be a corollary analytical study being performed along with all the testing.

Dr. Chen: Yes, so far we have an analytical study on the simulation and modeling on tangent track head-on collision of two four-car consists. We're only going that far in analytical study.

Mr. Pugliese: Fine, but what I'm saying is are there going to be additional analytical studies in this. Refine them out, maybe a simpler model with good input data is sufficient.

Dr. Chen: Yes, that's not in our area. In our area, we are talking about testing and evaluation.

Mr. Nelson: I think what he's trying to say, though, is that after you perform a test, you not only have the results for that one particular item that you tested.

Dr. Chen: Not the particular item. Say, we are testing at 200,000, 300,000 -- we are not talking about testing of one particular car. It would be different class of cars.

Mr. Nelson: Yes, but I think what he was saying, though, is you now have the results of the physical test. Now, that's done with. You're going to do no more testing. Now, the next time a car design comes up, are you going to start over again, or would it be cheaper to take and build at the same time that you're running these physical tests to build an analytical model, to duplicate so that the next time you came out with a design, you would then have the software to perform the necessary tests.

Dr. Chen: Sure, we could feed back this data from the test to improve the model. Is that what you mean?

Mr. Kochis: Yes, the test program ought to be designed to generate data that can be used to generate or validate a model.

Mr. Pugliese: Right now, in the automotive area, we static crush cars. For example, when Budd made that presentation showing that Volkswagon Rabbit into the Impala, that was crush tested first. Those force deflection characteristics which are going to be generating for components now, are then input into a lump mass spring model, which could be used for this.

Dr. Chen: Yes, I think that could be one of the purposes. We can obtain improved mathematical models or simulations. But, I don't know whether we're going to plan more of these studies. Probably we would but the point is we cannot do this modelling forever, because to a certain point there is no or little return from the effort.

Mr. Widmayer: Of course, when you talk about collisions on a curved track, what you've done to your mathematical model, you've introduced on each car that you represent in your model - you now have another, at least one more or two more degrees of freedom. So your equations are going this way, and the number of balls you've got to keep in the air to balance everything out makes it a much more difficult problem. That's why nobody's really tackled it.

Mr. Pugliese: But even from a simple problem, for example, on a straight track, you've got two different cars -- for example, on the New York City line -- you may test one or two cars here, but you're not going to be able to look at a full matrix of things -- the compatibility of a number of different cars with each other. With the model, if you validated the model for something like that, you could expand your available information tremendously.

Mr. Widmayer: I agree.

Dr. Chen: Yes, but the point is do you believe it?

Mr. Pugliese: Well, if you have a validation program as part, you'll be able to tell how good are the models.

Mr. Mirabella: But like we said before, this is development baseline. It doesn't really address the development of new designs. I think what you're talking about would fit in more with development of new designs where you have not only correlation with the full scale, but also go into scale model testing, where you go into parametric study, which you couldn't do at full scale, and all those things do need to be tied together. I think it addresses itself more to the new designs than it does to development of baseline of what we have now.

Mr. Pugliese: Suppose, first of all, no one's talked about the impact condition, but suppose you determine that this car, for example, you come up with some criteria -- half crush the car -- that's the maximum you're going to tolerate. So you determine some impact speed for that. Say it's thirty miles an hour. How does the car perform at twenty miles an hour? How does it perform at fifteen miles an hour? How does it perform at forty miles an hour? The number of parameters are great, and you can only do so much testing.

Mr. Mirabella: More degree of curvature.

Mr. Nelson: Well, we're just staying on straight track, aren't we?

Mr. Widmayer: Yes, just on straight track.

Mr. Nelson: As Ed says, that thing goes fantastically.

Dr. Chen: Well, we don't have much time left.

Mr. Nelson: But also, before we finish -- everything I've heard so far, we've already talked about a crashworthiness and a front end design, or, since most of the cars are either married pair -- how about what happens at the design of the mid-end -- the opposite end of the car -- like at the middle ends of a married pair?

Dr. Chen: We talked about three to one or something like that yesterday.

Mr. Nelson: Has that ever been addressed? Has that ever been looked at? What you would like to have is a controlled crush throughout the entire thing. As long as you're operating in married pairs, your front end designs are going to be the same, if it's, you know, two cars -- closing velocity -- two trains, that end is duplicated here, here and here. So what happens in the middle?

Dr. Chen: As I said, somebody said before yesterday, there is a three to one stiffness ratio.

Mr. Nelson: That's what they said. Is that a good number?

Dr. Chen: I don't know.

Mr. Nelson: What's the difference of finding that you have fine results on the nose end, but you have nothing on the tail end.

Dr. Chen: We just talked about the static test to destruction -- about four cars.

Mr. Nelson: You're going to have to put married pairs, though, in that condition.

Mr. Widmayer: The results from the analyses are pretty good if you compare it in the SOAC test that one where we killed one guy. We had all of that terrible damage to the impact end. The second car -- the shear pins failed on the couplers, the anticlimber got dinged and knocked a little paint off, and that's all. And that's the middle part you're talking about. This triangular loading continues on down through the train until it gets back to where you're talking about just one or two g longitudinal acceleration, and it's not the problem you're anticipating. It's a good point, but the problem is not there.

Dr. Chen: Okay, I'd like you to look at the Part "C" -- C-1, C-2, C-3. Do you want to say anything about it? We have about 15 minutes left, so we can address to anything in that time span. We've already talked about C-2 and we agreed to make some controlled field tests.

Mr. Marks: The initial dynamic testing should be conducted on tangent track to obtain the most useful data in the shortest time for development of crashworthiness specifications. The second phase of the testing program could include tests on curved track and crossovers, and the specifications modified accordingly.

Mr. Widmayer: There's always something.

Dr. Chen: In C-2, we all agreed to suggest a field test with controlled crush front. Anything on C-1, C-3? We want to address to either of those? We are talking about developing baseline data, and we want to verify these different kinds of crash modes, whether they are going to override, etc. It's a big problem.

Mr. Widmayer: Again you have your performance of these concepts. there will be additional concepts. New York has already come up with a concept that's different than the AAR and the FRA collision costs. They put two sets in. There are going to be other concepts.

Dr. Chen: Yes, we can include field tests on cars with a controlled crush front, different kinds of concepts in there.

Now, let us talk about secondary collision -- the injury part.

Mr. Kochis: Why not instrumented dummies in there too?

Dr. Chen: Do we want C-1 and C-3? The former is to find out whether computer predictions are correct and to verify the behavior of the failure mode. The latter is the injury part.

Mr. Kochis: Well, we had some biomechanic simulation there yesterday, too. That can be validated. If you're going to crash the car, you may as well glean the most you can out of it.

Mr. Widmayer: I think you should have dummies on any of your field tests until you get all of the information possible -- piggyback onto the Franco Belge test.

Dr. Chen: So do we propose to perform dynamic tests of consists of cars.

So we propose to conduct field crush tests on consists of cars to verify the collision dynamics and injury mechanism.

Mr. Widmayer: Please, enter in your notes that I'm submitting as a suggestion that you can look up the recommended test program in my report 856, second interim report and in the third interim report. Include it as part of the recommendations. What it essentially is, fellows, my recommendations I made on a FRA study for the testing of railcars, but it applies and it's ten pages, and how to test. It's one of the reasons I'm so mouthy in this thing. I've just been through the exercise. But I would like to submit it as my recommendation. There's no way you can endorse it. I couldn't explain it to you in that time. But it's for your reference; when you get further on, please refer to the second and third interim reports, number 856.

Dr. Chen: That is good, let me repeat it to you. We have come out with seven recommendations from this workshop.

The first one is that we want to piggyback on the Franco Belge's

Dr. Chen: cont. proposed test. We want to measure the deceleration on the floor, to measure the structure destruction, and to put dummies in as occupants which include passive dummies for the movies inside the car.

Number two, we want to conduct non destructive dynamic tests at low speeds to establish the relationship with buff load and other specifications such as collision posts, couplers, etc. The parameters will be 200K, 300K, 400K and 500K buff loads. I'm not going to mention the injury in here, because it would be taken care of by 200, 300, 400, and 500K buff loads.

Number three, we want to conduct static and dynamic component tests on draft gear, coupler, shear pin, anticlimber, collision posts, etc. -- full scale lab tests, not by scaled model but full scale.

Number four, we propose to conduct static and dynamic subassembly tests. Whether this is going to be conducted by scale model or full scale depends on the economic and technical feasibility.

Number five, we propose to conduct static tests to destruction of full-sized cars. It should also include new structure shells.

Mr. Pugliese: Would select tests of occupants in the interior be included in the subassembly tests?

Dr. Chen: No, that's only subassemblies of the components. So far, the dummy part is on No. 1 -- Franco Belge's -- and the last one, on the full scale field test.

Mr. Pugliese: Okay, so you're just going to generate the data, and nothing more as far as the occupants are concerned.

Dr. Chen: That's what we are talking about now, thus far.

Number six, we propose to conduct field tests on cars with controlled crush front.

Number seven, the last one, we propose to conduct field tests on consists of cars to verify modes of collision dynamics and injury mechanisms.

We'll also attach Ed Widmayer's recommendations on TSC Contract 856.

Mr. Widmayer: Feel free to edit them. I'm offering them as suggestions to you.

Dr. Chen: I will speak for the group.

Mr. Nelson: What is number seven?

Dr. Chen: Number seven is to conduct field tests on consists of cars to verify collision dynamics and injury mechanisms.

Mr. Pritz: I think that number 6 ought to include the same things that were mentioned in Number 1, with the Franco Beign test.

Mr. Kochis: I was going to say that if we're looking at injury mechanisms, we might as well look at the controller crush also.

Dr. Chen: Number 6, on the front controlled - do we want to include dummies in there?

Mr. Kochis: Yes, I think so.

Mr. Pugliese: On 5, 6, and 7, yes.

Dr. Chen: That means we not only have the mechanical tests, but injury tests also on 5, 6 and 7.

Mr. Kochis: Was that the one where we were talking about just the shell?

Dr. Chen? The shell was in number 5.

Mr. Widmayer: This is static test.

Dr. Chen: Including dummies?

Mr. Widmayer: In static tests?

Mr. Kochis: No, that's what I'm trying to get at. Where we're working the shell, we can't use the dummies.

Dr. Chen: Okay, so only number 6 and number 7 include dummies in addition to number 1.

Mr. Kochis: Yes.

Dr. Chen: I thank you all. If I am not correct on reporting the facts, please speak up. Thank you. We will reconvene after lunch.

URBAN RAIL VEHICLE CRASHWORTHINESS WORKSHOP

Test & Evaluation Session - Topics for Discussion

PURPOSES:

- * To verify and assess overall urban vehicle crashworthiness obtained from simulation and modeling
- * To verify and assess critical parameters of impact devices which govern whether cars crush, displace vertically and override, or crush, displace vertically and override, or crush with subsequent override
- * To verify future design recommendations of improved impact device
- * To validate subsystems and components
- * To establish limiting speeds for each crash mode
- * To establish baseline data
- * To develop data for revised modeling

SOME DISCUSSION TOPICS

A. Scale Model Testing

A-1 Are scale-model testings adequate?

A-2 How do we establish pertinent simulation parameters and to to what extent?

A-3 What quantities are to be measured?
Impact speed (drop test)
Impact force (horizontal, vertical, lateral)
Draft gear travel
Deformation of car frontal and super structure

A-4 Instrumentations needed
Accelerometers, etc.
Strain-gages technique
High-speed movie
Data collection and analysis system

A-5 Test Procedures:
Component test - draft gear
Component test - anti-climber
Component test - collision post
Car structure - crushable structures
Car dynamic model testing - measuring frequencies

A-6 Are specimens repairable?

A-7 Economics of scale model testing, e.g., scale model vs. full-scale laboratory testing.

B. Laboratory Testing

B-1 What are the criteria for lab testing?

B-2 Is buffload specification an adequate measure?

B-3 What dynamic laboratory testings are needed?

B-4 Is loss of survival volume vs. strength to weight ratio a good measure of vehicle crashworthiness?

B-5 Are recoverable and repairable testing feasible? How?

B-6 Other issues similar to part A. scale-model testing.

C. Field Testing

C-1 Testing-design for consists of cars, crush, override sequence, derailment, etc.

C-2 Effectiveness of vehicle frontals

C-3 Secondary collision - passenger and crew injury

C-4 Testing procedures

C-5 Instrumentation

C-6 Data collection, analysis and documentation

C-7 Limiting impact speeds

TEST AND EVALUATION - SUMMARY

Dr. Chen: I'm glad to hear that your session on crashworthiness and rail car design also favors test and evaluation. The test and evaluation session had twelve members. We had very lengthy and vivid discussions. Practically everyone participated in the discussion and raised his points.

I am about to report to you on the seven (7) recommended items which have come out of this workshop session on behalf of all the session members.

As you know, the purpose of this test is many folded. For instance, if we want to verify and assess the results of overall rail vehicle crashworthiness obtained from computer simulation and modeling, we need tests and evaluations. Tests could also identify the failure modes and assess the critical parameters of impact devices which govern whether the rail car in a crash displaces vertically and overrides or crushes with subsequent override, and so forth. These phenomena are also predicted by computer models. We want to find out whether this is true. The tests could also verify future design recommendations such as new concepts concerning the energy absorption device among others.

We also want to validate components and subsystems and to establish force deflection curves, like the research people showed to us yesterday. We want to establish a limiting speed for each crash mode. With these in mind, we hope that we eventually can set guidelines, standards and specifications for retrofit of existing railcars and the development of new cars. In the discussion, we considered long term and short term objectives. We consider cost effectiveness. We like to be sure whether the proposed items will be practical and feasible. To this end, we are proposing the following seven (7) recommendations:

1. To conduct static crush and dynamic tests on components such as draft gear, coupler, shear pin, anticlimber, collision posts, and others. These tests must be done by full scale laboratory test, not by scaled models.

2. To conduct static and dynamic tests on subassemblies. Whether the test is scale model or full size depends on the economics and the feasibility of the particular test to be conducted.

3. To conduct static tests to destruction of full sized urban rail cars. This may include new design concepts, such as new shell structures. In other words, on some underframes, we may put on a new concept, for instance, a superstructure. We want to test to destruction of full sized cars.

Dr. Chen: cont.

4. To conduct dynamic field tests on rail cars with various crashworthiness concepts on the front end, different kinds of newly developed configurations.

5. To conduct nondestructive tests on rail cars. The tests should be conducted at very low speeds, so that we can relate these results to buff loads and to the specifications of the collision posts and other crashworthiness devices. The nondestructive tests should be carried out for different kinds of cars, for example, cars with 200K, 300K, 400K, and 500K buff loads. Hopefully, through extrapolation, the results can be used for all classes of cars, since all rail cars are classified currently by buff load.

6. To conduct field crush tests on consists of urban rail cars and to identify and assess collision dynamic processes and injury mechanisms. There will be dummies inside the car in different positions, and some of them will be instrumented.

7. To suggest or attach tests to Franco Belge's Test. This item relates to Mr. George Zehnder's presentation today, who is a representative from Franco Belge. Franco Belge is planning some kind of collision test on their cars. Our session members proposed that we either ask or add on to the Franco Belge's test, accelerometers for measuring floor and structure decelerations, and instrumented anthropomorphic dummies in various positions for identifying injury mechanisms. We think it would be very beneficial for our part and also for Franco Belge if they have not already done so. Therefore, we would like to suggest this test, which is not too elaborate, but will provide useful information for the baseline data and future car designs.

   There is one other thing. Mr. Ed Widmayer stated that Boeing Vertol has done some work for FRA. Their last recommendations appear in the reports of TSC 856 project. It is a related research. It is suggested that one may look into it to see if there is anything else in there worthwhile for consideration in test and evaluation.

   Finally, I would like to thank all the session members for their contributions, and I am very pleased to be here and met many new friends here in this conference. I really enjoyed it and appreciate the opportunity. Thank you.

CLOSING REMARKS

William Rhine

Ronald Madigan

Mr. Rhine: I have to start off - and it's not just a duty - it's a real pleasure on my part to again thank all of you. I guess I'm more than happy. I'm kind of amazed at what transpired here for two days and, from several points of view. One is UMTA's interest in this delivery system we talk about all the time. I think this has proven to me to be a very effective way, perhaps one of the many way, in delivering a "product."

Secondly, given that what we really presented to you from UMTA's and TSC's point of view, were three research projects which were not necessarily in themselves related, they did have some points of technical commonality. They had the usual thing in analytical work, of some agreement and maybe some disagreement, and that's great from the research world's point of view. That's the way it should be. But the way the industry people from all sides picked up on this, and contributed is gratifying to me. Everytime I ask people that are out running transit properties or building cars, to come out to one of many government meetings, I have apprehensions about interfering with them. But we've seen such good support that I am very thankful.

I'd like to thank TSC also for the technical participation for all their contractors, themselves, and for the rather well done organization for the meeting here.

What we wanted to do in these two days was to present some research ideas, get some guidance from you people, some comments and criticism -- whatever is appropriate -- as to what we've done, what we might do, and what we're not doing and how important this topic is to you. This morning we kicked around the priorities between preventing crashes, for instance, and making a car more crashworthy. No absolute answer from anybody, but in spite of all our feelings about how safe rapid transit is, and we think it's a very safe form of transportation, there's always a push from somebody to be concerned about specific types of accidents, and we think that collisions represent a significant portion of that family of incidents.

What we would like to do in the finishing sessions today then is something we originally labelled policy, but as I said yesterday, policy is not a good word. What does it all come up to? What did you get out of this thing? What do you feel we might do up to, and including telling us to stay out of your way, and that you'll do it yourselves. In particular, how can we work together in R & D to carry on as appropriate. I always say of the federal government -- we don't own them, we don't run them, and thank God for that.

Mr. Madigan: I think that the next thing is to find out if there are any additional comments from the floor, questions that you may have had that didn't quite fit into the workshop or a particular session, that you want to bring out? If there are any ideas, I think now is the time to bring them out.

Mr. Hrize: I'm Mike Hrize, SEPTA. I'd just like to say that on testing, if the test program is to be undertaken to test aged cars as well as new, that we should try to develop some kind of crashworthiness degradation curve - if we can call it that -- so we can determine just how the crashworthiness (design) of a car will degrade over time.

Mr. Madigan: I think that's a good idea. Additionally, I think one of the first things we've got to do is eliminate the word crashworthiness which kind of bothers me. What does that mean? I think that question's been tossed around and ranges fron the infinitely stiff member to the crushable front end. Just what do we mean by crashworthiness? I think you people ought to entertain these questions. It also implies the inevitability of a crash.

These proceedings will be published. The speakers will be given an opportunity of reviewing the draft copy. I think there's an opportunity to put in some new thoughts or maybe even thoughts that you didn't think came out too clearly or that you want to re-emphasize.

There is one thing that I'd like to make sure you do complete. In your package, you have some evaluation sheets. I'd like you to please fill out those sheets. You've gone to the trouble of being here for two days and contributing your ideas, so please let us know what your opinion is of this conference especially the technical content.

If there are no more comments, I'd like to take this opportunity of thanking everyone. Like Bill said, I thought it was enlightening. In fact, I'm delightfully surprised with the candid answers, questions, and even the criticisms (which were couched very well) but came through very well. I want to especially thank the panel chairmen, session chairmen and the excellent panelists. It's been a very good meeting and I'd like to thank you all for your participation.

The conference is adjourned.

APPENDIX A

PUBLICATIONS RELATING TO VEHICLE CRASHWORTHINESS

1) An Assessment of the Crashworthiness of Existing Urban Rail Vehicles. Volume I Analyses and Assessments of Vehicles. Volume I Analyses and Assessments of Vehicles Chapters 1 through 7 DOT-TSC-UMTA-75-21.1 PB 249-142: PB 249-141/SET UMTA-MA-06-0025-75-16.I DOT-TSC 681 Final Report November 1975 Calspan Corporation
R.J. Cassidy, D.J. Romeo

2) An Assessment of the Crashworthiness of Existing Urban Rail Vehicles. Volume II: Analyses and Assessments of Vehicles, Chapters 8 through 12 and Appendixes and References DOT-TSC UMTA-75-21.II PB-249-143, PB-249-141/SET UMTA-MA-06-0025-75-16. II DOT-TSC-681 Final Report November 1975
Calspan Corporation
R. J. Cassidy and D.J. Romeo

3) An Assessment of the Crashworthiness of Existing Urban Rail Vehicles, Volume III: Train Collision Model, User's Manual DOT-TSC-UMTA-75-21.III PB-247-230. PB-249-141/SET UMTA-MA-06-0025-75-16, III DOT-TSC-681
Final Report November 1975
Calspan Corporation
D.J. Segal

4) An Assessment of the Crashworthiness of Existing Urban Rail Vehicles, Vol.I: Analyses and Assessments of Vehicles Chapters 1 through 7, Vol. II Analyses and Assessments of Vehicles, Chapters 8 through 12, Report No. UMTA-MA-06-0025-75-16,I and II PB 269 400 and PB 269 401
R.J. Cassidy and D.J. Romeo

5) Crashworthiness Analysis of the UMTA State-of-the-Art Cars, Report No. UMTA-MA-06-0025-75-15, October 1975 PB-247-230

6) A Structural Survey of Classes of Vehicles for Crashworthiness - Accident Data Review, Volume I, Rept. DOT-TSC-856-1, July 1975
W.J. Kesack, R. Ross, and E. Widmayer

7) A Structural Survey of Classes of Vehicles for Crashworthiness - Structural Design of a Crashworthy Locomotive - DOT-TSC-856-3, Dec. 1977
E. Widmayer

8) Train-to-Train Impact Tests, Volume I and II, Dynamic Science Report No. 8261-75-155, DOT-TSC-840

APPENDIX A

PUBLICATIONS RELATING TO VEHICLE CRASHWORTHINESS (cont.)

9) Increased Rail Transit Vehicles Crashworthiness in Head on Collisions Part I, Initial Impact Contract
DOT-TSC-1052, August 1976
E.E. Hahn

10) Increased Rail Transit Vehicles Crashworthiness in Head on Collision Part II, Primary Collision, September 1977
E.E. Hahn, S.C. Walgrave, and T. Liber

11) Increased Rail Transit Vehicles Crashworthiness in Head on Collision, Part III, Guidelines for Evaluation and Development of New Railcar Designs, November 1977
A.H. Wiedermann, A. Longinow, and E.E. Hahn

12) Dynalist II A Computer Program for Stability and Dynamic Response Analysis of Rail Vehicle Systems, Volume II, User's Manual. DOT-TSC-FRA-74-14-II Final Report February 1975, PB-257-733 FRA-OR&D 75-22 II J.H. Wiggins Company
Allen Bronowicki, T.K. Hasselman

13) Dynalist II A Computer Program for Stability and Dynamic Response Analysis of Rail Vehicle Systems Volume III: Technical Report Addendum DOT-TSC-FRA-74-14. III Final Report, July 1976 PB 258-193 FRA-OR&D 75-22 III DOT-TSC-990
J.H. Wiggins Company
Allen Bronowicki, T.K. Hasselman

14) Dynalist II A Computer Program for Stability and Dynamic Response Analysis of Rail Vehicle Systems Volume IV Revised User's Manual. DOT-TSC-FRA-74-14 IV PB258-194 FRA-OR&D, 75-22. IV DOT-TSC 990 Final Report July 1976
J.H. Wiggins Co.
Allen Bronowicki, T.K. Hasselman

15) Frequency Domain Computer Programs for Prediction and Analysis of Rail Vehicle Dynamics, Volume I: Technical Report. DOT-TSC-FRA-75-16. I PB 259-287, PB 259-286 SET FRA-OR&D 76-135 I Final Report December 1975 Transportation Systems Center
A.B. Perlman, F.P. DiMasi

16) Frequency Domain Computer Programs for Prediction and Analysis of Rail Vehicle Dynamics, Volume II: Appendixes DOT-TSC-FRA- 75016. II Pb-259-288, PB-259-286- SET FRA-OR&D 76-135 II Final Report December 1975 Transportation Systems Center
A.B. Perlman, F.P. DiMasi

17) Locomotive to Automobile Baseline Crash Tests DOT-TSC-FRA 75-18. PB 250- 564/AS FRA-OR&D 76-03 DOT-TSC 700 Final Report August 1975 Utrasystems, Inc. Dynamic Science Div.
R.L. Anderson

18) Performance Analyses of Intercity Ground Passenger Transportation Systems. DOT-TSC-FRA-75-25 PB 261-950 FRA-OR&D 76-248 Final Report April 1976 Transportation Systems Center
John S. Hitz

19) Mechanics of Train Collision DOT-TSC-FRA-76-5 PB258 993 FRA-OR&D 76-246 Final Report April 1976 Transportation Systems Center
Pin Tong

20) Evaluation of Prototype Head Shield for Hazardous Material Tank Car. DOT-TSC-FRA-76-8 FRA/OR&D 75-96 DOT-TSC 727 Final Report December 1976 PB-262-430 IIT Research Institute
Milton R. Johnson

21) Locomotive/Caboose Crashowrthiness DOT-TSC-FRA-76-18 PB 261-110 FRA-OR&D 76-289 Final Report October 1976 Transportation Systems Center
Pin Tong

22) Analytical Finite Element Simulation Model for Structural Crashworthiness Prediction DOT-TSC-NHTSA 73-12 PB 228-136 HS-801018 Interim Report February 1974 Transportation Systems Center
J. Rossettos, H. Weinstock, S. Pasternak

23) Instrumentation Methodology for Automobile Crash Testing DOT-TSC-NHTSA-74-1 PB 236-315/8GI HS-801211 Interim Report August 1974 Transportation Systems Center
Frank P. DiMasi

PUBLICATIONS (cont.)

24) Modular Approach to Structural Simulation for Vehicle Crashworthiness Prediction DOT-TSC-NHTSA 74-7 PB 246-784 HS-801-475 Final Report March 1975 Transportation Systems Center
Pin Tong, J.N. Rossettos

25) Crashworthiness, Sup. of 10th Society of Engineering Science Annual Meeting, 1975
P. Tong

26) Mechanics of Train Collision, FRA-OR&D-76-246, DOT-TSC FRA-76-5, April 1976
P. Tong

27) Locomotive/Caboose Crashworthiness, FRA-OR &D-76-289, June 1976
P. Tong

28) Structural Analysis and Simulation, Boeing Vertol Rept. D210-1130-1, Dec. 1977
A.E. Tanner and E. Widmayer

29) Analysis of Automobile Crash Test Data and Recommendations for Acquiring and Filtering Accelerometer Data DOT-TSC-NHTSA -75-2 PB 244-308 HS-801 521 Final Report June 1975 Transportation Systems Center
Frank P. DiMasi

30) A Preliminary Study of Head-On and Rear End Collisions Involving Locomotives, V-804-74-01, Association of American Railroads for the Locomotive Control Compartment Committee, Washington, D.C., Jan. 1974

APPENDIX B

SUBMITTED EVALUATIONS OF URBAN RAIL VEHICLE CRASHWORTHINESS WORKSHOP

During the conference, the participants were requested to respond to two questionnaires (blue sheet for comments and yellow sheet for meeting evaluation) which were available at the registration desk. Fifteen responses (3 foreign) were received.

Government - 2

Research - 2

Transit Property - 6

Manufacturer - 5

The results of both comments and meeting evaluations are summarized.

A. COMMENTS

1. A well organized workshop which was attended by key representatives who expressed a real concern for continuing work on urban rail vehicle crashworthiness research both in areas related to passenger injury and vehicle standard.

2. I thought this was a very well organized and useful workshop. It is a good thing to get the users and suppliers together and this is a first start towards getting some crashworthiness standards sorted out.

3. I look forward to the further work that is done to incorporate the research into hardware in the near future.

4. Suggest meeting every year.

5. The two workshop sessions were a little too large and unwieldy. More groups of smaller size would have allowed more discussion.

6. All three researchers had trouble relating to reality. This probably proved negative to many of the nonanalytical minds present. Could they add clarification on review of transcripts?

7. In a technical workshop, the Budd advertisement was unnecessary, it was devoid of useful technical data. There are many others equally good testing labs that were not afforded

8. In the "Proceedings" will it be possible to explain how to aquire copies of the European specifications UIC & UITP (mentioned by Zehnder)?

9. I felt that the free exchange of information was especially productive. Enough properties were represented to get a definite variability to possible requirements. Plus, a surprisingly complete reportage on state-of-the-art in this area including the European view. I came prepared more to listen than to discuss and I very certainly was not disappointed. Construction modifications are now very much more clearly understandable. Very worthwhile. I sincerely hope that transcripts to the verbal exchange will be made available to flush out my own hurried notes.

10. If possible, information provided during a presentation such as slides of graphs, etc., if available, should be provided separately-they can be reproduced or provided for viewing prior to or after the presentation-unfortuanately, it is sometimes impossible to fully understand the meaning of the exhibits presented on the screen and full benefit may not be obtained.

11. In this type of seminar, it would be good to provide a large number of examples of the conditions which are being discussed-possibly by means of a photograph display which can be viewed at one's leisure. Photograph of accident damaged cars could have been examined more thoroughly and might have prompted additional pertinent questions.

12. Crashworthiness criteria need to be standardized. Require test program to determine what existing cars can do determine criteria, build prototype or mock-up of car, test and write standard specifications. Treat Rapid Transit, Commuter and Light Rail separately because they operate under different conditions.

13. Expedite test program above, and let time-consuming computer program development and other theoretical work run concurrently or follow. Recommend that NYCTA's R-55 car specifications be model to determine criteria for future standard car and it be selected for mock-up and test. Expedite so that new buys can conform to the new standard.

14. Workshop was excellent forum for informing all participants as to where the industry stands on crashworthiness research. Much needs to be done starting with an UMTA design guideline (as an aid to all transit properties) to properly specify crashworthiness criteria in our railcar specifications.

I concur with NYCTA in that a well designed reliable signaling system is a must. I recommend this be considered along with car design.

15. Since BART is entering a new generation vehicle design phase, the discussions concerning design for vehicle crashworthiness was very timely. In particular, I felt the greatest benefit to me was getting acquainted with engineers from various transit properties and manufacturers who are experienced with designing vehicles to optimize crashworthiness. These contacts will be invaluable in our future design efforts.

16. Users and manufacturers alike are in agreement on the benefits of crashworthiness; an important first step. A good foundation has been laid by this workshop for future efforts in developing crashworthiness in railcar designs and 14 recommendations were presented to UMTA as a result. However, what is now needed is guidance from UMTA in the form of a formal developmental program with industry involvement to manufacture and demonstrate a crashworthy railcar design with full scale crash tests. Use that data and aircraft crashworthiness research to develop a design guide which would then lead up to development of a reasonable standard based on what the users and manufacturers will be willing to tolerate in the way of crashworthiness. More attention should be placed on interior structure as accident experience indicates that many injuries are inflicted to passengers by the rigid unpadded structure within the car.

17. Future sessions might extend the ground work started by focusing more on specifics of interior, rather than car body design. Much of the last workshop was devoted to structural features, particularly collision protection, with passenger secondary collisions receiving less importance. Perhaps some look at what is being done in this area might be in order.

18. Crashworthiness could be extended to other factors such as post accident hazards: fire, escape, lighting and so forth. While this is getting a bit far afield, some future workshop might consider some of these problems.

19. As a follow up on the past workshop, would it be possible to find out the eventual results of the European tests and to dissiminate the results to the workshop participants?

20. In order to develop feasible designs for more crashworthy cars using energy-absorption in the end structure, limit

criteria should be established on train collision speed and passenger acceleration.

21. This workshop offered a very straightforward way for a person working in related field to quickly "come up to speed", recognize many areas of mutual concern and then through the workshop sessions make the urban rail vehicle community aware of the overlapping areas. I have worked in the automotive safety area for a number of years and have been involved with numerous experimental investigation of both occupant and pedestrian crash protection. During the first day of the workshop, I was aware of the similarity in the dynamic crash environment and the fact that much of the experimental technique and methodology is directly applicable to the crashworthiness analysis of passenger protection in urban rail vehicle collisions. During the workshop session of the second day, I passed on much of this similarity in the experimental investigation of crash dynamics in automotive collisions and how the crash environment of the urban rail vehicle collision could be experimentally simulated in the laboratory. The results of a series of laboratory experiments would be very informative in understanding the dynamics involved and in validating and improving mathematical models.

It should be made clear that in making this comment I am considering urban rail crashworthiness to be totally related to the protection of passengers in a rail vehicle collision. It seemed that often during the workshop, and especially in comments from the transit authority participants, the term "crashworthiness" was related to the damageability of the rail vehicle.

B. MEETING EVALUATIONS

1. Which session(s) did you find most useful?

Crashworthiness Research Activities	(6)
Transit Authority Experience	(6)
Manufacturing Industry Experience	(5)

Distributions and workings are in their original form and Items 6,7,and 8 of meeting evaluation could probably be combined.

Crashworthiness and Railcar Design	(7)
Test and Evaluation	(5)
Boeing Vertol presentation	(2)
Budd Company presentation	(1)
NYCTA presentation	(1)

2. Which sessions(s) did you find least useful?

Crashworthiness Research Activities	(2)
Transit Authority Experience	(2)
Manufacturing Industry Experience	(2)
IITRI presentation	(3)

3. Comments on Time Allocation

Excellent	(2)
Good	(5)
Adequate	(2)
O.K.	(4)

Presentation Quality

Excellent	(1)
Good	(9)
O.K.	(1)
Not Good	(1)

4. Suggestions for future meeting topics

    1. Development of design guide
    2. Design standard/guidelines for crashworthiness
    3. Development of crashworthiness design guidelines
    4. Criteria for standard cars, specifications for cars, tests

   5. Specifications of railcar crashworthiness design features
   6. The implementation into standard specs
   7. Fire safety and interior design
   8. Vehicle fire in relation to use of plastic materials
   9. Use of energy absorption devices
   10. Draft gears and their energy absorption
   11. Policy
   12. Parallel studies in other transportation modes. Does that what is being done in aviation help rail? Automobiles?

5. Suggestions for future meeting locations.

Atlanta, GA	(1)
Cambridge, MA	(5)
Chicago, IL	(1)
Pueblo, CO	(1)
San Franciscso, CA	(2)
Toronto, Canada	(1)
Washington, DC	(2)

6. Suggestions or comments on the meeting format.

   1. Good format (2)
   2. Needs no improvement (1)
   3. Panels, workshops with smaller sized groups that will foster more discussion (2)
   4. Need more time for workshop sessions (1)
   5. Would have enjoyed more participations of heavy rail industry in addition to transit (1)

7. Comments or complaints on the meeting organization
    1. Well organized and well run
    2. Well organized workshop
    3. Generally quite good
    4. Would have enjoyed attending Workshop"B" as well as "A"
    5. Folders which were supplied were helpful.
    6. Provide writing surface for all sessions.
8. Any other comments
    1. Excellent representation by key people
    2. Not enough participation by other railroads and rapid transit
    3. Quick feedback from U.S. DOT and early implementation of testing program is required so that new car buys can conform to new standards developed.
    4. Am interested in Franco-Belge's crash tests
    5. Highly technical presentation should be edited
    6. Wanted more specific design details for increasing crashworthiness
    7. It seems that the research contractors have discovered what those in the industry (transit and car builders) have known.
    8. A lot can be learned from slow motion movies. The tank car movies shown during reception were very informative.
    9. The importance of keeping the trucks attached was very clear. More movies of this sort would be very useful.
    10. Some pre-meeting abstracts would have increased the value of the presentation.
    11. Providing the bibliography of pertinent publication is very useful.
    12. Topics covered were presented in reasonable order.

13. Entire experience great, good exchange of information

14. I enjoyed this meeting and I hope to attend any subsequent ones on the topic.

15. Generally a good meeting

16. Confirming existing practice

17. Workshop "A" would have been better in a smaller air conditioned room.

18. Possible sidetrip to view system for those interested

19. To see subway, street cars, trolleys and diesel buses

20. Distribute a list to all properties of prospective topics Based upon response from these properties, future programs can be established.

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